# (I4) CREEP PREDICTION FOR CONCRETE-FILLED STEEL TUBULAR STRUCTURES

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This paper proposes a creep prediction equation of concrete-filled steel tubular (CFT) structures by modifying an existing creep model for more accurate and convenient creep prediction of CFT structures. Firstly, the creep characteristics of CFT are analyzed by considering moisture transport, stiffness ratio and the confined effect of CFT structures. By evaluating the existing creep equations, the creep model of the CEB-FIP 90 was attempted to modify to consider the effect of stiffness ratio and the stress variation of filled concrete in the proposed equation. Then, verification of the proposed equation is carried out through comparison with several experimental data. It is shown that the proposed creep prediction equation for CFT structures predicts comparably well with experimental data and can be useful for the engineering practice and design.

***Key Words:*** *concrete-filled steel tubular (CFT) structure, creep charactreisitc, CFT experimental data, CFT creep prediction equation*

## 1. INTRODUCTION

In recent years, the hybrid structure system with composite of steel and concrete has been widely developed due to its structural and economical efficiency. The concrete-filled steel tubular (CFT) structures are well-known hybrid systems having higher stiffness, strength and ductility, and the CFT have been successfully applied to infra-structures such as columns, piers and arch-rib of bridge. For example, CFT girder system is developed for cable-stayed bridge as shown in Fig.1.

However, even significant researches and investigations have been carried out on the load carrying capacity of CFT structures, less emphasis has been placed on their time-dependent behavior.

Prediction of time-dependent behavior of cable-stayed bridge is important for not only serviceability after its completion but also the stress and deformation control during the erection stages of the cable-stayed bridge[1)]. Especially, creep prediction of CFT structures should be carried out more exactly considering that CFT structure is used for systems with high axial compressive strength.

In the past, creep effects of CFT have been accounted for by increasing the strength or reducing the initial elastic modulus of concrete[2)] or by considering it as some ratio of creep values of ordinary concrete for engineering practice.

Some reasercher[3,4)] have suggested creep prediction by complicated iteration methods in recent years, but the methods need long time for analysis in huge structures.

This paper proposes a method to predict the creep of CFT more exactly and more simply by modifying an existing creep equation, CEB-FIP 90[5)]. The proposed method is useful for the creep prediction without complicated iteration procedure and long program run-time.

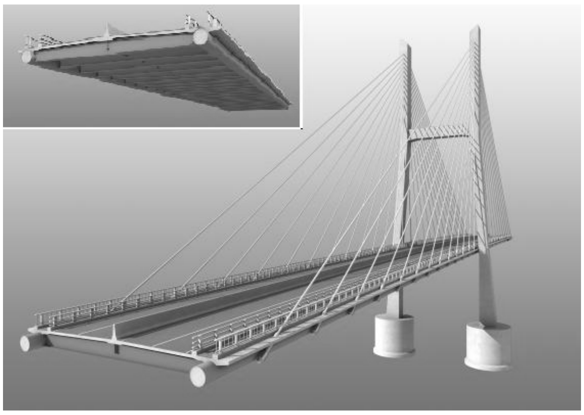


**Fig. 1** Cable-stayed bridge using CFT girder

## 2. CREEP CHARATERISTICS OF CFT

Time-dependant behavior of CFT structure is markedly different from that of ordinary concrete structures and these characteristics were verified by some researchers. Experiments by Terrey et al.[6] showed that the moisture egress from confined concrete was very small or totally eliminated. Thus, shrinkage of concrete core might be safely neglected, and creep coefficients might be 50-60% of those in ordinary concrete.

Russell and Corely[7] showed that creep of sealed concrete might be half as much as that of the exposed concrete, at the same age under the same sustained loads. Ichinose et al.[8] also concluded that creep coefficient of hybrid structure was smaller than that of ordinary concrete structure through a series of tests to obtain creep coefficients in composite steel-concrete columns.

Major characteristics of CFT creep behavior can be summarized in several aspects, as follows:

1) Concrete core is essentially sealed from migration of any moisture due to presence of surrounding tube, and therefore, drying creep and shrinkage strains are considerably lower in CFT.
2) External force is distributed according to stiffness ratio of concrete and steel in order to satisfy static equilibrium and strain compatibility.
3) Confinement of concrete by the tube offers resistance to the lateral expansion of concrete. This multi-axial effect does not allow concrete to freely creep in axial direction.
4) Stress transfer between concrete core and steel tube is possible, resulting in stress relaxation of concrete, and further reducing its creep.

In predicting CFT creep, these characteristics should be considered and it is needed to use complicated iteration procedure for it. However, if some factors which do not affect the entire creep strain seriously can be neglected, the procedure of creep prediction can be very much simplified without losing accuracy and can be useful for engineering practice, which will be attempted in this study.

