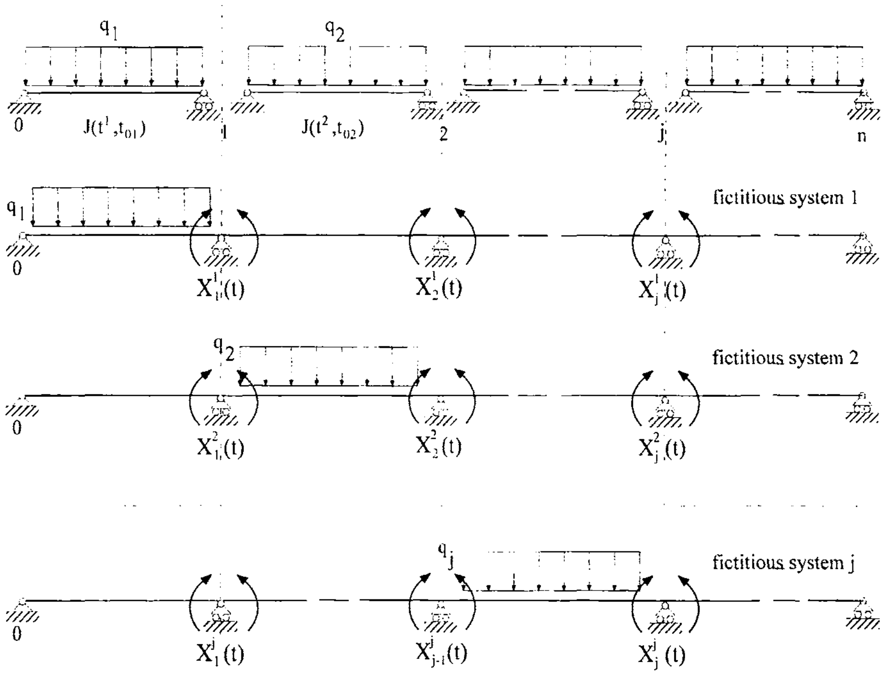


Fig 5-Heterogeneus structures with variable structural system. Application of the approximate method

