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STATIC PILE LOAD TEST: INTERNATIONAL PRACTICE REVIEW AND DISCUSSION ABOUT THE EUROPEAN AND JAPANESE STANDARDS

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ABSTRACT: This publication aims to describe the European and Japanese standards in order to discuss about the ongoing project of revision of the Japanese standard for static pile load tests, keeping in mind that the future version of this standard will have to take into accounts Japanese past experience, as well as the future needs to adapt to overseas practices, if necessary, for economical purposes. To do so, the different derived parameters that can be obtained by carrying out a static pile load test on a vertically loaded pile (instrumented or not) are described. Then, the current practice for static pile load tests in Japan is described, and the main current overseas practices (with an extra focus on the European practices) are inventoried, and their differences (if any) with the Japanese practice are highlighted. Finally, these differences are discussed, and their importance assessed for a possible integration in the future Japanese standard, that could this way be seen for an oversea point of view as viable and legitimate alternative to the other and until now more common practices.

Keywords: Piles, Load Test, State of the Art, Standardisation

1. INTRODUCTION

Static pile load tests are usually time consuming, difficult, and expensive. It necessitates thorough soil investigations and detailed planning, as well as involving skilled and dedicated staff.

However, such tests are the most reliable way to assess correctly the ultimate bearing capacity of piles and their behavior. Depending on the level of monitoring put into action, shaft resistance and base resistance can be differentiated, and even unit shaft friction can be measured. Also, depending on the testing protocol chosen, different behaviors can be studied in detail, such as creep, cyclic behavior, or tensile strength.

Moreover, while these kinds of tests are often performed to verify a design hypothesis for a particular project, they can and should always be used to create and continuously improve databases used to build the design rules for deep foundations, increasing the accumulated experience and hence the robustness and reliability of these design rules. This should in time translate into improved design standards, saving natural resources, and making the solutions proposed overseas more attractive and competitive.

Therefore, having a complete and well detailed test standard that is thoroughly linked to the design standard is a necessity, and countries without one feel the need for one [1].

This publication aims to first inventory the current practices for static pile load tests in Japan as well as overseas (mainly in the USA and in Europe), then to describe the ongoing project of revision of the Japanese standard for static pile load tests, keeping in mind that the future version of this standard will have to take into accounts Japanese past experience, as well as the future needs to adapt to overseas practices, if necessary, for economical purposes.

In this paper, only the compression load test is described with a focus mainly centered on:

(1) The distance between test pile and reaction piles,

(2) Loading protocols

(3) Failure criteria of pile loading tests.

2. MAIN MEASURED AND DERIVED PARAMETERS

Two main categories of tests can be carried out: non instrumented or instrumented tests. The purposes of these two kinds of tests are different, with the instrumented test evidently giving more information on the behavior of the pile.

2.1 Non Instrumented Test

This is the simplest test carried out on piles, giving also least information on the behavior the pile.

The first information available when performing a static load test is the load-displacement curve. This curve gives rough information about the behavior of the pile.

However, as this curve depends on the nature and state of the soil, as well as on the piling method and the pile geometry (Fig. 1), and furthermore on the loading procedure, its use is clearly limited to the determination of the bearing capacity or the validation of the design behavior of the pile for control tests.

The only other information given by a non instrumented test is the time-displacement curve and the load-creep rate curve, which can be used to determine the creep load of the pile (Fig. 2).

