Evaluation and Design of Large Precast Concrete Panels as Modules of Tanks for Smolt Breeding

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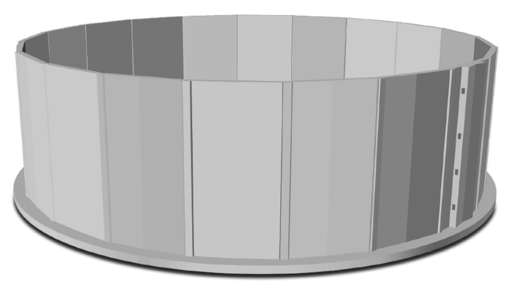
Problem

In accordance with an increasing entry into onshore fish farming, the concrete tanks tends to increase in size. This implies larger loads and typically the need for a more complex arrangement. In order to remain functional and sustainable, the performance of the individual panels should then be further investigated. By making use of prestressed concrete, which introduces beneficial compressive forces in the structure, the concrete cracking may be manipulated so to provide a watertight structure. As the vulnerability for buckling increases for larger and more slender panels, this failure mode may become dimensioning regarding the amount of prestress.

Introduction

Concrete is defined as a high-strength material possessing a large compressive capacity. However, it shows rather poor properties when loaded in tension as it cracks at a low value of tensile stress. By applying steel reinforcement for the uptake of tensile stress, one may obtain a composite useful in more general applications. The steel may either be introduced as slack or prestressed, the latter giving structural resistance prior to the intentional external loading.

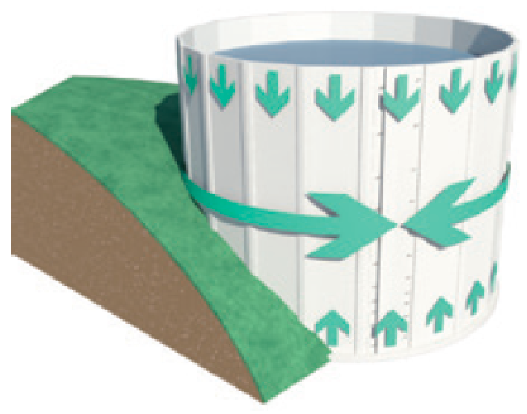
In relation to site casting of concrete, the use of precast concrete elements reduces the overall time of deliverance. As the elements are casted at fabrication halls in controlled environments, they are more likely to obtain the intended properties. The tank is then assembled by rectangular planar elements resulting in a polygonal shape.



[1] presents general rules when applying concrete in structural applications. It also covers the use of ordinary as well as prestressed reinforcement. As the tank should operate within the field of aquaculture, [2] highlights some special considerations to resist evacuation of fish. The tank may be classified as a liquid-retaining structure, which is further handled in [3]. This standard sorts the design issue with respect to the necessarily degree of watertightness.

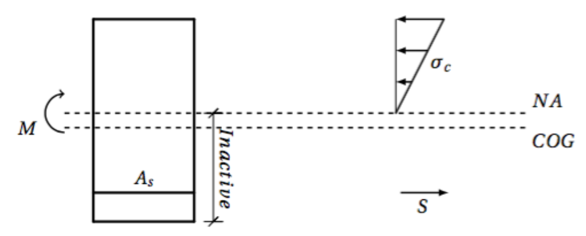
Tightness Class	Requirements for leakage
0	Some degree of leakage acceptable, or leakage of liquids irrelevant.
1	Leakage to be limited to a small amount. Some surface staining or damp patches acceptable.
2	Leakage to be minimal. Appearance not to be impaired by staining.
3	No leakage permitted

Typically tightness class 3 or 4, stating a more or less completely watertight structure, is governing for the design. [3] then suggest the use of prestressing in order to limit the width of the cracks. This may be done implicitly by enforcing a compressive zone of height $\min[50mm, 0, 2 \cdot t]$ in the examined member, while holding the resulting steel and concrete stress within *reasonable* values.



Material property

A steel reinforced concrete panel forms an inhomogeneous material. The presence of reinforcement leads to a stiffening effect of the cross-section. Since reinforcement typically are provided with different quantities in the load-carrying directions, this causes anisotropic material properties. As cracking of concrete is a directional issue, leading to cross-sectional degradation, this will further strengthen the anisotropicity.



