

Appendix-6: Cavity Repair Method Using Bagged Liquefied Stabilized Soil

1. Introduction

In Japan, the corrosion and perforation of steel sheet piles in sheet-pile type quaywalls have caused the backfill soil behind the wall to be washed out, resulting in cavity formation and apron collapse. This issue became a nationwide topic of concern. A typical example of apron collapse behind a quaywall is shown in Photo 1, and similar risks of collapse still remain at many sites throughout the country.

Therefore, at existing facilities, it is essential both to eliminate the causes of such collapses and to detect cavities that may lead to future collapses at an early stage so that appropriate countermeasures can be implemented.

For cavity repair, open-cut methods and filling methods using various filling materials are commonly adopted, depending on the scale of the repair. For cavities with particularly complex shapes, Liquefied stabilized soil (LSS) ¹⁾ is suitable. However, because Liquefied stabilized soil exhibits high alkalinity, there are concerns regarding its environmental impact when used in port or river environments. To address this issue, a new filling technique has been developed that utilizes bags.

In this method, LSS is filled inside bags inserted into the cavity, preventing leakage to the outside while enabling effective repair.

Moreover, LSS with adjusted strength can be re-excavated, making the method advantageous for future facility renewal. This section outlines the cavity repair method and presents representative repair cases.

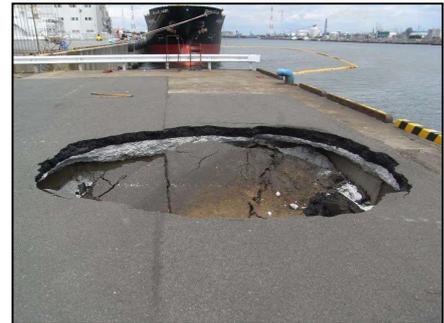


Photo 1 Apron collapse behind quaywall

2. Cavity Repair Method Using the Bags with Liquefied Stabilized Soil

2.1 Overview of the LSS Method

Liquefied stabilized soil (LSS) is a material developed for the effective reuse of construction by-products such as excavated soil and construction sludge. It is produced by mixing a solidification agent with construction-generated soil or construction sludge (muddy water) at appropriate proportions so that sufficient fluidity is maintained during placement. It is widely used as backfill material in narrow urban areas where compaction is difficult.

LSS has excellent uniformity and self-filling properties, making it well-suited for environments with limited working space where compaction is difficult. It also allows easy strength adjustment, is re-excavatable for future upgrades, and contributes to reducing environmental impact through the effective use of construction by-products.

Figure 1 shows an overview of cavity repair using the Bags with LSS ²⁾.

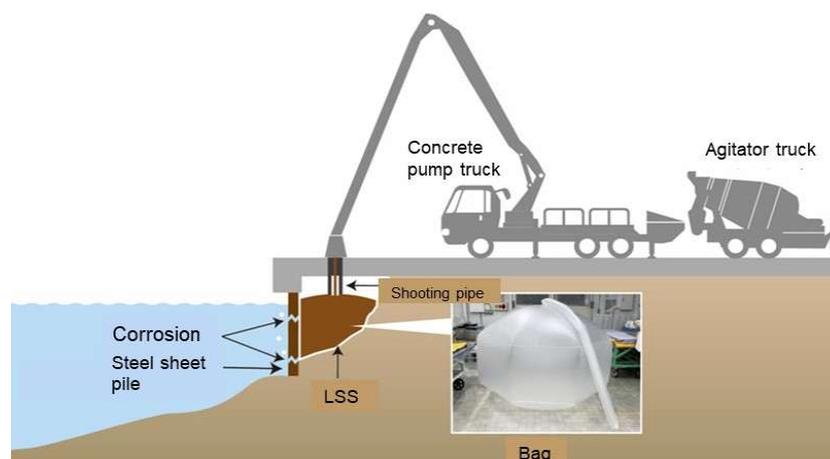


Figure 1 Conceptual overview of cavity repair using the bags with LSS

In this technology, a filling hole ($\phi 100\text{--}200\text{ mm}$) is created above the cavity, and a foldable, expandable bag is inserted. Liquefied stabilized soil is then injected into the bag to repair the cavity. Because the high-fluidity Liquefied stabilized soil is contained within the bag, no leakage occurs. Furthermore, Liquefied stabilized soil with adjusted strength provides re-excavatability, making excavation for future facility upgrades possible.

2.2 Construction Procedure

Figure 2 shows the construction flowchart. When carrying out repairs using this method, it is necessary first to conduct a preliminary survey to determine the existence and extent of cavities.

