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CRACKING OF PRESTRESSED LIGHTWEIGHT CONCRETE BEAMS UNDER REPEATED STATIC LOADS

Tests were made with repeated static loads, in load control equipments, one load cycle per minute. Before repeated loads, dial strain gauges with 10 to 15 mm bases, and 0.001 mm sensitivity, have been mounted on the first essential cracks - skew or normal to the beam axis. Otherwise, crack widths have been measured by means of a microscope. The test equipment was automatically controlled and it recorded the number of loading cycles.

The first loads were applied in increments of 2% of the calculated ultimate load up the appearance of the first crack. The characteristic minimum load ratio of load repetition was 0.25. Crack widths have been measured in cycles 1, 10, 50 and 250. In the series 11 there were three different levels of load repetitions with a maximum of 50 cycles at each level.

Cracks in the shear length belong to either of two groups. The first group includes cracks starting from the tensile flange, run perpendicular to the beam axis, and are deflected later, in compliance with the principal stress trajectories. Shear cracks in the second group starting at mid-web tend towards extreme fibres.

In our tests, cracks in I-beams of shear span a = 1.5ho always developed in compliance with the second group and under repeated loads they propagated towards the top and bottom flanges. In general, the first application produced a single crack/for a stirrup spacing of 210 mm/. By microc scope then, at load repetitions, even risible to the naked eye revealed cracks parallel to the first one in the zone of complicated stress state, in addition, also perpendicular ones in beams with 70 mm stirrup spacing. This phenomen is correlated exactly to the complex stress state. As a function of the ratio of the maximal primary to repeated load cracks extended to extreme fibres, always crossing the tensile, and sometimes even the compressive zone. In case of the shear a = 3.0 ho, cracking started at the tensile fibre, usually at the load application point, as a crack perpedicular to the beams followed by skew cracks. It is to be noted that the quoted cracks normal to the beam axis were hair cracks about 0,015 mm wide. These cracks remained hair cracks even when skew cracks became sharp with widths up to 0.12 mm. Subsequently, skew cracks begam to grow, and failure occurred along the skew section.

Once skew cracks have developed, further load repotitions cause them to propagate and widen. Experiments show the skew crack widths likely to exceed the limiting values under working conditions, depending on the relative shear span, the longitudinal and web reinforcement percentagess value, and other parameters. Actually, multiple load repetitions are reckoned with by a factor ks = 1.5 in Soviet standards [1] and COMECON recommendations [2] applying a factor of 1 for infrequent, instantaneous loads such as in our case. This approach to crack width calculatio is irrelevant to the phenomenon depending on several parameters [3].

Our observation showed the skew crack width to depend besider on the concrete strength and sort, longitudinal and transversal reinforcement, tyre and number of load applications alco on the way of repeated load applications, thet is not only on multiple dynamic loads, but also on static loads acting repeated but not exceedingly times.

Evaluation of results of tests on reinforced concrete beams made with normal aggregated at the Concrete and Reinforced Concrete Research Institute [4] led us to following conclusions.

a/ Skew crack widths are affected by the percentage of the longitudinal reinforcement an relative shear span values mostly in case of low percentage of the wed reinforcement.

b/ Concrete strength affects the crack width only slightly. This is why this factor is omitted from design formulae, partly for the sake of simlification.

In our some of the mentioned parameters have been varied. The small namber of beams tested for skew crack width did not permil us to determine the effect of the variables on the tested characteristics other than at low confidence. The following general trends were, however, quite definite:

a) Effect of shear span

Shear span obviously affects the skew cracks in aglite concrete even for stirrup percentages μ_w = 0,66 % and μ_w = 0.22 % (μ_w % = 100 2Aw/b *u, where Aw is he cross section area of one stirrup, bo the wed thickness and u the stirrup spacing.) For instance, beams BL-7 and BL-8 tested with different shear spans exhibited primary crack widths acr= 0.035 mm and acr = 0.1 mm, respectively, loads and all other circumstances being equal. Upon repeated loads, crack widths grew to 2.3 times ans 1.25 times the primar ones for shear spans a = 1.5 ho and a = 3.0 ho respectively.

b) Effect of stirrup spaceign

Repeated load test show the stirrup spaceing to affect skew crack width. In case of stirrup spacing u = 70 mm, skew crack width grew 2.7 times in general, after 250 loar repetitions, though with different repeated load maxima. For instance, skew crack widths of 0.085 mm and 0.01 mm in ordinary concrete beams BN-1 and BN-2 were produced by shear forces 80 kN and 60 kN respectively. Although the repeated load value was higher in the beam BN1 than in the beam BN-2, crack width grew by less at BN-1 because of the 70 mm stirrup spacing. This is due to the lower effect of external load on crack width growth than of the percentage of the wed reinforcement.

c) Effect of prestress

The grade of prestress affects the crack width in a way that a single loading of the same value and under otherwise identical conditions caused only a crack width 0.01 mm in the beam BN-2 (σ = 944 N/mm^2) while 0.12 mm in beam BL-10 (σ = 278.4 N/mm^2). Subsequent, repeated loadings increased the crack widths to the 2.65 fold on the average.

d) Effect of the longitudinal reinforcement percentage

Skew crack widths are also significantly affected by the longitudinal reinforcement percentage, rather than by the transversal one alone. This is appearent from results on beams BL-4 and BL-5 with nearly identical effective prestress values (888.9 and 900.0 N/mm^2) but different longitudinal prestressing wire percentages. A load of 80 kN caused in beam BL-4 with μ_W = 2.6 % a crack 0.055 mm wide, while in the other beam with μ_W =1.3 % a somewhat lowel load (70 kN) produced a skew crack 0.15 mm wide. Obviously, beams with lower longitudinal reinforcement percentaged are likely to exhibit wider crack than those with higher ones.

Our statements are supported by studies [5] on lightweight aggregate concretes under sustained /340-day/ load. These exhibited no constant for factor k_s and it was never less than but much higher ranging from 1.75 to 3.0.
Table 4 shows the encountered factors k.. in our cases to have ranged from 1.25 to 2.9.
The obtained k_s values - reckoning either with the duration or with the number of load applications - are close to those in the mentioned test series made with permanent load [6]. In these highfrequency , two-million-cycle load tests the k_s faktor changed in wide ranges, from 1.6 to 4.5, averaging 2.92. Keeping in mind that the reference beams differed both in stirrup spacing and concrete strength, beside being not prestressed, the following statements may be made.
Repeated instantaneous loads applied once in a minute affect the skew crack width to the same degree as both loads applied at 400 cycles per minute frequency, and as sustained loads. In connection with the load frequency and its effect on the stress-strain condition of beams, it has been stated 10 that under repeated loads, the absolute value of residual deformations increase with the decrease of the loading frequency.
The significance of the possibility of calculating the width of skew cracks - many times controlling the shear reinforcement design - imposes tests on great many specimens for supporting the observations. Unfortunately, the empirical formulae suggested in for the case of dynamic loads to improve the accuracy of the formulae in the COMECON recommendations [2] are not valid for repeated static loads.
Obviously, the significance of this problem is just as high for ordinaty concrete beams. It may be stated that test and calculated values are fairly consistent in the 0.2 to 0.40 mm crack width range admitted in the Soviet standard [5].

The indicated deviations are comprehensible: In the case of small crack widths the concrete plays an important role. E.g. for beam BN-2 with a test crack width of 0.01 mm although the value calculated according to the Soviet standard would be 0.146 mm. Increasing the shear to 91 % of the ultimate value resulted in a crack 0.6 mm wide, exceeding the calculated value of 0.43 mm, namely under this load, the stirrup stress is near the yield point.

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