SETTLEMENT OF A BLAST FURNACE FOUNDATION

TASSEMENT DE LA FONDATION DU HAUT-FOURNEAU

ОСАДКА ФУНДАМЕНТА ДОМЕННОЙ ПЕЧИ

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SYNOPSIS. A special type of foundation was used to support a blast furnace structure of weight 19,000 tons. The foundation is composed of a cylindrical walled steel pipe pile, 30.0 m in diameter, and concrete footing connected to the inside of the walled pipe pile. The load applied on the foundation is supported partly by the walled pipe pile driven into the dense gravel layer and partly by the footing rested on a stiff clay layer. In the settlement calculation, the load-settlement relation of the stiff clay layer was estimated from the results of consolidation tests, and that of the walled pipe pile was obtained from both the in-situ pile loading tests and model tests. The continuous observations of the settlement and partial loads on both the walled pile and footing have been carried out for about 500 days since the beginning of construction. The analysis of the results obtained in this case shows a good agreement between prediction and measurement.

SITE CONDITIONS AND FOUNDATION TYPE

In order to support a blast furnace structure of weight 19,000 tons, a special type of foundation was used at Mizushima area, about 800 km west from Tokyo in Japan. In this area typical subsoil consists of a loose fine sand layer, 6 m thick, overlying soft alluvial clay extending to a depth of 18.2 m below ground level. This soft clay overlies preconsolidated stiff diluvial clay layer, 5.2 m thick. The dense gravel extends from 23.4 m to at least 60.0 m depth. A soil profile with the N-value of standard penetration resistance is shown in Fig. 1(a).

Considering these subsoil conditions, the following type of foundation was selected to support the heavy structure. The foundation is composed of a cylindrical walled pipe pile, 30.3 m in diameter, and reinforced concrete footing connected to the inside of the walled pipe pile as shown in Fig. 1(b). This walled pipe pile consists of a lot of steel pipe piles, 1.2 m in diameter and 24.0 m long, interlocked to each other by a special device as shown in Figs. 1(c) and (d). These piles are driven into dense gravel layer and the footing is rested on the stiff clay layer, after the excavation of the inside of walled pile by means of lowering the water level.

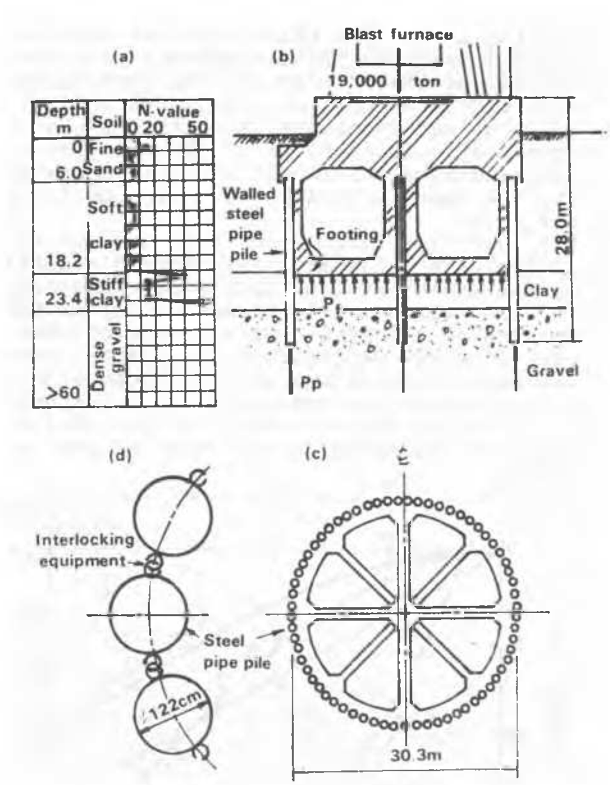

Fig. 1(a) Soil profile.
(b) Vertical section of foundation.
(c) Horizontal section of walled pipe pile.
(d) Interlocking equipment of piles.

PREDICTION OF SETTLEMENT

The total load P applied on such type of foundation as mentioned above is supported partly by the walled pipe pile driven into gravel layer and partly by the footing rested on stiff clay. The partial loads on both walled pile and footing are denoted by P_p and P_f, respectively.

