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DEVELOPMENT ON THE MORTAR MATERIAL FOR CABLE SYSTEMS IN A DIRECTIONAL DRILLING

Yoshinari NISHIYAMA, Chubu Electric Power Co., Inc. (Japan), Nishiyama.Yoshinari@chuden.co.jp
Hironori MASHIMA, Chubu Electric Power Co., Inc. (Japan), Mashima.Hironori@chuden.co.jp
Makoto UESAWA, Chubu Electric Power Co., Inc. (Japan), Uesawa.Makoto@chuden.co.jp
Hiroshi SAITO, Chubu Electric Power Co., Inc. (Japan), Saitou.Hiroshi2@chuden.co.jp
Takeshi ISHIZONE, Chubu Electric Power Co., Inc. (Japan), Ishizone.Takeshi@chuden.co.jp
Satoshi MIZUNO, Toenec Corp. (Japan), satoshi-mizuno02@toenec.co.jp

ABSTRACT

In Japan, directional drillings are used to install underground power cable duct in locations where it would be difficult to dig and bury it. After the tunnels are run, cable duct is installed in the tunnel duct and infill is used to fill in any dead spaces. In some cases, increases of infill thermal resistance interrupt cable heat dissipation and consequently result in breakdown. Therefore, we developed a new infill with low thermal resistance and the ability to be pumped into long tunnel ducts and then applied it under field conditions.

KEYWORDS

Tunnel duct, Infill, Thermal resistance

TUNNEL DUCT OUTLINE

In Japan, directional drillings are used in places where burial of cable duct by drilling from above is difficult, such as heavily-traveled main roads, rivers, and places where there are railway tracks. The basic directional drilling method consists of establishing shafts at both ends of the tunnel, drilling horizontally with an excavator, and then pressing concrete pipes into the drilled holes from the back end with a hydraulic jack.
After the tunnels are run, cable duct is installed and any dead space is filled with infill to produce a tunnel duct (refer to Fig.1).
The main purposes of filling the dead space with infill are to prevent sand from entering the tunnel duct, which would cause a depression in the ground if the tunel ducts became damaged, and to secure the cable duct in place for cable installation.

CABLE BREAKDOWN DUE TO INFILL INFLUENCE

A mortar material (hereafter referred to as air mortar) is normally used as the infill; this material is easily procured, low in cost, and about 50% air, and it can be pumped into long tunnel ducts.
Cable breakdown has occurred when air mortar is used in conjunction with heavy loaded transmission line (refer to Fig. 2). Estimation of the temperature of the cable using the cable insulator’s heat history indicated that abnormal overheating of the cable occurred.
Therefore, the air mortar in the tunel duct was examined, and the main breakdown area was located in an air gap on the upper side of the tunel duct. Furthermore, separation of the air mortar material was confirmed. Notably, the air mortar around the cable was dry and brittle and contained plenty of air bubbles. Measurement of the thermal resistance of the air mortar indicated that it was extremely high (about 16 K·m/W) compared with the value of normal soil (about 1 K·m/W). We believe that the high thermal resistance of the air mortar inhibited cable heat dissipation; the cable then overheated, and this resulted in breakdown.

