論文 Study on Characteristics of Expansive Concrete

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ABSTRACT: In past, a lot of research [1,2] was conducted to investigate the characteristics of the expansive concrete material and method of estimation of the capacity of the expansive concrete was proposed. However, these theories were not rigorously verified using actual site applications. Recently, there were scopes to verify the characteristics of expansive concrete in parallel to the actual site application. Later, further experimental studies were carried out at constant temperature to understand the effect of temperature. In this paper, these experimental results and its implications are presented.
KEYWORDS: Expansive Concrete, Temperature, Expansive Strain

1. INTRODUCTION

Shrinkage in concrete during the hardening process and drying might produce weak tensile strength or tensile cracks. To overcome such problem, expansive concrete had been developed. The use of expansive concrete can be traced back in history in the practical use of joint mortar for aqueduct of approximately 2000 years ago. However, expansive concrete in its present form was started in 1930. In Japan, expansive concrete components began to be marketed from 1966. In past, a lot of research was conducted to investigate the behavior of expansive concrete. Theoretical basis to estimate the capacity of expansion was also proposed and incorporated into Japanese Industrial Standard (JIS A 6202).

However, these results were not rigorously tested in parallel to the actual site applications. Recently, there was scope of application of expansive concrete in the walls of water reservoirs. The concrete walls made of expansive wall were attached with various types of monitoring devices to understand the long-term effect of the use of expansive concrete. In parallel, test specimens were made in accordance to the recommendation of past researchers. In these experiments, the effect of temperature was found to be very strong. Later experiment was conducted under constant temperature of 20ºC for various contents of expansive concrete. In this paper, experimental results are presented and compared with past results and recommendations.

2. STANDRAD SPECIMENS FOR ESTIMATION OF CAPACITY OF EXPANSION

Tsuji [1,2] had suggested that specimen (as shown **Fig. 1**) be used as a specimen to estimate the expansion capacity of this type of concrete and had been accepted in JIS A 6202 and

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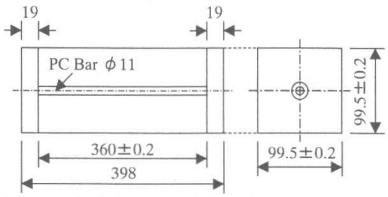
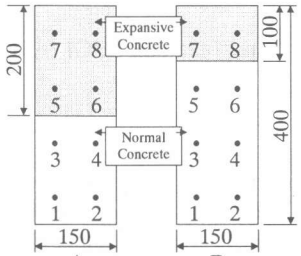


Fig. 1 JIS A 6202 Standard specimen



• D10 L=1500 Unit mm

Fig. 2 RC Specimen (by Tsuji)

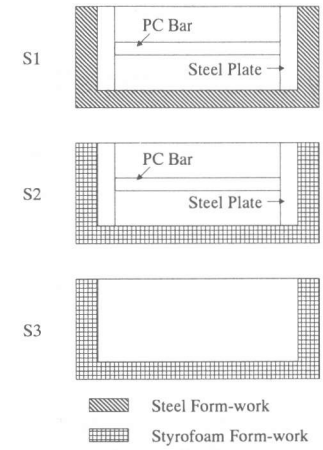


Fig. 3 Specimens used to understand expansion capacity of expansive concrete

JSCE Recommended Practice [3]. Let us henceforth call it standard specimen (or S1 of S Series). They assumed the principle of work per unit volume

$$U_s = \frac{1}{2} p_s E_p \varepsilon_{ss}^2 \tag{1}$$

where p_s is the ratio of steel area (0.96%), E_p is the elastic modulus of the PC bar. ε_{ss} is experimentally determined expansive strain using the standard specimen. Stress in RC members is then calculated using the following relation. Normal concrete is castes in bottom. After seven days, concrete with expansive material is casted to understand the restraining effect. Two types of specimens A and B as shown in **Fig. 2** were used.

$$\frac{1}{2}\varepsilon_x \sigma_c = -U_s = -\frac{1}{2} p_s E_p \varepsilon_{ss}^2 \tag{2}$$

In the standard specimen, normal steel formwork is used and removed after 24 hours. To check the effect of formwork, experiment is carried out using formwork made soft material of Styrofoam. Capacity of free expansion is also measured using standard specimen using Styrofoam formwork without PC bar. The three types of specimens(S series) are shown in Fig. 3.

3. EXPERIMENTAL RESULTS

3.1 CONSTANT TEMPERATURE CONDITIONS

Experiment was conducted at constant temperature of 20°C and future experiments would be conducted at other temperatures also. Tests were carried out using three different contents (25/30/35 Kg/m^3) of expansive material using S series specimens and A series specimen. Due to practical limitations, experiment of Specimen B was conducted for 30 Kg/mm^3 only.

