EARLY AGE CREEP OF SELF-COMPACTING CONCRETE USING LOW HEAT CEMENT AT DIFFERENT STRESS/STRENGTH RATIOS

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Abstract

In this paper I will investigate the influence of different stress/strength ratios on the creep of unsealed and sealed of self compacting concrete and normal concrete using Low Heat Cement and the corresponding properties of Ordinary Portland Cement is outlined in this studied. The results were compared with a similar mixture of Low Heat Cement and Ordinary Portland Cement. The creep strain was measured at different stress/strength ratios of 10, 20, 30, 40 and 60 percent, for a maximum period of 7 days. All the tests were carried out in the room at temperature of 20°C and relative humidity of 50%. The study included forty mix proportions of sealed and unsealed conditions with water-cement ratio equal to 0.3. Half of the mixes studied were based on self-compacting concrete and the other half were based on normal concrete. The age at loading of the concretes in the creep studied was carried out at 24 hours after casting. Parallel studies were performed on strength (f_c) and relative humidity (RH).

Creep of self-compacting concrete and normal concrete were found to vary linearly with logarithm of time for both sealed and unsealed concrete. Also, creep of self-compacting concrete and normal concrete were found to be a linear function of stress/strength ratio between 10 and 60 percent.

The results show that the specimens subjected to air-dried curing exhibited higher creep strains than sealed specimens; creep strains decrease with an increase in concrete compressive strength at the time of loading.

KEYWORDS: Creep, Shrinkage, Self Compacting Concrete, Low heat cement, Stress/Strength Ratios.

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Contents

List of Figures and Tables

Figure No.

Table No.

Chapter 1

INTRODUCTION

1.1 Objective and scope of study

During the hydration process, significant thermal and shrinkage gradient can cause stress that could lead to cracking of concrete at early age. The presence of creep during the hydration period, at an early age would have an effect of reducing this stress. During hydration when temperature is increasing, tensile stress develops near the concrete surface where the temperature is lower, and compressive stress develops at the center where higher temperature exists. In addition, higher shrinkage strain occurs on the surface, which also causes tensile stress near the surface and compressive stress at the center. During this phase the concrete has lower strength, lower elastic modulus, and significant early-age creep. Although the tensile strength of the concrete is low, the combined effect of low modulus and high creep will significantly reduce the tendency for surface cracking. When the center of the concrete starts cooling, the stress due to thermal gradient cause the reverse effect, with reduced compressive stress and perhaps even tensile stress due to thermal gradient cause the reverse effect, with reduced compressive stress and perhaps even tensile stress developing at the center of the concrete. During this phase the concrete strength is higher, resulting in an increased modulus of elasticity and reduced creep. Thus it is important to study the early age creep and shrinkage of concrete to accurately predict the resulting stress due to heat of hydration.

Several researchers have studied from different aspects on the effect of admixtures in concrete. However, very little information is available about the creep behavior at different stress/strength ratios for unsealed and sealed concrete using low heat cement (Unsealed condition means the moisture loss to the environment, put specimen in air dried condition and Sealed condition mean wrap specimen with polyethylene, do not let the moisture loss to the environment). Moreover, from JSCE and ACI codes have some limitation on cement contents: JSCE has limited the cement content to be less than 500kg/m^3 and ACI has limit the strength of concrete to be less than 1.3. The purpose of this study is to clarify whether JSCE or ACI codes can predict creep when cement content above the codes limitation or not and this study will give relationship between creep at the early age with vary water-cement ratios, stress-strength ratios and powder contents when comparing with time. All of the specimen will be carried out at the controlled room temperature of 20°C and the relative humidity of 60%.

The distinction between sealed and unsealed concrete for the practical designer is clearly illustrated by comparing mass and ordinary concrete structures. In mass concrete structures, such as dams and pressure vessel walls that have a thickness of over 5 ft (152.4cm), moisture is practically sealed within the concrete; while in ordinary structures that have a thickness of less than 5 ft. (152.4 cm), moisture within the concrete may evaporate into the atmosphere, depending on the environmental conditions.

LITERATURE REVIEW

1.2 General

Concrete properties change rapidly in the few days following the mixing of water into the cement. Hydration is induced at the interface between pore water and particles of cement. CSH gels form. This results in voids with diameters of a few decades of Å. The initial distribution of void diameter is determined by the distribution of cement particles as well as the distribution of aggregates in the mixture. The initial size of cement particles is almost the same as the initial minimum pore size, which is almost 1 um. Next, CSH gel penetrates into voids and forms smaller voids. CSH gel is said to have a size of $10 \sim 10^4$ Å near unhydrated cement particles separated with water, especially in the beginning. The water is called gel pore water or capillary pore water and can be vaporized. The existence of a pore system naturally affects the initial stress gradient if pore water pressure is somehow induced. Moreover, the initial concrete state also effects behavior at a later age in terms of physical properties [4]. And this is especially important for massive concrete structures; hydration heat can occur and thermal stress problems may induce. Since concrete stiffness may be increased with the advanced of chemical hydration at an early age, compressive thermal stresses may be mainly induced in the concrete. However, in the few days after casting, the stress history reveals a contrary pattern and tensile stress may be induced. At this stage, creep deformation may govern and may offset stress. However, these effects have not been clarified. If a deformational analysis of the creep problem is performed, the creep function for hardened concrete may be interpolated. If the pore water has an effect, however, it is the effect of size dependent. It is said that concrete creep is generally larger if a member size is smaller. However, creep is a material property and does not depend on size, while pore water migration is a process of diffusion [7]. Moreover, the effect of creep of compression and tension is considered to be the same, while the effect of pore water in the compressive stress state is quite different from that in tension. The time dependent behaviors of concrete at an early age can be assumed to be affected by pore water in the concrete. However, a clear mechanism is still being investigated.

Creep of concrete resulting from the action of a sustained stress is a gradual increase in strain with time; it can be of the same order of magnitude as drying shrinkage. As defined, creep does not include any immediate elastic strains caused by loading or any shrinkage or swelling caused by moisture changes. When a concrete structural element is dried under load the creep that occurs is one to two times as large as it would be under constant moisture conditions. Adding normal drying shrinkage to this and considering the fact that creep value can be several times as large as the elastic strain on loading, it may be seen that these factors can cause considerable deflection and that they are of great important in structural mechanics [9].

Two mechanisms of creep in absence of drying may be distinguished: short-term creep and long-term creep. Short-term creep is a consequence of redistribution of capillary water within the structure of the hardened cement paste, and the long-term creep is a consequence of displacement of gel particles under load and, to a lesser extent, of creep of the gel particles. Simultaneous drying further complicates the process because instantaneous plus creep deformation is larger than the sum of creep and shrinkage deformations measured separately. The additional strain is normally associated with drying creep. In analysis and design, creep is usually accounted for by using a creep factor that is the ratio of creep strain at any time to instantaneous strain.

If a sustained load is removed, the strain decreases immediately by an amount equal to the elastic strain at the given age; this is generally lower than the elastic strain on loading since the elastic modulus has increased in the intervening period. This instantaneous recovery is followed by a gradual decrease in strain, called creep recovery. This recovery is not complete because creep is not simply a reversible phenomenon [12].

It is now believed that the major portion of creep is due to removal of water from between the sheets of a calcium silicate crystallite and to a possible rearrangement of bonds between the surfaces of the individual crystallites.

Extensive research has been carried out to study the phenomena of creep in concrete. These investigations has been summarized by Neville, Dilger, and Brooks [5], Bazant and Wittmann [6] and CEB-FIP [3], factors influencing shrinkage and creep are concrete strength, water-cement ratio, relative humidity, temperature, content of aggregate, member size and loading age.

Creep of concrete is a complex problem, especially at very early ages, due to the complexity of the material [1]. A limited amount of research has been conducted to study the creep of concrete during the early period of hydration, particularly for high strength concrete using low heat cement. Byfors [7] studied the early-age creep of normal strength concrete with different concrete compositions and water cement ratios. The age at the time of loading varied from about 8 hrs to 28 days with an applied stress-to strength ratio equal 0.3. All of the specimens were sealed and kept at a relative humidity of 80 percent and a temperature of 20°C. It was found that specific creep increases considerably due to very early loading. Data are presented for the first 100 hrs after load was applied. Since the properties of concrete change very rapidly during the early period of hydration, this phenomenon is very complex and highly dependent on maturity (i.e., temperature and time) and moisture.

To account for the influence of moisture, creep of concrete is divided into basic creep and drying creep. Basic creep of concrete is defined as creep in a sealed condition, whereas drying creep, sometimes called the Picket effect, is the additional creep caused by moisture loss under constant stress. It is typically assumed that creep and shrinkage are phenomena that do not interact, and hence the total strain can be obtained by summing the elastic, creep and shrinkage strains.

It is well known that earlier age loading results in higher elastic and creep strains. In particular, very early loading may result in higher maturing creep due to the formation of cement hydration products [5]. It is interesting to note that at very early ages the applied stress to strength ratio actually decreases with time due to the hydration process (i.e., concrete strength increases with time).

1.3 The Origin of Creep

The first observation is the importance of the viscous component in the behavior of concrete. The strain which is produced in the course of a creep test (after subtracting shrinkage) at the end of loading may be three or four times intensity of the initial (elastic) strain, which is utterly exceptional for a mineral. The role of water content is very important here and is paradoxical; if tests are conducted in which there is no exchange of water with the ambient environment (basic creep) the lower the evaporation water content of the sample, the lower the creep strain, to the extent that it can become negligible. However, if the tests are conducted in a dry atmosphere, the greater the drying the greater the creep- up to five times more than the basic creep of the concrete with the highest water content. [11]

The water content of concrete plays an essential role in creep; concrete which has dried to the state where evaporable water has been totally eliminated is not subject to creep. Two mechanisms are apparent from kinetic analysis of basic creep for pure cement pastes [12] which are completely protected from desiccation. Both mechanisms are compatible with the mobility of water. The short characteristic time of the first mechanisms on the order of 7 days.[12] suggests a stress-induced water movement towards the largest diameter pores (characteristic distance of the order of 0.1-1 mm). This short-term creep mechanism was first suggested by [11]: it may be attributed to a change of the hygral equilibrium in the gas filling space which generates strain and stresses (and eventually microcracking), which results in the short-term component of creep. The activation energy of this first mechanism could be that of permeation in the saturated capillary pores.

The second mechanism corresponds to an irreversible viscous behavior, and seems to be more related to viscous flow in the hydrates (slippage between layers which is increasingly inhibited over time, particularly if the hydrates start to lose water). This long-term creep occurs under almost constant volume [13], which is consistent with a viscous slippage mechanism.

1.4 Factors Influencing Creep

Concrete that exhibits high shrinkage generally also shows a high creep, but how the two phenomena are connected is still not understood. The evidence suggests that they are closely related. When hydrated cement is completely dried, little or no creep occurs; for a given concrete the lower the relative humidity and the higher the creep.

The strength of concrete has a considerable influence on creep, and within a wide range creep is inversely proportional to the strength of concrete at the time of application of load. From this it follows that creep is closely related to the water-cement ratio. There is no doubt also that the modulus of elasticity of aggregate controls the amount of creep that can be realized and concretes made with different aggregates exhibit creep of varying magnitudes [12].

1.5 Effect of Creep

Creep affects strains, and deflections, also often stress distribution, but the effects of creep vary with the type of structure.

Creep of plain concrete does not affect the strength although under very high stresses creep hastens the approach of the limiting strain at which failure takes place; this applies only when the sustained load is above 85 or 90 percent of the rapidly applied static ultimate load [4].

The influence of creep on the ultimate strength of a simply supported reinforced concrete beam subjected to a sustained load is not significant, but the deflection increases considerably and may in many cases be critical consideration in design. According to Glanville and Thomas [10], there are two distinct neutral surfaces in a beam subjected to sustained loading; one of zero stress, the other of zero strain [8]. This arises from the fact that an increase in the strain in concrete leads to an increased stress in the steel and a consequent lowering of the neutral axis when an increasing depth of concrete is brought into compression. As a result, the elastic strain distribution changes, but the creep strain is not cancelled out, so that at the level of the new stress-neutral-axis a residual tensile strain will remain. At some level above this axis, there is a fiber of zero strain at any time although there is a stress acting [11].

With respect to reinforced concrete columns, creep results in a gradual transfer of load from the concrete to the reinforcement. Once the steel yields, any increases in load is taken by the concrete, so that the full strength of both the steel and the concrete is developed before failure takes place, a fact recognized by the design formula. However, in eccentrically loaded columns, creep increases the deflection and can lead to buckling [14]. In statically indeterminate structures, creep reduced internal stresses due to non-uniform shrinkage so that there is a reduction in cracking. In calculation creep effects in structures it is important to realize that the actual time-dependent deformation is not the free creep of concrete but a value modified by the quantity and position of reinforcement.

On the other hand, with regarding to mass concrete, creep in itself may be a cause of cracking when restrained concrete mass undergoes a cycle of temperature change due to the development of the heat of hydration and subsequent cooling. Creep relieves the compressive stress induced by the rapid rise in temperature so that the remaining compression disappears as soon as some cooling take place. On further cooling of concrete, tensile stresses develop and, since the rate of creep is reduced with age, cracking may occur even before the temperature has dropped to the initial value. For this reason, the rise in temperature in the interior of a large concrete mass must be controlled by the use of low heat cement, a low cement content, precooling of mix ingredients, limiting the height of concrete lifts, and cooling of concrete by circulating refrigerated water through a network of pipes embedded in the concrete mass.

The loss of prestress due to creep is well known and, accounts for the failure of all early attempts at prestressing. It was only the introduction of high tensile steel, whose elongation is several times the contraction of concrete due to creep and shrinkage that made prestressing a successful proposition [15].

The effects of creep may thus be harmful but, on the whole, creep, unlike shrinkage, is beneficial in relieving stresses concentrations and has contributed very considerably to the success of concrete as a structural material.

1.6 Autogenous Volume Changes and Expansion Cements

Before volume changes resulting from drying or wetting of hardened concrete are discussed, autogenous volume changes should be mentioned because they occur where little or no change in total moisture content is possible and are of particular importance in the interior of mass concrete. Two opposing effects can be produced. As reaction between water and the unhydrated cement proceeds, the actual volume of the solid increases. This causes stresses through the set structure and results in expansion. At later ages, the water available for the reaction will decrease, resulting in self-desiccation of the cement paste and a shrinkage ranging from 0.001 to more than 0.015 percent [13].

1.7 Volume Changes due to Moisture Changes

Although the mechanism of volume change that occurs during moisture change is not fully understood, much has been learned to provide useful information for engineering purposes. When concrete is dried, the first water to be removed causes no changes in volume. This is considered to be free water held in rather large “pores”. With continued drying, shrinkage becomes quite large and at equilibrium in 50 percent RH values in excess of 0.10 percent have been recorded for some concretes. Shrinkage values for neat cement paste have been observed in excess of 0.40 percent; the difference of this value from that of concrete is due to various restraints. A large portion of concrete is made up of relatively inert aggregate (from 3 to 7 times the weight of cement) and this, together with reinforcement, reduces shrinkage. In addition to internal restraints, some restraint arises from non-uniform shrinkage within the concrete member itself [14]. Moisture loss takes place on the surface so that a moisture gradient is established. The resultant differential shrinkage is associated with internal stresses, tensile near the surfaced and compressive is the core, and the result in warping or cracking.

1.8 Effect of Cement and Water Contents on Shrinkage

Water content is probably the largest single factor influencing the shrinkage of paste and concrete. Typical shrinkage values for concrete specimens with a 5 to 1 aggregate-cement ratio are 0.04, 0.06, 0.075 and 0.085 percent for water-cement ratio of 0.4, 0.5, 0.6 and 0.7, respectively. One of the reasons is that the density and composition of calcium silicate formed at different water-cement ratios may be slightly different. In general, a higher cement content increases the shrinkage of concrete; the relative shrinkages of neat paste, mortar and concrete may be of the order of about 5, 2, and 1. For given materials, however, and a uniform water content, the shrinkage of concrete varies little for a wide range of cement contents; a richer mix will have a lower water-cement ratio and these factors offset each other [10].

1.9 Effect of microcracking

The drying creep strain $sC_d(t,t',t_o)$, also called the stress-induced shrinkage, includes the effects of microcracking (or cracking) and of pore humidity rate on the apparent creep viscosities, both of which are almost equally important [1]. In a specimen under sufficient compression the observed shrinkage is much closer to the true material shrinkage (free shrinkage of a small element) than in a load-free specimen. The reason is that the shrinkage observed on a load-free specimen is significantly offset by microcracking.

This is true also of the final values, because microcracking is largely irreversible (the crackings, once formed, cannot close completely). This phenomenon causes the average cross-section shrinkage to depend on stress, which is taken into account by the term $sC_d(t,t',t_o)$.

The microcracking can be enhanced by restraint which reduces the shrinkage strain; the term $sC_d(t,t',t_o)$ is essential for realistic calculation of shrinkage stress in restrained concrete beams or slabs [1].

1.10 Moisture Diffusion in Concrete

The moisture flux (J) is proportional to the gradient of the pore relative humidity, and is expressed as Eq. 1 [1]:

$$J = -k \text{ grad } h \qquad (1)$$

Where h is the pore relative humidity, and k is the permeability. The specific water content (w) is the function of pore relative humidity (h) in the desorption isotherm, i.e.,
w = w(h), so that the mass balance equation can be expressed as follows:

$$\frac{\partial w}{\partial t} = \frac{\partial w}{\partial h}\frac{\partial h}{\partial t} = \frac{1}{c}\frac{\partial h}{\partial t} = -divJ \qquad (2)$$

where $\frac{\partial w}{\partial h}$ is the moisture capacity, which represents the slope of the desorption isotherm. Eliminating w and J from Eqs. 1 and 2, the nonlinear moisture diffusion equation can be obtained as follows:

$$\frac{\partial h}{\partial t} = c\,div(k \text{ grad } h) = div(D \text{ grad } h) \qquad (3)$$

where D is the moisture diffusion coefficient, and defined as ck. The moisture diffusion coefficient is dependent on the relative humidity and temperature. In CEB-FIP('90) model code, for isothermal conditions, the moisture diffusion coefficient is expressed as a function of the pore relative humidity $0<h<1$ according to Eq. 4:

$$D(h) = D_1\left(a + \frac{1-a}{1+[(1-h)/(1-h_c)]^n}\right) \qquad (4)$$

Where D_1 is the maximum of D(h) for h = 1.0, a = D_0/D_1, Do is the minimum of D(h) for h= 0.0, h_c is the pore relative humidity at D(h) = $0.5D_1$, and n is an exponent. a = 0.05, h_c = 0.08 and n = 15 are approximately assumed [3]. D_1 may be also estimated from Eq. 5:

$$D_1 = \frac{D_{1,0}}{f_{ck}/f_{cko}} \qquad (5)$$

Where $D_{1,0} = 3.6*10^{-6}$ m^2/h, f_{cko} = 10 MPa, and the characteristic compressive strength f_{ck} may be estimated by the mean compressive strength f_{cm}, i.e., $f_{ck} = f_{cm} - 8$ MPa.

As the boundary condition of moisture, it is necessary to correlate the surface moisture with the humidity of the environmental atmosphere. On the exposed surface S, the boundary condition is as follows:

$$D\left(\frac{\partial h}{\partial n}\right)_s = f(h_{en} - h_s) \qquad (6)$$

Where f is the surface factor, h_{en} is environmental humidity, and h_s is the relative humidity on the exposed surface. Bazant dealt with this problem by assuming an additional thickness to the specimen, i.e., the equivalent surface thickness [4].

1.11 Basic equation of creep and shrinkage

When some load acts on the section consisting of steel and concrete, the initial elastic stress s_{co} is generated in a concrete and a creep strain of concrete proceeds as time passes. This relationship can be shown by the Dischinger's basic equation regarding creep and shrinkage as follows:

$$e_{k+s}(t) = \frac{s_{co}}{E_c} \cdot j(t) + \frac{s_{k+s}(t)}{E_c} + \int_0^t \frac{s_{k+s}(t)}{E_c} \times \frac{dj(t)}{dt} + e_s(t) \qquad (7)$$

Where: $e_{k+s}(t)$ = strain caused by creep and shrinkage; $s_{k+s}(t)$ = stress caused by creep and shrinkage; $e_s(t)$ = strain of shrinkage; f(t) = creep coefficient; and Ec = Young's modulus.

This equation can be rewritten as follows when considering the assumption (8) and very short time intervals:

$$\Delta e_{k+s} = \frac{s_{co}}{E_c} \cdot \Delta j + \frac{\Delta s_{k+s}}{E_C}(1 + \frac{\Delta j}{2}) + \Delta e_s \qquad (8)$$

For ACI creep equation:

$$\Delta e_{k+s} = \frac{s_{co}}{E_j} \cdot \Delta h + \frac{\Delta s_{k+s}}{Eg} + \Delta e_s \qquad (9)$$

where:

$$Ef = \frac{E_c}{1 + \frac{\Delta j}{2}} \qquad \Delta h = \frac{\Delta j}{1 + \frac{\Delta j}{2}} \qquad (10)$$

If we divide the time Δt into very small intervals, we can obtain the generated strain to good accuracy by using the numerical integration method from this equation, because both Δf and Δe can be given as the increments during the very short time.

1.12 Role of Vapor Pressure in Hygral Deformations of Concrete

When concrete is exposed to drying, hygral equilibrium is upset and water will evaporate from the capillaries until the vapor pressure is reduced to the ambient value.[8] The tension in the capillary water rises, and, to maintain equilibrium, the compression in the solid phase also increases. Hydrostatic tension is only developed when a meniscus is formed in a capillary. The capillary stress is given by the simple formula $P = 2g / R$, where g is the surface tension of water in a cylindrical capillary and r is the radius of meniscus.

The capillary tension is indicated by the internal vapor pressure; the higher the tension, the lower the vapor pressure. Using the Kelvin equation, Powers calculated that for vapor pressure in the specimen equal to 50 percent of the saturated vapor pressure at the atmosphere pressure, the result was 110 MPa [5]. The physical possibility of tension is accepted by Powers because of cohesive forces between the solid and the water molecules. The mechanisms of increasing the tension can be that of increasing the menicus curvature by evaporation.

The vapor pressure controls not only capillary tension stress but also disjoining pressure. When the specimen is saturated, the disjoining pressure in the gel is at maximum. It decreases as the vapor pressure decreases, being proportional to the change in the logarithm of ambient relative humidity (RH). Any change in the disjoining pressure also changes the surface tension of the solid phase.

The water content of a capillary system depends on the moisture content of the surrounding air. At 100 percent RH, all the capillary voids are filled with water, at 0 percent RH, they become empty. At an intermediate RH, the quantity of capillary water is determined by the moisture content of the air and the capillary structure (diameter) of the porous system.

To better imagine the role of vapor pressure in shrinkage phenomena, it can be helpful to consider the following simplified scheme based only on the account of capillary tension stress developed when a meniscus is formed. Let's consider a single capillary of linear variable radius that reflect a variety of capillaries of different form and with different radii [4].

The contact angle between pure water, which has a tendency to wet surfaces, and the capillary wall is accepted as zero (as for clean glass capillary). The concave meniscus of the radius R, dependent on RH of the air and vapor pressure, rises on contact between the liquid surface and solid. Free water begins to evaporate when the relative humidity drops slightly below RH= 100 percent of saturated level [3]. The radius of the curvature R does not change until the meniscus of the spherical form will be formed. That is why the removal of free water should not be accompanied by shrinkage.

The capillary water can continue to be removed only if the radius of the meniscus will be decreased by $r<R$, but this will result in capillary contraction and consequent shrinkage of the material. The capillary radius at which evaporation of capillary water commences is a direct function of RH. For example, r = 0.1 um at RH=99 percent and 0.001 um at RH= 34.8 percent. [9] The removal of the capillary water continues as long as there is no need for the further decrease of meniscus radius and or the additional drop in vapor pressure [5].

When concrete is sealed, the vapor pressure increase quickly and changes the meniscus curvature so that the level of liquid becomes flatter and the effective average (radius of meniscus increases. The releases the capillary surface tension and immediately leads to capillary distention and consequent swelling deformation. However, if the material is dried out to the other moisture content that corresponds to the other value of meniscus curvature (r instead of R), it can be seen that the previous capillary distention radius will cause a similar value of swelling deformation [6].

1.13 Summary of Literature Review and Purpose of Study

Self compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural member. Self compacting concrete contain high amount of cement which cause high shrinkage (changed in strain due to loss of moisture) and can cause high creep(changed in strain due to loading). There are many empirical formulas to predict creep of self compacting concrete such as from JSCE codes or ACI codes or Dischinger's equation, etc. However, those empirical formulas have some limitation on the cement content such as the limitation of cement content for JSCE and ACI codes must be less than 500kg/m^3. But self compacting concrete contains the amount of cement higher tha n 500kg/m^3, then this study will clarify whether JSCE or ACI codes can predict of self compacting concrete or not. And this study will find a relationship of creep of self compacting concrete at the early age with vary water-cement ratios, stress-strength ratios and powder contents.

Chapter 2

EXPERIMENTAL PROGRAM

2.1 Test Variables

To study the effect of creep using Self-Compacting Concrete (Low Heat Cement) compared with Normal Concrete (Low Heat Cement), concrete were compressed with five levels of stress to strength ratios: 10%, 20%, 30%, 40% and 60% with varying water to cement ratios of 0.25, 0.3, 0.5 and 0.7: vary powder content in 250, 400, 550 kg/m^3. In this studied unseal-load, seal-load, unseal-unload, and unseal-unload conditions were examined.

2.2 Material and mix proportions

The chemical composition and physical properties of Low Heat Cement (LH) and Ordinary Portland Cement (OPC) are given in Table 2.2.1 and Table 2.2.2. Table 2.2.3 gives the mix composition and strength characteristics of studied concrete.

Table 2.2.1 Chemical Composition

Chemical Analysis, percent	LH-Analysis Results	OPC-Analysis Results
Silica (SiO_2)	25.4	21.69
Alumina (Al_2O_3)	3.5	5.89
Iron oxide (Fe_2O_3)	3.5	2.8
Calcium oxide (CaO)	62.5	63.15
Magnesium oxide (MgO)	1.1	1.87
Sulfur trioxide (SO_3)	2.2	2.05
Available alkalikes as Na_2O	0.22	0.5
K_2O	0.38	0.41
Physical Analysis	Analysis Results	
Fineness (g/cm$_2$)	3248	3400
Compressive strength at 3 days MPa	11.6	27.5
Compressive strength at 7 days MPa	17	42.8
Compressive strength at 28 days MPa	40.5	63.8

Table 2.2.2 Specific gravity of materials

materials	Specific Gravity
Ordinary Portland Cement	3.15
Low Heat Cement	3.27
Limestone	2.7
Sea Sand	2.58
Crushed sand	2.57
Coarse Aggregate	2.68
Fine Aggregate	2.64

Table 2.2.3 Mix Proportion

No.	Type	w/p	w/c	% replacement	cement	Ls	water	sand	gravel	SP
					(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)
1	Normal	0.94	0.3	0.5	485	2	144	758	1039	4.877
2	Normal	0.94	0.5	36.7	291	169	144	758	1039	4.599
3	SCC	0.94	0.25	0.5	597	3	179	774	848	9.295
4	SCC	0.94	0.3	22.6	448	131	179	774	848	6.94
5	SCC	0.94	0.5	36.7	358	207	179	774	848	5.938
6	SCC	0.94	0.7	53.6	259	293	179	774	848	4.91

Sealed condition, Air-dried condition, Stress Strength Ratios of 0.1, 0.2, 0.3, 0.4 and 0.6 are all applied to all mix proportions.

