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Stop Criteria for Proof Load Testing of Reinforced Concrete Structures

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Abstract

Existing bridges with large uncertainties can be assessed with proof load tests. In such tests, a load representative of the factored live load is applied to the structure. If the bridge can carry the load without any signs of distress or nonlinearity, the test is considered successful. Since large loads are applied in proof load tests, the monitored structural responses are used to define stop criteria. This paper presents stop criteria for shear and flexural failure based on existing codes and guidelines and theoretical considerations. The proposal is verified with the available information from previous tests on reinforced concrete beams, the pilot proof load tests and a collapse test carried out in the Netherlands. The results are that the stop criteria are not exceeded and therefore, the proposed stop criteria can be used for proof load tests. However, further experimental validation is needed, especially for shear failure.

1 Introduction

The assessment of existing bridges is an important aspect for the safety of society. In the Netherlands, many existing bridges, in particular reinforced concrete slab bridges, were built in the 1960s and 1970s which means that they are not designed for the actual traffic loads and they could present material deterioration. Additionally, in comparison with the old codes, the recent codes describe larger live loads, a closer distance between axles and lower shear capacity. Therefore, upon assessment with the new codes, a large number of these bridges rate insufficiently for shear or bending moment. Most of the existing bridges can be assessed with the increasing levels of approximation proposed in [1]. The first levels of approximation include spreadsheet calculations, linear and nonlinear finite element analysis and/or probabilistic approaches [2]. However, if analytical methods prove to be insufficient, proof load testing can be used to demonstrate that a bridge still fulfils the code requirements.

In a proof load test, a load representative of the factored live load is applied to the bridge. If the bridge can carry the loads without any signs of nonlinearity or distress, the proof load test is considered successful. Since the applied loads are large, the structural response of the bridge needs to be monitored during the test. The measurements of parameters such as strains, crack widths and deflections have been used to define limits or stop criteria. If a stop criterion is exceeded, the proof load test must be terminated and further loading is not permitted [3]. Stop criteria define the onset of irreversible damage or even the collapse of the structure.

This paper reviews the stop criteria found in the German guideline [4] and in the literature. This paper focuses on stop criteria for flexural and shear failure based on theoretical considerations. The stop criteria are verified with the available results from previous tests on reinforced concrete beams, the pilot proof load tests and a collapse test that were carried out in the Netherlands. The tests in which failure occurred are used to evaluate the margin of safety provided by the stop criteria and the proof load tests are used to check if the stop criteria are exceeded. This paper provides an update to the previous proposal [2], as it includes a limiting strain in the concrete based on a mechanical model for shear failure.

The results show that the proposed stop criteria were not exceeded during the proof load tests and therefore, they could be used during a proof load test as they are not overly conservative. However, further experiments are still needed to gather more information about the margin of safety, especially for shear failures on slabs. In the coming years, an experimental program will be conducted at Delft University of Technology on slabs under cyclic loads to confirm the validity of the proposed stop criteria.

2 Existing stop criteria

2.1 Codes and guidelines

The German Guideline [4] and ACI 437.2M-13 [5] prescribe stop and acceptance criteria for flexural failure. The stop criteria from the German guideline [4] are based on concrete strain, steel strain, maximum and residual crack width for new and existing cracks (see Table 1), and the residual deflection. The recent update [6] includes a stop criterion for the development of cracks with an inclination of < 60° in the shear span. The stop criterion for the concrete strains is:

$$\varepsilon_c < \varepsilon_{c,\lim} - \varepsilon_{c0} \tag{1}$$

with ε_c is the measured strain, $\varepsilon_{c,lim}$=800με for concrete with a compressive strength larger than 25 MPa, and ε_{c0} is the strain due to permanent loads.

Table 1 Requirements for new and existing cracks[4]

	During proof loading	After proof loading
New cracks	$w \leq 0.5$ mm	≤ 0.3 mm
Existing cracks	$\Delta w \leq 0.3$ mm	$\leq 0.2\ \Delta w$

The ACI 437.2M-13 [5] defines acceptance criteria for a prescribed cyclic loading protocol. The acceptance criteria are the repeatability index, permanency ratio, deviation from linearity, and a maximum and residual deflection.