Experiment was conducted in two stages both at temperature 20°C: a) Content 30 Kg/m^3 for Specimen A, Specimen B and Series S and b) Series A and Series S for Content 25 Kg/m^3 and 35 Kg/m^3. The mix proportion and characteristics of concrete are shown as **Table 1, Table 2**

Table 1 Mix Proportion of concrete

W·C (%)	S/A (%)	Air (%)	Content (kg/m³)					AE Material
			Water	Cement	Exp. Material	Fine Aggregate	Coarse Aggregate	
57	45.9	4.5	158	278	0	848	1031	2.78
57	45.9	4.5	158	253	25	847	1029	2.78
57	45.9	4.5	158	248	30	847	1029	2.78
57	45.9	4.5	158	243	35	847	1029	2.78

Table 2 Characteristics of concrete

Type	Exp. Material Content	Slump	Air
1	0 Kg/m^3	7.0 cm	2.6 %
2	30 Kg/m^3	10.5 cm	2.6 %
3	0 Kg/m^3	8.0 cm	2.7 %
4	25 Kg/m^3	11.5 cm	2.8 %
5	35 Kg/m^3	12.5 cm	2.4 %

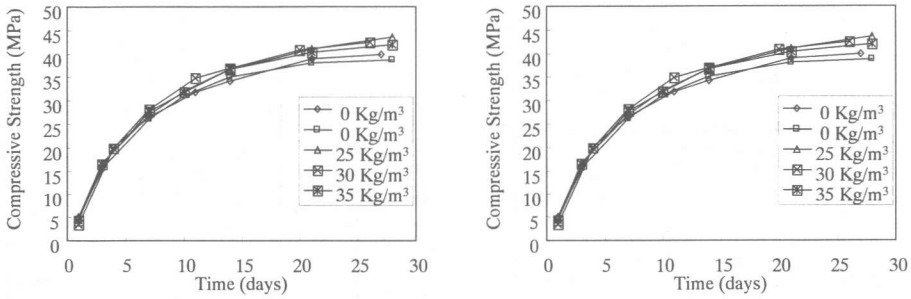
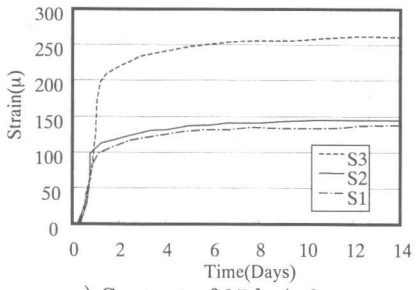


Fig. 4 Variation of compressive strength and elastic modulus at early stage

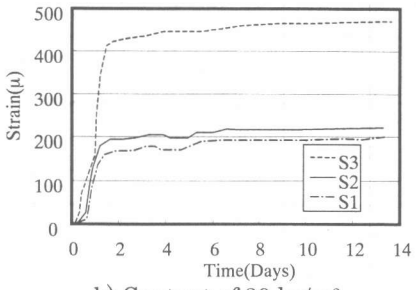
and **Fig. 4**. It can be noticed that the development of strength and modulus of elasticity of expansive concrete is similar to that of the normal concrete.

Fig. 5 shows the capacity of expansion using the S series experiment when three different content of expansive material is used. When expansion in standard specimen S1 with steel formwork is compared with S2 with soft Styrofoam formwork, it was noticed that the restraining effect of the steel formwork was not that significant in any of the three cases. The free expansion (S3) is higher than the restrained expansion of S2 for all the three cases. The capacity of expansion increases with increase in content. The expansion capacity of 25 kg/m^3 is quite low while the increase in capacity from 30 kg/m^3 to 35 kg/m^3 is relatively small. For this reason, it is planned to repeat experiment on 35 kg/m^3 to reconfirm the results.

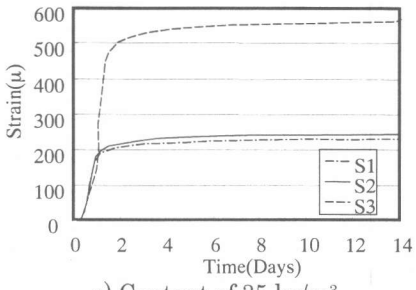
Fig. 6 and **Fig. 7** show the strain of measured from the reinforcement of specimen A and specimen B respectively. The normal concrete was caste about 7 days before the top layer of expansive concrete was casted. The experimental results show the trend of shrinkage strain. However, it can be noticed that when expansive concrete was casted, there was an increase in strain even in the normal concrete. This shows that there was adequate bond between the two concrete layers. The effect of specimen B is relatively smaller than specimen A. In all these



