ferrovial
construcción

Current challenges in designing concrete floaters

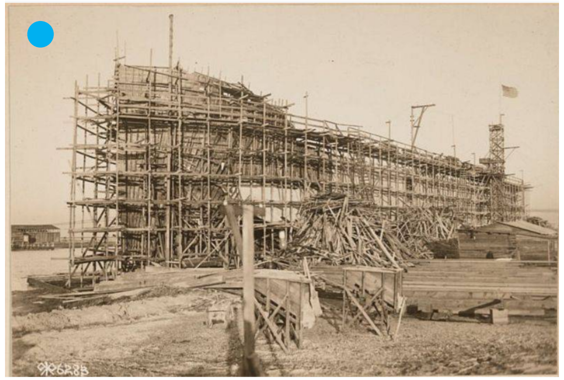
FIBREGY Open Industrial Day in Madrid
ETSI Navales - Technical University of Madrid
April 18th, 2024

Reinforced concrete has already been used to build ships, even if sporadically (1848-WWI)

Lambot's boat

1848

SS Faith



1918

1917

Namsenfijord

🔴 Ferrocement

🔵 Reinforced concrete

Reinforced concrete has already been used to build ships, even if sporadically (WWII-present)

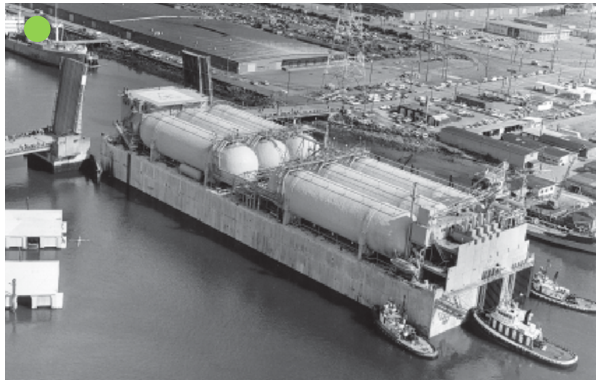
Vitruvius

1943

N´Kossa barge

1997

1977

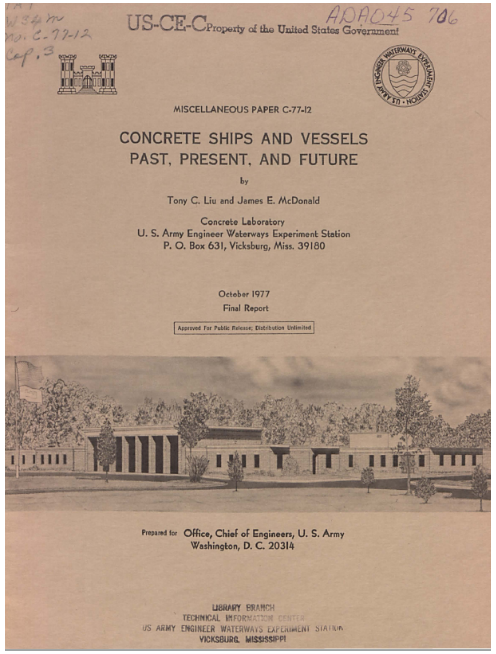


ARCO LPG barge

● Reinforced concrete

● Prestressed concrete

Over a period of more tan 150 years concrete hulls have exhibited good performances



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CONCRETE SHIPS AND VESSELS
PAST, PRESENT, AND FUTURE

by

Tony C. Liu and James E. McDonald

Concrete Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

October 1977
Final Report

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Report on Floating and Float-In
Concrete Structures

Reported by ACI Committee 357

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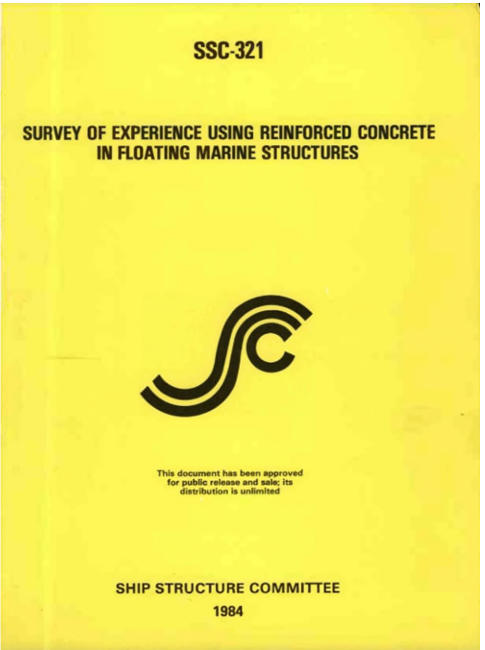

SSC-321

SURVEY OF EXPERIENCE USING REINFORCED CONCRETE
IN FLOATING MARINE STRUCTURES

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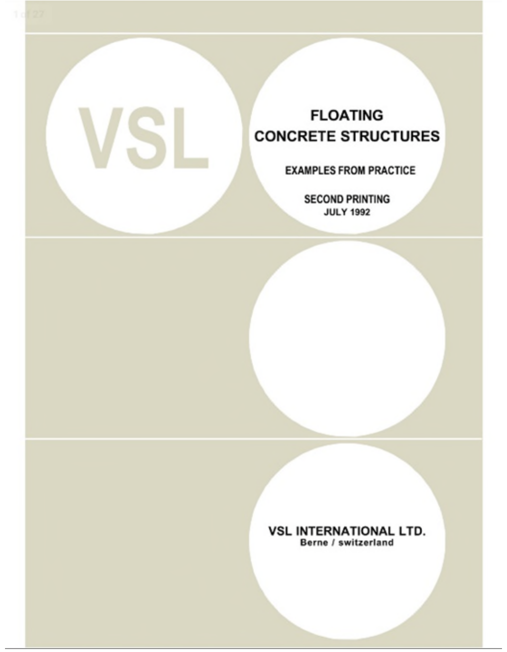
SHIP STRUCTURE COMMITTEE
1984



