APPLICATION OF REINFORCING METHODS FOR EXISTING PILE FOUNDATION ON SOFT GROUND (IN-CAP METHOD)

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Abstract

The foundations of many old bridges are without any doubt insufficiently resistant to Level-2 earthquake motion. Therefore, the authors propose the anti-seismic reinforcement of existing foundations resting on soft ground (In-Cap Method). This construction method yields increased horizontal and vertical resistance by driving underground walls around the existing foundation and solidifying the ground inside. This report describes the outline of the method and how it is used with an example of actual foundation reinforcement work for a bridge.

1.Introduction

Seismic resistance improvement and reinforcement of the foundation generally takes much time and money because of various restrictions including limited space above and below girders, and there are not many cases of such work compared with other reinforcement work projects. On the other hand, considering a growing need for revision of disaster prevention measures for infrastructure facilities and for effective use of the existing stock, development of a handy and efficient technique to seismic retrofit the foundations of existing structures will meet future social needs. Under these circumstances, we proposed and developed the In-Cap method, a technique to reinforce the bearing capacity of the foundation of an existing building and to seismic retrofit the foundation. The In-Cap method has a few advantages; its implementation does not cost much, or take up much time and space[1)].

With the structure shown in Figure 1, the In-Cap method surrounds the existing foundation footing to a required depth, solidifies the inside of the sheet piles for improvement of the footing and integrates the improved footing with the existing foundation. This report describes the outline of the method and how it is used with an example of actual foundation reinforcement work for a bridge.

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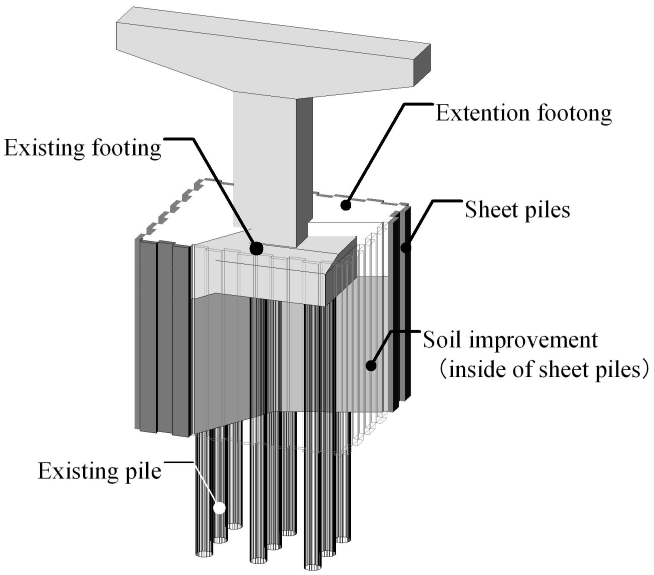

Fig. 1. Outline of reinforcing method for the existing foundation (In-Cap method)

2. Reinforcing Effects of the In-Cap Method and its Characteristics

Fig. 2 shows the foundation reinforced with the In-Cap method. This method is designed to improve the bearing capacity of the foundation by augmenting the number of resisting elements in the ground around the foundation and causing the solidified improvement body to constrain the piles to ultimately enhance the rigidity. This reinforcing effect can be qualitatively demonstrated by various model experiments. We have developed two types for the layout of the solidified improvement bodies, the peripheral solidification type and the pile restriction type, as shown in Fig. 3, so as to satisfy execution and structural requirements.

