Measurements of creep and shrinkage in actual prestressed concrete bridges

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Measurements of Creep and Shrinkage in Actual Prestressed Concrete Bridges

Les mésures du fluage et du retrait dans les ponts en béton précontraint existants

Kriech- und Schwindmessungen an bestehenden Spannbetonbrücken

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Introduction

Design and construction of prestressed concrete bridges in Japan is generally carried out in accordance with the Standard Specifications for Design and Construction of Prestressed Concrete of the Japan Society of Civil Engineers. In this code the standard values of creep and shrinkage considered for design of members are prescribed. However, these standard values were determined several years ago when the practical use of prestressed concrete was on the threshold of its flourishing era. Taking account of the progress and improvement of prestressed concrete brought about thereafter, the above standard values are to be subject to a reinvestigation for eventual renewal.

Creep and shrinkage of concrete are of such complicated phenomena, as it would be difficult to clarify creep and shrinkage of concrete in actual structures. In consideration of the above, measurements of time dependent deformations on concrete in 21 prestressed concrete bridges have been continued together with the experimental research. These bridges cover almost all of the representative types of Japanese prestressed concrete bridges, i.e. 7 highway bridges (the span lengths are 25 to 146 meters) and 14 railway bridges (the span lengths are 16 to 80 meters).

This paper presents the creep coefficients and shrinkage strain derived from the measurements and observations in actual prestressed concrete bridges, and also discusses the methods of measurements.

Some representative measurements in actual bridges

In Yagiyama highway bridge in Fig. 1, and Yoneshirogawa and Tamagawa railway bridges in Fig. 4, special treatments were made in order to divide the time dependent strain into creep and shrinkage.

In Yagiyama bridge, in addition to strain in concrete of upper and lower flanges of the box girders, strain in the concrete specimens, which had been inserted into the webs of the girders, were measured by Carlson type strain gages (see Fig. 1). Stress of the girder cannot be transmitted to the specimens while the state of drying of the specimens trend toward very similar to that of the body girders.

Measurements of strain were carried out in nine blocks. The results in the left fourth block are shown in Fig. 2 as an example, since stress level of concrete in the twelfth blocks are very low, and concrete girders in the side

