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Remarques de l'auteur du rapport introductif

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Foundation Structures for Long Span Bridges

1st Paper

The foundation of the Seine River Bridge Brotonne, a cable-stayed bridge of prestressed concrete with a main span of 320 m (fig. 1) (reported by J. L. Brault and J. Mathivat) is in different ways interesting. The bridge deck is about 54 m above water-level, the single pylon in the central axis of the bridge is 70 m high; pylon and pier together have a total height of 125 m (fig. 2). At the foot of the pier there act vertical loads of 17 300 tons and a transverse bending-moment due to wind forces of 31 800 tm. The French engineers chose a single circular column with a diameter of only 12.5 m and a depth of 35 m for the foundation of the tower-like piers of this very great bridge (fig. 3). The upper 9 m of the soil are soft, underlying are 8 m of alluvial sandy clay followed by 10 m of sand and gravel, resting on chalk with a compressive strength between 20 and 80 kp/cm^2 . The column of the foundation goes 8 m deep into this chalk corresponding to only 2/3 of her diameter.

For carrying the load and moment, the horizontal earth resistance was taken into account in spite of the fact that the stiffness coefficient of the 8 m thick alluvial soil is only 0.12 kp/cm^3 and that of the sand-gravel only 1.5 kp/cm^3. The chalk also has a rather small stiffness coefficient for horizontal pressure of 8 kp/cm^3. With these assumptions, the soil pressure distribution was calculated as shown in fig. 4 with a maximum horizontal pressure above the chalk of 2.6 and 2.8 kp/cm^2 . In the base section of the column, there is a remaining bending moment of 18 000 tm, which results in large differences of vertical soil pressure with a maximum value at the edge of 23.8 kp/cm^2. At this level, the stiffness coefficient of the chalk for vertical pressure would, therefore, cause a considerable deformation.

This is a daring foundation, however, one can expect that it will behave well, because the extreme wind loads caused by extraordinary gales in costal environment are relatively rare and their peak gusts, which develop highest wind velocities, last usually only one or two seconds. One knows that the statically calculated soil pressure will not realize by such short-time load attacks due to the mass inertia of the big structure and of the soil. Therefore the base of the foundation will mainly have to carry the vertical load and will not get to feel much of the wind loads.

But not only the small dimensions of the foundation of this large bridge are interesting but also the construction method. The construction was started with a self-supporting slurry trench wall acting as a cofferdam , built with 80 cm thick unreinforced concrete to a depth of 31 m (fig. 5) intruding 4 m deep into the chalk. The material inside this cylinder-cofferdam was dredged into the chalk and the concrete for the base could be executed in the dry. In this way it was also simple to construct the thick reinforced concrete walls of the main column.

This example demonstrates how economical such foundations of large bridges can be built, if one makes good use not only of the vertical bearing capacity of the soil, but also of the horizontal resistance. Hereto it is necessary to investigate reliably the data for soil behaviour, as it has been done for this bridge by several core drillings with 120 mm diameter to a depth of 50 m.

2nd Paper

In the second report, the Japanese engineers M. Ohashi, S. Kashima and O. Yoshida describe the foundation of the towers of the suspension bridge with a main span of 870 m, the Ohnaruto Bridge, which belongs to the system of bridges which shall connect the main island with Shikoku Island. The towers stand in shallow water of only 3 m depth on sandstone, the construction of the foundation will, however, be influenced by strong tidal currents with velocities up to 5 m/sec.

At the beginning it is reported that the Japanese turned during the last 12 years more and more to pile foundations for their large bridges. At the Ohnaruto Bridge, there are 9 big piles in steel pipes with diameters of 4.6 and 7.2 m under each tower leg (fig. 6), which intrude 15 m deep into the sandstone rock. The solid concrete pile cap has a thickness of 9 m. The caps for the two groups of piles are connected with a 6 m thick slab of reinforced concrete.