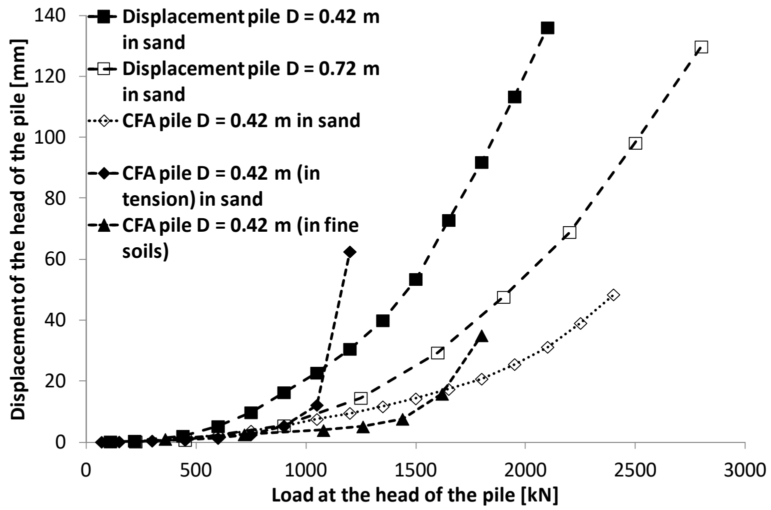

Fig. 1 Examples of load-displacement curve for different piles and sites

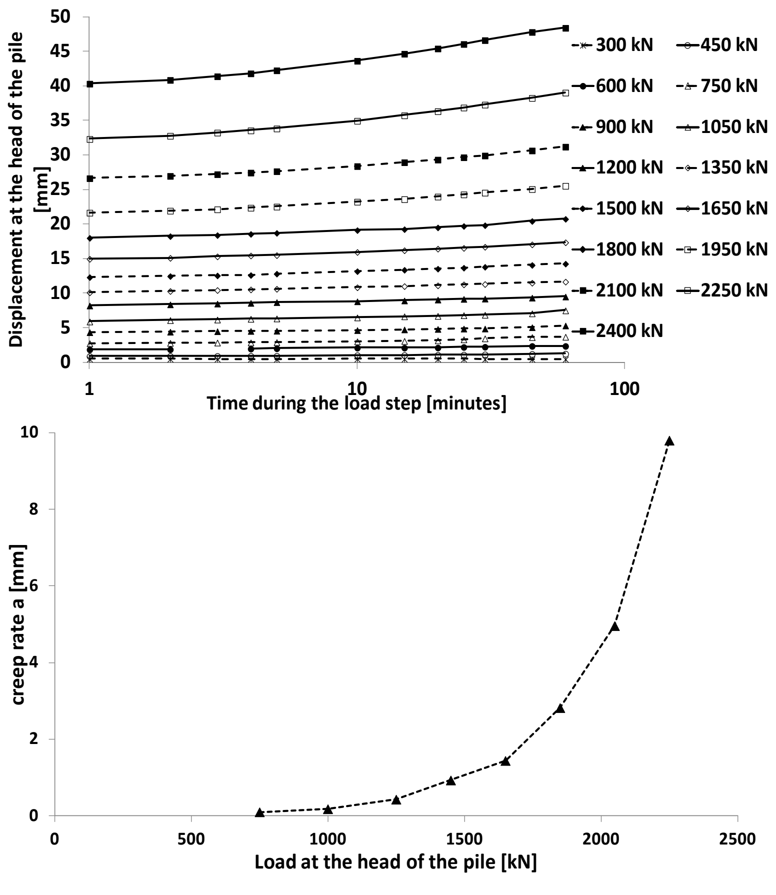

Fig. 2 Evolution of the displacement rate and creep rate during a load test.

2.2 Instrumented Test

Instrumented tests give away much more detailed information on the behavior of the pile.

Piles can be instrumented with strain gauges, vibrating wires or any other mean of achieving strain measurements, and also with embedded load cells (these are however much rarer).

Embedded load cells, when used, are often placed at the base of the pile, to measure directly the effort at this level, and therefore to distinguish the base resistance of the pile from its shaft resistance. However, this is relatively costly, and the quality of the concrete around this cell is often not as good as expected due to the presence of the cell, and therefore giving lower than expected results.

The distribution of the shaft resistance as well as the base resistance can also be determined by measurement of the strain at different depths. By knowing the strains at different depths, one can evaluate distribution of the efforts along the pile (Fig. 3), and from there determine the t-z curves (Fig. 4).

