A NEW TESTING METHOD FOR CREEP BEHAVIOR OF SELF-COMPACTING CONCRETE AT EARLY AGE

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Abstract

Creep and shrinkage of concrete are known to have significant effects at early age of concrete. To be able to simulate the behavior of creep and shrinkage during this stage, accurate and actual properties of concrete should be obtained from the test. However, by performing normal creep testing, applying constant dead load to specimen, some important and necessary parameters cannot be obtained. Furthermore, creep also has significant effects on loss of prestress. Such normal test cannot clearly explain this kind of behavior well. Therefore, a new testing method for creep test is proposed. From this testing method, the modulus of elasticity of concrete (as a function of time) that is a useful parameter in estimating creep and reliable strain value can be achieved. Concrete creep and shrinkage are affected by many parameters. The factors investigated in this research were type of cement, cement content and w/c ratio, age at loading/drying, and stress/strength ratio. The tests were performed on mortar of self-compacting concrete. It was found that type of cement has slight effect on creep due to its difference in chemical compositions. For the same day of loading and same stress/strength ratio of applied load, the higher the w/c ratio the larger creep. Age at loading also has effect on creep such that the later age at loading, the smaller creep is. Stress/strength ratio has significant effect on creep. A new creep factor is proposed and it is found to give good agreement with the conventional terms, which are specific creep and creep coefficient.

Acknowledgements

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INTRODUCTION

1.1 Objective and scope of study

The early age of concrete is known to have a significant control on the overall performance of concrete structures. During this stage, concrete may be subjected to severe internal actions due to thermal and hygric gradients within concrete itself and at the same time it may be affected by the external conditions of environment and loading. All these actions may lead to different deformations within the concrete that is just building its resistance and stiffness. Important examples of harmful effects of creep are prestressed concrete member, where creep causes loss of prestress, and mass concrete structures which undergo a heating-cooling cycle due to the development of the heat of hydration and then the temperature drop to the ambient temperature. During this cycle of temperature change, creep relieves the stress due to compression induced by the initial rapid rise in temperature. Thus, on cooling, tensile stress easily develop and cracking may easily occur. Creep and shrinkage of concrete are known to have significant effect at early age of concrete. Thus, discussing the performance of this young age concrete with special attention to the shrinkage and creep and time dependent deformations is of interest by many researchers.

Self-compacting concrete is a kind of concrete that can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compacting. Nowadays, this type of concrete is widely used. Normally, in order to obtain high self-compactability, the aggregate content is limited and the powder content is high. Due to this high powder content, creep and shrinkage of self-compacting concrete are significant.

The accurate and reliable information on properties of concrete at early age is very difficult to obtain. To be able to simulate the behavior of creep and shrinkage during this stage, accurate and actual properties of concrete should be obtained from the test. However, by performing normal creep testing, applying constant dead load to specimen, some important and necessary parameters cannot be obtained. Furthermore, creep also has significant effects on loss of prestress. Such normal test cannot clearly explain this kind of behavior well.

Therefore, a new testing method for creep test is proposed. The study focuses on creep of self-compacting concrete at early age where creep is thought to be significant.

LITERATURE REVIEW

2.1 Definition of terms used

Creep is defined as a deformation occurring under, and induced by, a constant sustained stress while shrinkage is termed changes in strain due to movement of water from or to the ambient medium when no external stress is acting [1]. The common practice over many years has been consider the two phenomena to be additive. The overall increase in strain of a stressed and drying member is thus assumed to consist of shrinkage (equal in magnitude to that of a similar unstressed member) and of a change in strain due to stress, i.e. creep. This approach has a merit of simplicity and is suitable for the many practical applications where creep and shrinkage occur together. The definition is, however, not correct because creep and shrinkage are not independent phenomena to which the principle of superposition can be applied. In fact, we know that the effect of shrinkage on creep is to increase the magnitude of creep. However, it is possible to define creep as the deformation in excess of shrinkage. Such a definition makes it possible to analyze the data of previous investigators who believed creep and shrinkage to be additive. Figure 2.1.1 shows the terms and definitions involved.

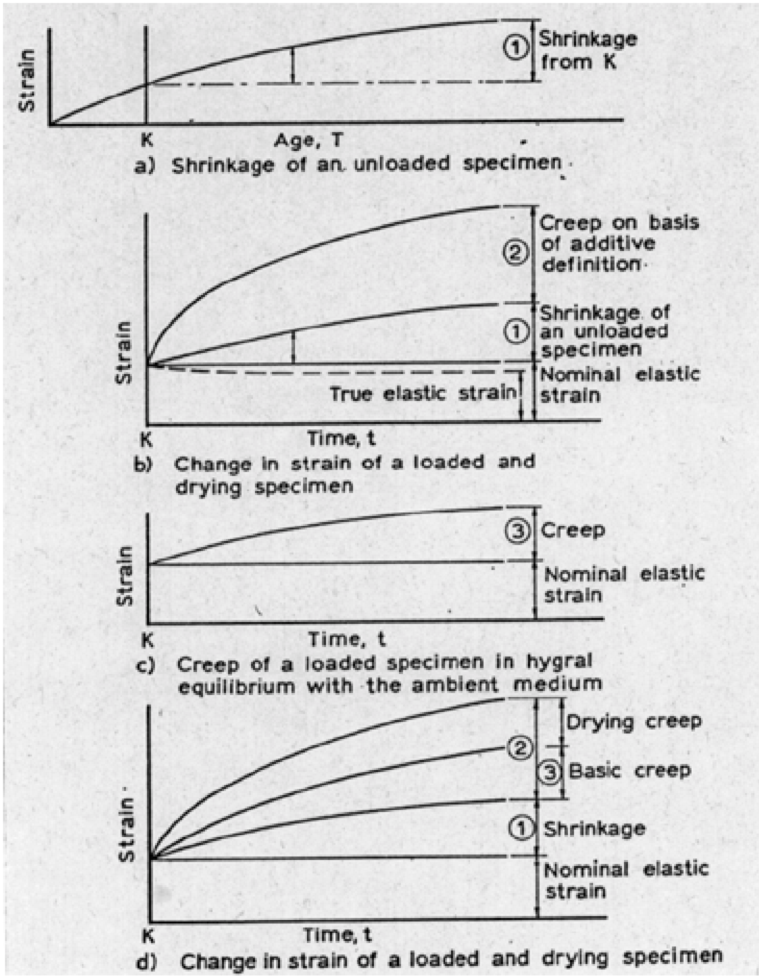
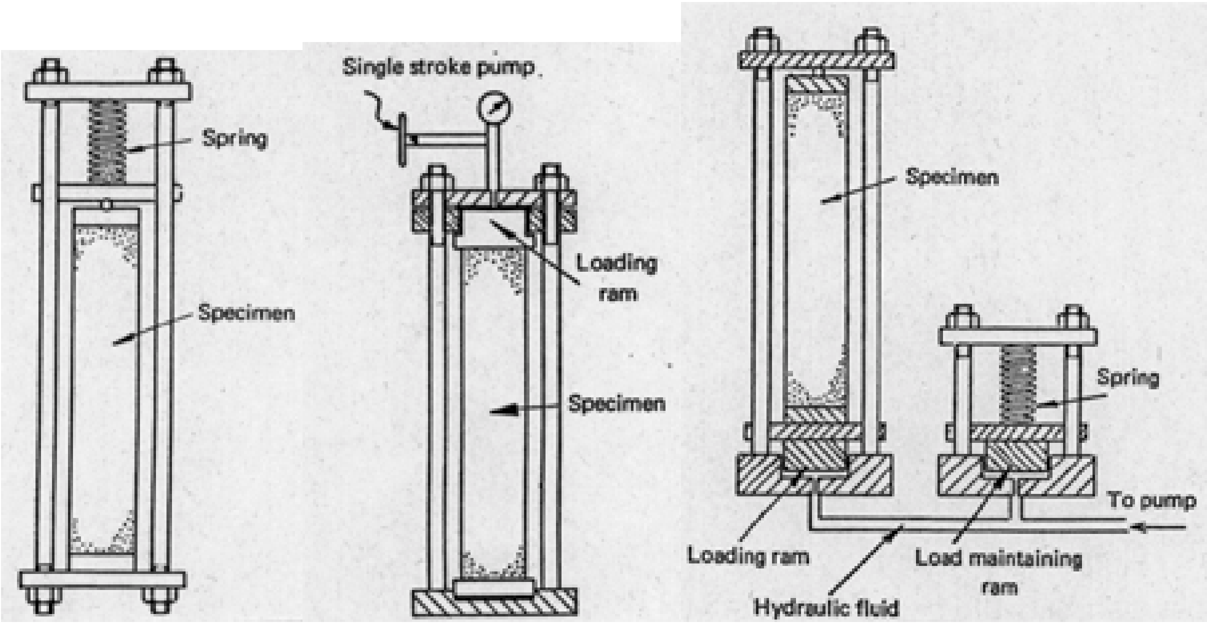


Figure 2.1.1 Definition of terms

It should be noted that, since the modulus of elasticity of concrete increases with time, the elastic strain decreases with time. Thus, creep should be reckoned as strain in excess of the elastic strain at the time considered and not in excess of the elastic strain at the time of application of load. However, this parameter cannot be obtained from conventional creep testing method.

2.2 Conventional creep test

The majority of creep tests are performed on compression specimens – prisms and cylinders – subjected to a uniaxial stress. General speaking, there are four loading methods: dead load, spring-loaded, hydraulic, and stabilized hydraulic. Figure 2.2.1 show different types of load systems for creep test as mentioned above.



(a) (b) (c)

a) a spring-loaded creep frame b) a hydraulic load creep frame c) a stabilized hydraulic load system

Figure 2.2.1 Different kinds of load systems for creep test

The dead load system is hardly ever used because for the usual size of specimens it requires large dead weight and is, therefore, cumbersome and often impractical.

The spring-loaded system, one or more heavy coil springs are held in a compressed position against a suitable frame. This procedure improves the constancy of the applied load. The main difficulties lie in the application of the proper load sufficiently rapidly so that no creep takes place.

In the hydraulic system [2], high loads can be applied more easily and can be maintained to a high degree of accuracy. This system is compact and flexible. The application of the desired load is simple and reliable. However, the maintenance of a sustained load is sensitive and often there is an unavoidable small leakage of the hydraulic fluid.

The stabilized hydraulic loading system [3,4,5] can be used for a number of specimens at the same time. This system solves the difficulties encountered in the hydraulic system.

However, the modulus of elasticity as a function of time couldn't be obtained from the above kinds of creep test. To be satisfactory, a loading system for creep tests should be able to maintain a constant stress with a minimum of maintenance and manual adjustment, and should ensure a uniform stress distribution over the cross-section of the specimen. It is also desirable that the loading system be compact to make possible operation in a room with controlled temperature and humidity.

2.3 Factors affecting creep

Cement is the most important factor in creep because the hydrated cement paste is the source of the phenomenon. The influence of cement is twofold: that arising from the physical and chemical properties of the cement, and that due to the variation in the amount of the hydrated cement paste [6]. Creep seems to be inversely proportional to the rapidly of hardening of the cement used. The more hardened the paste the more rigid it is and the lower its creep potential at a given applied stress.

The investigation [7] of the influence of the type of cement on creep lead to the establishment of an approximate stress/strength ratio rule, which states simply that, for constant mix proportions and same type of aggregate, creep is proportional to the applied stress and inversely proportional to the strength at the time of application of the load. From a wide rage of experimental results there exists a linear relationship between creep and the applied stress, except in specimens loaded a very early age: 1 to 3 days. Iriya, K., Hattori, T., and Umehara, H., [8] studied compressive creep at early age of mortar with w/c ratio of 55% by using 10x20 cm cylindrical specimen. The tests were carried out at control temperature of 30°C and relative humidity of 100%. The specimens were loaded 3 days after casting and kept applying load for 5 days and then unloaded for 3 days. Stress/strength ratio was varied by 4.4%, 20%, 29%, 49% and 60%. From the test, it can be concluded that final creep strain and stress/strength ratio has linear relationship up to stress/strength ratio of 20%. For the stress/strength ratio more than 20%, the relationship becomes exponential. The equation to estimate final creep strain as a function of stress/strength ratio is shown in Eqn. (2.3.1).

$$\left.\begin{aligned} \varepsilon_{cr} &= 109.91 e^{0.038(S/S)} && (20 \le S/S \le 60) \\ \varepsilon_{cr} &= 11.95(S/S) && (S/S \le 20) \end{aligned}\right\} \qquad (2.3.1)$$

where ε_{cr} is final creep strain (μ) and S/S is stress/strength ratio (%), respectively.

