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EXPERIMENTAL STUDY TO DEVELOP A REINFORCED CONCRETE HIGHWAY GIRDER BRIDGE WITH CONCAVELY CURVED SOFFIT

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Abstract- Reinforced concrete beams often have a fixed rectangular section all over the length, but in certain cases, the lower face of the concrete beam is concavely curved where the depth of the section is varying from supports to the middle of span. In this research, the experimental study dealt with a reinforced concrete beam with a concavely curved soffit and tested it in the laboratory to study the effect of the presence of the curve at the beams bottom face on the performance of the structure by finding the loading capacity and comparing it with the reference beam with a fixed rectangular section. Accordingly, four 2.2 m long concrete beams with different degree of curvature are tested under four-point static loading until failure. The experimental results showed that as the curvature degree increased from 7.5 to 22.5 the load carrying capacity reduced by 14.72-45.66%.

Keywords: Curved Soffit Girder, Reinforced Concrete Beam, Deflection Behavior, Crack Behavior.

1. INTRODUCTION

The term of curved soffit girder means that the depth of the beam is decreasing from the supported to middle span. curved soffit may be concave or straight according to the structural and architectural requirements. The most common structures that use this type are the bridges in various sizes and some modern building. Such as, Ponte Vecchio in Italia, Liben bridge in Czech, and Memorial Bridge, in Binghamton. Locally, this type of beam girders has long been used in highway structures especially in bridges over culverts and water courses. Although these bridges are commonly used in road networks all over the world, there are very little previous studies to investigate the behavior of these beams and their efficiency with the presence of curved soffit in multiple shapes. While previous studies indicated that there are few practical experiences on strengthening this type using FRP, very limited previous studies were monitored.

Aiello, et al. [1] studded the connection efficiency between concavely curved soffit concrete beam and FRP sheets. The testing program included eight beams, two of them without curvature, three with 50 cm radius soffit curvature and three have a 100 cm radius soffit. The results clarified that the ultimate strain of curved soffit is reduced compared with flat beam and showed that as the curvature increases the shear stress decreases. Porter, et al. [2]; Eshwar, et al. [3-5]; Al Ghrery, et al. [6-10], Alshimmeri [11] studied steel Asymmetrical Castellated curved beam, Lai, et al. [12] studied Prestressed Box Beams Curved Soffits, Vujovic, et al [13] studied the New Mandurah Traffic Bridge which was created with a distinctive curving soffit cross section that is consistent over the entire length of the bridge, creating a landmark building that is both affordable and attractive. A lot of papers have been studding the behavior of curved beam. [14] to [21].

Therefore, it is considered very necessary to study this type of beam to know its behavior with the curved soffit. The design guidelines and standards set limitations on the nature of the curved surface in the presence of FRP only [22] to [27], which is 5 mm/m to 3 mm/m. The results of previous studies that investigated the effectiveness of bottom curved concrete beams and strengthening with polymeric carbon fibers in which the curve ranging between 3 mm/m and 15 mm/m revealed that, in the concrete beams with a concaved soffit of 5 mm/m, the maximum load resistance is reduced about 5.3% and the beams with a degree of concaved soffit of 15 mm/m reduce the amount of maximum capacity of load about 14.15%, as contrasted to concrete beams without any curve soffit.

Previous studies about the performance of beams with concave soffits are quite limited and there is a vital need for more comprehensive studies to acquire a better understanding to the behavior of this type of beams. The principle aim of this article is to investigate the behavior of beams with curved soffit and the extent of the effect of the presence of this curvature as compared by beams with flat soffit.

2. THE CURVATURE DESIGN

All the curved soffits tested beams designed by assuming the surface of the curve to be cut out of a circle whose radius is the radius of the curve R. The maximum uneven between the depth of the beam in the middle and its depth at both ends represents the (rise). The horizontal distance between the bases of the curve is called cord, which depends on the radius of the circle, as detailed in Figure 1 [3].

