Site Exploration for Founding a Building by Sinking Method of a Large-Scale Caisson

Investigation du sous-sol pour le fonçage d'un grand caisson à air comprimé

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Summary

The site of a nine-storey building with four-floor basement, located in the centre of Tokyo, was explored, and physical, mechanical, and plate bearing tests were carried out with a view to founding the building by sinking a large-scale caisson, 25,000 tons in weight.

In this paper, the outline of the building scheme and the aim and method of the site exploration, the soil test results and their application to the design and work of caisson, and the phenomena observed during the sinking process are briefly stated.

Sommaire

L'emplacement prévu pour un bâtiment de neuf étages et quatre étages de soubassement dans le centre de Tokyo a été exploré. Les propriétés physiques et mécaniques ainsi que la résistance du sol ont été étudiées en vue de la construction d'un caisson de 25.000 tonnes.

Dans cette communication l'auteur expose brièvement les grandes lignes du projet, l'objet et la méthode des essais entrepris sur place, les résultats des essais du sol, leur application au projet et à la construction du caisson, et les phénomènes observés au cours de l'exécution des travaux.

Outline of the Building Scheme and Aim of Site Exploration

The site of the Nikkatsu International Building is located in the civic centre of the Metropolis. The area of unsymmetrical trapezoidal section is about 4,100 square metres and surrounded by a group of buildings on the further side of the encircling roads (Fig. 1). Under the circumstances, the patented method of constructing the four-floor basement of the nine-storey building on reliable layers as a whole by sinking a large-scale caisson, 25,000 tons in weight, was proposed.

The features of this method are the possibilities it offers of acquiring the maximum available floor area in the restricted area of the site and not exceeding the height of the building prescribed in the metropolitan districts. This method also minimizes the volume of soils to be excavated and hauled, constructs the earthquake-proof foundation with approved bearing capacity, and avoids any damage, by subsidence of the ground, to the surrounding buildings and roads, including underground utilities such as gas pipes, water supply, sewage lines and electric cables.

Exact information concerning the underground conditions of the site was indispensable for taking a decision as to the method of designing the caisson, and planning the construction work. Systematic exploration of the site was carried out.

The aim of the site exploration was to obtain exact knowledge of the following: arrangement of the soil layers to be penetrated by the cutting edge of the caisson, physical and mechanical properties of the constituent soils of the layers, ultimate bearing capacities of each soil layer for estimating the sinking of the caisson, reliability of the bed layer on which the building would be founded, and some other useful data for the construction work of the foundation.