Table 2.2.4 Properties of each mix proportion

No.	Type	w/p	w/c	Slump flow	Funnel speed	Box test	Temp.	Slump height
				(mm. X mm.)	(sec.)	(cm.)	(celcius)	(cm.)
1	Normal	0.94	0.3	-	-	-	23.8	13.9
2	Normal	0.94	0.5	-	-	-	22.8	18.4
3	SCC	0.94	0.25	650x640	11.3	32.2	22.1	-
4	SCC	0.94	0.3	668x670	15.4	31.5	22.8	-
5	SCC	0.94	0.5	670x663	15.9	32.3	22.3	-
6	SCC	0.94	0.7	658x660	15.2	31.2	23.2	-

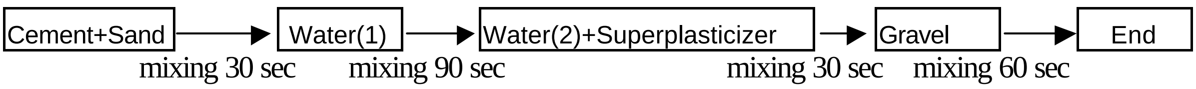


Figure 2.2.1 Mixing procedure of self-compacting concrete

2.3 Properties of fresh concrete

The slump of the control normal concrete was about 100-120 mm. The slump flow of the self-compacting concrete was in the range of 600-680mm, the funnel test flow times were in the range of 10-15 seconds and concrete can fill the box test up to 28-32 cm in height. All self-compacting concrete mixtures presented a slump flow between 600-680 mm, which is an indication of a good workability.

2.4 Specimen preparation

As shown in Table 2.3.1, four types of concrete specimens were prepared for experiments on moisture diffusion, self-desiccation. For measuring the internal relative humidity in concrete, both drying specimens and sealed specimens were used. Another specimen was prepared for measuring the total moisture loss of concrete during drying.

At the age of 1 day, the mould was removed from test specimens. After demoulded, test specimens were exposed to a constant temperature of 20°C and constant relative humidity of 60%.

A total of 42 specimens in the size of 10 cm x 10 cm x 40 cm in length, were studied. Double layers of polyethylene sealed half the number of the specimens. No moisture loss was observed from the sealed specimens during the study. The drying specimens were placed in the temperature controlled room at 20°C and RH = 60 after 1 day of curing in a steel mold.

Table2.3.1 Type and specimen size		Specimen size (cm)
Objective	Type of Specimen	
Measure of relative humidity in concrete	Seal with unload specimen	10x10x40
Measure of moisture loss	Unseal with unload specimen	10x10x40
Measure of relative humidity under loading condition	Seal with load specimen	10x10x40
Measure of moisture loss under loading condition	Unseal with load specimen	10x10x40

2.5 Experimental Method

Both air-cured and sealed concrete were studied. The creep specimens were placed in a new testing spring-loading device. The loading was 10%, 20%, 30%, 40% and 60% of the current strength, and was applied by about 1Mpa/sec. From 24 hours' age parallel studies were done on shrinkage. The total strain in the creep studies was reduced by the shrinkage strain in order to obtain the creep strain. During the creep test the loading was held constant. The compressive strength was obtained at 1, 3 and 7 days' age, three cylinders of each concrete mix composition. The creep and shrinkage measurement device was mechanical and calibrated.

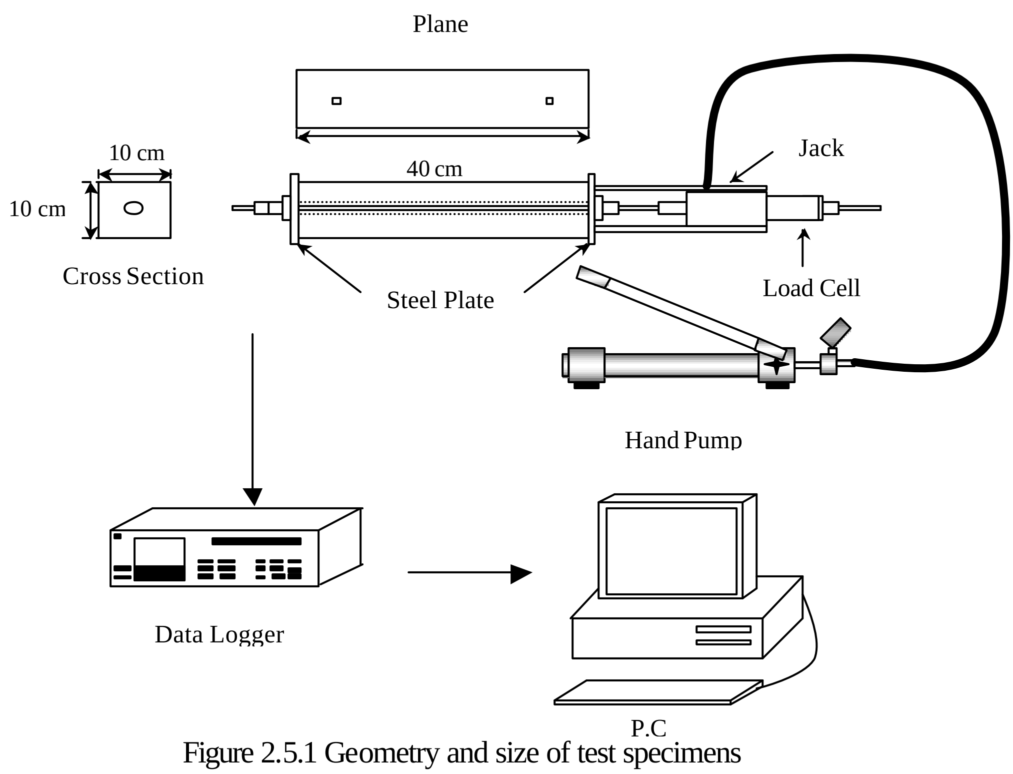


Figure 2.5.1 Geometry and size of test specimens

2.6 Experimental details and procedure

As shown in Figure 2.5.1, the exposed volume of the drying specimen is 10x10x40 cm^3. To measure the variation of moisture loss due to different stress to strength ratio, controlled specimen and sealed specimens were also used.

The concrete was mixed in a laboratory pan mixer. Four specimens were cast at a time in cast-iron molds. This procedure was chosen after some trial and error tests were performed for best results. The next day after casting, the specimens were demoulded and their compressive strength was determined from an average of 3 specimens to determine the required pressure to be applied in the creep tests. Four specimens were loaded for each stress/strength ratio, two were sealed and the other two are unsealed. Creep strain was measured regularly every six hours up to a total period of 7 days.

TEST RESULT AND ANALYSIS

3.1 Creep of self compacting concrete and normal concrete

In this part will focus on creep of self compacting concrete and normal concrete with varieties of stress strength ratio, powder content and water-cement ratio. First, I will start with the comparison of creep of self compacting concrete to normal concrete under sealed and unsealed conditions. Second part will be the comparison of creep of self compacting concrete under sealed, unsealed condition with vary stress-strength ratios. Third part will be the comparison of creep of self compacting concrete under sealed, unsealed condition with vary powder contents. Fourth part will be the comparison of creep of self compacting concrete under sealed, unsealed condition with variety water-cement ratio. Fifth part will be the comparison of test result with JSCE and ACI codes. And will end this part with the regression analysis.

3.1.1 Creep of normal concrete and self compacting concrete under unseal condition

Creep strain was taken to be equal to the total strain less shrinkage and the elastic strain determined after unloading the specimens. Shrinkage was determined from companion specimens made from the same mix as that used to determine the creep. The specimens were left at the controlled room temperature of 20°C and the relative humidity of 60%. Shrinkage was measured at the same time as the creep specimens. The shrinkage of the sealed specimens was found to be little when compared to the total creep as shown in Figure 3.1.3 and Figure 3.1.6

Figure 3.1.1 and Figure 3.1.4 show the comparison of creep of self compacting concrete and normal concrete. As show in the graphs that creep of self compacting concrete is higher than normal concrete due to the fact that normal concrete has higher compressive strength when comparison to self compacting concrete. (Show in Figure 3.1.7)

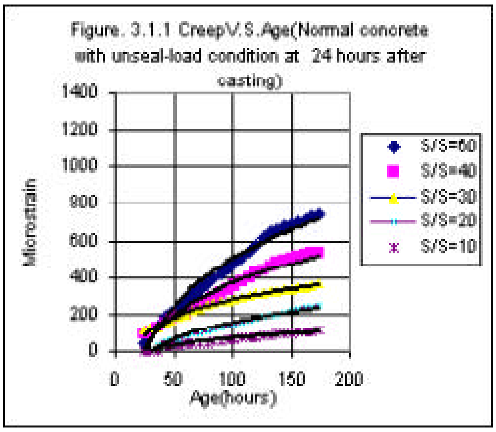


Figure. 3.1.1 CreepV.S.Age(Normal concrete with unseal-load condition at 24 hours after casting)

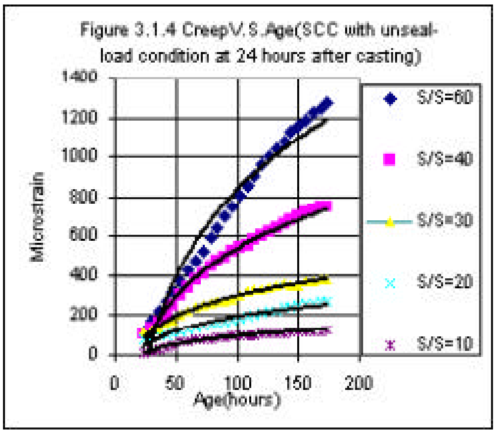


Figure 3.1.4 CreepV.S.Age(SCC with unseal-load condition at 24 hours after casting)

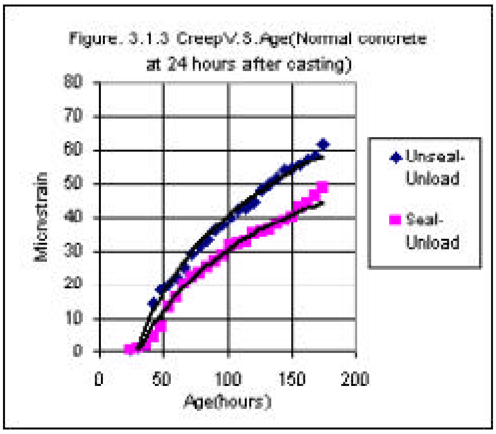


Figure. 3.1.3 CreepV.S.Age(Normal concrete at 24 hours after casting)

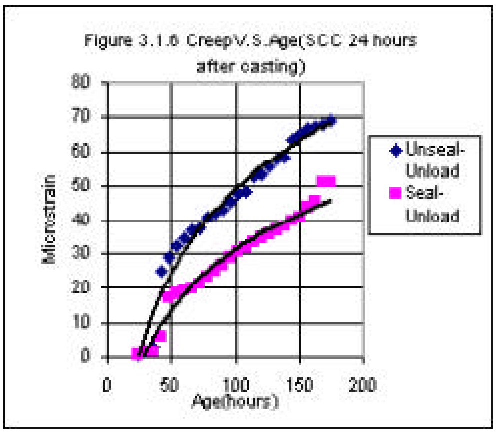


Figure 3.1.6 CreepV.S.Age(SCC 24 hours after casting)

3.1.2 Creep of normal concrete and self compacting concrete under seal condition

In Figure 3.1.2 and Figure 3.1.5 show the comparison of normal concrete and self compacting concrete under seal condition. The result still show that creep of self compacting concrete under seal condition has a higher creep value when comparison to normal concrete at every different stress strength ratios(stress strength ratio vary from 0.1 to 0.6).

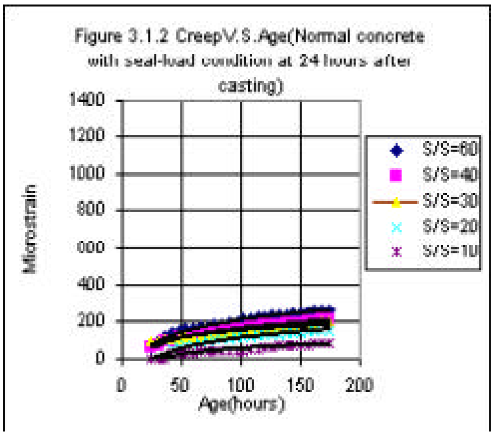


Figure 3.1.2 CreepV.S.Age(Normal concrete with seal-load condition at 24 hours after casting)

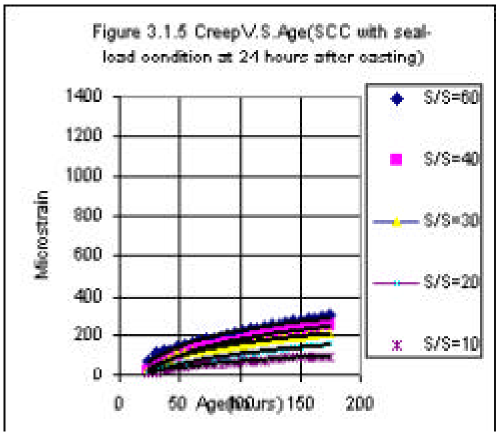


Figure 3.1.5 CreepV.S.Age(SCC with seal-load condition at 24 hours after casting)

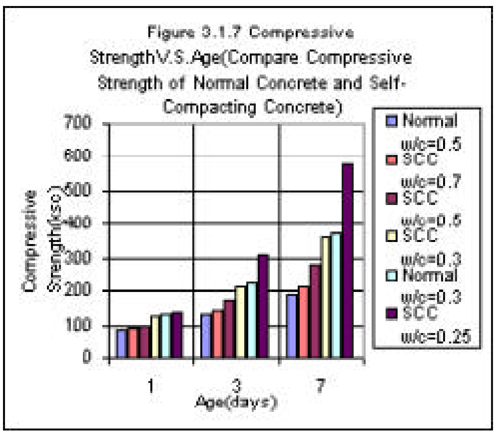


Figure 3.1.7 Compressive StrengthV.S.Age(Compare Compressive Strength of Normal Concrete and Self-Compacting Concrete)

As shown in the graph, normal concrete in this study produced low creep when compared to self-compacting concrete. The reason is that first, this study used the low water to cement ratio which make the strength of normal concrete a little higher when compared to self-compacting concrete as shown in Figure 3.1.7. Second, the porosity in normal concrete is denser when compared to self-compacting concrete.

The shapes of the curves for unsealed and sealed cases are similar. Creep was found to increase as the stress/strength ratio increased. Creep of both self-compacting concrete and normal concrete were found to vary linearly with an increase in stress/strength ratio. The increase in stress/strength ratio will result in higher in creep of unsealed concrete.

3.1.3 Effect of stress strength ratio on creep

The creep versus stress/strength ratio for both concretes, self-compacting concrete and normal concrete at the ages of 1, 3 and 7 days is plotted in Figure 3.1.8 to Figure 3.1.11. The higher stress/strength ratios the higher creep will be obtained in a linear relationship.

The creep strain of SCC and normal concrete under unseal condition give higher value of creep when comparison to seal condition.

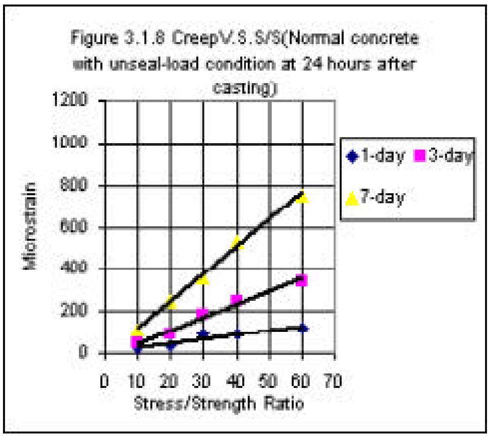


Figure 3.1.8 CreepV.S.S/S(Normal concrete with unseal-load condition at 24 hours after casting)

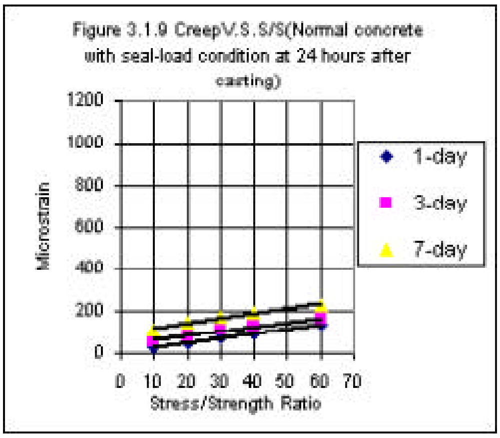


Figure 3.1.9 CreepV.S.S/S(Normal concrete with seal-load condition at 24 hours after casting)

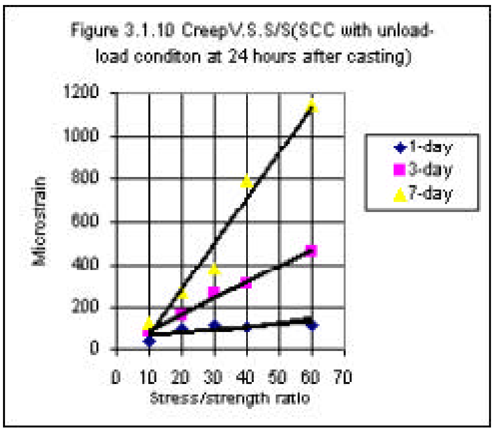


Figure 3.1.10 CreepV.S.S/S(SCC with unload-load conditon at 24 hours after casting)

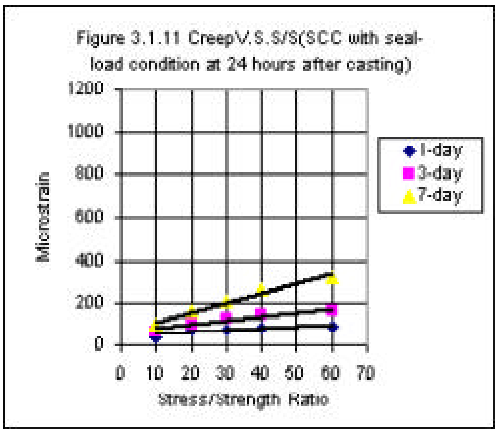


Figure 3.1.11 CreepV.S.S/S(SCC with seal-load condition at 24 hours after casting)

The value of creep strain in SCC (both of unseal and seal conditions) is higher than that of normal concrete as shown in the above figure. From the reason that shrinkage of SCC is higher than normal concrete that give value of creep of SCC to be higher than normal concrete as mentioned in 3.1.1 and 3.1.2

3.1.4 Effect of powder content on creep

Creep versus powder content by weight (%) of self-compacting concrete at the ages of 1, 3 and 7 days are plotted in Figure 3.1.12 to Figure 3.1.17. The higher powder content will result in higher creep value will be obtained in a linear relationship.

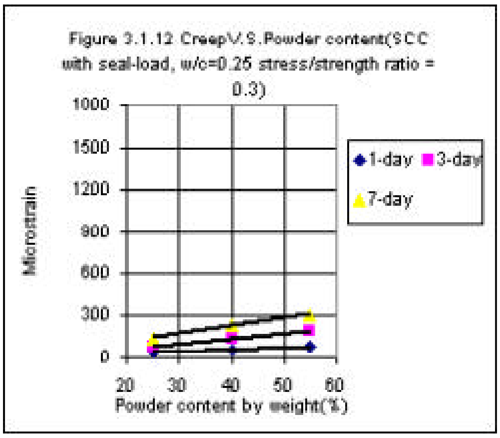


Figure 3.1.12 CreepV.S.Powder content(SCC with seal-load, w/c=0.25 stress/strength ratio = 0.3)

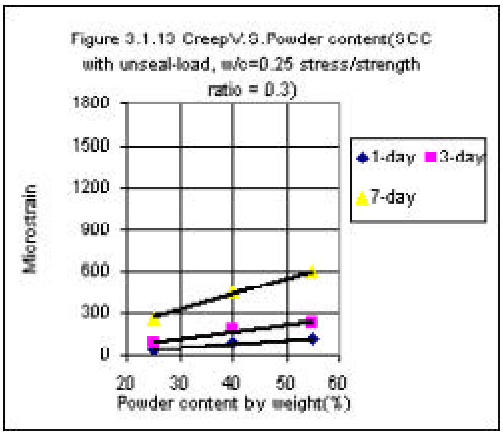


Figure 3.1.13 CreepV.S.Powder content(SCC with unseal-load, w/c=0.25 stress/strength ratio = 0.3)

The creep of SCC under seal load condition has a creep value lower than that of unseal load conditions as shown in the Figure 3.1.14 to Figure 3.1.17 due to the moisture loss to the environment.

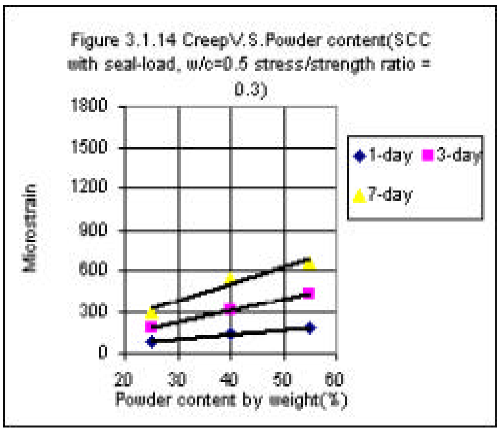


Figure 3.1.14 CreepV.S.Powder content(SCC with seal-load, w/c=0.5 stress/strength ratio = 0.3)

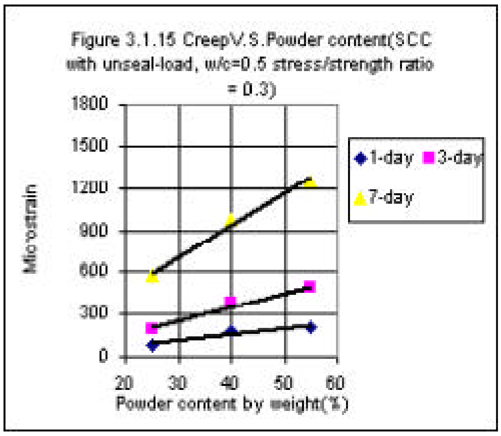


Figure 3.1.15 CreepV.S.Powder content(SCC with unseal-load, w/c=0.5 stress/strength ratio = 0.3)

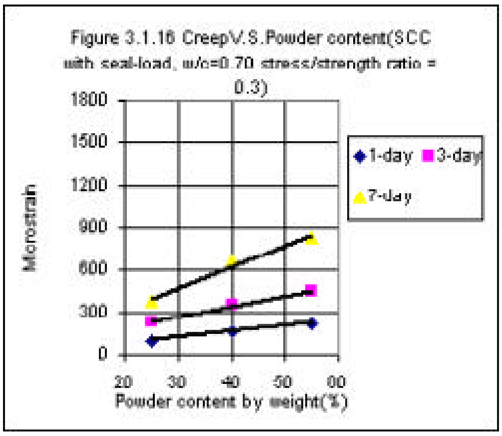


Figure 3.1.16 CreepV.S.Powder content(SCC with seal-load, w/c=0.70 stress/strength ratio = 0.3)

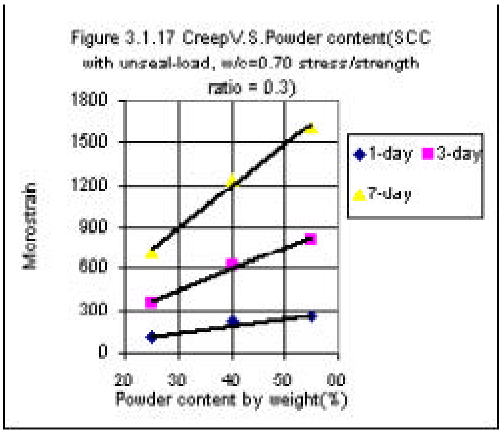


Figure 3.1.17 CreepV.S.Powder content(SCC with unseal-load, w/c=0.70 stress/strength ratio = 0.3)

3.1.5 Effect of water-cement ratio on creep

Graphs in figure 3.1.18 and Figure 3.1.19, show the relationship between creep and powder content by weight (%) and water to cement ratio. The higher powder content, water-cement ratio will result in higher creep value. The creep value using the water to cement ratio of 0.50 is about double of creep value of water to cement ratio of 0.25

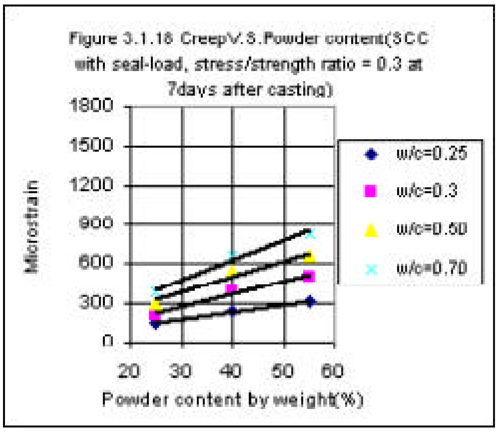


Figure 3.1.18 CreepV.S.Powder content(SCC with seal-load, stress/strength ratio = 0.3 at 7days after casting)

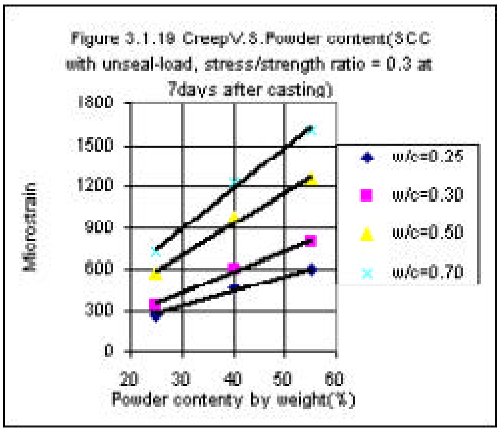
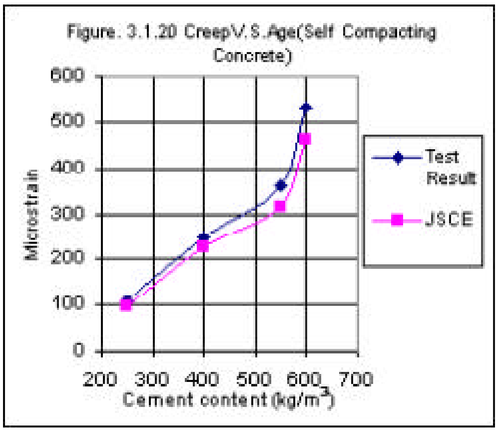


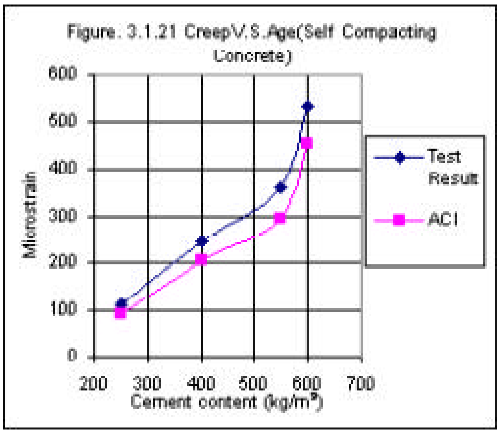
Figure 3.1.19 CreepV.S.Powder content(SCC with unseal-load, stress/strength ratio = 0.3 at 7days after casting)

The higher water-cement ratios will result in higher creep value in seal and unseal load condition of SCC. And the higher powder content will result in higher creep also in a linear relationship.