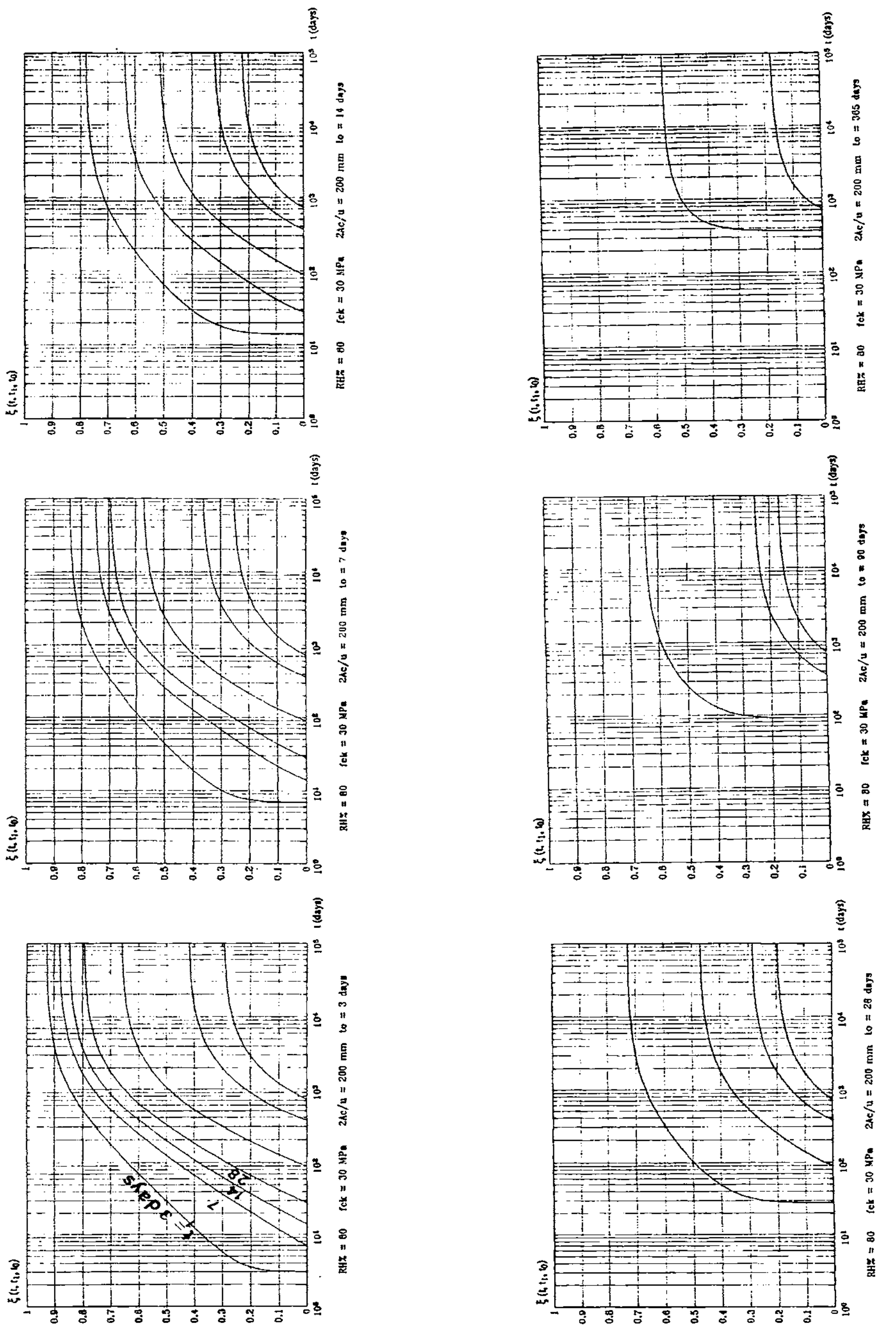
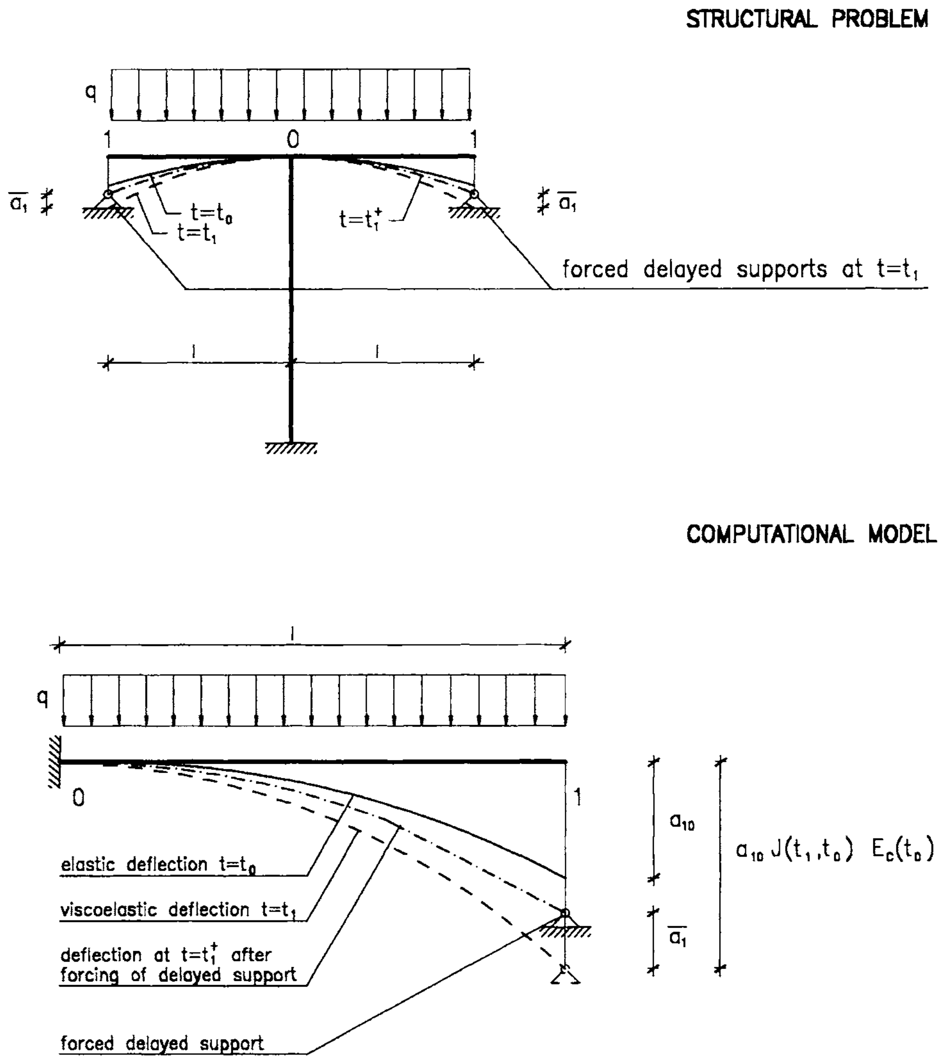