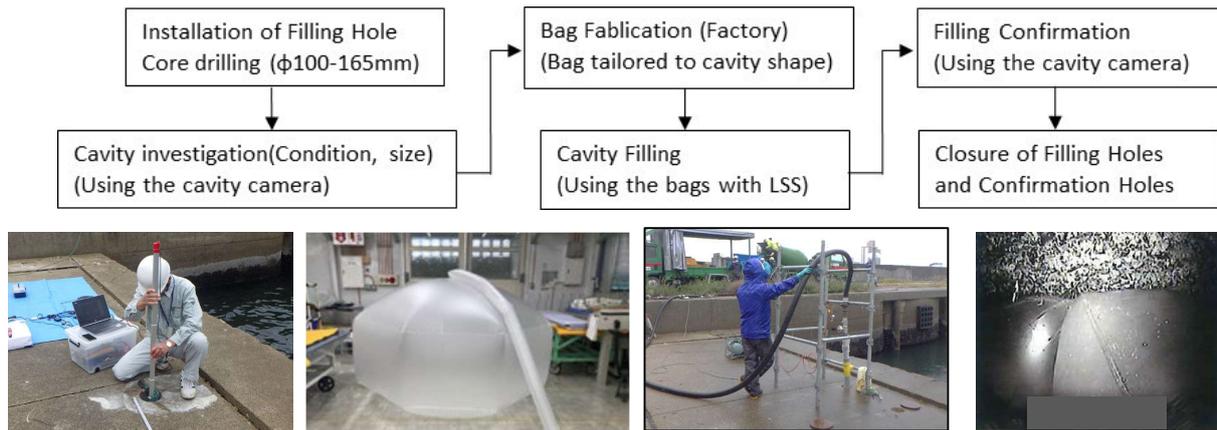


Figure 2 – Construction flow for cavity filling

First, a filling hole is created using a core drill, and a cavity-inspection camera is used to investigate the internal condition of the cavity. The camera, equipped with a laser distance-measuring function, accurately identifies the cavity's shape and dimensions. Based on the measured data, a bag suitable for the cavity geometry is fabricated at a factory. At the same time, the optimal location for confirmation holes is determined, and the holes are drilled on site.

Once the bag is fabricated, it is inserted into the cavity and expanded using air pressure to conform to the cavity's shape. Then, LSS is pumped into the bag using a grout pump. During this process, pressure is strictly controlled to consider safety and potential impact on the surrounding ground. Referring to backfilling injection work criteria, the upper limit of filling pressure was set to 0.2 MPa.

The filling condition is checked from the installed confirmation holes. If important structures exist within the area of influence, inclinometers or other monitoring instruments are installed in advance to carry out monitoring during construction.

3. Filling a Cavity Formed Behind a Revetment

3.1 Cause of Cavity Formation

This method was applied to repair a cavity identified behind a revetment. Investigation into the mechanism of cavity formation revealed that a Hume pipe had been embedded in the center of the cavity, as shown in Figure 3. Additionally, because the Hume pipe, located directly beneath the cavity, was damaged, seawater repeatedly flowed in and out through the pipe due to tidal action, causing soil to be washed out and resulting in cavity development.

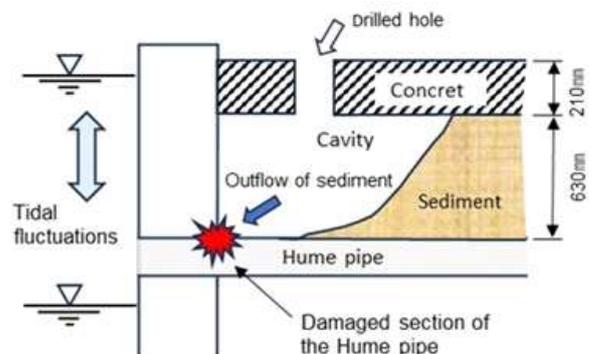


Figure 3 – Condition of cavity formation

3.2 Detailed Investigation Using a Cavity Camera

A detailed investigation was conducted using a cavity camera to identify the current condition of the cavity (height, direction, degree of submergence), to determine the appropriate bag dimensions, to check for long-term changes, and to estimate filling volume. Figure 4 shows the results of the detailed camera investigation. The cavity extended outward from the filling hole, and the cavity was found to be deeper directly beneath the hole and gradually shallower toward both ends.