Washa and Fluck's [9] discussed the applicability of the stress/strength ratio rule such that the change in strength while the concrete is under load, and hence a change in the value of the stress/strength ratio is a factor in creep.

Lorman [10] studied the effect of w/c ratio on creep and found that creep is approximately proportional to the square of the w/c ratio. Iriya, K., Hiramoto, M., Hattori, T., and Umehara, H., [11] studied compressive creep in concrete at early age. The important factors on this creep behavior in concrete at early age are loaded age, loaded stress level, and temperature effects. A creep model which is a function of stress/strength ratio, w/c ratio, quantity of cement paste, loaded age was proposed as shown in Eqn. (2.3.2).

$$\left.\begin{aligned} &\varepsilon_{cr}(t_e, S/S, W/C, P, \tau_e) = F_{S/S}(S/S) \cdot F_{W/C}(W/C) \cdot F_P(P) \cdot F_L(\tau_e) \\ &\cdot \left\{ 28.502(1 - e^{-206.08e}) + 47.442(1 - e^{-1.747 t_e}) + 9.144 t_e \right\} \end{aligned}\right\} \qquad (2.3.2)$$

$$F_{S/S}(S/S,\tau) = \begin{cases} C(\tau_e)S/S & (0 \le S/S \le 20) \\ D(\tau_e)e^{0.035S/S} & (20 \le S/S) \end{cases} \qquad (2.3.3)$$

$C(\tau_e), D(\tau_e)$: loading age coefficients

$$C(\tau_e) = 0.007(\tau_e - 1) + 0.036 \qquad (1 \le \tau_e \le 3)$$
$$C(\tau_e) = 0.001(\tau_e - 3) + 0.050 \qquad (3 \le \tau_e \le 5)$$
$$C(\tau_e) = 0.053 \qquad (5 \le \tau_e)$$
$$D(\tau_e) = 0.069(\tau_e - 1) + 0.359 \qquad (1 \le \tau_e \le 3)$$
$$D(\tau_e) = 0.014(\tau_e - 3) + 0.499 \qquad (3 \le \tau_e \le 5)$$
$$D(\tau_e) = 0.524 \qquad (5 \le \tau_e)$$

$$F_{W/C}(W/C) = 1.69(W/C)^{-2.43} \qquad (2.3.4)$$

$$F_P(P) = 1.58\ln(P) - 7.85 \qquad (2.3.5)$$

$$F_L(\tau_e) = 1.082(1 - e^{-0.86\tau_e}) \qquad (2.3.6)$$

where ε_{cr} is final creep strain (x10^{-6}), S/S is stress/strength ratio (%), τ_e is loading age (days), t_e is time duration of loading (days), W/C is water to cement ratio (%), and P is quantity of cement paste (cm^3/ m^3), respectively.

Moreover, creep is also affected by relative humidity and the temperature of the surrounding environment, the aggregate content, and the use of admixture.

Chapter 3

EXPERIMENTAL OUTLINE

3.1 Mix proportions of mortar

In this research, normal Portland cement and low heat cement were used. Fine aggregates were river sand and crushed sand. Table 3.1.1. shows specific gravity of materials used in this research. Properties of mortar are shown in Table 3.1.2. Mix design and mixing procedure of mortar in self-compacting concrete were done as suggested by Ouchi, M., Hibino, M., Ozawa, K. and Okamura, H. [12] and Ouchi, M. and Edamatsu, Y. [13], respectively. Figure 3.1.1. shows the mixing procedure of mortar in self-compacting concrete. Firstly, trial mixes of self-compacting concrete were performed. From the properties of fine and coarse aggregates, the amount of coarse aggregate was selected to be 53% of solid volume and the amount of fine aggregate was chosen as 45% of mortar volume. Fine aggregate consisted of river sand and crushed sand and the ratio was selected as 50% by volume. At the fixed aggregates content, the superplasticizer dosage and water to powder ratio by volume are to be varied in order to achieve proper deformability and viscosity of mortar. From the trial mixes, the appropriate water to powder ratio was 0.94. The mix proportion of mortar was then determined from the mix proportion of concrete by taking out the amount of coarse aggregate. This is aimed to further study the effect of coarse aggregate on creep of self-compacting concrete. The water to cement ratio was varied by varying the percent replacement of limestone powder.

Table 3.1.1 Specific gravity of materials

Material	Specific Gravity
Ordinary Portland Cement	3.15
Low Heat Cement	3.27
Limestone	2.70
Sea Sand	2.60
Crushed Sand	2.58

Table 3.1.2 Properties of mortar

No.	Type of cement	W/P (by volume)	W/C (by weight)	% Replacement of limestone	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	SP (% by weight of powder)	1-day f'c (kgf/cm^2)	3-day f'c (kgf/cm^2)
1	LH	0.94	0.3	0	615	179	783	1.4	110	295
2	OPC	0.94	0.3	0	597	179	783	1.6	288	706
3	OPC	0.94	0.5	36.7	358	179	783	1.1	148	410
4	OPC	0.94	0.7	53.6	256	179	783	0.9	79	211

**(OPC = Ordinary Portland Cement and LC = Low Heat Cement)
*Two types of sands were used: sea sand and crushed sand, with ratio 50:50 by volume

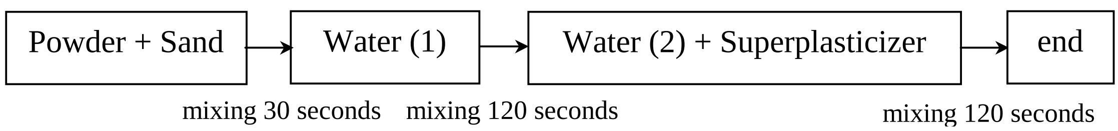


Figure 3.1.1 Mixing procedure of mortar in self-compacting concrete

The specimens were cast in control room at temperature of 20°C and were demolded 16 hours later after the setting time. Specimens were kept sealed until the day of loading or drying, i.e. 24 and 72 hrs after casting in this research. Three 10x20cm cylindrical specimens were tested at the loading age to obtain compressive strength. Creep specimens were loaded at stress/strength ratio of 20%, 30%, 40% and 60%.

3.2 Geometry of specimens

This research is mainly concerned with young age concrete where the effect of shrinkage and creep is significant. Therefore, two types of specimens were analyzed. The first group is subjected to drying only to study the factors affecting the shrinkage behavior and the other is subjected to simultaneous drying and loading to study the drying creep behavior. Figure 3.2.1 shows the specimen used for creep and drying shrinkage test. The test specimen was chosen as prism-shaped specimen of size 10x10x40cm. The creep specimen will be subjected to loading by applying pre-stress method. In order to do so, steel sheet was inserted at the center of the specimen before casting for both creep and drying shrinkage specimen so that they are subjected to the same condition except that creep specimen will be subjected to loading while drying shrinkage specimen will not. Figure 3.2.2 shows gauge point and the position of the gauge points on the specimen. The gauge points are put at the centerline of all four surfaces at 10 cm equal interval. Gauge point type was selected instead of strain gauge because at early age strain gauges are not attached well to the specimen and as a result the values of strain obtained are not reliable.

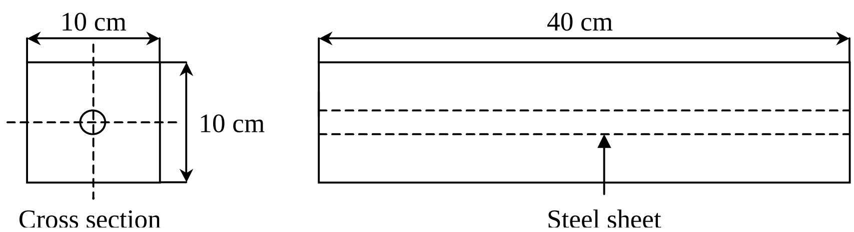


Figure 3.2.1 Geometry of specimens for creep and drying shrinkage test

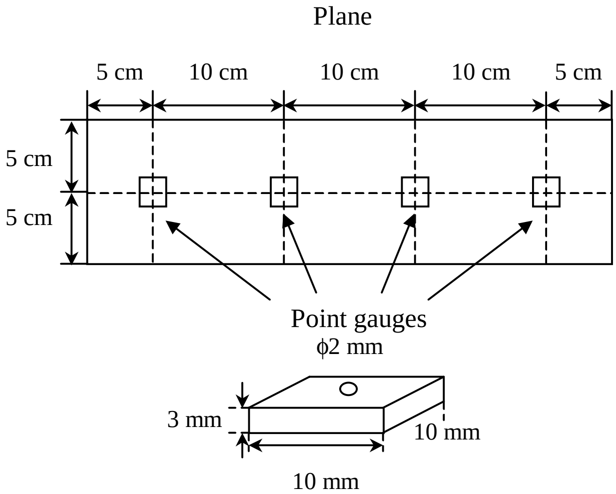


Figure 3.2.2 Point gauges and their positions on the test specimen

3.3 Setup method

Figure 3.3.1 shows the setup method of the creep test. The tension steel attached with two strain gauges was inserted into the creep specimen through a provided steel sheet. These strain gauges were used to monitor if the applied stress was constant or not. The load cannot be used to assured constant stress because for a while specimen undergo creep and increase in strain. Load applied should be also increased to keep applying constant stress but we cannot determine the magnitude. Two steel plates and nuts were placed on both sides of the specimen and the jack and load cell placed on one side of the specimen.

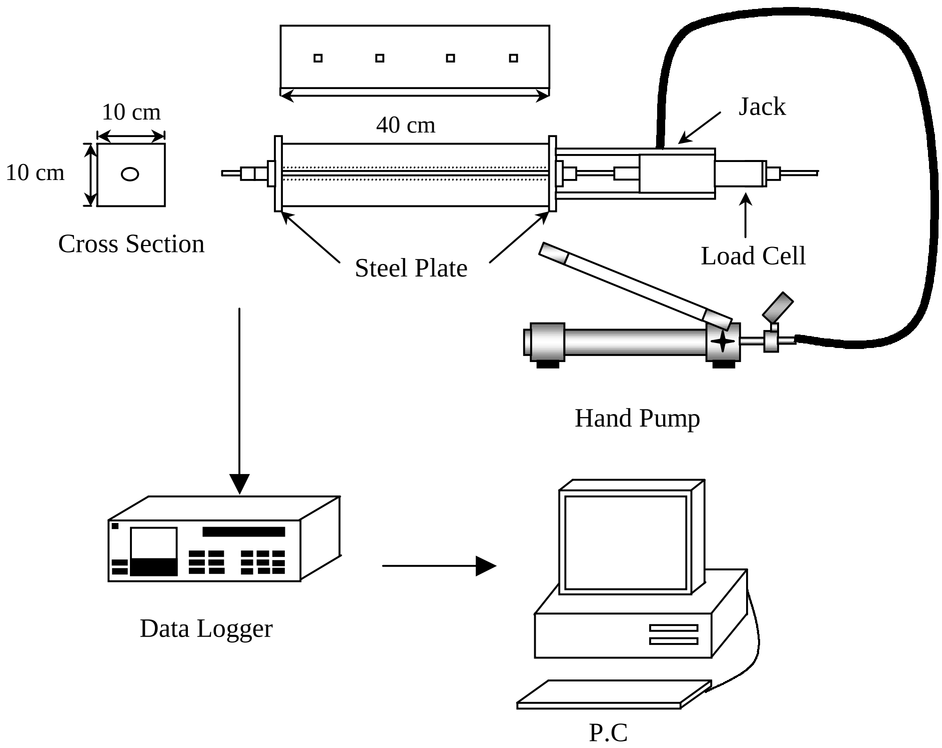


Figure 3.3.1 Setup method for creep test

Load was applied to the specimen by using a hand pump. The value of applied load and strain of steel were transferred from data logger to computer. Load should be applied very rapid because if the load is applied slowly some creep takes place. As a result of rapid loading, the elastic strain can be determined from measurement of the change in strain under a fluctuating stress of small magnitude. [14] The creep and drying shrinkage specimens were tested at control temperature of 20°C and 50% relative humidity.

3.4 Measuring method for strain

In this research, the shrinkage and creep strains were recorded for 7 days from the starting of the test. From the fact that, the change of shrinkage and creep strains is significant at early day of test, strains were measured every 6 hours for the first 3 days and every 12 hours for the later 4 days. To determine the shrinkage strain, the length change was measured using a contact gauge. Figure 4 shows the stages of creep test. The applied stress in this research was selected as 30% of its compressive strength at the testing day.

