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Calculus and experimental investigations on the caissons models used in construction of mooring keys

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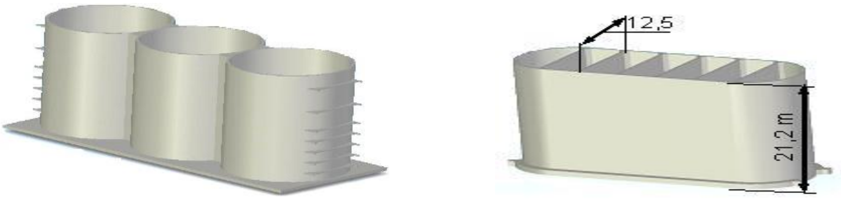
Abstract. The special quay infrastructure for mooring heavy boats is made of reinforced concrete caissons, in the form of thin-walled structures. These caissons are placed on the bottom of the sea, by means of radiators and filled with stone quarry. On these structures are built access roads for heavy trucks, rolling paths for rotary cranes and railways. The behaviour of these structures under service tasks has been investigated both by MEF and experimentally, using two combined techniques (reflexion-photoelelasticity and resistive strain gauge technique). The results of the researches carried out on two models of caissons showed that the maximum stresses recorded in their walls are below the allowable limit, and there is a good agreement between the calculation and experimental data.

Keywords. Mooring keys, caisson, finite elements, photoelasticity, strain gauge.

1. Introduction

The paper presents the results of a research program undertaken on the infrastructure elements used in the construction of special ships mooring.

On these elements, roadways for heavy trucks, rolling ways for rotating cranes and railways are constructed. High tonnage ships board at this quay in the Constanta South seaport. The infrastructure elements are built as partitioned caissons made of reinforced concrete, filled with quarry stones and leaning on the bottom of the sea.



a) b)

Fig. 1. Analysed structures.

The mechanical behavior of two types of partitioned caissons (Fig. 1, a and b) was analysed. The stress state due to the weight of the stones and supplementary loads transmitted through the rolling ways by the vehicles running on the upper part were determined both numerically using the finite element method and experimentally by reflection photoelasticity and strain gauges techniques.

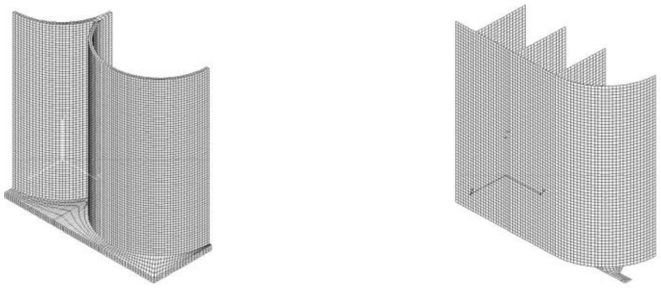
Due to the elevated dimensions of the caissons, the analyses were made using polycarbonate models, at a scale of 1:50. The data obtained through the investigations have put in evidence the maximum level of the stresses in the analysed structures and have given qualitative information about their mechanical behaviour. These results were taken into account in the design process of the infrastructure elements used in construction of the quay.

2. The Finite Element Analysis

The calculus models were meshed with 8 nodded or 20 nodded three dimensional isoparametric brick elements.

Owing to the symmetry, only a quarter of the structure was meshed. In Fig. 2 are presented meshes of the two types of caissons analysed.

The applied loads were: own weight of the caisson, weight of the padding materials (stones) with a value $q = 180$ kN/m^3, external pressure of the sea water and the load transmitted through the rolling ways by the vehicles running on the upper part of the structure.



Model 1

Model 2

Fig. 2. Meshes of the analysed caissons.

The load on the upper part of the structure was taken as a uniform distributed load of 100 N/m. Calculations were made for three different boundary set conditions (as Figure 4 shows):

1. supported at the ends;
2. supported at one end and in the middle;
3. uniform supported on the bottom of the sea.

In the Figure 3, the von Mises equivalent stress field is shown for the first models loaded only with the weight of the padding material and in the boundary condition 1.

