Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 57/1/57/2 (1989)

Artikel: Advanced repair techniques for reinforced concrete structures

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DOI: https://doi.org/10.5169/seals-44307

Advanced Repair Techniques for Reinforced Concrete Structures

Techniques de réparation évoluées pour les structures en béton armé

Fortgeschrittene Technologien zur Reparatur von Stahlbetonbauten

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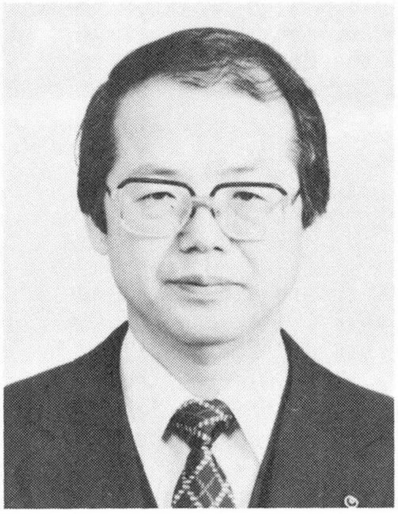

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SUMMARY

NTT has approximately 30,000 buildings with a total floor area of about 21,000,000 square meters. The majority of these buildings are reinforced concrete, many of which are in various stages of deterioration. This paper introduces three techniques: the crack filling method for exterior walls, the repairing method for basement walls, and the rebar corrosion-restriction method. With these methods good results have been obtained on many buildings.

RÉSUMÉ

NTT possède environ 30 000 bâtiments, occupant une surface au sol totale d'approximativement 21 000 000 mètres carrés. La majorité de ces bâtiments sont en béton armé, et beaucoup d'entre eux sont dans divers états de détérioration. Cet article présente trois techniques mises au point: la méthode de remplissage des fissures pour murs extérieurs, la méthode de réparation des défectuosités pour murs de soubassement, et la méthode de protection anti-corrosion pour barres d'armature. Ces méthodes ont permis d'obtenir de bons résultats dans un grand nombre de bâtiments.

ZUSAMMENFASSUNG

Die NTT ist im Besitz von ungefähr 30'000 Gebäuden mit einer Gesamtfläche von etwa 21'000'000 Quadratmetern. Die Mehrzahl dieser Gebäude besteht aus Stahlbeton, von denen viele mehr oder weniger baufällig sind. Dieser Bericht beschreibt drei Methoden: die Mauerriss-Füllmethode für Aussenwände, die Ausbesserungsmethode für Grundmauern und die Betonstahl-Korrosionsschutzmethode. Mit diesen Methoden wurden bei vielen Gebäuden gute Resultate erzielt.

1. INTRODUCTION

Presently, NTT has approximately 30,000 buildings with a total floor area of about 21,000,000 square meters. The majority of these buildings are reinforced concrete (RC) ones. Their average age is about 23 years, and many of them are in various stages of deterioration. The main cause of deterioration for RC buildings is rebar corrosion. Next is rain and underground water leakage, which cause cracking, peeling of concrete. NTT has been carrying out studies to find an effective method for diagnosing the durability and repair techniques for RC buildings [1]. This paper presents three techniques developed by NTT's Building Engineering Department for repairing deteriorating buildings.

2. CRACK-FILLING METHOD FOR EXTERIOR WALLS

2.1 Downward flow

Until recently, a low viscosity resin had been used to fill minute concrete cracks in exterior walls due to rain leakage. However, NTT discovered in the buildings repaired that the resin did not coagulate but instead flowed downwards. To confirm this experimentally, NTT injected the low viscosity resin into a crack in an existing RC wall. Test samples of the crack were taken from the RC wall after the resin coagulated. The relationship between the crack width and the filling ratio for the samples taken from the highest point along the crack is shown in Fig.1. As indicated in Fig.1, the injected low viscosity resin flowed downward in cracks more than 0.1 mm in width.

2.2 High viscosity resin

The resin was improved to satisfy the following conditions. Resin injected into a 1.5 mm width crack does not flow downwards at 5°-35°C. The resin can be used to fill cracks as narrow as 0.05 mm in width, at 5°-35°C. The improved resin, a high viscosity, is compared with the low viscosity one in Table 1.