3.1.6 Comparison of Test Result with Codes

From the test result above: The comparison of creep between test result and JSCE or ACI codes are show below:





From the fact that JSCE and ACI codes have some limitation of the creep prediction such as for JSCE code, cement content has to be less than 500 kg/m^3 and for ACI code, creep coefficient of concrete has to be less than 1.3. For the cement higher than the codes, the error does exist such as comparison between test result with JSCE or ACI codes give the value different to be 13% and 15% respectively. Then for predicting creep by using JSCE or ACI codes can not be use in self compacting concrete that has a cement content above the codes limitations.

3.1.7 Relationship between sealed and unsealed condition of SCC and normal concrete

Creep was found to vary linearly with an increase in stress/strength ratio, that is the stress/strength ratio increases, creep of concrete would also increase. A comparison was carried out between the creep of concretes with self-compacting concrete and normal concrete as shown in Table 3.1.1 to Table 3.1.3 at different ages of 1,3 and 7 days.

Table 3.1.1 Creep ratios for unsealed of SCC compared with Normal Concrete

Age,	Stress/strength ratio, percent					
days	10	20	30	40	60	**Average**
1	1.16	1.15	1.06	1.08	1.1	**1.11**
3	1.27	1.31	1.57	1.79	1.99	**1.6**
7	1.12	1.24	1.32	1.58	1.74	**1.4**
Average	**1.18**	**1.23**	**1.32**	**1.48**	**1.61**	**1.37**

Table 3.1.2 Creep ratios for sealed of SCC compared with Normal Concrete

Age,	Stress/strength ratio, percent					
days	10	20	30	40	60	**Average**
1	1.04	1.07	1.05	1.09	1.1	**1.07**
3	1.06	1.1	1.03	1.1	1.14	**1.09**
7	1.05	1.09	1.1	1.13	1.2	**1.15**

Average		**1.05**	**1.08**	**1.06**	**1.11**	**1.15**	**1.09**

Table 3.1.3 Creep ratios for unsealed/sealed using SCC and Normal Concrete

Type	Age,	Stress/strength ratio, percent					
	days	10	20	30	40	60	**Average**
Low	1	0.97	0.98	0.98	0.99	1.04	**0.99**
heat	3	1.4	1.79	2.03	2.39	2.63	**2.05**
concrete	7	1.23	1.6	1.87	2.79	3.87	**2.27**
Average		**1.2**	**1.46**	**1.63**	**2.06**	**2.52**	**1.77**
Ordinary	1	1.07	1.05	0.97	0.98	1	**1.02**
portland	3	1.7	1.84	1.91	2.01	2.2	**1.93**
cement	7	1.17	1.5	1.82	2.6	3.38	**2.09**
Average		**1.31**	**1.46**	**1.57**	**1.86**	**2.19**	**1.68**

The ratio of creep of unsealed/sealed concrete at different ages of 1, 3 and 7 days are shown in Table 3.1.3. It can be seen that the average value was found to be about 1.77 for Self-Compacting Concrete and 1.68 for Normal Concrete. This ratio tended to increase as age increased for both concretes.

3.1.8 Regression Analysis

The empirical formula to predict creep of self compacting concrete that have a cement contents above JSCE or ACI codes at difference water-cement ratios, stress-strength ratios and time domains can be expressed in the Table 3.1.4 to Table 3.1.7

Regression analysis was carried out for drying shrinkage and autogenous shrinkage of both concrete, normal concrete and self-compacting concrete, as a function of time using exponential, logarithmic, and power function. A summary of the equations and their coefficients of correlation are shown in Table 3.1.4 and Table 3.1.5. The logarithmic and power functions were found to give the best fit for both concretes

Table 3.1.6 and Table 3.1.7 shows equations of creep as a function of time and their coefficients of correlation using exponential, logarithmic, and power functions. The power function and logarithmic functions were found to give the best fit for all curves.

Table 3.1.4 Constants A and B and coefficient of Correlation R for equations of shrinkage versus age using normal concrete

	Exponential			Logarithmic			Power		
Type I	R	A	B	R	A	B	R	A	B
Unsealed	0.87	2.77	0.022	0.99	109.3	32.51	0.98	0.008	2.1
Sealed	0.87	1.997	0.0226	0.98	88.65	25.81	0.98	0.009	2.25

Exponential $S = A \times eBt$ S = Shrinkage strain x 10^{-6}

Logarithmic $S = A+B \times LN(t)$ $A = S/S$; $B = W/C$

Power $S = A \times t^B$ t = time (hours)

R = Regression (best fit is R=1.00)

Table 3.1.5 Constants A and B and Coefficients of Correlation R for equation of shrinkage versus age using self-compacting concrete

	Exponential			Logarithmic			Power		
Type I	R	A	B	R	A	B	R	A	B
Unsealed	0.85	4.59	0.019	0.98	112	35.02	0.97	0.007	1.86
Sealed	0.86	2.69	0.0203	0.97	85.4	25.37	0.98	0.005	1.89

Table 3.1.6 Constants A and B coefficient of Correlation R for equations of creep versus age using normal concrete.

	Stress/ strength ratio,	Exponential			Logarithmic			Power		
Type I	percent	R	A	B	R	A	B	R	A	B
Unsealed and Load	10	0.87	4.11	0.023	0.99	196	57.69	0.99	0.003	2.172
	20	0.83	8.06	0.022	0.99	351	131.53	0.99	0.003	2.306
	30	0.88	121.6	0.007	0.99	448	137.27	0.99	15.52	0.62
	40	0.89	96.59	0.011	0.99	811	257.05	0.99	4.08	0.96
	60	0.89	108	0.013	0.99	1219	373.39	0.99	2.82	1.093
Average		0.872			0.99			0.99		
Seal and Load	10	0.82	3.83	0.022	0.97	141	42.67	0.98	0.003	2.07
	20	0.84	6.15	0.025	0.97	253	79.14	0.98	0.002	2.32
	30	0.84	84.1	0.005	0.98	400	84.22	0.98	23.36	0.39
	40	0.86	77.1	0.006	0.99	472	92.34	0.99	12.28	0.56
	60	0.86	79.13	0.007	0.99	502	98.12	0.99	17.03	0.593
Average		0.844			0.98			0.984		

Table 3.1.7 Constants A and B and coefficient of Correlation R for equations of creep versus age using self-compacting concrete.

	Stress/ strength ratio,	Exponential			Logarithmic			Power		
Type I	percent	R	A	B	R	A	B	R	A	B
Unsealed and Load	10	0.87	4.11	0.023	0.99	196	57.69	0.99	0.003	2.172
	20	0.83	8.06	0.022	0.99	351	131.53	0.99	0.003	2.306
	30	0.88	121.6	0.007	0.99	448	137.27	0.99	15.52	0.62
	40	0.89	96.59	0.011	0.99	811	257.05	0.99	4.08	0.96
	60	0.89	108	0.013	0.99	1219	373.39	0.99	2.82	1.093
Average		0.872			0.99			0.99		
Seal and	10	0.82	3.83	0.022	0.97	141	42.67	0.98	0.003	2.07
	20	0.84	6.15	0.025	0.97	253	79.14	0.98	0.002	2.32
	30	0.84	84.1	0.005	0.98	400	84.22	0.98	23.36	0.39

Load	40	0.86	77.1	0.006	0.99	472	92.34	0.99	12.28	0.56
	60	0.86	79.13	0.007	0.99	502	98.12	0.99	17.03	0.593
Average		0.844			0.98			0.984		

Exponential $C = A \times e^{Bt}$ $C = \text{creep} \times 10^{-6}$

Logarithmic $C = A + B \times LN(t)$ A=S/S ; B = W/C

Power $C = A \times t^{B}$ t = time (hours)

R= Regression (best fit is R=1.00)

From 3.2 to 3.6 will explained about the factors that cause concrete to creep such as moisture loss of concrete from autogenous shrinkage, drying shrinkage and chemical shrinkage.

3.2 Relationship between shrinkage and creep

3.2.1 Effect of moisture loss on creep

Moisture loss from concrete specimens to the surroundings is related directly to moisture diffusion and is not affected directly by self-desiccation. Figure 3.2.1 shows the moisture loss of concrete with various stress/strength ratios. In Figure 3.2.1 the moisture loss of the concrete is represented as moisture loss in weight per unit volume (g/cm^3). The moisture loss of concrete increase linearly as the stress/strength ratio increases. This is because concrete subjected to higher stress gives higher creep strain.

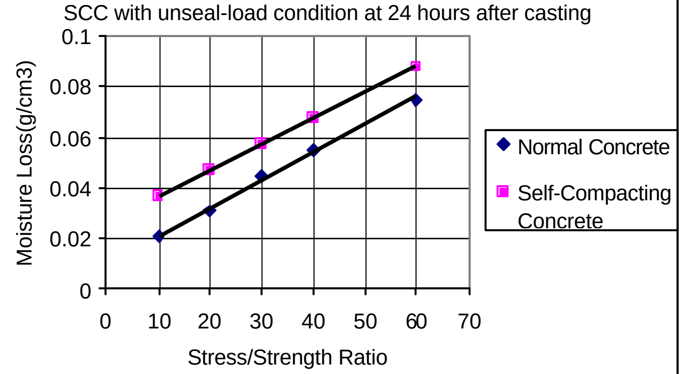
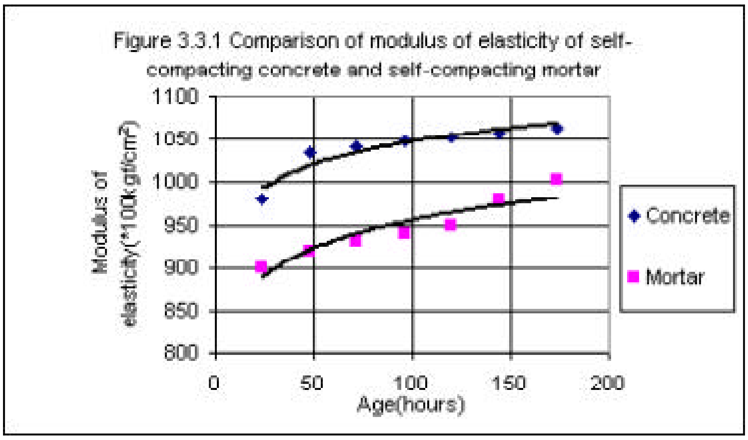


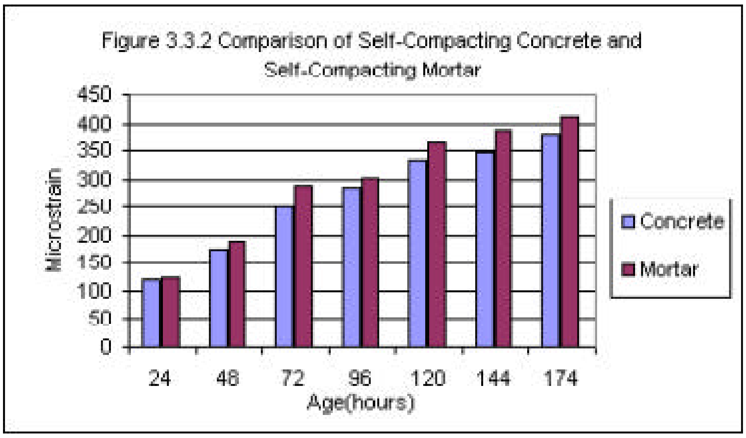
Figure 3.2.1Compare moisture loss of normal concrete and SCC with unseal-load condition at 24 hours after casting

3.2.2 Effect of aggregate content on autogenous shrinkage

The aggregate in the concrete restrained the shrinkage substantially compared with the free shrinkage that occurred in cement paste.

Inclusion of aggregate leads to a reduction in autogenous shrinkage, as in the case of drying shrinkage. This is due to the reduction in the cement paste content and to the elastic deformation of aggregate due to modulus of elasticity of self compacting concrete and self compacting mortar, which partly confines the shrinkage deformation of the paste as such, shown in Figure 3.3.1 and Figure 3.3.2





The test results show that increasing the cement content at constant water content or equivalently decreasing the aggregate content increasing the creep strain.

3.2.3 Relationship between autogenous shrinkage and drying shrinkage

Drying shrinkage and autogenous shrinkage of concretes with extremely low water-cement ratios are nearly the same. In other words, the shrinkage that has been regarded as the result of drying actually occurs independently of drying. Meanwhile, the weight does reduce, indicating that drying does not cause the shrinkage of such concretes with very low W/C. According to test results, the drying shrinkage takes place about 0.0005g/cm^3 for self-compacting concrete and 0.0015g/cm^3 for normal concrete, which are very low, negligible. Autogenous shrinkage takes place about 0.042g/cm^3 for self-compacting concrete and 0.023g/cm^3 for normal concrete. The difference between drying shrinkage and autogenous shrinkage increases as the water-cement ratio increases as shown in Figure 3.2.4 [14].

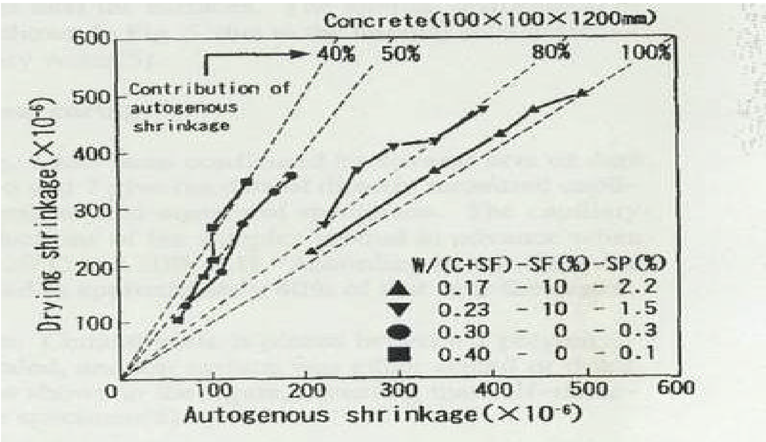


Figure. 3.2.4 Relationship between autogenous shrinkage and drying shrinkage

3.2.4 Autogenous drying near the surfaces during seal curing

The magnitude of the autogenous shrinkage also was dependent on the type of the cement [14]. Low-alkali cement causes less autogenous shrinkage than normal alkali cement; a slow hardening of cement has less shrinkage than a normal concrete using ordinary portland cement[14].

Autogenous shrinkage occurs as the result of the chemical reactions that take place during cement hydration. It can be significant in concrete with a very low water-cementitious materials ratio. It is possible for such concrete to shrink without the loss of any water to the environment. This is because, in general, it is accepted that the loss of water from the paste fraction of concrete due to external factors generates negative capillary pressures that cause the volume of the paste to contract, hence the shrinkage.

The water content distribution as shown in Figure 3.2.5 [14] has been confirmed by several sets of data measured on seal-cured specimens. The capillary water content is determined from the weight reductions of the samples ground in advance when they are dried to a constant weight in a room at temperature of 20°C and relative humidity of 50%.

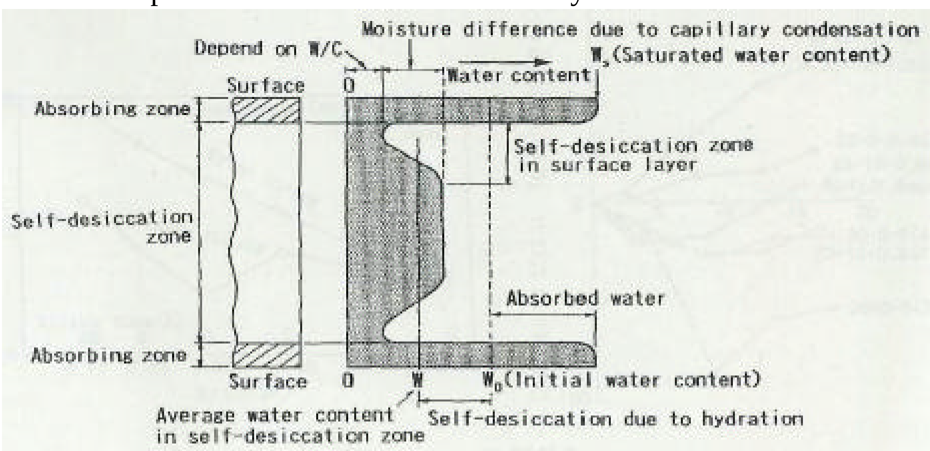


Figure 3.2.5 Moisture distribution of underwater specimen

A comparison between self-compacting concrete and normal concrete showed that self-compacting concrete obtained lower strength when compared to normal concrete. Also, the creep coefficient of self-compacting concrete is higher when compared to normal concrete.

It is conceivable that a very low water-cement ratio tends to lead to discontinuous capillary water. This is, however, a problem of balance between the volume of water transferred by capillary tension and the absolute volume shrinkage due to hydration.

The very strong increase of the autogenous shrinkage at the beginning of the hardening process can be related to the fact that at this early stage of the hardening process, the elastic modulus has only developed minorly. The volumetric contraction of the microstructure will then experience hardly any restraint of the stiffness of the paste. Consequently, large deformations can easily occur. For higher water/cement ratios, this contraction force will be much smaller so that the volumetric contraction of the microstructure will be less pronounced at that particular stage of the hardening process.

3.2.5 Chemical Shrinkage

Chemical shrinkage is a volume reduction due to the fact that resulting volume of reaction product formed by water/cement reaction is smaller than the volume of original constituents [19].

The chemical equations for each compound with coexisting gypsum are as follows;

$$2C_2S + 6H_2O \longrightarrow C_3S_2H_3 + 3Ca(OH)_2 \quad (11)$$
$$2C_2S + 4H_2O \longrightarrow C_3S_2H_3 + Ca(OH)_2 \quad (12)$$
$$C_3A + 3(CaSO_4 2H_2O) + 26H_2O \longrightarrow C_3A3CaSO_4 32H_2O \quad (13)$$
$$2C_3A + C_3A3CaSO_4 32H_2O + 4H_2O \longrightarrow 3[C_3ACaSO_4 12H_2O] \quad (14)$$
$$C_3A + Ca(OH)_2 + 12H_2O \longrightarrow C_3ACa(OH)_2 12H_2O \quad (15)$$
$$C_4AF + 3(CaSO_4 2H_2O) + 27H_2O \longrightarrow C_3(AF)3CaSO_4 32H_2O + Ca(OH)_2 \quad (16)$$
$$2C_4AF + C_3(AF)3CaSO_4 32H_2O + 6H_2O \longrightarrow 3[C_3(AF)CaSO_4 12H_2O] + 2Ca(OH)_2 \quad (17)$$
$$C_4AF + 10H_2O + 2Ca(OH)_2 \longrightarrow C_3AH_6 - C_3FH_6 \text{ (solid solution)} \quad (18)$$

At the earliest stage the reaction of C_3A will form ettringite as in equation (13) and at a later stage it will transform into monosulfoaluminate as in (14) and C_3A remaining from the shortage of gypsum will follow equation (15). The absolute volumes of all compounds are decreased after reaction, as is understood form each equation. An example of the shrinkage calculation as follows:

$$2C_2S + 6H_2O \longrightarrow C_3S_2H_3 + 3Ca(OH)_2 \quad (19)$$

	$2C_2S$	$6H_2O$	$C_3S_2H_3$	$3Ca(OH)_2$
Weight	456.6	108.1	342.5	222.3
Specific gravity	3.27	1.0	2.71	2.24
Volume	139.63	108.1	126.38	99.24
Sum volume	247.73		225.62	

Chemical Shrinkage $$\left(\frac{247.73-225.62}{247.73}\right)\times 100 = 8.93\%$$

Densities of each compounds used in the calculation were adopted from [18]. The degrees of hydration at each reaction time were adopted from DUCOM at early age of hydration. The total shrinkage of cement paste at each reaction time was obtained from the sum of the shrinkage of each compound obtained from the mineral composition, the shrinkage ratio and the degree of hydration of each compound. The volume change of gypsum was neglected in the calculation.

The results of the test show that, the autogenous shrinkage at 7 days is about 0.6%, and from [19] at the age of one year, autogenous shrinkage is about 1.3%. As time passed by the higher value of autogenous shrinkage strain can be obtained, but the shrinkage strain value is quite low when compared to chemical shrinkage.

The value of autogenous shrinkage strain compared to chemical shrinkage strain is lower from the reason that bleeding water takes effect. The water is absorbed in the cement paste after a certain period. If water is further fed on the top surface, the water continues to be absorbed, providing that the level of bleeding water in set cement is lower than the top surface[20]. The amount of the absorbed water corresponds to the chemical shrinkage after some point of time when the bleeding water disappears from the top surface, and is the volume change can be measured. When the water transfer is interrupted by a rubber film, the chemical shrinkage is measured while the bleeding water exists on the top surface, however, when the water level becomes lower than the cement surface, autogenous shrinkage thereafter is measured. The time when the level of bleeding water becomes lower than the top surface of water normally does not coincide with the setting time. The Le Chatelier method determined the total of the hardening shrinkage up to a very early age and the autogenous shrinkage after a certain point of time. In this sense, the data after a certain point of time is technically of little use, because chemical shrinkage at very early age is normally much larger than autogenous shrinkage.

In order to predict creep accurately, shrinkage that causes creep has to be investigate precisely. There are many types of shrinkage such as drying shrinkage, autogenous shrinkage, chemical shrinkage that are all explained in the above. Self compacting concrete contain high amount of cement that can cause high shrinkage age and high creep. At this moment, the empirical formulas that use to predict creep or shrinkage are still have some limitation such as JSCE or ACI codes limit the amount of cement to be less than 500kg/m^3. However, self compacting concrete contain the amount of cement more than 500kg/m^3, as a result JSCE or ACI codes can not use to be predict creep of self compacting concrete as shown in 3.1. Moreover, creep of self compacting concrete is higher than creep of normal concrete roughly about 1.4 times. One of the most important things that have to keep in mind about creep is that high amount of cement will give higher creep value as an explained in this chapter.

Chapter 4

CONCLUSIONS AND DISCUSSIONS

Creep tests of concrete must be rigorously standardized, because creep is a major factor of the mechanical behavior of the concrete material. It depends on many factors, and is very sensitive to air-dried conditions and environmental conditions. The need to establish robust and usable data bases leads to fixing a certain number of the parameters of the test. From this study some conclusion can be made:

1. The JSCE and ACI codes have limit the amount of cement content to be less than 500kg/m^3 but in fact self compacting concrete contain the amount of cement higher than 500kg/m^3. Then as a result JSCE and ACI codes give creep value under estimation in term of creep value when compared to the test result by 13% and15% respectively.
2. The value of creep of self-compacting concrete is larger than JSCE or ACI codes design value.
3. The higher water-cement ratios, stress-strength ratios, powder contents for self compacting concrete will result in higher creep in linear relationship.
4. The creep of unsealed self-compacting concrete was found to be about 1.4 times larger than normal concrete.
5. The creep of sealed self-compacting concrete was found to be about 1.1 times larger than normal concrete.

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RECOMMENDATIONS FOR FURTHER STUDY

1. Investigate the effect of cement replacement by fly ash, slag or the globalization is required.
2. Investigate the effect of applying light weight aggreagte, fiber aggregate in the self-compacting concrete.