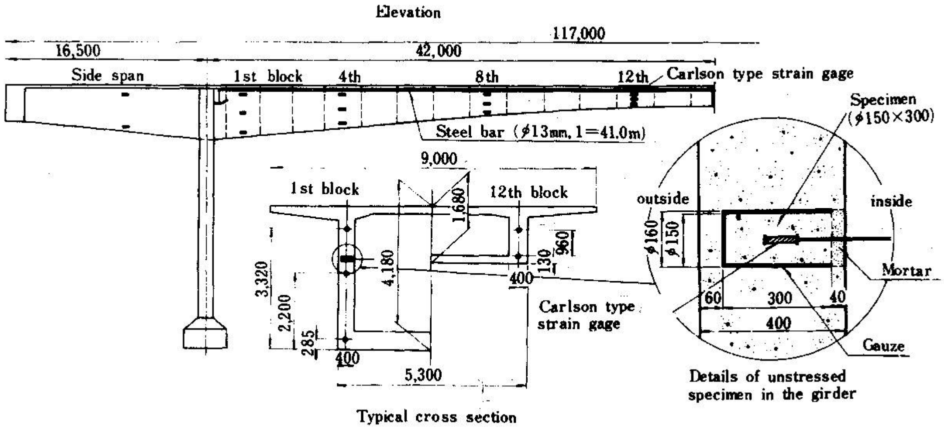


Fig. 1. Gage arrangement of Yagiyama highway bridge

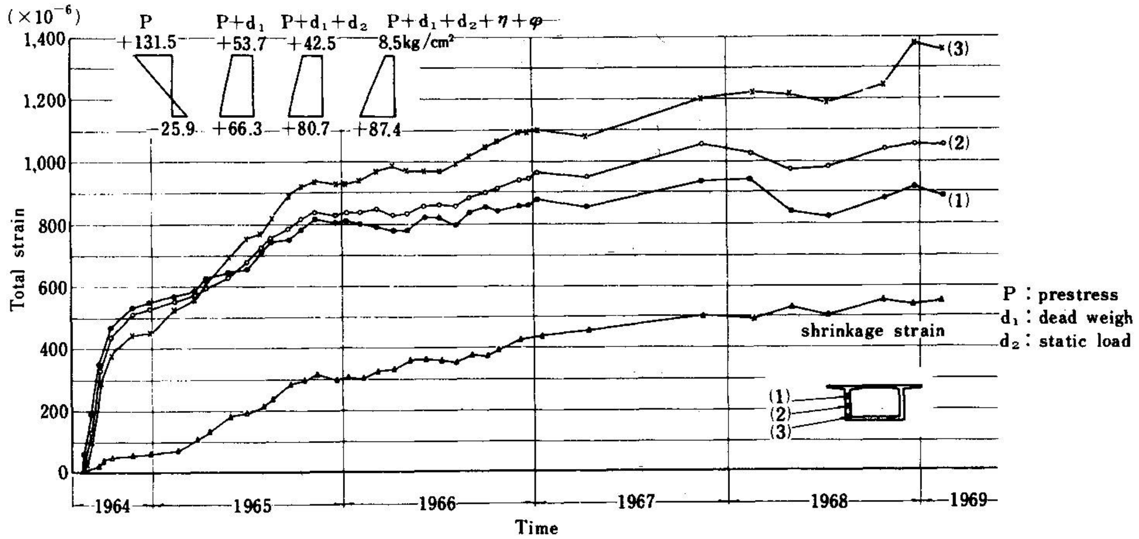


Fig. 2. Measurements of delayed deformation in the left 4th block of Yagiyama highway bridge

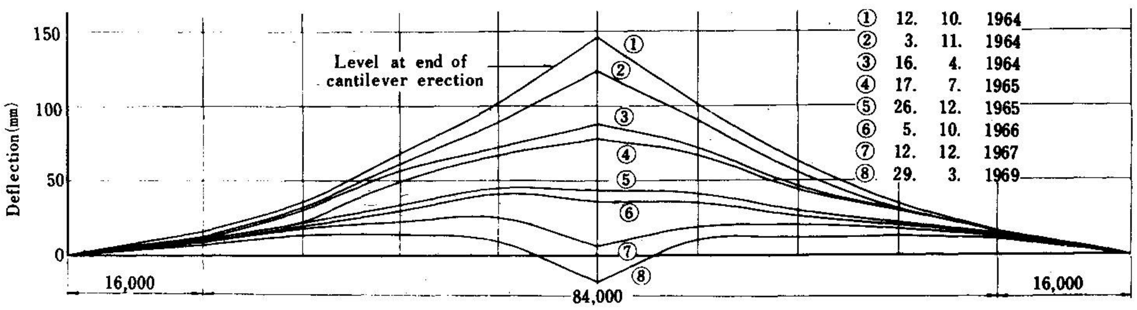


Fig. 3. Change of deflection at Yagiyama highway bridge

spans may be restricted by the abutments and the first blocks are very near to the supports. Change in length of the girders in the middle span was also measured by using steel bars of 41 m in length and 13 mm in diameter.

The middle span of this bridge was constructed by cantilever erection. As an example, the delayed deflections at various spots of the middle span as measured immediately after the connection of the left and right girders are shown in Fig. 3.

In this bridge fairly large differences in shrinkage were recognized between each side of the middle span as shown in Table 1. Measured shrinkage strains in web concrete for five years were 270×10^{-6} to 330×10^{-6} in the right side of the span, whereas 350×10^{-6} to 550×10^{-6} in the left. This seems to be mainly due to the differences in the degree of sunshade on the bridge and drying in the box girders. On the left side of the span interior surface of the girders were dried up by draft through the openings existing not only in the center hinge but also on the abutment. This result shows that in large prestressed concrete bridges there may be some cases of great difference in shrinkage even in a same girder.

Shrinkage strain in concrete in the webs of girders gradually increased for long period, say three or five years, and the rate of increase was rapid in summer whereas it was slow in winter. Rate of shrinkage showed a better correlation with the differences between the indications of dry and wet bulbs in hygrometer than the relative humidity of the surrounding air.

