Vertical Bearing Capacity of Pile Installed by "EX MEGATOP" Method - Base Enlarged Pre-boring and Grouting Method for Pre-cast Pile

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In Japan, most pile foundations using pre-cast concrete piles are installed by the bored pre-cast piling method, wherein pre-cast piles are installed in holes that have been excavated beforehand and filled with cement milk (term used for cement water slurry in Japan). The bored pre-cast piling method with enlarged base, in which the portion near the toe is enlarged during boring operation, is widely used because of the cost benefits and the increased vertical bearing capacity that this method offers.
The EX MEGATOP method, further developed as an improved bored pre-cast piling method with enlarged base, is reported here. The features of this method are: (1) High vertical bearing capacity; (2) High degree of freedom in design; (3) Excellent workability; and (4) Friendly to the environment. In particular, high vertical bearing capacity can be obtained using nodular piles and by enlarging the area at the pile toe and shaft. This method can gave a vertical bearing capacity coefficient at the toe of α=430, more than twice the corresponding value of α = 200 of a conventional bored pre-cast pile. Moreover, the shaft resistance can be several times larger than that of a conventional bored pre-cast pile. This report gives an overview of the EX MEGATOP method, evaluation of vertical bearing capacity, and examples of application of the method.

1.Introduction

Most pile foundations in Japan are installed by the bored pre-cast piling method, that is, in holes that have been excavated beforehand and filled with cement water slurry, referred to as 'cement milk'. The "bored pre-cast piling method with enlarged base" is frequently used. In this method an enlarged excavation is used near the pile toe to increase the vertical bearing capacity.

The EX MEGATOP method is a variation of the bored pre-cast piling method. Its features include the use of nodular piles and a long, enlarged excavation. The vertical bearing capacity of the EX MEGATOP method is described in this report.

2. Overview of the EX MEGATOP method

2.1 Nodular pile installation method

A nodular pile is a pre-cast concrete pile having protrusions in the form of nodes at fixed intervals on the pile shaft. Since its first appearance in the 1920's, the materials have changed from reinforced concrete (RC) to prestressed spun concrete (PC) to prestressed spun high-strength concrete (PHC). The cross sections have changed from square/octagonal to triangular/hexagonal to cylindrical. In spite of the above, the pile diameter at the node has remained 440 mm (diameter of pile shaft: 300 mm). The method used to install this pile until 1970 was generally the "sealing method" in which the pile was driven into the ground while filling gravel around it.

In the 1970's, piles could not be installed in urban areas by the "sealing method" because of noise and vibration problems; therefore, the bored pre-cast piling method began to be used. The "MT method" which is also a bored pre-cast piling method became a popular method for installing nodular piles. Three kinds of nodular piles were subsequently added with a pile at the node of up to 650 mm diameter (500 mm diameter at shaft); their main applications being as friction piles.

The GMTOP method was developed in the year 2000. It is a method for installing nodular pile in a hole formed by mixing and stirring excavated earth with cement milk. It uses a rotating blade for excavation, which has a slit in the helical part of the blade. This method has been used for installing friction piles, and it has been rated highly considering the economics, workability, quality of work and environmental aspects. This method has been used to install more than 4000 piles annually.

The EX MEGATOP method is an improved GMTOP method that has been developed in response to the demand for high bearing capacity of piles in recent years. The maximum diameter of the pile at the node has been increased to 1000mm. A straight shaft pile with diameter equal to the diameter at the node can also be joined above the nodular pile (enlarged head nodular pile). This arrangement enables full utilization of all the advantages of the GMTOP method and its application to bearing piles also. The end bearing capacity in the "bored pre-cast piling method with enlarged base" has been increased by enlargement of the excavation around the toe to 1.24 times (1.5 times in terms of cross section). Furthermore, by enlarging the excavation over a range of up to 50% of the pile length, the skin friction resistance can also be increased significantly, and high bearing capacity can be realized.

The Ministry of Land, Infrastructure and Transport in Japan generally "approves" the vertical bearing capacity of newly developed pile installation methods. The MEGATOP method, which is a precursor of the EX MEGATOP method developed in 2004, has already received approval of the same ministry in 2002.

2.2 Applicable piles

Piles to which the EX MEGATOP method can be applied include nodular piles (including enlarged head nodular piles) with maximum diameter of 800 mm (shaft diameter) to 1000 mm (diameter at the node) as shown in Fig.1, and straight piles (including enlarged head piles) such as PHC, PRC (prestressed and reinforced spun high strength concrete), SC (steel encased spun high strength concrete) and steel pipe piles with diameters below 1000 mm that can be joined to nodular piles. The lower section is always a nodular pile (including enlarged head nodular pile).