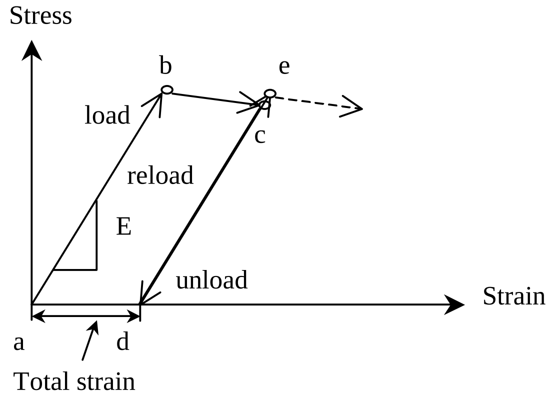


Figure 3.4.1 Stages of creep test

The initial length was measured (point a). The specimen was first loaded from zero stress to a certain compressive stress level (a-b) and the applied stress was maintained. Next time of strain record (point c in Figure 3.4.1), the specimen was unloaded to zero stress (c-d). Again the specimen was reloaded (d-e). The processes of unload and reload was performed alternately and the length change at each stage was measured (point b, c, d, e,...). The strain at each point is determined as ratio of length changes over initial length. The strain of creep specimen at each elapse time is determined from the difference of strain at zero stress stage. Since the applied stress is only 30% of the strength, the modulus of elasticity is simply calculated as the difference of stress divided by difference of strain on the reloading path.

ANALYSIS AND VERIFICATIONS

4.1 Analytical methods

From the test, we can calculate creep strain by subtracting shrinkage strain and elastic strain from the total strain of creep specimen measured at zero stress as shown in Eqn. (4.1.1).

$$\varepsilon_c = \varepsilon_t - \varepsilon_{sh} - \varepsilon_e \quad (4.1.1)$$

where ε_c is creep strain, ε_t is total strain, ε_{sh} is shrinkage strain, and ε_e is elastic strain, respectively.

By plotting shrinkage strain and creep strain against log (t+1), where t is the time when drying and loading start, a linear relationship can be obtained as illustrated in Figure 4.1.1 and 4.1.2, respectively.

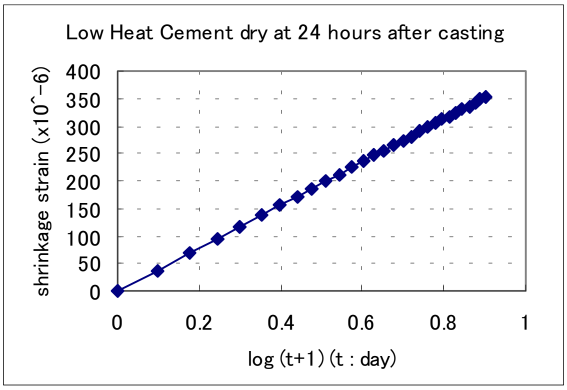


Figure 4.1.1 Shrinkage strain versus time (log scale)

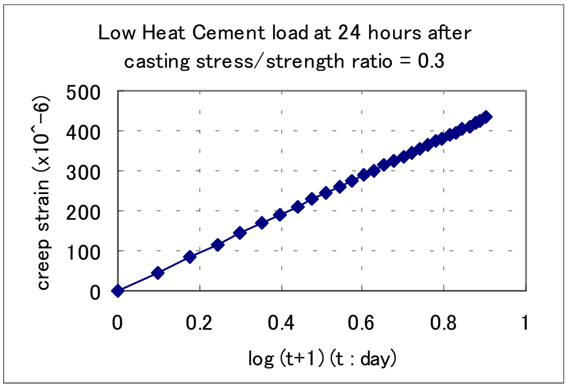


Figure 4.1.2 Creep strain versus time (log scale)

Moreover, from this kind of test the modulus of elasticity and elastic strain as a function of time can be obtained. Figure 4.1.3 and 4.1.4 shows the modulus of elasticity and elastic strain plotted against log (t+1), where t is the time when loading starts.

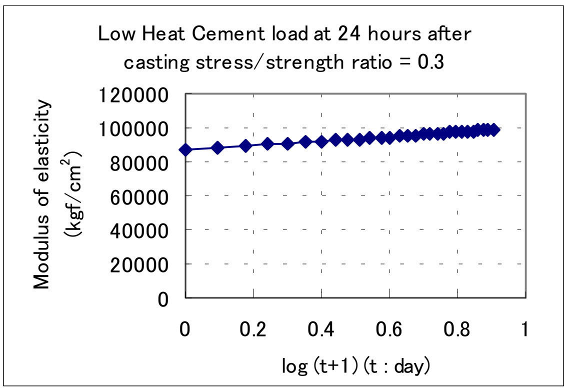


Figure 4.1.3 Modulus of elasticity versus time (log scale)

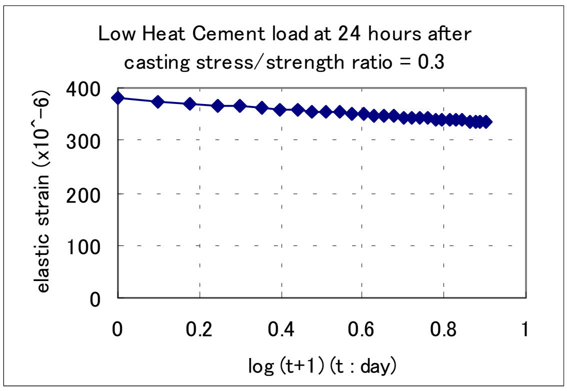


Figure 4.1.4 Elastic strain versus time (log scale)

To compare creep, it is common to express as specific creep or creep coefficient. Specific creep is defined by creep strain per applied stress Eqn. (4.1.2) and creep coefficient is defined as creep strain per initial elastic strain Eqn. (4.1.3).

$$J = \frac{\varepsilon_c}{\sigma} \tag{4.1.2}$$

where J is specific creep $(kgf/cm^2)^{-1}$, ε_c is creep strain and σ is applied stress (kgf/cm^2), respectively.

$$\Phi_c = \frac{\varepsilon_c}{\varepsilon_{ie}} \tag{4.1.3}$$

where Φ_c is creep coefficient, ε_c is creep strain and ε_{ie} is initial elastic strain, respectively.

Figure 4.1.5, 4.1.6 and 4.1.7 show the expression of specific creep, creep coefficient, and creep factor of the test result against log (t+1), where t is the time when loading starts.

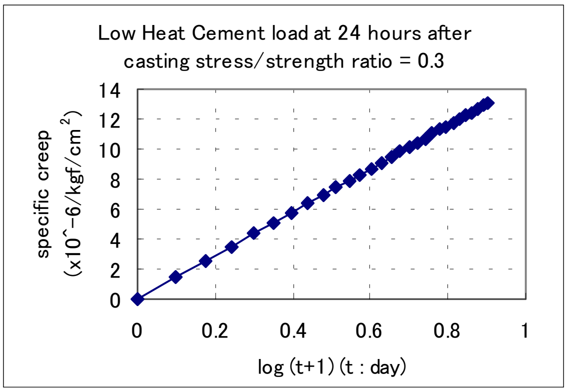


Figure 4.1.5 Specific creep versus time (log scale)

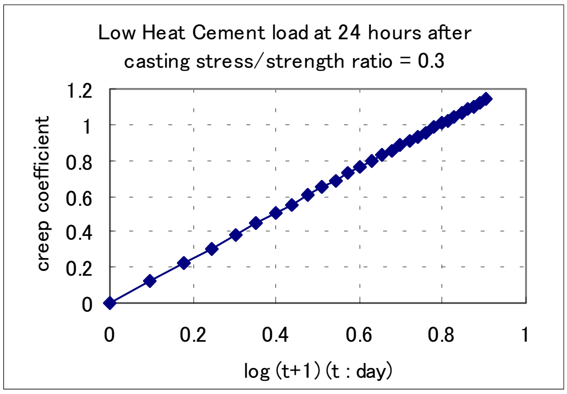


Figure 4.1.6 Creep Coefficient versus time (log scale)

However, those expressions are not quite correct since concrete undergoes strength development simultaneously. Therefore, it had better express creep as creep strain per elastic strain as a function of time. This parameter can only obtain from this newly introducing simple test. Figure 4.1.7 shows the graph of creep strain and modulus of elasticity as a function of time plotted against log (t+1), where t is the time when loading starts.

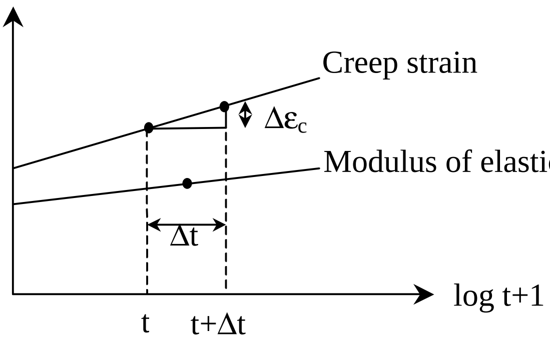


Figure 4.1.7Creep strain and modulus of elasticity versus time (log scale)

Thus, a new creep factor as a function of time can be expressed as Eqn. (4.1.4)

$$\phi_c(t) = \sum \frac{\varepsilon_c(t+\Delta t) - \varepsilon_c(t)}{\left[\dfrac{\varepsilon_e(t+\Delta t) + \varepsilon_e(t)}{2}\right]} \tag{4.1.4}$$

where $\varepsilon_c(t+\Delta t)$ - $\varepsilon_c(t)$ is difference of creep strain and $[\varepsilon_e(t+\Delta t) + \varepsilon_e(t)]/2$ is the average elastic strain which can be calculated from modulus of elasticity at time $(t+\Delta t)$ and t, respectively.

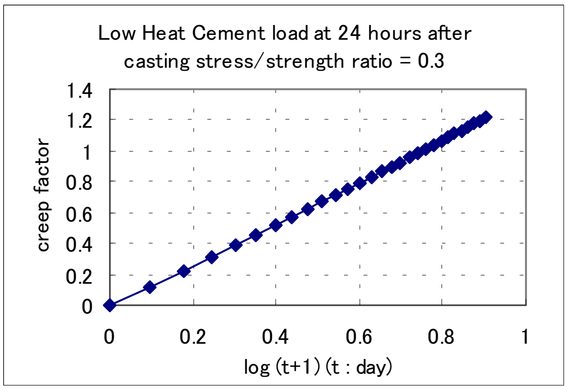


Figure 4.1.8 Creep factor versus time (log scale)

Figure 4.1.8 demonstrates the creep factor as the summation of difference of creep strain per average elastic strain from test result is plotted against log (t+1), where t is the time after start loading.

4.2 Compressive strength and Young's modulus

Figure 4.2.1 and 4.2.2 show the variation of compressive strength and Young's modulus of mortar made with different limestone powder replacement. The replacement of Ordinary Portland cement by limestone powder reduces the strength both at 1-day and 3-day age.

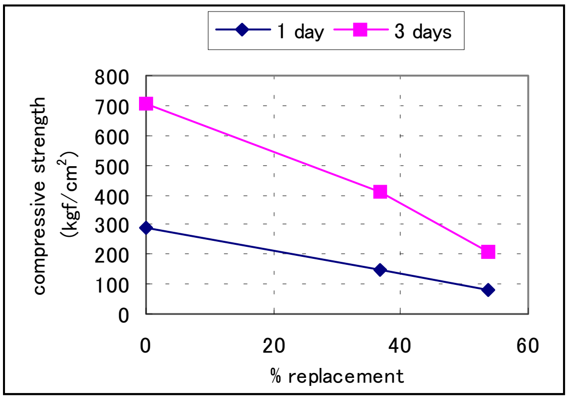


Figure 4.2.1 Compressive strength

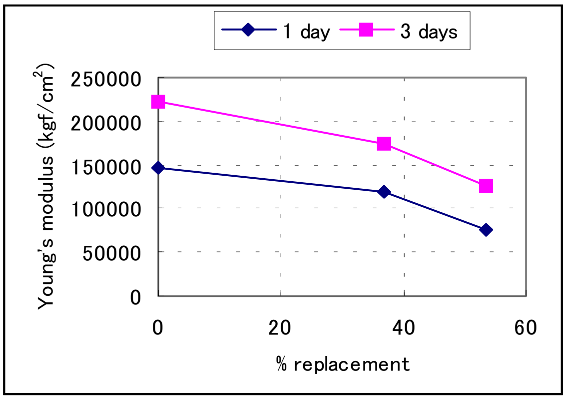


Figure 4.2.2 Young's modulus

It is clear that Young's modulus is directly proportional to the compressive strength as shown in Figure 4.2.3.