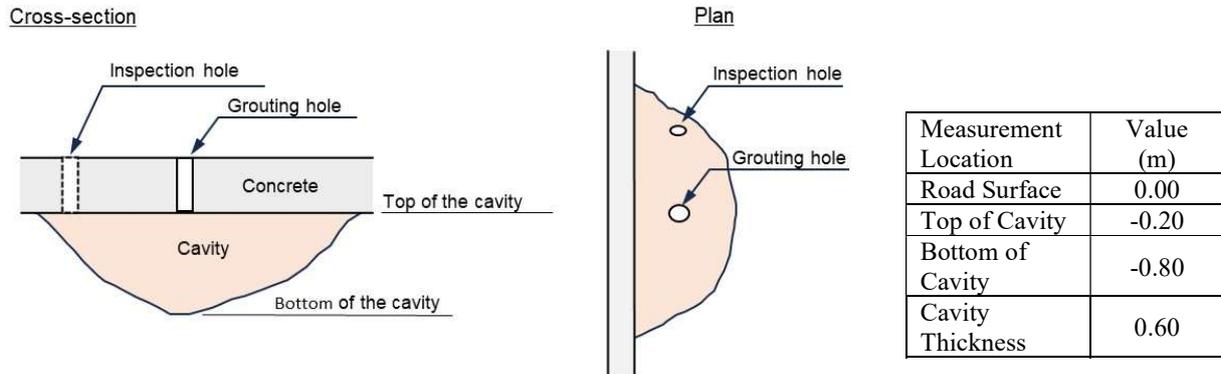


Figure 4 Investigation results of cavity

3.3 Materials and Mix Proportion

LSS was produced by adding a solidification agent to muddy water generated from the recycling process of construction sludge (excavated soil + water). Blast-furnace cement type B was used as the solidification agent. Table 1 shows the mix proportions of LSS used and the results of quality tests. For the bags, 200- μ m-thick polyurethane sheets with excellent workability and foldability were used.

Table 1 Mix proportion

Materials	Mix proportion			Test Results			
	Unit weight of sludge	Unit weight (kg/m ³)		Unit weight	Flow value	Breeding ratio	Compressive Strength σ_{28}
	(g/cm ³)	Solidification agent	Sludge	(g/cm ³)	(mm)	(%)	(kN/m ²)
LSS	1.21	130	1158	1.34	255	2.13	240

3.4 Filling Work

The bag was inserted through a ϕ 150 mm filling hole and expanded by injecting compressed air. The expansion condition was verified using a cavity camera inserted through the confirmation hole. The bag was adjusted through repeated inflation and deflation, and finally expanded to cover the entire cavity.

LSS was then pumped into the installed bag using a grout pump (filling hose ϕ 50 mm). Filling pressure was constantly monitored with a pressure gauge installed on the hose. When the arrival of LSS was confirmed from the confirmation hole, pumping was stopped, and a 30-minute observation period followed. No settlement or deformation was observed, and filling work was completed. No leakage of LSS was observed from the damaged Hume pipe or any other locations, confirming that the filling achieved the required quality.

3.5 Considerations

The cavity behind the revetment was successfully repaired using the bags with LSS method. Inspection during construction confirmed that the bags had no punctures or damage and that durability was sufficient. The filling proceeded as planned, with an actual filled volume of 1.5 m³ compared to the design volume of 1.4 m³, resulting in a loss rate of approximately 7%. No leakage or scattering of LSS into the surrounding environment was observed, confirming environmental safety.

4. Example of Repair of Collapse Behind a Revetment

This project involved the filling and emergency repair of five collapse locations that occurred behind the revetment in a private industrial site. Photos 1–3 show the construction sequence.

The collapse was caused by the opening of joints in concrete sheet-pile revetments due to long-term deterioration and ground deformation, which allowed backfill material to flow out from behind the revetment. During the review of emergency measures, repairing the joints from the seaside was judged difficult in terms of construction period and cost. Therefore, the bag with the LSS filling method was adopted, as it allowed all work to be performed from the land side without closing the opened joints, while preventing further soil loss.

LSS was transported from a dedicated LSS plant by agitator trucks and pumped using a concrete pump truck. By adopting this method, no marine work was required, and all construction could be completed from land.



Photo 1 Cavity Condition



(a)



(b)

Photo 2 Bag Filling



Photo 3 Completion View

References

- 1) https://www.tokura.co.jp/wordpress/wp-content/uploads/2021/12/20211102_CBK-210001-A.pdf
- 2) Izumi, A., Hirakawa, R., Toyoda, K. and Kaneda, K. : "Development of Cavity Repair Method Behind Revetments Using Bagged Liquefied Stabilized Soil", Proc. of the 60th Annual Conference of Japanese Geotechnical Society (JGS), Paper No. DS-4-05, 2025.7