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SYMPOSIUM

L'INFLUENCE DU FLUAGE ET DU RETRAIT, L'EFFET DES CHANGEMENTS DE TEMPÉRATURE SUR LES CONSTRUCTIONS EN BÉTON

DER EINFLUSS DES KRIECHENS, SCHWINDENS UND DER TEMPERATURÄNDERUNGEN IN STAHLBETONKONSTRUKTIONEN

DESIGN OF CONCRETE STRUCTURES FOR CREEP, SHRINKAGE AND TEMPERATURE CHANGES

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Magnitude of Creep and Shrinkage for Design of Light-Weight Concrete Structures

Importance du fluage et du retrait pour le calcul des structures en béton léger

Die Größe des Kriechens und Schwindens für die Bemessung von Bauwerken aus Leichtbeton

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Introduction

The advantage of using artificial light-weight aggregates, which is to decrease the weight of the structural members, is of course significant in structures with long span members, but in many cases it is also very significant in structures where the base ground is of low bearing power. Since large cities in Japan such as Tokyo, Osaka and Yokohama are generally built on weak ground, the use of light-weight aggregate concrete has been intensively studied. For example, light-weight prestressed concrete railway bridges were constructed on two sites of the outskirts of Tokyo, and the result have been economically satisfactorily.$^{1)}$ $^{2)}$ On one site light-weight concrete was used not only in the super structures but also in the rigid frame piers.$^{1)}$

In designing various prestressed concrete structures using light-weight concrete, it is necessary to investigate carefully the magnitude of creep and shrinkage to be considered in the design. Concerning the shrinkage and creep of light-weight aggregate concrete, Tertea et al$^{3)}$ and Okada et al$^{4)}$ also discussed them in the preliminary publication. The magnitudes of creep and shrinkage to be considered in the design of light-weight concrete structures are naturally dependent on the qualities of the light-weight aggregates, especially on their water absorption, mix proportion and age of concrete and so forth. In addition, the variation of magnitudes of creep and shrinkage due to the difference of the cross sectional dimensions and moisture conditions of a member makes the deduction of the magnitudes considerably complicated. That is, creep and shrinkage strains obtained from laboratory tests with small specimens are apt to differ greatly with those in actual structures.

This report discusses the magnitudes of creep and shrinkage to be considered in designing light-weight concrete structures, based on the results of measurements of laboratory tests specimens and of actual structures.

Measurements of creep and shrinkage in laboratory

Creep and shrinkage strains were measured for two years on concrete using four brands of typical structural light-weight aggregates now marketed in Japan (denoted by X, O, P and R) and the results were discussed comparing them with those of normal weight concrete.$^{5)}$

(a) Concrete

Light-weight fine and coarse aggregates were used in the saturated surface-dry state. The amount of water absorption of aggregates at the time was almost equal to that of the 24 hours' absorption. The specific gravity, fineness modulus and absorption are shown in Table 1. The amount of absorption of the aggregates varied from 3.5% to 17.5% when used according to the brands of the aggregate. Maximum size of coarse aggregates was 15mm.

High early strength portland cement was used in concrete and the water cement ratio was maintained at 0.45. Mix proportions of concrete were determined to yield a concrete of slump about 4 cm and air content about 3% . Compressive strengths of 10 X 20 cm cylinder specimens cured in water of 21°C at the age of 7 days, 28 days and 1 year are shown in Table 2. Strengths of light-weight concrete using river sand as fine aggregate regardless of the difference in coarse aggregates were very similar to that of concrete using river gravel and sand. This tendency is recognized at later ages when the compressive strength reaches 600 kg/cm^2. The reason seems to be that light-weight coarse aggregate particles do not crush until the failure of mortar occurs and that the bond strength between mortar and coarse aggregate particles is larger in light-weight aggregates, than in river aggregates. However the strength of concrete using light-weight aggregate as both coarse and fine aggregates are about 10% less than that of concrete using river aggregates. This seems to be due to the considerably large effect of the quality of fine aggregate particles on the strength of mortar.

(b) Drying shrinkage

Concrete specimens of 10 X 10 X 42 cm were placed in a condition controlled room of 21°C and 60% RH and measurements of shrinkage strain were carried out periodically for 2 years, using contact type strain gages of 20 cm length. The strains shown in Fig. 1 is believed to indicate the shrinkage strains along the axis of specimens, as gage points were embedded deep in concrete and shrinkage strains shown is the mean value of the measured values on two opposite faces.