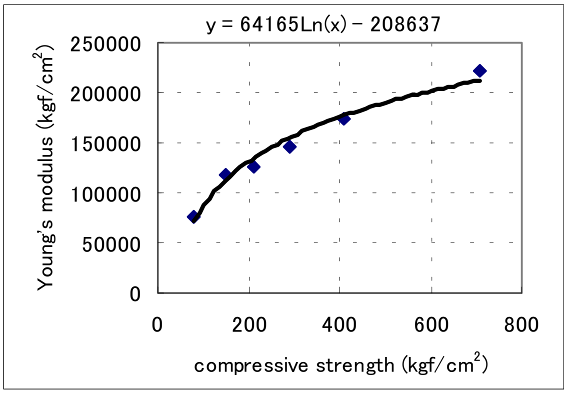


Figure 4.2.3 Relationship between compressive strength and Young's modulus

From the test results, the relationship between compressive strength and Young's modulus can be expressed as Eqn. (4.2.1).

$$E = (64165 \ln f_c') - 208637 \qquad (\text{kgf/cm}^2) \qquad (4.2.1)$$

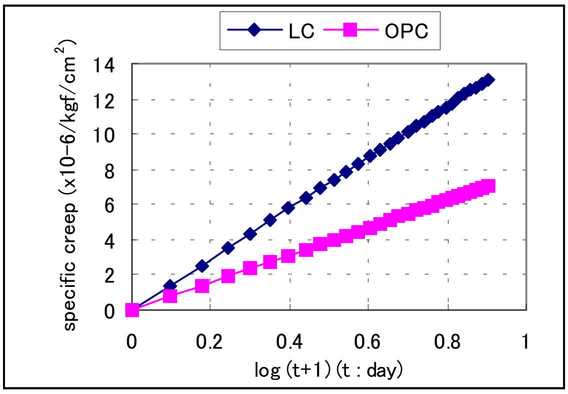
4.3 Effect of type of cement

Table 4.3.1 Mix proportion and environmental condition for the analysis

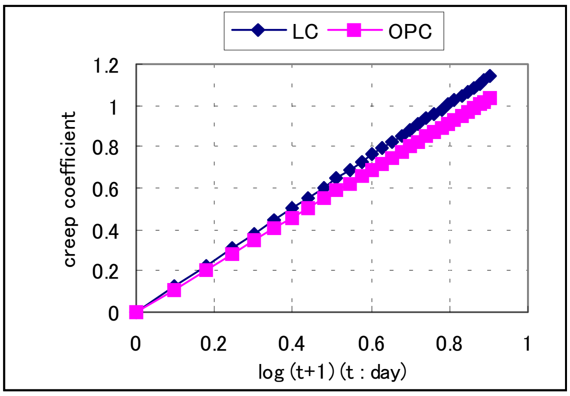
No.	w/c	Cement type	Ambient conditions
case 1	30	LC	RH = 50% after 1 day
case 2	30	OPC	RH = 50% after 1 day

(*LC = Low Heat Cement, OPC = Ordinary Portland Cement)

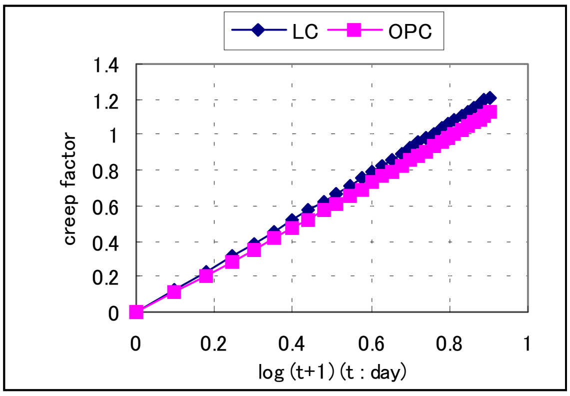
In this observation, only type of cement is different while the stress/strength ratio is 30% in both cases. From the test results, as shown in Figure 4.3.1 (a), (b) and (c), mortar made with low heat cement exhibits higher creep than mortar made with ordinary Portland cement. The differences result from their differences in chemical composition of cement.



(a) Specific creep



(b) Creep coefficient



(c) Creep factor

Figure 4.3.1 Effect of type of cement

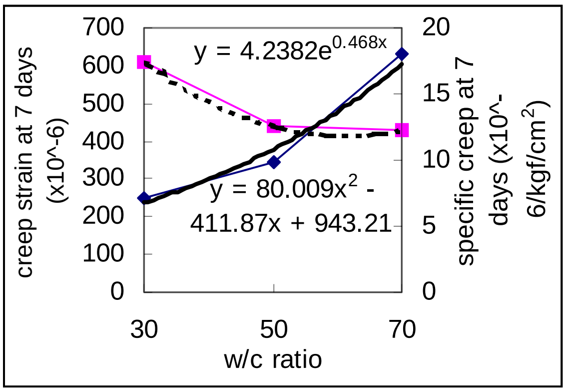
4.4 Effect of w/c ratio

Table 4.4.1 Mix proportion and environmental condition for the analysis

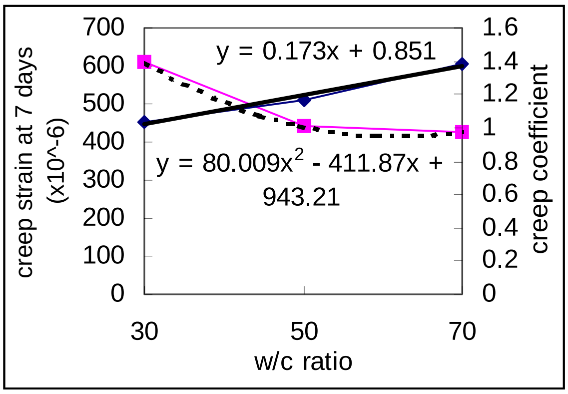
No.	w/c	Cement type	Ambient conditions
case 2	30	OPC	RH = 50% after 1 day
case 3	50	OPC	RH = 50% after 1 day
case 4	70	OPC	RH = 50% after 1 day

(*OPC = Ordinary Portland Cement)

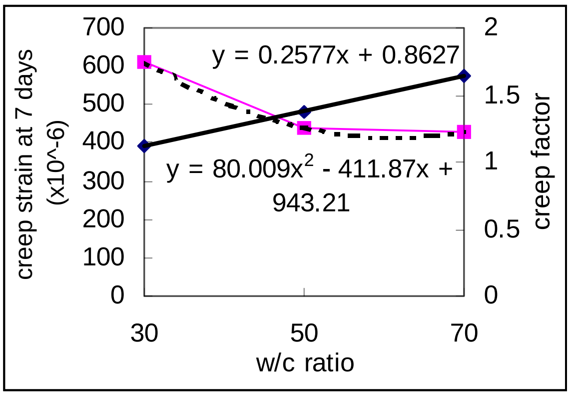
In this case, the w/c ratio is varied by varying percent replacement of Ordinary Portland Cement by limestone powder. From the test results, it is clear that as w/c ratio increases, creep also increases. This due to the fact that, as w/c ratio increases, the strength of mortar is reduced thus results in higher creep. Figure 4.4.1 (a), (b) and (c) show graph plotted between creep strain, specific creep, creep coefficient, and creep factor at 7 days of different w/c ratio.



(a) Specific creep



(b) Creep coefficient



(c) Creep factor

Figure 4.4.1 Effect of w/c ratio

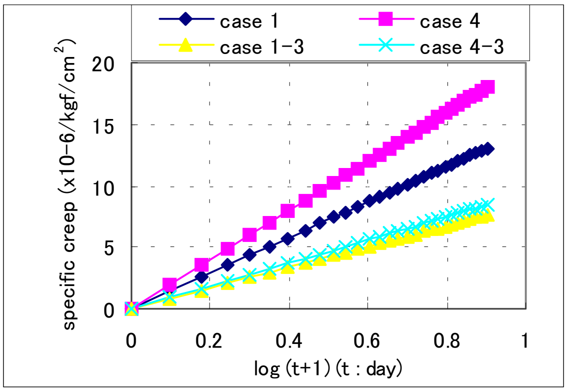
4.5 Effect of age at loading

Table 4.5.1 Mix proportion and environmental condition for the analysis

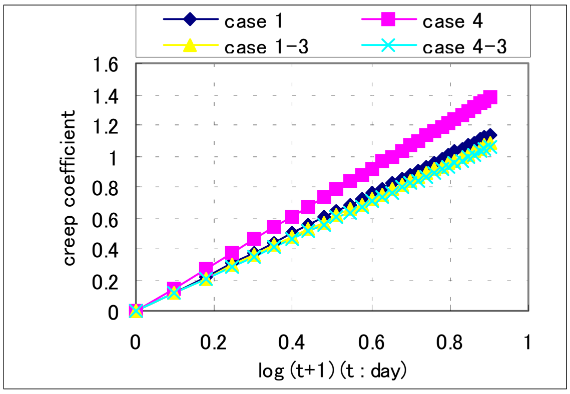
No.	w/c	Cement type	Ambient conditions
case 1	30	LC	RH = 50% after 1 day
case 1-3	30	LC	RH = 50% after 3 day
case 4	70	OPC	RH = 50% after 1 day
case 4-3	70	OPC	RH = 50% after 3 day

(*LC = Low Heat Cement, OPC = Ordinary Portland Cement)

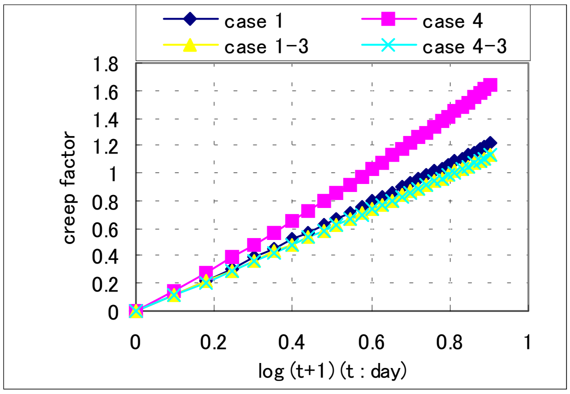
In this analysis, the tested specimens are studied under sealed conditions and the stress/strength ratio is kept constant so that just the effect of age development can be assessed. Figure 4.5.1 (a), (b) and (c) show the analytical results for this case. It can be observed that the smaller creep, the larger the value of the age at loading is. This can be explained as mortar loaded at different ages undergoes different growth in strength with creep being smaller the greater the value of strength, which is the case in older age [15].



(a) Specific creep



(b) Creep coefficient



(c) Creep factor

Figure 4.5.1 Effect of age at loading

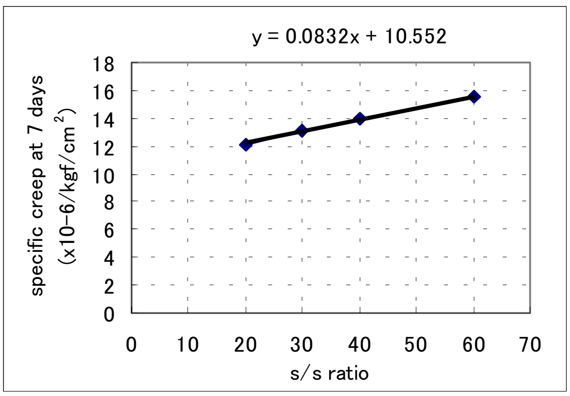
4.6 Effect of stress/strength ratio

Table 4.6.1 Mix proportion and environmental condition for the analysis

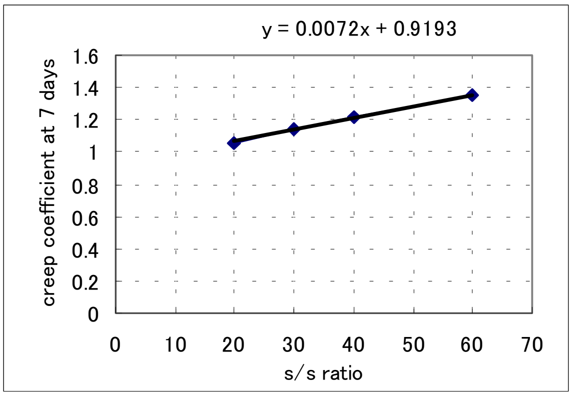
No.	s/s ratio	Cement type	Ambient conditions
case 1-20	20	LC	RH = 50% after 1 day
case 1	30	LC	RH = 50% after 1 day
case 1-40	40	LC	RH = 50% after 1 day
case 1-60	60	LC	RH = 50% after 1 day

(*LC = Low Heat Cement)

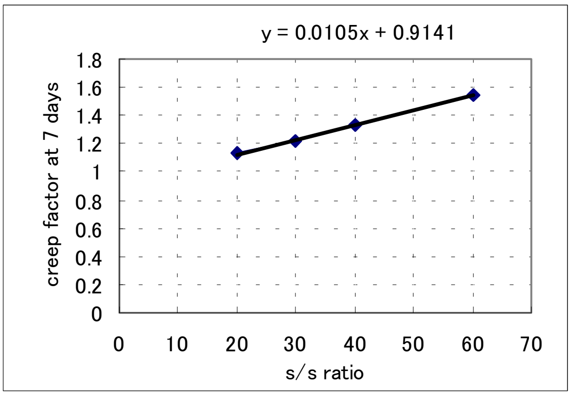
In this case, the stress/strength ratio is varied from 20%, 30%, 40% and 60%. It is evident that creep is significantly affected by stress/strength ratio. The higher stress/strength ratio, the larger creep. Figure 4.6.1 (a), (b) and (c) represent the effect of stress/strength ratio on creep.



