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Punching Shear in Deep Unreinforced Underwater Concrete Floors

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Summary: *In the relatively layered soft soil of the Netherlands, excavations very often consist of sheetpile walls and a concrete floor. A concrete floor is used because of the combination of the forces and water tightness. Due to the water level the concrete floor is constructed underwater. After construction of the concrete floor water can be drained out of the excavation. Because of the hydrostatical pressure, the concrete floor has to be anchored to the soil beneath with anchors or piles. Deep floors are constructed with an anchor, to keep the concrete floor in position. The small dimensions of the anchor related to the pile dimensions are subject of more examples related to the new Dutch recommendation.*

1 INTRODUCTION

Several methods were till 2001 used to design the unreinforced underwater concrete floor. In 2001 a new Dutch recommendation [1] in this field has been published. Background FEM models are set-up to simulate some phenomena of this typical unreinforced underwater concrete floors. The first split-up is made in undeep and deep floors. The undeep floors are normally constructed with piles, to keep the floor in position after casting. There are not so many doubts around this type of concrete floors. The phenomena, which has to be tackled, is a punching shear problem, with respect to the dimensions of the unreinforced floor thickness and the piles. Research in the past from publications of CEB-FIP [2,3], Schlaich and others [4] has been published in this area. The connection between the pile and anchor at one hand and the concrete floor at the other hand can be simulated very well by a FE non-linear analysis.

An additional doubt is the behaviour of the sheet pile to the concrete floor. A normal force and a bending moment from the sheet pile to the floor are assumed, the non-linear analyses can prove if this assumption is correct.

Post diction analyses of the performed half full-scale tests can confirm these model type results. Afterwards by simplicity in practise, these higher model results have to be transferred to beam model design environment. It is to complicate to prescribe at this moment 3D models in engineering practise for these types of structures.

2 CASE STUDY

In engineering practise the underwater concrete floor will be dimensioned by a linear beam model calculation. A strip over the width of the floor (the short direction of the pit) will be taken as the length of the beam model. The point of departure is a beam of 1 m wide, a depth of 1 meter and a length of 24 meters. The floor will be anchored by 8 anchors with a distance each to each other of 2.35 meter. A concrete strength for the underwater concrete of C25 was used. The water pressure to the floor has a value of 17.6-meter. Including the dead weight of the concrete floor, an overall vertical oriented pressure of 150 kN/m^2 will be positioned to the lower surface of the floor. The supports of the concrete floor from the sheet wall and anchors are translated into translation spring elements.
A spring constant has been calculated:

Sheet pile: K_{vert} = 90,000 kN/m for 1 m sheet wall
K_{hor} = 37,000 kN/m for 1 m sheet wall
Anchor: K_{anchor} = 47,000 kN/m for each anchor

A result of the beam model is the bending moment distribution over the length of the model.

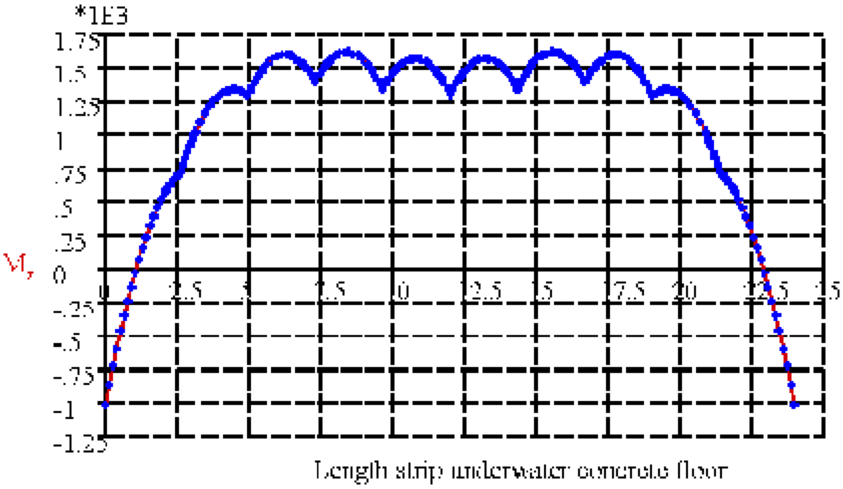

Figure 1: Bending moment distribution M_z over the length of the beam model

It is clearly shown that there are sharp changes in the moment values at the connection of the anchor to the concrete floor. Instead of the beam model, in a master thesis of Kwaaitaal [4] a shell model has been set-up to show the moment distribution over the width of the floor.
In this model also the head to head distance of the anchors (=2.4 meter) in the longest side of the pit, has taken into account. The differences of the bending moments over the length are 4% at the maximum, which means that upgrading of the model doesn't give a better design.
The distribution of the distributed moment over the width gives local peak behaviour near the connection of the anchor to the floor; which is presented in figure 2.

