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A study on the reinforced concrete column with the alkali-silica reaction in Hanshin Expressway viaducts

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ABSTRACT

A lot of cracks and the reinforcing steel rupture are detected at the reinforced concrete column which is 27 years old in Hanshin Expressway viaducts. It is suspected that the damage is due to the alkali-silica reaction (ASR). Detail observation of the cracks is conducted such as crack distribution. Field survey about the reinforcing steel rupture of the tie hoop is also conducted. Concrete cores are taken from the column. The compressive strength, static modulus of elasticity, carbonation depth and chloride ion content are measured using the concrete cores. The accelerated expansion test of the concrete cores is carried out. The aggregate visual observation is also conducted on the site. In this paper, the damage survey is described and the damage factors are studied.

Keywords. alkali-silica reaction (ASR), reinforced concrete column, detail investigation

INTRODUCTION

The structure is the reinforced concrete rigid frame with two columns that is located in the Higashi-Osaka Line on the Hansin Expressway network. Many cracks are discovered on the column face. The reinforcing steel ruptures are also founded at the corner of the columns. It is suspected that the damage factor is ASR. Detail investigations are conducted such as crack distribution, the accelerated expansion test, the aggregate visual observation. The compressive strength, the static modulus of elasticity, carbonation depth and chloride ion content are studied by the concrete cores collected on the site. The damage examinations and the damage causes are reported in this paper.

CHARACTERISTICS OF THE STRUCTURE

The structure of the reinforced concrete rigid frame is numbered as P369, shown in Figure 1. It was built in 1983. The history of the inspection is shown in Table 1. The concrete mix proportion is not stored as the construction record.

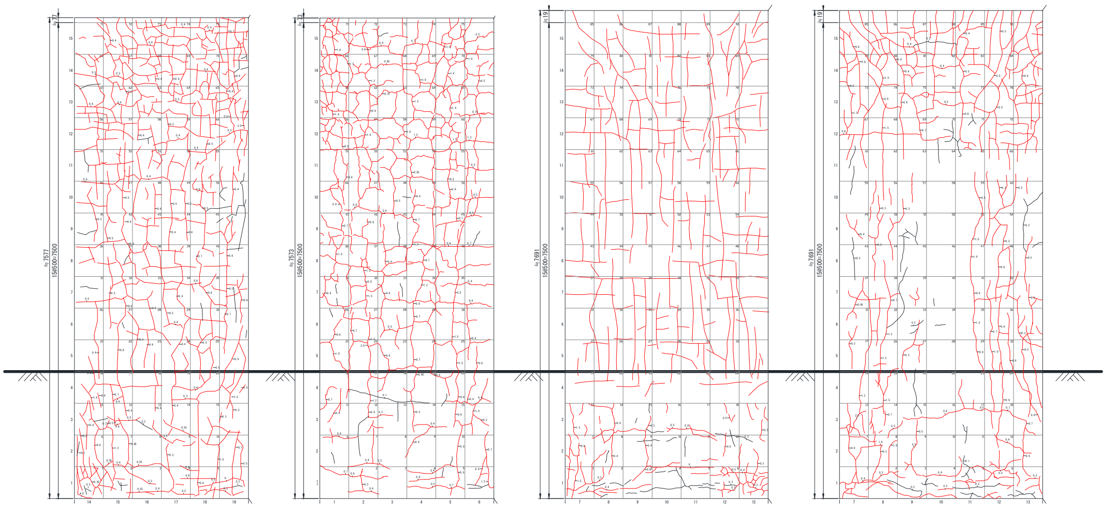
Figure 1. The reinforced concrete rigid frame with two columns (P369)

Table 1. The history of the inspection

Inspection year	Damage
1983	Construction completed
1987	The light cracks (C rank) are detected.
1994	The light cracks (C rank) are detected.
1997	The medium cracks (B rank) are detected.
2007	The serious cracks (A rank) are detected.

