A structured approach to forensic structural investigations of concrete damages

The development of an investigation methodology to determine the technical cause of damages to concrete structures

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The development of an investigation methodology to determine the technical cause of damages to concrete structures

by

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Preface

This report presents the result of graduation research into the forensic investigation process to determine the technical cause of a damage to concrete structures This graduation thesis has been performed to obtain a master degree in Civil Engineering - Building Engineering at Delft University of Technology with the specialisation structural design.

The first objective of this report is to give an overview of the available literature on the field of forensic investigation processes and connected topics in relation to structural forensic engineering. It will present a prototype of an 'investigation process model' applicable to investigations into regular concrete damages based on the information and recommendation of the literature. Secondly, I hope that the information in this report will inspire and give a fresh perspective on structural forensic engineering to practising structural forensic engineers.

The report consists of three parts. The report starts with an introduction (ch. 1) exploring the investigation question and scope. The first part (ch. 2-4) describes information collected during a literature study into the fields of structural forensic engineering, accident investigation protocols of aerospace engineering, fire cause investigation practices, reliability and credibility philosophies of cases study research, human error theory and concrete damage types. The second part (ch. 5 & 6) of the research presents the developed investigation process model and its validation. The report finishes with conclusions and recommendations (part three).

I would like to express my gratitude to all the people that contributed to the completion of this graduation thesis by sharing their knowledge, expertise, time and advice. In particular, I would like to thank the graduation committee for supporting me with practical feedback and giving me the freedom to discover and explore the field of forensic engineering. I also would like to thank all the people that granted me an interview and made ample time to share their thoughts and experience. My gratitude goes to the staff members at Adviesbureau ir. J.G. Hageman for allowing me to work for a few weeks at their office to validate my model and sharing their experience with me. Lastly, I would like to thank Fleur for reading my report and my family for their moral support.

I hope you will enjoy reading the report and discover some new ideas.

Margriet Verbiest

Bergen op Zoom,
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Abstract

In recent years, there has been an increasing interest in structural forensic engineering in the Netherlands. At the moment, there is no formal investigation process that is used by each investigator. In the Netherlands, there are generally two categories of structural forensic investigations. The first category are extensive investigations with the goal to learn from failure by investigating all aspects: technical, human and organisational. The second category are investigations that focus mainly on technical causes and the investigation goal varies from determining the failure cause including designing repair measures to determining (financial)responsibility for the failure. For this second category, there is little information available on what investigation process is generally used. In literature, several investigation methodologies have been described. However, they often describe only a very general process or on the other hand very specific material related laboratory tests. Descriptions and recommended techniques on how to perform the proposed steps of an investigation are scarce. To a client ordering a damage investigation, the most important parts of the investigation are the conclusion and the recommendations. The client expects that the conclusion is correct. Therefore, it is important to ensure that the used investigation process results in a reliable (consistently good quality and able to be trusted) outcome. Basic knowledge of bias may help to indicate possible threats to the reliability of investigations. Techniques used to increase the validity and reliability of case study research can assist in developing strategies to achieve reliable forensic structural investigations. Therefore, the question of this research is: what is a reliable methodology to perform investigations into the technical cause of damages to concrete structures?

The research question has been answered by studying available literature on structural forensic investigation techniques, interviewing investigators, researching investigation techniques used for aerospace accident investigations and fire cause determination, studying human error theory and case study research and concrete damage mechanisms.

Based on the resulting information from studying all these disciplines the conclusion can be drawn that using a structured investigation process is essential. Therefore, this information has been used to develop an investigation methodology called the 'investigation process model'. The model recommends, based on literature, the following phases: orientation, data collection, hypothesis generation, hypothesis analysis, conclusion, reporting and follow-up. These phases are split into individual steps that guide the investigator through the process. Each step contains suggestions for specific techniques varying from taking meaningful photographs of damages on location to using a standard layout for reporting in order to execute the step properly. The investigator can select the most appropriate techniques for the project. Special attention has been paid to provide techniques to generate and analyse hypotheses in a reliable way. An example is the tool 'Concrete Damage Handbook' to assist the investigator in linking visual damages to possible causes. As a common thread through the model measures have been provided to limit the negative influence of bias (based on the Delft approach). The result is a sound, thorough model for 'regular' damage investigation of concrete structures.

Validation of the model with 1) a test case based on a real damage file, 2) comparison with real investigation reports and 3) scientific papers proved that the model relates to the daily working practice. The model is usable, practical and functional within the scope of the defined criteria. The recommendation is to make some minor improvements in order to optimise the model's usability.

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Glossary

Concrete Damage	In this research, concrete damage is considered as every physical state of a structural element that unintentional deviates from the natural material characteristics of concrete.
Forensic structural investigation	The process of determination of the cause of damages for failures of structures.
Functional	The characteristic of operating or working in a correct way.
Investigation	In this report reserved for the application within forensic engineering. Not intended for the process of the thesis itself.
Reliable	The characteristic of good quality, being correct, complete and the outcome able to be trusted.
Research / study	In this report meant as the process of the graduation.
Site-vist	Visiting the location of the damage during an investigation and carefully inspect the damage and its context.
Structural forensic investigation	Same as forensic structural investigation.
Usable	Ready for use.

Chapter 1

Introduction

In recent years, there has been an increasing interest in structural forensic engineering in the Netherlands. On the one hand due to some large structural failures (FC Twente station, balconies in Maastricht, collapse of the parking garage floor in Eindhoven). On the other hand, several initiatives have been undertaken to learn from failures like: *Leren van instortingen, Platform voor Constructieve Veiligheid, het ABC meldpunt* and the introduction of forensic engineering practices in the education program.

In the Netherlands, there are roughly two categories of structural forensic investigations. The first category consists of large and very comprehensive investigations performed by the Dutch safety board (Onderzoeksraad Voor Veiligheid). It is their goal to learn from failure, and they investigate all aspects: technical, human and organizational. The investigations have a very broad scope and the investigation team will be multidisciplinary. They only investigate failures that have resulted in collapse, casualties or are exemplary for a significant problem in the construction world.

The second category of investigations are investigations that are focused mainly on technical causes and generally have a range of different investigation goals. The investigation questions can vary from determining the failure cause including designing repair measures to determining (financial) responsibility for failure or evaluating structural safety. The second category can be split into three types of companies performing structural forensic investigations which vary in size, goal and type of client.

The first type of company consist of the specialist structural failure investigation companies like TNO, Adviesbureau ir. J.G. Hageman and BAS Research & Technology (material science). These companies have a long history of structural failure investigations. In the construction world, they are regarded as experts on the field of structural forensic engineering and performing structural forensic investigations is their core business. Their investigations are generally technical oriented and when large or complicated failures occur they are the experts to contact. They investigate both small and large scale damages and collapses for a range of clients like insurers, municipalities, contractors or building owners. The second type of company performing structural forensic investigations consist of damage specialist companies. They investigate damage in a wide range of fields from car damages, fire damage to structural damage. They work mainly for insurance companies and specialize in the juridical and financial aspects of damage investigations related to different types of insurances. Depending on the insurance type organizational and human contributions to damage causes are also investigated. Investigators of this type are often registered in the Nivre-register[1]. The third group of companies performing structural forensic investigations consist of companies where structural forensic investigations is only part of their activities. Examples are consultancy firms, engineering companies, structural design companies, etc. The characteristic of this group is that forensic investigations are not a speciality or daily work of the company. Most of their investigations consist of small or medium size damages.

In the Netherlands, there is no formal or prescribed investigation process or methodology for structural forensic investigations. The investigation process of the Dutch safety board has been

1 The Nivre (Nederlands instituut van register experts) is a quality label for damage investigators, risk managers and fraud coordinators.

documented but this protocol has been developed for all sorts of failure/incident investigations. There is little information available on how investigations from the second category of structural forensic investigations are being performed. From a previous graduation study by Miro-Downey there is information based on interviews on how the specialized companies like TNO and Adviesbureau ir. J.G. Hageman approach the investigation process. It appears that each investigation company has its own protocol and way of working although there are common steps in the process they all perform like: document review, hypothesis generation and testing (Miro-Downey, 2010b). This corresponds to steps described in literature (ASCE,2012; ESReDA working group on accident investigation, 2009; Ratay, 2009). However, in this study no information is available on how the individual steps in the investigation process, for example hypothesis generating, are practically performed. There is no written information available about the investigation process of the other type of companies.

In literature, the general steps of a forensic investigation process are described (ASCE, 2012; ESReDA working group on accident investigation, 2009; Ratay, 2009). Generally, literature sources describe both the factors surrounding the investigation process like ethical behaviour as well as very detailed material specific analysis techniques. Generally, the middle-level of detail (in between the abstract theoretical models and the specific technical details) like techniques on how to perform the general steps of a forensic investigation have not been described. A study of investigation methodologies in other professions where the investigation field is more mature can help to identify and develop these strategies.

For a client ordering a damage investigation the most important aspects of the investigation are the conclusion and the recommendations. The client expects that the conclusion is correct and the investigation is reliable (see glossary). A forensic investigation process is partly a creative and intuitive process. Therefore it is important to ensure that the used process results in a reliable outcome. Basic knowledge of bias and decision making can help to indicate possible threats to reliability of investigations and to develop strategies to increase reliability.

Research question

This report presents the results of a study into the investigation process and techniques usable for a structural forensic investigation into the technical cause of damages of concrete structures. At the start of the research the following investigation question has been formulated:

What is a reliable methodology to perform a structural forensic investigation into the technical causes of regular concrete damage in Dutch practice?

Reliable in this research is defined as 'consistently good in quality and able to be trusted' (Oxford University press, 2019). In order to define the research and increase the usability of the research outcomes the scope has been outlined. The first limitation is that the research aims to develop an 'investigation process model' for usage on regular and relatively small investigations. This excludes the use of the investigation process model for failures where there have been collapses, casualties or very extensive damage. In these cases, other factors like liability and public opinion come into play. The second limitation is to focus only on technical causes of concrete damage. Technical causes are the most requested investigation aspect for regular investigations. Damage to concrete structures has been selected since concrete is widely used as a building material in the Netherlands. In concrete damage a variety of visual damages with different causes like cracks and different types of surface damage occur.

Approach

To be able to develop an investigation process model for investigating technical causes of regular concrete damages in Dutch practice, first a theoretical framework for investigation processes should be developed. In order to get a complete picture of possible approaches to investigation processes the literature study is divided into three parts:

- Structural forensic engineering (literature study and interviewing investigators);
- Forensic investigation processes and techniques in other fields (literature study);
- Concrete damage classification (literature study and model development).

The structural forensic engineering part contains an overview of the available literature concerning the investigation process and the structural forensic engineering world. Additionally, research into Dutch practice has been performed to get an understanding of the Dutch forensic investigation context and to get insight into the investigation processes. This part focusses on companies that perform structural damage investigations among other types of projects. This information is gathered by interviewing a selection of investigators. The second part contains a study of forensic investigation processes and techniques used in the fields of aerospace engineering and fire cause investigations. They have been studied to determine what can be learned from their approach. Regarding the aim of a reliable investigation both case study research and human error theory have been explored to indicate possible threats to the reliability of an investigation and to get practical input for improving the quality of the investigation process. A structural forensic investigation can be regarded as a case study. The techniques used to improve the reliability and validity of case studies can be adapted for use in the investigation process model. Human error and bias theory describe the functioning of the human mind regarding decision making and specifically what could go wrong due to the natural functioning of the brain. Knowledge of these mechanisms and their influence on the investigation process will help to develop a reliable investigation process model. The third part of the theoretical framework is knowledge of concrete damages, specifically how they manifest themselves in structures and how to deduct possible cause(s) from visual characteristics.

After the theoretical framework has been established the investigation process model can be developed considering all information from the theoretical framework. When the model has been developed, it should be validated. In this research the model has been tested using two scientific papers on investigation methodologies and existing reports from concrete damage investigations. In order to determine the usability and functioning of the investigation process model, one sample investigation into damage to a concrete construction (parking garage) has been performed using the developed model.

Collecting the results from all three parts of the research, conclusions and recommendations to improve the investigation process model have been formulated. For an overview of the structure of this thesis see Appendix A – Overview research structure.

Part I

Theoretical framework

Part I contains a literature study into several aspects related to structural forensic investigation processes into the technical causes of damage to concrete structures.

The literature study has three parts. Chapter 2 gives an overview of available literature on the structural investigation process and Dutch forensic engineering practice. Chapter 3 describes what lessons can be learned from investigation techniques and processes that are used in the fields of aerospace engineering and fire cause investigations and how knowledge of validity and reliability of case study research and human error theory can identify the threats to the reliability of structural damage investigations. Chapter 4 describes a method to identify the damage cause of damage to concrete constructions based on visual appearance and context information.

Chapter 2

Structural forensic engineering

Forensic engineering is a term best known in the United States of America. In the US the profession of forensic engineering is the most organized and developed as a designated professional field of practice. The term forensic engineering is becoming more internationally used, especially in research (Palmisano & Ratay, 2015). In the Netherlands equivalent terms used are: structural damage investigation and building pathology. First, this chapter will explain the meaning of forensic engineering, the professional context and the qualities and skills of a forensic engineer. Secondly, methodologies for performing a structural forensic investigation as suggested in literature will be described and discussed. The last part will explain how forensic engineering is organized and practised in the Netherlands.

Several definitions for forensic engineering are being used. Forensic science is defined as: 'the application of scientific methods and techniques to matters under investigation by a court of law' (University of Oxford 2018b). Engineering is defined as: 'the branch of science and technology concerned with the design, building and use of engines, machines and structures' (University of Oxford, 2018a). The definition of forensic engineering can be: 'the application of engineering principles, education and knowledge to problems where legal liability is to be decided in a legal forum' (ASCE, 2012). However, the term forensic engineering is commonly used in a much wider context. The term is also used in cases where no court of law is involved. Therefore, forensic engineering is defined by the ASCE (American Society of Civil Engineers) as: 'the application of engineering principles to the investigation of failures or other performance problems' (ASCE, n.d).

Structural forensic engineering can then be defined as the profession of investigation the cause of failure of constructed premises. Failure describes every unacceptable difference between actual and intended performance (Ratay, 2009). Failures of structures occur all over the world, but the practice of forensic engineering is only organized in some countries. Best known examples are the United Kingdom (ICE, IStrucE, Structural-Safety) and the US (ASCE and TCFE). A survey among IABSE (International Association for Bridge and Structural Engineering) member countries leads to the conclusion that only one-third of the countries have some sort of central obligatory protocol for forensic structural engineering . In most countries, the investigation process is developed and determined on company level (Palmisano & Ratay, 2015; Terwel et al., 2012).

The forensic engineer

Forensic engineering is often practised by specialized senior engineers. The differences between the tasks of an engineer and a forensic engineer explain the difference between the qualities and skills that are required. The primary task of a structural engineer is to develop a safe and functional structural design that meets the client's requirements. This process is based on conservative assumptions and simplifications and is solution driven. The structural forensic process works in some regards the other way round. It starts with the result and the cause needs to be identified based on facts and verifiable data (Brady, 2013). A forensic engineer needs additional skills besides the knowledge of structural behaviour, mechanics and materials.

According to literature, the skills and qualities of a structural forensic engineer are:

- General knowledge of day to day practices on a building site and within an engineering office. This should be part of the background knowledge to be able to perform a failure investigation (ESReDA working group on accident investigation, 2009);
- The skill of explaining technical evidence in a way a layman can understand and possibly weigh the value of the evidence in court (ASCE, 2012);
- The skill of providing a trustful and adequate court testimony in the best possible way for your client, within the ethical boundaries (ASCE, 2012);
- The skill of investigating and analysing technical content (ASCE, 2012);
- The drive to learn from each investigation by reflecting on the performed investigation (ESReDA working group on accident investigation, 2009);
- The skill of reporting observations, opinions, conclusions and recommendations (ASCE, 2012);
- The skill of understanding what the interests of the involved parties are and how they are can be affected by an investigation process (ASCE, 2012);
- Understanding of bias and its influence (ASCE, 2012);
- Qualities like open-minded, curiosity and a wide view (technical, process and human) (Janssen, 2018);
- The skill of organizing, managing and overseeing a team with different specialists when heading an investigation team (ASCE, 2012).

Methodologies for structural forensic engineering

In literature, there are several suggestions for practising structural forensic engineering. Three of the described methodologies will be discussed below.

The ASCE approach

The ASCE (American Society of Civil Engineers) has developed a publication with guidelines for structural forensic investigations. This guide describes the qualifications of a forensic engineer, the role of a forensic engineer in a legal setting, the investigation process and a code of ethics. This code of ethics describes how ethics have influence on accepting an assignment, conflicts of interest, the investigation process and testifying in a court of law (Kardon, 2012). The guide describes principles that are generally applicable, but the focus of the document is the legal circumstances of failure and preparation for legal proceedings.

The recommended investigation process consist of the following steps (Kardon, 2012):

1. *Conflict of interest clearance*: the first that needs to be established by the forensic engineering is if there are no conflicts of interest. This is done by not sharing information regarding the failure but only asking about the involved parties.
2. *Scope:* after accepting the assignment the scope should be determined with the client. The time and budget should be taken into account at this stage.
3. *Document* collection and review: all available documentation should be collected and carefully reviewed.
4. *Initial field visit:* the data collected during a field-visit will form the base of the analysis of the failure cause later in the process. Possible steps during the site-visit are:
   - » Photographing: to document the site conditions. Recommended is to make a distant and a close-up of each element you want to record. Another recommendation is to include a scale in your photo's to show the measurements.
   - » Interviewing: information coming from interviewing eyewitnesses should be checked

for reliability and correctness.

5. *Presentation of initial finding to client:* hypotheses can be communicated with the client and arrangements for additional investigations can be made.

The previous steps are repeated until the damage cause has been established.

Delft approach

The Delft approach has been developed by Delft University of Technology based on literature and practical knowledge from different expertise fields (civil engineering, aerospace engineering and biomedical engineering) practising some form of forensic investigations[1]. The Delft approach has been presented in an online open course: Forensic engineering; learning from failures (TUDF-FE01x). The investigation methodology consists of the following steps (Loeve, Schuurman, & Terwel, 2017):

- *Orientation:* stakeholders are identified, the scope and investigation question are determined, the investigation team is assembled, a data collection strategy is formulated, possible conflicts of interest are explored and initial information is collected;
- *Data collection:* the data collection step can be a desk study and/or a field investigation;
- *Hypothesis generation*: The goal of this step is to assemble a list with possible explanations for the cause of the failure. To systematically generate possible hypotheses, the Tree House of Failures (see figure 1) and the life-cycle of a technical system (see figure 2) have been developed (Loeve, Schuurman, et al., 2017). The tree-house of failure is a tool to support investigators to take all possible causes into account. The Tree-house of failure is divided into three main categories: product related causes, instruction related causes and execution related causes. Subsequently, these categories are subdivided into causal stems that each have different possible causal roots. The life-cycle phases diagram gives an overview of the stages a technical system will go through. The philosophy is that a failure potentially can have an origin in each of the life-cycle phases. By combining the two tools hypotheses can be generated. The investigator goes through each life-cycle phase and checks the Tree house of failure diagram for each causal stem and root that is relevant to the observed failure;
- *Hypothesis testing:* Each hypothesis is tested with the collected data to determine if the hypothesis provides a logical explanation for the data and failure. If none of the hypotheses provides a logical explanation you return to the previous steps;
- *Findings reporting*: All the above steps of the investigation are documented in a written report. The report should contain facts and give answer to the main investigation question;
- *Recommendations*: recommendations concerning safety and lessons to be learned are collected.

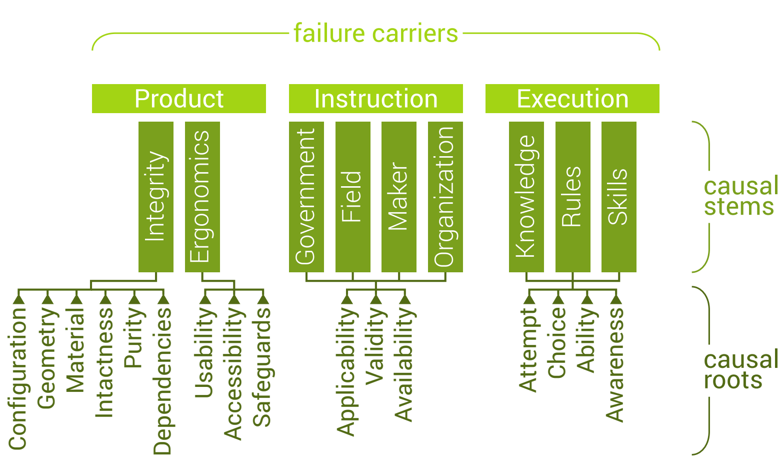


Figure 1 : Tree-house of failure. Source: (Loeve, Schuurman, & Terwel, 2017)

1 This material was created by or adapted from material posted on the Delftx website, delftx.tudelft.nl, and created by TU Delft faculty members (K.C. Terwel, A. J. Loeve & M. J. Schuurman), (Forensic engineering; learning from failures), (2017). DelftX is not responsible for any changes made to the original materials posted on its website and any such changes are the sole responsibility of M. Verbiest.

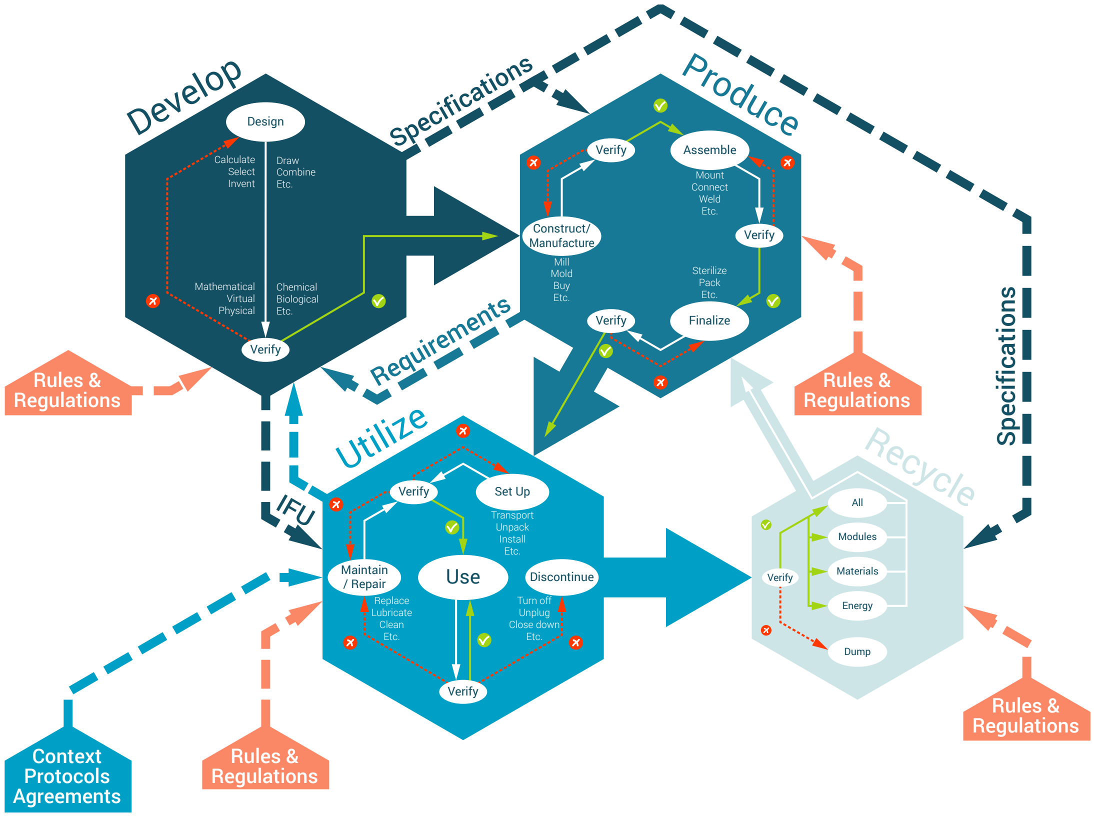


Figure 2 : Life-cycle of a technical system. Source: (Loeve, Schuurman, & Terwel, 2017)

The Delft approach introduces the principle of the ring of trustworthiness (see figure 3) to make an investigation trustworthy. The ring describes five principles (Loeve, Terwel, & Schuurman, 2017):

- *Objective*: the valuing and reporting of facts of an investigation has not been influenced by a person's personal opinion;
- *Repeatable*: the investigation should be repeatable based on the provided information in the report;
- *Verifiable*: the source of all information is clear and can be checked;
- *Complete*: no essential information to understand the investigation is missing;
- *Correct*: not containing errors.

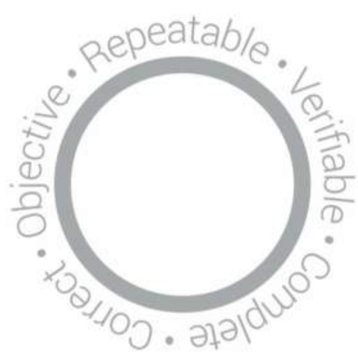


Figure 3 : Ring of trustworthiness. Source: (Loeve, Schuurman, & Terwel, 2017)

Investigation methodology for investigating leakage of subterranean concrete structures

For investigating causes of leakage in underground concrete structures an investigation methodology has been developed by employees of TNO (Borsje & van Zon, 2016). The process consists of six steps that are described below.

1A *Analysis of structure*: the idea is to analyse the behaviour of the structure by researching the following elements:

- Structural system: The material type of each element is determined and the connections between the elements are studied. This can be done by a desk study of detailed drawings and if possible on location;
- Construction order: The construction order can have an influence on how building

parts work together and also the climate conditions during construction have a significant influence;
- Loading of the structural elements: the goal is to determine how the loads and deformations of each element during construction and use could have influenced the damage and behaviour of the structure.

1B *Analysis of leakage*: this analysis consists of the collection of information on three topics:
- Location of the leakage: where does the moisture reach the surface and how does it travel through the structure;
- Development over time: how did the leakage develop and change over time;
- Moisture source: groundwater or rainwater or a combination.

2. *Possible causes*: based on the information from step 1A & 1B a list of all possible causes is developed. Each cause should be translated into a scenario explaining what happened before the leakage and explaining how the leakage developed.
3. *Verification and falsification*: All scenarios are analysed by verification and falsification. Verification is by observations that support the scenario and falsification is checking for every observation that excludes the scenario. Then, the scenarios are listed according to a qualitative estimation of their probability based on the collected information. The most probable scenario(s) are selected.
4. *Verification of most probable cause*: The most probable cause is then additionally analysed to prove the failure cause. For leakage, the most used method is by semi-destructive testing, exposing the moisture travel through the structure (Borsje & van Zon, 2016).

Structural forensic engineering in Dutch practice

In the Netherlands, the structural forensic engineering business can be roughly split into three parts. There are the investigations by the Dutch Safety Board (Onderzoeksraad voor Veiligheid) that focus on learning from failure and investigate all aspects contributing to the actual failure (technical cause, organisational aspects and human influence). The second category consist of the investigations by a few specialist companies (examples are TNO and Adviesbureau ir. J.G. Hageman) that have years of experience in structural forensic engineering. They participate in the investigation of large and/or well-known damages. Employees of these companies present theire investigation process and approaches regularly in lectures, presentations and published reports. The third category consist of all the companies that perform some kind of damage investigation. There is little public or written information available about this category regarding the number of companies involved, what type of investigations they perform and what investigation process they follow. This last group is the main focus of this research as they likely perform most of the small and regular straightforward damage investigations within the scope of this graduation research. Secondly, the amount of investigations they perform as a group are larger than the amount of investigations by the two other categories. In order to get a full picture on what investigation processes are common in Dutch forensic engineering practice information from within companies and investigators is needed.

This research tries to answer the following two questions:
1. What are the characteristics of Dutch structural damage investigation business?
2. What methodologies or protocols are used when investigating damage?

The goal of the first question is to get a description of the structural forensic investigation business to be able to make a comparison with other investigation fields. For a functional comparison between disciplines information on the following aspects has to be collected:
- Goal of the investigation
- Legal framework

- Available time
- Available budget
- Solo or teamwork
- Size of the damage under investigation
- Training of investigators
- Cooperation of stakeholders

Information on these aspects will give a more complete picture of the structural damage investigation business. This information is partly knowledge in the industry itself. Therefore, interviewing professionals in the business will give the best data. As a reference an estimation by the author as shown in Table 1 has been made.

The goal of the second question is to find out what investigation methods are used in Dutch practice. Currently, little information is available on investigation methods used in Dutch practice. For a master graduation thesis from 2010 (Miro-Downey, 2010) three interviews have been conducted with structural forensic engineers working in Dutch companies. All these interviewees belong to the group of specialist companies (category 2). In these interviews the interviewees were asked about the protocol they use when starting an investigation and if there are any governmental regulations regarding investigation methodologies. According to these interviews, the only standardisation is the ISO certificate. The ISO certificate regulates only the organizational quality of the business and not of the content or investigation methodologies used. Companies are free to develop their own protocols and methodologies. From the description of the protocols used it seems that methodologies generally follow the same scheme as proposed in literature: orientation, data collection, hypotheses generation, hypotheses testing and reporting (ASCE, 2012; Ratay, 2009)). The interpretation and execution of the individual steps seem to vary (Miro-Downey, 2010). As this conclusion is drawn upon three interviews and the interviewees were not asked in more detail on how they execute the different steps, additional research is needed to get a better picture of Dutch structural forensic engineering practice.

Table 1: Estimation of the characteristics of the structural damage investigation business

ESTIMATION OF CHARACTERISTICS OF THE BUSINESS	
Goal of investigation	Determination of responsibility/what party should pay
Legal framework	Non
Available time (man-hours)	?
Available budget	Depending on cost of replacement
Size of investigation team	Solo
Scale of average damage	Cracking, deformation etc.
Training	Self-educated / experience
Cooperation of stakeholders	Not obliged by law/ maybe by contract?

Based on the above described information, the following expectations regarding investigation processes used in practice have been formulated:

In Dutch practice, companies do follow roughly the same methodology (orientation, data collection, hypothesis generation, hypothesis testing and reporting) for investigating structural damage. However, the execution and interpretation of these steps vary among investigators.

Methodology

The method that has been used in this research is an interview. The interview consisted of two parts. The first part consist of open questions to get a description of the current Dutch structural damage investigation business. The second part will consist of an example damage case (fictional or a report of a case from the interviewee's own practice) where the interviewee will be asked to explain how he would perform the investigation. By posing supplementary questions about execution of the steps of the method used, more detailed data will be gathered. For the interview protocol and questions see Appendix B – Interview protocol.

The interview focusses on investigators from the third category (non-specialized companies that perform some form of damage investigation) where as discussed earlier little information on their investigation process is available. To select the participants of the investigation an internet search on companies that advertise with damage investigations has been performed. Additional companies are traced by looking into the arbiters and their workplace of the *Raad van Arbitrage voor de Bouw* and members of the *Nivre register* (register for damage investigation specialists). This resulted in approximately 30 companies that advertise damage investigation expertise. Looking at the results there is a distinction between technical oriented companies that sometimes specialize in certain building parts or materials and the more general damage investigation companies. For the comprehensiveness of the research an even selection of both categories is made. The same is done for the size of the companies both large and small companies where included. The companies are approached by phone or email.

For this research five investigators have agreed to participate in an interview. Two of them work for damage experts firms that mainly work for insurance companies. The other three investigators work for engineering firms. Two of the investigators work for large companies (multiple locations), two for middle-sized companies and one for a small firm (<10). The interviews have been recorded (when agreed by the interviewee) to allow concentrating on the conversation instead of note taking. The interviews are processed in a report, which is sent for approval to the interviewed person. For the interview reports see Appendix C – Interview.

Results

The interviews have been split into three parts: general information on the companies and interviewee's individual experiences, the professional context of structural forensic engineering and the investigation process the interviewee follows. The results are presented and discussed in the same order.

General information

The interviewees work for companies that have diverse backgrounds, specialties and sizes. Two companies perform damage investigations as their core business. They are specialized in damage advise and investigations in different professional fields like electrical and mechanical engineering, fire investigations and infrastructure. The other three companies have different core businesses, mainly engineering and structural design. Damage investigation is a small part of their work.

There is a large variation in type, scope and goal of damage investigations the interviewees perform. Even within the same company, there is a great variety in scope, goal and type of damage investigation. However, there are some general scenario's that reoccur through the interviews. They are described below:

- *The investigations appointed by insurance companies*: the investigated damages range in size from vibration damage to nearby buildings caused by constructing work to serious and large structural failures. These insurance investigations are mainly damages occurring during or soon after construction. The insurance driven investigations are mostly performed by a select group of companies that work regularly together with insurers. For these types of damage investigations, knowledge of the insurance world and legal proceedings is necessary. Within these investigations there are roughly two types of investigations.

   - *Construction all risk (CAR) – insurance investigations*: The CAR is a general insurance for building projects that covers the financial cost of technical damage independent of what party within the project contributed to the damage. The main goal of the investigation is to determine the damage sum/cost; investigating the damage cause is less relevant;
   - *Aansprakelijkheidsverzekering voor bedrijven (AVB)-insurance investigations*: The AVB is an insurance that is taken by individual companies involved in a project and covers next to technical damage also the financial consequences of the damage, An example is lost income due to a delayed opening caused by a third party. The damage cause and root cause are very important as this will determine liability and who has a legitimate claim. In these investigations both the technical and the organisational cause is important.

- *Investigations appointed by contractors and building owners*: the primary goal of the investigation is to solve/repair the damage. To do so, the technical cause of the damage needs to be determined. The scale of these damages can range from one crack somewhere in a building or damage occurring on multiple places within the structure or at different structures. These investigations can range from structures under construction to historic buildings. The investigation is in most cases followed by repair measures.
- *Investigations for building owners appointed by the government*. This concerns mainly investigations into a specific construction method or material because there is suspicion of structural safety problems. Examples are problems with balconies and the corrosion of corrosion-resisting steel inside swimming pools.

None of the participants received a special training to perform structural forensic investigations. All based their knowledge and expertise on working experience and own research. Two of them did special training to become a Nivre-registered damage expert. This is an organisation that controls a quality label given to the associated damage experts for several fields of expertise. All the participants had a construction or engineering background and came in contact with structural damage investigation during their projects. One of the participants had previously worked for the damage investigation department of TNO where the interviewee worked full time on structural damage investigations. This resulted in obtaining a lot of experience in a relatively short time period.

During their investigations the reoccurring damage types are: damages occurring during renovation/refurbishment projects, foundation failures, government advised investigations (balconies, corrosion of corrosion-resisting steel inside swimming pools etc) and small damages occurring in residential and office buildings. The scale of the projects differs from cracking in sheds for individual house owners to monitoring the building stock of a real estate manager or housing association.

The clients mentioned are:

- Insurance companies
- Real estate managers
- Housing associations

- Private parties
- Construction companies
- Municipalities

Professional context
Most interviewees indicate that they work solo on a damage investigation. Only when they need specialist knowledge they will consult a colleague or specialist. One of the interviewees indicated that they work as a small project team of two or three persons (project manager, inspector and construction engineer).

Both budget and time were not experienced as really restricting an investigation. Most clients give an investigator time and room to properly investigate and let them decide what is necessary. Most investigators are paid by an hourly wage. Man hours are the main component of the costs of an investigation, so will determine the total cost of an investigation for the largest part. In order to let budget not be a restriction on the investigation most interviewees explained that it is possible to perform the investigation in phases. After each phase a client can determine if he wants to continue. So first a preliminary investigation is performed that results in the damage cause and/or formulates aspects that need further investigation. The second step contains the costlier steps of investigating like tests on location or laboratory testing.

Investigation methodology
All interviewees have described their investigation process (see Figure 4). Most of the interviewees use a general process that is applicable for every investigation. In general, the following process is used by all interviewees although sometimes named differently: data collection/field visit, data analysis and reporting.

There are differences in the way the individual steps are executed. Some investigators follow detailed structured processes, others follow more their experience and instinct. The difference is more in the nuance between an analytical, highly organised approach and a freer 'go with the flow' line of action.

On the question how the investigators get from data collection to establishing the damage cause the most given answer is a sort of intuition. In other cases the damage cause is so obvious the process goes naturally. Other remarks are that often the same type of damages occur and with gaining experience the damage type is recognized faster. When asked on how to collect data during a site-visit and what type of data is collected the following techniques and data is mentioned:
- Interviewing of involved people (2x)
- Archive investigation (2x)
- Measurements on location or in laboratory (3x)
- Checking drawings with actual situation (2x)
- Collection of drawings and calculations (4x)
- Collection of contracts (2x)
- Collection of photographic evidence on location (3x)

All interviewees do make reports of their investigations. Some of them make interim reports depending on the investigation and the client. An overview of the different reporting structures can be seen in Table 2 and Table 3.

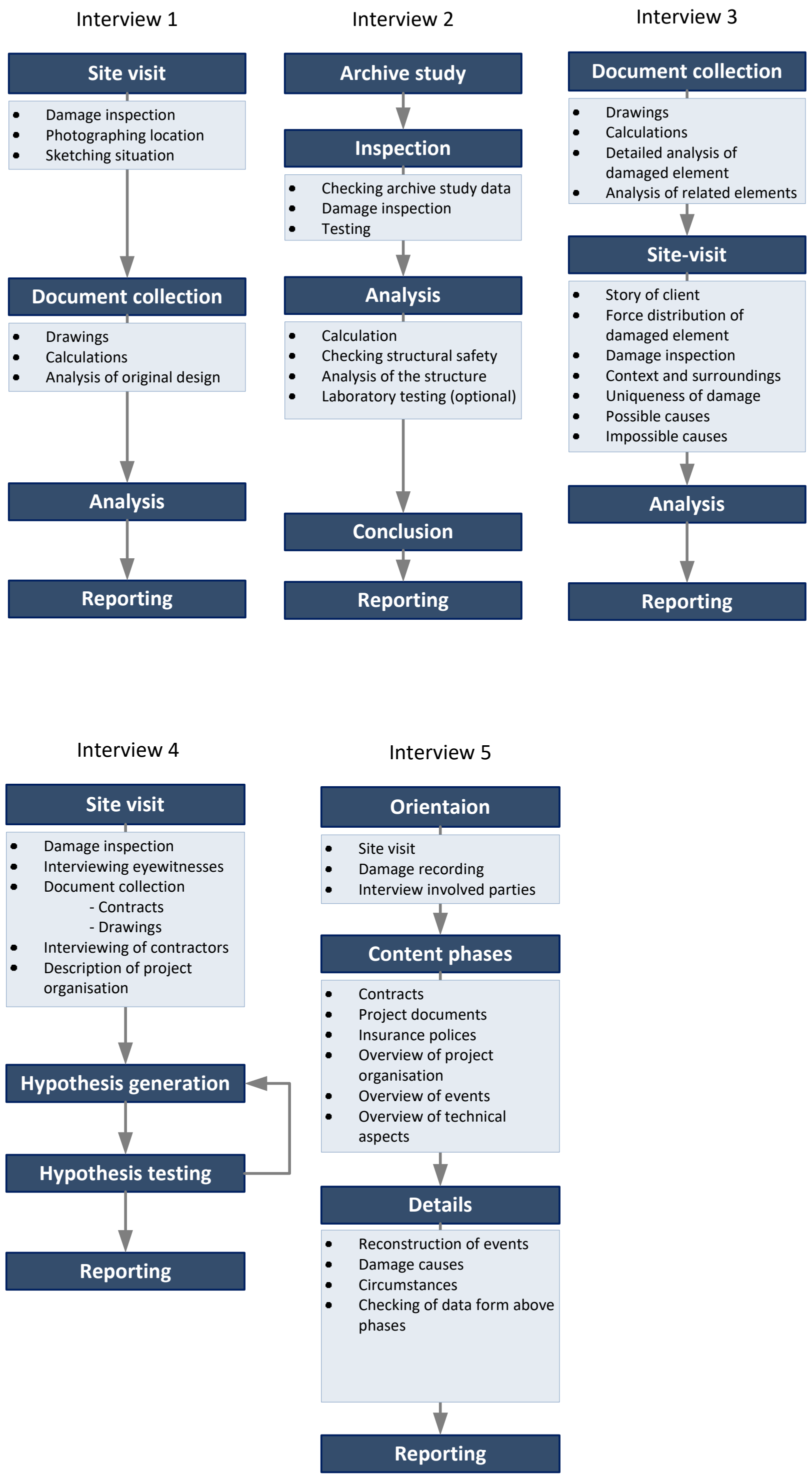


Figure 4: Investigation process of the interviewees

Table 2: Reporting structure general damage investigations

GENERAL DAMAGE INVESTIGATIONS		
Interview 1	Interview 2	Interview 3
1. General information: a. Client b. Problem c. Available info d. Description of the site visit and the data collected 2. Conclusion	1. Introduction a. Assignment description b. Investigation goal c. Context d. Investigation approach e. Chapter structure 2. Archive investigation 3. Inspection results 4. Calculations 5. Analysis 6. Conclusions 7. Recommendations	1. Introduction a. investigation question b. Reading guide 2. Description structure 3. Inspection information 4. Structural analysis 5. Conclusion and Recommendations

Table 3: Reporting structure of investigations for insurance companies

INVESTIGATIONS FOR INSURERS	
Interview 4	Interview 5
1. Facts 2. Relations between involved parties 3. Description of damage 4. Assessment of claim (monetary price) 5. Other insurance policies	1. Assignment and investigation process 2. General info a. Description claiming party b. Involved parties c. Capacity parties d. Description operations e. Contracts f. Other insurance policy 3. Event 4. Liability 5. Investigation a. Information client b. Information other parties c. Information third persons d. Own observations 6. Cause 7. Damage cost 8. Remarks

Other results are:

- Clients and people involved in the damaged building are generally not required to cooperate in an investigation, although this is generally not a problem. Regarding insurance investigations the clients are required to cooperate with the investigator by their insurance policy. Keeping in mind the rule that the burden of proof is with the claiming party;
- Two interviewees indicate that work experience on building projects and knowledge/experience of construction sites adds to a better and easier conversation when performing a damage investigation;
- Reasons to not accept an investigation assignment are: the client, not enough time for the investigations, lack of expertise or unsafe working conditions;
- When performing a damage investigation, awareness of the existence of different interests and the position of the investigator is needed. This means acknowledgement of the fact that the investigation can be sensitive is necessary. A diplomatic approach can be required;
- Reports should be written in such a way that it is clear what is meant and that the content cannot be interpreted in more than one way. This means a clear reporting structure and use

of clear language.

- Interviewees of the general damage investigations indicate that most of the time the data collected from location is very clear. The potential causes of the damage follow generally directly from the site visit.

Discussion

When comparing the outcome of the interviews and the expected outcomes formulated before the interview, several interesting aspects surface. When comparing the general expectations of the forensic engineering context with the interview results the following conclusions can be formulated:

- The goals of damage investigations are very diverse. The most mentioned investigation goal is to design or recommend repair measures and to make an analysis of the structural safety of the construction. For the damage experts, working for insurers determination of the financial value of the damage and the relation between the damage and the rules of the relevant insurance policy is the most important element of an investigation. Regularly, liability seems the underlying motive for a client to ask for an investigation, especially when related to insurances. However, the investigators explained that they report on the damage cause, relevant circumstances and repair measures but not on their opinion regarding liability. This liability conclusion is up to the client himself based on the investigation report.
- The available time and budget for an investigation seems to be different for each investigation. Time doesn't seem to play a very important role in the investigation process and won't influence the investigation process. Budget is in some way determining the investigations process because available budget can determine the level of detail and scale of the investigation process. The budget is influenced by the type of client (private person or real estate manager) and the investigation question (only a quick repair measure or a full structural safety assessment). A conclusion from the interviews is that there are strategies to ensure that budget is not defining the quality of the investigation result. Investigators offer to investigate in phases, in order to keep the cost as limited as possible. Other reasons to split the investigation in phases are to show the client the need and urgency of a thorough investigation and give the client intermediate results for presenting to their financiers or clients. Another strategy is to investigate to the point where a good indication of a damage cause can be given. If these causes all require the same approach in repair measures, proving the exact cause can be excluded in order to save costs. The investigators prefer being paid afterwards for real worked hours rather than making an fixed price contract beforehand. The main reason is that determining the final cost of an investigation is largely dependent on worked hours and investigations tend to be unpredictable beforehand.
- There is no legal framework. Clients and persons which are in some way involved in the damage, are also not obliged to provide all information. The exception is when this is included in a contract or with insurance investigations. Insurance policies include the obligation to cooperate in an investigation.
- Almost all investigators work alone on an investigation and are self-educated in the forensic investigation process.

At the start of this research, the expectation concerning the used investigation processes was there would be a general process used by all investigators. Interpretation of steps and used techniques would differ. The results of the interviews show that all interviewees use the steps: data collection, data analysis and reporting. Some investigators also identify the step of orientation and make a distinction between hypothesis generation and hypothesis testing. Data collection is often split into document collection/archive study and a site-visit. The general model hypothesis generation step is to most interviewees part of the data collection step. During the site-visit possible causes are formulated but not recorded in writing. Concerning data collection techniques and how to make sure to collect all available data it appears in most cases an intuitive approach is used. The same applies to hypothesis generation.

These conclusions give an indication of the processes used by investigators generally working on smaller and more straightforward investigations. By performing these interviews, the author has tried to collect some information on the group investigators of which little written information is available. The conclusions are based on only five interviews and can therefore not be interpreted as a general picture. However, the interviewees have been carefully selected to get a representable selection of company types, sizes, specialities and location in the Netherlands. The results are also in line with the results from the research by Miro-Downey (2010). This indicates that the results from these interviews give a fairly representative indication of the investigation processes used in Dutch forensic investigations.

Chapter 3

Forensic engineering in a broader context

Investigations into failure, damage, incidents, accidents and mistakes are practised in a broad context. Examples are aerospace industry, forensic investigations by the police, accident investigation in factories and on plants, medical incident investigations, investigations by the government, etc. Some of these disciplines have dealt with incident investigation for a long time and have developed protocols, methodologies and legal frameworks wherein they operate. The nature and context of the incident investigation can differ from profession to profession, but the question is: do these other professions offer valuable input for the structural forensic investigation process?

In this chapter, investigation methodologies used in two different professions (aviation accident investigation and fire cause investigation) and two connected research areas (case study research and human error) are discussed. First, the selection process of the to be discussed professions is described. The used investigation methodology and the professional context of the field are analysed. This is followed by an inventory of elements in their process that are useful in structural forensic investigation. The last part of this chapter will discuss the influence of research on theories about case study research and human error theory on a structural damage investigation process and methodology.

Profession selection

As stated before, there are several disciplines in which accident or damage investigations take place. To determine what fields are most useful to research for information on how to improve structural damage investigations, an analysis of the different fields has been made. The context in which the investigations are performed will have an influence on the investigation process and methods used. The discipline contexts are compared to the structural forensic investigation context by looking into several characteristics (see Table 4).

Table 4: Profession characteristics for comparison

CHARACTERISTIC	DESCRIPTION
Goal of the investigation	What is the main goal of the investigation: to learn from it to prevent future incidents or to assign some form of liability like blame or financial responsibility?
Investigation topic	Is the investigation about a technical topic or does it deal with human behaviour or organisational processes?
Range of investigation	What scale the investigations have: national or international?
Organisational structure	Is the investigation organisation of the profession hierarchical or does it have a more or less flat organisational structure?
Team size	How many members does a regular investigation team have?

CHARACTERISTIC	DESCRIPTION
Budget	How much investigation budget is available?
Training	To what extent did the investigators receive special training to perform investigations?
Protocol	Is there any prescribed protocol on how to perform the investigation and who issues the protocol?
Notification	Is there any obligation to report an incident/failure or event?
Cooperation	Are there any obligations for parties involved in the incident, failure or accident to cooperate with the investigation team?
Law	Is investigating an incident/accident/scene obliged by law?

The following disciplines are discussed:

1. Forensic investigation (police): tasks are to investigate crime scenes for traces of evidence to what happened.
2. Medical incident investigations into the cause of medical (near) mistakes or failure of protocols or equipment. (see Appendix D – Profession analysis);
3. Aviation incident investigation: determination of the cause of the accident or incident.
4. Fire cause investigation: determination of the start, cause and development of a fire.

By comparing the different characteristics of the investigation practices to structural forensic investigations (see table 5) it follows that fire-cause investigation has the most comparable characteristics. The incident investigation from the aviation industry and the medical profession have the most opposite characteristics of structural forensic engineering. The aviation incident investigation methods are chosen to discuss further in this research as the medical profession has based the development of the investigation methods and systems on the aviation industry (Legemaate, 2017; Molendijk, Legemaate, & Leistikow, 2008). Another argument is that medical investigations tend to investigate human error, while aviation has an equal technical and human influence part in the investigation. This fits more with the technical goal of structural forensic engineering within this research. For more analyses on the different professions and their characteristics see Appendix D – Profession analysis.

Table 5: Comparison investigation practices of professions to structural forensic engineering

CHARACTERISTIC	STRUCTURAL FORENSIC ENGINEERING (FSC)	AVIATION ACCIDENT INVESTIGATION (AV)	POLICE FORENSIC INVESTIGATION (P)	MEDICAL INCIDENT INVESTIGATION (M)	FIRE CAUSE INVESTIGATION (FI)
Goal	Liability/cost	Learning	Liability	Learning/liabiility *	Learning/liabiility
Investigation topic	Technical cause	Technical / human	Human	Human / technical	Technical
International/National	National	International	National/ International	National	National
Organisational structure	Flat	Hierarchical	Hierarchical	Hierarchical	Hierarchical
Team size	1 a 2	2 to >20	3 - +/- 10	+/- 5	1 a 2
Budget	Small - Large	Small - Large	Small - Large	Small	Small
Training	Non	Yes	Yes	Non	Yes
Investigation protocol	Every company different	Fixed (ICAO)	Fixed	Fixed	Investigator dependent
Notification of incident/ damage	non	Obligatory	Voluntary/Obligatory **	Obligatory	Voluntary
Cooperation	Voluntary	Obligatory	Obligatory	Obligatory	Voluntary
Embedment in law	No	Yes	Yes	Yes	No
		Most different		Most different	Most matching

* The main goal is learning but in case of a serious incident, the information can be used in a disciplinary board.

** Reporting of a crime is only obligatory in some cases like murder, abduction or threat to the state.

Green: match
Red: different
White: no compliance

Aeronautical forensic investigations

The aviation industry has long been providing guidelines and standards regarding incident and accident investigations. The first international legally established norm for incident/accident investigation was ratified on April 11th, 1951 as part of the International Civil Aviation Convention held in Chicago 1944. The Chicago convention *article 26* provides that the state[1] in with an accident on an aircraft occurs, has to start an investigation into the circumstances of the accident according to standards of the International Civil Aviation Organization (ICAO - part of the United Nations) as long as this fits within the national law (*Convention on international civil aviation* 1944). As an appendix to the convention agreement *Annex 13* was added. This document describes the international procedures for notification, investigation and reporting of an accident or serious incident. Over the course of time, Annex 13 has been revised and adjusted to new understandings and changing co-operations. The latest version is the 11th edition from 2016 (ICAO, 2016).

Because of this early international agreement on aviation incident investigation, procedures have become globally standardized and enshrined in law. Examples are *regulation no. 996/2010* of the European Union and *Rijkswet onderzoeksraad voor de veiligheid* in the Netherlands. Both laws point back to the Chicago convention agreement.

The goal of all investigations is to prevent future accidents and incidents and it is not intended for the determination of liability (ICAO, 2016) (council, 2010). The conception is that involved parties are therefore more likely to fully cooperate. The second reason for cooperation is the public opinion that aviation is considered a riskier means of transport, so proper incident investigation is a method to be trustworthy and therefore secure that public will keep using aviation as a means of transport. This will benefit the whole industry.

1 In aeronautical standards, the term State is used instead of country. This research uses the term state in line with the original documents.

LAW ON ACCIDENT INVESTIGATION

Article 26 of the Chicago convention: Every state has to start an investigation into the circumstances of an accident involving according to ICAO standards within their national law.

Annex 13: regulates the notification, investigation and reporting procedures.

N996 / 2010: goal of the investigation is only to avoid future accidents. The law bounds signatories to follow the procedures of Annex 13, assembling an investigation team and gives a reporting and investigation duty of every incident (council, 2010).

Rijkswet onderzoeksraad voor de veiligheid (2010): This national law (The Netherlands) regulates the authorization of the investigation board, the organisation of the board and the procedure for appointing members. Article 47 of the law states that only for avaiation investigations support of parties within registered members of the European union and the European economic area is allowed. Article 37, 38, 40 states that parties involved in the incident are obliged to fully cooperate with the investigation within their possibilities (Rijkswet onderzoeksraad voor veiligheid, 2004).

Additional to Annex 13 the ICAO also published a document (Doc. 9756) containing four parts that give more detailed recommendations for each of the phases in an investigation and provides recommendations for usable investigation techniques. As Annex 13 and this Doc. 9756 give a detailed description of how accident and incidents in aviation should be investigated their regulations and recommendations will be discussed in the following paragraphs.

Investigation methodology

When an accident or serious incident occurs, predefined protocols enter into force. These protocols are defined in Annex 13. The investigation will normally contain the following steps: the gathering, recording and analysis of the relevant data on the accident site, the protection of accident investigation records, the publication of safety recommendations, if possible the determination of causes and a publication of a final report. The investigating authority decides on what investigation procedure is appropriate (ICAO, 2016). The following order is regularly used: notification, investigation team composition, data collection, data analysis and reporting. Data collection and analysis have a circular nature. The main content of each phase is described below.