2.2 Theoretical stop criteria

Table 2 presents a summary of the existing theoretical formulations for stop criteria in flexural and shear failure found in the literature.

A theoretical derivation of a limiting strain in the concrete at the bottom of a cross-section (ε_{stop}) was developed in [7]. For this criterion, the stress in the tension steel is limited to 65% of the mean yield strength f_{ym}. This limit is used to calculate the strain at the bottom of the cross-section with Eq.(2), where h is the height of the member, c is the height of the compression zone, d is the effective depth of the member, and E_s is Young's modulus of the steel.

Two proposals for a maximum crack width can be found in the literature. The first limiting crack width (w_{stop}) was proposed in [7] and it is based on the crack width model [8] of large reinforced concrete members subjected to bending. The stress in the reinforcement is limited to $0.65f_{ym}$ and w_{stop} is found using Eq. (4), where d_c is the concrete cover in mm, s is the reinforcement spacing, f_{perm} is the stress caused by the permanent loads and β_{fr}=1+3.15×10$^{-3}d_c$ is the strain gradient term. The second proposal for a limiting maximum (w_{Vos}) and residual crack ($w_{res,Vos}$) width was proposed in [9]. The proposal is based on the experimental work [10] carried out on specimens reinforced with plain bars. This research was chosen since many existing structures in the Netherlands are reinforced with plain bars. The maximum crack width is computed with Eq. (6) and the residual crack width with Eq. (7), with β as the ratio between the permanent load or cyclic load and the total load, $\sigma_{s,1}$ the steel stress in the crack in MPa and s_a is the crack spacing in mm with ϕ the rebar diameter in mm and n the number of rebars.

A deflection stop criterion was proposed in [9] and it is based on the moment-curvature diagram developed by [11], which represents the decreasing of stiffness under first-time loading and unloading. The relation between the deflection and the curvature is the bending stiffness. The bending stiffness of the unloading branch after yielding has occurred, $(EI)_{te}$, is used to calculate the limit deflection (Δ_{Vos}). It considers a 10% margin of safety and it is equal to Eq. (8), where ρ_0 is the tensile reinforcement ration in percentage and b is the width of the member.

Stop criteria for shear were based on the Critical Shear Displacement Theory(CSDT) [12]. This theory considers that the opening of the critical inclined crack starts with the opening of a dowel crack, which develops along the tensile reinforcement. The opening is triggered when the shear displacement of a flexural crack reaches a critical value (Δ_{cr}). In the CSDT, the shear capacity is equal to the sum of the shear transfer in the compression zone (V_c) determined with Mörsch´s approach [13], the dowel action (V_d) calculated with the expression proposed by Baumann and Rüsch [14], and the shear transfer by aggregate interlock (V_{ai}) using a simplified formulation based on Walraven's work [15].

A stop criterion for a limiting strain was proposed in [16]. It is based on the consideration that a flexural failure occurs after the development of flexural cracks and before the yielding of the reinforcement. First, the shear capacity is calculated according to the CSDT and then, the corresponding bending moment at the critical cross-section. The value of the curvature (φ_{CSDT}) is found by linear interpolation considering the cracking moment and the yielding moment. The strain at the bottom of the cross-section can be found with Eq.(3).

A stop criterion for a limiting crack width was proposed in [17]. The crack width (w_{ai}) is based on the simplified aggregate interlock formulation of the CSDT and it can be calculated with Eq. (5) with Δ_{cr} as the critical shear displacement, s_{cr} as the height of a fully developed crack, R_{ai} as a correction factor for high strength concrete (f_c>65 MPa) and v_{RBK} as the shear capacity taken as the one prescribed in the Dutch Guideline for Assessment of Bridges RBK [18]. The proposal considers the value of 0.4 w_{ai} for elements not cracked in bending and 0.75 w_{ai} for elements cracked in bending.