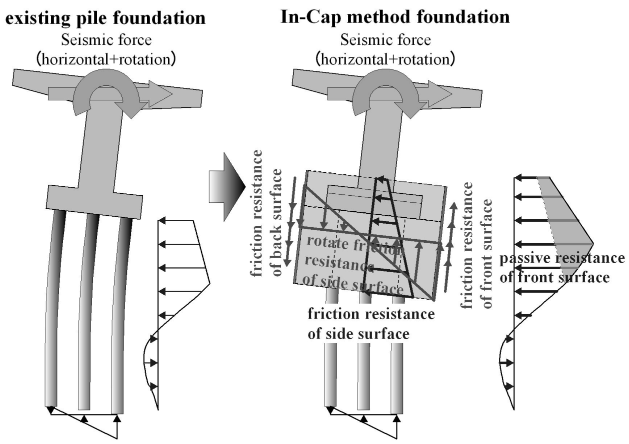

Fig. 2. Mechanism of the In-Cap method to reinforce the bearing capacity

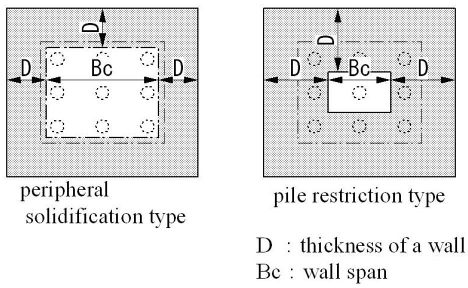

Fig. 3. Types of solidified improvement body arrangements

The reinforced structure model for the method was established after confirming reproducibility of the experiment results based on an analytical simulation. The model is a combination of the spring frames and the plane strain elements to express the behavior of the existing pile foundation and the solidified improvement bodies. This method was designed such that the arrangement of the solidified improvement bodies and the penetration depth are determined so that the subject building, after reinforcement, can satisfy the required seismic performance.

A combination of proven engineering methods may be used to implement the In-Cap method. The In-Cap method has the following features:

a) The surrounding steel sheet piles can also serve as a temporary retaining wall during the work.
b) The structural dimension of the method and the area required are both small.

In the In-Cap method, a high-pressure jet grout method using triple piping, which is known to have little influence on the existing structure, is supposed to be used as the standard engineering method for solidification improvement inside the steel sheet piles, which are the major component of the In-Cap method.

3. Application Example

(1) Outline of the actual construction

The In-Cap method was applied to an approximately 170 m long six-span simple composite steel girder bridge. The In-Cap method was applied to the bridge's five steel pile foundations for the single-layer two-column rigid-frame bridge piers. Constructed in the 1965 to 1974, the seismic resistance of the bridge foundations was checked according to the current version of Design Codes for Japan Highway Bridges, and it was found that the lateral displacement failed to satisfy the required performance for Level 1 seismic motion and the load-carrying capacity fail to satisfy Level 2 seismic motion.

The economic performance of various reinforcing techniques was compared, and the In-Cap method was chosen because of the structural features shown below. The structural drawings are illustrated in Fig. 4.

a) Additional piles were driven around the existing footing to ensure sufficient load-bearing capacity (14 cast-in-situ piles 1,000 mm in diameter each).
b) The area of the additional piles alone was reinforced by constructing the solidified improvement bodies (in a pile-constraining pattern) considering constructibility and economic efficiency.

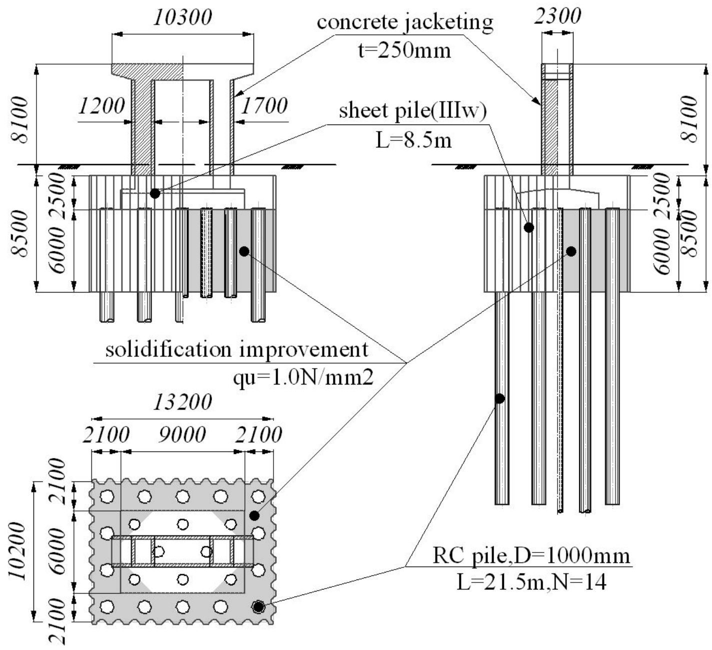

Fig. 4. Structural reinforcement diagram

(2) Design outline

The bridge is located in the floodplain of the Tone River standing on ground composed of a soft clay layer of 0 to 2 in N value for some 20 m under the ground level. Therefore, the initially selected reinforcement method, or additional piling, should require a large number of additional piles to control displacement, and the execution design was drawn based on the use of additional steel pipe sheet piles for reinforcement of the foundation. But since this method was economically outperformed by and therefore replaced with the In-Cap method used in combination with additional piling. The conditions of the In-Cap reinforcing design and the important points noted are shown below:

a) Considering the local construction environment, cast-in-place piles using the top drive reverse (TBH) method were used for additional piling.
b) For the arrangement of additional piles, the distance from the edge of the existing footing to the center of the pile and from the center of the steel sheet pile to the center of the pile were both set to 1D in consideration of constructability.
c) The diameter of each additional pile was 1,000 mm, the maximum diameter that does not cause the width of the improved foundation footing in the orthogonal direction to exceed the site boundary.
d) Additional footings were connected to steel sheet piles with the plate bracket method.
e) For the layout of the solidified improvement bodies, haunches were formed on the corners as shown in the plan of Fig. 4 to control tensile stress imposed by the load on the improvement body in the direction of the bridge axis.

