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A REINFORCED CONCRETE BUILDING DEFORMED BY ALKALI AGGREGATE REACTION

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1. INTRODUCTION

A three storied reinforced concrete school building showed excessive deformation and many cracks at the third story several years after the completion. The dislocation of longitudinal roof end of the 60 meter long building was over 2 cm and many cracks were found through the structural members such as girders, columns, floor slabs and walls. There was no leak in the roof. The maximum crack width was 8 mm in girders and 2 mm in columns. Window locking became impossible due to the deformation of the sash frame caused by column bending.

The investigation of the detailed crack map and the deformation of the columns revealed that the damages were caused by the expansion of the roof slab. And observation of the behavior of the cracks and deformation of the structure in summer and winter indicated that the temperature change contributed to the expansion of the roof slabs to some extent [1].

Recently concrete cores were obtained from the roof slabs and walls. Observations and several tests on these cores revealed the deterioration of the concrete was caused by the alkali aggregate reaction. The report presents the description of the building deformation, the history and the state of the cracks and their behavior due to thermal response. Observation results of cores with X-ray analysis and pictures of scanning electron microscope of them are also presented. Contents of Na and K soluble in water were analized. The results of experiment on potential expansion of the cores and thermal expansion coefficient of the cores are reported.

2. BUILDING STRUCTURE AND ITS CRACKS

The school building consists of three blocks and they were constructed one block after the other in each winter from 1969 to 1971. The concrete mix records are given in Table 1. No expansion joint was provided between them (Fig.1). In 1975 the west block (5 years after construction) showed excessive deformation in southern part of the block that the locking of window sashes became impossible. Many cracks appeared through the structural elements. The maximum crack width was 8 mm in roof girders and 2 mm in columns.

In December the same year, the north block (two and a half years after the construction) showed several cracks in roof girders at the eastern part of the block. But it was very small that no counter measure was discussed.

Table 1. Concrete Mix

Cement : 400 kg/m³, Water Cement Ratio : 0.59 , Slump : 21 cm, Sand : 2.5 mm , Gravel : 25 mm , Steel mesh (4mmϕ ,10 cm pitch) was placed on the slab reinforcement.

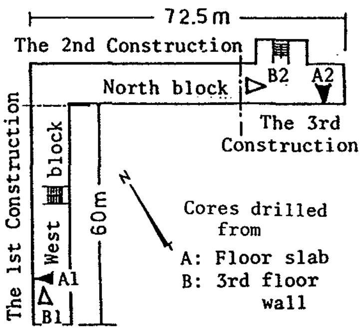


Fig.1 Construction process and core boring.

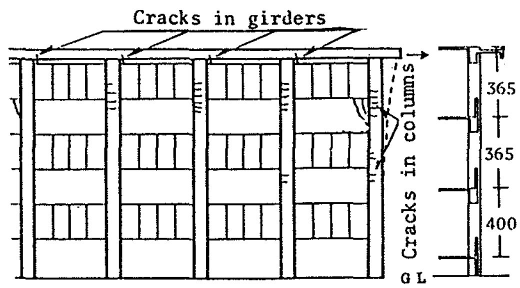


Fig.2 Crack pattern of the south side of the north block.

In July 1979, it was found that cracks through the girders, columns, floor slabs and walls developed to the extent similar to the west block (Fig.2).

Investigation of detailed crack map, behavior of the cracks and dislocation of the eastern roof end in August 1982 and January 1983 revealed that the main cracks were caused by the expansion of roof slab in the longitudinal direction of the building. The roof slab shrinked in winter and the dislocation at the eastern end of the north block was measured as 8 mm. However the dislocation of 20 mm in southside and 11.5 mm in northside of the building at the eastern end still remained. And width of cracks also reduced in winter but about 80 percent of it still remained.

In 1987, any distinct progress of cracks were not observed in their number and width.

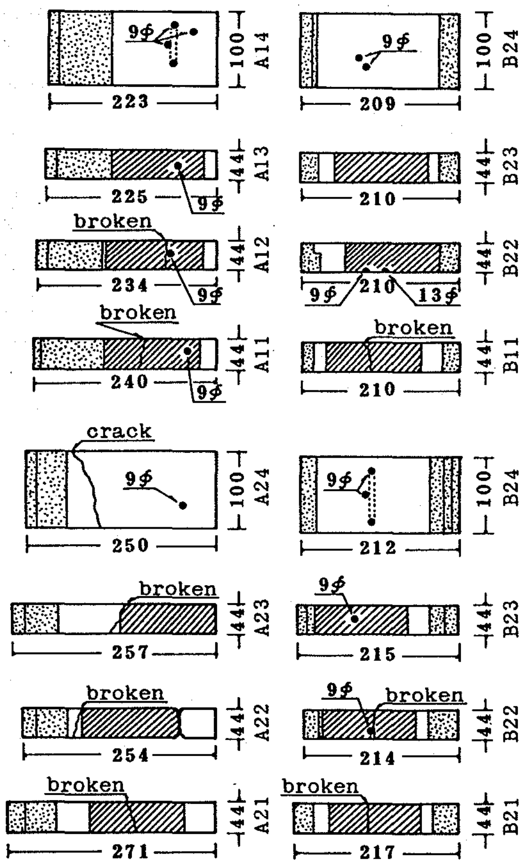
3. DESCRIPTION OF CORES

Twelve cores of 4.4 cm diameter and four cores of 10 cm diameter were drilled from the roof slab and inner walls of the third floor of the west and the north block of the building as shown in Fig.1. The length of the concrete were 12-19 cm as shown in Fig.3.