Table 2 Existing theoretical stop criteria

Flexure	*Shear*
$\varepsilon_{stop} = \left[\frac{h-c}{d-c} \times \frac{0.65 f_{ym}}{E_s}\right] - \varepsilon_{c0}$ (2)	$\varepsilon_{CSDT} = 0.65\left[\frac{h-c}{d-c}[\varphi_{CSDT}(d-c)]\right] - \varepsilon_{c0}$ (3)
$w_{stop} = 2\left[\frac{0.65 f_{ym} - f_{perm}}{E_s}\right]\beta_{fr}\sqrt{d_c^{\,2} + \left(\frac{s}{2}\right)^2}$ (4)	$w_{ai} = \frac{0.03 f_c^{\,0.56} \frac{s_{cr}}{d}(-978\Delta_{cr}^{\,2} + 85\Delta_{cr} - 0.27) + R_{ai}}{v_{RBK}}$ $+0.01mm$ $s_{cr} = \left[1 + \rho_0 n_e - \sqrt{2\rho_0 n_e + (\rho_0 n_e)^2}\right]d$ $\Delta_{cr} = \frac{25d}{30610\phi} + 0.0022 \leq 0.025mm$ $R_{ai} = 0.85\sqrt{\left(\frac{7.2}{f_c - 40} + 1\right)^2 - 1} + 0.34$ (5)
$w_{Vos} = 0.9[6.12\beta f_{ym} s_a 10^{-6}]$ $s_a = \left(d_c + \frac{1}{2}\phi + 0.3n \cdot \phi\right)\left(1 + \sqrt{\frac{1}{\rho_0 n}}\right)$ (6) $w_{res,Vos} = 6.12\beta\sigma_{s,1} s_a 10^{-6}$ (7)	
$(EI)_{te} = \left(\frac{-4.91 \cdot \rho_o^{\,2} + 17.66 \cdot \rho_o + 117.72}{7.274 \cdot 10^{-4} \cdot f_{ym}^{\,2} + \rho_o + 4}\right) bd^3 \cdot 10^2$ (8) $\Delta_{Vos} = 0.9\iint \kappa dx = 0.9\left[\iint \frac{M(x)}{(EI)_{te}} dx\right]$	

3 Experimental results

3.1 Laboratory beam tests

Two series of beam experiments served for the verification of the stop criteria. The beams were simply supported and subjected to a concentrated load. The first series, RSB, consisted of five tests on three beams sawn from the Ruytenschildt bridge [19]. One test resulted in shear failure and the other tests in flexural failure. The second series of tests, P, encompassed six tests on three beams cast in the laboratory reinforced with plain bars [20]. Two tests resulted in shear failure. In general, the beams were instrumented with LVDTs to record crack openings and strains, and laser distance sensors for the measurement of deflections. Fig. 1 shows photographs of the beam experiments.

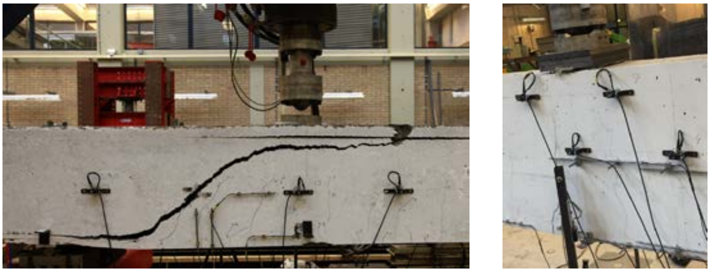

Fig. 1 Left: Beam RSB03A after shear failure. Right: Beam P804A1 after flexural failure.

3.2 Proof load tests

Since 2007, a series of proof load tests have been carried out in the Netherlands [21]. Four bridges and viaducts were proof loaded: the viaduct Vlijmen Oost [22] (see Fig. 2), the Halvemaans bridge [23] (see Fig. 2), the viaduct Zijlweg [24] and the Viaduct De Beek [25]. Vlijmen Oost was tested in flexure, shear, and at the joint with a BELFA truck, because it presented material damage due to ASR. The maximum load was of 900 kN, however, the final assessment was carried out with finite element models since the applied load showed to be lower than the Eurocode serviceability limit state level. The Halvemaans bridge was tested for flexure using a steel spreader beam and hydraulic jacks. The maximum load was 900 kN, which directly proved that the bridge fulfills the requirements of the Renovation load level of RBK [18]. The ASR-affected viaduct Zijllweg was tested in flexure and shear using a system of a steel beam spreader, jacks, and counterweight. The maximum loads were 1368 kN and 1377 kN, respectively. The result of the tests was that the bridge fulfills the requirements of RBK Design levels. Viaduct De Beek was tested in the flexure with a load of 1751 kN and in shear with 1560 kN in the first span. However, the critical second span was not tested for safety reasons.