a) Content of 25 kg/m³

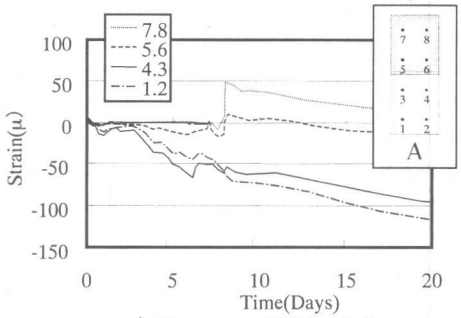


b) Content of 30 kg/m³

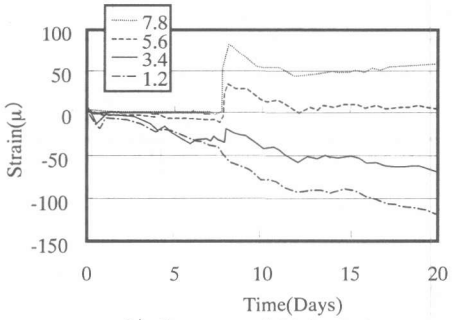


c) Content of 35 kg/m³

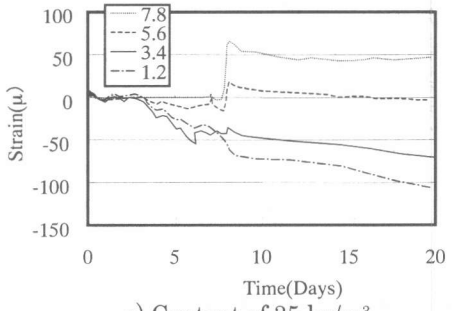
Fig. 5 Strain using S series Specimens



a) Content of 25 kg/m³



b) Content of 30 kg/m³



c) Content of 35 kg/m³

Fig. 6 Strain using A series Specimens

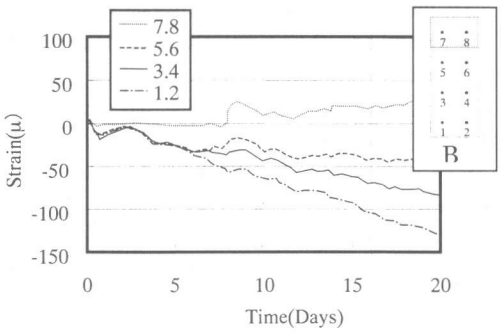


Fig. 7 Strain using B series Specimens

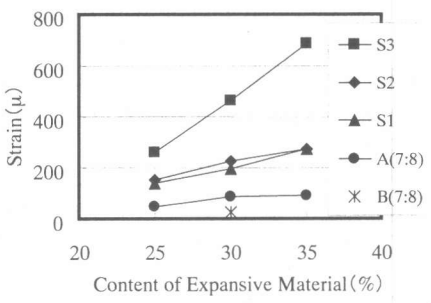


Fig. 8 Overall Maximum Strain of various specimen

experimental results it can be seen that the effect of expansion almost comes to an end within about two days as shown in **Fig. 5** (or **Fig. 6** and **Fig. 7** – Number of days –7).

Fig. 8 shows the overall maximum expansive strain obtained in all these experiments. We can see that expansive strain increase with increase in content of expansive material. The amount of free strain is considerably higher than rest of the cases with restrain. S2 and S3 series almost showed similar behavior. This implies that the restraining effect of formwork can be neglected. Strain recorded in specimen series A and B are considerably lower then Series S3. It should be noted Series A and B has similar reinforcement ratio as series S. This decrease in expansive strain is exhibiting the restraining effect of concrete below.