2.3 Ground conditions and installation length

The ground conditions and maximum installation length recognized during the approval of the EX MEGATOP method are as follows:

* The ground around the pile toe is sandy soil, gravelly soil, or clayey soil.

* The ground around the pile shaft is sandy soil (including gravelly soil) or clayey soil (including silty soil).

* The maximum installation depth is 47 m when the ground around the pile toe is sandy soil, 49 m when it is gravelly soil, and 45 m when it is clayey soil.

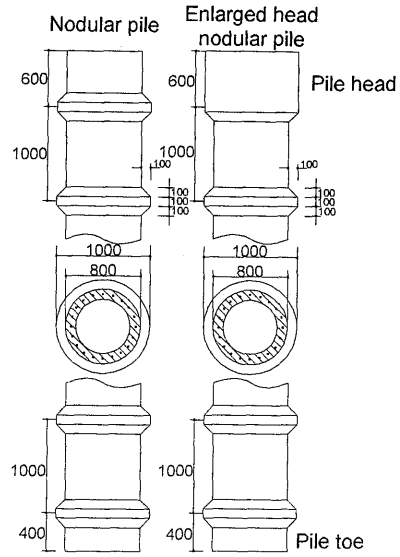

Fig.1 Shape of HC-TOP pile (φ1000-800)

2.4 Installation method

An overview of the installation by the EX MEGATOP method is as shown in Fig.2.Items (1) to (5) in the figure are briefly explained below.

(1) Pile centered to excavation
Center pile and excavate (auger) to the specified depth.

(2) Expand blade to enlarge excavation
Reverse the auger at the toe to open the enlargement blade; perform enlargement excavation up to the specified depth while pumping grout.

(3) Re-excavation for mixing and stirring
Change over to normal rotation, re-excavate to the pile toe, reverse the rotation, and mix and stir up through the enlarged shaft section.

(4) Grouting to withdrawal
While injecting slurry for grouting through the excavated base, stir and mix similar to the enlarged shaft part; grout the lower part, and withdraw the auger in the normal rotating condition.

(5) Pile installation
Install the pile while checking its uprightness, and secure it at the specified position. Photo1 shows the status of the installation work.