(a) Specific creep



(b) Creep coefficient



(c) Creep factor

Figure 4.6.1 Effect of stress/strength ratio

From the experimental results, creep depends on type of cement, w/c ratio, age at loading, and stress/strength ratio, or the other word, the strength at the time of the application of load and the applied load. Due to lack of data, it cannot be definitely conclude that creep of self-compacting concrete which contains high volume of cement exhibits high creep. Due to the fact that self-compacting concrete gains high strength even at early age, creep can be less. The effect of cement content is found to be more pronounced on shrinkage. However, shrinkage and creep are not independent phenomena. In fact, effect of shrinkage is to increase the magnitude of creep. In addition, it was found that high replacement of cement by limestone powder results in lower compressive strength, thus creep is larger. It is suggested that limestone powder can act as filler in concrete. Filler is defined as a very finely-ground material, of about the same fineness as Portland cement, which, owing to its physical properties, has a beneficial effect on some properties of concrete such as workability, density, permeability, capillarity, and bleeding or cracking tendency. Non-reactive limestone filler is not considered as an integral part of cement but rather as a replacement for a certain proportion of aggregate. The filler effect is expected primarily through the reduction of the paste porosity. It is of interest to study the filler effect of small replacement of limestone powder, about 5, 10 and 15%, in self-compacting concrete. It may be possible that the strength of self-compacting concrete made with small replacement of limestone powder is not much different from strength of self-compacting concrete made with no replacement, while the reduction of the paste porosity can be enhanced and thus creep is reduced.

Moreover, some difficulties were encountered and result in errors of data. This is very important because it is an interactive test where one factor affects the other. For example, for the case of start drying at 24 hours after casting, it is found that the higher the cement content the greater the shrinkage strain. However, when drying starts at 72 hours, ordinary Portland cement gives the lowest shrinkage strain. There are two possible reasons to explain this result. The first reason is that shrinkage itself is small. Second, it is possible that there occurs surface cracking due to the great difference between pore water pressure of the inner core of specimen and the outer surface, which is exposed to drying at 20°C and relative humidity of 50%. For the corresponding creep specimen, crack may not be observed due to the applying stress. As mention earlier, if shrinkage strain is wrong, creep strain would be also wrong due to the adoption of superposition method. Moreover, it is very hard to apply load very fast and at the same time get the required stress. This also results in some errors of the value of the modulus of elasticity as a function of time and elastic strain. Errors due to measuring contact gauge are also found to be significant. It is also important to keep constant stress all the time. This kind of test requires skill work and good control.

CONCLUSIONS

Based on the test results of mortar of self-compacting concrete, it was found that:

1. Creep depends on type of cement, w/c ratio, age at loading, and stress/strength ratio, or the other word, the strength at the time of the application of load and the applied load.

2. Replacement of cement by limestone powder about 36.7-53.6% results in decrease in strength, and thus increases creep at early age.

3. The new testing method proposed is beneficial in determining modulus of elasticity as a function of time. However, good results are difficult to obtain because it is an interactive test and requires skill.

4. The new creep factor proposed is found to give good agreement with the conventional terms, which are specific creep and creep coefficient.

RECOMMENDATIONS FOR FURTHER STUDY

1. Improvement on the testing method in order to reduce errors and obtain good results.

2. To study creep behavior of self-compacting concrete with small replacement of limestone powder.

3. To study creep behavior of self-compacting concrete blended with pozzolanic materials, for example, fly ash, slag, and silica fume.

4. To study the effect of relative humidity, temperature, superplasticizer on creep of self-compacting concrete at early age by performing the new testing method.

5. To study the differences in behavior of creep of mortar and concrete of self-compacting concrete in order to simulate a model which can predict creep of concrete from mortar test.

6. To study the differences in behavior of creep of normal concrete, high strength concrete, and self-compacting concrete by performing the new testing method.

7. To study tensile creep of self-compacting concrete.

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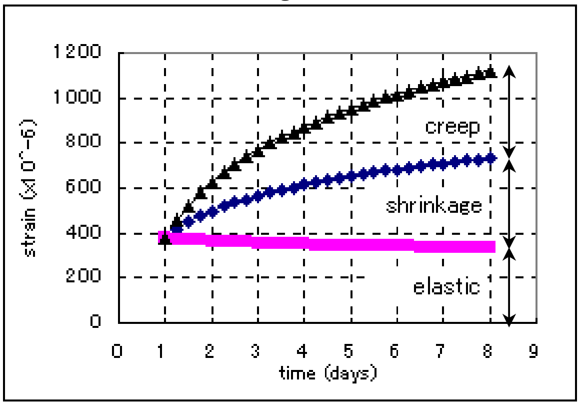
14. Neville, A. M., *Creep of Concrete: Plain, Reinforced, and Prestressed*, North-Holland Publishing Company, Amsterdam, 1970, pp. 17.

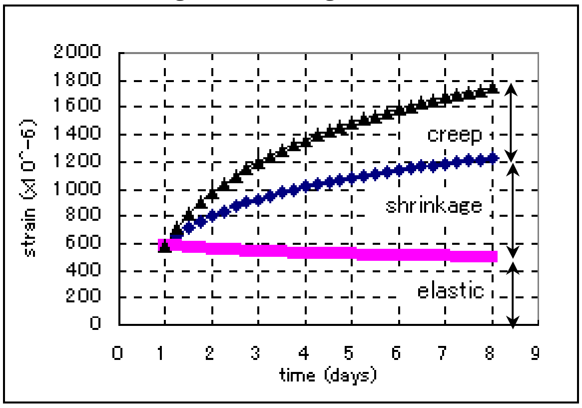
15. Neville, A. M., *Creep of Concrete: Plain, Reinforced, and Prestressed*, North-Holland Publishing Company, Amsterdam, 1970.

Appendix A Total strain, shrinkage strain, and elastic strain of all specimens

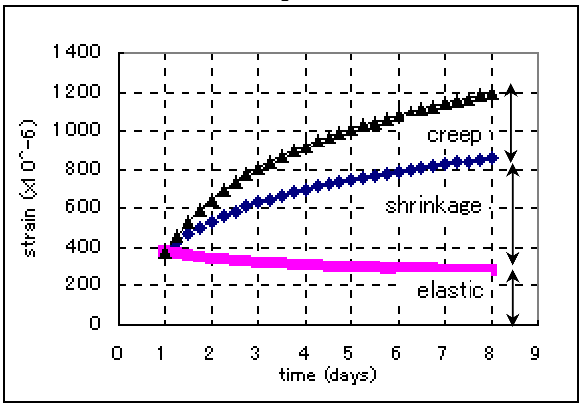
case 1 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 30%



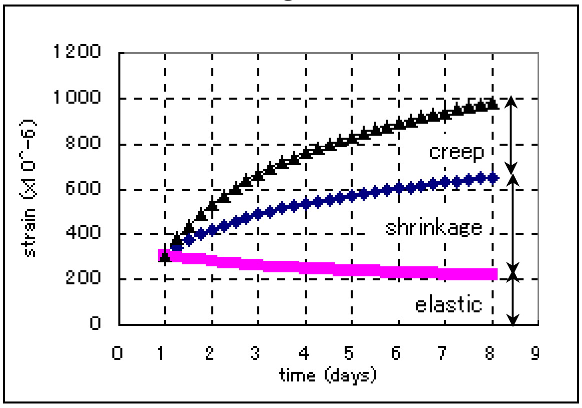
case 2 : Ordinary Portland Cement, load at 24 hrs after casting, stress/strength ratio = 30%



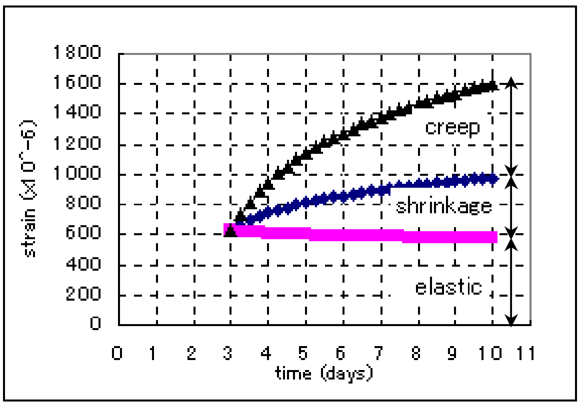
case 3 : OPC : LS = 50 : 50, load at 24 hrs after casting, stress/strength ratio = 30%



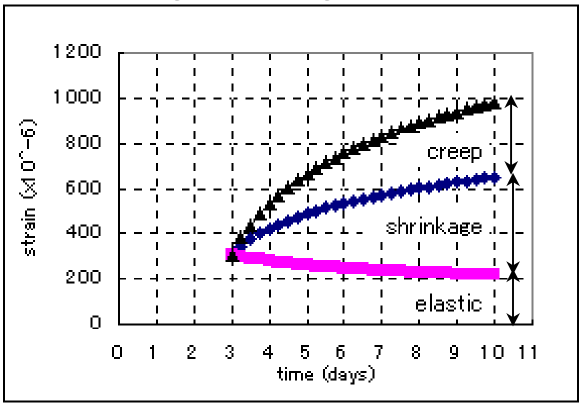
case 4 : OPC : LS = 30 : 70, load at 24 hrs after casting, stress/strength ratio = 30%



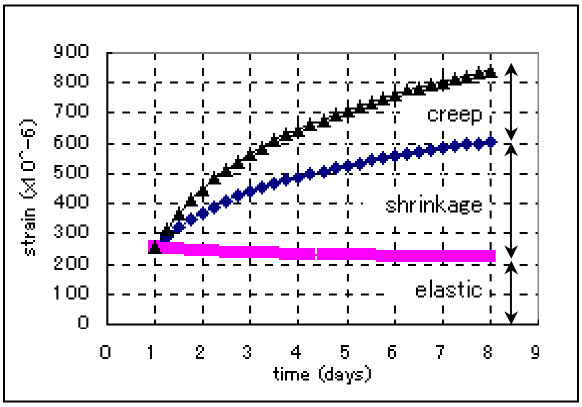
case 1-3 : Low Heat Cement, load at 72 hrs after casting, stress/strength ratio = 30%



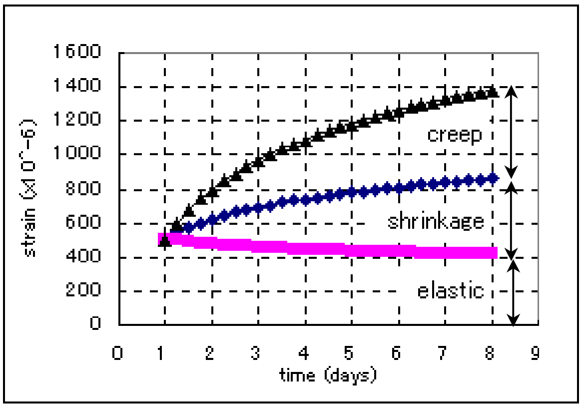
case 4-3 : OPC : LS = 30 : 70, load at 72 hrs after casting, stress/strength ratio = 30%



