Dry Shrinkage of Reinforced Concrete Mixed with CSA-Cements

Kazuo OHNO*

and

Takashige HATTORI**

(Received September 10, 1968)

Abstract

This paper presents the results of two series of observations on the change in length and crack distribution of reinforced concrete mixed with CSA-cements and the usual aggregates.

In the first series, a CSA-cement with 13% CSA was tested with the specimens of rectangular plates for the convenience of observing cracks which would be caused by dry shrinkage.

The second series was a test on a CSA-cement with 10% CSA consisting of two parts. The first part was the repetition of the foregoing test with this cement and the second part was a study on the change in length by beam type specimens which enable the observation of the change in length from the first stage of hardening of concrete.

Each series of tests included some comparisons of CSA-cement concrete with ordinary portland cement concrete.

Test Series I

The purpose of this study was to observe the influence of steel reinforcements on the change in length and the crack distributions for reinforced concrete mixed with a CSA-cement.

1. Specimens

Type and size A rectangular plate of $50 \times 50 \times 10\ \mathrm{cm}^3$ was adopted as the specimen.

Reinforcements Four types of double meshes made of deformed bars of 10 cm in diameter were applied, as shown in Fig. 1.

Cements Three types of cements were tested; a CSA-cement of Denki Kagaku Kogyo Co. Ltd., which contained 13% CSA (denoted by *C*), a portland cement made by the same plant (denoted by *P*), and an another manufacturer's portland cement (denoted by A) (Table 1).

* Professor of Building Construction, Dep. of Architectural Engg.

** Assistant

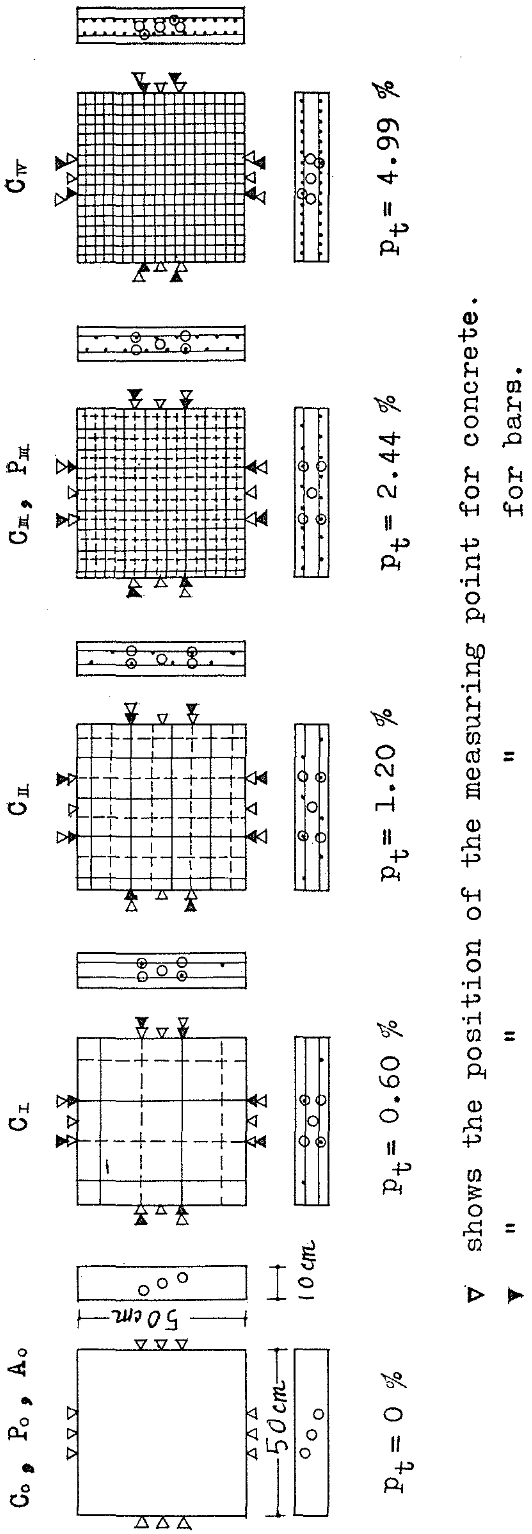

Fig. 1. Types of reinforcement

Table 1-a. Components of cements

kind of cement	ig. loss	insol.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	total	gravity	fineness
CSA-cement	0.7	0.9	20.0	6.1	3.0	61.6	1.1	6.2	99.6	3.11	3100
portland-cement *P*	0.7	0.8	22.0	5.3	3.2	63.9	1.3	1.9	99.1	3.15	3160
portland-cement *A*	0.5	0.6	22.6	5.0	2.9	64.3	1.4	1.9	99.2	3.16	3120

Data were supplied by the manufactures.

Table 1-b. Strength of cements

kind of cement	mod. of rupture (kg/cm²)			compr. strength (kg/cm²)		
	3 days	7 days	28 days	3 days	7 days	28 days
CSA-cement	17.9	22.0	46.5	76	113	208
portland-cement *P*	31.2	41.0	59.9	119	182	324
portland-cement *A*	24.3	30.4	54.5	93	153	305

Aggregates Sand and gravel from the same river were used. Their physical properties are shown in Table 2.

Table 2. Physical properties of aggregates

item	gravity	gross wt. (kg/ℓ)	size	fineness modulas
sand	2.57	1.65	less than 2.5 mm	2.43
gravel	2.53	1.67	15~5 mm	6.53

Mixtures The mixtures were selected as described in Table 3, where w/c was 0.6 and the slump was controlled to be about 21 cm.