The creep coefficients for 5 years based on the measurements in the fourth and the eighth blocks were between 2 and 3 as shown in Table 1. These creep coefficients φ_n were calculated by the following equation.

$$\varepsilon_{total} = \varepsilon_{d+p}(1+\varphi_n) + \varepsilon_{\zeta+\varphi}(1+0.5\varphi_n) + \varepsilon_s$$

where ε_{total} : Measured total strain including elastic strain, creep and shrinkage, ε_{d+p} : Calculated elastic strain due to dead load and prestress with E_c of 350,000 kg/cm², $\varepsilon_{\zeta+\varphi}$: Calculated elastic strain due to loss of prestress with 3% relaxation, ε_s : Measured shrinkage strain.

In the same table the creep coefficients derived from the measurements by steel bars are also indicated.

Yoneshirogawa bridge and Tamagawa bridge are both three span continuous box girder railway bridges as shown in Fig. 5. Yoneshirogawa bridge was constructed by prestressing the precast blocks arranged on the shoring, the prestressing was done in three sequences. Tamagawa bridge was constructed by the cantilever erection of cast-in-place concrete.

In these bridges, at the positions of measurements the flanges were made thicker with appendages where the strains were to be measured afterward (see Fig. 4). To measure instantaneous recovery strain, appendant concrete would be cut out after 6 months, 3 years and 5 years respectively (Measurements are still in course though partially finished). The cut-out concrete specimens were to be put into water, and the recovery of shrinkage was to be measured. In addition to these, shrinkage strain was measured with specimens making free from the stress of the girders (see Fig. 4 (b)) or in unstressed parts made in the lower flanges (see Fig. 4 (d)). Examples of the results obtained from the concrete cut out after 6 months are shown in Fig. 5 (a) and in Fig. 5 (b). The shrinkage strain for 6 months was 118×10^{-6} in Yoneshirogawa and 70×10^{-6} in Tamagawa. It is considered that by subtraction the measured shrinkage and the instantaneous recovery strain from the measured total strain, the time dependent strain due to stress can be obtained. The ratios of the time dependent strain to the instantaneous strain are deeply related to the creep coefficients. The magnitudes of these ratios are naturally larger than those of the so-called creep coefficients to some extent because of larger Young's modulus of concrete. Although the strains in the cut-out concrete do not always agree with those in the body girders, reliability of the creep coefficients derived from the measurements of this kind can be heightened if the instantaneous strain at prestressing are also measured together.

Table 1. Creep coefficient and shrinkage strain in the representative blocks of Yagiyama bridge

Side	Block No.	Upper Side		Lower Side	
		φ_n	ε_s	φ_n	ε_s
Left	4	2.00	550×10^{-6}	1.95	550×10^{-6}
	8	3.00	420 〃	2.66	420 〃
Right	4	2.55	330 〃	1.52	330 〃
	8	2.78	270 〃	2.66	270 〃
Left		1.42 *	400 〃 **		
Right		2.75 *	220 〃 **		

Remarks

φ_n : Calculated creep coefficient derived from measurements by Carlson type strain gage.

* : Derived from measurements by steel bar.

ε_s : Measured shrinkage strain by Carlson type strain gage.

