3B/17

Some Piling Problems

Quelques problèmes de fondations sur pieux

by T. Mogami, Professor at the University of Tokyo, Civil Engineering Department, Faculty of Engineering, Tokyo, Japan
and
H. Kishida, Student of the graduate course, University of Tokyo, Japan

Summary

The authors review the results of five experiments, from which they have drawn the following conclusions :

(*i*) Stress developed in the ground when a pile is driven into it is of two kinds, one of which is directly due to the applied load and vanishes when the load is taken off, and the other is " the displacement stress ", developed by displacement of soil, which remains after the load has been removed.
(*ii*) Stresses due to displacement developed in clay ground by the penetration of a pile vanishes gradually, whilst in sandy ground such stresses remain.
(*iii*) When considered in relation to stress distribution, the load required to cause penetration acts near the tip of a pile.
(*iv*) The point of application of the load moves from upper part of pile to the tip as the load increases.
(*v*) Stress developed by the load on the pile, after the displacement stress has been subtracted, can be superposed.
(*vi*) Stress developed in the ground cannot be superposed when the distance between piles is as small as twice the diameter of the piles.
(*vii*) Stress distribution in the ground is influenced by the distance between piles, the order of driving and the density of sand, etc...
(*viii*) Increase in bearing capacity of a pile in clay with time is closely connected with pore water pressure.

Sommaire

Ce rapport présente les résultats de cinq essais. Les conclusions sont les suivantes :

(*i*) L'effort développé dans le sol lors du fonçage de pieux peut être divisé en deux composantes. La première est celle qui est développée directement par la force appliquée et disparait quand la force est enlevée. L'autre est due aux contraintes qui sont développées par le déplacement du sol, qui résultent de la pénétration du pieu et ne disparaissent pas quand la force est enlevée. Ces contraintes sont appelées « contraintes du déplacement » dans ce rapport.
(*ii*) Les contraintes du déplacement dans la terre argileuse disparaissent graduellement, mais celles dans la terre sableuse ne disparaissent pas.
(*iii*) Au point de vue de la répartition des contraintes dans le sol, on peut considérer que la force nécessaire à la pénétration des pieux est appliquée près de la pointe du pieu.
(*iv*) Ce point d'application change de position de la partie haute du pieu à sa pointe lors de l'augmentation de la force.
(*v*) Négligeant les contraintes du déplacement, les contraintes développées dans le sol par la force du forçage peuvent être superposées.
(*vi*) Les contraintes développées dans la terre ne peuvent être superposées quand la distance est inférieure au double du diamètre du pieu.
(*vii*) La répartition des contraintes dans le sol est influençée par la distance des pieux, l'ordre de battage de pieux, la densité du sable, etc.
(*viii*) L'augmentation avec le temps de la capacité portante du pieu dans le sol argileux se produit au fur et à mesure de la disparition de la pression interstitielle.

1. Soil properties and types of piles

Table 1
Soil properties and type of piles

Tableau 1
Propriétés des sols et type de pieux

Soil constants type of piles Experimental		*Soil constants*						*Type of piles*		
		Water content W per cent	*Bulk density* γ (g/cm^2)	*Void ratio e*	*Liquid limit L.L.* per cent	*Cohesion* C (kg/cm^2)	*Angle of internal friction* $\varnothing$ (°)	*Material*	*Diameter*	*Length*
Cohesive soils	Tokyo	90·6	1·46	2·58	99	0·22		Steel Concrete Wood	5	200
	Yokohama	110	1·44	2·92	115	0·36		Steel	30	661
Sand	I	1·45	1·44∼1·55	0·95∼0·80			40∼44	Concrete Wood	4 2	56 51
	II and III	0·83	1·3 ∼1·5	0·92∼0·85			40	Concrète Wood	5	70

2. Equipments for experiments

Equipments for laboratory experiments (Exp. 1, 2, 3) are shown in Fig. 1. Pressure gauges are located at the bottom and on one side of a sand box. The model pile is penetrated by screw action. Sand was made as uniform as possible before the tests. In the case of field tests performed in Tokyo and Yokohama, piles were driven into ground at a constant penetration speed (Fig. 2).

