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COMPUTER NONLINEAR ANALYSIS OF THE INFLUENCE OF MATERIAL CHARACTERISTICS ON THE RESPONSE OF A BASEMENT STRUCTURE LOADED BY GROUND WATER BUOYANCY

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Abstract: *The paper focuses on a computer nonlinear analysis of the formation and development of cracks in a concrete slab exposed to a uniform continuous load on the lower surface. The analysis is based on an actual example of the formation and development of cracks of the width of approx. 0.3 mm in a basement slab exposed to ground water buoyancy. The paper illustrates the setting of the material model of the reinforced concrete slab according to the actual material properties and the similarity of the computer results to an incident of real damage to the basement structure. On the basis of the same cracks on the model and on the real structure, a load value that caused this damage was estimated. The aim of this article was to find such material characteristics of a basement structure of the same size and shape and under the same extreme load that shows cracks with a maximum width of 0.1 mm to ensure the waterproofing safety.*

Keywords: Concrete, Cracks, Computer analysis, Ground water buoyancy, Material characteristics.

1. Introduction

This paper deals with the analysis of the development of cracks in a basement reinforced concrete slab of a residential building. The thickness of the slab is predominantly 300 mm, the thicker parts being 600, 800, 900 and 1000 mm. The variations in thickness between the different parts are solved by bevels. Due to the expected groundwater buoyancy (1.5 m), the building foundation is still supplemented by 9 tension micropiles holding the slab in the middle of the span, in the place with the maximum anticipated effect of buoyancy. The thickness of the perimeter walls is 300 mm.

2. Computer Analysis

The basement slab contains significant cracks and water leaks up to the upper surface of the slab. To determine the causes of the damage, a detailed computer analysis of internal forces, stress, strain and the crack width was carried out . The static model was created in ATENA software 4.3.1, ATENA 3D ENGINEERING (Červenka et al., 2002, 2013).

The program is based on the finite element method. The model of the structure was loaded by the the structure's own weight, by the forces from the upper structure, and by the hydrostatic pressure of the water column, corresponding to the ground water level 1.5 m over the basement slab (as it was designed).

The static model comprises plate macro-elements reinforced by the specified degree of reinforcement. The plate elements are quadrangular, to be meshed by finite elements - quadratic bricks. Concrete C 30/37, with mean values of the material properties, is used as the construction material of the slab. The

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steel reinforcement B 500B is specified, inputted also with the mean values. Bevels under the columns are modeled using standard macro-elements. The walls and pillars are replaced by the load distribution elements, which are modeled as plates with a height of 300 mm. For these units, 3D Elastic material is specified. The underlying bedrock is modeled using springs for areas with a compression stiffness of 45 MPa. The length of the spring corresponds to the gravel layer thickness of 200 mm. Extra horizontal supports are attached to the slab and its bevels, because the springs support the slab only in the vertical direction. Additional vertical supports are represented by piles modeled by a load distribution plate of 400 x 400 mm. The upper face of the plate is propped against the slab in a vertical direction. This support is put in action only when the model is loaded by increasing the ground water level. Thus, the value of the pressure from the water level of 1.5 m corresponds to the value of the vertical reaction 0 kN. The model is loaded by the slab's own weight (step 1),, by the upper structure (values of forces and loads according to the static calculation - 5 steps), by the basic ground water level 1.5 m over the basement slab (in five steps, each 20 % of the total value), and by the rising ground water level, when at each step the load increases by the equivalent of 0.1 m of the ground water level up to the level of 3.5 m (the level rises by 2 m in 20 steps). The water level then falls to 1.2 m, before rising again to the original level of 1.5 meters, again in steps of 0.1 m.

The aim of this procedure was to determine whether the significant cracks in the slab could have been caused by the effect of groundwater buoyancy, and what the approximate critical value was.

During the decrease from the water column height of 1.663 m to the height of 1.54 m, the numerical model showed an average crack width decrease of 0.0133 mm. During the further water column decrease down to a height of 1.267 m, an average crack width decrease of 0.02 mm was calculated, and in a further decrease down to the water column height of 1.238 m, an average crack width of 0.008 mm was determined. In a subsequent increase up to a level of 1.485 m, the average crack width increased up to 0.018 mm. These results agree very well with the measured values.

The computer analysis shows that the cracks in the slab are caused by water buoyancy on the lower surface of the slab. The static load, according to which the slab was designed, took into consideration water pressure corresponding to the height of the water column of 1.5 m over the basement slab. The results of the computer analysis of loading the basement slab by the upper construction and the pressure of the water column of 1.5 m showed cracks with a width of 0.072 mm. More cracks started to appear with the increase in water level (and therefore the pressure). The cracks of the width exceeding 0.1 mm are critical for the impermeability of the structure. In some places of the tested slab a crack width of 0.1 mm was already exceeded by a water column height of 1.8 m. The next increase in the water level up to 3.5 m induces the development of a network of cracks, some of them reaching a width of 0.295 mm. In the following simulation of the decrease of the water column height back to the value of 1.5 m, the maximum crack width falls to 0.172 mm (refer with: Fig. 1.).