** : Average along the bar.

Table 2. Summary of creep and shrinkage in prestressed concrete bridges

No.	Name of bridges (1)	Cross section of girder	Span length (m)	Concrete: Comp. strength σ_{28} (kg/cm²)	Concrete: Comp. strength σ_c at prestressing (kg/cm²)	Concrete: Age at prestressing (days)	Concrete: Cement content (kg/cm³)	Concrete: Water content (kg/cm³)	Dalayed deformation: Measurement (2)	Dalayed deformation: Period of measurement (months)	Dalayed deformation: Creep coefficient φ_n (3)	Dalayed deformation: $\varepsilon m / \varepsilon calc.$ (%) (4)	Climatic conditions: Mean temperature in month (℃) max.	Climatic conditions: Mean temperature in month (℃) min.	Climatic conditions: Mean humidity in month (%) max.	Climatic conditions: Mean humidity in month (%) min.
1	Wagagawa	I	19.2	518	338	15	440	137	C	33	1.41	74	23.8	− 4.6	84	67
2	Yoshiigawa	Box	3 x 33.2	490	-- ,413	11,24	380	137	C	43	1.16	52	28.5	0.8	84	64
3	Omarugawa	Box	22.3	494	409	3	380	145	B	10	0.53	61	27.0	5.1	84	65
4	Ohtogawa *	I	30.0	508	440	9	450	162	A	68	0.78	37	26.6	1.7	86	76
5	Ajigawa	I	20.4	547	384	5	420	164	B	7	1.14	67	22.4	5.1	74	64
6	Yagumo-1	I	18.7	589	460	7	420	164	B	11	0.96	60	28.1	5.1	74	64
7	Yagumo-2	I	19.0	556	451	7	420	164	B	45	1.35	76	28.1	5.1	74	64
8	Bentencho	I	22.4	558	434	7	420	156	B	10	1.41	77	22.4	5.1	74	64
9	Osaka st. **	T	14.2	420	250,360	4,9	340	141	B	12	1.62	85	28.1	5.1	74	64
10	Yoneshirogawa	Box	3 x 56.2	517	--	75	460	170	C	5	0.28	34	23.2	− 1.4	82	67
11	Kongo-Ohashi	T	30.4	589	430,480	4,5	470	169	B	36	1.51	84	28.2	4.6	82	60
12	Johgashima *	T	38.29	550	--	5,63	480	175	A	7	0.93	58	17.1	6.7	81	69
13	Hisayoshi	Box	27.23	--	435	6	450	162	B	14	1.14	66	25.1	3.1	82	50
14	Ukishima	Box	25.25	476	--	39	--	--	B	10	0.18	28	26.1	5.4	84	60
15	Washinosugawa	Box	24 -- 44 -- 24	480	240~	5 ~ 70	400	137	C	24	2.35	123	23.8	− 4.6	84	67
16	Yagiyama	Box	16 -- 84 -- 16	427	250~	2 ~ 65	390	148	B,C,D	54	1.90(D)	110(D)	26.8	1.0	87	35
17	Shibuya	Box	45 - 80,96-45	455	250~	2~120	405	151	D	36	1.99	92	28.3	3.7	80	46
18	Amakusa-4	Box	40-- 3x146 - 32	540	260~	2~255	380	149	B,D	36	1.70(B) 1.88(D)	90(B) 96(D)	29.4	5.2	82	65
19	Yui-ko	Box	30 -- 70 -- 30	470	260~	2 ~ 90	390	156	B,D	24	1.82(B) 1.22(D)	99(B) 78(D)	27.4	5.8	84	47
20	Tamagawa	Box	59.3 - 80 - 59.3	480	260~	2 ~ 80	395	142	C	7	0.32	14	26.8	3.8	74	56
21	Kanayama	I	15.8	549	480	5	470	179	C	24	−	−	27.2	2.9	80	46

Remarks:

(1) * : Design concrete strength of 450 kg/cm² ** : 300 kg/cm²

(2) A : Contact gage B : Long steel bar C : Carlson type strain gage D : Deflection

(3) $\varphi n = (\varepsilon total - \varepsilon d \cdot p - \varepsilon s)/\varepsilon d \cdot p$ for No. 1 to 14

$\varphi n = (\varepsilon total - \varepsilon' d \cdot p - \varepsilon \eta \cdot \varphi - \varepsilon s)/\varepsilon d \cdot p + 0.5 \varepsilon \eta \cdot \varphi$ for No. 15 to 20

$\varepsilon' d \cdot p$: Elastic strain during measurment (part of $\varepsilon d \cdot p$)

(4) εm : Measured delayed deformation $\varepsilon calc.$: Calculated delayed deformation