Outline of the prediction of settlement is as follows : First, the load P_f - settlement s_1 curve of the stiff clay layer is estimated from the results of oedometer-tests, and second, that of the walled pipe pile, P_p - s_1 curve, is obtained from both the in-situ pile loading tests and model tests. Both settlements of the footing and the walled pipe pile are equal to s_1. Third, the settlement of gravel layer s_2 is calculated from the Terzaghi & Peck's Formula. Lastly, the total load P - settlement s relation is derived from the following equations :

$$P = P_f + P_p \quad \text{and} \quad s = s_1 + s_2 \qquad (1)$$

In Fig. 2 are given the results of prediction and more details are as follows.

a) Settlement of footing

As shown in Fig. 1(b) below the concrete footing is a 4.7 m thick layer of stiff clay which is responsible for a major part of settlement of the foundation. The content of clay size particles of this layer is 40 - 55%, the water content 24 - 36%, LL about 50 and Pl 20, giving PI of 30. The clay has a undrained shear strength of 0.8 - 1.1 kg/cm^2 and the preconsolidation pressure of 4.0 - 4.4 kg/cm^2.

As the stiff clay layer is laterally confined by the walled pipe pile, the settlement s_1 may be calculated almost entirely from the results of oedometer tests on undisturbed clay samples. In the test the special care was paid to investigate the rebound and re-consolidation processes of clay which will occur during the excavation of the inside of wall and following construction of the foundation.

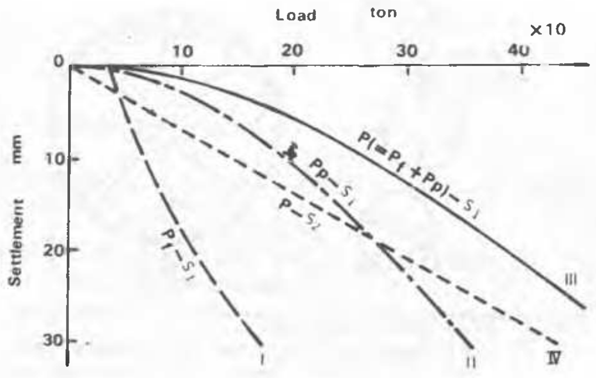

Fig. 2 Predicted load-settlement relationships.

Moreover, in order to investigate some rheological behaviours of stiff clay, a number of strain-controlled consolidation test had been carried out. Curve I in Fig. 2 indicates estimated P_f - s_1 curve of the stiff clay layer for the same rate of loading as the practical performance.

b) Settlement of walled pipe pile

The settlement of a single pile may be obtained by means of the full-scale pile loading tests, but it seems rather difficult to clarify the group action of such a walled pipe pile. In this paper, therefore, a series of model tests were carried out in an attempt to make clear qualitatively the load - settlement relation of walled pipe pile.

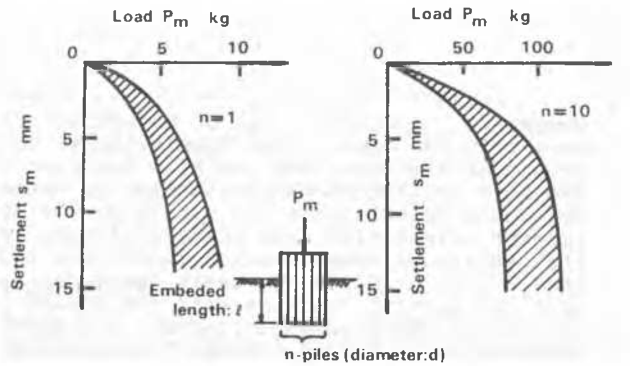

Fig. 3 Examples of pile loading tests (ℓ=4d).

In the model tests the embeded length of piles ℓ in the sand and the number of piles n were varied as ℓ = d, 4d, 8d and n = 1, 2, 5, 10, where d is the diameter of model pile, 2.6 cm. The piles were adjoined to each other to make a model walled pipe pile. In Fig. 3 are shown the range of typical test results of total load P_m - settlement s_m curves obtained for the number of piles n = 1 and 10, and from these curves average load per one pile, P_m/n, may be obtained, where suffix m indicates the model test.

The average loads per one pile, P_m/n, thus obtained are plotted against the embeded length of piles ℓ for the cases of s_m = 4 and 10 mm in Fig. 4. In these figures the straight lines are drawn through the point obtained from the tests on single pile, n = 1.

