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INVESTIGATION OF GROUT INFILTRATION PROCESS BY FLUORESCENCE METHOD

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INTRODUCTION

An accurate understanding of the improvement effects of grouting is crucial when performing foundation treatment for dams. For this, it is necessary to clarify the mechanisms of grout penetration and filling into cracks in rock masses (Hamada *et al.*, 2004).

Due to its ability to reveal the progress of grout penetration and filling, we focused on a method that employs fluorescent agents, referred to hereafter as the fluorescent method (Terada *et al.*, 2002). In this method, grout containing a fluorescent agent is injected into cracks in rock masses. It is then exposed to ultraviolet radiation to make it glow, thereby allowing determination of the progress of penetration and filling in the form of image data.

To simplify data analysis and interpretation of results, curtain grouting, which has few injection requirements, was used in combination with the fluorescent method. Here, we report the results of investigation of cracks filled with grout (referred to hereafter as filled cracks).

This article first presents an outline of the study along with application of the fluorescent method. Then, based on the obtained images of the filled cracks, the progress of grout penetration and filling, its range, processes, and the characteristics of the filled cracks are discussed. Finally, through association of the results with indicators, such as Lugeon value, we depict our attempts to accurately determine the improvement effects.

OUTLINE OF THE STUDY

The study was conducted in a rim tunnel located on the right bank of Iwaigawa Dam in Nara Prefecture, Japan. Figure 1 shows an outcrop sketch of the study area. This figure shows the arrangement of injected holes, locations of check holes, degree of injection, fluorescent agents used, and the order of injections. The main rock type in the study area was banded gneiss. The cracks intersected the injection line at angles of 30°-40°, and some had a high-angle dip.

Injection was performed in accordance with the revised "Guideline and Commentary for the Grouting Technique (Japan Institute of Construction Engineering, 2002)," while applying