Fig. 2 Left: Viaduct Vlijmen Oost. Right: Halvemaans bridge[21]

3.3 Collapse test

A collapse test was performed on the Ruytenschildt bridge [19],[26]. Two spans were tested at a shear-critical position. In the first span, the maximum load of 3049 kN was limited by the available counterweight and only flexural distress was observed. In the second span, the maximum load was 3991 kN which caused a failure mode that was a combination of the settlement of the support and yielding of the reinforcement with large flexural cracking.

4 Verification of stop criteria

4.1 Comparison with failure tests

The tests in which failure was reached were used to study the margin of safety provided by the stop criteria for flexure and shear. This analysis was carried out for the results of the beam experiments (see Table 2 and Table 3) and the collapse test (see Table 4). The verified stop criteria included the strain limits, maximum and residual crack width and the deflection limit reviewed in the previous section. In addition to the limit of the 25% reduction of stiffness calculated from the load-deflection diagram (S), and the deformation profiles with for the longitudinal deflection (LD), the transversal deflection (TD), the horizontal deformation (HD) and the vertical deformation (VD).

From the results in Table 3, it can be observed that the governing criterion for most of the beams (highlighted in gray and bold) is the maximum crack width w_{stop}. The results from $w_{res,Vos}$ were neglected since the limit values were smaller than 0.05 mm, which resulted in the stop criterion being exceeded in the first load cycle. Regarding the deflection criterion Δ_{Vos}, it was not able to reflect accurately the effect of existing cracks on the stiffness of the beam. The stop criteria were exceeded between 42-70% of P_{max}.

Table 4 shows the results for the shear stop criteria. For the beam previously cracked in bending the governing criterion is the limiting strain $\varepsilon_{lim.CSDT}$ at 50% of the maximum load, for the uncracked beam three stop criteria (S, HD, and VD) were exceeded at 56% of F_{max} and for the beam from the RSB series, S and the HD were reached at 57% of the ultimate load. While the number of experiments is small, the results are promising: the range of percentages for which the first stop criterion is exceeded is between 50% - 57%.

Table 3 Overview of the margin of safety (% of F_{max} when the stop criterion is reached) for flexural

	ε_{DAfstB} [%]	ε_{stop} [%]	$w_{max,DAfstB}$ [%]	$w_{max,Vos}$ [%]	w_{stop} [%]	$w_{res,DAfstB}$ [%]	$w_{res,Vos}$ [%]	Δ_{Vos} [%]	S [%]	DH [%]	DV [%]
P502A1	64	71	96	70	**70**	-	-	96	-	-	-
P502A2*	62	81	100	56	**52**	-	-	99	100	84	84
P502B	63	67	93	51	**50**	67	42	78	67	-	-
P804A1	44	**52**	87	58	56	68	36	68	58	58	77
RSB01F†	54	53	99	72	**53**	54	45	91	28-99	54	54
RSB02A	53	62	-	69	64	-	15	69	-	**42**	**42**
RSB02B†	53	71	100	62	**53**	61	47	70	47-100	61	61
RSB03F	54	**62**	100	80	64	100	49	80	100	58	58

*previously cracked in bending

†two lasers measured the deflection under load (one on each side of the beam). The deflection measurements were unequal because the beam was not sawn completely straight.

Table 4 Overview of the margin of safety (% of F_{max} when the stop criterion is reached) for shear

	ε_{DAfstB} [%]	$\varepsilon_{lim.CSDT}$ [%]	$w_{max,DAfstB}$ [%]	$w_{ai,CSDT}$ [%]	S [%]	DH [%]	DV [%]
P804A2*	47	**50**	69	65	-	86	-
P804B	57	57	-	88	**56**	**56**	**56**
RSB03A	85	82	-	81	**57**	-	**57**

*previously cracked in bending

Table 5 provides an overview of the loads at which the stop criteria is exceeded for the collapse test on the Ruytenschildt bridge. For both spans, the stop criterion that was exceeded first was the deformation profiles. The criterion was exceeded at 62% of F_{max} for span 1 and 65% of F_{max} for span 2 in the longitudinal and transverse direction.

