Sustainable Design Development of a Concrete Lock Chamber

Reaching a sustainable and durable design of a ship lock concrete hard structure, enabling navigation through the Haringvliet storm surge barrier as part of the Delta21 Project

Sóley Hjörvarsdóttir

Thesis defence

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Agenda

01. Introduction

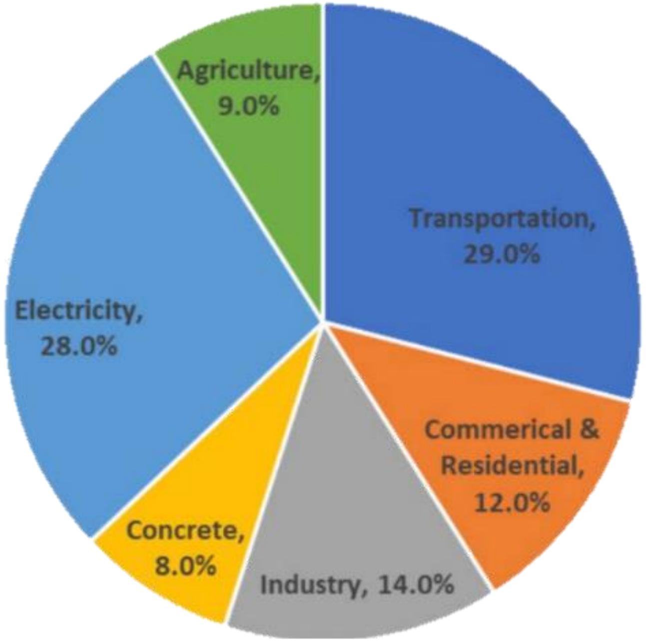
02. Design

03. Life Cycle Assessment Results and discussion

04. Conclusion

Introduction

Introduction



Environment and the construction sector

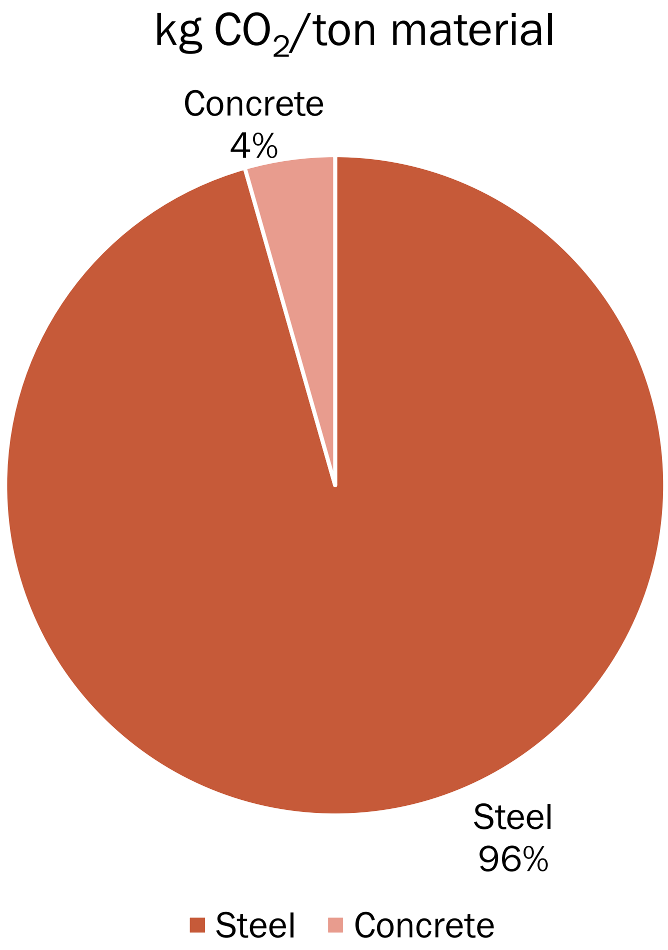
- Construction industry is responsible for 25% of global GHG emissions
- Concrete is the 2nd most consumed material in the world
- Responsible for roughly 8% of global CO^2 emissions
- Global cement production has increased more than 30-fold since the 1950s

Why concrete was chosen for this study

- **Steel structures have much lower global warming potential than concrete structures**
  - Steel has better tension properties, high strength and stiffness per weight, thus resulting in a much lighter structure

However

- Concrete is very popular; not showing any trends in decreasing popularity worldwide
- Important to make concrete structures more sustainable

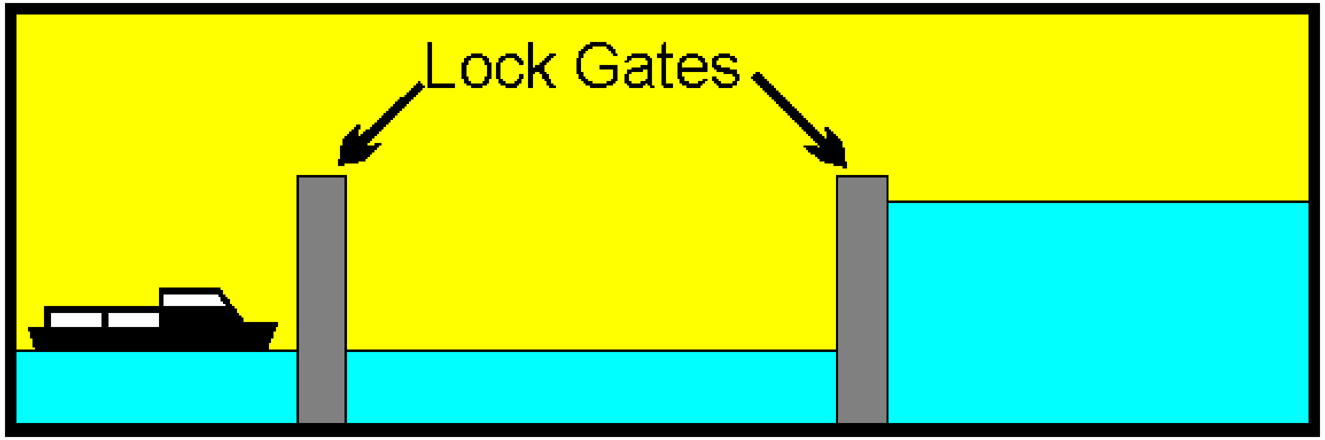


Research Question

How can a concrete hydraulic hard structure be designed sustainably, using a ship lock chamber as a case study, with the aim of reducing CO_2/year by 50%?

