




Research Article

Effects of pre-cracked reinforced concrete in compression zone on prefabricated RC beam behavior

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ABSTRACT

Cracks can occur in the compression zone of a beam cross section, in the middle part of the span due to different reasons. For instance, due to accidents happened during transportation of the prefabricated Reinforced Concrete (RC) beams on manufacturing site. In this study, effects of such cracks on the behavior of RC beams are investigated experimentally. Compression strength of concrete and intensity degree of pre-created cracks were adopted as test parameters. A total of eight RC beam specimens were tested under the effect of bending, applying three-point loading. According to the results it was observed that the pre-cracked RC beams had almost the same strength with the reference beams; but bending stiffness of the RC beams decreased when the intensity of the cracks increased relatively.

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1. Introduction

Due to accidents happened during transportation of the prefabricated Reinforced Concrete (RC) beams on manufacturing site, cracks can occur in the compression zone of a RC beam cross section, in the middle part of the span (Fig. 1). In the current structures, similar cracks can also occur in the RC beams because of earthquake effects. Compression zone has a significant impact on beam bearing capacity. Thus, it is thought to be an important question to investigate how these types of cracks affect the beam behavior. Since this topic in literature was not tackled directly, as to our knowledge, it is decided to conduct this research.

In this study, the effects of pre-created cracks, in compression zone of the section in the middle part of the span, on the behavior of RC beams were investigated experimentally. The parameters of the experiment were essentially the intensity degree of the pre-created cracks and the compression strength of concrete. To conduct the experiment in the lab, a total of eight RC beams were prepared with a 1/3 scale of applicable dimensions in real structures. The Specimens were tested under the effect of bending applying three-point loading.

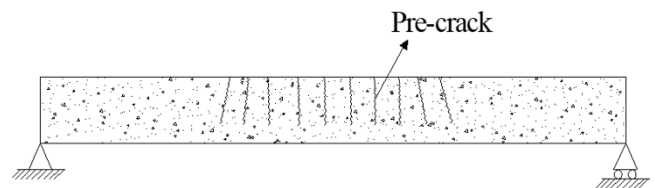


Fig. 1. Pre-cracked reinforced concrete beam.

In previous studies, usually the cracks were pre-created in the tension zone of the beam section in the span middle part, or in the shear segment of the beam close to the supports. In these research, it is noticed that Arnaud Castel, a researcher in University of New South Wales (Australia), stands out with significant experimental and theoretical studies. In his studies, deflection of the pre-cracked beams and their static (Castel et al. 2012, 2013, 2014; Castel and François 2013; Xu et al. 2018a, 2018b) and dynamic (Xu and Castel 2016; Xu et al. 2018c) stiffness were examined, and the accuracy of the proposed models and methods were investigated. Along with these studies, there are some other theoretical and experimental studies conducted by other researchers about

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effective shear stiffness (Pan et al. 2014), long-term deflections (Rahman et al. 1998), various creep analysis (Zhang and Hamed 2020) and long-term flexural behavior (Sryh and Forth 2022) of pre-cracked beams. Reviewing the literature, it is concluded that the pre-cracked beams in compression zones were not investigated thoroughly despite the importance of compression zone for the beams' strength and behavior.

2. Experimental Study

2.1. Test specimens and materials

A total of eight 1/3 scale RC beams were tested under the effect of bending, applying three-point loading. Each

specimen had a length of 1000 mm and rectangular cross section of 100 mm width and 150 mm height. All beams had the same reinforcement configuration shown in Fig. 2. Specimens were reinforced with two longitudinal ribbed bars of 8 mm diameter at the top, three longitudinal ribbed bars of 8 mm diameter at the bottom of the cross section. The longitudinal ribbed bars were of grade S420. Beams were also reinforced with stirrups of 4 mm diameter spaced at 60 mm. Stirrups were of plain bars.

100x100x100 mm size cubic concrete specimens were tested to obtain the compressive strength of the concrete. One group of 4 beams had a concrete compressive strength of 45 MPa (36 MPa for standard cylindrical sample) and the other group had a concrete compressive strength of 55 MPa (44 MPa for standard cylindrical sample).