Figure 2: Cable breakdown in a tunnel duct

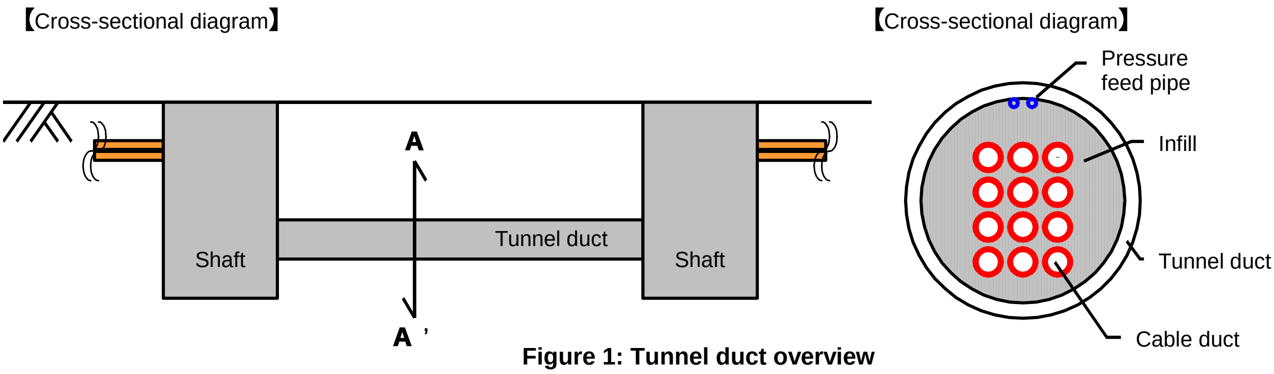

Figure 1: Tunnel duct overview

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INFLUENCE OF INFILL ON CABLE CONDUCTOR TEMPERATURE

Fig. 3 shows a conceptual diagram of the temperature rise in the tunel duct. The heat generated from the cable is comprised of conductor loss, dielectric loss, and sheath loss, clearly indicating that the thermal resistance of the infill inhibits heat dessipation. If the heat generated by the cable is set to 30 W/m based on the assumption of a heavy loaded status equivalent to that when cable breakdown occurred under transmission line conditions, it is clear that the thermal resistance of the infill could greatly influence the cable's conductive temperature and that the cable could abnormally overheat, resulting in breakdown.

Therefore, we developed a new infill with low thermal resistance to minimize the increase in cable temperature.

DEVELOPMENT GOALS

The following were our goals for infill development.

Thermal resistance

A low thermal resistance value is important in order to minimize the increase in cable temperature.

The target thermal resistance value was set to be equivalent to that of normal soil (thermal resistance value of 1 K·m/W). Fig. 4 outlines the method used to calculate the thermal resistance value.

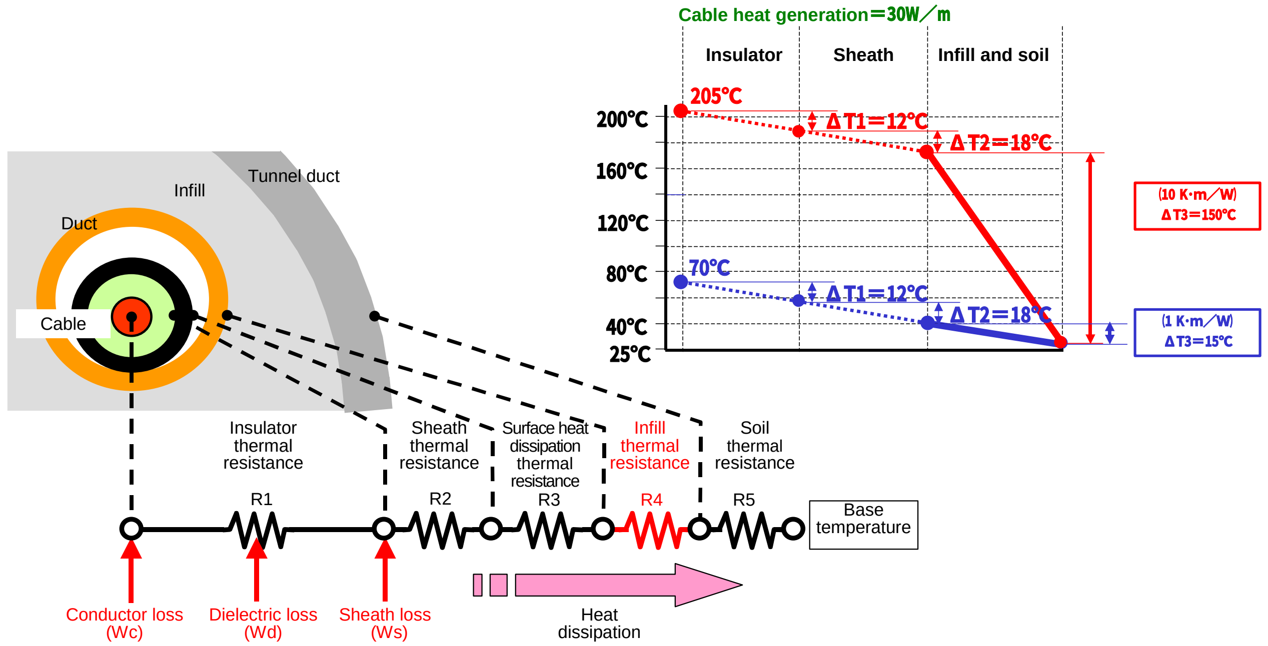

Figure 3: Relationship between increase in tunnel duct temperature and thermal resistance