The illustration shows a cracked reinforced concrete section of a panel strip. An equivalent concrete moment of inertia may then be expressed according to [4] as:

$$I_{c-eq} = \frac{1}{2} \cdot \alpha^2 \cdot \left(1 - \frac{\alpha}{3}\right) \cdot 10^3 \cdot d^3$$

Where $\alpha = \frac{x}{d}$ and x denotes the height of the compressive zone. d is the vertical distance from reinforcement to the upper edge of the concrete section.

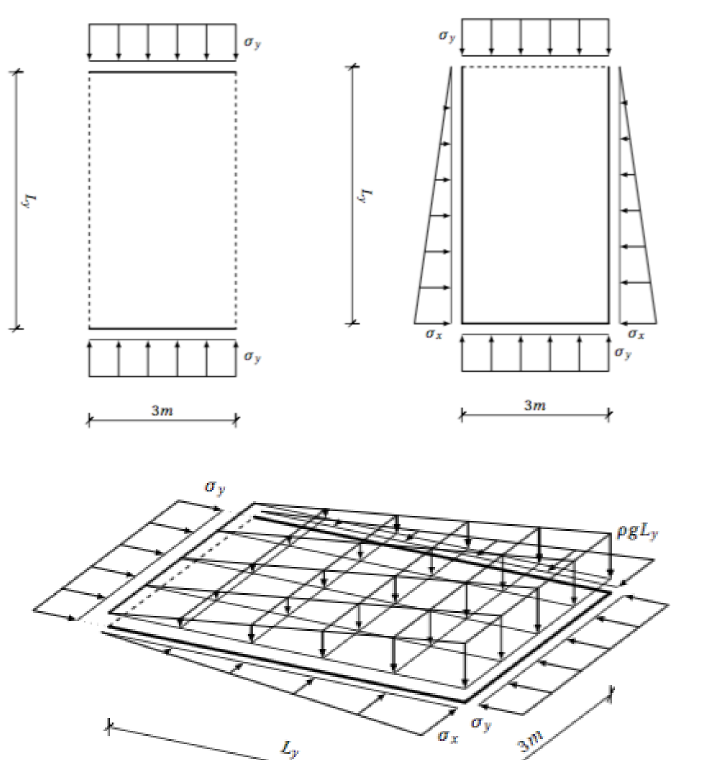
The buckling analysis makes use of a homogenous and isotropic material model. A simplified approach to incorporate the structural effects from reinforcement and cracking makes use of a equivalent panel thickness. By enforcing equality in the moment of inertia corresponding to a cracked reinforced section, a reduced equivalent thickness may reflect these *non-linear* material properties.

$$t_{eq} = \sqrt[3]{\frac{12 \cdot I_{c-eq}}{10^3}}$$

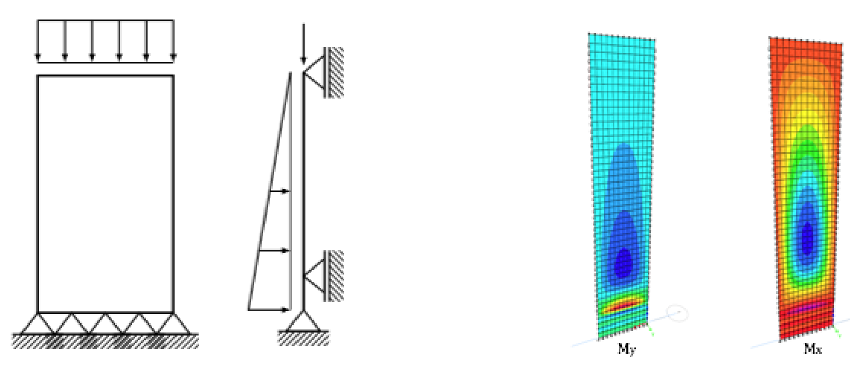
Buckling of prestressed panels

Buckling analyses are performed in Abaqus/CAE by the use of shell elements. It is differentiated with respect to three load-configurations, representing the stages in the construction. The effect of prestress is captured by considering external in-plane loading. The panel thickness is taken as 300mm, while the width is given as 3m. Within each stage, the panel performance is examined in terms of span ratio $\frac{L_y}{L_x}$ by increasing the panel height.

