EXPERIMENTAL STUDY AND NUMERICAL MODELING OF CRACKED REINFORCED CONCRETE BEAMS

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Summary: *This article presentsan experimental investigationofthe influence of pre-existing cracks on the behavior of reinforced concrete beams under vertical loads. The cracksin the concrete beams were created by preloading the beams in three-point bending and four-point bending tests. The cracked and non-cracked beams were thencompared. Non-linearmodeling of a cracked reinforced concrete beam was also performedin order to compare the predicted results with the test results.*

Key words: *Cracks, reinforced concrete, beam, behavior, three-pointbending, four-point bending.*

I. INTRODUCTION

Concrete cracking is an irreversible phenomenonthat occursdue to both structural and non-structural effects, once crackingdevelops in the concrete, the structure will not be able to recoverits initial state, and cracks will tend to propagate under loading condition. Normally, cracks in concrete affect the service life of reinforced concrete (RC) structures, especially in a corrosive environmentas concluded by a number of studies in literature. The influence of undesired cracks on the behavior of RC structures including RC beams is a question that should be clarified. Some authors such asPimanmas and Maekawa (2003), and Pimanmas (2007) analyzed the influence of pre-existing cracks in concrete on the behavior of RC beams.They demonstrated the effects of cracks due to axial and double flexural loading on the shear resistance of RC beam,however,such case studies arenot relevant to the behavior of RC beamsinvolving RC bridge girders andRC building girders.

This researchaims to clarify the influence of pre-existing cracks on the behavior of RC beams by conducting experimental and numerical modelling studies. RCbeams arepre-loaded in three-points bending (3PB) and four-points bending (4PB) tests to create pre-cracks without causing failure of beams.These beamsare then respectively loaded in 4PB and 3PB tests to study its behavior post cracking.Test results arecompared with those in the case of un-cracked beams which were considered reference beams.

II. EXPERIMENTAL STUDY

2.1. Preparation of specimens and testingarrangement

Concrete with thecharacteristic strength of 35MPa (C35) (using15 x 30cm specimens) was used in this study. The RC beams to be testedwithdimensions and reinforcement shown in Figure 1 (note that dimensions arein mm). Rebarswith diameter of 8 mm (named d8), 10 mm (named d10), and 4 mm (named d4) were used.The concrete cover is10 mm.

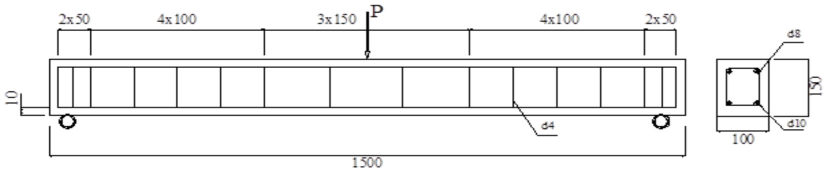

Figure 1. *Beam specimens with reinforcement arrangement*

Testing arrangement are shown in Figure 2.Load-cells recording the valuesof applied loads and mid-span deflection were connected witha datalogger and a computer.

Figure 2. *Testing arrangement*

2.2. Testing procedure

Sixteen beam specimens were cast in laboratory, and after 28 days of curing, they were divided in three sets.

Set 1 consisted of4beams (divided in two groups named D01 and D02).These beamswere tested to study the reference behavior of RC beams in a 4PB test (D01) and a 3PB test (D02). Relationshipbetween the applied load(P) and the mid-span deflection (V)and the failure load (Pmax) were recorded. The maximum loadsin 4PB and 3PB tests were called Pmaxand P’max, respectively.

Set 2 consisted of 6 beams (divided in three groups named D11, D12, and D13) that were preloaded in a 4PB tests with varying load magnitudeP (P = 0.6Pmax, 0.8Pmax, and 0.9Pmax).These beams were then reloaded in3PB test until failure (Figure 3).

Set 3 also consisted of 6 beams (divided in three groups named D21, D22, and D23) that were pre-loaded in a 3PB test with varying load magnitude P (P = 0.6P’max, 0.8P’max and 0.9P’max). These beams were then reloaded in a 4PB test until failure (Figure 4).