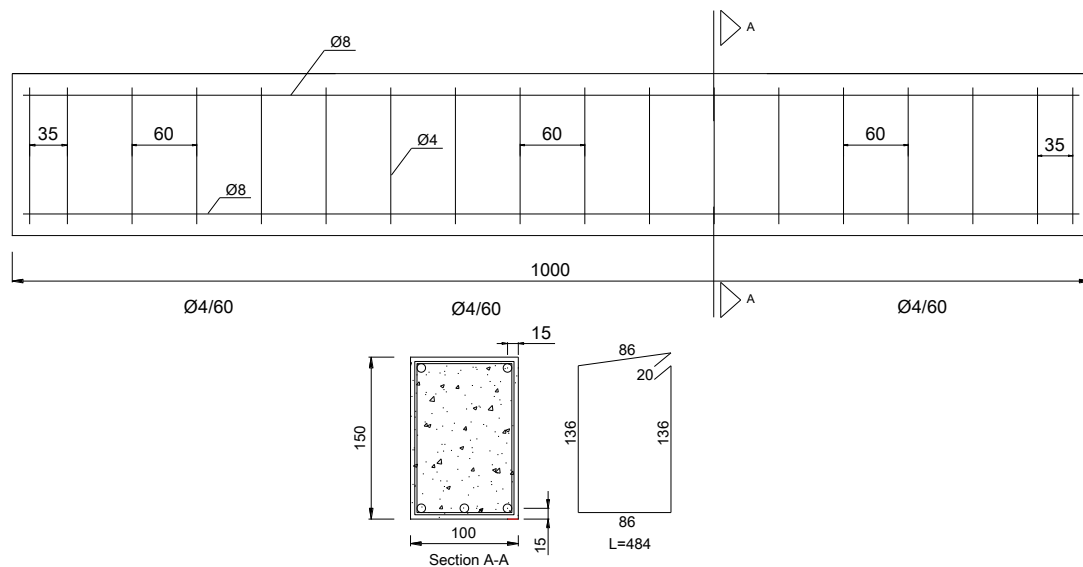


Fig. 2. Reinforcement dimension and configuration of the tested RC beams.

Before the testing, cracks with different intensity were created, in the compression zones of the sections in the middle part of the span, by loading the beams placed upside-down on the bending test setup. No cracks were created on the reference beams. Degree of the pre-created cracks' intensity of the least damaged specimen was identified by number 1 and of the most damaged specimen was identified by number 6. As the identification number increases the crack intensity and damage level increases. For the non-pre-cracked beams (reference beams) the number 0 is used. The number of cracks, crack width and depth were considered to determine the pre-created cracks' intensity degree.

Test specimens were named as RB45-0, B45-1, B45-2, B45-3, RB55-0, B55-4, B55-5 and B55-6. The specimens RB45-0 and RB55-0 were reference beams. The first two digit refers to the compressive strength of the concrete. Final digit refers to the degree of the intensity of the pre-created cracks. For example: the specimen named as B45-2 has a concrete compressive strength of 45 MPa and degree of pre-created crack intensity 2. Pre-created crack damages of each RC beam were shown in Fig. 3. Table 1 shows the compressive strength and degree of pre-created crack intensity of each specimen.

Table 1. Properties of the tested RC beams.

Name of the specimen	Compressive strength of concrete (MPa)	Degree of intensity of pre-crack
RB45-0	45	0
B45-1	45	1
B45-2	45	2
B45-3	45	3
RB55-0	55	0
B55-4	55	4
B55-5	55	5
B55-6	55	6

2.2. Test setup and instrumentations

RC beams were tested by the bending test setup, applying three-point loading (Fig. 4). RC beam specimens were placed on the test setup with simple support. A concentrated load was applied on the span midpoint of the beams by a load cell having a capacity of 20 kN. An elec-

tronic displacement measure device was used to measure the deflection at the span midpoint. Obtained load

and deflection data were transferred to the computer by a data logger.

