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Influence of Creep and Shrinkage upon Cracking and Deflection of Lightweight Reinforced Concrete Beams

L'influence du retrait et du fluage sur la fissuration et la déformation des éléments fléchis en béton léger armé

Der Einfluss des Kriechens und Schwindens auf die Rissebildung und die Durchbiegung von bewehrten Leichtbetonbalken

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1. OBJECT OF INVESTIGATION

An experimental investigation was planned to study the behaviour in flexure of beams from lightweight reinforced concrete under sustained load. Two series of simple span rectangular beams were tested. Simple reinforced beams (Series 1) were tested to study the influence of the load level on the cracking and deformation of beams. Double reinforced beams (Series 2) from lightweight and gravel concrete, for comparing the results, were investigated to follow the influence of compressive reinforcement on the cracking and deflection of beams in the range of normal working loads.

2. EXPERIMENTAL PROGRAM

Test specimens. All the beams were 320 cm long, having a 10 x 15 cm cross section. The longitudinal reinforcement used in Series 1 consisted of mild steel bars, having a yield point of about 2600 kg/cm^2; the longitudinal reinforcement used in Series 2 consisted of deformed bars, having a conventional yield point of about 3700 kg/cm^2. The vertical stirrups were distributed along the outer thirds of span for the beams of Series 1 and along the entire length of beam for the specimens of Series 2.

The principal characteristics of the test beams are given in Table 1 and Table 2. Typical details of the beams are shown in Fig.1.

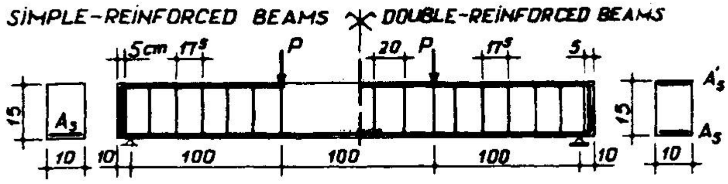

Fig.1. Typical details of test beams

TABLE 1. BEAM CHARACTERISTICS OF SERIES 1

Mark	$\frac{M}{M_u}$	Tensile steel ratio p %	Concrete properties after 28 days				Aggregate
			Bulk density kg/m^3	Compressive strength kg/cm^2	Flexural strength kg/cm^2	Elastic modulus kg/cm^2	
A 1:1 A 1:2 A 1.3	0,25 0,50 0,75	0,33	1720	249	41,6	191.000	expanded clay
A 1:4 A 1:5 A 1.6	0,25 0,50 0,75	1,00	1728	254	36,7	185.000	expanded clay
A 1:7 A 1:8 A 1.9	0,25 0,50 0,75	2,00	1766	269	38,5	205.000	expanded clay
B 1:1 B 1.2 B 1.3	0,25 0,50 0,75	1,00	1860	222	47,5	202.000	expanded blastfurnace slag

M = bending moment M_u = ultimate bending moment

TABEL 2. BEAM CHARACTERISTICS OF SERIES 2

Mark	$\frac{M}{M_u}$	Tensile steel ratio p %	Compressive steel ratio p' %	$\frac{p'}{p}$	Concrete properties after 28 days				Aggregate
					Bulk density kg/m^3	Compressive strength kg/cm^2	Flexural strength kg/cm^2	Elastic modulus kg/cm^2	
A 2.1 A 2.2 A 2.3	0,50	0,99	- 0,44 0,99	- 0,44 1,00	1680 1680 1680	279 233 239	31,5 32,6 34,0	133;000 144;000 127.000	expanded clay
A 2:4 A 2:5 A 2.6	0,50	1,95	- 0,99 1,95	- 0,51 1,00	1705 1680 1680	286 233 239	31,0 32,6 34,0	164.000 144;000 127.000	expanded clay
C 2:1 C 2:2 C 2.3	0,50	0,99	- 0,44 0,99	- 0,44 1,00	2360 2410 2360	315 345 315	39,4 39,4 39,4	273;000 333;000 273.000	gravel

M = bending moment M_u = ultimate bending moment

Test procedure. The beams subjected to concentrated loads at the third-span points were maintained under constant loading for about 460 days (Series 1) or 360 days (Series 2).

At the time of loading the specimens were 25 - 35 days old.

Deflections of the test beams were measured using 1/100 mm dial gauges resting against the underside of the beams at mid-span. Cross section deformations in the constant moment zone were measured with strain gauges, reading to 1/1000 mm.

The cracks of beams on loading and under sustained load were visually observed using Brinell - microscopes. All the tests were carried out in a room with a relative humidity of 60 - 70 per cent.

