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Experimental Study of Concrete Class Influence on Cracks Openings

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Abstract. The aim of this experimental work is to study reinforced concrete continuous beams cracking by considering different classes of concretes. As it is well known, the design of reinforced concrete structures considers three limit states (limit state of collapse, limit state of strain and limit state of cracking). The cracks in reinforced concrete structures are admitted in the phase II (cracked sections). Thus, the phenomenon of cracks can be treated as a normal state only when the cracks opening is limited to avoid a permanent risk of collapse and ensure durability for the civil engineering constructions. Tests on real scale reinforced concrete continuous beams were carried out under concentrated loads increasing from zero up to collapse. The influence of the concrete classes on crack opening has been investigated.

1 Introduction

The study of concrete cracking is nowadays particularly important because it requires a safety consideration according to crack apparition and its excessive opening within a structure.

Indeed, in ordinary reinforced concrete, steel reinforcements currently used have an increasingly high yield stress.

Although its bond characteristics and the constructive provisions are chosen so as to limit the crack opening in concrete, the performance of these reinforcement bars cannot be exploited if the crack thus developed is not acceptable in service state.

It is therefore necessary to adopt limit values for cracks and openings by safety methods to ensure that they are not exceeded in exploitation.

2 Purpose of the cracking calculation

In reinforced concrete constructions, it is attempted to limit the openings of the cracks to certain defined values. Also, excessive cracking is a danger to the sustainability of the construction to be performed and can be detrimental to the appearance and the behavior of the concrete.

It is therefore essential to explain and clarify the complex behavior of reinforced concrete under the effect of loads applied to it.

These openings depend mainly among other things, of the stress in the steel tensile bars, whereas the increases in these openings, under the loads application, result from the rheological phenomena occurring in the concrete.

2.1 Limit state of cracking

The cracking is a specific phenomenon to the concrete because the structure elements subjected to tensile and bending are normally cracked in their usual conditions of service. However, the durability of structures requires that certain limits cracking, more precisely, the maximum crack openings, are not exceeded. These latter define, in each case, taking into account the environmental conditions and normal exploitation of structures, the limit state of cracking of a part or the entire structure.

2.2 Calculation of the crack width w_f

To better understand the mechanism of cracking in the bent beams, Saliger [1] proposed a Bond - Slip theory based on various studies of this phenomenon on tie rods. This theory applies to the prisms with symmetrical reinforcement subjected to a tensile load. Broms [2] proposed a theory which can be called ' non slip theory', based on the main assumption that the bond is not broken between the concrete and the reinforcement at the cracks. This theory assumes that a linear relationship exists among the distance between cracks and the coating thickness. Similarly, the opening of a crack at a given point is proportional to the distance between cracks and the strain of the closest bar. Tests have shown that the Saliger theory is the more correct for the study of tie rods. The Ferry Borges theory [3-4] is a combination of these two previous ones. This is distinguished by the manner of determining the distance between cracks.

This method is that used in our work. It is also adopted by the European concrete committee, for the calculation of cracks openings at the loading moment.

2.2.1 Cracks opening according to the CEB [5] method

At the cracking stabilized state, the average crack opening can be calculated according to the method described in the model code CEB-FIP [6-7] dealing with the limit states of cracking. The average of the crack openings Wm is calculated from the average relative elongation of the reinforcing steel $\varepsilon_{sm,r}$ which occurs on the S_{rm} average distance between cracks :

$$W_m = S_{rm} \cdot \varepsilon_{sm,r} \qquad (1)$$

where;

W_m : average value of the crack openings.
S_{rm} : average spacing between the crack openings (in mm),
$\varepsilon_{sm,r}$: relative deformation from the armature with respect to the surrounding concrete.

2.2.2 Cracks opening calculation according to the kuczynski [8-11] method

For the calculation of the cracks openings, Kuczynski has given the following approximate formula for the case of a constant bending moment in the interval between two adjacent cracks:

$$W_f = [\mu_u\, \varepsilon_{sc}(1+m\, \delta_\xi)\chi(m) l_f]/W_0' \qquad (2)$$

where;

W_0' : Reduced index that indicates the section resistance, obtained using the charts given by Kuczynski.
$\chi(m)$: Mean curvature depending on the m loading step.
l_f : Average cracks spacing.
ε_{sc} : Deformation of the concrete in compression.
μ_u : Reduced value of the bending moment.
δ_ξ : Factor characterizing the position variation of the neutral axis, expressed in percent.

3 Experimentation

3.1 Tests limits

The aim of our work is to study the behavior vis-à-vis the state of cracking of concrete statically indeterminate beams loaded by concentrated loads varying from zero to the collapse.

This presentation concerned the spacing between cracks noted lf. The tests were conducted in the structural laboratory of the civil engineering department at the National Polytechnic School of Algiers.

3.2 Testing program

The followed experimental program consisted on testing twelve (12) statically indeterminate reinforced concrete beams at real scale. The tests conditions were identical in terms of formwork and mode loading.