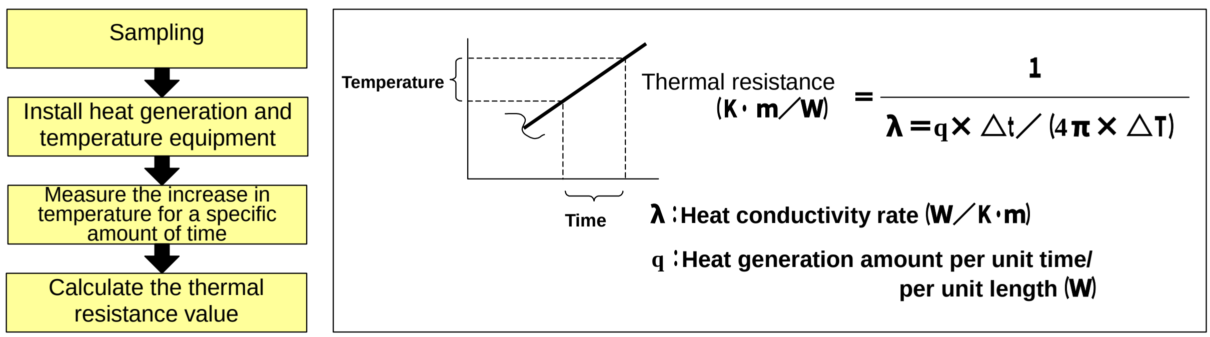

Figure 4: Calculation method for thermal resistance value measurement

Pressure feed ability

High flow and good pressure feed properties are important in order to be able to uniformly pump infill into the tunnel duct without producing any gaps.
Therefore, we used a method in which spread (flow value) of the infill on a flat slope was measured as an indicator of the infill's flow properties (refer to Fig. 5). Taking into consideration that our longest tunnel duct is 400 m and the results of previous measurements of the flow value and pressure feed length, the target flow and pressure feed length values were set to 350 mm or more and 400 m, respectively.

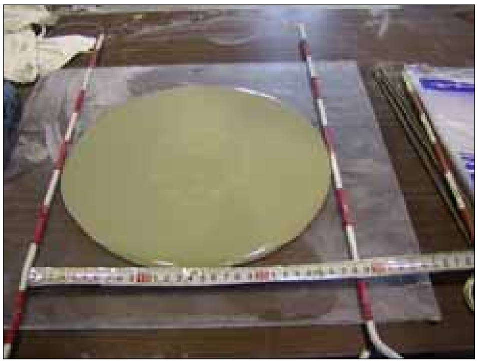

Figure 5: Flow value measurement conditions

Infill filling ability

Water is normally added to infill. When water moves to the top side of the tunnel duct due to settling of the infill, gaps may be created due to evaporation of moisture as heat is generated by the cable. These gaps have the potential to interrupt heat dissipation and adversely effect the cable temperature. There is also some risk of the ground above the duct caving in as a result of runoff of soil into the duct if the tunel duct becomes damaged.
We used the breathing rate, which is a measure of the amount of water after the infill stood still for 24 hours (refer to Fig. 6), to evaluate infill filling ability; the target value for the filling rate was set to 99% or more (breathing rate of 1% or less), taking into consideration the level that does not influence the rise in cable temperature after evaporation of floating water.

Figure 6: Breathing rate measurement conditions

Strength

Proper infill strength is required to enable duct fixation during cable installation.
The target strength value was set to an unconfined compression strength of 0.2N/mm^2 or more, which is equivalent to the value of ground improvement soil.