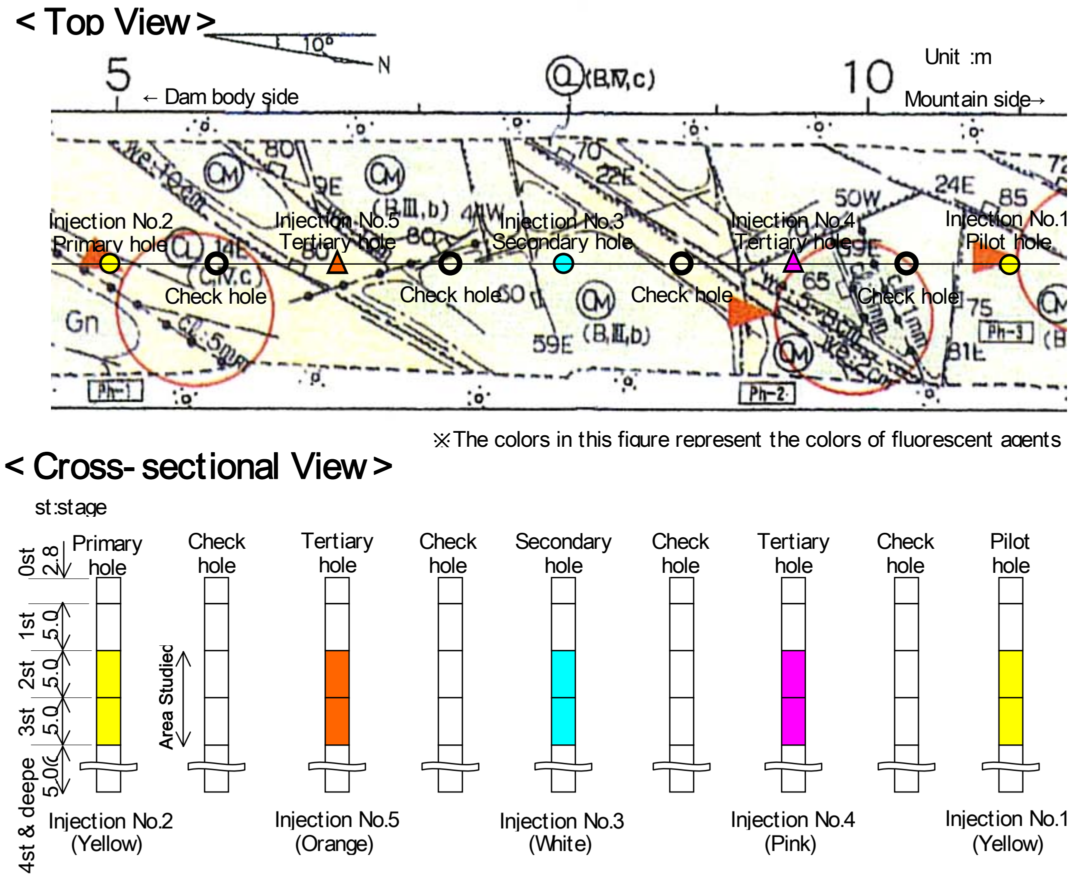


Figure 1. Geological conditions and locations of holes

a staging method in which every 5m comprised 1 stage. The test depth ranged from GL-7.8m to GL-17.8m (2nd and 3rd stages), and from these depths, grouts with added fluorescent agents were injected. The fluorescent agents were added at a concentration of 5% of the mass of cement, and the colors added were yellow for pilot and primary holes, white for secondary hole, pink for the mountain-side (northern) tertiary hole, and orange was added to the remaining tertiary hole closer to the dam body-side (southern). Moreover, for identification purposes, the white fluorescent agent is shown in light blue. The study procedures are out-

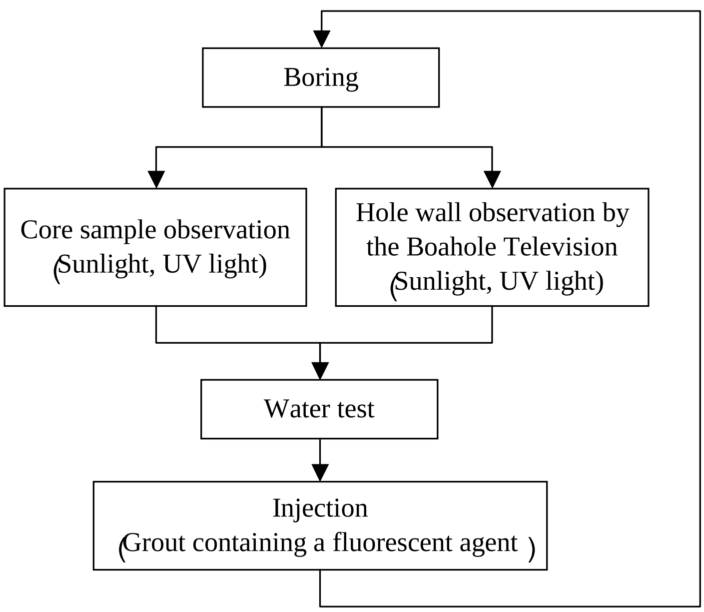


Figure 2. Procedure of investigation

liend in Figure 2. As shown in the figure, the study was per- formed in the following order:

(1) Boreholes were drilled.

(2) The obtained cores were then observed under sun- light as well as UV light. Using the Borehole Television, hole walls were observed concurrently under sunlight as well as UV light. A summary of the method used for observing the hole walls is shown in Figure 3.

(3) Water tests were carried out to record the Lugeon values.

(4) Grout containing a fluorescent agent was injected to record the per-unit quantities of injected cement.

(5) The above steps were repeated for each of the injection holes. When injection was completed, steps (1) to (3) were also performed on the check holes.