3. TEST RESULTS

3.1. Flexural cracking

Examination of the test data (Table 3) indicates that for the specimens with mild steel reinforcement the cracks number recorded on loading, increases with time. For the beams subjected to a lower load level (Beams A 1.4, A 1.7 and B 1.1) increase of

TABLE 3. CRACK DEVELOPMENT OF BEAMS

Beam	Number of cracks			Average crack spacing(cm)			Crack widths (mm)						Sum of crack widths(mm)		
	t=o	after 3o days	after 36o days	t=o	after 3o days	after 36o days	t=o		after 3o days		after 36o days		t=o	after 3o days	after 36o days
							av.	max.	av.	max.	av.	max.			
A 1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A 1.2	-	-	2	-	-	85	-	-	-	-	o,o3	o,o4	-	-	o,o5
A 1.3	1	5	17		23,7	1o,5	o,o3	o,o3	o,o5	o,o8	o,o5	o,1o	o,o3	o,27	1,o8
A 1.4	2	2	11	91	91	15,1	o,o1	o,o2	o,o3	o,o4	o,o3	o,o8	o,o3	o,o7	o,41
A 1.5	2o	2o	24	1o	1o	9,1	o,o3	o,o7	o,o4	o,o8	o,o6	o,12	o,57	o,84	1,42
A 1.6	25	26	3o	6	6	6	o,o5	o,o8	o,o6	o,13	o,o8	o,17	1,2o	1,62	2,42
A 1.7	7	17	25	18	11,2	7,5	o,o2	o,o2	o,o3	o,o6	o,o4	o,o8	o,13	o,58	o,92
A 1.8	23	24	31	9	9	7,5	o,o4	o,o7	o,o7	o,1o	o,o8	o,15	o,96	1,63	2,46
A 1.9	33	36	36	7,1	6,6	6,6	o,o7	o,15	o,o8	o,17	o,o9	o,2o	2,29	2,96	3,36
B 1.1	1	18	25	-	9,1	7,8	o,o2	o,o2	o,o3	o,o8	o,o4	o,11	o,o2	o,48	o,93
B 1.2	5	22	26	23	7,8	7,8	o,o5	o,o6	o,o4	o,1o	o,o6	o,18	o,23	o,95	1,63
B 1.3	19	32	33	1o	6,9	6,9	o,o6	o,o8	o,o7	o,11	o,1o	o,2o	1,o8	2,12	3,2o
A 2.1	31	31	31	7,7	7,7	7,7	o,o6	o,1o	o,o8	o,11	o,o8	o,13	1,93	2,34	2,57
A 2.2	27	27	29	7,8	7,8	7,5	o,o5	o,o8	o,o7	o,1o	o,o7	o,13	1,26	1,84	2,12
A 2.3	28	28	28	8,6	8,6	8,6	o,o5	o,o9	o,o7	o,11	o,o8	o,15	1,53	1,91	2,16
A 2.4	36	36	36	7,1	7,1	7,1	o,o6	o,1o	o,o7	o,12	o,o7	o,14	2,16	2,44	2,51
A 2.5	39	39	39	6,3	6,3	6,3	o,o5	o,o9	o,o6	o,1o	o,o7	o,1o	1,91	2,37	2,58
A 2.6	45	45	45	5,3	5,3	5,3	o,o4	o,o7	o,o4	o,o8	o,o4	o,o9	1,71	1,86	1,98
C 2.1	28	28	28	7,6	7,6	7,6	o,o5	o,1o	o,o6	o,11	o,o7	o,12	1,3o	1,74	2,o3
C 2.2	25	25	25	8,1	8,1	8,1	o,o3	o,o9	o,o5	o,1o	o,o5	o,12	o,83	1,19	1,3o
C 2.3	34	34	35	6,2	6,2	6,o	o,o3	o,o7	o,o5	o,11	o,o6	o,1o	o,98	1,64	2,o5

cracks number is more pronounced. When the beams were reinforced with deformed bars cracks number occured on loading was greater but practically constant with time.

In any case the cracks number on loading increases with the reinforcement ratio and load level.

The average crack spacing on loading decreases with increasing of stress level and is less influenced by the duration of loading. This means that cracks occured under sustained load are, generally, outside of initial cracked region of the beam.

The average crack widths increases with the reinforcement stress and the time of loading period. For the double reinforced beams the greater the compressive steel ratio the smaller the average crack widths.

After the removal of load the average crack widths are, generally, of the same order of magnitude as those observed immediately after loading.