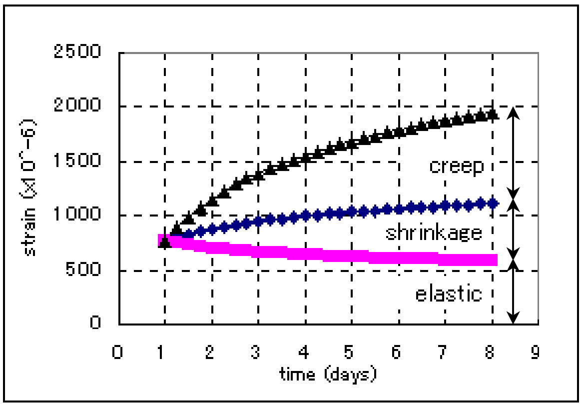
case 1-20 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 20%



case 1-40 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 40%

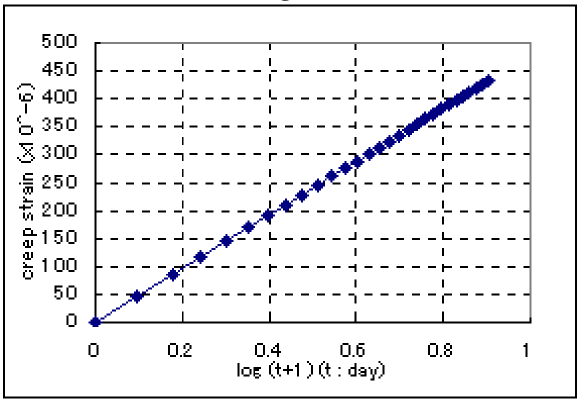


case 1-60 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 60%

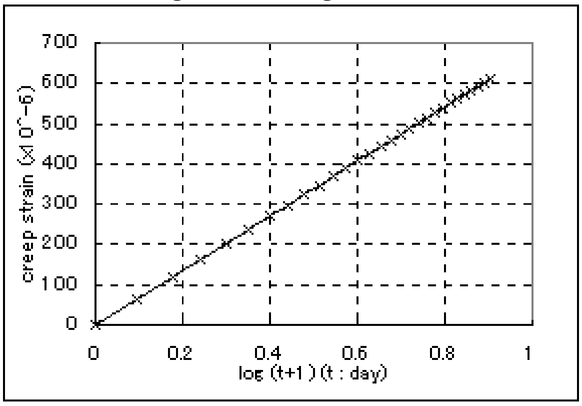


Appendix B Creep strain of all specimens

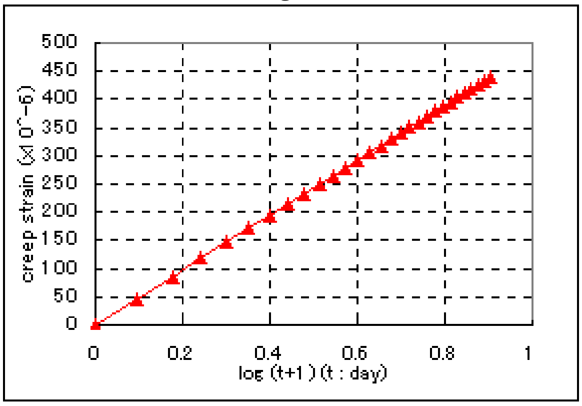
case 1 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 30%



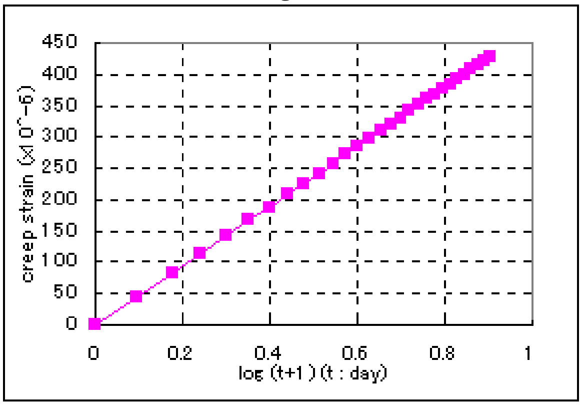
case 2 : Ordinary Portland Cement, load at 24 hrs after casting, stress/strength ratio = 30%



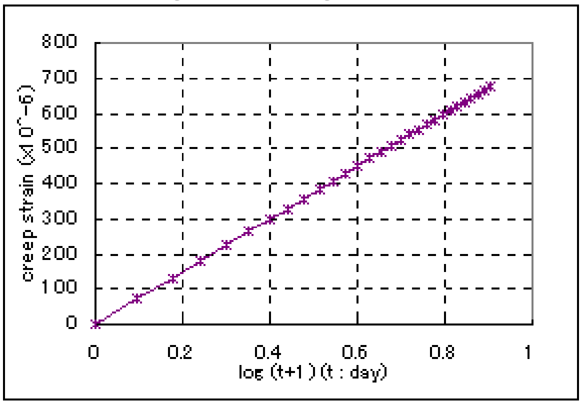
case 3 : OPC : LS = 50 : 50, load at 24 hrs after casting, stress/strength ratio = 30%



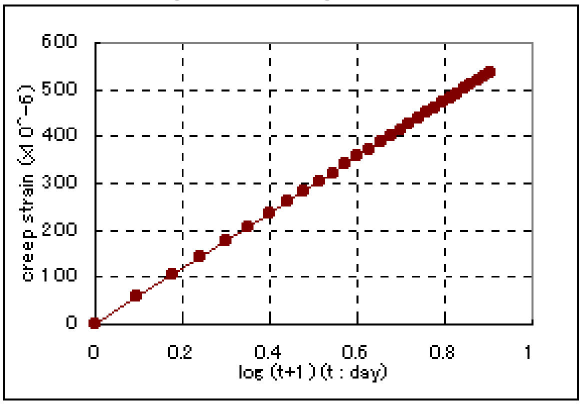
case 4 : OPC : LS = 30 : 70, load at 24 hrs after casting, stress/strength ratio = 30%



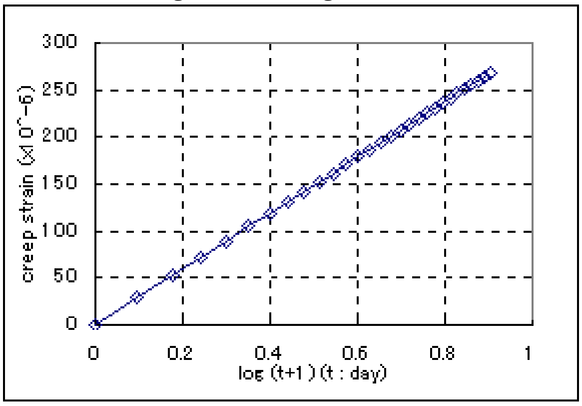
case 1-3 : Low Heat Cement, load at 72 hrs after casting, stress/strength ratio = 30%



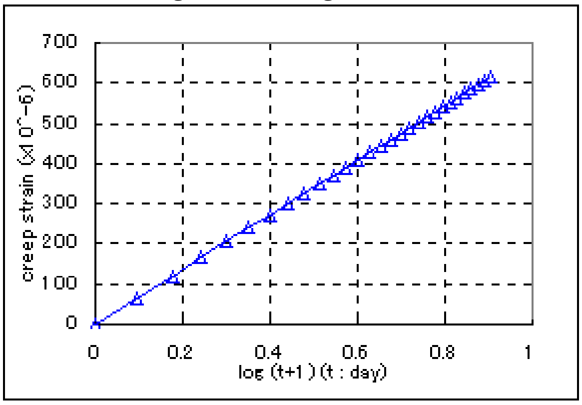
case 4-3 : OPC : LS = 30 : 70, load at 72 hrs after casting, stress/strength ratio = 30%



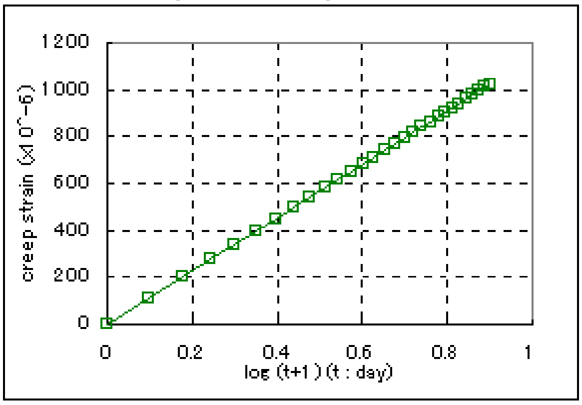
case 1-20 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 20%



case 1-40 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 40%

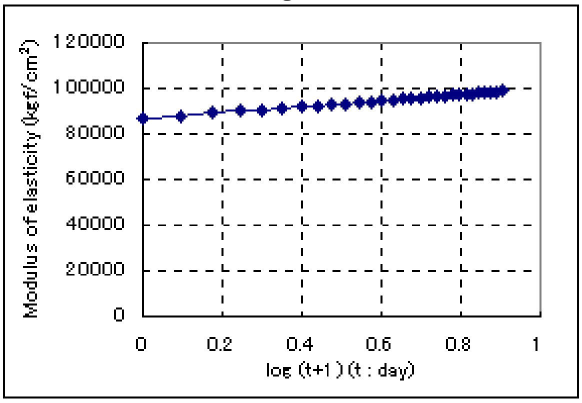


case 1-60 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 60%

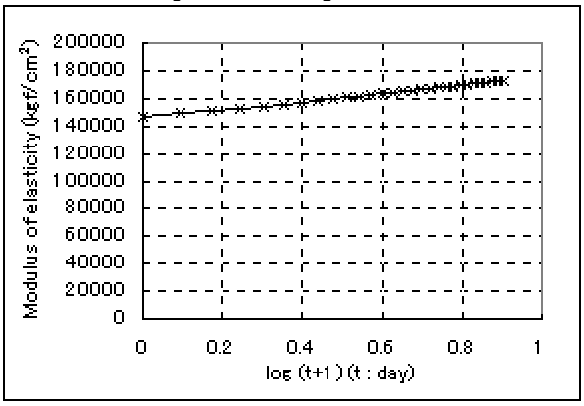


Appendix C Young's modulus of all specimens

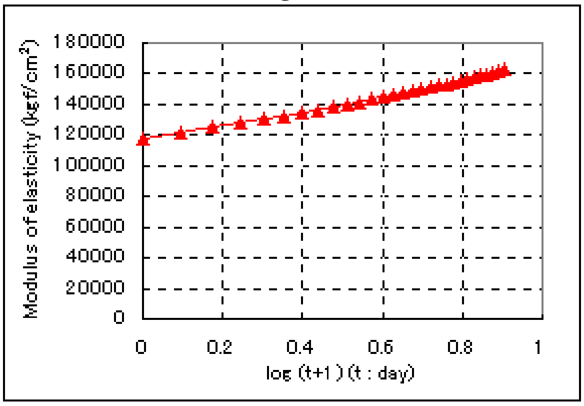
case 1 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 30%



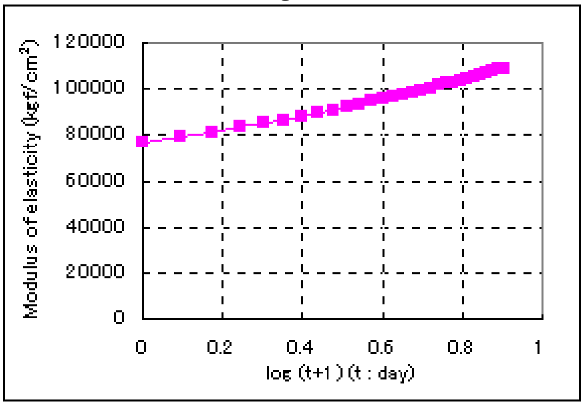
case 2 : Ordinary Portland Cement, load at 24 hrs after casting, stress/strength ratio = 30%



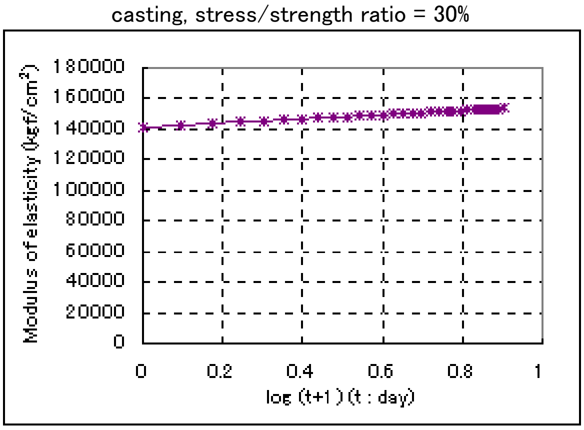
case 3 : OPC : LS = 50 : 50, load at 24 hrs after casting, stress/strength ratio = 30%



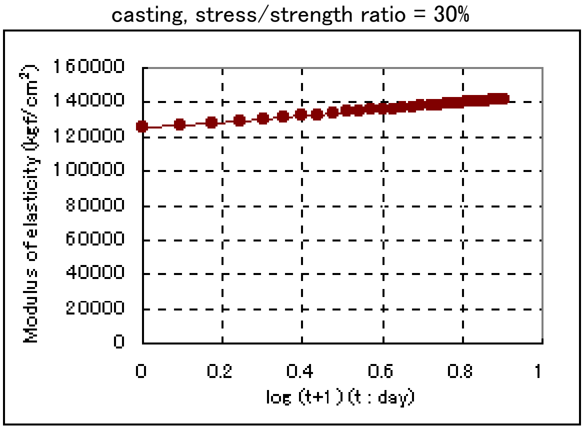
case 4 : OPC : LS = 30 : 70, load at 24 hrs after casting, stress/strength ratio = 30%



