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Technical session 2g: Pile foundations (I): Piled rafts, bearing capacity, and analysis

Séances techniques 2g: Fondations sur pieux (I): Radier sur pieux, capacité portante et analyse

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This session was held in the No.1003 conference room on September 14, Wednesday, 13:30-15:30. Professor Hong-Taek Kim of Hongik University, Korea acted the session chairman, and the secretary was the Associate Professor Makoto Kimura of Kyoto University, Japan.

1 GENERAL REPORT BY PROFESSOR KATZENBACH

A total of 33 papers were shown and explained on the 1 ppt slide per 1 paper. The papers can be classified into following five categories:

(1) Analytical and numerical methods: development and improvement of the new solution method, and parametric study.
(2) Model tests: 1g-model test, centrifugal model test, and shaking table test.
(3) Full-scale model tests: static and dynamic tests by full-scale pile using the different ground material, and inverse analysis of test result.
(4) Case histories: settlement analysis based on measuring result, and load sharing behavior of the piled rafts foundation.
(5) Field penetration tests: new proposal and improvement of bearing capacity formula of the pile based on field penetration test and boring test.

The following four discussion items were shown:

1) Analytical and numerical methods:
How rigorous are the existing methods to handle geotechnical boundary value problem?
→ How reliable would be such a comparison??
In the comparison with FEM, observed differences range from 20% to 30%. Here a question may be raised regarding the maximum difference to be considered acceptable
→ What should be the maximum acceptable difference??
2) Model Tests:
What precautions shall be taken in the application of the results of static 1g-model tests for combined pile raft in earth quake areas with and with out liquefaction? Would it be necessary to consider the influence of the height of gravity center in the static 1g-model test?
3) Full-scale model tests and case histories:
The deformation behavior of pile group foundation in which axial force works has been clarify to which degree?
4) Pile bearing capacity from penetration tests:
Expressions were formulated for the bearing capacity of piles based on field penetration tests. Here, the point that worth discussion is the precaution to be taken in the applications of those expressions for cases other than they have been developed for.

Photo 1. Prof. R. Katzenbach as a General Reporter

2 PANELISTS PRESENTATION

2.1 *Alessandro Mandolini (Second University of Napoli, Italy)*

Piled rafts subjected to vertical loads provide an economical foundation option for circumstances where the performance of an unpiled raft does not satisfy the design requirements. Under these circumstances, the addition of a limited number of piles may improve the ultimate load capacity and the settlement performance.

While in the last decades the research has been aimed to the use of piles as settlement reducers, less attention has been dedicated to the bearing capacity of piled rafts. In view of innovative design approaches, it is believed that the development of a general approach to evaluate their bearing capacity is mandatory.

At the present time, the evaluation of the vertical bearing capacity Q_{PR} of piled rafts is made by taking the smaller of the following values: (a) the ultimate capacity Q_{BF} of the block containing the piles, plus that of the portion of the raft outside the periphery of the pile group; (b) the sum of the ultimate loads of the raft Q_R and of all the piles Q_P. The installation of the piles, however, may affect the soil properties beneath the raft and consequently modify its performance in comparison with that of the unpiled raft. Moreover, the behaviour of the piles may be affected not only by the interaction among piles but also by the surcharge exerted by the raft. From all above the following general expression:

$$Q_{PR} = \alpha_{UR} \times Q_R + \alpha_P \times Q_P \quad (1)$$

can be considered (α_{UR}, α_P = coefficients affecting the failure load of raft and piles when combined in a piled raft).

Traditional design approach, being based on neglecting the contribution of the raft, assumes $\alpha_{UR} = 0$ and $\alpha_P = 1$ in eq. (1). On the other hand, suggestion (b) yields to $\alpha_{UR} = \alpha_P = 1$.

The presentation has been aimed to contribute to this field of research; particular emphasis has been placed on piled rafts resting on clayey soils where the problem of the bearing capacity is of particular concern.

The main conclusions in his presentation are summarized in the following points

1) Piles uniformly distributed over the raft area (A_G /A~1) at spacing larger than usual or piles concentrated in a small portion of the raft (A_G/A<1) at usual spacing allow the structural element connecting the pile heads to transmit a portion of the external load directly to the foundation soil ($\alpha_{UR} > 0$)(A_G = area occupied by piles and A = area occupied by the raft).
2) This beneficial effect, well known for piled rafts under working conditions and consequently more and more included in new design approaches (Plenary Session, Sept. 16 by Prof. Viggiani), seems to be significant also at failure.
3) The chance of applying innovative design criteria is, in Prof. Mandolini's opinion, strictly related to our capability in defining the factor of safety for such piled rafts, that is the key goal of any Regulatory Authorities.
4) Under working loads WL, it has been clearly demonstrated that the traditional CBD approach tends to be unnecessarily conservative, especially in those cases where the bearing capacity of the UR is sufficient to carry the total load with a reasonable margin against failure (i.e. large piled rafts on granular soils).
5) Although limited, the collected experimental and theoretical evidence seems to support the idea of taking advantage from the contribution of the raft also when a PR is approaching failure. Worked examples indicate possible piling cost savings in the range 20-40% for the investigated cases.

2.2 *Tamotsu Matsui (Fukui University of Technology, Japan)*

The load tests of piles can be classified into static and dynamic load tests. The latter includes the dynamic load test by hammering and the rapid load test using explosives, which have some advantages on the time efficiency and economics, although the reliability should be confirmed. In his presentation, a case history of the dynamic load test by hammering is shown for estimating the bearing capacity of large steel pipe piles, taking the foundations of the Kobe Sky bridge as an example, followed by the discussions on the applicability of the dynamic load test.