For the lightweight concrete beams the average crack width exceeds with about 35 per cent the average crack width observed in similar speciemns from gravel concrete (Beams A 2.1 - A 2.3 and C 2.1 - C 2.3).

The maximum crack widths for the lightweight concrete beams subjected to a load level equal to 50 per cent (Beams A 1.5, A 1.8, B 1.2, A 2.1 - A 2.3 and A 2.4 - A 2.6) lie between 0,06 mm to 0,10 mm on loading and 0,09 mm to 0,18 mm after 360 days. According to the C.E.B. recommendations concerning the limiting values of crack widths, it may be concluded that the lightweight concrete beams satisfy the requirements of normal work conditions.

On unloading the maximum crack width is less than 0,10 mm.

3.2. Deflection

Typical variation of deflection for the test beams in relationship with applied load and time is shown in Fig.2.

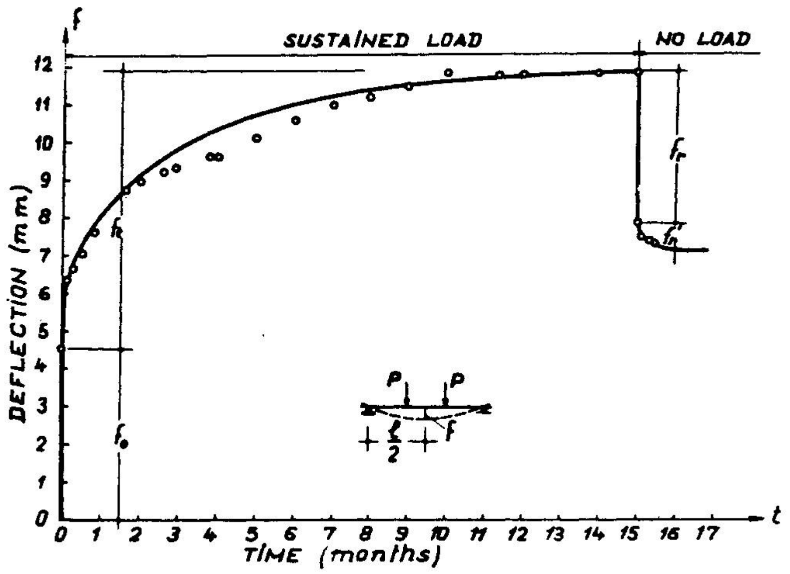

Fig.2. Time-deflection relationship for the beam A 1.5

Instantaneous deflection (f_0). Figs. 3 and 4 show that deflection of beams on loading increases with the tensile reinforcement ratio and the steel strength. Presence of compressive reinforcement results in a decrease of deflection. Except the

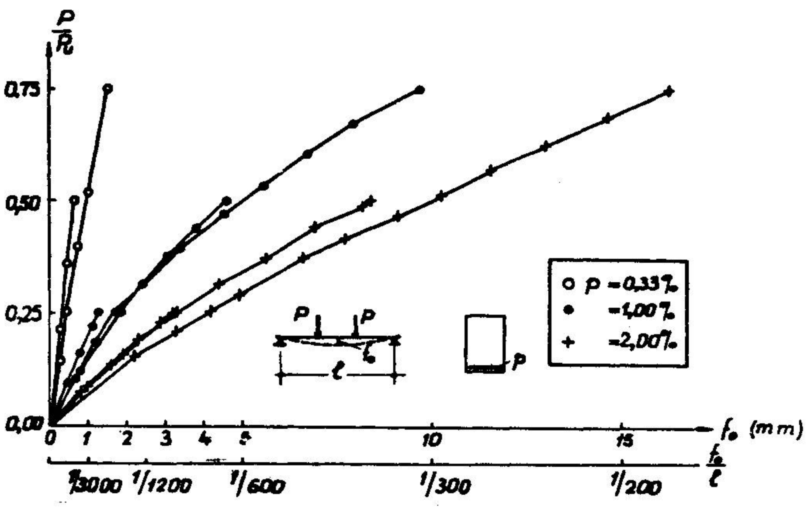

Fig.3. Instantaneous deflections of expanded clay concrete beams of Series 1

beam A 2.4 the span-instantaneous deflection ratio corresponding to the working loads is less than 200.