The coarse aggregate observed at the core side were mainly (about two thirds) andesite and the rest were granite and gneiss. Small pores which was thought to be formed by gas eject at its birth were observed in andesite aggregate.

Cracks were found through the andesite aggregate and some of it extended into the mortar portion in the slab cores as shown in Fig.4. One of the slab cores showed white gel material at the broken section as shown in Fig.5. This segregation of the section was thought to be formed before the core boring.

Black rims were also observed around the andesite aggregates as shown in



Mortar (mm)
Portion used for specimen

Fig.3 Detail of cores.

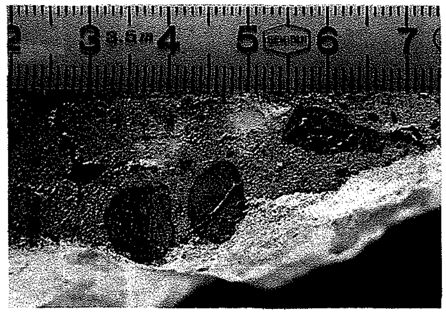


Fig.4 A. side of slab core A24.

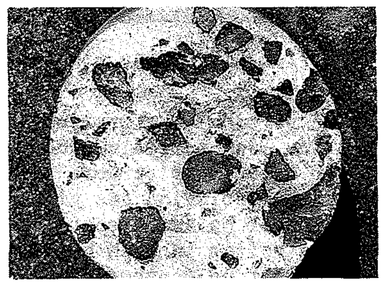


Fig.5 A section of slab core A24.

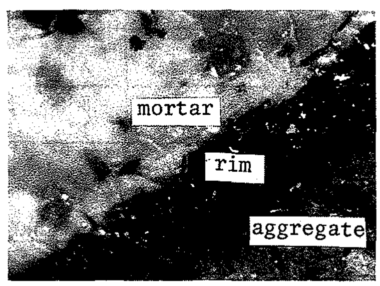


Fig.6 Black rim around a aggregate particle.

Fig.5 and Fig.6. At the side of cores these black rims were not so clearly visible as in the above mentioned section. These cracks and black rims were not observed in the wall cores from the both blocks. Deterioration of concrete as such were considered to be prevailed over the whole roof slab and not at inside walls, if any it might be very limited.

The roof slab had been finished with mortar (6-9 cm thick) alone. The penetration of rain and sun heat through the mortar might have caused severer condition for durability of slab concrete than the inner wall concrete.

Scanning electron microscope pictures and results of X-ray analysis of the inner portion of aggregate, black rim, mortar and white gel near the crack are shown respectively in Fig.7.

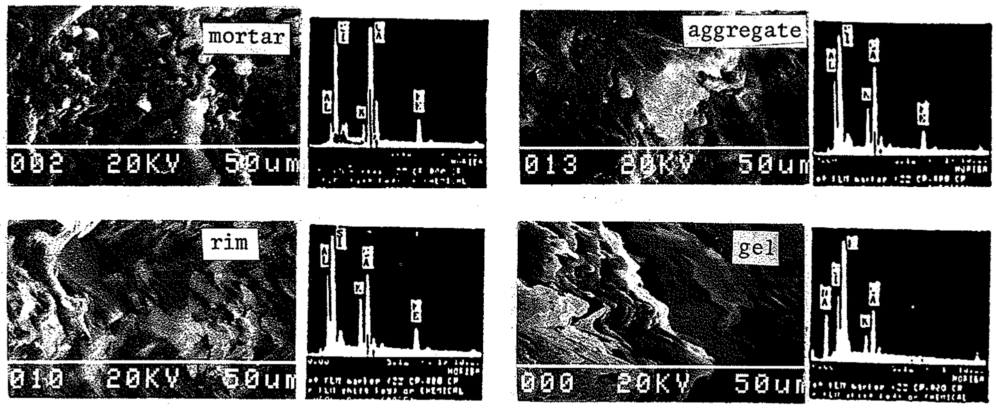


Fig.7 Scanning electron microscope photograph and X-ray analysis.

The portion of mortar obtained from four cores with 10 cm diameter were crushed to fine particle under 0.15 mm and soaked in water for 4 days. These filtered water samples were tested with a flame photometer. The content of Na and K in the solution are given in relation to mortar as shown in Table 2. The values of Na and K content of slab core mortar are smaller than that of wall core mortar in both building blocks. The decreased amount of the alkali content might be consumed for the reaction with the aggregate.