VSL

FLOATING
CONCRETE STRUCTURES

EXAMPLES FROM PRACTICE

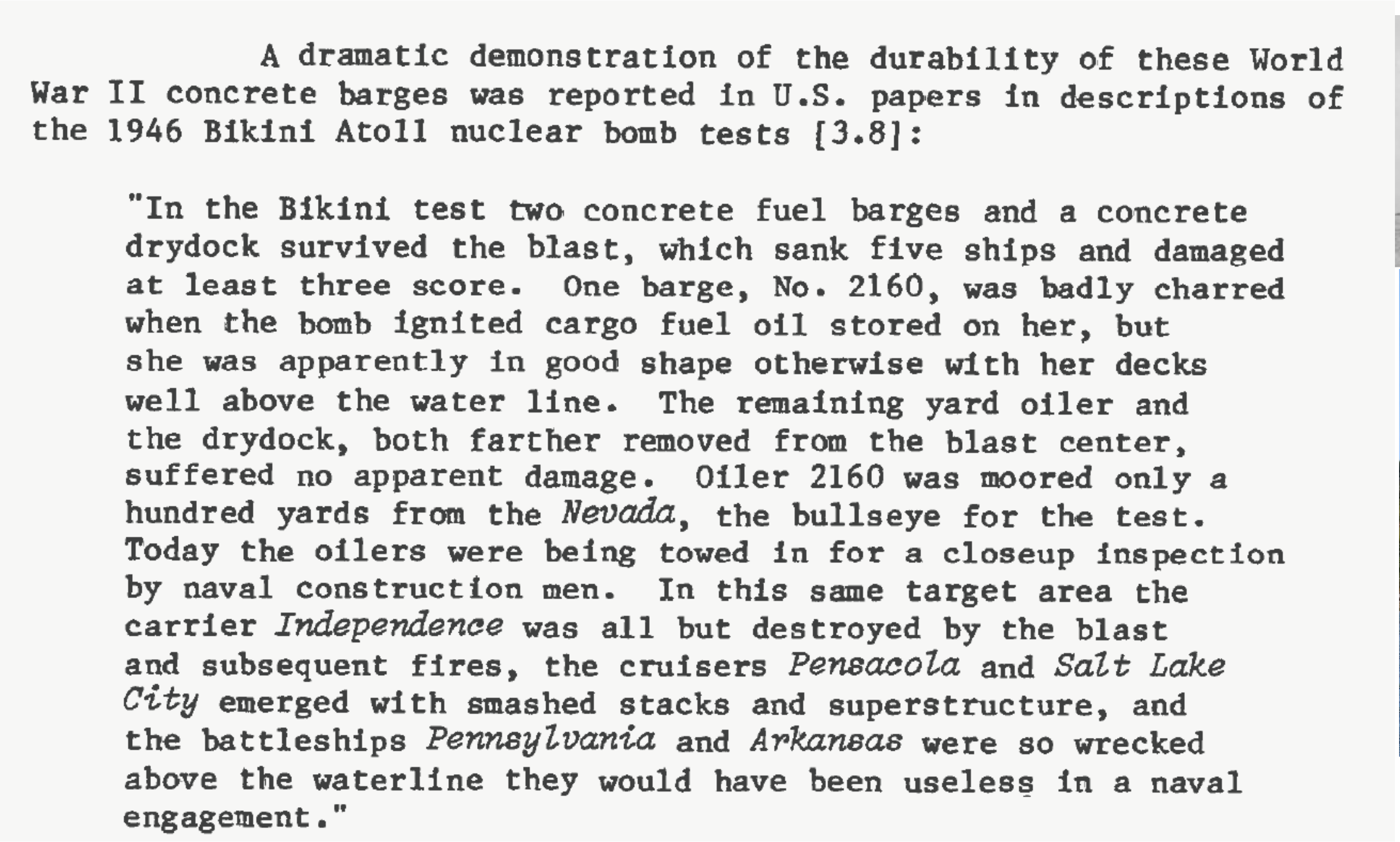
SECOND PRINTING
JULY 1992

VSL INTERNATIONAL LTD.
Berne / switzerland

"The historical review and operational experience reveal that concrete is an ideal material for ships and vessels because it is economical, durable, watertight, easy to repair, and less affected by fire and explosions."

"There is ample evidence that concrete hulls are dependable, seaworthy and structurally as sound as hulls of any other material used for seagoing vessels. Concrete hulls have been put to as severe tests as have been given any other vessels and it has been shown conclusively that, when properly designed and well equipped, they will perform on equal basis with comparable steel vessels"

Astonishing durability of the concrete hulls



A dramatic demonstration of the durability of these World War II concrete barges was reported in U.S. papers in descriptions of the 1946 Bikini Atoll nuclear bomb tests [3.8]:

> "In the Bikini test two concrete fuel barges and a concrete drydock survived the blast, which sank five ships and damaged at least three score. One barge, No. 2160, was badly charred when the bomb ignited cargo fuel oil stored on her, but she was apparently in good shape otherwise with her decks well above the water line. The remaining yard oiler and the drydock, both farther removed from the blast center, suffered no apparent damage. Oiler 2160 was moored only a hundred yards from the *Nevada*, the bullseye for the test. Today the oilers were being towed in for a closeup inspection by naval construction men. In this same target area the carrier *Independence* was all but destroyed by the blast and subsequent fires, the cruisers *Pensacola* and *Salt Lake City* emerged with smashed stacks and superstructure, and the battleships *Pennsylvania* and *Arkansas* were so wrecked above the waterline they would have been useless in a naval engagement."