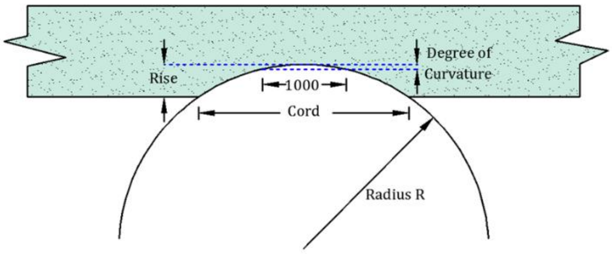

Figure 1. Details of curvature design

3. EXISTING MECHANISM

Four beams were tested to study the effect of curvature soffit in tension zone of simply supported reinforced concrete beam. The first beam CB which is an ordinary reinforced concrete beam with dimensions 2500×200×300 mm. This beam is used as a control specimen and with flat soffit. The remaining three beams are also 2500 mm in overall length with cross section of 200×300 mm near to the supports and a cross section varied between 200×270 mm at midspan for CBC1 and 200×240 mm at midspan for CBC2 and 200×210 mm at midspan for CBC3. the curvature degrees of tested specimens are 7.5 mm/m, 15 mm/m to 22.5 mm/m for CBC1, CBC2, and CBC3 respectively. Figure 2 depicts the geometry and the details of these specimens. Experimental program details are presented in a Table 1.

Table 1. Experimental program details

Specimen	f_c' MPa at 7 day	Cord (mm)	Rise (mm)	Curvature degree mm/m	Notes
CB	38.5	0	0	0	Reference
CBC1	38.5	2000	30	7.5	
CBC2	38.5	2000	60	15	
CBC3	38.5	2000	90	22.5	

3.1. Wood Molds Manufacturing

To ensure the precision of the dimensions of the concrete beam samples, the wooden framework for the molds were manufactured by the use of smooth faced plywood sheets 25 mm thick. These sheets are available in the dimensions of 2440×1220 mm. accordingly, a special care should be paid in the process of designing and manufacturing the wooden formwork of the molds that have the length of 2500 mm, a height of 300 mm and a width of 200 mm, with different curvatures with respect to each sample representing the beams CB, CBC1, CBC2, CBC3. The curved wooden pieces were connected with screws to ensure firm attachment without leakage during the casting process. The parts were connected well, cleaned and lubricated before the casting process. Figure 3 shows the wooden formwork used.

3.2. Mixing

The objective of the mixing process is to obtain a homogeneous concrete mixture with good workability. Where a specific procedure was followed for mixing the ingredient components proportions by weight. Where the concrete was mixed using an electrostatic mixture, it was cleaned and the inner surface moistened before placing the required materials. The fine and coarse aggregates were placed in the mixer for a few minutes after adding the cement. The components are mixed to obtain a uniform color. Then half the amount of water is added and the mixture is stirred to obtain a homogeneous mixture. Then finally, the remaining amount of water is added and mixed for about three minutes, and the mixture becomes ready for pouring. Figure 4 showing the mixing machine used in the test.

3.3. Casting and Curing Process

After the mixing process is finished, the mixture is poured into the wooden molds in the form of two layers, as in Figure 5, When the concrete mixture is placed in the molds, the mixture is hammered and shaken by a rubber leg so that the mixture is consolidated inside the mold. Then the concrete is compacted using a concrete vibrator for each layer for a period of 40 seconds, where the vibrator is set to the state of compaction in the normal case Figure 6 In order to let out unwanted air inside the mixture. Then the surface is leveled and the samples are covered with pieces of cloth to prevent water evaporation. After 24 hours, the concrete beam samples are extracted from the wooden molds by careful disassembling and treated in a water bath specially manufactured to occupy these concrete beam specimens, at a temperature of 25 °C for one month. Finally, the concrete samples are taken out of the water bath and are ready for testing Figure 7.

3.4. Details of Reinforcement

All specimens reinforced by steel rebars with deformed surface. The bottom reinforcement included three ϕ16 mm while two ϕ10 mm are placed at the top. The stirrups are made of ϕ10 mm for all specimens. The reinforcement steel has a 200 Gpa elasticity modulus and a 400 MPa yield stress. Details of Reinforcement are shown in Figures 8-11 for the concrete beam specimens referenced as CB, CBC1, CBC2, and CBC3 respectively.