Table 3. The mixtures

kind of cement	w/c	mixture in weight (kg/m³)				comp. str. (kg/cm²)	
		cement	sand	gravel	water	cured in water	cured in air
CSA-cement	0.60	305	820	985	183	185	148
portland-cement *P*	0.60	300	835	985	180	256	162
portland-cement *A*	0.60	295	844	985	177	250	170

Concrete form Wooden froms were used. Vinyl chrolide plates of 1 mm in thickness were lined inside the forms, which gave smooth surfaces to the specimens for the inspection of hair cracks on the surfaces.

Casting of concrete and curing The wooden forms were set up edgewise as in the case of conventional walls, and the concrete was cast in the upper edge and covered with polyethylene films. The forms were removed after 48 hours and the specimens were also set up edgewise at a room temperature of about

18°C and 70% R.H. for one week. Then, the relative humidity was droppod to 45% for three weeks. After 4 weeks the temperature was controlled at 16°C, but the relative humidity gradually rose to 70%.

2. Measurement of the change in length

Small steel screws were inserted into concrete surface and at the end of reinforcement bars, as shown in Fig. 1. The distance between a pair of screw heads, which were placed on the opposing edges of the specimen, was measured by a simple apparatus with a couple of 1/1000 mm dialgages. The accuracy of measurement was calculated to be abont 2×10^{-6} mm/mm.

The measurement was started immediately after removing the wooden form, and was continued for 15 weeks.

(1) Change in length of plain concrete

The CSA-cement concrete C_0 expanded remarkably in its early age, although ordinary concrete P_0 and A_0 showed almost no expansion, as shown in Fig. 2. The maximum expansion of C_0 reached over 450×10^{-6} mm/mm at the 9th day. Then, C_0 showed dry shrinkage similar to that in ordinary concrete. The magnitude of these shrinkage reached about 500×10^{-6} mm/mm after 15 weeks. Consequently, the amount of change in length became nearly zero compared with the initial length of this test.

There can be seen some difference between the change in length of the

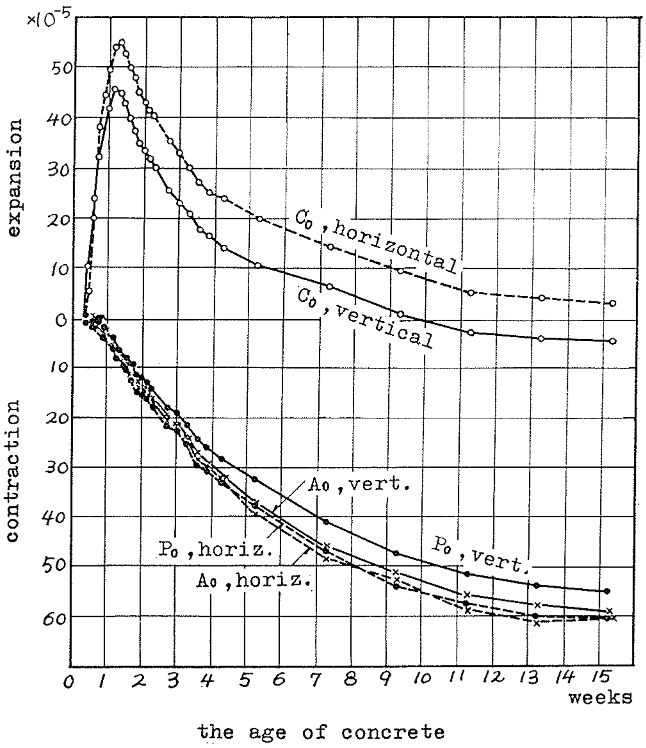

Fig. 2. The change in length of plain concrete

CSA-cement concrete in the vertical direction and that of the horizontal direction: the former was smaller than the latter. The reason for this phenomenon may be attributed to the constraint against expansion of young concrete by its own weight.

On the other hand, the magnitudes of dry shrinkage of P_0 and A_0 were $540 \sim 610 \times 10^{-6}$ mm/mm compared with their initial length.

(2) Change in length of reinforced concrete

Some trouble was encountered in the measurement of change in length for the first two days. Therefore, the data were conveniently arranged by taking the length at the fourth day after casting concrete as the standard. The test results are plotted in Fig. 3.

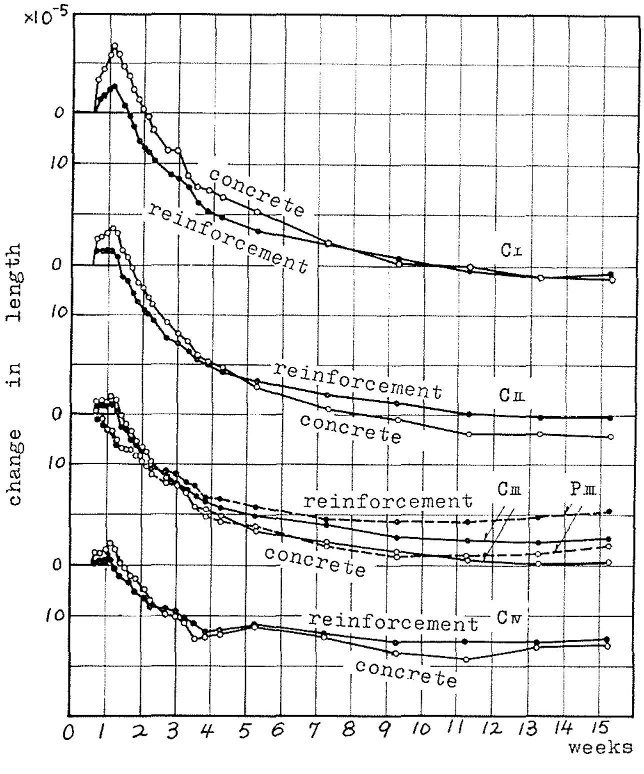

Fig. 3. The change in length of reinforced concrete

There were some differences between the change in length of reinforcing bars and those of the concrete body. The former was less than the latter in both cases of expansion and contraction. It may be assumed that these differences would be caused by the plastic deformation of the bond between the concrete and bars, and possibly by the warp of concrete surface constrained by the bars.