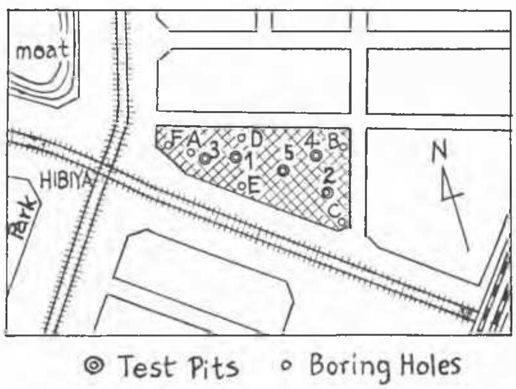

Fig. 1 Location of the Building Site
Emplacement du bâtiment

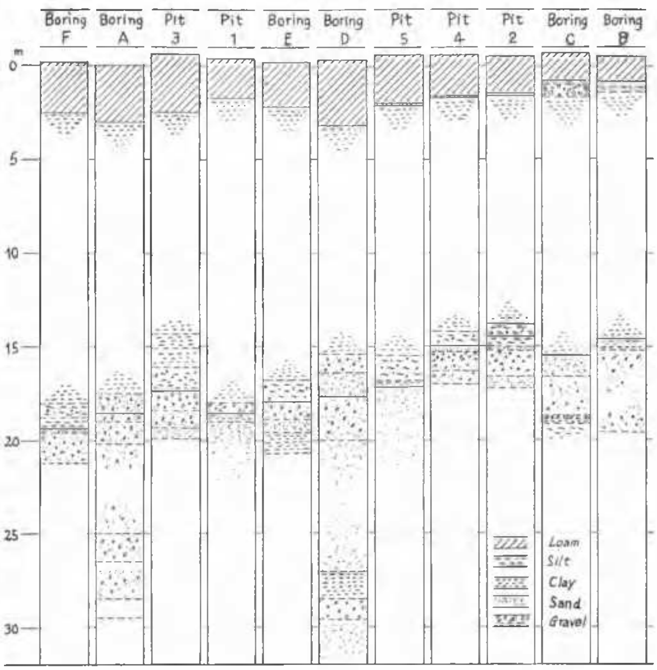

Fig. 2 The Soil Profile of the Site
Coupe du sous-sol

Method of Site Exploration

The building site was explored by five test pits (Figs. 1–5) and six borings (A to *F*). The location of the pits and borings is shown in Fig. 1. The pit holes were drilled to the depth of 20 meters. The inside wall of each pit was protected by cylindrical frames made of reinforced concrete with an inner diameter of 1.8 (Nos. 1 and 2) or 1.2 meters (Nos. 3 and 5) and a height of 1.5 meters. The first was equipped with a set of metal fittings to connect a cross beam which would serve as counter support of the test load. At each stage of excavation, plate bearing tests were carried out in the pits.

Test loads were applied by a hydraulic jack inserted between the bearing plate and the cross beam fixed to the side of the concrete frame. Three circular bearing plates, 50, 30, and 20 cm in diameter, and two testing rings, 5 and 10 tons in capacity, were used in the tests.

Undisturbed soil samples taken from the particular layer at the bottom of the pits were delivered to the laboratory established on the site and subjected to physical and mechanical tests.

The boring machine equipped with a core tube supplied cores with a diameter of 5 cm which were only disturbed samples. Some of the samples were delivered to the laboratory and subjected to physical and mechanical tests. The maximum depth of the boring holes reached 30 meters.

During the sinking process of the caisson, mechanical and plate bearing tests were repeated at the same depth as for the exploration of the pits with an intention to compare the test results in both cases.

Arrangement of Soil Layers in the Site

The soil profile disclosed by the test pits and borings is shown in Fig. 2. The profile consists of three major layers: the surface layer, the intermediate soft layer, and the firm bottom layer. The surface layer consists of loamy fill materials, 2 to 3 m thick, dry and well compacted. Under those materials is located a very soft layer of greyish blue alluvial silt and clay, 13 to 15 m in total thickness. The firm reliable bottom layer of sandy and gravelly strata lies 15 to 19 m below the ground surface. An inclination of about 4 per cent upward towards east was observed on the surface of the bottom layer with a difference of height of 3.5 m in a distance of 90 m.

Laboratory Test Results

In the laboratory, physical property tests were carried out on apparent specific gravity and moisture content in natural state, specific gravity of soil particles, mechanical analysis, liquid and plastic limits. Typical test results are shown in Fig. 3, which represents the distribution of physical properties with depth from the ground surface at pit No. 1. Similar results were obtained from samples at other pits and boring holes.

The fill materials of the surface layer are loamy, sufficiently dry and well compacted to support a heavy load. The intermediate layer of soft silt and clay has a rather constant low density of about 1.4, liquid limit values of 50 to 120 tending to increase gradually with increasing depth, and a high natural moisture content ranging from 90 to 120. The moisture content in natural state is always higher than the liquid limits. The fact indicates a dangerous situation, namely that the soft soils will lose stability and liquify by kneading during foundation work. A warning was issued that extreme care should be taken in the construction work. Mechanical analysis disclosed that the grading of the soft layer changed from