INFILL DEVELOPMENT

More than 50 types of infill were experimentally manufactured to achieve the described development goals.
We determined that combining materials with a high relative density and high heat conductivity is effective for reducing thermal resistance by producing different combinations of various types of materials and formulations. We also manufactured other types of infill and evaluated them based on the findings above.
However, a high relative density results in an unavoidable increase in weight and decrease in pressure feed ability. In regard to the currently used air mortar, its pressure feed ability can be increased via the lubricating effect of air bubbles using a foaming agent, which entrains air bubbles into the materials; however, as described above, its thermal resistance is high because it contains air. We also evaluated use of a water reducing agent that does not contain air, that weakens gravity, and that heightens flow ability by electrostatic repulsion between the particles of cement and calcium carbonate.
As a result, we were able to develop an infill that is capable of achieving our development goals. A comparison of the currently used air mortar with the newly developed infill is shown in Table 1. Fig. 7 shows a comparison of the surfaces of the air mortar and new infill; it is clear that the new infill has a fine texture and few air bubbles.
Various verification tests were performed to examine use of the new infill in the field.

Table 1: Infill material comparison

Infill	Material	Thermal resistance value (K·m/W)	Relative density (g/cm^3)	Previous pressure feeding result
Air mortar	Cement, water, porcelain clay, and foaming agent	About 10	0.75	450 m
Developed infill	Cement, water, calcium carbonate, and water reducing agent	About 1	2.0	None

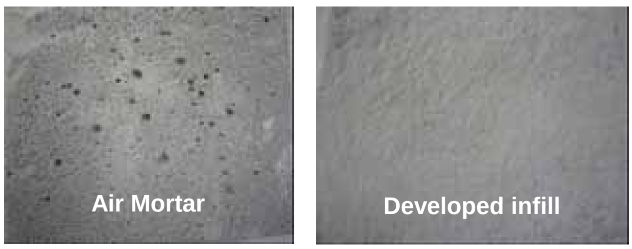

Figure 7: Comparison of infill surface conditions

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PRESSURE FEED ABILITY TEST

Test facilities were constructed to verify the pressure feed ability of the new infill in long tunnel ducts in the field; we verified whether pressure feed could be conducted for 400 m and evaluated infill performance at the pressure feed end position.

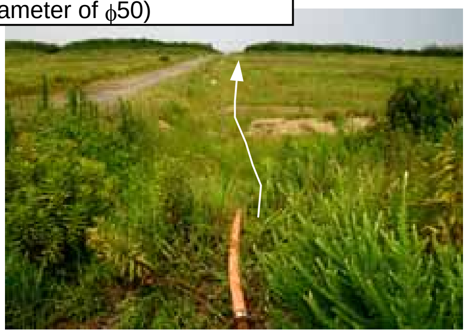
Test outline

New infill was pumped into a 400 m duct (ϕ50 mm duct) from a mixing plant to verify whether or not pressure feed could be conducted.

The flow and breathing values of the new infill were measured before and after it was pumped into the duct. Furthermore, the new infill was enclosed in a 1350-mm-high container, its thermal resistance value was measured, and its separation status was checked at upper, middle, and lower positions (refer to Fig. 8).

Pressure feed start position (mixing plant)

Pressure feed (400 m duct with a diameter of ϕ50)



Pressure feed end position (sample extraction)

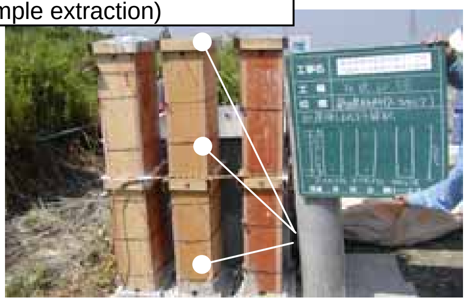


Figure 8: Pressure feed test conditions

Test results

It was possible to pump the new infill into the 400 m duct, and there appeared to be no change in infill quality after pumping of the new infill was complete. Furthermore, its thermal resistance value was low and stable, and its other basic performance characteristics satisfied our development goals (refer to Table 2 and Fig. 9).

Table 2: Pressure feed test results

Item	Developed infill
Pressure feed ability	Pressure feed for 400 m possible
Thermal resistance value	About 1.0 K·m/W
Relative density	About 1.9 g/cm^3
With or without material separation	None
Filling ability	Breathing rate of 1%
Compressive strength	About 7 N/mm^2

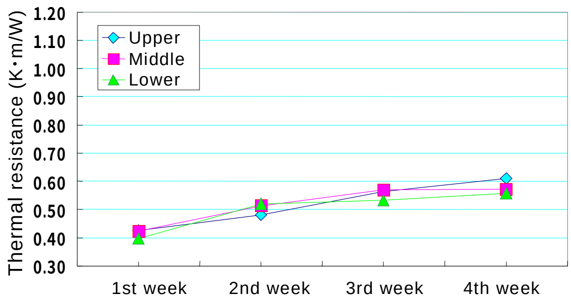


Figure 9: Thermal resistance transition

FULL-SCALE TEST

Test facilities were constructed to verify usage efficiency of the new infill and its filling ability in the field.