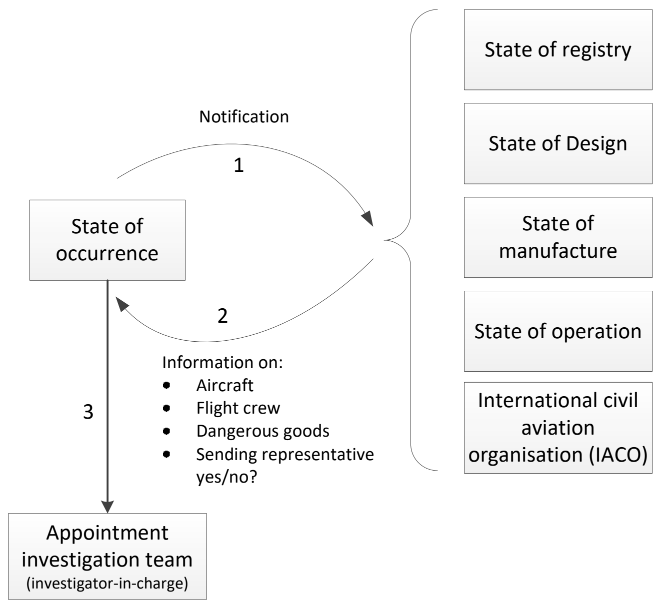


Figure 5: Notification procedure serious incident or accident. (based on ICAO 2016)

Notification

All parties involved in a serious incident or accident must be informed of the incident (Figure 5). The notification procedure is embedded in Annex 13 and therefore required by law.

Investigation team composition

Normally the state in which the accident/ serious incident occurred will take responsibility to form an investigation team. In the Netherlands, this is done by the Onderzoeksraad voor Veiligheid. First, an investigator-in-charge is appointed. The investigator-in-charge decides in collaboration with the investigating authority of the state what investigation team composition is needed and assembles the investigation team (ICAO, 2016). The investigator-in-charge has the following tasks and responsibilities (ICAO, 2012a, 2015):

- Verify that arrangements for securing the wreckage are made, normally in coordination with the police;
- Brief all investigation team members on safety practices and known and possible hazards;
- Assign responsibilities to the investigation team members;
- Coordinate investigation activities with other parties;
- Manage the investigation process;
- Assemble and analyse group reports;
- Draft final report.

The investigator-in-charge could in case of a large investigation be supported by a team of assistants (see Figure 6).

Under the investigator-in-charge several investigation teams with dedicated investigation topics are formed. In doc 9756 part II the possible teams are described. The teams can be divided into two categories (ICAO, 2012a):

- *Operational investigators*: Their responsibility is the gathering of the facts of the flight and flight crew activities before, during and after the incident, witness information, environmental conditions and all operational processes belonging to the flight.
- *Technical department*: their responsibility is to gather facts on the technical aspects of the flight. This includes the structure of the aircraft itself, maintenance, power supply of the aircraft, the survey of the incident site and collection and recording of all photo and video material on the incident.

In Doc 9756 a distinction is made between major accidents and smaller investigations. This distinction is made with respect of the investigation organisation and composition of the investigation team. This means that the scope and magnitude of the investigation should be determined in an early stage of the investigation. For large investigations, a large team is necessary. This can result in a large investigation team with individual members or even small sub-teams covering all investigation topics (see Figure 6). For smaller investigations, the topics can be divided among for example three investigation groups (see Figure 7). For the investigation into incidents or small accidents sometimes the investigator-in-charge only has help from one or two specialists to investigate. When an investigation has limited resources, it is important to do an initial survey of all the topics and decide which topics need a more thorough investigation (ICAO, 2012a). It is possible that in an early phase of the investigation the possible cause or investigation direction that will likely lead to the cause of the accident becomes clear. This can give direction to the investigation effort and resources, but it is important that all investigation aspects that might have contributed to the accident are covered by the investigation (ICAO, 2012a).

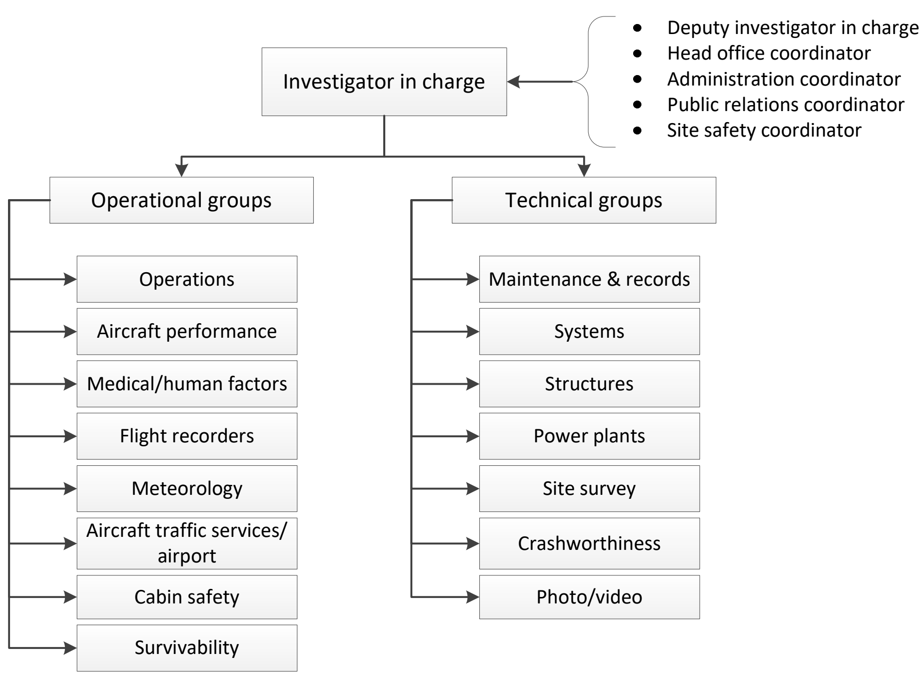


Figure 6: Example of an investigation team composition (ICAO, 2012a).

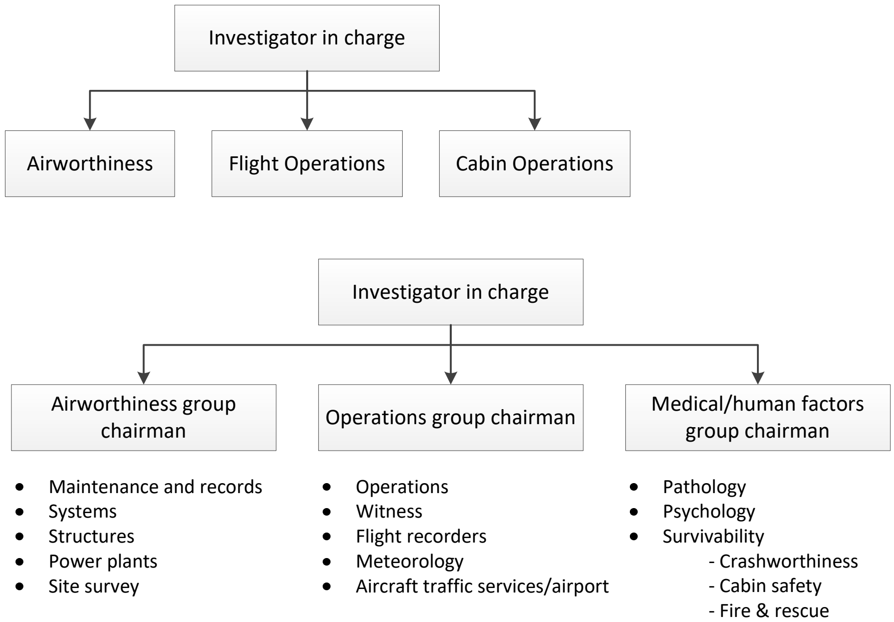


Figure 7: Examples of small investigation team compositions (ICAO, 2012a).

Data collection and analysis

Data collection and analysis will often be done in a circular manner as analysis will require new data collection. Document 9756 part III published by the ICAO gives guidelines for the execution of these phases. A list of all the focus areas and what the meaning of the investigation topic is given in Appendix E - Focus areas aeronautical incident investigation. The investigations that are of interest for the structural damage investigation process are further described below.

Wreckage investigation

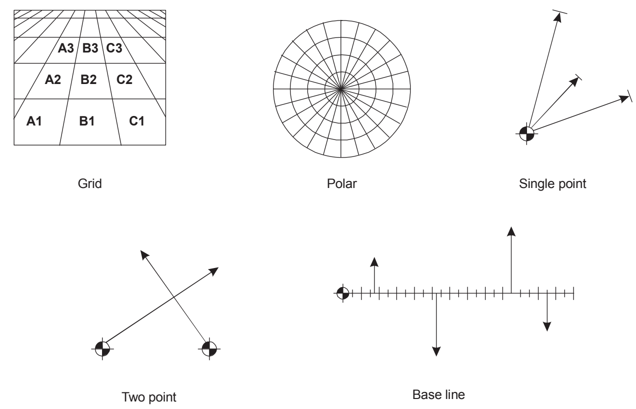
The wreckage investigation consists of three phases. The first step is to make photographs and video material of the accident site. In Doc 9756 part III there are checklists and descriptions of photographing equipment that are usable. Investigation team members are advised to practise incident photographing through special training situations and to train with forensic units of the fire brigade and the police. The photographs are taken in the following order to make sure that every aspect is covered:

1. Photographic and video material of the rescue operation.
2. Photographs of the ground markings.
3. Photographs of human tissue and their location.
4. Aerial photographs of the incident site.
5. Video of the walk-through of the site with video notes of first impressions. This can be used as a first briefing material for new investigation team members.
6. Photographs of the wreckage.
7. Photographs of the environmental conditions.

The second step is to record the wreckage distribution and annotate this in a wreckage distribution chart. This chart is used in the final report to describe the accident. The chart describes each part on scale compared to a starting measuring point. There are several possibilities for the starting point depending on the spread of the wreckage (see Figure 8).

The chart is composed by executing the following steps:

- Locate all the major structural parts of the aircraft by using a print of the aircraft and colouring all located structural parts;
- Basic terrain investigation;
- Recording the scope of the aircraft breakup;
- Retrieving recorded material from onboard the aircraft;
- Stacking of removed small parts and recording them with identification numbers in a logbook.



Items to be included on the diagram in addition to location of significant aircraft parts and surface features and reference marks:

a) magnetic north	i) location of witnesses
b) scale	j) prevailing wind and velocity
c) flight path	k) direction of sun and elevation
d) initial point of contact	l) location of navigation aids or airports
e) location of major components	m) date/time of accident
f) centreline of wreckage flow	n) point of contact for person making the diagram
g) location of crew and passengers	o) type and registration of the aircraft
h) location of fire pattern	p) geodesic survey standard (i.e. WGS-84)

Figure 8: Possible techniques for recording of the wreckage distribution Source: (ICAO,2012b)

The last step is to examine the impact marks and the debris. This will help to deduct what part of the aircraft struck the ground first. This examination will result in data of the direction, angle and speed of the aircraft.

Organisational investigation

This type of investigation has the goal of investigating how human behaviour has had influence on the incident or accident. To perform this part of the investigation a lot of different techniques are available. The investigator is responsible for selecting the most accurate investigation technique according to the goal of the investigation. Since this type of models are a theoretical research area on their own and not all techniques are relevant for this research into investigation methods for technical causes of damages a short explanation is provided in the text-box on page 38. This text box gives a limited description of the type of accident investigation models there have been developed over time. Each type is based on a different philosophy on how human behaviour has influence on a system. Some of the give examples are also mentioned in Doc 9756 like the Swiss cheese model and STAMP.

Operational investigation

The data needed for this part is mainly by interviewing witnesses. In Doc 9756 several recommendations regarding interviewing are made:

- The interview should be an interview and not an interrogation;
- The interviewing should take place as soon as possible after the incident as this will result in the most accurate data. There has been less time for interpretation by the witness;
- Interview eyewitnesses on the place they witnessed the incident as this will help to get context and likely more information;
- Interview in isolation and avoid influencing of the witnesses by keeping them separate so there is no room for discussion among themselves;
- Interview in two stages. First, let the witness speak freely and secondly ask specific questions and uncertainties without implying answers;
- Interview with two persons so one can record, and one can concentrate on the interviewee

Reconstruction of the wreckage
The following criteria demands for a wreckage reconstruction:
- Evidence of in-flight fire of smoke;
- Parts of the aircraft found at a considerable distance from the wreckage;
- Major parts are missing;
- Suspicion on explosives or sabotage of the aircraft;
- Evidence coming from autopsies that requires a reconstruction.

There are several reconstruction methods possible varying in time consumption, cost and needed equipment. The investigator-in-charge decides in collaboration with the relevant investigation groups if reconstruction is needed. Normally, the reconstruction will start with the simplest method and depending on the needs and effectiveness the reconstruction will be upgraded with a more complicated methodology.

1. *Simple layout*: parts are put on a surface to visually inspect and analyse the relationship between parts. This method is used in almost every accident or larger incident investigation. The cost of this technique is relatively low and can be performed by the already available team members.

Through the years several accident investigation models have been developed. Accident investigation models are the product of a research field that researches the contribution of human behaviour and technical failures to accident and incidents. The models are developed over time following new theories on human behaviour and can be categorized into three main types of accident investigation models.

Sequential models: These models consider an accident as a chain of events resulting in a failure. Examples are: Domino model, fault tree analysis and the 5 why method (Underwood & Waterson, 2013). These type of accident models are very usable for investigating technical cause and effect relations. The models provide possibilities to easily communicate the investigation e.g. by graphical representation of the events and their relations. Possible measures are relatively easy to point out. The problem with this type of model is that the causal links between events are subjective and by definition incomplete. Also, the starting point of the sequence is not a factual item but is open for discussion (Dekker, 2006).

Epidemiological model: The models in this category are based on the view that accidents are related to latent failures hiding in the system. The accident happens because of the activation of the latent failures with an outside factor. An example is the Swiss cheese model (Abdelhamid & Everett, 2000). These models help to identify more complex contributions to failure like organizational factors. The problem of this approach is that it can quickly become a waste of time as possible latent failures make up an endless list. This means that you can become overwhelmed by possible contributing factors (Dekker, 2006).

Systemic models**:** the philosophy behind this type of accident investigation models is that accidents are caused by an inadequate control of the interactions between the processes and components of a complex system. Accidents are considered the by-product of the normal functioning of a system. The great advantage of this approach is that the whole the system is considered and not only individual components and processes. This is a better representation of reality as accidents often will happen during normal functioning of the system. Examples are: STAMP model, FRAM model and the Accimap (Underwood & Waterson, 2013). The downside of these models is that the interactions of a complex system are difficult to model accurately. Secondly, it is hard to define when an interaction becomes not properly controlled (Dekker, 2006).

2. *Comprehensive 2D reconstruction*: This is a more extensive but relatively cost-effective method. The original layout of the aircraft is outlined with chalk and tape measure. The pieces are scaled up and with a distance between the pieces, so investigators can walk in between the wreckage pieces. This allows for an overview of the dependence of the pieces and will reveal irregularities in surfaces.
3. *3D reconstruction*: this is the most extensive, time consuming and costly investigation method. The method is not always needed for technical reasons but might be a tool for gaining of political or public support of the investigation. Most important is to develop exit criteria before starting the reconstruction because this reconstruction is never finished and continuing beyond a certain point will not always result in better understanding or additional information.
4. *Virtual reconstruc*tion: The possibility exists but is not jet used in practice as sole reconstruction method. The problem is the possibility of manipulating the data. The systems that can assure absolute data security are not developed enough. At the moment the virtual reconstruction is used for recording purposes after one of the physical reconstructions have been carried out.

Structure investigation
In aviation, there are several types of material failure. Two are comparable with possible material failures in construction. The first is a major component failure. This is not very common in aircraft accidents. In general, they result from (ICAO, 2012b):

1. *Inadequate design*: when a relatively new design fails this should be high on the suspicion list but is not very common. Mostly the cause is inadequate design when an accident happens after major modifications or extensive repair.
2. *Excessive loads on a component*: this can be the cause when the aircraft is operated outside its limitations. Most of the time this will happen after the aircraft recovers from an unusual situation. For this type of cause the witness statements are most likely to give relevant information.
3. *Deteriorating of static strength through fatigue or corrosion*: mainly occurring in older aircrafts. The major causes are: inadequate detail design, poor maintenance by improper installing or handling of parts, defective manufacturing and the occurrence of alternating loads that are not anticipated by the designer.

The second category of material failures are the partial failures. These are difficult to investigate because root cause and contributing causes are not always obvious. Often this type of failure can be recognized in alterations of the flight characteristics. Advised is to follow a routine investigation protocol and follow various leads and clues up to the point the cause is found. Examples of these techniques are the elimination technique and the reconstruction technique. The result or product of this investigation is a chain of events and a sequence of failure.

System design issues investigation
Historically aircrafts are designed with great attention for safety issues. However, during aircraft accident and incident investigation, the establishment of relations between the aircraft system design and the causes found in investigations is lacking. Accident investigations regularly make recommendations on design improvements or find design mistakes, but often it is not analysed how the cause of the accident was accounted for in the design. The objective of the system design investigation is to compare the real causes of the accident with the way these risks were accounted for in the design phase. This will give information on how risks and preventive measures can be better analysed and estimated in future designs, in order to prevent future accidents/incidents. The investigation should include analysis of: operation at time of failure, the safety assessment

process during the design phase, original design specifications, inspection intervals and the test and evaluation programm (ICAO, 2012b). This will answer questions like: Did the aircraft system exceed normal operating? Was the result of the failure properly addressed in the safety assessment process? Was the design adequate for the use of the aircraft? Were the specifications that directed the design fulfilling the real requirements?

Reporting

During a major investigation, all groups within the investigation will prepare a report for the investigator-in-charge. This report contains the following elements (ICAO, 2014):

1. *Introduction*: information on the organisation of the group, the investigation activities time and location and group members.
2. *Investigation*: description of the facts (considered relevant or not) and conditions of the areas investigated.
3. *Analysis*: discussion of the meaning of the above listed facts.
4. *Conclusions*: record of the findings by the group related to the investigated areas.
5. *Safety recommendations*: information on safety problems, safety actions taken and proposals for safety recommendations.

Based on the group reports the investigator-in-charge will draft a final report. In Annex 13, several agreements are made on the format and distribution of the draft- and final report. The draft report should be send to the following states for comments: state that instituted the investigation, state of registry, operation, design, manufacturing and any state that participated in the investigation. The final report should be sent to the above and states that suffered fatalities or serious injuries and states that provided facilities and relevant information. The final report has to be publicized by the state that did the investigation for use of accident prevention. If publication of the final report is not possible within a year, the investigation authority will present each year an interim report that describes the progress of the investigation. During investigation safety issues can be discovered. The investigation authority will then publicize safety recommendations as soon as possible even before the final report on the accident.

The goal of the final report is to prevent accidents in future and should therefore describe in detail what, how and why the incident/accident happened. The recommended format of the report is described in Annex 13 and detailed in Doc 9756 part IV. The final report contains the following items (ICAO, 2014, 2016):

1. Title containing information on: operator, manufacturer, model, nationality and registration of aircraft, place and date of incident/accident.
2. *Synopsis* containing all information on notification, accident investigation authority and the representation, organization of investigation, the date of publication and a summary of events leading to the accident.
3. *Factual information*
    a. History of flight
        i. Flight intention (flight number, departure place and time, point of landing)
        ii. Actual flight (preparation, description of flight and events leading to accident, reconstruction of flight path)
        iii. Location and time of accident
    b. Injuries of persons
    c. Damage to aircraft
    d. Other damage
    e. Personnel information

f. Aircraft information
g. Meteorological information
h. Aids to navigation
i. Communications
j. Aerodrome information
k. Flight recorders
l. Wreckage and impact information
m. Medical and pathological information
n. Fire
o. Survival aspects
p. Test and research
q. Organizational and management information
r. Additional information
s. Useful and or effective research techniques: indicate reason for using technique, the main features and results under the relevant sub-heading listed above.

4. *Analysis*: only information relevant for determination of causes and contributing factors.
5. *Conclusions:* containing a list of the findings, immediate and deeper causes and contributing factors resulting from the investigation.
6. *Safety recommendations*: all recommendations and safety actions should be with the purpose of accident prevention.
7. *Appendices*

The purpose of the recommended reporting order is to present information in a logical and convenient manner. When reporting on small investigations it is possible to use a predefined reporting template published by investigation authorities. This template can be more compact but will contain history of flight, analysis of factors contributing to the incident, deficiencies and the findings related to the deficiencies discovered by the investigation.

Liability and other purposes

The purpose of investigation is to use the information to prevent accidents in the future and not the determination of liability. Therefore, recommendations and provisions are made to protect investigation data and recordings. One of these provisions is the balancing test by a competent authority. This means that if a court of law wants disclosure of protected investigation records a competent authority considers and reviews if the disclosure is necessary and considers the consequences for future investigations (ICAO, 2016).

Another aspect is the use of the public final report of the investigation. The goal of the investigation is prevention of accidents and its perspective of the final report. Therefore, authorities should consider limiting the use of the final report for other purposes. Possible actions are (ICAO, 2016):

- Separate investigations;
- Only allow the factual information of the report being used for other purposes;
- Preventing the use of the final investigation report in proceedings for determination of liability.

All these protection measures should be regulated and implemented by the national law of a state.

Conclusion and recommendations

Aircraft incident and accident investigation is a very structured and organized business. The organization and structure are notable in all layers of an investigation, from the notification process of the accident to the recommendations given for techniques to perform specific investigations. The structure can be partly attributed to the enshrining of investigation procedures in the international law (Annex 13). The other reason is the availability of an international organisation (ICAO) that gives recommendations on how to perform an accident investigation. The positive result of this structured organisation is that every person involved in an investigation knows the process is and how the investigation is performed. This makes it possible to start working quickly together with a group of international people who have never met before at any location.

However, in the construction industry this degree of structure and organisation is not available. As the business of structural failure investigation is not international and performed by smaller teams, the need of such rigid organisational structure can be questioned. So, what can be learnt from this different world of aeronautics?

Possible lessons could be:

1. Some sort of investigation team structure with appointed roles can be functional if there is a larger investigation. This will help to divide responsibilities and tasks in a clear way.
2. Practical techniques that are recommended for aircraft investigation could be useful in construction investigation. Some of the precisely described techniques and their tips and tricks in the aviation investigation documents can be almost copied one to one to structural investigations. Examples are: interviewing techniques, damage description techniques like the wreckage distribution chart and suggested reconstruction techniques.
3. Investigation topics covered in aircraft investigation like system design investigation and organisational investigation can also be useful in structural forensic investigation as they help to uncover common design estimation mistakes, mistakes in the risk assessment and communication and organisational problems. Knowing about these issues can improve design quality of future designs. The techniques on how to investigate these aspects are not fully described and should therefore be further researched.
4. Reporting layouts of the aircraft investigation practice can be used to make a report template for structural investigations. By using some sort of fixed report outline, there is guaranteed that every report is logical, structured and complete. This enhances the usability and quality of the reports.

Another relevant discussion is the friction between the official goal of an investigation (to prevent accidents) and the reality of parties wanting to assign liability or blame. In the aviation accident investigation, the sharing of data and the cooperation of involved parties is regulated by law. Additional the publication of investigation reports is required by law. However, this can have serious consequences for parties when this information is used in courts for the assigning of liability or blame. A current problem is how to balance on the one hand the transparency of publication investigation results for learning and accident prevention purposes and on the other hand the not intended use of this information in courts of law. The same dilemma occurs in the construction industry. Currently, the primary goal is information for liability, although there is a growing interest in failure prevention. This results in the same area of tension and challenges. The aviation industry gives some recommendations on how to deal with this problem. The recommended measures are not directly applicable to the construction industry but can be used as a starting point in the discussion on how to shape this balance between sharing information for a common goal (improving safety)and the usage of the same information in a possible negative context of liability.

Fire cause investigation

Investigations to the cause of fires have been performed for a long time. The vision and the methods used have developed over time, parallel with the development of knowledge on fire, physics and chemistry. Fire investigation is a mix between science and law enforcement. The primary task of an investigator is to determine the origin and cause of a fire. Besides the technical aspect, there is also the task to determine if the fire has been started by a person as this will require a different approach to the investigation.

The fire cause investigator should be someone that has knowledge of combustion principles and ignition. He or she should also be able to use his scientific knowledge to interpret evidence and to determine the origin and cause of the fire (Technical committee on fire investigations, 2004). Other characteristics of a good fire investigator are: being able to apply accepted methods to interpret the physical data and verifiable observations (Noon, 1995). Because fire investigation is interdisciplinary task teamwork is essential.

There is not an international recommendation/framework for fire investigation methodology, although there exist some influential reports. Basically, it is up to the investigator or the organisation to determine the investigation process (Lentini, 2013). In the Netherlands, three types of fire investigations are possible: investigations by the forensic department of the police (prosecution), investigations by insurance companies (liability) and since 2011 investigations by the fire brigade and the Instituut Fysieke Veiligheid (IFV) with the goal to learn lessons for the future and to discover/monitor patterns. The fire brigade has one national team fire investigation with regional support teams. Their investigations concentrate on the following situations (Bureau brandweer nederland, n.d):

- Fires with casualties;
- Fires with unknown or technical causes;
- Fires that haven't been limited to one fire compartment;
- Fires with unexpected development;
- Fires with failing or good functioning preventive measures;
- Fires where there have been incidents or accidents with fire brigade personnel;
- Fire cases with a similar context to research patterns.

In the Netherlands, there is a training institute (Brandweeracademie) with an education program to become a fire investigator and where refresh training is given (Bureau brandweer nederland, n.d).

Methodology

In literature, there have been several methods suggested for investigating fire causes. The goal of a fire investigation methodology is to create a logical working frame, so an investigation can be performed effective. It consists mostly of two goals: determining the origin and the cause of the fire (Technical committee on fire investigations, 2004). The most influential publication on investigation methodologies has been the NFPA 921 document Guide for Fire and Explosion Investigations (1992). Initially, there was a lot of discussion about the recommended methodology as this method differed from the approach used up to that time. The procedure recommended by the NFPA 921 document Guide for fire and explosion investigations will be discussed later (Technical committee on fire investigations, 2004). First the main steps will be stated followed by a short explanation of the step and a description of techniques relevant to the structural damage investigation process.

The following steps are recommended in a fire investigation (Lentini, 2013; Technical committee on fire investigations, 2004):

1. Receiving of the assignment
2. Preparing for the investigation:
    a. Identifying the available resources
    b. Collection of basic information on the incident
        i. Location: this will determine the logistic side of the investigation and will indicate if there is need for special equipment.
        ii. Data and time: this gives an indication what data is available and where it can be found. When some time between incident and notification has elapsed, review of pre-existing records, photos and other data becomes more important.
        iii. Weather conditions: this will determine the personal equipment of the investigator and influence the fire ignition and spread. So, recording both weather conditions during incident and current conditions is important.
        iv. Size and complexity.
        v. Type and use of the structure: the use will indicate the possible hazards occurring during investigation (chemical exposure, number of involved people). Information on the type of structure makes anticipation regarding safety of site conditions possible.
        vi. Nature and extent of the damage: determined the need for special equipment and expertise
        vii. Security of scene.
        viii. Purpose of investigation.
    c. Organizing the investigation functions.
    d. Pre-investigation team meeting: only needed when there is a team. The goal is to assign the tasks, establish the investigation boundaries and brief the team on the on-site conditions.
    e. Invite specialist and technical consultants
    f. Case management: a system to organize the gathered data and to coordinate the tasks should be set up.
3. Conducting the investigation according to the scientific method (see text box pg 45).
    a. Examination of scene.
    b. Data collection and preservation.
    c. Analysis of the incident.
    d. Conclusions.
4. Reporting.

Receiving the assignment

This step includes the notification of the fire, establishing the investigators role and what the investigator is expected to accomplish during the investigation. In many cases the fire cause seems to be relatively obvious because of eyewitnesses. However, often the question remains why for example fire prevention measures didn't work or why machinery did fail. Also, the question if the fire was accidental or deliberate needs to be answered by the investigator (Lentini, 2013). As all these different expectations ask for a slightly different approach it is important to discuss these with the client.

Preparing for the investigation

The goal of this step is to make the investigation as effective as possible. The idea is to consider the information first and then determine the investigation process, resources and techniques.

Examination of the scene

When arriving on the scene, it is useful to make an initial walk-through when it is safe to do so. During the initial walk-through it is important to keep an open mind and not try to formulate hypothesis as this will cloud your observations. The goal is to get an impression of the scene and to determine a general plan for a detailed site inspection. Therefore the EOMSHIP approach is recommended: Eyes open, mouth shut and hands in pockets (Lentini, 2013).

Data collection techniques

There are several methods mentioned to collect data for a fire investigation. The goal is always to document the investigation, make it possible to revisit the site in your mind and to communicate the observations made at the scene. When reporting this data will serve as the verification and support for the conclusions of the investigation (Technical committee on fire investigations,

THE SCIENTIFIC METHOD

The scientific method is a methodology to investigate phenomena in a systematic and reliable way. The first version of the scientific method is thought to be developed by friar Roger Bacon in the 13th century. He combined the inductive method of Aristotle with scientific experiments. His ideas were not well received at the time as they were considered a threat to the teachings of the church (Noon, 2009). The first modern version of the scientific method is contributed to Sir Francis Bacon (1561-1626). He described the method in his book Novum Organum (1620) containing the following steps: first you collect facts and make observations that need to be verifiable of your to be studied subject. Then you analyse the data and make a proposition that corresponds with the data by using inductive reasoning. When you gather more data, you compare this with your proposition and you improve/alter the proposition to keep it consistent with the verifiable data. Bacon described that it was important to not generalize further than what the data factually tells (Editors of encyclopaedia Britannica, 1998; Noon, 2009).

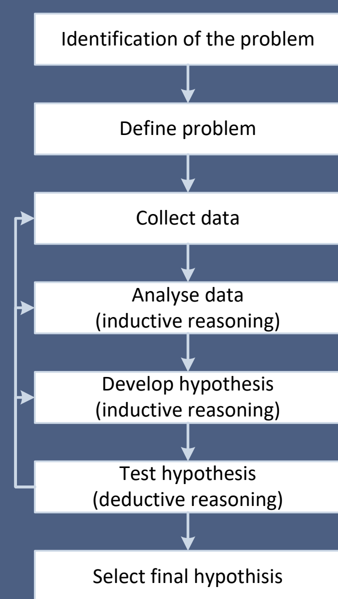


Figure 9: Process of the scientific model (Lentini 2013)

The modern version of the scientific method was influenced by the vision of rationalism (knowledge is considered possible to be gathered by deductive reasoning from basic principles). It consists of the steps presented in Figure 9 (Technical committee on fire investigations, 2004).

Inductive reasoning: is the analysis of data and the development of generalized propositions fitting with this data. This is a method that is suitable for developing hypotheses (Noon, 2009).

Deductive reasoning: is the process of developing theories by intellect (not experiments) from basic principles. This is a suitable method for hypotheses testing. From general principles a theory can be developed that can predict data. When again considering the earlier gathered data or gathering new data the predicted evidence will be found or contradicted. This process is also described as the falsification process (Noon, 2009).

2004). A lot of different data collection techniques can be used. Relevant techniques for structural forensic engineering are discussed below.

- *Photography*: this is one of the most important visual ways to document a scene. Photographes help an investigator to remind what he has seen. A method to systematically photograph the scene is by starting on the outside of the fire scene. The goal is to document the location of the fire and the structural elements of the building. When there is also fire damage on the outside of the building or to adjacent buildings, this should also be documented. The next step is to photograph the interior of the scene. As the main goal of the investigation is to determine the origin of the fire, it is recommended to start on the not burned parts of the room and work towards the most burned parts. This order is recommended so the investigators judgment is not directly influenced by an obvious fire origin with the risk of missing curcial clues visible on the lesser burnt areas (Lentini, 2013). To place a detail into the correct context sequential photos can be useful. Start with a distant position to the object that needs to be photographed in order to put it in its context and continue to take photo's while zooming further in on the detail.
  To document where pictures are taken a floor-plan is made. On the floor-plan indicate the position of the photographer and the direction of the photo with a symbol (see Figure 10). Other details are the date and time of the photograph taken, identity photographer and the fire. The data are important because when recordings are compared, changes in the scene can be registered (Technical committee on fire investigations, 2004);

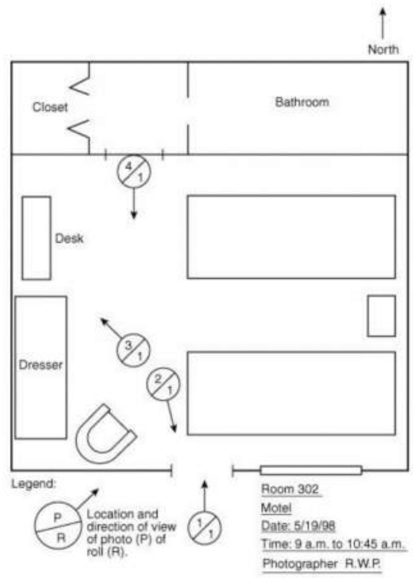


Figure 10: Photo location recording technique (Technical committee on fire investigations, 2004)

- *Note taking*: examples of data normally documented by note taking are: investigators observations, names and addresses, interviews and identification of evidence. Some note-taking can be done by checklist. For some examples of checklists see Appendix F – Fire investigation checklist;
- *Diagrams and drawings*: There are lots of drawings that can help clarify the situation during the fire investigation. Essential is a floor plan, as this will help people that didn't visit the site to orientate and is helpful to explain where evidence is found and where photographs are taken. Another helpful technique is the use of a floor-plan and side view drawings of the rooms affected by the fire. These can be used as a template to record/draw types of visual damage (see Figure 11);
- *Physical data:* Before removing physical data from a fire scene it is important that the entire site is documented. When removing

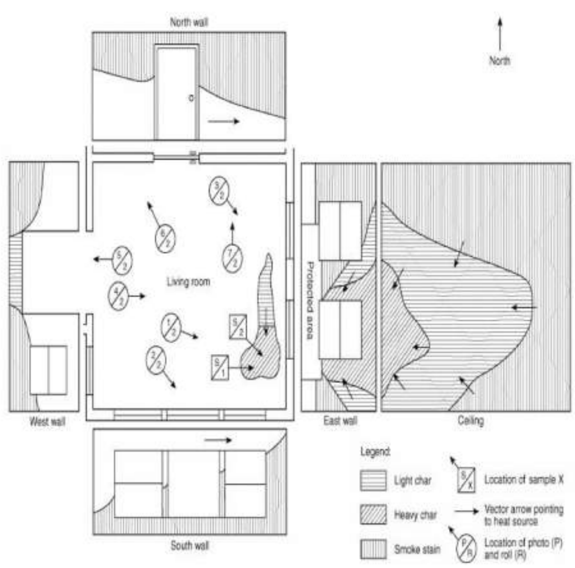


Figure 11: Example of damage type recording drawing (Technical committee on fire investigations, 2004)

physical evidence, it should be sufficiently labelled. The minimum information should be: the case number of the fire scene, the samples serial number, a description of the material, the location, the date of collection and the identification of the investigator taking the sample (Lentini, 2013).

Data analysis and hypotheses forming

For data analysis there are several techniques suggested. A selection is (Technical committee on fire investigations, 2004):

- *Time lines*: this is a graphic chronological representation of the events. This can help establish possible relationships between events and can assist in the investigation of the fire. A time line consists of hard times (factual validated times) and soft times (estimated times). All this information is important to determine the development of the fire;
- *Fault tree analysis*: this is a deductive reasoning technique where a logic diagram is constructed starting with the fire and describing possible events of conditions from before the fire. This tool can be used to develop alternative scenarios;
- *Failure mode and effect analysis*: This is a technique that is useful in complex and large incidents. It helps to identify the origin of a failure in a system. In case of a fire investigation, it is mainly used to identify all actions and material that could have contributed to the fire;
- *Heat transfer analysis*: This is a technique used for analysing the conduction, radiation and convection behaviour of the fire.

The hypotheses forming is a process that translates all observations and data into workable hypotheses. In this phase the investigator uses inductive reasoning to define the hypothesis and is therefore subjective. It is important to keep in mind that the hypotheses formed are only a mare possibilities and not certainties. The difficulty of this phase is to keep an open mind as an investigator can get too attached to his or her hypothesis, making him blind for other options. Therefore it is recommended to actively think in different/opposite directions (Lentini, 2013).

Hypotheses testing

Hypotheses testing is done by deductive testing. This means that a logic sentence is constructed of the form: If A is true then B will be true. The problem is that this sentence can be valid but doesn't need to be true. For it to be true the premises (A) has to be true. Therefore, the investigator is advised to test the hypothesis against all relevant validated data. When there is validated data that contradicts the hypothesis the investigator should theoretically abandon the hypothesis and reformulate a new hypothesis. In practice this is impossible as there is likely to be always some contradicting data. Therefore, the investigator should carefully analyse contradicting data and determine if it is relevant (Lentini, 2013).

Reporting

There are many possible reporting forms and will depend on the purpose of the report. A recommended format is (Lentini, 2013):

- Background section;
- Summary of important witness observations;
- Description of investigators observations;
- Conclusion.

A suggested approach is to present all the relevant photographs, video material, sketches and drawings in the discussion order. This will help structure the argumentation of the observations and accompanying conclusions.

Conclusion

The fire investigation community is like the structural forensic community divided by the different goals for investigation. There are three main goals: learning, liability and criminal prosecution. In the Netherlands, there are separate organisations that deal with the different goals: the fire brigade and the IFV, the insurance companies and the police. Like the structural forensic engineering investigations there are no fixed protocols for fire investigations. How a fire is investigated is up to the organisation that does the investigation. However, there are standards and books available that recommend using the scientific method. This method (containing the steps: identification of the problem, definition of the problem, data collection, data analysis, hypotheses development, testing hypotheses and selection of final hypothesis) can form a base for a structural damage investigation.

Because a major part of fire cause investigation is related to technical matters like fire origin and technical cause, the techniques recommended can be valuable in structural damage investigations within the scope of this research. Examples of useful techniques for structural forensic investigations are:

- *Site visit*: recommended is to start the site visit with an orientation round on your own to get an impression of the situation and to determine the best approach. When an investigation plan has been made, the actual inspection can start. This is an interesting idea for structural damage investigation site visits. The question is to what level this orientational walk through is applicable to the structural site visit context. A fire scene is a closed off, limited access and evacuated area and a location with a structural damage will often still be open to the general public. An orientation round during a structural site visit should be generally possible and useful, but it will most likely not be possible for the investigator to perform it on his own.
- *Photographing techniques*: the strategy used by fire investigators of systematic investigating the whole scene can be translated into a system to use for inspecting structural damages. The idea is to start from the outside and work towards the inside of a space and from the not affected parts to the worst damaged areas, in order to limit the risk of missing information and clues. Another useful method is the scaling of photographs from large scale to detailed. Also the recording of the photograph location on a plan drawing can be used during structural damage investigation site visits (possibly digital registration systems exist).
- *Damage recording by drawing*: the technique of sketching damages on plan and facade drawings is directly applicable to structural damage recording. The observed damages are coded on a plan or wall drawing with a different symbol for each type of damage. For example: white area's are denoted by dots, area's with map cracking with crosses, etc. This gives information of the spread of the damage over the space and can possibly be used for linking different damages.
- *Hypotheses forming*: the fault tree analysis and the failure mode and effect analysis are both possible techniques to use for structural damage hypothesis development. The functionality and applicability need to be assessed further.

Case study research

Case study research is a research method used in scientific studies. Research fields that use case study analysis are psychology, social science and anthropology. It is mostly used for: building upon theory, produce new theory, dispute existing theory, exploration of a phenomenon, situation or object (Yin, 2014). Case study research is defined as:

'An empirical inquiry that investigates a contemporary phenomenon in depth and within its real-world context especially when the boundaries between phenomenon and context may not be clearly evident.' – page 16 (Yin, 2014)

A case study research generally consists of the following phases (Reige, 2003):

- Research design (scope, objectives, etc.);
- Data collection (interviews, document review, observations, etc.);
- Data analysis;
- Report writing (document outline, facts and observations, etc.).

A comparison between the definition and the outline of a cases study research and structural forensic investigations shows that there are parallels (Table 6). A damage investigation is also a 'contemporary single phenomenon in a real-world context that needs in-depth investigation'. Also, the general outline of the process and the techniques that are used within the process are more or less the same. This means that the challenges related to getting a reliable, consistent result are also present in both case study research and forensic structural investigations.

Table 6: Comparison of case study research and structural damage investigation

CASE STUDY	STRUCTURAL DAMAGE INVESTIGATION
Similarities: • Scope is one single situation/object • Research methodology is not fully developed and described in literature • In-depth study • Risk of influence of the study by the researcher	Similarities: • Scope is one damage case • Investigation is not fully developed and described • In-depth investigation. • Influence on the investigation by the investigator
Differences: • Goal of the research is to do scientific study and to develop new theory.	Differences: • Often the goal is to find cause to determine who has to pay for the damage or to be able to restore or solve the damage.

In the scientific world, there is some discussion on the quality of the method, especially on the topic of reliability and validity of the methodology (Shenton, 2004). Advantages of the case study research method mentioned are (Krusenvik, 2016):

- Provides detailed analysis of an individual case;
- Result can be a suggestion on what to do in a comparable situation (Merriam, 1998);
- Helps to generate hypotheses for development of new theories;
- The method is appropriate for explaining the what, why and how of the events (Merriam, 1998; Yin, 2014).

Disadvantages of the method mentioned are:

- Difficult to generalize and determine causality of the results from a case study research (Flyvbjerg, 2006);
- Lack of validity and reliability of the results (Krusenvik, 2016);

- Possibility of influence by the authors bias (Merriam, 1998);
- Results in too much specific data and is therefore to costly and time consuming to analyse (Huberman & Miles, 1994);
- Lack of rigour. There are not many described methodologies to do case study research and therefore the researcher often does not follow systematic procedures. This allows for bias and dubious data to enter the research. This influences the quality of the findings and the direction of the conclusions (Yin, 2014).

Especially the disadvantage of the problems with validity (the outcome being factually sound) and reliability (the quality of being trustworthy and consistent) of the method and the results of a case study and the lack of rigour are relevant for damage investigation, since this can be a potential problem in damage cause investigations. There has been extended research on techniques to improve reliability and validity in the field of case study research. The most proposed technique is to pursue eight tests. Four of them are the traditional test and the other four are described by Guba (1981) and are more specific to qualitative research.

Traditional test criteria (Yin, 2014):

- *Construct validity*: measure of the extent to which subjectivity is avoided;
- *Internal validity*: measure to which the phenomena are established in a credible way;
- *External validity*: measure to which extend the relations between theory and results are established;
- *Reliability*: measure to which extend the procedures of the research are repeatable.

Additional test criteria for case study research (Guba, 1981):

- *Credibility*: The level of how the study measures what was intended to measure;
- *Transferability*: the extent to which generalization is possible;
- *Confirmability*: the extent to which the interpretation of the data is drawn in a logic and bias free manner. Other words used are objectivity and neutrality;
- *Dependability*: a measure for stability and consistency of the research process.

There are practical measures derived from these tests to improve the level of these eight test elements. The measures are developed for the different research phases and will help to improve the overall validity and reliability of case study research. For the measures see Table 7

As earlier established, similarities between the case study research and the process of a damage investigation occur. This means that techniques that are used in case study research can be applied to structural damage investigation process. When translating the eight test criteria into a structural forensic damage investigation, not all test criteria are relevant. Transferability is not very relevant for a structural investigation as most of the time the goal of a damage investigation is to study one case only without achieving generalization or new theory. The suggested techniques to improve the other test criteria can be translate to an application in the structural damage investigation process (see chapter 5)

Table 7: Techniques to improve the quality of a case study research

TEST	RESEARCH PHASE	TECHNIQUE TO IMPROVE
Construct validity	Data collection	• Use multiple sources of evidence (Yin, 2014). • Use triangulation (the use of several research techniques at the same time. When they result in the same conclusions this reduces bias or subjectivity) (Reige, 2003). • Establish a chain of evidence (Hirschman, 1986).
	Report writing phase	• Review of the draft reports by key informants and research assistance to check if interpretation is correct (Yin, 2014).
Internal validity	Data analysis	• Cross check the results and the data (Yin, 2014) • Use illustrations and diagrams to explain the data. This will make it easier to notice irregularities or errors in the data and forces to draw logical and correct conclusions (Huberman & Miles, 1994).
External validity	Research design phase	• Have a clear definition of the scope and boundaries of the research as this will make the level of generalisation clear (Reige, 2003).
	Data analysis	• Compare the results with existing literature and generalize within the scope of the study, not outside (Yin, 2014).
Reliability	Research design phase	• Describe for each research phase all the theories and idea's (Goetz & LeCompte, 1982). • Do the research with multiple researchers who continuously communicate and discuss the methodological approach (Goetz & LeCompte, 1982). • Use a structured case study protocol (Yin, 2014).
	Data collection	• Record observations as specific as possible (Goetz & LeCompte, 1982). • Develop a case study database for organizing and documenting of the data (Guba, 1981).
	Data analysis	• Perform a peer review and examination of your data analysis (Goetz & LeCompte, 1982).
Credibility	Research design	• Use research methods that are well established in qualitative research (Shenton, 2004) • Use triangulation (Shenton, 2004)
	Data collection	• Use random sampling (Shenton, 2004). • Use tactical questions (iterative questioning, voluntary participation) when interviewing informants to ensure honest responding (Shenton, 2004).
	Data analysis	• Consider the researchers assumptions and world view (Reige, 2003; Shenton, 2004). • Use negative case analysis (look for contracting or unsporting data) (Shenton, 2004). • As researcher, be theoretically oriented (Reige, 2003). • Present data analysis to colleagues (Hirschman, 1986).
	Report writing	• Present findings to respondents and take their feedback into account during reporting (Guba, 1981). • Write an extensive report on the research so you can convey nuance and circumstance (Shenton, 2004).
Transferability	Data collection	• Use specific procedures for coding and analysis of the data (Yin, 2014). • Make a database (Guba, 1981).

TEST	RESEARCH PHASE	TECHNIQUE TO IMPROVE
Confirmability	Data collection &analysis	• Do data audits by other researchers. The audit should contain: examination of the raw data and recommendations, examination of the quality of the findings and interpretations (Guba, 1981). • As researcher write a part on own predispositions and reflect on them (Shenton, 2004).
Dependability	Research design phase	• Be aware of researcher's theoretical position and bias (Hirschman, 1986). • Describe the processes of the study in detail so repeating is possible (Shenton, 2004). • Do an audit of the process by checking if the process is correct, understandable, well documented and provides mechanisms for bias prevention (Guba, 1981).

Conclussion

In the field of case study research, much research has been performed on how to improve reliability and validity of case study research. Since structural forensic investigation has a lot in common with case study research, it can be concluded that the principles suggested in literature to improve reliability and validity can also be applied to the structural investigation process. In case study research eight test criteria have been developed, some overlapping. In order to apply this to a structural investigation process the criteria should be limited and if possible reformulated. The practical measures that have been suggested to achieve each test criteria can, where necessary be translated to measures that are functional within an investigation process. Some of the listed measures serve different test criteria so the presented list can be compacted.

Human error theory

Human error theory describes the science behind human behaviour in the context of complex systems and discusses how human behaviour contributes to errors or incidents. In the context of this research human error theory is studied to understand the influence the investigator can have on a structural damage investigation he or she is conducting. As human error is a very broad research field only the aspects that have a connection with the context of this research are discussed. The following topics are included: how to categorize human error, biases that can influence the structural damage investigator and specific measures to limit the influence of each bias. Only biases and failure modes that can have an application in a forensic structural investigation have been considered.

There are several ways to categorize human error. The most common method is to split them into intentional[2] and unintentional actions and the reached outcome (good or wrong). For an overview see Table 8. Another way of defining human error types is to regard the cognitive performance level at which they take place. There are three cognitive performance levels: skill-based performance, rule-based performance and knowledge-based performance. Each level has its own type of failures (Reason, 2009). A selection of the failure modes is described below. Some of them are connected to the investigation process itself others are connected to the personal view of the damage investigator.

Table 8: Overview human error types

	Unintended action	Intended action	
Good outcome	Theoretical option/ lucky	Perfect situation	
Wrong outcome	**Slip of action** Two conditions: • Action is largely automatic • Attention is caught by something else to a certain degree	**Mistake** (planning failure) When there is discrepancy between intention and consequences.	**Slips and lapses** (execution failure) When there is discrepancy between intended actions and their execution.

Skill based failure modes

Skill-based failures can be split into failures caused by inattention or over-attention. Skill based failures mostly are connected to (semi) automated or familiar actions.

Reduced intentionality

This type of error happens when there is some time between the planning of an action and the execution. The risk is that you are diverted from the intended action by something that captures your attention and you forget or wrongly execute the planned action (Reason, 2009). This can be relevant to a structural damage investigation in the case of for example a site visit. The investigator plans what he wants to do during a site visit but is diverted during the site visit by something he sees and forgets half of the planned actions.

Measure: work in a fixed order so the steps are structured. This will help returning to the process after an unexpected interruption, so in the end the whole process has been followed and there is no step forgotten.

2 Intentional action in this contexts has the meaning of a delibarate/well thought off action with the intention of a good result. Intentional action in this context does not mean an intentional action with the intention of making a mistake or produce wrong outcome. This is malicious intend or foul action. This type of error is not considered in this research.

Perceptual confusion

This error can occur in a situation or with an object that appearce to be similar to the routine situation, is at the same location or functions the same. The error is that the object or situation is perceived as the object of situation that has been seen multiple times before (Reason, 2009). This is a mistake that can happen to a damage investigator when during investigations often the same damages are investigated. When encountering a seemingly same situation a too fast a conclusion can be drawn.

Measure: work with a systematic hypothesis generation approach that forces to consider 'out-side the box' options. A second solution is working with other persons. This automatically results in a dialogue and can limit the influence of this bias type. Another measure is to document for example all observations objective (without an interpretation) so they can later be reviewed.

Rule based failure modes

Rule based failure modes can be distinguished into the misuse of good rules and the application of wrong rules.

The first exception

This is a failure in the category of the misapplication of a good rule. When a rule has multiple times proven right in the past it is hard for humans to accept the first time the rule doesn't seem to work. It takes longer to realise that this is the exception although there is a clear indication of the rule not being applicable (Reason, 2009).

Knowledge based failure modes

This type of failure occurs when using the highest cognitive level. To this category belong the more widely known failures e.g. tunnel vision, that can have a large influence on the investigation and its outcome.

Confirmation bias

Confirmation bias is described as selecting a logical and reasonable good explanation and sticking to it. The problem starts when there is new information that contradicts the explanation and the person is not capable of letting the explanation go or altering it (Reason, 2009).

Measure: being aware of the existence of this bias reduces its influence.

Selectivity

When doing an action with a large amount of information, humans need to select where their attention is directed. Problems occur when attention is directed to the wrong information or not directed to the needed or most important information (Reason, 2009). This can happen during a forensic investigation during the inspection of the damage on location or when the wrong hypotheses are selected for analysis.

Measure: using a process that has reviewing loops. These reviewing loops force to consider if the right direction has been chosen.

Prior information bias

From prior research in the field of forensic science there are indications that information given before a site visit to a scene can influence the conclusions and hypothesis formulated after the site visit (Eeden van den, Poot de, & Koppen van, 2016). In the research there has been an experiment with a crime scene set-up, where experienced forensic investigators received a briefing with different information prior to entering the crime scene. After searching the crime scene, the investigators formed as a group the same two hypothesis but the percentage of investigators selecting one of the two hypothesis or choosing the option 'not conclusive' was significantly influenced by the information received beforehand. The research also showed that the amount and type of evidence material gathered was not significantly influenced by prior information given to the investigator (Eeden van den et al., 2016). In the case of a structural forensic engineer this means that it is possible that information on the damage received by the client can influence the way an investigator looks at the damage during a field visit. This is not always a problem but it could negatively influence the investigation when the prior information indicates strongly the wrong damage cause and the investigator becomes blind to contradicting evidence.

Measure: be aware of the existence of the bias. This reduces its influence.

Cognitive dissonance
When people get information that triggers them to change their opinions, this can be challenging and can cost some time. The danger is that people try to minimize the importance of the information, so they don't have to change their opinion (Kletz, 2001).

Cognitive entrenchment
Cognitive entrenchment is linked to experience. When a person has a level of experience he is likely to lose some flexibility. The problem with this phenomenon is that due to his or her experience the individual restricts the search space with the risk of the solution being outside this search space. Another problem of cognitive entrenchment is that it is often unconscious. The individual doesn't see the problem and is not aware of the mechanism (Brady, 2013).

Measure: use the insights and feedback of other people. When discussing something with another person they can provide the fresh insight in the situation so the search space widens.