3.5. Materials

The materials used in casting the concrete beam samples in this study included the ordinary Portland cement and graded gravel size 19 mm and sand size 4.75 mm, all from local sources. To obtain the targeted compressive strength of concrete, several mixes were prepared with varying water cement ratios, from each one of these mixes, three cubic samples were taken, each of which is 10×10×10 cm. These cubes are kept in the same processing conditions and are practically tested at the same time for the purpose of obtaining their compressive strength. The proportions of concrete mixing shown in Table 2. Returned an average compressive strength of 36.7 MPa after laboratory testing, which were the closest one to the targeted compressive strength of 36 MPa. The reinforcement steel bars, on the other hand, are as in Table 3 which shows the mechanical characteristics of the reinforcement utilized in concrete samples.

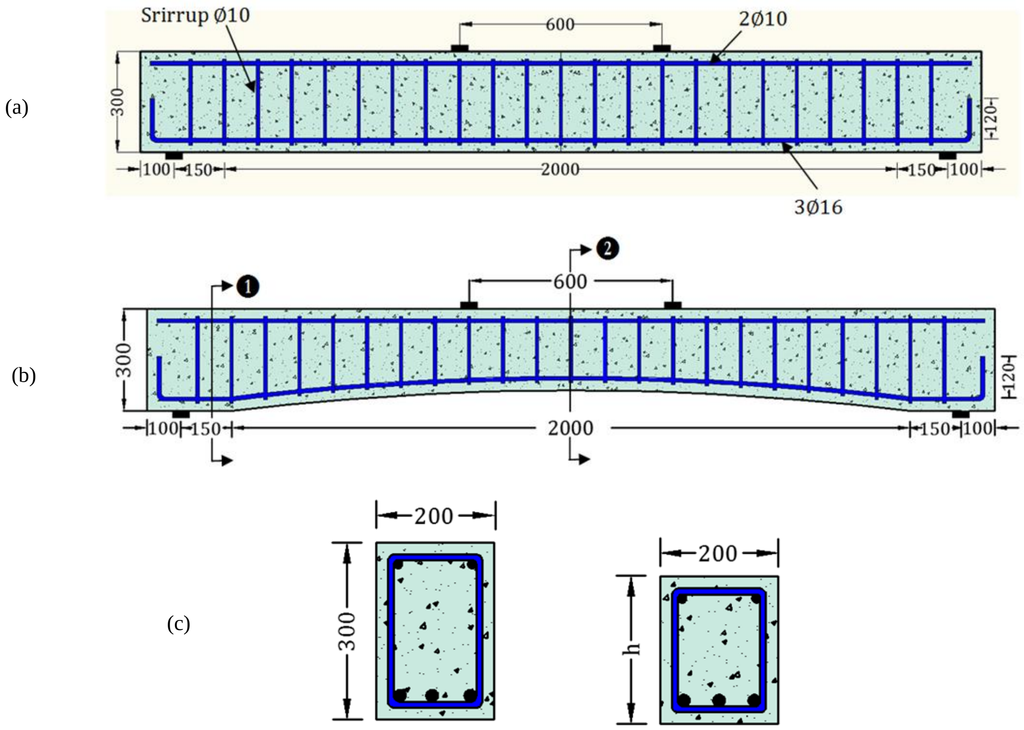

Figure 2. Plane and concaved soffit specimens, (a) plane soffit, (b) concaved soffit, (c) Cross-sections

Figure 3. Details of wood molds

Figure 5. Casting the first layer of mixture

Figure 4. Mixing operation

Figure 6. Vibrating the mixture

Figure 7. Specimen after 28 days

Figure 8. Details of reinforcement for CB specimen

Figure 9. Details of reinforcement for CBC1

Figure 10. Details of reinforcement for CBC2

Figure 11. Details of reinforcement for CBC3

Table 2. Proportions of the concrete mixture

Mix designation	Cement (kg/m^3)	Aggregate (kg/m^3)		Water (kg/m^3)	w/c for Slump 120±10 mm
		Sand	Gravel		
C40	445	750	800	222	0.50