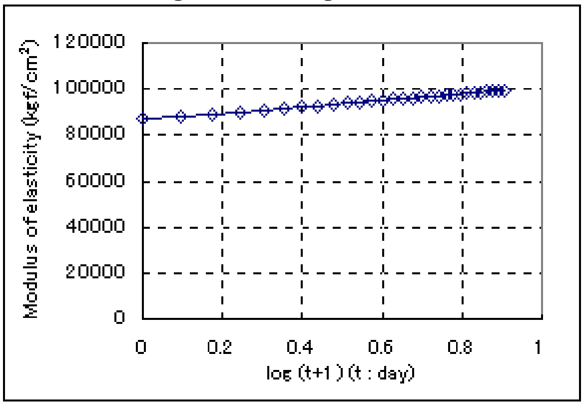
case 1-3 : Low Heat Cement, load at 72 hrs after casting, stress/strength ratio = 30%



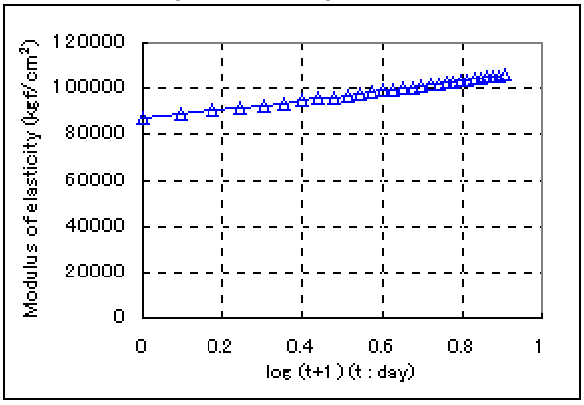
case 4-3 : OPC : LS = 30 : 70, load at 72 hrs after casting, stress/strength ratio = 30%



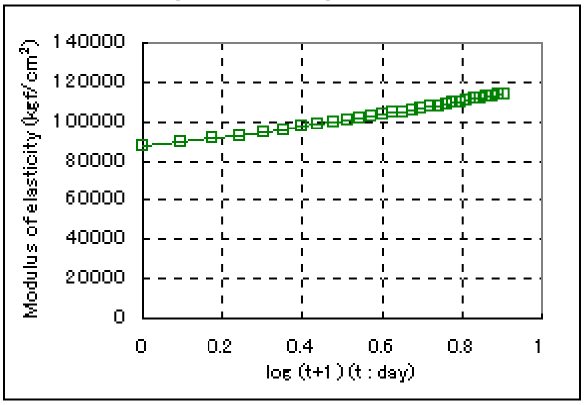
case 1-20 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 20%



case 1-40 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 40%

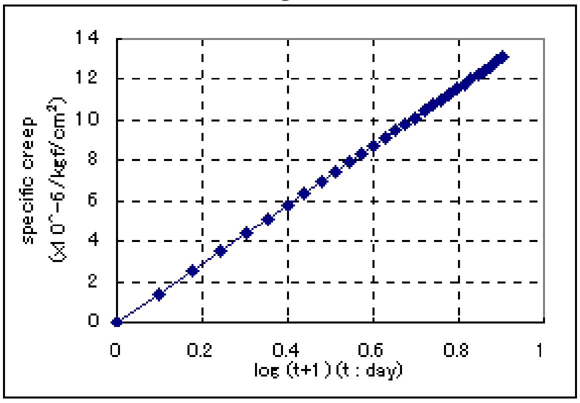


case 1-60 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 60%

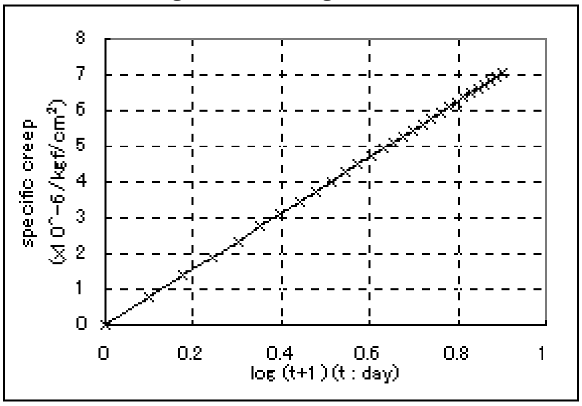


Appendix D Specific creep of all specimens

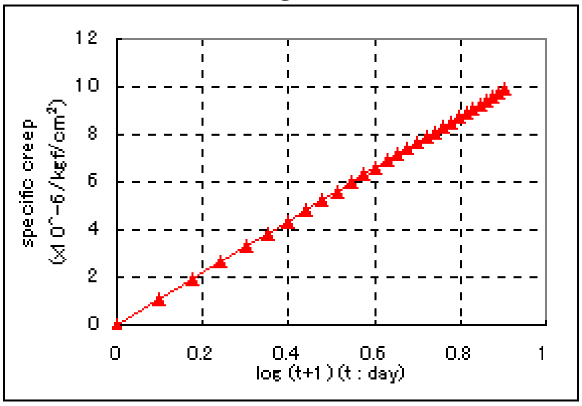
case 1 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 30%



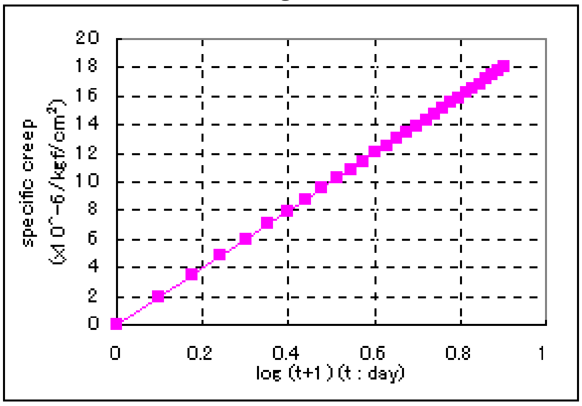
case 2 : Ordinary Portland Cement, load at 24 hrs after casting, stress/strength ratio = 30%



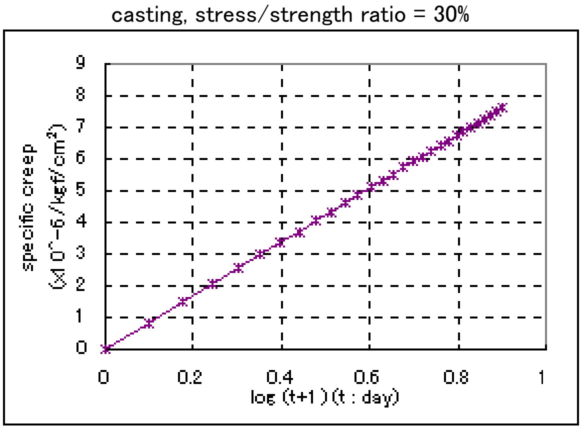
case 3 : OPC : LS = 50 : 50, load at 24 hrs after casting, stress/strength ratio = 30%



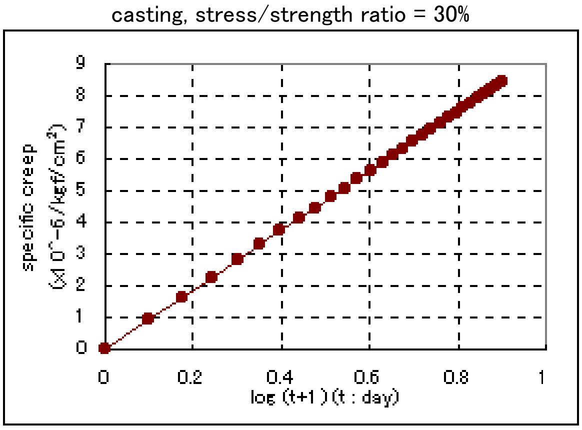
case 4 : OPC : LS = 30 : 70, load at 24 hrs after casting, stress/strength ratio = 30%



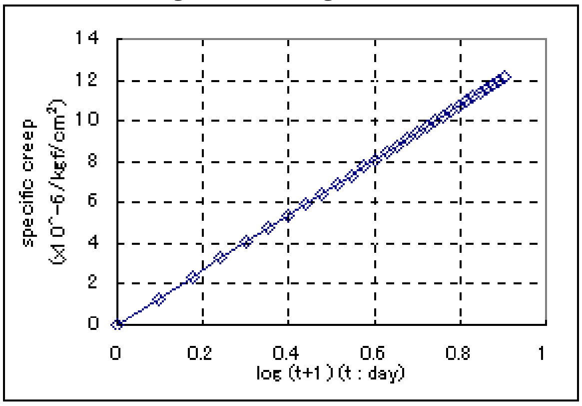
case 1-3 : Low Heat Cement, load at 72 hrs after casting, stress/strength ratio = 30%



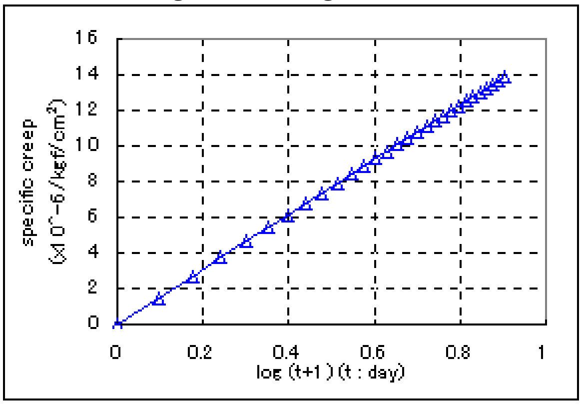
case 4-3 : OPC : LS = 30 : 70, load at 72 hrs after casting, stress/strength ratio = 30%



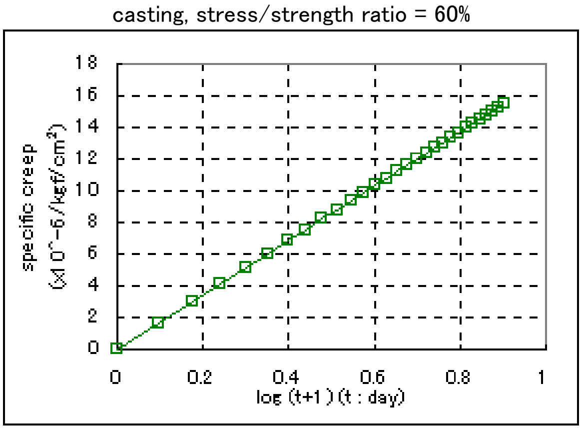
case 1-20 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 20%



case 1-40 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 40%

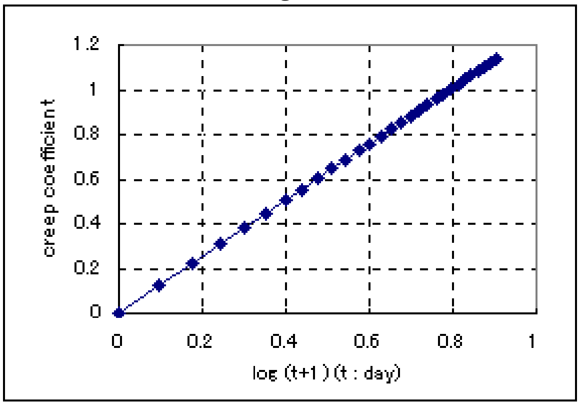


case 1-60 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 60%

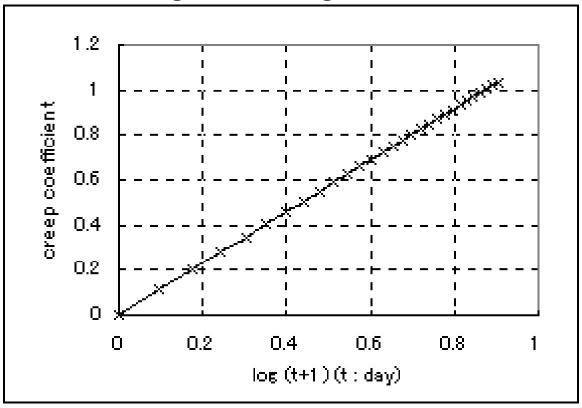


Appendix E Creep coefficient of all specimens

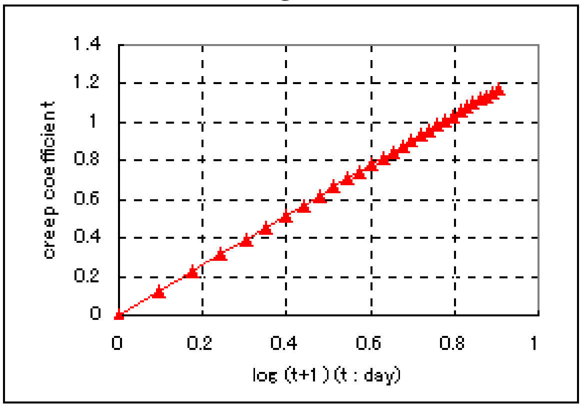
case 1 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 30%