Filling tests using both resins were performed on crack models. The models used in the test and the results are shown in Fig.2. Each model was made of two clear acrylic panels that were placed together to form a specified crack width. Resin was injected into three holes spaced at 25 cm apart along the seam of each model on the right side as shown in Fig.2. In the case of the 0.1 mm in width crack, both types of resin did not flow downwards. For the cracks 0.3 mm and 1.0 mm in width, the low viscosity resin flowed downwards, but the high viscosity one did not.

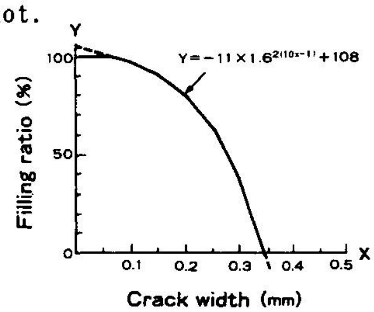


Fig.1 Crack width and filling ratio

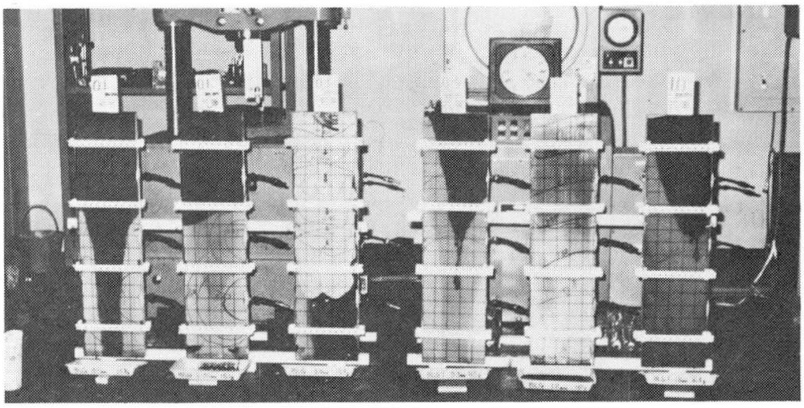
Table 1 Quality of usual and improved resin

Comparison Items	Usual resin	Improved resin
Specific gravity	1.15	1.12
Viscosity	510 cp	8,000 cp
Thixotropy index	—	4.8
Compressive yield strength	642kg/cm^2	650kg/cm^2

NOTE) Thixotropy index (T.I.value): Expressed as the ratio of the 2rpm viscosity to the 20rpm viscosity, both of which are measured by means of the B-type rotary viscometer using the same rotor.

2.3 Injection method

The injector adopted is a cartridge type and the part containing the resin is a synthetic rubber ballon, as shown in Fig.3 and Fig.4. The resin is slowly injected using the balloon's contractile pressure (2.5 kg/cm^2 for 25mm in diameter), and the amount of resin packed can be controlled easily. After the injectors are inserted into the drilled holes along the crack, the crack is filled with resin. This injection method greatly simplifies the work and improves work safety [2]. A picture of the injection work is shown in Fig.4.



Crack width	0.1 mm		0.3 mm		1.0 mm	
Viscosity resin	low	high	low	high	low	high

Fig.2 Test results for crack model

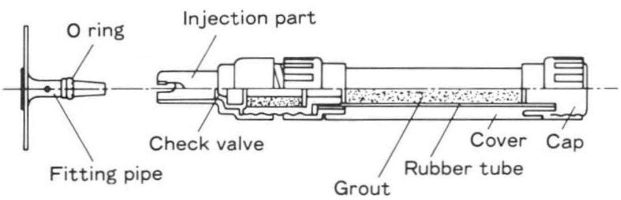


Fig.3 Injector (cartridge type)

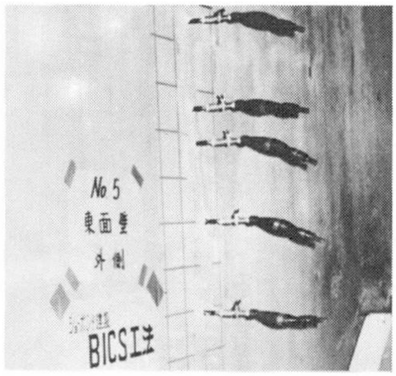


Fig.4 View of injection

3. METHOD FOR ELIMINATING LEAKS IN BASEMENT WALLS

3.1 Characteristics

Since the groundwater level in Japan is shallow, basements sometimes experience water leakage. The leading source of leaks in basements is from cracking, honeycombing or construction joints.