Hindsight bias
Hindsight bias is the situation that when looking back more information is available than the people had during the incident investigation. The advantage of information is the possibility to look back in time to determine what events lead up to the incident and what the real circumstances were compared to how they were experienced. The problem as an investigator is that knowing the outcome will influence his ability to objectively consider the events. One pitfall is thinking that events inevitably lead to the incident whereas in reality also other outcomes could have been possible. Another pitfall is oversimplifying the causality of events leading up to the incident or damage. The last pitfall is the illusion of cause. This phenomenon is described as the human mind naturally linking visually small outcomes with a small, insignificant cause and large outcomes with a serious or severe cause. In reality, relatively small causes can have serious consequences and vice versa (Dekker, 2006). Another example of problems with hindsight bias is the judging of an existing structure with the current standards for structural capacity and requirements if the building has been designed using older norms and regulations. Applying new rules can result in an outcome that the structural capacity is not sufficient or the design was not correct according to new standards. This may mean that measures have to be taken but doesn't mean the original design was wrong or with mistakes. This should influence the way conclusions in an investigation report are presented.

Measure: place yourself diliberately in the position of the original person. Think what choices he/she had to make, under with circumstances and with what information. This will result in a more realistic view on the past decision-making process.

Cognitive fixation

One of the characteristics of cognitive fixation is that it is likely to appear in a situation where there is an amount of incomplete, uncertain and sometimes contradictory data. People tend to make a first interpretation of the data to have some sort of explanation to the data. The problem arises when people hold on to their first interpretation even when there is new evidence. The difficulty is to determine when to abandon an idea. There are two extremes: the end where you never abandon an interpretation even when it is obviously wrong (cognitive fixation) and constantly switching between idea's to the extent that you get lost (Dekker, 2006). This process is a kind of balancing act where in many cases the so-called 'middle-way' is the best solution.

Measure: constantly ask yourself the question, is this still the best explanation or do I have serious counter-evidence? Being aware of this phenomenon is in itself a measure to reduce its influence.

Chapter 4

Concrete damage

Concrete damage is a collection of different deterioration mechanisms that can occur in concrete. Another definition of concrete damage is everything of the concrete construction part that doesn't fulfil the expected functioning and/or purpose of the structural element. As there are a lot of different aspects to concrete damage mechanisms and different levels of detail to examine them, a selection of the to be considered theory has been made. This chapter will focus on information about concrete damage mechanisms that is applicable and functional during a forensic structural investigation process. This means that this chapter does not aim to provide a complete detailed discussion on all possible damage mechanisms or available test methods. The chapter starts with a general overview of possible characterisations and classifications of concrete damage. Then the chapter will discuss information required to determine the applicable damage cause based on the visual appearance of the damage. This is the most relevant link as during investigations the first available information on the damage is generally its visual appearance.

Classification systems

Concrete damage can be described by several characteristics: visual appearance, size, moment the damage is revealed, location it surfaces and date of construction. All these characteristics are usable in a classification of concrete damage types. In literature different systems are used (Delatte, 2009):

- Type of concrete material and production
- Cause of failure
- Origin of damage
- Mechanisms of attack
- Frequency of defects
- Monetary loss
- Structural element
- Repair measure
- Visual appearance
- Time when damage surfaces
- Level of damage

Some of these classification systems are more common than others. The classification by damage cause, attack mechanism and visual appearance (discussed further down) are often used in literature. There have been published several classification lists based on the damage causes (see Table 9). Classification according to cause can be difficult because damage can originate from a combination of causes and from the lists in Table 9 can be concluded that there are differences in categorisation techniques. This means that this type of classification is hard to get complete.

Classification by attack mechanism results in four categories (Delatte, 2009):

- Chemical attack
- Physical attack
- Biological attack
- Mechanical attack

This classification system results in a clear categorisation. However, this type is not so useful for an investigation into the technical cause of the damage. The unknown in the investigation is in most cases the attack mechanism.

Table 9: Concrete damage classification according to cause of the damage

Portland cement association (Portland cement association, 2002)	**International Union of Laboratories and Experts in construction Materials, Systems and Structures (RILEM)** (Javor, 1991)	**Concrete repair guide by bureau of reclamation** (Smoak, 2015)
• Corrosion of embedded materials • Freeze-Thaw deterioration • Chemical attack • Alkali-Aggregate reactivity • Abrasion/ Erosion • Fire • Restraint to volume changes • Overload • Impact • Loss of support • Surface defects	• Large foundation movement • Shrinkage • Creep • Temperature influence • Overload • Dynamic influences (fatigue) • Chemical influences	• Excess of concrete mix water • Faulty design • Construction defects • Sulphate deterioration • Alkali-aggregate reaction • Deterioration caused by cyclic freezing and thaw • Abrasion erosion damage • Corrosion of reinforcing steel • Cavitation damage • Acid exposure • Cracking • Structural overloads • Multiple causes

The classification of damage by visual appearance results in the following list (Delatte, 2009):

- Scaling: small, thin patches of the concrete surface come off.
- Spalling: thick (>25 mm) patches of concrete disintegrate from the surface.
- Curling: deformation of concrete planes.
- Colourization: other colours to the concrete that are not intended.
- Cracking

This type of classification can be useful for application in structural damage investigations, because the investigation starts most of the time with the visible element of the damage. This classification will later be discussed in more detail. Another less used type of characterisation can be functional to a forensic structural investigation: classification according to time when the damage became apparent. For example damages in existing older buildings are often caused by other mechanisms that damages occurring during construction or just after completion.

Visual characteristics to damage cause

The forensic structural investigation reasons from visual characteristic to damage cause(s). So in order to do this, knowledge of existing damage mechanisms is required. This list is very long and some causes can have endless appearances like wrong detailing of reinforcement. As the goal of this research is to develop an investigation process for regular damages of buildings and building like structures, only damage causes that are likely to occur in this category of constructions have been taken into account. This excludes damage causes that are found in for example dams, large water retaining structures or pipelines.

Previous research into damage causes per building typology shows that some type of damage causes are more common than others. One research listed the most found aggressive action causes for certain building typologies, see Table 10 (Somerville, 2008). Other often occurring damage causes are: excess of concrete mix water causing drying shrinkage cracks (Delatte, 2009), thermal cracking due to different temperature changes of building parts. Design mistakes give often problems with detailing of connections (reinforcement) that result in damage at supports.

Table 10: Concrete damage causes due to aggressive action (Somerville, 2008)

Building typology	Most registered failure mechanism (aggressive action)	Other significant failure mechanisms (aggressive action)
Buildings	• Carbonation related corrosion	• Alkali-silica reaction
Multi-story parking garage	• Chloride induced corrosion • Carbonation induced corrosion	• Damage due to frost action • Alkali-silica reaction
Foundations	• Sulphate attack	• Alkali-silica reaction

The challenge within this research is to draw conclusions on the possible damage causes from the visual appearance. This link has already partly been made for cracking in a publication of the concrete society (The concrete society, 1982). This resulted in Figure 12. There is less information available for other types of damages and for structural cracks. Therefore, a tool has been developed to quickly assess concrete damage.

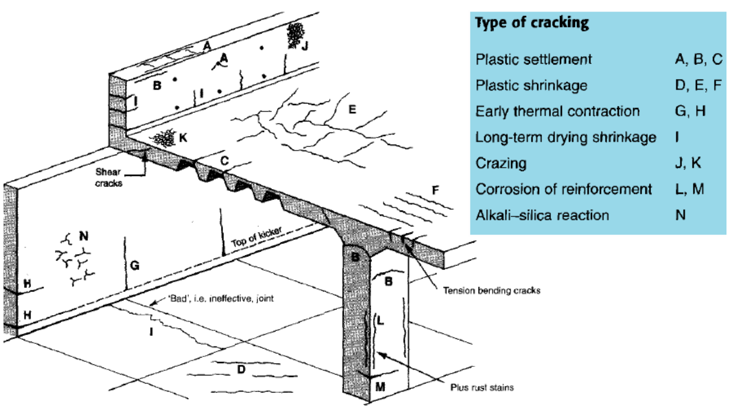


Figure 12: Examples of non structural cracks in concrete (The concrete society, 1982)

The concrete damage investigation tool

The concrete damage handbook (see Appendix G - Concrete damage handbook) has been developed to assist an investigator to determine possible damage causes based on the visual appearance of the damage. The tool gives possible damage causes that can help to develope hypotheses. This doesn't prove the damage cause. For functionality, four damage types have been distinguished: loss of surface, de-colouring/deposits, cracking and deformations. Each damage type has been split into distinguishing characteristics unto the point there is a collection of damage causes that have the same visual characteristics. For each collection an information page has been made with:

- Description of the damage
- Examples: photographs or drawings of the damage.
- Possible causes: a list of possible damage causes belonging to the visual characteristics is given. The list has been based on multiple sources that describe the resulting damages of the failure mechanisms.
- Conditions: some damage mechanisms are limited to certain element shapes, material stage

(plastic or hardened), environmental conditions, etc. These conditions can help further exclude possible causes.
- Test possibilities: first suggestions for tests to determine if the possible cause can be proven.
- Additional information sources: the classification and the formulation of the hypotheses is based on numerous information sources. The most functional and readable sources have been documented.

For the full concrete damage handbook see Appendix G.

Damage recording during a site-visit
When investigating a damage, a site-visit is part of the investigation process. Some specific concrete related information needs to be gathered. Collecting the following information is recommended in other to later be able to determine the damage cause.(Somerville, 2008):
- What effect can the failure cause have on the safety and integrity of the construction?
    - » Loss of cross-section
    - » Effect on resistance (shear, bending, torsion, bond, fire)
    - » Effect on material properties
    - » If the structure is likely to have changed failure mechanisms.
- What are the effects of the damage on the overall structural performance (strength, stability, stiffness, function, service life etc.)?
- What is the development of the failure mechanism over time?
- Are immediate actions are necessary?
- What are the environmental conditions of the overall structure?
- What are the environmental conditions at the damage location (wet/dry, exposed to outside, exposed to salts or chemicals, etc.)
- What is the overall concrete quality?
- What is the quality of the cover of the reinforcement?
- What is the overall load bearing system of the structure?
- What type of concrete elements have been used (prefab, in-situ, composite, pre-stressed, etc)?
- What connections have been used?

Part II

Research results

Part II contains the development and validation of an investigation process model for investigations into the causes of concrete damage.

First the development of the model is described followed by the end result (chapter 5). The next part describes how the model is validated. The part concludes with a description of the changes to the investigation process model based on the validation by two scientific papers, an analysis of several reports of real damage investigations and one performed case with the proposed investigation process model.

Chapter 5

Investigation process model

This chapter describes the development of a structural damage investigation protocol that can be used for the investigation of the technical cause of damage to concrete structures. The model is limited in its use to concrete damages that have a regular nature like surface damages, cracking etc. The investigation process model is not developed for usage after collapses or very severe damages.

The chapter starts with the requirements of the model. Followed by a description of the development process of the model. The last part presents an overview of the model. For a description of the investigation process model see Appendix H – Handbook investigation process model.

Requirements

The model should meet certain requirements to serve the intended purpose and users. Therefore, the following requirements have been stated before development of the investigation process model:

- The outcome of the process should be the technical damage cause or causes.
- The investigation model should be specific for concrete damages.
- The investigation model is to investigate regular (re-occurring) concrete damages like material / durability damages, cracking, surface damages, corrosion etc.
- The investigation process and/or the recommended techniques should be adaptable depending on the available time, budget and resources of the investigator/client.
- The investigation process should be usable by an individual investigator or a small investigation team.
- Within the model there should be mechanisms to limit the influence of bias and increase the credibility of the investigation and its outcome.
- The investigation process model should be presented as a tool and/or inspiration not as a strict prescription.
- The investigation process model should be adaptable or usable for different investigation goals within the scope of determining the technical cause of concrete damages.
- The investigation process model is not developed for usage in insurance investigations as they present other factors like organisational and human influence. This is not part of this model.

Development

The model has been developed based on a broad theoretical frame, complemented with practical input from interviews with structural damage investigators. The base of the investigation process model are the phases (orientation, data collection, hypotheses generation, hypotheses testing conclusion and reporting) described in the Delft approach. This decision is made based on the results from the literature studies. A number of existing investigation methodologies use the same main phases. Examples are the method described in chapter two for investigation of leakage in concrete structures and the scientific method used as base for fire cause investigation processes. The information from the interviews with investigators in practice also show more or less the same phases. Another feature of the Delft approach is the introduction of a reliability philosophy called the ring of trustworthiness. This principle is also usable within the investigation process model. How this is implemented will be discussed later on. The Delft approach introduces two techniques to generate hypothesis: the tree-house of failure and the life-cycle approach. These techniques have not been included in the developed investigation model. The technique is rather labour intensive and also focuses on human and organisational factors contributing to the damage. These factors have been disregarded in this research. So these techniques are very useful for large or complicated investigations but in this context a bit to extensive.

To complete the investigation process model, the phases client input and follow-up have been added to the general outline. The client input is located at the start of the process and is an element that is part of every investigation. The reason to explicitly state this phase is that the first contact with the client can be used in an effective way. This will result in a fast start of the investigation. The follow-up phase has been added at the end of the process. This step allows the investigator to review and analyses his/her process and improve the efficiency and quality of the next investigation. A company can collect the results of this self-reflection and improve the investigation process company wide.

As the main core of the model has been established, the question is: how to perform each phase? From the study into the fields of aerospace incident investigation and fire cause investigation several practical techniques have been translated into techniques that are useful in a structural forensic investigation. These techniques and their application for the general model are described below for each phase separately.

Orientation

Ethics (ASCE investigation process): the ASCE describes that ethical behaviour is one of the main attributes to a good investigation process. The ASCE guidelines describe the code of conduct where independence is one of the main features. In Dutch practice this means that an investigator should not accept an investigation project when there is a conflict of interest. Other judgments are to determinate if the investigation has the resources and knowledge to perform the investigation.

Receiving of the assignment (fire cause investigation): the goal of this step is to prepare the investigation and to establish the investigation goal. The following elements are also applicable to the structural investigation model: the determination of the investigation question/goal together with the client, the preparation of the investigation by analysing the location conditions (safe access to site visit) and required equipment. Additional necessary information for a structural forensic investigation is:

- The scope and goal of the investigation: this influences the focus within the investigation;
- Planning;
- Team size and composition;
- Expected problems.

Data collection

Document collection (interviews): the interviews show the importance of document collection. Documents that need to be collected are: plan-drawings, detail drawings, structural drawings and calculations.

Non-destructive concrete testing (concrete damages): when investigating damages on concrete structures, several test methods are available. A distinction between non-destructive testing and destructive testing is made. In practice non-destructive testing is most usable. Examples are: tapping (for determination of loose concrete parts), reinforcement detecting by either using a reinforcement scanner or removing the concrete cover, crack width measuring, deformation measuring etc.

These techniques can be useful during a site-visit depending on the damage type.

Wreckage investigation (aeronautical forensic investigations): the wreckage investigation is divided into three parts: photographing and filming of the incident site, recording of the wreckage distribution and an examination of the impact marks and debris. This will assist in deducting what happened when. The application for a structural concrete damage is: systematic recording of the structure, the damages and the context of the structure. If tests are being performed during a site-visit the process should be recorded. Other lessons are: record the damage related to a starting point so the scale, distances between damages and location of the damage is known. In most structural damage applications, the grid of the building (from plan drawing) can function as this starting point. If line like structures exist, it is functional to use a base line and investigate along and relate all damage locations to this base line.

Interviewing (aeronautical forensic investigations): for interviewing people several recommendations have been given. Within the context of the intended users and type of investigation some of the recommendations are relevant, others aren't. The relevant applications are:
- Interview, if possible, people in isolation to avoid influencing each other;
- Interview in two stages (first let them talk freely, then start asking questions);
- Interview in the form of conversation and not interrogation.

Site-visit (fire cause investigation): The site-visit for fire-investigations is divided into two parts: first an initial walk through to get a feeling for the scene and to determine the inspection approach. A silent, only observing approach is recommended. The second step is to perform a detailed examination of the scene. For a site-visit of a structural damage it is also possible to split the visit into two parts. The first walk-through can be used to get an impression of the situation. Normally the investigator will be accompanied by the client and a silent, only observing approach is therefore not realistic. It might be a suggestion to swap the order, do the silent walk trough secondly. To make the most of the first walk-trough, interviewing the client on the events is a good possibility. The initial walk-through can also be used to gather information from the owners or residents and to get a general picture of the load bearing structure. It is recommended to do a second walk-trough on your own. This allows the investigator to concentrate and focus on the inspection and damage data collection.

Data collection techniques (fire cause investigation): There are several data collection techniques that are proposed:
- Photographing order: to keep photographing and inspecting systematic it is advised to start on the outside of the building and work towards the inside. It is recommended to start at the non-damaged parts and then work towards the damage. This makes it less likely that small damage indicators or clues are missed.
- Photographing of the damage itself: start with a distant position that shows the damage with context. Continue photographing closer to the damage until the wanted level of detail is reached.
- Photographing recording: draw on a plan the locations of the photographs and in what direction they have been taken. This will later be helpful to

distinguish between photographs and different damages.
- Diagrams and drawings: take available diagrams and drawings to the site-visit so that damages can be annotated on the plan and wall / facade drawings.

Reconstruction techniques (aeronautical forensic investigations): There are several types of wreckage reconstruction possible. They increase in cost, difficulty and execution time. With the intended type of damage for this investigation process reconstruction will not be common. If there should be a situation that requires some small form of reconstruction the most relevant is the most basic form of reconstruction: a simple layout. This means that pieces are spread on a surface to inspect the individual pieces and determine the relation between them.

Hypotheses generating

Hypotheses generation techniques (fire cause investigations): the literature on fire investigation processes describes several hypothesis generation techniques. Most of them are specific for fires. Others are more general (time-lines) but as time has not a significant role in concrete damage causes the technique is not useful in this context. One of the interesting techniques is the fault tree analysis. This is an investigation technique that is used many fields. It tries to reason from the actual failure back to the cause in a tree like diagram. The selections and diversions are qualified by using for example formal AND, OF an OR ports. As this is a rather extensive method and this model is for regular investigations a similar technique, the cause and effect diagram, has been selected. This technique follows the same approach but is less formal prescribed and results in less reporting.

C*ommon failure mechanisms (concrete damages):* the resulting concrete damage model described in chapter four can be used as a hypotheses generation tool for concrete damages.

In order to present other usable hypotheses generation techniques additional research has been performed into hypotheses developing techniques. This resulted in the additional methods called: brainstorm and general hypothesis generation (see Appendix H - Handbook investigation process model).

Hypotheses analysis

Mathematical analysis and laboratory testing (interviews): both are mentioned in the interviews as techniques to prove hypotheses.

Validation and falsification principle (scientific method): hypotheses testing should contain two phases according to the scientific method. First the hypotheses should be validated with earlier gathered data. This results in one or a few remaining hypotheses. Secondly the most probable hypothesis will be tested by falsification. This means that effectors are done to prove the hypothesis wrong. If this is unsuccessful the hypothesis can be accepted as the damage cause. The value of this method is that it limits the influence of tunnel-vision and other biases. By explicitly trying to prove the favoured hypothesis wrong, any hypotheses that have remained due to tunnel-vision are dismissed.

Reporting

The aeronautical forensic investigations, the structural forensic investigation literature, the interviews with investigators and the fire-cause investigation literature all recommend using a f*ixed reporting structure*. The elements that at least should be present are: some form of introduction with a context and problem description, an description of the collected data, a data analysis and a conclusion. For this model the report has been structured according to the investigation process phases. This means that the report will contain:

- Introduction with goal and scope;
- Data collection;
- Hypotheses generation;
- Hypotheses testing;

Reliability of the investigation

Reliability in this context is defined as a measure for the level of trustworthiness of the investigation process and subsequently the investigation results. This has two aspects: the client expects a good investigation and wants an outcome that he can be sure of to be correct and technically sound. An investigator/consultancy wants to deliver a quality product, in this case a damage investigation of good quality. On the other hand, humans are bound to make mistakes. The damage investigation process also has elements that are of a creative nature, which is more open to taking wrong decisions and reasoning the wrong way round. The literature study has shown there are possible measures and thought processes that can be put in place to improve the reliability of an investigation process and its outcome. These measures also limit the influence of bias and faulty decision making.

As discussed before, the Delft approach introduced a reliability philosophy by defining the ring of trustworthiness. The principles of the ring can be integrated into the investigation process model. This is possible by applying the results of the study of validity and reliability of case study research to the definitions of the ring of trustworthiness. These practical measures will assist in reaching the principles of the ring. Some measures are applicable to the all phases of the investigation process model. Others are specific to a certain phase. For the application of the ring of trustworthiness see table 11.

Table 11: Overview application ring of trustworthiness

PHASE	PRINCIPLE	RECOMMENDED ACTION
All	Objective	• Be aware of your theoretical viewpoints and bias. • Use triangulation (the use of several research techniques at the same time). Reaching the same result is proof of the objectivity of the results. • Conduct the investigation with a team that discusses the methodological and theoretical approach.
	Repeatable	• Describe the used theories and ideas for each investigation phase • Use a structured investigation process and write it down in the final report.
	Verifiable	• This is mainly applicable in the data processing and reporting phase. For recommendations see these steps.
	Complete	• Perform an audit of the investigation process by a colleague. The audit should contain a check of the completeness of the process, if the process is logical, understandable and fully documented. • Check if there is a clear scope definition and if this is respected in the investigation.
	Correct	• Use triangulation. • Perform an audit of the investigation process by a colleague. The audit should check the correctness of the used process (logic, well documented, understandable and the presence of bias prevention measures). • Use research techniques that are widely regarded as reliable and of high quality.

PHASE	PRINCIPLE	RECOMMENDED ACTION
Orientation	Objective	• Execute the investigation in a team and discuss the investigation process and techniques.
Data collection	Repeatable	• Describe the investigation process in detail so repeating of the process is possible.
	Objective	• Use multiple sources to collect data. • Establish a chain of evidence for physical evidence and test material by recording all actions and changes that have taken place. • Perform regular data audits by other investigators to review the quality and techniques of data collection.
	Repeatable	• Record data as detailed as possible. Including the original location and its appearance. • Record observations as precise as possible. • Make a database for storage and organisation of the original data. • Record the used data collection techniques. • Use specific procedures for coding, recording or storage of data.
	Verifiable	• Make a database for storage and organisation of the original data. • Record data as detailed as possible. Including the original location and its appearance. • Record observations as precise as possible.
	Complete	• Use a systematic data collection approach during a site visit.
	Correct	• Use specific procedures for coding, recording or storage of data.
Hypothesis analysis	Objective	• Consider your personal assumptions and predispositions and view on forensic engineering, construction world and theory and determine if they influence your analysis. • Use falsification and actively search for unsuporting data. • Present hypothesis analysis results to colleagues. • Be theoretically oriented.
	Repeatable	• Document your analysis and argumentation in detail.
	Verifiable	• Document your analysis and argumentation in detail
	Complete	• Perform a peer review on your analysis and conclusions.
	Correct	• Crosscheck results with data. • Use illustrations and diagrams to explain data and arguments. This will expose irregularities and mistakes and forces to draw logical conclusions. • Compare results with literature.
Reporting	Objective	• If people have contributed their professional opinion to the investigation and this is recorded let them review the final report to make sure you have the correct interpretation.
	Repeatable	• Report on the investigation procedures and techniques.
		• Present all relevant data, arguments and observations in a structured and systematic way. • Make a separation between factual data and personal observations or theories.
	Complete	• Write a detailed report on the investigation so you can include all steps of the investigation including nuances and circumstances.

Result

Combining all this information on investigation processes, the model requirements and the information on concrete damages, an investigation process model has been developed. For a schematic overview of the investigation process model see figure 13. The model has been designed as an independent guide. Therefore descriptions of the individual steps have not been included in this chapter. For the description of the model see Appendix H - Handbook investigation process model.

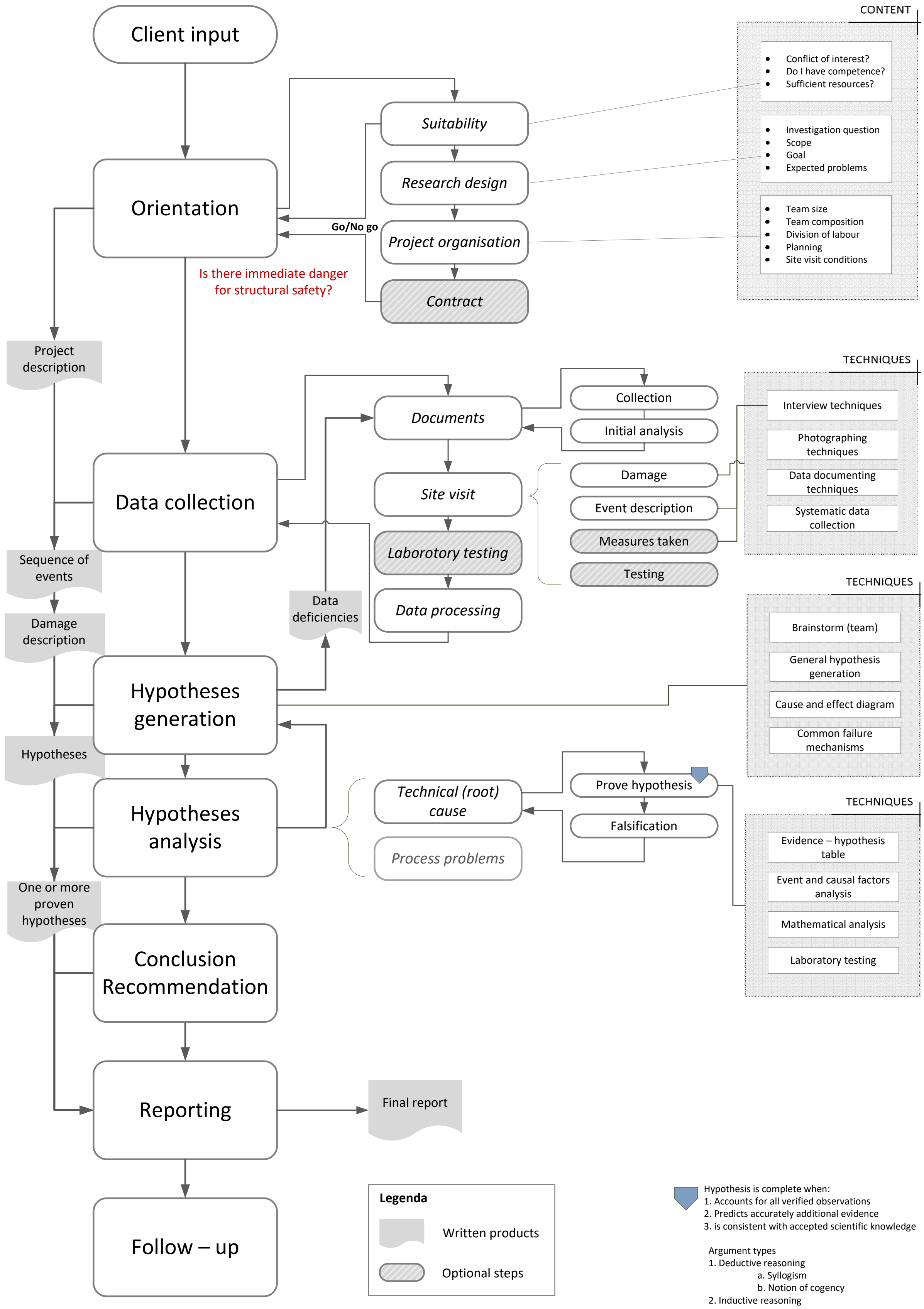


Figure 13: Schematic overview investigation process

Chapter 6

Validation

The proposed investigation protocol/model is mainly based on theoretical information from literature on structural forensic engineering and practices used in other industries (aerospace and fire cause investigations). This theoretical information was complemented by some insights from the interviewed investigators. To be able to give information on the usability and practical value of the model/protocol a validation has been performed. Validation gives information on the functionality, completeness, practicality and quality of the developed model. The goal of the validation is to test the model against practice. This will result in input to improve the model. To perform the validation two methods have been chosen. First the model is tested with real cases to determine the practical value, functionality and completeness. Secondly the model is compared with two articles on structural investigation protocols that have been recently published.

Case study

During the last phases of my research I got the opportunity to study real damage investigations performed by Adviesbureau ir J.G. Hageman B.V. I was invited to work in their office, search their project database and read reports on damage investigations to get an impression of the investigation process as performed in practice. Based on this opportunity to compare the developed model/ protocol for investigation of technical causes of concrete damages with investigation in practice, a validation method was developed to analyse the proposed model. The goal of this validation method is to compare the developed model with the common practice and to test its practical value. First the used method will be discussed, followed by the results of the actual analysis. The analysis will be concluded with recommendations on improvement of my model/protocol.

Method

The developed protocol/model focusses on regular, smaller concrete damage investigations. The model is largely based on theory with some input from the interviews with investigators. Adviesbureau ir J.G. Hageman B.V. is a specialist company with extensive experience in the field of structural damage investigations and has a long history of performing damage investigations. They perform both large specialist and publicly well-known cases and more regular investigations. Generally, the investigation process for small investigations is not fully or extensively described in investigation reports. As the focus of the model is actually on these small cases the challenge is to find a way to compare the developed model with practical cases and their sometimes limited documentation. Another challenge with a case analysis is that comparing the model to a single case is not very reliable as a case that fits with the model can (deliberatly) be chosen. This can result in an unfair comparison. To accommodate both mentioned possible unfavourable effects, the verification process will consist of two parts. First a general comparison between the phases of the developed model and the investigation process and gathered data of a couple of cases will be made. The goal of this first part is to make an analysis between multiple cases and the model to establish the completeness and feasibility of the model. The second part will be the execution of a small concrete damage investigation according to the developed model based on the available data (photographs, drawings, client input) for a case from practice executed in the past by Adviesbureau ir. J.G.Hageman B.V. As it is not possible to perform a site visit the case will be performed as a desk-study with the input data from the site visit by the investigator of Adviesbureau Hageman. The goal of this analysis is to test the individual steps of the model and in particular the hypothesis generating and hypothesis analysing techniques for practicality and usability.

To get an idea of the possibilities a first rough scanning through the available case reports has been made. This resulted in an indication of what type of cases there are available and what level of documentation besides final reports is available. The conclusion from this first scan is that there are many concrete damage cases varying from large, extensive investigations to small, routine like investigations. In general, there is more documentation and data available for the very large cases, but the reporting and available data (photographs and drawings) for the smaller investigations is extensive enough to be able to test the model and execute an investigation.

The analysed cases for the first part were selected on the following criteria:

- The cases should be a technical investigation into a concrete damage cause.
- The cases with collapses, casualties or extreme damages are not selected.
- The cases should be possible to make anonymous, so very specific/recognizable structures or cases are not selected.
- The cases should represent a variety of damages occurring in different types of structures.
- The cases should have some final report in the form of an actual report or a memo (short report) and some available data.
- The cases should be finalized.
- The cases should be selected in such a way that the investigations have been performed over time. This to avoid over-representing damage types that occurred during a specific period.

The analysed case for the second part should fulfil the same criteria as for the first part but additionally the damage should represent a small damage investigation that is within the scope of the model with enough unfiltered data like photographs and drawings.

Analysis

As stated before the analysis consists of two parts. First, a large-scale analysis of the differences and similarities between the steps of the model and the process followed by the investigators of the existing cases. Secondly, performing of a small investigation within the boundaries of a desk study. The cases for the first part consist of: three damages in car-parks with crack forming, leakage and scaling problems to columns, floors and connections, two damages on balconies, three cases of damage to concrete floors and/or walls (crack formation and deflection) and one concrete façade damage. All cases have the goal/one of the goals to investigate the technical damage cause.

A summary of the results from the analysis of the nine concrete damage investigation reports are reported in Table 12. The full analysis of phase one is described in Appendix I - Case study general. In general the main phases of the model are clearly recognizable in the nine reports. Therefore it can be assumed that the main line of the developed model has been used in the studied real investigations.

Table 12: Overview results of the general analysis of nine case reports

PHASE	ANALYSIS RESULTS
Orientation	• Both the model and the cases define the scope, investigation question and investigation goal during the orientation phase of the investigation. The main difference is that the cases report these elements in the introduction of the final report and the model uses a separate initial project description document. • A contract with a client is optional in the model. However with these cases it seems that at the end of the orientation stage almost always a contract has been made. The contract describes the investigation goal, the documents that the client has to present and a first indication of the total cost including the hourly tariff.

<table>
<tr><th>PHASE</th><th>ANALYSIS RESULTS</th></tr>
<tr><td>Data collection</td><td>
Techniques like photographing, plotting damages in plan drawings and interviewing have been used in the cases. The model recommends to use these techniques for every investigation. With the cases it seems that the use of these techniques is dependent on the individual initiative of the investigator.
Different types of documents have been collected:
Plan drawings (all)
Structural drawings
Reinforcement (all)
Cross-section (all)
Foundation plan (case 8, 9)
Details (all)
Work drawings (case 1, 8, 9)
Prefab elements (case 1, 3)

Structural calculations (case 1, 4, 5, 6, 7, 9)
Concrete mixture (case 1)
Photo/sketch material damage (case 4, 6, 7, 8, 9)
Construction/production records (case 1, 3)
Temperature at location (case 1)
Earlier damage investigation reports (case 3, 4, 7, 6)
Groundwater level (case 7)
Relevant norms and regulations (all)

Each investigator uses his own technique to photograph. This varies from no system to a system of first taking large scale photographs and continuing to detailed photos of the damage. In general the quality of the photographs is high. However, it is not always clear which photograph shows which damage. Especially when there are for example multiple cracks. In order to avoid this problem the model recommends including location markers in photographs.
Some reports also include photographs of testing performed on location.
Laboratory tests have not been performed for any of the analysed cases. On-site testing appears in some of the cases. The most mentioned tests are tapping for loose concrete and the removing of the concrete cover to expose the reinforcement for inspection.
Data processing is not done by drafting a sequence of events but by systematic storage of information in separate electronic folders that are easy to access. This is for this type of damages a more appropriate technique.
</td></tr>
<tr><td>Hypotheses generation and analysis</td><td>
Both the cases and the model have separated the hypotheses generation and hypotheses analysis steps. The difference is that in the cases the hypotheses generating process is not reported, although the considered hypotheses are sometimes mentioned in the final reports. For completeness and repeatability the hypotheses generating process should be reported, at least in the appendices.
Extensive argumentation supported by calculations and data have been used in the case reports to prove the hypothesis.
In the model falsification is part of the hypotheses analysis phase. This is not present in the case reports (keep in the model).
</td></tr>
<tr><td>Conclusion</td><td>
The conclusion of the case reports often focusses on the damage cause and possible repair measures, depending on the investigation question. This is the same as in the model.
</td></tr>
<tr><td>Reporting</td><td>
Both the recommended reporting structure of the model and the used reporting structure of the case reports is almost the same. The differences are:
In the case reports the involved parties have been listed (add to the model).
In the case reports a list with all available documentation and drawings has been included (add to the model).
The proposed model recommends to list all considered hypothesis in the final report. In the appendix the process of developing the hypothesis can be included. This has not been found in the case reports (keep in the model).
In the case reports the date of the site visit and the people present have been included (add to the model).

</td></tr>
<tr><td>Follow - up</td><td>
The model recommends a reflection as a last phase in an investigation. This is not present in the case reports, which doesn’t say it isn’t done.
</td></tr>
</table>

For the second part of the analysis, a damage investigation using the investigation process model has been performed. Regarding the usability of the model it can be concluded that the model functions well and as expected. By following the protocol phases all aspects of an investigation are covered. Most importantly, following the phases of the process results in identifying damage causes and an answer to the investigation question. However, there are some specific elements and techniques recommended in the model that are not as functional as expected (sequence of events), take a lot of time to execute compared to the result (project description report, general hypothesis generation), are functional but have additional specific conditions (event and causal relation diagram, brainstorm technique) or need a bit of fine tuning (event and causal factor analysis). The full analysis of part two is described in Appendix J - Case study parking.

Literature validation (papers)

To be able to determine the quality and theoretical value of the developed model, the model is compared with the investigation processes proposed in two papers. Each paper has been selected because it will give insight in a different aspect to the developed model. The first paper is an article (Improving reliability in forensic engineering: the delft approach) published in the ICE journal: Proceedings of the institution of civil engineers – forensic engineering (Terwel, Schuurman, & Loeve, 2018) and discusses a systematic approach to forensic investigations called the Delft approach. This approach is based on literature and practical input from the fields of aerospace engineering, biomechanical engineering and civil engineering. In the paper four elements of a forensic investigation are discussed: the life cycle of products, the tree house of failure to categorise failure causes, a standard investigation protocol and the ring of trustworthiness. The basics of the Delft approach have been presented in an online open course and are described in chapter 2 of this thesis report. As the paper used for this validation has only recently been published (obtained august 2018) it hasn't been used in the literature study of this research. In the online open course, the first three elements have been explained in detail. The concept of the ring of trustworthiness was introduced by defining the elements of the ring and their meaning. However, in this recently published paper this ring of trustworthiness is further detailed and has been given a practical application. Because in this research the same detailing has been done for the ring of trustworthiness this paper presents an excellent opportunity to validate this aspect of the proposed model. The other elements of the Delft approach described in the paper will not be used as their concept has been used as input for development of the investigation model.

The second paper is an (until now) unpublished article on an investigation protocol developed for structural forensic investigations for the damaged buildings in Groningen (Terwel & Schipper, september 2018). This article is used to review the investigation process model as a sequence and to validate proposed data collection techniques.

Method

Both papers have been studied and a comparison between the information from the papers and the proposed model has been made. The purpose is to analyse if there are similarities between the model and the recommendations from the articles. The article on the Delft approach[1] is used to review the practical applications of the ring of trustworthiness and the Groningen protocol article[2] is used to analyse the investigation process model as a whole.

1 Terwel, K., Schuurman, M., & Loeve, A. (2018). I*mproving reliability in forensic engineering: the Delft approach*. Proceedings of the institution of civil engineers - foresic engineering, ahead of print. doi:https://doi.org/10.1680/jfoen.18.00006

2 Terwel, K., & Schipper, R. (2018). *Innovative wayes of dealing with existing problems: how to reliably assess the cause of damage of masonry structures in an area with man-induced earthquakes?* 40th IABSE Symposium Conference paper. Nantes, France

Analysis

The analysis of the developed damage investigation protocol against the two papers has been done separate for each paper. The result of each analysis is presented below.

Article 1 – Delft approach

The goal of the analysis is to validate the measures recommended in the proposed investigation process model for improving the reliability and credibility of the investigation and its outcomes. The proposed model uses the ring of trustworthiness criteria as a base. Theory on case study research has been used to recommend practical measures to comply with the criteria of the ring of trustworthiness. After analysing the article, it becomes clear that the theory on which the ring of trustworthiness was based is the case study theory. This means that the ring of trustworthiness is originally based on case study research techniques to improve reliability and validity of case studies. In this report the concept of the ring of trustworthiness is combined with the case study reliability and validity improving techniques, without being aware that this originally was the basis of the development of the ring of trustworthiness. This results in almost the same outcome of the developed investigation process model and the measures mentioned in the article. The differences are:

- The paper describes practical measures in a general sense, not related to specific investigation phases as the model does.
- The list of measures presented in the paper is much more explicit and compact presented than the rather extensive descriptions used in the model.
- The safe and structured storage of relevant data is placed under repeatable and verifiable in the model and under verifiable in the paper.
- The model recommends to use illustrations and diagrams to explain data and arguments. During diagram making irregularities and non-logical argumentation will faster surface. It also forces to draw logical conclusions. This technique is not mentioned in the paper.
- Additional interesting measures mentioned in the paper are: reporting on rival explanations and counter fact evidence (Terwel, K.C., Schuurman, M.J. & Loeve, A. 2018)

Article 2 -Conference paper on damage assessment of masonry structures in earthquake area

The goal of the analysis is to validate and measure the developed investigation process model against the protocol described in the paper. Before valid conclusions can be drawn, the scope and intentions of both protocols need to be compared. Both investigation protocols have been developed to investigate damages that can be classified as 'regular' based on their visual appearance, like cracks, deformations, etc. In both cases the investigated damages can have multiple concurrent causes and based on the visual appearance different causes are possible. The difference between the two investigation protocols is that the protocol described in the paper is for masonry damage in a very specific environment where earthquake loading is possible. For use as a validation tool this doesn't make a difference since the goal is to compare the overall process, this is independent of material. In the conference paper the earthquake loading cases play of course a significant role but the investigation is also used to determine other damage causes as not all existing damages can be contributed to earthquake loading.

The other significant difference is the client and end user of the results of the investigation. The damages to buildings in the Groningen area are a sensitive topic with a lot of political debate and some level of distrust of investigation results by building owners and residents. This influences the design of the investigation protocol. The proposed investigation protocol in this research report is intended for clients that mainly want a solution to their damage problem and do generally have confidence in the outcome of an investigation. For the validation, this means that the protocol in the conference paper will likely have more attention to transparency and thoroughness than maybe is technically necessary. This means that this level of transparency and thoroughness in the protocol is possibly not applicable/wanted in the context of the use of the developed investigation protocol.

The relevant similarities between the investigation protocol from the paper and the model proposed in this report are listed below. The relevant differences are listed in Table 13.

- Both protocols use the general scientific approach as base of the investigation process. This results in the same main phases: orientation, data collection, hypothesis generation, hypothesis testing, findings reporting.
- The paper describes which information and data you want to collect. Most of the required information is also recommended within the proposed model. Examples are: construction date, if there have been renovations or changes to the building in the past, the load bearing system, etc.
- Both models use drawings (plan and facade) to record damage by annotating the damages in the drawings on the correct locations. The paper additionally uses this technique to determine if damages are related.

Table 13: Differences between the conference paper and investigation process

	CONFERENCE PAPER INVESTIGATION PROTOCOL	INVESTIGATION PROTOCOL
1.	The hypothesis testing step uses the following order: list with possible damage causes (hypothesis generation), falsification by data, and then verification of the remaining hypothesis.	The hypothesis analysis phase uses the following steps: verification of the hypothesis and then falsification of the remaining ones.
2.	Data collection has been divided into three categories: building characteristics, building context and damage.	The data collection phase covers the same three categories but this has not been made explicit.
3.	The hypothesis validation is done using the causality principle. The principle describes that a damage is linked to an event when the following requirements are met (Terwel, K.C., & Schipper, R.; 2018): • An event that occurred before the damage should provide that if it did not take place, the damage would not have occurred. • The event would have caused the same damage if it had occurred in other similar circumstances.	

At further analysing the differences the following side notes can be made for each difference:

1. The falsification process in the conference paper has been used to sift through the different hypothesis excluding the irrelevant and thus keeping the relevant ones. The falsification within this report is defined as deliberately trying to prove the hypothesis is false as a method to avoid bias (e.g. tunnel vision). Some of the techniques recommended in the proposed investigation process model like the cause and effect diagram (hypothesis generation) and the hypothesis-evidence table (hypothesis analysis) have elements of falsification as defined within the conference paper within them. The principle of eliminating the hypotheses, which are impossible based on available data is useful as this limits the hypotheses that need further analysis. This early elimination saves time.
2. By making the three categories explicit, data collection becomes more systematic. There are also two types of data mentioned in the conference paper that are useful for concrete damage investigations: registration of past exceptional loadings like explosions, lightning or impact loading like collisions and the registration of context information like vibration due to heavy traffic, nearby construction work, oscillations in the groundwater table or earthquake

loadings.

3. The causality principle is an interesting way of argumentation. This can also be used in concrete damage investigations. It is a universal principle that gives an indication of a possible argumentation structure to prove a hypothesis.

Discussion

After validating the investigation process model by testing the model with real investigation reports and two scientific papers, the conclusion is that the developed model functions correctly. The outline of the model has a lot in common with the investigation processes used in the real cases and described in the papers.

The analyses showed some differences in the detailed description between the investigation process model and the cases and papers. These differences and how they will influence the investigation model are discussed below. To show where the remarks originate the following code has been used: items marked 'analysis 1' are the results from the analysis of the nine case reports, 'analysis 2' are the results of performing the test investigation of the damage of the parking garage and 'paper' are the results of the analysis of the two papers.

- In the model a report to document the *orientation phase* has been proposed. This is not included in the real case reports. During analysis 2 it appeared unnecessary as reporting the orientation phase directly into the introduction of the draft final report has the same result and is less work. Another option is to incorporate the orientation phase results in the contract with the client.
- Concerning the *data collection phase* the general picture is that the main structure of this phase is functioning properly. Some details of the steps within the phases need some changes.
  - » Analysis 1 resulted in the conclusion that it can be more practical to collect documents first, analyse them, develop some hypothesis and then do the site visit. In the model the first step is that to collect and analyse the documents, then the site visit takes place and then hypotheses are developed. Going to location with possible hypotheses in your mind, can help to better determine which measures you need to take to be able to observe all possible damage locations. For example if scaffolding is needed to reach heights. Another argument is that when hypotheses have been developed before the site visit more specific searching for damage is possible. This can cause directly also a negative effect: tunnel-vision. Literature recommends doing a site visit open minded in order to avoid missing information because you are focussed on certain hypotheses. This is the main reason that the model will keep using the original format of hypotheses development after the site visit and the use of an loop between hypotheses genereation and data collection.
  - » The results of the document analysis can be recorded in the draft final report version under the heading: construction description. This can later be expanded with relevant data from the site visit (analysis 2).
  - » In the paper on the Groningen protocol the data collection has been split into three parts: building, context and damage. The model describes the content of each of these parts but doesn't explicitly mentions them. This should be changed in the second version of the model as this categorisation makes remembering what to collect during a site visit easier for the investigator (paper).
  - » Data collection on the context of the construction should include information on nearby construction work, the presence of heavy traffic or extreme loading in the past like explosions or fire (paper). During the site visit also the weather conditions should be recorded (analysis 1).

  - In the model the following elements should be added to the site visit step: use number cards showing the grid numbering of the plan drawing and include these in photographs to record the location of the damage (analysis 1). When photographing cracks include a photograph with a crack width meter (analysis 1).
  - Concerning the data processing step the model presents the sequence of events as a tool to order and validate collected data. During the validation this appeared to be a non-functional system. It was not mentioned or used in one of the cases (analysis 1). It also proved impossible to execute this technique during the test investigation (analysis 2). The technique itself can still be functional but not in relation to the damage types that are the focus of this model. The sequence of events is based on a time component leading the failure. Concrete damages generally don't have this specific time component. If there is a time component the client most of the time isn't aware of it and can't give relevant information. Concluding: the sequence of event technique is useful for time related failures like water-accumulation damages, damages due to special loadings or collapses but not generally for the damages within the scope of this model.
  - The data processing step should describe how to safely and systematic store all the collected data. Examples of possible techniques are: record location of damages, report oral information in memo's, store data digitally in organized digital folders (analysis 2).
- Regarding the *hypotheses generation phase* the general conclusion is that the described techniques, although not used in one of the cases or mentioned in the papers, are useful, easy to execute and give good results (analysis 2). A short reflection on each technique based on the authors experience is presented below:
  - Brainstorm: workable technique but hard to execute by one person. The lack of feedback by other persons makes it more difficult to think in different directions and get creative ideas. The technique is very useful when the damage cause is not directly obvious. It's power is that there is room for opposing directions.
  - Cause and effect diagram: the best part of this technique is that it works almost intuitive and directly documents the considered options, the reason why some options are invalid and therefore disregarded. The drafted graph is almost self-explaining so additional reasoning is not needed. This results in saving time while still recording every decision as described by the principle of validity and completeness of the ring of trustworthiness. The limitation to the technique is the use when there are multiple damage types at one damage. The tree can only start with one damage type.
  - Common failure mechanisms protocol: when used for the investigated damages it functioned correctly and very fast but further testing is needed.
  - Multiple hypothesis generation: this method works really well if there is one specific hypothesis that is very obvious and others need only to be considered to be sure every option is covered. The method is systematic in its approach and results in other relevant hypothesis. Because of the systematic approach the method also results in nonsense hypothesis. Both the relevant and nonsense hypothesis need to be reported. This is time consuming. A solution for limiting the writing is by not requiring to write every step down and to not write down obvious irrelevant or ridiculous results.
- The *hypotheses analysis phase* resulted in the most and largest differences. The model uses the validate and then falsification approach. This system hasn't been used in the real investigation cases. They only contain the validation. The papers describe the validation and falsification but change the order. They first use falsification to limit the amount of hypotheses that need to be investigated. The remaining hypotheses will be validated. This concept has the advantage that the amount of hypotheses that need to be analysed in detail is limited. This saves time and investigation budget. The disadvantage is that the principle of being thorough by actively trying to eliminate a proven hypothesis is lost. When considering

the approach of the model this system of eliminating hypotheses with data is embedded in some of the hypothesis generating techniques (cause and effect diagram and the common failure mechanisms protocol). In the hypotheses analysis technique of the hypothesis-evidance table, this principle has also been used.

- A specific *hypotheses analysis* technique (causality principle) proposed in a paper can be base for argumentation structure (paper).
- The proposed *hypotheses analysis* techniques have been tested in a real case (analysis 2). When reviewed they result in the following conclusions:
  - Hypothesis-evidence table: a very compact and good functioning technique. The technique worked for every type of damage. This technique eliminates all impossible hypotheses with collected data. The downside is that when hypotheses have been eliminated the remaining ones have not directly been proven. Other techniques like calculations or good argumentation are necessary to prove the damage cause.
  - Event and causal factors diagram: the technique gives a good overview of all the factors that contributed to the damage and predicts data that should be present when the hypothesis of the damage cause is correct. After using the technique it is suggested to add a field to the event box where the data that proves the event can be annotated. This will create a complete overview of the events leading up to the damage, which one of them are supported by data (including which data) and which of them still need to be supported by data. This technique is also relevant when comparing two hypotheses. The diagrams visualise which hypothesis is best supported by data. To use the technique as a validation method an additional step is necessary. After completing the diagram, the missing data should be actively collected. When this is complete and the damage cause scenario is supported with data, the best data supported hypothesis can be regarded as a proven hypothesis and can be taken to the falsification phase (analysis 2).
- Regarding the *reporting phase* there are some small improvements needed to the model. First the hypothesis generating and hypothesis analysis can be reported together as long as for both the argumentation and used methods are being presented in the report. This can be in the main text or in the appendices (analysis 2). The second improvement is to include a list of the received and used documents in the final report. This includes the norms used for calculations (analysis 1). The third improvement is the inclusion of the name and role of all persons present at the site visit (analysis 1).

With all the above suggested improvements the investigation process model will be more efficient and ready to be further tested in other real investigations. For the resulting model see figure 14

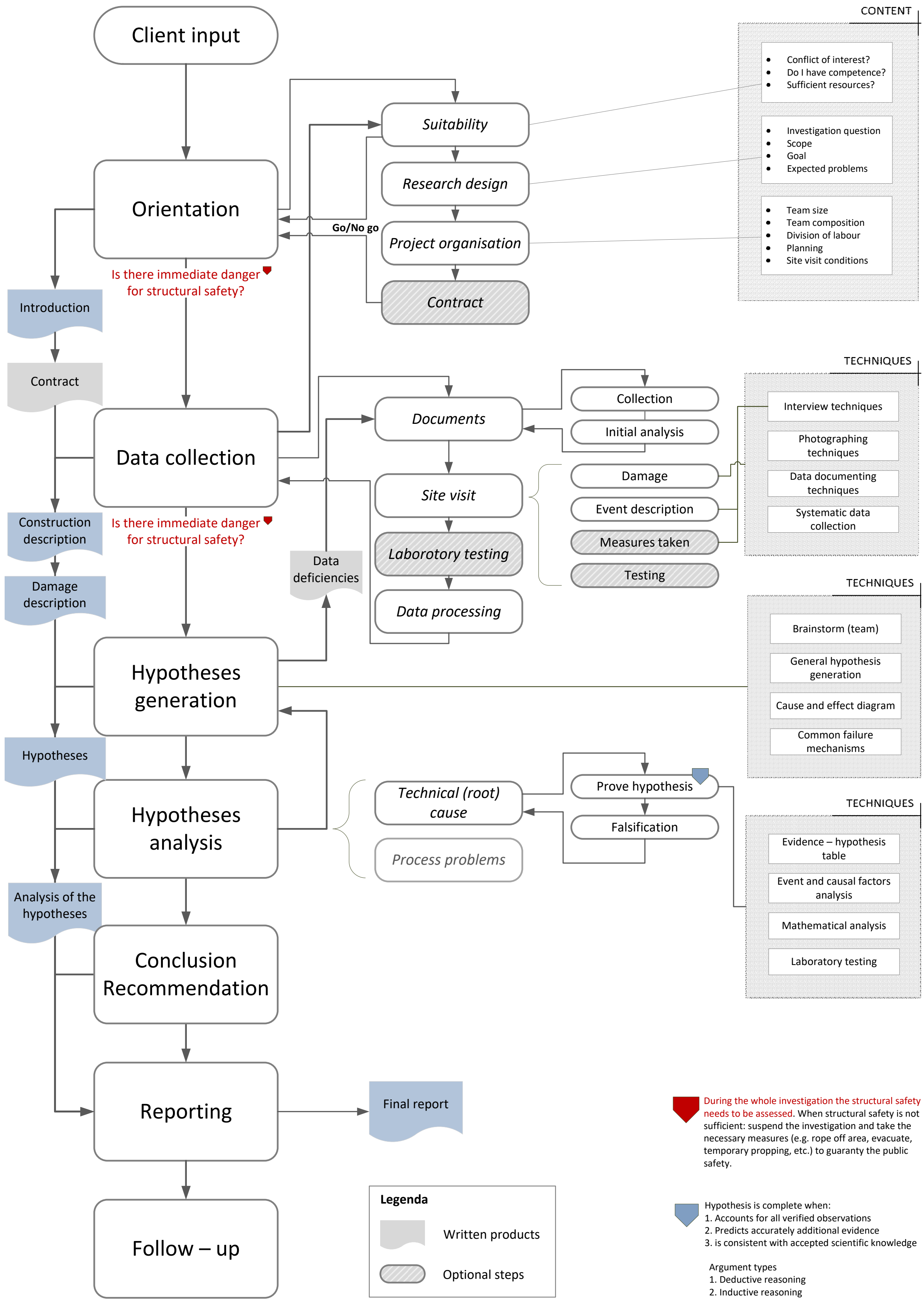


Figure 14: Scematic overview improved investigation process

Part III

Final remarks

Chapter 7

Conclusion

The main question of this research was: what is a reliable methodology to perform a structural forensic investigation into the technical causes of regular concrete damage in Dutch practice? In order to answer this question literature on structural forensic engineering processes and the investigation methodologies of aerospace engineering and fire cause investigations have been reviewed. Interviews with investigators at companies have been performed and damages to concrete structures have been studied. The overall result is a structural investigation process model. This model has been validated with scientific papers and real cases.