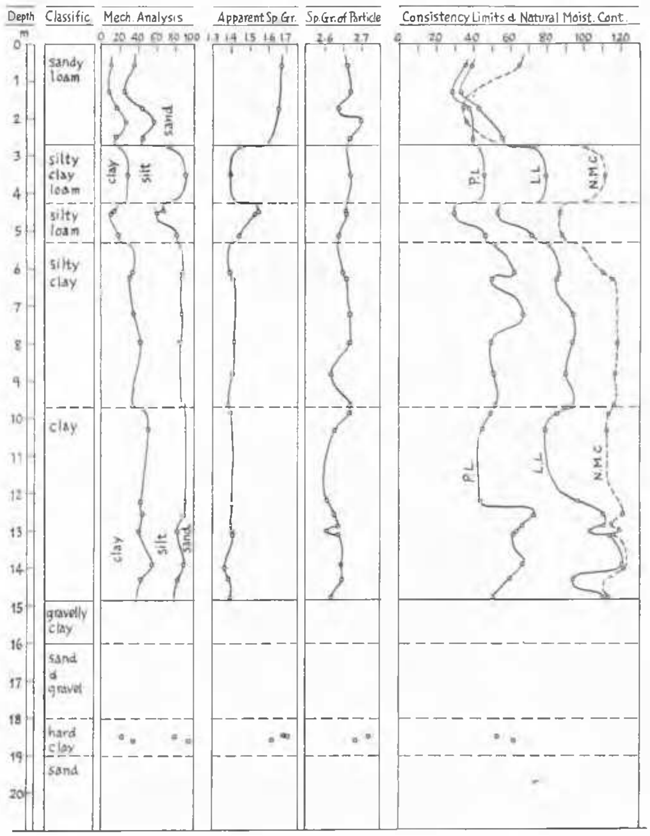

Fig. 3 Typical Test Result of Physical Properties on the Samples from Pit No. 1
Résultat d'un essai typique déterminant les propriétés physiques d'échantillons provenant du puits No 1