Presently, all repair work is carried out from inside the basement. However, in a newly developed method by NTT all repair work is done from outside the basement. It is particularly effective in stopping leaks in walls with numerous cracks or from an unknown source [3].

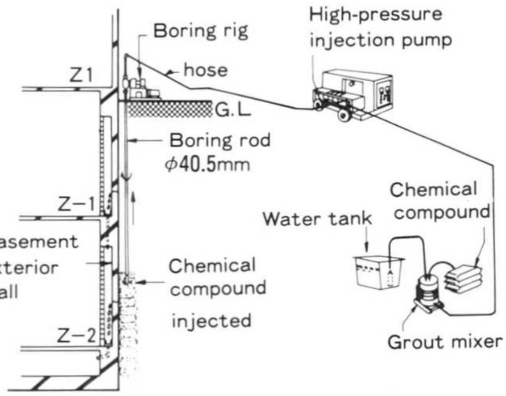


Fig.5 Filling system

The new method uses a chemical compound to stop underground water leakage. The chemical compound is pumped into the ground outside the basement walls at high pressure. The activated silica in the chemical compound reacts to the calcium hydroxide produced by the reaction between water and cement. A silicic acid calcium produced by the reaction enters with water into the concrete defects, becomes implanted, grows and finally fills up the defect. This method is shown in Fig.5.

3.2 Experimental testing

Six models in the shape of boxes and constructed of concrete panels with defects such as cracking and honeycombing were used in the testing. The inside of a box was regarded as the outside of a basement wall and the outside was considered the inside of a basement wall. Model configuration and the test method are shown in Fig.6. Chemical compounds with soil samples were mixed and placed into the models. Water was then pumped into them at 3 ton/m² pressure from a water tank placed three meters above the models. Leakage from the models was measured continuously. Chemical compound mixings are shown in Table 2. The effects of the various compound mixings on water leakage are compared and shown in Fig.7. In the case of a fat mix agent (cement 300 kg/m³, chemical compound 18 kg/m³), water leakage was reduced by 96.1 - 99.7% by the 30th day of testing. In the case of a lean mix agent (cement 150 kg/m³, chemical compound 15 kg/m³), leakage only decreased 30.2% by the 30th day of testing.

3.3 Testing in an existing building

The test was performed on the external perimeter walls of the third basement (see Fig.8). The mixing of the chemical compound used was exactly the same as that of No.6 in Table 2. Boring rods were driven in 25 cm from the outer surface of the exterior walls to the required depth. The chemical compound was injected into the rods, 23 in total. During the injection, the rods were pulled up at 10 cm/step.

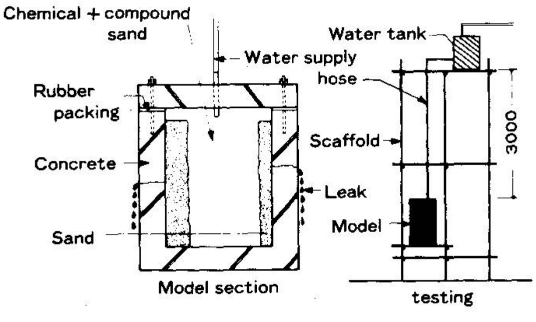


Fig.6 Test model

Table 2 Chemical compound mixing and soil (Unit of dimension : kg/m³)

No.	Cement	Admix-ture	Water	Soil
1	600	36	724	sand
2	300	30	857	sand
3	150	15	928	sand
4	600	36	724	Silt sand
5	300	18	862	Silt sand
6	450	27	792	Gravel & sand

