AN EXPERIMENTAL STUDY ON CREEP OF CONCRETE FILLED STEEL PIPES

コンクリートを充填した鋼管柱のクリープに関する実験的研究

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要　約

鋼外殻と充填コンクリートとが外力に抵抗するようにした複合構造物は，鉄筋コンクリート柱や鋼管柱よりも剛度が高く，耐荷力が大きいなどの優れた力学的特性を有している．そのため，これまでの鉄筋コンクリート柱や，鋼管柱よりも小さい断面構成が可能となり，経済的な設計が行える．したがって，軸方向力が卓越して作用するアーチ橋のリブ部材，あるいはラーメン橋の柱部材などへの利用が期待されているが，まだ解決すべき多くの課題が残されているのも事実である．

その一つの課題として，クリープやリラクセーションの問題が挙げられる．すなわち，クリープとは一定応力のもとにおけるひずみの進行現象であり，リラクセーションとは一定ひずみのもとでの応力の進行現象である．

限界状態設計法によると，これらの現象は，終局状態にあまり影響しないが，使用限界状態には大きく影響を及ぼすため，コンクリートのひびわれに対する安全性の照査や構造物の架設中の変形の制御，あるいは建設後の複合構造物の維持・管理の面から慎重に検討すべき項目が多々ある．

そこで本研究では，コンクリートを充填した鋼管柱に持続荷重を載荷し，クリープに関する実験を行った．あわせて，乾燥収縮に関する実験も行い，クリープに関する実験の実測値から差し引くことで乾燥収縮の影響を考慮した．また，バネとダッシュポットを用いた簡単なレオロジーモデルを考え，これから誘導された式の係数を，最小自乗法で同定することにした．この方法で得られた式から，今後，複合構造物の設計に必要な経時挙動が予測できるのである．

160日間にわたる計測結果から次のような結果が得られた．

(1)コンクリートを充填した鋼管柱の乾燥収縮ひずみは著しく小さく，設計する際，無視してもよいと考えられる．

(2)コンクリートを充填した鋼管柱のクリープひずみは，コンクリート柱のクリープひずみの10～15%であった．

(3)荷重の低下率を，リラクセーション的な現象と，指数的なクリープ現象とが重なったものとして捉える手法は，同定結果によると，ほぼ妥当なものであることがわかった．

(4)経時挙動をKelvinモデルを用いた理論式に基づき，最小自乗法で処理したものと実際の経時挙動とはよく一致している．

(5)コンクリートを充填した鋼管柱のクリープ係数は，コンクリート標準示方書から求めたクリープ係数の約0.6倍である．

I. INTRODUCTION

Combining the advantages of both concrete and steel, one of the alternatives to improve the resistance of steel members to compression load is to use concrete filled tubular steel members. Avoiding the problem of buckling of steel members, this alternative would provide smaller cross section and improve the structural aesthetics.

Researches and investigations on the load carrying capacity of composite structures has been widely carried out, but not much has been done related to their time-dependent behavior. Creep, although not compromising the structural strength directly, was found to be one of the causes of excessive deformation and crack occurrence, specially in structures involving concrete under long time compression. Therefore, although the phenomenon can not be considered relevant to the Ultimate Limit State, it may turn into an important point when considering the design for the Serviceability Limit

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State. In addition, the prediction of the structural time-dependent behavior is important for the stress and deformation control during the erection of the structure, as well as to its maintenance after completion.

2. ANALYTICAL MODEL

To allow an easy application to a FEM analysis in future, one of the most basic viscoelastic models, the Kelvin model, was adopted. Fig. 1 shows the analytical model, consisting of an elastic spring connected in parallel to a dash-pot.

$$\eta\dot{\varepsilon}(t)+E_c\varepsilon(t)=\sigma(t) \qquad \cdots(1)$$

where $\sigma(t)$ = stress
$\varepsilon(t)$ = strain
E_c = Young's Modulus
η = viscosity coefficient

and the dot ($\dot{\varepsilon}$) indicates derivation in relation to time.

