FIFTH INTERNATIONAL CONFERENCE ON

SELF-HEALING MATERIALS

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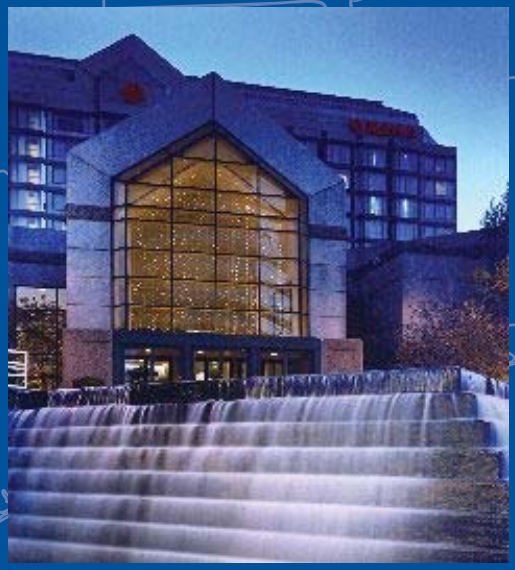

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A STUDY ON THE NEW WATER LEAK REPAIR METHOD FOR SUBWAY TUNNELS USING CRACK SELF-HEALING REPAIR MATERIALS

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1. INTRODUCTION

1.1 Tokyo Metro System

The Tokyo Metro system constitutes a part of important transportation infrastructure in the capital area of Japan. 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. About 85% of its total length are reinforced concrete tunnels (Figure 2), with some of them being in service for more than 80 years (Table 1).

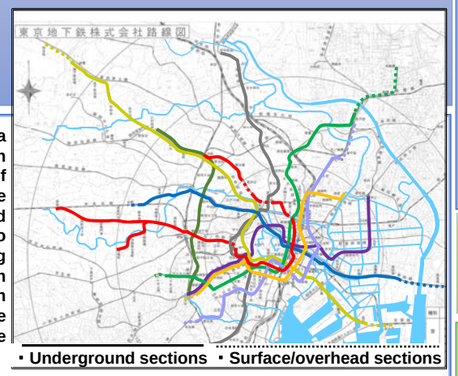


Figure 1: Metro network

Table 1: Distance and year of opening by line

Line	Distance (km)	Year of opening	Line	Distance (km)	Year of opening
G Ginza Line	14.3km	1939	Y Yurakucho Line	28.3km	1988
M Marunouchi Line	27.4km	1962	Z Hanzomon Line	16.8km	2003
H Hibiya Line	20.3km	1964	N Namboku Line	21.3km	2000
T Tozai Line	30.8km	1969	F Fukutoshin Line	11.9km	2008
C Chiyoda Line	24.0km	1979	Total	9 Lines	195.1km	-

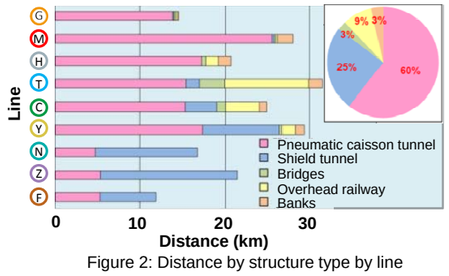


Figure 2: Distance by structure type by line

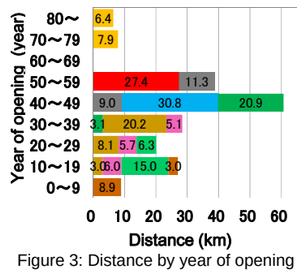


Figure 3: Distance by year of opening

1.2 Water Leak Repair

Water leaks have become apparent recently [Figure 5(a)]. Damage can occur in the following three different mechanisms:
Type 1: water enters the tunnel through defects in the waterproof layer or through cracks and penetrates the concrete from the tunnel surfaces, causing steel corrosion and other damage;
Type 2: local corrosion can occur inside the concrete where the cracks or other water passages meet the reinforcing bars; and
Type 3: extensive corrosion can occur where the waterproof layer is ineffective due to construction difficulty or other reasons, allowing ground water to penetrate from the outside.
Corrosion can be severe when the ground water contains chloride ions. The influence of chloride content is taken into account in carrying out repairs of water leaks.
However, water leaks found in the tunnels include recurrence at previously repaired areas [Figure 5 (b)]. The purpose of this study is to investigate the effectiveness of the crack self-healing repair materials [1, 2, 3, 4] developed by the Institute of Industrial Science, the University of Tokyo, through test application to an existing underground tunnel.