Concluding, the research question can be answered with the statement that it is possible to develop a reliable investigation process model based on literature and practical input. The general steps of the Delft approach or scientific method on which this investigation process model has been based, are universal principles. They are a good base for each forensic investigation process model. This investigation order has proven its quality over time and across disciplines.

The developed model consists of three layers. The first layer is the main structure of the investigation process that consist of the phases: orientation, data collection, hypotheses generation, hypotheses analysis, conclusion and recommendation, reporting and follow-up. A phase can consist of steps that define and help execute the phase (second layer). The third, most detailed layer are specific techniques that are recommended to use during the execution of the phase. These techniques are intended as examples and some are only suitable in specific situations or contexts. The conditions, requirements and execution process of each technique has been included in the description of the technique. The investigator selects the best applicable techniques during the investigation. The structure of the developed model is in line with the more or less intuitive approach to a damage investigation, as has been shown by the interview results. The developed investigation process model has proven to be workable. However, to become more effective an optimisation is recommended.

Another conclusion is that a universal full protocol to investigate all different types of structural damages doesn't exist. In reality, there are so many different investigation questions, goals and visions in practice that it is not possible to develop a one fits all detailed protocol. However, it is possible and useful to have some guidance through the investigation process. This will help to establish a reliable investigation outcome and consistent quality. When speaking with investigators in practice the often-heard opinion is that a lot of the investigation process is based on experience. This is true in the sense that experience can help an investigator to make good investigation choices. Experience also means that the investigator becomes more proficient and effective in for example data collection during a site visit. However, this doesn't mean they don't need or use a process. When questioned further they all have techniques and strategies for reporting, data collection, photographing, damage recording etc. It appears that experience has provided the investigators with a figurative toolbox, which all kinds of equipment. The challenge of the investigator is to select the right tool for the job.

In the author's opinion, the general line should be the steps of the Delft approach / scientific method. The techniques selected to perform the steps are open for debate as long as they are valid techniques. The techniques that are usable in an investigation depend on the material, complexity of the damage and the factors to be included in the investigation like technical, organisational or human factors. The developed model presents a part of the toolbox, selects strategies and techniques and makes them explicit by writing them down.

Concerning concrete damages, it can be concluded that there are loads of information sources on specific concrete damage mechanisms, their development and the physical results of the damage mechanisms. They are ordered and categorized in multiple systems. However, significantly less information is available on the relation between the physical appearance of damage and the possible underlying damage causes and how to determine them. One reason can be that the list of physical expressions of concrete damages is theoretically endless, so it is impossible to make a hundred per cent complete list. Therefore a first draft of a concrete damage handbook has been developed. This handbook tries to structure the relation between visual appearance and possible causes.

Chapter 8

Recommendations

Based on the information from literature, the results of the validation of the model with a test case and analyses that have been made with real investigation reports, recommendations have been formulated. The recommendations cover general recommendations to optimize investigating practice, specific improvements to the developed model and suggestions for additional research. They are discussed below.

Use of an investigation methodology
Use an investigation methodology to perform a structural forensic investigation. Firstly, one of the main suggestions to improve the reliability of a case study (damage investigation) is to use a systematic approach (objectivity) and report all steps and methods that have been used during an investigation (repeatability). This is achieved by using a fixed investigation process and use reliable techniques to perform the individual steps of an investigation. Secondly, the use of a structured approach is a measure to avoid bias like cognitive entrancement, confirmation bias and selectivity. The idea of using an investigation protocol is also widly acknowledged in similar type of investigations in other disciplines. These investigation protocols are very diverse. Some of the investigation protocols are very detailed and strict (aerospace accident investigations) others are more meant as guidelines and suggest possible techniques for each step.

Improvement of the proposed model
Based on the result of the validation, changes and improvements to the investigation process model need to be made using the suggestions from chapter 6. When the second version of the model has been developed the investigation process model needs to be further tested with real investigations, making further optimisation possible. The model can also be extended with other specific techniques to execute the individual phases. The result will be a collection of useful techniques that can help investigators select the right technique for each investigation.

During the literature study into human error theory and decision making errors, a lot of interesting concepts were found. It has been tried to incorporate the different measures against the influence of bias into the model. However, this is only partly achieved. Considering the relevance of a lot of the bias mechanisms, the generally limited knowledge of this field to technical professionals and the potential 'easy' measures there is room for improvement. The author believes that additional suggestions and smart introduction of measures to limit bias can be incorporated into the model.

Study related disciplines
As a forensic investigator try investigation techniques from other forensic investigation fields, as they are often (with a little adjustment) applicable to structural forensic engineering. In connection to this, the author would like to encourage interested readers to read through the Doc. 9756 parts published by the ICAO and the book *Scientific method applications in failure investigation and forensic science* by Randall Noon. The Doc. 9756 mainly gives an insight in organisation related issues during an investigation. The book is very inspirational regarding specific hypothesis developing and analysing techniques.

Team work

When performing an investigation try to work in a team, although this is not the standard. It is not necessary to perform the whole investigation in a team but starting an investigation in a team and discussing ideas together during the hypothesis generating and hypothesis analysis phase is very useful. The first advantage of working with two or more will help in getting new insights to the damage cause and the damage investigation process. The second advantage is that when working together mistakes are faster recognized and lastly it reduces the influence of bias. This will result in more reliable investigation processes and results.

Further research

For further research, there are two topics that need further development or are interesting to study.

- Testing and improving the concrete damage handbook (see Appendix G - Concrete damage handbook). This document needs to be tested and can be improved by adding more information on testing methods and possibilities, adding more damage causes and references.
- Studying how organisational and human factors are part of a damage cause and how this can be investigated. Only some investigations for insurers include organisational factors. The challenge would be to develop a technique to give an opinion on design choices and process without the trap of hindsight bias. Some inspiration and information can be found in the investigation protocols of the ICAO (aerospace engineering) and accident investigation models.

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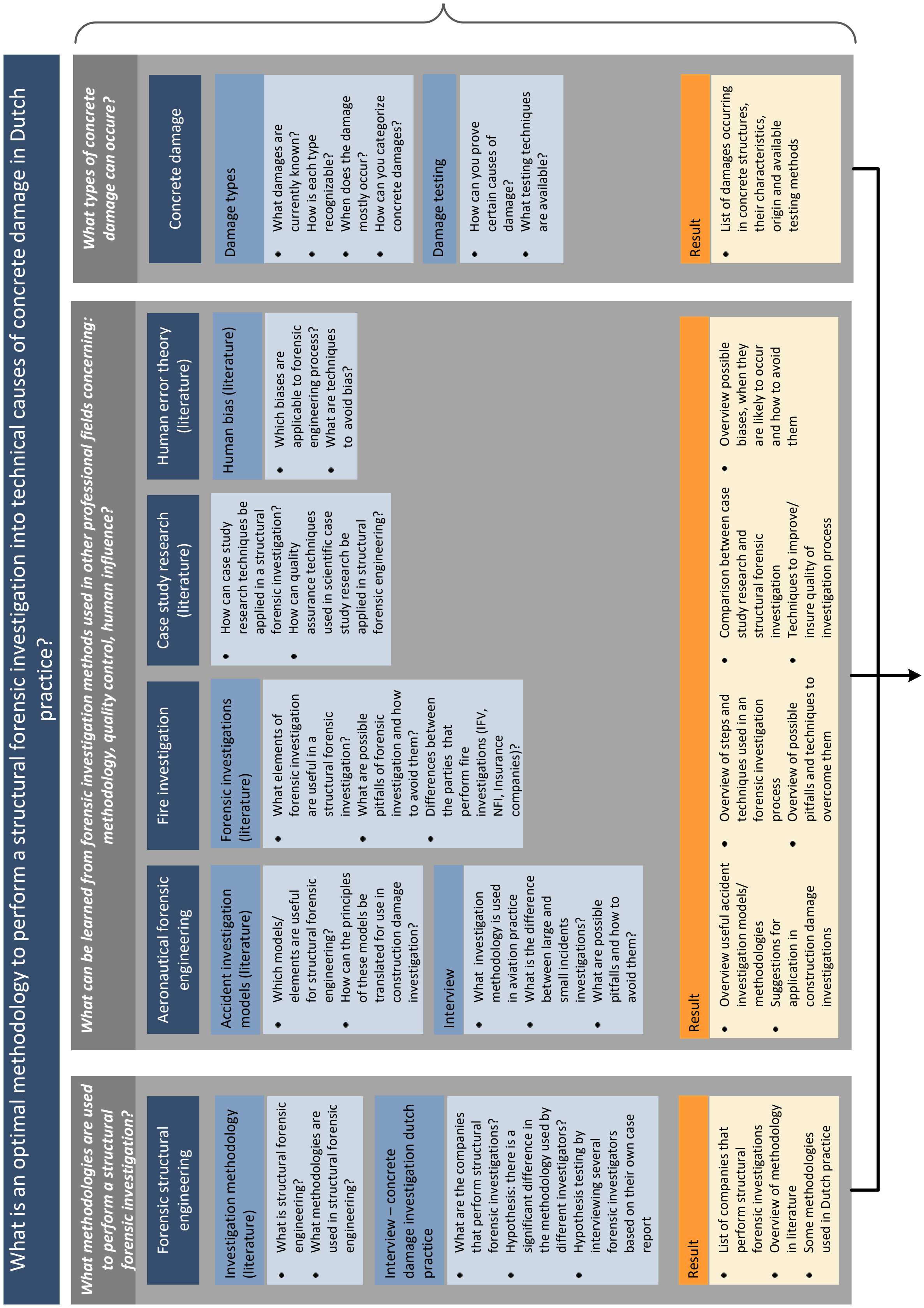
Appendices

Appendix A - Overview research structure

This appendix shows the research strucure of this thesis with the main research questions.



Model development

- Based on the information from phase I a step by step methodology is written

Result

- Model with steps to follow to perform an investigation into concrete damage (see table)
- As input of there can be a flowchart type scheme that navigates and structures the thought process of possible causes of concrete damage.

Step	Technique(s) to perform step	What are possible pitfalls?	Techniques to avoid the pitfalls?

Phase II

↓

Model verification and validation

Case testing

- The developed methodology is compared to investigation documents and reports from existing concrete damage cases
- What are steps that need to be taken according to the developed methodology based on the initial available information?
- What are the differences between investigation steps used in the case and the suggested steps of the developed model? Can they be explained?
- What needs to be adjusted on the developed investigation methodology?

Article review

- The developed model is compared with methodologies described in two scientific papers determining the:
- practicality
- quality
- completeness
- feasibility

Result

- Comparison reports between methodology used in real cases and the steps proposed in the developed model
- Reviewed investigation methodology

Phase III

Appendix B - Interview protocol

The interview consists out of three parts: general information, professional context and the investigation methodology used. The interview focuses on regular damage investigations.

- Is it allowed for me to record the interview to make processing of the interview easier?

General information

- Can you tell me a bit about this company? (size/ specialization/ work area)
- What type/scale of damage do you most investigate?
- How did you become a damage investigator? Did you follow special training or is it based on self-educating and experience?
- From what parties do you get your assignments?

Professional context

- What do you think is the main goal of most investigations? (responsibility/ learning/ designing a solution for the damage/ Finding the cause)
- With how many people do you usually work on an investigation?
- What is the time available for 'routine' investigations? Does this influence your investigation methodology?
- In what order of magnitude are the available budgets of regular investigations? Does this influence your investigation methodology?

Methodology
Case: one month after completion cracks in a concrete first floor are reported by the owner of an office building. The cracks are reported to the contractor and askes your company to investigate the cause of the cracking. Can you take me through the process of the investigation, what steps do you take and in what order?

Additional questions:

- On what criteria do you decide to accept or reject the assignment?
- In other professional fields there several phases during an investigation. Do you also work with phases?
- What data do you need to do your investigation?
- How do you collect the data you need?
- Are people involved in the investigation required to give all information and their full co-operation?
- How do you generate potential causes of the damage?
- What techniques do you use to exclude or include damage causes?
- Do you use laboratory testing or only a desk study?
- What is the structure of your report?
- What elements do your reports contain?

Thank you for your time and cooperation. I will send you a copy of the transcribed interview to review and check. Can I mention your name and the company name in my graduation paper (public document) or do you want me to make the interview anonymous?

Interview – protocol (NL)

Het interview bestaat uit drie delen: algemene vragen, professionele context en vragen over de gebruikte onderzoeksmethodieken. Het interview focust op ‘normale/gemiddelde schadeonderzoeken.

- Is het goed als ik het interview opneem als assistentie bij het uitwerken van het interview?

Algemene informatie

- Kunt u mij iets vertellen over dit bedrijf? (grootte/specialisatie/werkgebied)
- Wat voor type en grootte schade onderzoeken jullie in het algemeen?
- Hoe/waarom bent u dit werk gaan doen? Heeft u een speciale cursus of opleiding gevolgd?
- Van welk type bedrijven krijgt uw bedrijf zijn schade onderzoeksopdrachten?

Professionele context

- Wat is het belangrijkst doel van de meeste schadeonderzoeken? (verantwoordelijkheid/ leren voor de toekomst/ het bedenken van een oplossing/ het achterhalen van het probleem)
- Met hoeveel werken jullie tegelijk aan een onderzoek?
- Hoeveel tijd is er normaal gemiddeld beschikbaar voor een onderzoek? Beinvloed dit het onderzoeksproces?
- Kunt u mij een orde grootte geven van het beschikbare budget voor een regulier schadeonderzoek? Beinvloed dit het onderzoeksproces?

Methodologie
Case: een maand na oplevering worden er door de eigenaar van een kantoorgebouw scheuren in de betonnen eerste verdiepingsvloer gemeld aan de uitvoerder. De uitvoerder vraagt uw bedrijf om onderzoek te doen naar de oorzaak van de scheuren. Kunt u me meenemen in het onderzoeksproces en vertellen welke overwegingen en stappen u zou doen?

Aanvullende vragen:

- Op basis van welke criteria neemt u een beslissing over het wel of niet aannemen van de opdracht?
- In andere vakgebieden bestaat een onderzoek uit verschillende fasen. Volgt u ook verschillende fasen in uw schade onderzoek?
- Welke data wilt u hebben?
- Hoe verzamelt u de benodigde data? (Veldonderzoek, documenten etc.)
- Zijn de betrokken partijen verplicht om informatie te verstrekken en volledig mee te werken?
- Hoe bedenkt u mogelijke oorzaken van de schade? Welke technieken gebruikt u hiervoor?
- Welke technieken gebruikt u om oorzaken uit te sluiten?
- Gebruikt u laboratoriumonderzoek of alleen een bureau onderzoek?
- Wat is de structuur van uw eindrapportage?
- Welke onderdelen zitten in uw rapport?

Bedankt voor uw tijd en medewerking aan mijn onderzoek. Ik zal een kopie van het uitgeschreven interview naar u toesturen per e-mail ter controle. Mag ik uw naam en die van uw bedrijf gebruiken in mijn eindverslag (openbaar document) of zal ik het uitgeschreven interview anoniem opnemen in het verslag?

Appendix C - Interviews

In this appendix five transcriptions of interviews with professional structural damage investigators have been collected. The interviews have been made anonymous.

Interview 1

2 mei 2018

Algemene informatie

- *Kunt u mij iets vertellen over uw bedrijf? (grootte/specialisatie/werkgebied)*

  Dit is een ingenieursbureau dat zich primair bezighoudt met ontwerp, berekenen en tekenen van constructies in nieuwbouw en bestaande bouw. Het gaat hierbij voornamelijk om utiliteitsbouw, woningbouw, weg- en waterbouw en constructies in dijkversterkingen. Tot de bouwcrisis (grofweg 2008) zijn er voornamelijk grote projecten gedaan, sindsdien werden de projecten geleidelijk aan kleiner. Er worden bijvoorbeeld nieuwbouwprojecten (appartementen en woningen), aanpassingen aan de bestaande woningen (uitbreidingen woningen), bedrijfshallen en kraanbouw gedaan. De locaties zijn vaak binnenstad Dordrecht en Rotterdam (voornamelijk bestaande bouw). Af en toe zijn er prefab projecten. De echte grote projecten (tunnels, metrolijnen, grote appartement complexen) worden niet gedaan, wegens de capaciteit van het bedrijf. De kracht van het bedrijf is het vinden van innovatieve en creatieve oplossingen voor bestaande bouw en de problemen die we tegenkomen in bestaande bouw. Schadebeoordeling is een, weliswaar belangrijke, bijzaak voor het bureau. Hierbij is de financiële afhandeling minder belangrijk. Het gaat voornamelijk om het oplossen van het voorliggende probleem: de oorzaak van de schade en de versterking van bestaande constructies.

- *Wat voor type en grootte schade onderzoeken jullie in het algemeen?*

  De geinterviewde heeft zich sinds 2012 primair beziggehouden met het toetsen van constructies in dijkversterkingen, zoals damwanden, diepwanden, palenwanden en funderingsversterkingen. Tijdens en na de uitvoering van de dijkwerken ontstonden voornamelijk door forse uitbreiding van de binnenbermen, schades aan bestaande panden. Sinds 2016 zijn, naast het opstellen van constructieve eisen aan nieuwbouwplannen bij de dijk onderzoek naar schades ontstaan door dijkversterkingen de hoofdmoot van zijn werk. Een voorbeeld van dit werk zijn de constructies voor de dijkversterkingen van Kinderdijk- Schoonhovenseveer (60-70 miljoen). In het project heb je diepwanden, damwanden, paalwanden en allerlei varianten daarop. Het project is bijna klaar en nu worden schades aan bestaande panden zichtbaar. In het gebied staan ongeveer 400-500 woningen. Ongeveer 10% daarvan is gesloopt. Er spelen in dit project twee problemen. Het eerste probleem is dat heel veel panden niet onderheid zijn, waardoor zakkingen zijn opgetreden. De vraag is of de dijkversterking de oorzaak is of dat de zakkingen natuurlijk zijn. Als tweede hebben de panden die op palen gefundeerd zijn problemen met de horizontale belasting op de palen ten gevolge van ondergrondse grondverplaatsingen. Hierdoor worden de panden de polder in gedrukt (verplaatsingen van 20 cm gemeten). Dit kan leiden tot schade aan de funderingen van panden. Er wordt dan een oordeel gegeven over de vragen: is de schade door de bestaande constructie opneembaar? Of moeten er maatregelen genomen worden? De financiële afhandeling is geen onderdeel van het onderzoek. Het resultaat van het onderzoek is een constructief advies. Dit advies omvat: wat is de capaciteit van de constructie, welke maatregelen moeten er genomen worden en hoe moeten die maatregelen uitgevoerd worden?

  Verder komen onderzoeken naar funderingsschaden, kopgevelschaden (doorgeroeste ankers), galerijplaten problematiek en de problemen met de uitkragende balkons ook voor.

- *Hoe/waarom bent u dit werk gaan doen? Heeft u een speciale cursus of opleiding gevolgd?*

  Het bedrijf is begonnen met het doen van veel nieuwbouwprojecten en in de loop van de tijd is het uitgebreid met vragen die voorbijkomen. Als je iets nog nooit gedaan hebt dan ga je dat uitzoeken en neem je de uitdaging aan en zo bouw je ervaring op. Zo zijn ook de schade projecten begonnen.

  Rond 1980 kwam er via een woningbouwvereniging een vraag binnen of een woonwijkje langs een dijk gesloopt moest worden, kon blijven staan of gerenoveerd moest worden. Er bestonden al verschillende rapporten, maar die spraken elkaar tegen. De vraag kwam om dit uit te zoeken. Hiermee kwam het eerste contact met de Waterschappen Grondmechanica Delft tot stand. Tijdens het onderzoek kwam naar voren dat de panden op zich wel konden blijven staan maar dat er constructief grote gebreken aan waren. Dit had te maken met de historie van de woningen (palen geheid net voor de oorlog – 1939 en de fundering gestort in 1945). Uiteindelijk zijn alle funderingen versterkt en opgeknapt. Dit was het eerste grote schadeproject en daarmee zijn contacten gelegd die later meer schadewerk hebben opgeleverd. Met name gedurende de dijkversterking van de hele IJsselmonde regio waren we betrokken bij de schade afhandeling. Hier waren panden waarvan de voorgevel los van het gebouw kwam door de dijkversterkingen.

- *Van welk type bedrijven krijgt uw bedrijf zijn onderzoeksopdrachten?*

  Voornamelijk grote projecten van waterschappen. Ook komt er werk binnen van particulieren, woningbouwverenigingen, etc.

Professionele context

- *Wat is het belangrijkst doel van de meeste schadeonderzoeken? (Verantwoordelijkheid/ leren voor de toekomst/ het bedenken van een oplossing/ het achterhalen van het probleem)*

  Het onderzoek wordt gedaan omdat er een probleem is en daar moet een oorzaak en oplossing voor gevonden worden en eventueel een schuldige. Het is het vinden van het antwoord op een technische vraag en het bedenken van een herstelmaatregel.

- *Met hoeveel werken jullie tegelijk aan een onderzoek?*

  Op dit moment hebben we eigenlijk alleen kleine schadegevallen en die doe je alleen. Tussen 2001 en 2005 was er een groot project waarbij veel funderingen in Dordrecht gecontroleerd moesten worden. Hierbij was er een samenwerking met Fugro die al het uitvoeringswerk deed. Op dat moment waren we met een man of drie, vier aan een project aan het werk. Of er overleg plaats vindt hangt af van de moeilijkheidsgraad van het project.

- *Hoeveel tijd is er gemiddeld beschikbaar voor een onderzoek? Beinvloed dit het onderzoeksproces?*

  Het zijn vaak klussen die op urenbasis afgerekend worden. In de meeste gevallen is het afhankelijk van hoeveel tijd er nodig is om je onderzoek te doen (1 a 2 dagen). Tijd is meestal niet een maatgevende factor in een onderzoek.

- *Kunt u mij een orde grootte geven van het beschikbare budget voor een regulier schadeonderzoek? Beinvloed dit het onderzoeksproces?*

  Budget is bijna nooit leidend. Er wordt zelden een vast budget afgesproken. Dit heeft twee redenen: het gaat vaak om kleine onderzoeken (1 a 2 dagen) dus dan is het niet de moeite om een afspraak te maken en anderzijds komen de opdrachten vaak van bekende samenwerkingspartners of opdrachtgevers en daar heb je een goede werkrelatie mee. Dit betekend dat ze vertrouwen hebben in je werk en het aan jouw overlaten om te bepalen wat redelijk is. Herstelkosten en wie die moet betalen staan los van het onderzoek. Het gaat dus om een onafhankelijk onderzoek.

In het geval van funderingsonderzoeken, waarbij vaak een aannemer ingehuurd moet worden om de werkzaamheden voor een inspectie te kunnen doen wordt met de opdrachtgever overlegt en een offerte gemaakt. Dit is voornamelijk omdat de onderzoekskosten in deze gevallen hoger zijn.

- *Hoe zit dat bij particuliere opdrachtgevers?*

  Bij particulieren wordt er soms wel een raming van de kosten gegeven omdat het dan gaat over andere bedragen, maar meestal komt het dan via de verzekeraar en dan maakt het budget ook niet zo veel meer uit.

Methodologie

- *Kunt u me meenemen in een onderzoeksproces en vertellen welke overwegingen en stappen u zou doen?*

  Als voorbeeld: je krijgt een vraag over schade aan een balkon, de stalen liggers lijken doorgeroest. De opdrachtgever belt omdat hij het niet vertrouwt en vraagt of je wilt komen kijken en een rapportje wilt maken.

  Je gaat met je fototoestel en beiteltje naar de schade toe. Daar kijk je wat er aan de hand is. Je beitelt het geroeste staal eraf en kijkt wat er overblijft. Als je met de hand niet ver genoeg komt vraag je iemand om het te slopen. Je gaat eigenlijk net zo lang door met ter plaatse onderzoeken totdat je het gevoel hebt dat je in staat bent om een rapport over de situatie te schrijven. Als de inspectie te veel sloopwerk is dan vraag je een bevriende aannemer om dat te doen. Dit is vaak het geval als er funderingsproblemen zijn.

- *Maakt u voordat u ter plaatse gaat een opdrachtverslagje met onder andere wat de onderzoeksvraag is?*

  Nee, je gaat naar aanleiding van de vraag gewoon ter plaatse kijken.

Aanvullende vragen:

- *Op basis van welke criteria neemt u een beslissing over het wel of niet aannemen van de opdracht?*

  Je begint geen onderzoek als je weet dat je geen verstand hebt van wat er gevraagd wordt en als je weet dat je er ook geen verstand van zou kunnen krijgen. Er zijn verder eigenlijk geen redenen waarom je iets zou weigeren.

- *In andere vakgebieden bestaat een onderzoek uit verschillende stappen. Volgen jullie ook een vast stappenplan? Zo ja, welke stappen zijn dat dan?*

  In het geval er een bureaustudie gedaan wordt (bijvoorbeeld voor de uitkragende balkons) dan hebben we de volgende stappen:

1. Kijken naar de originele tekeningen: hoe is de constructie ooit bedacht?
2. Bestaande situatie controleren: is het naar de tekening uitgevoerd?
3. Advies rapport maken.

Voor een groter onderzoek zoals het funderingen onderzoek in Dordrecht werd de volgende onderzoek volgorde aangehouden:

1. Put naar de fundering graven en paal onderzoeken (met Fugro).
2. Monsters nemen en analyseren in het laboratorium (met Fugro).
3. Resultaten op kantoor bekijken en een analyse maken.
4. Rapporten maken.

De algemene volgorde van een onderzoek is:

1. Kijken ter plaatse. Dit houdt in: de schade opnemen bedenken wat de oorzaak zou kunnen zijn.
2. Tekeningen achterhalen van het originele ontwerp.
3. Analyse maken van alle gegevens die je hebt verzameld. Je ordent je informatie. Je bedenkt of je voldoende informatie hebt om een oordeel over de oorzaak te kunnen geven.
4. Rapport maken: hier kan je meteen de conclusie aan verbinden wat er aan de hand is, wat eraan gedaan kan worden of welk aanvullend onderzoek nodig is.

- *Hoe verzamelt u de benodigde data? En hoe zorg je ervoor dat je geen informatie over het hoofd ziet? (Veldonderzoek, documenten etc.)*

  Om de schade te kunnen beoordelen moet je ter plaatse gaan kijken. Negen van de tien keer is er iets wat niet deugt dus dan moet je de situatie ter plaatse bekijken. Als er tekeningen beschikbaar zijn dan zijn ze handig om te hebben omdat het je een idee kan geven over de gedachtegang van het ontwerp. Het probleem met bestaande bouw is dat er vaak geen tekeningen en berekeningen meer zijn. Dit is meestal het geval met + 100 jaar gebouwen en gebouwen in Rotterdam (veel archief delen verbrand). Tekeningen en berekeningen zouden bij gemeente aanwezig moeten zijn (is niet altijd zo). Verder is de beste bron de constructeur of eventueel een aannemer, als ze mee willen werken. Dan heb je informatie uit de eerste hand.

  Voorbeeld: een gestorte begane grond vloer waar alle paalkoppen doorheen geponst waren. Je kan ter plaatse zien wat er misgegaan is, maar je hebt de originele berekeningen nodig om de oorzaak te vinden. Er was namelijk niet gerekend aan pons, alleen de situatie van een tweezijdig opgelegde vloer en pons is de kritische situatie. Er was dus verkeerd gewapend.

  Data ter plaatse wordt vastgelegd doormiddel van foto's, schetsen van de situatie met daarop de locatiebepaling van de schade en hoe de constructie werk en waar eventueel de oorzaak van het probleem ligt. Je maakt vaak op locatie al een verhaaltje waardoor je in je hoofd informatie kan ordenen en je eventueel meteen aanvullend onderzoek kan doen.

- *Zijn de betrokken partijen verplicht om informatie te verstrekken en volledig mee te werken?*

  Dit gaat op vrijwillige basis. Het maakt ook niet zo veel uit of ze mee werken, want uiteindelijk kom je meestal altijd achter de benodigde informatie. Het gebeurd vaak ook dat archieven bij bedrijven opgeruimd zijn. Bouwtoezicht heeft ook vaak niet de nieuwste tekeningen.

- *Hoe bedenkt u mogelijke oorzaken van de schade? Welke technieken gebruikt u hiervoor?*

  Je hebt je ervaring maar het belangrijkste is dat je voor jezelf een beeld vormt van hoe de constructie bedacht is. Hoe worden de belastingen afgedragen? Waar hangt je constructie aan? Als je dat in beeld ziet dan kan je op basis daarvan bepalen waar de mogelijke oorzaak van de problemen ligt.

- *Hoe overtuig je jezelf dat je de goede oorzaak hebt?*

  Als er meerdere opties mogelijk zijn, stel je aanvullend onderzoek voor. Je bekijkt of er signalen zijn dat je een oorzaak kan uitsluiten. In de meeste gevallen is het meteen duidelijk wat de oorzaak van de schade is.

- *Maakt u een eindrapportage? Zo ja wat zijn dan de onderdelen van uw eindrapportage?*

  De rapporten zijn vaak beperkt (5 A4'tjes max). De opzet is als volgt:

  1. Algemeen: wie is de opdrachtgever, wat is er aan de hand en wat zijn de beschikbare gegevens?
  2. Beschrijving van wat je op locatie gedaan hebt en gezien hebt.

3. Conclusie: met de oorzaak en eventueel de herstelmaatregelen die genomen kunnen worden.

In het geval van een korte memo (2 á 3 kantjes):
1. Inleiding.
2. Omschrijving van de constructie.
3. Alle metingen die gedaan zijn.
4. Alle schade die zichtbaar is.
5. Conclusie
6. Advies

Bij het schrijven van een rapport is het van belang dat je volstrekt duidelijk bent in wat je opschrijft. Het mag maar voor één uitleg vatbaar zijn. Het moet taalkundig logisch in elkaar zitten en logisch opgebouwd zijn. De verschillende stappen mogen niet vermengen. Ook moet je opletten dat je niet schrijft in de trant van 'zou kunnen...' Dit vinden opdrachtgevers niet prettig. Je bent of zeker van de oorzaak of niet en dan vermeld je aanvullende onderzoeksmogelijkheden.

De rapporten worden alleen aan de opdrachtgever verstrekt. Als een opdrachtgever wijzigingen wil aanbrengen dan moet je kijken of dat constructief en technisch juist is. Daarom is het ook belangrijk om je rapporten niet in Word format af te leveren. Je moet zorgen dat niemand, zonder jouw toestemming de tekst kan veranderen.

- *Bestaat er een vakgroep, vereniging of kennisuitwisseling voor schadeonderzoek in de bouw? En zou daar behoefte aan zijn?*

  Nee dat is er niet echt. Bedrijven onderling organiseren wel eens middagen om kennis te delen en uit te wisselen over nieuwe normen. Binnen een bureau is het wel van belang dat er communicatie en overleg is. De overkoepelende organisaties zijn meer voor de grotere bedrijven.

  Dit bedrijf heeft niet zulke goede ervaringen met kwaliteitscontroles zoals de ISO-9000 omdat het zorgt voor een vorm van schijnveiligheid. Het is beter om je ''gezonde verstand'' te gebruiken. Je moet als bureau aan je kwaliteit werken en kwaliteit ''streng'' hanteren. Kwaliteit komt tussen de oren van de mensen vandaan en kwaliteit borg je niet met het invullen van meer formulieren.

Interview 2

10 april 2018

Algemene informatie

- *Kunt u mij iets vertellen over uw bedrijf? (grootte/specialisatie/werkgebied)*

  De geinterviewde werkt sinds kort bij een nieuw bedrijf. Haar functie is om een team op te zetten dat zich richt op het doen van schadeonderzoeken en beoordelingen van bestaande gebouwen. Op dit moment worden deze projecten nog door verschillende afdelingen en teams binnen het bedrijf gedaan. Het idee is om alle schadeprojecten door een team te laten doen, zodat er een centraal team en specialisme ontstaat.

- *Wat voor type en grootte schade onderzoeken jullie in het algemeen?*

  De schade types zijn heel wisselend. In Groningen, als gevolg van de aardbevingen zijn er veel dezelfde type schades. Voorbeelden zijn: scheuren in vloeren, gevelpanelen die loslaten, scheurvorming metselwerk, corrosie of bezwijken spouwankers of lekkages. Het zijn over het algemeen wel constructieve schades die in verband met constructieve veiligheid staan, hoewel er soms ook bouwkundige schades onderzocht worden. De grootte van de schades varieert sterk, van een schuurtje met schade tot een appartementencomplex waar alle galerijen problemen hebben. Het hangt vaak af van de opdrachtgever. Particulieren opdrachtgevers hebben vaak kleine schades aan een woning. Woningbouwverenigingen of vastgoed bezitters komen met grotere projecten en daar is dan ook meer geld voor beschikbaar.

- *Hoe/waarom bent u dit werk gaan doen? Heeft u een speciale cursus of opleiding gevolgd?*

  De geintervieuwde heeft eerst bouwkunde gedaan en is daarna over gestapt naar civiele techniek. Daar waren vakken over bestaande bouw en herbestemming. De hele master had ze ingericht op bestaande bouw en hoe daar mee om te gaan. Later heeft ze een afstudeeronderzoek naar funderingsherstel gedaan. Tijdens de crisis was het lastig om een baan te vinden. Dus eerste werk was een baan om een funderingsherstel afdeling op te zetten. Later bij een groter ingenieursbureau gewerkt. En toen bij Bartels terecht gekomen voor schadeonderzoek. Nu werk ze sinds kort bij een ander bedrijf.

- *Van welk type bedrijven krijgt uw bedrijf zijn onderzoeksopdrachten?*

  Opdrachten kunnen van verzekeraars komen, maar die hebben vaste bedrijven waar ze mee samen werken. Verder komen de meeste opdrachten van woningbouwverenigingen, aannemers, vastgoedontwikkelaars, particulieren en vastgoedeigenaren. Bij aannemers gaat het vaak om projecten waar binnen de termijn van 10 jaar schade ontstaat en ze daar dan een bepaalde verantwoordelijkheid voor dragen. De schade moet dan door een onafhankelijke partij onderzocht worden. De laatste paar jaar was er veel werk voor o.a. woningbouwverenigingen en VVE's omdat ze verplicht waren bepaalde onderzoeken te laten uitvoeren (controle uitkragende galerijplaten). Afgelopen jaar zijn er ook veel opdrachten geweest voor onderzoek naar spanningscorrosie in ophangconstructies in zwembaden. Deze onderzoeken worden door de overheid verplicht voor zwembadeigenaren. Ook bubbeldeck vloeren en parkeergarages kwamen afgelopen jaren vaker voor.

Professionele context

- *Wat is het belangrijkst doel van de meeste schadeonderzoeken? (Verantwoordelijkheid/ leren voor de toekomst/ het bedenken van een oplossing/ het achterhalen van het probleem)*

  Is afhankelijk van de opdrachtgever en het vraagstuk. Het is vaak het in kaart brengen van wat nu eigenlijk het probleem is (oorzaak van schade). Soms het toetsen van de constructieve veiligheid, ontwerp van een herstelmaatregel of het aanwijzen van een verantwoordelijke. Dat wordt niet in het rapport geschreven, maar dat is waar je onderzoeksrapport uiteindelijk wel voor gebruikt wordt in bijvoorbeeld een rechtszaak. Je rapporteert wat de oorzaak is en dan moet een rechtbank interpreteren wie verantwoordelijk is. Het gaat om de technische oorzaak.

Voor een onderzoek wordt met een opdrachtgever doorgesproken wat het doel van het onderzoek is. Dit bepaald in een kleine mate ook hoe het onderzoek gedaan wordt. De onderzoeksopzet is vaak gelijk, bepalender is het budget en de informatie die beschikbaar is en welke informatie nog zelf achterhaald moet worden. De rapportage kan wel anders zijn naar gelang het doel van het onderzoek. Bijvoorbeeld als een particuliere opdrachtgever eigenlijk alleen wil weten hoe de schade hersteld kan worden en de oorzaak niet zo belangrijk vindt wordt daar niet heel uitgebreid over gerapporteerd. Als de oorzaak juist wel heel belangrijk is voor de opdrachtgever komt dat in de rapportage uitgebreid aan bod. Als de oorzaak al bekend is en een herstelmaatregel onderzoek gedaan moet worden is de onderzoeksopzet anders.

- *Met hoeveel werken jullie tegelijk aan een onderzoek?*

  De teamgrootte is wisselend. Het gaat in de meeste gevallen om maximaal vijf mensen, maar meestal twee of drie: projectleider, inspecteur, een constructeur of bouwkundige en soms een specialist.

- *Hoeveel tijd is er gemiddeld beschikbaar voor een onderzoek? Beinvloed dit het onderzoeksproces?*

  Er lopen tegelijk meerdere kleine projecten maar een gemiddeld schadeonderzoek aan een gebouw waar niet te veel gekke dingen aan de hand zijn is een week aan gewerkte uren met het team voldoende. Deze uren zijn dan wel vaak verspreid over een aantal weken. Het is wel afhankelijk van of een team goed op elkaar ingespeeld is en alle informatie in een keer goed verzameld wordt. Het kan bijvoorbeeld voorkomen dat er tijdens een inspectie blijkt dat er veel meer aan de hand is, dan in eerste instantie gedacht. Dit heeft invloed op de onderzoekstijd.

- *Kunt u mij een orde grootte geven van het beschikbare budget voor een regulier schadeonderzoek? Beinvloed dit het onderzoeksproces?*

  Je bespreekt met de opdrachtgever de onderzoeksmogelijkheden en de kosten die daarmee samenhangen. Soms gebeurt het dat opdrachtgevers (vaak particulieren) niet zoveel budget hebben voor een onderzoek en dan wordt soms voorgesteld om eerst alleen een visuele inspectie te doen zodat er een beter beeld ontstaat wat er aan de hand is en dan kan daarna besloten worden waar verder in detail naar gekeken moet worden. Vaak is de visuele inspectie de basis voor gerichter vervolgonderzoek. Er komt dan gemakkelijker onderzoeksbudget vrij als de noodzaak is aangetoond. Soms is het ook mogelijk om een paar stappen uit het onderzoek weg te laten omdat zonder die informatie naar alle waarschijnlijkheid ook conclusies getrokken kunnen worden. Dit moet wel altijd beslissing van de opdrachtgever zijn. Een andere optie, die vooral bij particulieren helpt om de kosten te verminderen is het laten aanleveren van de informatie door de opdrachtgever zelf. Dit bespaard tijd voor het bezoek van een gemeentearchief of het opvragen van documenten bij bijvoorbeeld een gemeente. Het is wel belangrijk dat je dan pas begint als je alle informatie hebt om dubbel werk te voorkomen.

  De kosten worden voornamelijk bepaald door de tijd die medewerkers aan een project werken. Verder zijn er benzine kosten, afschrijving van apparatuur, huur van apparatuur en bijvoorbeeld laboratorium kosten. De kosten van een schadeonderzoek lopen sterk uiteen. Om toch een indicatie te geven: een gemiddeld schadeonderzoek kost ca. 3.000 - 5.000 euro, maar het is zeer afhankelijk van de vraagstelling en de grootte van het werk. Als er meerdere mensen ingehuurd moeten worden bijvoorbeeld voor funderingsonderzoek of laboratoriumonderzoek loopt dit bedrag op.

Methodologie

- *Kunt u me meenemen in het onderzoeksproces en vertellen welke overwegingen en stappen u zou doen?*
  1. *Archiefonderzoek*: Als het een bestaand gebouw is dan worden archiefstukken bij het gemeentearchief opgevraagd. Soms heeft de opdrachtgever deze ook zelf in beheer (oude bouwtekeningen). Als het een relatief nieuw gebouw is dan worden de bij de bouw betrokken partijen in kaart gebracht en worden bij hun tekeningen en berekeningen opgevraagd. Als het gaat om een vrij nieuw gebouw met schade na oplevering wordt het laatste gedaan. Het lijkt een constructief probleem en dan wil je, in geval van een betonconstructie, bijvoorbeeld weten: is er genoeg wapening toegepast, is er goed op sterkte en krimp (gaat vaak mis) gewapend?
  2. *Inspectie:* Je brengt een bezoek aan de locatie van de schade en je doet de volgende stappen:
     a. Het controleren van alle gegevens die je uit het archiefonderzoek hebt, bv of tekeningen overeenkomen met de werkelijkheid.
     b. Het in kaart brengen van de schade. Je probeert zo goed mogelijk in kaart te brengen wat er aan de hand is en vast te leggen wat de huidige situatie is. Je kijkt o.a.: welke constructie onderdelen heb ik, hoe zit het mechanica schema in elkaar.
     c. De inspectie kan aangevuld worden met het doen van metingen afhankelijk van wat je aantreft. In dit geval neem je misschien boorkernen, of als er weinig of geen gegevens beschikbaar zijn kan je met een scanner de wapening in kaart brengen. Het gaat dan om de dekking, light de wapening op de goede diepte, is de goede staalsterkte toegepast (laboratoriumtest van een wapeningstaaf). Als het een ouder gebouw is met een buitensituatie dan kan je nog kijken of er spraken is van chloride-indringing, of carbonatatie. Als er scheuren zijn, meet je meestal het scheurverloop in. De scheurwijdtes, locatie van de scheuren (constructief relevante locatie ja of nee), doorbuigingen (vergelijken met berekende waarde).
  3. *Analyse:* Alle gegevens worden dan op kantoor geanalyseerd en soms is op basis van de inspectie al genoeg informatie verzameld. Voorafgaand aan de inspectie wordt al nagedacht welke toetsingen en berekeningen nodig zijn. Dit wordt dan met de constructeur besproken. Parallel aan de berekeningen wordt een analyse van de situatie gemaakt waaruit eventueel aanpassingen aan de berekening kunnen volgen. Bijvoorbeeld er is corrosie en je moet met een afname van sterkte rekenen dan lever je de rekenwaarden van de sterkte aan de constructeur voor zijn berekening. Je levert de gegevens aan waar een constructeur zijn berekening mee doet. Soms volgt er uit de inspectie dat er laboratoriumonderzoek gedaan moet worden. Bedrijven die hier ver mee zijn, zijn Nebest en B.A.S. Aan het einde van de analyse kijk je terug naar je hoofdvraag.
  4. *Conclusie:* in deze stap geef je antwoord op de hoofdvraag van het onderzoek en eventueel geef je een hertelrichting aan.
  5. *Eventueel herstelvoorstel maken*. Dit wordt vaak losgekoppeld van het onderzoek naar de oorzaak, voornamelijk omdat voorafgaand aan het onderzoek moeilijk is in te schatten wat de omvang en oorzaak van de schade daadwerkelijk is. Daarmee is het lastig vaststellen wat hoeveel tijd (en dus geld) het kost om een hersteloplossing te ontwerpen.

Wat betreft de projectorganisatie en werkvolgorde wordt over het algemeen de volgde lijn aangehouden:

1. De projectleider contacteert de opdrachtgever en gaat naar de locatie van de schade toe.

Dan volgt er een gesprek over wat er aan de hand is en een kleine inspectie (niet betaald).
2. Een offerte met een onderzoeksaanpak wordt opgesteld.
3. Opdracht van de opdrachtgever. Vanaf nu is er een contract tussen opdrachtgever en opdrachtnemer en liggen er afspraken vast over planning, budget etc.
4. Er is een overleg tussen projectleider en inspecteur over wat er ingemeten moet worden en welke onderzoeken gedaan moeten worden.
5. Inspecteur voert op locatie de onderzoeken uit en neemt data mee terug naar kantoor.
6. Eventueel berekeningen of andere analyses van de situatie.
7. Rapportage door projectleider of andere medewerker.
8. Controle door een tweede persoon.

Aanvullende vragen:

- *Op basis van welke criteria neemt u een beslissing over het wel of niet aannemen van de opdracht?*

  Het moet een vraag zijn die gaat over het vakgebied (constructies)en de inhoud moet overeenkomen met de expertise binnen het bedrijf. Ook moet er afstemming zijn over: budget, planning en tijd. Ethiek zou kunnen maar is tijdens de werkperiode van de geinterviewde nog niet voorgekomen. Het kan voorkomen dat je bijvoorbeeld een second opinion moet doen voor en schade waarbij een grote opdrachtgever van jouw bedrijf betrokken is. Soms is onderzoek ook niet mogelijk omdat de omstandigheden niet veilig genoeg zijn.

- *In andere vakgebieden bestaat een onderzoek uit verschillende stappen. Volgen jullie ook een vast stappenplan? Zo ja, welke stappen zijn dat dan?*

  In de bouw ligt de aanpak voor het doen van schadeonderzoek niet echt vast. Het verschild per bureau/ bedrijf hoe dit aangepakt wordt. De kwaliteit van rapporten kan heel erg verschillen.

- *Hoe verzamelt u de benodigde data? En hoe zorg je ervoor dat je geen informatie over het hoofd ziet? (Veldonderzoek, documenten etc.)*

  Het werkt op basis van samenwerken. Je brengt een eerste bezoek op locatie. Hierbij kijk je op grote lijnen. Je krijgt dan een bepaald beeld over waar een inspecteur zich op moet richten. Als de inspecteur op locatie komt kijkt hij nogmaals wat er nodig is. Als hij het idee heeft dat er meer moet gebeuren wordt dat in overleg met de projectleider afgestemd. Dan kan er besloten worden ter plaatse aanvullend onderzoek te doen of later nog een keer terug te komen. Soms kom je er tijdens de analyse achter dat er informatie ontbreekt en dan ga je terug. Het werkt volgens een twee ogen principe. Sommige onderzoeken zijn niet meteen helemaal duidelijk dus dan kan het gebeuren dat later blijkt dat informatie mist. Dan ga je terug om die informatie te krijgen. Soms bestaat een onderzoek sowieso al uit twee inspectie dagen en dan wordt na dag een geëvalueerd wat de eerste informatie als onderzoeksrichting aangeeft en dan wordt de inspectie van de tweede dag daar eventueel op aangepast.

- *Zijn de betrokken partijen verplicht om informatie te verstrekken en volledig mee te werken?*

  Nee er is geen verplichting. Een schade kan heel gevoelig liggen en dan wordt soms niet alle informatie gedeeld. Bij een gemeentearchief kan je echter wel veel opvragen dus dan probeer je daarvandaan informatie te krijgen. Vaak staat in de offerte wel dat het onderzoek pas gestart wordt als alle gegevens aangeleverd zijn. Het gebeurt een enkele keer dat een opdrachtgever niet alle informatie zoals bouwtekeningen deelt. Dat bemoeilijkt een onderzoek en het gevolg is dat in het rapport dan vermeld wordt welke informatie niet ontvangen is en dat een conclusie getrokken is op basis van bijvoorbeeld een inspectie. Je onderzoek is dan wat beperkter en je conclusie is soms dan ook wat beperkter.

Soms zit je als schade onderzoeker in een lastige positie omdat je soms midden in een conflict erbij gevraagd wordt. Je moet dan voorzichtig zijn met wat je opschrijft en zegt omdat het op dat moment gevoelig ligt en soms ook een boodschap is die liever niet ontvangen wordt. Het is een verantwoordelijke taak om daar op een goede manier mee om te gaan.

- *Hoe bedenkt u mogelijke oorzaken van de schade? Welke technieken gebruikt u hiervoor?*

  Meestal is de verzamelde data zo duidelijk dat eventuele oorzaken daar meteen uit volgen. Dan is het zaak om met de data nog te bewijzen dat dat specifiek de oorzaak is. Je werkt ook op basis van ervaring. Soms pak je ook oude normen erbij. Als er problemen zijn wil dat niet altijd zeggen dat iets fout gedaan is. Het kan volgens oude normen ook correct ontworpen zijn maar toch problemen opleveren. Vb oudere zwembaden die niet op krimp gewapend zijn maar wel blootgesteld worden aan chloride. Het geeft nu problemen maar is correct volgens de toen geldende normen,

- *Maakt u een eindrapportage? Zo ja wat zijn dan de onderdelen van uw eindrapportage?*

  Het hangt een beetje af van opdrachtgever en het doel van het onderzoek. De volgorde die in dit vakgebied meestal alles omvat is:
  1. Archiefonderzoek (data verzamelen)
  2. Inspectieresultaten (data verzamelen)
  3. Berekeningen (zelf data genereren op basis van informatie uit 1 en 2)
  4. Analyses (interpretatie)
  5. Conclusies
  6. Aanbevelingen

  Soms vervalen sommige onderdelen zoals berekeningen of inspectie.

- *Staat in het rapport ook je onderzoeksmethodiek?*

  Vaak in de inleiding. Daarin staan:
  1. De aanvraag en aanleiding van het onderzoek
  2. Het doel: komt ook weer terug in je conclusies
  3. Context
  4. Stappenplan
  5. Hoofdstukindeling

- *Bestaat er een vakgroep, vereniging voor schadeonderzoek in de bouw? En zou daar behoefte aan zijn?*

  Je komt allerlei type onderzoeken tegen. Dat is ook een beetje de bouw eigen. Er worden wel richtlijnen opgesteld via de CUR. Dit gaat vaak over bepaalde type schadeonderzoek dat landelijk gedaan moet worden en daar staat dan ook in hoe het onderzoek aangepakt moet worden. Voorbeelden zijn: de zwembaden inspecties en galerijplaat inspecties. Je wordt daar niet voor gecertificeerd. Verder wordt via het CURnet ook kennis gedeeld. Het gaat dan wel vaak over specifieke situaties of type constructies. De CUR stelt dan soms ook richtlijnen op hoe je met dat type constructie om kunt gaan. Verder heb je de stufib, een vereniging die gericht is op beton. Zij geven ook lezingen en maken rapporten over onderwerpen gerelateerd aan betonconstructies. Verder laten sommige bedrijven zich ISO certificeren. Dat gaat meer in op de bedrijfsprocessen en werkwijze binnen een bedrijf, maar dat is niet vakspecifiek.

  Bij bestaande bouw is het probleem vaak ook dat ze volgend oudere normen gemaakt zijn en dan moet je een constructeur hebben die volgens die oude norm kan kijken en ook los van de norm een goed oordeel kan geven over een constructie.

  Verder vraag je, indien aanwezig de eerder opgestelde onderzoeksrapporten op en dan zie je wel dat er kwaliteitsverschillen bestaan tussen de verschillende rapportages opgesteld door verschillende partijen. De kwaliteitsverschillen zitten bijvoorbeeld in de manier van rapporteren (onoverzichtelijk, heel summier), het snel trekken van conclusies op basis van eerdere gevallen, geen onderscheid maken tussen feiten en mening. Soms is ook de onderzoeksvraag niet juist gesteld waardoor de kern van het probleem niet boven komt.

Interview 3

22 mei 2018

- *Is het goed als ik het interview opneem als assistentie bij het uitwerken van het interview?*

  Ja dat is goed.

Algemene informatie

- *Kunt u mij iets vertellen over uw bedrijf? (grootte/specialisatie/werkgebied)*

  Dit bedrijf heeft als specialisatie prefabbeton constructies. Het bedrijf doet prefab engineering voor verschillende prefab leveranciers in Nederland, België. De meeste projecten zijn in de omgeving van de randstad. Deze werkzaamheden bestaan dan voornamelijk uit het maken van productietekeningen. Daarnaast worden er gebouwontwerpen voor met name utiliteitsbouw gemaakt. Het logische gevolg is dan meestal wel dat er ook prefab constructies in deze gebouwen gebruikt worden. De klanten zijn voornamelijk prefab leveranciers en aannemers. Het bedrijf heeft op dit moment ongeveer 30 werknemers verdeeld over drie afdelingen: constructeurs, Revit modelleurs, en Tekla modelleurs.

- *Wat voor type en grootte schade onderzoeken jullie in het algemeen?*

  Het gaat voornamelijk om schades die binnen eigen gebouwen optreden. Dus bijvoorbeeld scheurvorming in prefab elementen tijdens een bouw en dan is de vraag wat er aan de hand is. Verder worden er voor drie gemeenten plantoetsingen gedaan, waarbij er soms ook vragen zijn over schades. Soms komen klanten direct met een schade vraag.