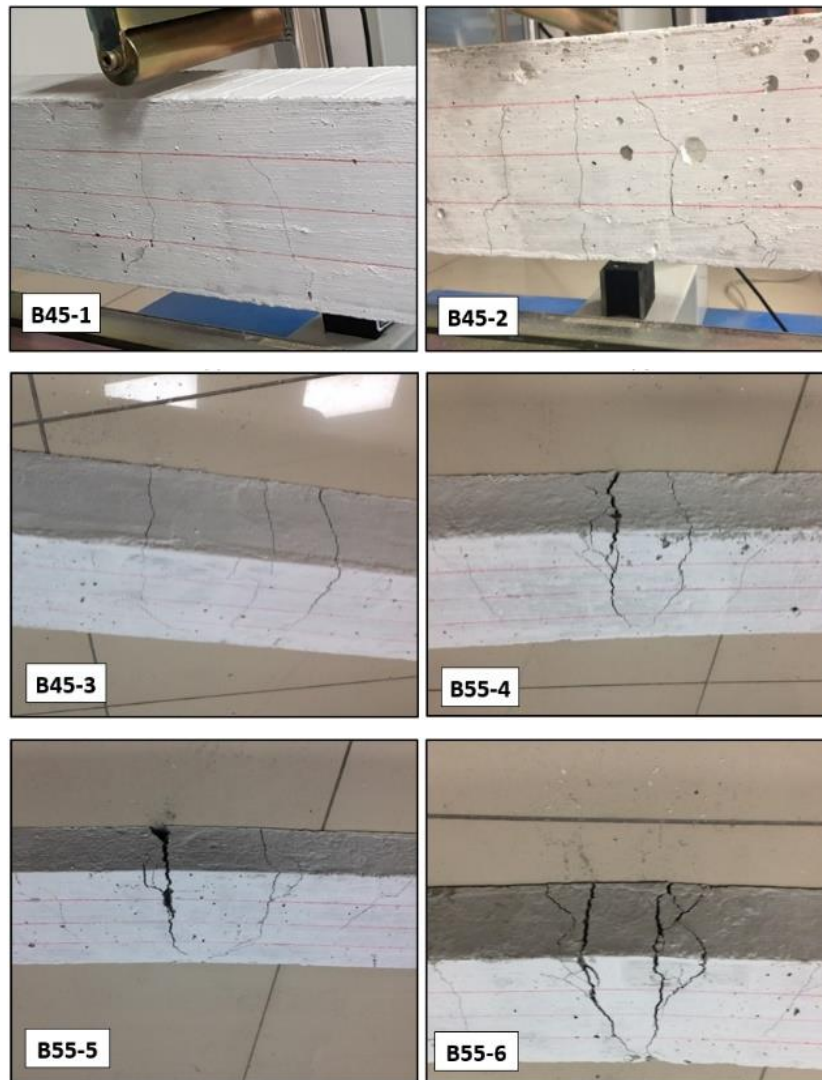


Fig. 3. Pre-created crack intensity of the specimens.

3. Experimental Results

Specimens RB55-0, B55-4, B55-5 and B55-6 collapsed in bending failure mode. Collapse of the specimens RB45-0, B45-1, B45-2 and B45-3 was predominant in bending failure mode, however large shear cracks also occurred in the beams. Fig. 5 is shown failure modes of specimens.

Obtained load-deflection curves of two group of specimens having concrete compressive strength of 45 MPa (RB45-0, B45-1, B45-2 and B45-3) and 55 MPa (RB55-0, B55-4, B55-5 and B55-6) were illustrated in Figs. 6 and 7, respectively.

Values of yielding load, ultimate load, yielding deflection and bending stiffness of the beam specimens were given in Table 2. Value of bending stiffness of the beams was obtained via dividing the yielding load by yielding deflection.