Table 3. Properties of reinforcement

Reinf. Diameter mm	Yielding strength (f_y) MPa	tensile strength MPa
16	400	605

4. SETUP PROCEDURE

The schematic drawing of the test beam and the locations of dial and strain gauges are illustrated in Figure 12. The examination was carried out in the laboratories of the Civil Engineering Department in the college of engineering in the University of Diyala, Baqubah, Iraq. Samples were subjected to tests as simply supported members on which four loading points are operated. A hydraulic jack of an ultimate pressure of 2000 kN was used to apply the load and it was measured using a load cell with a 600 kN maximum capacity as shown in Figures 13-16. Vertical deflections were measured at a single point which is the midspan point, to obtain the central vertical deflections using three-disc gauge having an accuracy of 0.01 mm attached at the upper face of the beam sample when subjected to the loading. while the dial gauge is located at the midpoint of the lower surface of the beam.

The concentrated load was increased gradually with increments of 2.5 kN each time to record the deflection until failure. An optical micrometric device with accuracy of 0.02 mm was used to measure the width of the cracks, Figure 13. White paint was used to coat all surfaces of the beams to make it easier to see the cracks and measure their widths.

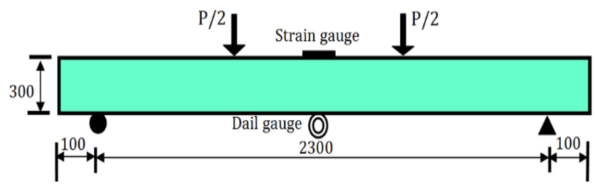

Figure 12. Schematic view of setup and instrument

Figure 13. Test setup of CB

Figure 14. Test setup of CBC1

Figure 15. Test setup of CBC2

Figure 16. Test setup of CBC3

5. THE RESULTS AND DISCUSSION

5.1. Load-Mid Span Deflection Behavior

The bending behavior of all the beams under the influence of two points was studied to observe the effect of the bending. Up until the beam's breakdown, the applied loading magnitude was gradually raised. The ultimate load carrying capacity of each beam was noted and the deflection of the beams was calculated. The ductile behavior of the tested beams was expected before conducting the examination, because the completion of the models was calculated on a under reinforced basis. The examination should be stopped considering that the models reached the maximum load carrying capacity and after a clear yielding to the reinforcing bars, as well as cracking and breaking of the concrete, which became possible to see through the visual examination.

Through the Figures of load-deflection, two stages can be observed through which the curve passes, where the first stage is represented by the initial crack appearance in the lower area of the beam, while the next stage is characterized by the occurrence of inelastic behavior of reinforcement, where it can be observed that the damage to the hardness is greater compared to the performance of the hardness in the stage Post crushing of concrete. The calculated values are illustrated in Table 4. The load mid span deflection for all specimens is shown in Figures 17-20. When the load is gradually applied to the reinforced concrete beam, the amount of deflection grows linearly and resiliently with the applied load. After cracks begin to appear, the beam deflection increases rapidly.

After the stage of crack development in the concrete beam, the path of the load and the curve of deflection becomes almost linear until the yield of the reinforcing steel bars. After that, the deflection keeps rising without any noticeable change in the applied load.

Table 4. Maximum load capacity of samples

Specimen	Angle of soffit	Ultimate load, P_u (kN)	% $\frac{P_u}{P_{u,Reference}}$	% Decreasing in P_u
CB	0	265	Reference	Reference
CBC1	7.5°	226	85.28	14.72
CBC2	15°	180	67.92	32.08
CBC3	22.5°	144	54.34	45.66