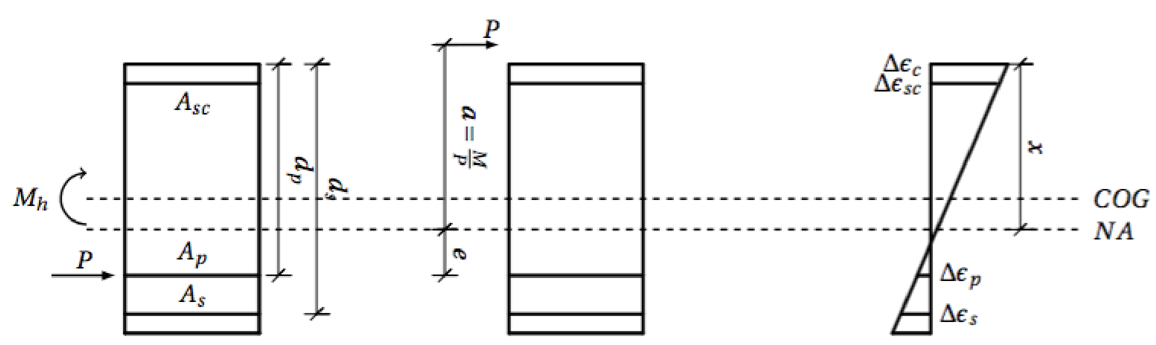
- Vertical prestressing in fabric, i.e panel subjected to compressive stress at the short edges
- Further perimetric prestressing at site, i.e panel subjected to biaxial compression
- Operational condition, i.e biaxial compressed panel subjected to lateral pressure



Design for watertightness

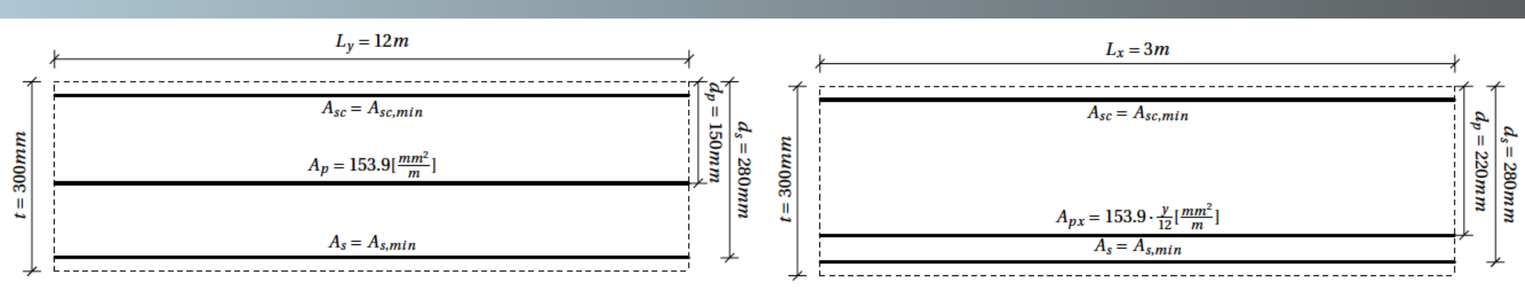


A prestressing design proposal is performed based on a linear calculation model adopted from [4]. The prestressing force and the moment contribution from the hydrostatic pressure are captured as one single eccentric load. As the panel acts as a two-way slab in flexural action, the study is carried out for critical strips in each of two principal directions of the panel. The maximum directional values of M_h, considering a panel of height 12m subjected to water pressure are found by an analysis in a building software named Etabs.



Either by increasing the amount of prestress or the distance d_p, this will lead to a relaxation of the loading introduced by the hydrostatic pressure. The compressive zone of the section, x, may then be manipulated so to fullfill requirements related to watertightness.

Results and conclusions



The figures shows the proposed directional prestressing design. While the y-directional prestressed reinforcement are provided at panel centre, the equivalent x-directional reinforcement are placed with an eccentricity giving even more beneficial characteristics. The amount of ordinary reinforcement is taken as a minimum value corresponding to [1]. Buckling by application of vertical prestress in fabric turns out to be most critical. Although the proposed prestressing design do not violate this limit, it may become a potential design issue for even larger and more slender panels.

References

[1] NS-EN 1992-1 (2008): *Eurocode 2: Design of concrete structures - Part 1: General rules and rules for buildings.*

[2] NS 9416 (2013): *Landbased aquaculture farms for fish - Requirements for risk analysis, design, execution, operation, user handbook and product data sheet.*

[3] NS-EN 1992-3 (2009): *Design of concrete structures - Part 3: Liquid retaining and containment structures.*

[4] Sørensen, S.I. (2013): *Betongkonstruksjoner, 2nd edition.*