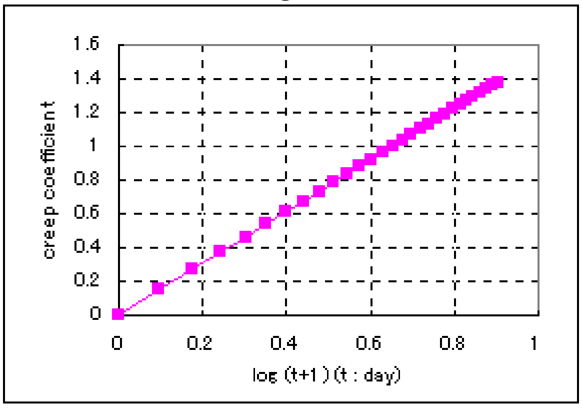
case 2 : Ordinary Portland Cement, load at 24 hrs after casting, stress/strength ratio = 30%



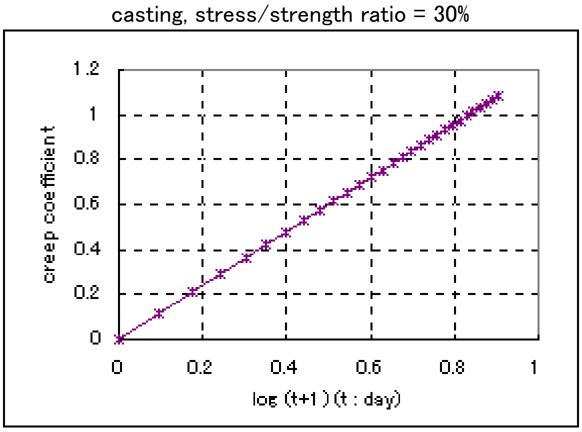
case 3 : OPC : LS = 50 : 50, load at 24 hrs after casting, stress/strength ratio = 30%



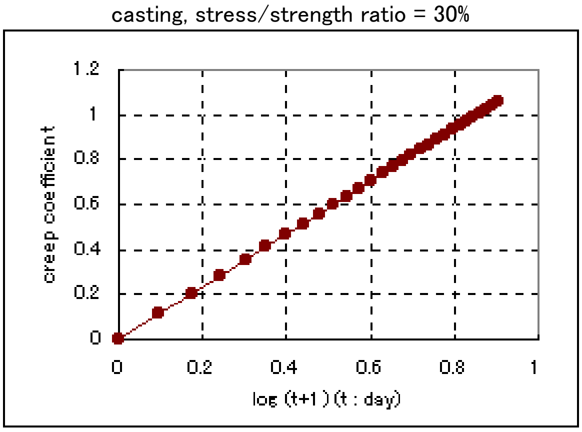
case 4 : OPC : LS = 30 : 70, load at 24 hrs after casting, stress/strength ratio = 30%



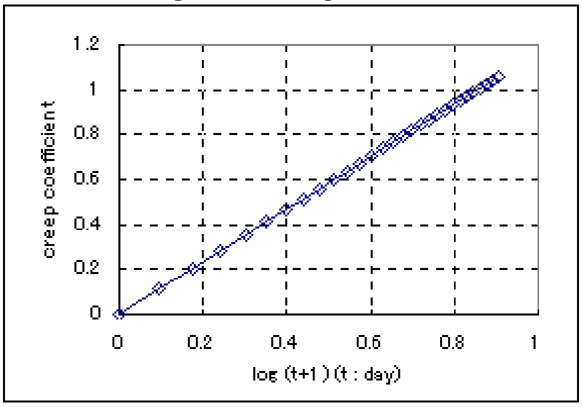
case 1-3 : Low Heat Cement, load at 72 hrs after casting, stress/strength ratio = 30%



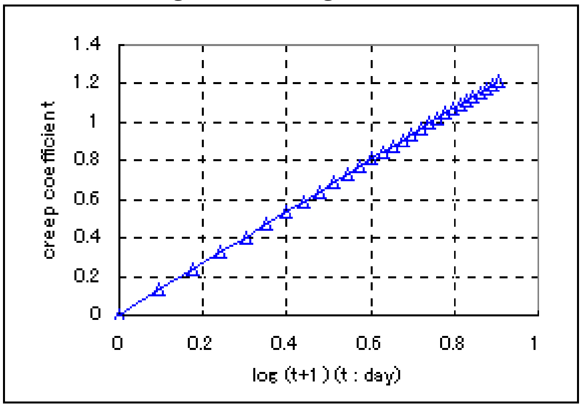
case 4-3 : OPC : LS = 30 : 70, load at 72 hrs after casting, stress/strength ratio = 30%



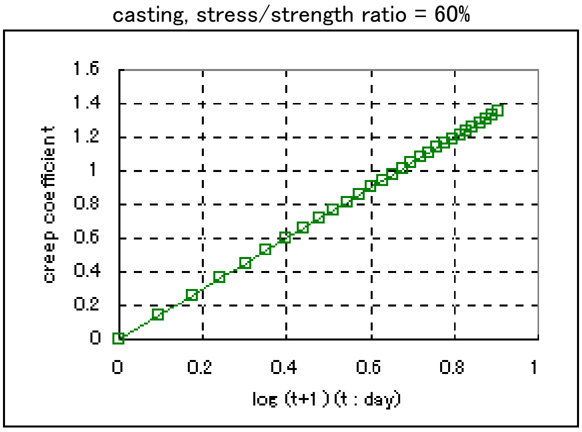
case 1-20 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 20%



case 1-40 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 40%

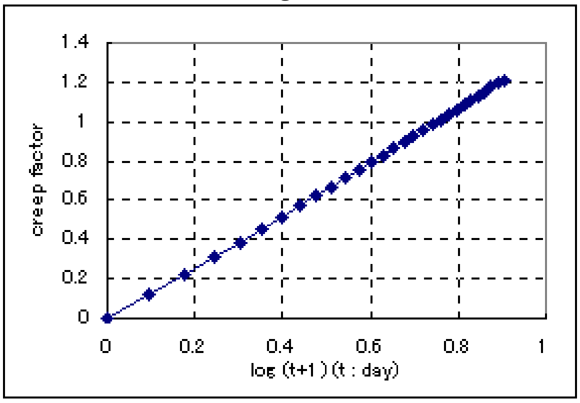


case 1-60 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 60%

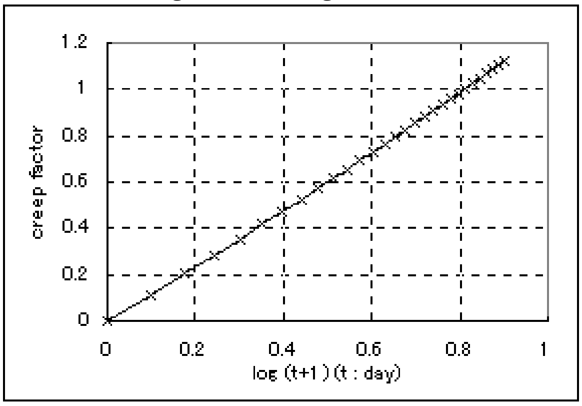


Appendix F Creep factor of all specimens

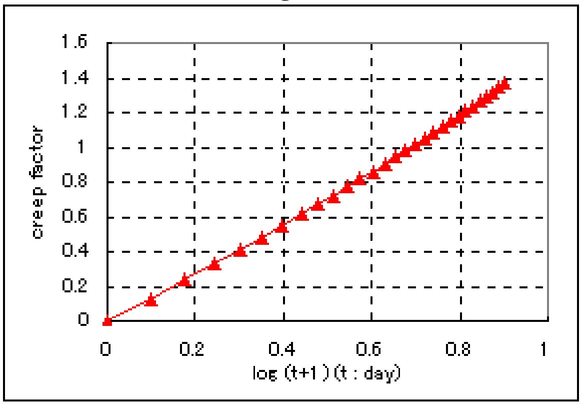
case 1 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 30%



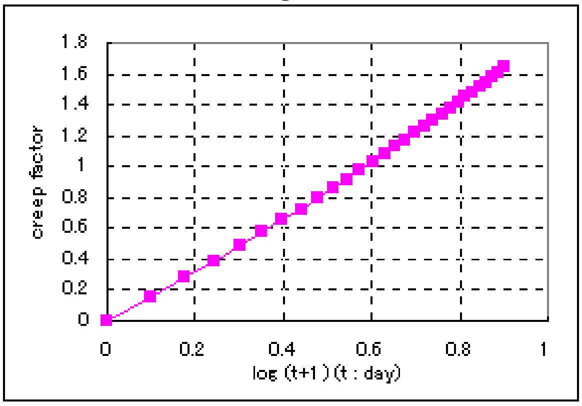
case 2 : Ordinary Portland Cement, load at 24 hrs after casting, stress/strength ratio = 30%



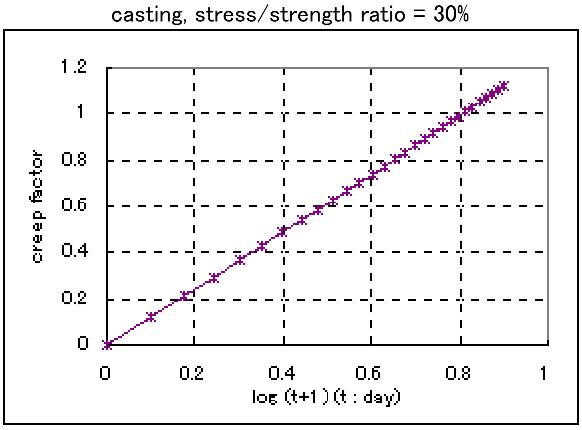
case 3 : OPC : LS = 50 : 50, load at 24 hrs after casting, stress/strength ratio = 30%



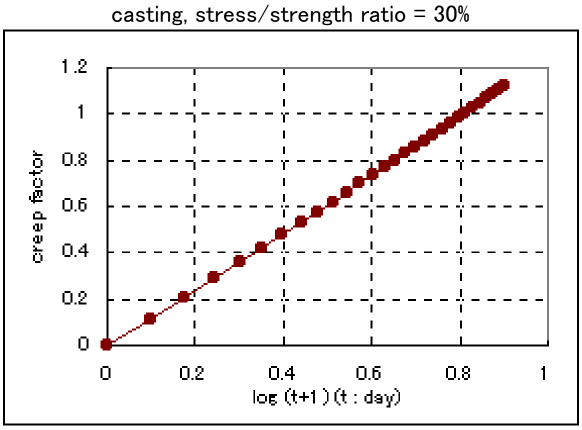
case 4 : OPC : LS = 30 : 70, load at 24 hrs after casting, stress/strength ratio = 30%



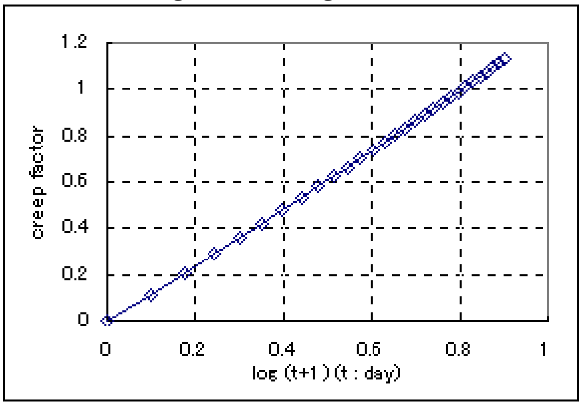
case 1-3 : Low Heat Cement, load at 72 hrs after casting, stress/strength ratio = 30%



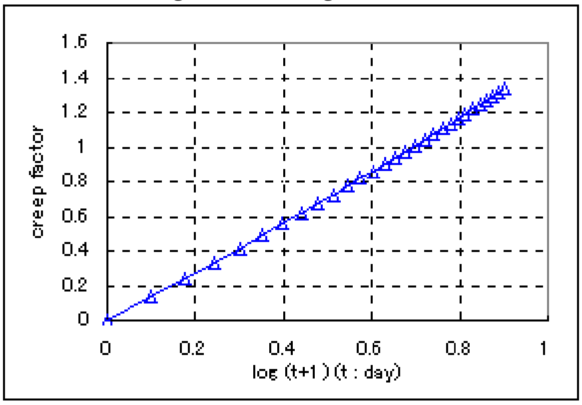
case 4-3 : OPC : LS = 30 : 70, load at 72 hrs after casting, stress/strength ratio = 30%



case 1-20 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 20%



case 1-40 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 40%



case 1-60 : Low Heat Cement, load at 24 hrs after casting, stress/strength ratio = 60%