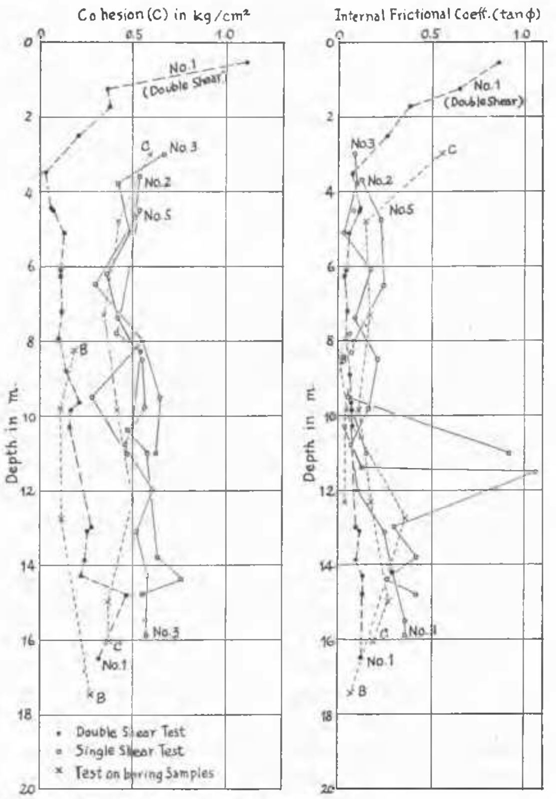

Fig. 4 Direct Shear Test Result
Résultat d'un essai de cisaillement direct

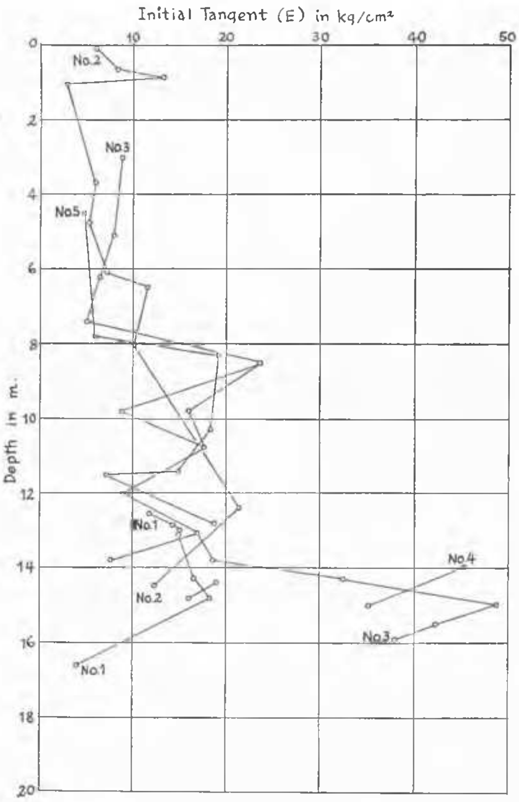

Fig. 6 Compression Test Result—Initial Tangent (E)
Résultat d'un essai de compression – Tangente initiale (E)

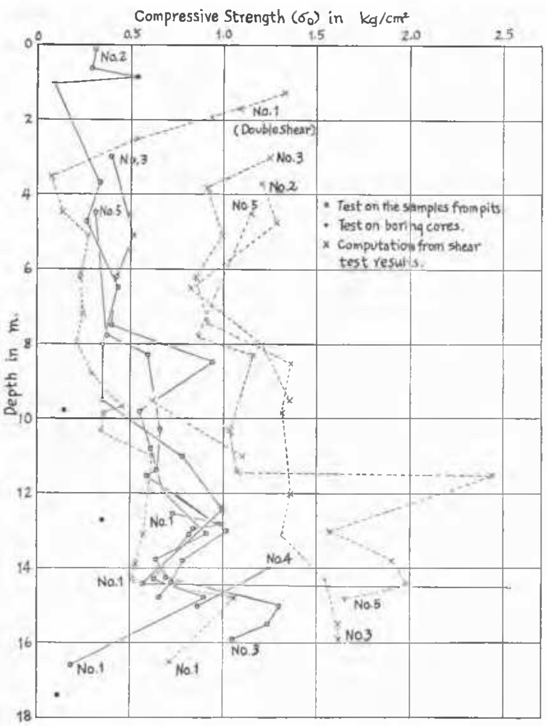

Fig. 5 Compression Test Result—Compressive Strength (σ_c)
Résultat d'un essai de compression – Contrainte de compression (σ_c)

silty soil to clay soil with depth. The corresponding values of the specific gravity of soil particles tend to decrease slightly.

The mechanical tests include two types of direct shear test, single and double, and an unconfined compression test. Specimens for unconfined compression tests were prepared from undisturbed samples cut by a brass cylinder with inner diameter of 6.03 cm and height of 7.00 cm. From the test results, the initial tangent (E) of the stress-strain curve and the compressive strength (∂_c) were determined. Samples for double shear tests have a rectangular section of 4 cm by 4 cm and a height of 6 cm, but samples for the single shear tests have a circular section of 5 cm in diameter and of 1.1 cm in height. Test results are shown in Figs. 4, 5, and 6. Loamy fill materials have high strength and stability.

The blue soft layer, on the other hand, has a comparatively low strength with the minimum value just below the surface layer, though gradual increase of the value with depth was ascertained. An abrupt reduction of strength and stability at the boundary line between two layers was assumed to exist, which is a most undesirable situation for the sinking work of a caisson.

The firm bed layer of sand and gravel was not subjected to those tests, but its high stability and sufficient bearing capacity was ascertained by inspection and loading tests.

Remarkable different values of cohesion (C) and internal frictional coefficient ($\tan \varphi$) were obtained in both cases by direct shear tests. The single shear tests have shown higher values of both constants than the double shear tests. The tendency is marked especially in the values of cohesion.

Theoretical values of unconfined compressive strength computed from the shearing constants applying the following relationship

$$\sigma_c = \left(\sqrt{1 + \tan \varphi} + \tan \varphi\right) C$$

are somewhat low in the case of double shear tests, but are excessively high in the case of single shear tests, when compared with the observed values (Fig. 5).

Physical property test results may contribute to estimating the stability of a soil layer by introducing the ratio of liquid limit to the natural moisture content, which corresponds to the strength of the soil layer (Fig. 7).