f) Since the ground is made of very soft clay, the dead weight of the solidified improvement bodies was set on the safe side by considering the generation of holes under the improvement bodies by subsidence of the surrounding ground.
g) For additional footing, the interface with the existing structure was checked, and anchoring bars necessary for the existing footings were determined to be necessary in addition to the ordinary design specifications.

The structural calculations based on the above conditions found that 14 additional piles were necessary to ensure sufficient load-bearing capacity under Level 1 seismic motion. To reduce the bending moment that would occur to the additional piles under Level 2 seismic motion, the necessary penetration depth of the solidified improvement bodies was 6.0 m as shown in Fig. 5. The height of the footing is 2.5 m.

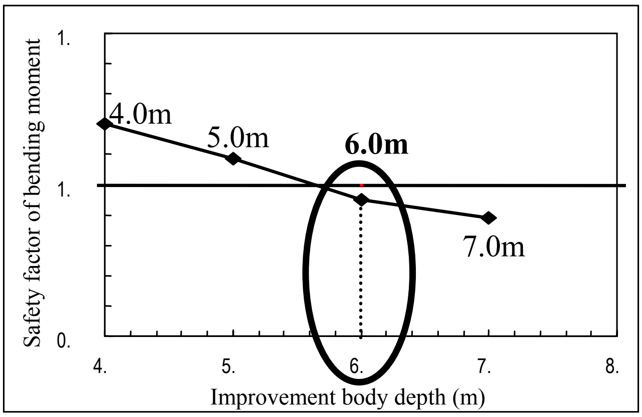

Fig. 5. Penetration depth of the solidified improvement bodies

(3) Outline of the work procedure

The important points to note about the improvement work using the In-Cap method are shown below:

a) Displacement to the existing bridge piers while the bridge is in service should be minimized.
b) The work was to be conducted with space restrictions under the girder, and the space available for the work was the minimum requirement for the work.

Considering the above, it was necessary to choose a method that causes minimal impact on the bridge and bridge piers and can be employed in a small space.

During the work, measurement control was conducted using (real-time) behavior monitoring. A communication management system was also put in place that allows quick response in case any abnormal displacement occurred during the work because of earthquakes, heavy rain, or other natural disasters. Fig. 6 shows the flow of the work.

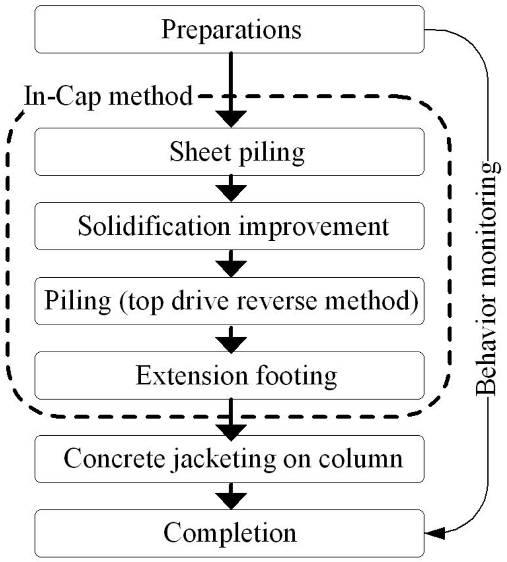

Fig. 6. Work flow

1) Behavior monitoring

The behavior of the bridge and bridge piers was monitored during the initial stage of work in 2004 using the measurement items listed in Table 1. All the subject bridge piers were monitored automatically round the clock. The management standard values were set in two stages, or warning level and limit level, based on the preliminary measurement results about a month before commencement of the work and the past work data.