Fig 6-Redistribution function $\xi(t,t_0,t_1)$



$$X(t) = X^{el}\,\xi(t;t_0,t_1) + \bar{X}^{el}[R(t,t_1)/E_c]\cdot[E_c/E_c(t_1)]$$

Fig 7-Forced delayed supports at terminal sections of cantilever built beams. Values of parameters: t_0=28 days, t_1=90 days, RH = 80%, f_{ck} = 30 MPa, $2A_c/u$ = 200 mm.

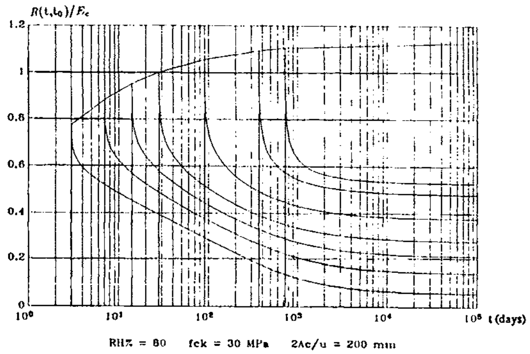


Fig 8-Non-dimensional relaxation function $R(t,t_0)/E_c$

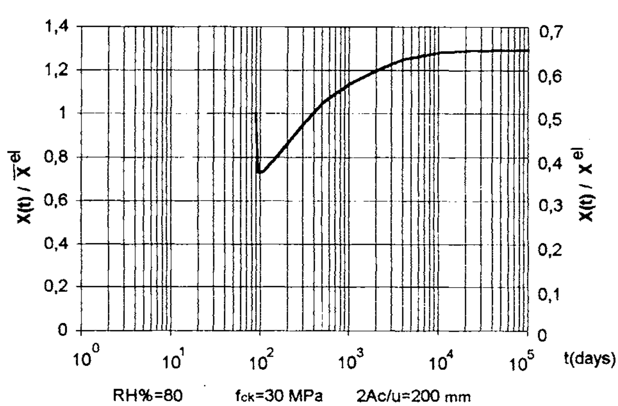


Fig. 9-History of the restraint reactions X(t) in sections

SP 194—7

Effect of Ambient Temperature and Humidity on Creep and Shrinkage of Concrete

by K. Sakata and T. Ayano

Synopsis:

The effect of ambient temperature and humidity to which concrete is exposed prior to or during loading should be taken into account; when creep and shrinkage are predicted. The purpose of this study is to clarify the effect of ambient temperature and humidity on the creep and shrinkage of concrete. In this study, we carried out creep and shrinkage tests under constant and varying histories of temperature and humidity. Creep and shrinkage tests subjected to ambient temperature and humidity were also carried out in the room where the effect of rain and wind were negligible.

The effect of temperature on shrinkage is much bigger than that of changes in humidity. The shrinkage strain on concrete subjected to increase in temperature is much bigger than that measured under constant temperature. The magnitude of creep and shrinkage is highly influenced by the difference of the season in which concrete is cast. The effect or variance of humidity on creep seems to be small. The temperature of curing water before application of load significantly influenced creep of concrete.

