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Load Capacity of Curved-up Beams

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Abstract

Straight and curved-up beams are cast as part of portal frame models. The models are made as single-span, double-span, and triple-span models. Experimental investigation is conducted to predict load capacity of curved-up beams compared to straight beams. Load was applied onsite using traditional load application. The enhancement of load capacity of a curved-up beam compared to straight beam is predicted. The enhancement in load capacity is predicted for single-span, double-span, and triple-span portal frame models is presented.

Keywords: Curved-up, Straight, Beams, Camber, Load capacity

Introduction

The importance of the effect of axial force on the behavior of the member is proved, especially for long/slender members. The axial force can be actioned/motivated in curved-up (cambered) members.

This point gives rise to the concept of using geometric nonlinearity because it builds the procedure of structural analysis on large deformations, also on geometry of the member after the occurrence of these large deformations. As a result, this non-linear behavior controls the sequence of plastic hinge formation and their expected locations.

The failure load (load capacity) under sustained load for a long time is less than that for short time tests (Troxell, Davis, and Kelly, 1968). The failure load ratio may be within the range (80 – 82 %) (Price, 1951). In concrete, the lateral expansion is restricted by adjacent strips. This results in a slight strengthening and stiffening (Nilson, Winter, 1986).

Membrane action, in reinforced concrete, was considered by Westergaard and Slater (Westergaard and Slater, 1921), who noticed a significant increase in the load carrying capacity due to arching. Other research works (Brotchie, Holey, 1971), (Cotsovos and Levas, 1990), (Roberts, 1968) have reported similar results.

The compressive strength of concrete was found to have negligible influence on the peak load of the tensile membrane action (Vessali, 2015).

Tharmarajah, Taylor, and Robinson (Tharmarajah, Taylor, and Robinson, 2023) reported that the failure load was 80–100% higher than the flexural strengths predicted by Eurocode and ACI 440.1R. The increased failure load of restrained slabs and the strength of unreinforced slab can be attributed to the compressive membrane action which is not considered in many design codes to determine strength of in-plane restrained reinforced concrete slabs.

The contribution of membrane force to the resistance of slabs is negative under compressive membrane action, but it is gradually shifted to positive after the mobilization of tensile membrane action when the tension zone in the center of the slab develops into a certain area and tensile membrane forces in the tension zone can offset the compression force near the edge (Wang, Kang, Fu, Ma, Ziolkowski, 2021).

Load Capacity of Curved-Up Beams

MODELS: Six models are presented in this study, details of which are shown in **Table (1)** and **Fig. (1)**.

Table (1) Details of the study models

Model	No. of Spans	Beam Type	f'_c (N/mm^2)	Beam Reinf.
F1	Single	Straight	26.6	1 – φ 5 mm Top & Bottom
F4		Curved-up		
F2	Double	Straight	26.6	1 – φ 5 mm Top & Bottom
F5		Curved-up		
F3	Triple	Straight	26.6	1 – φ 5 mm Top & Bottom
F6		Curved-up		

GEOMETRICAL DETAILS:

Geometrical details of the six portal frame models are shown in **Fig. (2)**.