Speaking of the change in length of concrete body, a tendency of expansion was also observed in the early stage of hardening of concrete. However, the magnitudes were considerably smaller than those of plain concrete and the maximum expansion decreased when the reinforcement ratio increased.

Since the dry shrinkage of concrete was also constrained by the existence of reinforcement bars, the specimens which had higher reinforcements showed smaller shrinkage and the magnitudes of shrinkage after the primary expansions at a certain age decreased almost linearly with the increase of reinforcement ratios.

Fig. 4 shows the relation between the reinforcement ratio and the amount of change in length, when the length at the 4th day after casting concrete was taken as the standard. It is of considerable interest that the specimens with a moderate reinforcement ratio showed the largest shrinkage at the 15th week.

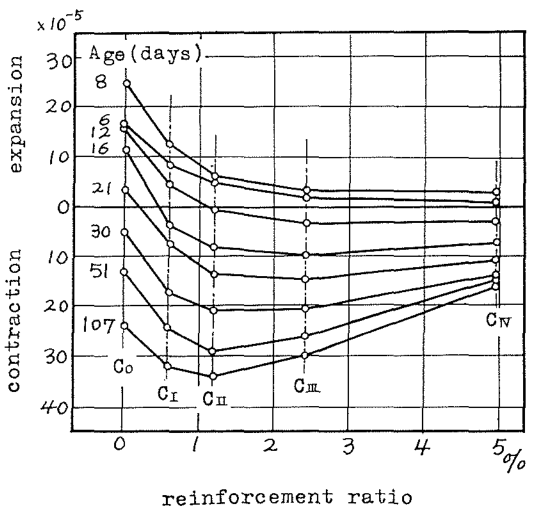

Fig. 4. The relation beween the change in length and the reinforcement ratio.

3. Observation of cracks

An observation of cracks on the surfaces of specimens was done by a magnifying glass.

The first hair cracks were observed on every specimen at the age of 16 days, when the relative humidity of the test room was about 42%. It seemed that there was no difference between the age of initial cracking of concrete and the types of cements as well as the quantity of reinforcement, in the range of such a low humidity. Fig. 5 and Fig. 6 show the sketches of crack distribution at the age of 3 weeks and 15 weeks, respectively, and Table 4 shows the distribution factors of cracks, i. e., the mean length of crack per unit area. Both data indicate that there were not so much difference on the crack distribution for every specimen, in spite of the variation of cement, mixtures and reinforcement ratios, except for the specimens of P_{III} which showed little cracking regardless of the same grade of shrinkage. If the crack distributions were the same, the width of crack should theoretically increase with the increase of reinforcement, but a remarkable difference could not be found in this CSA-cement concrete. Each crack had a width