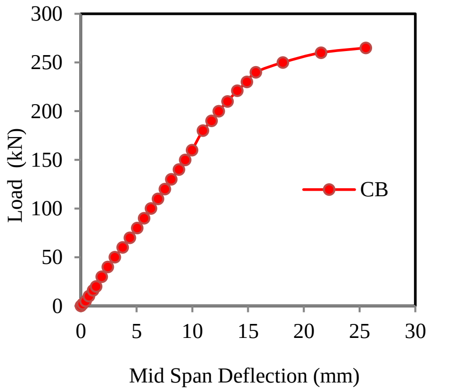

Figure 17. Load - deflection plot for CB specimen

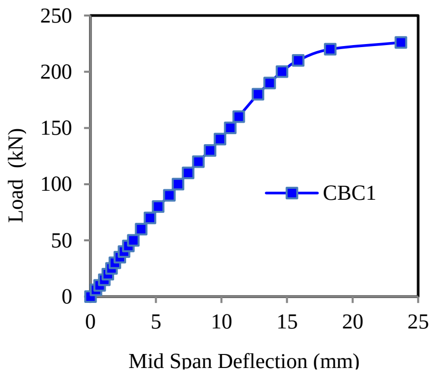

Figure 18. Load-deflection plot for CBC1 specimen

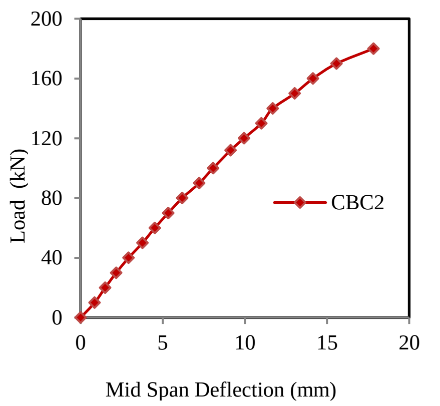

Figure 19. Load-deflection curves for CBC2 Beam

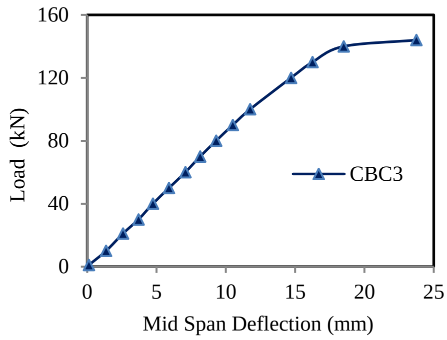

Figure 20. Load-deflection plot for CBC3 specimen

Table 4 and Figures 18-20, for specimens CBC1, CBC2 and CBC3, respectively, show clearly that, as the angle of soffit increases, the ultimate load decreases. CBC1 with an angle of 7.5° decreased by 14% in ultimate load compared by the CB specimen, CBC2 with an angle of 15° decreased by 32% in ultimate load compared by CB while CBC3 with an angle of 22.5° decreased by 45% in ultimate load compared by the CB beam. This is due to the process of cutting a part of the concrete and steel reinforcement in the tension zone of specimen.

5.2. Compressive Strain in Concrete

The strain gauge is attached to the center of the concrete beam on the midline of the upper face to measure the strain arises due to the application of the load. The results are shown in Figures 21-24 which reveal that at the stage of elastic behavior the compressive stress in concrete is relatively small but it rapidly increases after the appearance of the first crack with the presence of a continuous load application.

The increment of the concave degree at the bottom of concrete beams from 7.5° to 15° and 22.5° in specimens (CBC1, CBC2 and CBC3) respectively, lead to gradual decrease in the compressive strain of the concrete as compared to the reference specimen CB Because the volume of concrete decreases in the tension area because of the curvature as could be observed in Figure 25. The compressive strains occurred in concrete specimens are listed in Table 5.

Table 5. Compressive strains in concrete specimens

Specimen	Angle of soffit	Ultimate strain ε_u (mm/mm)	% $\frac{\varepsilon_u}{\varepsilon_{u,Reference}}$	% Decrease in ε_u
CB	0	0.002723	Reference	Reference
CBC1	7.5°	0.00245	89.97	10.03
CBC2	15°	0.001995	73.26	26.74
CBC3	22.5°	0.001552	56.99	43.01