Table 5 Overview of the margin of safety (% of F_{max} when the stop criterion is reached) for flexural on Ruytenschildt bridge

	$P_{\varepsilon stop}$ [kN]	$P_{\varepsilon stop}/P_{max}$ [%]	P_{wstop} [kN]	P_{wstop}/P_{max} [%]	P_S [kN]	P_S/P_{max} [%]	P_{LD} [kN]	P_{LD}/P_{max} [%]	P_{TD} [kN]	P_{TDP}/P_{max} [%]
Span 1	$>P_{max}$	-	$>P_{max}$	-	1923	63	**1900**	**62**	**1900**	**62**
Span 2	3377	85	3072	93	3159	79	**2600**	**65**	**2600**	**65**

4.2 Comparison with proof load tests

Table 6 and Table 7 show an overview of the results of the comparison of the measurements obtained during the tests and the proposed stop criteria. The crack widths smaller than 0.05 mm are neglected and taken equal to 0 mm. Therefore, the results from residual crack widths are not considered in the tables since most of them were negligible. The stop criteria that are verified are ε_{stop}, w_{stop}, S, LD and TD profiles. The stiffness of the Halvemaans bridge for the flexural test slightly increased during the loading protocol. For Vlijmen Oost no measurements were available of the deflection in the transverse direction. The results show that none of the stop criteria was exceeded during the pilot proof load tests. This conclusion corresponds with the measurements gather with the extensive instrumentation during the pilot proof load tests, where no onset of nonlinearity was observed. The proposed stop criteria are adequate for the application to field testing. However, no information could be gathered regarding the margin of safety since we don't know the ultimate load.

Table 6 Comparison between the measurements obtained during the proof load tests and the stop criteria for flexure

	$\varepsilon_{c,\ max\ measured}$ [$\mu\varepsilon$]	ε_{stop} [$\mu\varepsilon$]	$w_{max,measured}$ [mm]	w_{stop} [mm]	S	LD	TD
Vlijmen oost	80	869	0	0.15	3.7%	$>P_{max}$	NA
Halvemaans	150	729	0	0.11	-	P_{max}	$>P_{max}$
Zijlweg	240	842	0	0.17	4%	$>P_{max}$	$>P_{max}$
De Beek	887	919	0.12	0.13	18	$>P_{max}$	$>P_{max}$

Table 7 Comparison between the measurements obtained during the proof load tests and the stop criteria for shear

	$\varepsilon_{c,\ max\ measured}$ [$\mu\varepsilon$]	ε_{CSDT} [$\mu\varepsilon$]	$w_{max,measured}$ [mm]	w_{ai} [mm]	S	LD	TD
Vlijmen oost	35	459	0	0.16	7.8%	$>P_{max}$	NA
Zijlweg	224	416	0	0.06	12%	$>P_{max}$	$>P_{max}$
De Beek	225	697	0.11	0.13	10%	$>P_{max}$	$>P_{max}$

5 Discussion and future research

The stop criteria for flexural and shear failure were evaluated. The stop criterion for limiting concrete strain for shear failure (ε_{CSDT}) proved to be more adequate in comparison to the limit proposed by the German guideline. Regarding the stop criteria for flexural failure proposed in [9], the results for residual crack width were not consistent and the limit values were smaller than 0.05 mm. The limit for maximum deflection did not reflect accurately the effect of existing cracks on the beams. Thus, these criteria are not suitable.

Table 7 shows the updated proposal for flexural and shear stop criteria. It includes four theoretically derived stop criteria: the limiting concrete strain (ε_{stop}) and the maximum crack width (w_{stop}) for flexural failure, as well as the limiting concrete strain (ε_{CSDT}) and the maximum crack width (w_{ai}) for flexural shear failure. The addition of ε_{CSDT} is an improvement to the previous proposal [7] since it has a theoretical background compared to the stop criterion from the German guideline that uses one limiting strain value. This proposal neglect all cracks widths that are smaller than 0.05 mm. The limit for residual crack width w_{res}, was taken from the German guideline (see Table 1) and it is evaluated after each cycle. For the case of a specimen previously cracked in bending, the crack widths can be taken as the width of a new crack or the increase of an existing crack. For all cases, the reduction of stiffness is limited to 25% and it is determined from the load-deflection diagram. Additionally, the proposal contains qualitative stop criteria: load-deflection diagram and the deformation profiles. The overall structural behavior can be assessed with the load-deflection diagram during and after the test. The deformation profiles can be determined with the deflection in the longitudinal and transversal direction and they provide an insight into the overall structural behavior.

