Mechanism of Efflorescence on Historical Masonry Buildings Seismically Reinforced with Concrete

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Abstract: The use of concrete for the seismic reinforcement of historical masonry buildings has been related to the accumulation of alkali salts on external brickwork, resulting in accelerated decay of the original masonry. A survey of a reinforced historical building revealed that efflorescence occurs most heavily in areas that become wet due to rainfall. This mode of efflorescence was successfully reproduced using a test wall of brickwork with cement mortar backing. Efflorescence was found to accumulate most heavily on areas of the brickwork that become wettest, and efflorescence was shown to progress with repeated wetting and drying of the brickwork. The porosity of brick after the efflorescence tests was also measured using a mercury intrusion method, and it was confirmed that the porosity of brickwork in regions with heavy efflorescence is much lower than in areas with little surface efflorescence.

1. NTRODUCTION

The conservation and renovation of historical buildings through the application of modern construction techniques such as masonry, reinforced concrete, and steel-frame structures has become widespread. Most historical buildings need to be seismically reinforced using appropriate conservation and renovation methods in order to preserve the buildings, which were built predominantly in urban areas, for continued use. In the planning of reinforcement of these historical buildings, due consideration should be given to their historical value, the original method of construction, the original materials used, and the intended manner of reinforcement, as inappropriate reinforcement methods can reduce the historical value of the building and in fact promote decay.

In Japan, seismic reinforcement is necessary in many cases because the original building does not provide sufficient seismic safety. Of the various materials such as concrete, steel, synthetic resins, and high-strength fibers that have been used for seismic reinforcement, concrete is most widely used as inner wall, column or slab reinforcement. The reinforcement effect expected in such cases is quite good considering the similarity to masonry walls in terms of rigidity. However, reinforcement with concrete has been noted to cause heavy efflorescence on brickwork due to the leaching of alkali salts from the cement, resulting in extensive decay of the original structure.

This paper experimentally analyzes the mechanism of efflorescence on historical masonry buildings that have been seismically reinforced with concrete.

2. EXAMPLE OF MASONRY BUILDING REINFORCED WITH CONCRETE

Many historical masonry buildings have been reinforced with concrete in Japan. An example of such a building, built in 1890 and reinforced with inner concrete walls in 1977, was assessed in 2003 to evaluate the extent of efflorescence on exterior walls. Figures 1 and 2 show examples of the efflorescence on the exterior wall of this historical masonry building. Efflorescence was observed on most exterior walls, with a considerable accumulation below the eaves, around cornices, below window frames, and at joints between walls - areas that are likely to remain wet after rainfall. Spalling of the brickwork was also observed, as shown in Figure 3. It is supposed that this spalling is induced by the accumulation of crystalline salt residue inside the brick.

From this survey it was inferred that the mechanism of efflorescence on masonry buildings reinforced with concrete appears to be related to the movement of moisture and salt in the masonry wall.