Normal concrete NN using river coarse and fine aggregates shows rapid increase of shrinkage at early age of drying, the amount of shrinkage for the first 28 days being 490 X 10^{-6}. On the other hand, Concrete XX using light-weight coarse and fine aggregates with large water absorption shows very small shrinkage at early age of drying, the amount of shrinkage being only 110 X 10^{-6} for the first 28 days, which is only about 20% of that of normal concrete. Shrinkage strains of light-weight concrete increase during the first 18 months at a constant rate, but the magnitude of shrinkage is still smaller than that of normal concrete. This is due to the difference of water absorption in aggregate particles. Dried concrete absorbs moisture at high humidity, and the degree of absorption is remarkably larger in light-weight concrete. Therefore, in the design of prestressed concrete structures exposed to weather, the magnitude of shrinkage for light-weight concrete may be considerably smaller than for normal concrete.

(c) Effect on properties of light-weight concrete due to drying

Drying shrinkage of light-weight concrete, as a whole, is smaller than that of normal concrete as described in section (b). In general the inner part of light-weight concrete is more wet than normal concrete, therefore the undesirable effect of surface drying is much larger in light-weight concrete. The degree of this effect is not simple, being affected by water absorption of aggregate, mix proportion and age of concrete, dimension of member, drying speed and degree of drying.

Fig. 2 shows a comparison of the compressive strengths of concrete specimens cured in water of 21°C for 7 days and after that dried in a room of 21°C and 60% RH. Compressive strength increases with increase of age for all specimens, but the degree of increase is larger in light-weight concrete. It is believed that this is because the hydration of cement continued by the large amount of water absorbed in light-weight aggregate particles. In usual structures, concrete is not dried as much as in room, being affected by weather and more increase of strength at later ages can be expected for light-weight concrete, than normal concrete.

On the other hand, in tensile and bending strength, adverse effect of drying appears in light-weight concrete. Table 3 shows the results of tensile and bending strength of concrete cured in water for 10 or 8 days and after that dried in a room of 21°C and 50% RH for 20 days and 14 days respectively. Tensile and bending strength of light-weight concrete decrease with drying, and the decrease becomes remarkably large in case of using highly water absorbed aggregates. This is due to the larger moisture gradient between the surface and the inner part of concrete existing in light-weight concrete. It was ascertained by experiments that the strength recovered remarkably if dried concrete was moistened again.

(d) Creep

For environments of the creep tests, three cases, which were a condition controlled room of 21°C and 60% RH, immersion in water of 21°C and natural condition in courtyard were selected. In case of outdoors, specimens of 15 X 15 X 55 cm were used in addition to those of 10 X 10 X 42 cm, since the influence of environment varies with the dimensions of specimens. Specimens were cured in water and stressed at the age of 7 days then placed in the

TABLE 1. PROPERTIES OF AGGREGATES

Type				Specific Gravity	Absorption %	Fineness Modulus
Coarse aggregate	River Gravel		N	2.66	1.1	6.50
	Light-weight aggregate	Expanded Shale	X	1.46	16.1	6.43
		〃	O	1.50	10.5	6.50
		〃	P	1.45	3.9	6.49
		Fly-ash	R	1.55	5.1	6.44
Fine aggregate	River Sand		N	2.63	1.9	3.05
	Light-weight aggregate		X	1.88	17.5	2.84

TABLE 2. PROPERTIES OF CONCRETE

Aggregate		Water Content, kg/m³	Air Content %	Unit Weight, t/m³	Comp. Strength, kg/cm²		
Coarse	Fine				7d	28d	1y
N	N	158	2.7	2.39	402	491	574
P	N	161	3.8	1.90	406	491	570
R	N	160	2.9	1.95	385	479	596
O	N	159	3.2	1.92	408	472	544
X	N	162	2.9	1.92	383	444	556
X	X	178	2.7	1.70	357	439	524

Remarks:

(1) Water cement ratio was 0.45; sand percentage was 40; slump was 4 cm.