The multi-column-foundation was analysed as a space frame, the pile legs being spring-supported horizontally and vertically to imitate the response of the rock. The analysis was checked by model tests and by large scale models on the real ground.

With regard to earthquakes, dynamic model tests were also conducted not only with the pile-foundation but for comparison also with solid block-foundation.

The result was, that the multi-column-foundation shows larger deformations but also higher natural frequencies than the solid block-foundation (fig. 7). The natural frequency of the foundation is, on the other side, so different from the frequency of the steel towers, that the dynamic analysis of the tower and of the foundation can be done individually. The first mode of vibration is dominant, because the pile cap is so heavy.

The analysis as space frame gave a good agreement with model measurements. It was found also that the horizontal spring constant of the ground related to the total multi-pile-foundation is equal to that of one pile multiplied by the number of piles.

3rd Paper

Pile-foundation for long-spanned bridges are also described by the Russian engineers K.S. Silin, N.M. Glotov, V.N. Kutzenko and G.P. Solovyev (fig. 8). They often use piles made of prefabricated reinforced concrete tubes with a diameter of 3 m and a wall thickness of only 12 cm. 6 m long elements are flanged together with bolts. These large pipes are driven into the alluvial ground by vibration and simultaneous dredging. If the foundation reaches rock, then 3 to 4 m deep holes are drilled into the bed-rock by the use of a special turbo-drilling machine, which was developed for the oil industry of the USSR. After cleaning, the hole and the concrete pipe are filled with heavily reinforced concrete.

For a large railroad bridge, inclined drilled piles with steel pipes of 1.4 m diameter had been used, which reach to 40 m depth under the water level and end in dense clay (fig. 9). At the foot of the pile a conical cave is cut out of the clay with a diameter up to 3.5 m in order to increase the bearing area of the pile. This hole was filled with bentonite slurry to protect it against possible soil slides. After introducing the reinforcing cage, the concrete was filled in through pipes. The allowable capacity of such a pile is 800 tons, test loadings went up to two times this value.

4th Paper

In the fourth report, the Japanese engineers T. Okubo, K. Komada, K. Yahagi and M. Okahara describe a new type of foundation in deep water with sheet piling, using steel pipes with diameters up to 1.2 m and wall thicknesses up to 19 mm (fig. 10).

At the outer steel pipe faces, there are two small diameter steel pipes with a slot, which are used to guide each following pile during the driving process. The voids of the small pipes are filled with mortar in order to get a stiff and tight connection between the pipes.

The flexural stiffness of the pipes allows to use the structure as a cofferdam. With such pipes, ring shaped or oval or rectangular,foundation arrangements can be made in sizes suitable for bridge piers (fig. 11).

The authors describe different possibilities of application (fig. 12). The footing of a bridge pier can be placed directly on top of the steel pipes above the water level. The water can also be pumped out of the interior of the sheet piling to a certain depth and steel brackets can be welded to the pipes for carrying the footing of the pier. After concreting the pier, the sheet piling above this level can be cut off.

The authors describe how they calculate such sheet pile foundations by means of a finite strip method, using different coefficients of the sliding resistance in the connection between adjacent pipes and assuming different distribution of the soil pressure. The results of these analyses have been compared with measurements at a large scale foundation with circular pile arrangement. The analytical result is strongly influenced by the amount of sliding resistance between the steel pipes and the comparison with measurements is not satisfactory. The authors conclude that more rational design methods should be developed and good design standards should be established.

This pipe-sheet pile foundation has already been used for 12 bridges with good success und with pile lengths up to 57 m. This special foundation can undoubtedly be further developed, a stiff connection between the pipes will be desirable in order to get a good use of the possible spatial resistance of such structures.

5th Paper

In the last contribution, the Japanese engineers S. Suzuki, M. Ishimaru, F. Nemeto and Y. Nojiri give a report on model tests for the foundation of the main pier of the Hamana Ohhashi Bridge, which has with 240 m the longest span of prestressed concrete box girder bridges. The foundation has to carry 27 000 tons vertical load and must be able to resist the horizontal inertial forces caused by the heavy superstructure during earthquakes, which result in bending moments longitudinally of 181 000 tm and transversely of 188 000 tm.