- What is a sustainable concrete structure
- Which aspects of the design are the most influential on the sustainability of the structure
- Which aspects of the design are most influential when it comes to the cost of the structure

Ship Lock



Methodology

- Two Concrete lock chamber alternatives are designed
  - Base case: Designed based on what is most commonly done in practice
  - Optimised design: Sustainable concrete chamber alternative
- A more sustainable concrete chamber alternative is chosen:
  - Different structural wall types are investigated. Best performing one, resulting in the lowest shear forces and moments is chosen for the optimised design
- Partial LCA performed

Case study

- Design of a concrete ship lock chamber as part of the Delta21 project

- Delta21 plans:
    - Protect the Dutch coast against floods
    - Open Storm surge barrier (no. 3)
    - Energy storage lake connected to the tidal lake via a spillway (no. 2)
    - Fish migration river
    - Ship passage
    - Pumps to discharge water into the North Sea (no.1)

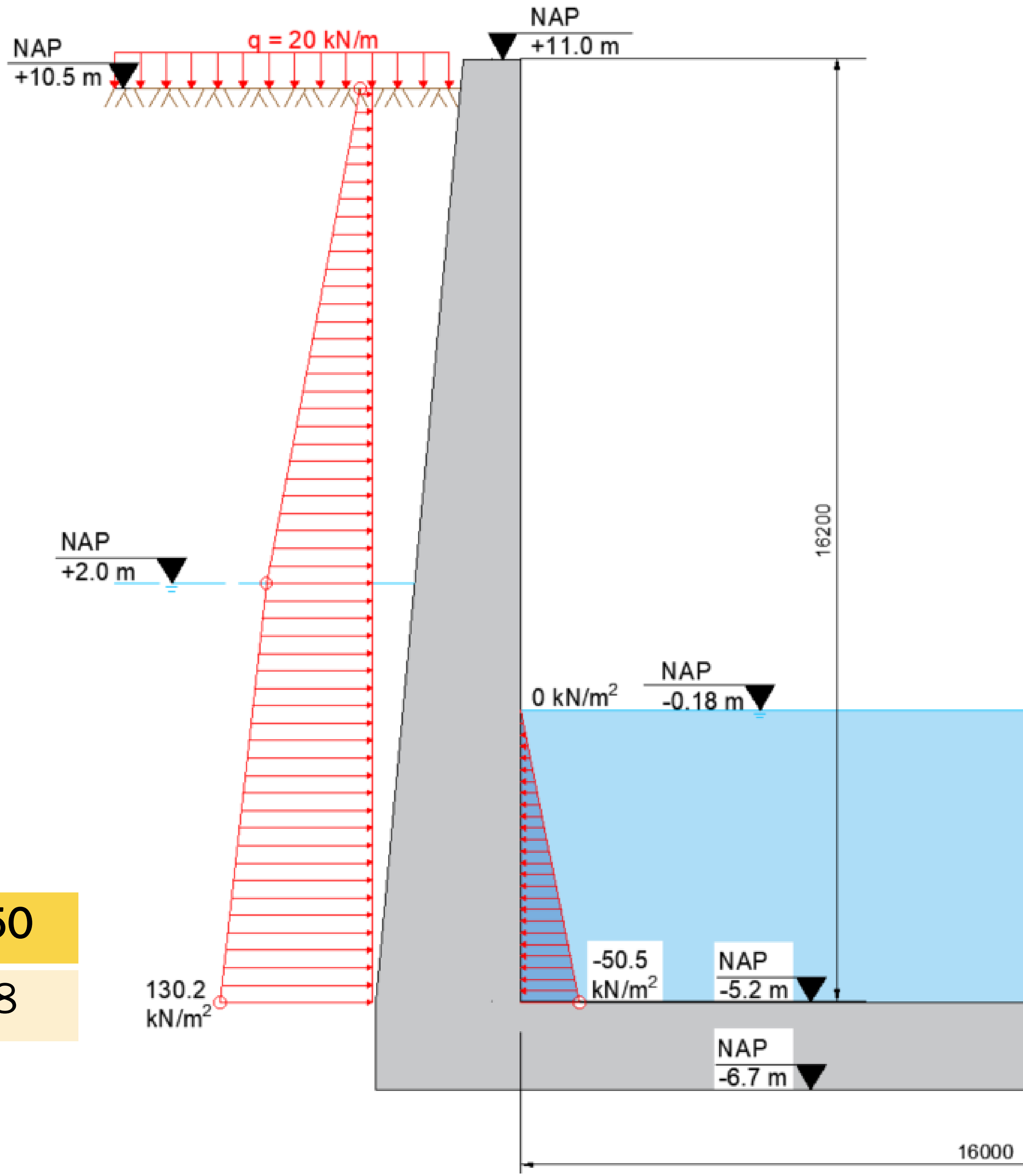
Design of the Lock Chamber

Load case

Wall load case:

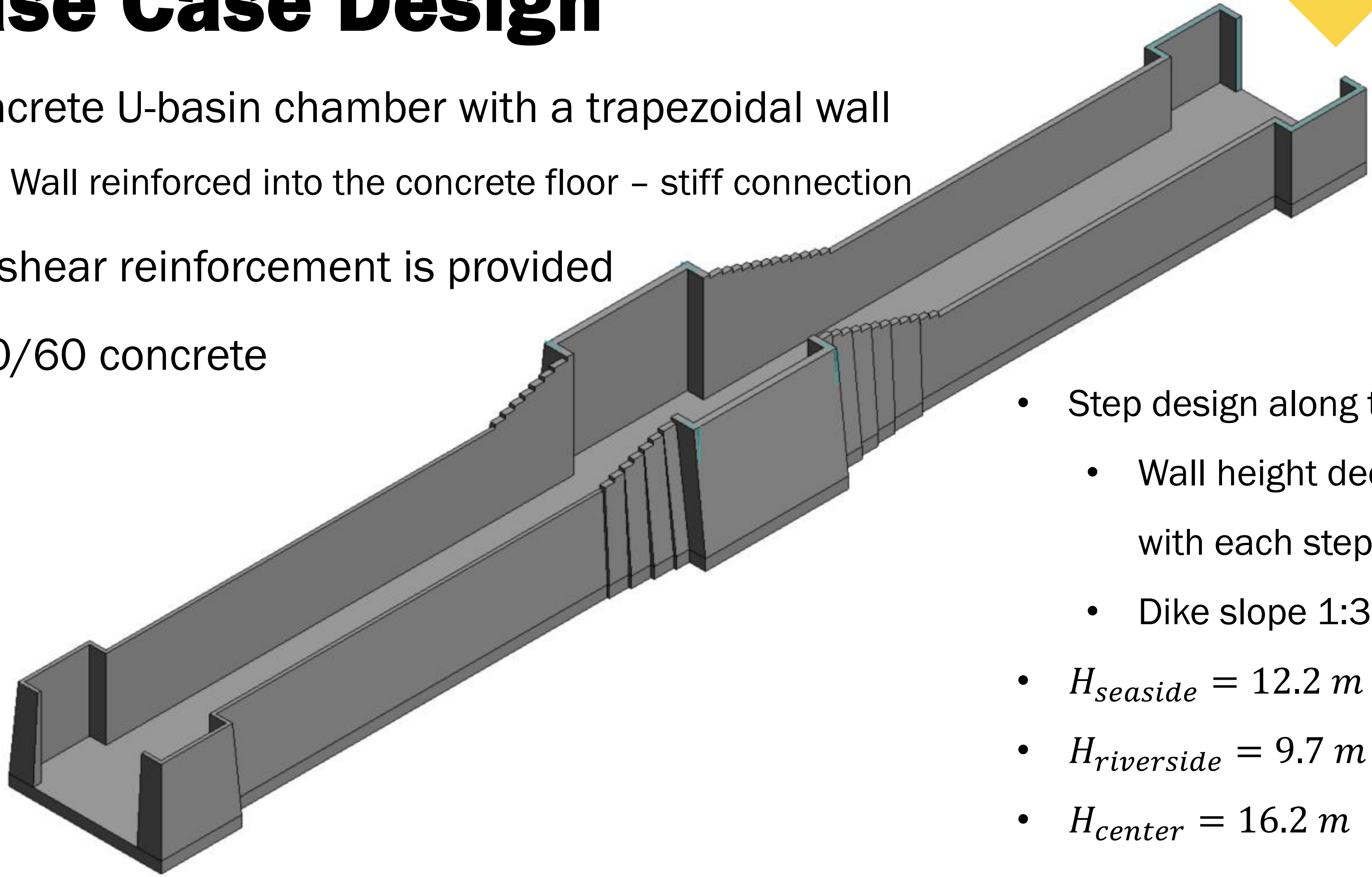
- Soil pressure
- Hydrostatic pressure from ground water
- Surcharge load on the surface
- Self weight
- Water within the chamber at minimum locking level