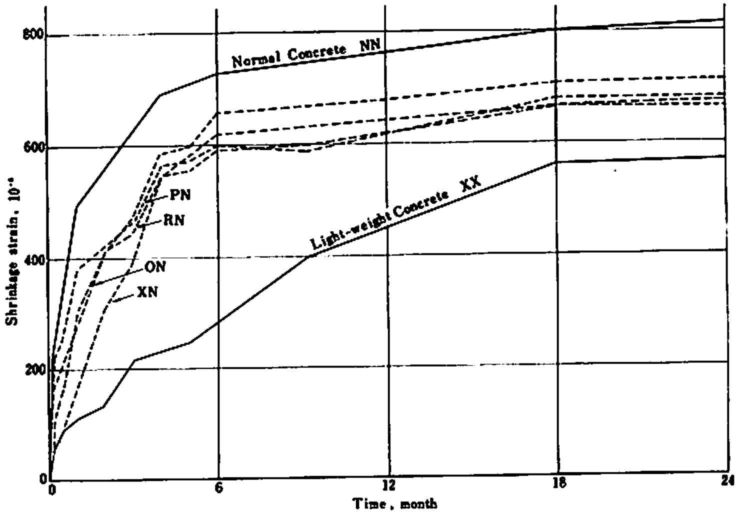

Fig. 1 Shrinkage strain of concrete specimens

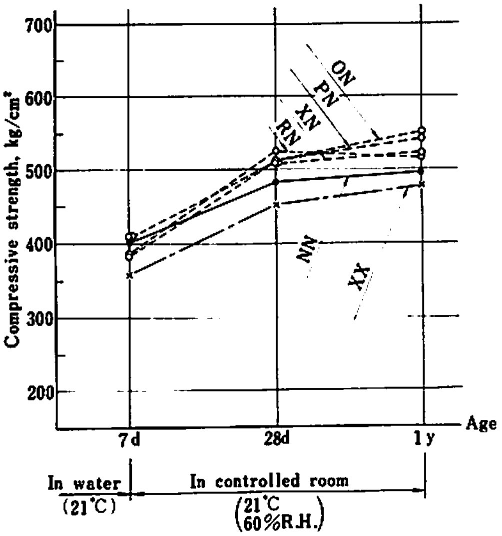

Fig. 2 Compressive strength of concrete specimens

pre-determined environment immediately after stressing. Compressive strengths at the age of 7 days were approximately 400 kg/cm^2. Creep tests by measuring the strain on a total of 60 kinds of specimens consisting of 6 combinations of aggregates, 3 kinds of environmental conditions and 5 levels of stress on concrete; were conducted for 2 years.

The concrete specimen was stressed by stretching a high-tensile steel bar placed through a sheath embedded in the center of section and anchored to anchor plates with ample rigidity at both ends of the specimen. Load applied on concrete was controlled through the measurements of two wire strain gages on the bar. Strains on the surfaces of specimens were measured by contact type strain meter with gage length of 20 cm. In this test method, since the strain of bar decreases as the creep and shrinkage of concrete increases stress of concrete gradually decreases with the increase of loading time. Therefore, in order to obtain creep values under constant stress condition from this kind of test, creep per unit stress should be calculated based on such assumptions as that creep is in proportion to applied stress. Accordingly, increase of creep strain per unit stress was assumed to be the quotient of the increment of difference in strain between loaded specimens and that of unloaded specimens divided by the stress at the time. This creep strain increase at loading time was added and the creep per unit stress was determined.

Creep per unit stress of light-weight concrete determined by the aforementioned method are shown in Table 4. When strength and other conditions are similar, creep of various kinds of light-weight concrete is very similar with each other during two years, regardless of the differences of the brands of aggregates. Furthermore, whether in controlled room or in water or in outdoors, large differences were not recognized between typical light-weight aggregate concrete and normal concrete. Creep of specimens in condition controlled room of 60% RH were twice as much as that in water and 1.7 times as much as that in out-doors, that is, effects of environmental conditions on creep of light-weight concrete are very similar to that of normal concrete. The reason of a little larger creep strain of light-weight concrete XX seems to be due to its lower strength.

These results indicate that creep phenomenon in concrete with artificial light-weight aggregates is essentially the same as that in normal concrete and influence of the difference in absorption and elastic modulus of aggregates on creep of concrete is negligible. However, creep coefficient of light-weight concrete differs greatly according to the kinds of light-weight aggregates because the elastic modulus of concrete differs greatly according to the different kinds of light-weight aggregates. Therefore, it is not proper that magnitude of creep of light-weight prestressed concrete to be used in design is calculated based on a creep coefficient as in the case of normal concrete, but it may be proper for example to specify a certain creep per unit stress according to the compressive strength of the concrete.