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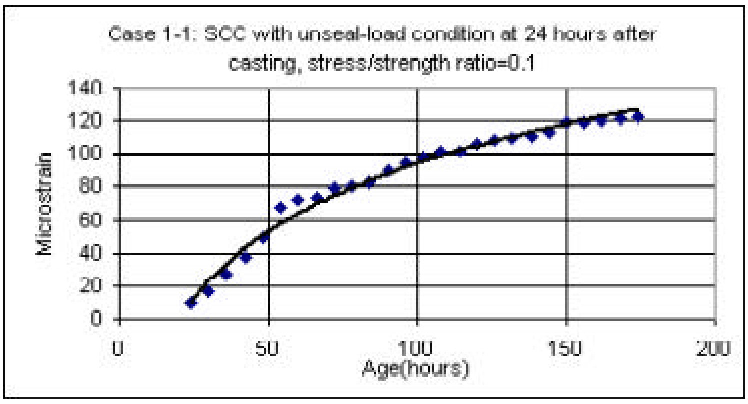
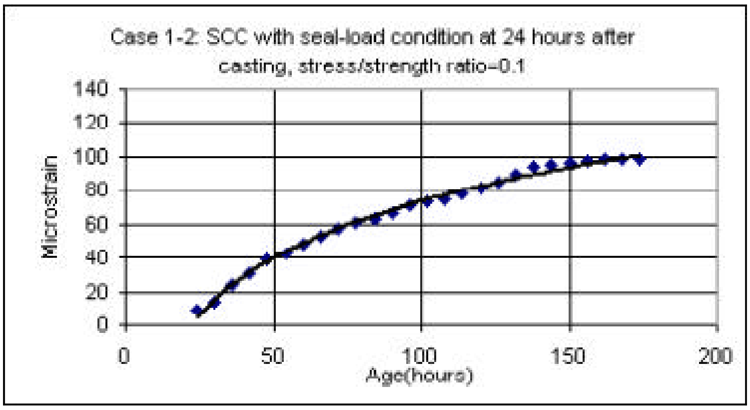
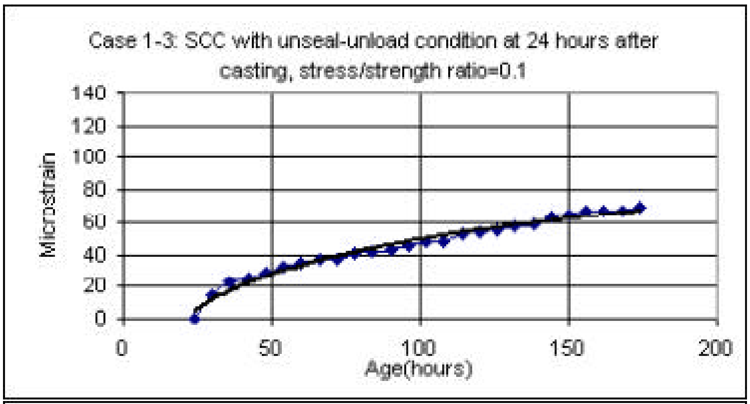
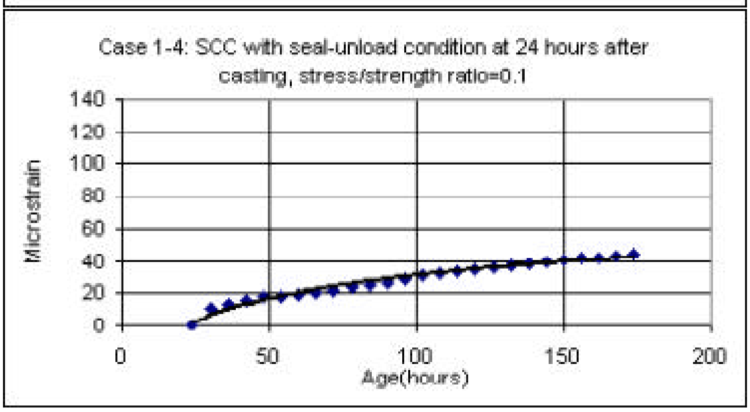
Appendix A: Total Strain, unseal-load condition, seal-load condition unseal-unload condition and seal-unload condition

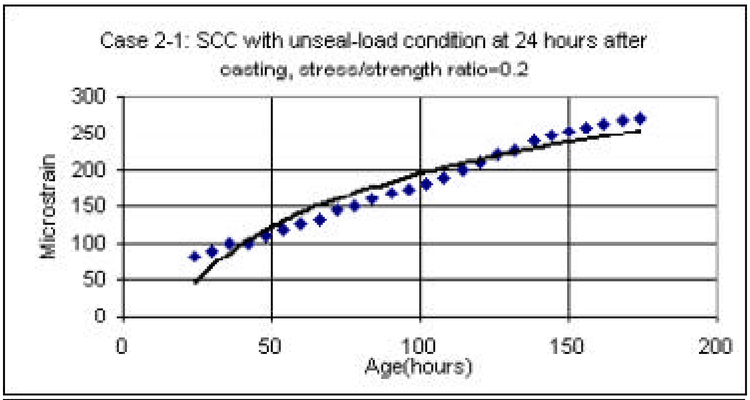
Appendix B: Creep Coefficient

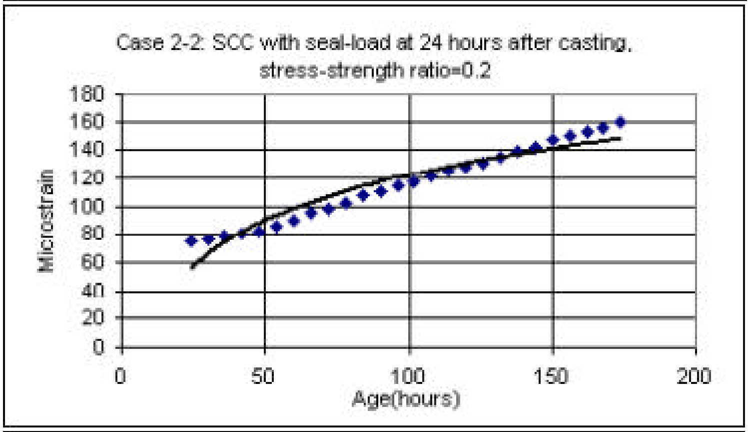

Case 1-1: SCC with unseal-load condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
0
20
40
60
80
100
120
140
0
50
100
150
200
Age(hours)

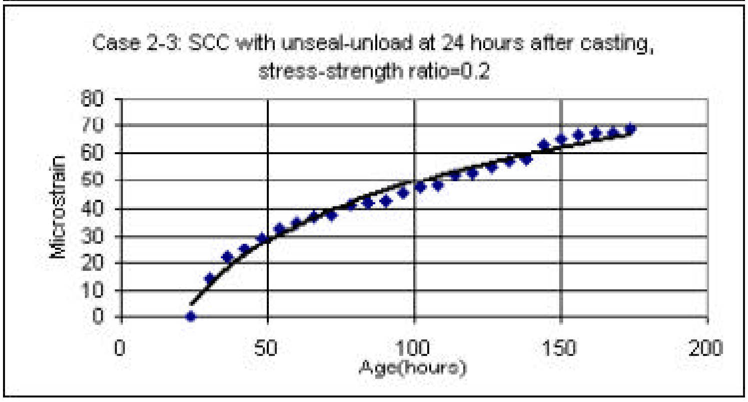

Case 1-2: SCC with seal-load condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
0
20
40
60
80
100
120
140
0
50
100
150
200
Age(hours)

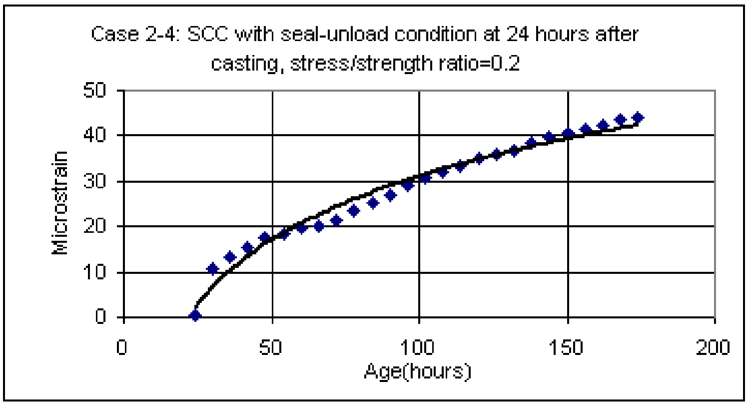

Case 1-3: SCC with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
0
20
40
60
80
100
120
140
0
50
100
150
200
Age(hours)

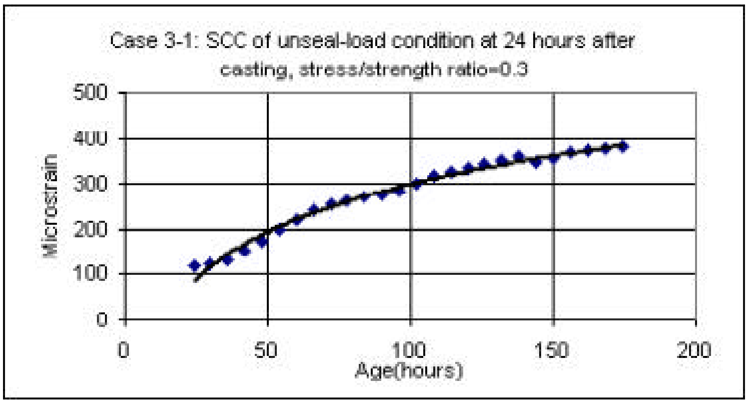

Case 1-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
0
20
40
60
80
100
120
140
0
50
100
150
200
Age(hours)

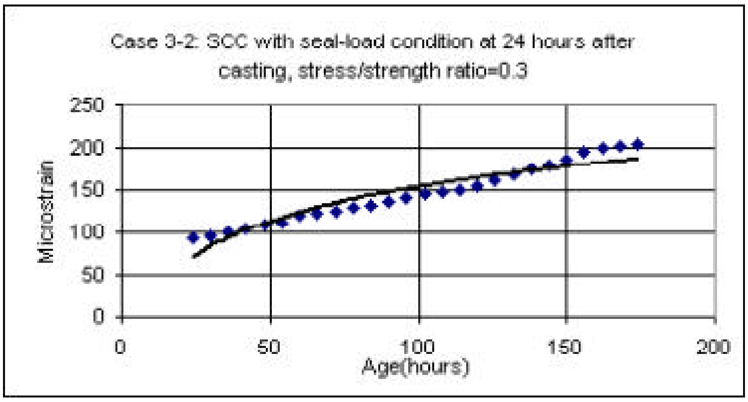

Case 2-1: SCC with unseal-load condition at 24 hours after casting, stress/strength ratio=0.2
Microstrain
Age(hours)
0
50
100
150
200
250
300
0
50
100
150
200

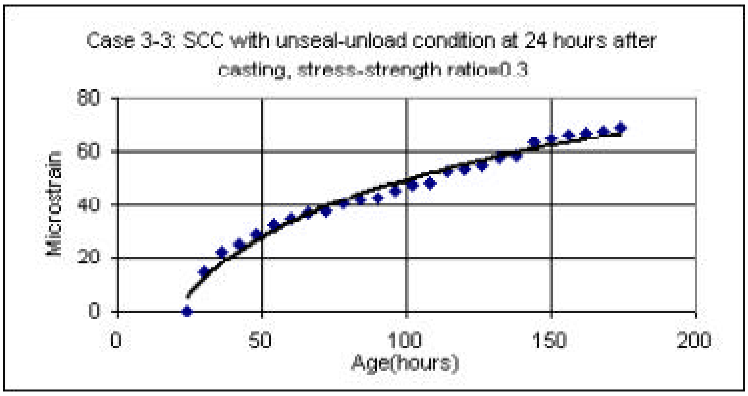

Case 2-2: SCC with seal-load at 24 hours after casting, stress-strength ratio=0.2
Microstrain
Age(hours)
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200

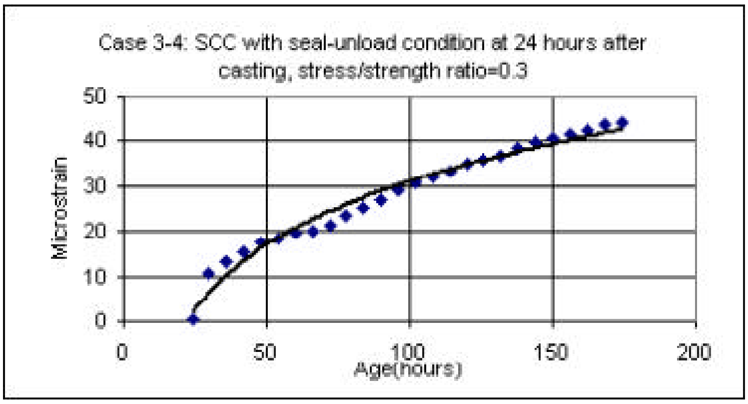

Case 2-3: SCC with unseal-unload at 24 hours after casting, stress-strength ratio=0.2
Microstrain
Age(hours)
0
10
20
30
40
50
60
70
80
0
50
100
150
200

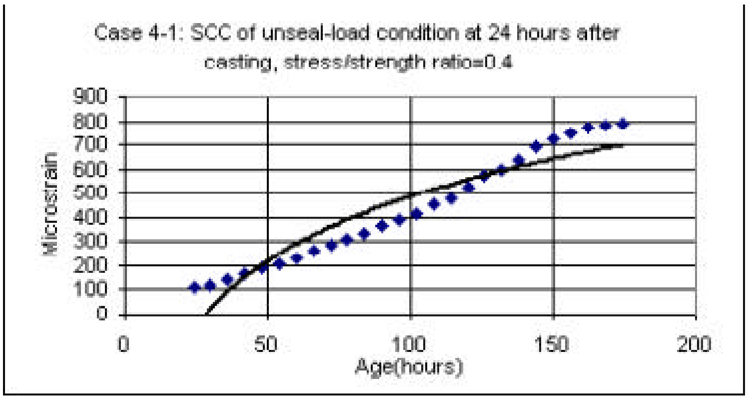

Case 2-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.2
Microstrain
Age(hours)
0
10
20
30
40
50
0
50
100
150
200

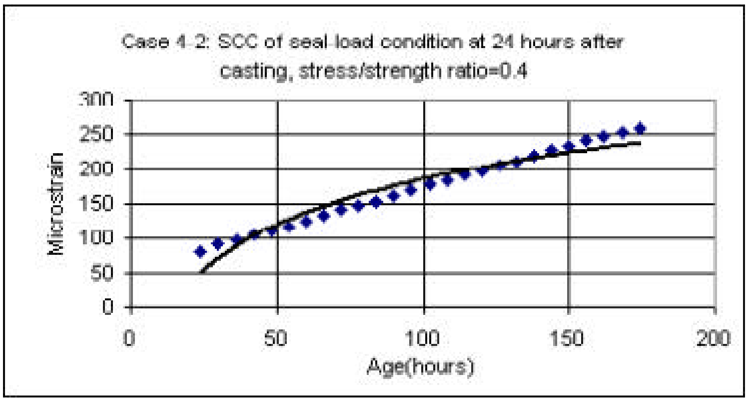

Case 3-1: SCC of unseal-load condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

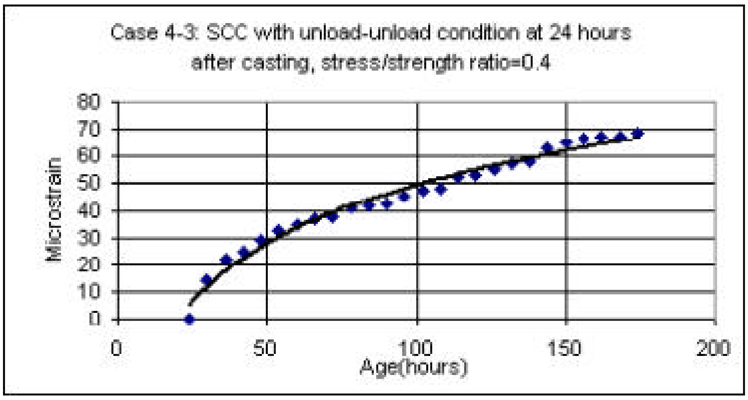

Case 3-2: SCC with seal-load condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

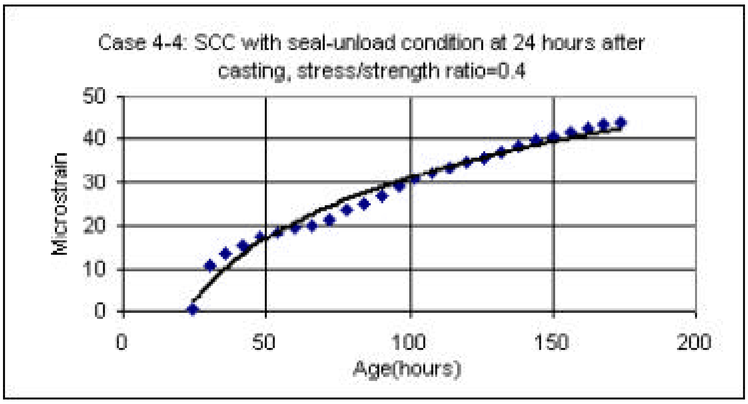

Case 3-3: SCC with unseal-unload condition at 24 hours after casting, stress-strength ratio=0.3
Microstrain
Age(hours)

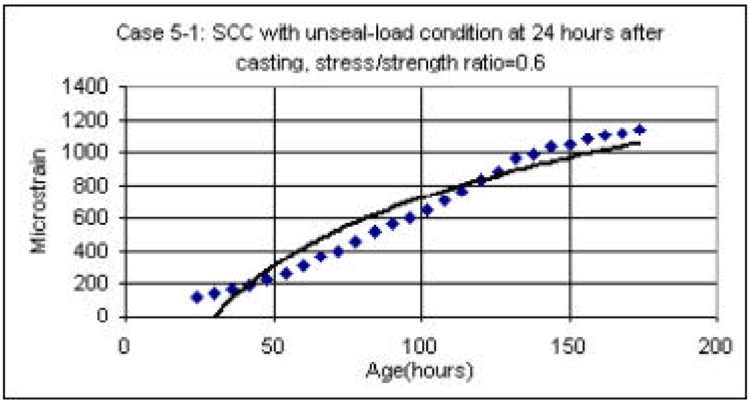

Case 3-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

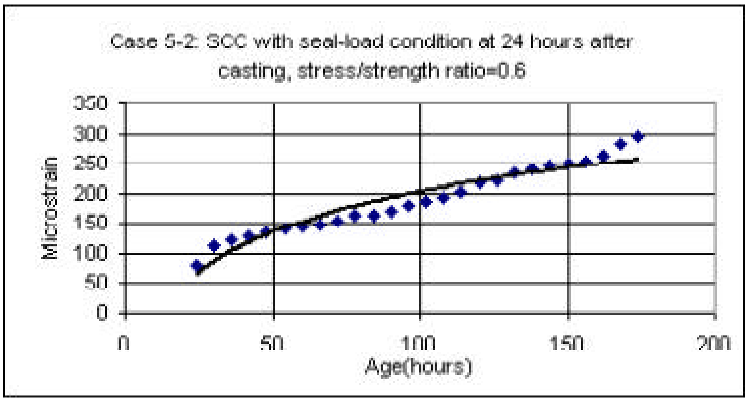

Case 4-1: SCC of unseal-load condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
Age(hours)
0
100
200
300
400
500
600
700
800
900
50
150

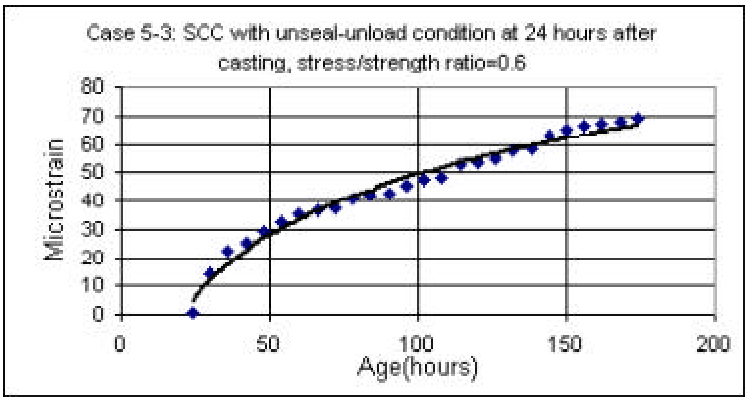

Case 4-2: SCC of seal-load condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
Age(hours)
0
50
100
150
200
250
300

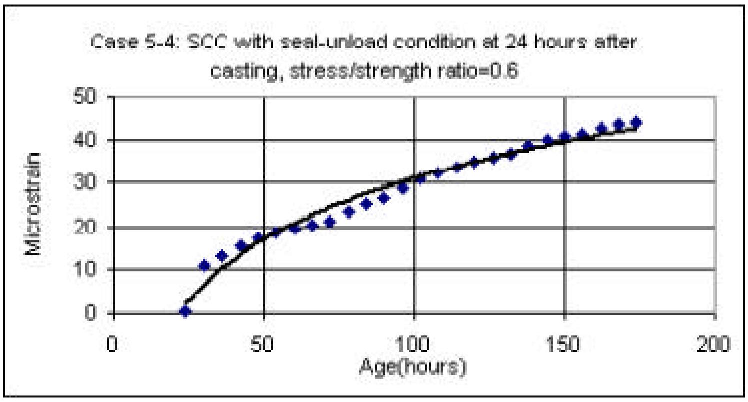

Case 4-3: SCC with unload-unload condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
Age(hours)
0
10
20
30
40
50
60
70
80
100
150
200

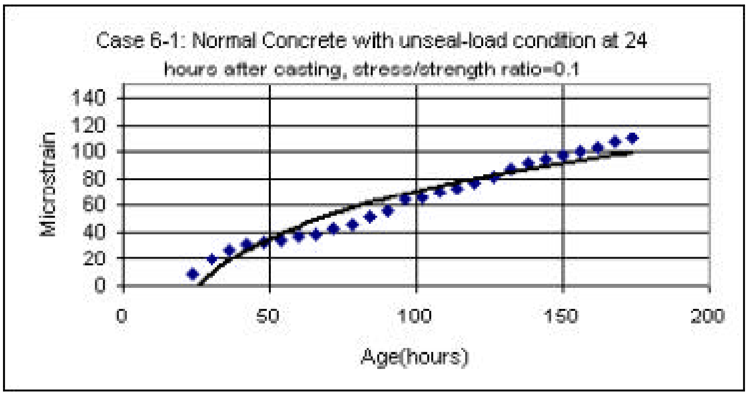

Case 4-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
Age(hours)
0
10
20
30
40
50
100
150
200

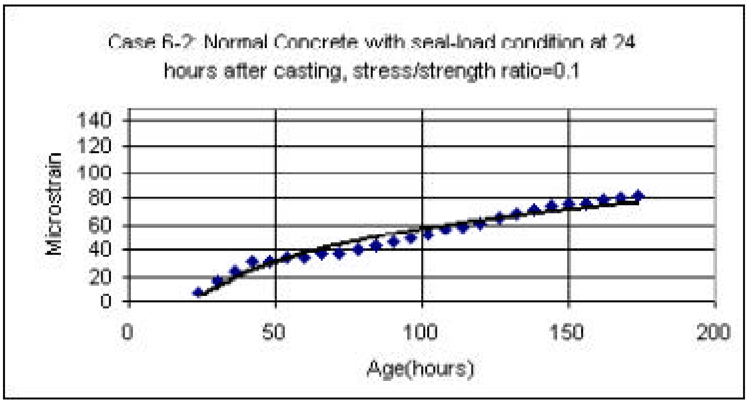

Case 5-1: SCC with unseal-load condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)

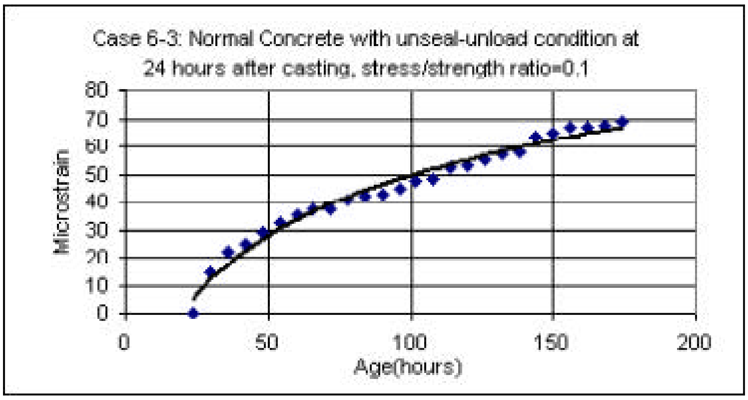

Case 5-2: SCC with seal-load condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)

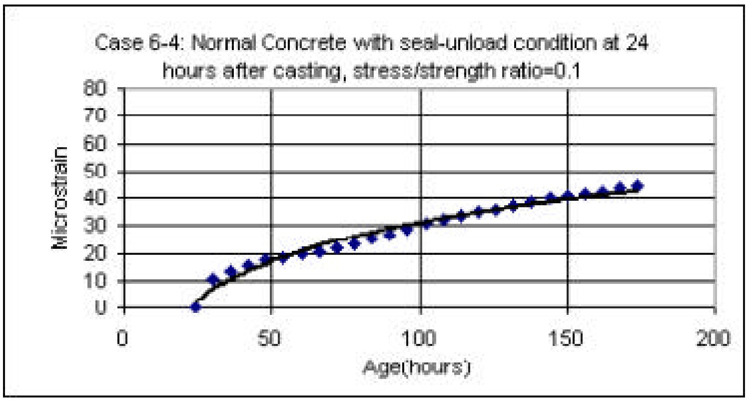

Case 5-3: SCC with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)

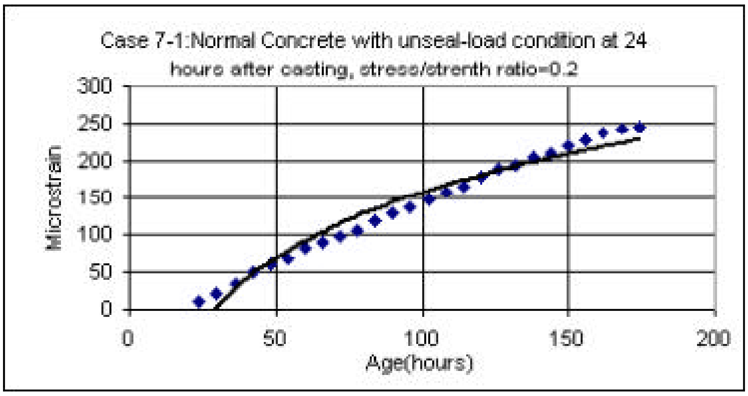

Case 5-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)

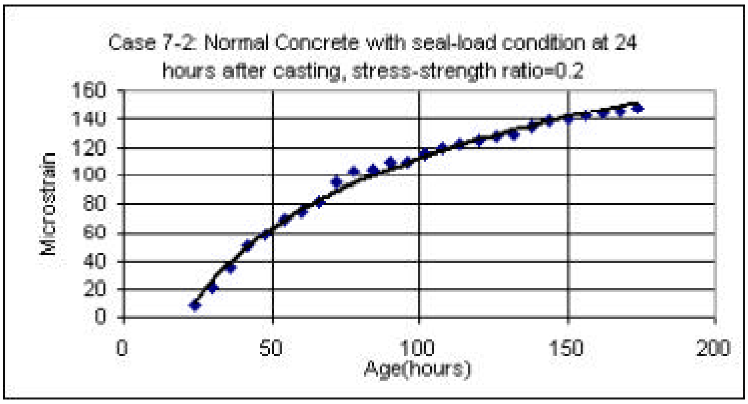

Case 6-1: Normal Concrete with unseal-load condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
140
120
100
80
60
40
20
0
0
50
100
150
200
Age(hours)

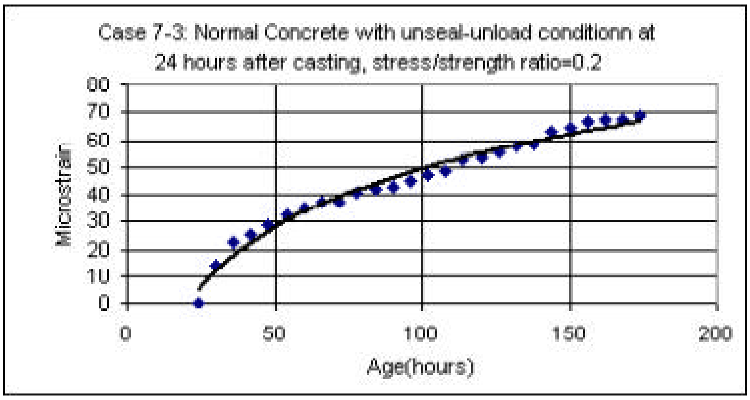

Case 6-2: Normal Concrete with seal-load condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
140
120
100
80
60
40
20
0
0
50
100
150
200
Age(hours)