Test outline

The infill filling status was checked and various other performance characteristics were examined after the infill was pumped into a 6-m-long tunel duct having a diameter of ϕ1350 mm with 12 ϕ150 cable ducts installed (refer to Fig. 10 and 11).

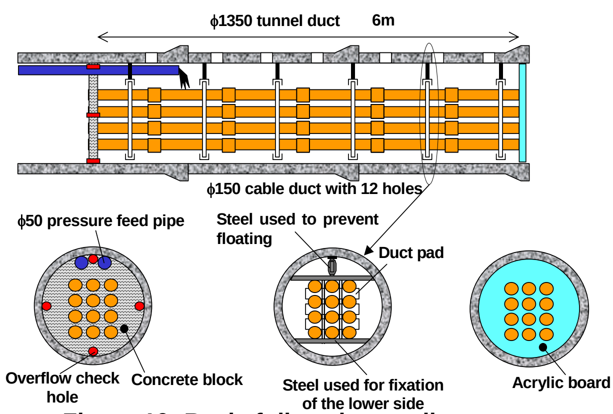


Figure 10: Basic full-scale test diagram

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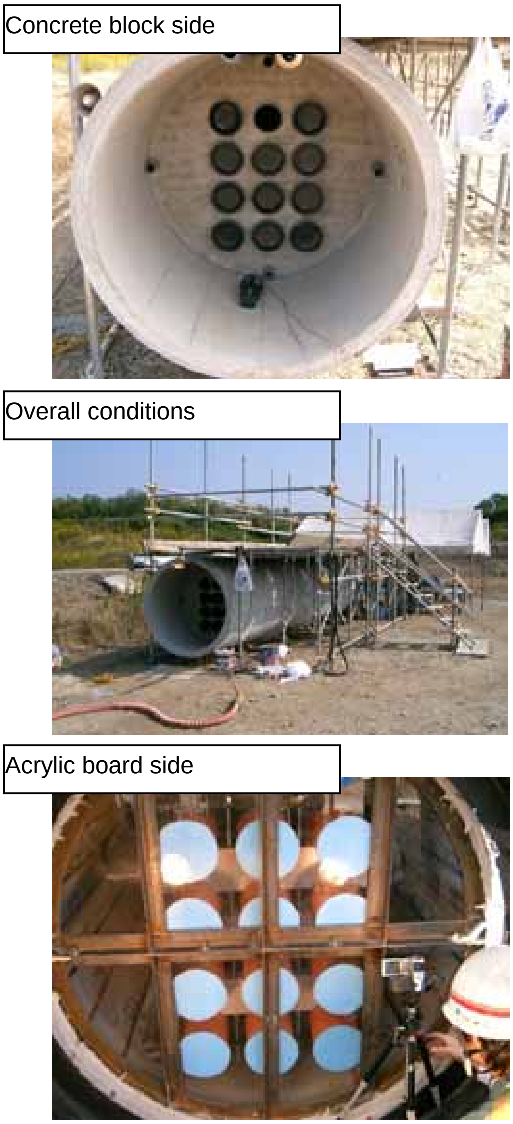

Figure 11: Full-scale test conditions

Test results

We verified that the new infill filled the entire tunel duct without any gaps because of its extremely high flow ability. Its thermal resistance value and other basic performance characteristics were also good; therefore, use of this new infill is within sight (refer to Fig. 12 and 13).

Figure 12: Filling conditions of the full-scale test tunnel duct

Figure 13: Infill filling state after the full-scale test

EXECUTION MANAGEMENT AND QUALITY CONTROL IN THE FIELD

The following execution management and quality control items were determined in order to secure constant and stable quality for utilization of the new infill in the field:

For plant installation

Prior to full-scale usage, conduct preliminary mixing, check the performance of plant equipment in terms of material quality, such as relative density, flow value, breathing ratio, and mixing status.