## 3. MODIFICATION OF CREEP MODEL FOR CFT

Fig 2 shows the deformational behavior variation in order of a CFT under the sustained load, in which it is assumed that complete interaction takes place between the steel and concrete.

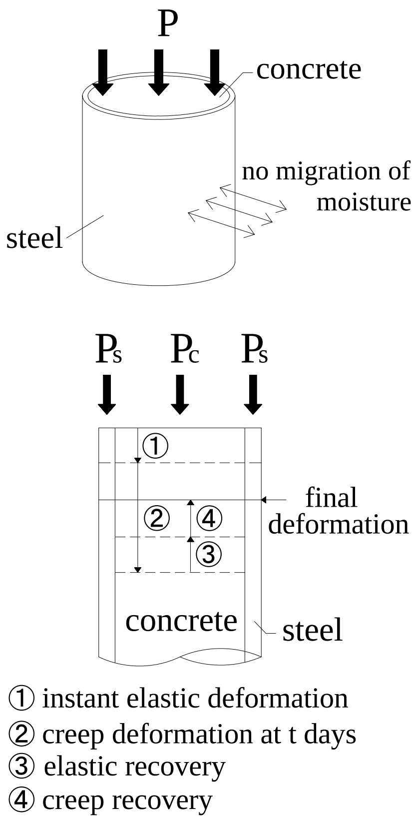



**Fig. 2** Sequential deformations of CFT

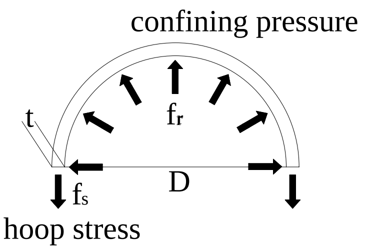
Firstly, instant elastic deformation is generated by the total sustained load, P, on the section of CFT. The total load is divided into loads resisted by steel and concrete so that load distribution can be calculated as,

$$P = P_c + P_s \tag{1}$$

$$P_c = \frac{E_c A_c}{E_c A_c + E_s A_s} P \tag{2}$$

where, E and A designate modulus of elasticity and area of cross section, respectively, and subscripts c and s denote concrete and steel, respectively.

The confing pressure, $f_r$ can be analytically calculated by considering the relation of lateral confining pressure on concrete and the hoop stress $f_s$, in the steel tube for more accurate load distribution ratio (see Fig. 3). But the change of load distribution due to confining effect is expected to be negligible due to the higher Poisson’s ratio of steel in its elastic range when steel and concrete are loaded simultaneously[9)].




$$f_r = \frac{2 f_s t}{D}$$

**Fig. 3** Confining pressure and hoop stress behavior inside CFT

After instant elastic deformation, concrete part has aging effect such as creep and shrinkage with time. But, shrinkage and drying creep deformations are so small because concrete core is sealed by the steel tube and migration of moisture is not permitted. Ichinose et al.[8)] showed that the shrinkage strain in the encased concrete specimen was about 9% of the value of the shrinkage strain in the plain concrete specimen from concrete shrinkage measurements. Terry et al.[6)] showed that shrinkage of concrete core in steel tubes might be safely neglected, too. In this paper, drying creep and shrinkage are neglected.

Creep strain of concrete inside steel tube drying is less than that under uniaxial stress of the same magnitude because of multi-axial stresses. Gopalakrishnan et al.[10)] and Jordaan and Illston[11)] have shown that despite anisotropy and creep nonlinearity, creep strain in concrete conforms to the principle of superposition by adding creep strain in each direction caused by each stress component acting separately. Also, Gopalakrishnan et al.[10)] defined an effective Poisson’s ratio (as total lateral strain / total axial strain) and showed that the effective Poisson’s ratio was constant over time with its value ranging from 0.09 to 0.17.

Previous experiments shows that the difference in creep for uniaxial and multi-axial loaded concrete is not markedly important due to bulge effect of steel when steel and concrete are loaded simultaneously without interation by shear connectors[6,9)]. But, creep and elastic recovery deformation should be considered according to reduction of concrete stress by stress redistribution.