Year	2050	2100	2150	2200	2250
SLR [m]	0.32	0.82	1.50	2.60	3.88



Base Case Design

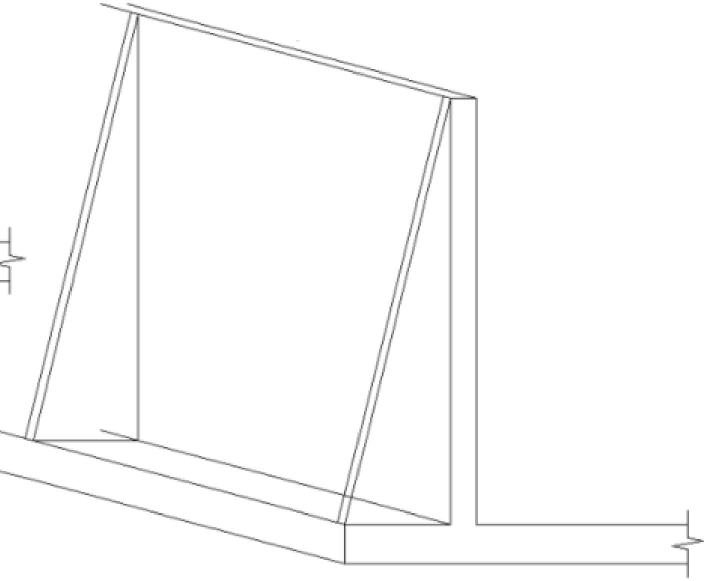
- Concrete U-basin chamber with a trapezoidal wall
  - Wall reinforced into the concrete floor – stiff connection
- No shear reinforcement is provided
- C50/60 concrete

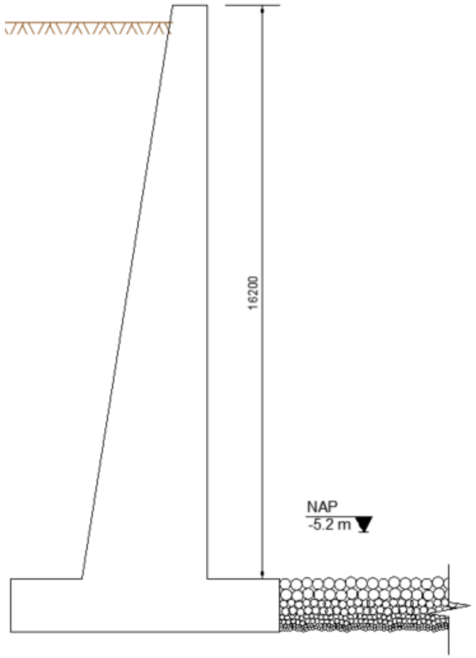


- Step design along the dike
  - Wall height decreases by 0.5 m with each step
  - Dike slope 1:3
- $H_{seaside} = 12.2\ m$
- $H_{riverside} = 9.7\ m$
- $H_{center} = 16.2\ m$

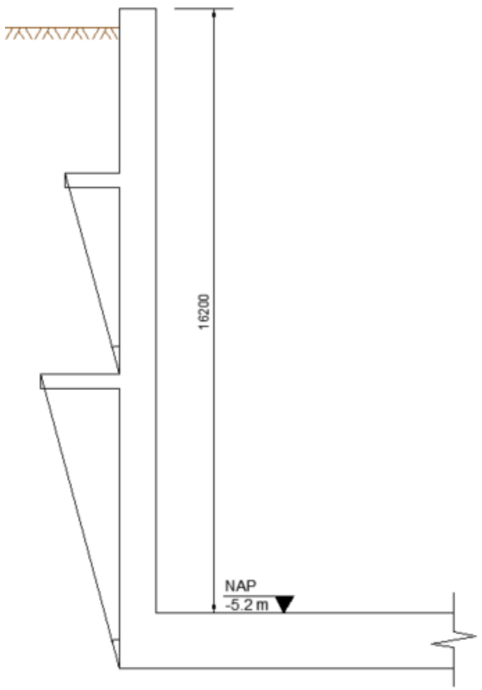
Alternative design

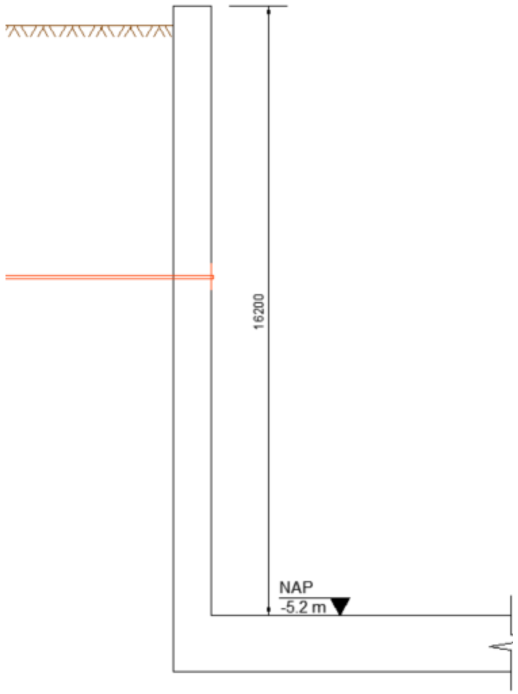
- Goal of the thesis: Find a sustainable concrete chamber design alternative to the base case
- Four different shape typologies were considered for the optimized design