The applied stress $\sigma(t)$ was assumed to vary exponentially

$$\sigma(t)=\sigma_0\ \{\alpha+(1-\beta)e^{-\kappa t}\} \qquad \cdots(2)$$

where σ_0 is the initially applied stress and β and κ are parameters to be evaluated experimentally. Thus, introducing Eq. (2) into Eq. (1) and solving the differential equation, the following is obtained:

$$\varepsilon(t)=\frac{\sigma_0}{E_c}\ \{\alpha(1-e^{-\kappa t})+\frac{1-\alpha}{1-\kappa/\beta}(e^{-\kappa t}-e^{-\beta t})\} \qquad \cdots(3)$$

where $\beta=E_c/\eta$ and η is to be evaluated by applying the least square method to the measured data.

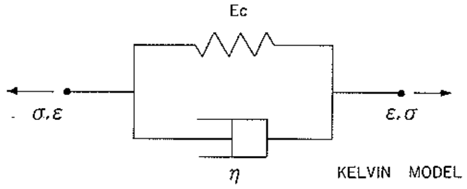


Fig. 1 Analytical Model

3. CREEP TEST AND MEASUREMENT OF THE DRYING SHRINKAGE

Long-time measurements were carried out on axially loaded concrete filled steel columns, so as to obtain the above mentioned viscoelastic parameters, which characterize the structural time-dependent behavior.

(a) SPECIMEN

The specimens consisted of 1.0m long concrete filled steel pipes with an external diameter of 165.2mm. To account for the influence of the concrete-steel ratio, three specimen types, having different steel wall thickness (4.5mm, 5.0mm and 0.0mm), including one of plain concrete, were considered. Table 1 shows the specimen types and their dimensions.

The material type applied in the fabrication of the specimen was STK41 for the steel pipe and the concrete design strength for the 28th day was 300kgf/cm^2(29.4 MPa). Their mechanical properties are presented in Table 2. Besides these values, to follow the changes in the material properties, the concrete Young's modulus was periodically measured on test pieces kept under the same environmental condition as that of the column specimens.

(b) EXPERIMENTAL METHOD

Due to the difficulty in isolating the strain due to the concrete drying shrinkage from the ones due to creep, the experiment was divided into two parts, namely creep test and drying shrinkage strain measurements, which were carried out simultaneously.

Creep strain measurement was carried out on specimens submitted to long time axial load and drying shrinkage measurement, on specimens without loading, with the same dimensions and in the same environmental condition of those undergoing the creep test.

The experiment was carried out in a laboratory where the temperature is almost constant during the whole year,

Table 1 Specimen Types

EXPERIMENT	APPLIED STRESS σ_c	SPECIMEN NAME	THICKNESS t_w (mm)	EXTERNAL DIAMETER (mm)	LENGTH (m)
CREEP	80kgf/cm^2	CR-80-0.0	0.0	165.2	1.0
		CR-80-4.5	4.5	165.2	1.0
		CR-80-5.0	5.0	165.2	1.0
DRYING SHRINKAGE	0kgf/cm^2	SH-0-0.0	0.0	165.2	1.0
		SH-0-4.5	4.5	165.2	1.0
		SH-0-5.0	5.0	165.2	1.0

(1kgf/cm^2 = 0.098MPa)

Table 2 Mechanical Properties of Steel and Concrete

MATERIAL	COMP.STRENGTH (kgf/cm^2)	YOUNG'S MODULUS (kgf/cm^2)	POISSON RATIO
CONCRETE(28days)	283.98	2.32×105	0.169
STEEL(4.5mm)	4268	2.36×106	0.291
STEEL(5.0mm)	4495	2.32×106	0.286

(1kgf/cm^2 = 0.098MPa)