These test specimens are classified in three trials (03) series (A, B, C) according to different classes of concrete (high, medium and low cement content), respectively. The main reinforcement bars are of steel with high adhesion of 12 mm in diameter while the transverse ones are of 8 mm in mild steel and spaced every 15 cm.

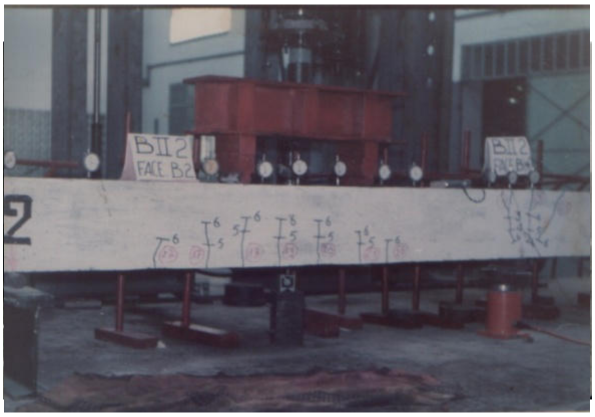
3.3 Testing machine

The used machine is a test slab with three metal frames movable in the longitudinal direction.

Each frame has a hydraulic cylinder, sliding on its transverse direction (perpendicularly to the frame movement) (figures 1 and 2).

Two equal and symmetrical concentrated loads were applied to the tested elements.

The load transmitting device included a lintel of distribution made of metal section resting on two supporting uppers receiving the forces applied by the actuator by means of a spherical joint (ball).



Photos 1. and 2. : Overviews of test devices.

4 Comparative study of the results

The following diagram shows a beam test outlining the monitoring of the cracks.

The formed cracks localized in the zone of constant moment, were selected during these experimental investigations, as developed by Zorkane [12].

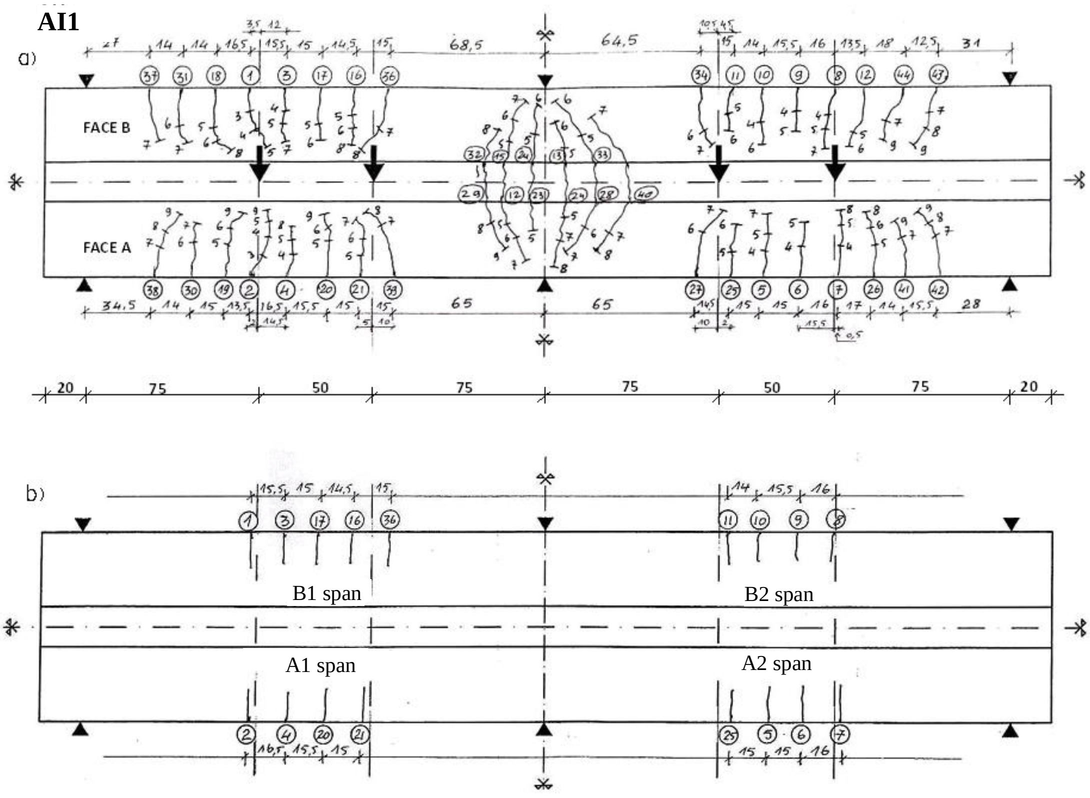


Fig. 1. Schematic representation of the tested beam.

The tables 1 and 2 below provide the experimental and theoretical results calculated by both the two methods of Kuczynski and CEB for three levels of loads, selected to monitor the appearance of cracks and their progressions.