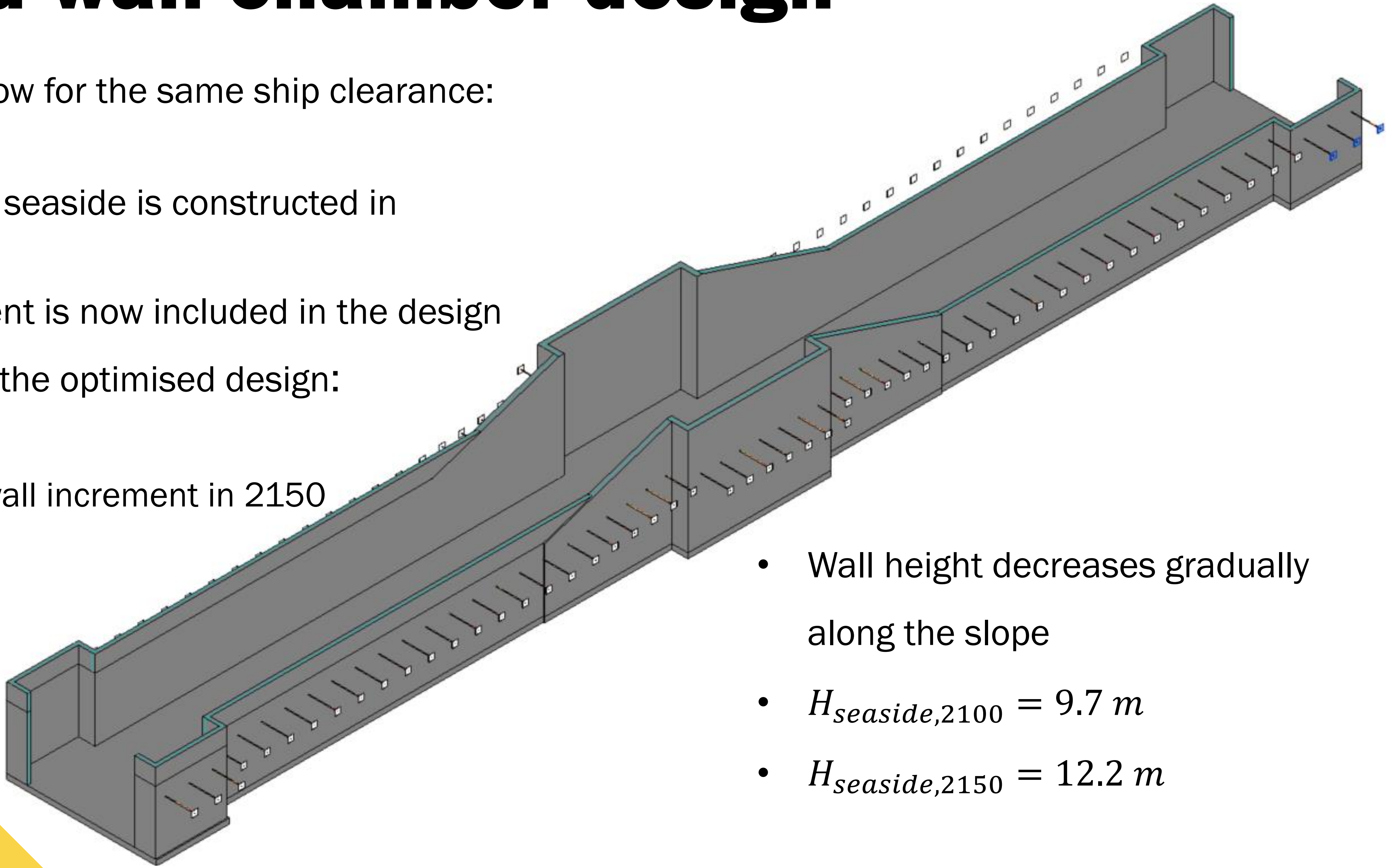
- The wall that best performed in terms of shear and moment was chosen for the design
  - **Anchored chamber wall**





Anchored wall chamber design

- Added width to allow for the same ship clearance:
  - $B_{ch} = 16.5\ m$
- Wall height on the seaside is constructed in stages:
- Shear reinforcement is now included in the design
- Concrete used for the optimised design:
  - C35/45
  - C25/30 – wall increment in 2150



- Wall height decreases gradually along the slope
- $H_{seaside,2100} = 9.7\ m$
- $H_{seaside,2150} = 12.2\ m$

Design results

- 88% reduction in maximum moments
- 56% reduction in shear force at the bottom of the wall

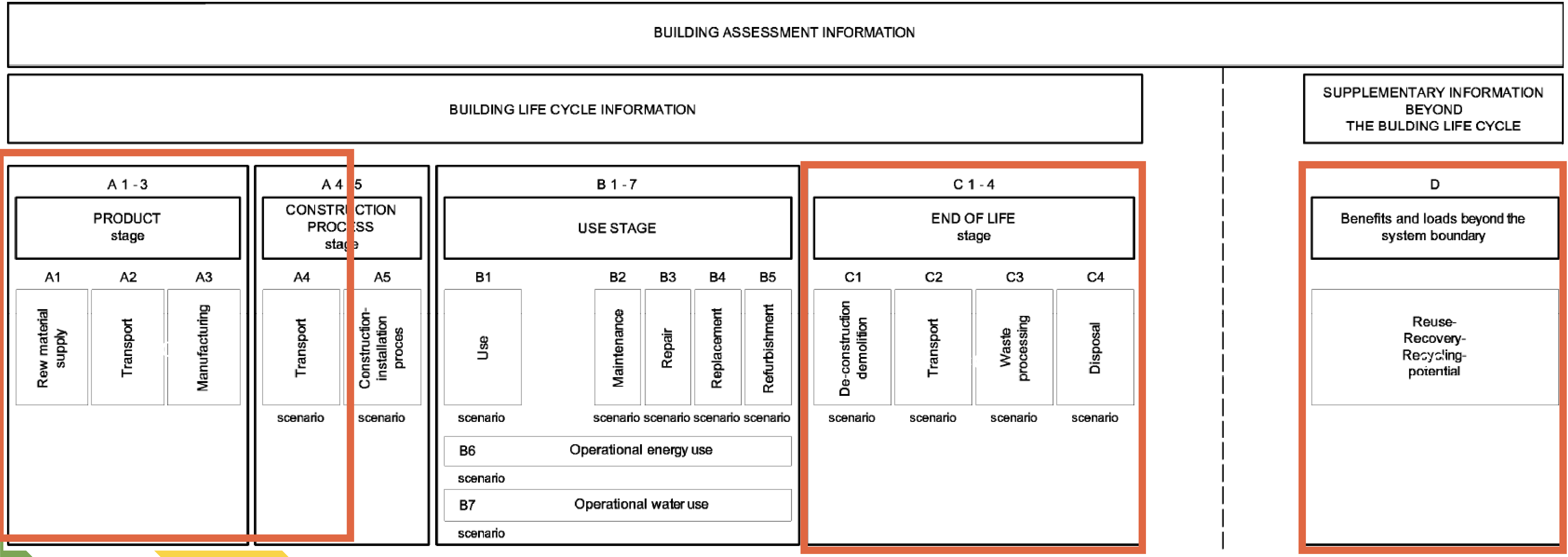
- 47% reduction in concrete volume
- 46% reduction in reinforcement volume