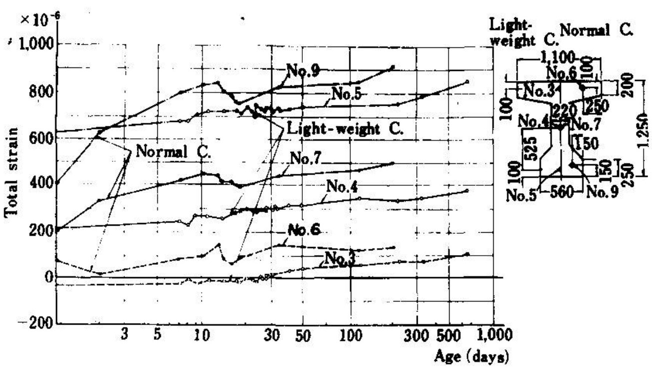
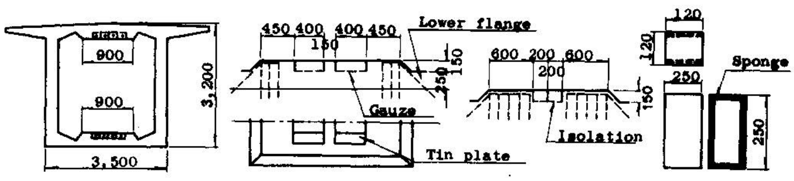


Fig. 8. Measured deformations in light-weight aggregate and normal gravel concrete girders with same section



(a) Cross section of Yoneshirogawa bridge
(b) Details of specimens in Yoneshirogawa bridge
(c) Details of specimens in Tamagawa bridge
(d) Unstressed part in lower flange of Tamagawa bridge

Fig. 4. Arrangement of concrete specimens for cut-out

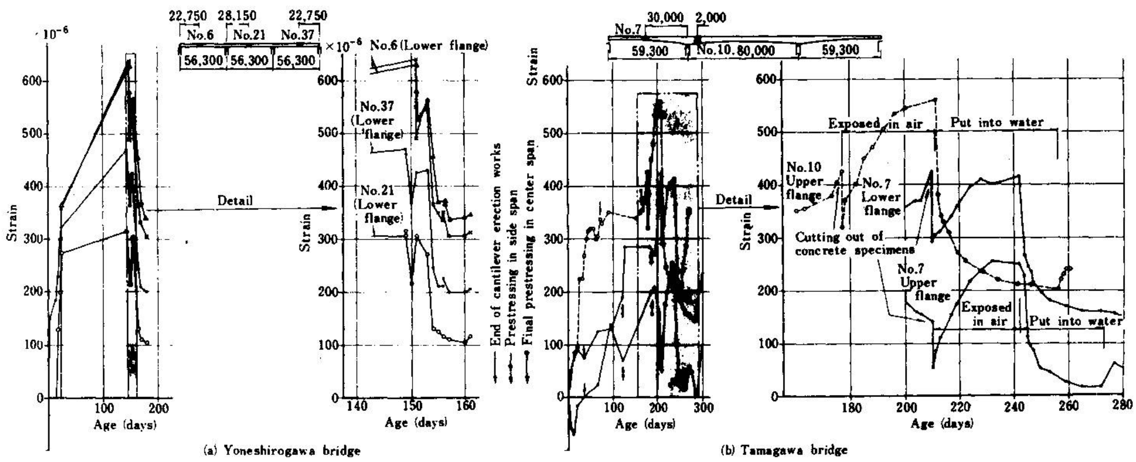


Fig. 5. Measured delayed deformations of cut-out specimens

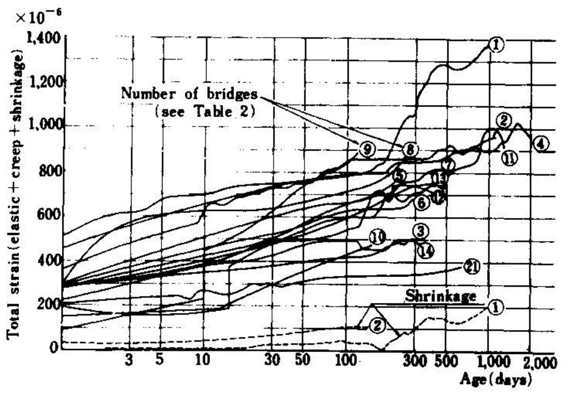


Fig. 6. Summary of measurements of delayed deformations in prestressed concrete bridges