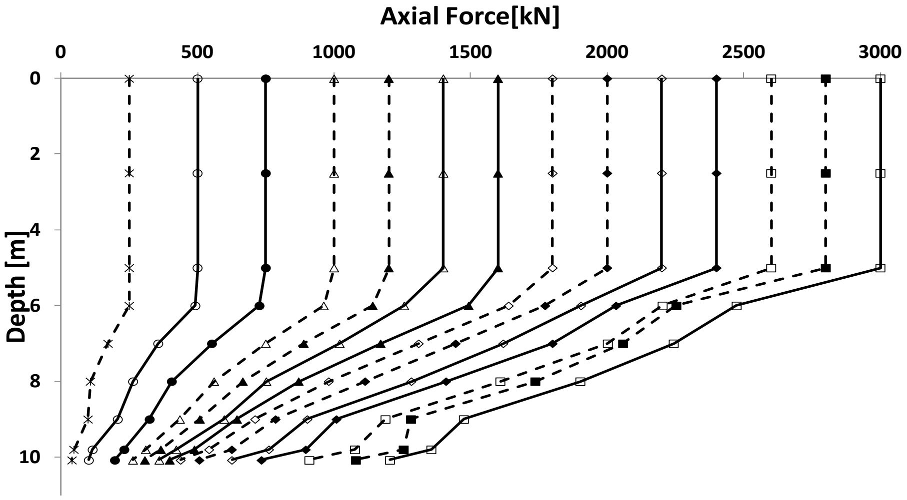

Fig. 3 Evolution of the distribution of the efforts along the shaft during a load test.

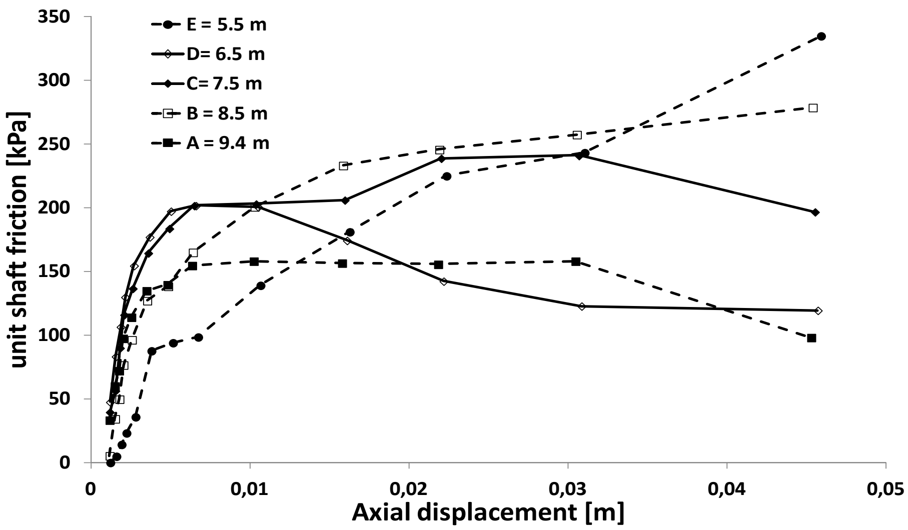

Fig. 4 t-z curves achieved from an instrumented load test.

To determine load from strain, the cross section and the pile material modulus of elasticity have to be assessed and all the materials present in the pile shall be considered. Strain sensors close to the pile head can be used to do this, if the geometry of the cross section and its composition is constant along the depth. Compression test on cored samples can also be considered. It is important to keep in mind that the type of strain sensor used has an impact on the modulus to take into account.

3. TESTING PROCEDURES OF JAPANESE STANDARD

3.1 History of Standard Revision

In Japan, the first standard “Method for Static Axial Compressive Load Test of Single Piles” [2] was published in 1972 by the Japanese Geological Society (JGS). This standard has been revised twice in 1993 and 2002. The third revision committee was established in 2018, and the discussions about the different changes are still ongoing. In this chapter, the testing procedures of the current standard revised in 2002 are mainly mentioned.

3.2 Distance Between Test Pile and Reaction Piles

Usually, the reaction device can be tension piles or anchors. In the JGS standard (2002), the following rules are defined as such: "As a general rule, the distances between the centers of the test pile and the tension piles (or anchors) shall be more than 3 times the maximum diameter of the test pile, and also more than 2.5 meters.” (Fig. 5).