- Rebar-to-concrete ratio:
  - Base case chamber: 1.1%
  - Anchored wall chamber: 1.1%

LCA Results

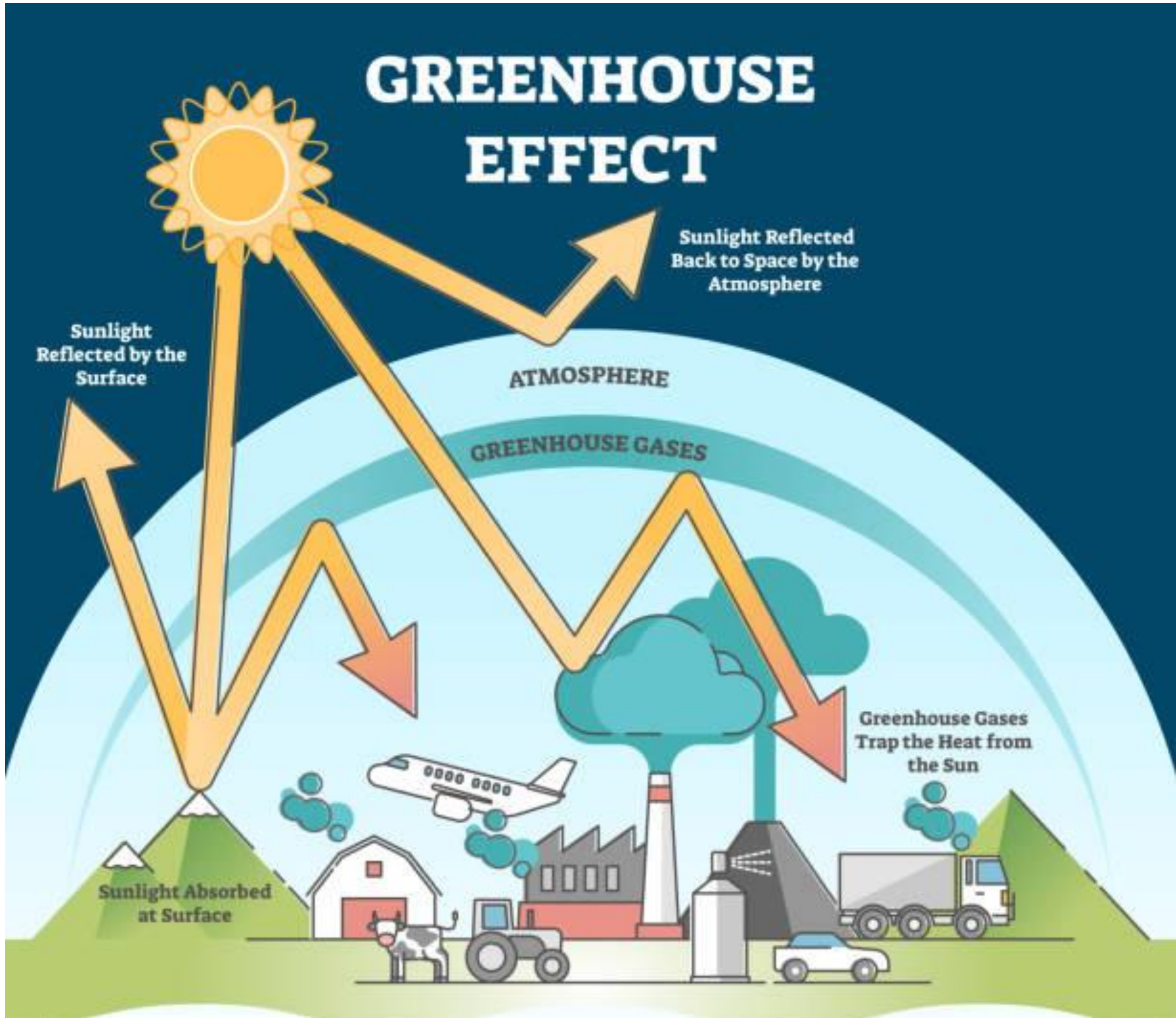