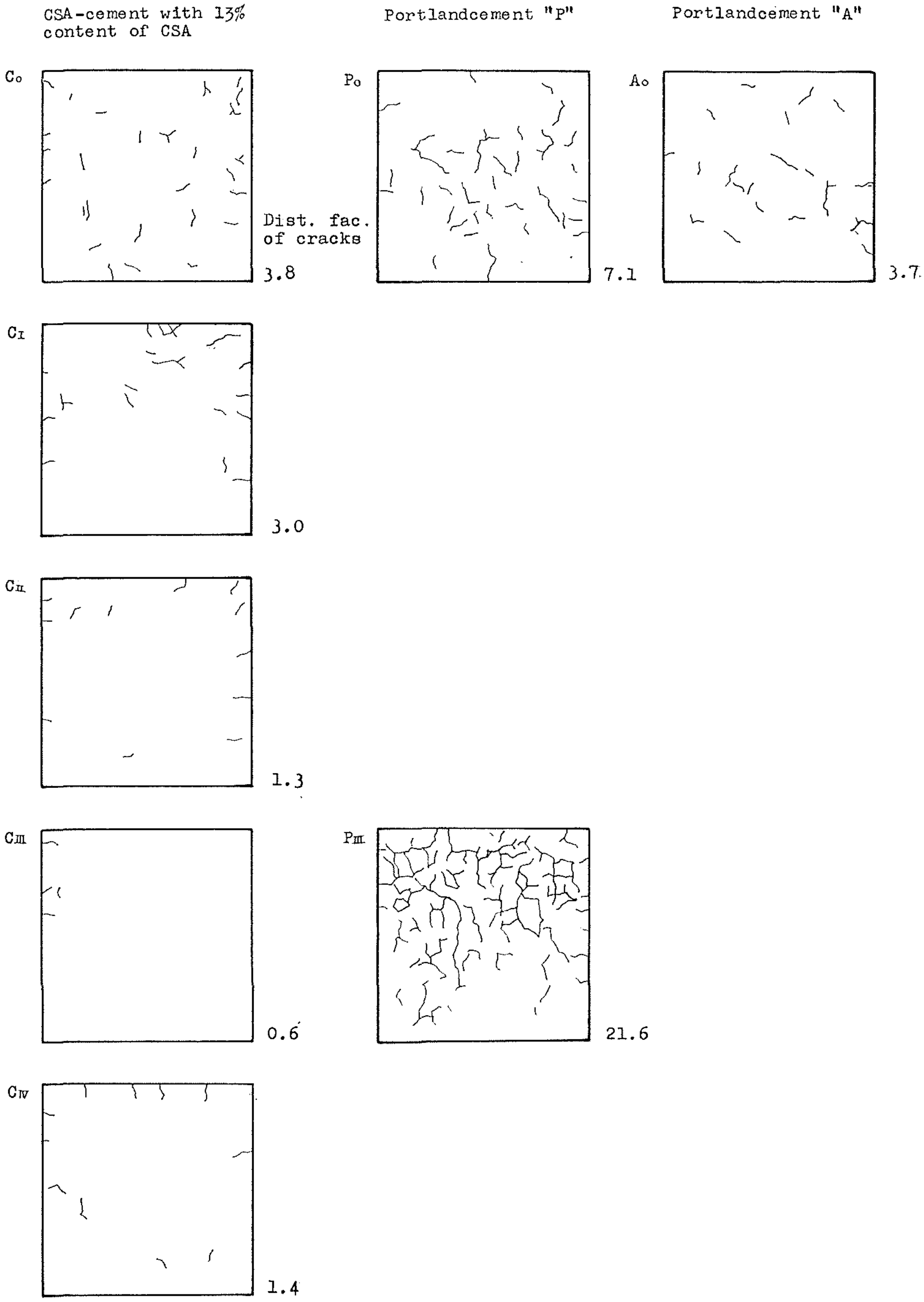

Fig. 5. Sketch of cracks at the age of 3 weeks

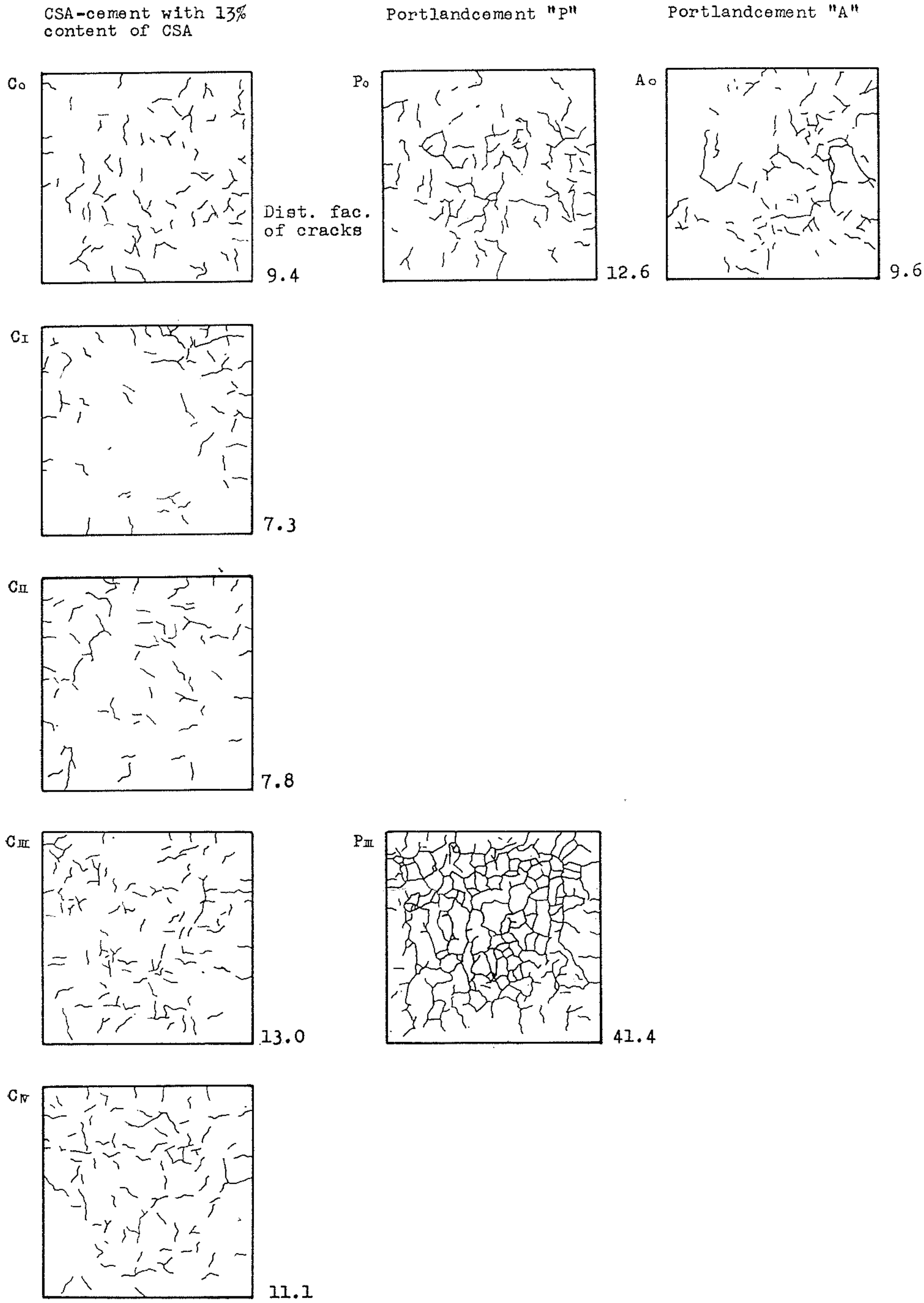

Fig. 6. Sketch of cracks at the age of 15 weeks

Table 4. Distribution factors of cracks at the age of 15 weeks

symbol	type of cement	reinforcement ratio (%)	distr. factor of cracks ($\times 10^{-2}$ cm/cm^2)						
			No. 1		No. 2		No. 3		mean
C_0	CSA-cement	0	9.4	12.6	5.6	6.3	12.4	13.3	10.0
C_{I}	"	0.60	7.3	6.2	7.2	6.9	—	11.2	7.8
C_{II}	"	1.20	7.8	12.8	7.8	3.4	7.5	8.2	7.9
C_{III}	"	2.44	9.7	13.0	11.9	12.5	16.6	17.5	13.5
C_{IV}	"	4.99	6.9	11.6	14.8	11.1	13.4	8.2	11.0
P_0	portland-cement P	0	14.8	13.4	11.8	8.0	13.5	12.6	12.4
P_{II}	"	2.44	31.6	32.0	45.4	34.4	47.2	41.4	38.7
A_0	portland-cement A	0	6.5	7.0	10.6	10.1	9.6	10.7	9.1

of 0.02–0.04 mm. It was very difficult to distinguish the deep cracks from hair cracks on the surfaces of specimens.