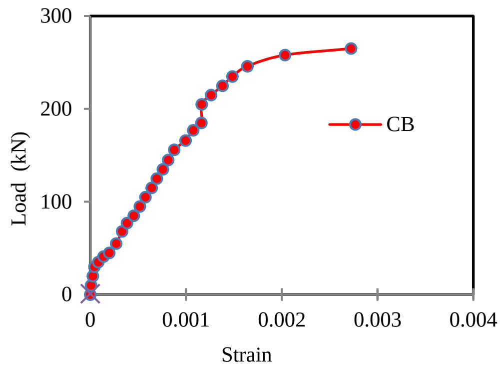

Figure 21. Load-strain curve of CB specimen

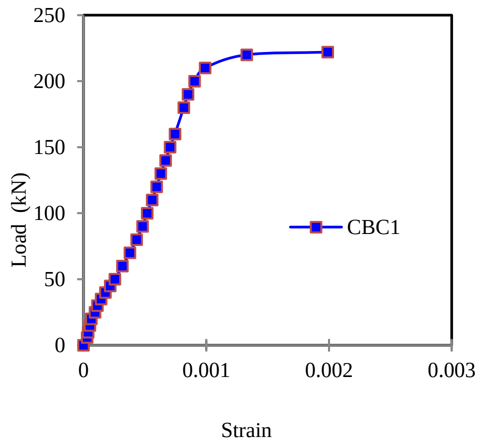

Figure 22. Load-strain curve of CBC1 specimen

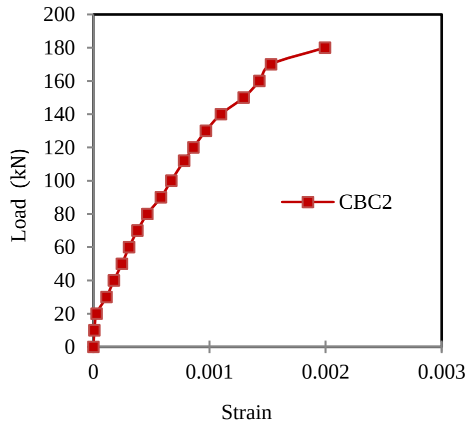

Figure 23. Load-strain curve of CBC2 specimen

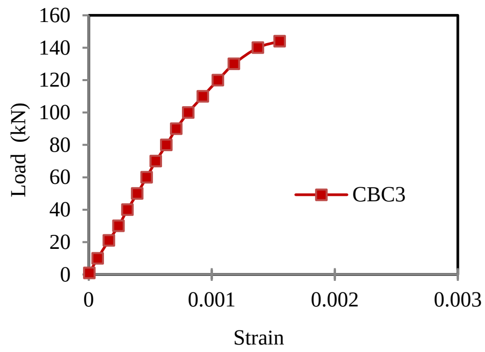

Figure 24. Load-strain curve of CBC3 specimen

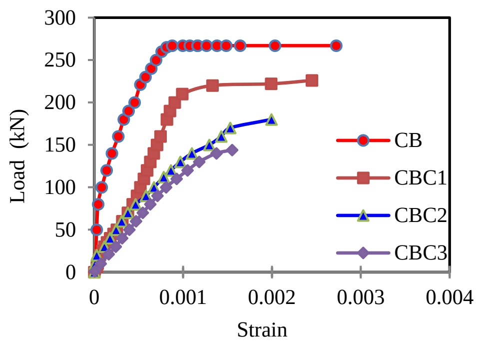

Figure 25. Combined load-strain curves for all beams

5.3. Crack Behavior

For the reference beam without the CB curve. The appearance of longitudinal cracks in the center of the concrete beam in the tension zone is observed firstly. As the applied load continues to increase, these cracks will increase in number and expand towards the upper side of the compression zone. When the applied load reaches the failure point, all samples showed a state of flexural failure in the presence of flexural cracks. The first cracks appeared at loads represent (15.09%, 16.37%, 18.33%, and 21.52%) of the failure loads of the samples (CB, CBC1, CBC2, CBC3) respectively, see Table 6. The relation between the width of crack and the applied load for all samples are illustrated in Figures 26-29, while Figures 30-33 show the patterns of cracks propagations in each sample.