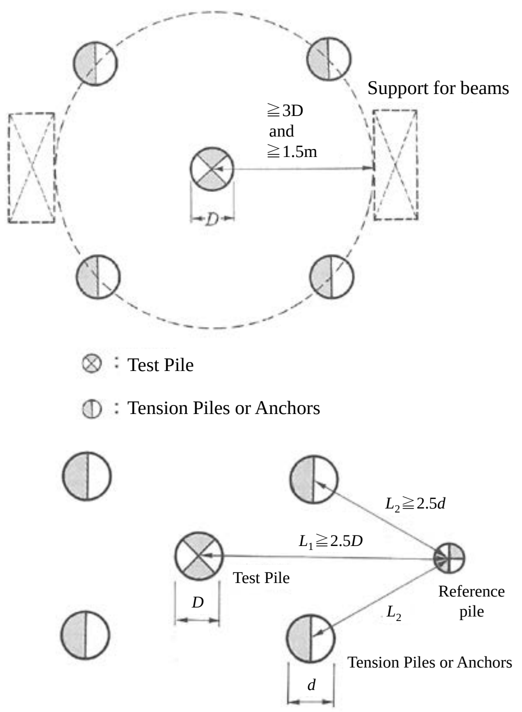

Fig. 5. Distance between the support point or tension piles (or anchors) and the test pile.

The rule of "more than 3 times the maximum diameter of the test pile" has been traditionally used since the first edition of the standard in 1972. In the revision of 2002, the experiment using model piles and the re-analysis of the data of the bi-directional load tests using the actual piles were conducted. As a result, it became clear that when this rule was satisfied, it did not have a big influence on the value of the second limit resistance which will be described later, and therefore this rule was judged to be appropriate for the purpose of assessing the resistance of the pile.

3.3 Time of testing

In Japan, it seems reasonable to think that a waiting period of more than 5 days for the piles in sandy soil is needed, and a period of more than 14 days is necessary for the piles in cohesive soil. However, these waiting periods do not take into account the structural resistance of the pile (i.e the resistance of the concrete).

3.4 Loading method

In the JGS standard, four loading methods are defined. These are classified into "step loading method" in which load holding is performed step by step and "continuous loading method" without load holding. In addition, two methods of "single cycle" and "multi cycle (not less than 4 cycles)" (Fig. 6) are defined respectively. The continuous loading method is a new loading method added as a revision in 2002 seen as a method suitable for reproducing the load condition acting in the short term such as seismic action.

Also, if the step loading method is applied, the load holding time for new loading steps is defined as "a constant period not less than 30 minutes". Regarding the validity of this load holding time, it was carefully examined at the time of revision in 1993. Thirty-four test cases with a load holding time of 120 minutes were collected and “the limit-resistance” and “the second-limit-resistance”, which will be described below, were calculated. Errors on the evaluation of the limit resistance were estimated by virtually shortening the duration of the load steps. The result showed that the error is large when the load holding time is about 10 minutes, but the error converged to several percent in about 30 minutes. As a result, it was judged that a rule of "not less than 30 minutes" is enough for the duration of a load step for engineering applications.

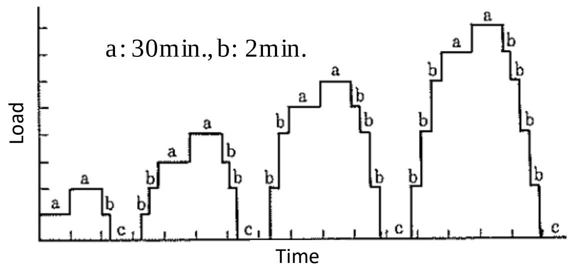

Fig. 6. Procedure of multi cycles loading method.

3.5 Failure Criteria of Pile Loading Tests

In JGS standard, two failure criteria are defined, and called "the first-limit-resistance" and "the second-limit-resistance", which is defined by the 1993 revision.

"The first-limit-resistance shall be defined as the load at the point of maximum curvature which appears clearly in the log t - log z curve.

"The second-limit-resistance shall be defined as the largest load measured within the displacement of the pile toe less than 10 % of the pile toe diameter." In the design standards for each field (railway, road, port etc.), the second-limit-resistance is considered as the bearing capacity, and used for deriving the estimation formula of bearing capacity from the database of the loading tests.