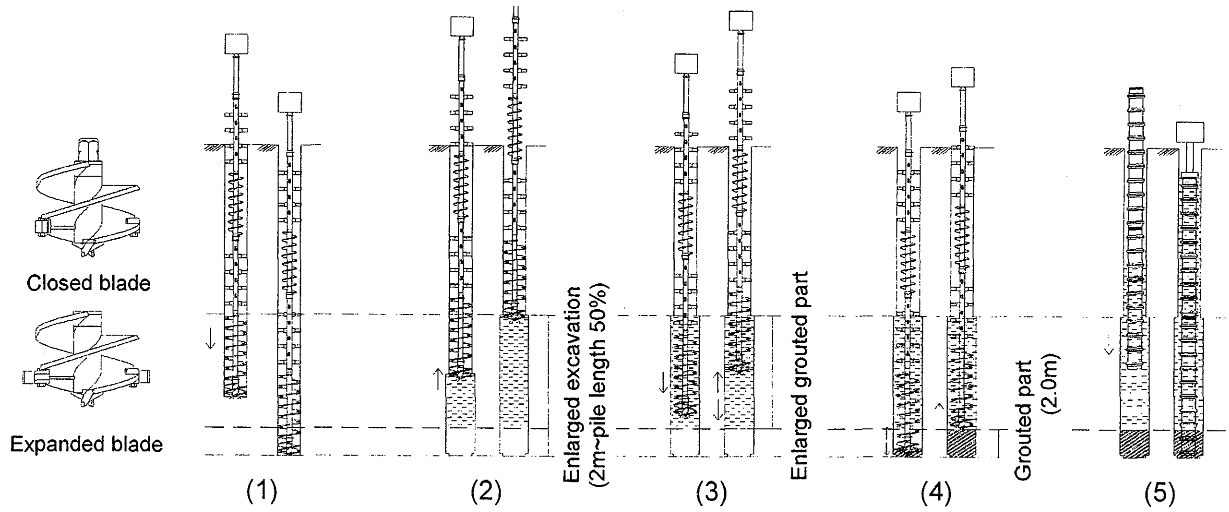

Fig.2 Installation method

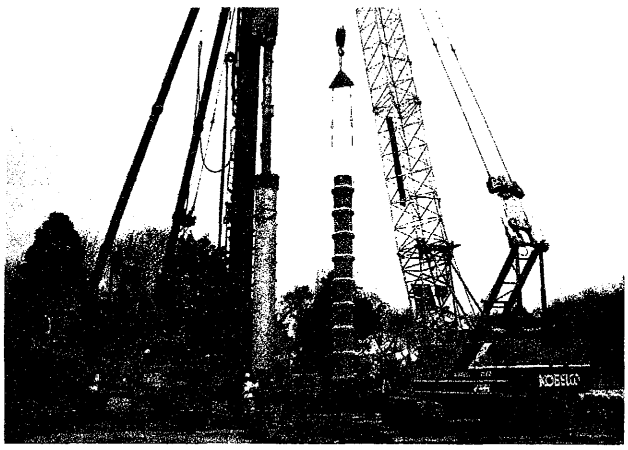
Photo1 Installation scene

3. Features of the EX MEGATOP method

The main features of the EX MEGATOP method are as given below.

3.1 Guaranteed high bearing capacity

By taking the excavation diameter at the toe as 1.23 times the normal excavation diameter (excavation diameter of GMTOP method, diameter at node + 50 mm), the grouted area at the base was made 1.5 times the original area. As a result, the toe bearing capacity factor α became 430, which is more than 2 times the value of α=200 (decided by law) of normal bored pre-cast piles. (The position at which the toe bearing capacity was assessed was at the upper end of the grouted base (length 2 m).)

The skin friction resistance of nodular pile installed by the GMTOP method has been verified to have a value of 1.5 to 2.5 times the skin friction resistance of general bored pre-cast piles (decided by law). In the EX MEGATOP method, the upper part of the pile shaft is excavated to an enlarged diameter in the range from the upper end of the grouted base to 50% of the pile length same as the diameter at the pile toe, but in this method a skin friction resistance 20% greater than the skin friction resistance of the GMTOP method has been confirmed at the enlarged excavated part. The skin friction resistance of the straight pile connected to the nodular pile can also be determined by calculation to be greater than that obtained by the general bored pre-cast piling method.

Also, the "expansion type" can be selected in the EX MEGATOP method, wherein the skin friction resistance can be increased further by adding expansive admixture to the cement milk.

In the general "bored pre-cast piling method with enlarged base," the major part of the total bearing capacity depends on the toe bearing capacity. However, since the skin friction resistance is also large, the reliability of the very large bearing capacity in the EX MEGATOP method is high.

3.2 High degree of freedom in design

The upper limit of length of the enlarged excavation can be varied up to 50% of the pile length. The axial bearing capacity can be adjusted accordingly.

By using straight piles above the nodular pile such as PRC, steel pipe and SC piles, which offer increased resistance to bending and shear, the design can be made to suit the required lateral resistance. Furthermore, even if the required lateral resistance is extremely large, an enlarged head nodular pipe connected to a straight pile of same diameter as the diameter at the node can be used.

3.3 Superior workability

The expertise in the GMTOP method, which has an extensive record of accomplishment, has been followed up in the EX MEGATOP method. Both methods offer excellent installation rates; EX MEGATOP method about 100 to 150 m/day; GMTOP method about 150 to 200 m/day).

Workability and maintenance are simple because no special equipment is used and all machines and equipment are commonly available. Labor skill requirements are minimal, and work can be managed easily.

3.4 Environmental considerations

Work can be performed with very little vibration and noise. The excavated earth can be effectively used by mixing and stirring with the slurry and sand. By using a pile with open toe, the quantity of surplus soil can also be reduced.

4. Vertical bearing capacity obtained by the EX MEGATOP method

4.1 Equation for long-term allowable vertical bearing capacity

The long-term allowable bearing capacity of piles installed by the EX MEGATOP method is calculated by the equation below. This equation has been formulated based on the results of a large number of load tests, and is approved by the Ministry of Land, Infrastructure, and Transport.

$$R_a = \frac{1}{3}\left\{\alpha \overline{N} A_p + \left(\beta \overline{N_s} L_s + \gamma \overline{q_u} L_c\right)\psi\right\}$$

Here,

R_a: Long-term allowable vertical bearing capacity (kN)

α: Pile tip bearing capacity coefficient = 430 kN/m^2

$\overline{N}$: Average N-value of pile tip

If the ground at the pile tip consists of sandy soil or gravelly soil:

$$\overline{N} = (N_U + 3N_L)/4$$

$\overline{N}$ is taken as greater than 3; the upper limit is taken as 60.

If the ground at the pile tip consists of clayey soil:

$$\overline{N} = (2N_U + 3N_L)/5$$

Where the upper limiting value of $\overline{N}$ is taken as 57.2.