Table 6. Cracking load of specimens

Specimen	loading of Crack P_{cr} (kN)	Failure load, P_u (kN)	$\frac{P_{cr}}{P_u}$ %	% Decrease in loading crack
CB	40	265	15.09	Reference
CBC1	37	226	16.37	7.5
CBC2	33	180	18.33	21.21
CBC3	31	144	21.52	22.5

6. CONCLUSIONS

In light of the results of laboratory experiments conducted on concrete beams with curvature in the tension region when tested as simply supported members on which four loading points are operated, the draw conclusions are as follows:

1) Significant decrease in ultimate load for specimens (CBC1, CBC2 and CBC3), with the increase in the angle of curved soffit. the ultimate load decreased by (14%, 32%, 45%) for CBC1 CBC2 and CBC3 respectively whose curvature degrees are 7.5°, 15° and 22.5° respectively.
2) The increase in the degree of the curve in the concrete beams in which the angle increases from (7.5°, 15° and 22.5°) in specimens (CBC1, CBC2 and CBC3) respectively, it will lead to a gradual decrease in the compressive strain of the concrete compared to the reference specimen CB.
3) Increasing the degree of the curve in the specimens leads to decreasing the cracking load by (7.5%, 21.21% and 22.5%) in specimens (CBC1, CBC2 and CBC3) respectively compared with the reference beam CB.
4) The reduction factor for reinforced concrete beams with curved soffit should be provided in the design guidelines based on it, with the mention of the design equations and percentages of the permissible degree of curvature.

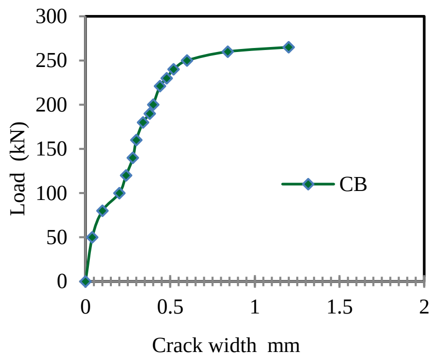

Figure 26. Load-crack width curves for CB

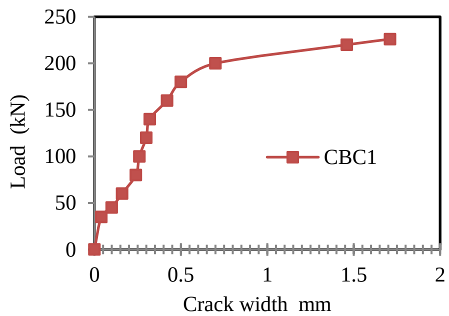

Figure 27. Load-crack width curve for CBC1

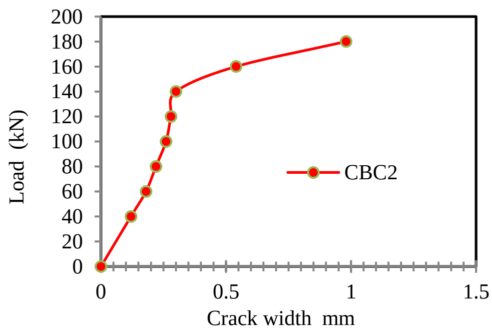

Figure 28. Load-crack width curves for CBC2

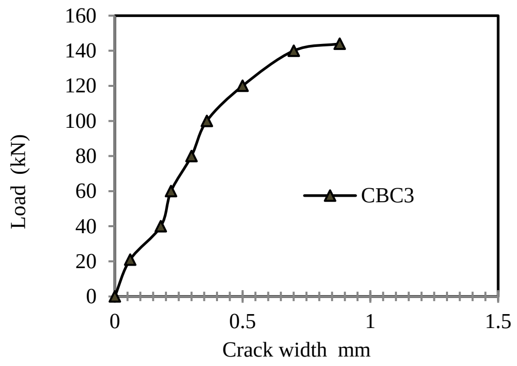

Figure 29. Load-crack width curve for CBC3

Figure 30. Cracks in CB beam

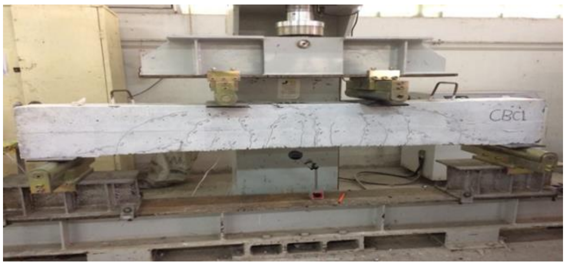

Figure 31. Cracks in CBC1 beam

Figure 32. Cracks in CBC2 beam

Figure 33. Cracks in CBC3 beam

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