USS Quartz is still afloat as a part of a breakwater in Powell River, British Columbia

The water tightness pillars for reinforced concrete hull according to DNV

1. General
Low permeability concrete, limitations to stresses and nominal crack widths, well distributed cracks, and focus through constructability on proper placement of concrete

2. Compression zone
Requirement is based on the element's thickness and magnitude of the external/internal hydrostatic pressure differential. Compression zone depth typically exceeds concrete cover depth

3. Membrane compression
Where loss of tightness may lead to loss of stability, elements that shall remain watertight shall be designed with a minimum membrane compressive stress

Pillars 2 and 3 are hot topics in the ocean-based industry. Currently, DNV-ST-0119 does not allow through cracks during normal operating loading because:

a. Maintaining compression zone is an established goal to achieve leak tightness (i.e. proven historically)
b. Through cracks are known in some cases to impact the long-term durability of reinforcement
c. Dynamic cracks, which are constantly opening and closing, leading to degradation of concrete material

According to DNV a relaxation of the pillars 2 and 3 may be possible if bullets are satisfactorily addressed (a JIP is working on this)

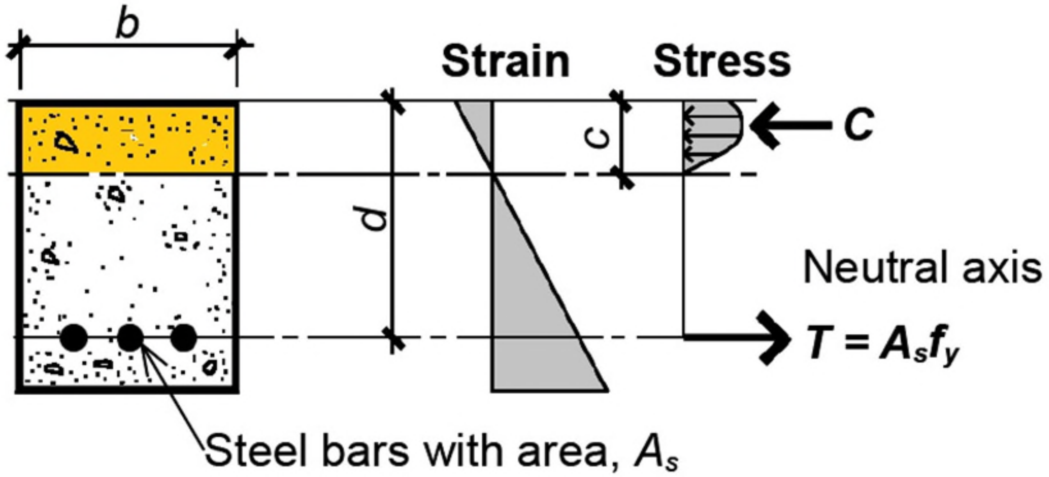
Water tightness pillar 2: Compression zone

DNV-ST-0119 - 7.5.1.7 All elements subjected to an external/internal hydrostatic pressure difference shall as a minimum tightness requirement be designed with a permanent compression zone not less than the larger of:

- 0.25 h
- Values as given in the following table

Pressure difference [kPa]	Depth of compression [mm]
< 150	100
> 150	200

Compression zone



Proceedings of (osti.gov)