Keywords: casting season; creep; curing temperature; relative humidity; shrinkage; temperature; temperature history

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INTRODUCTION

The effect of ambient temperature and humidity to which concrete is exposed prior to or during loading should be taken into account when creep and shrinkage is predicted. In countries like Japan which have four seasons with significant variation in temperature, it is very important to predict the effect of ambient temperature on creep and shrinkage of concrete effectively and appropriately for design of concrete structures. The effect of environmental temperature change on creep and shrinkage of concrete is not considered in most of the prediction equations in the codes and specifications, even though it is very important. CEB-FIP/90 Model (1) may be a representative model which takes the effect of temperature on creep and shrinkage of concrete into consideration. Even in this prediction equation, however, the effect of temperature history on creep and shrinkage of concrete is not clear.

Our model for prediction of creep and shrinkage (2) was adopted by Japan Society of Civil Engineers (JSCE) as Japanese standard equations in "Standard Specification for Design and Construction of Concrete Structures" (3) published in 1996. In our model, the effect of temperature on creep and shrinkage of concrete is not taken into account.

The purpose of this study is to clarify the effects of environmental temperature and humidity changes on the creep and shrinkage of concrete. In this study, we carried out the creep and shrinkage tests under constant and varying histories of temperature and humidity. Creep and shrinkage tests were also carried out in the room where the temperature and relative humidity were not controlled and the effect of rain and wind were negligible.

We discussed the relationship between the creep and shrinkage obtained in constant temperature and constant relative humidity room and those observed where the temperature and relative humidity were not controlled. The effect of temperature when concrete was cast was also studied. We also studied the effects of temperature and humidity histories and the effect of temperature of curing water on creep and shrinkage. In addition, a coefficient that estimated the effect of temperature history on shrinkage was proposed.

EXPERIMENTS

The outline of the experiments, which were carried out on the effect of ambient temperature and humidity on creep and shrinkage of concrete, is as follows:

In this experiment, normal portland cement type-I was used. The fine aggregate was river sand (specific gravity: 2.61, water absorption: 1.61%, F.M.: 2.51), and the coarse aggregate was crushed stone (maximum size: 20 mm, specific gravity: 2.75, water absorption: 0.74%, F.M.: 6.47). The mixture proportion of concrete is shown in Table 1. The strength of the concrete at the age of 28 days was 36.9 $\pm$ 3.5 MPa. The slump was 5.1 $\pm$ 3.3 cm and the air content was 2.1 $\pm$ 0.1%.

The size of the prism specimen for measuring creep and shrinkage strain was 100x100x400 mm. The surfaces of the specimen are not sealed. The age at the start of drying was 14 days and the first application of load for creep test specimen was also 14 days. Two pairs of gauge points are put on the right and left sides. Creep and shrinkage strain were measured by the Whittemore strain meter whose minimum reading is 1/1000 mm.

The creep and shrinkage tests subjected to actual environmental conditions were carried out in a room where the effects of rain and wind were negligible. The following temperature and relative humidity feature in the room is described from records that were kept for two years. The change of temperature in a day is very small, but, over a year is very big and ranged from 5 ℃ to 35 ℃. On the other hand, the change of relative humidity in a day is very big. But, the change in one year ranged from 55% to 65% which was small. The concrete specimens which were tested without controlling temperature and relative humidity of atmosphere were cast in March (temperature: 14℃), July (temperature: 29℃), September (temperature: 25℃) and December (temperature: 8℃).

Table 2 shows the temperature histories applied to the specimens in the constant temperature and constant humidity room. The period for one interval of temperature history is 70 days. The relative humidity was held 75$\pm$5% for all temperatures.

Creep was determined by subtracting the data of unloaded specimen from that of the loaded specimen. The coefficient of thermal expansion used to isolate the shrinkage strain from experimental data is 9.6x10-6. This value was experimentally obtained by using the concrete specimen whose size and mix proportion are the same as the shrinkage test specimen.

RESULTS AND DISCUSSION

Fig. 1 shows the relationship between shrinkage strain and ambient temperature. The symbols ○ and ● denote the shrinkage strain for 28 days and 140 days, respectively. When the drying time is 28 days, the relationship between temperature and shrinkage strain is almost linear. However, when the drying time is 140 days, the shrinkage strains obtained in the room of 20℃, 27.5℃, 35℃ and 42.5℃ are almost the same. In the temperature range of 20℃ to 42.5℃, it is considered that the ultimate shrinkage strain is the same and that the development of shrinkage strain with time depends on the temperature; the higher the temperature, the faster the shrinkage strain development. Symbol ■ denotes the shrinkage strain at the age of 140 days predicted by the CEB-FIP/90 Model. This model is applicable in the range of temperature from 5℃ to 30℃ (1). In this range, the relationship between shrinkage strain and ambient temperature can be considered to be linear as shown by the broken line in Fig. 1.