A rectangular multi-cell box caisson with slide lengths of 26 / 19 m and a depth of 30 m was adopted (fig. 13). The piers on top of this caisson are 20 m high.

Two models of acrylic resin were made. At the first model surface strains were measured in the usual way. The second model was used for three-dimensional photoelastic stress analysis, it was heated up to 130° C, loaded and cooled down. Thin slices of the model are then cut out which show the interior stress distribution in polarized light. The results (fig. 14) confirm the nonlinearity of stress diagrams in thick members. The distribution of shear stresses is not reported. Also the lengths of introduction of load attacks in prismatic bodies are confirmed.

The caisson was also analysed three-dimensionally with a finite element program which, however, was developed for thin plates, therefore this analysis is questionable. It was also used to study the influence of Poisson's ratio which is 0.39 for acrylic resin and 0.17 for concrete. The smaller value of the concrete leads to smaller flexural stresses in the thick upper plate of the caisson.

At this investigation, data are missing about the distribution of soil pressures, which must play a considerable part in the resistance of earthquake forces. The results show, on the other side, that the forces due to earthquakes do not cause serious stresses in such caisson foundations, even not under such heavy loads.

Remarks

From the contributions to the preliminary report we can gather that big progress is made with pile foundations. The diameters of the piles and their lengths are more and more increasing. The reports deal mainly with stress analysis, mathematically or by model tests, but say nothing about the distribution of the load carrying reactions of the soil either by the pile foot or by friction along the pile's surfaces. One misses also considerations or means to secure the durability and life of the piles, for instance in salt water or in polluted harbour waters. One is further missing structural details, mainly details of the reinforcement of piles and pile caps. In my introductory report I have pointed to the splitting forces at thick reinforcing bars caused by high bond stresses as they develop in pile caps under large bridge loadings. Such splitting forces can be a considerable danger for the safety of such structures which most engineers do not yet realize.

The pile caps are usually large size solid concrete members in which the concrete stresses due to loads may be smaller than the stresses due to interior restraint caused by temperature or shrinkage differentials. For such thick concrete members prestressing to a degree to counteract tensile stresses under permanent load can lead to better behaviour and more safety than a heavy reinforcement with thick bars.

It is desirable that researchers and practising engineers being responsible for the safety of the structures, will pick up these problems and do not simply place several layers of thick reinforcing bars with small spacing into such pile caps. It can safely be predicted, that such reinforcements will not give the carrying capacity as calculated, but the concrete will split in the plane of the reinforcing bars before the structure reaches the required ultimate load.

Closing, I wish to draw your attention again to my introductory report for this Congress in which I have described a proposal for the foundation of the towers of a cable-stayed bridge with a span of 1 470 m for the crossing of the Straits of Messina which would have to be built in 95 m deep water. I proposed an economical ringshaped foundation of which the lower part would have to be built in a dry dock and then floated to the bridge site. The proposal was made in 1972 before Ekofisk in the North Sea was built. The extraordinary achievements of the engineers who have meanwhile built the oil tanks and drilling-platforms in the North Sea did prove that such a construction method will also be safely applicable for bridge piers in these days.

In the preliminary report of this Congress you find under theme IVa a paper of our French engineer colleagues M. Gerbault and P. Xercavins informing us that the Shell platform CORMORANT will be founded in the North Sea at a place where the water is 154 m deep. Compared to these gigantic structures our bridge piers are small. But the large height of the foundation tower suggests to use ring foundation similar to those which I developed for large TV towers. The proposed ring foundation will cut down the necessary amount of concrete and steel considerably and will result in great economy compared to conventional types of foundation. I would appreciate if this proposal would be considered for the big bridges crossing sea straits, which are being planned in several parts of the world.

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