

## A study on new repair methods for subway tunnels using crack self-healing technologies

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In this research, the application of repair methods of water leakage cracks using self-healing technologies for subway tunnels is presented. In order to apply crack self-healing water stop agents and quick setting agents in subway tunnels, laboratory and field tests were performed based on various previous researches. Especially, this study focused on development of crack repair materials and their new repair methods. Therefore, various repair materials were examined for new repair materials with self-healing capability applied to crack sealing method and to patching repair method. The results show that the proposed water leak repair methods using water stop agent, quick setting agent and patching materials using self-healing ingredient were effective under the subway tunnel conditions. It is preferable in water leak repair to add self-healing components to sealers and water stop agents.

**Key words:** Crack, Self-healing, Water stop agents, Quick setting agents, Subway tunnels.

### Introduction

The Tokyo Metro (Subway) system constitutes a part of important transportation infrastructure in the capital area of Japan. Tokyo Metro Co., Ltd. operates and maintains a subway system of about 195 km consisting of nine lines. Tunnels account for about 85% of the total length, and most of them are located under the center of Tokyo. The subway is used by more than 6,000,000 people per day and operated at intervals of less than two minutes minimum, meeting strong demand for reliable on-time operation from users [1]. About 85% of its total lengths are reinforced concrete tunnels, with some of them being in service for more than 80 years [1]. Therefore, water leaks have begun to be found in some of them where they cross under or run near rivers, channels, canals or reclaimed lands. Should an incident that affects the subway operation occur due to deterioration of these structures, serious social impacts and tremendous economic loss will result. Proper maintenance of these civil engineering structures will be increasingly important as they will

become aged [2, 3].

One of the serious problems recently found in the tunnels is water leakage as shown in Fig. 1(a). In order to stop the water, it had been spent considerable amounts of budget every year, many of the repaired areas exhibit the same problem again as shown in Fig. 1(b). It is urgently needed to develop new materials and techniques to stop water for proper long-term maintenance of these structures. In previous researches [4, 5, 6], various repair materials were examined for new repair materials with self-healing capability applied to water stop agents and quick setting agents. Mineral admixtures such as expansive agent, geomaterials, and chemical agents were used in order to manufacture the self-healing agent based on previous research [7, 8].

Especially, the formation of gel phases for self-healing technology in matrix was modified in order to apply for the water stop under the high water press. The purpose of this study was to evaluate the effectiveness of new self-healing materials developed for repair of cracks by testing them on an existing subway tunnel.

### Experimental Methods

#### Materials

The self-healing materials used in this study contained CSA expansive agent, geo-material and carbonate

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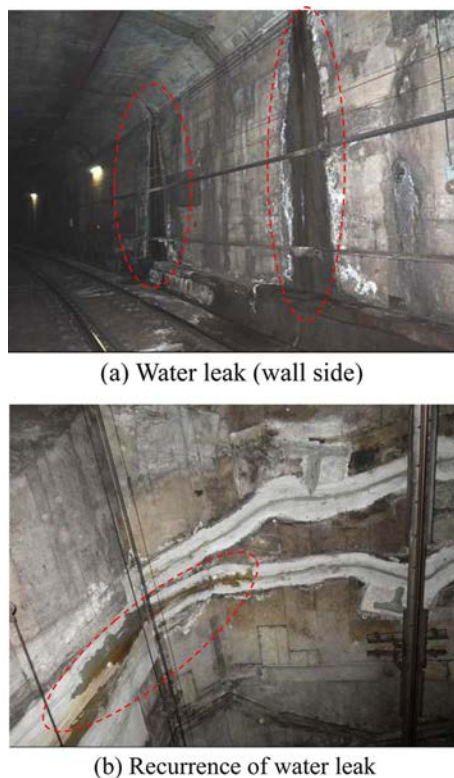


Fig. 1. Water leaks of Subway tunnels.