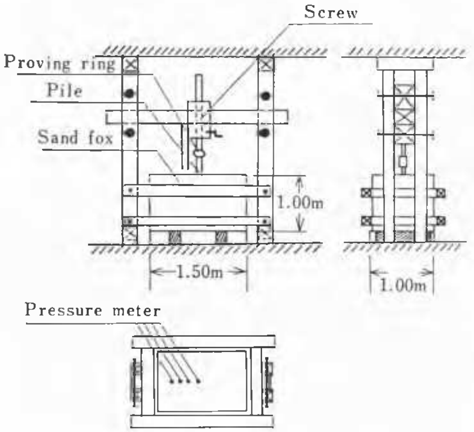

Fig. 1 Equipment for testing.
Schéma du dispositif d'essais.

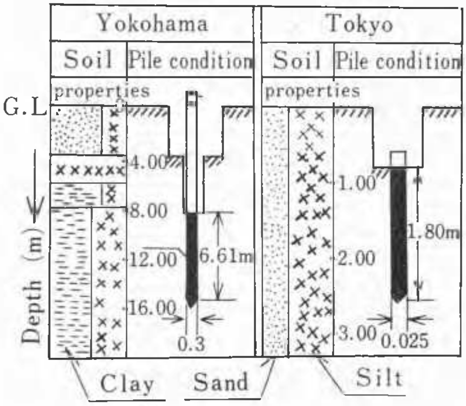

Fig. 2 Soil profiles and pile condition.
Coupe du terrain et condition d'essais des pieux.

3. Distribution of stress in sand

The load necessary to cause penetration of the pile, the penetration depth, and the vertical stresses were observed (Fig. 3).

Comparisons of the observed stresses with those calculated by the theory of elasticity assuming that the load on the pile is concentrated at a depth a from the surface is shown in Fig. 4.

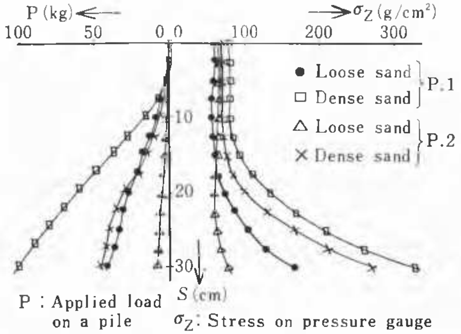

Fig. 3 Vertical stress at the bottom of a pile during penetration.
Contrainte verticale pendant la pénétration.

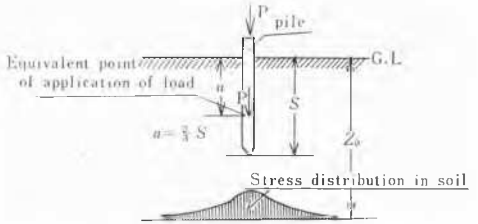

Fig. 4 Conventional assumption for the point of application of equivalent load.
Position conventionnelle du point d'application de la charge équivalente.

Fig. 3 shows that stress does not increase until the pile has penetrated to a depth which depends on the density of sand and the diameter of pile. The prevailing conventional assumption (Fig. 4) for the equivalent point of application of force on pile is not true when the penetration does not reach some depth, Fig. 5 reveals us that a is not equal to

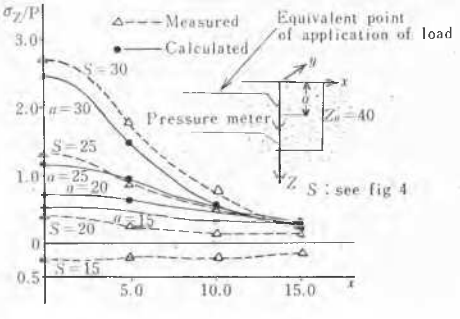

Fig. 5 Observed stress distribution compared with calculated stress.
Comparaison de la répartition des contraintes observées et de celle déduite du calcul.

$s/3$ but $a = s$. Distributions of these pressures were independent of penetration speed, which were 0·32, 0·64, 1·6 and 3·2 cm/min. The pressure was small when the sand was very loose ($e = 0{\cdot}95$), however, it was almost constant for $e < 0{\cdot}9$.

It was greater for piles of greater diameter, which may have some connexion with the stress developed by the displacement of sand. The stress which does not vanish even when the load was taken off from the pile is that developed by the displacement of sand during penetration to this depth (Fig. 6). This will be designated as "the displacement stress".