Previous experiments by Morino et al.[12)] have shown that the axial stress variation in the tube may be in the order of 10-20% of the initial stress, whereas stresses in concrete may vary about 5-10%. Based on the above discussion, the equation for total deformation(=①+ ②+ ③+ ④) of CFT is expressed as

$$\varepsilon_{cftc} = \frac{P_c(t_0)}{A_c} \times \left( \frac{1}{E_c(t_0)} + \frac{\phi(t,t_0)}{E_{ci}} \right) +$$

$$\int_{t_0}^{t} \frac{df_c(\tau)}{d\tau} \frac{1}{E(\tau)} d\tau + \frac{1}{E_{ci}} \int_{t_0}^{t} \frac{df_c(\tau)}{d\tau} \phi(t,\tau) d\tau \quad (3)$$

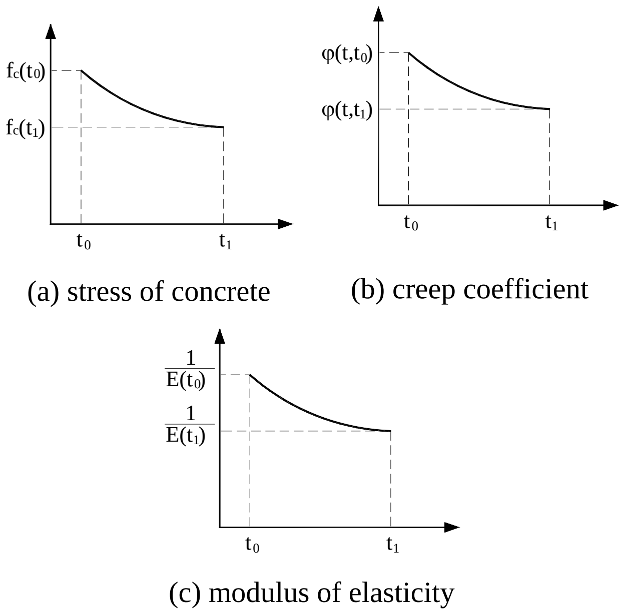
where, $f_c$ is the stress of concrete part, $\phi(t,t_0)$ is creep coefficient, $t_0$ is age at loading and $P_c$ can be written as the following equation (4).

$$P_c(t_0) = \frac{E_c(t_0) A_c}{E_c(t_0) A_c + E_s A_s} P \qquad (4)$$

In this equation, first and second terms are for initial elastic deformation and creep deformation, respectively and third and fourth terms are concerned about creep recovery and elastic recovery deformation, respectively, due to the stress redistribution.

In order to simplify third and fourth integration terms, this study assumes that the stress of concrete, creep coefficient and inverse modulus of elasticity of concrete decrease with time in similar manner as shown in Fig.4.

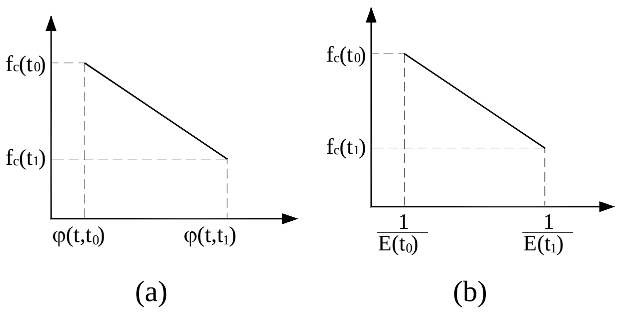
With assumption, relations of concrete stress with creep coefficient and modulus of elasticity can be expressed as shown in Fig.5, respectively.




(a) stress of concrete (b) creep coefficient

(c) modulus of elasticity

**Fig. 4** Variation of stress, creep coefficient and modulus of elasticity according to time




(a) (b)

**Fig. 5** Variation of stress distribution according to creep and elasticity.

Then, using the relations as Fig.5, we can rewrite equation (3) into equation (5).

$$\varepsilon_{cft}(t) = f_c(t_0)\left(\frac{1}{E(t_0)} + \frac{\phi(t,t_0)}{E_{ci}} - \frac{\beta(E(t)-E(t_0))}{2E_c(t)E(t_0)} - \frac{\beta\phi(t,t_0)}{2E_{ci}}\right) \quad (5)$$

where, $\beta$ is ratio of redistribution of stress (=0.05~0.1), which can be obtained as equation (6), and $f_c(t_0)$ is the stress of concrete at age $t_0$ as the equation (7).

$$\beta = \frac{f_c(t_0) - f_c(t)}{f_c(t_0)} \quad (6)$$

$$f_c(t) = \frac{E(t_0)P}{E(t_0)A_c + E_s A_s} \quad (7)$$

In respect of the modulus of elasticity in the creep equation of the CEB-FIP 90, $E(t)$, for evaluating the elastic strain and, $E_{ci}$ ,for calculating creep are used respectively. Thus, if the difference of $E(t)$ and $E_{ci}$ is small due to loading after long aging, the equation (5) can be further simplified.

## 4. MODEL VALIDATION

Proposed equation in this study validated with the experimental data of Kwon et al.[9], Terry et al.[6] and Hilmi[13] for CFT specimen at age 18 days and 28 days of loading. The mechanical properties and test conditions of the test specimen are shown in Table 1, 2 and 3.