Plate Bearing Test Results

A series of plate bearing tests were conducted in the pits, and load intensity (q) and settlement of plate (s) were recorded. Settlement coefficient (k) and ultimate bearing capacity (q_u) were derived from test results. The distribution of both values with depth is shown in Figs. 8 and 9. The bearing capacity of the surface layer ranges from 1.1 to 1.5 kg per sq. cm. The lowest value of the soft clay layer, just under this layer, is estimated to be 1.0 kg per sq. cm, or 10 tons per sq. m and the maximum value, at the deepest part of the layer, 2.7 kg per sq. cm, or 27 tons per sq. m. The bed layer can support a load of 26 tons per sq. m or more and is high enough to support the building foundation.

The diameters of the bearing plates have shown slight effects on the ultimate bearing values, but, on the contrary, a remarkable influence on the k-values, which became lower when the diameter increased.

The product value of the settlement coefficient (k) and the diameter (D) may be assumed to be a constant of the soil layer as justified by the theory of elasticity (Fig. 10).

The ultimate bearing values are nearly three times as high as the unconfined compressive strength of the undisturbed samples (Fig. 9). The kD-values are nearly ten times as high

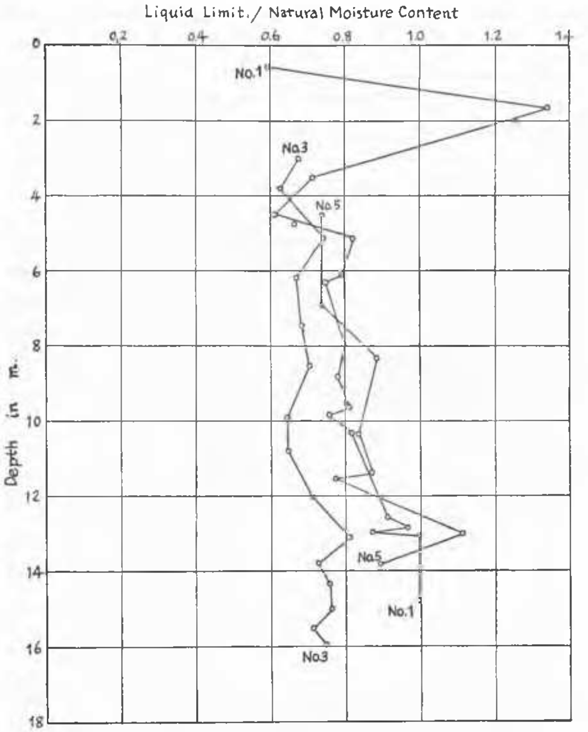

Fig. 7 Ratio of Liquid Limit to Natural Moisture Content
Relation entre la limite de liquidité et la teneur en eau naturelle

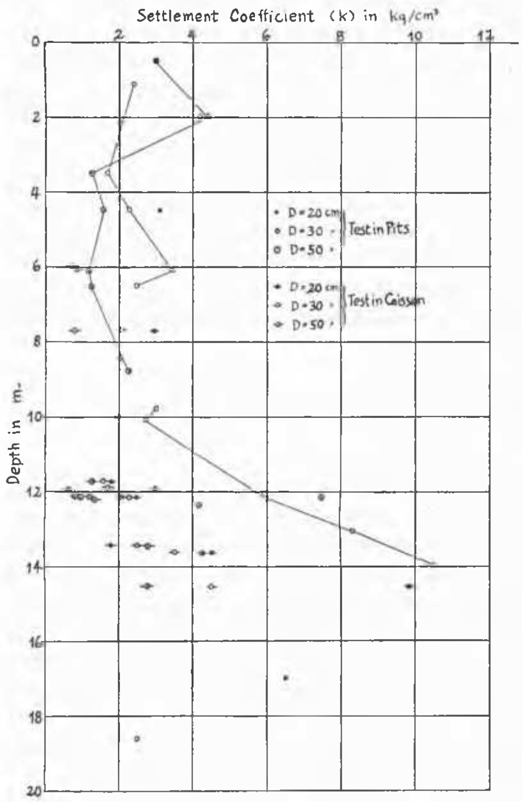

Fig. 8 Plate Bearing Test Result—Settlement Coefficient (k)
Résultat d'un essai de charge sur plaque – Coefficient de tassement (k)