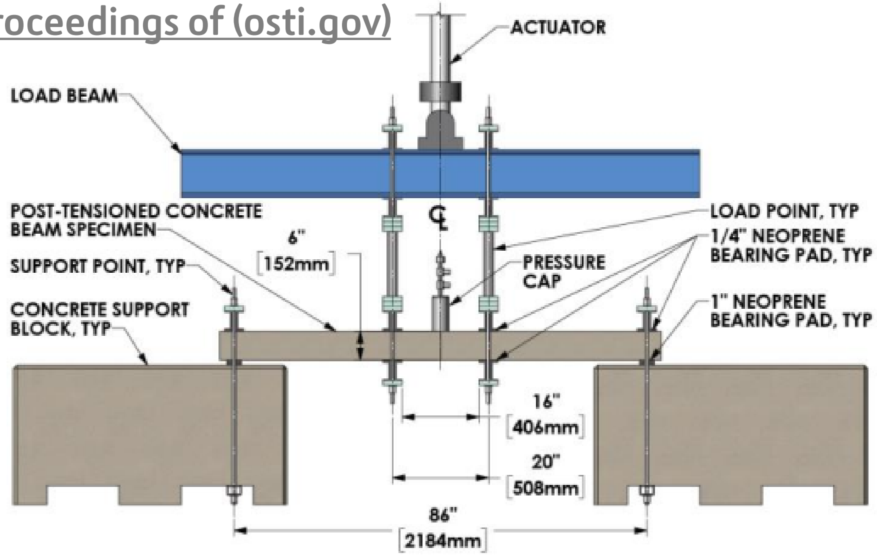


FIGURE 5. SIDE ELEVATION OF TEST SETUP

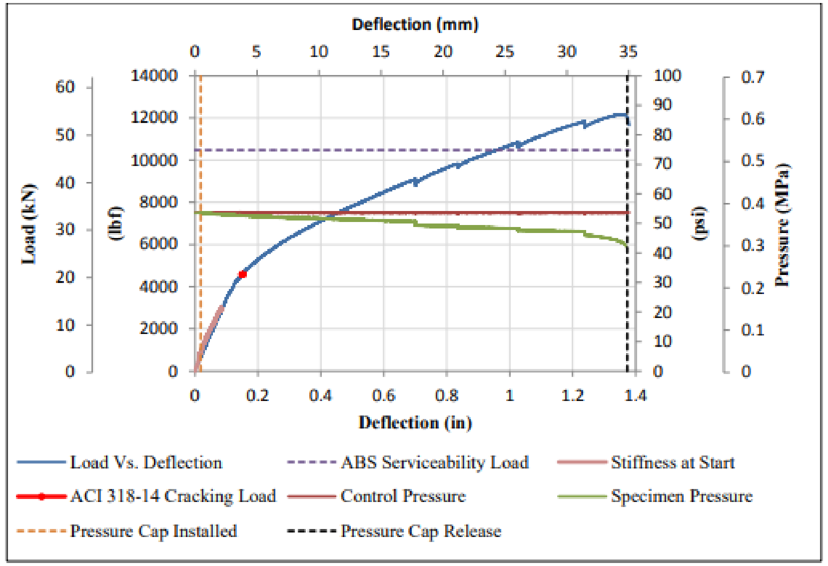
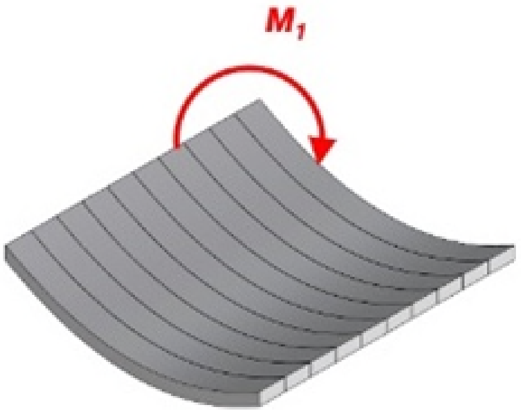


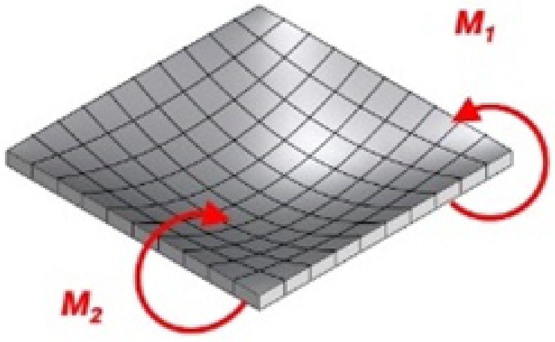
FIGURE 12. FATIGUE A #2, STIFFNESS VERIFICATION AND ULTIMATE STRENGTH TEST, MAXIMUM LOAD 12,249 LBF

Pillar 2: It is not straightforward extending the compression zone concept from one-way to two-way slabs

One-way slab

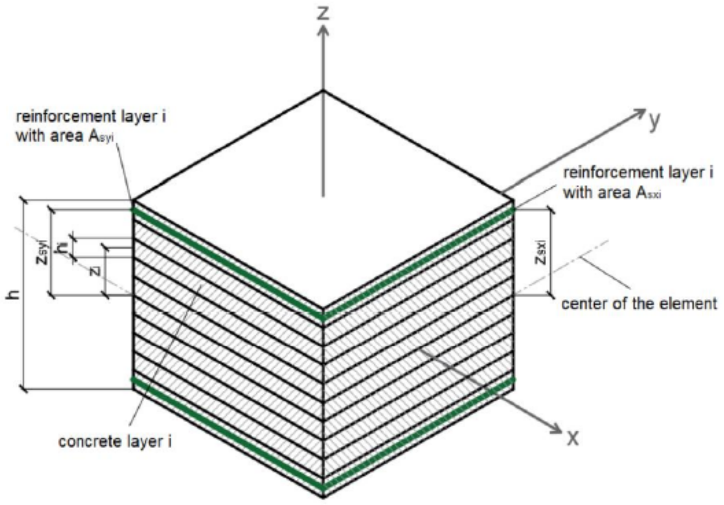


Two-way slab



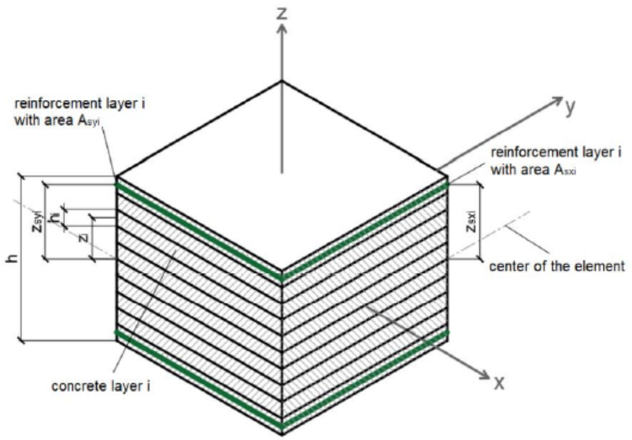
Compression zone depth definition?

RC shell modelled as multi-layered shell

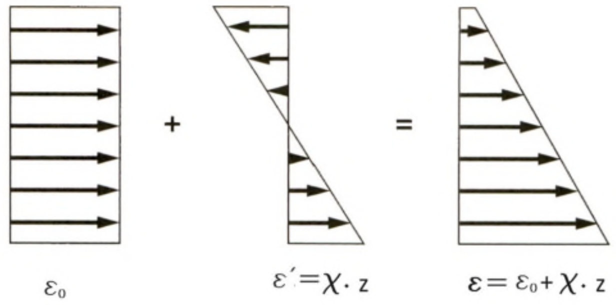


Pillar 2: Proposal for the extension of the compression zone concept from one-way to two-way slabs