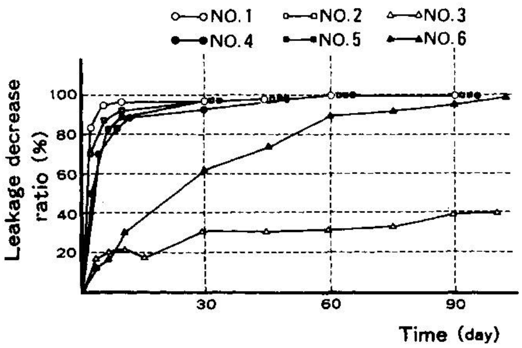


Fig.7 Effect of various chemical compound

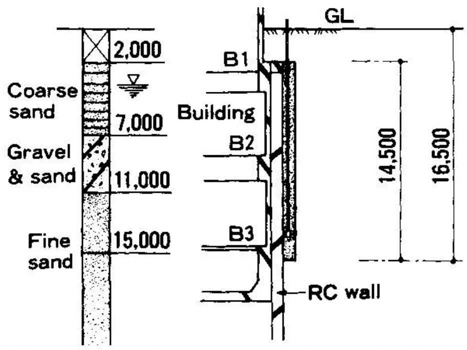


Fig.8 Testing in existing building

The number of leaks was 88, and all of them were observed carefuly by eye. The amount of leakage for six of these leaks was measured. Eye observations are shown in Fig.9. The number of leaks decreased 52% by the 30th day of testing and 86% by the 90th day. The measurements for six leaks are shown in Fig.10. The number of leaks by the 110th day of the testing was one. As each day passed, the effect of this method was noticeable.

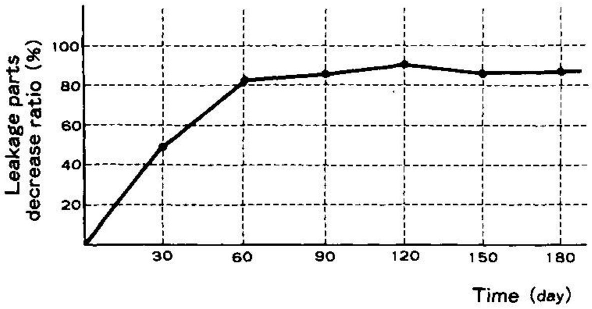


Fig.9 Eye observation

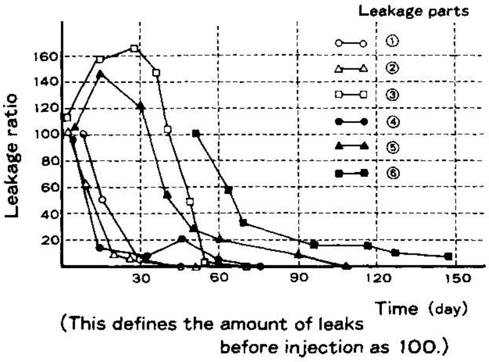


Fig.10 Amount of leakage

4. REBAR CORROSION-RESTRICTION METHOD

4.1 Concept

The method of restricting concrete carbonation has generally been adopted in Japan to improve the durability of concrete structures. However, concrete carbonation and the coverage concrete thickness for rebar vary widely. This means that the concrete around some rebar in existing buildings has probably carbonated, even if a building is not old. Therefore, NTT developed the method of restricting rebar corrosion in the carbonated concrete [4], as shown in Fig.11.