Life Cycle Assessment

Life cycle stages

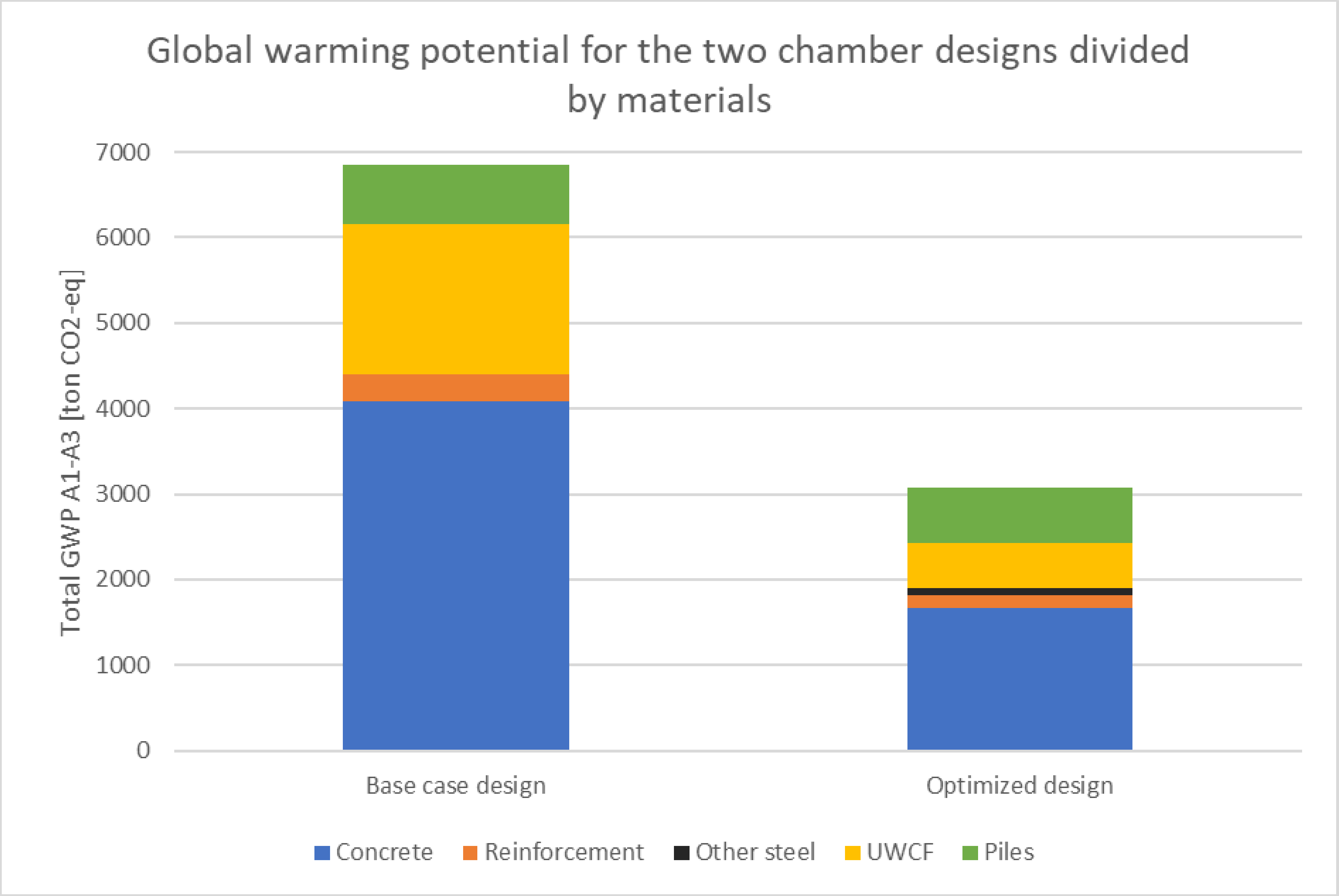


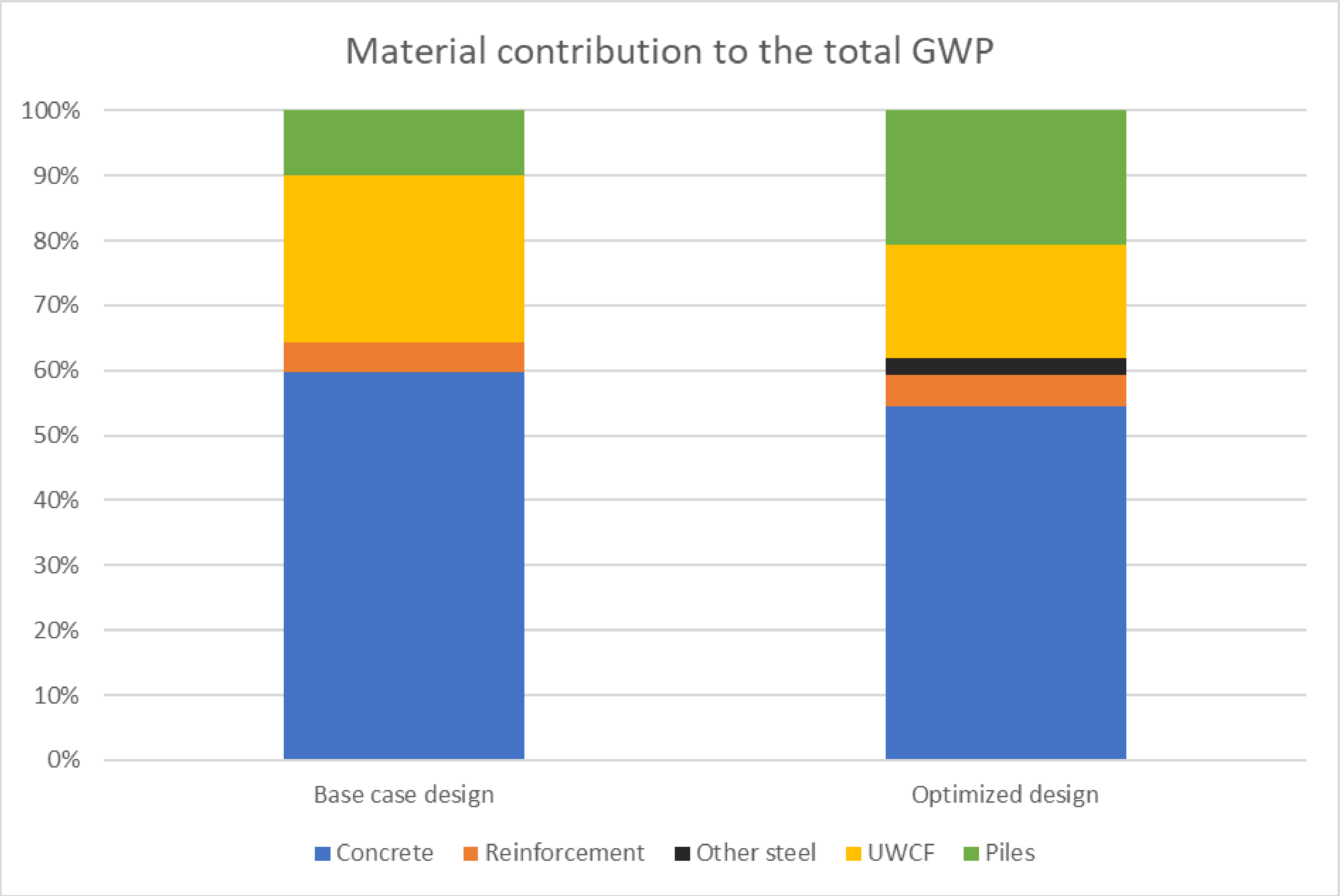
Global Warming Potential (GWP)