For the gravel concrete beams, deflections on loading are

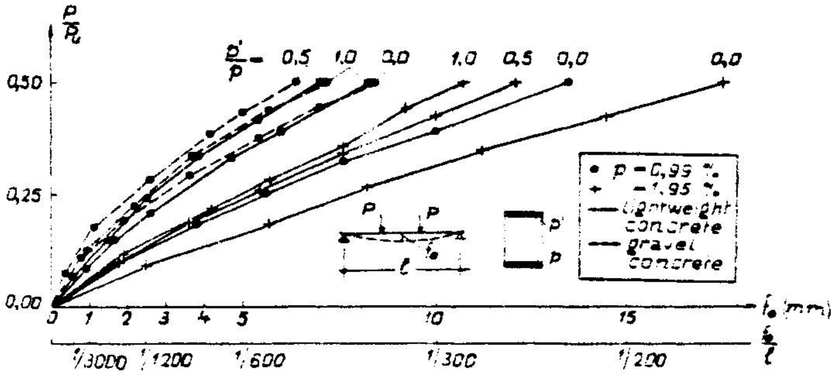

Fig.4. Instantaneous deflections for the beams of Series 2

smaller than those of similar lightweight concrete specimens.

It is a similarity between the behaviour on loading of expanded clay concrete or blastfurnace slag concrete beams.

<u>Long term deflection</u> (f_t) due to creep and shrinkage - see Fig.2 - is influenced by several parameters as seen from the following.

The variations of the long term - instantaneous deflection ratios are shown in Figs. 5, 6 and 7. It can be observed that

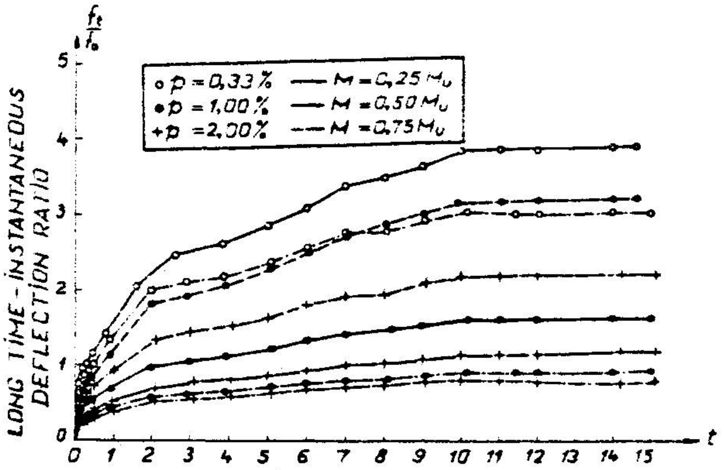

Fig.5. Long time deflection of expanded clay concrete beams

for a given time the smaller the tensile reinforcement ratio and the load level, the greater the value of f_t/f_o ratio. For the beams reinforced with mild steel bars the f_t/f_o ratio is higher than for the beams reinforced with deformed bars. This means that for the beams reinforced with deformed bars, the tensile zone of concrete has smaller influence on the long term deformation, because of more pronounced cracking degree.

The blastfurnace slag concrete beams have the long term deflections exceeding with about 30 per cent those of expanded clay concrete beams.

For the reinforced beams with deformed bars, the long term deflection of gravel concrete specimens is smaller than that of