Test Series II–1

The purpose of this test was to compare CSA-cement with ordinary portland cement from a view point of crack distribution of reinforced concrete. The testing method of Series I was followed in this study by using CSA-cement with 10% CSA and portland cement "A".

1. Specimens

Type and size, Aggregates, Concrete forms These were the same as in the foregoing test.

Reinforcements Two types of double meshes were used as shown in Fig. 7.

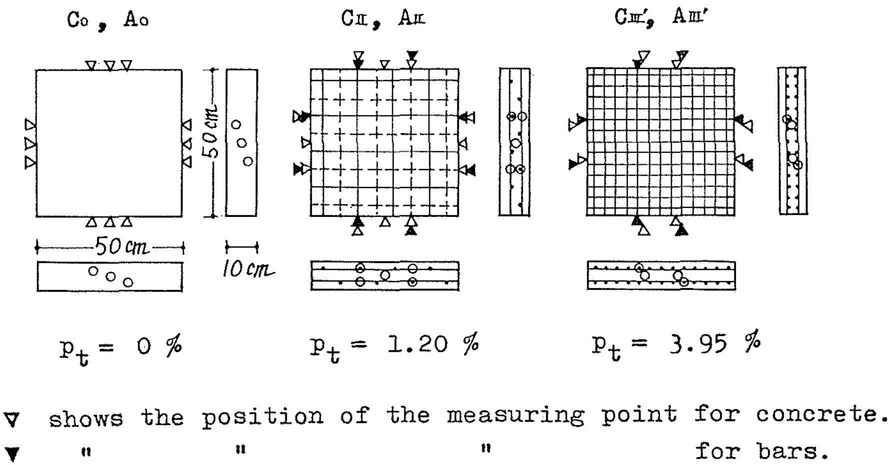

Fig. 7. Types of reinforcement

Cements Two types of cements, mentioned above were used.

Mixtures The mixtures were selected as shown in Table 5, where w/c was 0.7 and the slump was controlled at about 18 cm.

Curing The wooden forms were removed at 48 hours after casting the

Table 5. The mixtures

type of cement	w/c	slump (cm)	mixture by weight (kg/m³) cement	sand	gravel	water	comp. str. (kg/cm²)
CSA-cement	0.70	18.3	275	990	850	193	179
portland-cement *A*	0.70	16.8	275	990	850	193	255
CSA-cement*	0.55	17.6	335	900	911	184	269

* This mixture was used in Test Series II-2.

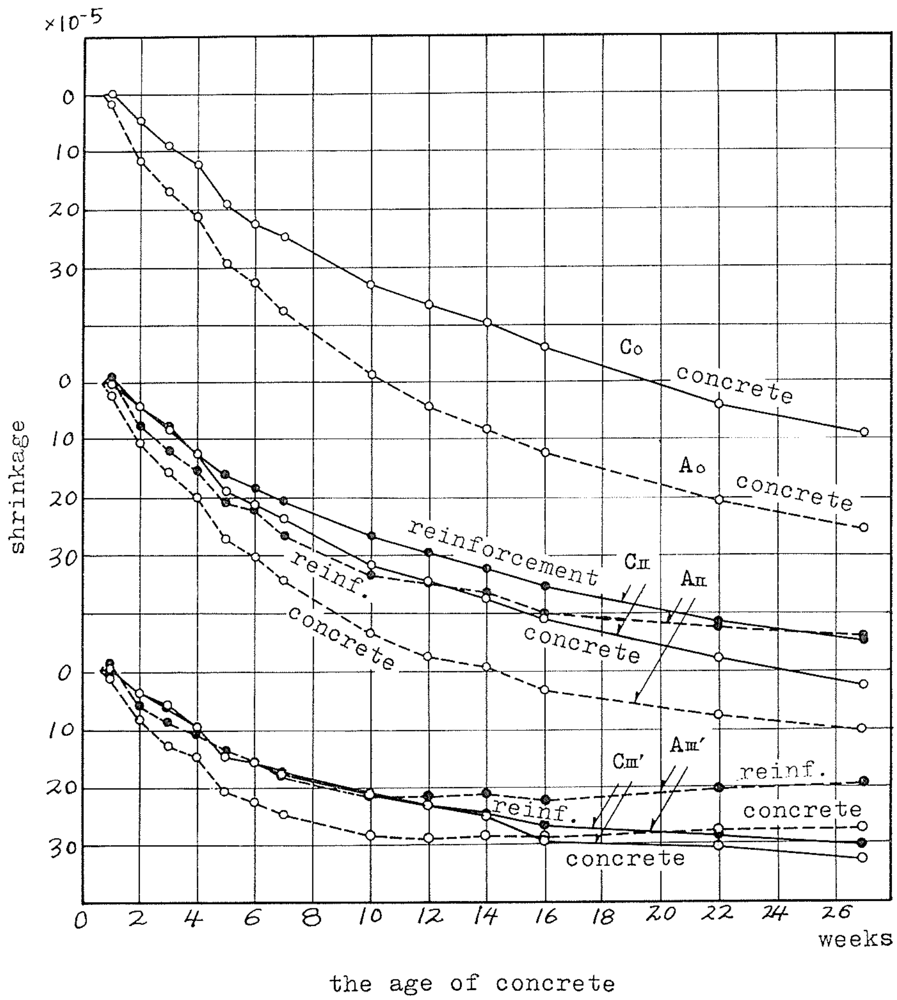

Fig. 8. The change in length of the specimens

concrete and the specimens were cured in a room air of 16°C and 75% R.H. for three weeks, and then at 16°C and 55% R.H.