- Quantifies the impact of GHG emission on global warming
- kg CO_2/unit

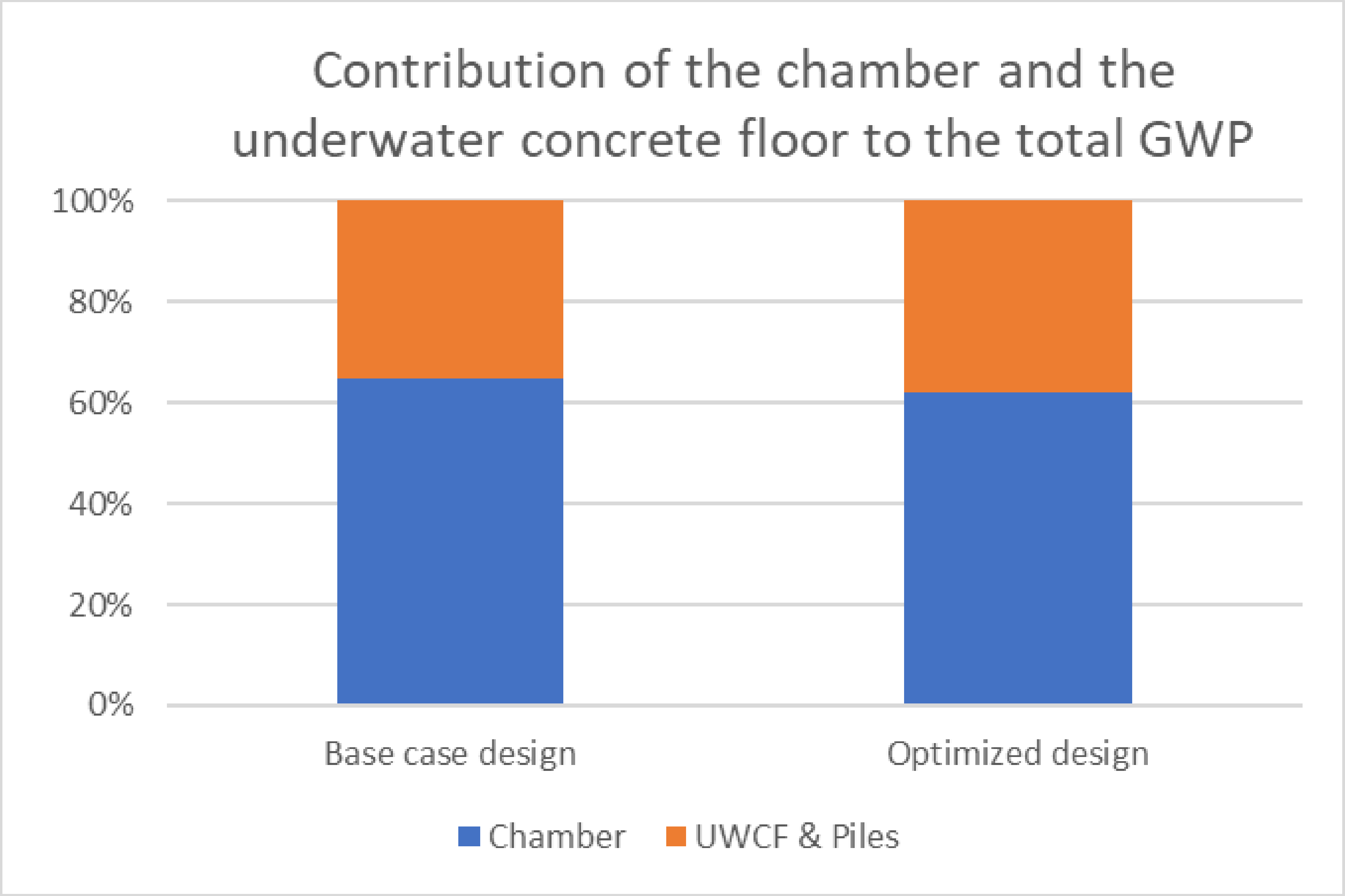


LCA Results


Global warming potential for the two chamber designs divided by materials
Total GWP A1-A3 [ton CO2-eq]
7000
6000
5000
4000
3000
2000
1000
0
Base case design
Optimized design
Concrete
Reinforcement
Other steel
UWCF
Piles