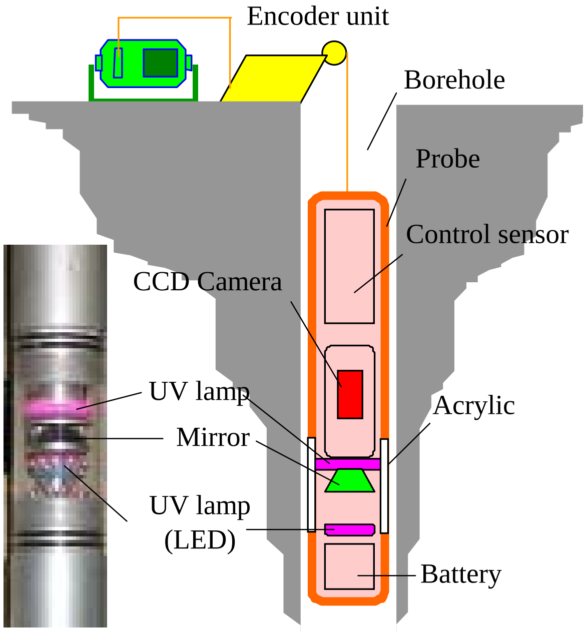
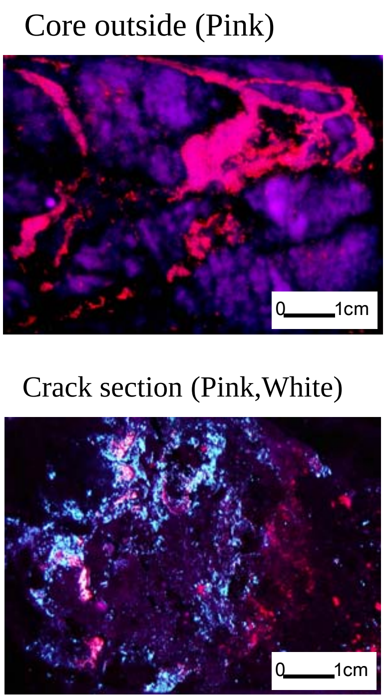


Figure 3. Summary of Borehole Television used for observing the hole walls

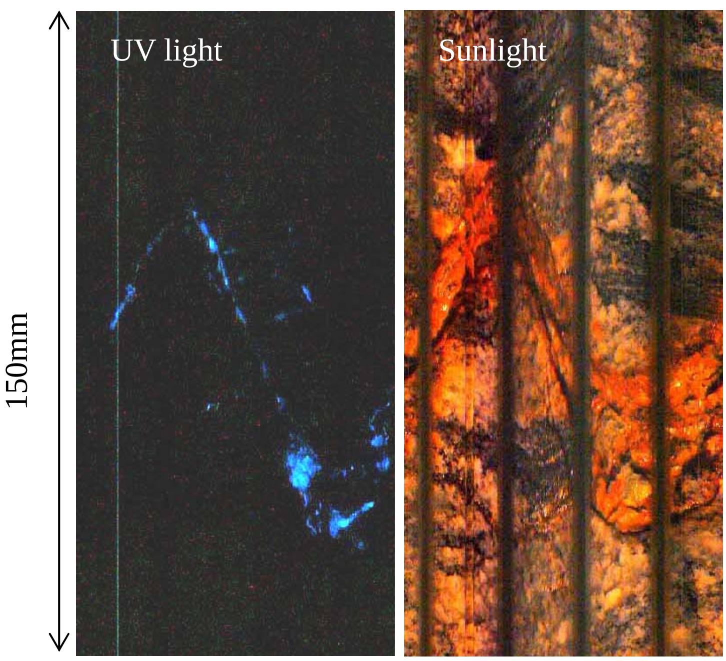
STUDY RESULTS AND ANALYSIS

Observation of filled cracks

An example of core observations under UV light is shown in Picture 1, while that of hole wall observations by the Borehole Television is shown in Picture 2. According to the results of both types of observation, the majority of the filled cracks contained only one color. In



Picture 1. Fluorescent agents glowed by ultraviolet radiation



Picture 2. Observation of hole walls by Borehole Television

contrast, some of the filled cracks contained a mixture of two colors. These cracks with two colors can be evaluated as those that did not reach blockage with just one injection. These were the cracks into which grout penetrated from multiple injection holes, suggesting that they were part of a water pathway with high continuity.

Depth distribution of filled cracks

The depth distribution of filled cracks is shown in Figure 4. The results shown in the figure are for filled cracks prior to grout injection of each hole. While taking into account the strikes and dips of the observed cracks, linear lines were drawn in the figure to connect the shallowest and deepest points at which the cracks and the hole walls intersected with each other.

The number of filled cracks was the greatest for yellow, followed by white, pink, and finally orange. This order corresponds to the degree of injection, as yellow corresponds to the primary and pilot holes.

The yellow filled cracks observed within the primary hole at depths of 12.8m or less were caused by injection of grout into the pilot hole. This indicated that grout penetrated to reach locations at a horizontal distance of 6m. It is likely that a series of cracks between the pilot and primary holes acted as pathways for grout to penetrate into the rock masses. Qualitatively, this demonstrated that water-tightness was improved after each injection in the range between the pilot and primary holes.