For full-scale usage

Check equipment and control material quality such as over flow and filling amount before filing duct with infill (Table 3).

Table 3: Control items for full-scale usage

Inspection contents/frequency		Standard value
Pressure feed pipe position and number Overflow check hole position Power duct fixation method		Refer to the designs
Formulation check	Control of material bag No. (the automatic measurement equipment is controlled by the set value) Input check	—
Relative density measurement	Sampling from the mixer 3 times/day	1.96 g/cm^3 ±0.05
Flow value	Same as above	350 to 450 mm
Overflow check	Visual inspection of check holes Take photographs	—
Filling volume check	Comparison of the design pressure feed value with the actual pressure feed value	Design value or more

Examination of quality and usage in the field using the above control items resulted in good usage characteristics and achievement of the standard values for all basic performance characteristics, indicating that the new infill completely filled in the entire tunnel duct (refer to Fig. 14). We confirmed that the new infill has low thermal resistance by measuring the thermal resistance value of a sample of infill used in the field.

CONCLUSIONS

Breakdown resulting from abnormal generation of heat of the heavy loaded cable in the tunnel duct, created an opportunity to develop a new infill with low thermal resistance and high pressure feed ability. As a result, this new infill was developed.
Furthermore, optimized infill filling and inspection methods were established to secure constant and stable quality for usage in the field.

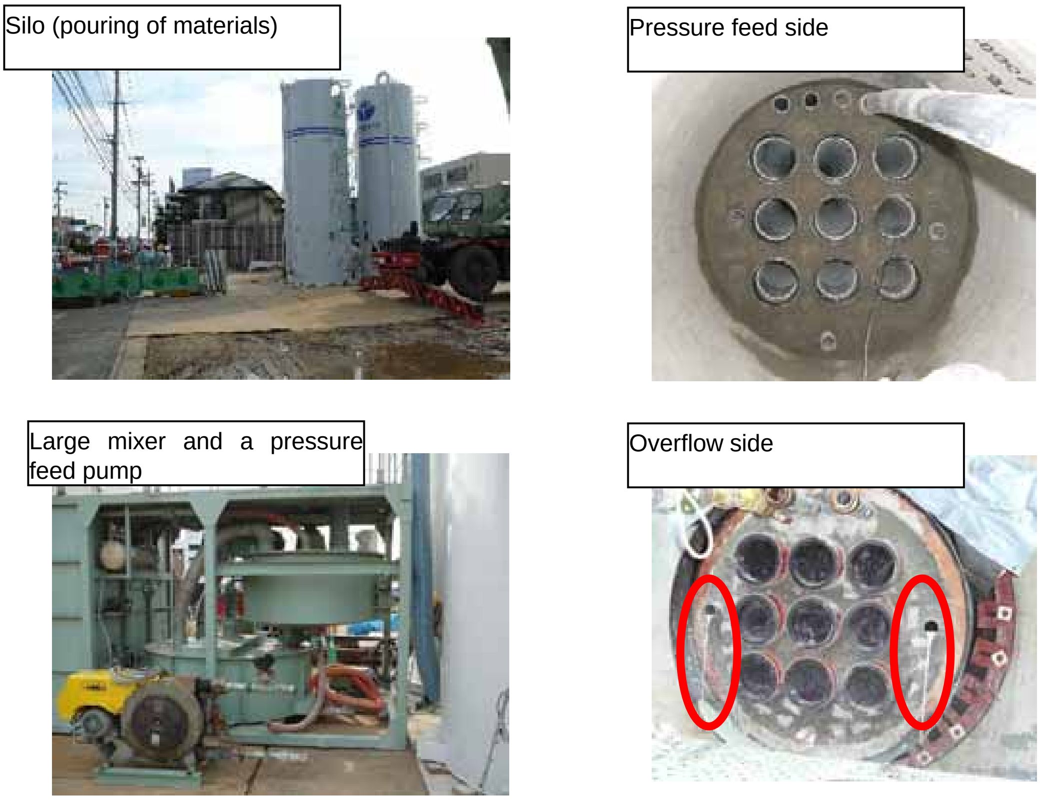

Figure 14: Status during application of infill in the field