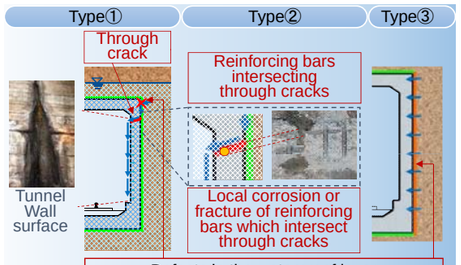


Figure 4: Leak water supply routes

(a) Water leaks (b) Recurrence of water leak

Figure 5: Water leaks

2. TEST CONSTRUCTION METHOD

2.1 Materials Used

The self-healing materials used in this study contained CSA expansive agent, geo-material and carbonate group-based chemical additive. The CSA agent which gives expansion by forming ettringite ($3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$) 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. Figure 6 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.
Figure 7 shows pictures from a performance evaluation test on the hardened inorganic compound. Specimens of the self-healing cement paste (W/C = 45%) were cured for 120 days, artificial cracks (0.2 mm) were made in them, and further water curing was provided. White deposits appeared in the cracks in 3 days during the water curing, closing the cracks.
The self-healing repair materials have already been used on some structures of other organizations for water leak repair, with their sealing effect verified.
Figure 8 shows a case of repair on the water leaks through cracks found in the bottom of a concrete slab.

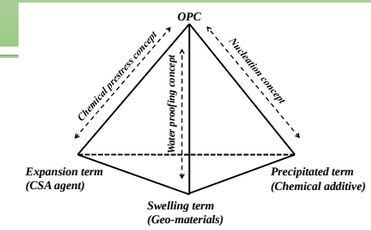


Figure 6: Design concept of crack self-healing materials [1]

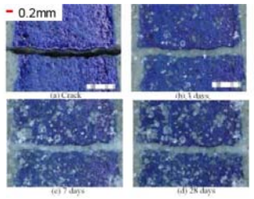


Figure 7: Crack closure process by the inorganic compound [1]

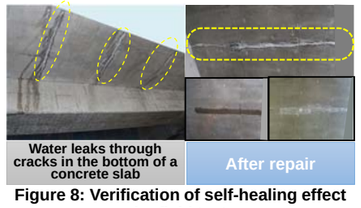
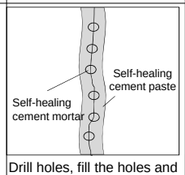
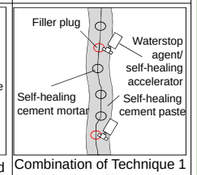


Figure 8: Verification of self-healing effect by field test

2.2 Test Construction Method

Two different repair techniques were used, depending on the amount of leak water as shown in Table 2.
Technique 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.
Technique 2 is a combination of Technique 1 and injection of inorganic waterstop agents developed for crack repair.

Table 2: Repair techniques

Classification	Technique 1	Technique 2
Leakage amount	Small	Large
Method	 Drill holes, fill the holes and finish the surface with self-healing materials.	 Combination of Technique 1 and injection of inorganic waterstop agent.

3. TEST CONSTRUCTION RESULTS

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.

Figure 9 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.

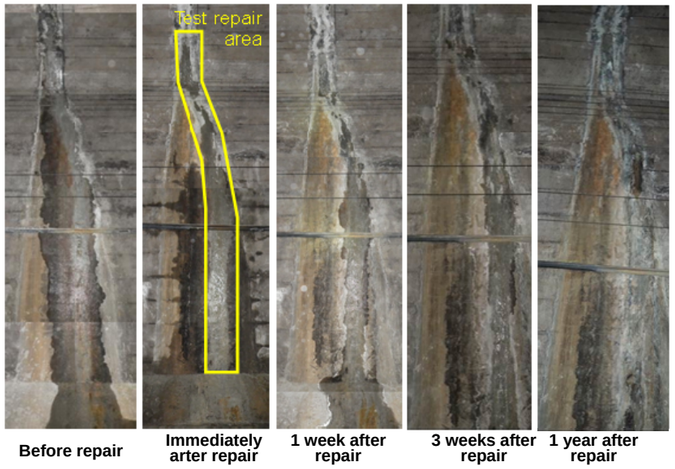


Figure 9: Test construction results (Technique 2)

4. CONCLUSIONS

(1)The proposed water leak repair method using self-healing repair materials was found to be effective under the subway tunnel conditions.
(2)Combined use with waterstop agent is necessary where the amount of leak water is large. Simple water leak repair (Technique 1) using self-healing repair materials provides sufficient results where the leak amount is small.
(3)It is preferable in water leak repair to add self-healing components to sealers and waterstop materials. Such new self-healing materials are currently under research and development.

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Tokyo Metro