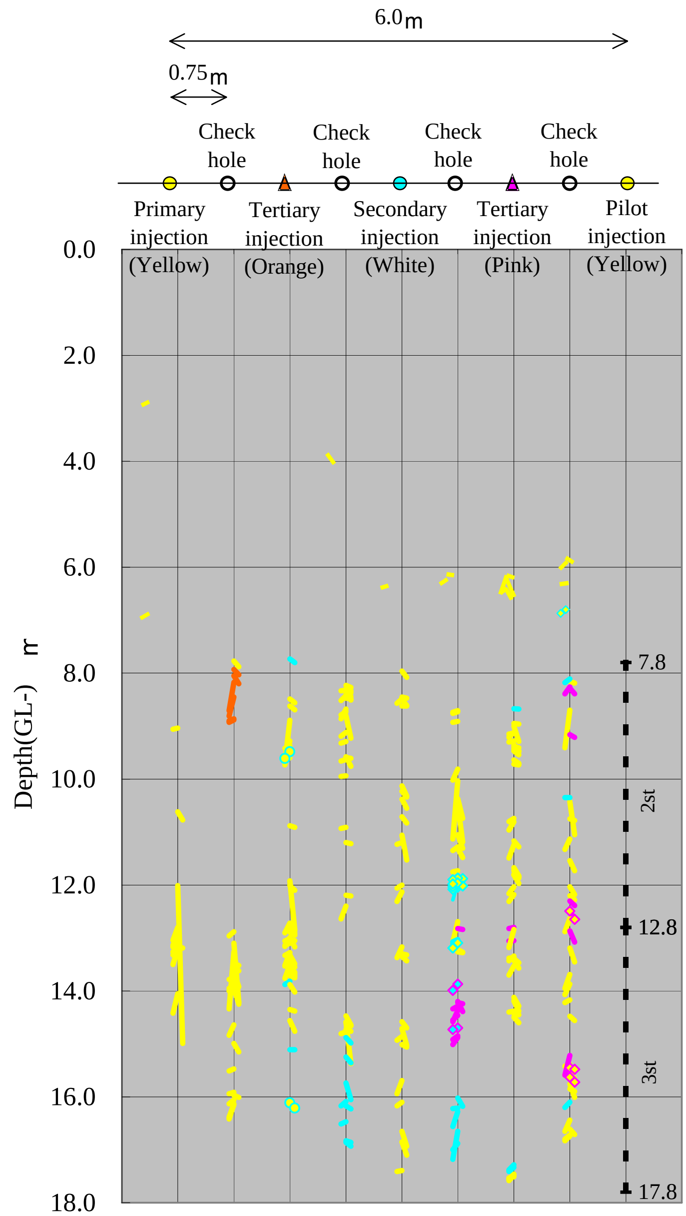


Figure 4. Depth distribution of filled cracks (longitudinal section)

Directional distribution of filled cracks

The directional distributions of filled cracks are shown in Figure 5. Along with the distribution for each degree of injection, distributions are also listed in the figure for all filled cracks as well as all cracks in the hole walls. Furthermore, directional distributions of filled cracks are provided in the figure using the Schmidt net (projection of lower hemisphere), rose diagrams of strike frequency, as well as rose diagrams of dip frequency.

As shown in Figure 5(a), a high occurrence of the filled cracks resulting from the pilot and primary injections had certain directions, many showing a N10°-20°E strike and a 60°-70°W or about 30° dip. Thus, grout almost certainly penetrated selectively into cracks in certain directions within the rock masses during the pilot as well as primary injections. In contrast, Figure 5(b) and (c) indicate that the directions of filled cracks resulting from the secondary and tertiary injections differed from those of the earlier injections, the directions of high occurrence being too scattered to be determined. It is likely that this indicates that cracks with easily penetrable directions were filled by the pilot and primary injections, and that the cracks into which grout could penetrate differed in direction during the later injections.