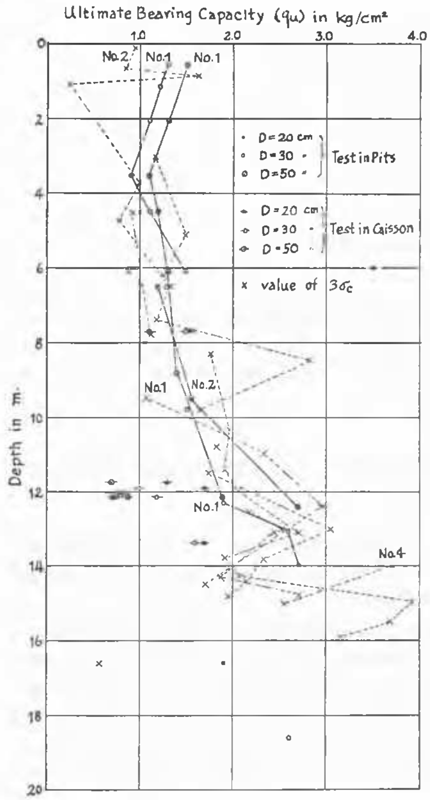

Fig. 9 Plate Bearing Test Result—Ultimate Bearing Capacity (q_u)
Résultat d'un essai de charge sur plaque – Capacité portante maximale (q_u)

as the values of the initial tangents (E) in the compression tests.

The results of the loading tests made in the narrow pits may be influenced by the surcharge load of soils around the pits. In order to check this effect, comparative tests of bearing capacity were carried out on the same layers but in open spaces in the caisson during its sinking. The test results have shown comparatively low bearing capacities and low kD-values as expected (Figs. 9 and 10). However, the results are questionable for the reason that probably some disturbances took place

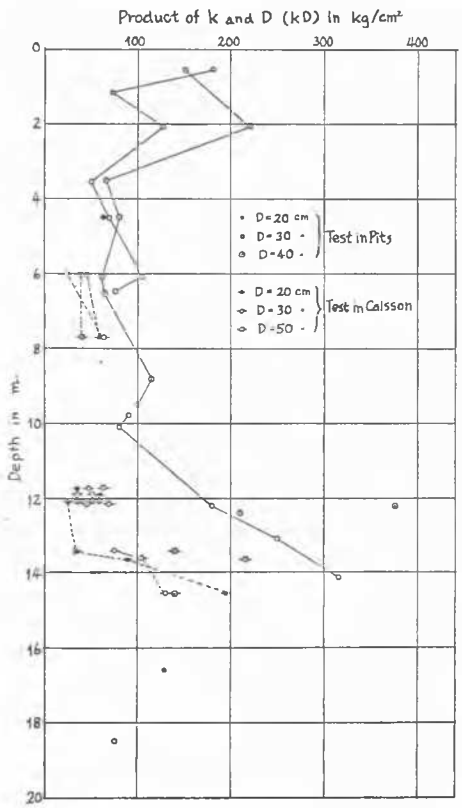

Fig. 10 Plate Bearing Test Result—kD values
Résultat d'un essai de charge sur plaque – valeurs kD

around the slip planes which appeared in the soil layers when the settlements of the caisson took place. Therefore the rate of the surcharge effect or the effect of confinement was not determinable.

Application of Test Results to the Design and Work of the Caisson

The underground conditions disclosed by the exploration and the characteristic features of the soil layers determined by the tests are as follows:—

(1) The soil profile in the site consists of three major layers: surface layer, soft intermediate layer, and firm bottom layer.

(2) The fill materials in the surface layer, 2 to 3 meters deep, are loamy, dry and of high stability. Special attention was drawn to the fact that an abrupt change of bearing capacity may occur at the boundary between this layer and the underlaid soft layer.