3.2 UNCONTROLLED TEMPERATURE CONDITIONS

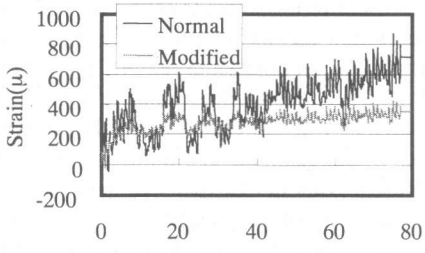


Fig. 9 Strain in Specimen S1

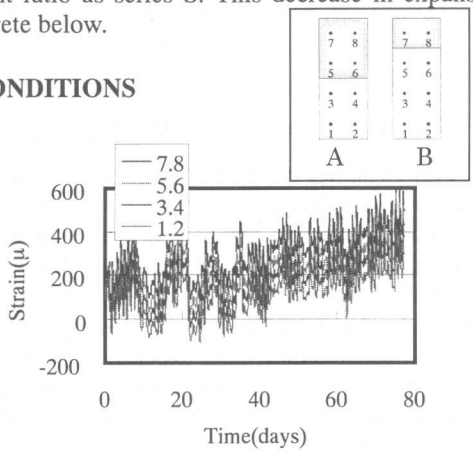
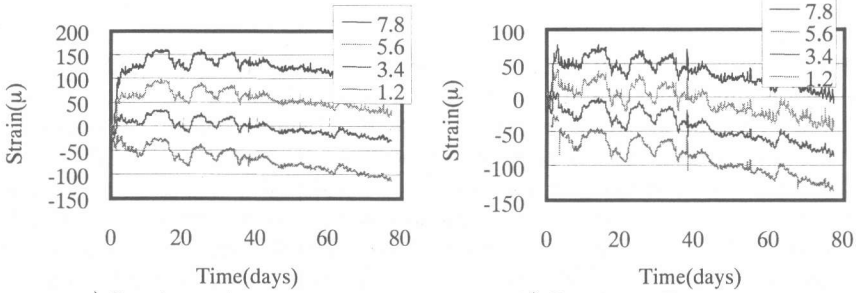


Fig. 10 Strain recorded for Specimen A



a) Specimen A b) Specimen B

Fig. 11 Modified Strain in RC specimens

Experiment was also conducted in parallel to the actual construction. Measurements were also done in the real structures and will be presented in future. It was anticipated that there would be strain due to the temperature variation. It is assumed that the steel and concrete has almost similar strain variation with temperature. Hence a dummy reinforcement was inserted inside each of the specimens so that strain of the reinforcement under zero stress is recorded to understand the effect of temperature. This strain is then subtracted to get the modified strain without the effect of temperature. **Fig. 9** shows the recorded strain of the standard specimen (S1) along with the strain after the modification. **Fig. 10** shows the strain recorded on the reinforcement of Specimen A before modification. A sample specimen cross-section showing the reinforcement numbers are also shown above the figure. It can be understood that the effect of temperature is very significant. **Fig. 11** shows the strain of specimen A and specimen B after the modification. We can see that presence of expansive material indeed induces a compressive strain in the structure, which is expected.

4 STRAIN PROFILE IN RC MEMBERS

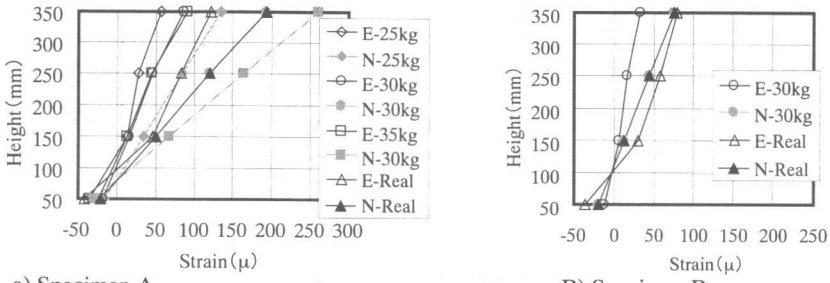


Fig. 12 Strain Profile in RC Members and Comparison with Numerical Prediction

Fig. 12 shows the strain profile as measured from the reinforcement of the RC specimens. Experimental results (marked E) show linear profile, which means good bond existed between the two concrete layers. Fig. 11 also shows the numerical predictions (marked N). The labels are chosen for easy comparison such that similar labels with and with fills are used for each set of experimental and numerical results. Numerical prediction was done as explained in **Section 2**. The ε_{ss} of **eq. 2** is taken from corresponding S3 series of experiment. The top 3 sets correspond to that of constant temperature experiment with 3 different content of expansive material and the last one shows the experiment without temperature control. It is noticed that the numerical prediction shows higher strain in comparison to the experimental results. The reasons for this are being investigated.

5. CONCLUSION

Experiment was conducted using different type of specimens as recommended by previous researchers under normal and controlled temperature. It was realized that the effect of expansion comes to an end at the end of two days and surely stabilized within seven days. Experiment to test the effect of restrain by formwork showed that there was negligible effect of the formwork. The expansion of concrete under free condition was considerably higher than the standard specimen. The expansive strain increased with increase in content of expansive material. Under controlled temperature, the RC specimens showed considerable effect of drying shrinkage. However the positive effect of applying expansive concrete can be noticed. Under uncontrolled normal temperature, the effect of temperature seems to be prominent and is taken care by measuring the temperature of a dummy reinforcement under zero stress condition.

When compared with numerical prediction, they showed slightly lower strain. However, the linear distribution of strain was noticed. This showed that little more attention is required. From these results, requirement of experiment under other temperature conditions and different reinforcement ratios are being conducted and would be presented in future presentations.

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