Table 1 Distance between the test pile and the reaction device

Reaction device	NFP 94-150-1 [3]	NF EN 61773 [7]	ICE Specifications [6]	SIA 267/1 [5]	EA Piling [4]	GCP-18 [10]	ASTM D1143_07 [9]	NF EN ISO 22477-1 [8]
Dead load	N/A	N/A	At least 1.3 m	2.5 m or 2.5 time D *	2.5 m or 2.5 time D *^	3 m or 5 time D *^	1.5 m	2.5 m or 2.5 time D *^
Vertical tension piles (shorter than the test pile) or	2 m or 1.5 e *+	2 m or 1.5 e *+	2 m or 3 time D_{max} *+	N/A	2.5 m or 2.5 time D *^	3 m or 5 time e *^	2.5 m or 5 time D_{max} *^	2.5 m or 2.5 time D *^
Vertical tension piles (longer)			At least 5 time D_{max} *+		2.5 m or 2.5 time D *^			4 m or 5 time D *^
Raking piles	N/A	N/A	N/A		N/A	N/A	N/A	N/A
Vertical anchors	N/A	N/A	N/A	N/A	3 m under the base and 3 m or 3 D from the shaft *	N/A	N/A	N/A
Raking anchors	3 m both ways	N/A	N/A	N/A		N/A	N/A	3 m both ways

* whichever is the greatest
+ from center to center
^ from edge to edge
e is the sum of the diameters of the test pile and the reaction pile
D is the diameter of the test pile

4. OVERSEA LOADING PROCEDURES AND REACTION DEVICES SETUPS

In this section, the main differences between several loading procedures are presented, mainly from Europe (French standard NF P 94-150-1 [3], German recommendations on piling [4], Swiss standard SIA 267/1 [5], ICE Specifications for piling and embedded retaining walls [6], European standard on Overhead lines – testing of foundations for structures [7], the European standard (also ISO) on static compression load testing NF EN ISO 22477-1 [8]) and USA (the Standard Test Methods for Deep Foundations Under Static Axial Compressive Load D 1143-07 [9] and the Geotechnical Control Procedure GCP-18 [10]) as well as the expected impact on the result.

4.1 Reaction Devices

Usually, the reaction device can be dead load or tension piles or anchors. Alternatively, in some cases, an existing structure situated over the test pile can be used. Moreover, for piles with a very high loading capacity, embedded jacks can be used.

When using dead load, tension piles or anchors, special attention should be paid to the distance between the test pile and the reaction piles (or anchors), so as to minimize the influence of the reaction system on the test pile, during the setup and the loading sequences.

Table 1 summarizes some of the practices in Western countries.

It can be seen that there are some notable differences between the different procedures, especially when a dead load is used. However, for more common reaction devices using vertical tension piles, characteristic values tend to stand out

Table 2 Recommended waiting time between the realization of the pile and the load test

Type of piles	NFP 94-150-1 [3]	NF EN 61773 [7]	ICE Specifications [6]	SIA 267/1 [5]	EA Piling [4]	GC P-18 [10]	ASTM D1143_07 [9]	NF EN ISO 22477-1 [8]
Displacement piles	7 to 28 days without any other precisions	7 (non cohesive soils) to 21 (cohesive soils) days	12 hours	At least 10 days in saturated clayey soils	3 (non cohesive soils) to 21 (cohesive soils) days	7 days	3 to 30 days without any other precisions	7 (sandy soils) to 28 (cohesive) days
Cast in place piles (bored)		14 days	4 days		N/A			7 (sandy soils) to 21 (cohesive) days

4.2 Time of Testing

The period of time between the day of the completion of installation of the test pile and testing is an important factor, for two reasons:

(1) In the case of displacement piles, this period allows for the dissipation of any excess pore pressures due to the installation of the pile;

(2) In the case of a cast in place pile, this period allows for the strength of concrete to build up so as to ensure that the pile shall not be damaged during the test.

No clear pattern can be extracted from the analysis of the different standards and recommendations: nevertheless, it seems reasonable to think that a waiting period of 14 days for bored piles is enough to reach a sufficient concrete strength, and a period of 21 days is sufficient for displacement piles. Table 2 summarizes the recommended intervals in Western countries.

4.3 Size of Pile Related to Piles Project

This question is of great importance, when the objective of the test is to verify a design hypothesis: indeed, the ratio diameter to length has a direct impact on the performance of the pile, as the rigidity of the pile change with it. Moreover, quality of concreting at the base can also be impacted by the diameter: for some execution methods, base resistances for large diameter are smaller than for smaller diameter.

Therefore, it seems logical to keep the test piles founded at the same level and in the same soils as the project piles, with a diameter as close as possible to the diameter of the project piles.

4.4 Loading Sequence and Load Steps Durations

The international (meaning not Japanese) standards and recommendations cited in this paper offer two different approaches for performing a maintained load compression test: with or without cycles.