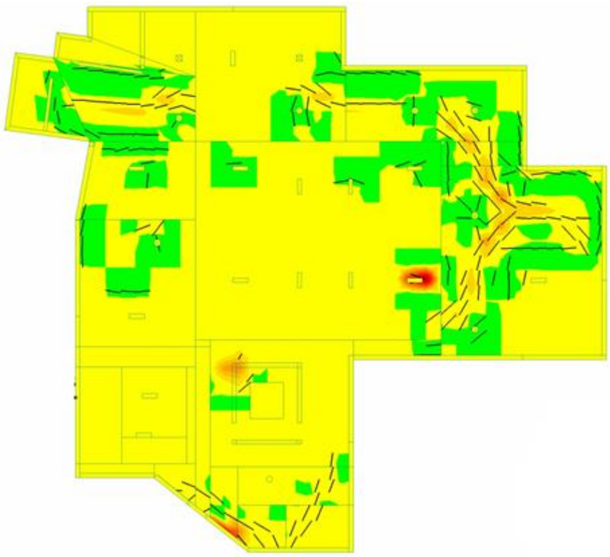

Fig. 1: Formation and development of cracks in a reinforced concrete slab - equivalent height of water column 3.5 m, max. crack width 0.295 mm.

Tab. 1: Table of crack widths depending on the height of water column.

Load direction	Height of water column [m]	Max. crack width [m]	Load direction	Height of water column [m]	Max. crack width [m]
increasing	1,5	$7,15*10^{-5}$	decreasing	3,1	$2,76*10^{-4}$
	1,6	$8,6*10^{-5}$		3	$2,67*10^{-4}$
	1,7	$9,37*10^{-5}$		2,9	$2,59*10^{-4}$
	1,8	$1,03*10^{-4}$		2,8	$2,52*10^{-4}$
	1,9	$1,11*10^{-4}$		2,7	$2,45*10^{-4}$
	2	$1,19*10^{-4}$		2,6	$2,39*10^{-4}$
	2,1	$1,31*10^{-4}$		2,5	$2,32*10^{-4}$
	2,2	$1,47*10^{-4}$		2,4	$2,25*10^{-4}$
	2,3	$1,56*10^{-4}$		2,3	$2,18*10^{-4}$
	2,4	$1,67*10^{-4}$		2,2	$2,11*10^{-4}$
	2,5	$1,63*10^{-4}$		2,1	$2,05*10^{-4}$
	2,6	$1,84*10^{-4}$		2	$2,01*10^{-4}$
	2,7	$1,98*10^{-4}$		1,9	$1,97*10^{-4}$
	2,8	$2,05*10^{-4}$		1,8	$1,90*10^{-4}$
	2,9	$2,17*10^{-4}$		1,7	$1,84*10^{-4}$
	3	$2,32*10^{-4}$		1,6	$1,77*10^{-4}$
	3,1	$2,43*10^{-4}$		1,5	$1,72*10^{-4}$
	3,2	$2,47*10^{-4}$		1,4	$1,66*10^{-4}$
	3,3	$2,62*10^{-4}$		1,3	$1,61*10^{-4}$
	3,4	$2,84*10^{-4}$		1,2	$1,55*10^{-4}$
	3,5	$2,95*10^{-4}$	increasing	1,3	$1,61*10^{-4}$
decreasing	3,4	$2,87*10^{-4}$		1,4	$1,66*10^{-4}$
	3,3	$2,92*10^{-4}$		1,5	$1,72*10^{-4}$
	3,2	$2,84*10^{-4}$		1,6	$1,77*10^{-4}$

In the next step, by successive iterations, the combination of material properties which gave a maximum crack width of 0.1 mm in a structure of the same dimensions and shape were found. Concrete C50/60 was used, and the reinforcement area was proposed as being double the area of the original proposal. So that along the upper surface bars of 25 mm were used at a distance of 50 mm in both directions, and along the lower surface of the profile bars of 12 mm were used at a distance of 125 mm. Thus, the remodeled structure carried a groundwater pressure of the equivalent water column height of 3.5 m with a maximal crack width of 0.1 mm (refer with: Fig. 2).

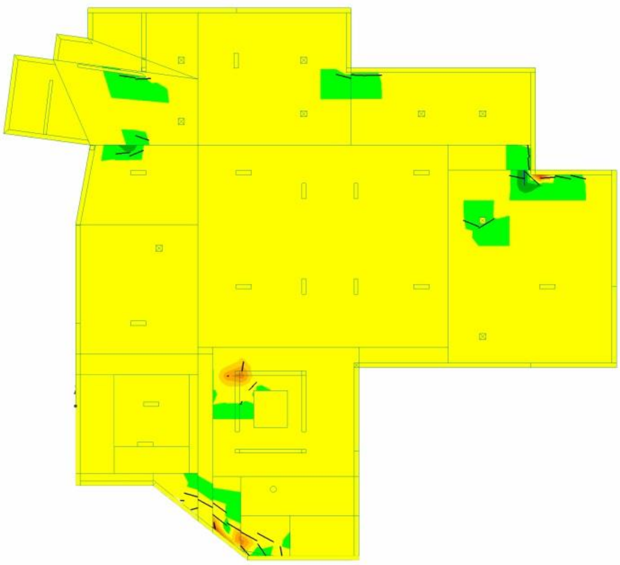

Fig. 2: Formation and development of cracks in a reinforced concrete slab with adapted material characteristics - equivalent height of water column 3.5 m, max. crack width 0.1 mm.

3. Conclusions

Cracks represent a typical failure mode of reinforced concrete slabs used as foundation plates. Considering the durability and serviceability of a structure, the most crucial cracks are those which lead to water penetration. Water generally leaks into cracks wider than 0.1 mm.

The cracks can originate in the process of chemical shrinkage during the setting and hardening of concrete, respectively in the process of bound contraction during the building of individual parts of the structure. The other cause of the crack development can be water buoyancy exceeding the design value.

It is therefore necessary to design the structure base plates so as to prevent water leakage. The structure should be designed using quality class of concrete and adequate reinforcement that can withstand water pressure.

Due to the frequent failures of the base plates caused by groundwater pressure is extremely important to perform preliminary surveys of groundwater layers and design the structure to the value of the maximum water pressure acting the structure.

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