**Table 1** Mechanical properties and test conditions of the experimental data by Kwon et al.(2001)

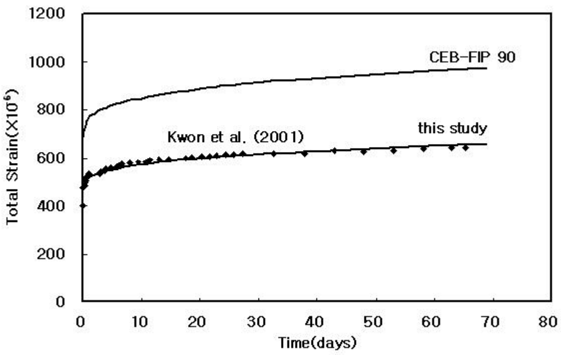
| Material | Concrete | Steel |
|---|---|---|
| D × h | 134.2×560 | - |
| Thickness, t | - | 2.9mm |
| Elastic modulus | 37.8 GPa | 213 GPa |
| Strength of concrete | 57.1 MPa (at 28days) | 265 MPa (at yielding) |
| Poisson’s ratio | 0.16 | 0.29 |
| Age at loading | 28 days | |
| Loading, P | 372 kN | |

**Table 2** Mechanical properties and test conditions of the experimental data by Terry et al.(1994)

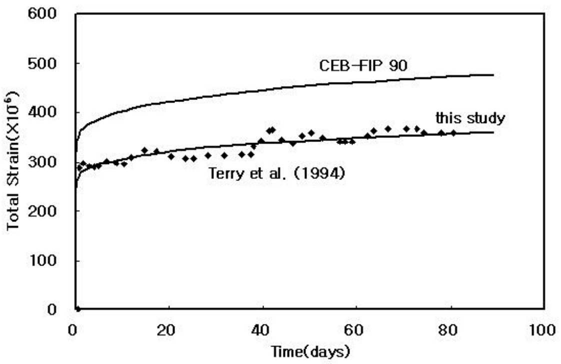
| Material | Concrete | Steel |
|---|---|---|
| D × h | 196×600 | - |
| Thickness, t | - | 1.5mm |
| Elastic modulus | - | - |
| Strength of concrete | 45.2 MPa (at 28days) | 210 MPa (at yielding) |
| Poisson’s ratio | - | - |
| Age at loading | 18 days | |
| Loading, P | 350 kN | |

**Table 3** Mechanical properties and test conditions of experimental data by Hilmi(2002)

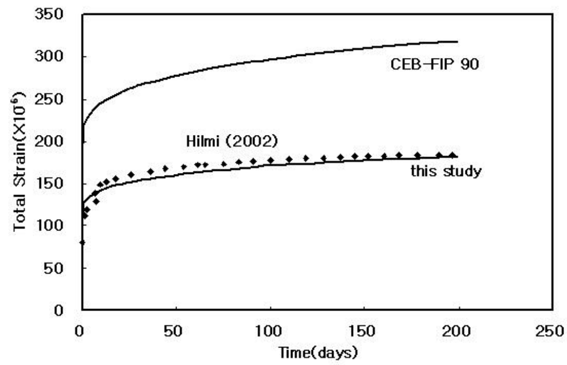
| Material | Concrete | Steel |
|---|---|---|
| D × h | 325×4500 | - |
| Thickness, t | - | 7.5mm |
| Elastic modulus | 37 GPa | 206 GPa |
| Strength of concrete | 38 MPa (at 28days) | 386 MPa (at yielding) |
| Poisson's ratio | - | - |
| Age at loading | 18 days | |
| Loading, P | 500 kN | |




(a) Comparison with Kwon et al.(2001)




(b) Comparison with Terry et al.(1994)




(c) Comparison with Hilmi (2002)

**Fig. 6** Comparison with experimental data and CEB-FIP 90 model

Fig. 6(a),(b) and (c) show comparisons between the experiments and the proposed equation in the total strains of CFT. The comparisons show that the existing CEB-FIP 90 model overestimates the creep of CFT, but the proposed creep equation accords well with the experimental data.

It was found that the stiffness ratio and stress redistribuiton have great influence on the creep behavior of CFT because the age at loading of experiments are relatively old (18, 28 days) and creep coefficient and strength development of young concrete inside steel case must be important factors affecting the behavior of CFT when loaded in young age[14)].

## 5. CONCLUSION

The existing creep equation in CEB-FIP 90 was attempted to modify for the prediction of creep of the CFT structures by considering the effect of stiffness ratio, stress of filled concrete. Then, a verification of the proposed equation is carried out through comparison with several experimental data and the creep equation of CEB-FIP 90.

It is shown that the proposed creep prediction equation for CFT structures accords well with experimental data and can be useful for the engineering practice and design due to simplicity of the equation.

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