

Technological Report: Repair Technology for Tilted Structures by Grouting

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Grouting method is generally used for the improvement of fissured grounds or grounds lacking in strength when they are excavated. In recent years, the repair method for the buildings and other structures which had tilted were developed by employing the grouting method. This method is named "Jacking of Grout Method (JOG Method)" and has been used in repairs of over 100 cases from tilted buildings to monuments and culverts after the Kobe Earthquake and the Taiwan Ji-Ji Earthquake. This report introduces the basic principle of this new technology and some examples of its application.

Principle of Jacking and the Work Procedure

When the grouts such as the cement milk are injected into the ground, they infiltrate the permeable ground without disturbing the soil skeleton (the seepage injection). However, in the ground whose permeability is low, they split the structure of the soil particles as it expands, causing the ground to bulge (split injection).

Although ground bulge due to grouting

should be controlled to be as small as possible not to affect the ground surface or surrounding structures, tilted buildings and other structures can be repaired by effective use of the ground bulge due to grouting. The method, introduced in this report, can control the ground bulge accurately through appropriate selection of the grouting material and schedule according to the ground properties and the size and structure of the foundation with the base of the knowledge that had been cultivated in the usual grouting construction. Figure-1 indicates the working procedures and defines the overview of this method.

1) Bore through the foundation of the structure. Insert a double tube consisting of an outer pipe with the internal diameter of 27.2~34mm and an inner pipe with the internal diameter of 15mm, so that their tips are placed just at the bottom of the foundation. The double tube is employed when using grouts whose gel time is extremely short, in order to prevent premature solidification. In this case, two types of grouts are injected separately and are mixed and solidified at the outlet of the tube.

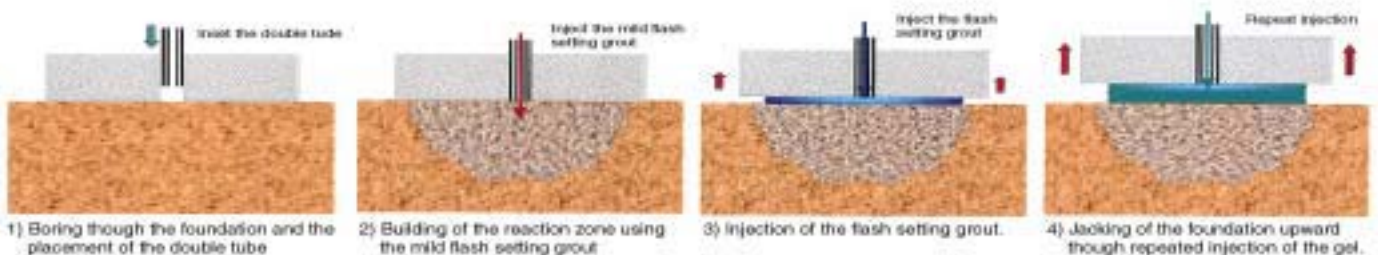


Figure 1: Construction Procedure of JOG Method

2) Inject the mild flash setting grout, whose gel time is scores of seconds, through the double tube. Although the grout will infiltrate in the hemispherical zone in the ground, the zone will be gradually expanded by the repetitive work of the seepage injection in the permeable ground or of the split injection in case of the ground with lower permeability. This zone will play a role of the reactions for jacking after it has been solidified.

3) Inject the flash setting grout whose gel time is within a few seconds. Because the previous grouting has created a solidified zone of low permeability, the newly injected grout cannot infiltrate this zone and then it splits the clearance between the foundation and the ground surface as a wedge effect. Thus, it becomes a thin layer and expands as it raises the foundation.

4) Lift the foundation gradually by repeating the procedure indicated in 3). Because the area to which the grout can be injected through one hole is limited, the multiple injection system has been developed in the JOG method. In this system, the plural holes are bored at the designed points on the foundations of structures and they are linked with the injection pipe on which the branching valves are placed. The grouting is carried out by the interval injection method in which the grout is injected through each hole intermittently in a short time and in turn. The order of the hole to be injected in each cycle and time of the injection at each hole are controlled according to grouting schedule determined from the ground properties and other conditions. The foundations of structures are lifted gradually, keeping their balance by this interval injection method.