Table 1. List of measuring apparatuses and the number of measuring points

Measurement item	Apparatus	Number of the installed points	Remarks
Displacement of a pier (3D position measurement)	Total station	2 points	Automatic tailing x、y、z
Inclination (bridge axis & right-angled)	Stanchion type Inclinometer	1point 2axies	automatic
Temperature	Thermometer	3 points	automatic
Displacement of shoe	Displacement Transducer	2 points	automatic

When the measured value exceeds the warning level, the system automatically sends off a warning. During the work, a personnel arrangement was established in which the staffs in charge do the monitoring and immediately send instructions to the supervisors at the site whenever necessary.

No harmful changes were measured to the existing structure during any stage of work, or steel sheet piling, solidification improvement work or cast-in-situ piling work, and the work was completed without trouble.

2) Steel sheet piling

Pressure pile driving with static penetration force, which generates no vibration and is suited to pile driving in small spaces such as under the girder, was employed to drive steel sheet piles. Type III wide steel sheet piles were used since the sheet piles had to also serve as a retaining wall for excavation during construction of the footing. The pressure penetration length was 8.5 m, and where there was no influence on the girder, a single sheet pile was used. Under the girders, two piles (5.0 m + 3.5 m, and partly 4.0 m + 4.5 m) were spliced due to the overhead limitation. Since the steel sheet piles had to be integrated with the additional footings to form part of the reinforced structure, every operation was carefully conducted to satisfy the management standard for all factors including placement location and height, verticality and other factors. Finally, the steel sheet piling work was successfully completed.

3) Solidification improvement

The jet grout triple-pipe method, which has less impact on the subject structure and the surrounding ground, is used for solidification improvement of the In-Cap method. The solidified improvement bodies for the subject work were arranged in a cylindrical pattern so that there would be complete improvement in the necessary range. An example of solidified improvement body arrangement and the actual improvement work under the girder are shown in Fig. 7.

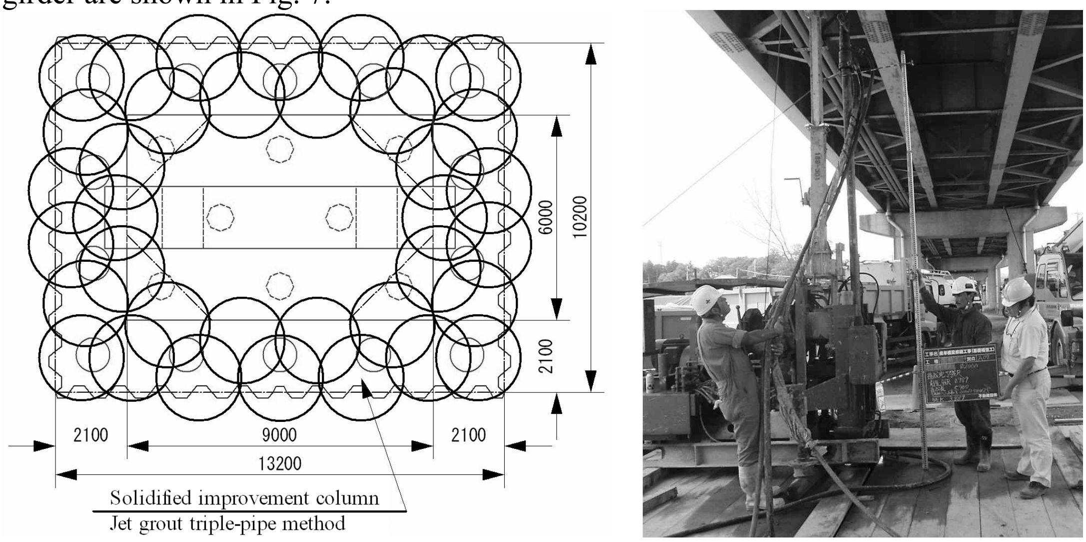

Fig. 7. Example of solidified improvement body arrangement and the actual improvement work under the girder

It was confirmed after the investigative boring and by the condition of the excavated bottom when the additional footings were constructed that the solidification improvement work had been successfully completed. There was a fear that the uncontrolled force of delivery pressure for air, water, and cement from the jet grout method would raise the pressure inside the ground to cause an uplift force on the footing, but this fear was eliminated by releasing the pressure through a borehole 250 mm in diameter drilled in the center of the footing. Prior to the work, a test pile was driven at the location where the impact on the bridge pier would become greatest and increased the monitoring frequency.

For the construction order of solidified improvement bodies, those near the existing foundation were constructed first to strengthen the foot of the pier, and then the bodies in the surrounding sheet pile area were constructed. During the work, slight deformation occurred due to poor removal of earth. The order of placement was changed as a result of the detailed check of the measurement results, and the work was successfully completed with no values exceeding the management standard.