The proposed stop criteria are promising, however, it is still necessary to continue studying the margin of safety with further experiments as well as to explore other parameters. Moreover, research is needed to investigate the effects of the transverse redistribution of the load on slabs and the implication on the proposed stop criteria.

Table 7 Updated proposed stop criteria for flexural and shear

Failure mode	Not cracked in bending	Cracked in bending
Flexural	ε_{stop} $w_{max} \leq w_{stop}$ $w_{res} \leq 0.3 w_{max}$	ε_{stop} $w_{max} \leq w_{stop}$ $w_{res} \leq 0.2 w_{max}$
Shear	ε_{CSDT} $w_{max} \leq 0.4 w_{ai}$	ε_{CSDT} $w_{max} \leq 0.75 w_{ai}$
Flexural and shear	25% stiffness reduction Deformation profiles Load-deflection diagram	

6 Summary and conclusions

A proof load test consists of applying a factored lived load to structure to directly prove that it can carry the load and fulfill the code requirements without any signs of distress. Proof loading involves heavy loads, so it is necessary to monitor the structural responses during the test. Limits are given to the structural responses to avoid any irreversible damage; these limits are denoted as stop criteria. Some existing codes and guidelines provide stop criteria, however, they are limited to flexural failure and are usually related to serviceability requirements or single limit values.

Stop criteria for flexural and shear failure were proposed based on theoretical background. For flexure, the flexural beam theory was used to derive a stop criterion for limiting concrete strain and crack width [7]. For shear, the Critical Shear Displacement Theory was chosen to derive a stop criterion for limiting crack width [17] and limiting concrete strain [16]. The stop criteria include the limit of 25% of the reduction of stiffness and the evaluation of the deformation profiles.

The stop criteria were evaluated. First, the results from the two series of beam experiments and the failure tests on the Ruytenschildt bridge were used to analyze the margin of safety. The flexural tests had a margin of safety between 42 and 65% and for the shear tests the range was 50% to 57%. Thus, the stop criteria showed to have a sufficient margin of safety. Secondly, the stop criteria were compared to the results from the measured structural responses from the pilot proof load tests. The conclusion was that none of the stop criteria were exceeded and thus, the tests did not lead to irreversible damage.

The proposed criteria can be used for proof load testing, however, the number of experiments used to draw these conclusions is still limited, especially for the specimens failing in shear. Further experiments on slabs are needed for further validation in combination with noncontact measuring techniques.