Table 1. Comparison of the measured cracks widths with those of the CEB method.

Beams categories	$W_{f,exp}$ (mm)	$W_{f,theo}$ CEB	$\frac{W_{f,th}}{W_{f,exp}}$	Δ%	$W_{f,exp}$	$W_{f,theo}$ CEB	$\frac{W_{f,th}}{W_{f,exp}}$	Δ%	$W_{f,exp}$	$W_{f,theo}$ C.E.B	$\frac{W_{f,th}}{W_{f,exp}}$	Δ%
AI1	m =0.38				m = 0.615				m = 0.85			
	0.04	0.058	1,45	+45	0.12	0.105	0,87	-13	0.20	0.15	0,75	-25
AI2	m =0.45				m = 0.75				m = 0.85			
	0.09	0.073	0,81	-19	0.19	0.13	0,68	-32	0.28	0.15	0,53	-47
BI1	m = 0.35				m = 0.63				m = 0.77			
	0.05	0.055	1,1	+10	0.16	0.11	0,69	-31	0.24	0.136	0,57	-43
BI2	damaged beam											
CI1	m = 0 .30				m = 0.67				m = 0.85			
	0.04	0.0507	1,26	+26	0.20	0.12	0,6	-40	0.31	0.153	0,49	-51
CI2	m = 0.30				m = 0.60				m = 0.85			
	0.06	0.051	0,85	-15	0.113	0.107	0,95	-5	0.25	0.15	0,6	-40

Table 2. Comparison of the measured W_f cracks widths with those of Kuczynski method.

Beams categories	$W_{f,exp}$	$W_{f,Kucz}$	$\frac{W_{f,th}}{W_{f,exp}}$	Δ%	$W_{f,exp}$	$W_{f,Kucz}$	$\frac{W_{f,th}}{W_{f,exp}}$	Δ%	$W_{f,Exp}$	$W_{f,Kucz}$	$\frac{W_{f,th}}{W_{f,exp}}$	Δ%
AI1	m =0.38				m = 0.615				m = 0.85			
	0.04	0.034	0,85	-15	0.12	0.09	0,75	-25	0.20	0.30	1,50	+50
AI2	m =0.45				m = 0.75				m = 0.85			
	0.09	0.043	0,47	-53	0.19	0.157	0,82	-18	0.28	0.294	1,05	+5
BI1	m = 0.35				m = 0.63				m = 0.77			
	0.05	0.034	0,68	-32	0.16	0.105	0,65	-35	0.24	0.20	0,83	-17
BI2	damaged beam											
CI1	m = 0 .30				m = 0.67				m = 0.85			
	0.04	0.037	0,93	-7	0.20	0.15	0,75	-25	0.31	0.37	1,19	+19
CI2	m = 0.30				m = 0.60				m = 0.85			
	0.06	0.046	0,76	-24	0.113	0.13	1,15	+15	0.25	0.47	1,88	+88

5 Influence of concrete class on cracks opening

In the following table 3, the experimental results are presented, highlighting the influence of the concrete class depending on load levels.

Table 3. Variation of the cracks openings according to the concrete classes.

Beams categories	*Concrete class*		*0.38 ≤m≤ 0.4*		054 ≤m≤ 0.75		0.75 ≤m≤ 0.9	
			W_f *(mm)*	$\overline{W}_f$	W_f	$\overline{W}_f$	W_f	$\overline{W}_f$
Elasto conform beams	A	AI1	0.04	0.065	0.12	0.155	0.20	0.24
		AI2	0.09		0.19		0.28	
	B	BI1	0.05	0.05	0.16	0.160	0.24	0.24
		BI2	/		/		/	
	C	CI1	0.04	0.05	0.20	0.156	0.31	0.28
		CI2	0.06		0.113		0.25	

Nota: The A, B and C classes of the concrete correspond to resistance values of 40, 30 and 15 MPa, respectively.

6 Results interpretation

The experimental study carried out over a dozen of statically indeterminate beams of two identical-spans under increasing loads until collapse permitted to confront our results with those obtained by two methods of calculation recommended by Kuczynski and the CEB (The comparison focused on the experimental results).

This is due to the plasticization of concrete before crushing. After cracking, there is a decrease in the value of the rigidity in the beam span in function of the load increasing in the compression zone.

This phenomenon is due to the redistribution of internal forces of statically indeterminate systems.

Under very light loads, when the reduction of the stiffness is negligible, the distribution of the bending moments is almost the same as for elastic beams. In the final phase, when the system becomes a mechanism, we arrive at a solution based on the bearing capacity theory.

7 conclusion

The experimental results are close to those obtained by the two methods of calculation (CEB and Kuczynski).

These tests have shown that independently of the used concrete class (only those appropriate to concrete reinforced constructions are considered), the cracks widths increase depending only of the incremental load step and they become significantly widest before collapse.

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