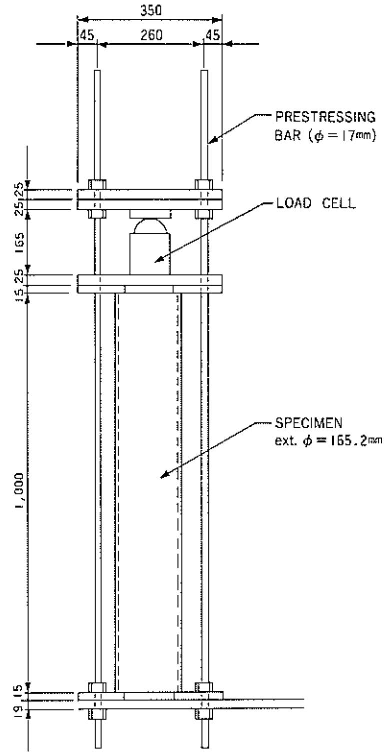


Fig. 2 Loading System

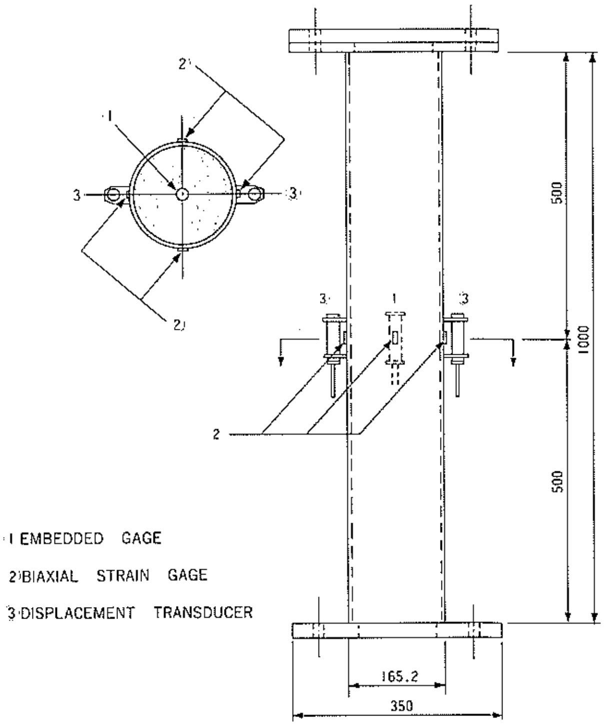


Fig. 3 Measurement Points

so as to keep the influence of temperature gradient as small as possible. Creep strain was assumed to be the values obtained from the loaded specimen subtracted by the ones obtained from the specimen without any load.

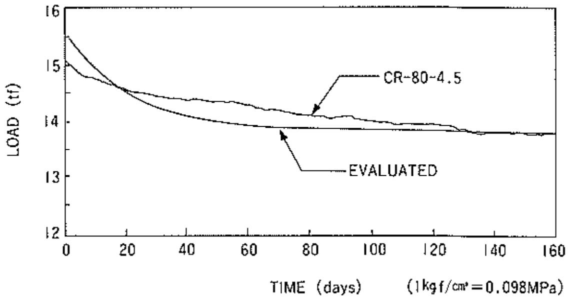
The load, as shown in Fig.2, was applied by prestressing bars and measured by means of a load cell. Strain measurements were obtained in the central part of the column for the concrete, as well as for the steel. The measurement points are as it is illustrated in Fig.3.

4. RESULTS

After six months measuring both creep and drying shrinkage data, the process is now showing a tendency to stabilize. Fig.4 illustrates the time-dependent behavior for one of the specimens, showing the measured load variation with time and the approach curve of Eq. (2), whose parameters were evaluated based on the measured data. Except for the initial phase, the curve is in good accordance with the data.

Drying shrinkage strains measured in each type of speciemen are represented in Fig.5. The curves show that the strain in the concrete filled columns were very small compared to the strain in the pure concrete columns, whose surface is free to interact with the environment.

The time-dependent behavior of the axial strain in the concrete and in the steel pipe due to creep is shown in



(1kgf/cm² = 0.098MPa)

Fig.4 Load Variation with Time

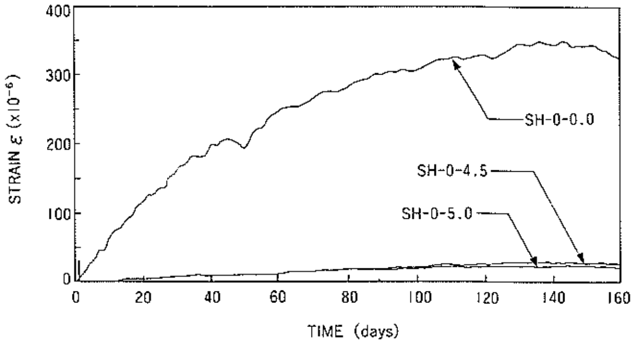


Fig. 5 Concrete Drying Shrinkage

Fig.6 (a) and Fig.6 (b), respectively. These values were obtained from the measured data, taking the drying shrinkage into account. The correspondent curves evaluated according to the analytical model is also illustrated in the figures showing good agreement with the experimental data.