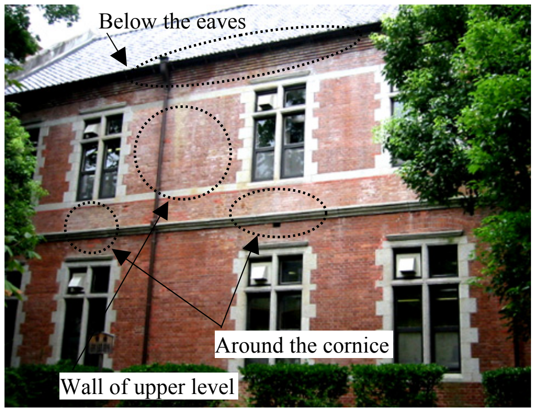

Figure 1 Efflorescence on a historical masonry building reinforced with concrete

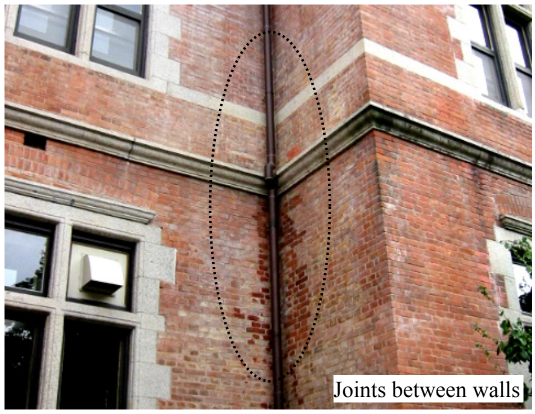

Figure 2 Efflorescence at joints between walls


Figure 3 Spalling caused by crystalline salt residue inside the brickwork

3. MODEL TEST FOR EFFLORESCENCE

3.1 Test Wall

The model wall fabricated to attempt to reproduce the efflorescence appearing on masonry walls reinforced internally with concrete is shown in Figure 4. Brickwork was laid using cement lime mortar and allowed to cure for 28 days. A lining of cement mortar was then formed in direct contact with the brickwork. The joint mortar included a lime constituent, as commonly employed before the Second World War. The conditions of specimens are listed in Table 1.

Table 1 Absorption of brick, joint mortar and cement mortar backing

	Position of brick	Absorption of cold water (%)	Joint mortar	Cement mortar backing
Cement mortar backing	Upper	8.0	cement:lime:sand=1:3:12 (by volume), lime:water=1:1 (by weight)	w/c=0.6, cement:sand=1:2.5
	Lower	9.0		
No backing	Upper	9.0		
	Lower	8.6		

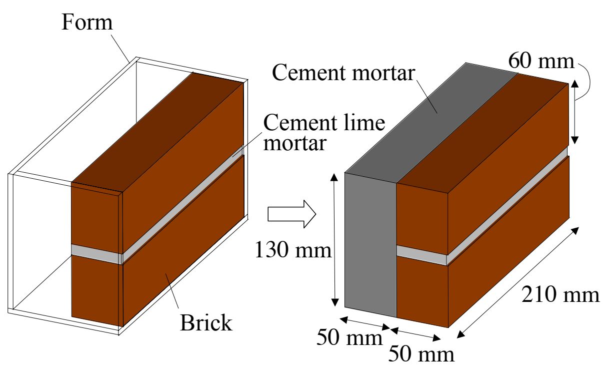

Figure 4 Test wall specimen

3.2 Test Method

Epoxy resin was applied to the surfaces as shown in Figure 5. The test procedure is outlined in Figure 6. In the test, a reservoir on the top of the specimen was filled with a fixed quantity of water (300 mL), and the efflorescence was observed after the brick surface had dried. This process was repeated. The test was carried out in a thermostatic chamber maintained at 20 ºC and 60% relative humidity, and airflow was applied to the brick surface to accelerate drying.

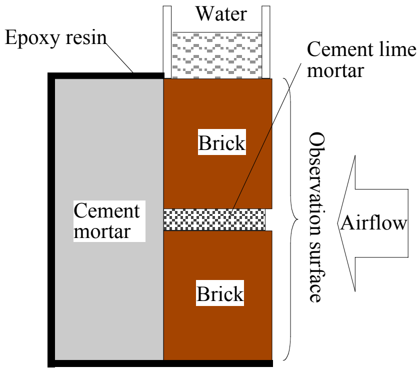

Figure 5 Summary of test method

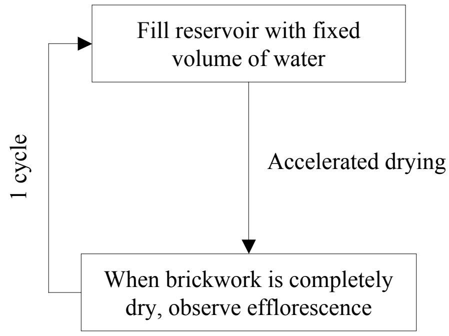

Figure 6 Procedure of test

3.3 Results

The test results are shown in Figure 7. The ratio of efflorescence area to the total exposed brickwork area (except joints) was also calculated (see Figure 8) and the results are shown in Figure 9. The efflorescence area increased with repeated wet/dry cycles. The joint mortar (cement-lime) appeared to contribute little to the efflorescence compared to the cement mortar backing, indicating that cement lime mortar supplies less salts than the cement mortar backing.

The distribution of efflorescence accumulation was not uniform, with heavy efflorescence appearing on the upper portion of the brickwork. This is attributed to a non-uniform distribution of water content in brickwork, varying from high content near the top (closest to the reservoir), to low water content near the base.