(3) The thick soft clay layer, 13 to 15 meters deep, is of uniform character and of low stability with a tendency to lose stability when kneaded. The bearing capacity of this layer is dangerously low at the top and becomes somewhat higher with depth. The minimum value is assumed to be 10 tons per sq. m and the maximum 27 tons per sq. m.

(4) The bottom layer of sand and gravel located at the depth of 15 to 19 meters are reliable as building foundation. The inclination of the layer is not prejudicial to the caisson sinking.

Under the circumstances, the caisson was designed as follows:—

The curb shoe of the caisson was built on the foundation in the soft layer at the level of 5 m below the ground surface so

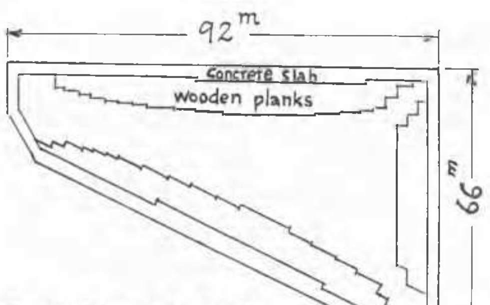

Fig. 11 Plan of the Caisson
Plan du caisson

that the caisson would not be damaged by sudden and unequal settlement which might occur in the initial stage of sinking due to an abrupt change in the bearing capacity.

In order to support the excessive weight of the caisson when the cutting edge penetrates the strata of lowest supporting capacity, additional wooden planks were provided to relieve the permanent concrete slabs projected horizontally inside the wall of the caisson at the height of 5 meters from the cutting edge. The initial area of the wooden planks sufficient to support the excessive weight was assumed to amount to 1,260 sq. m, in addition to the area of 500 sq. m of concrete slab, under the estimation of 10 tons per sq. m of bearing capacity. The cutting edge of the caisson, 300 meters in total length, was assumed to have a bearing power of 27 tons per linear meter.

The supplementary wooden planks were carefully designed and arranged as shown in Fig. 11 so as to prevent an uneven settlement corresponding to the distribution of the weight of the caisson with irregular section. The wooden planks were scheduled to be removed one by one while the excavation proceeded and when the cutting edge would support the weight more effectively.

Sinking Process of the Caisson and the Observed Phenomena

Sensitive indicators of settlement and inclination were attached to the caisson and the readings were taken continuously. The excavation work proceeded inside the caisson under extreme care. In spite of extreme caution, the first settlement occurred somehow accidentally and unexpectedly. The amount of settlement reached the maximum of 1.5 m with a difference of 0.5 m over a distance of 60 m. The experience gained during the first settlement was invaluable and the recorder registered a settlement curve which indicated the symptom of gradual increase in settlement several hours before the substantial settlement. Prediction of the occurrence of further settlements was possible with practical accuracy. Control and regulation of the excavation work were also improved with satisfactory results. The settlements took place intermittently at an interval of about a week, and the amount decreased by degrees as the sinking went on. The sinking proceeded smoothly even when the cutting edge reached the firm bed layer.

After a settlement had occurred, relative displacements of the ground surface, were observed inside the caisson amounting to 60 cm, with sharp slip planes as if they had been cut by a razor blade.

The amount of seepage water was negligible and caused no trouble during excavation. Signs of a probable accident caused by the liquified soil mass flowing into the caisson from the outside of the wall through the lower edge never appeared. The deeper the caisson was sunk, the more the resistance of the wooden planks was reduced by their gradual removal. Thanks to precise control of the work, unequal settlement was eliminated and the sinking process was completed successfully. Then the basement chamber was accomplished with the construction of the bottom floor, columns, and side walls. The building was opened to service as stores, offices, and hotel rooms in June 1952. The basement floors are being utilized as parking space.

Acknowledgment

The plan, design and execution of the project was done under the supervision of Mr. *F. Ohuchi*, director of the Takenaka Komuten Co. Ltd. Mr. *M. Ohi* was the field engineer. The Soil Mechanics Laboratory of the Institute of Industrial Science, University of Tokyo, was responsible for the plan and site exploration under the direction of *G. Miki*, Assistant Professor, and the writer.