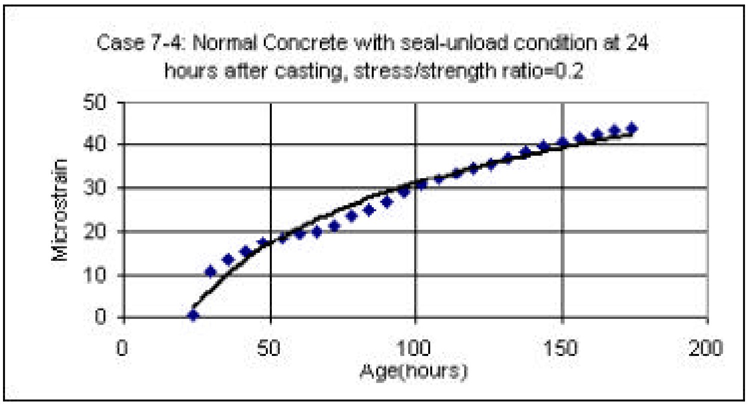

Case 6-3: Normal Concrete with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
80
70
60
50
40
30
20
10
0
0
50
100
150
200
Age(hours)

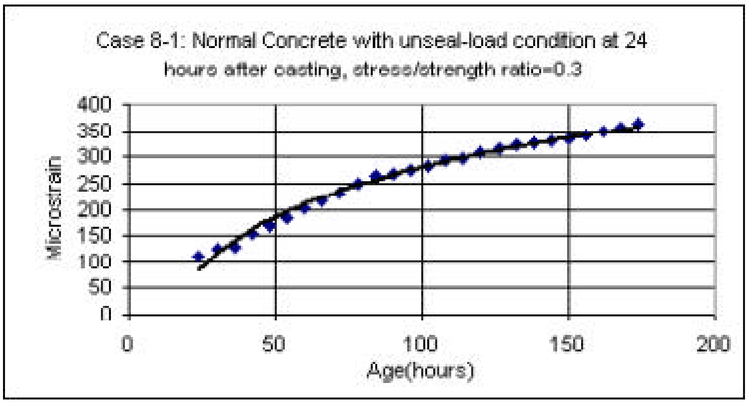

Case 6-4: Normal Concrete with seal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Microstrain
80
70
60
50
40
30
20
10
0
0
50
100
150
200
Age(hours)

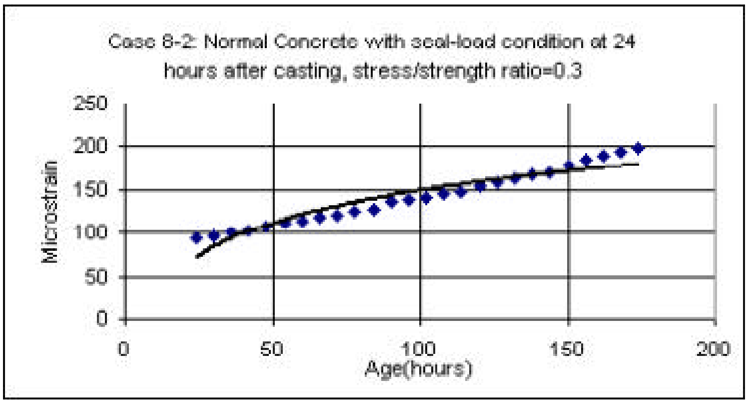

Case 7-1:Normal Concrete with unseal-load condition at 24 hours after casting, stress/strenth ratio=0.2
Microstrain
Age(hours)

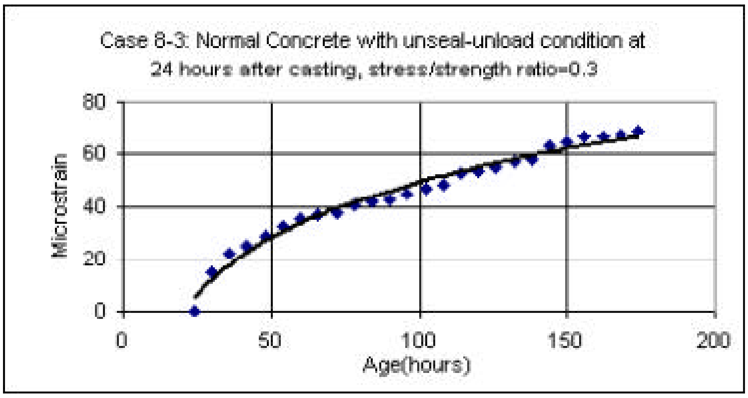

Case 7-2: Normal Concrete with seal-load condition at 24 hours after casting, stress-strength ratio=0.2
Microstrain
Age(hours)

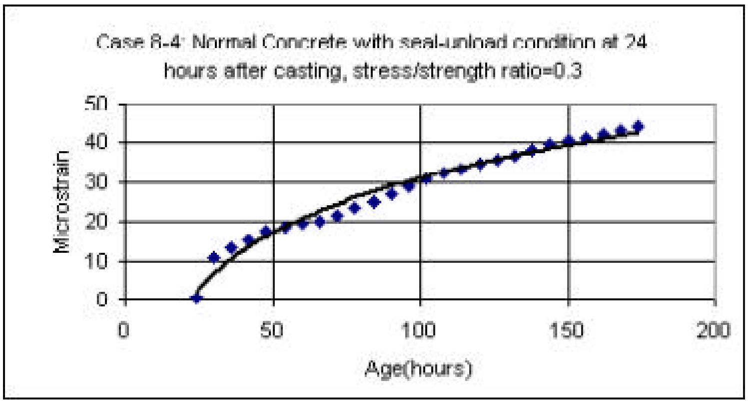

Case 7-3: Normal Concrete with unseal-unload conditionn at 24 hours after casting, stress/strength ratio=0.2
Microstrain
Age(hours)

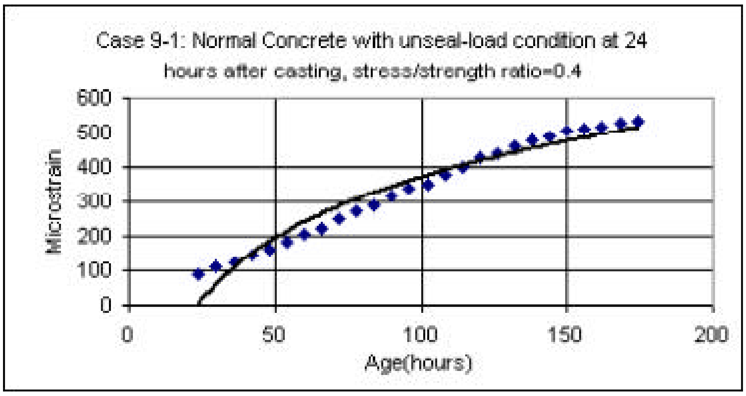

Case 7-4: Normal Concrete with seal-unload condition at 24 hours after casting, stress/strength ratio=0.2
Microstrain
Age(hours)

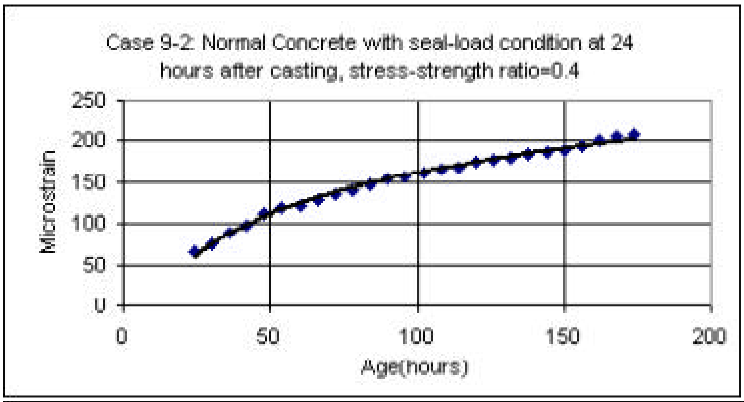

Case 8-1: Normal Concrete with unseal-load condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

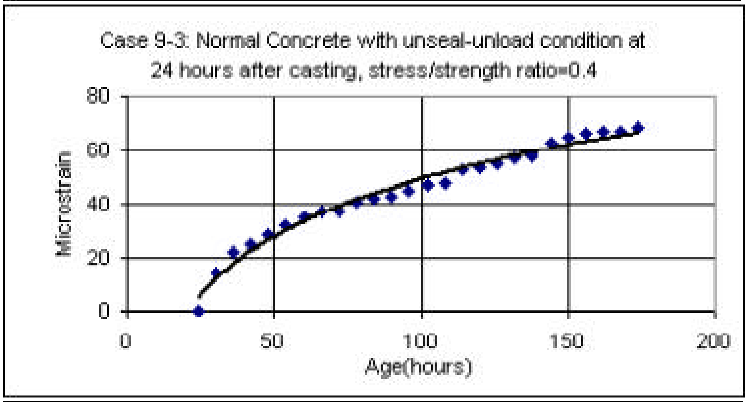

Case 8-2: Normal Concrete with seal-load condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

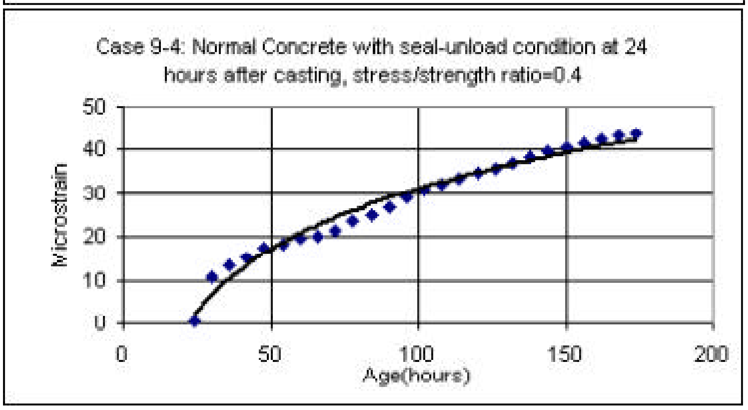

Case 8-3: Normal Concrete with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

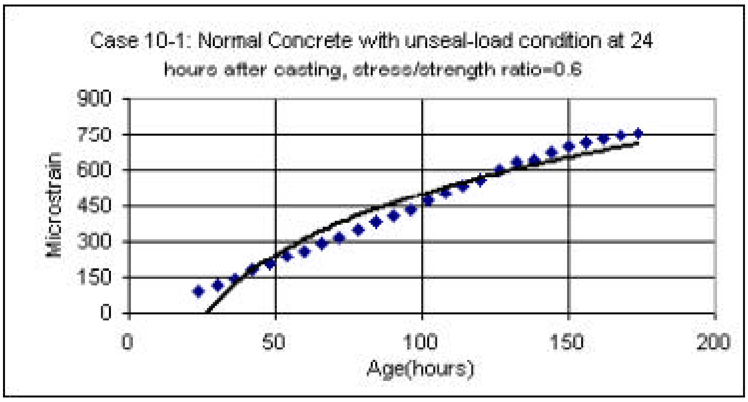

Case 8-4: Normal Concrete with seal-unload condition at 24 hours after casting, stress/strength ratio=0.3
Microstrain
Age(hours)

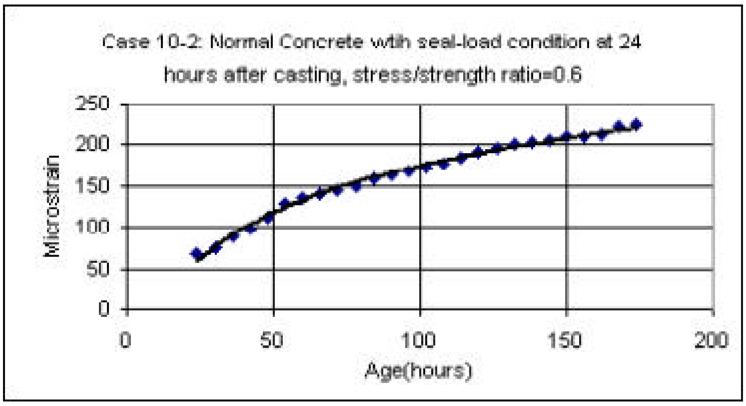

Case 9-1: Normal Concrete with unseal-load condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
600
500
400
300
200
100
0
0
50
100
150
200
Age(hours)

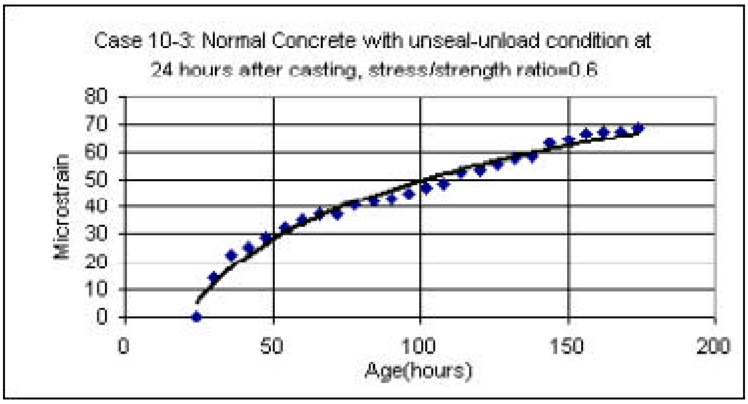

Case 9-2: Normal Concrete with seal-load condition at 24 hours after casting, stress-strength ratio=0.4
Microstrain
250
200
150
100
50
0
0
50
100
150
200
Age(hours)

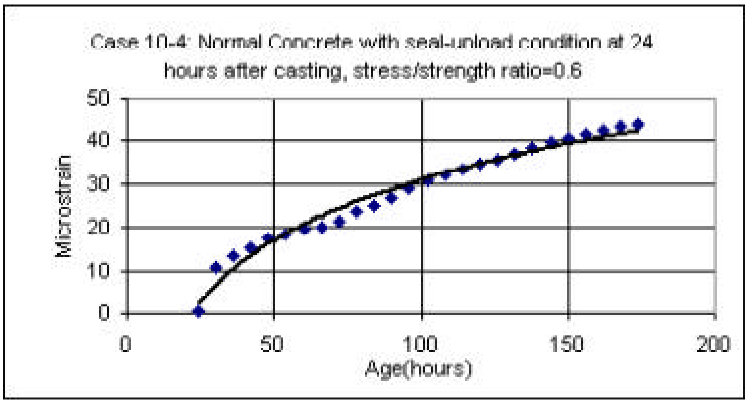

Case 9-3: Normal Concrete with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
80
60
40
20
0
0
50
100
150
200
Age(hours)

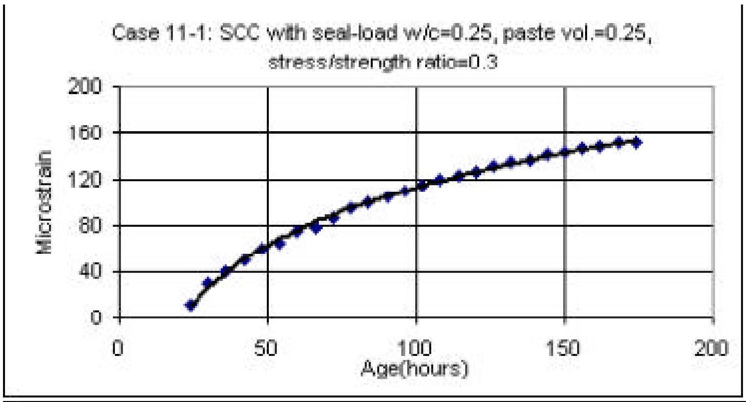

Case 9-4: Normal Concrete with seal-unload condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
50
40
30
20
10
0
0
50
100
150
200
Age(hours)

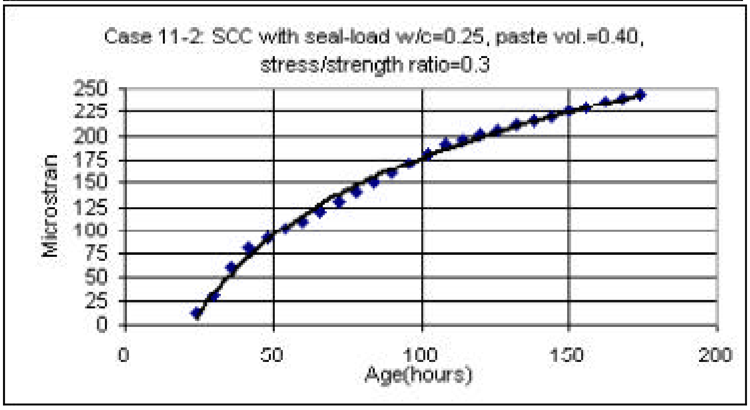

Case 10-1: Normal Concrete with unseal-load condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)
0
150
300
450
600
750
900
0
50
100
150
200

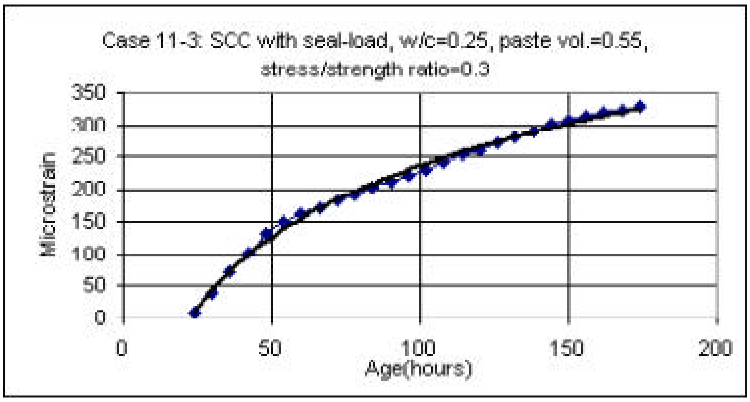

Case 10-2: Normal Concrete wtih seal-load condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)
0
50
100
150
200
250
0
50
100
150
200

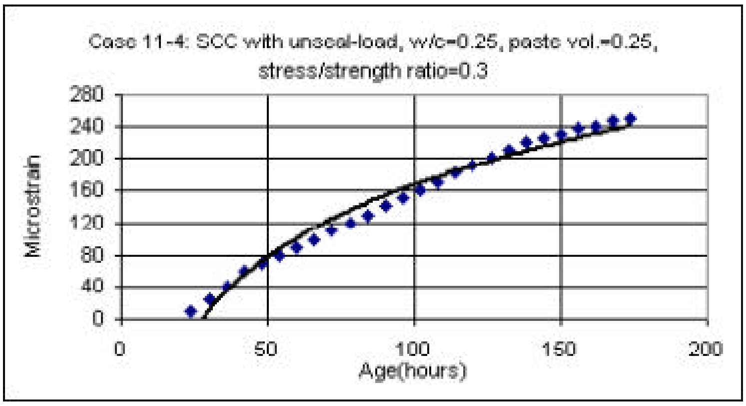

Case 10-3: Normal Concrete with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)
0
10
20
30
40
50
60
70
80
0
50
100
150
200

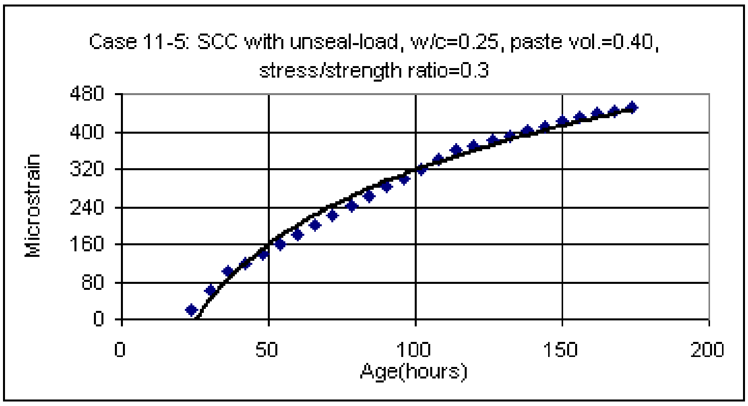

Case 10-4: Normal Concrete with seal-unload condition at 24 hours after casting, stress/strength ratio=0.6
Microstrain
Age(hours)
0
10
20
30
40
50
0
50
100
150
200

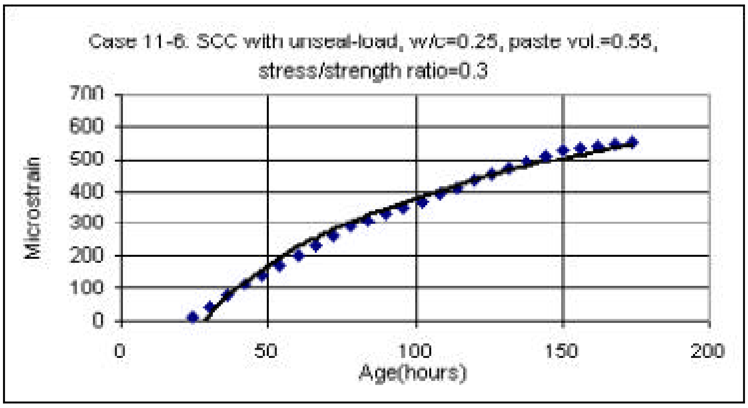

Case 11-1: SCC with seal-load w/c=0.25, paste vol.=0.25, stress/strength ratio=0.3
Microstrain
Age(hours)

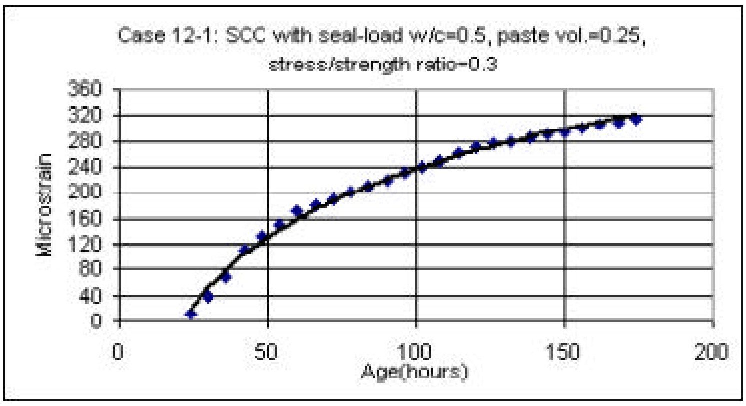

Case 11-2: SCC with seal-load w/c=0.25, paste vol.=0.40, stress/strength ratio=0.3
Microstrain
Age(hours)

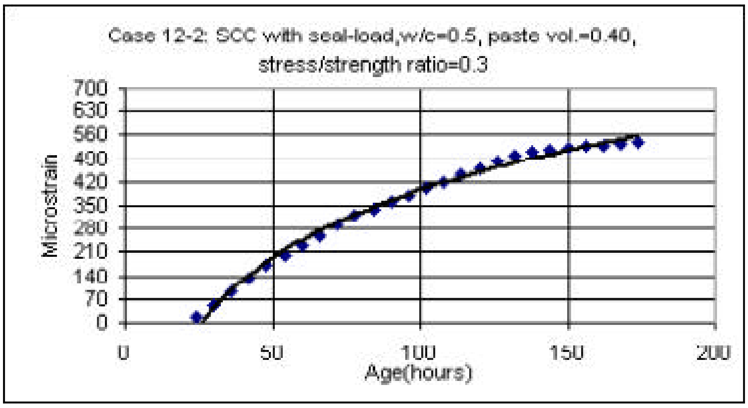

Case 11-3: SCC with seal-load, w/c=0.25, paste vol.=0.55, stress/strength ratio=0.3
Microstrain
Age(hours)

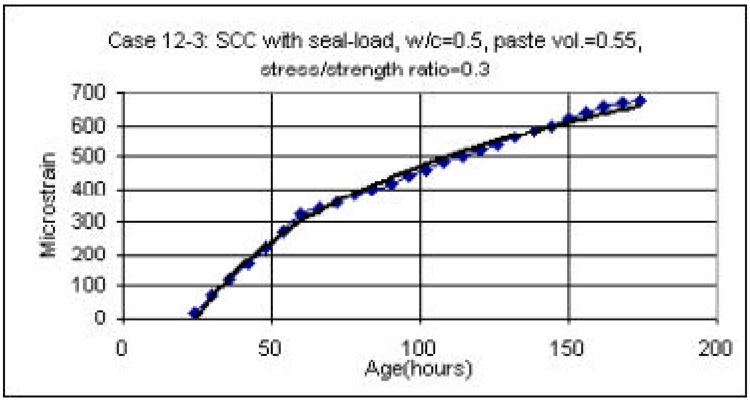

Case 11-4: SCC with unseal-load, w/c=0.25, paste vol.=0.25, stress/strength ratio=0.3
Microstrain
Age(hours)

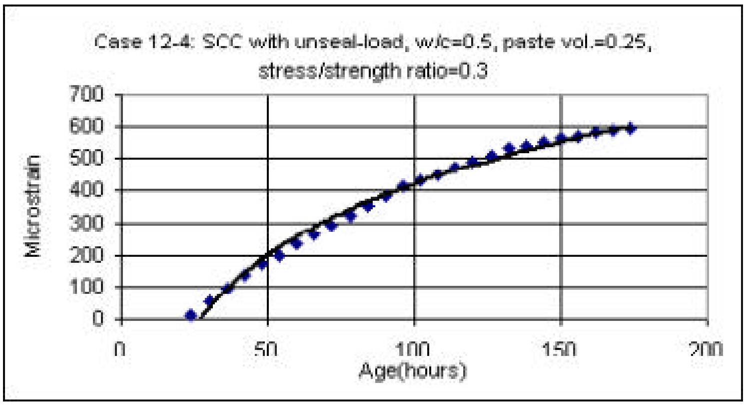

Case 11-5: SCC with unseal-load, w/c=0.25, paste vol.=0.40, stress/strength ratio=0.3
Microstrain
Age(hours)
0
80
160
240
320
400
480
0
50
100
150
200

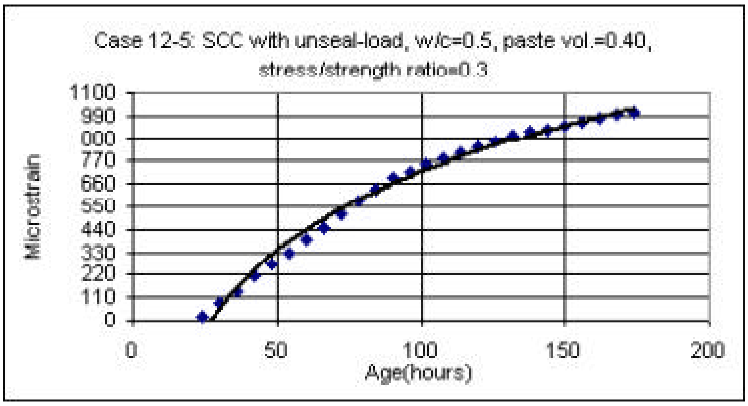

Case 11-6: SCC with unseal-load, w/c=0.25, paste vol.=0.55, stress/strength ratio=0.3
Microstrain
Age(hours)
0
100
200
300
400
500
600
700
0
50
100
150
200