It is possible to select the grouting manner by varying the cycle time defined by the time interval of injection for each hole in the interval injection. For example, in building a reaction zone with a mild flash setting grout, when the cycle time is shorter than the gel time, the grouting takes place in a yet-to-be

solidified zone. This will minimize the risk of ground bulge but will increase the risk of grout overflowing the previously set zone. On the other hand, when the cycle time is longer than the gel time, the following grout is repeatedly injected into the zone where the grout at the previous step has already been solidifying, and thus the risk of grout overflow will be minimized but that of ground bulge will increase. Based on the understanding of these interrelationships, the grout time for each injection pipe could be adjusted in a unit of 1/ 10 second and the sum of the injection time for all the holes in a cycle could be set as the cycle time.

In grouting works, the behavior of the structure is measured with precision using displacement sensor and tilt sensor. In order to control the grouting in multiple pipes based on these data, the grouting control system was built by combining the automatic switch valves and a central processing computer system.

Characteristics of the Method and its Applicable Condition

In the method, which had been employed so far to repair tilted structures, the ground was excavated around and beneath the foundations of structure to build a reaction zone at the bottom of the foundation and then the foundation was jacked upward by using the reaction from this zone. The clearance created by the jack was finally grouted. This method requires numerous steps, extending the work period and augmenting the cost. On the other hand, the grouting method suffices to place the injection pipes in the foundation and to jack it up by injecting the grout through them. As this method does not require excavating around and beneath the structure, it enables to restore the structure in question with almost no influence on adjoining structures. Moreover, as the method does not place partial pressure in the foundation, the security of the work is ensured. The

method has numerous other merits such as the absence of vibration and noise, and the short work period of approximately 1~2 weeks in general.

This method is suitable in cases of spread foundation with sufficient rigidity and strength. Contrarily, it is not suitable when the structure is supported by a pile foundation, especially by point bearing piles, as grouting at the pile points is not feasible.

This method may not result in successful repair when there are damages of the buckling on important parts of the structure such as its columns or its walls, or when sufficient rigidity and strength of the foundation cannot be guaranteed because additional damage may be induced even by the grout jacking method.

In cases when the supporting ground consists of sand, gravel or other types of soil of low compressibility, there is almost no problem. However, working on insufficiently consolidated clay and other types of ground with high compressibility often require careful consideration because there is a possibility of delayed ground subsidence after the completion of the work, which would diminish the preciseness of the final result of the construction.

Examples of Construction Works

Repair of a Box Culvert

Photo-1 shows the box culvert prior to the repair work. It was presumed that the box culvert was tilted due to subsidence of the supporting ground after the construction was completed. When the repair work was considered, the embankment had already been loaded over the boxes and the subsidence had settled. At that stage, the subsidence of 116mm was measured at the maximum. Each of the five reinforced concrete boxes, which were linked to

comprise the culvert, was tilted. The soil, which supports the mat foundation of the culvert, was made of alternating strata of silty clay and sandy silt.



Photo 1: Box culvert prior to the repair



Photo 2: Box culvert after the repair

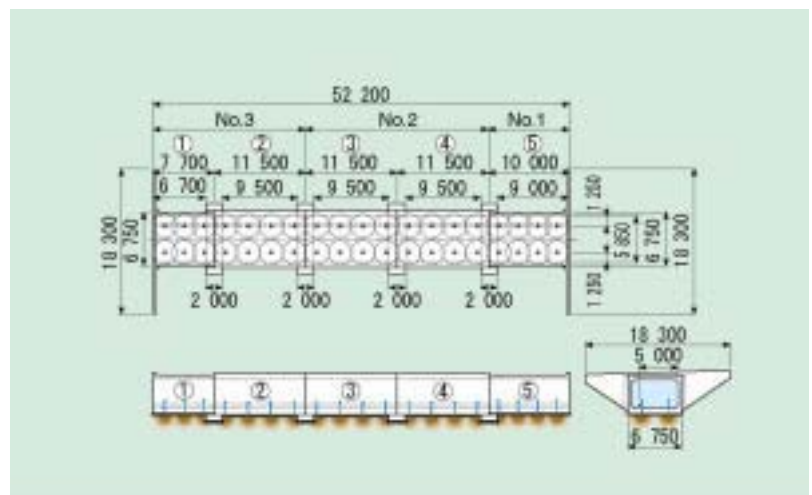


Figure 2: Plan for the repair of the position of the box culvert

As Figure-2 shows, the box culvert was repaired by grouting at 45 spots of the culvert foundation and by jacking one box at a time. All five culverts were finally restored to their designed position.