References

1. FIB 2012, *Model Code 2010*. International Concrete Federation: Lausanne, Switzerland.
2. Lantsoght, E.O.L., C. van der Veen, and D.A. Hordijk. 2016. *Proposed stop criteria for proof load testing of concrete bridges and verification*. in *IALCCE*. Ghent, Belgium.
3. Lantsoght, E.O.L., *Verification of stop criteria for proof load tests*, in *Stevin Report*. 2017, TU Delft: Delft.
4. Deutscher Ausschuss für Stahlbeton, *DAtStb-Guideline: Load Tests on Concrete Structures (in German) DAfStb-Richtlinie : Belastungsversuche an Betonbauwerken*, D.A.f. Stahlbeton, Editor. 2000: Berlin.
5. ACI Committee 437, *Code requirenments for Load Testing of Existing Concrete Structures (ACI 437.2M-13) and Commentary*. 2013, American Concrete Institute: Farmington Hills, MI.
6. Deutscher Ausschuss für Stahlbeton, *DAfStb-Guideline Load Tests on Concrete Structures (Draft) (in German) DAfStb-Richtlinie Belastungsversuche an Betonbauwerken (Entwurf)*, D.U.B.v. Bestandsbauwerken, Editor. 2019: Berlin.
7. Lantsoght, E.O.L., et al., 2019, *Stop Criteria for Flexure for Proof Load Testing of Reinforced Concrete Structures*. Frontiers in Built Environment. **5**.
8. Frosch, R.J., 1999, *Another Look at Cracking and Crack Control in Reinforced Concrete*. ACI Structural Journal. **96**(3).
9. Vos, W., 2016, 'Stop criteria for proof loading.The use of stop criteria for a safe use of 'Smart Proof loading''. **Master Thesis**.TU Delft, Master Thesis
10. Van Leeuwen, J., 1962, *About the cracking in slabs and beams (in Dutch) Over de scheurvorming in platen en balken*. Heron **10**(1): p. 50-62.
11. Monnier, T., 1970.*The Moment-curvature Relation of Reinforced Concrete*. Stevin-Laboratory of the Department of Civil Engineering, Delft University of Technology; Riijswik (ZH).
12. Yang, Y., J. den Uijl, and J. Walraven. 2016, *Critical shear displacement theory: on the way to extending the scope of shear design and assessment for members without shear reinforcement*. Structural Concrete. **17**(5): p. 790-798.
13. Mörsch, E., 1909.*Concrete-steel Construction: (Der Eisenbetonbau)*. Engineering News Publishing Company.
14. Baumann, T. and H. Rüsch. 1970, *Experimental study on dowel action in reinforced concrete beams (in German) Versuche zum Studium der Verdübelungswirkung der Biegezugbewehrung eines Stahlbetonbalkens*. Deutscher Ausschuss für Stahlbeton (DAfStb).
15. Walraven, J.C., 1981, *Fundamental Analysis of Aggregate Interlock*. Journal of Structural Engineering-ASCE. **107**: p. 2245-2270.
16. Benitez, K., E.O.L. Lantsoght, and Y. Yuguang. 2018. *Development of a Stop Criterion for Load Tests based on the Critical Shear Displacement Theory*. in *IALCCE*. Ghent, Belgium.
17. Lantsoght, E.O.L., 2017, *Development of a stop criterion for shear based on aggregate interlock*. **Stevin Report**(25.5-17-09): p. 33.
18. Rijkswaterstaat, *Guideline for Assessment of Structures, evaluation of the safety of a existing structure for renovation, reused and demoliton (in Dutch) Richtlijnen Beoordeling Kunstwerken, Beoordeling van de constructieve veiligheid van een bestaand kunstwerk bij verbouw, gebruik en afkeur.*, in *RTD 1006:2013*. 2013. p. 117.
19. Lantsoght, E.O.L., et al., 2016, *Ruytenschildt Bridge: Field and laboratory testing*. Engineering Structures. **128**: p. 111-123.
20. Lantsoght, E.O.L., et al., 2017, *Beam Experiments on Acceptance Criteria for Bridge Load Tests*. ACI Structural Journal. **114**(4).
21. Lantsoght, E., et al., 2017, *Proof load testing of reinforced concrete slab bridges in the Netherlands*. Structural Concrete. **18**(4): p. 597-606.
22. Fennis, S.A.A.M., et al., 2015, *Assessment of Viaduct Vlijmen Oost by Proof Loading*. **Stevin Report**(25.5-15-10): p. 126.
23. Fennis, S.A.A.M. and D.A. Hordijk. 2014, *Proof Load Halvemaans bridge in Alkamar(in Dutch) Proefbelasting Halvemaansbrug Alkmaar* **Stevin Report**(25.5-14-05): p. 72.

24. Koekkoek, R.T., E. Lantsoght, and D.A. Hordijk. 2015, *Proof loading of the ASR-affected viaduct Zijlweg in highway A59*. **Stevin report**(25.5-15-08): p. 189.
25. Koekkoek, R.T., et al., 2016, *Assessment of Viaduct De Beek by Proof Loading*. **Stevin Report**(25.5-16-01): p. 125.
26. Lantsoght, E., et al., 2016, *Collapse test and moment capacity of the Ruytenschildt reinforced concrete slab bridge*. Structure and Infrastructure Engineering. **13**(9): p. 1130-1145.