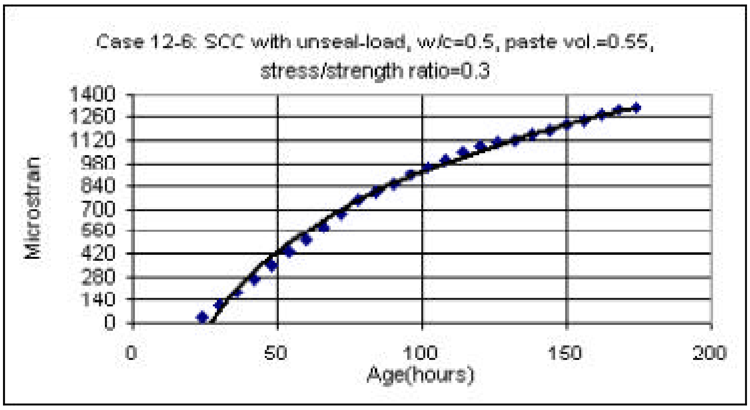

Case 12-1: SCC with seal-load w/c=0.5, paste vol.=0.25, stress/strength ratio=0.3
Microstrain
Age(hours)
0
40
80
120
160
200
240
280
320
360
0
50
100
150
200

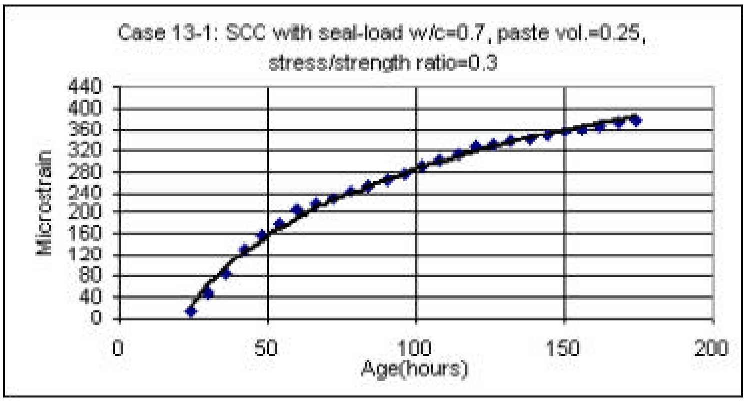

Case 12-2: SCC with seal-load,w/c=0.5, paste vol.=0.40, stress/strength ratio=0.3
Microstrain
Age(hours)
0
70
140
210
280
350
420
490
560
630
700
0
50
100
150
200

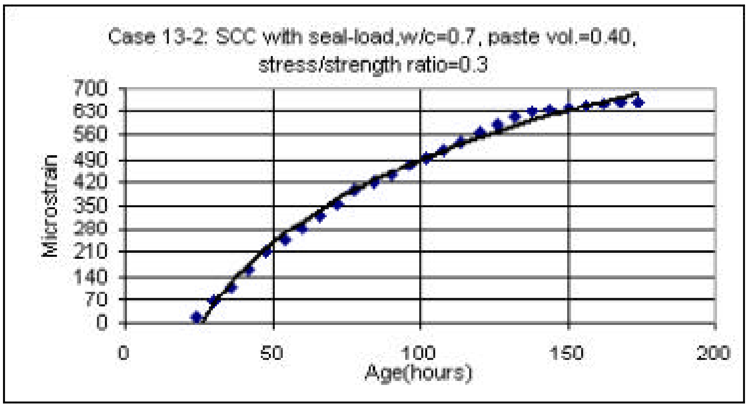

Case 12-3: SCC with seal-load, w/c=0.5, paste vol.=0.55,
stress/strength ratio=0.3
Microstrain
Age(hours)

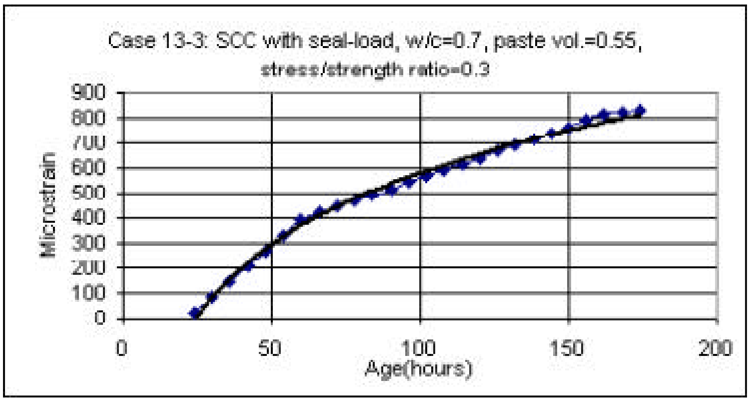

Case 12-4: SCC with unseal-load, w/c=0.5, paste vol.=0.25,
stress/strength ratio=0.3
Microstrain
Age(hours)

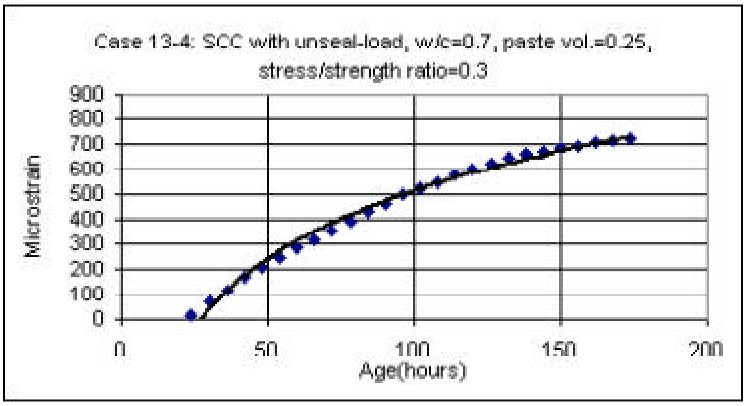

Case 12-5: SCC with unseal-load, w/c=0.5, paste vol.=0.40,
stress/strength ratio=0.3
Microstrain
Age(hours)

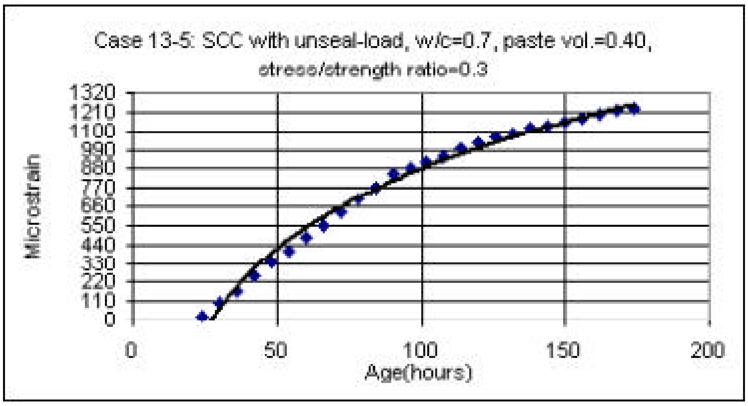

Case 12-6: SCC with unseal-load, w/c=0.5, paste vol.=0.55,
stress/strength ratio=0.3
Microstrain
Age(hours)

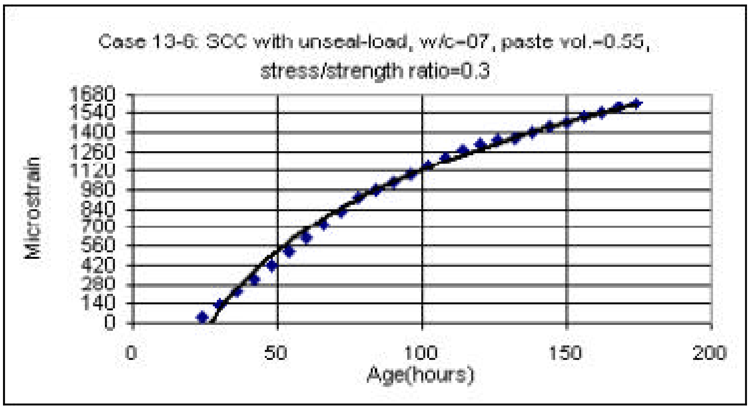

Case 13-1: SCC with seal-load w/c=0.7, paste vol.=0.25,
stress/strength ratio=0.3
Microstrain
440
400
360
320
280
240
200
160
120
80
40
0
0
50
100
150
200
Age(hours)

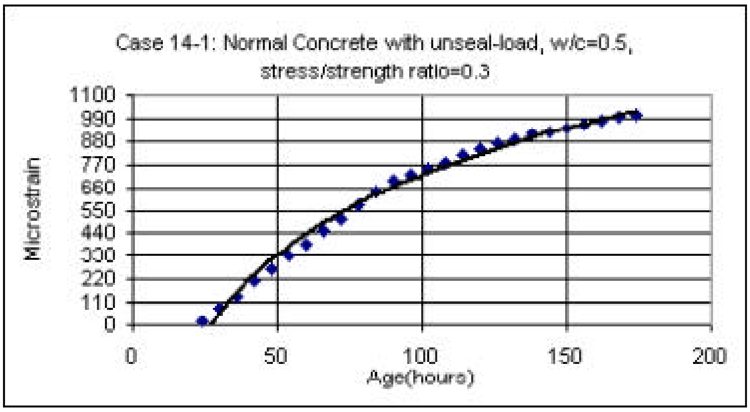

Case 13-2: SCC with seal-load,w/c=0.7, paste vol.=0.40,
stress/strength ratio=0.3
Microstrain
700
630
560
490
420
350
280
210
140
70
0
0
50
100
150
200
Age(hours)

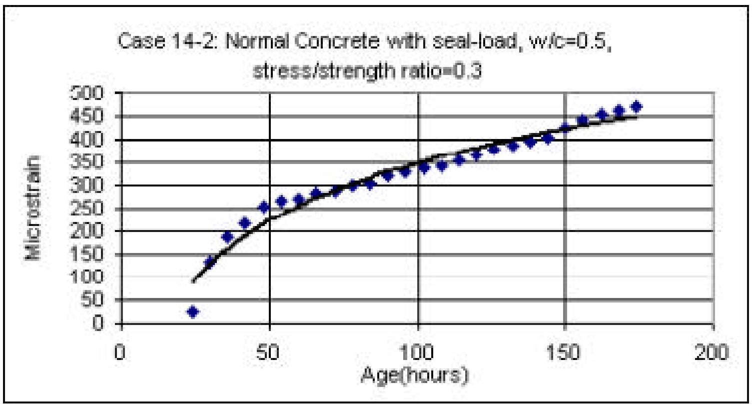

Case 13-3: SCC with seal-load, w/c=0.7, paste vol.=0.55,
stress/strength ratio=0.3
Microstrain
900
800
700
600
500
400
300
200
100
0
0
50
100
150
200
Age(hours)

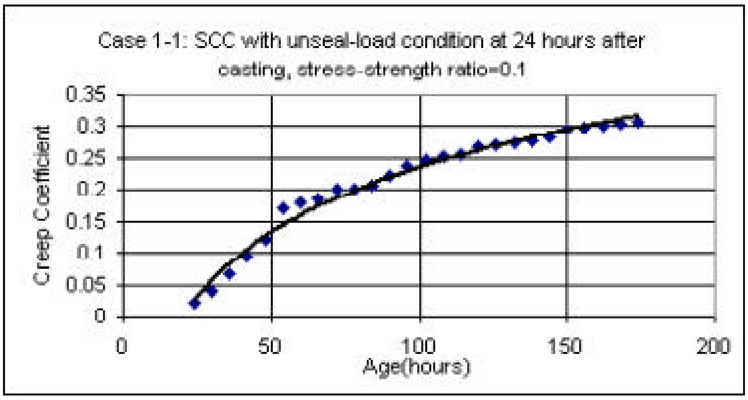

Case 13-4: SCC with unseal-load, w/c=0.7, paste vol.=0.25,
stress/strength ratio=0.3
Microstrain
900
800
700
600
500
400
300
200
100
0
0
50
100
150
200
Age(hours)

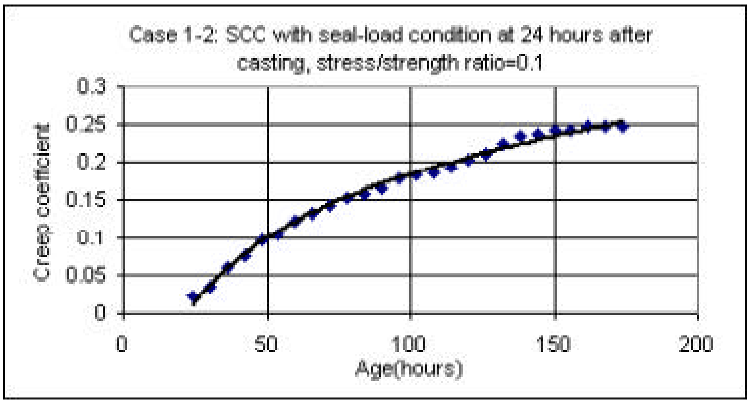

Case 13-5: SCC with unseal-load, w/c=0.7, paste vol.=0.40,
stress/strength ratio=0.3
Microstrain
Age(hours)

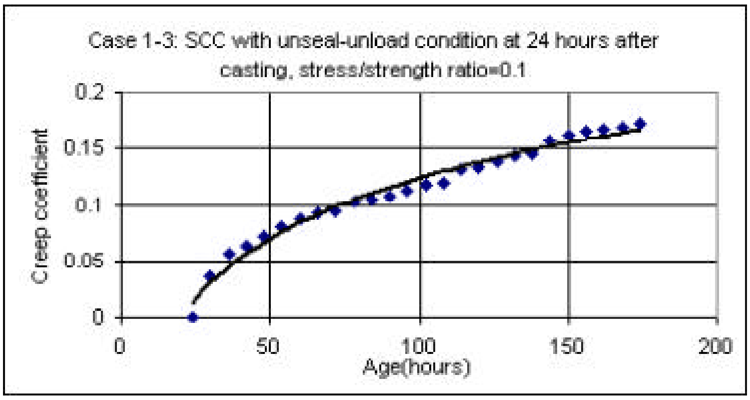

Case 13-6: SCC with unseal-load, w/c=07, paste vol.=0.55,
stress/strength ratio=0.3
Microstrain
Age(hours)

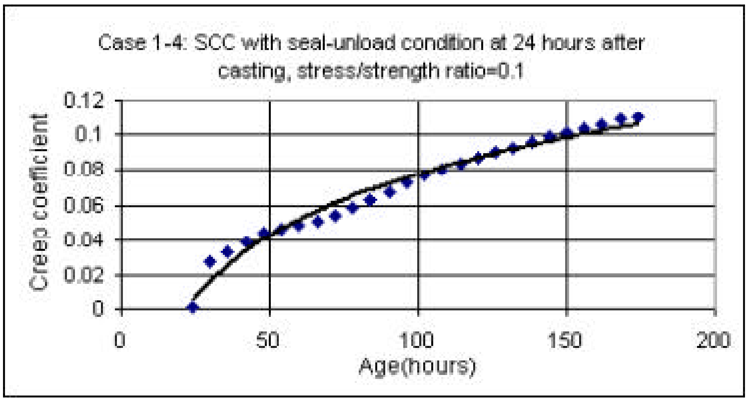

Case 14-1: Normal Concrete with unseal-load, w/c=0.5,
stress/strength ratio=0.3
Microstrain
Age(hours)

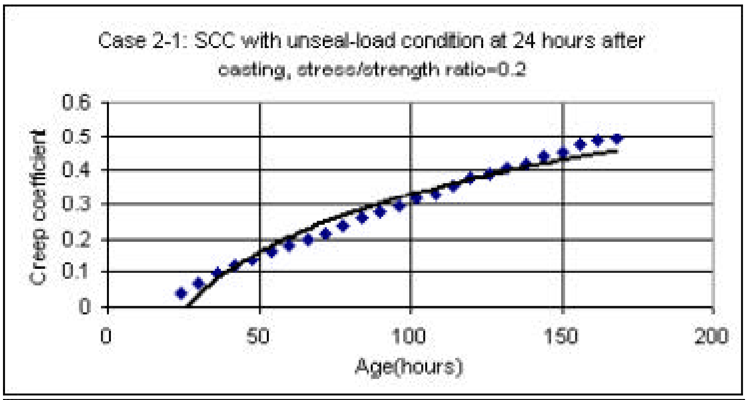

Case 14-2: Normal Concrete with seal-load, w/c=0.5,
stress/strength ratio=0.3
Microstrain
Age(hours)

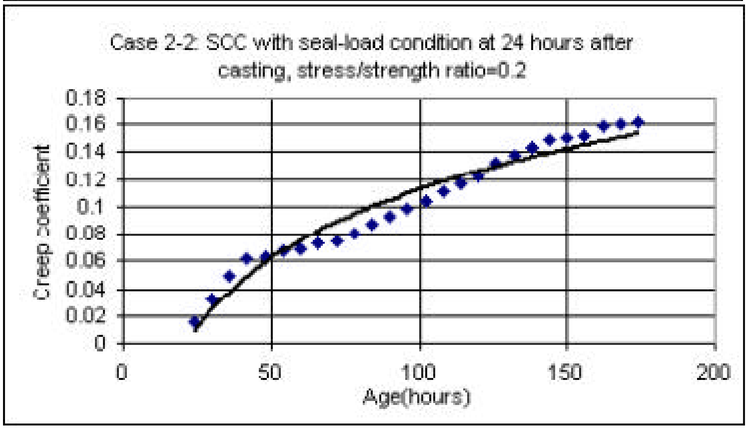

Case 1-1: SCC with unseal-load condition at 24 hours after casting, stress-strength ratio=0.1
Creep Coefficient
Age(hours)

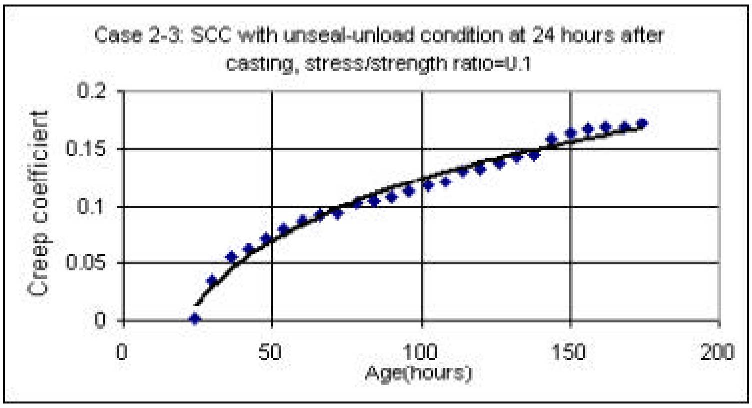

Case 1-2: SCC with seal-load condition at 24 hours after casting, stress/strength ratio=0.1
Creep coefficient
Age(hours)

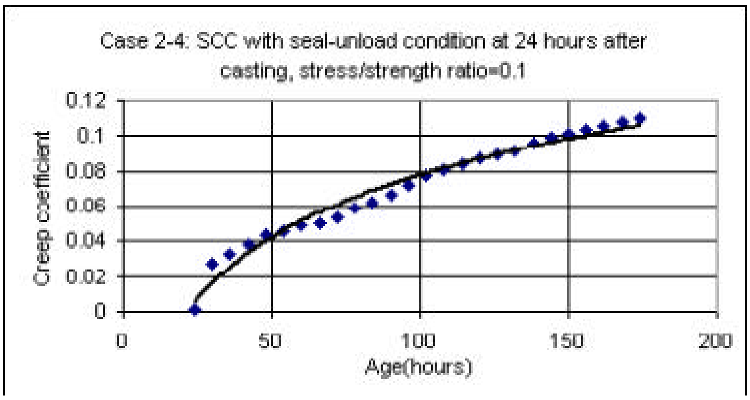

Case 1-3: SCC with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Creep coefficient
Age(hours)

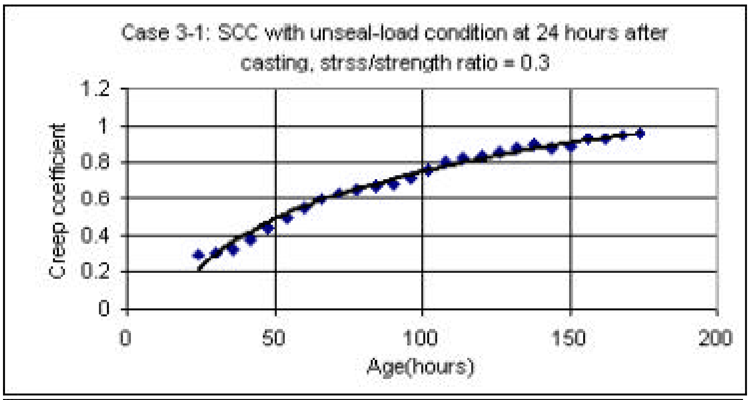

Case 1-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Creep coefficient
Age(hours)

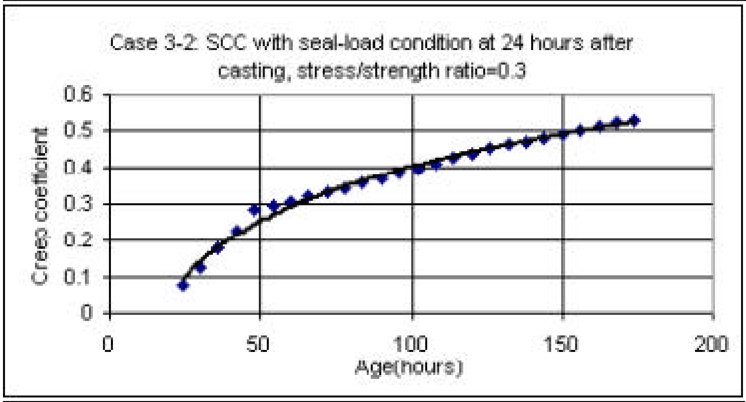

Case 2-1: SCC with unseal-load condition at 24 hours after casting, stress/strength ratio=0.2
Creep coefficient
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

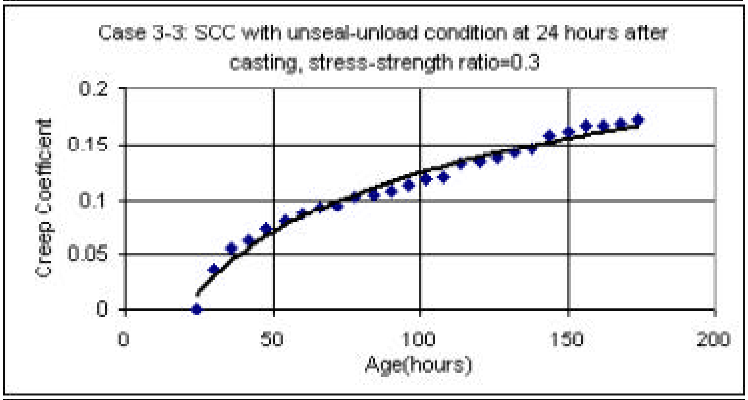

Case 2-2: SCC with seal-load condition at 24 hours after casting, stress/strength ratio=0.2
Creep coefficient
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
Age(hours)

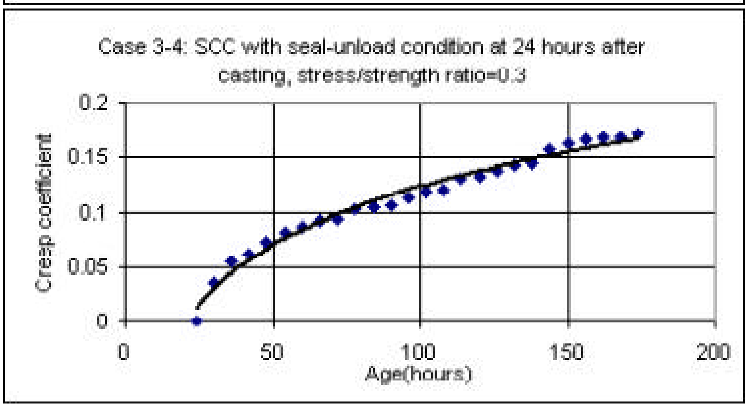

Case 2-3: SCC with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Creep coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

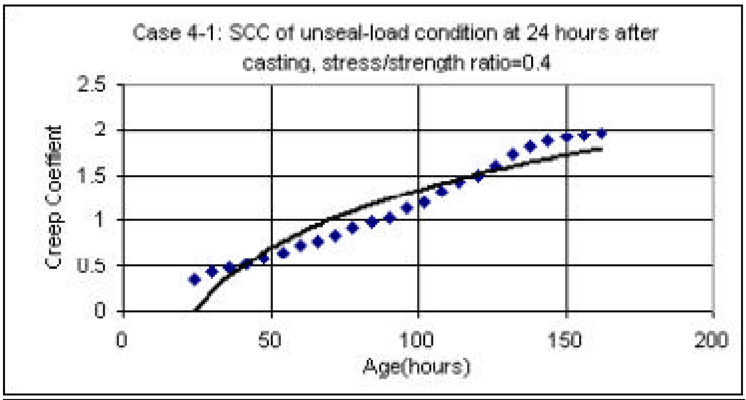

Case 2-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.1
Creep coefficient
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
Age(hours)

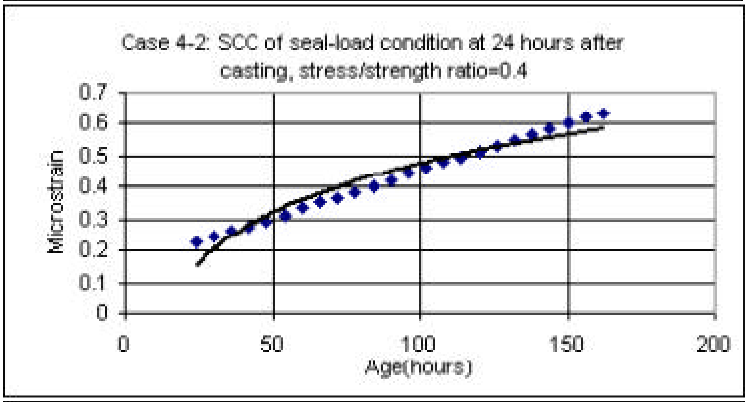

Case 3-1: SCC with unseal-load condition at 24 hours after casting, strss/strength ratio = 0.3
Creep coefficient
Age(hours)
0
0.2
0.4
0.6
0.8
1
1.2
0
50
100
150
200