2. Measurement of change in length

The results of measurement are plotted in Fig. 8.
The expansions of CSA-cement concrete were very little, even in the case of plain concrete C_0, and there was not so much difference in the change in length between C_0 and ordinary concrete A_0 for the first week. However, A_0 showed thereafter a somewhat larger shrinkage than C_0. The magnitudes of dry shrinkage are given in Table 6. It shows that the shrinkage of reinforced concrete at the end of the 7th week almost linearly decreased with the increase of reinforcement ratio for both types of cements.

Table 6. The influence of reinforcements on the shrinkage ($\times 10^{-5}$ mm/mm)

symbol	type of cement	reinf. ratio (%)	28 days		49 days		70 days		189 days	
C_0	CSA-c.	0	12.0	1.00	24.5	1.00	32.8	1.00	59.0	1.00
C_{II}	"	1.20	12.5	1.04	23.7	0.97	31.4	0.96	52.2	0.89
$C_{III'}$	"	3.95	9.6	0.80	17.8	0.73	21.2	0.65	32.8	0.56
A_0	port. A	0	21.1	1.00	37.5	1.00	48.8	1.00	75.6	1.00
A_{II}	"	1.20	19.9	0.94	34.2	0.91	43.3	0.89	60.0	0.80
$A_{III'}$	"	3.95	14.8	0.70	24.8	0.66	28.5	0.58	27.2	0.36

3. Observation of cracks

The crack distributions on the surfaces of specimens which were sketched at the 7th week and the 50th week are respectively, shown in Fig. 9 and Fig. 10, and their distribution factors are calculated in Table 7.

Table 7. The distribution factors of cracks ($\times 10^{-2}$ cm/cm^2)

symbol	5th week (max. min.)	7th week (max. min.)	15th week (max. min.)	27th week (max. min.)	50th week (max. min.)
C_0	0.30–0 0.20	0.30–0 0.21	1.24–0.22 0.71	1.80–0.42 1.22	3.26–1.12 0.96
C_{II}	0.16–0 0.04	0.20–0 0.09	2.64–0.52 1.11	3.72–0.80 1.81	5.12–1.78 3.47
$C_{III'}$	0.58–0 0.18	1.12–0 0.51	6.64–1.34 3.08	13.26–3.44 6.18	16.78–4.42 8.22
A_0	0.40–0 0.17	0.66–0 0.34	1.68–0 0.84	1.80–0.16 0.99	3.66–0.24 1.62
A_{II}	1.14–0.36 0.73	2.26–0.60 1.30	5.12–0.76 3.17	5.96–1.76 4.82	9.58–1.96 5.79
$A_{III'}$	7.30–1.26 2.52	9.74–1.62 4.13	15.36–3.46 7.99	19.82–7.32 12.87	21.06–8.36 13.82

Each figure in the lower rows shows the mean value of six data.