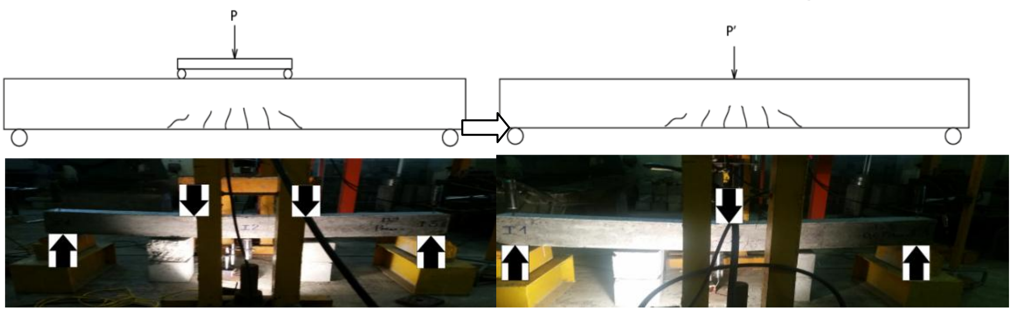

Figure 3. *3PB test of cracked beams after preloaded in 4PB test*

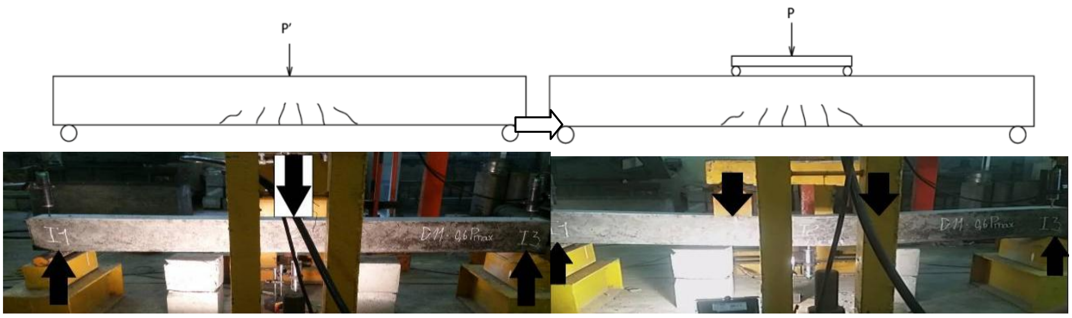

Figure 4. *4PB test of cracked beams after preloaded in 3PB test*

III. NUMERICAL MODELING

TheABAQUS softwarewas used to model the behavior of a cracked beamconsideringa non-linear material model.The 3PB and 4PB beams were modeled with their dimensions and material properties similar to the tested beams.The material properties of concrete (C35) and reinforcement weredetermined from the relevant laboratorytests and the reference [6].

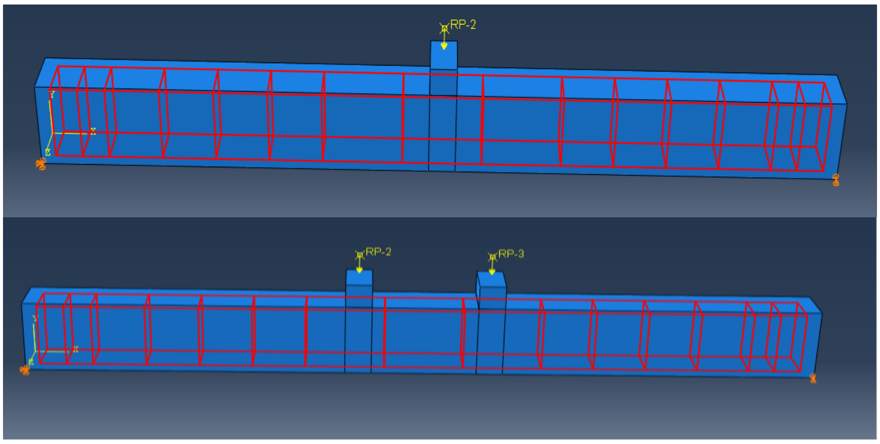

Figure 5. *Model of concrete beam in 3PB and 4PB test*

The mechanicalproperties of the concrete used (C35) were as follows: Young's modulus(E) of 3.09E10 N/m², Poisson'sratio(v)of 0.2, density of 2400 kg/m3,compressivestrength (f'c) of3.62E7 N/m², and tensile strength(f't) of 4.18E6 N/m². The continuum plasticity-based damage model was assigned for the concrete (this concrete model assumes that the main two failure mechanisms are tensile cracking and compressive crushing of the concrete material).

The reinforcement rebar hadYoung's modulusof 1.9E11 N/m², Poisson'sratioof0.3, yield stress (fy) of 2.1E8 N/m², and density of 7800 kg/m3. Elastic-perfectly plastic material model is assigned for the rebar.

Numerical RC beamswere loaded to 0.6Pmaxin a simulated 3PB test, thenunloaded.Loading history was recorded. The cracked beams were reloadedin a simulated 4PB test until failure.

IV. RESULTS AND DISCUSSION

The reference beams were loaded until failure to obtain the relationship between the applied load(P) and mid-span deflection (V).The maximum load Pmaxcausing the failure of beams were also recorded in the two test casesof 4PB (D01) and 3PB (beams D02). The results are shown in Figures6 and 7.

Figure 6 shows the depths and widths of the largest cracks in the 4PB tested- beams D11, D12 and D13 which are 40, 125, 150mm and 60, 860, 2850 µm,respectively. Those for the 3PB tested- beams are 58, 97, 96 mm and 80, 100, 140 µm,respectively.