Measurements of creep and shrinkage in an actual bridge

Measurements of delayed deformation in Kanamayam Railway Bridge made of light-weight prestressed concrete girders were conducted by Japanese National Railways. This bridge (completed in 1965) is the first light-weight prestressed concrete bridge in Japan. The bridge has six tracks each of them being composed of three simply-supported post-tensioned prestressed concrete girders, which span length was 15.8 m as shown in Fig. 3.$^{2)}$ Mix proportion of concrete used in this bridge is shown in Table 5. Compressive strength at 28 days was 565 kg/cm^2, and unit weight was 1.9 t/m^3. Light-weight aggregate was used for the size of coarse aggregate smaller than 10mm, and for 10mm to 20mm crushed stone was used. This was adopted in order to ensure good durability.

Strains were measured by Carlson type strain gages embedded in the middle of web and upper and lower flanges of girders. For comparison, measurements of strain were conducted in normal concrete girders with the same cross sections constructed in parallel to the light-weight girders. The results are shown in Table 6. Total delayed deformations for 200 days in light-weight concrete girders were very small compared to that of normal concrete. Especially during 10 days after prestressing rapid increase of deformations are recognized in the girder of normal concrete. On the other hand, the increase of strain during the same period is not very great in light-weight concrete girders. This seems to be due to the extremely smaller shrinkage of light-weight concrete compared to that of normal concrete, and the points of argument described in the preceding chapter seems to be conformed by the case of the actual bridge. However, the number of measured data in actual bridges are so few that more data of measurements of creep and shrinkage in actual light-weight prestressed concrete bridges are still desired hereafter.

TABLE 3. EFFECTS OF DRYING ON TENSILE AND FLEXURAL STRENGTH OF LIGHT-WEIGHT CONCRETE

Coarse Aggregate⁽²⁾		Tens. Strength, kg/cm²		$\frac{F_{td}}{F_{tw}}$	Flex. Strength, kg/cm²		$\frac{F_{bd}}{F_{bw}}$
		F_{tw}⁽³⁾	F_{td}⁽⁴⁾		F_{bw}⁽⁵⁾	F_{bd}⁽⁶⁾	
River gravel	N	34.6	35.6	1.03	46.8	30.0	0.64
Light-weight	O	27.2	22.5	0.83			
〃	X	25.4	18.6	0.73			

Remarks:
(1) Water cement ratio was 0.50.
(2) River sand was used.
(3) Cured in water for 10 days.
(4) Dried in air for 20 days after 10 days' curing in water.
(5) Cured in water for 8 days.
(6) Dried in air for 14 days after 8 days' curing in water.

TABLE 4. RESULTS OF CREEP TESTS

Condition	Aggregate	Elastic Strain, ε_e, $\times 10^{-6}$/kg/cm²	Creep Strain, ε_c, 10^{-6}/kg/cm²			Ratio of ε_c at 2y	$\frac{\varepsilon_c}{\varepsilon_e}$ at 2y
			28d	6m	2y		
In air (21°C 60%RH)	NN	3.49	4.10	7.22	8.10	1	2.32
	PN	3.61	3.17	5.40	6.75	0.83	1.87
	RN	3.54	3.31	5.53	6.79	0.84	1.92
	ON	4.13	3.11	5.50	6.63	0.82	1.60
	XN	4.29	3.45	5.75	7.03	0.87	1.64
	XX	6.81	4.57	8.08	9.86	1.22	1.45
Out-door	NN	3.54	3.66	5.10	6.40	1	1.80
	PN	3.70	2.61	4.43	5.21	0.81	1.41
	XN	4.82	3.40	5.68	—	—	—
	XX	6.58	3.82	5.90	6.76	1.06	1.03
In water (21°C)	NN	3.58	1.80	3.26	3.45	1	0.96
	PN	3.60	1.37	2.48	2.84	0.82	0.79
	XN	4.01	1.61	2.49	3.67	1.06	0.91
	XX	7.01	1.88	3.68	4.32	1.25	0.62