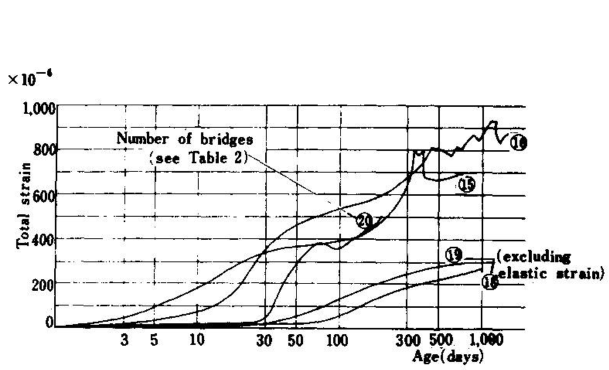


Fig. 7. Summary of measurements of delayed deformations in cantilever erected prestressed concrete bridges

The original purpose of the measurements of this method is to obtain the internal stresses of concrete by loading tests of the cut-out specimens. Clue to fulfil the original purpose was obtained, though the results derived from the present measurements are not always rational. Therefore, this kind of research is planned to be continued through the future.

Summary of measurements of creep and shrinkage in prestressed concrete bridges

Measured delayed deformations in actual prestressed concrete bridges in various sites of Japan are in Fig. 6 and 7.[1),2),3)] These bridges are different in their types, span lengths, age at prestressing, climatic conditions etc. as shown in Table 2. In all bridges with few exceptions, design strength of concrete was 400 kg/cm^2, and high early strength portland cement with similar quality and aggregates of good quality were used throughout. These results of measurements could be useful despite the methods of measurements were not the same.

In Table 2 the ratios of the measured delayed deformations to the design values of the ultimate delayed deformations are indicated. Their measured values for two to five years are 75 to 125 percents of the design values. The calculated creep coefficients were derived from the measurements of delayed deformations on the assumption that Young's modulus of concrete equals to 350,000 kg/cm^2 and shrinkage strain is 150×10^{-6}. The bridges numbered from 1 to 14 in this table are of the types different from those of 15 to 20, and the methods of calculation of creep coefficients are also different, therefore the creep coefficients of the latter are generally larger than those of the former. Though, the creep coefficients for two to five years are in the range from 1.3 to 2.4 in most of the cases.

There were very limited numbers of long time measurements of shrinkage strain in concrete specimens kept in the same condition as in actual bridges. In a few bridges the measured shrinkage strain for three to five years were 200×10^{-6} to 400×10^{-6}.

Creep and shrinkage in light-weight prestressed concrete bridges

In Fig. 8 are shown the delayed deformations in the prestressed concrete railway girders with concrete using structural light-weight aggregates under 15 mm[4)] (see No.21 in Table 2). Normal river gravel sized from 15 to 25 mm were used together. For the purpose of comparison, normal gravel concrete girders with same cross sections as above were constructed in parallel in the same place. It revealed that the total delayed deformations for 200 days in light-weight concrete were extremely small and only less than 50% of those in the normal concrete. This would mainly be due to the fact that the drying shrinkage in the light-weight concrete was far smaller than that in the normal concrete. Shrinkage strain was obtained from the specimens with the same cross sections as the actual girders of one meter long with both ends sealed. The measured shrinkage strain of light-weight concrete for 200 days was 80×10^{-6} to 110×10^{-6}, which shows fairly good agreement to that in the concrete at extremely low stress level (see No.3 in Fig. 8).

Besides, creep and shrinkage tests were conducted in laboratory on small specimens with 10 x 10 cm cross sections made by the concrete with the typical artificial structural light-weight aggregates, the compressive strength at 7 days being about 400 kg/cm^2.[5)] The total delayed deformations of light-weight concrete specimens weathered for 3 years were only about 75% of those in the normal concrete specimens simultaneously tested. The drying shrinkage strain was 150×10^{-6}, which was only about 30% of the normal concrete while the magnitudes of creep were similar. This result shows a similar tendency to the case of the actual bridge. The minor shrinkage of the light-weight concrete is mainly due to the large water absorption of the aggregates.