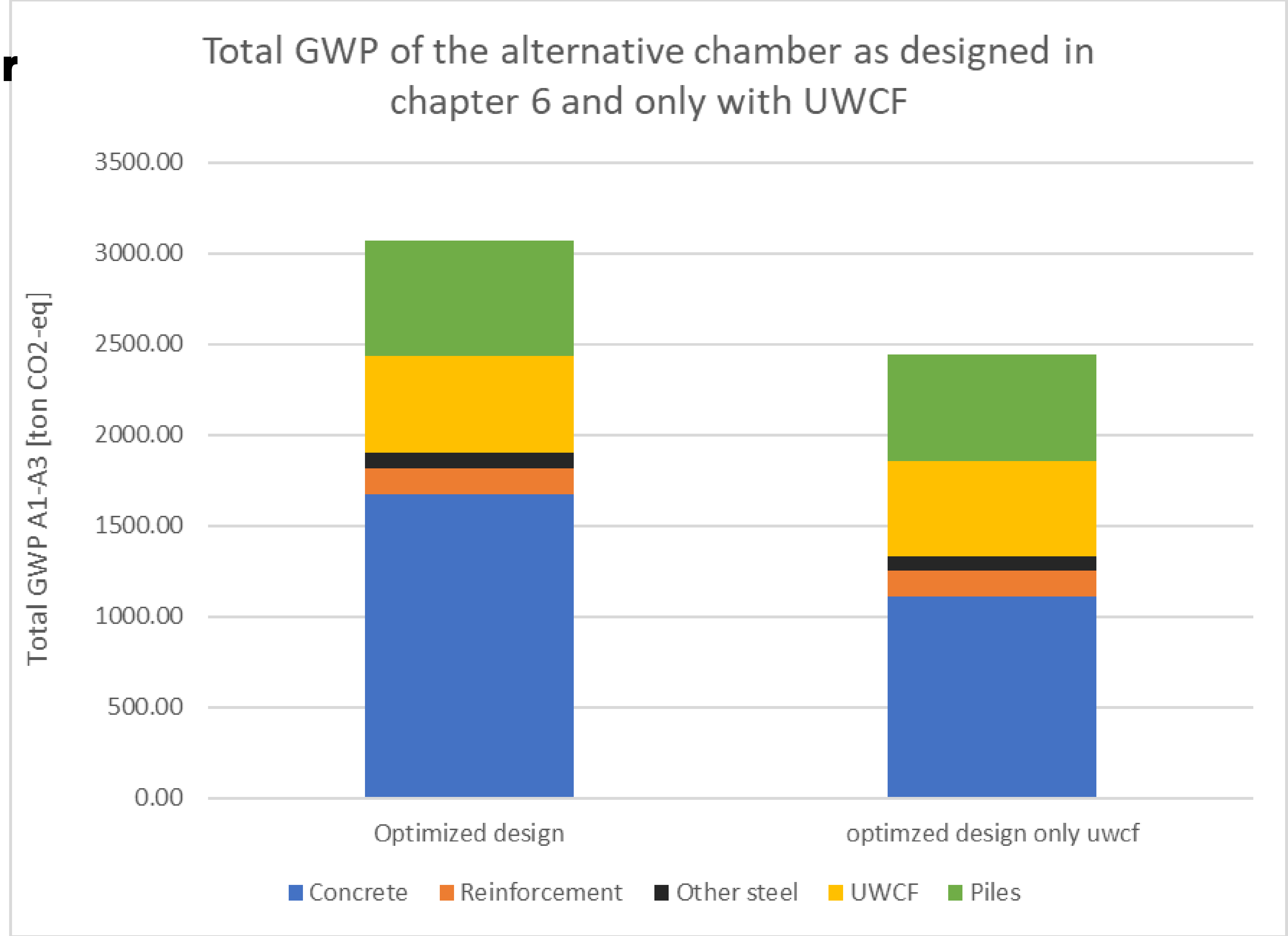


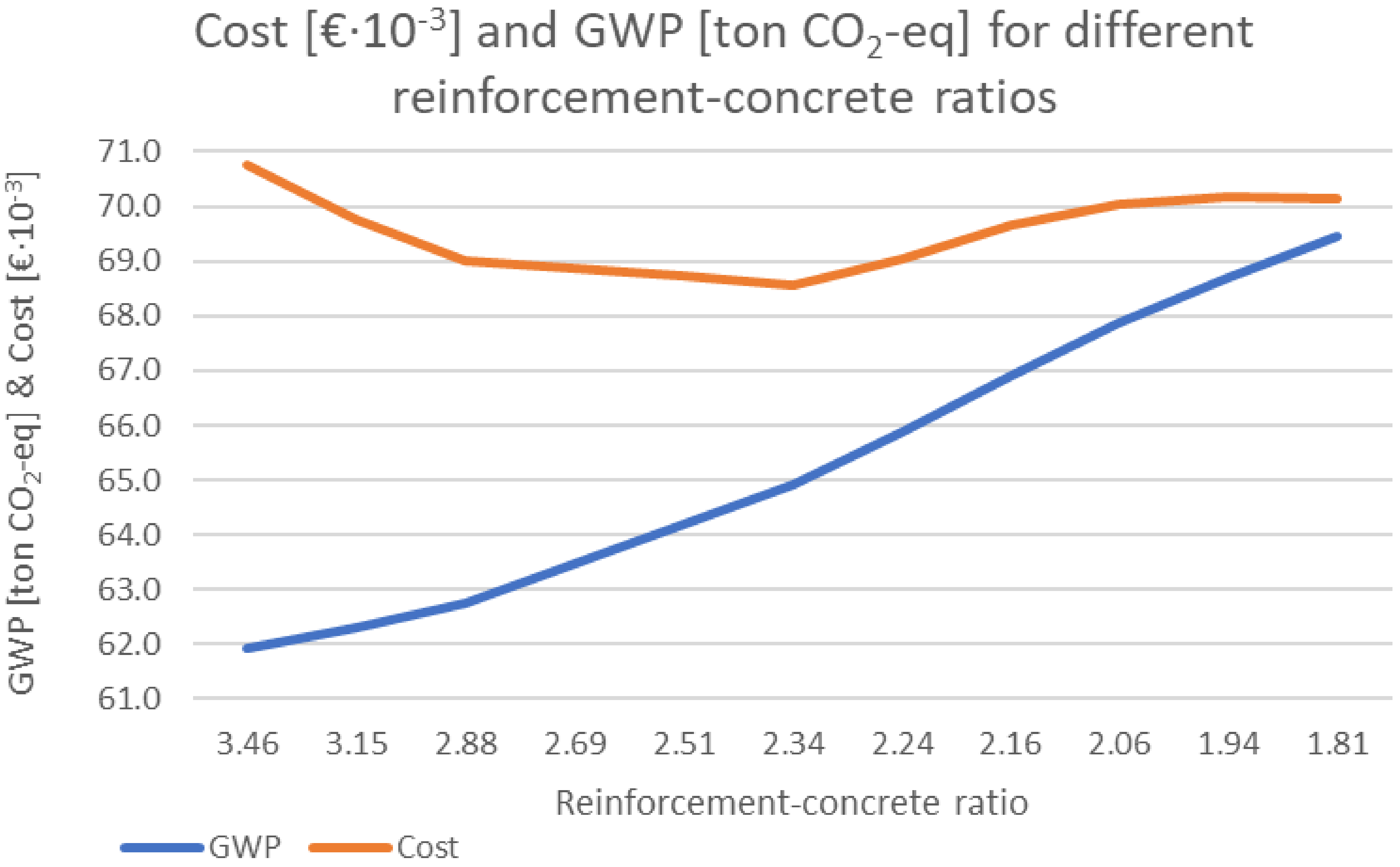
Material contribution to the total GWP
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Base case design
Optimized design
Concrete
Reinforcement
Other steel
UWCF
Piles



Contribution of the chamber and the underwater concrete floor to the total GWP
100%
80%
60%
40%
20%
0%
Base case design
Optimized design
Chamber
UWCF & Piles

Underwater concrete used as the chamber floor




Cost [€·10-3] and GWP [ton CO2-eq] for different reinforcement-concrete ratios
GWP [ton CO2-eq] & Cost [€·10-3]
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
63.0
62.0
61.0
3.46
3.15
2.88
2.69
2.51
2.34
2.24
2.16
2.06
1.94
1.81
Reinforcement-concrete ratio
GWP
Cost

Conclusions

Conclusion

- Goal of the thesis: reduce carbon footprint by 50%
- Anchors effectively reduced the maximum moments and shear forces
- Optimising the design was beneficial in two ways:
  - Improved structural performance
  - Reduced carbon footprint

Conclusion

- An optimum reinforcement-to-concrete ratio for the anchored chamber wall was found as 2.3%
  - Sustainable design solutions can be economically viable
  - This ratio can be used as a guide for other concrete walls with shear reinforcement

Conclusion

- Potential for integrating sustainability objectives into the structural design process
- Principles underlying the optimisation process can be applied to other soil retaining concrete structures:
  - Optimisation through structural elements
  - Reduction of material volumes
  - Comparative analysis

Recommendations

- Development of integrated design frameworks that consider sustainability from early stages in design
  - Optimum reinforcement-to-concrete ratio for different types of concrete elements

- Research on the feasibility of using underwater concrete floor as a primary flooring in a hydraulic structure


Thank you