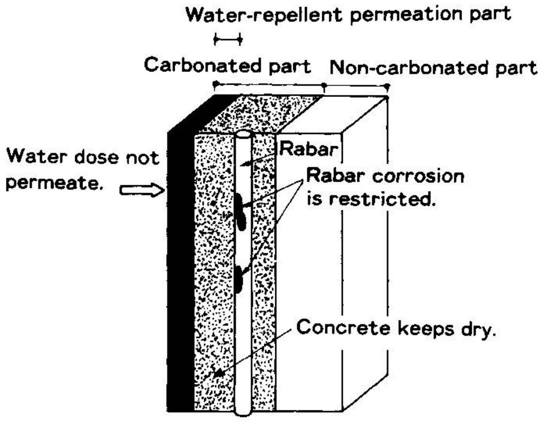


Fig.11 Concept of the method

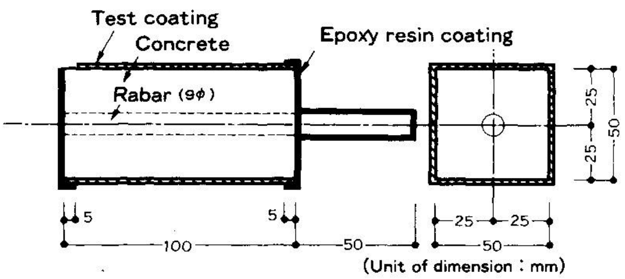


Fig.12 Test sample

Table 3 Code No. for various coatings samples

No.	Various coatings	
1	——	Exposed concrete
2	Water-repellent	Acrile polymer
3		Silane monomer
4		Methyl-silicon polymer
5	Water-proof	Acrile emulsion
6		High elastic acrile rubber
7		High elastic polymer-cement
25	Water-repellent + Water-proof	No.2 + No.5
26		No.2 + No.6
27		No.2 + No.7
35		No.3 + No.5
36		No.3 + No.6
37		No.3 + No.7
45		No.4 + No.5
46		No.4 + No.6
47		No.4 + No.7

4.2 Effect of restriction

An accelerated aging test was performed to confirm the effect of restriction. A reinforced concrete sample used in the testing is shown in Fig.12. After the concrete samples were forcibly carbonated to the rebar position, the surface of the samples were painted with various coatings. Next, the samples were alternately placed in wet or dry environment every seven days. This procedure accelerated rebar corrosion. The test extended over 110 days. The code No. for the various coatings samples used are listed in Table 3.

The ratio of the corrosion area to the entire surface area of the rebar and the average weight of permeated water are shown in Fig.13. The weight of permeated water is the weight of a sample in the wet environment minus its weight in the dry environment. Samples of the rebar corrosion are shown in Fig.14. As indicated in Fig.13 and Fig.14, impermeability to water was satisfied in the case of the samples coated with the water-repellent silane coatings (No.3), waterproof coatings (No.5,6,7), and the water-repellent and waterproof complex coatings (No.25-47).

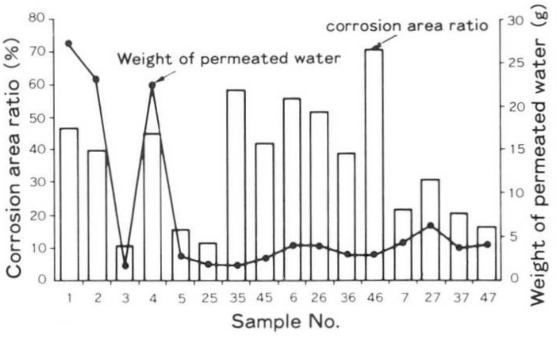


Fig.13 Test results (corrosion area ratio)

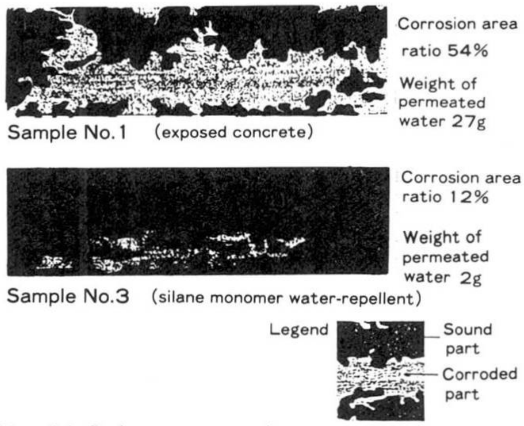


Fig.14 Rebar corrosion

4.3 Requirement standards for restrictive coatings

As the restrictive performance of the coatings varied in the test, NTT set standards to select the most suitable coatings. One of the some requirements is that permeability after accelerated age testing shall not be more than 1.5 times compared with that before testing. Also, in the case of the water-repellent coatings, the permeated water-repellent depth in concrete shall be 5 mm and over in model testing. In the case of waterproof coatings, it must be confirmed by model testing that corrosion is not caused by an ingredient in them.

5. CONCLUSIONS

Three repair methods for concrete structures were introduced. NTT has employed these methods in repairing many of its buildings, and has obtained good results.

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