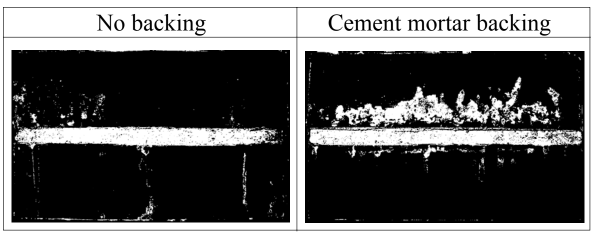

Figure 8 Example of before and after pictures (7 cycles)

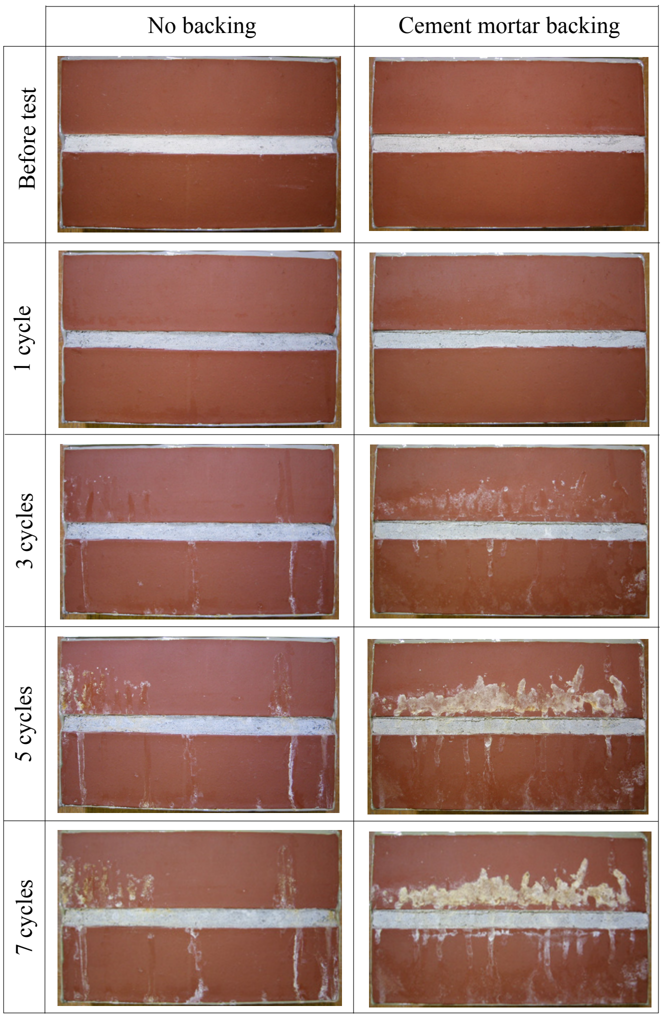

Figure 7 Test result: View of observation surface at each cycle

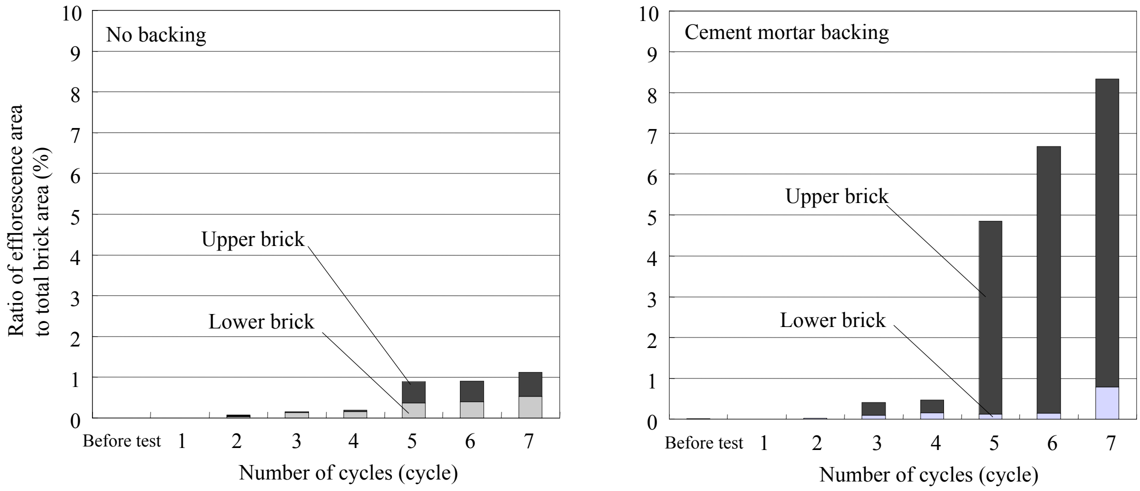

Figure 9 Ratio of efflorescence area to total brickwork surface area except joints