- *Hoe/waarom bent u dit werk gaan doen? Heeft u een speciale cursus of opleiding gevolgd?*

  De geinterviewde heeft de studie constructief ontwerpen aan de TU gevolgd. Nadat hij dat had afgerond, is hij gaan werken bij dit bedrijf. Hij heeft hier acht jaar gewerkt. Daarna heeft hij bij TNO gewerkt op de afdeling die betonconstructies beoordeeld. Daarna is hij weer teruggegaan naar dit bedrijf. Bij TNO is de basis voor de schade beoordelingsexpertise gelegd. Bij TNO varieerde de schades van scheuren in een muur door bouwwerkzaamheden in de omgeving tot de grote schades met instortingen. Ervaring en kennis doe je op door het meelopen met mensen die al heel lang schadeonderzoek doen. Dan ga je langzamerhand zien wat het systeem is en waarom bepaalde dingen op een bepaalde manier gedaan worden. Het werken bij TNO was een goede leerschool.

- *Van welk type bedrijven krijgt uw bedrijf zijn onderzoeksopdrachten?*

  Prefab leveranciers, aannemers, gemeenten en soms particulieren via de website

Professionele context

- *Wat is het belangrijkst doel van de meeste schadeonderzoeken? (Verantwoordelijkheid/ leren voor de toekomst/ het bedenken van een oplossing/ het achterhalen van het probleem)*

  De belangrijkste doelen van een schade onderzoek zouden moeten zijn: wat is er aan de hand en is de veiligheid niet in gevaar? Daarna komen de juridische aspecten aanbod. In Nederland hebben we het constructieprincipe dat een constructie moet waarschuwen voordat het misgaat Een scheur is in principe een waarschuwing. Het belangrijkste moet dus zijn om te bepalen of de veiligheid gewaarborgd is. Op basis van ervaring kan je meestal wel vrij snel beoordelen of veiligheid echt een probleem.

  In de praktijk komt het wel voor dat opdrachtgevers een iets andere insteek hebben. Zij zijn meer gefocust op schuld of een oplossing. Zij kijken niet met een constructief oogpunt maar met hun eigen bril (gebouweigenaar, aannemer). Voor het onderzoek maakt dat verschil in insteek niet zo veel uit, want in je zoektocht naar de vraag 'is het veilig' kom je de andere aspecten ook tegen. De verschillende doelen kunnen naast elkaar bestaan.

Soms is het ook niet altijd duidelijk of het een beperkte schade is of dat het groter is. Je zult dus altijd eerst moeten bekijken of extra maatregelen zoals extra ondersteuning of eventueel ontruiming nodig is.

- *Met hoeveel werken jullie tegelijk aan een onderzoek?*

  Binnen dit bureau werkt de geinterviewde voornamelijk zelf aan de schadeopdrachten. Waar nodig vraagt hij andere collega's erbij. Het doen van schade beoordelingen is toch een apart vak en omdat het niet dagelijks werk is, hebben niet alle collega's de ervaring om dat te doen.

- *Hoeveel tijd is er gemiddeld beschikbaar voor een onderzoek? Beinvloed dit het onderzoeksproces?*

  De beschikbare tijd is niet direct van invloed op een onderzoek. Meestal werkt het zo dat als er iets aan de hand is, dit voorrang krijgt op andere werkzaamheden. Een reden is kan zijn dat de vraag van een directe klant komt. Meteen reageren is een vorm van klantenservice. Een andere reden is dat je niet weet hoe ernstig het is. Elke schade wordt in eerste instantie als urgent behandeld. Na een eerste beoordeling wordt bepaald hoeveel prioriteit een schade heeft en de termijn waarop het afgehandeld dient te worden. De looptijd van een schadeonderzoek is erg afhankelijk van het soort schade.

- *Kunt u mij een orde grootte geven van het beschikbare budget voor een regulier schadeonderzoek? Beinvloed dit het onderzoeksproces?*

  De onderzoeksmogelijkheden zijn binnen dit bureau beperkt tot niet destructief onderzoek. Dus ten eerste moet bepaald worden of het onderzoek alleen met visuele inspectie uitgevoerd kan worden. Als destructief onderzoek nodig is dan wordt de klant verwezen naar een partij die dit wel kan. Welk type onderzoek (destructief of niet-destructief onderzoek) nodig is bepaald in grote mate de prijs. Aan de start van het onderzoek wordt een kostenraming gemaakt. Vaak worden onderzoeken ook in fasen opgedeeld. Eerst alle documenten verzamelen en een bezoek op locatie (twee à drie dagen). De eerste fase resulteert in een klein rapportje met eerste bevindingen. Er zijn dan meestal twee smaken: of er is een idee van de oorzaak of er moet vervolgonderzoek gedaan worden. Hiervoor wordt dan een nieuwe offerte gemaakt. Op dat moment is er een veel beter beeld van wat er onderzocht moet worden, dus dan kan de offerte ook specifieker zijn. De meeste klanten vinden dit een prettige aanpak.

- *Welk type betonschade komen veel voor?*

  Productie en uitvoeringsfouten zijn vaak de oorzaak van schade. Het gaat dan vaak om dingen die in de loop van het proces gewijzigd maar niet altijd op de goede manier verwerkt zijn. Ook het anders uitvoeren van constructie elementen dan op tekening komt regelmatig voor. Doorgaans openbare dit type schades zich tijdens de bouw. Dit komt omdat er op dat moment meer mensen rondlopen die hier oog voor hebben.

Methodologie

Case: een maand na oplevering worden er door de eigenaar van een kantoorgebouw scheuren in de betonnen eerste verdiepingsvloer gemeld aan de uitvoerder. De uitvoerder vraagt uw bedrijf om onderzoek te doen naar de oorzaak van de scheuren.

- *Kunt u me meenemen in het onderzoeksproces en vertellen welke overwegingen en stappen u zou doen?*

  Voorbeeld casus van een scheur in een plafon prefab breedplaatvloer in een berging van een appartement.

De volgende stappen worden gevolgd:

1. Gegevens verzamelen: dit gaat om het verzamelen van tekeningen en berekeningen van de constructie en eventueel fotomateriaal van de klant. Documenten worden allereerst aan de opdrachtgever gevraagd. Een tweede optie is het opvragen van documenten bij de gemeente en een laatste optie is het vragen van documenten aan de bouwer (meestal via opdrachtgever onderzoek). De voorkeur is dat de klant zelf de documenten aanlevert omdat het opvragen en achterhalen van documenten tijd kost en dus relatief duur is.
2. Documenten analyseren: aan de hand van de beschikbare gegevens wordt gekeken hoe de constructie werkt en hoe krachten worden afgedragen. Hierbij start je met een gedetailleerde analyse van het element met schade. Van daaruit bekijk je gerelateerde elementen. Dit is het moment waarop duidelijk wordt of het gaat om een geïsoleerde schade (bijvoorbeeld prefabbeton element die alleen aan constructie verbonden is met ankers) of om een schade aan een element dat verbonden is met de gehele constructie (dragende balk). Dit bepaald het deel van de constructie die geanalyseerd moet worden.
3. Locatie bezoek: deze stap bestaat uit meerdere onderdelen. Alle informatie wordt vastgelegd door middel van foto's.
    a. Eerst laat je klant zijn verhaal doen.
    b. Je probeert een beeld te krijgen hoe krachten worden afgedragen. In het voorbeeld van de scheur in de beeldplaatvloer kijk je naar de voeg. Dat is de overspanningsrichting.
    c. Je kijkt hoe de schade zich verhoudt tot de krachtsafdracht van de constructie. In het voorbeeld van de breedplaatvloer: de scheur was parallel aan de overspanning. Dit heeft een andere impact constructief gezien dan een scheur loodrecht op de overspanning.
    d. Je brengt de schade in kaart: hoe groot is de scheur, wat is de lengte?
    e. Je bekijkt de omgeving: Is er ook schade zichtbaar in ondersteunende constructie? Zijn er opvallende dingen zichtbaar? Hoe ziet de aansluiting tussen een dragende en niet dragende wand eruit? Is er een kier (indicatie voor vervormingen)? Is de kitvoeg gescheurd (nieuwbouwproject wordt netjes afgewerkt en voegvrij opgeleverd dus scheur is indicatie voor vervormingen)?
    f. Je bekijkt door middel van een gesprek met aanwezigen of het de enige locatie is waar de schade voorkomt. Als er op meerdere locaties schade is, bekijk je deze ook waar mogelijk.
    g. Je kijkt of er aan in dit geval de bovenkant van de vloer ook nog schade te zien is.

Tijdens deze analyse denk je na over wat de oorzaak van de schade zou kunnen zijn en wat de oorzaak NIET kan zijn. Het proces verloopt meestal in de volgorde van het wegstrepen van oorzaken op de lijst met mogelijke oorzaken in je hoofd. Het resultaat van het bezoek op locatie is een goed beeld van de schade en de context.

4. Op kantoor analyseer je nogmaals alle gegevens en probeer je meer mogelijke oorzaken weg te strepen of een meest waarschijnlijke oorzaak aan te tonen. Hierbij is vaak een interessante vraag: waarom is de schade nu specifiek op die locatie aanwezig en niet op soortgelijke andere locaties? Vaak moet je ook naar de bouwkundige details kijken om bijvoorbeeld te achterhalen hoe temperatuur invloeden van buiten de constructie beïnvloeden.

De belangrijkste twee principes zijn als eerste dat je de van de lijst met mogelijke oorzaken,

oorzaken uitsluit. Als tweede dat je goed naar de omgeving kijkt. Daar zijn vaak goede aanwijzingen te vinden voor mogelijke oorzaken. Bijvoorbeeld: waar staat de zon op het gebouw? Wat was het weer in de afgelopen periode?

Aanvullende vragen:

- *Is dit een representatieve vraag voor de praktijk?*

  Ja dit kan een echte vraag zijn. Ook de hoeveelheid informatie is representatief voor een echte opdracht.

- *Op basis van welke criteria neemt u een beslissing over het wel of niet aannemen van de opdracht?*

  Algemeen geformuleerd: als het een eigen project is dan moet je de opdracht aannemen. Als het een vraag van buiten is dan hangt het af van de aard van de schade en van de hoeveelheid informatie die je hebt en kan krijgen. Bijvoorbeeld als het een heel oud pand is met heel veel scheurvorming en weinig beschikbare informatie dan wordt aan de klant ter overweging meegeven dat het wel mogelijk is om er iets over te zeggen maar dat het resultaat misschien niet zo eenduidig en zeker is als dat er verwacht wordt. De klant kan dan kiezen of hij dat wil. Het gaat erom dat de klant ook een goed resultaat heeft. Een andere afweging is hoe politiek gevoelig de opdracht ligt. Dit speelt vooral een rol bij second-opinion. De overweging is dan gebaseerd op welke partijen erbij betrokken zijn. Als er een partij bij betrokken is die ook klant is dan is de vraag hoe die over jouw betrokkenheid denken. Dat zijn situaties die je niet wilt opzoeken en dan verwijzen we meestal door naar een ander bedrijf. Dit is een situatie die niet zo vaak voorkomt, maar het is een aspect waar je wel rekening mee moet houden.

- *Zijn de betrokken partijen verplicht om informatie te verstrekken en volledig mee te werken?*

  Het is afhankelijk van wie de klant is. Normaalgesproken lukt het wel om het meeste te verzamelen alhoewel er altijd wel iets van informatie mist. Het komt natuurlijk ook voor dat bepaalde informatie niet meer bestaat of nergens meer opgeslagen is.

- *Hoe bedenkt u mogelijke oorzaken van de schade? Welke technieken gebruikt u hiervoor?*

  Er wordt een soort mentaal lijstje gebruikt. Op dit lijstje staan ongeveer 15-20 mogelijke oorzaken. Het is een lijstje dat je met een beetje kennis van constructies zo kan maken. Vb: zettingen, overbelasting (tijdens bouw of gebruik, extreem weer, verkeerde berekening, tekening), etc. Het beste resultaat krijg je als je aan de ene kant dit lijstje weg streep en aan de andere kant met de gegevens die je krijgt en wat je ziet een verklaring op te bouwen. Het doel is om een verklaring te vinden die logisch is opgebouwd en ook logisch past bij de dingen die je ziet. Bijvoorbeeld er is een scheur en als oorzaak worden zettingsverschillen aangegeven. Dan moeten er op andere plaatsen in de constructie ook schade te zien zijn.

  Het kan natuurlijk ook voorkomen dat er twee mogelijke verklaringen voor de schade zijn. Dan wordt dit gerapporteerd. Als deze twee mogelijkheden vervolgens twee totaal verschillende vervolgstappen veroorzaakt dan heb je een probleem. Dan ga je proberen met vervolgonderzoek een van de mogelijkheden uit te sluiten. Als de vervolgstap voor beide gelijk is dan maakt het niet zo veel meer uit.

- *Maakt u een eindrapportage? Zo ja wat zijn dan de onderdelen van uw eindrapportage?*

  De rapportage heeft een vaste structuur.

  1. Algemeen deel: dit beschrijft hoe de vraagstelling tot stand is gekomen. Meestal wordt in de bijlage een samenvatting opgenomen van alle aangeleverde documentatie.
  2. Leeswijzer

3. Omschrijving constructie: een algemene beschrijving van de constructie en een gedetailleerde beschrijving van de door de schade beïnvloede delen van de constructie.
4. Inspectieverslag: een bescrijving van wat er is waargenomen en specifieke verwijzingen naar opvallende informatie. In de bijlage worden meestal wat fotos van de inspectie opgenomen.
5. Constructieve analyse: voor dit onderdeel zijn twee manieren van beschrijven. Welke gekozen wordt hangt onder andere af van de klant, type schade en de onderzoeksvraag.
    a. Een directe analyse van de oorzaak
    b. Alle mogelijke oorzaken worden opgesomd en een voor een behandeld. De reden voor het uitsluiten van een oorzaak bij de oorzaken die niet mogelijk zijn en een uitleg waarom een oorzaak wel mogelijk is voor de overblijvende mogelijke oorzaken.
6. Conclusie en aanbevelingen

Een aantal overige opmerkingen:

- Je moet in een rapport bij ontbrekende gegevens aangeven wat je aannamen zijn. Het hangt een beetje af van de invloed die deze aanname heeft op de oorzaak van de schade. Als de aanname invloed heeft op de oorzaak van de schade dan wordt er gerapporteerd dat iets een verwachte oorzaak is onder de aanname dat…, maar dat vervolgonderzoek nodig is om dit vast te kunnen stellen. Dit wordt dan in de conclusie opgenomen als een aanbeveling voor vervolgonderzoek of hoe de schade gemonitord kan worden.
- Je moet niet tijdens je bezoek op locatie al zeggen wat de vermoedelijke oorzaak is. Het is verstandig om alle informatie even te laten bezinken en pas na de rapoortage te vertellen aan de klant.

Interview 4

7 mei 2018

- *Is het goed als ik het interview opneem als assistentie bij het uitwerken van het interview?*

  Ja

Algemene informatie

- *Kunt u mij iets vertellen over uw bedrijf? (grootte/specialisatie/werkgebied)*

  Het bedrijf bestaat uit twee onderdelen: een schade expertise bedrijf (allesbehalve letselschade en zeevaart) en een bedrijf dat zich bezighoudt met bouwkundige opnames en (nul)metingen (zowel voor als tijdens de uitvoering). Binnen het bedrijf zijn er voor de afdeling schadeonderzoek verschillende specialistische onderdelen: transport en techniek (o.a. vrachtwagens, diesels), brandschades (zakelijk en privé), bouw en infra schades. Die laatste categorie bestaat uit: kabel en leiding schades, schades van het waarborgfonds motorverkeer, schades van Rijkswaterstaat en bouwprojecten en hun omgeving.

- *Wat voor type en grootte schade onderzoeken jullie in het algemeen?*

  Er worden schades in alle orde van grootte behandeld. De schade aan belendingen gaat doorgaans over een kleiner bedrag, maar er zijn ook schades die over miljoenen gaan. Als je voor CAR-verzekeringen komt, gaat het om materiele schade en is het vinden van een oorzaak niet altijd relevant. De geinterviewde is van mening dat het voor de meeste zaken nuttig is om wel de oorzaak uit te zoeken en het dus als een aansprakelijkheidsvraagstuk te behandelen. Het gaat dan om de vragen: wie heeft het gedaan en wie moet het eigenlijk betalen? Je komt dus soms ook bij ontwerpers uit. Ook de processen binnen het project worden geanalyseerd. Je bekijkt bijvoorbeeld de contracten en verzoeken tot wijzigingen (vtw's). Hoe is dat gegaan? Zijn er verschillen van interpretatie/inzicht bij partijen over de inhoud? Zit de vraagspecificatie goed in elkaar en waarom is het niet goed gegaan in de uitwerking en of uitvoering?

- *Hoe/waarom bent u dit werk gaan doen? Heeft u een speciale cursus of opleiding gevolgd?*

  De geinterviewde heeft 20 jaar bij aannemers gewerkt, waarvan 15 jaar bij Ballast Nedam en 5 jaar bij Van Wijnen. Bij een schadegeval maakte hij kennis met een aandeelhouder van dit bedrijf en is de stap naar schade expertise gemaakt. Bij de aannemers was een van zijn werkzaamheden risicobeheer. Wat er toen in een jaar aan eigen problemen/schades voorbijkwam, komt nu bij dit bedrijf langs in een werk week. Nu bestaan zijn werkzaamheden onder andere uit het uitzoeken van de problemen van klanten en dat is echt een uitdaging, omdat het een puzzel is en de bedrijfscultuur van de bouw is er in het algemenen niet een van open zijn over problemen en het vertellen wat je fout gedaan hebt. Het doen van onderzoek gaat in basis over het bovenwater krijgen van het hele verhaal, ook in verband met een eventuele rechtszaak. De vraag is wel: wat is echt onderzoek? Je komt namelijk al snel bij interpretatie en belangenbehartiging terecht. Voor de echte puur technische aspecten moet je dan ook een technisch specialist inhuren.

- *Welke eigenschappen of vaardigheden moet een schade onderzoeker volgens u hebben?*
  - Nieuwsgierig zijn.
  - Open-mind hebben.
  - Niet te snel denken dat je er bent.
  - Mensen in hun waarde laten.
  - Goed kunnen analyseren.
  - Weten wat je moet analyseren.
  - In een context analyseren.
  - Flexibel zijn. Zowel de technische oorzaak als de aansprakelijkheidsvraag kunnen

oplossen. Daar zit vaak de sleutel tot de oplossing.
» Het verstaan van en kunnen communiceren in de technische taal en de juridische taal.

- *Van welk type bedrijven krijgt uw bedrijf zijn onderzoeksopdrachten?*

  Het grootste gedeelte van het werk voor de bouw komt van verzekeraars, aannemers en opdrachtgevers van aannemers zoals gemeenten.

Professionele context

- *Wat is het belangrijkst doel van de meeste schadeonderzoeken? (Verantwoordelijkheid/ leren voor de toekomst/ het bedenken van een oplossing/ het achterhalen van het probleem)*

  Het doel van het onderzoek is erg afhankelijk van de vraag, in wiens belang je komt en wat de context van het onderzoek is.

  Een schadetype dat vaak terugkomt zijn claims van mensen uit de omgeving van een bouwproject. Het gaat dan vaak om scheuren in gebouwen naar aanleiding van bijvoorbeeld heiwerkzaamheden. Claims komen via de eigen (opstal) verzekering van een omwonende of de opdracht komt via een uitvoerder of projectorganisatie. Deze schades vallen bijna altijd onder het eigen risico en dan worden er door aannemers drie verschillende strategieën gebruikt: niet reageren (niet ethisch verantwoord), zelf gaan kijken en de schade oplossen of het inhuren van een onafhankelijke partij om de schade vast te stellen. Andere type opdrachten zijn calamiteiten op het werk of discussie over garanties en veiligheid.

- *Met hoeveel werken jullie tegelijk aan een onderzoek?*

  In de meeste gevallen werkt een expert alleen aan een onderzoek, omdat het onderzoek per expertise aangewezen wordt. Soms is er binnen een onderzoek kennis van een ander vakgebied nodig en dan betrek je die expert bij het onderzoek. Je moet altijd kijken naar je eigen hoedanigheid. Je mag iets vinden van de voorgestelde werkmethode maar je bent geen ingenieursbureau dus je kan niet een voorstel tot verbetering doen. Dan in het beter om een extern specialistisch technisch bedrijf in te schakelen.

- *Hoeveel tijd is er gemiddeld beschikbaar voor een onderzoek? Beinvloed dit het onderzoeksproces?*

  Een schade aan een belending is meestal drie à vier uur werk. De tijd die je aan het onderzoek besteed is de tijd die je nodig hebt om je onderzoek goed te doen. Het probleem ontstaat bij aangenomen werk (niet zo veel binnen dit bedrijf), want daar staan een vast aantal uren voor en dan loop je het risico dat het onderzoek niet volledig gedaan kan worden binnen de beschikbare tijd. Meestal wordt er in stappen gewerkt. Dus je doet een eerste onderzoek en dat rapporteer je. Dan overleg je met opdrachtgever over waar je verder de diepte in wilt gaan. Verzekeraars willen dat meestal pas als er een bedreiging is (risicobeheersing) en als verdieping in dat kader niet noodzakelijk is nemen ze niet altijd het voortouw.

- *Kunt u mij een orde grootte geven van het beschikbare budget voor een regulier schadeonderzoek? Beinvloed dit het onderzoeksproces?*

  Er wordt op urenbasis gewerkt dus het voornaamste is de urenverantwoording. Er zijn ook opdrachten met vaste contracten maar die zijn er binnen het schade deel van dit bedrijf bijna niet. Met dat soort contracten moeten alle opdrachten voor een vast bedrag gedaan worden, ook de complexen.

- *Kunt u me meenemen in een onderzoeksproces en vertellen welke overwegingen en stappen u zou doen?*

  Het begint met de vraag is er iets fout gegaan of is er een klacht. In het geval van deze casus is het een kwestie van de constructeur van het gebouw bellen en sturen en die moet dat dan beoordelen. Hij is degene die weet hoe het gebouw in elkaar zit en wat het gebouw kan hebben, dus hij kan daar het snelst een goed oordeel over geven. Het is het belangrijkst op zo'n moment om de constructieve veiligheid te beoordelen en de constructeur heeft daar de kennis en kunde voor. Bij schade-experts hangt het af van hun achtergrond hoeveel technische ervaring ze hebben. Dit kan verschillen van een aantal jaar als werkvoorbereider tot werkervaring als constructeur.

  In het algemeen geld dat een opdrachtgever met een vraag komt. Dit kan gaan om iets wat verkeerd gegaan is en uitgezocht moet worden, iets waar zorgen om zijn bij de klant en beoordeeld moet worden etc. Hierbij is het van belang dat je eerst bekijkt of de analyse van de klant volledig is of dat je breder moet gaan kijken. Je vraagt je dan af: is het een uitvoeringsfout of zit de fout ook al in het principe ontwerp? De basis van een gebouw is: het moet constructief veilig zijn, wind en water dicht, geschikt voor zijn functie en als laatste moet het er ook mooi uitzien.

  In basis volgt altijd een discussie over de ontwerpkeuzes die gemaakt zijn. Op papier gelden de principes: form-follows-function en hoofd en bijzaken, maar dat is niet altijd de praktijk. Vaak ontstaan er problemen met onmogelijke eisen. Bijvoorbeeld wat betreft toleranties, waarbij het een element hele andere toleranties heeft dan een aansluitend element. Daar loop je een groot risico. Om de vinger op het probleem te kunnen leggen speelt ervaring mee. Iemand die veel met tunnels gewerkt heeft kan bijvoorbeeld op basis van de uitvoeringsmethode al aanwijzen waar waarschijnlijk problemen/schades zullen ontstaan. De geinterviewde maakt dus graag gebruik van het sparren met specialisten tijdens een onderzoek. Als onderzoeker hou je het overzicht en integreer je kennis van specialisten, waar nodig, in je onderzoek.

- *Als u wel zelf een schade beoordeeld wat voor type schade gaat het dan om?*

  De schade beoordelingen van bedrijven of projecten waar het risicobeheer voor gedaan wordt, worden door een collega gedaan. Als voorbeeld: een bestaand gebouw waarbij het middelste gedeelte 5 cm omhooggekomen is. De vraag is: wat is de oorzaak en hoe kan het weer veilig terug gebracht worden in de oude situatie?

- *Hoe pak je het onderzoek naar zo'n schade dan aan?*

  Je gaat ergens kijken, je maakt een hypothese en vervolgens moet je die hypothese bewijzen. Je gaat tijdens je onderzoek steeds verder de diepte in. Dus je begint op basisniveau: wat is er aan de hand? Dan heb je meestal al snel een idee waar het probleem ligt. Het kiezen van een onderzoeksrichting is gebaseerd op alle informatie die je ter plaatse verzameld hebt maar ook je indruk van bijvoorbeeld de organisatie van de bouwplaats. Hierbij speelt ervaring ook een rol. Vervolgens moet je net zolang spitten totdat je er bent, waarbij het spitten een iteratief proces is.

  Naast technische aspecten spelen er natuurlijk ook contractuele omstandigheden en allerlei andere belangen tijdens een onderzoek. Het onderzoek begint bij de basis en daarna kan je dat binnen een context plaatsen.

- *Hoe verzamelt u de benodigde data? (Veldonderzoek, documenten etc.)*

  Je gaat ter plaatse kijken. Daar bekijk je de schade en je praat met medewerkers/ bewoners/ gebruikers over wat er is gebeurd. Je kijkt hoe het contract in elkaar zit, welke werktekeningen aanwezig zijn, wie ze gemaakt heeft en hoe het bedacht is. Uit al die informatie blijkt waar het fout gegaan is of lijkt te zijn en daar ga je de diepte in.

Als je ter plaatse bent dan loop je rond en praat je met de uitvoerders. Op basis van hun verhaal stel je vragen als: waarom het je dat dan gedaan, hoe heb je dat gedaan, met welk materieel? Ook vraag je naar ondersteunende documenten als werkinstructies en uitvoeringstekeningen. Dat gesprek gaat makkelijker als ze merken dat je zelf ervaring hebt met bouwen. Dat levert meer informatie op en helpt je ook om een goed gefundeerd onderzoek te doen. Het is hierbij belangrijk om objectiviteit zo lang mogelijk vast te houden. Dit kan bijvoorbeeld door alleen open vragen te stellen.

- *Hoe kom je van de technische oorzaak van de schade bij de oorzaak in het proces, bijvoorbeeld ontwerpfouten? Hoe onderzoek je dat en hoe kom je aan informatie?*

  Eerst bekijk je het type contract, UAV, UAV-GC of RAW. Dan ga je kijken hoe de informatiestroom heeft gelopen: wie heeft op welk moment welke keuze gemaakt? Je brengt de projectorganisatie in kaart en kijkt hoe de aansluiting met het bouwteam is gegaan. Dit zit bij ieder project anders in elkaar en daarom is het lastig om een goede blauwdruk te maken hoe je het aan moet pakken. Als je niet ver genoeg uitzoomt, is het lastig om verbanden te zien.

  De stappen die je doet zijn dus wel familie van elkaar, maar waarom je het de ene keer zo en de andere keer anders doet is afhankelijk van de context. Er zijn ook terreinen waar standaardisatie eerder voorkomt, bijvoorbeeld autoschades. Hierbij onderzoek je vaak dezelfde type schades, je maak volume werk. Bij vrachtwagens is dat alweer niet mogelijk omdat de frequentie van een type schade laag is. Dit is ook het geval met bouwschades. De frequentie van specifieke schades is erg laag. Het gaat dan dus meer over de volgorde van de stappen die je doet tijdens je onderzoek. Ook is het belangrijk om met een soort expertsysteem te kiezen welke kant je met je onderzoek opgaat. Dit misschien wel een van de redenen waarom er weinig herkenbare uniformiteit in onderzoek is.

Aanvullende vragen:

- *Op basis van welke criteria neemt u een beslissing over het wel of niet aannemen van de opdracht?*

  Wie de opdracht geeft en of er een redelijke tijd beschikbaar is om het onderzoek te doen.

- *Zijn de betrokken partijen verplicht om informatie te verstrekken en volledig mee te werken?*

  Bij een verzekeraar dekt de polis dat er medewerking aan het onderzoek verleend wordt. Anders is er geen verzekering. Als je op een grote bouw komt om iets te onderzoeken en je hebt van de bouworganisatie opdracht gekregen dus dan heb je op die manier een mandaat.

- *Hoe overtuig je jezelf dat je de goed oorzaak hebt en hoe voorkom je dat je informatie mist?*

  Je moet een open-mind houden. Dus je probeert zo weinig mogelijk tegen jezelf te zeggen: dit is het. Daarom is het ook lastig om te rapporteren als je er nog niet helemaal uit bent. Degeinterviewde ervaart dat het rapporteren ervoor zorgt dat alle gedachten en ideeën uit je hoofd omgezet worden in iets feitelijks. Hij heeft allerlei aantekeningen en notities maar zolang de hoofdredenatie nog niet in het hoofd compleet is, schrijft hij het liever niet op in een rapportage. Gedurende het onderzoek is het echter wel essentieel om de klant via rapportage en communicatie op de hoogte te houden, zodat deze ook verder kan in het proces.

- *Maakt u een eindrapportage? Zo ja wat zijn dan de onderdelen van uw eindrapportage?*

  Er worden altijd rapporten gemaakt, maar wanneer en hoeveel hangt af van de afspraken. Als er een schade is dan moet je binnen ongeveer drie weken rapporteren. Als er echter informatie ontbreekt of het is complex dan maak je tussenrapportages. Voor sommige onderzoeken maak je een brief met een tussenstand en ga je daarna de diepte in. In de gevallen dat er een procedure bij bijvoorbeeld een rechtbank loopt maak je tussenverslagen zodat de procedure verder kan. Het is dus afhankelijk van de klant en de context.

De stappen in de rapportage zijn als volgt:

- Context: een feitelijke beschrijving van het project met wat, waar, waneer)
- Betrokken partijen: een overzicht van de betrokken partijen en hun relaties
- Voorval: Een beschrijving van de eigenlijke gebeurtenis
- Bevindingen van het onderzoek: een beschrijving van alle waarnemingen. Hierbij is het belangrijk om een objectieve weergave van deze bevindingen te geven.
- Oorzaak: een conclusie van de bevindingen
- Omvang van de schade, herstelmaatregelen en herstelkosten
- Overige verzekeringen
- Verhalings mogelijkheden

Interview 5

19 april 2017

Algemene informatie

- *Kunt u mij iets vertellen over uw bedrijf? (grootte/specialisatie/werkgebied)*

  Dit bedrijf is een schade expertise bedrijf met vier takken van expertise: Electronica/werktuigbouw, milieu, bouw/civiel en property. Het bedrijf heeft drie vestigingen in Rotterdam, Amstelveen en Utrecht. Binnen het bedrijf is er een platte bedrijfsstructuur met op iedere vestiging een directielid en verder acht tot tien medewerkers. Verder zijn er verschillende specialistische consultants verbonden met dit bedrijf. De medewerkers werken vrij zelfstandig aan projecten: ze organiseren zelf hun werkzaamheden, projecten en rapportages.

- *Wat voor type en grootte schade onderzoeken jullie in het algemeen?*

  De grootte en type schade is heel divers. Het kan variëren van grote schades waarvan het onderzoek wel een jaar kan duren tot kleine schadeonderzoeken die een maand lopen. Dit bedrijf doet voornamelijk onderzoeken in opdracht van verzekeraars. In de bouw werkt de verzekering vaak als volgt: een aannemer of project sluit een polis met een tussenpersoon of een verzekeringsmakelaar. Deze verzekeringsmakelaar benaderd verzekeraars die het project willen verzekeren. Dit kan één verzekeraar zijn of verschillende verzekeraars die een percentage verzekeren (Figuur 1 Projectstructuur). Bij hele grote risico's kan er ook nog spraken zijn van een herverzekering. We werken vaak in opdracht van een verzekeraar of een verzekeringsmakelaar.

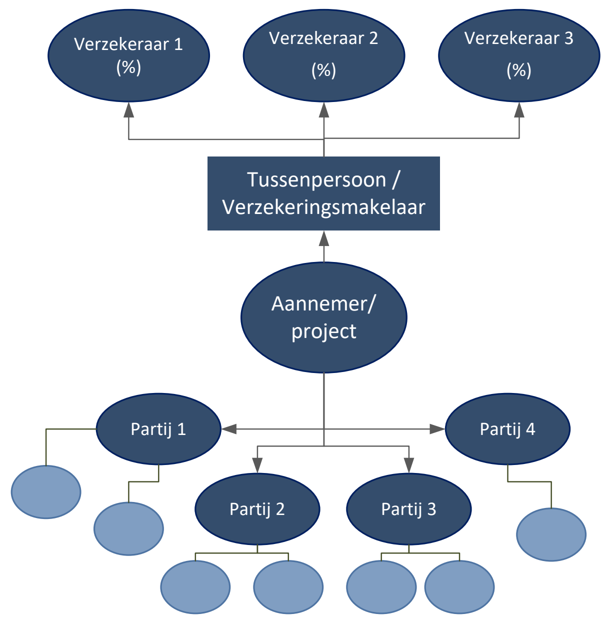


Figure 1: Project structuur

  Er zijn twee belangrijke verzekeringen in verband met bouwschade: De aansprakelijkheidsverzekering voor bedrijven (AVB) en de Construction all-risk verzekering (CAR).

  a. AVB: dit is een verzekering waarbij van alles, in relatie tot aansprakelijkheid, gedekt kan zijn. Bijvoorbeeld ook geclaimde bedrijfsschade, verlies van inkomsten etc. Het doel is het bepalen van het financiële nadeel dat geclaimd wordt dat geleden is door de onzekere gebeurtenis die heeft plaatsgevonden.
  b. CAR: is een 'paraplu verzekering'. Een CAR verzekering kan alleen voor het project zelf gelden, maar het is ook mogelijk om deze verzekering door te laten lopen. Het gaat om de grootte van de schade aan het object/project. Dit gaat dus om de financiële waarde van de fysieke schade aan het project.

  Om te begrijpen wat beide verzekeringen dekken is een overzicht gemaakt van een typisch projectstructuur (Figuur 2: CAR en AVB verzekering). De CAR is dus een parapluverzekering, vaak voor het project zelf en de AVB is een verzekering die betrokken partijen zelf afsluiten. Hierbij is het dus mogelijk dat de verschillende partijen binnen een project elkaar aansprakelijk stellen via de AVB voor bijvoorbeeld bedrijfsschade. Bij de CAR is dat niet mogelijk omdat alle

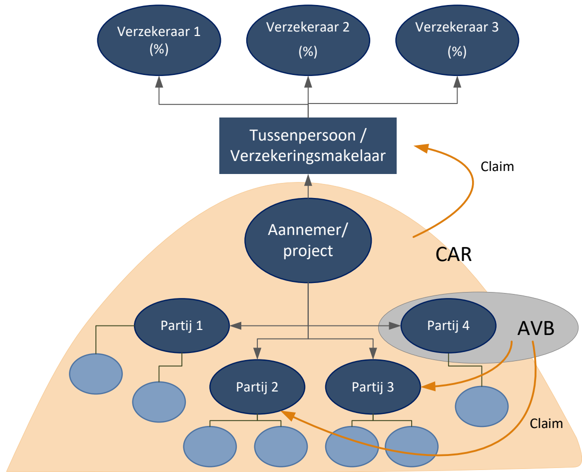


Figure 2: CAR en AVB verzekering

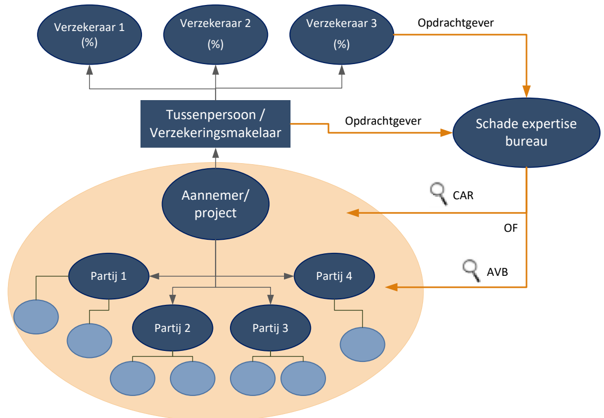


Figure 3: Positie schade expertise bureau

partijen samen onder een paraplu verzekerd zijn voor materiele schade aan het project. Hierbij is het belangrijk om op te merken dat een schadeclaim maar bij een door een verzekering betaald wordt. Alles dat onder de CAR is uitgekeerd kan niet opnieuw onder de AVB geclaimd worden.

- *Hoe/waarom bent u dit werk gaan doen? Heeft u een speciale cursus of opleiding gevolgd?*

  De geinterviewde heeft eerst in diverse functies bij een grote aannemer gewerkt. Hierbij werkte hij mee aan grote utiliteitsprojecten. Op een bepaald moment was er sprake van een grote schade aan een project en heeft hij meegewerkt aan het onderzoek naar de schade. Dit was eigenlijk een eerste kennismaking met het doen van schadeonderzoek. Later is de geinterviewde bij dit bedrijf gaan werken omdat hij een andere uitdaging zocht. Wat hem het meest aantrekt in het bedrijf is de zelfstandigheid, het afwisselende van het werk en de fijne bedrijfsstructuur (plat) en -cultuur. Op dit moment volgt hij een opleiding om zich te kunnen inschrijven als Nivre register expert.

- *Van welk type bedrijven krijgt uw bedrijf zijn onderzoeksopdrachten?*

  Voornamelijk van verzekeraars en of verzekeringsmakelaars (Figuur 3: Positie bedrijf). Ook komen er soms opdrachten binnen van aannemers en overheidsinstellingen.

Professionele context

- *Wat is het belangrijkst doel van de meeste schadeonderzoeken? (Verantwoordelijkheid/ leren voor de toekomst/ het bedenken van een oplossing/ het achterhalen van het probleem)*

  Doel van het onderzoek hangt af van het belang (financieel) van de verzekering die aangesproken wordt. Bij onderzoeken voor CAR verzekeringen is de oorzaak relevant maar minder belangrijk dan onderzoek naar wat er door de partijen gedaan is om de schade te beperken en het bepalen van de omvang van de herstelkosten. Voor de AVB is de oorzaak en het proces dat heeft geleid tot de schade wel een belangrijk onderdeel van het onderzoek.

- *Hoeveel tijd is er gemiddeld beschikbaar voor een onderzoek? Beinvloed dit het onderzoeksproces?*

  Onderzoeken kunnen lopen van een maand tot soms wel twee jaar. Afhankelijk van de grote van de schade en de complexiteit van de projectorganisatie waar de schade heeft plaatsgevonden.

Methodologie

- *Kunt u me meenemen in het onderzoeksproces en vertellen welke overwegingen en stappen u zou doen?*

  In grote lijnen heeft ieder onderzoek dezelfde opzet. De insteek en wat er precies gedaan wordt tijdens een onderzoek hangt wel een beetje af van om welke verzekering het gaat en waar de verzekeraar opdracht tot geeft. Bij een CAR verzekering wordt onderzoek gedaan naar de oorzaak, de maatregelen die genomen zijn om de schade te beperken en de herstelkosten. Het gaat voornamelijk om de vragen: wat is er gebeurd, hoe is het gebeurd, wat zijn de herstelkosten en wat is er gedaan om de schade te beperken? Bij een AVB verzekering gaat het meer om de oorzaak van de schade en welke partijen er een aandeel aan gehad hebben. Hier is het dus belangrijk om een overzicht te maken van alle betrokken partijen in het project, hun rol en de onderlinge contracten. Verder wordt er geprobeerd een overzicht te krijgen van alle gebeurtenissen voorafgaand aan de schade.

  Het onderzoeksproces bestaat uit drie fasen. De eerste fase is een **oriënterend gesprek.** Dit gebeurd zo snel mogelijk nadat de schade heeft plaatsgevonden. Dit wordt als het mogelijk is gedaan op locatie van de schade. Als dat niet mogelijk is wordt er een rondje gebeld met betrokken personen om eerste informatie te krijgen. Tijdens een veldbezoek gaat een medewerker van het bedrijf naar de schade toe en probeert zo veel mogelijk mensen die ter plaatse zijn 'informeel' te spreken over wat er gebeurd is. Dit gesprek kan geclassificeerd worden als het zogenoemde 'oriënterend gesprek'. Het heeft tot doel om contact te maken met de betrokken personen, een bepaald vertrouwen te winnen, daarmee meer informatie te krijgen en een eerste indruk van de situatie te krijgen. In de praktijk blijkt vaak dat op dit moment de informatie die gedeeld wordt het meest ongecensureerd is. Later in het proces wordt er een soort van stelling genomen en is de informatie al meer overdacht. In deze fase is het belangrijk om contact te maken met medewerkers en ook te laten zien dat je als onderzoeker begrijpt wat het bouwproces inhoud en met welke problemen en uitdagingen de medewerkers aan een project te maken hebben. Dit helpt om een beter contact te maken. Verder wordt in deze fase de schade vastgelegd. Dit kan met behulp van fotomateriaal en beschrijvingen. Hierbij is het belangrijk dat je in basis alleen observaties zonder interpretatie vastlegt. Als voorbeeld: Je ziet een kale plek op een muur met op de grond verfschilfers. Dan moet er gerapporteerd worden: een kale plek op de muur en schilfers van deze kleur en textuur op de grond. Niet: Op de muur is een kale plek ontstaan waarna de afgebladerde verf op de grond terecht gekomen is. Dit geeft namelijk meteen de interpretatie mee dat de verf op de grond afkomstig is van de muur en dat de muur eerder geen kale plek had en dat is niet de bedoeling tijdens het registeren van de schade. Aan het einde van deze fase wordt een voorbericht (Zie bijlage 1) gemaakt en verstuurd naar de opdrachtgever. Het voorbericht wordt zo mogelijk 2 a 3 dagen na de eerste informatie naar de opdrachtgever gestuurd.

  In de tweede fase wordt er meer **inhoudelijke informatie** verzameld. Dit is veelal in de vorm van het verzamelen van contracten, project documenten (tekeningen, inspectierapporten), het bekijken van de relevante verzekeringspolissen etc. De producten van deze fase zijn overzichten van de projectorganisatie, een overzicht van de gebeurtenissen zoals beschreven door de verschillende betrokken personen, technische input, etc. Van al deze informatie wordt een overzicht gemaakt dat laat zien wat er precies gebeurd is.

  In de laatste fase wordt op basis van de eerdere informatie **doorgevraagd**. Het gaat hier om een uiteindelijk beeld te krijgen van wat is er precies gebeurd (reconstructie), de oorzaak van de schade, wat waren de omstandigheden van de betrokken partijen en het controleren van eerdere informatie. Ook wordt er gekeken welke aspecten van de schade relevant zijn voor de geldende polis van de verzekering. Alle informatie wordt vastgelegd in een rapport.

Aanvullende vragen:

- *Welke data wilt u hebben om een schadeonderzoek te kunnen doen?*

  Onder andere beschrijvingen van de betrokken personen over wat er gebeurd is, verzekeringspolissen, contracten, observaties van de schade op locatie.

- *Hoe verzamelt u de benodigde data? (Veldonderzoek, documenten etc.)*

  Eigen onderzoek op locatie, interviews en gesprekken met medewerkers van het project, het opvragen van de relevante documenten.

- *Zijn de betrokken partijen verplicht om informatie te verstrekken en volledig mee te werken?*

  De partij die aanspraak maakt op zijn verzekering is verplicht medewerking te verlenen en alle data aan te leveren. Dit is vastgelegd in de verzekeringspolis die het bedrijf of project afsluit met de verzekeraar. Partijen die geen contract of polis hebben met de verzekeraar die opdrachtgever is voor het schadeonderzoek zijn niet verplicht informatie te delen. Voor een AVB verzekeringsonderzoek geldt het principe dat wie stelt bewijst. Dit betekent dat bij het beoordelen van een AVB claim de eisende partij het bewijs dient aan te leveren.

- *Maakt u een eindrapportage? Zo ja wat zijn dan de onderdelen van uw eindrapportage?*

  Over het algemeen gebruiken alle schade expertise bureaus dezelfde rapportage vormen (afhankelijk van het type verzekering). Er wordt een voorbericht naar de opdrachtgever gestuurd aan het begin van het onderzoek. Dit bericht geeft een indicatie van een onderzoeksrichting aan en het verwachte schadebedrag. Dit is ter informatie van de opdrachtgever. Na gelang de grootte van het onderzoek volgt een eindrapportage of verschillende tussen rapportages (Zie bijlage 2). Zowel het voorbericht als de rapporten hebben een vaste template.

  Toelichting onderdelen rapport

  » *Hoedanigheid*: Dit is informatie over de betrokken partijen. Het gaat dan om informatie zoals grootte van het bedrijf, kennis en expertise niveau, reputatie. Dit is van belang voor een verzekeraar omdat dit bij een eventuele rechtszaak van belang kan zijn. Het gaat dan om de beoordeling van de vraag: had van een partij redelijkerwijs verwacht mogen worden dat ze de situatie beheersten omdat ze de kennis en kunde hebben. Hierbij kan bijvoorbeeld van een grote aannemer meer expertise en dus een snellere herkenning van risico's verwacht worden als van een klein bouwbedrijf. Met behulp van deze informatie kan een verzekeraar een beoordeling maken of het voeren van een eventuele rechtszaak succesvol kan zijn.

  » *Omschrijving opgedragen werkzaamheden*: het gaat hier om zowel schriftelijk als mondeling opgedragen werkzaamheden.

  » *Overeenkomsten en voorwaarden:* dit gaat in op de contracten en overeenkomsten die tussen de betrokken partijen gemaakt zijn.

  » *Andere verzekeringen:* is van belang omdat schade maar door een verzekering tegelijk uitgekeerd wordt. Hierbij wordt dus gekeken of een andere verzekering eventueel ook een deel van de claim dekt.

  » *Informatie van ??*: hier wordt letterlijk opgeschreven per betrokken partij wat er aan informatie is geven. Dit zijn documenten en mondelinge informatie (interview). Dit kan informatie zijn van bijvoorbeeld omstanders, ooggetuigen, camera beelden etc.

Onze ref. :
Expert :
E-mail :
Controle :

Aan

[redacted] 19 april 2018

VOORBERICHT

Schadenummer	:
Polisnummer	:
Verzekerde	:
Tegenpartij	:
Betreft	: instorting gevel pand ,xxxxxx
Schadeadres	: "x"
Schadedatum	
Claimbedrag	: € 100000

OPDRACHT EN VERRICHTINGEN

Wij informeren u hierbij over onze eerste indrukken. Hiervoor hebben wij de beschikbaar gestelde informatie bestudeerd en partijen gesproken. In dit bericht gaan wij in op de volgende onderwerpen:

1. Is naar onze mening de door de benadeelde gestelde oorzaak aannemelijk?
2. Is naar onze mening de hoogte van de geclaimde schade aannemelijk?
3. Is verder onderzoek wenselijk/aanbevolen op welke wijze?

Indien de wenselijkheid van verder onderzoek voor ons niet duidelijk is, dan zullen wij dit aangeven en hierover contact opnemen. Heeft u vragen en/of opmerkingen naar aanleiding van dit bericht, dan zien wij die graag tegemoet.

ONDERZOEK

Contact met verzekerde: "x" Kies Ja/Nee
Gesproken met: "x" *Naam inclusief voorletters en titels*
Functie: "x" *[liefst zijn of haar formele status/ functie, bijvoorbeeld DGA/Uitvoerder*
Datum overleg: "x"

Contact met benadeelde/tegenpartij: "x" Kies JA/Nee
Gesproken met: "x" *Naam inclusief voorletters en titels*
Functie: "x" *[liefst zijn of haar formele status/functie, bijvoorbeeld DGA/Uitvoerder*
Datum overleg: "x"

"x" *Uitleg!*

1) *Indien meer partijen betrokken, deze benoemen (voorgaande regels copiëren en daarna invullen). Daarna deze regel weghalen.*
2) *Indien geen andere partijen, deze regel weghalen.*

OORZAAK

Is de vermeende oorzaak van de schade duidelijk gesteld? "x" Kies JA/Nee
"[Beknopte info toelichting omstandigheden. Indien JA, hier aangeven wat met name tegenpartij stelt]"

Is op basis van onze eerste indruk de door de benadeelde gestelde oorzaak aannemelijk? "x" Kies JA/Nee
"[Indien JA, korte motivatie en eventueel wat verzekerde hiervan vindt]"

SCHADE

Is de claim/ schadehoogte waarvoor verzekerde wordt aangesproken duidelijk? "x" Kies JA/Nee
"[Ja of nee, met korte omschrijving en we noemen altijd een bedrag]"

Is naar onze mening de hoogte van de geclaimde schade aannemelijk? "x" Kies JA/Nee
"[Eerste inschatting/raming van werkelijke schade door gestelde oorzaak]"

VERDER ONDERZOEK

Is verder onderzoek wenselijk en op welke wijze: "x" Kies JA/Nee
☐1. Hoedanigheid en overzicht van partijen
☐2. Omschrijving van de opgedragen werkzaamheden

☐3. Overeenkomst en voorwaarden
☐4. Andere verzekeringen
☐5. Precieze omschrijving van de gebeurtenis (wat/waar/wanneer)
☐6. Aansprakelijkstellingen (wie is aangesproken en hoe en op basis van wat?)
☐7. Gestelde oorzaak beoordelen
☐8. Inspectie
   ☐8.1 Bezoek verzekerde
      - Indien reeds ingepland: [ ]
   ☐8.2 Bezoek tegenpartij
      - Indien reeds ingepland: [ ]
   ☐8.3 Bezoek schadelocatie
      - Indien reeds ingepland: [ ]
☐9. Vaststellen schade

Is overleg over het verdere onderzoek naar onze mening nodig?: "x" Kies JA/Nee

(Bij ja: nemen wij binnen vijf werkdagen contact met u op)

Hoogachtend,

Dit document is elektronisch gegenereerd en daarom niet voorzien van een handtekening. Authentieke documenten zijn te vinden in e-ABS, op onze server of zijn voorzien van een originele handtekening.

Onze ref. :
Expert :
E-mail :
Controle :

[redacted] 19 april 2018

RAPPORT I

Schadenummer :

Verzekering :

Polisnummer :

Verzekerde :

Tegenpartij :

Betreft : instorting gevel pand

Schadeadres : "x"

Schadedatum : 12 juli 2017

Claimbedrag : € 100000

1 OPDRACHT EN VERRICHTINGEN

Wij refereren aan uw opdracht via "x" van 19 juli 2017 waarin u ons verzocht onderzoek te verrichten naar "x"

2 ALGEMEEN

Wat wordt gebouwd, wat doet verzekerde

2.1 Betrokken partijen:

Verzekerde :

Tegenpartij :

"x" :

"x" :

2.2 Hoedanigheid ;
"x"

2.3 Hoedanigheid :
"x"

2.4 Omschrijving van de opgedragen werkzaamheden:
"x"

2.5 Overeenkomsten en voorwaarden:
"x"

2.6 Andere verzekeringen:
"x"

3 GEBEURTENIS

"x"

4 AANSPRAKELIJKSTELLING

"x"

5 ONDERZOEK

5.1 Informatie van eigen partij:
"x"

5.2 Informatie van ???:
"x"

5.3 Informatie van derden:
"x"

5.4 Eigen waarnemingen:
"x"

6 OORZAAK

"x"

7 SCHADE

7.1 Claim:
"x"
1.1.1.1.1.1.1
7.2 Omvang van de schade:
"x"

7.3 Raming van de schade / Schadevaststelling:
"x"

8 OPMERKINGEN

"x"

Hoogachtend,

Dit document is elektronisch gegenereerd en daarom niet voorzien van een handtekening. Authentieke documenten zijn te vinden in e-ABS, op onze server of zijn voorzien van een originele handtekening.

201700895 4 van 4

Appendix D - Profession analysis

This appendix starts with a brief description on the investigation practises of the medical incident investigation context. This is followed by an analysis of the professions by their characteristics.
Medical incident investigation

In the medical world there has been a discussion on how to deal with medical incidents. The general opinion was that transparency about medical incidents would help prevent incidents in future and could be helpful if learning was the main goal. The problem however was the culture of investigating blame. In 2007 a document (beleidsdocument veilig melden KNMG) was published on how to organise safe reporting of incidents. This was the start to the creation of a culture of open sharing of incidents with the goal to learn from incidents. In July 2016 this idea was imbedded in law with the 'wet kwaliteit, klachten en geschillen zorg' (sport, 2016). In the medical world there is a distinction between incidents and calamities (serious incidents/accidents). For both there is a reporting duty within the law, but the follow-up is different. Reporting incidents takes place within the internal safety system of the relevant healthcare facility. For the reported incidents an investigation will take place with the goal to learn from it and prevent similar situations in future. Information of the reporting and the investigation cannot be used in liability procedures. For the calamities there is the reporting duty to the control body: Inspectie Gezondheidszorg (IGZ). These will start the investigation on first instance with the goal of learning but can use the investigation results to start legal procedures (Legemaate, 2017).

Characteristics analysis professions

The individual characteristics of the different professions are plotted to find qualitative relations. The plots are shown below with a small description on the side. Conclusions are described after the last plot.