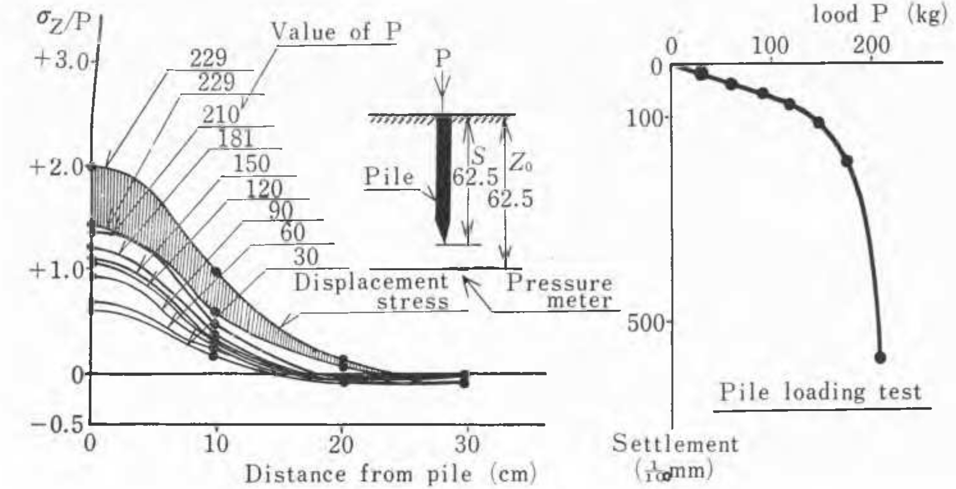

Fig. 6 Observed stress distribution at each stage of a pile driving test. Hatched area corresponds to the displacement stress distribution.

Répartition des contraintes à chaque chargement du pieu ; la surface hachurée correspond à la contrainte de déplacement.

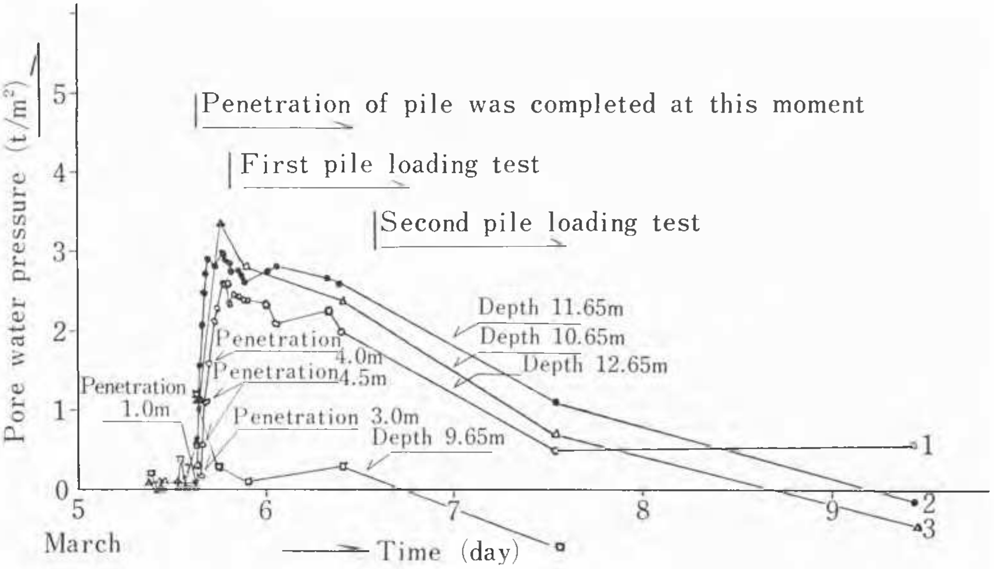

Fig. 7 Change of pore water pressure with time after penetration.

Variation de la pression interstitielle en fonction du temps, après la pénétration.