4) Cast-in-situ piling work

TBH method, which is suited to small space work such as under the girder, was employed for cast-in-situ piling. At the beginning, there was a fear of improper excavation near the solidified improvement bodies, but the piling work was completed without any problem.

5) Additional footing and bridge pier lining

For construction of additional footings and bridge pier lining, the ordinary seismic retrofit procedure was applied. Plate bracket connectors such as those used for steel sheet pile foundations were installed to ensure unification of the inside of the steel sheet piles at the additional footings with the existing structure.

4. Summary

This report describes the outline of the In-Cap method, a newly developed seismic retrofit technique for existing pile foundation structures, and how it is used.

The In-Cap method was applied in the seismic retrofit of a bridge, the application example used in this report, and the work was successfully completed without disturbing traffic flow of the elevated bridge with the help of meticulous measurement control.

Seismographs were installed at the bridge piers reinforced by the reported work in 2004 and at other piers with no reinforcement, and monitoring continues. So far the bridge experienced a few earthquakes with a seismic intensity of about II, and the data were recorded. With the earthquake measurements shown in Fig. 8, the absolute values of acceleration at the reinforced foundations were remarkably reduced compared with the un-reinforced foundations. We intend to analyze the results and use them to demonstrate the seismic reinforcement effects of the In-Cap method.

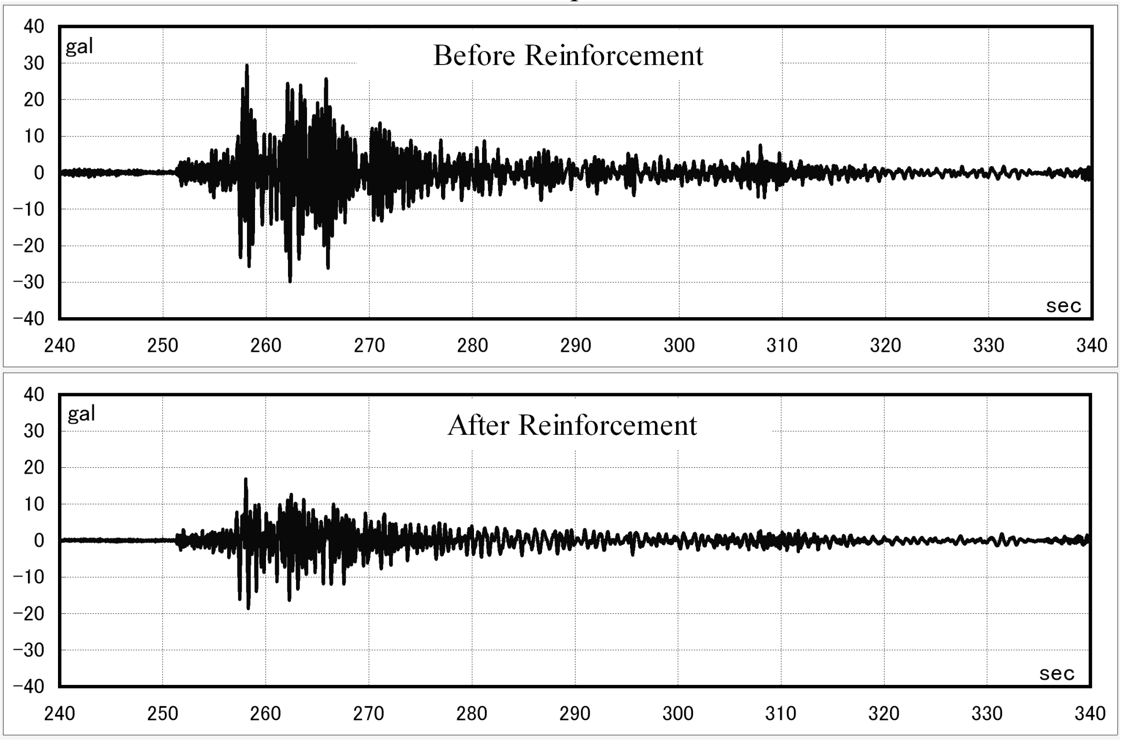

Fig. 8. Acceleration of seismic waves at the bridge piers before and after reinforcement

Acknowledgments

The In-Cap method was granted a Construction Technology Examination Certificate [2)] by the Japan Institute of Construction Engineering in March 2005.

References

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2) Japan Institute of Construction Engineering: Construction Technology Examination and Demonstration Project (General Civil Engineering Method) Report, In-Cap Method, March 2005. (in Japanese)