N_U: Average N-value between the pile tip surface to a point 2 m above it

N_L: Average N-value between the pile tip surface to a point $2D_o$ below it (where D_o is the outer diameter at the node). If the N-value has not been measured in this section, then the average of the measured values just above and just below is to be used.

The upper limit of each N-value obtained during the calculation of N_u and N_L is taken as 100.

A_p: Cross section area blocking the pile tip surrounded by nodes (m^2)

$$A_p = \pi D o^2/4$$

β: Skin friction resistance coefficient of pile in sandy soil

Standard type (charging slurry around pile shaft that does not use expansive admixture):

(1)Straight pile part

$$\beta N_s = 4.8N_s$$

(2)Nodular pile with normal excavation

$$\beta N_s = 5.3N_s + 32$$

(3) Nodular pile with enlarged excavation

$$\beta N_s = 6.0N_s + 40$$

Expansion type (charging slurry around pile shaft using expansive admixture):

(1)Straight pile part

$$\beta N_s = 8.0N_s$$

(2)Nodular pile with normal excavation

$$\beta N_s = 9.0N_s + 20$$

(3)Nodular pile with enlarged excavation

$$\beta Ns = 9.0Ns + 31$$

γ: Skin friction resistance coefficient of pile in clayey soil

Standard type (charging slurry around pile shaft that does not use expansive admixture):

(1) Straight pile

$$\gamma q_u = 0.9 q_u$$

(2) Nodular pile with normal excavation

$$\gamma q_u = 0.9 q_u + 15$$

(3)Nodular pile with enlarged excavation

$$\gamma q_u = 1.0 q_u + 20$$

Expansion type (charging slurry around pile shaft using expansive admixture):

(1)Straight pile

$$\gamma q_u = 0.7 q_u$$

(2)Nodular pile with normal excavation

$$\gamma q_u = 0.5 q_u + 20$$

(3)Nodular pile with enlarged excavation

$$\gamma q_u = 0.55 q_u + 30$$

N_s: Average N-value of sandy soil of ground around the pile shaft

However, N_s is greater than 1; the upper limit is taken as 30.The maximum limit of each N-value obtained during the calculation of N_s is taken as 100.

q_u: Average value of axial compressive strength of ground around the pile shaft consisting of clayey soil (kN/m^2)

q_u is to be taken greater than 10 kN/m^2; the upper limit is taken as 200 kN/m^2.

L_s: Total length of ground around the pile shaft consisting of sandy soil (m)

L_c: Total length of ground around the pile shaft consisting of clayey soil (m)

ψ: Effective length of circumference of foundation pile

$\psi = \pi D$ (D: Pile diameter; outside diameter in case of straight pile ; taken as outside diameter D_o at node in case of nodular pile (m))

The skin friction resistance in the range of 2 m above the pile toe surface is not considered.

The short-term allowable bearing capacity is two times the long-term allowable bearing capacity.

4.2 Validity of the bearing capacity equation

The long-term allowable bearing capacity equation shown in Section 4.1 is based on the results of a large number of pile load tests. Fig.3 shows correlation between the long-term allowable vertical bearing capacity R_{at} from the results of load bearing tests and the long-term allowable vertical bearing capacity R_a from the bearing capacity equation. From this figure, it can be observed that all values of R_{at} are greater than those of R_a. The regression equation of the two kinds of bearing capacity is determined as $R_{at} = 1.29\ R_a$. The actual bearing capacity from load tests is about 30% greater on an average than the value calculated by the bearing capacity equation. This also suggests that the bearing capacity equation gives a safe long-term allowable axial bearing capacity.

4.3 Example of results of vertical load bearing tests

Fig.4 shows an example of the results of load

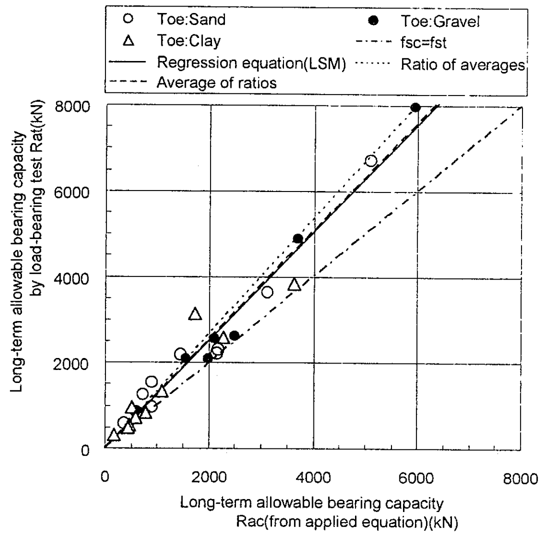

Fig.3 Correlation diagram of long-term axial bearing capacity by load-bearing test and bearing capacity equation