Based on the experimental data, the viscoelastic coefficients were evaluated and their values are shown in Table 3.

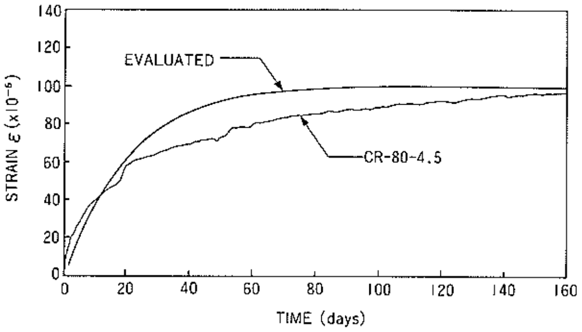


Fig. 6(a) Concrete Axial Strain Due to Creep

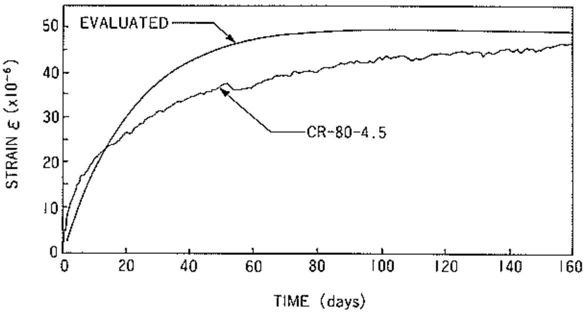


Fig. 6(b) Steel Pipe Axial Strain Due to Creep

Table 3 Evaluated Viscoelastic Parameters

PARAMETER / SPECIMEN	α	κ(day$_E$)	β(day^{-1})	
			EMBEDDED GAGE	STRAIN GAGE
CR-80-4.5	0.890	0.0464	2.20×10^{-2}	1.86×10^{-2}
CR-80-5.0	0.882	0.0460	2.26×10^{-2}	1.99×10^{-1}

Table 4 Comparison of Creep Coefficients ϕ

JAPANESE SPECIFICATION FOR CONCRETE BRIDGES	2.26
CONCRETE COLUMN	2.72～2.84
CONCRETE FILLED STEEL COLUMN	1.44～1.61

5. CREEP COEFFICIENT

The effect of creep is usually considered in practice in the form of creep coefficient. According to the Japanese Specifications, the creep coefficient ($\phi = f/\varepsilon$) is defined as being the ratio between the final strain value f and the elastic strain ε. Thus, for each type of secimen, this coefficient was evaluated as being the ratio between the final predicted value obtained by the calculated time-dependent curve, when time is infinite, and the initial strain,when $t=0$. These values and the ones obtained by the Japanese Specification method are compared in the table below.

As it can be seen from the above results, the creep coefficients obtained for the concrete filled steel columns is smaller than that of the pure concrete columns and about 0.7 times the ones of the Japanese Specification, suggesting that the usually used design values are conservative.

6. CONCLUSIONS AND REMARKS

Comparing the curves obtained by the substitution of the viscoelastic parameters into Eq.(3), it seems that they agree well with the measured data, except for the initial part of the curve. This difference may be partially attributed to the simplicity of the analytical model and of the approach function initially adopted for the applied stress, which are not able to characterize the complicate accommodation mechanism of the concrete particles in early ages. Thus, if other terms were added to the initial assumption, or more sophisticated models were adopted, the curves would fit better to the measured data. However, such measures would lead to complicated elements in the FEM analysis, which would take an enormous computation time for the analysis. Thus, when considering its future applicability, the model herein presented may be considered satisfactory.

Except for the early ages, the time-dependent behavior seemed to be well evaluated by the present method, in particular when it comes to the prediction of the final creep strain, which is what concerns in terms of design, where creep coefficient is used.

As for the creep coefficient, the present method suggests us that the values of the current Japanese Specification are conservative, The evaluated values being between 1.6 to 1.7, show that in this kind of structure the influence of creep phenomenon is smaller than in plain concrete structures. Furthermore, from the drying shrinkage measurements it was proved that the strain due to the concrete drying shrinkage can be neglected in the design of such structures.

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