Here the efficiency of walled pile α is defined as the ratio of average load per one pile of the walled pile P_m/n and the load on single pile $P_{m.n=1}$ for the fixed amount of settlement: viz.

$$\alpha = P_m/n/P_{m.n=1}. \qquad (2)$$

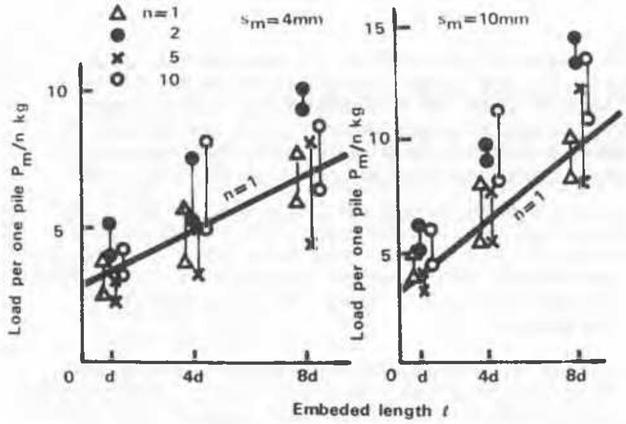

Fig. 4 Relationships between load per one pile and embeded length of pile.

From Fig. 4 the values of α may be found as 0.8 - 1.4, and therefore it will be roughly assumed that the total load on walled pile which contains n piles almost equals to n times of the load on a single pile.

In the field four kinds of full-scale single pile loading tests were carried out by varying the diameter of pile and the embeded length into the gravel layer : two examples of test results are shown in Fig. 5. In the present design, the embeded length of walled pipe piles into the gravel layer is 4.6 m and diameter of each pile 122 cm. Using the result of such a full-scale loading test on single pile as shown in Fig. 5 and assuming that the efficiency of walled pile α equals unity, the load P_p - settlement s_1 relation of the walled pipe pile may be predicted to be like curve II in Fig. 2. Then the load on whole foundation P - s_1 curve is constructed as curve III in Fig. 2, where P eqüals (P_f + P_p).

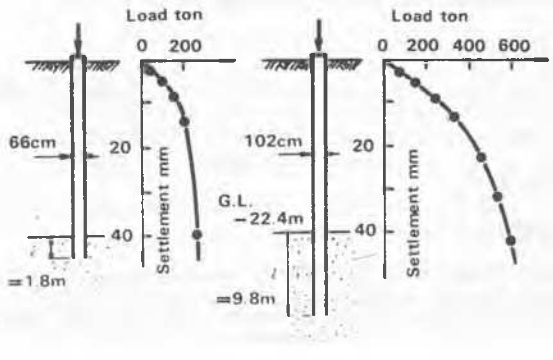

Fig. 5 Examples of full-scale steel pile loading tests.

c) Settlement of gravel layer

Below the stiff clay there exists a layer of dense gravel as shown in Fig. 1.

The content of gravel size grains than 10 mm is 25 - 80%, and the N-values of standard penetration resistance greater than 40. The load P applied on the gravel layer is assumed as the sum of P_f and P_p, where P_f and P_p are the partial loads on the footing and walled pipe pile respectively, and the diameter of the loading area is about 30 m as shown in Fig. 1(c).

The prediction of settlement s_2 of this layer is as follows: In order to calculate the settlement s_2, the settlement records of an other circular foundation which is located at 220 m from the present foundation and rests directly on this gravel layer are used. The diameter of that circular foundation was 26 m and the amount of settlement s' was 3.2 cm when the pressure measured at the foundation base was 6.1 kg/cm^2. The coefficient of soil reaction of this case is therefore 1.90 kg/cm^3.

Now, according to Terzaghi & Peck (1948) the correlation between settlements and diameter of a loaded area can be predicted from the empirical formula. Using the above mentioned two diameters of foundations, 26 and 30 m, the ratio of their settlement, s_2/s' may be calculated as

$$\frac{s_2}{s'} = \left(1 + \frac{0.3}{26}\right)^2 / \left(1 + \frac{0.3}{30}\right)^2 = 1.0$$

where 0.3 is the diameter of standard loading plate in meter. On the other hand, according to the result of comparison between settlement and dimension of loaded area made by Bjerrum & Eggestad (1963), a slightly greater value of s_2/s' = 1.08 may be obtained, if the sand is loose than if it is medium or dense.

On the basis of the above considerations, the settlement calculation of the present foundation was made by using the coefficient of soil reaction 1.85 kg/cm^3. As a result P - s_2 relation is given in Fig. 2 by the straight line IV. Lastly, the total load P - settlement s curve may be constructed from Fig. 2 and Eq.(1) as shown in Fig. 6.