4. POROSITY CHANGE IN BRICK DUE TO CEMENT SALTS

4.1 Test of Efflorescence without Joint Mortar

4.1.1 Test Method

The effect of cement salts leached from the concrete reinforcement and accumulating in the masonry brickwork was investigated in more detail using a test model consisting of bricks and a cement mortar backing, without joint mortar. The specimen is shown in Figure 10. The absorption of water into the brick after 24 h immersion in cold water was 8.0% (by weight). The backing cement mortar had a water content of 0.6 and a cement:sand ratio of 1:2.5. The test configuration is shown in Figure 11. The test procedure and conditions were the same as in the previous experiments.

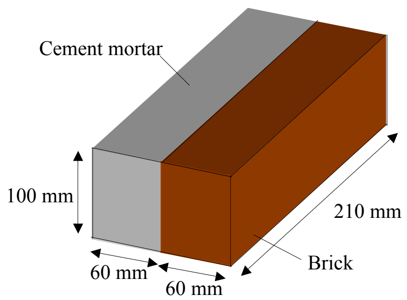

Figure 10 Test specimen

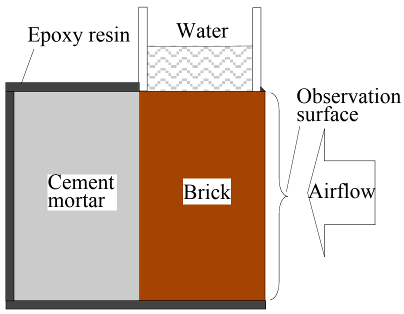

Figure 11 Test method

4.1.2 Results

Figure 12 shows photographs of the brick surface before the test and after 6 cycles. Heavy efflorescence can be seen due the cement mortar backing. Again, the distribution of efflorescence was not uniform, but in this case, heavy efflorescence accumulation occurred on the lower part of the brick. The ratio of efflorescence area to total exposed brick surface calculated from such photo pairs is shown in Figure 13. These results clearly show that efflorescence

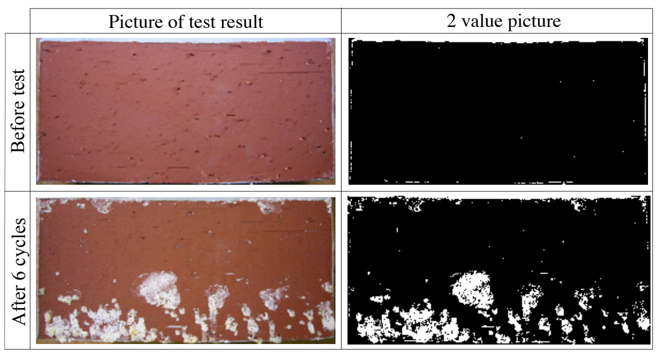

Figure 12 Test result: View of observation surface before test and after 6 cycles

accumulated progressively on the brick surface with repeated wet/dry cycles.

4.2 Porosity of Brick after Efflorescence Test

Although the cement salts could be readily seen to accumulate on the brick surface, it is also important to investigate whether cement salts are crystallizing inside the brick as well, which may be the cause of spalling and decay. This was examined by measuring the porosity of the bricks using a mercury intrusion method.

The samples for measurement were cut from two places of the specimen after the accelerating test, as shown in Figure 14, from an area exhibiting little surface efflorescence and an area with a heavy accumulation of efflorescence. The measurement results are shown in Figure 15. While pores of approximately 10 μm or more in diameter are present in the upper part of the brick (low efflorescence), the porosity of the lower part is significantly lower, from 1 μm to 10 μm. This difference in porosity between the upper and lower parts of the same brick after the efflorescence test indicates that cement salts were crystallizing inside the brick due to efflorescence, reducing the porosity of the brick in regions that exhibit heavy efflorescence on the surface.