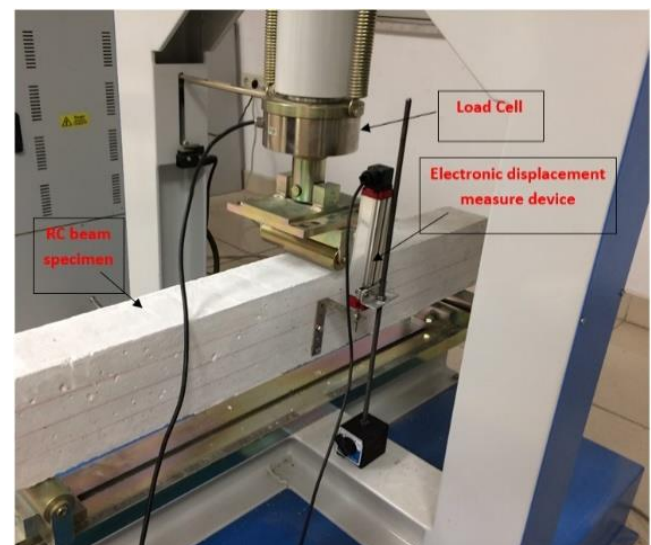


Fig. 4. Test setup.

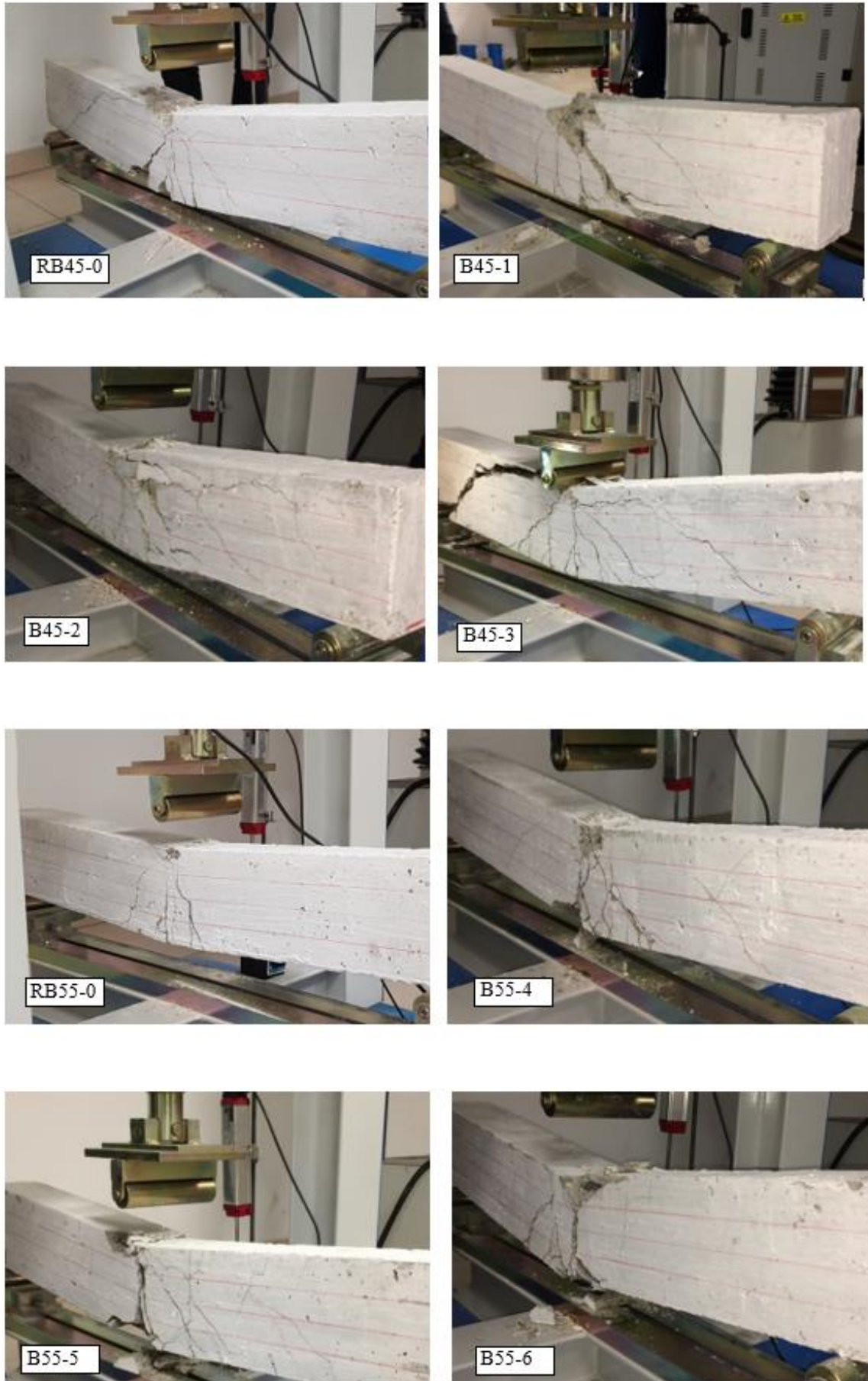


Fig. 5. Failure modes of specimens.

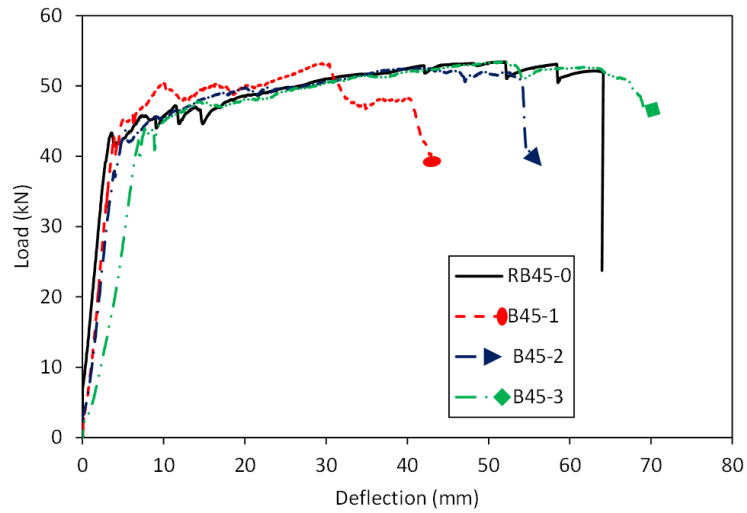


Fig. 6. Load-deflection curves of