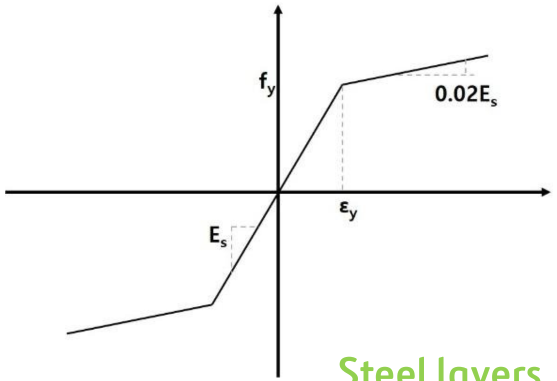
https://doi.org/10.1590/S1983-41952021000300005



Estimation of strains in each layer



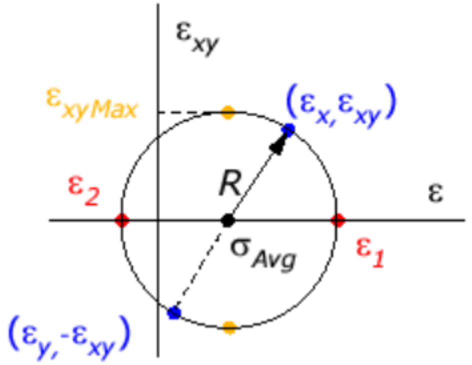
Evaluation of the stresses along the x-y directions



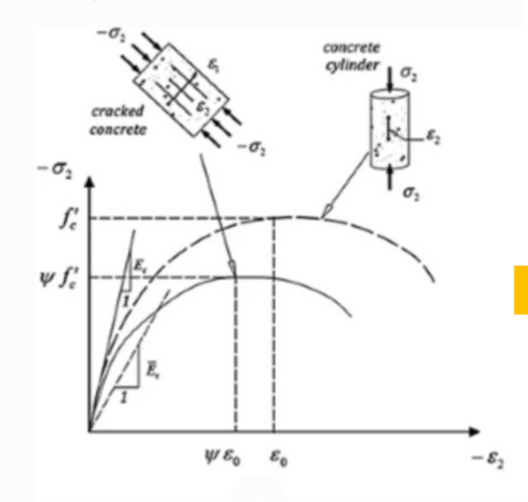
Steel layers

Concrete layers

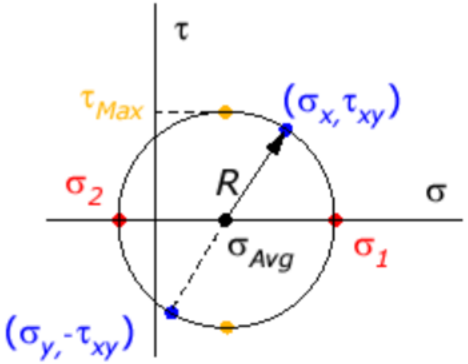
Evaluation of the principal strain directions



Evaluation of the principal stresses



Evaluation of the stresses along the x-y directions

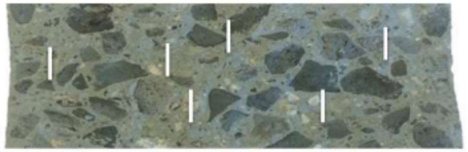


Integration

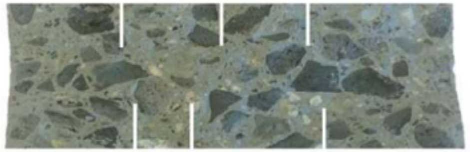
Concrete layers	Steel layers
$N_{cx} = \Sigma(\sigma_{xi} \cdot h_i)$	$N_{sx} = \Sigma(\sigma_{sxi} \cdot A_{sxi})$
$N_{cy} = \Sigma(\sigma_{yi} \cdot h_i)$	$N_{sy} = \Sigma(\sigma_{syi} \cdot A_{syi})$
$N_{cxy} = \Sigma(\tau_{xyi} \cdot h_i)$	
$M_{cx} = \Sigma(\sigma_{xi} \cdot h_i \cdot z_i)$	$M_{sx} = \Sigma(\sigma_{sxi} \cdot A_{sxi} \cdot z_{sxi})$
$M_{cy} = \Sigma(\sigma_{yi} \cdot h_i \cdot z_i)$	$M_{sy} = \Sigma(\sigma_{syi} \cdot A_{syi} \cdot z_{syi})$
$M_{cxy} = \Sigma(\tau_{xyi} \cdot h_i \cdot z_i)$	