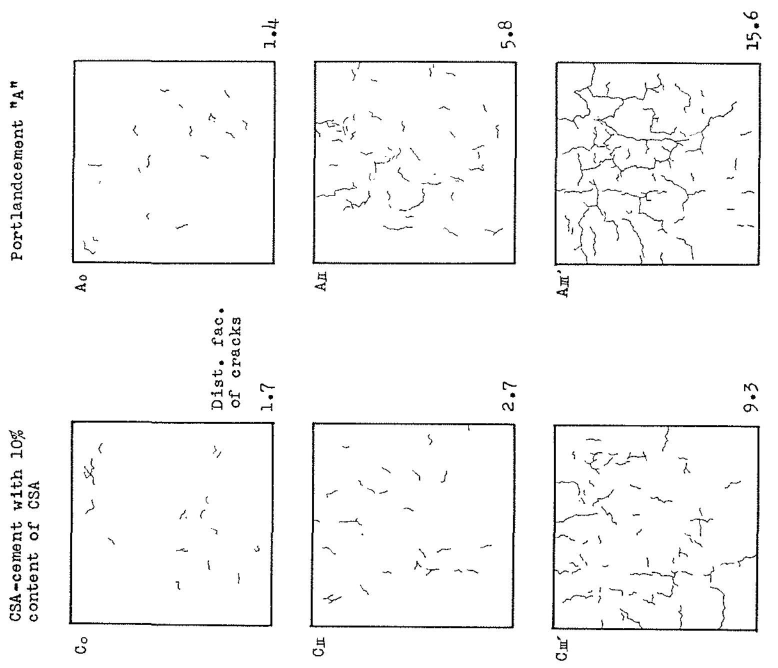

Fig. 10. Sketch of cracks at the 50th week

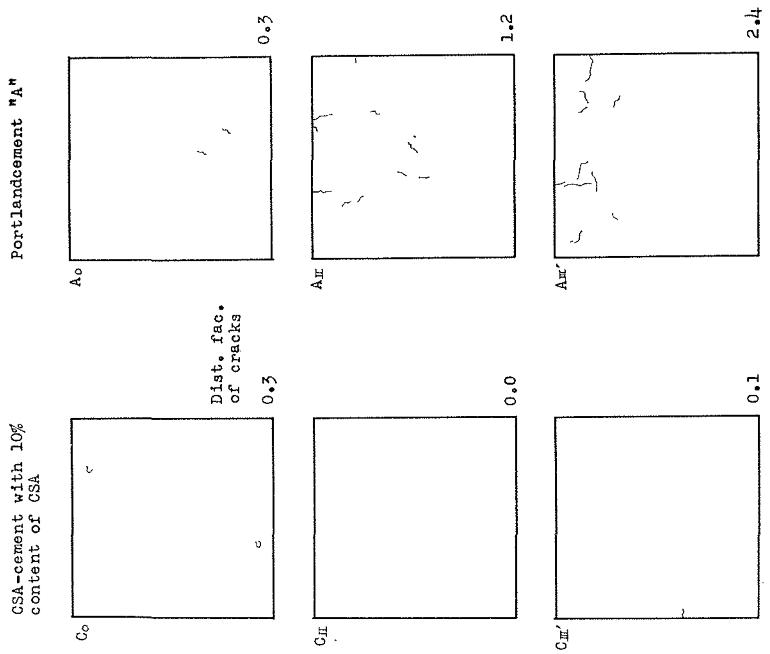

Fig. 9. Sketch of cracks at the 7th week

These results were somewhat different from those in Test Series I. Both figures show that few cracks were observed on the specimens of plain concrete C_0 and A_0, even at the 50th week, and that cracks of reinforced concrete mixed with the CSA-cement increased considerably after the 7th week, although the cracks did not extend so much at an earlier age.

It seems notable that the dry shrinkage of ordinary reinforced concrete with the high reinforcement ratio showed some relaxation after a certain age. It means some deep cracks reached to the reinforcement bars and the compressive stress of steel bar had partly been released.

Test Series II-2

The aim of this test was to start the measurement of change in length immediately after the casting concrete, because the CSA-cement concrete in the foregoing test did not show a remarkable expansion.

1. Specimens

Type and size A modified beam with a cross section of $20 \times 20\ cm^2$ and a length of 200 cm was adopted for the specimens of reinforced concrete, as shown in Fig. 11. A beam with the same cross section and a length of 50 cm was adopted for the specimens of plain concrete. Each beam had steel end plates of 9 mm in thickness, where the measuring points consisting of small screws were installed. These end plates would serve to prevent the drying of concrete from the ends of the beams.

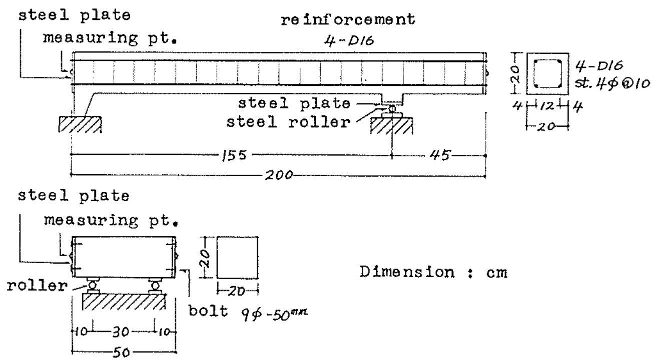

Fig. 11. The specimens of beam type

For the specimens of reinforced concrete, the end plates were previously welded to both ends of the reinforcement bars; four deformed bars of 16 mm in diameter. The reinforcement ratio became 1.96%. For the specimens of plain concrete, four small bolts were attached to the inside of the end plates in order to secure the bond strength between the plate and concrete body.

Wooden forms were used for manufacturing the specimens. The above-mentioned end plates were fitted as parts of the form.

Aggregates, Cements These were the same as in the first part of this test series.

Mixtures For CSA-cement concrete, two kinds of w/c were applied, i. e., 0.70 and 0.55. For ordinary concrete w/c was 0.70. The mixtures were selected as shown in Table 5 by controlling their slumps at about 18 cm.

Curing The wooden forms were removed at the age of 5 days. Then, the specimens were cured in a room air of 18°C and 70% R.H.

2. Measurement of change in length

The measurement was started at 6~8 hours after casting the concrete. Similar measuring devices as used in Series I were used by using exclusively one apparatus to one specimen. The results are shown in Fig. 12.