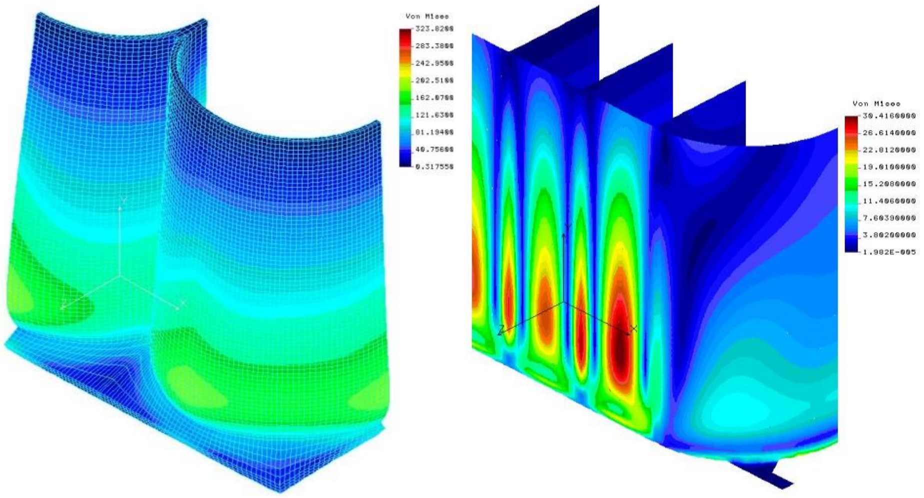


Fig. 3. Equivalent von Mises stress field for those two models.

The results of the finite element analyses show that the highest stresses appear in the second and third boundary condition cases on the upper and lower parts of the caissons, with smaller values on the lower part due to the stiffness effect of the foundation plate.

The highest stresses appear in the first model (18…20% higher than for model nr. 2) in the fillet areas between the vertical cylinders, both at the upper and lower part, due to the stress concentration effect.

3. Experimental Investigations

The stress state was determined using combined experimental techniques: reflection photoelasticity and strain gauges.

The aim of the photoelastic investigations was to put in evidence the areas of highest stresses.

Furthermore, in these areas, strain gauge rosettes on two-directions and three directions were glued.

Photoelastic investigations were carried out on the models of the caissons manufactured from polycarbonate at a scale of 1:50, for the same boundary conditions as those used in the numerical analysis. The models were covered on half of the lateral surface with a photoelectric foil of Araldit D, with a thickness of 1.3 mm.

The loading of the models was made by filling compartments with shots of cast iron of 2mm diameter having a specific weight $\gamma = 63$ kN/m^3.

A concentrated force $P_s = 10$ kN was applied, by means of a testing machine, on the upper part on the longitudinal axis, simulating the load transmitted through the rolling ways. Figure 4 shows loading of the photoelastic models.

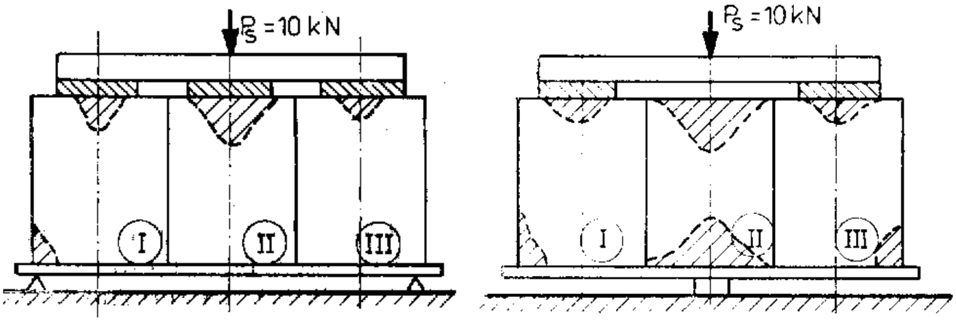


Fig. 4. Resting and loading of the models.

Surface of models covered with photoelastic foil were inspected with a reflection polariscope. Using the circularly polarized light, the high stressed areas were located. In these areas, the directions of the principal stresses were determined, with the polariscop fixed for plane polarized light.