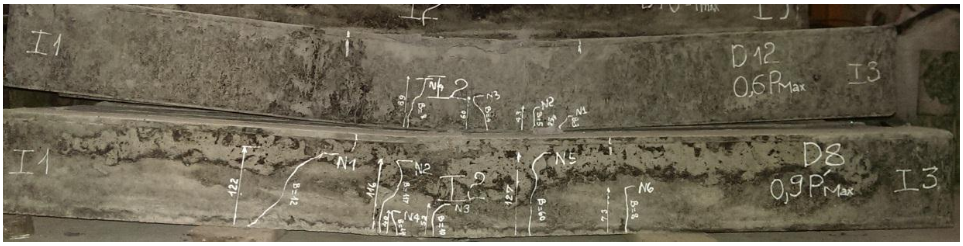

Figure 6. *Cracks in RC beam preloaded in 4PB test (P = 0.6Pmax and P = 0.9 Pmax)*

The resultsshow thatthe applied load versus mid-span deflection (P-V)curve of reference beamsis abovethose of preloadedRCbeamsfor bothof 3PB and 4PB cases (Figures 7 and 8).This means the pre-existing cracks created by preloading of RC beam at 0.6Pmax(0.6P'max), 0.8Pmax(0.8P'max), and 0.9Pmax (0.9P'max) influence the rigidity of cracked beams, which is very clearat the initialstage of loading,however after a threshold of applied load (at about 10-12kN) when cracks occurin the concrete, the P-V curve of reference beams tends to reach those of preloaded beams. The similar magnitudes of failure loadsreveal that the ultimate flexural strengths of cracked beams and uncracked beams are similar or the cracks do not have a significant effect on flexural strengths of RC beams.The 3PB testsof preloaded beams show the failure loads superior tothose of 4PB tests meaning the four-point loading is safer than that of the three-point for the RC beams.

Numerical results show the upper P-V curve of the both cases compared to those obtained experimentally. However, the effect of the cracks on the beam rigidity was not obtained like the experimental ones.This could be explained byusing thesimplified boundary conditions such as the perfect bond concrete-rebarsin the numerical modeling. In addition, a continuous approach like damaged-plasticity based model may not consider a discrete medium like cracked concrete.

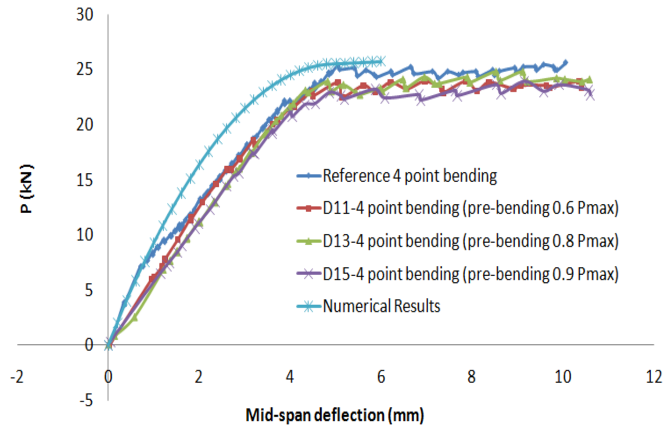

Figure 7. *Load versus mid-span deflection of tested beams in 3PB (4PB pre-loaded)*

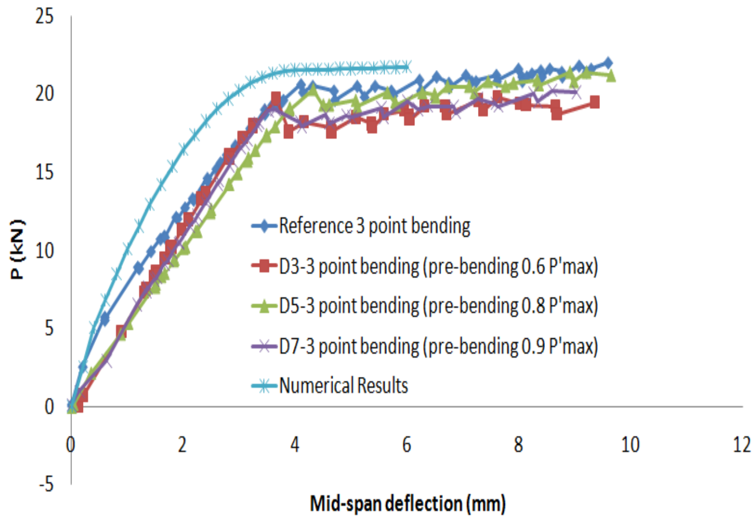

Figure 8. *Load versus mid-span deflection of tested beams in 4PB (3PB pre-loaded)*

V. CONCLUSION

The effect of pre-existing crackson the flexural rigidity of reinforced concrete beamswas experimentally demonstrated. The cracked reinforced concrete beamsand the non-cracked beams failed at a veryclose magnitude of failure loadbut the latter aremore rigid. The results confirm that cracks in reinforced concrete beams have no significant effects on the ultimate resistance ofreinforced concrete beams but on the deflection, especiallyat the initial loading stage.To match the experimental results, it is necessary to improve the concrete material model as well as use a relevant reinforcement-concrete bond law for numerical modeling with finite element method, especially for cracked structures.

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