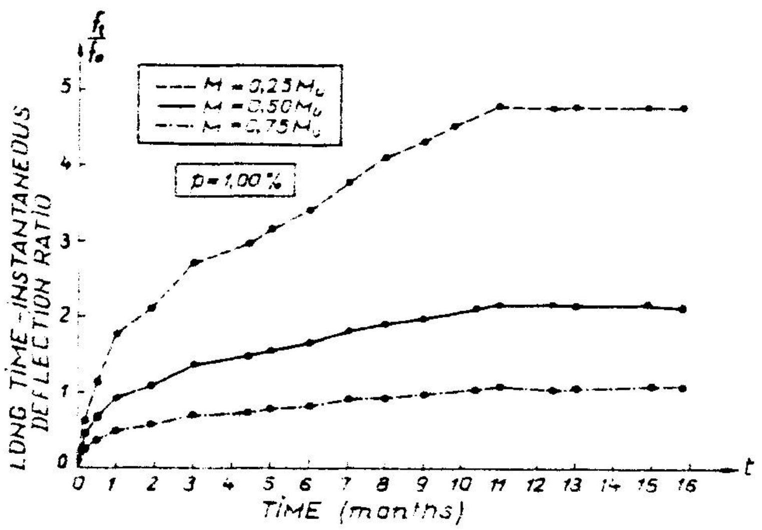

Fig.6. Long time deflections of expanded blastfurnace slag concrete beams

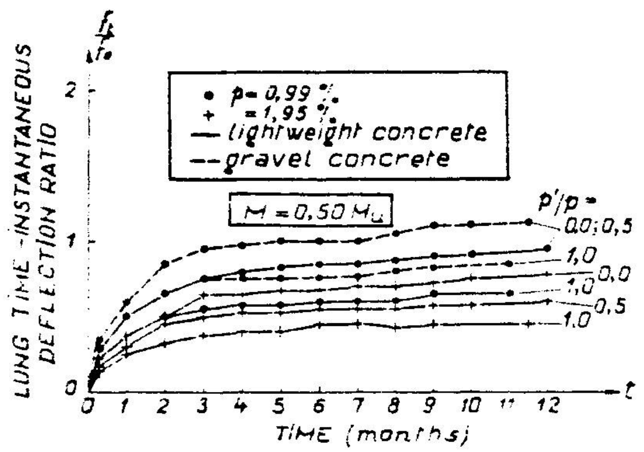

Fig.7. Long time deflections of the beams reinforced with deformed bars

lightweight concrete specimens but the f_t/f_0 ratio is slawly greater for the gravel concrete beams - see Fig.7 - because of greater deformability of lightweight concrete on loading [2].

Presence of compressive reinforcement results in a more pronounced decrease of long term deflection than that of instantaneous one.

Overall deflection ($f = f_0 + f_t$) corresponding to the working loads exceeds the limiting value accepted by the Romanian Standards [4].

Instantaneous recovery deflection (f_r) recorded on unloading the beams of Series 1 varies between 84 and 98 per cent of instantaneous deflection f_0, because the elastic modulus of concrete has increased during the loading period.

Delayed recovery deflection (f_r') of loaded beams within the range of working loads is about 12 per cent of that measured on unloading. The delayed recovery time is about 10 - 15 days after unloading.

Instantaneous rotation (θ_0) of a cross section of beam increases with a long term rotation (θ_t) due to creep and shrinkage phenomena, the neutral axis tending to displace towards the bottom of the beam (Fig.8). The investigations carried out

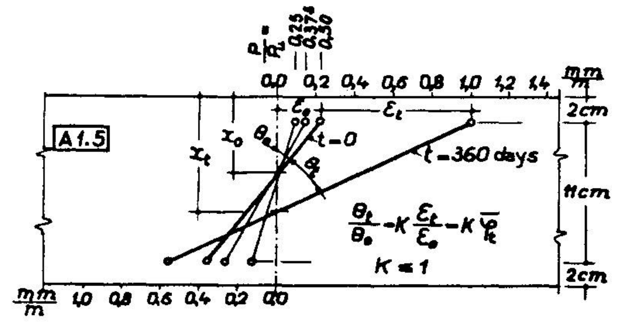

Fig.8. The rotation of cross section at mid span on loading and after 360 days (Beam A 1.5)

indicate that the θ_t/θ_0 ratio, respectively the f_t/f_0 ratio are less than the creep factor ($\bar{\varphi}_t$) of compressive strain at the top of the beam.

For the specimens A 1.5 and A 1.8 the midspan f_t/f_0 ratio represents 45, respectively 72 per cent of creep factor for the compressive strains.

4. CONCLUSIONS

The crack widths of lightweight reinforced concrete beams loaded in the range of working loads after a 360 days period of loading are less 0,2 mm.

It is suggested that depth-span ratio of lightweight concrete beams must be at least 1/15.

The effect of long term phenomena recorded at several stress levels up to 75 per cent of ultimate strength is essentialy the same.

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SUMMARY

An experimental investigation of the rheological behaviour of lightweight reinforced concrete beams is described. Expanded clay or expanded blastfurnace slag concrete beams were tested. The influence of the magnitude of sustained load and of tensile or compressive reinforcement ratios, on the cracking and deflection of beams, is discussed.

RÉSUMÉ

Des études expérimentales concernant le comportement rhéologique des poutres fléchies en béton léger armé sont décrites. Les essais ont été effectués sur des éléments fléchis éxécutés avec du béton à base d'argile ou de laitier expansé. On discute l'influence de la grandeur de la contrainte de durée et des pourcentages d'armatures tendues ou comprimées sur l'état de fissuration et de déformation des poutres.

ZUSAMMENFASSUNG

In der vorliegende Arbeit werden die Ergebnisse von experimentellen Untersuchungen, betreffend das rheologische Verhalten von bewehrten Leichtbetonbalken dargelegt. Die Versuchsbalken wurden aus Blähton- und Hochofenschaumschlackbeton hergestellt. Der Einfluss der Dauerbeanspruchung und des Bewehrungskoeffizienten der Zug- und Druckzone des Querschnitts auf die Rissebildung und die Durchbiegungen der untersuchten Balken wird ebenfalls besprochen.