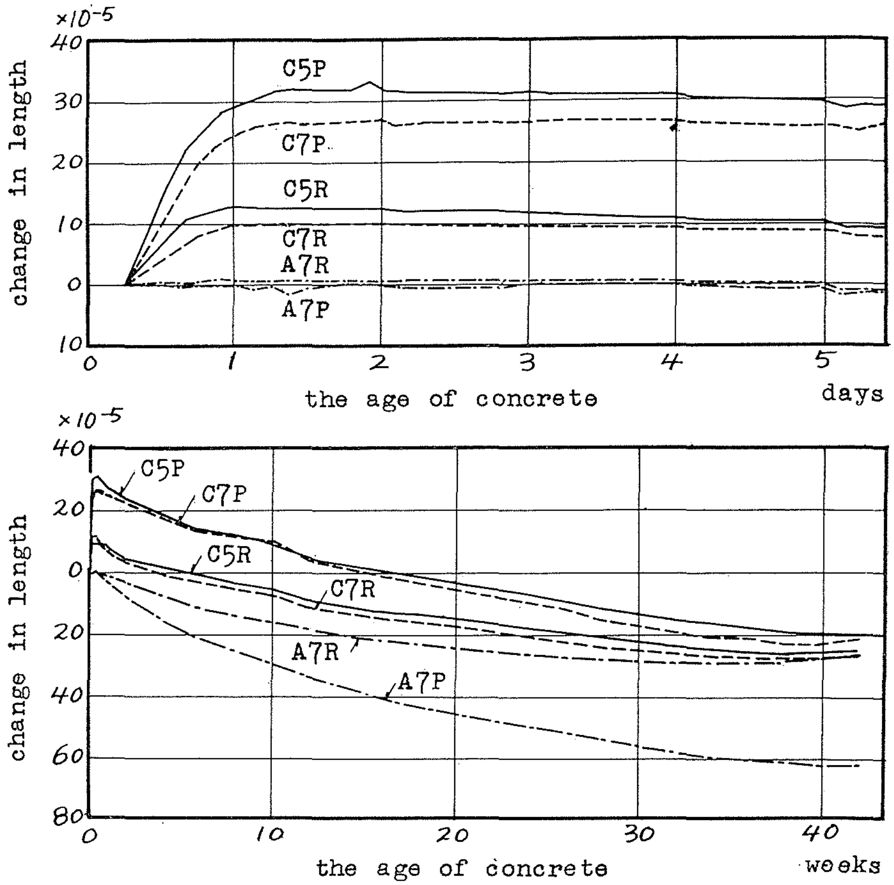

Fig. 12. The relation between the age of concrete and the change in length

(1) Change in length in young age

All of the specimens of CSA-cement concrete showed a tendency of expansion in the period of one or two days after casting the concrete, although the specimens of the ordinary concrete did not show any expansion nor contraction in this period. The magnitudes of expansion in the plain concrete were about 60% of the test results in Series I. The reason could mainly be attributed to the difference of CSA content of 13% and 10%. Besides, the forms would constrain the concrete against the free expansion as in the case of reinforcement bars.

According to Table 8, which indicates the magnitude of the maximum expansion of each specimen, $C5$ ($w/c=0.55$) showed a somewhat larger expansion than $C7$ ($w/c=0.70$), in both cases of plain concrete and reinforced concrete. And the expansion of reinforced concrete was only 37 and 38% compared with plain concrete for corresponding w/c of 0.7 and 0.55, respectively.

Table 8. Influence of reinforcement

symbol	type of cement	w/c	reinf. ratio (%)	max. expans.		length at 42 w.	shrinkage	
				magn.	ratio		magn.	ratio
C 5 P	*C*	0.55	0	33.1	1.00	−19.7	52.8	1.00
C 5 R	"	0.55	1.96	12.6	0.38	−25.1	37.7	0.71
C 7 P	*C*	0.70	0	27.0	1.00	−21.2	48.2	1.00
C 7 R	"	0.70	1.96	10.0	0.37	−27.0	37.0	0.77
A 7 P	*A*	0.70	0	—		−61.9	61.9	1.00
A 7 R	"	0.70	1.96	—		−25.9	25.9	0.42

(2) Dry shrinkage and crack

After the primary expansion, both the plain concrete and reinforced concrete mixed with CSA-cement showed day shrinkage. The behaviors of these dry shrinkage were not overly affected by the difference of water-cement-ratios.

According to the observations on the cracks of the specimens up to 42 weeks, many cracks transverse to the longitudinal axis of the specimens were found in a pitch of about 10 cm for the ordinary concrete, but very few cracks were found for the CSA-cement concrete.

Summary

1. The change in length and crack distribution of plain concrete and reinforced concrete mixed with CSA-cement were studied. Two kinds of CSA-cements which contained 13% and 10% of CSA were used in the separate test series.

2. In the case of a CSA-cement with 13% CSA ($w/c=0.6$),

(i) the plain concrete expanded remarkably in the first week after manufacturing the specimens. Maximum expansion was observed at the 9th day and the magnitude reached over 450×10^{-6} mm/mm. However, after these primary expansions, the CSA-cement concrete showed a large dry shrinkage similar to that in ordinary concrete. Consequently, the amount of change in length became nearly zeo after 15 weeks, when the length at 48 hours after casting concrete was taken as the standard.

(ii) The reinforced concrete showed a similar tendency of primary expansion and successive shrinkage. However, the magnitudes were considerably small and the magnitudes of dry shrinkage after the primary expansion decreased almost

proportionally with the increase of reinforcement ratio.

(iii) According to the observation of crack distribution on the surfaces of specimens, very little difference could be found between the plain concrete and the reinforced concrete with various kinds of reinforcement ratios. It is uncertain whether this phenomenon was proper to the CSA-cement with 13% CSA or whether it could be attributed to the low humidity of the test room.

3. In the case of CSA-cement with 10% CSA ($w/c=0.70$), even for the plain concrete, almost no expansion was observed after removing the concrete form.

The observation of cracks showed that plain concrete mixed with CSA-cement and the ordinary portland cement had a few cracks in a similar degree, and that the crack distribution increased with the increase of reinforcement ratio for both concretes, less cracks being found in the CSA-cement concrete than the ordinary concrete.

4. A study on the CSA-cement concrete with 10% CSA by a special testing method gave the following results.

(i) For plain concrete, a considerable expansion was observed in the first one or two days and the magnitude of maximum expansion was about 60% of the CSA-cement concrete with 13% CSA. There was not so much difference in the primary expansion and successive shrinkage between two types of water-cement-ratios ($w/c=0.55$ and 0.70), although the smaller water-cement-ratio gave a somewhat larger expansion. The magnitude of dry shrinkage after the primary expansion was about 500×10^{-6} mm/mm at the age of 42 weeks. The corresponding shrinkage of the ordinary concrete was about 600×10^{-6} mm/mm.

(ii) In the case of the reinforced concrete (reinforcement ratio=1.96%), the magnitude of the primary expansion was less than 40% of the plain concrete for the both water-cement-ratios. The shrinkage after the primary expansion was about 70% of the plain concrete at the age of 42 weeks and the amount of the change in length became almost equal to that of ordinary reinforced concrete. However, very few cracks were observed on the specimens of the CSA-cement concrete, although a considerable number of cracks were found on ordinary concrete.