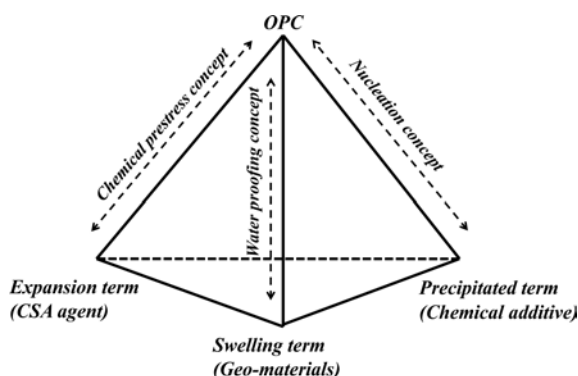


Fig. 2. Design concept of basic crack self-healing materials [3].

group-based chemical additive. The CSA agent which gives expansion by forming ettringite ( $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 32\text{H}_2\text{O}$ ) through hydration is commonly used for shrinkage compensation or chemical prestressing. Geo-materials generally include sand, clay, rock and other natural sediments. In this study clay-based material was used. The carbonate group-based chemical additive was used to form crystalline hydrates in cracks. Fig. 2 shows the material design concept for crack self-healing technology, explaining the role of each material in relation to ordinary Portland cement which is the main ingredient.

The authors conducted test construction in an existing subway tunnel to stop water leaking from cracks, using self-healing materials.

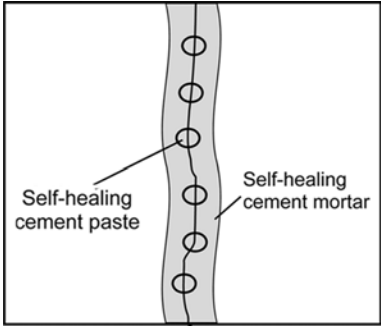
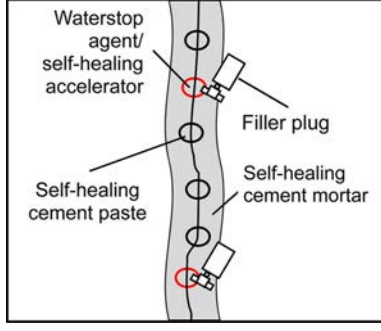
### Estimation method of field construction

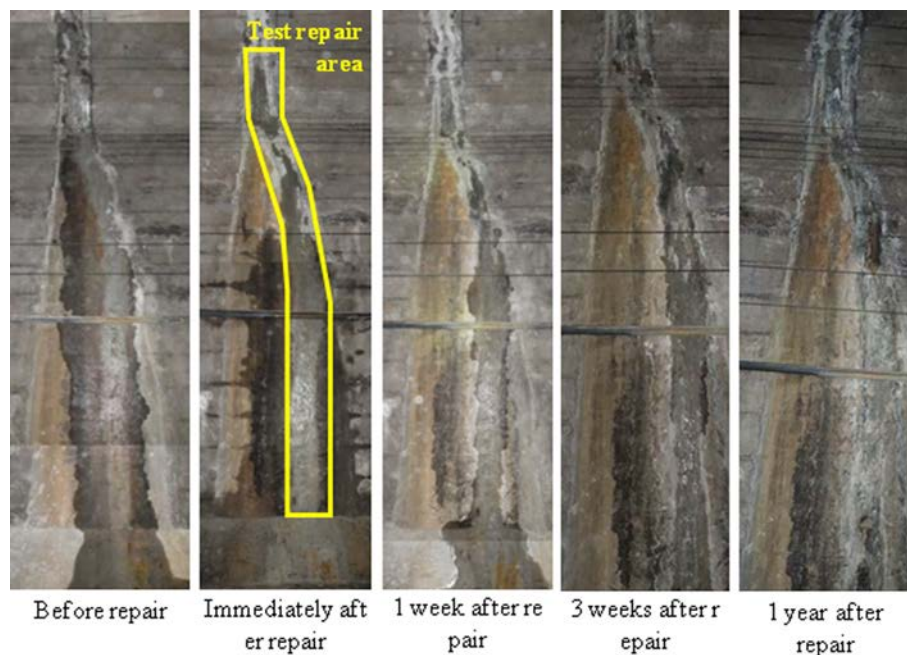
Two different repair techniques were used, depending on the amount of leak water as shown in Table 1. Case 1 is to drill holes of about 15 mm in diameter to a depth of about 30 mm at intervals of 30 to 50 mm, fill the holes with the self-healing materials, and finish the surface around the crack with the self-healing materials in a width of about 150 mm. Case 2 is a combination of Case 1 and injection of inorganic water stop agents developed for crack repair.