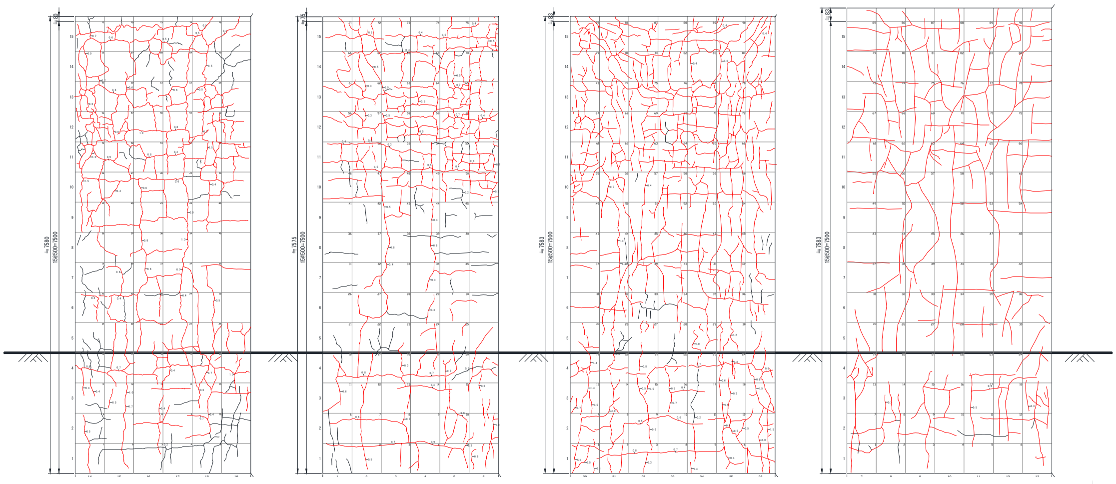
CRACK DISTRIBUTION

The crack distribution on the column surface is shown in Figure 2. The cracks are distributed all over the column surface. The total length of the cracks is 1,070.6m. The crack density is 5.4 m/m^2. Since the value of 5.4 m/m^2 is much more than the judging standard crack density of ASR, 1.0 m/m^2 in Hanshin Expressway maintenance manual (Hanshin Expressway Company, 2008), ASR is suspected with the two columns. The large crack with 10mm width is detected at the corner of the column bottom, shown in Figure 3. The water supply from the ground is supposed to be the main reason for the crack growth in the column bottom.



East side **West side** **South side** **North side**

(a) The left column



East side **West side** **South side** **North side**

(b) The right column

Figure 2. The crack distribution on the column surface

Figure 3. More than 15 mm crack at the corner of the column bottom

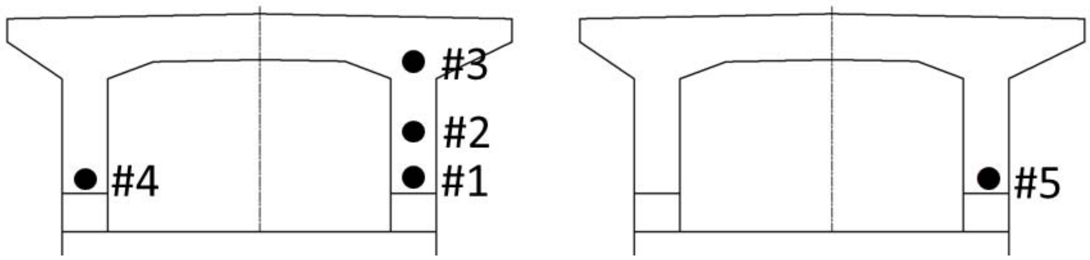
REINFORCING STEEL RUPTURE

The reinforcing steel rupture of the tie hoop is shown in Figure 4. The 120 points of the corner of the column are investigated by the destructive or non-destructive method. The reinforcing steel rupture is confirmed at 70 points out of 120. The 70 points are located in the bottom or intermediate height of the column. It is not clear that the reinforcing steel is electric furnace or blast furnace.