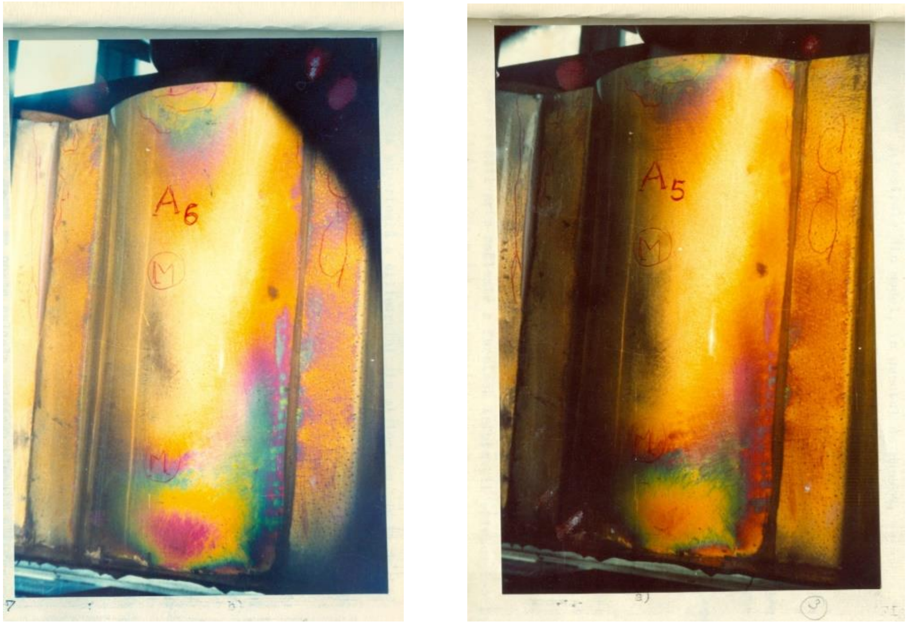
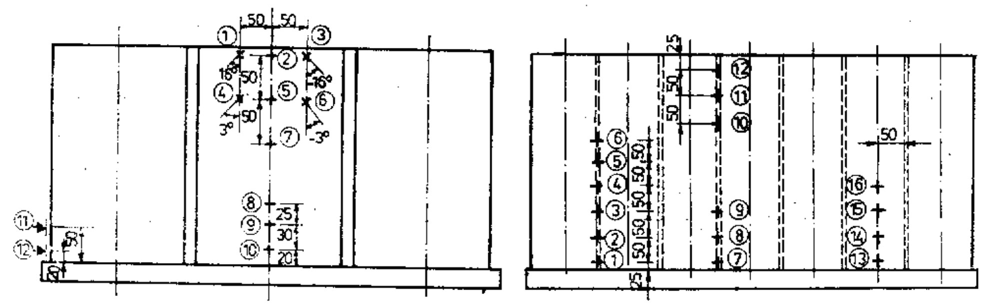


Fig. 5. Isochromatics field for the type1 caisson.



a. Type 1

b. Type 2

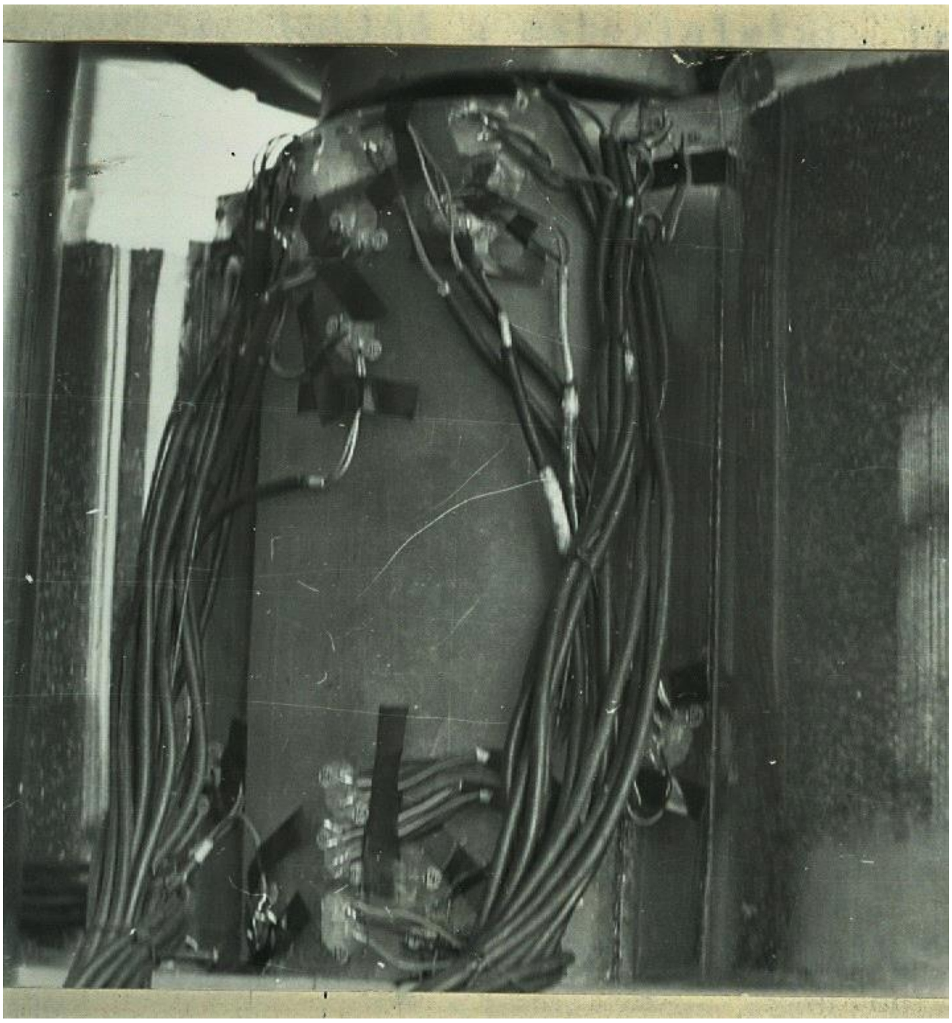


Fig. 6. Placement of stain gauge transducers on the two tipe of models.