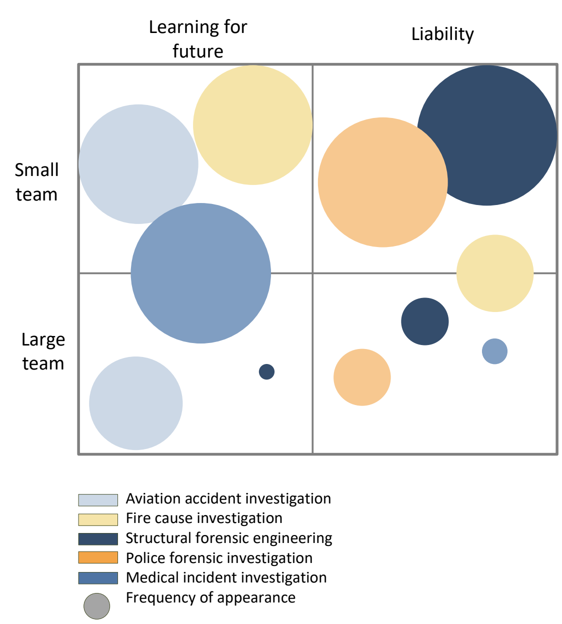


Figure 1: Comparison team size and invesitgation goal

In this graph is visible that there is a relatively large spread in investigation team size. This means that large and small teams are both possible. The exception is the medical field where all investigation teams have a comparable size. Their investigations are performed by the medical team of a specialisation (doctors, nurses and all other involved staff) in the form of an audit meeting. They will discuss the reported incidents on a regular basis together.

The structural forensic teams are generally small. The investigations with the aim of learning (onderzoeksraad voor de veiligheid) are performed with a large team as the scope of their investigations demands different specialists.

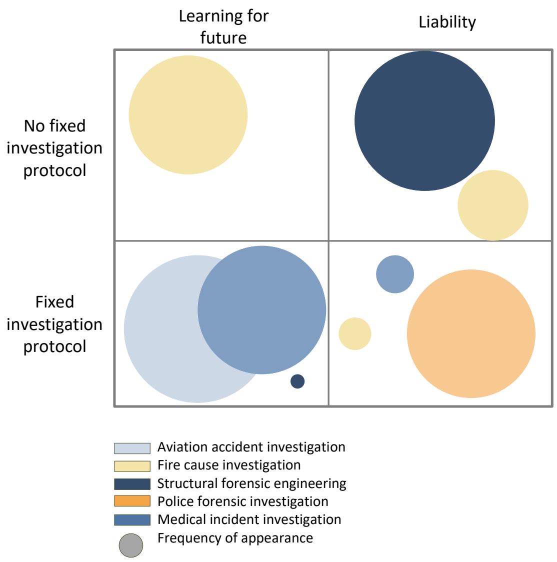


Figure 2: Comparison investigation goal and protocol availability

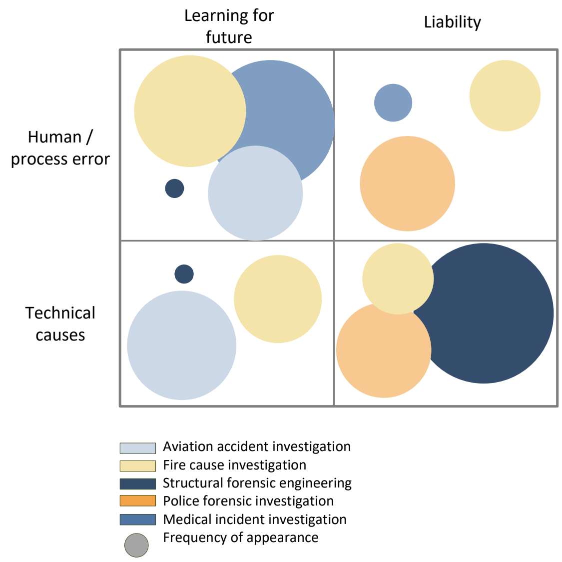


Figure 3: Comparison investigation goal and topic

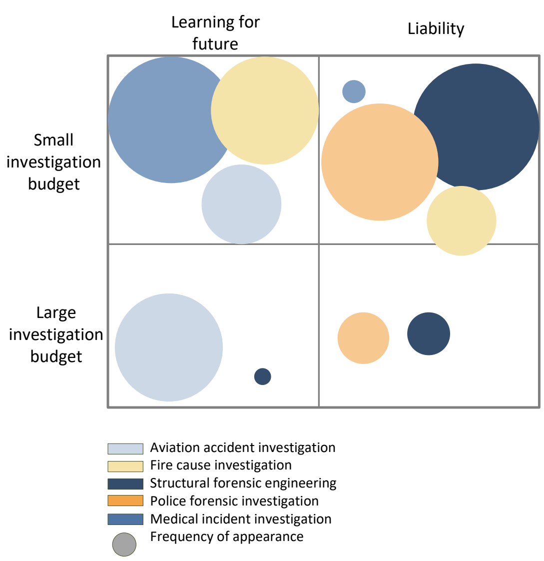


Figure 4: Comparison available investigation budget and investigation goal

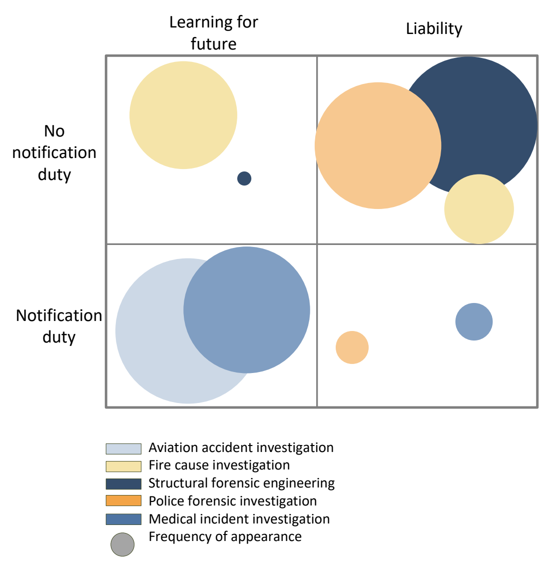


Figure 5: Comparison incident obligation and investigation goal

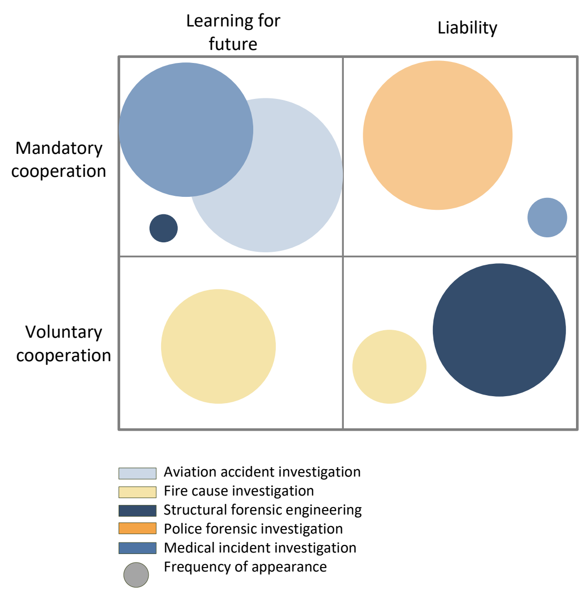


Figure 6: Comparison investigation cooperation and investigation goal

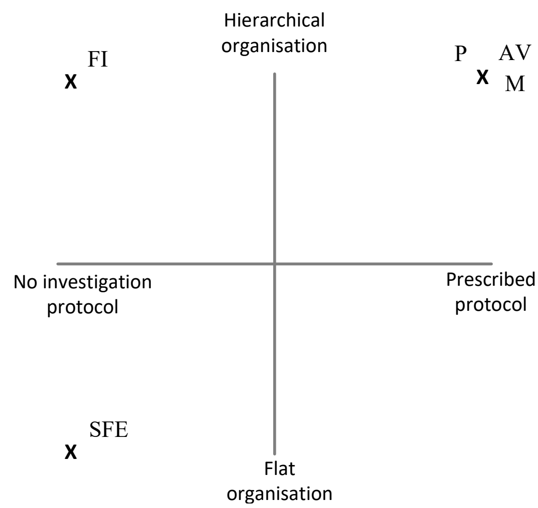


Figure 7: Comparison investigation protocol and investigation organisation

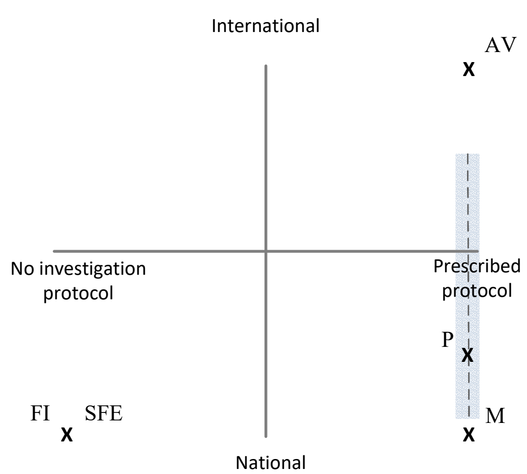


Figure 8: Comparison investigation protocol and investigation scale

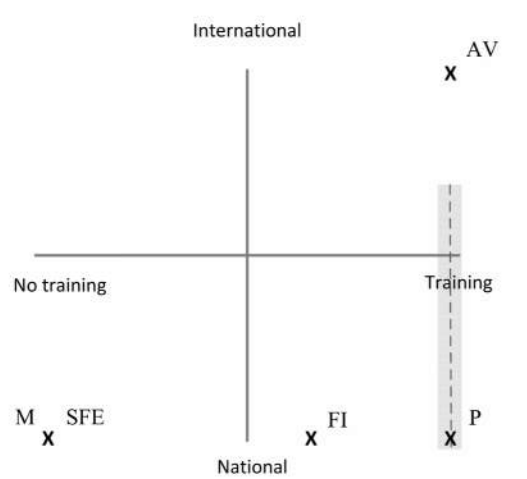


Figure 9: Comparison investigation team training and investigation scale

Legend

AV	Aviation accident investigation
FI	Fire cause investigation
SFE	Structural forensic investigation
P	Police forensic investigation
M	Medical incident investigation

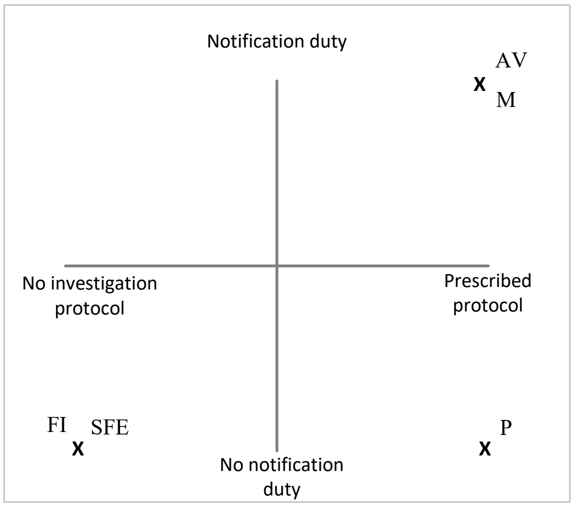


Figure 10: Comparison investigation protocol and investigation notifocation

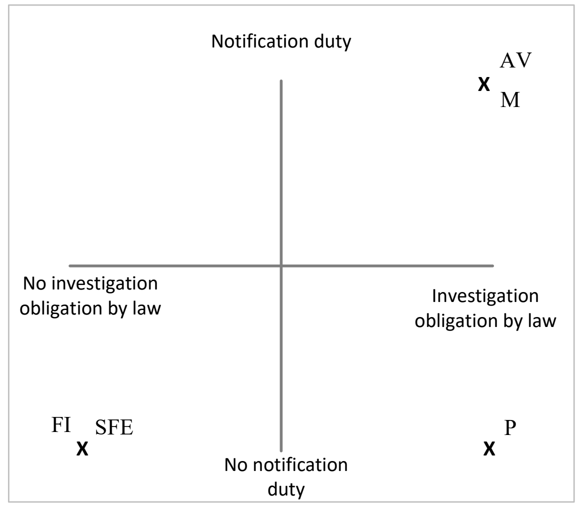


Figure 11: Comparison investigation oblication and investigation notificaiton

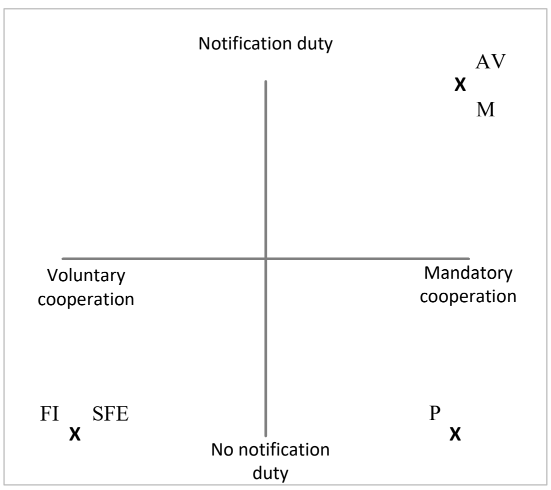


Figure 12: Comparison investigation cooperation and investigation notifocation

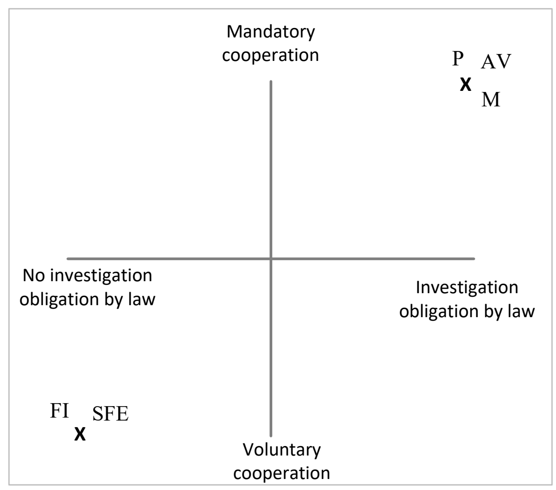


Figure 13: Comparison investigation obligation and investigation cooperation

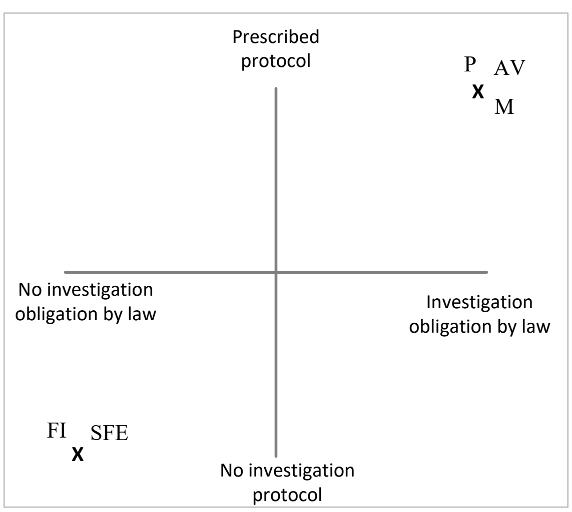


Figure 14: Comparison investigation obligation and investigation protocol

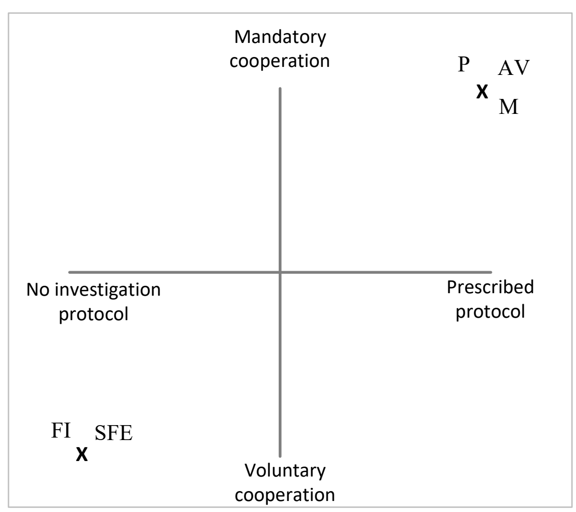


Figure 15: Comparison investigation cooperation and investigation protocol

After plotting the characteristics of each profession several remarks can be made:

- From the qualitative analysis of the embedment of investigations in law, the prescription of a protocol, the obligation to investigate and report on incidents and the obligatory cooperation with the investigation it follows that these characteristics are interconnected (see Figure 10-15). With the professions where there are regulations embeddend in the law, there are also obligations to notification and cooperate and prescribed investigation protocols. The exception is the police where notification of a crime is voluntary and only in a few specific cases obligatory.
- Investigations that have the goal to draw lessons for the future contain an investigation into the technical and the human/process aspects of failure causes. The same rule applies to investigations with the goal to determine some form of liability. The exception is structural forensic engineering. These investigations are generally limited to investigations into the technical causes (see Figure 3).
- Generally, the investigations into liability seem to start from voluntary notification of the accident, failure or damage. The obligatory notifications of failure, damage or accidents generally seem to result in investigations that have the goal to learn something and prevent incidents in the future (see. Figure 5).

Appendix E- Focus areas aeronautical incident investigation

This appendix describes the different investigation area's that are regarded during an accident or incident investigation of airplanes.

FIELD	EXPLANATION
Wreckage investigation	Gathering of the facts concerning the location and distribution of the wreckage.
Organizational investigation	Uncover the characteristics within a organization that increased the probability of the accident occurring and when not corrected could become the cause of additional accidents
Operations investigation	Investigation of the fact relating to the history of the flight and the activities of the flight crew before, during and after the incident.
Aircraft operating environment	Investigation into the meteorological conditions, the air traffic service and icing conditions.
Aircraft performance investigation	Investigation into the aircraft performance, the flight path from the start of the flight unto the end.
Flight recorder investigation	Collection of data from all recorders available in an aircraft. This includes the cockpit voice recorders, flight data recorders and all other recorders that are on and off board.
Reconstruction of wreckage	Investigation method that can be used if the cause is difficult to find or when an overview of (part of) the wreckage is hard to get. Depending on available resources and amount of expected new information outcome.
Structure investigation	Investigation to collect all facts and evidence with respect to the airframe and the flight controls.
Mid-air collision	Investigation only performed when relevant
Fire pattern investigation	Investigation only performed when relevant
Systems investigation	Investigation of all systems of the aircraft. For example: hydraulics, electronics, fire detection and instruments.
Powerplant investigation	Investigation of all systems, structures and components that have a connection to the power supply of the aircraft. For example: Engine, fuel and oil systems, propeller units, fire systems of the engine, anti-icing systems of the propeller and engine etc.

FIELD	EXPLANATION
Maintenance investigation	Gathering of the facts about the maintenance history of the aircraft and al actions of the maintenance organisation and staff. Investigation goal is to determine if the aircraft had properly been maintained according to regulations, if there is any suggestion that maintenance should be a line of inquiry of the investigation and if maintenance is a contributing factor of rout cause of the incident.
Human factors investigation	Investigation into the human performance and if they contributed or caused the incident.
Survival, evacuation, search, rescue and fire fighting	Gathering of all data and facts on the rescue operation and all related factors. The level of detail of the investigation is depending on the circumstances of the incident.
Pathology investigation	Objective is to obtain evidence of the cause and sequence of the accident by examining people involved in the incident/accident.
Investigation of system design issues	Investigation into the safety design process of the aircraft and how the causes of the accident are treated in the safety design. This will help preventing underestimating failure modes and safety measures in future design.

Appendix F - Fire investigation checklist

In this appendix some examples of data collection checklist and forms used in fire investigations are shown (Technical committee on fire investigations, 2004)

FIRE INCIDENT FIELD NOTES

Agency: ______________________ File No: ______________

TYPE OF OCCUPANCY

Location/ Address						
Property Description	Structure	Residential	Commercial	Vehicle	Wildland	Other
Other Relevant Info						

WEATHER CONDITIONS

Indicate Relevant Weather Information					
	Visibility	Rel. humidity	GPS	Elevation	Lightning
	Temperature	Wind direction	Wind speed	Precipitation	

OWNER

Name			DOB
d/b/a (if applicable)			
Address			
Telephone	Home	Business	Cellular

OCCUPANT

Name			DOB
d/b/a (if applicable)			
Permanent Address			
Temporary Address			
Telephone	Home	Business	Cellular

DISCOVERED BY

Incident Discovered by	Name		DOB
Address			
Telephone	Home	Business	Cellular

FIRE INCIDENT FIELD NOTES (Continued)

File No: ____________________

REPORTED BY

Incident Reported by	Name		DOB
Address			
Telephone	Home	Business	Cellular

INVESTIGATION INITIATION

Request Date and Time	Date of request	Time of request
Investigation Requested by	Agency name	Contact person/Telephone no.
Request Received by	Agency name	Contact person/Telephone no.

SCENE INFORMATION

Arrival Information	Date		Time		Comments		
Scene Secured	Yes	No	Securing agency		Manner of security		
Authority to Enter	Contemporaneous to exigency		Consent		Warrant		
			Written	Verbal	Admin.	Crim.	Other
Departure Information	Date		Time		Comments		

OTHER AGENCIES INVOLVED

	Dept. or Agency Name	Incident No.	Contact Person/Phone
Primary Fire Department			
Secondary Fire Department(s)			
Law Enforcement			
Private Investigators			

ADDITIONAL REMARKS

PHOTOGRAPH LOG

Roll #: ______________________ Exposures: ______________________

Case #: Date:

Camera make/type: Film type: Film speed: ASA:

Number	Description	Location
1)		
2)		
3)		
4)		
5)		
6)		
7)		
8)		
9)		
10)		
11)		
12)		
13)		
14)		
15)		
16)		
17)		
18)		
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22)		
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24)		
25)		
26)		
27)		
28)		
29)		
30)		
31)		
32)		
33)		
34)		
35)		
36)		

Photos taken by: ______________________ Initials: __________

Appendix G - Concrete damage handbook

This appendix presents a tool to assist in determining possible causes of certain concrete failures. The goal of the tool is to assist the structural damage investigator with selecting possible causes of the observed damage. The tool is based on the visual appearance of a damage. Based on the type, shape and colour possible causes have been listed. Some cases occur only under specific circumstances or have specific characteristic. This context info has been collected to make a futher selection of possible damage causes possible.

The tool has been based on literature on concrete damage mechanisms[1]. The tool does not claim to give a complete overview off all possible damage causes, but tries to give an overview of the most common deterioration mechanisms and damages. The model has not been tested with real damages. The user is expeced to have some basic knolwedge on concrete deterioration mechanisms in order to understand the definitions used in the tool.

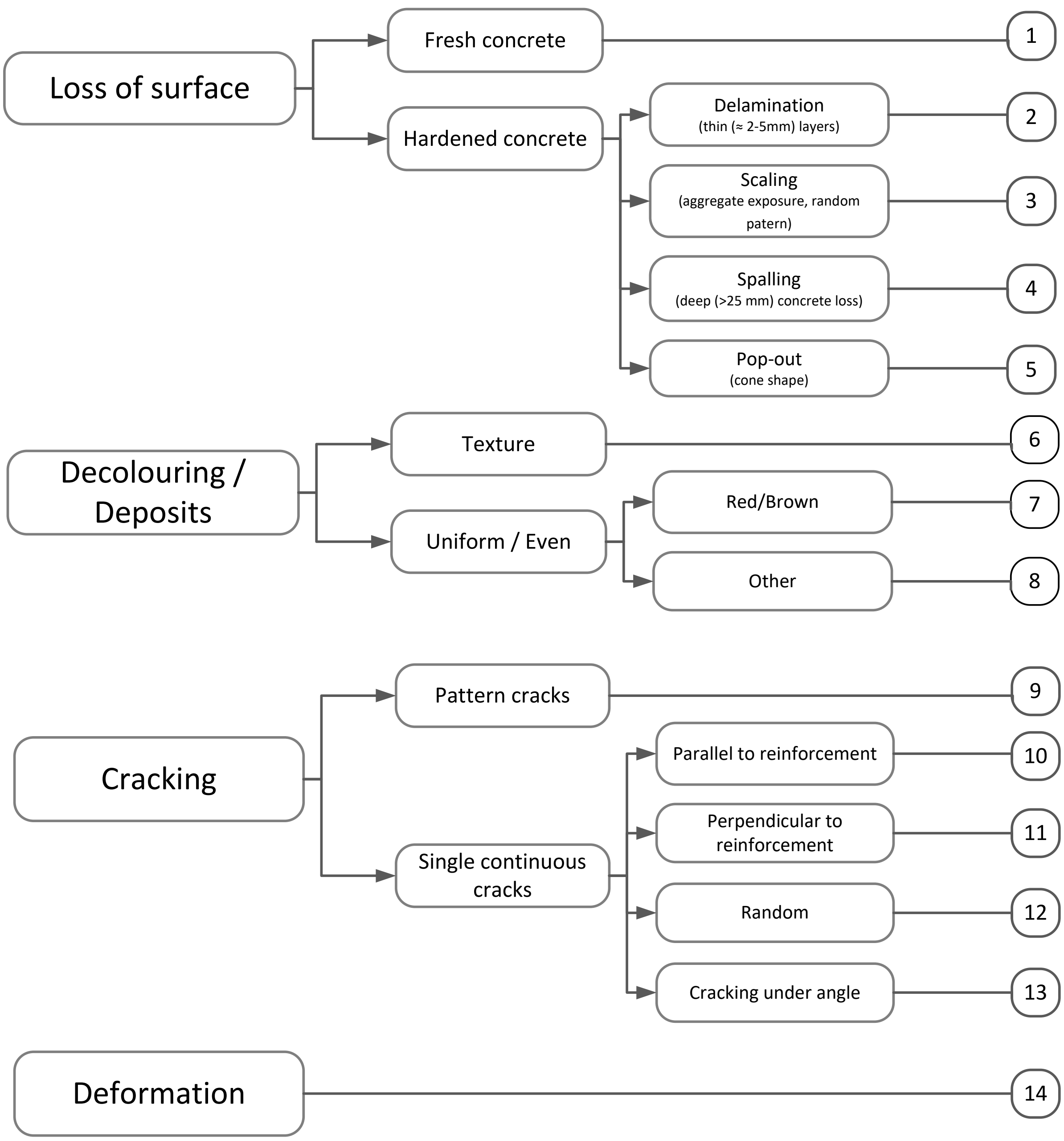
The tool can be used as follows: when a damage has been observed, the relevant damage type is selected from the first colomn. Then the most fitting description form the second and third colmn will be selected. This results in a number. This number corresponds with an information page that first gives a description and some example photographes of the selected categorie. If this corresonds to the observed damage the investigator can study the proposed possible damage causes. Then the investigator can find under condition if context information or special characteristic can assist in determining the most likey hypotheses and to exlude impossible ones. Possible tests for proving certain damage cuaes have been listed allong with aditional relevant literature that gives more information on the mentioned damage mechanisms.

x condition that makes hypothesis more likely
o condition that excludes the hypothesis

1 The format of this concrete damage model has been on the format of the paper: Prototype of a diagnostic decision support tool for structural damage in masonry by De Vent ISBN: 978-90-8570-759-2

Flow-chart visual appearance of damages to concrete structures[1]

The first row shows the damage type. The second and third row show further specifications. The numbers correspondent to information pages that ave been collected on the following pages.



1 The format of this concrete damage model has been based on the format of the paper: Prototype of a diagnostic decision support tool for structural damage in masonry by De Vent ISBN: 978-90-8570-759-2

Nr. 1

Loss of surface in fresh concrete

Damage description

In fresh concrete, there are several possible surface disturbances or losses possible. The main visual characteristic of blistering are bumps on the surface of fresh concrete (figure 2).

Another type of surface damage are honeycombs. They are described as clusters of course aggregates without the smaller particles and cement. This results in holes and voids between the course aggregates (figure 1). In extreme cases this damage can cause leakage or loss structural cross-section.

Figure 1.1: Honeycombes (ConRep concrete repairs, n.d.) (Patricia, 2016))

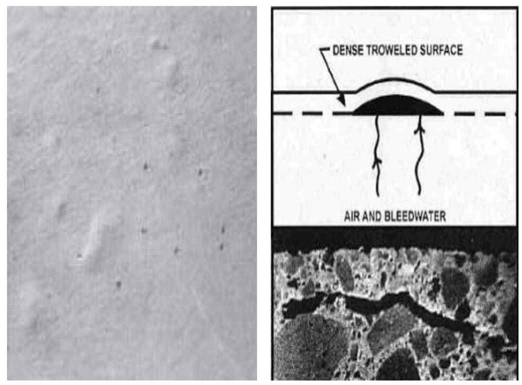


Figure 1.2: Blistering (CADMAN Heidelberg cement group, n.d.; Fratzel, n.d.)

Hypotheses

1.1 Honeycombing caused by reinforcement detailing mistakes.
1.2 Honeycombing caused by lack of fine aggregate material in concrete mix.
1.3 Honeycombing caused by leakage of the formwork during construction.
1.4 Honeycombing caused by unsufficient compacting.
1.5 Blistering of the finished concrete surface.

Conditions

	1.1	1.2	1.3	1.4	1.5
Cement that has leaked from the formwork.			x		

Tests

1.1 - 1.4 Scanning of the concrete element for voids using a ground penetrating radar.

Additional information

- Beton lexicon
- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .

Nr. 2

Delamination

Damage description

A thin layer of mortar separates from the concrete below. The thickness of the layer is around 2-5 mm.

The surface loss can be caused by air and water trapped under the surface layer during hardening. When the surface is loaded, the blisters will burst and the thin layers come off. Delamination will occur soon after construction.

Delamination can also be the result of reinforcement corrosion. In that case is the delaminating layer thicker. When the delamination is caused by corrosion the structural capacity is can be effected.

Figure 2.1: Delamination (CoGRIpedia, n.d.)

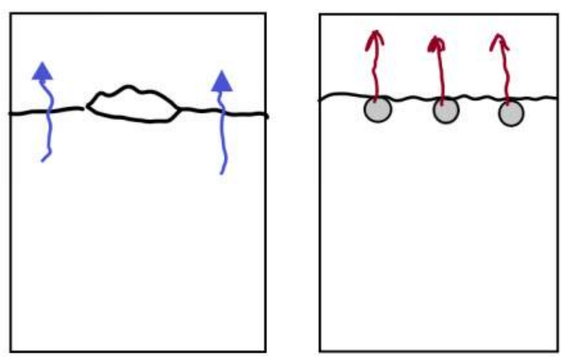


Figure 2.2: Delamination due to air and water entrapment (L) and due to corrosion of reinforcement (R)

Hypotheses

2.1 Delamination caused by air and water trapped under the top mortar layer.
2.2 Delamination caused by stresses due to reinforcement corrosion.

Conditions

	2.1	2.2
Recently poured element (< 1 year)		o
Reinforcement present		x

Tests

Loose patches can be detected by tapping the surface of hollow sounds.

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .

Nr. 3

Scaling

Damage description

The finished concrete surface mortar flakes/peels off. Scaling can be observed in levels of severity from light (no aggregate exposure), medium (aggregate exposure and mortar loss from 2-10 mm depth), and severe scaling (loss of mortar and exposure of aggregate up-to more than 20 mm depth).

The damage starts with small patches and can grow into larger area's with more and more in depth loss of mortar and exposure of aggregates. It is not directly a structural problem, but as it is a progressive deterioration mechanism it can finally expose reinforcement. This can lead to other damage types.

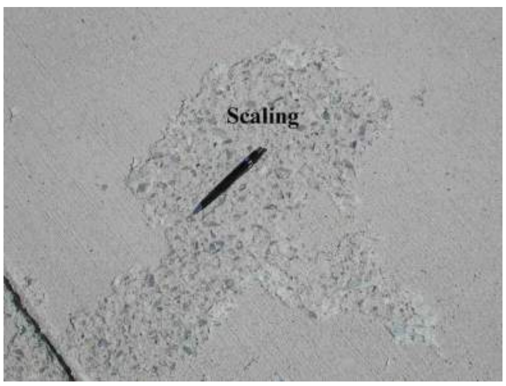


Figure 3.1: Scaling (Power line usa, n.d.)

Figure 3.2: Scaling (Power line usa, n.d.)

Hypotheses

3.1 The scaling is caused by freeze-thaw cycles where water in the concrete pores expands due to ice formation and form stresses inside the concrete.
3.2 The scaling is caused by freeze-thaw cycles and is worsened by de-icing salts.

Conditions

	3.1	3.2
Recent temperatures below zero degree Celsius	x	x
Water present before freezing	x	x
De-icing salts used		x

Tests

Visual inspection

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .
- Valenza, J. J., & Scherer, G. W. (2006). *Mechanism for salt scaling.* Journal of the american ceramic society, 86(4), 1161-1179. doi:10.1111/j.1551-2916.2006.00913.x

Nr. 4

Spalling

Damage description

A deep loss of surface. The spalling starts with cracking of the concrete and develops into parts to breaking away. Generally more than 25 mm in depth. The shape of the damaged area is often oval. Spalling is potentially a structural safety problem as there is loss of capacity involved in all the possible causes. For some of the causes the spalling is a progressive mechanism. Besides, there is a durability problem because the reinforcement has or a very small or no cover left.

Figure 4.1: Spalling due to corrosion (JHA Australia, n.d)

Hypotheses

4.1 Spalling caused by extreme heating of the concrete by fire
4.2 Spalling caused by reinforcement corrosion
4.3 Spalling caused by alkali silica reaction
4.4 Spalling caused by corrosion of embedded building elements
4.5 Spalling caused by impact loading

Conditions

	4.1	4.2	4.3	4.4	4.5
There has been a fire recently	x				
Reinforcement present		x			
Rust staining present		x		x	
Extensive cracking present		x	x		x
Gel inside spalled area	o	o	x	o	
Recent contact of object with structure with high force					x
Explosion occurred					x

Tests

Laboratory testing to prove alkali silica reaction.
Removing of concrete cover for exposing corrosion.

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .
- Rademaker, E (2002) *Handboek voor orienterende inspectie ASR;* Bouwdienst Rijkswaterstaat
- Somerville, G. (2008). *Management of deteriorating concrete structures* (second ed.). Oxon: Taylor & Francis.

Nr. 5

Pop-outs

Damage description

A conical part that bursts out of the concrete surface. The size of the particle can between 5-50 mm in diameter. The effect on the structural safety depends on the cause of the pop-out. ASR and wood contamination will have rather severe consequences.

Figure 5.1: Pop-outs (Sheenhan, n.d)

Figure 5.2: Pop-out (Courard, H, & Darimont, n.d)

Figure 5.3: Pop-out (Architectura.be, 2010)

Hypotheses

5.1 Pop-out due to aggregate expansion
5.2 Pop-out due to alkali silica reaction
5.3 Pop-out due to wood contamination

Conditions

	5.1	5.2	5.3
Aggregates with high absorption capacity present	x		
Frost	x		
Aggregate at bottom of pop-out has split	x		
Aggregate complete at bottom pop-out		x	
Presence of gel at bottom of pop-out	o	x	o
Historic wood present in aggregate mix			x

Tests

Laboratory test to determine the aggregate material

Additional information

- NRMCA (2007) *Concrete in practice what, why and how? CIP 40 - Aggregate pop-outs*
- Beton lexicon (n.d) *Oerhout*. betonlexicon.nl
- Rademaker, E (2002) *Handboek voor orienterende inspectie ASR*; Bouwdienst Rijkswaterstaat

Nr. 6

De-colouring with texture

Damage description

All type of surface deposits, surface disintegrations or efflorescence that appear on the surface of a concrete element. The damages can vary from dry powdery substances to softening of the concrete. Most of the damage causes are only a cosmetic problem but some of them have serious consequences.

Lime leaching, dirt and dusting are relatively common damages. The sulphate attack forms are more rare but have consequences for the structural capacity of an element.

Figure 6.1: Efflorescence (Hering, 2012)

Hypotheses

6.1 Dusting of the surface due to a weak surface layer
6.2 White deposits due to lime weeping
6.3 Softening of the concrete surface due to sulphate attack
6.4 Mushy white formations on the concrete surface due to thaumasit formation (sulphate attack)

Conditions

	6.1	6.2	6.3	6.4
Hard white deposits		x		
Mushy white mass				x
Dry powder structure	x			
Concrete is soft			x	x
Solvable in water		o		
Exposed to rainwater and run-down		x		
The following elements present: • Sulphates or sulphides present • Mobile groundwater • Source of calcium silicate hydrate (in cement)			x	x
Carbonate present			o	x
Low temperature (<15)			o	x

Tests

Laboratory test to determine what form of sulphate attack is present.

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair.* (Dusting and lime weeping)
- Somerville, G. (2008). *Management of deteriorating concrete structures* (second ed.). Oxon: Taylor & Francis. (sulphate attack)

Nr. 7

Decolouring - Red/Brown

Damage description

The presence of brown or dark red/orange areas on the concrete. The area size can vary from a pattern of dots, stripes below a crack or whole area. The possible influence on the structural safety depends on the cause. Some of the causes are signals for serious damage mechanisms, others are just an aesthetic problem.

Figure 7.1: Red spots

Hypotheses

7.1 Red colour spots due to pitting corrosion
7.2 Red spots due to the remaining of formwork binding material
7.3 Red colouration due to the presents of old wood (oerhout)
7.4 Red colour due to the presence of pyrite in the concrete mixture
7.5 Red colour across an area due to rust staining

Conditions

	7.1	7.2	7.3	7.4	7.5
Local spots	x	x	x	x	
Reinforcement present	x	x	x	x	x
The spots have an almost black colour					
Presence of cracks	x				x
Reused aggregates in the concrete mixture				x	
Prefab element		o			
Pop outs present			x		

Tests

Removal of the concrete cover to expose reinforcement (corrosion)
Analysis of the concrete mix (pyrite and 'oerhout')

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .
- Von Fay, K.F. (2015) *Guide to concrete repair,* second edition, U.S. Department of the interior Bureau of Reclamation

Nr. 8

Decolouring - other

Damage description

All types of un intended changes of the colour of a concrete surface. White is the most often observed colour.

Figure 8.1: Delamination (The Concrete society, n.d.)

Hypotheses

8.1 White areas due to lime bloom.
8.2 Difference in colour due to dirt
8.3 Darker coloured areas due to leakage

Conditions

	8.1	8.2	8.3
Large flat white patches	x		
Moisture present	x		
Recent rainfall			x
Solvable in water	o	x	

Additional information

- Portland Cement Association (n.d) *Types and Causes of Concrete Deterioration*

Nr. 9

Cracking - Patern cracks

Damage description

A random network of interconnected cracks appearing on a concrete surface. The crack width can range from very thin cracks to wide open cracks. There is a variety of possible causes ranging from cosmetic only (crazing) to serious consequence for the structural capacity of the element (ASR and ACR).

Figure 9.3: Map cracking (123 rf, 2018)

Figure 9.1: Map cracking (Hess, n.d)

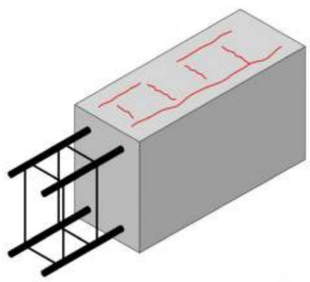


Figure 9.2: Settlement cracking (Van den Bosch, 2016)

Hypotheses

9.1 The cracking is caused by crazing of the concrete.
9.2 The cracking is caused by alkali silica reaction (ASR).
9.3 The cracking is caused by alkali carbonate reaction (ACR).
9.4 The cracking is caused by settlement cracking above reinforcement or objects.

Conditions

	9.1	9.2	9.3	9.4
Recently poured element (few hours)	x	o	o	x
Presence of dolomite containing aggregate			x	
Cracking developed in an existing structure (5 >)	o			o
Availability of moisture		x	x	
Very fine cracks forming small (<50 mm) islands	x			

Tests

ASR and ACR can be tested by taking samples and do laboratory test.

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .
- Cement&Beton Centrum (n.d) *Alkali-silicareactie (ASR)*
- Von Fay, K.F. (2015) *Guide to concrete repair,* second edition, U.S. Department of the interior Bureau of Reclamation.

Nr. 10

Cracking - Parallel to reinforcement

Damage description

Cracking in the direction of the reinforcement bars. The cracks are relatively long and deep. Depending on the damage cause coloured deposit can be present from the cracks. When corrosion of the reinforcement is the cause of the cracking attention for structural safety is needed. Corrosion is an progressive damage mechanism.

Figure 10.1: Development of corrosion cracking (The helpfull engineer, 2010)

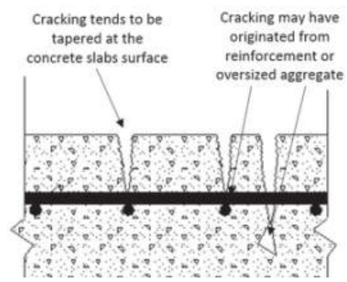


Figure 10.2: Plastic settlement cracking (Cap-It-All, 2015)

Hypotheses

10.1 Cracking due to carbonation induced corrosion
10.2 Cracking due to chloride induced corrosion
10.3 Cracking caused by settlements over reinforcement, embedded items, connections to hardened concrete or near form work

Conditions

	10.1	10.2	10.3
Recently poured element (few hours)	o	o	x
Specific location near other material			x
Rust stains present	x	x	
Hardened concrete (>28 days)			o
Exposure to sea water or water containing salts		x	
Concrete cover < 15 mm	x		

Tests

For corrosion: removing of concrete cover.

Additional information

- Somerville, G. (2008). *Management of deteriorating concrete structures* (second ed.). Oxon: Taylor & Francis. (sulfate attack)
- Ahmad, S. (2003). *Reinforcement corrosion in concrete structures, its monitoring and servicelife prediction - a review*. Cement & Concrete Composites(25), 459-471. doi:doi:10.1016/S0958-9465(02)00086-0
- Portland Cement Association (n.d) *Types and Causes of Concrete Deterioration*

Nr. 11

Cracking - Perpendicular to reinforcement

Damage description

Cracking appearing perpendicular to the tensile reinforcement. The cracks can appear on the bottom side of a beam or at the top when continuously supported (at the location of the tensile stresses). When cracking due to drying shrinkage the cracks will generally be present at beams with long un-dilated length.

Hypotheses

11.1 Cracking caused by overloading (bending)
11.2 Cracking caused by overloading (tensile stress)
11.3 Cracking caused by too little reinforcement
11.4 Cracking caused by drying shrinkage

Conditions

	11.1	11.2	11.3	11.4
Soon after use phase has started			x	
Change of function of the building	x	x		
Shallow cracks				x
Thin cracks				x
Deformation present	x		x	

Tests

Review of the structural calculations and design/work drawings.

Additional information

- Portland Cement Association (n.d) *Types and Causes of Concrete Deterioration* (drying shrinkage)
- Delatte, N. (2009). *Failure, distress and repair of concrete structures* (First ed.). Cambridge: Woodhead Publishing Limited.

Nr. 12

Cracking - Random

Damage description

Cracking that apprears randomly on a concrete surface and consist of single continuing cracks. The cracks can be equally spread with an almost fixed interval or random spread over a surface. The width, length and depth can vary.

Hypotheses

12.1 Cracking caused by plastic shrinkage
12.2 Cracking caused by delayed ettringite formation (DEF)
12.3 Cracking caused by early removal of formwork
12.4 Cracking caused by sulphate attack
12.5 Cracking caused by the mistaken transport or handling of precast elements.
12.6 D-cracking due to freeze thaw cycles
12.7 Cracking caused by drying shrinkage
12.8 Cracking caused by thermal expansion
12.9 Cracking due to settlements

Conditions

	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9
Recently poured element (few hours)	x	o	x	o			o	o	
Specific location near other material			x					x	
Deformation present		x	x	x					x
Cast without removable formwork			o						
Cracks are on pavement						x			
Cracks have shape of banana/letter D						x			
The following elements present: • Sulphates or sulphides present • Mobile groundwater • Source of calcium silicate hydrate (in cement)		x		x					
Shallow cracks	x						x		
Thin cracks (<0.3 mm)	x						x	x	
Structure is partly exposed to outside temperature and partly inside even climate								x	
White deposits in cracks		x							
High temperatures (>70) during hydration process cement		x							

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .
- Somerville, G. (2008). *Management of deteriorating concrete structures* (second ed.). Oxon: Taylor & Francis. (sulphate attack, DEF)
- Von Fay, K.F. (2015) *Guide to concrete repair,* second edition, U.S. Department of the interior Bureau of Reclamation.
- Suleiman, A.R (2014) P*hysical Sulphate attack on Concrete,* Electronic thesis and disertation repository. 2058

Nr. 13

Cracking - Under angle

Damage description

The cracking on beams that show as cracks under an angle with the horizontal. These cracks are typically seen on beams or at connections between beams and columns.

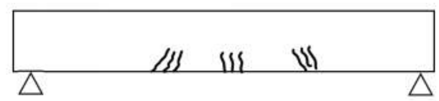


Figure 13.1 :Bending cracking (Verbiest, 2018)

Hypotheses

13.1 Cracking due to bending caused by overloading
13.2 Cracking on a console caused by horizontal overloading
13.3 Cracking on console due to too large rotation (crushing of the edge of console)
13.4 Cracking of the end part of beam at support due to wrongly detailed reinforcement. (no reinforcement at the support)
13.5 Cracking due to lack of shear capacity
13.6 Cracking due to corrosion of shear reinforcement in a beam.
13.7 Cracking due to settlements

Conditions

	13.1	13.2	13.3	13.4	13.5	13.6	13.7
Wrong detailing of reinforcement in console		x	x				
Cracks have ~45 angle with the horizontal	x						
Cracks are located near the supports of a beam					x	x	
Cracks are located at midspan	x				o		
Rust stains are present						x	
Recent renovation or additions to building	x						x
Recent change of function of the building	x	x	x				

Tests

Review of the design drawing and work drawings for the detailing of the reinforcement.
Removing of concrete cover to expose the reinforcement (amount of reinforcement, corrosion).
Inspection for cracking in other adjacent parts of the construction (settlements)

Nr. 14

Deformation

Damage description

Deformation means all unwanted changes in the shape of the concrete element. Deformations can be changes in shape of the element itself or changes to the orientation of the element.

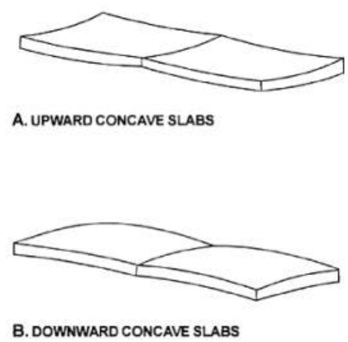


Figure 14.1 curling of concrete slab (CADMAN Heidelberg cement group, n.d.-b)

Hypotheses

14.1 Deformation due to too little tensile reinforcement
14.2 Deformation due to too fast removal formwork
14.3 Deformation due to deformation of formwork
14.4 Deformation due to overloading
14.5 Deformation due to settlement of the foundation
14.6 Curling of the slab due to differences in moisture content and temperature between top and bottom of slab

Conditions

	14.1	14.2	14.3	14.4	14.5	14.6
Cracking present	x	x	o	x	x	x
Edges of the concrete slab are raised (like a bowl)						x
Cast in-situ concrete		x	x			
Deformations at all levels and to other elements					x	
Presence of exceptional loading/ heavy material	x			x		
Recent change in function of building	x			x	x	
Recent renovation	x			x	x	

Additional information

- Portland Cement Association (2001) *Concrete information: concrete slab surface defects causes, prevention and repair* .
- Portland Cement Association (n.d) *Types and Causes of Concrete Deterioration*

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Appendix H

Handbook

Investigation process model

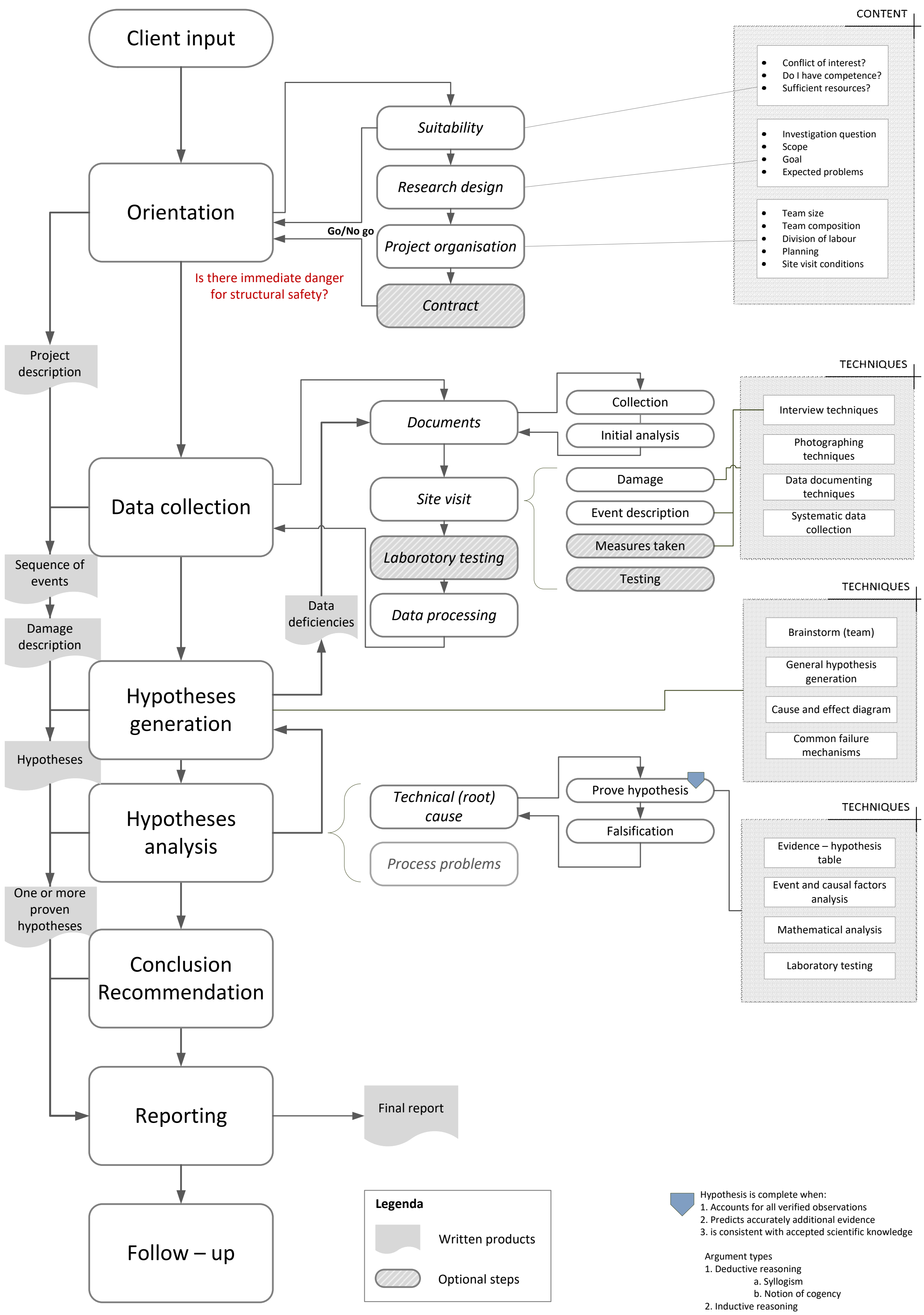
In this handbook a model for a structural damage investigation process is described. The model is developed as a tool to investigate small and regular structural damages to concrete structures. The model is a tool that gives an inside on the phases of an investigation process. For each phase of the investigation process there are steps and/or techniques recommended to execute the phase as complete as possible. In the case of a small damage investigation there is a balancing act between the scale of the investigation and time and budget on the other side the model consist out of necessary steps and optional steps. The phases and steps of the model are also scalable by choosing how detailed a technique, step or phase is executed. The investigator is invited to choose a technique that fits with his or her investigation goal, damage type, size and time frame.

The goal of the model is to give a tool to a starting investigator to navigate through the investigation process in a conscious and qualitative way. For experienced investigators the model can serve as an information tool or inspiration for a new approach.

The model is mainly based on theory of forensic engineering, accident investigation models and cases study research theory although a limited amount of interviews has been performed with experienced Dutch structural damage investigators to get some practical input.

This handbook starts with an overview of the investigation process model. Then the concept of the ring of trustworthiness is explained (a tool to improve the reliability of an investigation). This is followed by a detailed description of each phase supported by text boxes with explanations of specific techniques. Each phase is concluded with recommendations to achieve the principles of the ring of trustworthiness (gray text boxes).

Overview model



Ring of trustworthiness

To increase the validity and the trustworthiness of the investigation the ring of trustworthiness is introduced in the Delft approach. The ring consists of five principles that together increase the credibility of the investigation (TU Delft Forensics, 2017).

- Objective: the judgment or investigator is not influenced by opinions or personal feelings when considering or representing factual information (TU Delft Forensics, 2017).
- Repeatable: the investigation can be re-done (TU Delft Forensics, 2017).
- Verifiable: all information can be checked by presenting it in a transparent way. This means recording how and where information was gathered and only using verifiable sources (TU Delft Forensics, 2017).
- Complete: containing all the required parts (TU Delft Forensics, 2017).
- Correct: not containing errors (TU Delft Forensics, 2017).

To achieve the principles above, there are formulated practical recommendations. They are collected from case-study research theory and human error theory. In table 1 recommended practices that are applicable to the whole investigation process have been described. Practices that are specific to a certain step in the investigation process are mentioned in a text box at the relevant step.

Table 1: overview of recommended actions to full-fill principles of the ring of trustworthiness

PRINCIPLE	RECOMMENDED ACTION
Objective	• Be aware of your theoretical viewpoints and bias. • Use triangulation (the use of several research techniques at the same time). If they result in the same conclusions it is prove of the objectivity of the results. • Do the investigation with a team that discusses the methodological and theoretical approach.
Repeatable	• Describe for each investigation phase the used theories and idea's. • Use a structured investigation process and write it down in the final report.
Verifiable	• This is mainly applicable in the data processing and reporting phase. For recommendations see these steps.
Complete	• Perform an audit of the investigation process by a colleague. The audit should contain a check of the completeness of the process, if the process is logical, understandable and fully documented. • Check if there is a clear scope definition and if this is respected in the investigation.
Correct	• Use triangulation. • Perform an audit of the investigation process by a colleague. The audit should check the correctness of the used process (logic, well documented, understandable and the presence of bias prevention measures). • Use research techniques that are widely regarded as reliable and of high quality.