Table 2. Contents of Na and K.

	WALL		SLAB	
Block	West	North	West	North
Core	B14	B24	A14	A24
Na	900	930	540	530
K	218	326	124	124

(ppm in mortar)

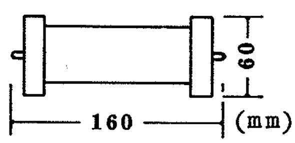


Fig.8 Specimen for length change measurement.

4. TEST ON POTENTIAL EXPANSION OF CORES

Twelve core specimens were stored in saturated condition of 18 and 40°C respectively for 32 weeks. The specimens were made with concrete portion of cores with 4.4 cm diameter as shown in Fig.3. The detail of the specimens are shown in Fig.8. The length change of each specimens were measured with a dial guage. The initial length was set at two weeks after stored in saturated condition where expansion by saturation of specimens became stable.

Two slab cores and two wall cores, each from north and west block of the building, were kept in 40°C for 16 weeks. The rest, four slab cores and four wall cores, were tested through 32 weeks. They were placed in 18-20 °C but every three of them were kept in 40 °C at the last nine weeks. The test results are shown in Table 3.

In the 16 weeks test results, three of six cores stored in 18-20 °C showed expansion of 0.017 - 0.062 %. But the other cores stayed under very small amount of length change regardless of their stored condition.

In the 32 weeks test results, one of six cores stored in 40°C showed 0.123 % expansion but the expansion of the rest stayed below 0.022 %.

Table 3. Expansion of cores.

Period			16 weeks		32 weeks	
Element	Block	No.	Temp. (°C)	Expans. (%)	Temp. (°C)	Expans. (%)
Slab	West	A11	40	0.004	---	-----
		A12	18	0.017	**	0.022
		A13	18	0.004	**	0.013
	North	A21	40	0.005	---	-----
		A22	18	=0	**	0.011
		A23	18	0.006	*	0.015
Wall	West	B11	18	=0	**	=0
		B12	18	0.016	**	0.017
		B13	40	=0	---	-----
	North	B21	18	0.062	**	0.123
		B22	40	0.003	---	-----
		B23	18	=0	*	0.004

* 18-20°C ,** 40°C for 9 weeks.

Regarding the wall cores, only one of the three cores showed remarkable expansion. This fact indicates that all wall cores did not always contain the same amount of potential expansion.

It is observed also that no distinct difference of expansion is exist between the two wall cores and three slab cores. If it is assumed that the both group have the same amount of potential expansion and the slab cores already expanded to some extent, the wall cores should have revealed larger expansion than the slab cores. The test results suggest also that the concrete has different potential expansion at their different portion.

5. THERMAL EXPANSION OF CORES

Five expansion test specimens were wrapped with vinyl sheet one by one and kept under the specified temperature conditions over six hours and the length were measured with a dial gauge. The temperature were 11°C and 47°C. The coefficients of thermal expansion were calculated from the test resuts as shown in Table 4.

The coefficients of thermal expansion ranges from 0.74 to 0.99 x 10^{-5}/°C. The values might be affected by the difference of aggragate volume in each cores. The mean value was 0.84 x 10^{-5}/°C.

Table 4. Thermal expansion coefficients (α).

No.	α (10^{-5}/°C)
A12	0.74
A13	0.75
A22	0.92
B11	0.99
B12	0.80
mean	0.84

6. DISCUSSION

As the bending cracks through the columns and girders were so extensive that the restraining effect of them on the expansion of roof slab is thought to be very slight. The elongation of roof slab was calculated as 7.6 mm and 9.1 mm for the half of slab length of 72.5 meters and the temperature rises of 25°C and 30°C respectively. The values correspond nearly to the thermal expansion behavior of 8 mm (0.02 %) obtained for dislocation of longitudinal roof end between summer and winter.

The slab deformation remained in winter means the expansion of 0.06 % and the value stays within the expansion of a wall core tested. The expansion is thought to be the result of alkali aggregate reaction.

7. CONCLUSION

With the investigation of potential expansion due to alkali aggregate reaction and thermal expansion of the cores, the deformation of a three storied reinforced concrete building and its crack behavior were brought to a quantitative discussion.

Building deformation process was summerized as follows :
Cracks at girder ends were very small three years after the construction. In five to ten years the expansion of slab by the alkali aggragate reaction extended to 0.06 % (over 2 cm of dislocation of roof end in longitudinal direction). With the remarkable progress of cracks at the girders and columns, the restraining effect of the structure against the expansion of the roof slab decreased and thermal expansion behavior of the roof reached its full extent of 0.02 % between summer and winter.

The whole roof was covered with sheets ten years after the construction and no distinct progress of cracks was observed since. It is not clarified that the whole potential expansion due to alkali aggragate reaction appeared already or the part of it still remains unrevealed by the drying of roof slab after the refinishing.

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REFERENCES

[1] Kawakami,H,. Behavior of Cracks Due to Temperature Change, Transactions of the Japan Concrete Institute, 5, 501, 1983.