Figure 4. The reinforcing steel (tie hoop) rupture

COMPRESSIVE STRENGTH AND STATIC MODULUS OF ELASTICITY

The core location is shown in Figure 5. The target columns are P369. In order to compare P369 with the harmless column, the #5 core is taken from P370 that is the adjacent pier in the same construction unit where the same concrete material was used. The relationship between the compressive strength and the static modulus of elasticity is shown in Figure 6. The design compressive strength of concrete in P369 and P370 is 27 N/mm^2.The solid line in Figure 6 indicates the standard relationship between the compressive strength and the static modulus of elasticity by Japan Society Civil Engineers (JSCE, 2007). The modulus of elasticity of the #1, #2 and #4 cores is found to deteriorate from the JSCE solid line.



(a) P369 (The target column) **(b) P370 (The harmless column)**

Figure 5. The location of the cores

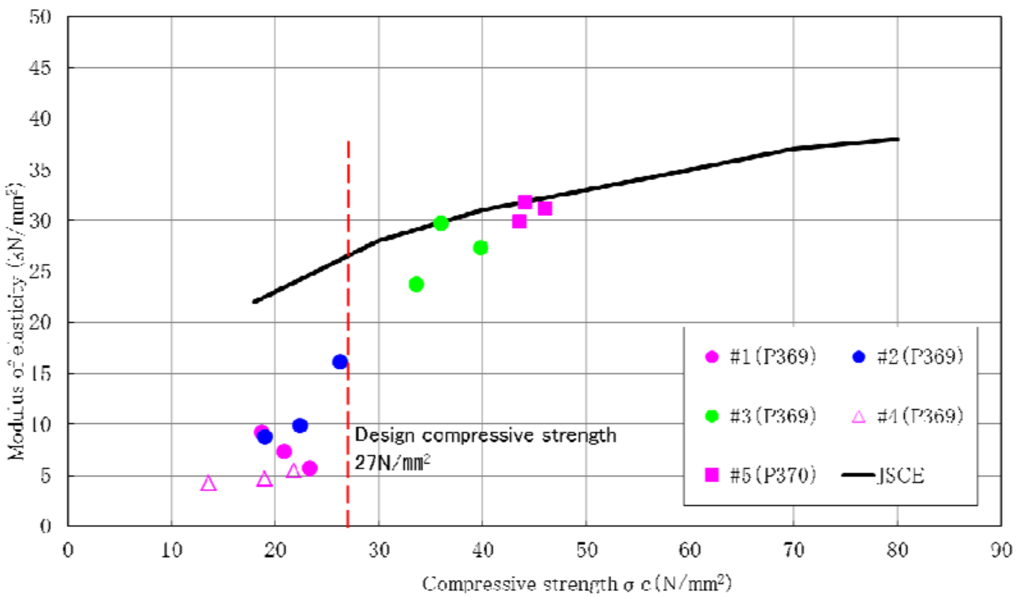


Figure 6. The relationship between the compressive strength and the static modulus of elasticity

CARBONATION DEPTH AND CHLORIDE ION CONTENT

The carbonation depth of the #1 to #5 cores is shown in Table 2. The non-carbonation thicknesses that means the cover thickness minuses the carbonation depth are about 60mm in the #1, #2 and #4 core locations and about 45mm in the #3 core location. The effect of the carbonation to the reinforcing steel corrosion is thought to be small. The chloride ion content of the cores at the depth of 5, 39, 73 mm from the surface is shown in Table 3. They are much less than 1.2 kg/m^3 that are the limit value of the reinforcing steel corrosion. The effect of the chloride ion content is also small.

Table 2. The carbonation depth of the cores

Core #	Carbonation depth (mm)
1	1.9
2	6.6
3	19.9
4	1.0
5	1.3

Table 3. The chloride ion content of the cores

Core #	5 mm deep from surface (kg/m^3)	39mm deep from surface (kg/m^3)	73mm deep from surface (kg/m^3)
1	0.12	0.18	0.14
2	0.18	0.18	0.14
3	0.64	0.14	0.14
4	0.25	0.21	0.18
5	0.14	0.14	0.09

RESIDUAL EXPANSION CAPACITY

The accelerated test of residual expansion capacity (the JCI-DD2 method) is conducted using the 5 cores. The relationship between the exposure period and the expansion rate is shown in Figure 7. The total expansion rate of the #2 core reaches 0.1% that is the judging standard of ASR. In the #2 core, the residual expansion rate occupies 90% of the total expansion rate that means the #2 section has high capacity of ASR expansion in the future.