### Results and Discussion

Two different techniques were used in the test construction, depending on the amount of leak water. For locations with a small amount of leakage, holes with diameters of about 15 mm were drilled into a depth of about 30 mm at intervals of 30 to 50 mm along the crack and filled with self-healing cement paste, and the surface was finished with self-healing cement mortar. Locations with a large leakage (about 14 liters per minute) were treated by a combined technique using inorganic water stop agents for cracks

Table 1. Repair techniques for subway tunnels.

Classification	Case 1	Case 2
Leakage amount	Small	Large
Method	 <p>Drill holes, fill the holes and finish the surface with self-healing materials.</p>	 <p>Combination of Case 1 and injection of inorganic water stop agent.</p>



**Fig. 3.** Effects of water stop agents (Case 2).

which was placed before the placement of self-healing cement paste. The results showed a high potential applicability of the materials and techniques tested in the study for use in subway tunnels. The previously repaired area suffered leakage of water again, most likely due to deterioration of the repair materials with age and concrete shrinkage by temperature change.

Fig. 3 shows the results of one-year monitoring from immediately after the test construction. Although seepage of water was observed at the upper part immediately after the test construction, the surface was found gradually drying at one week and three weeks. The surface was dry and sound at one year, with no recurrence of leakage. These suggest the effectiveness of the proposed water leak repair method using self-healing repair materials under the subway tunnel conditions.

### Conclusions

The proposed water leak repair method using self-healing repair materials was found to be effective under the subway tunnel conditions.

Combined use with water stop agent is necessary where the amount of leak water is large. A simple water leak repair (Case 1) using self-healing repair materials provides sufficient results where the leak amount is small.

It is preferable in water leak repair to add self-healing components to sealers and water stop materials. Such new self-healing materials are currently under research and development.

### Acknowledgments

This work (Grants No. C0193581) was supported by Business for Academic-industrial Cooperative establishments funded Korea Small and Medium Business Administration in 2014. The author would like to thank the SERIC (Sustainable Engineering Research Innovative Consultant) Co., Ltd. for their advice ([www.seric.co.kr](http://www.seric.co.kr)).

### References

1. Y. Morohashi, T.H. Ahn, T. Hashimoto, N. Ogura, T. Kishi, The 15th JSMS Symposium on Concrete Structure Scenarios, Kyoto, Japan, Oct. 16-17 (2015).
2. A. Hosoda et al, The 2<sup>nd</sup> International Conference on Concrete Repair, Rehabilitation and Retrofitting (ICCRRR 2008), Cape town, South Africa, Nov. 24-26 (2008).
3. T.H. Ahn and T. Kishi, Journal of Advanced Concrete Technology 8[2] (2010) 171-186.
4. T.H. Ahn et al., Cement Science and Concrete Technology 64 (2010) 477-484 (in Japanese).
5. T.H. Ahn and T. Kishi, Proc. of 4th International Conference on Construction Materials: Performance, Innovations and Structural Implications, Nagoya, Japan, Aug. 24-26 (2009) 1339-1346.
6. T. Kishi et al., The 1st International Conference on Self-healing Materials, Noordwijk, The Netherlands, April 18-20 (2007).
7. T.H. Ahn and T. Kishi, Journal of Ceramic Processing Research 16 [1] (2015) 117-123.
8. T.H. Ahn, M. Morita, T. Kishi, The 3<sup>rd</sup> International Conference on Self-Healing Materials 2011, Bath-United Kingdom, June 27-29 (2011) 40-41.