bearing tests. The figure shows the variation of axial load with pile head displacement and pile toe displacement obtained from a test carried out using a PHC straight pile of diameter 800 mm + enlarged head nodular pile of diameter 600 to 800 mm (total pile length 25 m). The test ground consisted of fine sand with N-values below 10 up to near G.L of -13 m, silt and sand with N-values between 15 and 25 in the range of -13 m to -30 m. The ultimate bearing capacity (maximum load) was 10900 kN, and one - third of this value, that is 3633 kN, becomes the long-term allowable bearing capacity R_{at}. For the above condition, the pile head displacement S_o was 4.78 mm (0.60% of diameter at node); the pile toe displacement S_p was 0.59 mm (0.07% of diameter at node).

The long-term allowable bearing capacity R_a was calculated using the bearing capacity equation, and its value was found to be 75% of R_{at}, that is 2719 Kn. The value at S_o at this stage was 3.19 mm (0.40% of the diameter at the node). The value of S_o was 10.04 mm (1.26% of the diameter at the node), relatively small in both cases, while the short-term allowable bearing capacity R_a' was 5438 kN.

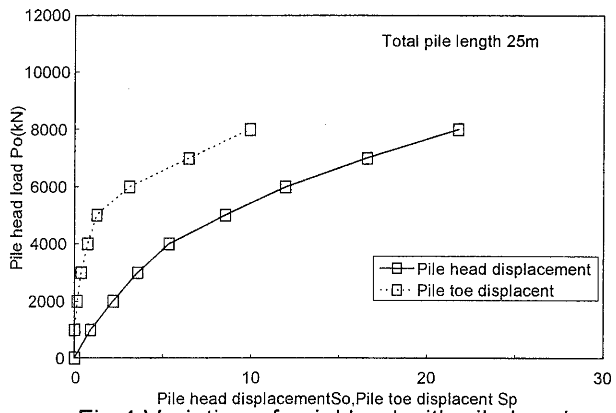

Fig.4 Variation of axial load with pile head displacement and pile toe displacement

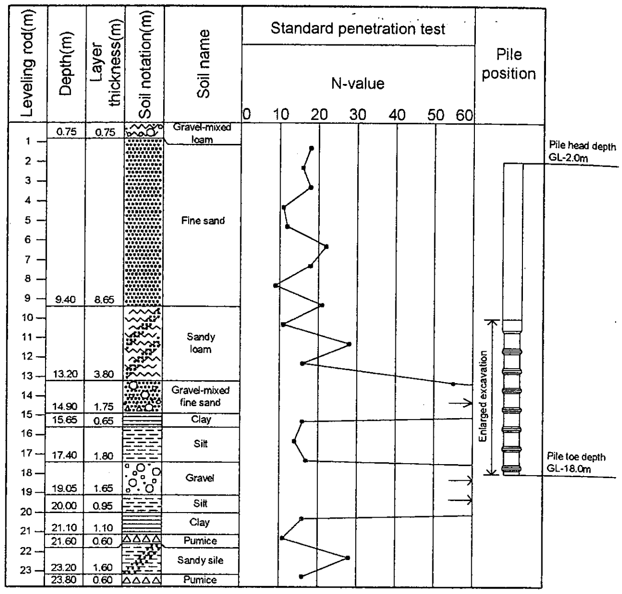

Fig.5 Ground boring diagram & pile profile

5. Example of application of the EX MEGATOP method

The example of a axially supported pile is given here as an application example.

*Overview of building: Ten-story warehouse of S-construction

*Type of pile: Lower pile HC-TOP pile (enlarged head type, φ1000-800, pile length 8 m)

*Upper pile: PHC straight pile of diameter 1000, pile length 8 m

* No. of piles: 87

*Design bearing capacity: 3300 kN

Boring diagram and profile sketch of pile is shown in Fig.5.

To illustrate the advantage of using this type of pile over the use of cast-in-place concrete as an alternative was evaluated. For the soil condition consisting of bearing layer with N-value grater than 60 in Fig. 5, cast-in-place concrete piles of diameter 1300mm and length 24m with long term bearing capacity of about 3500kN/pile may be considered based on the Japanese practice. This would mean a total foundation cost of about 1.6 times that of the case when EX-MEGATOP is utilized.

6. Conclusion

Although only six months have elapsed since the development of the EX MEGATOP method, 300 projects have already been completed using it, and an increase in the application of this method is likely in the future.