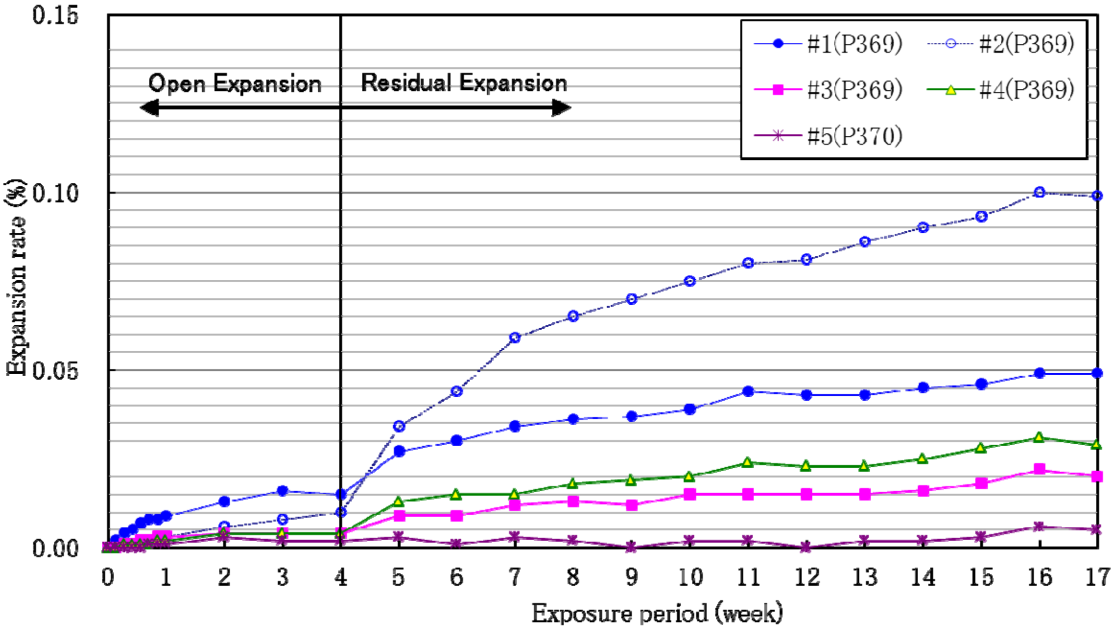


Figure 7. The relationship between the exposure period and the expansion rate of the 5 cores

AGGREGATE VISUAL OBSERVATION

The aggregate visual observation is conducted in P369. From the observation, the gel and the reaction ring are detected, shown in Figure 8. The alkali reactive aggregates such as cristobalite and microcrystalline quartz are observed in in all cores. The aggregate component is the andesite 60 % and the sandstone 40 % in the #1 and #4 cores. On the other hand, the aggregate component is the andesite 5 %, the sandstone 85 % and the mudstone 10 % in the #3 and #5 cores. The andesite component percentages of the #1 and #4 cores are larger than those of the #3 and #5 cores. Although the pessimum condition of the aggregate component is not clear, the difference of the andesite component percentages can affect the reactivity level of ASR.

Figure 8. The gel and the reaction ring observed in P369 concrete

CONCLUSION

The reinforcing concrete columns on suspicion of ASR are investigated. The crack distribution, the reinforcing steel rupture and the aggregate visual observation are carried out. The compressive strength, the static modulus of elasticity and the accelerated test of residual expansion capacity are also conducted using the cores taken from the column. The ASR is strongly suspected by the above survey. Careful attention should be paid to the columns in the future maintenance.

REFERENCES

Hanshin Expressway Company Ltd. (2008). "Maintenance manual of alkali-silica reaction (ASR)", Japan

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