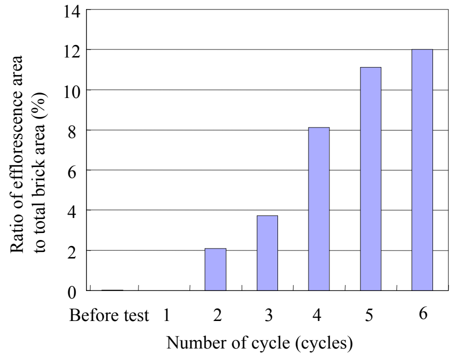

Figure 13 Ratio of efflorescence area to total brick area

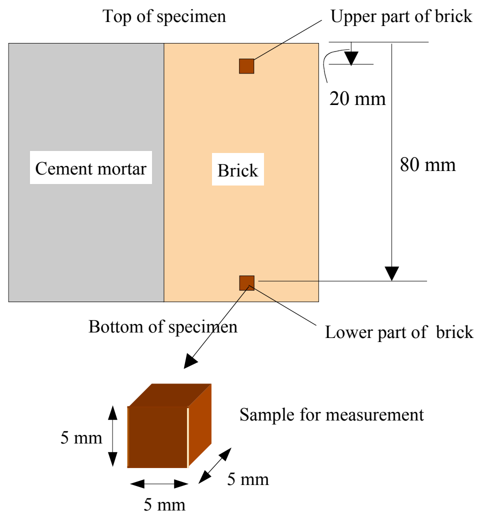

Figure 14 Position of samples for porosity measurement by mercury intrusion method

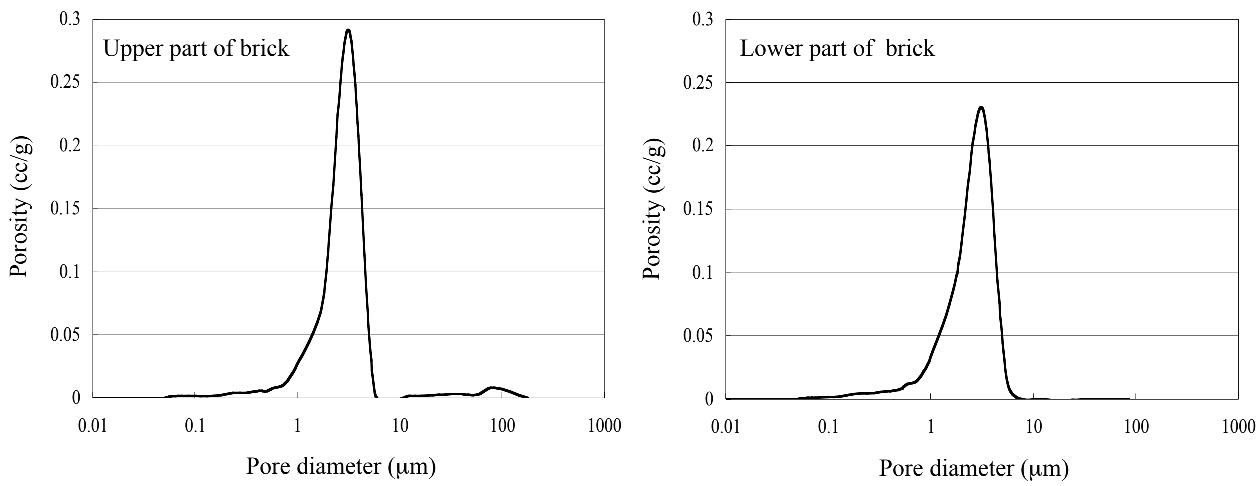

Figure 15 Porosity of bricks measured by mercury intrusion method

5. CONCLUSIONS

This study considered the mechanism of efflorescence on historical masonry buildings that have been seismically reinforced with an internal backing of concrete. A survey of a historical masonry building that had been reinforced with concrete, revealed that efflorescence occurred on most areas of exterior walls, with particularly heavy accumulations below the eaves, around cornices, below window frames, and at joints between walls, which are area that are likely to become wet due to rainfall. An experiment using a model wall with a concrete backing successfully reproduced the efflorescence observed in the field, and showed that the efflorescence on brickwork accumulates with repeated wetting and drying of the brickwork The distribution of surface efflorescence was not uniform, and is considered to be related to the vertical variation in water content in the brickwork. Finally, the porosity of bricks after efflorescence tests was measured using an mercury intrusion method, and it was found that the porosity of brick in areas with heavy surface efflorescence was significantly lower than that in areas exhibiting less surface efflorescence.

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