the specimens RB45-0, B45-1, B45-2 and B45-3.

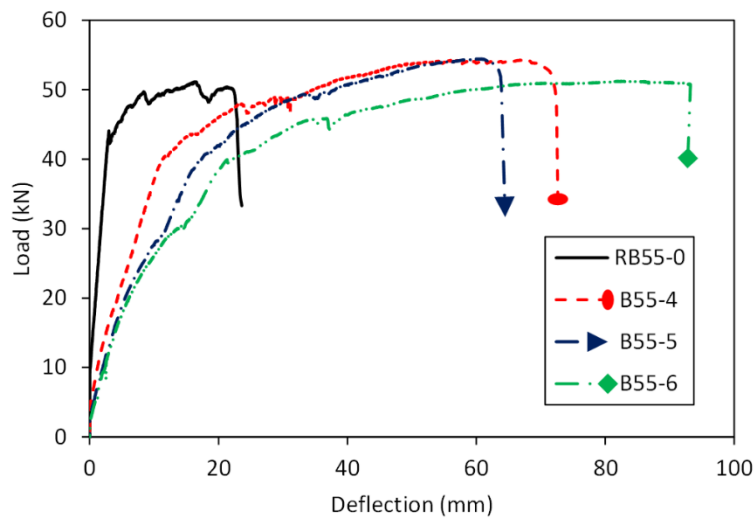


Fig. 7. Load-deflection curves of the specimens RB55-0, B55-4, B55-5 and B55-6.

Table 2. Experimental results of the specimens.