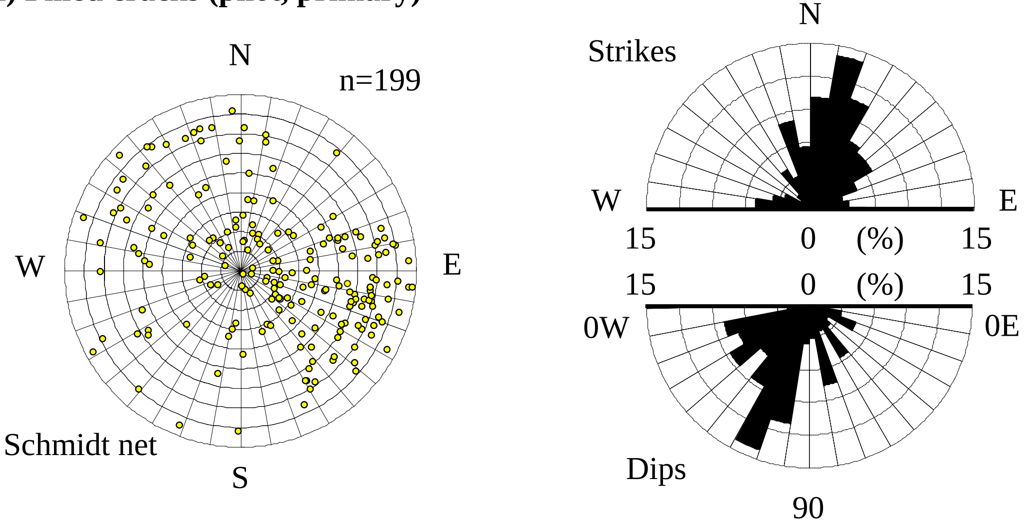
Based on Figure 5(d) and (e), the characteristics of filled cracks comparable to all cracks in the hole walls are given below. Strikes were similar between the two, and the largest percentage possessed a strike of about N10°-20°E. In addition, of all cracks inside the hole walls, those with the highest occurrence received the largest percentage of grout penetration. In contrast, the two crack types displayed different characteristics with regard to dip, and the highest percentage of filled cracks dipping to 60°-70°W. Compared to all cracks in hole walls, a larger percentage of filled cracks had a higher angle of dip. This indicates that grout penetrated easily into cracks with a high-angle as compared to a low-angle dip.

Estimation of the penetration range of grout

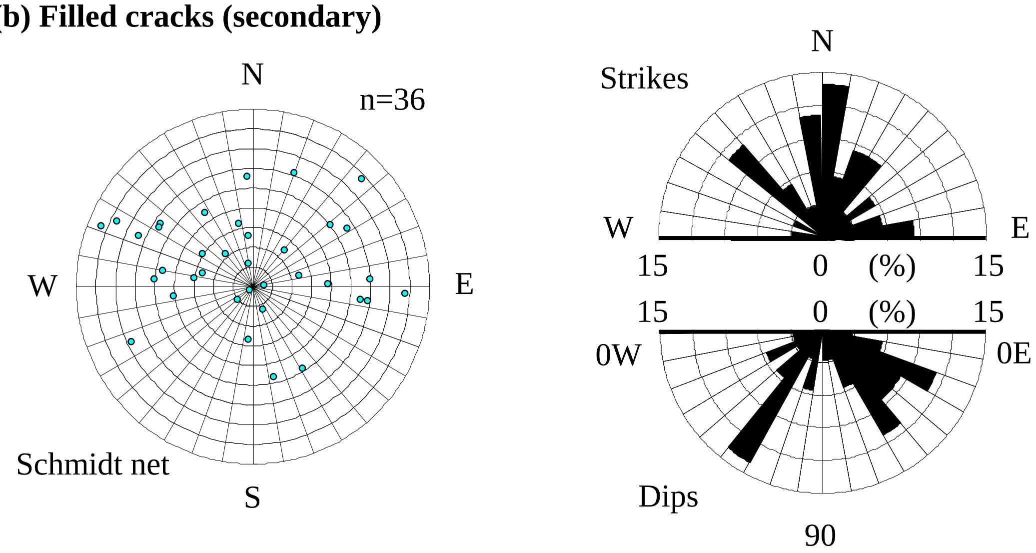
The direction and distance of penetrated grout were estimated based on the fluorescent colors, strikes, and dips of filled cracks, relative positions of holes, and the injection order. The results are shown in Figure 6. This figure is a horizontal projection of the three-dimensional penetration pathways. Arrows in color represent the fluorescent colors of grout and their direction as well as distance of penetration.