Water tightness pillar 3: Membrane compression

Permeability porosity dependent

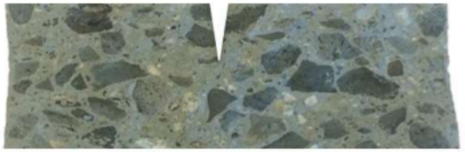


Internal micro-cracks



Surface cracks

Pillar 2



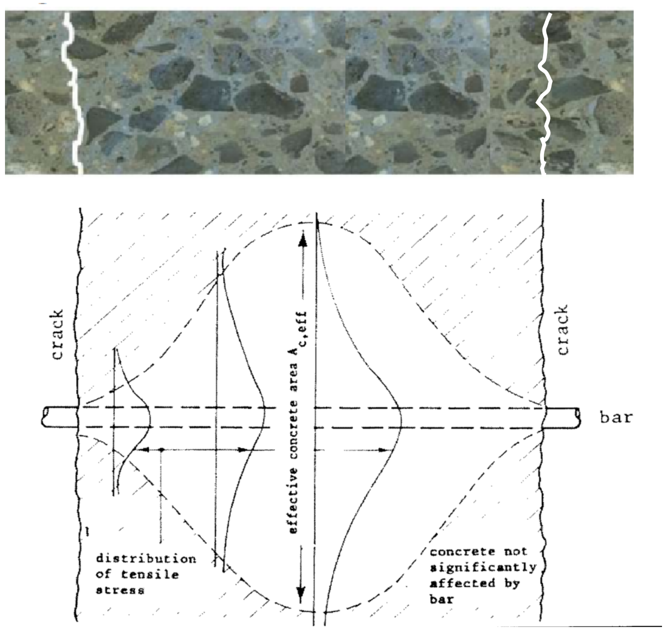
Flexural cracks

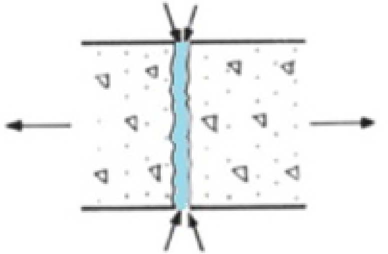
Permeability cracking dependent

Through cracking

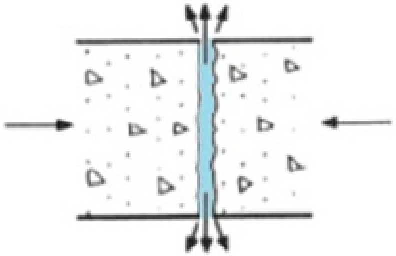
Pillar 1

Pillar 3

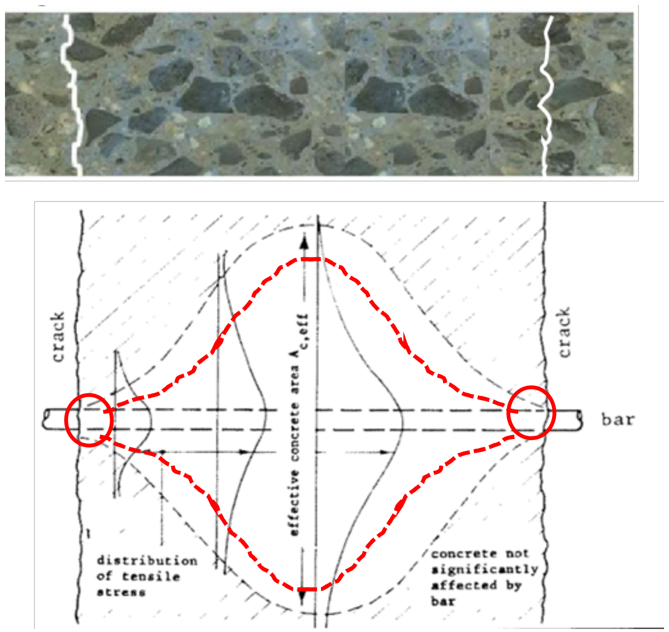




Opening crack



Closing crack

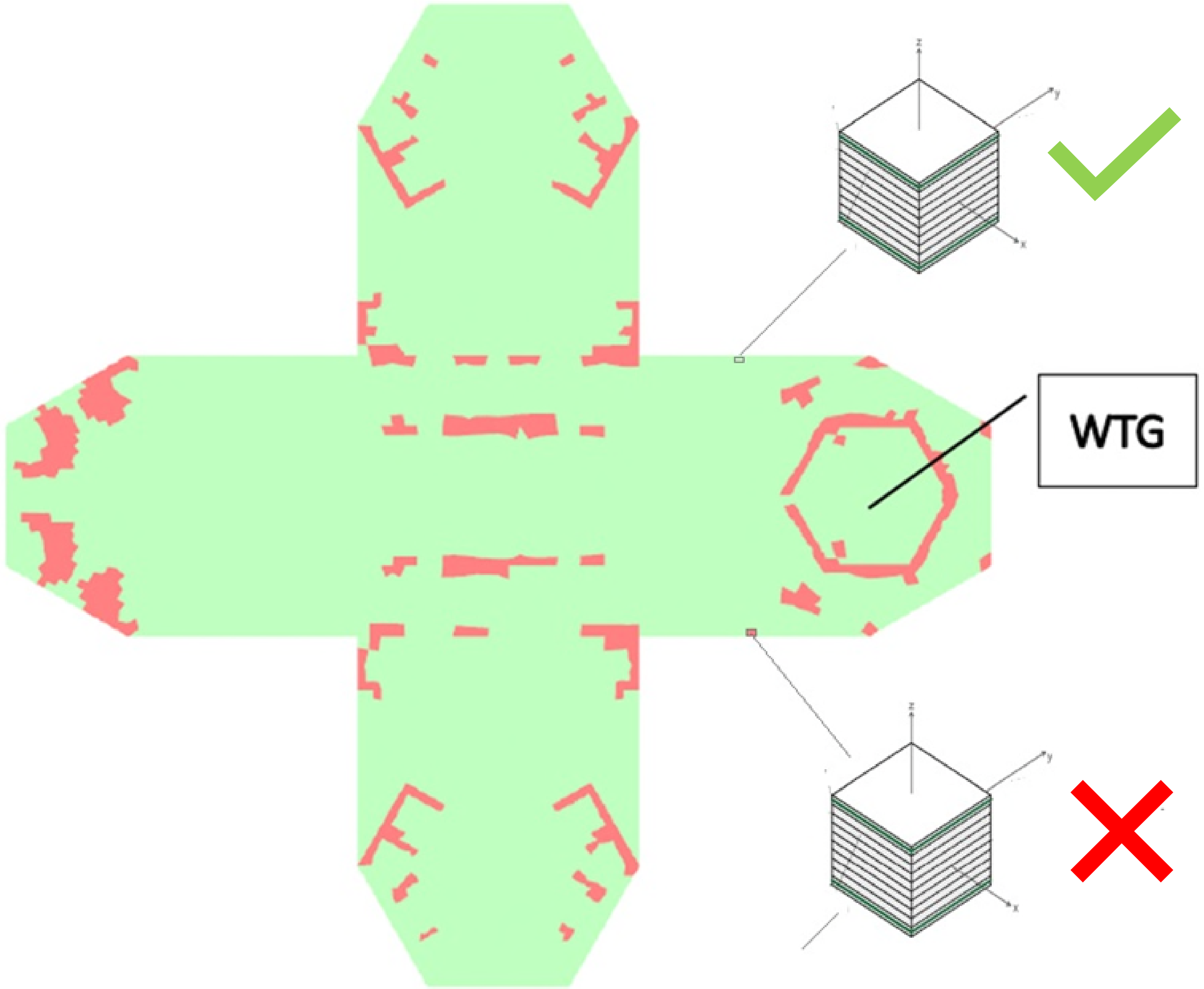


Watertightness pillars: watertightness check example

Step 1: ULS is checked with the minimum amount of passive requirement prescribed by the code