Some standards are offering the possibility to perform a one cycle procedure, whereas the others offer a multi-cyclic procedure only, or both. Most of the procedures use the displacement rate as a criterion to increase the duration of the load step, so as not to allow a change of load step without stabilization of the pile. The magnitude of the load steps is mostly adjustable.

It is important to note that these differences in the procedures may be explained by the necessity to adapt to the local design method, as well as to the purpose of the test. When a sudden increase appears in the duration of a load steps, it is usually because the pile has to be tested at the working load. Then the magnitude and duration of the steps vary again to assess the overall bearing capacity. However, these changes in the loading pattern are detrimental to other aspects, like the determination of the critical load, which can be used in some countries for serviceability limit state. This is the case in France, for example, where the national standard reflects this particular need, by fixing the length and duration of all the load steps.

Moreover, some standards allow, like the

Japanese one, the possibility to carry out test at a constant rate of penetration. However, it is very uncommon and will not be described here.

4.5 Failure Criterion

The most widely accepted failure criterion is the load at 10 % displacement of the diameter. However, some other standards recommend a higher displacement (to 15 %) or a combination of the displacement rate and a percentage of the diameter in terms of displacement.

Table 3 Key points of the loading procedures

<table>
<tr><th></th><th>NFP 94-150-1 [3]</th><th>NF EN 61773 [7]</th><th>ICE Specifications [6]</th><th>SIA 267/1 [5]</th><th>EA Piling [4]</th><th>GCP-18 [10]</th><th>ASTM D1143_07 [9]</th><th>NF EN ISO 22477-1 [8]</th></tr>
<tr><td>Cycles (number)</td><td>Multi-cyclic (2)</td><td>1 or more</td><td>1 or more</td><td>Multi-cyclic (3)</td><td>Multi-cyclic (2)</td><td>Multi-cyclic (3)</td><td>1 or more</td><td>1 or 2</td></tr>
<tr><td>Typical length of a load step</td><td>60 min</td><td>3 to 10 min</td><td>10 to 360 min</td><td>90 min</td><td>N/A</td><td>30 min</td><td>20 to 60 min</td><td>60</td></tr>
<tr><td>Shortening of a load step</td><td colspan="7">No</td><td>Yes</td></tr>
<tr><td>Criterion for the shortening</td><td colspan="7">/</td><td>Disp. rate</td></tr>
<tr><td>Prolonging a load step</td><td>no</td><td colspan="7">Yes</td></tr>
<tr><td rowspan="2">Criterion for lengthening</td><td colspan="2">/</td><td>Overall head displacement</td><td>D, load applied</td><td></td><td></td><td>Overall duration</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="4">+ displacement rate</td><td></td></tr>
<tr><td>step of equal magnitude</td><td>yes</td><td>no</td><td>no</td><td>No</td><td>no</td><td>no</td><td>no</td><td>not if multi-cyclic</td></tr>
</table>

5. CONCLUSION

In this paper, we described the Japanese standard for compression pile loading test, and compared it with international standards.

The revision work of JGS standards is currently ongoing, and harmonizing it with overseas standards, including ISO, is one of the important viewpoints, for economical reasons for instance. In addition, it is necessary to consider the situations unique to Japan. One is the very large earthquake action in the Japanese standards for seismic design, and the other is the interaction between the installed pile and the neighboring structures in very narrow places such as renewal projects.

Comparisons of the different procedure tend to show some clear similarities between the different practices, from which we can conclude that the Japanese method and its interpretation of the results is already transposable overseas. However, it is important to note that for the duration of the load steps, as well as the loading pattern, some notable differences exist, that can be explained either by :

- A difference in the purpose of the test, with a special focus on the behavior under the service load, on the determination of the creep load or the determination of the overall bearing capacity. Therefore, the loading procedure could be adapted to this principal purpose.
- The fact that some of the cited standards are the results of a consensus achieved between practitioners of different countries, and therefore reflecting different national practices. Therefore, these standards have to allow the different practices to be used, by being transgenerational. This means that these standards have to be made of a succession of options to be 'activated' by the practitioners depending on their nationality and historical practice.

It is still expected that this paper will be useful for the revision of the JGS standards and further improvement of pile foundation design standards.

6. ACKNOWLEDGEMENTS

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