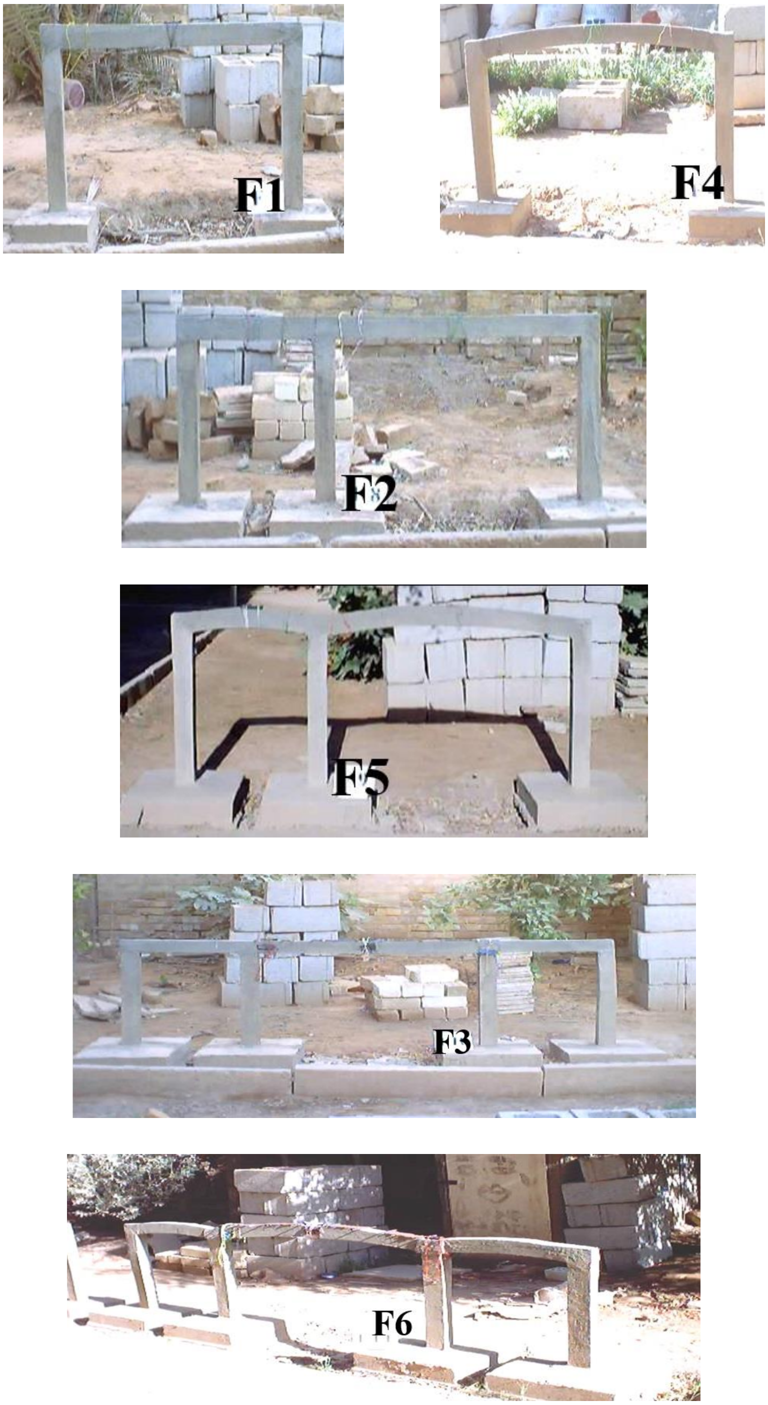
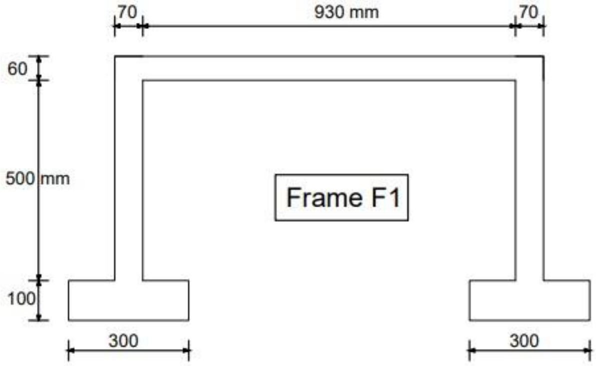
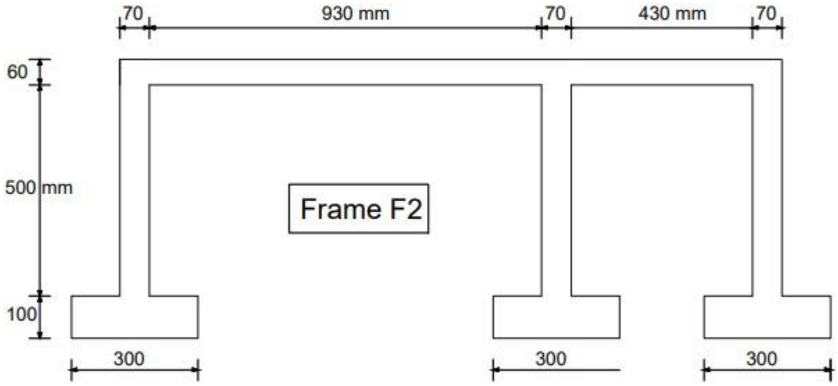
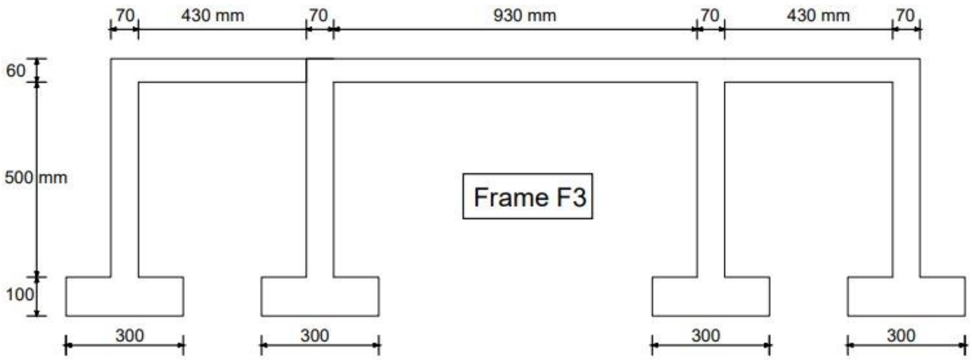


Figure (1) Models F1, F2, F3, F4, F5 and F6.