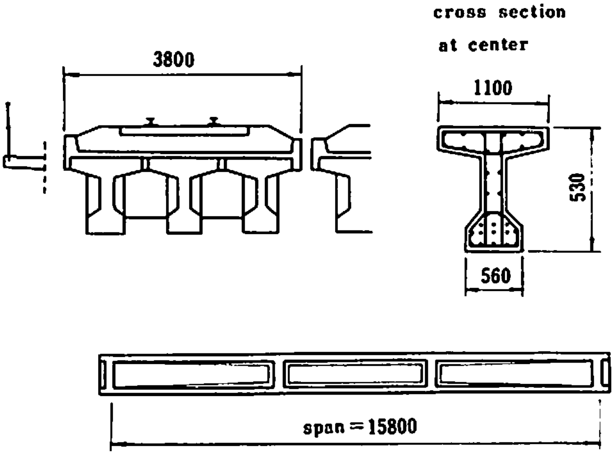

Fig. 3 Sections of Kanayama Railway Bridge

TABLE 5. PROPERTIES OF CONCRETE

Aggregate		Water Content, kg/m³	Air Content, %	Unit Weight, t/m³	Compressive Strength, kg/cm²		
25-10mm	Under 10mm				3d	7d	28d
N	X	179	4.9	1.92	377	519	565

Remarks:

(1) High early portland cement was used; water cement ratio was 0.38; sand percentage was 37; slump was 3.5 cm.

TABLE 6. RESULTS OF MEASUREMENT IN KANAYAMA RAILWAY BRIDGE

Measured Position	Concrete	Elastic Strain at Prestressing,(1) 10^{-6}	Delayed Deformation, 10^{-6}		
			28d	6m	2y
Lower flange	Normal	410	390	500	—
	Light-weight	630	100	130	220
Web	Normal	210	210	290	—
	Light-weight	220	80	120	160
Upper flange	Normal	0	130	130	—
	Light-weight	−30	40	100	130

Remarks:

(1) Prestressed at 5 days' age

Conclusion

The following can be said within the limits of the investigations regarding concrete using structural artificial light-weight aggregates now marketed in Japan.

(1) Shrinkage strain along the axis of concrete members made of concrete using light-weight aggregates with high water absorption is extremely smaller than that of normal aggregate concrete. Therefore, magnitude of shrinkage to be considered in design of statically indeterminate structures or prestressed concrete members may be considerably smaller for light-weight concrete.

Concrete used in usual structural members can not dry like small specimens in laboratory. Therefore, undesirable effect of drying on tensile strength of light-weight concrete is quite reduced in actual members, and a little amount of shrinkage reinforcement is enough to cope with the danger of cracking by drying.

(2) Amount of creep strain of light-weight concrete, when the stress and age at loading are the same, were recognized to be almost the same as that of normal concrete with the same compressive strength regardless of the kinds of light-weight aggregates used. However, creep coefficient of light-weight concrete is different according to the kinds of light-weight aggregates because of the large difference of elastic modulus between the kinds of light-weight concrete. Therefore, it is not proper to use a constant creep coefficient regardless of the kind of aggregate used in the design of prestressed concrete. It seems to be a practical method at this stage that a certain creep per unit stress be specified according to the compressive strength of concrete.

It is quite natural that careful investigation should be taken whether or not the above conclusions can be applied to concrete with light-weight aggregate of different quality from those investigated in this experiment. However, the above conclusions seem to be able to be applied to considerably wide range of light-weight concrete, since light-weight aggregates used in this investigation include those with extremely different water absorptions.

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SUMMARY

Magnitude of creep and shrinkage to be considered in designing light-weight concrete structures is discussed based on the results of measurement in laboratory tests specimens and in actual structures. The results on concrete using artificial light-weight aggregates of good quality are as follows, so long as those produced in Japan are concerned: (1) magnitude of shrinkage can be made smaller than that of normal weight aggregate concrete, (2) creep may have the same magnitude as that of normal weight concrete.

RESUME

On applique les résultats des essais effectués en laboratoire et sur le chantier au calcul des structures en béton léger. On a obtenu les résultats suivants pour l'examen du béton contenant des agrégats légers produits couramment au Japon: (1) le coefficient du retrait peut être inférieur à celui pour le béton normal, (2) celui du fluage peut être égal à celui du béton normal.

ZUSAMMENFASSUNG

Die Grösse des Kriechens und Schwindens, die bei der Bemessung der Bauwerke aus Leichtbeton berücksichtigt werden soll, wird unter Zugrundlegung der Messergebnisse von Laborversuchen und an bestehenden Bauwerken diskutiert. Die Ergebnisse für Beton mit künstlichen Leichtstoffzuschlägen guter Qualität sind die folgenden, sofern die Herstellung in Japan berücksichtigt wird: (1) Das Schwindmass kann gegenüber jenem für Normalbeton verringert und (2) das Kriechmass in der gleichen Grössenordnung wie für Normalbeton gehalten werden.