Conclusions

1) It is difficult to estimate the exact values of shrinkage and creep in concrete based on the measurements in actual prestressed concrete bridges. The main reason is that exact values of elastic strain of concrete in structural members are hardly obtainable and moreover, a separation cannot be clearly made between the values of shrinkage and creep without applying special treatments. So it is indispensable to measure with accuracy shrinkage strain in bridges in strict conformity with the fundamental rule required, that is, by keeping the concrete specimens in the same condition as in actual structural members as far as possible. In order to conform to the above imperative it is proposed to make measurements of the shrinkage in the unstressed parts of concrete prepared beforehand in actual structures, which should make higher the reliability in accuracy of the magnitudes of creep.

2) Measured shrinkage strains in a few actual bridges in Japan were 200×10^{-6} to 400×10^{-6} for 3 to 5 years, but it is quite natural that shrinkage strain of concrete in structural members is affected by various factors. Among these factors, the effects of climatic conditions were especially complicated and the effects of the directions of sunshine, wind, rain and snow were considerably remarkable. In fact, even such an example was found that the difference in five years' shrinkage strains between each side of the cantilever prestressed concrete girders amounted to 150×10^{-6}.

3) From the results of the careful measurements in two prestressed concrete river bridges, it is recognized that the creep coefficients of concrete in one bridge were 2 to 3 for five years, and about 1.2 for 3 years in another bridge. Although it is not adequate from this small numbers of measurements to discuss the creep coefficients of concrete, the results show that the creep coefficients differ remarkably due to variations in conditions. Therefore, in determining the creep coefficients for design, it is by all means necessary to take into consideration the variations in such conditions, and strictly speaking, it is not rational to use sole constant creep coefficient even only for the case of river bridges.

4) Creep and shrinkage of concrete are of very complicated phenomena as mentioned in 2) and 3). However, the creep coefficients derived from the measurements of strain in the twenty post-tensioned prestressed concrete river bridges with similar concrete in the various sites of Japan on the assumptions that Young's modulus of concrete is 350,000 kg/cm^2 and shrinkage strain is 150×10^{-6}, ranged between 1.5 to 2.5, even though the kinds and types of bridges, span lengths, cross sections and ages of concrete at prestressing differed to large extent in each case. Therefore, at this stage it is considered to be practical that standard values of creep coefficients for design of prestressed concrete bridges should be stipulated within an adequate range.

5) The results of measurements of delayed deformations in a prestressed concrete bridge using light-weight aggregate concrete showed that the magnitude of creep strain was almost equal to that in the case of the normal concrete used for comparison, although the shrinkage strain was much smaller than the latter. Though this result is derived from sole example, it may be considered as a representative result on structural light-weight aggregate concrete. Naturally, the modulus of elasticity of light-weight concrete differs considerably from that of normal concrete. Moreover, it depends also on the kinds of light-weight aggregates. Therefore, this should be taken into consideration in determining creep coefficients of light-weight aggregate concrete.

Acknowledgments

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Summary

Measurements of time dependent deformations in concrete and also deflections have been taken from 21 prestressed concrete bridges constructed in various sites in Japan. In three bridges, special treatments was made to separate the shrinkage strain from the creep strain. From the results, method of measurements and creep coefficients and shrinkage strains in the prestressed concrete bridges are discussed. Moreover creep and shrinkage of light-weight concrete are also discussed.

Résumé

Les mesures des déformations lentes du béton ainsi que des flèches ont été faites sur 21 ponts en béton précontraint construits aux divers endroits du Japon. Pour trois d'entre eux, un traitement spécial a été effectué en vue de séparer les déformations unitaires dues au retrait de celles dues au fluage. Se référant aux résultats, les méthodes de mesures ainsi que les coéfficients du fluage et les déformations unitaires du retrait dans les ponts en béton précontraint sont discutées. De plus, il est mentionné le problème relatif au fluage et au retrait du béton léger.

Zusammenfassung

Messungen der zeitabhängigen Formänderung des Betons und auch der Durchbiegungen sind an 21 Spannbetonbrücken durchgeführt worden, die an verschiedenen Orten in Japan gebaut wurden. Bei drei Brücken wurden besondere Massnahmen getroffen, um die Schwind- und Kriechdehnung getrennt zu messen. Aus den Ergebnissen werden Messverfahren, Kriechzahlen und Schwindmasse der Spannbetonbrücken erörtert. Darüber hinaus wurde das Kriechen und Schwinden des Leichtbetons diskutiert.