This figure indicates that the penetration range of grout tends to decrease as the degree of injection increases. As injection proceeds, the area of improvement expands due to the filling of cracks. Consequently, the decrease in penetration range can be explained as a result of fillable area becoming limited to the proximity of injection holes. That is, the validity of the central interpolation method was demonstrated through these grout penetration and filling processes.

(a) Filled cracks (pilot, primary)



(b) Filled cracks (secondary)



(c) Filled cracks (tertiary)

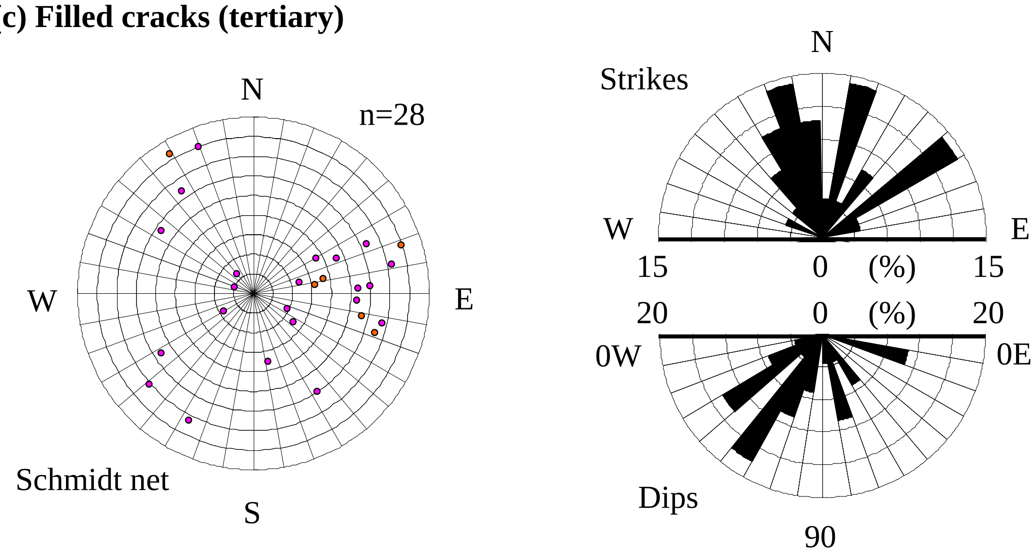


Figure 5. Distribution of cracks (2nd/3rd stage)