Step 2: Active reinforcement is introduced to guarantee the minimum compressive membrane stress (Pillar 3)

Step 3: The minimum depth of the compressed zone of the walls is checked (Pillar2)



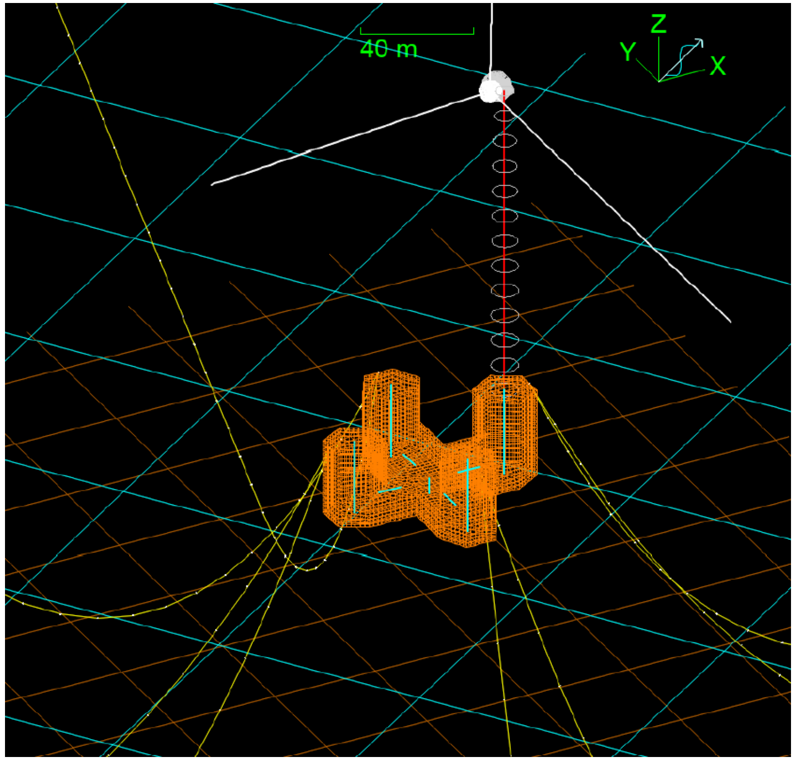
Pillar 2 AND Pillar 3 satisfied

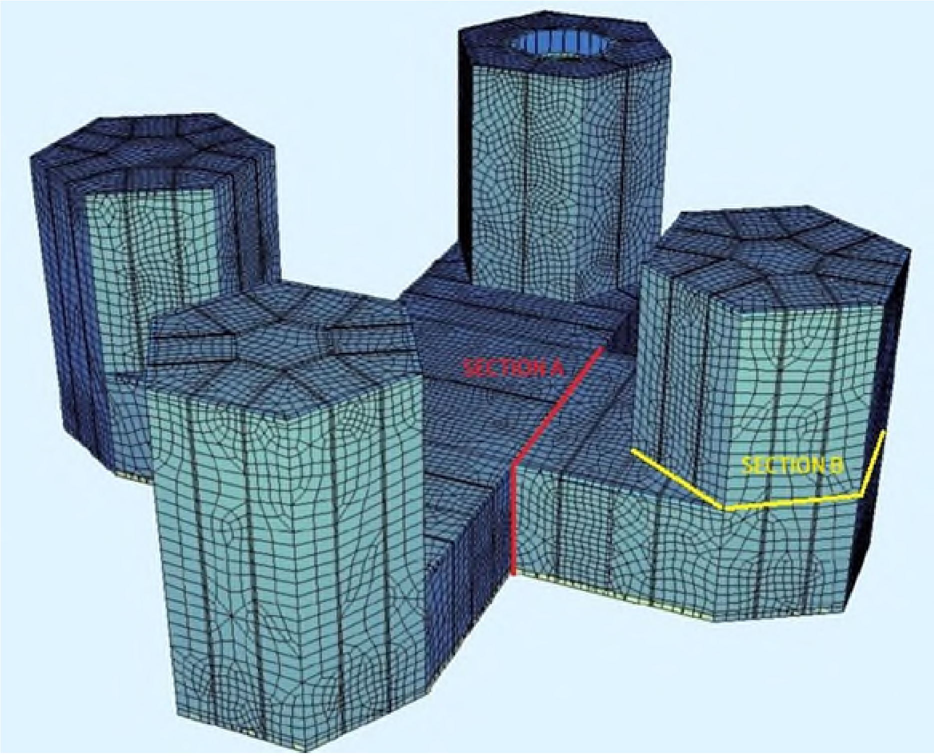
Pillar 2 OR Pillar 3 NOT satisfied

Water tightness checks: Evaluation of the internal forces

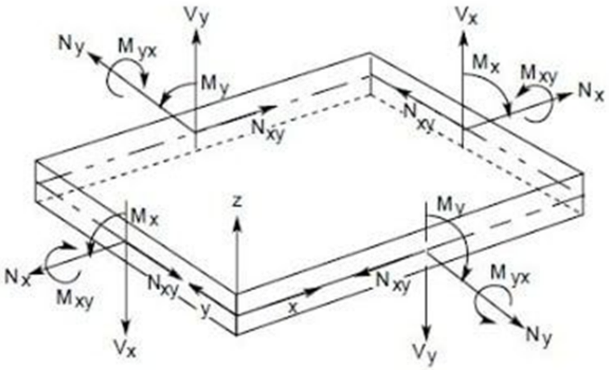
DNV-ST-0119 - 7.5.3.1 The environmental loading effect (E) used to check for watertightness should be determined as the environmental load effect which is not exceeded more than 100 times during the design life of the structure. It shall be demonstrated that in the periods where this load is exceeded, any potential leakage does not lead to the loss of stability of the structure.