70
930 mm
70
60
500 mm
100
Frame F1
300
300


70
930 mm
70
430 mm
70
60
500 mm
100
Frame F2
300
300
300


70
430 mm
70
930 mm
70
430 mm
70
60
500 mm
100
Frame F3
300
300
300
300

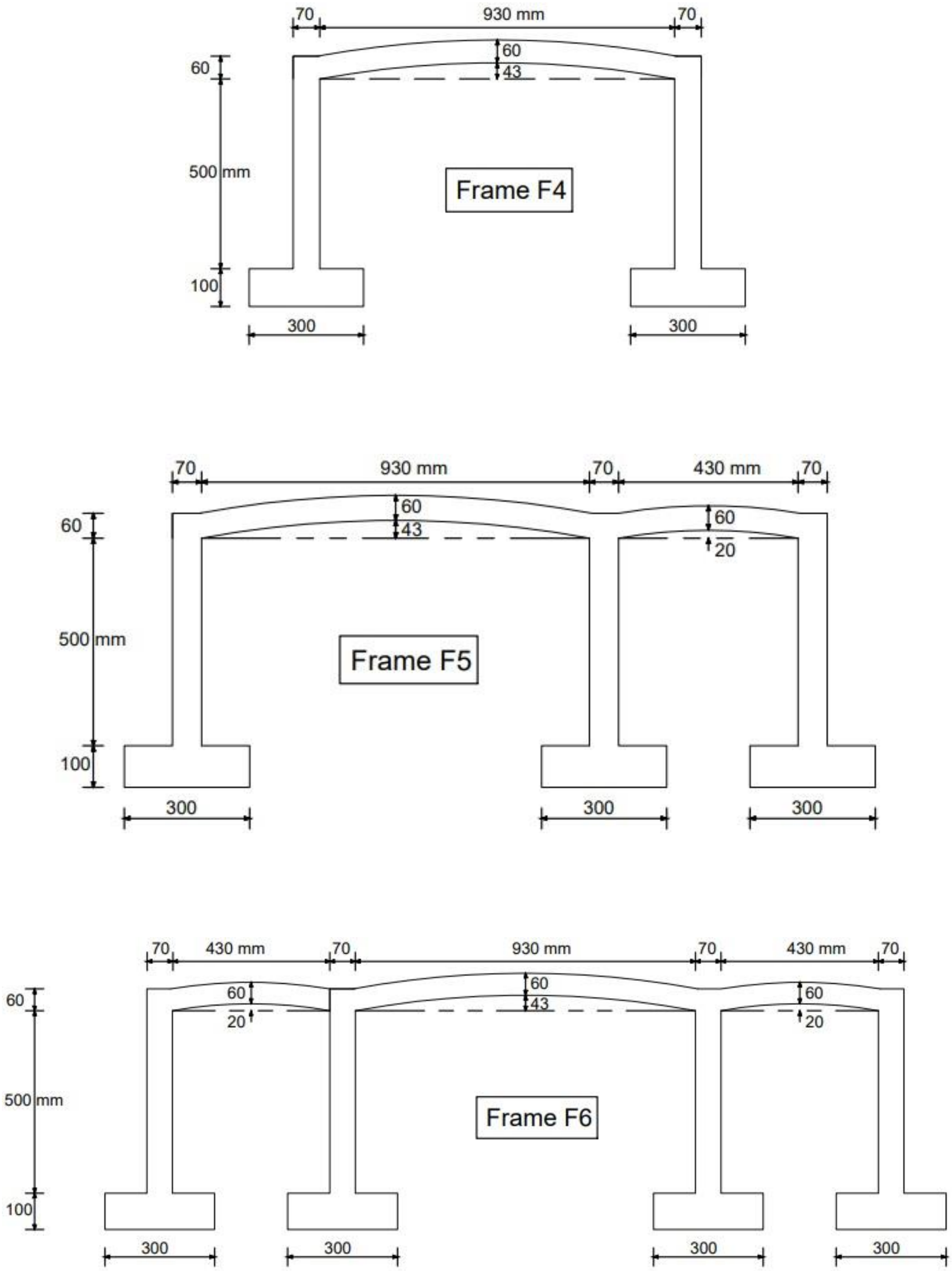


Figure (2) Geometrical details of models F1, F2, F3, F4, F5 and F6.

LOAD APPLICATION:

Traditional (non-mechanical/machine) load application is conducted by using real life materials such as masonry concrete blocks, masonry bricks, steel circular hollow sections (pipes) and sacks filled with of gravel, **Fig. (3)** gives indication to this traditional load application. Load is applied as uniform distributed load (UDL).