Fig. 2 shows the development of the shrinkage strain with time under the constant ambient temperatures of 5℃, 20℃ and 35℃. The shrinkage strain under the temperature of 5℃ is smaller than those under other temperatures. Fig. 3 shows the development water loss from specimen with time under the constant ambient temperatures of 5℃, 20℃ and 35℃. Fig. 3 has similar trends to that shown in Fig. 2.

Fig. 4 shows the relationship between creep coefficient and ambient temperature. The symbols ○ and □ denote the creep coefficient for 28 days and 98 days, respectively. It is clear that creep coefficient is in proportion to ambient temperature irrespective of loading time. In these experiments, the environmental relative humidity is 75±5%. The water curing condition of all specimens is the same. The water temperature to cure the concrete specimen is 20 ℃.

The effect of ambient relative humidity on creep and shrinkage is a little bit different. Fig. 5 shows the relationship between shrinkage strain and ambient relative humidity. Fig. 6 shows the relationship between creep coefficient and ambient relative humidity. In these experiments, the environmental temperature is 20 ± 1 ℃. The water temperature to cure the concrete specimen is 20 ℃. As shown in these figures, the lower the ambient relative humidity, the bigger the shrinkage strain and creep coefficient.

Fig. 7 and Fig. 8 show the development of concrete shrinkage strain with time under actual environmental conditions. The data shown in these figures have been deprived of the thermal strain. Fig. 7 shows the results of concrete cast in spring and autumn. Fig. 8 shows the results of concrete cast in summer and winter. It is clear from Fig. 7 that the difference of shrinkage strain between concrete cast in spring and autumn is not big for 60 days from the start of drying. That is because the average temperature for 60 days from the start of drying is about 20℃ in both cases. After 60 days of drying, the temperature surrounding the concrete cast in spring is higher than that surrounding the concrete cast in autumn and the shrinkage strain of concrete cast in spring is bigger than that of the concrete cast in autumn. After one year of drying, however, the shrinkage strain of concrete cast in spring is almost the same as that of concrete cast in autumn. On the other hand, it is clear from Fig. 8 that the shrinkage strain of concrete cast in winter is much bigger than that of concrete cast in the summer.

Fig. 9 and Fig. 10 show the development of concrete creep coefficient with time under actual environmental conditions. Fig. 9 shows the results of concrete cast in spring and autumn. Fig. 10 shows the results of concrete cast in summer and winter. It is clear from Fig. 9 that the difference of creep coefficient between concrete cast in spring and autumn is not big. On the other hand, the creep coefficient of concrete cast in winter is much bigger than that of concrete cast in the summer as shown in Fig. 10. In other words, the moisture content in concrete when drying starts and the degree of maturity at the age of loading are very important to consider the effect ambient temperature on creep and shrinkage of concrete. Especially in these cases, the degree of maturity of concrete when drying and loading start is different, because the curing temperature is different as above-mentioned.

These data were obtained by using concrete specimen stored in the room where the ambient temperature and the relative humidity were not controlled. It means that the concrete was suffered variable temperature in curing and variable temperature and relative humidity in drying. It is evident that the creep and shrinkage strain are influenced by the season in which concrete is cast.

Fig. 11 shows the development of concrete shrinkage strain with time subjected to the temperature history of 20℃→35℃→20℃→5℃ and that of 20℃ →5℃→20℃→35℃ in the constant relative humidity room. Fig. 12 shows the development of concrete shrinkage strain with time subjected to the temperature history of 5℃→20℃→35℃→20℃ and that of 35℃→20℃→5℃→20℃. Each period of temperature history is 70 days. The temperature history 20℃→35℃→20℃→5℃, 35℃→20℃→5℃→20℃, 20℃→5℃→20℃→35℃ and 5℃→20℃→35℃→20℃ are simulated for the concrete cast in spring, summer, autumn and winter, respectively. The tendency of shrinkage strain development with time and the magnitude of shrinkage strain for one year of drying given in Fig. 11 and in Fig. 12 are very similar to those shown in Fig. 7 and Fig. 8, respectively. This means that the effect of change of relative humidity on concrete shrinkage strain is very small and that the shrinkage strain under actual conditions can be simulated in the constant relative humidity room. Furthermore, the swelling of the concrete subjected to temperature history is observed when the temperature is 5℃.