…but at which level do we need to consider the load effect?

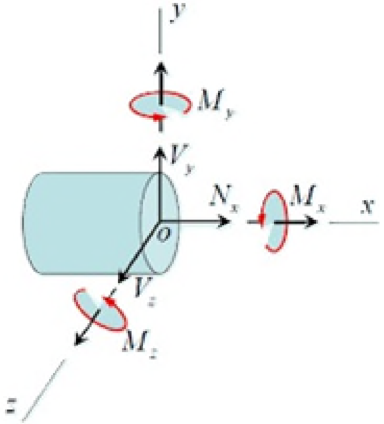




…at element level?

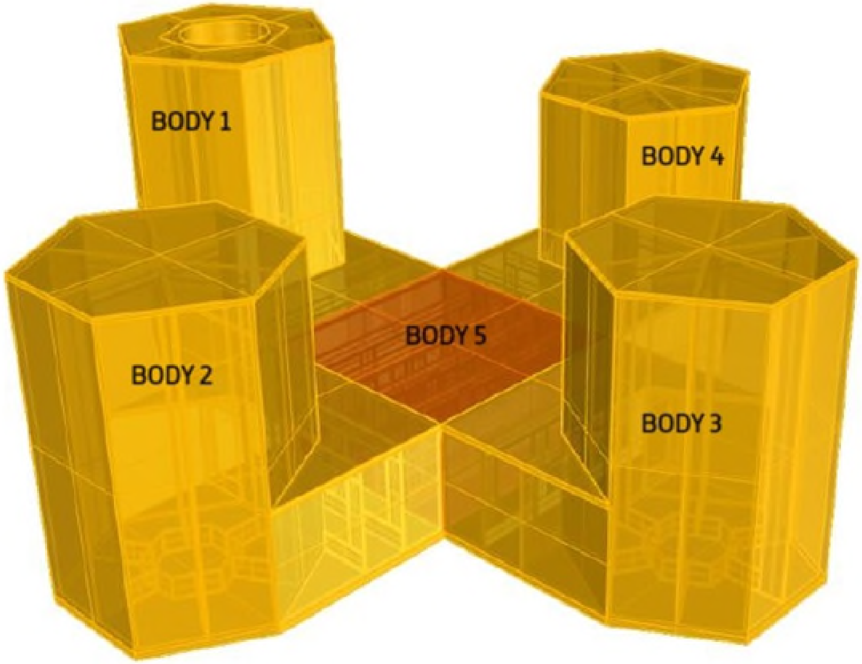


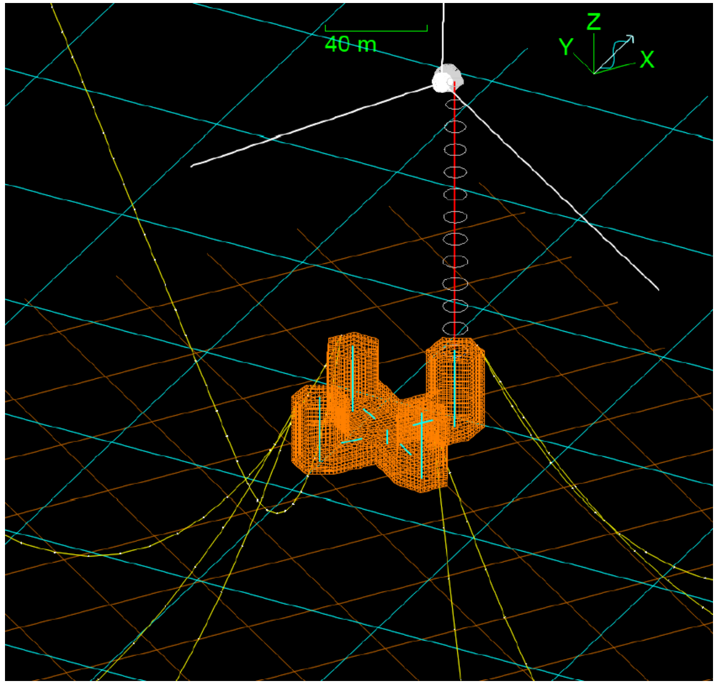
…at section level?



Water tightness checks: Evaluation of the internal forces

It seams reasonable performing this evaluation at section level using a multibody model (for ring pontoons is not straightforward)





	Hydrostatic	Selfweight	Environmental	Prestress
ULSa	1.25	1.25	0.70	0.9/1.1
ULSb	1.00	1.00	1.35	0.9/1.1
SLS (crack, watertigh)	1.00	1.00	0.50	1.00

Conclusions

- A review of pillar 3 is desirable especially of the level of membrane compressive stress to be guaranteed (i.e. $\geq$ 0 Mpa; $\geq$ 0.5 MPa) due to its high impact on the active steel quantity

- A more operative definition of the load level to be considered for the watertightness verifications is advisable (similar to that contained in DNV-ST-C502)