Specimen	Yielding load, P_y (kN)	Ultimate load, P_{max} (kN)	Yielding deflection, δ_y (mm)	Bending stiffness (kN/mm)
RB45-0	43.4	53.45	3.60	12.06
B45-1	42.8	53.20	3.89	11.00
B45-2	43.8	52.55	5.27	8.31
B45-3	42.2	53.43	6.91	6.11
RB55-0	44.1	51.17	2.97	14.85
B55-4	41.0	54.41	12.45	3.29
B55-5	40.9	54.47	18.28	2.24
B55-6	39.9	51.26	21.96	1.82

Table 3 shows the relative comparison of the beam specimens in terms of yielding load, ultimate load, yielding deflection and bending stiffness. Despite the pre-existing cracks in the beams B45-1, B45-2 and B45-3, the ultimate load and yield load values of these beams were almost the same as the values of the reference beam RB45-0. The difference compared to the reference beam

was no more than 2% for ultimate load and 3% for yielding load. However, bending stiffness values decreased as the intensity of the pre-created cracks in beams increased. Difference of bending stiffness values with respect to reference beam was around 9%, 31% and 50% for the specimens B45-1, B45-2, and B45-3, respectively.

Table 3. Relative comparison of the experimental results of the specimens with respect to the reference beams.

Specimen	Reference beam	Ratio of the yielding load	Ratio of the ultimate load	Ratio of the yielding deflection	Ratio of the relative bending stiffness
B45-1	RB45-0	0.99	0.99	1.08	0.91
B45-2	RB45-0	1.01	0.98	1.46	0.69
B45-3	RB45-0	0.97	1.00	1.92	0.51
B55-4	RB55-0	0.93	1.06	4.19	0.22
B55-5	RB55-0	0.93	1.06	6.15	0.15
B55-6	RB55-0	0.90	1.00	7.39	0.12

During the study, since there was no considerable difference in terms of ultimate load and yielding load values when the specimens B45-1, B45-2, and B45-3 compared with the reference beam RB45-0, it was decided to increase the intensity of pre-created cracks on specimens B55-4, B55-5, and B55-6. Accordingly, 4th, 5th and 6th degrees of damage intensity were caused on the specimens B55-4, B55-5, and B55-6, respectively. Although there was larger pre-created damage in B55-4, B55-5, and B55-6 than B45-1, B45-2 and B45-3, the yielding load and ultimate load values obtained for the specimens B55-4, B55-5 and B55-6 weren't very different from those obtained for the reference beam RB55-0. There were mostly 9.5% and 6.4% difference in terms of yielding and ultimate load values, respectively.

Bending stiffness values of the specimens B55-4, B55-5 and B55-6 decreased as the pre-created cracks damage in beams increased. Difference of bending stiffness values with respect to reference beam RB55-0 was obtained around 78%, 85% and 88% for beams B55-4, B55-5, and B55-6, respectively. When the crack damages were created in those three beams, permanent vertical deflection occurred in the mid-span of the beams. Permanent vertical deflection of 9, 12 and 15 mm occurred in the beams B55-4, B55-5, and B55-6, respectively. It is thought that one of the reasons of the decrease in the bending stiffness is these permanent vertical deflections.

According to these results it is concluded that pre-created cracks with the studied intensity have an important effect especially in terms of bending stiffness of the beams. Therefore, in such cases, pre-created cracks damage should be considered when the deflection of RC beams is analyzed.

4. Conclusions

In this study, the effects of pre-created cracks, in compression zone of the section in the middle part of the span, on the behavior of RC beams were investigated experimentally. Compression strength of concrete and the intensity degree of pre-created cracks were adopted as test parameters. A total of 8 RC beams were tested under the effect of bending by three-point loading.

Conclusions obtained from the study summarized below.

- Specimens having a concrete compressive strength of 45 MPa, collapsed predominantly in bending failure mode, however, large shear cracks also occurred in the beams.