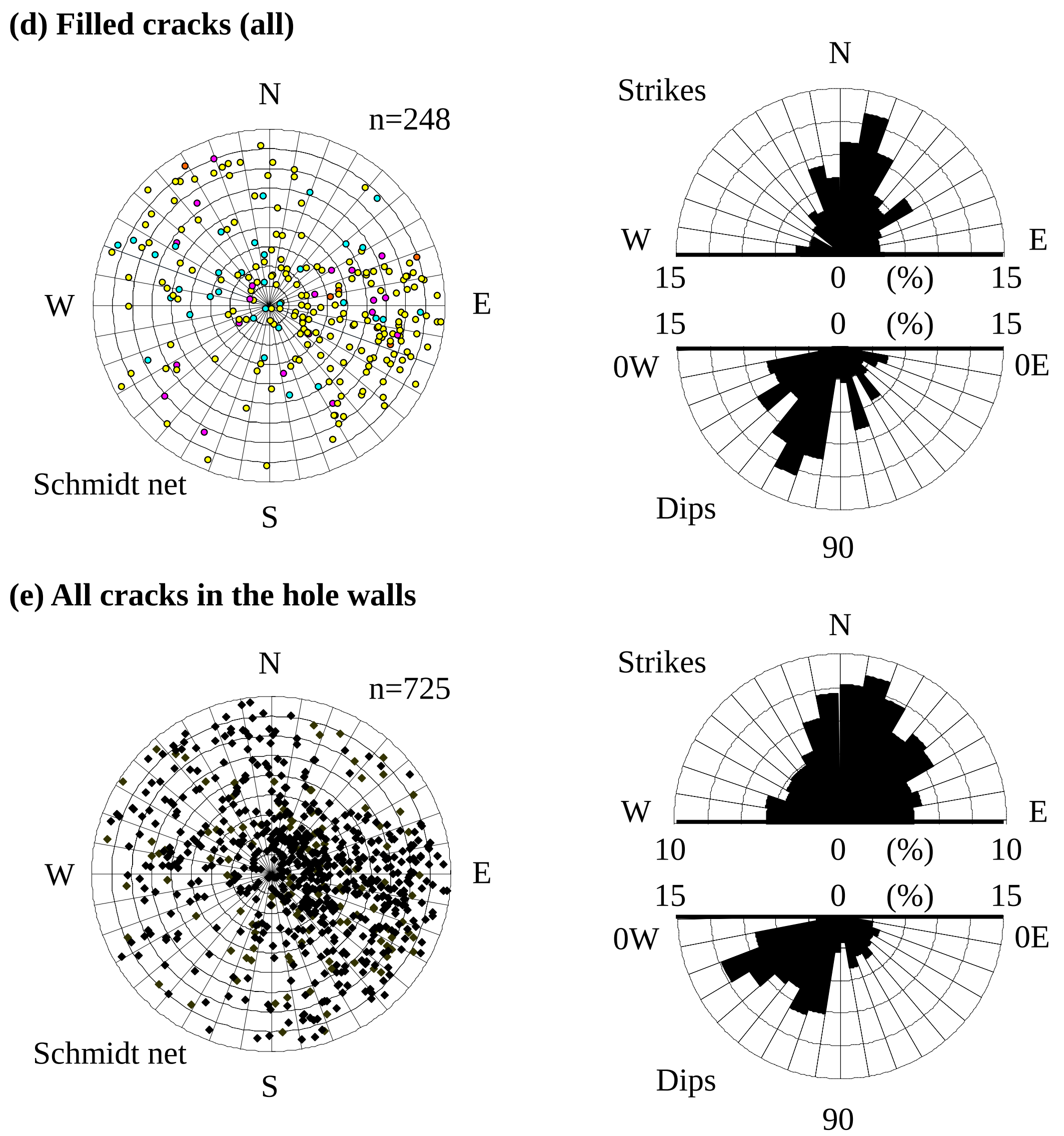


Figure 5. Distribution of cracks (2nd/3rd stage)

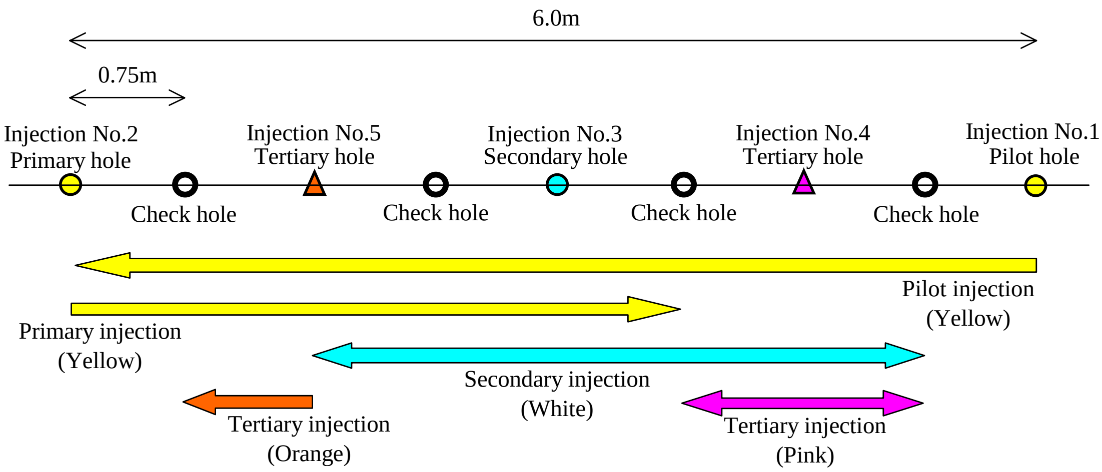


Figure 6. Penetration range of grout (planar projection)

Relationship between filling factor of cracks and actual injected amount

Figure 7 shows the relationships between the increase in degree of injection and each of the filling factors, Lugeon value, and per-unit quantity of injected cement. The filling factor is the ratio of the number of filled cracks to all cracks observed on the walls of boreholes.

When the degree of injection was secondary, all of these values showed marked changes. The filling factor increased, while the Lugeon value and per-unit quantity of injected cement decreased. The marked increase in filling factor is believed to have been caused by the grout injected into the pilot and primary holes, which filled many of the cracks connected to the secondary hole. As such, the number of unfilled cracks connecting with the secondary hole decreased, thereby decreasing the Lugeon value and per-unit quantity of injected cement for the hole.