Fig. 13 shows the typical swelling phenomenon of shrinkage strain. The temperature history shown in this figure is 20℃→5℃ and a constant temperature of 5℃. Fig. 14 shows the weight loss in the second period whose temperature in the first period is 20℃. It is evident from these figures that the swelling phenomenon of concrete is accompanied with moisture absorption. It can be guessed that the humidity in the concrete dried in 20℃ for 70 days is less than the ultimate humidity in the concrete dried at 5℃. That is why concrete absorbed moisture and swelled when it was moved from 20℃ to 5℃.

Fig. 15 shows the shrinkage strain of concrete whose temperature history is 20℃→5℃→20℃ and constant temperature of 20℃. It is clear that the shrinkage strain of the swelled concrete goes over the shrinkage strain in the constant temperature of 20℃. Namely, the effect of swelling on the ultimate shrinkage strain is very small after the ambient temperature rises up once again.

Fig. 16 shows the development of shrinkage strain subjected to the temperature history of 5℃→ 20℃→ 35℃, 5℃→ 5℃→ 35℃ and 35℃→ 35℃→ 35℃. The symbols ○, □ and △ denote that the ambient temperatures are 5℃, 20℃ and 35℃, respectively. As evident from this figure, the shrinkage strain subjected to increasing temperature history is bigger than that of concrete under constant temperature. Table 3 shows the shrinkage strain subjected to various temperature histories whose temperature in the third period is 35℃. The drying time of the shrinkage strain shown in this table is 210 days. It is clear in this table that the shrinkage strain is bigger when the ambient temperature is low in the first or the second period.

Fig. 17 and Fig. 18 show the calculated shrinkage strain proposed by the authors. The symbols ○ and □ in Fig. 17 denote the shrinkage strain of concrete cast in spring and autumn, respectively. The symbols ▽ and △ in Fig. 18 denote the shrinkage strain of concrete cast in winter and summer, respectively. These data are obtained by experiment. The broken lines with the symbols ●, ■, ▼ and ▲ are the shrinkage strain under constant temperature, which is equal to the average temperature from the start of drying until the drying time when the shrinkage strain is calculated. The solid lines with the symbols ●, ■, ▼ and ▲ is obtained by multiplying the above calculated data by a coefficient which depends on the temperature history. Namely, the coefficient due to increasing temperature history such as in the concrete cast in spring and winter is 1.4. While the coefficient for temperature history of the concrete cast in autumn and summer is 1.2 and 1.0, respectively. As evident from these figures, the solid lines with the symbols ●, ■, ▼ and ▲ can simulate the tendency of experimental data well. Furthermore, if it is taken into consideration that the swelling behavior of concrete after drying of one year is not important from the engineering point of view, the calculated shrinkage strain given by the solid lines with the symbols ●, ■, ▼ and ▲ is a very reasonable value.

Fig. 19 shows the development of creep coefficient with time subjected to the temperature history of 20℃→35℃→20℃→5℃ and that of 20℃→5℃→20℃→35℃ in the constant relative humidity room. Fig. 20 shows the development of creep coefficient with time subjected to the temperature history of 5℃→20℃→35℃→20℃ and that of 35℃→20℃→5℃→20℃. The development of creep coefficient with time is different depended on the temperature history. However, the magnitude of creep coefficient at 280 days after the application of load is almost the same irrespective of temperature history. It is considered that the effect of temperature history in drying on ultimate creep coefficient is not so big.

Fig. 21 shows the creep coefficient of concrete under the alternate relative humidity change every one week. The ranges of relative humidity change are shown in Fig. 21. For example, ○ indicates the creep coefficient of concrete stored in 50% and 70% relative humidity room every one week. Fig. 22 shows the creep coefficient of concrete stored in 50% and 70% relative humidity room every 3.5 days, one week, two weeks and four weeks. The temperature of the room was