For the type 1caisson, the high stressed areas were determined, for the first two resting modes, at the top of the central cylinder, as shown in Figure 4.

For the second type of caisson, the high stressed areas were recorded at the bottom of the caisson, in the vicinity of the support area.

In Figure 5 is presented isochromatic field recorded , at the top of the central cylinder for the first two resting modes.

In the measurement points, identified by reflection polariscope technique, electro-resistive transducers were applied on the two directions (12 transducers on the first model of the caisson and 16 on the second one). In Figure 6 is shown the location of the electro-resistive transducers for the two caissons models.

Fig. 7. Measurement equipment during tensometric determinations in the testing machine.

Strain measurement was done with Vishay equipment using the three-wire montage. Models were loaded in the same way as for the photoelastic determinations.

The Figure 7 presents the first model of the cheson, with the location of the electro-resistive transducers, during the tensometric determinations in the testing machine.

The principal stresses σ_1 and σ_2 in the measurement points were calculated with the expressions:

$$\sigma_1 = \frac{E}{1-\upsilon^2}\left(\varepsilon_1 + \upsilon\varepsilon_2\right) \tag{1}$$

$$\sigma_2 = \frac{E}{1-\upsilon^2}\left(\varepsilon_2 + \upsilon\varepsilon_1\right) \tag{2}$$

where E = $2{,}6.10^3$ MPa (experimental determined) is longitudinal modulus of elasticity of models material, υ = 0,38 is the Poisson`s coefficient, ε_1 and ε_2 are principal measured strain. Following the undertaken study, was found that for the all considered resting cases, the stresses in the type 1 caisson model are much higher (20,64MPa) than the stresses in the type 2 caisson. Thus, in case of the type 2 caisson, the highest stress was recorded at the upper side of the central cylinder, for case 2 of resting and was of 14.12 MPa.

4. Conclusions

The results obtained and presented in this papere showed an acceptable agreement between data obtained by the finite element calculus and data provided by experimental investigations.

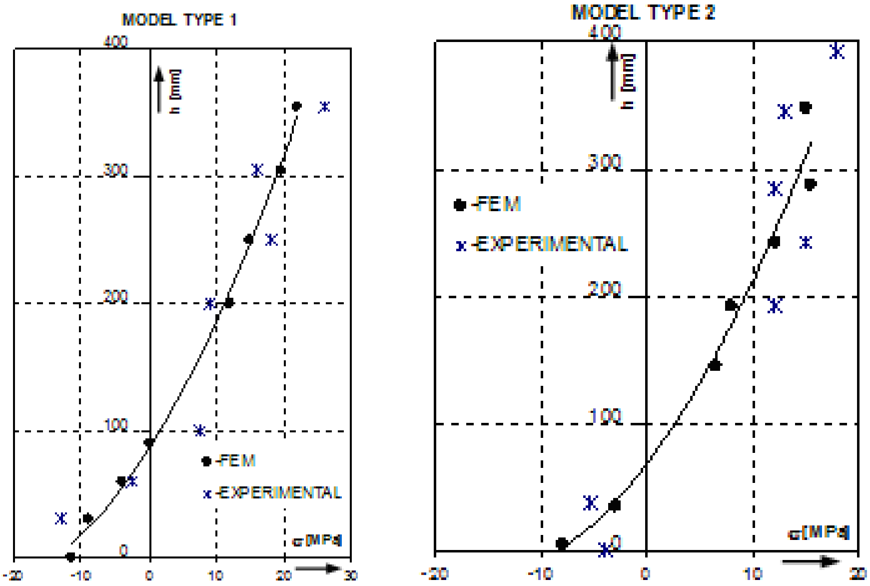


Fig. 8. Comparison between data provided by FEM analysis and experimental investigations.

The variation of stresses obtained both by finite element analysis and experimentally, in a section near the support-console (Fig.4, b) is presented in Fig.8. These results are for the most unfavorable type of leaning.

For the type 2 caisson model, the maximum stress of 1.7 MPa was the same recorded in the central area, but at the bottom, for the same resting case.

In reality, the caissons are rested on the sea bottom, on the whole surface of the radier; so, the stress in its walls will be smaller.

Finite element analysis were made for two cases: with and without taking into account of the hydrostatic pressure. Calculus results showed that the hydrostatic pressure influence little the stress state in the structures walls.

The results of the finite element analyses showed also that the stresses for both models are 8…10 % lower if the water pressure is taken into account.

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