The Kobe Sky bridge is the access bridge to the new Kobe Airport Island from the Port Island, Japan. The length is 1180 m. The superstructure is composed of 9 spans and the substructure is constructed by the submerged steel pier foundation. Each pier is composed of 49 steel pipe piles of 1.5 m in diameter and 54-60 m in length.

As for the ground formation, the uppermost is the soft clay layer of Recent Deposits of about 20 m thick. The underlain gravel layer of Pleistocene is the bearing layer for piles. Among the 8 steel pier foundations, dynamic load tests are applied on the 3 piers for optimizing the designed bearing capacity of steel pipe piles, and the other 2 piers for checking the quality of pile performance during execution.

The measuring system using computer is used during dynamic load tests. Two transducers which are composed of accelerometer and strain gauge are installed on pile surface at around pile top, and the data are collected to computer through the junction box.

To accurately confirm the required curing period for large diameter steel pipe piles, the dynamic load tests are carried out several times during 23 days after pile execution. To avoid the effect of soil disturbance due to repeated use of a pile, a certain number of piles are used.

The main conclusions in his presentation are summarized in the following points on the bearing capacity of large diameter steel pipe piles.

1) The dynamic load test by hammering can be effectively applied for estimating the bearing capacity of large diameter steel pipe piles.
2) The end bearing capacity of large diameter steel pipe piles has only about 30% of the fully plugging effect.
3) For sandy and gravel layers, the designed skin friction is measured after curing of about 5 days, as expected in the Specifications. In contrast, for clayey soil layers, the measured skin friction is significantly less than expected in the Specifications. Consequently, it is suggested in this case history that around one month of curing period might be required to reach the designed one.
4) In such large penetration as 30 to 40 mm into bearing layer, and/or in the case of the initial impact with 3 to 4 times the conventional transmitted energy of hammering, the designed pile end resistance can be measured. Consequently, it is recommended that, to confirm the end bearing resistance of pile by the dynamic load test, a greater capacity of hammer than several times the conventional one should be used and measured in the initial impact, so as to induce the plastic deformation in soils around pile surface.

2.3 *Shamsher Prakash (University of Missouri Rolla, USA)*

Shallow foundations in seismic area are commonly designed by the equivalent static approach in non-liquefiable soils. Little is known for design of shallow footing in liquefiable soil. Pile foundations response depends upon if the soils is liquefiable or not.

Response of shallow foundations to dynamic loads is affected by (1) the nature and magnitude of dynamic loads (2) number of pluses and (3) the strain rate response of soil. Shallow foundations for seismic loads are usually designed by the equivalent static approach. Seismic settlements of foundations on partially saturated dense or compacted soils (not associated with liquefaction or densification soils) could be easily explained in terms of seismic bearing capacity reduction. However, Codes recommend higher allowable pressure under shallow footings during earthquakes! This is a Fallacy of Codes.

Behavior of piles in non liquefiable soils depends upon:

1) Soil shear modulus degradation with increasing strain/ displacement
2) Material damping increase with increasing strain/ displacement

Piles in liquefiable soils may undergo lateral spreading after liquefaction, if the residual strength of the soil is less than the static shear stress caused by a sloping site or a free surface such as a river bank, significant lateral spreading or down slope displacement may occur. The moving soil can exert damaging pressures against the piles, leading to failure. Such failures were prevalent during the 1964 Niigata and the 1995 Kobe earthquakes.

The design requires a reliable method of calculating the effects of earthquake shaking and post liquefaction displacements on pile foundations.

Key to good design depends upon:

1) Reliable estimates of environmental loads
2) Realistic assessments of pile head fixity
3) The use of methods of analysis that can take into account adequately all the factors that control significantly the response of the pile-soil-structure system to strong shaking and/or lateral spreading in a specific design situation

North America's Practice is to multiply the p-y curves, by a uniform degradation factor p, called the p-multiplier, which ranges in values from 0.3 to 0.1. Japanese Practice is more involved and therefore is comprehensive.

The main conclusions in his presentation are summarized in the following points

1) The behavior of both shallow and deep foundations is considerably involved.
2) Shallow foundations are still designed by considering seismic load as an equivalent static load. A dynamic analysis approaching needed. Shallow foundations in liquefiable soils are not addressed at all.
3) Pile foundations are receiving more attention for their analysis and design both in non-liquefiable and liquefiable soils.

3 CONTENTS OF DISCUSSION

Main questionnaires were the following two points:

1) Euro-Code and so on adopts a design method based on bearing capacity. However, it may be necessary to change into the design method based on the settlement by rightly estimating the settlement of the foundation structure.
2) Since the dynamic load test is more economical than the static loading test, it is necessary to promote it strongly and to recognize again that the pile can be rationally designed if dynamic load test result was used.

This session that handled content including many topics closed without completing the discussion items by Professor Katzenbach due to time restriction.

Table 1 Members of Technical Session 2g: Pile Foundation (I)

General Report:
Rolf Katzenbach (Technische Universität Darmstadt, Germany)
Panelists Presentation:
Alessandro Mandolini (Second University of Napoli, Italy) The bearing capacity of piled rafts
Tamotsu Matsui (Fukui University of Technology, Japan) Application of dynamic load test for estimating bearing capacity of large diameter steel pipe piles
Shamsher Prakash (University of Missouri Rolla, USA) The factors affecting dynamic behavior of piles under earthquake and machine foundations, and the difference in solution techniques.
Discussion Issues:
Analytical and Numerical Methods
Model Tests
Full Scale Tests
Case Histories
Field Penetration Tests

Photo 2. Chairman, General Reporter and Panelists.
(Prof. Hong-Taek Kim, Prof. R. Katzenbach, Prof. A. Mandolini, Prof. T. Matsui and Prof. S. Prakash in order from left side))