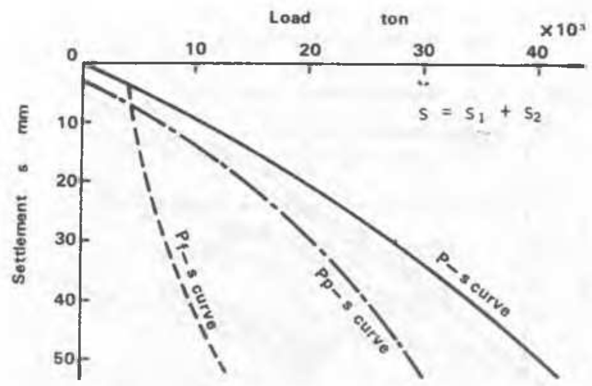

Fig. 6 Predicted load-total settlement relationships.

ANALYSIS OF RESULTS

The following three observations have been carried out continuously for about 500 days since the beginning of construction : i) vertical pressure at the base of footing, ii) stress in the walled pipe pile, iii) settlement of foundation.

In order to measure the intensity and distribution of the vertical pressure at the base of footing, 20 sets of differential transformer type earth pressure cells were placed at some intervals on the surface of stiff clay, 18.2 m depth, just before the casting of concrete. The result of measurement shows that the intensity of vertical pressure reaches maximum under the center of the loaded area, decreasing smoothly with distance from the center. The load P_f was therefore computed by integration of vertical pressure and area, and the variation of P_f with duration time is shown in Fig. 7(a).

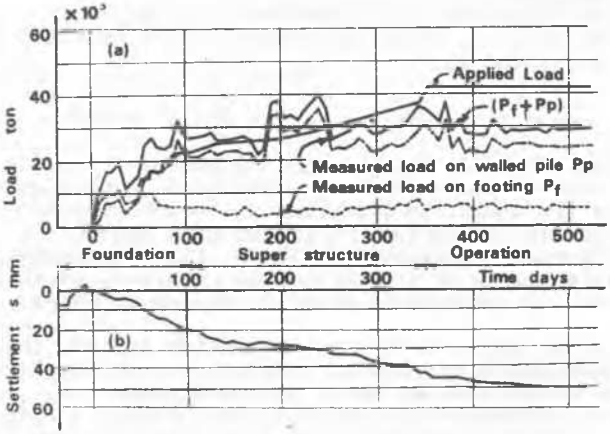

Fig. 7 Results of observations on loads and settlement.

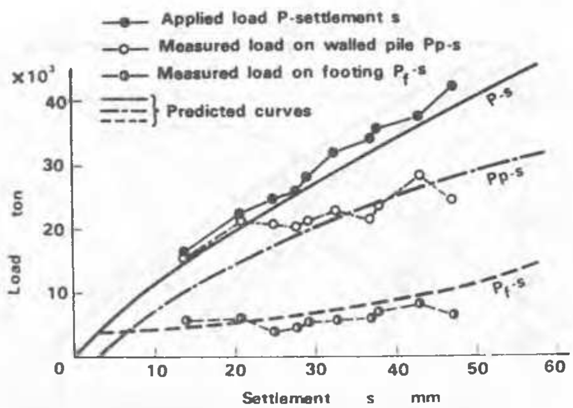

Fig. 8 Comparisons between predicted and observed settlements.

To measure the stress in the walled pipe pile at the same level as the base of footing, 24 sets of differential transformer type strain guage were installed inside of each piles at 18.2 m depth. The change of thus measured and calculated load P_p with time is also shown in Fig. 7(a). Next, the observed total settlement of foundation is shown in Fig. 7(b), and from this figure the settlement seems to be settled at 50 mm after 5 months from the time of the operation starting.

In Fig. 8 are shown the comparison between the predicted and observed load - settlement curve, where the predicted curves are reproduced from Fig. 6. It will be seen from Fig. 8 that the analysis of the results obtained in this case shows a good agreement between prediction and measurement.

CONCLUSION

A settlement of special type of foundation supporting a heavy blast furnace structure was predicted and compared with the observed one. As the foundation was composed of the walled pipe pile and footing, the load - settlement relationships of piles and footing were estimated respectively. The stiff clay and dense gravel were responsible subsoils for a settlement.

In the settlement calculations of the foundation, the following results of tests were used : viz. the consolidation tests on stiff clay samples, the full-scale loading tests on piles penetrated into the gravel layer and the loading tests of model walled pile. The continuous observations concerning with the total settlement and the partial loads on both the walled pipe pile and the footing have been carried out for about 500 days since the beginning of construction. The analysis of the results obtained in this case shows a good agreement between prediction and measurement as shown in Fig. 8.

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