- Specimens having a concrete compressive strength of 55 MPa, collapsed in bending failure mode.
- Pre-cracked beams having a concrete compressive strength of 45 MPa, had closer values to the reference beam in terms of yielding load and ultimate load. The difference in terms of yielding load and ultimate load was at most 3% and 2%, respectively.
- Bending stiffness value of the pre-cracked beams having a concrete compressive strength of 45 MPa decreased as the intensity of pre-created cracks damage increased. Bending stiffness value of beams having intensity degree of 1, 2 and 3, was 9%, 31% and 50% less than the value of reference beam, respectively.
- Pre-cracked beams having a concrete compressive strength of 55 MPa, had closer values with the reference beam in terms of yielding load and ultimate load. The difference in terms of yielding load and ultimate load was at most 9.5% and 6.4%, respectively.
- Bending stiffness value of the pre-cracked beams having a concrete compressive strength of 55 MPa decreased as the intensity of pre-created cracks damage increased. Bending stiffness value of beams having intensity degree of 4, 5 and 6, was 78%, 85% and 88% less than the value of reference beam, respectively.
- Pre-created cracks with the studied intensity didn't have significant effect on RC beams in terms of yielding and ultimate load. However, there can be important decrease of the bending stiffness of the beams due to this kind of pre-created cracks damage.

Therefore, in such cases, it is concluded that pre-created cracks damage should be considered when the deflection of RC beams is analyzed.

For future studies, this kind of investigation can also be implemented for RC slabs. Specimens with a scale 1/3 to 1/5 are planned to be tested similarly in a future phase of this study using the same experimental method.

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Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

REFERENCES

- Castel A, François R (2013). Calculation of the overall stiffness and irreversible deflection of cracked reinforced concrete beams. *Advances in Structural Engineering*, 16(12), 2035-2042.
- Castel A, Vidal T, François R (2012). Finite-element modeling to calculate the overall stiffness of cracked reinforced concrete beams. *Journal of Structural Engineering*, 138(7), 889-898.
- Castel A, Gilbert RI, Ranzi G (2013). Overall stiffness reduction of cracked reinforced concrete beams due to long term effects. *In Mechanics and Physics of Creep, Shrinkage, and Durability of Concrete: A Tribute to Zdeňk P. Bažant*, 443-450.
- Castel A, Gilbert RI, Ranzi G (2014). Instantaneous stiffness of cracked reinforced concrete including steel-concrete interface damage and long-term effects. *Journal of Structural Engineering*, 140(6), 04014021.
- Pan Z, Li B, Lu Z (2014). Effective shear stiffness of diagonally cracked reinforced concrete beams. *Engineering Structures*, 59, 95-103.
- Rahman MA, Ayano T, Sakata K (1998). The use of physical phenomena to predict time effects in cracked reinforced concrete beams. *Magazine of Concrete Research*, 50(3), 219-227.
- Sryh L, Forth J (2022). Long-term flexural behaviour of cracked reinforced concrete beams with recycled aggregate. *International Journal of Concrete Structures and Materials*, 16(1), 19.
- Xu T, Castel A (2016). Modeling the dynamic stiffness of cracked reinforced concrete beams under low-amplitude vibration loads. *Journal of Sound and Vibration*, 368, 135-147.
- Xu T, Castel A, Gilbert RI (2018a). On the reliability of serviceability calculations for flexural cracked reinforced concrete beams. *Structures*, 13, 201-212.
- Xu T, Huang J, Castel A, Zhao R, Yang C (2018b). Influence of steel-concrete bond damage on the dynamic stiffness of cracked reinforced concrete beams. *Advances in Structural Engineering*, 21(13), 1977-1989.
- Xu T, Zhu L, Castel A, Gilbert RI (2018c). Assessing immediate and time-dependent instantaneous stiffness of cracked reinforced concrete beams using residual cracks. *Journal of Structural Engineering*, 144(4), 04018022.
- Zhang S, Hamed E (2020). Application of various creep analysis methods for estimating the time-dependent behavior of cracked concrete beams. *Structures*, 25, 127-137.