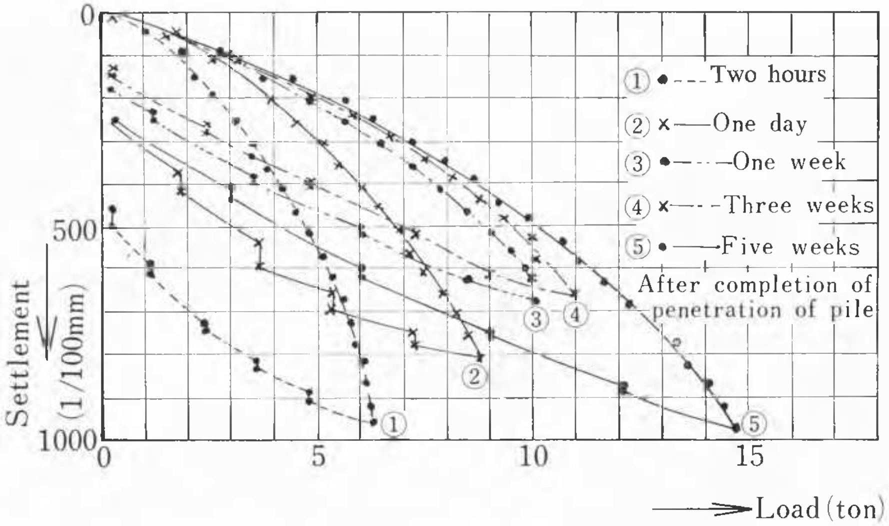

Fig. 8 Comparaison of load-settlement curves obtained from pile loading tests performed at various intervals of time after penetration.

Comparaison des courbes charges-tassements obtenues par des essais de chargement des pieux à des intervalles de temps différents après pénétration.

This is fairly large under the tip and it was observed that the displacement stress was about 0·4 times of that developed by the load and vanishes when the load was taken off. Vertical displacement stress vanishes at a distance greater than five times the diameter of the pile, and horizontal stress at the side of the box at a distance of 15 times the diameter of the pile. This circumstance was kept unchanged for two days and therefore it can be concluded that this phenomenon does not depend upon the sides of the box but rather upon the properties of the sand.

In the case of clay, the displacement stress, if developed, will fade away with time because of its creeping characteristics (refer to 4).

Results of pile loading tests are shown in Fig. 6, in which the stress is that developed by the load, with the displacement stress substracted. As the distance between the tip and the bottom is constant, σ_2/P should be independent of P if the sand is elastic, however, observed σ_2/P increases as P. This shows that the point of application of load on a pile approaches the tip as the load reaches the failure point.

4. Load bearing capacity of a pile in clay

Field experiments were performed in Tokyo and Yokohama in which piles penetrated the ground and the penetrating force was observed to be proportional to the depth penetrated, contrary to cases of laboratory tests for sand. Pore water pressure around the pile was observed by pressure gauges placed at the middle of a pile group and those attached to a pile (Fig. 7). They show rapid changes immediately after penetration, but they return to the static values after about three days. Earth pressure on the side of a pile has a higher value immediately after penetration, but it decreases with time.

Fig. 8, which was obtained from pile loading tests, shows the change of inclination of the load-settlement curve. Change in axial stress developed in the side of a pile was also observed by strain gauges. Increase in bearing capacity was large a week after penetration; however, it is not so large thereafter. Observations made after a lapse of two hours, one day and one week show that about 50 per cent of ultimately developed load bearing capacity is gained in one day. The bearing capacity of pile in clay is developed in a short time after its penetration and its increasing rate is closely connected with the decreasing rate of pore water pressure (Figs. 7 and 8). Axial stress along the pile decreases almost in linear proportion from top to tip of the pile, which shows that the shearing resistance of clay along the pile is distributed almost uniformly. The ultimate load for extracting the pile divided by its embedded surface area is nearly equal to the cohesion of clay (Fig. 9). Resisting shear stress when the

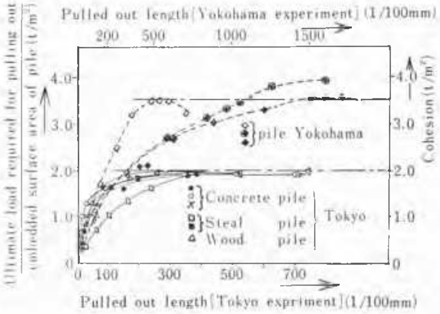

Fig. 9 Relationship between cohesion and ultimate load required for pulling out pile divided by embedded surface area.