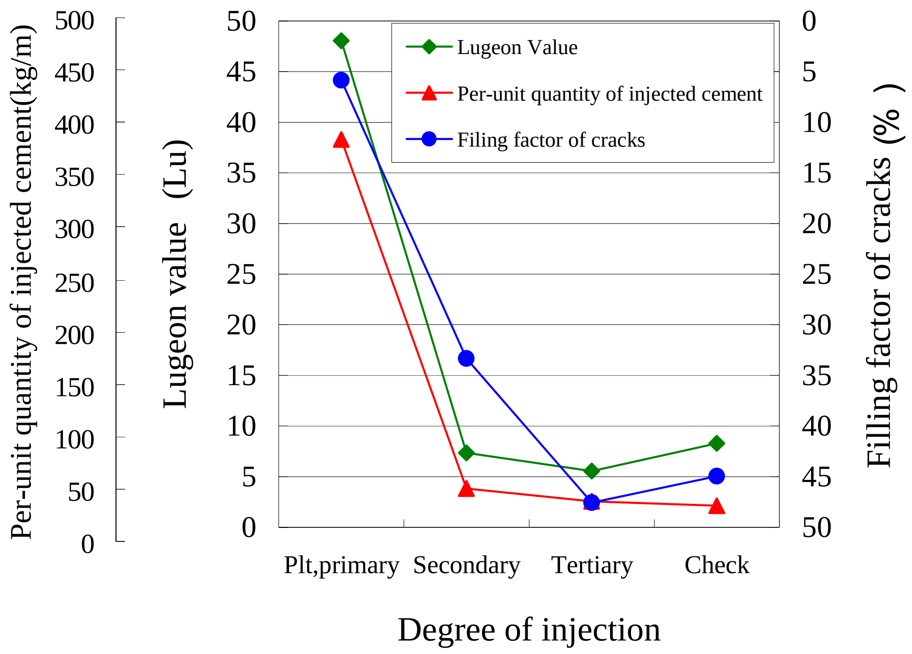


Figure 7. Changes in the filling factor of cracks, Lugeon value, and per-unit quantity of injected cement for each degree of injection

SUMMARY

By applying the fluorescent method to grouting, we analyzed the processes of grout penetration and characteristics of filled cracks. Furthermore, through its association with such indicators as Lugeon value, we attempted to accurately determine the improvement effects. The results are summarized as follows.

(1) Based on the observation that the majority of the filled cracks contained only one color, it is believed that many of the cracks reached blockage with the first injection. In contrast, some of the filled cracks contained a mixture of two colors, suggesting that they were part of a water pathway with high continuity.

(2) In the pilot as well as primary injections, it is believed that grout penetrated selectively into cracks in certain directions. On the other hand, during the subsequent secondary as well as tertiary injections, cracks with highly penetrable directions had already been filled. Therefore, the directions of cracks into which grout was able to penetrate were different in comparison to the earlier injections.

(3) Among all cracks in the hole walls, larger amounts of grout penetrated into those cracks with strikes of the highest occurrence. A large percentage of filled cracks had high angles of dip, which indicates that grout can penetrate easily into cracks with high-angle dip.

(4) Through estimation of the penetration range of grout, it was determined that the area of improvement expanded with progress in injection, and as a result the fillable area became limited to the proximity of injection holes. Moreover, through the grout penetration and filling processes, the validity of the central interpolation method was confirmed.

(5) Following the injection, which caused a substantial decrease in the Lugeon value as well as per-unit quantity of injected cement, the filling factor increased markedly. It is determined that the Lugeon value and per-unit quantity of injected cement were decreased markedly by the filing of many cracks in earlier injections. Thus, it was demonstrated that accurate evaluation of the improvement effects is possible.

CONCLUSIONS

By applying the fluorescent method, we determined the characteristics of cracks related to improvement of water-tightness. The present study also confirmed the validity of the central interpolation method through analyses of the processes of penetration and filling of grout into cracks. Furthermore, it was demonstrated that evaluation of improvement effects became more accurate through the addition of filling factor into the indexes used. Finally, we are grateful to the Japan Dam Engineering Center for advice regarding this research.

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