Traditional Load Application

Failure mechanism and load scattering after Failure

Figure (3) Samples of traditional load application and failure mechanism.

Weight of all the above materials used as loading is measured before applying the loading. The load is applied/increased gradually up until the occurrence of the failure mechanism which gives an indication to the load capacity of the six models. **Table (2)** gives the load capacity / failure load of the models predicted experimentally and represented as uniform distributed load (UDL).

Table (2) Load capacity represented as UDL.

Model	No. of Spans	Beam Type	UDL (kN/m)
F1	Single	Straight	6.11
F4		Curved-up	6.64
F2	Double	Straight	10.87
F5		Curved-up	11.95
F3	Triple	Straight	13.46
F6		Curved-up	15.36

STUDY OBSERVATIONS:

Experimental investigation gives rise to the following observations:

1. *Effect of Curved-Up (camber) on Load Capacity*

Considering load capacity results, in **Table (2)**, an enhancement to load capacity is observed in the range between 8.67 % to 14.12 %. This enhancement ratio is shown in **Table (3)**. The average enhancement ratio can be taken as 11% due to curved-up (camber) effect.

Table (3) Load capacity enhancement ratio.

Model	Beam Type	UDL (kN/m)	Enhancement
F1	Straight	6.11	8.67 %
F4	Curved-up	6.64	
F2	Straight	10.87	9.94 %
F5	Curved-up	11.95	
F3	Straight	13.46	14.12 +
F6	Curved-up	15.36	
+ Ratio = [(15.36 – 13.46) / (13.46)] = 14.12 %			

The ratio of the enhancement in load capacity can be represented as:

***Ratio of Enhancement in Load Capacity* = (11 ± 3) %** …....……… Eq. (1)

2. *Effect of Number of Spans on Load Capacity*

The results are taken for the single-span beam, and for the larger span of the double-span and triple span beams.

Table (4) gives enhancement ratio in load capacity for the above three span scenarios.

Table (4) Load capacity enhancement ratio.

Models Compared	Beam Type	UDL (kN/m)		Enhancement
F1 (single) – F2 (double)	Straight	6.11	10.87	77.9 %
F1 (single) – F3 (triple)	Straight	6.11	13.46	115.4 % ++
F2 (double) – F3 (triple)	Straight	10.87	13.46	23.8 %
F4 (single) – F5 (double)	Curved-up	6.64	11.95	78.0 %
F4 (single) – F6 (triple)	Curved-up	6.64	15.36	131.3 %
F5 (double) – F6 (triple)	Curved-up	11.95	15.36	28.5 %
++ Ratio = [(13.46 – 6.11) / (6.11)] = 115.4 %				

The following can be concluded from **Table (4)**:

1. Adding shorter span to one side of the single span beam model, will enhance the load capacity by 77.9 % and 78.0 % for both straight beam and curved-up beam models respectively.
2. Adding shorter span on each side, will enhance the load capacity by 115.4 % and 131.3 % for both straight and curved-up beams.
3. Adding another shorter side span, to the opposite side of the existing shorter span for the double-span model (i.e., making a double-span model as triple-span model), will enhance the load capacity by 23.8 % and 28.5 % for the larger span of both straight beam and curved-up beam models respectively.

Previous results prove that making the interior span as a curved-up (cambered) beam will enhance the load capacity of the beam.

REASON BEHINED THE ENHANCEMENT OF THE LOAD CAPACITY:

It is believed that introducing some shallow upward curvature to beams is mobilizing the end restraint forces. When the load is applied, a curved-up member tends to straighten. This tends to increase the length of a curved-up beam.

In trying to maintain the original length, a horizontal axial force will be initiated at both ends due to the restraining supports.

This axial restraining force increases the intensity of compressive stresses and decreases the intensity of tensile stresses across the concrete section. Such stress field improves the flexural performance and, as a result, the load capacity will be enhanced.

Conclusion

1. Straight and curved-up beams are investigated within three different models.
2. The models are single-span, double-span, and triple-span models.
3. The effect of curved-up beams is investigated compared to straight beams, both in similar models.
4. The experimental load is applied using traditional approach (non-mechanical/machine) load application. This was by using and weighing different construction materials.
5. Load capacity enhancement, due to curved-up beams, ranges between 8.67 % and 14.12 % compared to straight beams.
6. For curved-up beams, the load capacity enhancement due to number of spans, ranges between 28.5 % (changing from double-span into triple-span) to 78.0 % (changing from single-span into double-span).
7. For straight beams, the load capacity enhancement due to number of spans, ranges between 23.8 % (changing from double-span into triple-span) to 77.9 % (changing from single-span into double-span).

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