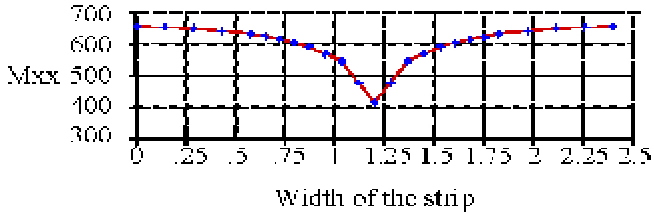

Figure 2. Moment distribution m_{xx} over the width of the strip of the concrete floor

The linear static analysis was to investigate the behaviour of the anchor connection to the concrete floor. The research confirms the punching behaviour near the anchor connection.

3 NONLINEAR INVESTIGATION

The most important parameters in engineering practise related to the underwater concrete floor are varied in the non-linear study. In this case the water pressure is so high, that the anchor dimension counts already the maximum. The distance between the anchors has been varied into 2.0-2.5-3.0-3.5-4.0 meter, the floor thickness into 0.8-1.0-1.2-1.4 meter and the normal pressure into 0.0-0.5-1.0 N/m^2. A total of 55 non-linear analyses are made. A first minimalisation of the model is made to take 1/8 (a triangle) of the concrete floor, including 6 (partly taken) anchors. To minimize the solid model, an inner (triangle) part of the model enclosed to 3 anchors has been made non-linear, which is shown in the upper view of the left upper corner of figure 3.

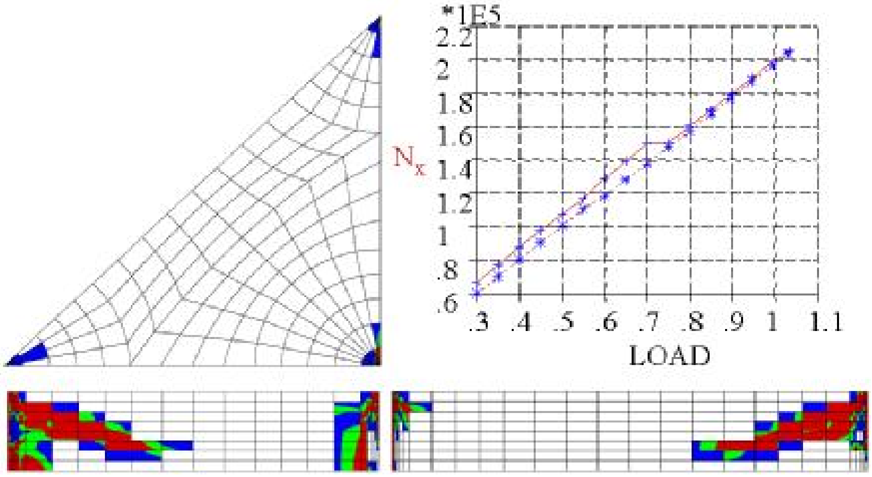

Figure 3. Overview results non-linear analyses part of the concrete floor

The non-linear material model, which is used for the concrete, is the Total Strain Model with a crack brittle branch and a constant plasticity compression branch. The ultimate tension limit is 1.15 N/mm^2; the plasticity compression limit has a value of 15.0 N/mm^2.

Figure 3 shows in the right upper corner a view of two axial force developments. The straight line represents the axial force of an anchor in the linear area, the other line the axial force of the anchor in the non-linear area by loading the water pressure to the floor. The drop back of the axial force of the anchor arises at a load factor of 0.7. At this point the non-linear part of the floor has estimated the limit of the chosen model. The left upper corner shows an upper view of the non-linear area including the cracks; a front side view of the cracked area and a backside view over the diagonal of the cracked area complete the figure. A cone from the concrete floor has been formed already, which is similar to the punching behaviour of a floor.

4 EXPERIMENTS

Half full-scale tests of the concrete floor with punching behaviour have been made in 2003 by the Delft University of Technology [6]. Floors with a thickness of 0.5 and 0.75 m were carried out. These floors have been prestressed with the already mentioned values. It has been split up in tests with one side prestressing and two sided prestressed.

Figure 4 Test set-up + a result of the punching behaviour of the floor with the cone

Post diction analyses will tell us the coming months if we can simulate this behaviour. Conclusions can be made after completing the numerical simulation.

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