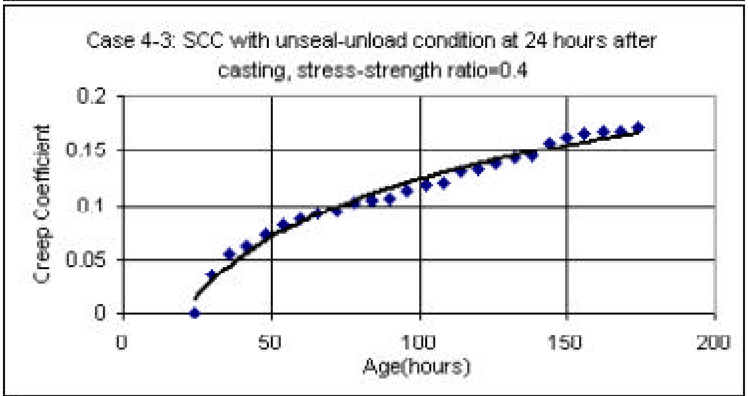

Case 3-2: SCC with seal-load condition at 24 hours after casting, stress/strength ratio=0.3
Creep coefficient
Age(hours)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200

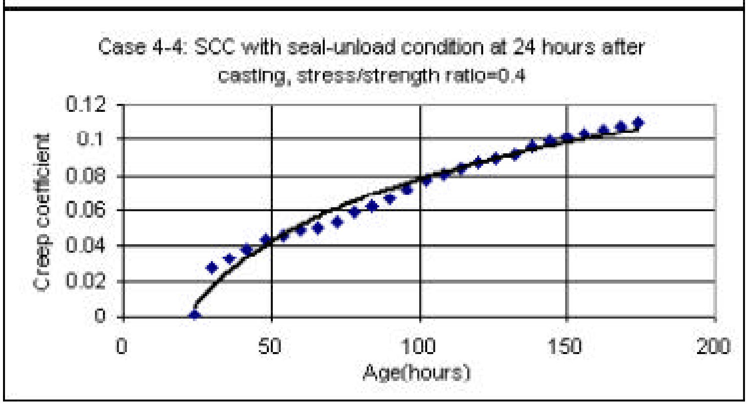

Case 3-3: SCC with unseal-unload condition at 24 hours after casting, stress-strength ratio=0.3
Creep Coefficient
Age(hours)
0
0.05
0.1
0.15
0.2
0
50
100
150
200

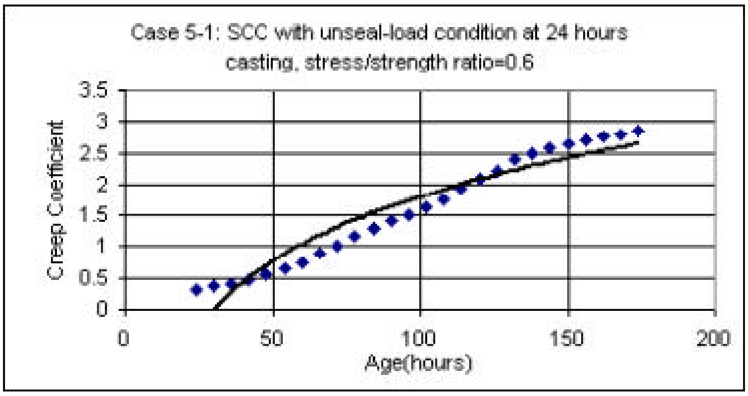

Case 3-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.3
Creep coefficient
Age(hours)
0
0.05
0.1
0.15
0.2
0
50
100
150
200

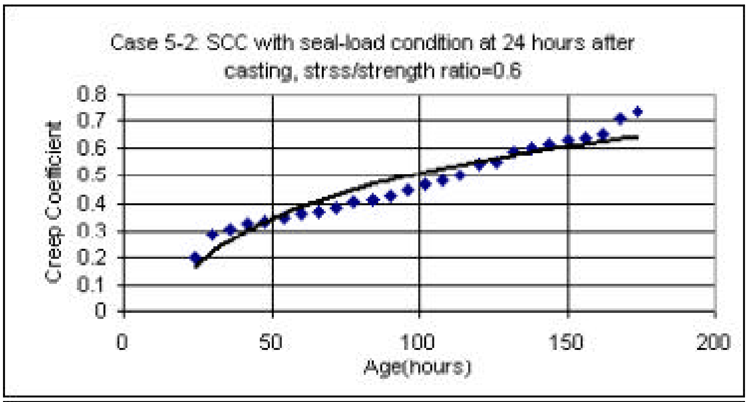

Case 4-1: SCC of unseal-load condition at 24 hours after casting, stress/strength ratio=0.4
Creep Coeffient
2.5
2
1.5
1
0.5
0
0
50
100
150
200
Age(hours)

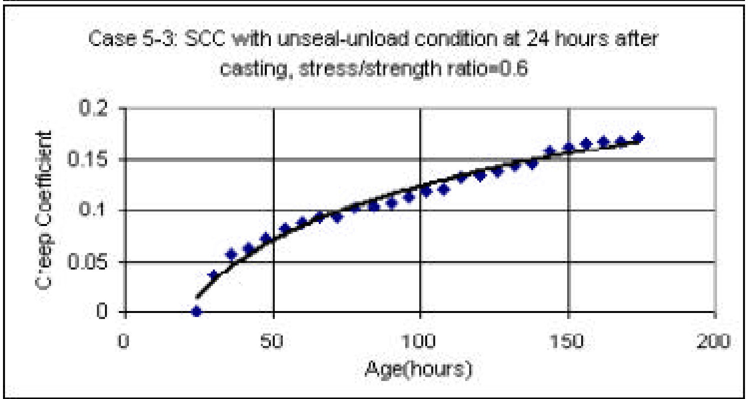

Case 4-2: SCC of seal-load condition at 24 hours after casting, stress/strength ratio=0.4
Microstrain
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

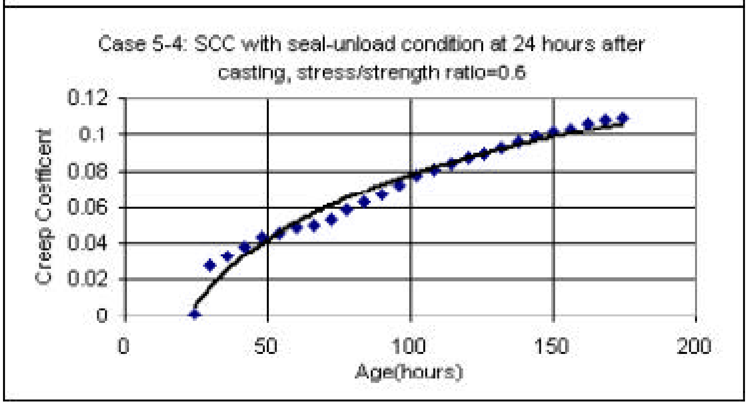

Case 4-3: SCC with unseal-unload condition at 24 hours after casting, stress-strength ratio=0.4
Creep Coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

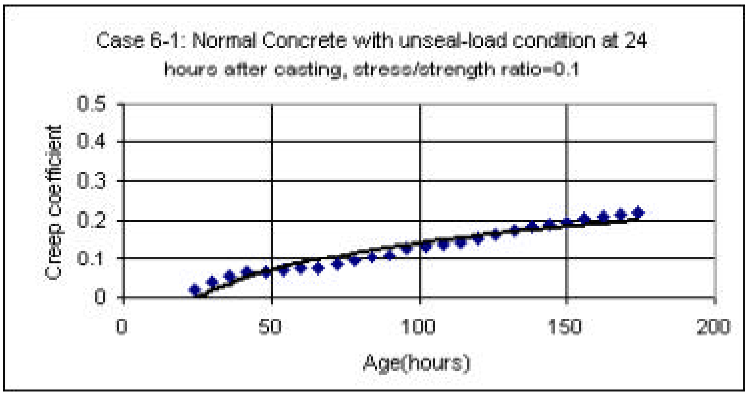

Case 4-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.4
Creep coefficient
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
Age(hours)

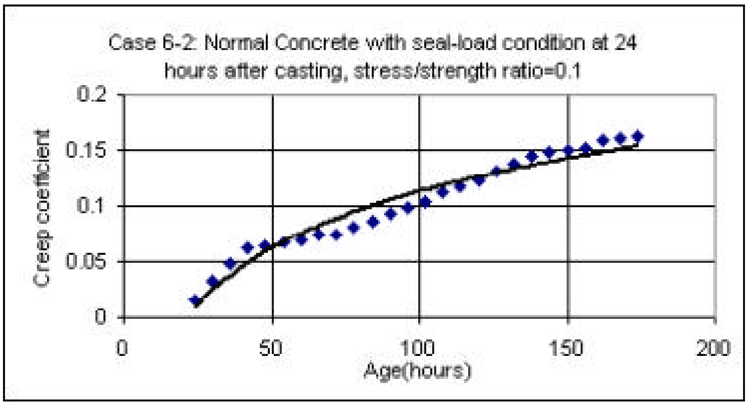

Case 5-1: SCC with unseal-load condition at 24 hours casting, stress/strength ratio=0.6
Creep Coefficient
0
0.5
1
1.5
2
2.5
3
3.5
0
50
100
150
200
Age(hours)

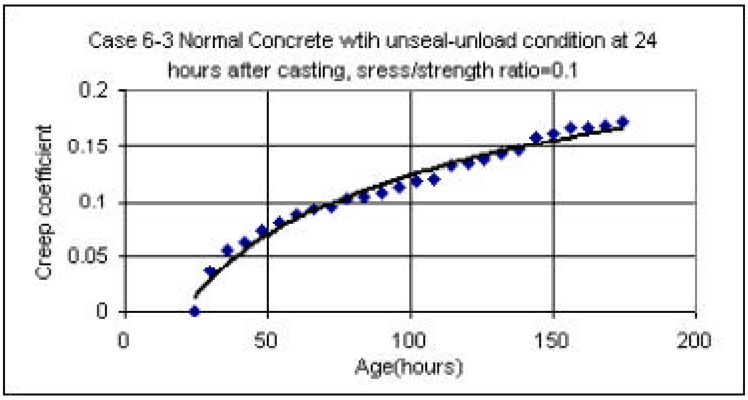

Case 5-2: SCC with seal-load condition at 24 hours after casting, strss/strength ratio=0.6
Creep Coefficient
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
50
100
150
200
Age(hours)

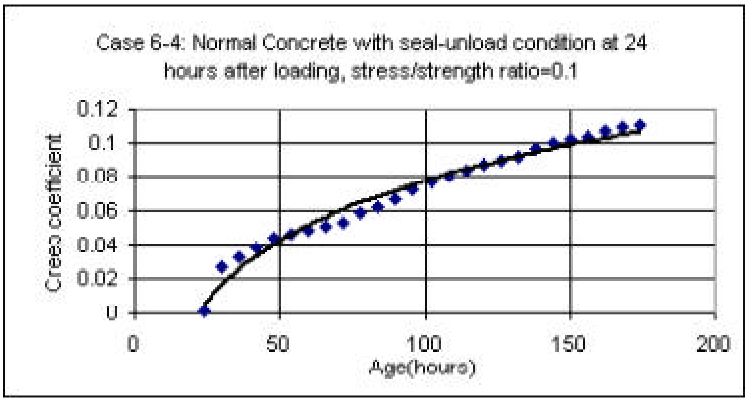

Case 5-3: SCC with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.6
Creep Coefficient
0
0.05
0.1
0.15
0.2
0
50
100
150
200
Age(hours)

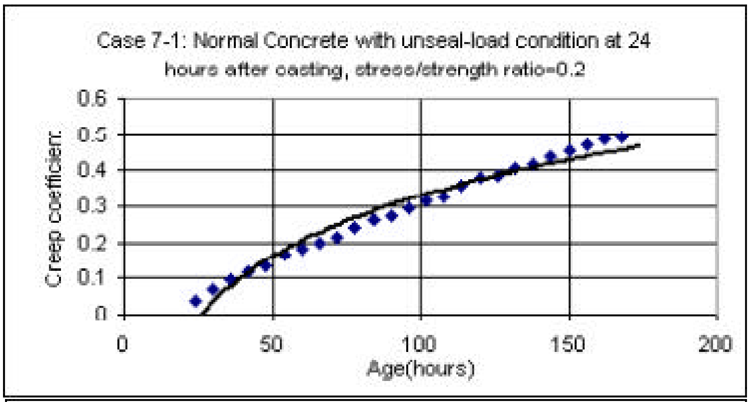

Case 5-4: SCC with seal-unload condition at 24 hours after casting, stress/strength ratio=0.6
Creep Coefficient
0
0.02
0.04
0.06
0.08
0.1
0.12
0
50
100
150
200
Age(hours)

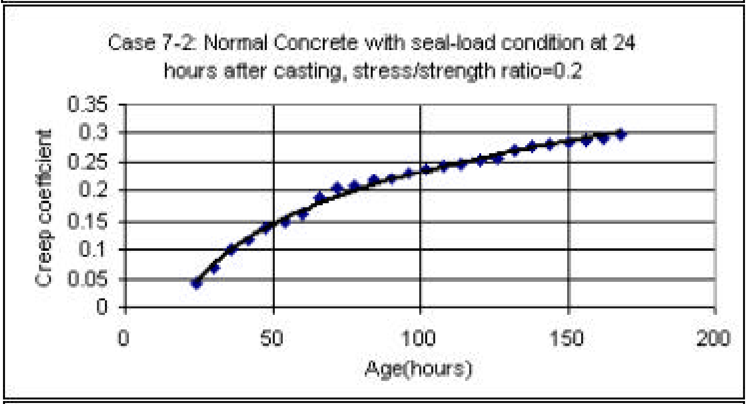

Case 6-1: Normal Concrete with unseal-load condition at 24
hours after casting, stress/strength ratio=0.1
Creep coefficient
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

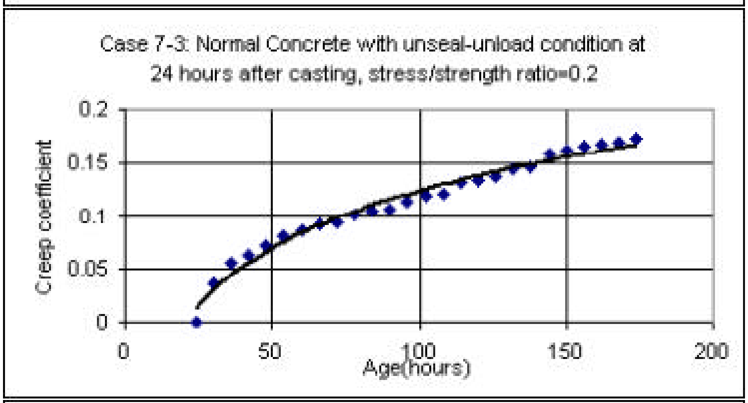

Case 6-2: Normal Concrete with seal-load condition at 24
hours after casting, stress/strength ratio=0.1
Creep coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

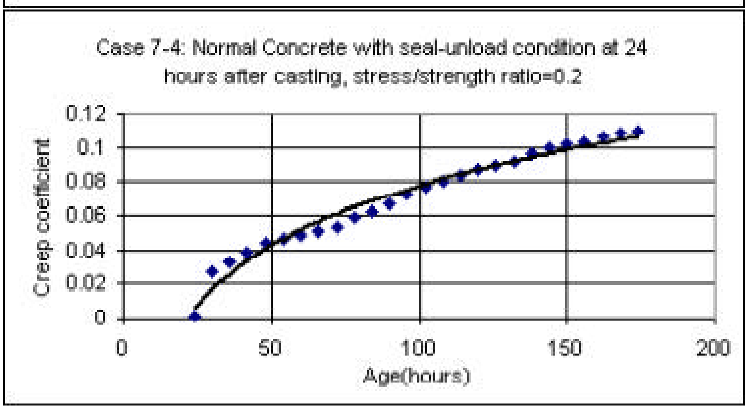

Case 6-3 Normal Concrete wtih unseal-unload condition at 24
hours after casting, sress/strength ratio=0.1
Creep coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

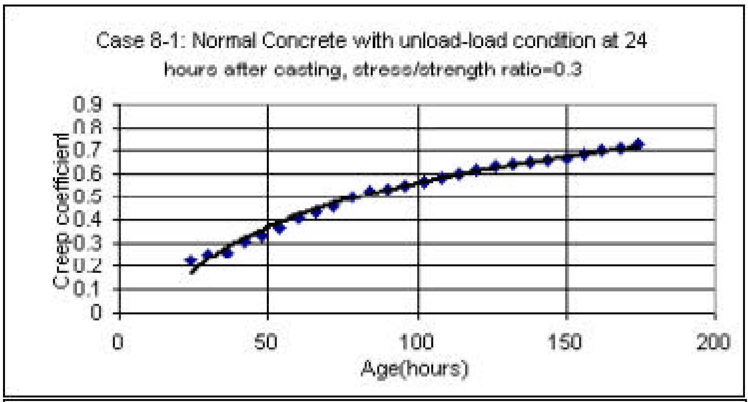

Case 6-4: Normal Concrete with seal-unload condition at 24
hours after loading, stress/strength ratio=0.1
Creep coefficient
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
Age(hours)

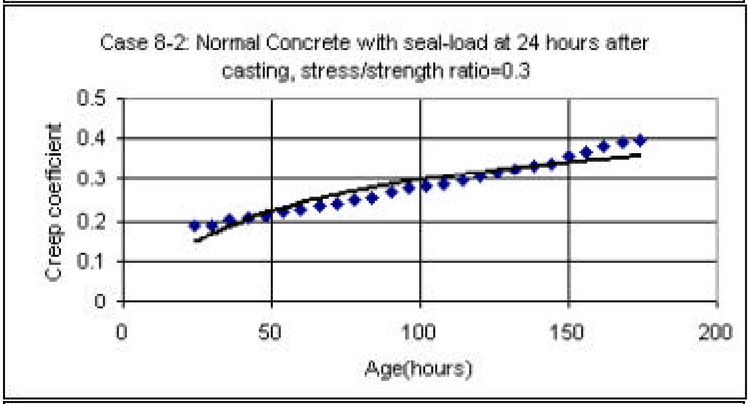

Case 7-1: Normal Concrete with unseal-load condition at 24 hours after casting, stress/strength ratio=0.2
Creep coefficient
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

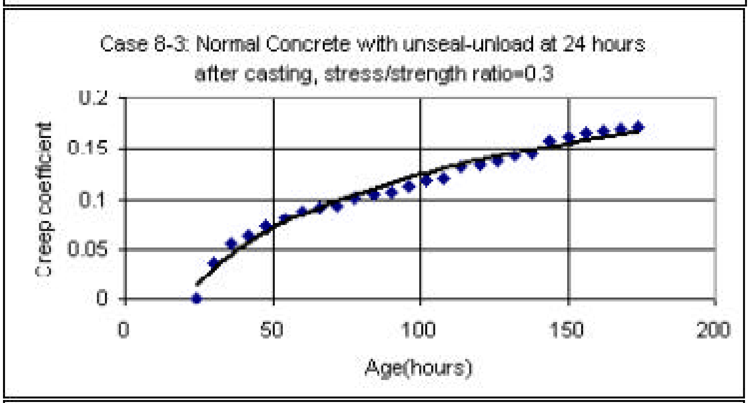

Case 7-2: Normal Concrete with seal-load condition at 24 hours after casting, stress/strength ratio=0.2
Creep coefficient
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

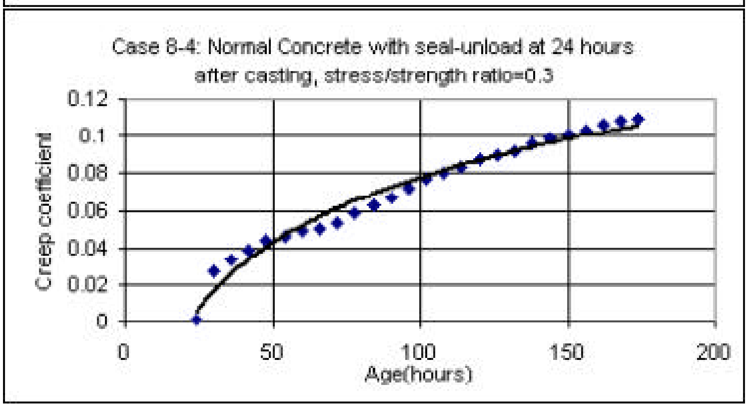

Case 7-3: Normal Concrete with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.2
Creep coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

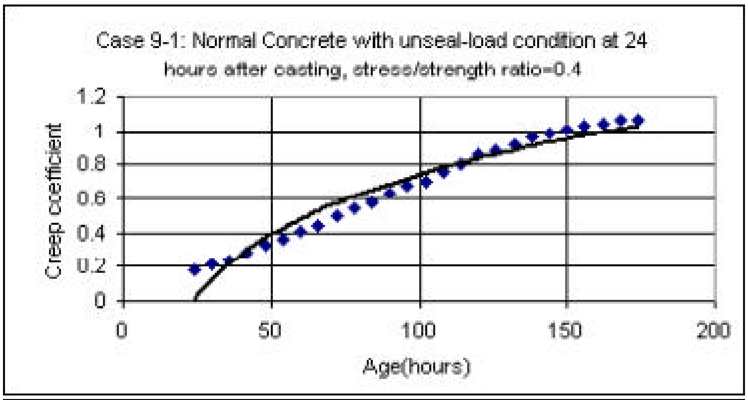

Case 7-4: Normal Concrete with seal-unload condition at 24 hours after casting, stress/strength ratio=0.2
Creep coefficient
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
Age(hours)

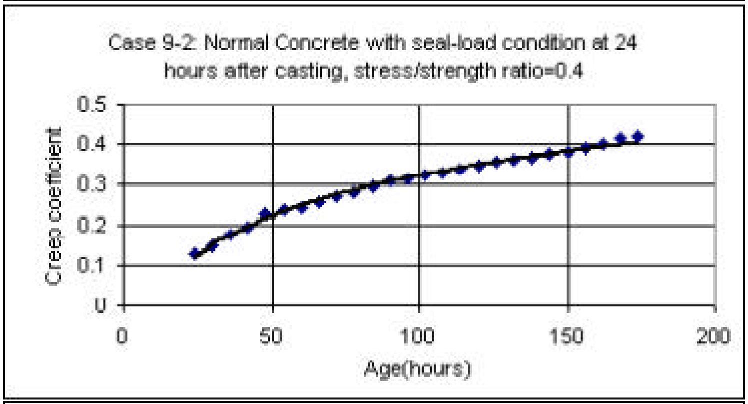

Case 8-1: Normal Concrete with unload-load condition at 24 hours after casting, stress/strength ratio=0.3
Creep coefficient
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
50
100
150
200
Age(hours)

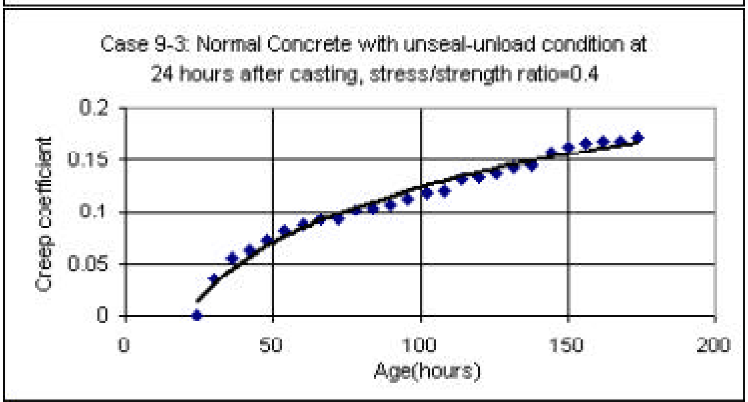

Case 8-2: Normal Concrete with seal-load at 24 hours after casting, stress/strength ratio=0.3
Creep coefficient
0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
Age(hours)

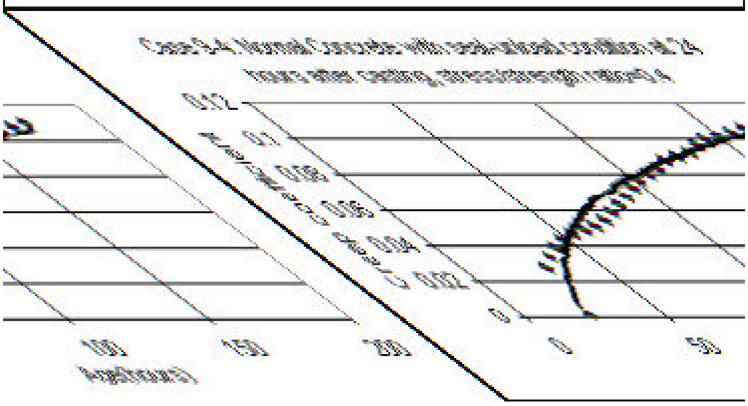

Case 8-3: Normal Concrete with unseal-unload at 24 hours after casting, stress/strength ratio=0.3
Creep coefficient
0
0.05
0.1
0.15
0.2
0
50
100
150
200
Age(hours)

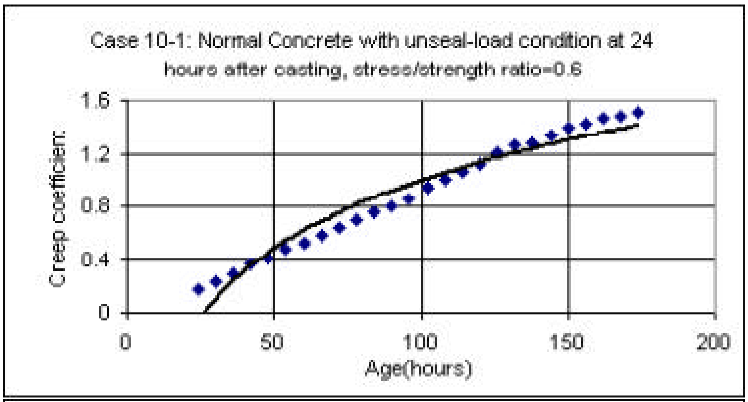

Case 8-4: Normal Concrete with seal-unload at 24 hours after casting, stress/strength ratio=0.3
Creep coefficient
0
0.02
0.04
0.06
0.08
0.1
0.12
0
50
100
150
200
Age(hours)