Model description

Below is a brief explanation of each step of the methodology. Within each step the sub steps are explained, investigation techniques are described and the conditions are listed.

Client input

The client input is the start of an investigation process. The assignment will likely come via e-mail or a phone call. When receiving the first information you make a quick assessment of the type of assignment. You can ask for a first description of what happened and what the context of the damage is. It is also important to ask what the client wants to be investigated and what he/she expects. Later, this is helpfull to determine the investigation goals and scope.

Orientation

After receiving the assignment the investigator determines if the assignment will be accepted. This phase is called the orientation phase. It is divided in three compulsory and one optional step.

Suitability

The first step (suitability) aims to determine if an assignment can be done in a correct and qualitative way. A couple of questions should be answered. If the answer is no you should not take the assignment.

- Do I or does my company haven't got a conflict of interest (designer and investigator, personal link etc.) when accepting the assignment?
- Do we have the competence and knowledge or are we able to get it (material, theoretical, experience etc.) to perform this investigation?
- Do we have or are able to get sufficient resources (time, manpower, machinery, etc.) to finish the investigation in a qualitative manner?

Research design

The second step is to establish what the content of the assignment will be (research design). The following aspects will be regarded and reported in a short memo:

- *Investigation question*: what is the question of the client and what does he wants to be investigated?
- *Scope*: what are the boundaries of the investigation and what are the elements within and outside the investigation?
- *Goal:* what is the expected outcome (damage cause, liability, damage solution, assessment of the structural safety) as expected by the client and by the investigator? Are expectations the same?
- *Method*: what are the needed steps and their order to be able to finish the assignment?
- *Expected problems*: what are possible bottle neck points (lack of information, damage location inaccessible, etc.) during the investigation?

Project organisation

After determining the project content, the project planning and organisation needs to be developed. The goal is to allocate the needed time and people to the assignment and think ahead to overcome difficulties and risks.
In this step you describe the following elements:

- *Team size and composition*: can I handle the investigation on my own or do I need a team for the whole investigation or parts of the investigation?

- *Division of labour*: if we work in a team who is responsible for what part?
- *Planning*: draw a planning of the investigation process and make the appropriate appointments with the client if possible.
- *Site visit conditions:* get some information on the conditions of the damage site. This will help to determine what machinery and apparatus is needed during the site visit.

The results from the research design and project organisation step are documented in the project description document. This document is the base of the investigation and formalizes the investigation question, goal, scope and approach.

Contract

When working with fixed contracts this, is the stage to make agreements.

Objective	• Discuss the investigation process and techniques in a team.
Repeatable	• Describe the investigation process in detail so repeating of the process is possible.

Data collection

The data collection phase is one of the most important steps in the process as it can heavily influence the course of the investigation. The goal is to gather and document data in an organized, structured and objective way. The following information needs to be collected:

- Building date
- Function of de building
- Foundation type
- Main load bearing system (material quality, force flow, connection principles)
- Renovations or additions to the building.
    - » Date
    - » What has been altered
    - » What material has been used
    - » Did the building had a change of function?
- Damage
    - » When was the damage first observed?
    - » Development over time
    - » Have there been repairs and what has been done

This information will be collected during the steps: document collection, site visit, laboratory testing and data processing. They are described below.

Document collection and analysis

The first thing you try to get is all the available documentation on the damage, building history and construction (see table 2).

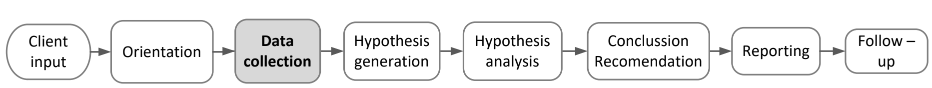


Table 2 overview documents to collect according to building age

BUILDING AGE	DOCUMENTS TO COLLECT	PLACES TO FIND DOCUMENTATION
Under construction	• Construction drawings	Contractor
	• Construction calculations	
	• Work drawings	
	• Execution checklist	
	• Concrete mixture content and quality indication	
	• Manufacturer of prefab elements	
	• Construction method	
	• Repairs done yes or no?	
	• Photo's and documentation of damage	
New construction (0-5 years)	• Construction drawings	Contractor or designer
	• Construction calculations	
	• Concrete mixture content and quality indication	
	• Manufacturer of prefab elements	Production company
	• Construction method	
	• Groundwater info (in case of leakage)	DINO loket
	• Repairs done yes or no?	Owner
	• Previous damage investigations reports	
	• Photos and documentation of damage	
Existing building	• Construction drawings	Municipality/owner
	• Construction calculations	
	• Concrete mixture content and quality indication (not likely to be available)	
	• Manufacturer of prefab elements	
	• Maintenance reports	Owner
	• Repairs done yes or no?	
	• Previous damage investigations reports	
	• Photos and documentation of damage	
Historic building	• Construction drawings	Municipality
	• Construction calculations (not likely to be available)	
	• Building history	Owner, archive
	• Construction methods and concrete quality at time of construction	Owner, municipality
	• Refurbishment documentation	Owner
	• Previous damage investigations reports	Owner
	• Photos and documentation of damage	

Then a first analysis of the information is done. You can analyse the following topics:

- Construction: what is the overall structural system (prefab beams and columns, in-situ concrete structure, composite system, floor system, roof system etc.) and what is the structural system at the location of the reported damage?
- Damage: is it a local problem or is damage occurring on several locations within the building or in similar constructions? Is the damage located on a critical structural location?
- Previous investigations (when relevant): are previous investigations on the same damage? What are the conclusions of previous investigations into the damage? Which data have previously been collected and analysed? What repair measures have been proposed and/or executed?

A side note to this form of data collection is that it is not always possible to access all documentation because it can be lost or no longer available. The result of the analysis is a general idea of how the construction is made up (mechanical system, structural system, concrete quality indication and location of reinforcement), an idea of the scale of the damage and an indication of where you want to have a closer look to the construction during a site visit.

Site visit

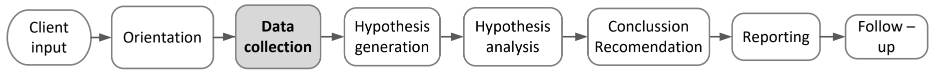
The goal of the site visit is to examine the damage by yourself and to collect available data. Before you go to a site you can take the following preparations:

- Print a plan drawing.
- Think what questions you want to ask.
- Determine what equipment you need to take to be able to reach all the damages (tower wagon, measuring equipment, safety equipment etc.).
- Arrange the necessary access clearances if needed.
- Check what parties will be present.
- Check the storage and battery capacity of your camera.

At the end of the site visit you want to have collected data on the following topics:

- Overview and description of the damage.
- Overview of what happened.
- History of damage investigation and repairs (when relevant).

During a site visit there are several ways to collect and record information. This can be done by inspecting visually, interviewing people on location, non-destructive testing and destructive testing. For each way of collecting the data several techniques are advised. Each investigator will have his own way to perform a site visit and the order of actions will also depend on the location, damage and the accompanying people. However, it is recommended to follow, if possible the following order in order to avoid missing information.



Step 1

Talk to the people on location as they can give you access and first general information. Use this time to get a general overview, first impression and to find out if the damage is local or on more locations, when the damage is first observed and the development of the damage over time. Examples of questions that you can ask are documented in the *text-box Interview questions*. During this walk-trough you can inspect the surroundings of the building. You develop an idea on the construction and the scheme it follows. You compare this with the information from the drawings you received before. When doing this you validate the data from the received documents.

Resulting documentation:

- Sketch of general structural concept and system.
- Notes of all noticeable differences between reality and drawings (document collection).
- Notes on the information provided by the local people.

Step 2

Ask if you can make a second round along the damage locations alone. This will allow for you to concentrate on the damages and to make sure you don't miss information. During this round you can use several damage collection techniques, like photographing techniques, systematic data collection techniques (in case of multiple damages to a structure) and data documenting techniques. They are described in more detail in the text boxes: photographing, data documenting techniques and systematic data collection.

When needed, on site tests can be performed to collect data. Possible test and their function are described in text-box in-situ test.

Resulting documentation:

- A sketch of the construction system of the damaged element as it is in reality.
- Photographs of all damages (see box photographing).
- Descriptions on how the damage looks. Be as objective as possible and don't use failure mechanisms or possible explanations to describe the damage.
- Sketches of the damage in is relation to the surrounding area by using the damage sketching system (Useful for extensive cracking or surface damage).

When finished with the detailed inspection of the construction, you return to the people that invited you, so you can explain what you did and ask remaining questions.

Laboratory testing

When information on the concrete quality or properties is needed cores can be taken to analyse at a laboratory. Recommended is to hire a specialist company to perform the tests and to collect the samples.

Data processing

The last part of the data collection phase is the sorting and validating of all the collected data. This is done by properly storing and filing the photographic material and oral information. Another technique to sort the data is by making a sequence of events. This is a technique where the data is sorted in chronological order. By listing the data and the events that took place in chronological order gaps or irregularities in information will become apparent.

Objective	• Use multiple sources to collect data. • Establish a chain of evidence by recording all actions and changes that have taken place for physical evidence and test material • Perform regular data audits by other investigators to review the quality and techniques of data collection.
Repeatable	• Record data as detailed as possible. Including the original location and its appearance. • Record observations as precise as possible. • Make a database for storage and organisation of the original data. • Record the used data collection techniques. • Use specific procedures for coding, recording or storage of data.
Verifiable	• Make a database for storage and organisation of the original data. • Record data as detailed as possible. Including the original location and its appearance. • Record observations as precise as possible.
Complete	• Use a systematic data collection approach during a site visit.
Correct	• Use specific procedures for coding, recording or storage of data.

INTERVIEW QUESTIONS

The questions you want to ask and document are:

- Does the damage only appear on this location or also on other locations?
- Do other types of damage appear in this construction?
- When did you first notice the damage?
- Did you hear sounds?
- Did the damage develop over time? How did it develop?
- Is it still changing?
- Have there been repairs on this damage or other damages? What did you do?
- Have there been recent refurbishments or changes to the building or its use?
- What is normally the function of this area and what was in it when the damage occurred?
- Do you remember what the weather conditions were?

DATA DOCUMENTING TECHNIQUES

Below are several suggestion to document the data you collect during a site visit in a systematic way.

- Use the grid-numbering of the drawing and put a mark/sign near the damage. So it appears on every photograph (location).
- Take a plan drawing to the inspection and note the location of your photographs on the plan, including the photograph numbers and photographing direction, or use software that performs this task.
- Indicate crack location and progression with markers before taking photographs (this makes sure they are still visible on the photograph).
- Sketch the damage on an outline drawing of the plan, walls and roof of a space using different symbols for each type of damage (see figure 2)
- Use a damage description template (for an example see figure 1)
- When describing damage, make sure you do this in an objective manner. This means only describing what you actually see without documenting explanations or suggestions.

Site-visit damage recording

Location:
Date: Time:
Persons present:
Wheather conditions: °C Wet/Dry Sun/Cloudy
Documents recieved:

Information by the guide

General state building

Damages

Nr. 1
Type: crack / deformation / decolouring / spalling / other..........
Location: floor / wall (loadbearing) / wall (non loadbearing) / beam / column
foundation / roof
Photo: Yes/no amount:
Description:

Nr. 2
Type: crack / deformation / decolouring / spalling / other..........
Location: floor / wall (loadbearing) / wall (non loadbearing) / beam / column
foundation / roof
Photo: Yes/no amount:
Description:

Figure 1: Example template for data recording on site

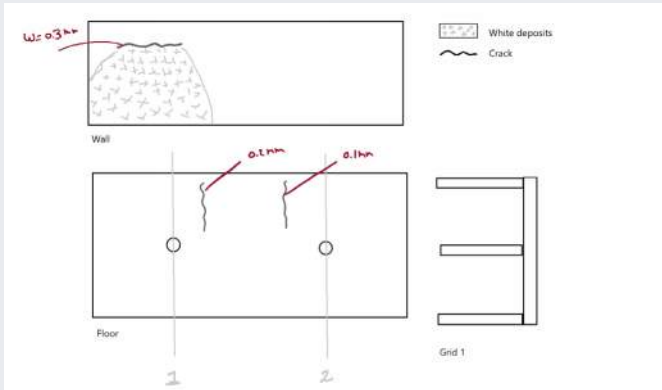


Figure 2: Damage recording by drawing in plan and facade drawings

SYSTEMATIC DATA COLLECTION

When you start collecting data, it depends on the type of building and the number of damages how challenging systematic data collection can be. When inspecting a structure with multiple damages the following techniques can assist in keeping it systematic.

- Work from the outside of a building towards the inside, from ground-floor to roof, scanning each space from left to right and bottom to top.
- When investigating parking garages with a clear grid use this to annotate location of data.
- When investigating a line like structure (e.g. galleries/balconies) choose a recognizable starting point and an end point. The line in-between is the base line and relate all measurements and locations to this base line.
- In case of surface damage or extensive cracking, work from area's with little or no damage to the area with most damage to avoid becoming "blind" to little damages.
- When inspecting cracks record:
  - » Location
  - » Shape
  - » Length
  - » Depth
  - » Width
  - » Colour (dirt)
  - » Width over length
  - » Repairs

PHOTOGRAPHING

A very common way of damage recording is making photographs. When photographing it is important to keep the following things in mind:

- Make sure you have enough light to get good quality photographs.
- Make sure your photos are focused.
- Start by making overview photographs that show the context of the construction/building.
- When photographing a damage start by taking an overview photograph(s) of a damage with some indication of location present (this helps to separate the damages on the photographs from each-other when later viewing the photographs). Then make a photograph with some zoom-in in on the damage. At last make a detailed photograph of the damage.
- Photograph the damage with a measuring tape along for indication of size.
- Photos should record the destructive testing process. Take at least photographes of the initial situation, the material that you used to do the test and the final situation.
- Use the grid-numbering of the drawing and put it near the damage. So it appears on every photograph (location).

IN-SITU TESTING

There are several on location tests possible. They are listed below:

- Measuring of crack width with a crack width meter.
- Tapping of concrete surfaces with a hammer (determination of loose parts)
- Removing of the concrete cover to expose the reinforcement (to check for corrosion or the type, configuration and amount of concrete)
- Wetting of the concrete to get a better overview of the cracks present
- Taking cores of concrete so laboratory tests into different deterioration mechanisms can be done.

Hypotheses generating

The hypotheses generation step has been designed to develop ideas on possible failure causes or combination of failure causes. The goal is to establish the what and how of the damage. As you want to do this efficiently and correctly it is recommended to use a structured way to develop hypotheses. From the data collection phases follows validated data and possibly a sequence of events. In this step the data will be used as base for the hypothesis.

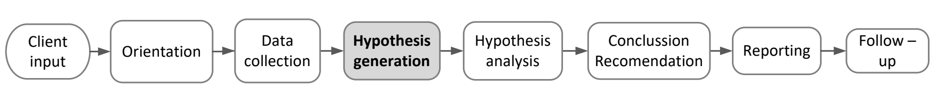
A good hypothesis has the following characteristics (Heuer & Pherson, 2014; Noon, 2009):

- The hypothesis should be a statement, not a question.
- The hypothesis should be based on data that is factual and therefore verifiable.
- The hypothesis should be able to predict results like data, patterns or events.
- The hypothesis should be testable.

The most important pitfall of this stage is getting into a tunnel vision. Therefore, it is important to keep an open-mind and make a logical line of reasoning. To achieve this and to get the best result working in a team is recommended during this stage. If you choose to do so make sure that each team member has access to the data from the data collection phase. To assist in hypothesis making these are numerous techniques developed in literature. It is possible depending on the damage scale to combine techniques. Within the scope of this model (small structural damage investigation into technical causes) the following techniques are recommended and explained in the text boxes on the following pages:

- Brainstorm
- General hypothesis generation
- Cause and effect diagram
- Common failure mechanisms

The final step is to make an overview of the data that is still missing and needs to be collected. If there is missing data you go back to the data collection phase.



Brainstorm

The goal of this technique is to assemble as many possible failure mechanisms and causes that could be an explanation for the observed damage as possible. This technique can assist in overcoming thought restrictions (the tendency to select the usual or regular solution or cause). The output will be a list with possible technical causes for the damage and/or scenarios of the development of the damage.

Pros
- Easy technique so limited training/experience needed.
- Limited time needed.
- Quick results.
- Intuitive technique.

Cons
- Can be time consuming if not properly organised.
- Can result in idea's that need to be translated and developed in hypothesis afterwards.

Execution

The execution of a brainstorm consists of three phases (Ridder de, Soons, & Voskamp, 2011)[1].

1. **Exploration phase**: in this phase the problem and the available data is discussed. The goal is to make the problem abstract and as clear as possible. This is also the time to get rid of presuppositions concerning the cause of damage.
2. **Creative phase**: this is the brainstorm itself. There are basic assumptions: give imagination free rein, don't judge or give value to any idea and the more idea's the better.
3. **Evaluation phase:** in this phase the criteria to evaluate the generated ideas are developed. The ideas are compared to available data and from the possible scenarios hypothesis are formulated.

Preconditions

The following preconditions have to be taken into account:
- The brainstorm technique can be performed individual and in a team. When doing brainstorming by yourself you have to consider the risk of tunnel vision. Therefore, brainstorming in a small team is recommended. This will result in a group interaction and can result in fresh ideas and new lines of reasoning. When brainstorming in a team you need to make sure that everyone feels comfortable to propose idea's as otherwise the added value of a group is limited (Mashoed, 2006).
- A time-frame needs to be set to avoid spending unnecessary amounts of time on a brainstorm.
- When doing a brainstorm in a team a group leader has to be appointed to structure the process.

1 Mashoed, V. (2006). *Scenario's en visualisaties in brainstorming*. Universiteit Twente, Enschede.
Ridder de, H. A. J., Soons, F. A. M., & Voskamp, R. (2011). *Dictaat CT1062 Inleiding intergraal ontwerpen*. Delft: TU Delft.

Multiple hypotheses generator

The goal of this technique is to generate alternative hypotheses when one hypothesis is dominant. To make sure you don't overlook possible damage causes you can try to generate alternative explanations.

Pros
- Stimulates thinking out of the box.
- Useful when you are having tunnel vision.
- Very systematic approach.

Cons
- Time consuming method.

Execution

The execution starts with a main hypothesis (Heuer & Pherson, 2014)[1].

1. Split this hypothesis into the relevant variable components (Why, How, When, What, Who, Where).

   Example: the vertical cracking (What) in the middle of the concrete floor (Where) is caused by thermal expansion and shrinkage (Why) over time (When).

2. Generate for each element possible and relevant alternatives.

   What and Where stays the same. Alternatives for why are: drying shrinkage, prevented deformations, plastic shrinkage, reinforcement corrosion. Alternatives for When are: after construction, during construction.

3. Combine the alternatives of all elements (you get a long list).
4. Exclude the ones that make no sense.

   Example: the vertical cracking in the middle of the concrete floor is caused by reinforcement corrosion during construction.

5. Evaluate the probability of each alternative hypothesis and list them from most relevant to least relevant.
6. Select the alternative hypothesis you want to analyse.

Preconditions

The following preconditions have to be taken into account:
- You need to have a starting hypothesis that is relevant to your problem.

1 Heuer, R., & Pherson, R. H. (2014). *Structured analytic techniques for intelligence analysis.* In (pp. 384).

Cause and effect diagram

The goal of the technique is to get from the damage as it is visible to possible technical underlying causes. The method follows the idea that a visual damage belongs to certain direct linked causes or events. These events or causes have also certain possible pre-events or failure mechanisms. When listing these events or mechanisms in a tree structure you can develop workable hypotheses.

Pros
- A useful method when a variety of types of causes are possible.
- Reasoning starts with the visual damage, similar to a damage investigation.

Cons
- Some training in the technique is needed.
- Can be time consuming when cause is straight forward.

Execution

For the execution of this technique you follow the following steps:
1. Place on the top of the tree the visual damage as reported by the client.
2. Link damage of step 1 to the direct prior event or damage.
3. Verify the events of step 2 with data from the data collection phase. Eliminate the one's that are not possible due to the data by giving them a grey colour.
4. List possible underlying events or mechanisms for all the relevant events of step 2.
5. Verify again with data and eliminate the irrelevant possibilities.
6. Continue until you reach the level of detail that is testable with data and is a root technical cause.

For an example and the visual result see figure 3.

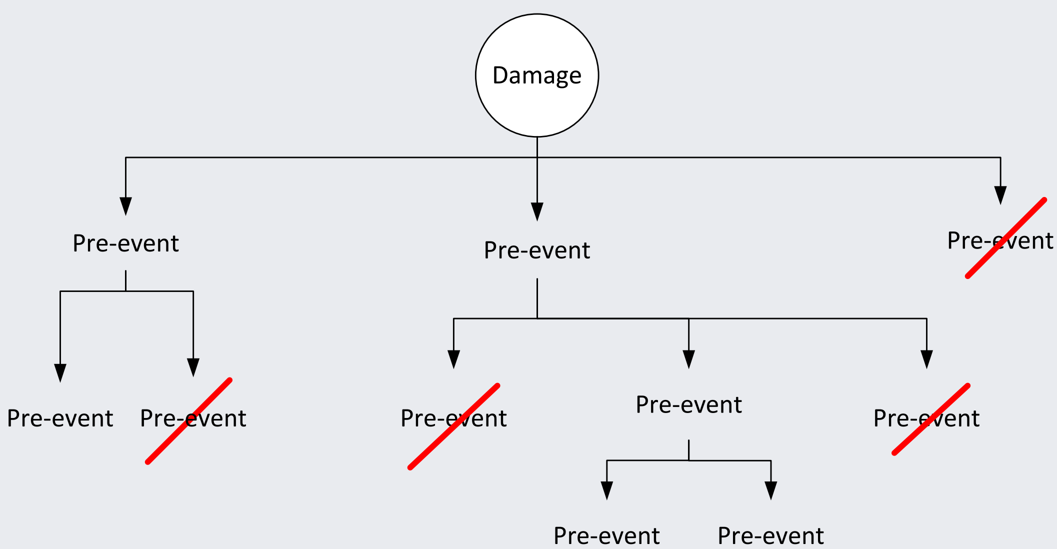


Figure 3: Cause and effect diagram scheme

Common failure mechanisms

This technique uses a tool that describes the connection between visual characteristics of a concrete damage and possible damage causes. The tool additionally describes conditions that are relevant for specific possible damage mechanisms and list information sources.

Pros
- A useful method when investigating common concrete failure mechanisms.
- A fast hypotheses making method.

Cons
- The tool is available for massonary failures and concrete damages.
- The tool is limited to the discussed damages, all damages outside the tool are not regarded so caution is required.

Execution

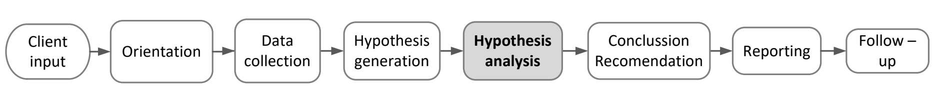
For the execution of this technique you follow the handbook concrete damage causes. (see Appendix G - Concrete damage handbook)

Hypotheses analysis

The goal of the hypotheses analysis is to test the developed hypotheses from the previous stage. Hypotheses testing is done using deductive reasoning. This means that theory is used to develop a line of proof that gets you to the correct hypothesis. Each hypotheses will be measured against the available data and theory. If there is a miss-match between the two the hypotheses can be rejected. The argumentation and the relevant data is reported.

To analyse the hypotheses several techniques are available:
- Evidence - hypothesis table (see text-box evidence-hypothesis table)
- Event and causal factors analysis (see text-box)
- Mathematical analysis: this can be calculations or modelling based on mathematical principles.
- Laboratory testing: this type of analysis is not often used as it can be quite expensive. If there is a very specific hypothesis left, concerning a material damage it can be useful to do material tests to exclude or prove damage causes.

If a hypothesis seems true the last step is to falsify the hypothesis by actively looking for contradicting evidence. If there is no contraticing evindence, you can consider the hypothesis proven.



Objective	• Consider your personal assumptions and predispositions and view on forensic engineering, construction world and theory and determine if they influence your analysis. • Use falsification and actively search for unsupporting data. • Present hypotheses analysis results to colleagues. • Be theoretically oriented.
Repeatable	• Document your analysis and argumentation in detail.
Verifiable	• Document your analysis and argumentation in detail
Complete	• Perform a peer review on your analysis and conclusions.
Correct	• Cross-check results with data. • Use illustrations and diagrams to explain data and arguments. This will expose irregularities and mistakes and forces to draw logical conclusions. • Compare results with literature.

Conclusion/ recommendation

This step in the process has the objective to conclude the investigation and to make sure that you have answered the main investigation question. During this phase you summarise the main conclusions and results from the investigation and answer the main investigation question. You also make an analysis of the consequences of your conclusions. This can vary from problems with the structural safety to the conclusion that everything is safe and there is actually not a real problem.

Reporting

The report is the result of the damage investigation and is the physical product that client receives. In order to communicate the quality and completeness of the investigation it is advised to give a fixed structure to your reporting. The following elements are recommended:

1. Front page: on the front page you can put the title of the investigation, the date and the type of investigation (damage cause investigation, repair measures, structural safety etc.).
2. Introduction: the goal is to give an overview of the investigated situation and the context of the investigation. The introduction consists of the following parts:
    a. Situation description: the problem in its context is described.
    b. Investigation question: a description of the question of the client and the main investigation question is given. The scope (what is and is not part of the investigation) of the investigation is also described in this part.
    c. Investigation process: a short description of the investigation process you have followed is included.
3. Data: the goal is to present all the relevant collected information. This part consists of the following parts:
    a. Description of the structure: this is a general overview of the type of structural systems and their connection and a more detailed description of the structural parts that have been damaged.
    b. Context description: a short description of the buildings surroundings and conditions, the main observations of the site visit

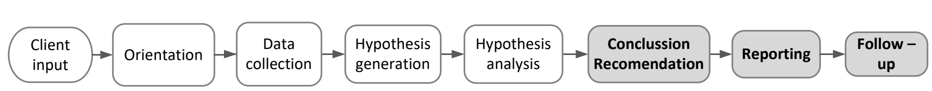
and the information given by local and/or involved people.
   c. Damage: an objective and factual description of the damages supported by photographs, sketches, measurements and drawings.
   d. Test results: summary of the performed tests, their relevance and limitations and an overview of the relevant results.
4. Hypothesis: an overview of all the considered hypothesis
5. Analysis: a description of the analysis of all the considered hypotheses. This includes the argumentation with calculations (when relevant) and supporting data to reject or accept a hypothesis.
6. Conclusion: this chapter will answer the main investigation question and appropriate recommendations about structural safety.
7. Appendixes: all larger calculations, drawings or analysis that are not relevant for the main text can be included in the appendixes.

Some general guidelines when writing a report:
- Keep facts and your own analysis separate and make clear what are facts and what are own interpretations.
- Try to be as compact as possible without losing too much detail and context.
- Make sure that your write in such a manner that your public understands what you write and that the content is not open for misinterpretation.
- When a report is finished let a colleague read the report for completeness and correctness before sending it to the client.

Objective	• If people have contributed a professional opinion to the investigation and this is recorded, let them review the final report to make sure you have the correct interpretation.
Repeatable	• Report on the investigation procedures and techniques.
Verifiable	• Present all relevant data, arguments and observations in a structured and systematic way. • Make a separation between factual data and personal observations or theories.
Complete	• Write a detailed report on the investigation so you can include all steps of the investigation including nuances and circumstances.

Follow-up

This is the last step of the investigation and has the goal to keep improving the investigation process. The idea is to take a few minutes after finishing the investigation to think of two things that did go right in the process and two things that are open for improvement. When there are specific and relevant observations it is recommended to store them collectively over a longer period to investigate if there are general patterns that can be analyses to improve the quality and efficiency of the investigation process.



Evidence-Hypothesis table

The goal of this technique is to prove or falsify hypotheses that are generated before by comparing the hypothesis with the available data. By indicating the data that falsificates a hypothesis you can exclude the hypothesis.

Pros
- Quick method to compare and exclude impossible hypotheses.
- The results are directly visual and systematic presented.
- Possible to use for every type and amount of damage.

Cons
- When it is not possible to exclude hypothesis it is possible that multiple hypotheses remain relevant and you need to use an other technique to prove the hypothesis.

Execution

The goal of the method is to collect all possible hypotheses on the top row of the table and list all the available data and information on the first column of the table. Keep in mind that you only want to include verified and factual data.

Then you look if the data supports the hypothesis (X), falsificates the hypothesis (O) or neither. When a hypothesis has an O this automatically excludes the hypothesis. The hypothesis with the most X is more likely as it has more supporting evidence. (Take care: there are cases where excluding evidence doesn't mean that the hypothesis doesn't describe the cause or a contribution to the damage. The same counts for the most likely hypothesis, it is not proof.)

DATA	a	b
Data 1	X	
Data 2		X
Data 3	X	X
Data 4		
etc.	X	O
		O
	X	X

Preconditions

The following preconditions have to be taken into account:
- You can only use validated and factual data.

Event and Causal factors analysis

The goal of this technique is to analyse the developed hypotheses by comparing them to the order of events that are indicated by the hypothesis. This theoretical information is compared with the available data. The more data matches with the predicted events the more likely the hypothesis is true. It is possible to link time to the events. It is important that this technique is followed by falsification.

Pros
- Visual presentation of the match between data and hypothesis.
- It can be used as a next step to the cause and effect diagram as both techniques follow almost the same structure of ordering information.

Cons
- The damage type should have some sequence of events.

Execution

You start with the final event. This is annotated with a circle. Then you work your way back by adding all previous events or visual appearances. The validated events (there is data that supports the event) are visualised with a rectangle. The events that are predicted by the hypothesis but without supporting data are presented by rectangles with dotted line. Attributing factors or causal factors are presented as an ellipse. It is possible to add critical events by using diamond shapes[1].

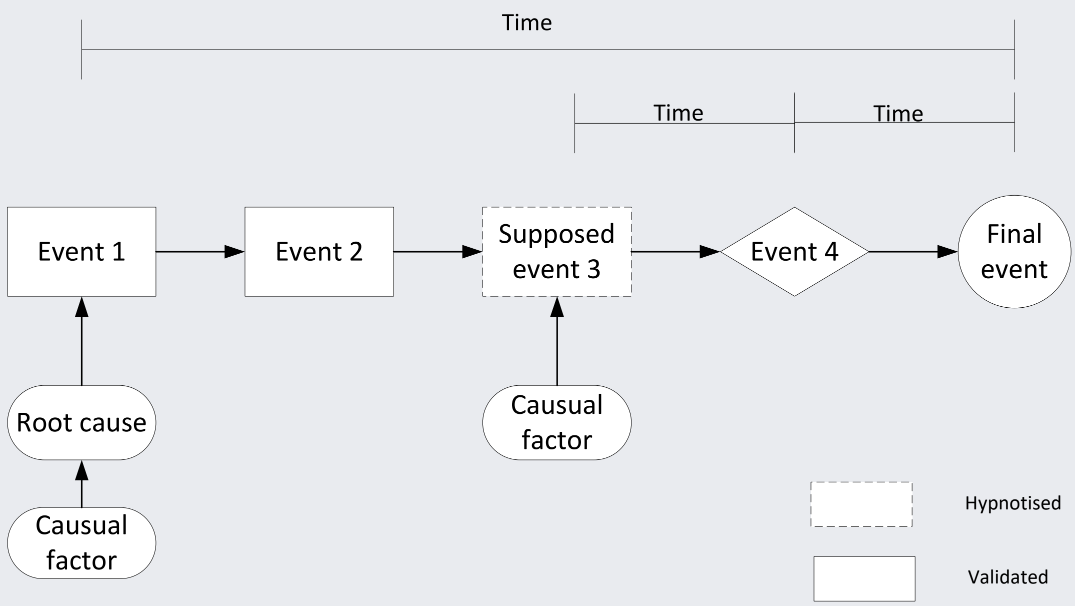


Figure 4: Event and Causal factors analysis

1 For more information see the book scientific method applications in failure investigation and forensic science by Randall K. Noon

Appendix I - Case study general analysis

This appendix describes the results of an analysis of the differences and similarities between the proposed investigation model and several real investigations into the technical cause of concrete damages. The goal of the study is to test and improve the proposed model. As base for the analysis the investigation order of the proposed model will be used. The analysis has been performed as follows: first the steps and information that the proposed model describes will be recorded. Secondly the equivalent information and process steps in the cases will be discussed (as far a reported on). Finally a small conclusion will be given.

Cases

Nine cases have been selected from dossiers of Adviesbureau ir. J.G Hageman B.V. The cases are selected to represent a diversity of concrete damages in a cross-section of structural typologies. A short description of the cases is given in table 1.

Table 1: Damage cases description

Nr.	Structural typology	Structural element	Damage description
1.	Residential building	Façade element	Crack forming in multiple prefabricated concrete façade elements. The crack forming was discovered during construction of the building. At that time production was still going. The investigation question was the determination of cause, structural and aesthetic consequence and possible repair measures. In this investigation a desk-study, site-visit, factory visit and laboratory tests have been performed. The investigation was concluded with a report.
2.	Residential building	Balcony elements	Crack formation with some water penetration on the bottom side of multiple balcony elements consisting out of prefabricated consoles and in-situ plates. Previous there had been some crack repairs. The investigation question was to determine the damage cause. During the investigation there has been a site visit and a desk study. The investigation has been concluded with a memo document.
3.	Residential building	Balcony element	Crack formation and some scaling of concrete in multiple balcony plates at the location of the connection with the steel balustrade. The investigation question was the determination of cause. The investigation consisted of a desk study and site visit and was concluded with a report.
4.	Residential building	Story floor	Deformation on the bottom side of a wide-slab floor. The deformation was discovered during finishing work on the building. The investigation question was to assess the structural safety. The investigation is based on a desk-study and concluded with a report.
5.	Parking garage	Floor and wall	Multiple crack formation on a hollow core slab floor and spalling of a wall on one location. The investigation question was determining the cause of the damages and designing possible repair measures. The investigation consisted out of a desk study and a site-visit and was concluded with a report.
6.	Parking garage	Floor	Crack formation in and leakage of a reinforced concrete floor below ground level. There had been previous investigation into some of the damages. The investigation question was to determine the water-tightness and the determination of the damage cause of some of the cracking. During investigation a desk-study and a site visit have been performed. The investigation was concluded with a report.
7.	Parking garage	Floor and outside walls	Crack formation in wide slab floors and concrete walls below ground level. The cracking has been discovered during usage of the garage. The investigation question was to analyse the structural safety of the construction. The investigation consisted out of a desk study and a site visit. The results of the investigation have been reported.

Nr.	Structural typology	Structural element	Damage description
8.	Industrial hall	Floor and columns	Locally wide cracking and reinforcement failure in the reinforced concrete floor. Some scaling of concrete at the bottom of some main columns. The investigation question was an inspection of the structure and an assessment of the structural safety. There has been a desk study and a site visit. The investigation is concluded with a report.
9.	Assembly building	Floor and walls	Multiple crack formation in the top layer of a hollow core slab ground floor and in walls around the building. The cracking has occurred in a later added part of the building. The investigation consisted out of a site visit and a desk-study and was concluded with a memo.

Client input

Cases

The correspondence with the client is recorded and stored in most of the cases. Oral agreements are also put in writing by sending an e-mail or letter confirming the agreement. The question of the client is most of the time related to the safety aspect or the repair possibilities. In both cases it is communicated that to answer this question an investigation into the cause of the damage or failure is necessary.

Proposed model

The information you get from the client is:

- An investigation question.
- Some initial description of the damage.
- A time frame or budget question.
- Request for available drawings and calculations.

The conclusion of the comparison between the reality and the model is that it seems that the presumed information and start of an investigation within the model also holds in practice. A side note is that the information from practice is based on the available documentation and it is likely that this is not fully recorded and stored. It seems that the timeframe and the budget question in reality are not that important in this phase of the process.

Orientation

Cases

Based on the available information it is not possible to compare the steps ethics and project organisation as both steps are likely be considered in practice but are not documented in the cases.

In all the cases the investigation question, scope and goal of the investigation have been reported in the final report and most of the time also in a price quotation. Reported are the clients name and his or her role (owner, resident, builder etc.). Secondly the initial question of the client is translated into research questions that are also reported on in the first paragraph of the final reports. When a client has specific questions, these are reported in the final report. For example, in case 1. the client had four specific questions. These are directly copied in the final report and addressed as separate questions within the investigation and the reporting. When appropriate the boundaries to the investigation are also mentioned. In one of the cases (case 4) there hasn't been a site visit and the analysis is only based on the

Proposed model

The orientation phase uses four steps to determine if the assignment will be taken, to plan the investigation process and to initiate the investigation. The prescribed steps are: ethics, research design, project organisation and if needed a contract.

These steps will be documented in a template where mostly information from the research design step is recorded. This will later be used to formulate the introduction of the report.

received documentation. This limitation and the norms (NEN and safety-class) where the calculations are based on are recorded in the final report. In the cases 4 and 6. the involved parties are listed with their role. In both cases there where several involved parties who performed earlier inspections or investigations. In the other cases there was only one client and no earlier investigations by other parties were done.

In most of the cases there is no written record on the investigation process. From the reports becomes clear that in two cases two people worked on the investigation. In all other cases it was performed individual. In all cases the followed investigation process is re-constructable from the reports. In the reports of case 2 and 8 the investigation process is made explicit in the final report.

In all cases there is an assignment confirmation or a price quotation made that describes the assignment, what documents need to be delivered by the client and an initial price (based on a work hours estimation).

It is not possible to compare the steps of ethics and project organisation from the proposed model with practice as this is not documented. However, it is likely that both factors are considered when starting on an assignment. Regarding the project research step the main elements like investigation question, scope and goal are used and documented in almost the same manner in both the proposed model (project description document) and the cases (introduction chapter of final report). In the model there is also the recommendation to think about problems to expect. It is possible that an investigator does this, but this is not recorded. The project organisation step is made formal in the proposed model but is likely to be a more informal agreement in practice. This is also stimulated due to the fact that most investigations are performed individual. The largest difference between practice and the proposed model is that a contract in the model is optional. In reality it seems to be normal to make a contract in this stage of the investigation. Even when the pay system is based on real worked hours and therefore calculated at the end of the project. In this contract there is an agreement on what is going to be investigated, what documents need to be provided and an hour price rate.

Data collection

Cases

The data collection of the cases consist, except for case 4, out of document collection and data collection during a site visit. The following type of documents are collected:

- Plan drawings (all)
- Structural drawings
  - » Reinforcement (all)
  - » Cross-section (all)
  - » Foundation plan (case 8, 9)
  - » Details (all)
  - » Work drawings (case 1, 8, 9)
  - » Prefab elements (case 1, 3)
- Structural calculations (case 1, 4, 5, 6, 7, 9)

Proposed model

The data collection phase in the model is divided in several steps. They will be discussed below.

- Document collection:
- Construction drawings.
  - » Plan.
  - » Main structure.
  - » Relevant detailing.
- Calculations.
- Information on concrete quality and reinforcement.
- Previous investigation

- Concrete mixture (cases 1)
- Photo/sketch material damage (case 4, 6, 7, 8, 9)
- Construction/production records (case 1, 3)
- Temperature at location (case 1)
- Earlier damage investigation reports (case 3,4,7,6)
- Groundwater level (case 7)
- Relevant norms and regulations (all)

According to the available information the following information is collected during a site visit:

Case 1
Demonstration of production process.
- Photographs (in order):
  » Outside building overview photographes.
  » Detail photographs of cracks.
  » Crack scale photographs with tape measure and a pencil.
- Measures of the curvature (with a spirtlevel) of the façade panels in relation to cracking.
- Description of observations: crack development is described by where the cracks are located, how they are positioned (vertical/horizontal), starting point, width, depth, and development (one size/ getting wider etc.).

Case 2
- Photographs (in order):
  » Outside building.
  » Other non-related damage.
  » Details of the damage on balconies.
  » Details of the damage of parts of a staircase.
  » House number with front view.
  » Detail of damage.
- Repair mortar is cut away to expose the reinforcement. This is to investigate corrosion.

Case 3
- Description of the differences between drawings and reality.
- Description of the damages (typology, colour etc.) and the patterns that can be recognized.
- Measures of the crack width.
- Measure of the cover by cutting away a corner of a gallery plate to expose anchorage and location reinforcement.
- Description from what location the damage is inspected (from ground floor up and from the balconies).
- Testing of the stability of the balustrade by documents.
- Available photo documentation.

The collection is followed by an initial analysis of the documents. The goal is to get a global picture of the structural system and on the location of the damage.

Site visit
In the proposed model a site visit is recommended. During this site visit several data collection techniques are proposed: interviewing, photographing, measuring and reporting. They can be found in Appendix H.

Laboratory testing is an optional step. The last step is data processing. In this step you select and organize the data you got from the site visit and document collection. In this step you try to validate data and a sequence of events is proposed to present the data.

pushing and pulling it.

- Photographs (in order):
  - » Outside impression location
  - » Details of damages with several levels of detail/zoom.
  - » Outside of building 2.
  - » Details of damages, both to balconies and other (unrelated) elements that have damage.
- Calculation of capacity balustrades performed. To determine the developing forces.

Case 4 (no site visit)

Case 5

- Conversation with the residents of the building for information on damage and its development.
- Recording of the weather conditions during inspection.
- Recording from where elements are inspected.
- Visual inspection of floor to locate the crack formation.
- Visual inspection of wall for damage and leakage.
- Cracks documented on plan drawings.
- Crack width measurement and recording with tape measure and photograph.
- Photographs (in order):
  - » Outside of the building.
  - » Entrance of building.
  - » Wall overview.
  - » Wall detail in different levels of zoom.
  - » Photographs of removing repair material around dilatation.
  - » Other damage in surroundings of wall.
  - » Overview of parking.
  - » Detail cracking with measure tape.
  - » Overview photo of cracking.
  - » Roof details.

Case 6

- Description of concrete damage observations.
- Registration of context (construction site nearby).
- Measurements of length and crack width with measure tape.
- Recording of observation position.
- Photographs (in order)
  - » Historic situation.
  - » Detail of damage.
  - » Several damages first photographed within context and secondly detailed.
  - » Some vertical damages photographed from top to bottom.
  - » Photographs from discolouration of concrete on several locations.
  - » Photographs of water pools on floor.
  - » Outside photograph.
  - » Entrances and exit photographs.

Case 7 (visited location twice)

- Memo on the weather condition at time of site visit.
- Documentation on orientation (vertical/horizontal/angle), location, length, width and visual characteristics of the damages.

- Photographs (in order) (visit 1)
  - Outside overview terrain.
  - Outside photographs of visible parts garage structure (taken through grids).
  - Detailed pictures of damages (cracking, discolouring, loose strips of thin white supports fabric.
  - Liquid deposits on the concrete.
  - Photographs (visit 2)
  - Documentation on the location of the reinforcement measured by a re-bar locator.
  - Documentation on the removal of the cover at a location to expose the reinforcement.

Case 8
- Memo on what elements of the structure were not accessible.
- Measurements of crack width.
- Photographs:
  - Overview of the structure.
  - Details of damages (cracks, spalling)
  - Stored goods
  - The roof surface.
  - Façades

Case 9
- A map where all cracking and damage is located with accompanying illustrative photographs of the observed damages.
- Recording of the damage size, direction, width development and orientation relative to structural elements.
- Conversation with local people
- Photographs:
  - Outside of the building
  - Old building inside and outside impression
  - New building impression
  - Several damages recorded in the following order: Overview picture room, large picture with visible damage and context first and then two or three increasing detailed photographs of the damage.

When comparing cases with the model it becomes clear that the steps document collection and analysis and the site visit occur in both systems. From the list of the collected documents for each case it becomes clear that documents on concrete quality are not commonly collected. It seems that this information is also available in the structural drawings/calculations and used from that source. In the cases frequently documents on weather reports and the construction process are also included in the investigation. They can give data on conditions during construction that can have an influence on the development of the fresh concrete. In the cases almost everywhere an initial analysis of the documents is made because there are regular mentions of differences between drawings and the actual structure in the descriptions of the observations made during a site visit.

The site visit is also in practice an important method to collect data. During the site visit photographs of the damage and crack width measurements are always made. From the analysis of the cases there doesn't seems to be a fixed protocol or system to follow during a site visit. However different techniques have been used. Site visit techniques that regularly occur across the cases are:
- Interviews with local people;
- The removal of the concrete cover to expose the reinforcement;

- Elaborate descriptions of the damage (location, size, colour, width, orientation regarding to structural element etc.).

Techniques that are only used in one or two cases are:
- Plotting of the damages in a plan drawing of the structure;
- A description or demonstration of the production process;
- A recording of the observation locations and angles (from ground floor up- from the top, non-accessible parts etc.);
- Recording of the weather condition during inspection;
- Recording of the surroundings and their conditions
- An analysis of the differences between the drawings and the actual situation.

Some of these techniques are situation specific, like recording of the production process and the weather conditions. The other techniques can be useful in all cases.

The techniques of photographing, plotting damage in plans, interviewing of locals, elaborate descriptions of the damages and documenting the observation location are also suggested in the proposed model. The difference is that these techniques are recommended for each investigation in the model and in practice they seem to be chosen by the individual investigator.

Regarding the photographing techniques used in the cases it seems that each individual investigator has his own system of photographing. This varies from no system to systems like first photographing a large overview and then zooming in on the damage in detail or the other way round and photographing the process of removing the concrete cover. In general, when viewing the photographs, the damages are recorded in great detail, but it is not always clear where the location of the photographs is and what photographs are of what damage in the cases there are for example cracks on multiple locations.

In the proposed model there is the suggestion to ask for measures taken to repair or limit the damages. This was not included in the cases. Regarding the testing on site in the cases, measuring crack width and removing repair mortar and loose concrete to inspect the underlying conditions have often been used. These are all testing techniques that the investigator can do during the site visit.

Regarding the laboratory testing step of the protocol this was not an issue in most of the cases. It seems that with this type of damage investigations, laboratory testing is not often useful for the investigation and therefore not often used.

In the proposed model the last step of the data collection phase is data processing. The suggested technique is the use of an events time line where you order collected data according to the development of the events and damage over time. This technique has not been used in any of the cases. The data processing that is done is the recording of all data in the document database at the office. The different types of data (photographs, documents collected by investigator, documents received from various parties, lab results, correspondence with clients or other involved parties etc.) are collected and stored in separate file folders. By using this storage system the records are kept very well-organized and easy accessible.

Hypothesis generation and analysis

Cases

As hypothesis generation is often a thought process that is not recorded it is difficult to completely analyse only based on the available documentation. This means that the following observations can be limited and have to be reviewed with care.

From the cases it seems that there is not an unequivocal system for the process and the reposting of these steps. Below a description of the different systems used is given.

1. *A split between hypothesis generation and analysis* (case 1, 4, 5, 8, 9). For example in case 1 seven hypothesis are described in the report followed by an reasoning or argumentation with data why the hypothesis is true or false. In case 1 also a loop is used. After hypothesis generating the investigator went back to data collection by ordering laboratory test to get data to be able to test specific hypothesis. In case 4 the excluding technique is used. This means that the hypothesis are one by one removed by argumentation based on collected data unto the point there is one left.
2. *One hypothesis only* (case 2, 6, 7): in these cases there is reported on only one explanation of the damage with an argumentation based on the collected data. The argumentation is often accompanied by calculations.
3. *Different hypothesis are mentioned* but are not tested as they have the same end result and result in the same future approach (case 3).

Proposed model

In the proposed model the step following the data collection is the generation of possible hypothesis.

The following techniques are suggested:
- Brainstorm
- Cause and effect diagrams
- Common failure mechanisms
- Multiple hypothesis generator

After the formulation of some possible hypothesis the analysis of these hypothesis can start. In the model this consist of two stages. The first is to prove the hypothesis with the available data.

Suggested techniques are:
- Evidence-hypothesis table
- Event and causal factors analysis
- Mathematical analysis
- Graphical analysis

This process will result in a one or two proven hypothesis. The second stage is falsification of this hypothesis. This means making a real effort to overthrow the hypothesis by trying to find evidence that contradicts the hypothesis. When this is unsuccessful the hypothesis can be regarded as proven and true.

In the model there is a circular loop between hypothesis generation and data collection and hypothesis analysis and generation. This is because hypothesis can predict evidence that you didn't collect so going one step back is required. Analysis can conclude that none of the suggested hypothesis is correct and it is necessary to go back to generate new ones.

When comparing the proposed model with the approach in the cases there are similarities and differences. The similarities are: both use hypothesis generating and analysis. In practice this process may be not that structured and with techniques executed as suggested in the proposed model. It seems to be a more or less intuitive process. Extensive argumentation with calculation and supporting data has been used to support the final technical damage cause in the case reports.

A difference between the model and the studied cases is that the model requires a falsification to prove a hypothesis. This step is not coming back in practice.

Conclusion / Recommendation

Cases

In the cases the conclusion is part of the reporting when the main result of the investigation has been described. This result is often the damage cause and the recommended repair measures.

Proposed model

In the model this step is to answer the main investigation question. It states the damage cause and the expected effects and/or consequences.

The conclusion in the model is limited to the damage cause. In practice the repair measures are often included in the investigation and are reported in the conclusion.

Reporting

Cases

There are two types of reports a report and a memo. The difference is the extent and length of the report. A memo is a short and brief version of a report. There is no specific format for reporting. However, all reports of the cases followed the same structure although written by different investigators.

The following reporting structure has been used:

1. Front page: this gives the case number, title and date.
2. Intro: describes the investigation goal, the client his/her question, site -visit date, persons present and sometimes the investigation process.
3. Documents: a list of available documentation and norms that are used.
4. Description of the structure: a description of the construction of relevant parts is given.
5. Observations: description and relevant photo material collected during the site-visit.
6. Damage analysis: a description of possible damage causes and an argumentation why it is (in)possible.
7. Repair measures (optional)
8. Conclusion: a summary of the damage cause and the possible repair measures. This part is concluded with date, name and signature of the investigator.
9. Appendix with relevant additional material like calculations, drawings, photographs etc.

In specific cases there are additional chapters, for example the results of laboratory tests.

Proposed model

The model recommends the following reporting order:

1. Introduction
   - Problem description
   - Investigation question and scope
   - Investigation process
2. Data
   - Description of structure
   - Context description
   - Damage description
   - Test results
3. Hypothesis
4. Analysis
5. Conclusion
6. Appendixes

The proposed reporting structure of the model follows roughly the same structure as used in the case reports. The main differences are:

- In the proposed model the investigation scope and the investigation process is made explicit in the report besides the investigation question.
- In some of the case reports the involved parties and their role as been listed.
- The listing of all available documents and their date and origin in the case reports. Also missing documents are listed.
- The proposed model recommends listing all the considered hypothesis separately from the actual analysis. In the case reports this distinction is not so clear.
- The date of the site visit and the people present are reported in the case reports.

Follow-up

Cases

This is not a step that occurs in the case documentation. It is possible that this is verbally discussed within a company.

Proposed model

The idea of the follow-up in the model is to quickly evaluate as an investigator what you learned from this investigation and what whent well and what can be improved next time. This can be shared with colleagues when patterns over more investigations are discovered.

Appendix J - Case study parking

This appendix contains the results of the test damage case. From the reported information of a historic damage investigation performed by Adviesbureau ir. J.G. Hageman a new 'test' investigation is performed following the procedure of the developed investigation process model. The goal is to test the proposed model and especially the recommended techniques for practical value and effectiveness. From the original cases the collected photographic material and drawings will be used as input for the investigation. Performing the test case with the process model will give an insight in the workability and effectiveness of the proposed techniques. [1]

Method

The investigation will follow each step of the proposed investigation model. The activities and notes of each step will be included in this report for research purposes. This in contrast with using the model in practice, where not every thought will be documented. When techniques have some difficulties in the execution this will be noted in a text box in the margin.

Results

Client input

The question of the client is: can you give an opinion on the condition of several damages inside their parking garage? With the assignment several pictures of damages have been provided.

Orientation

Suitablility: there is no conflict of interest as there is no personal connection with the client or other projects. There are enough resources (time and knowledge) to finish the project.

Research design:

- Investigation question is: what is the cause of the damages and do they have impact on the structural safety, if so what are possible measures to take?
- Scope of the investigation is limited to the damages in the parking garage. The building above the garage is only relevant where it influences the damage inside the parking.
- Goal: to give a professional opinion on the structural safety of the parking garage and the damages occurred.

Project planning: the investigation will be performed by one investigator and the expected work load is four working days. The investigation process is as follow: first the already collected data material form the client will be studied to get an impression of the building and the damages. Then a site visit will

1 The investigation is based on the documentation available in the original investigation dossier. For privacy reasons drawings and photographs used are not included in this report and some sketches are generalized where possible. In the proposed model a site-visit is required, but in this case not possible. The analysis is therefore solely based on collected and recorded material of the original site visit. This means that information can be missing and the results are not usable in reality.

take place, where additional data will be collected. [2] The next step is to process the collected data and to make hypothesis using all the proposed techniques. When the hypothesis are formed they will be analysed by using again all the proposed techniques. Depending on the result some steps will be repeated or a conclusion will be given. All the steps will be documented in a report that is written after the investigation.