Relation entre la cohésion et la force d'arrachement du du pieu, divisée par la surface de contact.

pile is extracted is uniformly distributed, because the axial stress changes almost linearly along the pile.

5. Interference of piles on stress distribution

Two or more piles driven in sand influence each other, the amount depending on pile distance and the order of driving, etc... When one pile follows another which has already been driven the stress, in the sand, including the displacement stress, tends to be concentrated just below the tip of the penetrating pile and decrease in stress is observed directly under the pile which has already been driven. This phenomenon is observed when the distance between piles is less than twice of the diameter of pile; however it is not observed when this distance is over four times the diameter (Fig. 10).

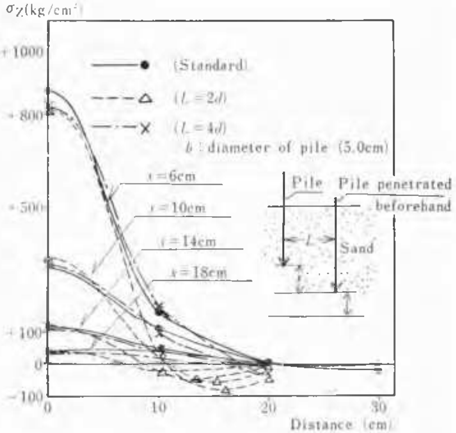

Fig. 10 Stress distribution showing the interference of two piles.

Répartition des contraintes montrant l'interaction de deux pieux.

When three of five piles have been driven, comparisons of stress distribution reveal that large concentration of stress occurs when the central pile has penetrated the ground. which may be result from heavier consolidation of sand between piles (Fig. 11).

Distribution of stress under two piles, after displacement stress has been subtracted, due to the load of 100 kg on each pile for each case shown as *a* in Fig. 12 when the distance was two, three, four or six times of diameter was compared with the distribution of stress when two piles were connected at the tops by a steel plate and loaded by 200 kg at the center of the plate shown as *b* in Fig. 12. Distribution of stresse due to two single piles obtained by superposition law is shown as *c* in the Fig. 12. Comparing these values, it is found that the superposition law of stress is true for cases when the distance between piles is beyond three times the diameter, however, this does not apply when this distance is twice the diameter. When the displacement stress which may exist in the actual sandy ground is taken into account, it can be said that the superposition law of stress is violated even when the pile distance is fairly small.

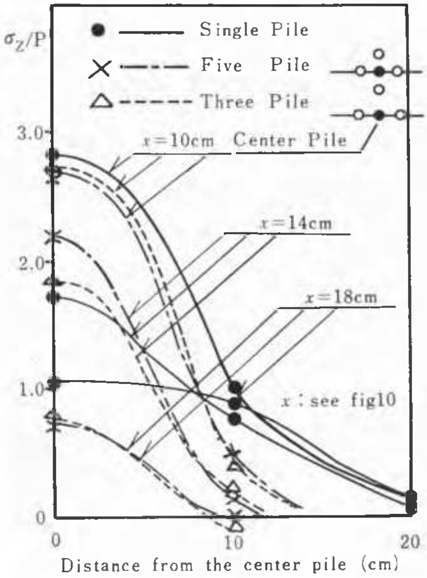

Fig. 11 Stress distribution showing the concentration effect observed at the centre pile.

Répartition des contraintes montrant l'effet de concentration sur le pieu central.

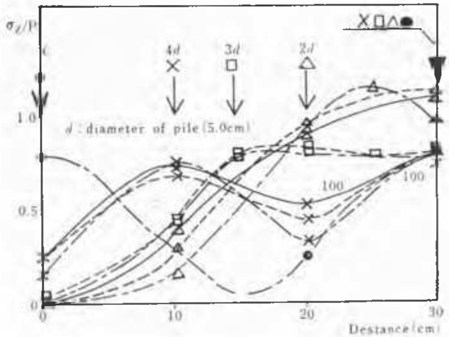

Fig. 12 Observed stress distributions under two piles when their distance apart is 2, 3, 4 and 6 times of their diameters, compared with stress distribution calculated by superposition law applied to two single piles.

Répartitions des contraintes observées sous deux pieux dont la distance est 2, 3, 4, et 6 fois leur diamètre, comparée à la répartition des contraintes calculée par la loi de superposition appliquée à deux pieux isolés.