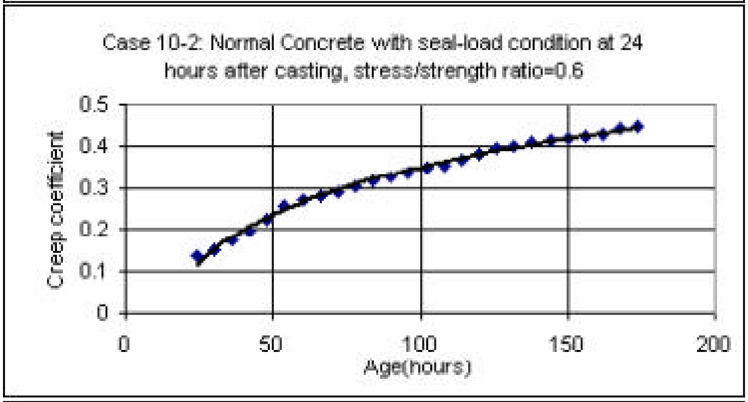

Case 9-1: Normal Concrete with unseal-load condition at 24 hours after casting, stress/strength ratio=0.4
Creep coefficient
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
Age(hours)

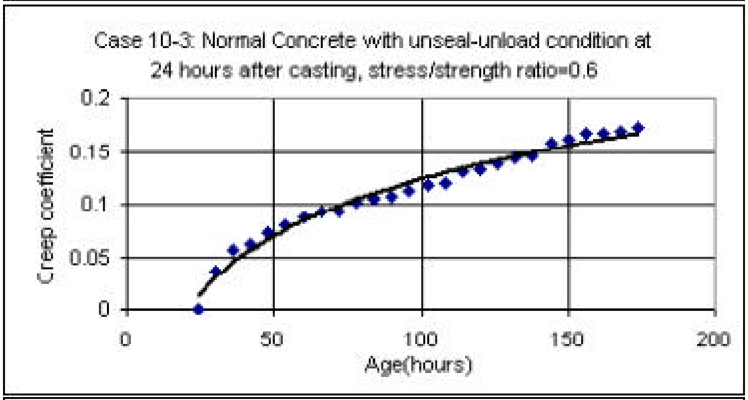

Case 9-2: Normal Concrete with seal-load condition at 24 hours after casting, stress/strength ratio=0.4
Creep coefficient
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

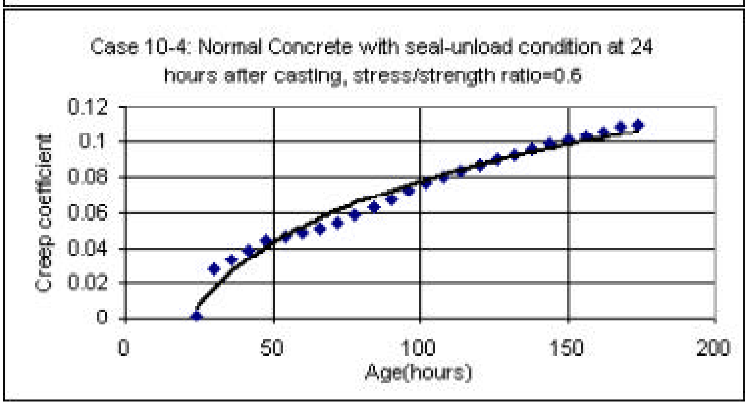

Case 9-3: Normal Concrete with unseal-unload condition at 24 hours after casting, stress/strength ratio=0.4
Creep coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

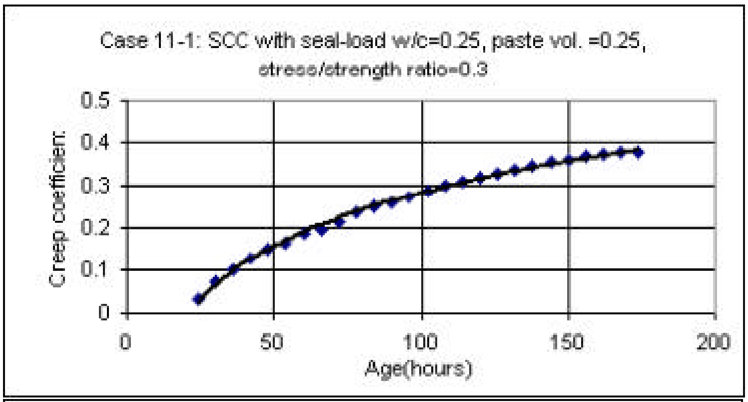

0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200

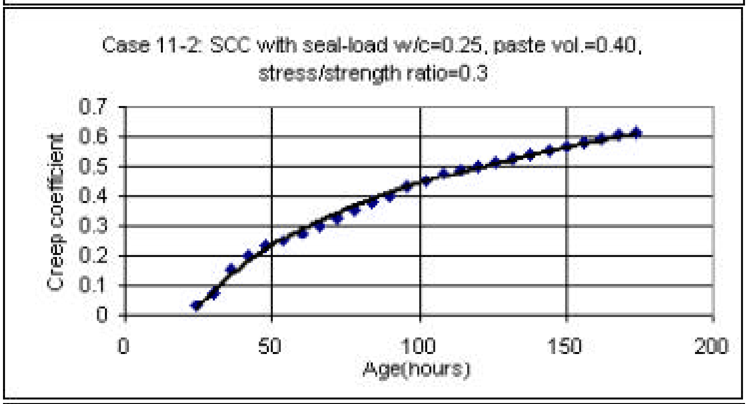

Case 10-1: Normal Concrete with unseal-load condition at 24
hours after casting, stress/strength ratio=0.6
Creep coefficient
1.6
1.2
0.8
0.4
0
0
50
100
150
200
Age(hours)

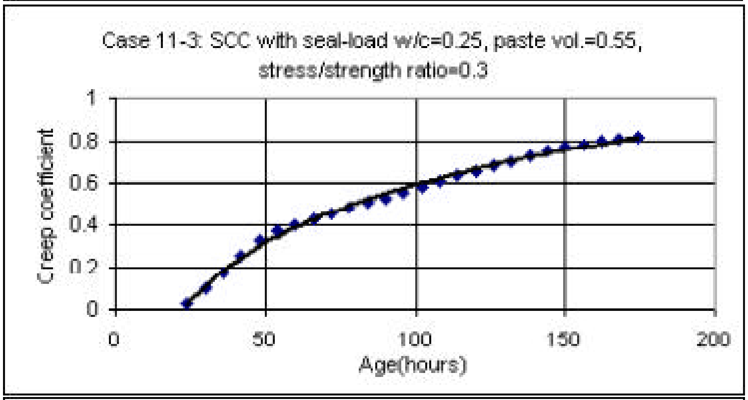

Case 10-2: Normal Concrete with seal-load condition at 24
hours after casting, stress/strength ratio=0.6
Creep coefficient
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

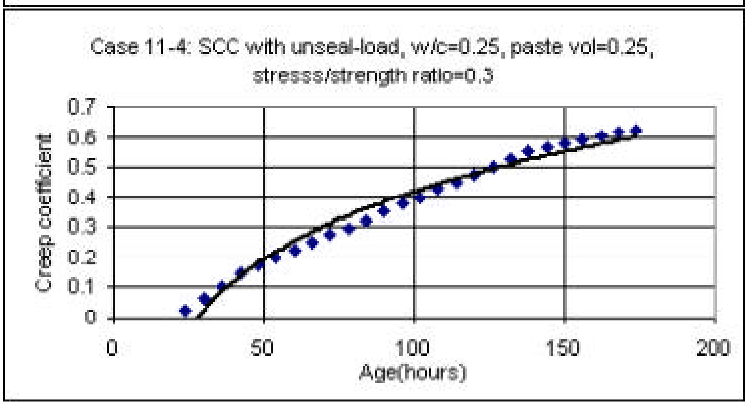

Case 10-3: Normal Concrete with unseal-unload condition at
24 hours after casting, stress/strength ratio=0.6
Creep coefficient
0.2
0.15
0.1
0.05
0
0
50
100
150
200
Age(hours)

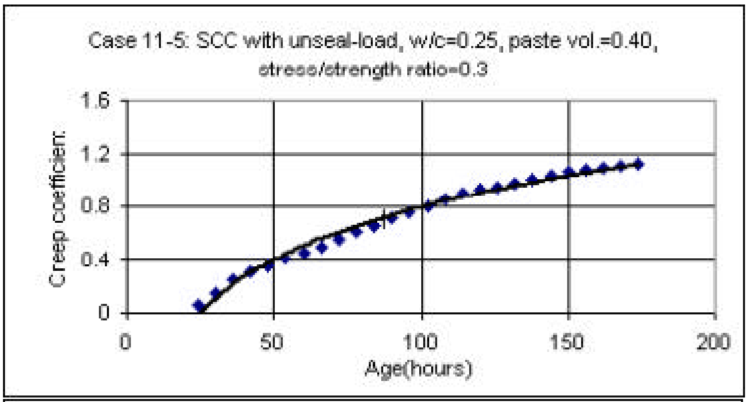

Case 10-4: Normal Concrete with seal-unload condition at 24
hours after casting, stress/strength ratio=0.6
Creep coefficient
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
Age(hours)

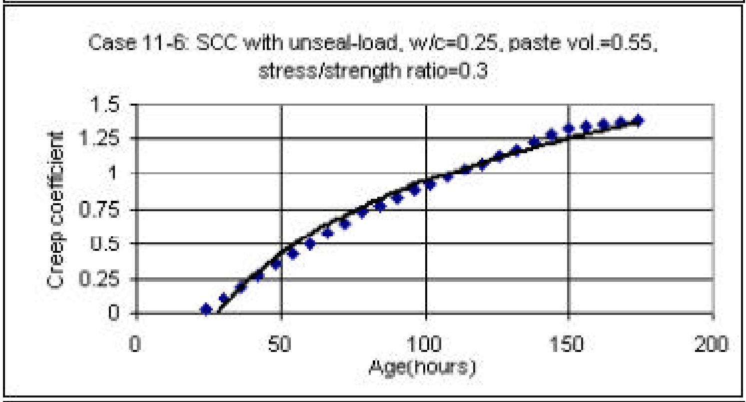

Case 11-1: SCC with seal-load w/c=0.25, paste vol. =0.25,
stress/strength ratio=0.3
Creep coefficient
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

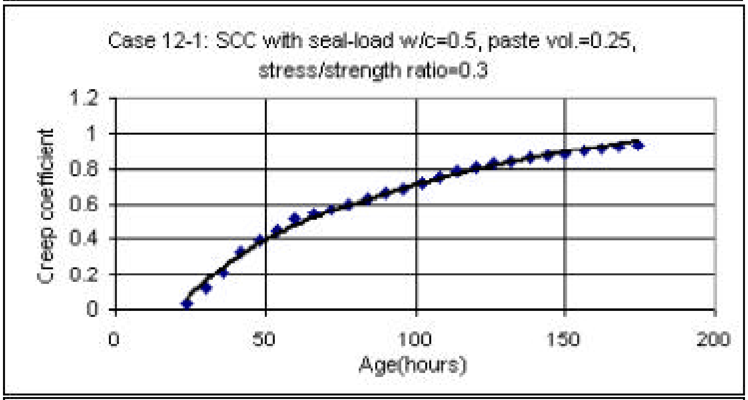

Case 11-2: SCC with seal-load w/c=0.25, paste vol.=0.40,
stress/strength ratio=0.3
Creep coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

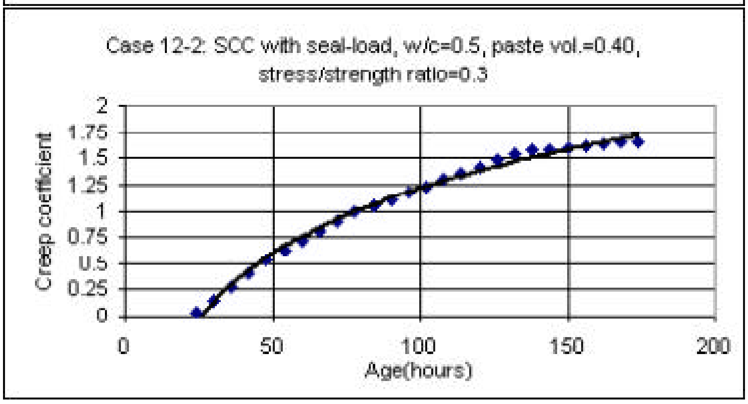

Case 11-3: SCC with seal-load w/c=0.25, paste vol.=0.55,
stress/strength ratio=0.3
Creep coefficient
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
Age(hours)

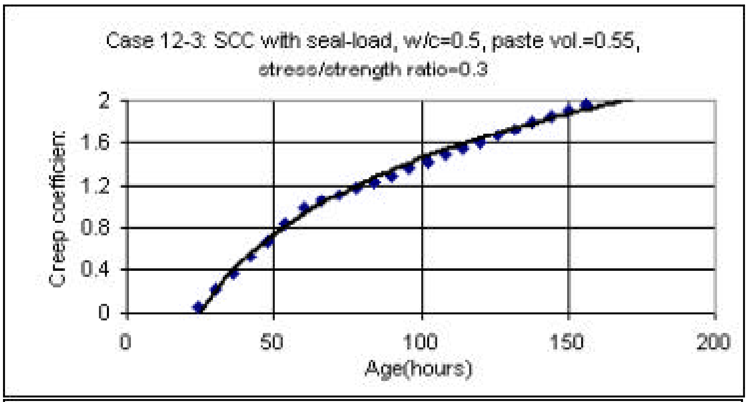

Case 11-4: SCC with unseal-load, w/c=0.25, paste vol=0.25,
stresss/strength ratio=0.3
Creep coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
Age(hours)

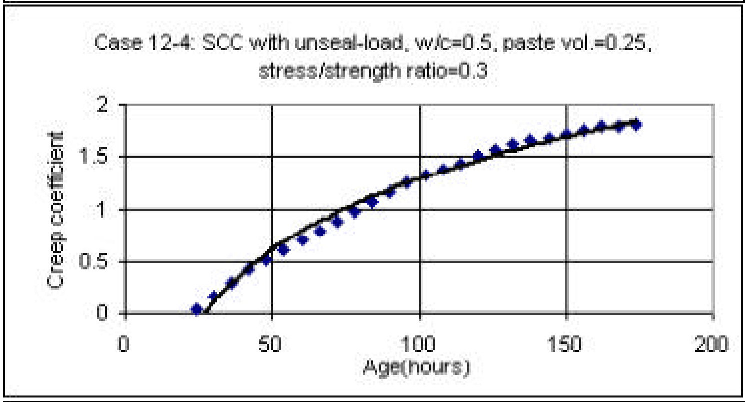

Case 11-5: SCC with unseal-load, w/c=0.25, paste vol.=0.40,
stress/strength ratio=0.3
Creep coefficient
Age(hours)
0
0.4
0.8
1.2
1.6
0
50
100
150
200

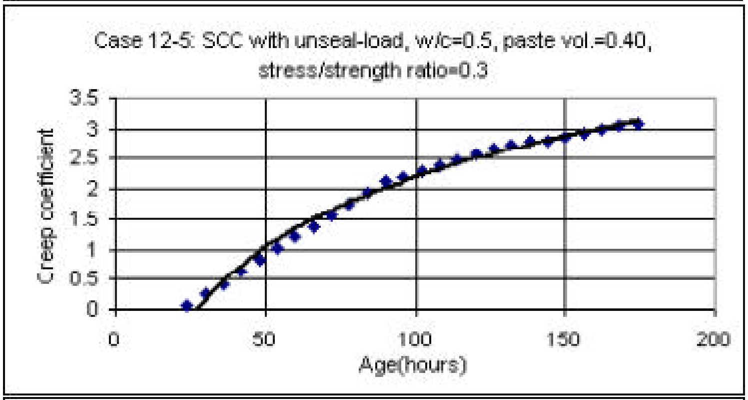

Case 11-6: SCC with unseal-load, w/c=0.25, paste vol.=0.55,
stress/strength ratio=0.3
Creep coefficient
Age(hours)
0
0.25
0.5
0.75
1
1.25
1.5
0
50
100
150
200

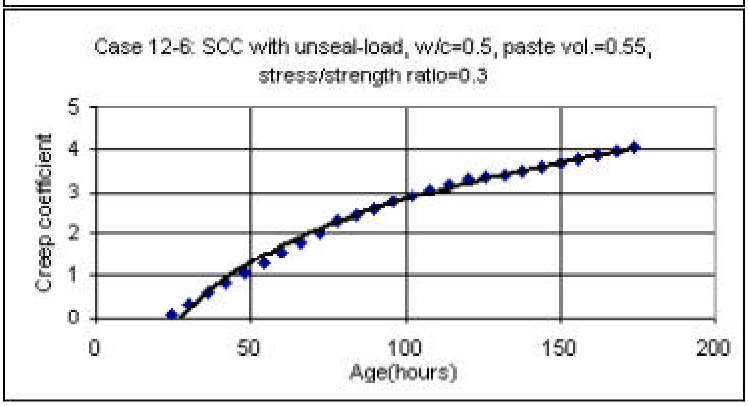

Case 12-1: SCC with seal-load w/c=0.5, paste vol.=0.25,
stress/strength ratio=0.3
Creep coefficient
Age(hours)
0
0.2
0.4
0.6
0.8
1
1.2
0
50
100
150
200

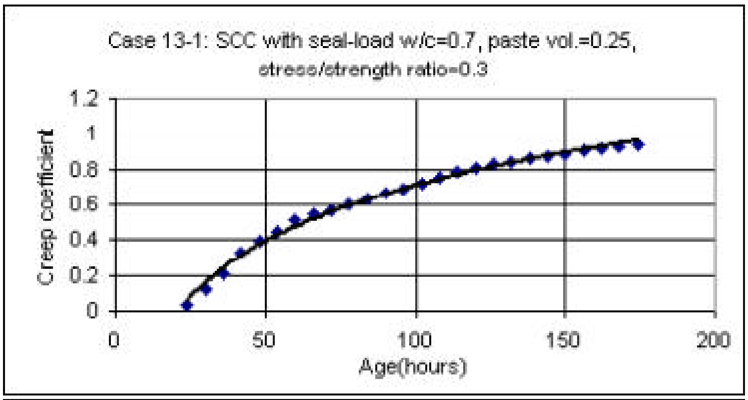

Case 12-2: SCC with seal-load, w/c=0.5, paste vol.=0.40,
stress/strength ratio=0.3
Creep coefficient
Age(hours)
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0
50
100
150
200

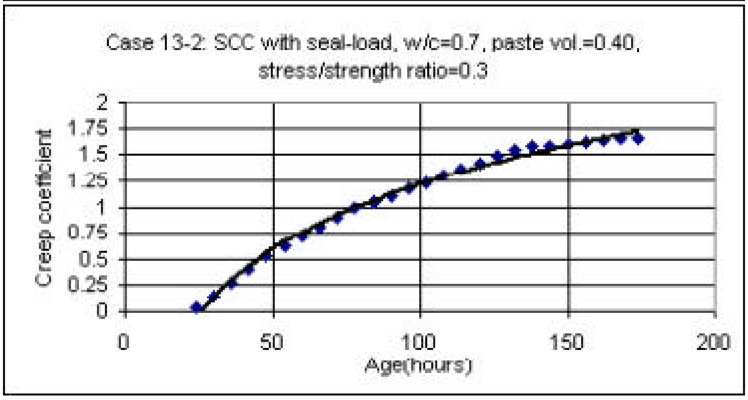

Case 12-3: SCC with seal-load, w/c=0.5, paste vol.=0.55,
stress/strength ratio=0.3
Creep coefficient
2
1.6
1.2
0.8
0.4
0
0
50
100
150
200
Age(hours)

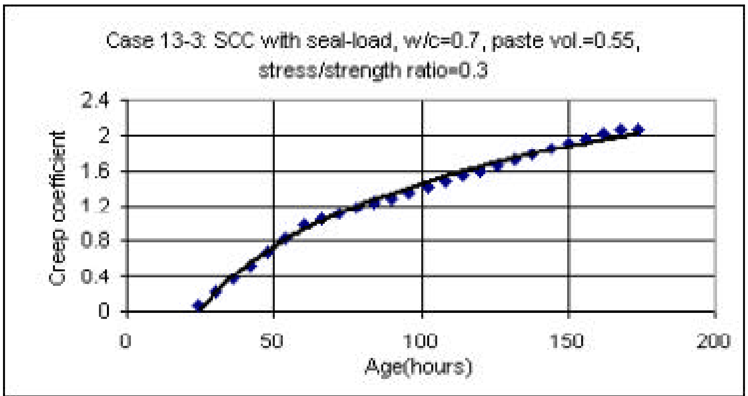

Case 12-4: SCC with unseal-load, w/c=0.5, paste vol.=0.25,
stress/strength ratio=0.3
Creep coefficient
2
1.5
1
0.5
0
0
50
100
150
200
Age(hours)

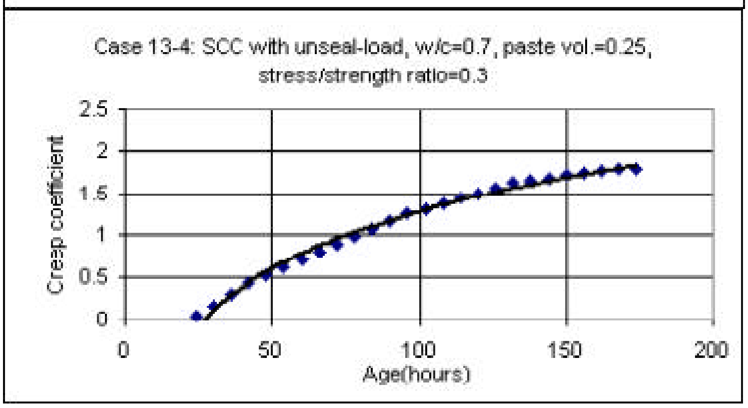

Case 12-5: SCC with unseal-load, w/c=0.5, paste vol.=0.40,
stress/strength ratio=0.3
Creep coefficient
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
Age(hours)

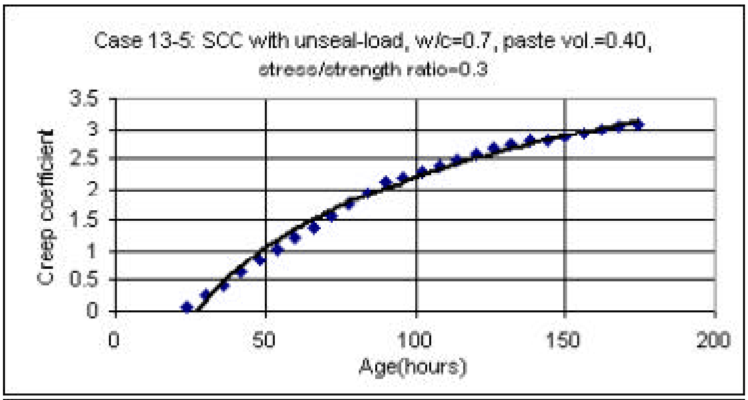

Case 12-6: SCC with unseal-load, w/c=0.5, paste vol.=0.55,
stress/strength ratio=0.3
Creep coefficient
5
4
3
2
1
0
0
50
100
150
200
Age(hours)

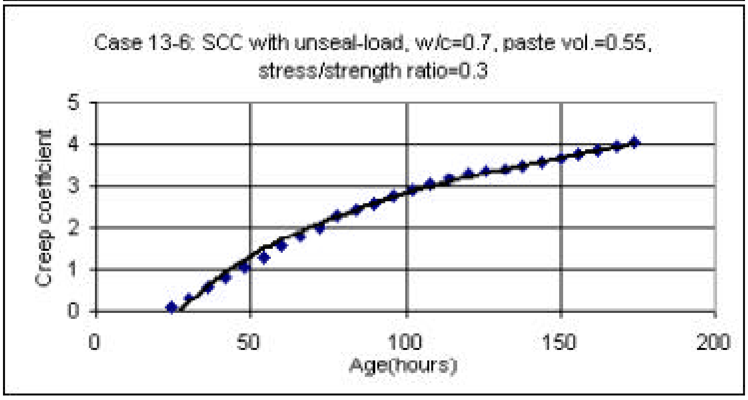

Case 13-1: SCC with seal-load w/c=0.7, paste vol.=0.25,
stress/strength ratio=0.3
Creep coefficient
Age(hours)

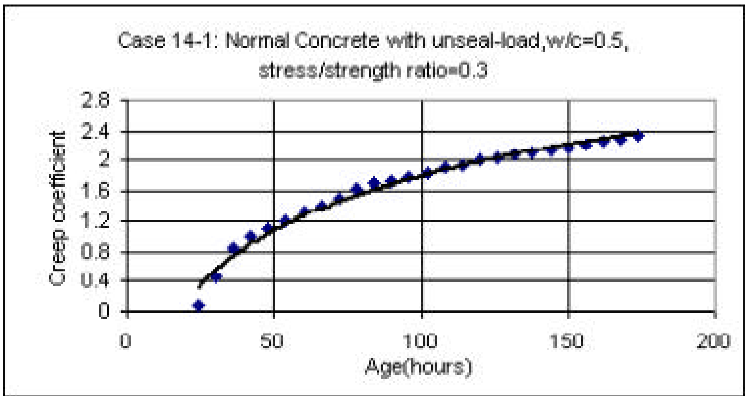

Case 13-2: SCC with seal-load, w/c=0.7, paste vol.=0.40,
stress/strength ratio=0.3
Creep coefficient
Age(hours)

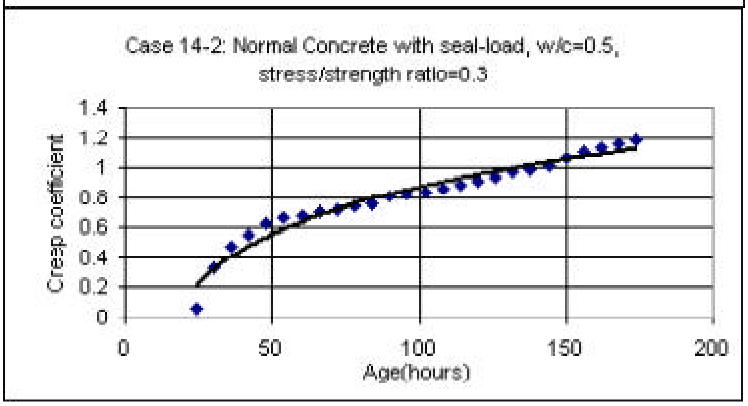

Case 13-3: SCC with seal-load, w/c=0.7, paste vol.=0.55,
stress/strength ratio=0.3
Creep coefficient
Age(hours)


Case 13-4: SCC with unseal-load, w/c=0.7, paste vol.=0.25,
stress/strength ratio=0.3
Creep coefficient
Age(hours)


Case 13-5: SCC with unseal-load, w/c=0.7, paste vol.=0.40,
stress/strength ratio=0.3
Creep coefficient
Age(hours)


Case 13-6: SCC with unseal-load, w/c=0.7, paste vol.=0.55,
stress/strength ratio=0.3
Creep coefficient
Age(hours)


Case 14-1: Normal Concrete with unseal-load,w/c=0.5,
stress/strength ratio=0.3
Creep coefficient
Age(hours)


Case 14-2: Normal Concrete with seal-load, w/c=0.5,
stress/strength ratio=0.3
Creep coefficient
Age(hours)