Data collection

The following documents are collected (existing building from the 80's):

- Plan drawing of the building on ground level and on level of parking deck.
- Details of the entrances of the parking.
- Maintenance information (not available).
- Cross-sectional drawings of the parking.
- Photo material of the damages by the client.
- Previous damage reports (non-existing).

Analysis of the drawing shows that the parking is part of a residential building complex with several connected building blocks. The parking is the connecting structure below ground level and runs below parts of above ground level buildings. The building is from the 80's and the parking is constructed out of reinforced concrete floors, walls and columns. The floor at ground-floor level (so the roof of the parking) is an in-situ concrete floor. This floor is supported by the concrete outer-walls and concrete in-situ columns. Over the length of one of the column rows the floor is additionally supported by a reinforced concrete beam.

Photographic material by the client: the client has sent eight photographs with different damages. The photographs show several different types of damages depending ranging from discolouring to cracking, deformation and spalling. For an overview of the damages see table 1.

Based on these photographs and the drawings the site visit has been prepared. The following provisions are taken:

- A photo-camera with enough storage capacity and flash-light (dark space) is taken to location.
- A sketch of the plan of the parking with the grid-numbering is made to locate the damages and pictures taken.
- The template damage recording is taken to location.
- Writing material, a note book and coloured sticking paper is taken.
- Measure tape, a hammer and a crack-width measure paper is taken.

During this investigation no laboratory testing will be needed considering the damages.

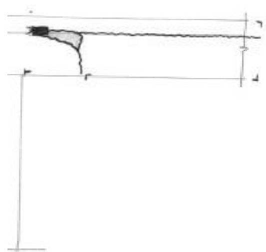
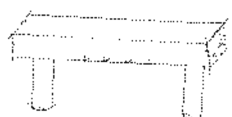
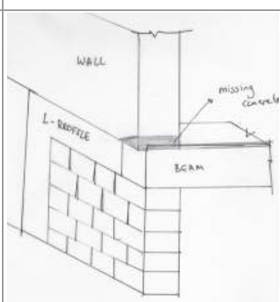
For the data processing step the model describes the sequence of events technique of using a time line where data and damage development can be plotted. This technique is not possible to use with this type of damages. There is no time factor known nor is it important. So making a time line has no added value. However it is possible to store the data and material collected

2 For practical reasons no site visit has been perfomed during this case study.

> The event time-line doesn't have a function for this type of damages. The factor time is not relevant to the damage .

during the site visit in an organised way. This will help the investigation as the different damages seem to have different, separated causes. The system used in this case is to number all the damages and store all photographs/ data of the same damage together. It is possible to do this in one folder as the damages are so distinct their photographs are hard to get mixed up or mistaken for the wrong damage. The locations of the damage can be recorded on a plan drawing and coded with the correct number (see figure 2, 3, 4).

Table 1: Overview of the damages presented by the client and discovered during the site visit

Nr.	Damage photographs	Damage description
1.		A damage consisting out of two crack directions and a spalling of concrete located at the bottom side of an overhead beam (lintel) The beam is located at the cross-section of grid-line 1,2 and G (see figure 2) . One crack runs parallel to the span of the beam. The crack starts at the crossing of the beam with the wall, where first a large peace of concrete is missing. The crack continues after the end of the spall and runs to the other wall. The other crack runs perpendicular to the span of the beam. At the spall it is visible that the crack is located at the dilatation between the parking garage and the connecting building starting from the ground floor. Inside the dilatation white Styrofoam is visible. At the spall some of the foam is removed. Some reinforcement is visible. The exposed reinforcement is not visibly corroded. At the vertical joint of the tiles on the wall at the location of the damage a small crack is visible in the vertical joint line.
2.		At several locations in the parking there are small cracks at the corner of the bottom and side of the beams connecting the columns and supporting the floor at ground-floor level. The cracks are perpendicular to the span of the beams and are maximum 0.1 cm wide. The beams show traces of white discolouration at the sides. The discolouration runs from the top of the beam in stripes and flame pattern to about halfway.
3.		Several discolourations visible on photographs send by <<name client>>. The locations are unknown. One damage with white discolouration around a pinkish coloured patch. Through the pink patch runs a small (< 0.1 cm) crack. One photograph by the client shows a concrete surface with white and darker grey patches.
4.		A deformation of the ceiling located in the middle between grid-line 10&11 and the columns on each side (see figure 4). The ceiling is of concrete and has a panel pattern. The panels are not actual panels with seams but the relief is only a print. At the location of the difference in height there is a jump in the ceiling with a curve. The ceiling is coloured dark grey and the side view is light grey coloured.
5.		At the location of the entrance of the parking a part of a concrete wall at a connection with a beam has crumbled away. The wall is also slightly out of line with the beam below so there is some cantilevering visible.
6.		During inspection some honeycombs have been observed at the top of some of the columns. There have been taken repair measures in the past.

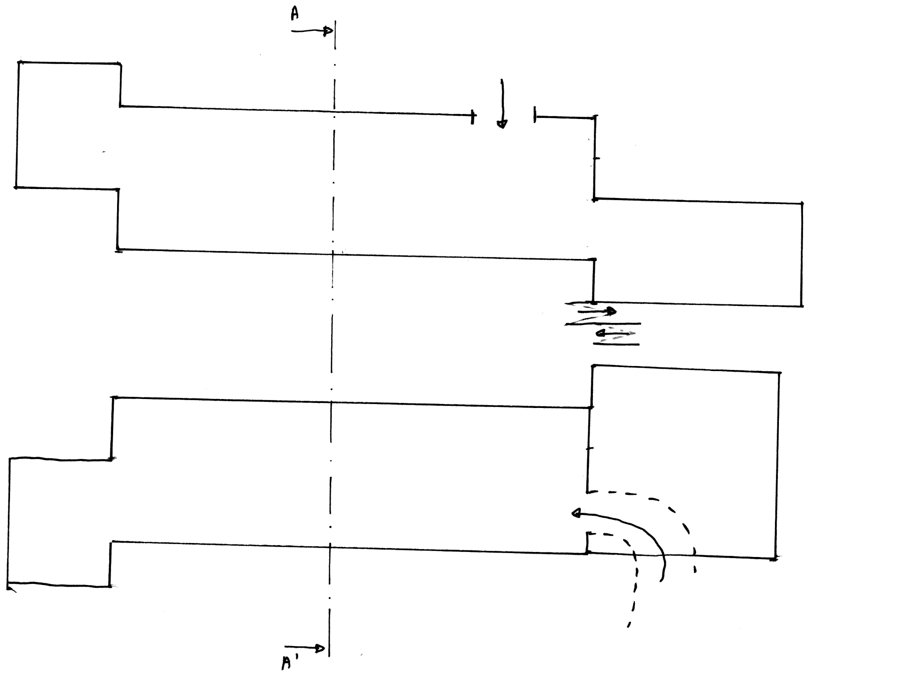


Figure 1: Plan building complex

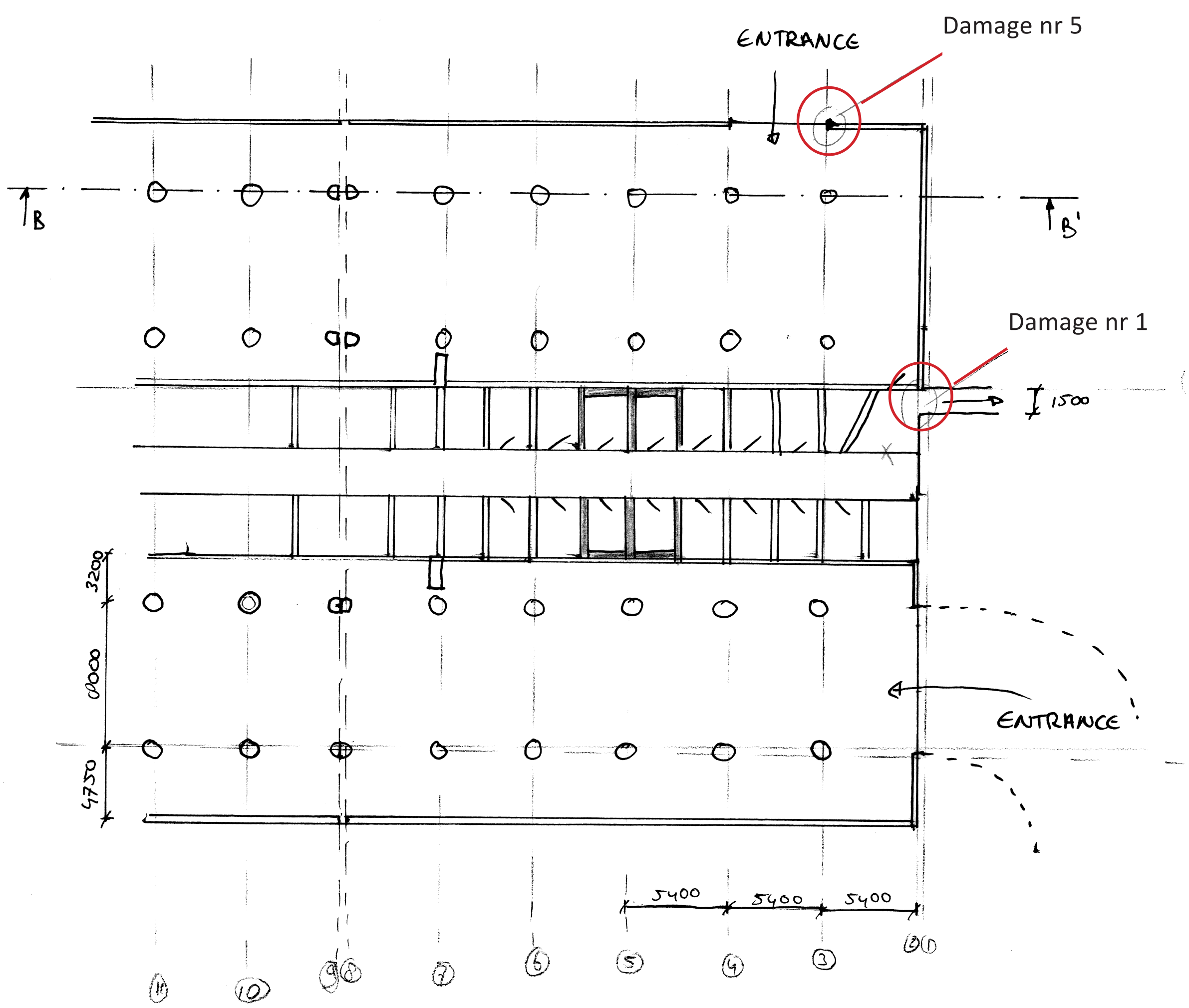


Figure 2: Plan parking with damage locations annotated

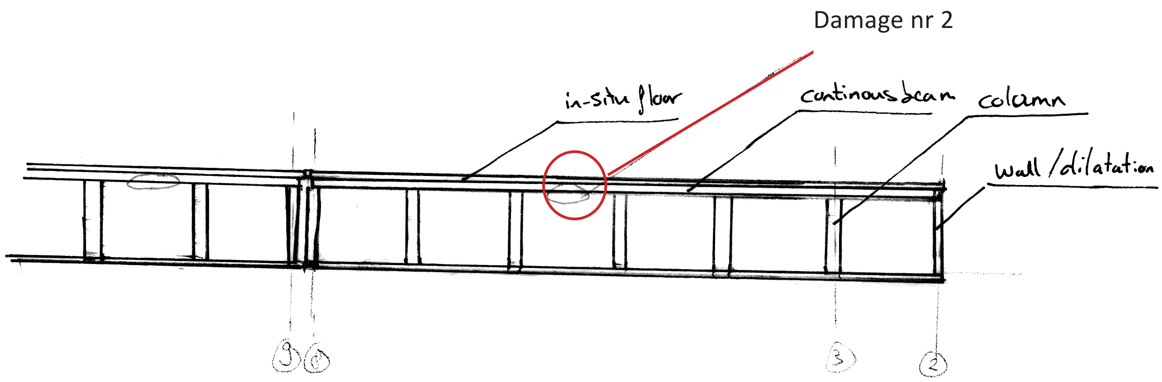


Figure 3: Cross - section BB′

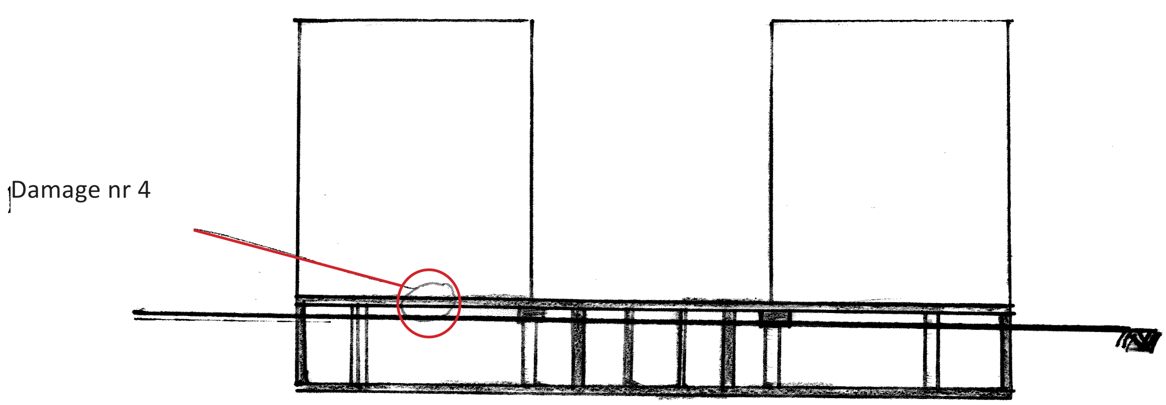


Figure 4: Cross - section AA′ at location of dilatation 10

Hypotheses generation

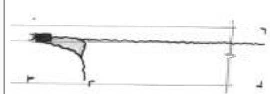
As the damages don't seem to be connected, hypotheses are developed for each one. For the purpose of validation of the proposed model the damage hypothesis are generated using all the proposed techniques (see table 1). In reality you select one appropriate technique based on the conditions of the damage and the limitations of the thechnique.

Table 1: Overview damages and techniques used

TECHNIQUE	DAMAGE NUMBER
Brainstorm	1, 5
Cause and effect diagram	1, 4
Multiple hypothesis generator	3
Common failure mechanisms protocol	2, 3, 4

Damage 1

Cracking and a small spall at the bottom side of a beam located at the foot and bicycle entrance of the parking.

1.		A damage consisting out of two crack directions and a spalling of concrete located at the bottom side of an overhead beam (lintel) The beam is located at the cross-section of grid-line 1,2 and G (see figure 2) . One crack runs parallel to the span of the beam. The crack starts at the crossing of the beam with the wall, where first a large peace of concrete is missing. The crack continues after the end of the spall and runs to the other wall. The other crack runs perpendicular to the span of the beam. At the spall it is visible that the crack is located at the dilatation between the parking garage and the connecting building starting from the ground floor. Inside the dilatation white Styrofoam is visible. At the spall some of the foam is removed. Some reinforcement is visible. The exposed reinforcement is not visibly corroded. At the vertical joint of the tiles on the wall at the location of the damage a small crack is visible in the vertical joint line.

This technique gives some challenges when performing it on your own. It is harder to thick in different and original directions due to the lack of feedback.

Using the **brainstorm** technique hypothesis are generated. This technique is functional for this damage because the damage cause is not obvious and the damage can consist of different damages.

The first step is the exploration phase: the question is how can a crack develop at this location. The crack is located at the bottom side of a dilatation between the parking and the connected building starting on the ground floor and runs along the whole dilatation. At one side of the crack near the wall is a spall and a crack running perpendicular to the dilatation. The spall is deeper than only the concrete top-layer as aggregates and reinforcement is exposed.

Creative phase: The following idea's are the result of a one person brainstorm:

1. Uneven movement between the two buildings while the dilatation between the two was locally not sufficient. The two elements have interacted and the developed forces caused cracking and crushing of concrete.
2. Natural movement between buildings resulting in tension forces within the mortal fill of the dilatation that couldn't be resisted by the used

mortar. This results in cracking.
3. Corrosion of the reinforcement resulting in cracking and spalling.
4. Frost damage.
5. Uneven settlements of the buildings.
6. Prevented horizontal movement of the beam by the floor-beam connected perpendicular. Local high forces will be introduced to the weaker axis of the beam. This can cause the perpendicular cracking.
7. Dilatation is not a real dilatation because locally the two parts are connected. This can cause cracking due to prevented movement due to temperature changes.

Evaluation phase:
1. The damage is too limited and to local to make this idea possible. If this was an possible explanation there should have been very clear visual damage on other locations along the dilatation, for example the floor. So this explanation is not likely.
2. Possible. Doesn't explain the perpendicular cracking.
3. Not likely because on photographs some reinforcement is visible and this reinforcement is not corroded.
4. Not possible as the location is not exposed to outside. There is also no contact with de-icing salts.
5. Possible but not likely to cause such local damage. So if the case other damages expected along the same foundation line.
6. Possibility.
7. Possibility.

So the possible hypotheses are:
1. The damage is caused by the an ability of the dilatation filling mortar to accommodate the tensile forces introduced by the natural movement of the two building parts.
2. The damage is caused by the prevention of horizontal movement due to the stiffness of the perpendicular connected floor beam.
3. The damage is caused by a dilatation that is not constructed as one and this can cause cracking by prevented expansion due to temperature differences.

To be able to analyse some of the hypotheses additional drawings of the building are needed. Specific drawings of the connection between the parking and the connected building and drawings of the foundation.

Damage 2

This method is complex to execute when there is a combination of two damage types.

Because the damage cause is not directly obvious using the **cause and effect diagram** method (see figure 5) can be functional. The resulting hypotheses are:
1. Damage caused by prevented movement of elements.
2. Damage caused by uneven settlements of the two building parts.
3. Damage caused by thermal shrinkage and expansion of the concrete elements.

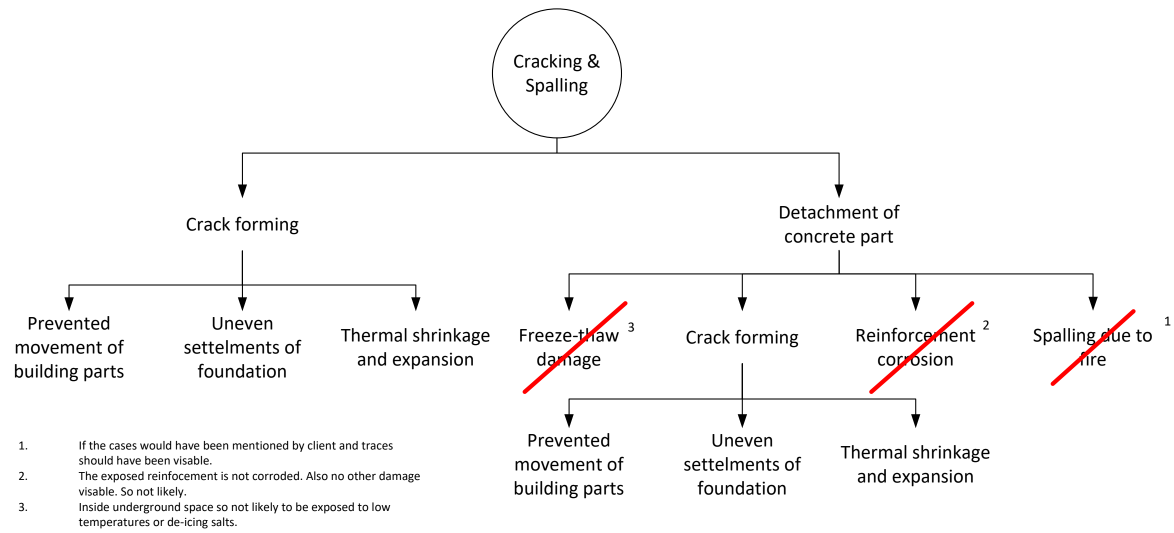


Figure 5: Cause and effect diagram for damage nr. 1.

Damage 3

Cracking on the bottom side of several beams that support the ground floor. As this type of damage can have several possible causes but is limited to one damage type (crack) the **common failure mechanisms** protocol is a useful tool to generate hypotheses. This results in the following possibilities:

1. Bending cracking caused by overloading.
2. Bending cracking caused by underestimation of the reinforcement.
3. Cracking due to drying shrinkage.

Discolouring and deposits on several locations. Using the **common failure mechanisms** protocol you get the following hypotheses:

1. The white deposits and discolouring have been caused by lime leaching due to moisture transport.
2. The white discolouring is caused by leakage of rainwater along the structural elements causing lime weeping leaving a white deposit behind.

> This method is not so difficult or time consuming to execute but is time consuming to report on. It would be a better idea to not report on every possible combination but make the combinations mentally and only report the most relevant ones.

This damage is also possible to analyse using the **multiple hypothesis generation** system because the damage cause can be regarded as obvious. To avoid tunnel vision you want to make sure you regarded all possibilities. This is what the multiple hypothesis generating system facilitates. The following process is followed: the hypothesis that is obvious is that the white colour is caused by leakage resulting in lime leaching. To broaden the view and avoid tunnel vision this hypothesis is taken as a base to develop other hypothesis.

Basis hypothesis: The white deposits are caused by moisture transport through the concrete by drying of the concrete causing lime deposits on the surface.

How: Drying of the concrete
What: lime deposits
Why: moisture transport.

Alternatives are:
How: wetting and drying by rain, groundwater penetration, wetting and drying by wetting the concrete manually (car wash)
What: paint
Why: water put on the concrete surface.

The following hypotheses are possible:
1. The white deposits are caused by moisture transport through the concrete by wetting and drying by rain of the concrete causing lime deposits on the surface.
2. The white deposits are caused by moisture transport through the concrete by wetting and drying by wetting the concrete manually causing lime deposits on the surface.
3. The white deposits are caused by moisture transport through the concrete by groundwater penetration causing lime deposits on the surface.
4. The white deposits are caused by moisture transport through the concrete by drying of the concrete causing paint on the concrete surface.
5. Etc.

Number 5 makes no sense. However the idea of paint is not that non-logical without connecting moisture transport to it.

The hypotheses that are interesting to analyse are:
- The white deposits are caused by moisture transport through the concrete by drying of the concrete causing lime deposits on the surface.
- The white deposits are caused by moisture transport through the concrete by wetting and drying by rain of the concrete causing lime deposits on the surface.
- The white deposits are caused by moisture transport through the concrete by groundwater penetration causing lime deposits on the surface.

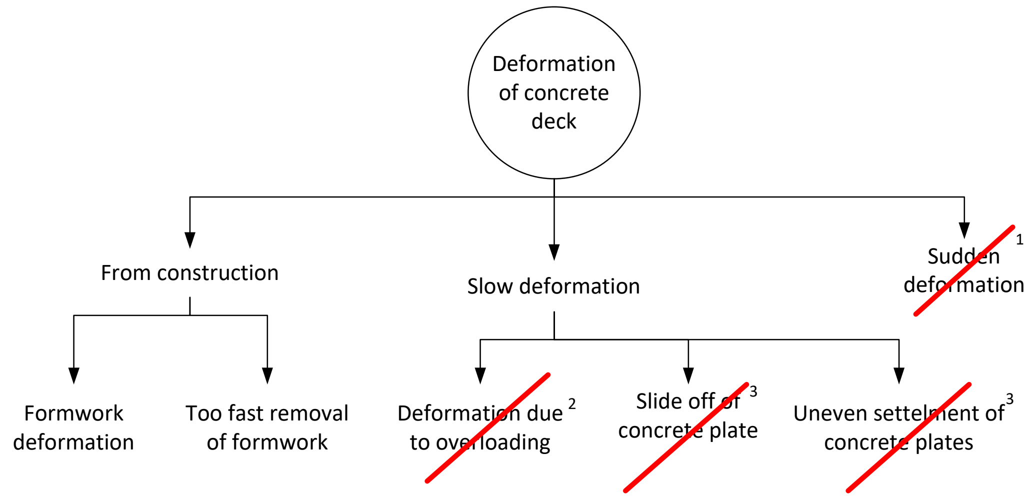
Damage 4

The deformation of the bottom of the ground-floor/ roof of the parking is analysed using the **cause and effect diagram**. The cause of this damage is not directly clear and therefore this method will help explore different directions (see figure 6).

The resulting hypotheses are:
1. The deformation of the concrete plate is caused by deformation of one form work plate during construction.
2. The deformation of the concrete plate is caused by too fast removal of the form work which caused the fresh concrete to deform.

Damage 5

The damage located at the entrance of the parking with the crumbled/ missing concrete is analysed using the **brainstorm** method, because this damage cause is not very obvious. The first step is the exploration phase. The structure consists out of a turned L profile a concrete beam with on top



1. If the cases would have been mentioned by client and damage would be more extensive.
2. The damage would also be visible on the adjacent concrete panels.
3. There was no crack at the location of the deformation so no indication the panels are not longer connected by concrete.

Figure 6: Cause and effect diagram for damage nr. 4.

an concrete wall. At the location of the connection between the concrete wall and the L profile concrete is missing from the corners of the wall. The wall is slightly eccentric to the L profile. This results in an dislocation of about 2 cm. At the location of the missing concrete the reinforcement is exposed and white Poly foam is visible.

The next step is the creative phase. The following hypotheses are suggested:

1. The edges of the concrete wall have been crushed by horizontal movement of the beam.
2. The concrete edge has been manually removed during construction due to placing problems.
3. The wall has had horizontal movement due to extreme loading and has spalled the edges (without reinforcement) off.
4. Settlement of the L-profile and wall. At the location of the beam the compression force of the concrete was exceeded.

The next step is the evaluation phase.

1. This is possible but to cause this amount of damage the movement should have been extensive and this is not corresponding with the surroundings.
2. Possible option.
3. Possible but also damage expected to the L-profile due to friction.
4. Not likely as the wall and beam are supported on the same location.

So the hypothesis for this damage is: the damage cause is the manual removal of the concrete edge of the wall due to placing problems during construction.

Hypotheses analysis

Both the evidence - hypothesis table and the event-causal factor diagram are useful and rather easy to execute. It seems there is some overlap with the cause- event diagram from the hypothesis generating phase.

The next step in the investigation is to perform an hypotheses analysis for each damage. In the proposed model there are several techniques suggested. For validation two of the techniques will be used to perform the analysis (see table 3). The mathematical analysis and laboratory testing are not relevant in these cases. In practice you choose a technique that fits your goal and data. For the result of the analysis see the reporting added at the end of this appendix.

Table 3 Hypotheses analysis techniques

TECHNIQUE	DAMAGE NUMBER
Evidence-hypothesis table	1, 2, 4
Event and causal factors analysis	3 ,5
Mathematical analysis	-
Laboratory testing	-

Conclusion

In this part of the investigation the main results of the investigation are summarised. For the result see the report.

Reporting

For the report see the next pages. In the report there are some <<....>> this is to indicate information that should normally be included but is removed for privacy reasons.

Follow-up

For the next investigation I would not skip the site-vist and it is advised to do the site-vist by yourself as it is difficult to reconstruct the situation and the location, severity and scale of the damage form photographs without knowledge of your own observations. The cause and effect diagram is a nice tool to use to structure your thought process with relatively little reporting, although getting all information on paper. However it doesn't functions as nicely when there are multiple types of damages that are connected on one location. The tree like structure doesn't account for multiple starting points.

Report

damages parking garage

An investigation into damage causes and analysis of the structural safety

Date: August 2018

Introduction

This report is commissioned by <<name client & Company>> with the purpose of reviewing the safety of the structure of the parking garage in << location>> and determining the cause of the multiple damages. The investigation consisted out of the following steps: document collection, a site- visit (<<Date and members present>>), hypotheses generation and analysis and a conclusion.

Data

This chapter will give a description of the structure, the observed damages and the information collected during the site visit.

Description of construction

The one-story parking is situated below two parallel residential buildings. The parking connects these two buildings below ground level and has two separate entrances on either side of the two buildings (see drawing 1 and 2). The floor plan consists of two separated (only connected by a walking corridor) parking spaces with separate entrances. The middle of the parking has a walking corridor with storage compartments for the residences. They are accessible from the parking spaces and from the outside by stairs at the end of the corridor. The parking has a concrete floor, first floor, columns, beams and walls. The parking is founded on a pole-foundation. The structure is dilatation every 32 meters in length direction. Above the corridor with the storage spaces the street is slightly elevated above ground level along the length of the parking. This street is a traffic free zone, so only accessible by foot or bicycle.

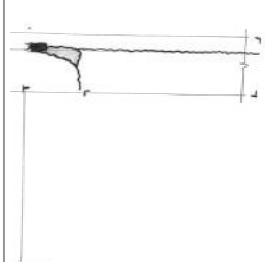
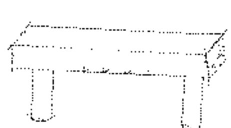
Site visit general

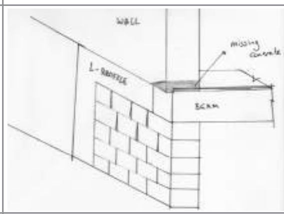
Normally here would be a short description of the site visit, the impressions, information received etc. >>

Damage description

With the assignment << name client>> has send eight photographs of different damages inside the parking garage. During the site-visit additional damages have been discovered. They are described in Table 4. The location of the damages is visible in the drawings of Figure 8, 9&10.

Table 4: Damage overview

Nr.	Damage photographs	Damage description
1.		A damage consisting out of two crack directions and a spalling of concrete located at the bottom side of an overhead beam (lintel) The beam is located at the cross-section of grid-line 1,2 and G (see figure 8) . One crack runs parallel to the span of the beam. The crack starts at the crossing of the beam with the wall, where first a large piece of concrete is missing. The crack continues after the end of the spall and runs to the other wall. The other crack runs perpendicular to the span of the beam. At the spall it is visible that the crack is located at the dilatation between the parking garage and the connecting building starting from the ground floor. Inside the dilatation white Styrofoam is visible. At the spall some of the foam is removed. Some reinforcement is visible. The exposed reinforcement is not visibly corroded. At the vertical joint of the tiles on the wall at the location of the damage a small crack is visible in the vertical joint line.
2.		At several locations in the parking there are small cracks at the corner of the bottom and side of the beams connecting the columns and supporting the floor at ground-floor level. The cracks are perpendicular to the span of the beams and are maximum 0.1 cm wide. The beams show traces of white discolouration at the sides. The discolouration runs from the top of the beam in stripes and flame pattern to about halfway.

Nr.	Damage photographs	Damage description
3.		Several discolourations visible on photographs sent by <<name client>>. The locations are unknown. One damage with white discolouration around a pinkish coloured patch. Through the pink patch runs a small (< 0.1 cm) crack. One photograph by the client shows a concrete surface with white and darker grey patches.
4.		A deformation of the ceiling located in the middle between grid-line 10&11 and the columns on each side (see figure 9). The ceiling is of concrete and has a panel pattern. The panels are not actual panels with seams but the relief is only a print. At the location of the difference in height there is a jump in the ceiling with a curve. The ceiling is coloured dark grey and the side view is light grey coloured.
5.		At the location of the entrance of the parking a part of a concrete wall at a connection with a beam has crumbled away. The wall is also slightly out of line with the beam below so there is some cantilevering visible.
6.		During inspection some honeycombs have been observed at the top of some of the columns. There have been taken repair measures in the past.

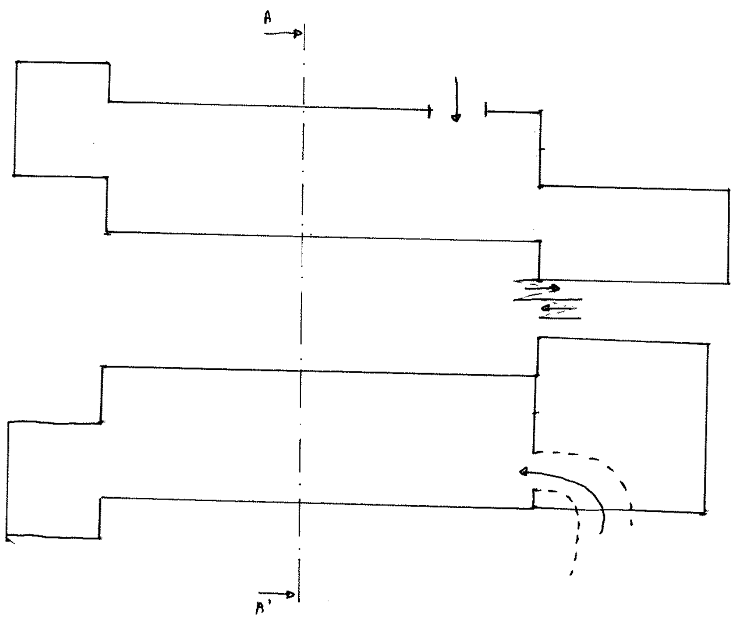


Figure 7: Plan building complex

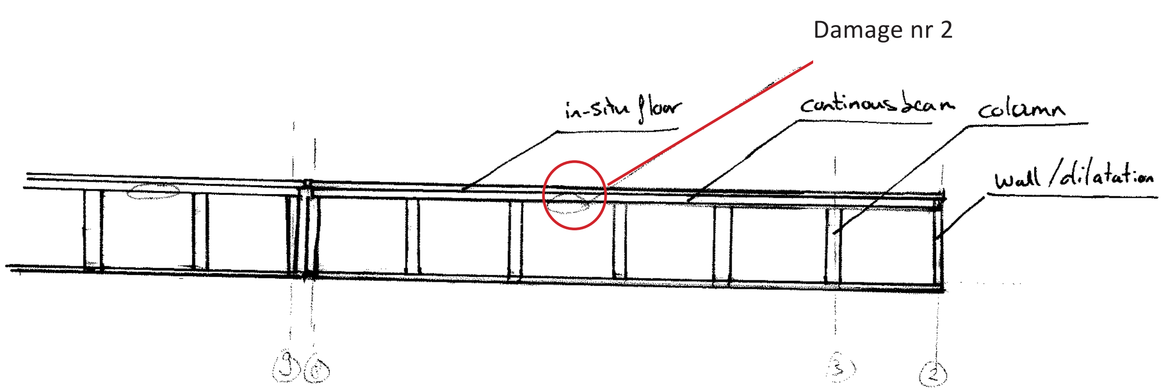


Figure 8: Cross - section BB'

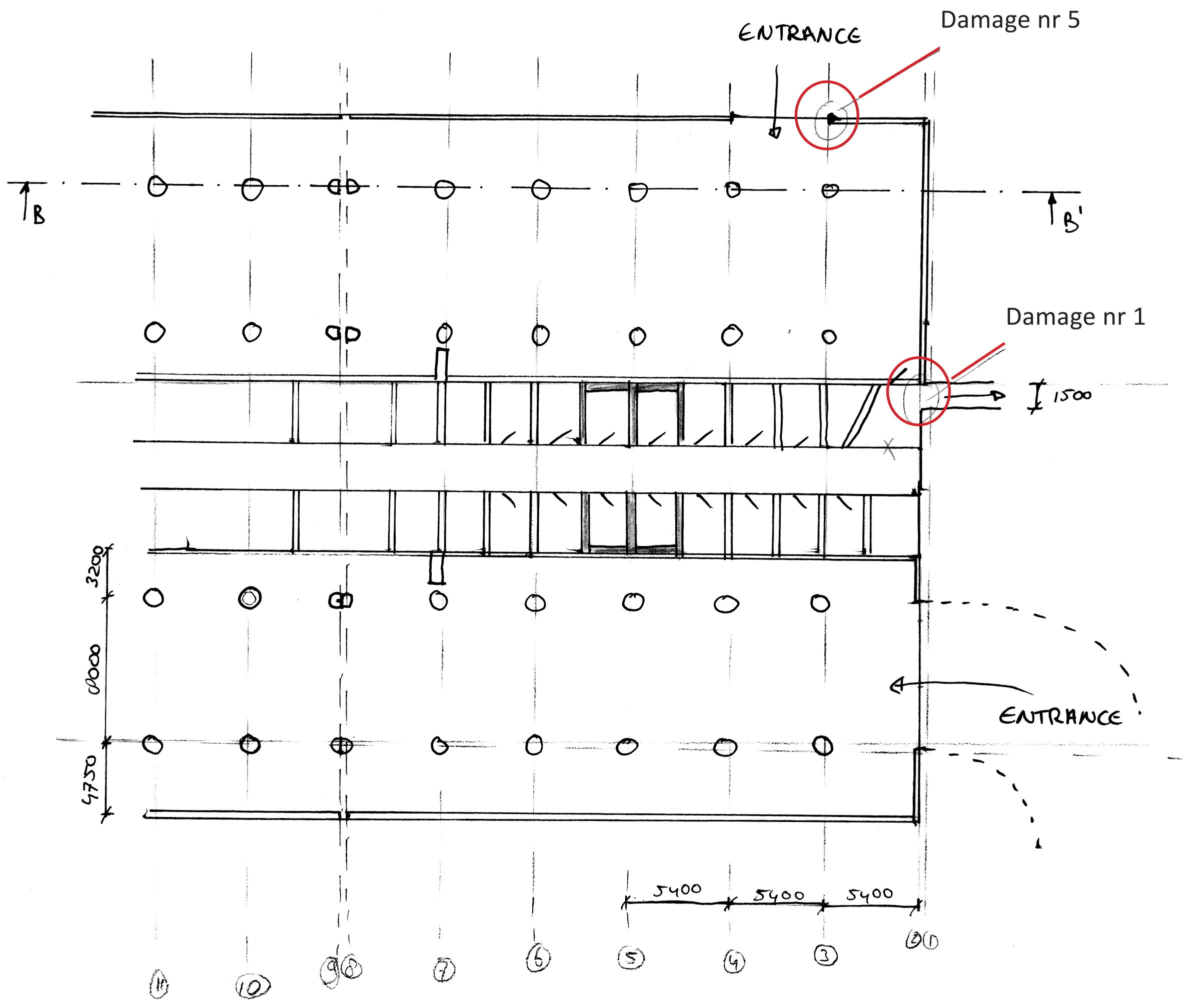


Figure 9: Plan parking with damage locations annotated

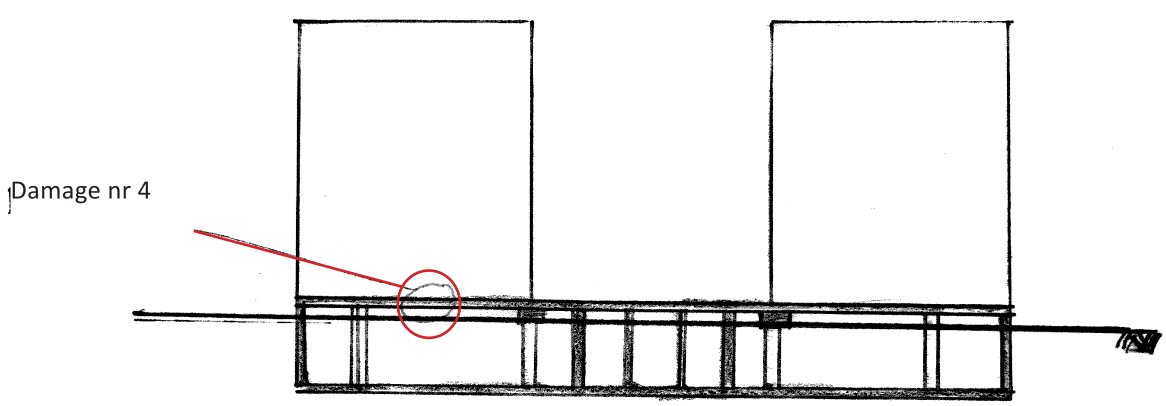


Figure 10: Cross - section AA' at location of dilatation 10

Hypotheses

For each of the damages, hypotheses are made using one of the following techniques (for considerations see appendix):

- Brainstorming
- Cause and effect diagram
- General hypothesis generating tool
- Common failure mechanisms tool

Nr.	Hypothesis
1.	a. The damage is caused by the inability of the dilatation filling mortar to accommodate the tensile forces introduced by the natural movement of the two building parts. b. The damage is caused by the prevention of horizontal movement of the beam due to the stiffness of the perpendicular connected ground-floor beam. c. The damage is caused by a dilatation that is not constructed as one preventing temperature related expansion and shrinkage. d. The damage is caused by uneven settlement of the building parts and the location where the two parts are lightly connected by filling mortar the mortar couldn't take the deformation.
2.	a. Bending cracking caused by overloading. b. Bending cracking caused by underestimation of the reinforcement. c. Cracking due to drying shrinkage. d. Normal concrete cracking.
3.	a. The white deposits and discolouring have been caused by lime leaching due to moisture transport. b. The white discolouring is caused by leakage of rainwater along the structural elements causing lime weeping leaving a white deposit behind.
4.	a. The deformation of the concrete plate is caused by deformation of one form work plate during construction. b. The deformation of the concrete plate is caused by too fast removal of the form work which caused the fresh concrete to deform.
5.	a. The damage cause is the manual removal of the concrete edge of the wall due to placing problems during construction.

Analysis

In this part of the report all hypotheses for each damage are investigated by proving them and when successful trying to falsify them. If the first is successful and the last unsuccessful the damage cause of the hypothesis is proven.

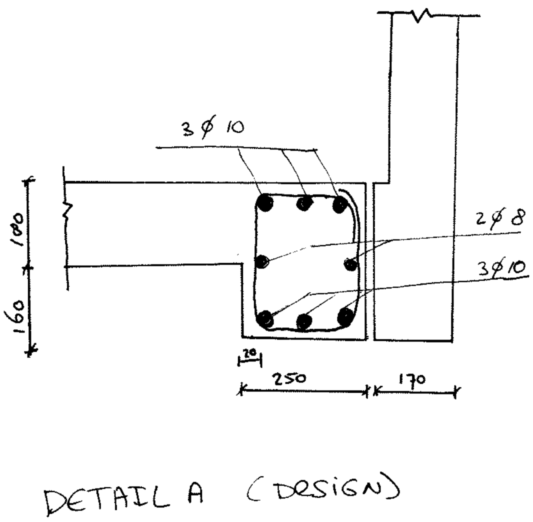
Damage nr 1.

There have been considered three relevant hypotheses for this damage. They are analysed using an evidence hypothesis table. The result is visible in table 5. X means supporting evidence and O means the data falsificates a hypothesis.

Table 5: Evidence hypothesis table for damage 1

DATA	a	b	c	d
Thin cracking along the dilation.	X			X
Thin crack perpendicular to the dilatation at level of the end of the perpendicular connecting beam.		X		
Floors of two building parts connected by starter bars	O		X	
Wall connected to damaged beams is connected by starter beams according to the work drawing, compromising the dilatation (see figure 11)	O		X	
Spalling of concrete part.				

DATA	a	b	c	d
No corrosion of reinforcement visible.				
Small part reinforcement exposed.				
No evidence of leakage.				
Parking is underground. Connected building part is exposed to outside weather.			X	
No cracking or other damage on floor at location				O
Small crack running along a joint of the tile-work of the wall at the location of the crack in the above beams.	O		X	X



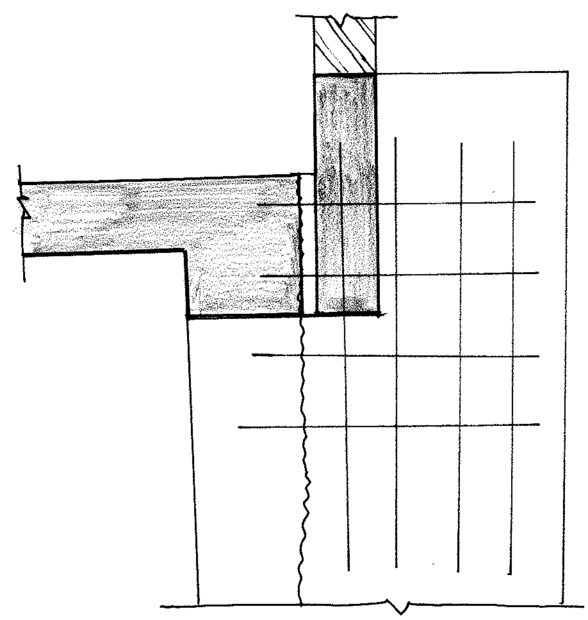


Figure 11: Connection between the damaged beams, Dilatation designed (L) Workdrawings (R)

There are two hypotheses left. The most likely explanation is that the damage is caused by a combination of the two. So the dilatation as designed is not consequently executed. In later working drawings it is visible that the detailing in the zone of the building is altered and the original dilatation is compromised by connecting the beam and wall with starter beams (see Figure 11). This means that the two building parts are not fully uncoupled. As the parking is underground and not exposed to the outside the temperature differences are likely to be small. So no or little thermal expansion or shrinkage. However the adjacent and 'coupled' building is exposed to outside temperature changes and therefore the building will expand (heating) and shrink (cooling) over time. In combination with the prevented deformation by the parking this can causes cracking visible in the connection.

The perpendicular crack can be explained by the prevented horizontal movement of the beam connected to the parking. The movement of the beam is prevented by a perpendicular connected ground-floor beam. As this beam is stiffer than the floor plates that are perpendicular to the other part of the damaged beam, cracking can be occurring (see figure 11).

Damage 2.
The cracking is only appearing at the bottom of the beams. The width of the cracks is max 0.1mm and the cracks are vertical orientated. As bending cracking is located near midspan and has an angle of around 45 degrees, hypotheses a and b are false. If the cracking is just normal concrete

cracking or caused by drying shrinkage is not possible to prove. Both are possible. However, due to the very small crack width, there is no problem with structural safety or durability.

Damage 3.
The white deposits and discolouring on some concrete elements in the parking can possible be caused by two mechanisms. Both hypotheses are tested by the use of an event and causal factor diagram.

Hypothesis a: The white deposits and discolouring have been caused by lime bloom due to moisture transport. For the analysis see Figure 14.
Hypothesis b: The white discolouring is caused by leakage of rainwater along or through the structural elements causing lime weeping leaving a white deposit behind. For the analysis see figure 13.

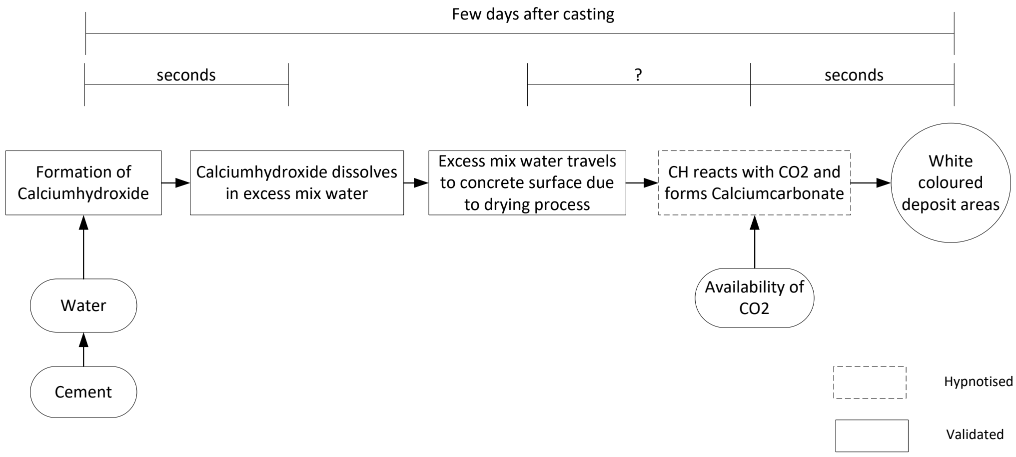


Figure 12: the event and causal factor analysis of damage 3 hypothesis a

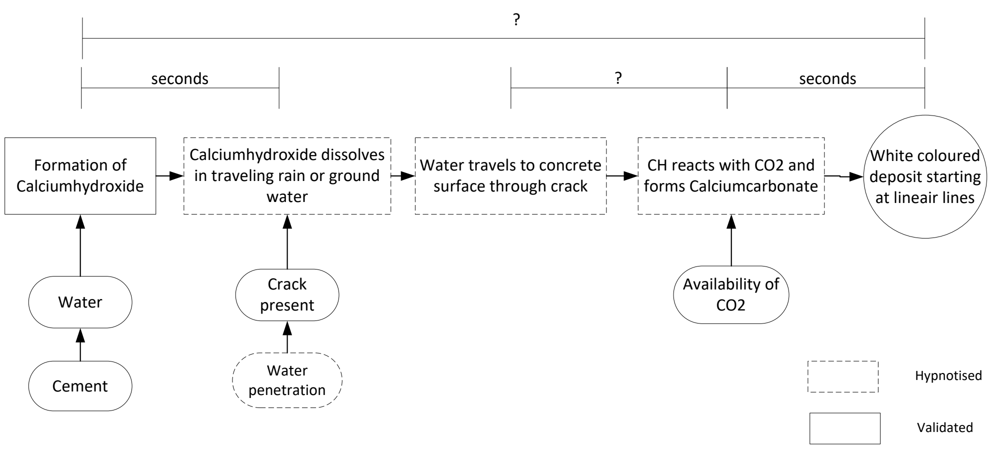


Figure 13: the event and causal factor analysis of damage 3 hypothesis b

The conclusion is that the white deposits are caused by lime bloom, due to moisture transport by the drying of the concrete. The white patches don't show cracking above or under so water transport by leakage is not likely. As the parking is not likely to experience wet and dry cycles it is likely that the white patches will not expand over time.

Damage 4.
There have been considered two relevant hypotheses for this damage. They are analysed using an evidence hypothesis table. The result is visible in table 6. X means supporting evidence and O means the data falsificates a hypothesis.

Table 6: Evidence hypothesis table for damage 4

DATA	a	b
Deformation has a curved shape.	X	X
No vertical dilatation or joint.	X	X
No crack between the deformed panel and the other panels.	X	X
Much lighter colour of the concrete at the side-view / jump plane.		
No cracking on the bottom of concrete panels visible.	X	O
Only one deformed concrete panel	X	X
Cast in-situ concrete floor.	X	X

The most likely cause of the deformation is deformation of the form work during construction. This caused the jump in the roof. The deformation is definitely not structural as the joint between the two panels and no cracking. This means that the roof/floor is still a monolith concrete floor but locally just a bit thicker.

Damage 5.
The hypothesis that the damage is caused by manual removal of the concrete during construction of the entrance of the building is analysed using the event and causal factor analysis (see figure 14). The problem with this analysis is that there is not enough data available to prove the hypothesis. The only option to prove this is to contact the workman that did the construction With the current information and the visual appearance this is not a structural safety problem. For durability reasons it would be advised to inject the missing concrete to cover the exposed reinforcement to avoid corrosion in the future

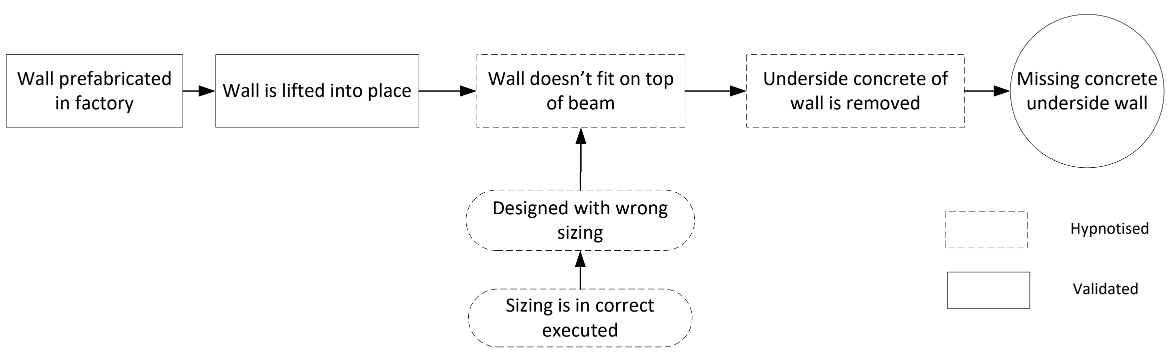


Figure 14: the event and causal factor analysis of damage 5

Conclusion
<<client>> asked to investigate and give an opinion on the various damages in the parking in <<location>>. The investigation goal was to determine the courses of the damages and their impact on the structural safety of the building. Based on documentations received from <<name>> and the information gathered during the inspection of the building on location five relevant damages have been reported. The damages can be regarded as separate cases. For each of the damages hypothesis have been developed and analysed. This resulted in the following conclusions:

- Damage 1: The damage is caused by a combination of prevented movement due to the connected ground-floor beam and an intended dilatation that was not constructed as one. Due to the prevented expansion and shrinkage by temperature changes of the building adjacent to the parking stresses can develop that caused the cracking. As some reinforcement is exposed it is recommended to repair the damage by covering the reinforcement for durability reasons.
- Damage 2: The cracking on the beams is caused by drying shrinkage and as the crack width is very limed (max 0.1mm) compared to the allowed crack width of 0.3 mm there is no action needed.
- Damage 3: The grey and white deposits are caused by lime leaching due to moisture transport from within the concrete to the surface. There is no consequence for the structural safety.
- Damage 4: The deformation is caused by a deformation of the form work during construction and has no structural complications.
- Damage 5: The damage to the concrete wall seem s to be man made. However with the current available data this can't be said with certainty. Recommended is to repair the missing concrete to create a cover for the exposed reinforcement to prevent future corrosion.

Margriet Verbiest August 2018