Restoration of a Tilted Apartment Building

Many buildings were damaged during the Kobe Earthquake, which occurred in 1995. Photo-3 shows one such example. This apartment building in the coastal area was tilted to a great degree due to the ground liquefaction and the violent shaking. This structure was concrete reinforced and was supported on a sandy ground by a mat foundation with continuous footings. The total weight of the structure was approximately 1100t, its surface area was approximately 113.40m², and a maximum subsidence measured was 410mm. The grouting method, which could minimize the vibration and the noise and could be undertaken safely, was applied in the repair works of this structure because an investigation after the disaster revealed that the rigidity and the strength of the structure itself was maintained, and from consideration to the fact that the floors above the second are still inhabited.



Photo 3: Tilted apartment building



Photo 4: Restored apartment building

In repair works, 19 holes were drilled from the first floor through the foundation, and the injection pipes were subsequently placed in these holes. The grouting was controlled by precise measurement using laser level at the four corners of the building and its center. The building has finally been restored to its original state in 19 days as shown in Photo-4.

Restoration of a Tilted Clock Tower

Photo-5 shows the clock tower at Citizen's Square in Port Island, Kobe. Port Island is an artificial island built from land reclamation. During the Kobe Earthquake, liquefaction occurred at various sites on this island. This clock tower was also tilted due to liquefaction. Luckily, no fissure was observed on the exterior wall of the tower and there was no damage to the structure. However, due to the tilt, the tower swayed in the south-north direction as the bell rang. The tower was concrete reinforced and was 20m in height and 250t in weight. It was supported on a sandy ground by a single footing of 42.25m². During the earthquake, the maximum subsidence of 112mm was observed and the tower was tilted by 2 degrees, displacing the top part of the tower by 650mm at maximum.



Photo 5: Clock tower tilted due to an earthquake



Photo 6: Restored clock tower

As Figure-3 demonstrates, the injection pipes were placed at the four corners of the footing. By grouting control based on measurement, the tower was restored to its original position in six days as shown in Photo-6.

Future Developments

So far, the JOG method has been applied mainly to repair the structures that are tilted due to earthquakes and other incidents. However, by placing the injection pipe at the time of construction of the structure that are prone to subsidence or tilting, it

becomes possible to readjust the position or the level of the structure anytime such needs arise. Moreover, this method possesses various other possible usages.

The JOG Method was developed in eastern Osaka area where “the development of a satellite through the collaboration of some small and medium-sized enterprises “drew public attention last year. The authors wish to introduce this method to our readers, in hopes that this may encourage the revitalization of technological development in the private sector.

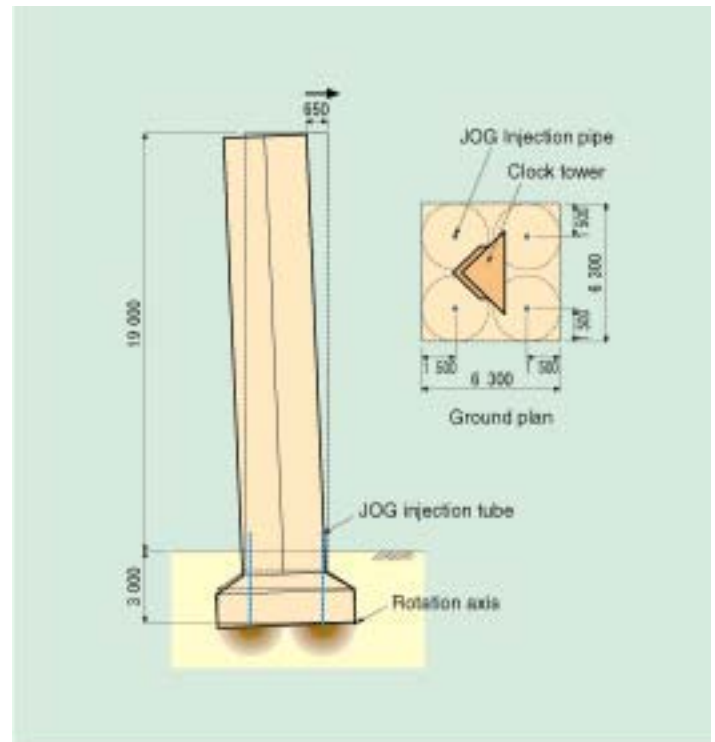


Figure 3: Tilt of the clock tower and the overview of the repair work