Finite Element Analysis of Deep Beams with Enhanced Shear Reinforcement for Shear Strengthening

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ABSTRACT

This paper presents the analytical analysis and experimental investigation of six deep beams with enhanced shear reinforcement to study the shear behaviour and various strength parameters. Both experimental and analytical studies are done and validated in terms of shear and other parameters. Experimental investigation proved that deep beams could carry load up to 1000 kN for a web reinforcement percentage of 0.55% of total gross area. It is proved that shear failure is the primary failure in deep beams and most of them failed in shear. In addition to shear failure, diagonal tension and diagonal compression failures also occurred in deep beams.

Keywords

Deep Beams; Shear Strength; Diagonal Tension; Diagonal Compression; Web Reinforcement;

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Introduction

According to IS 456:2000 (IS 456-2000), a beam shall be deemed to be a deep beam when its length to depth ratio is greater than or equal to 2. Deep beams have numerous applications where they can be used as transverse girders for transformation of load; in foundation pile caps to join the piles together; as bridge girders to support the carriage way. Utilization of deep beams in increasing day to day because of its ease of use and ability to carry heavier loads and moments. The most common problem developed in concrete is formation of cracks which are unavoidable and makes the element week. These allow water to seep through the cracks and damages the concrete layers (Bhavana and Poluraju 2017). In deep beams, these cracks are mainly formed due to low shear strength capacity in the pure bending region. In fact, deep beams are also used as major structural element to resist earthquake loads especially in the developing countries like India which is having more than 60% of land area susceptible to earthquakes. (Poluraju 2012) investigated on earthquakes using the non linear pushover analysis and concluded that many existing buildings do not have capacity to resist the earthquakes and they need to be retrofitted with additional members like deep beams.

Deep beams which are studied analytically will give more accurate results in terms of stress and deformations as they are investigated at minute levels with more simulations. Rolled I section is an alternative for enhancement of shear strength in deep beams by replacing the web reinforcement (Pavani and Sri Harsha 2018). ACI 318 (ACI 318-14) suggests that strut and tie method is the other alternative to resist shear in deep beams and empirical equation is developed to calculate the shear strength. Without change in the construction cost of deep beam, the shear strength of deep beam can be enhanced by altering the reinforcement in the form of truss reinforcement (Vidyadhari and Sri Harsha 2018). The capacity of shear strength for a structure containing deep beams calculated using response spectrum analysis in etabs shown that 80% of strength is increased in the structure due to presence of deep beams only (Sri Harsha 2019). The shear strength of deep beams increased in the range of 20%-30% by adding of nuts and bolts in addition to the web reinforcement (Manjusha and Sri Harsha 2019). The use of reinforced concrete jacketing as a part of retrofitting the deep beams will tremendously increase the strength of the structures even after certain years of completion of construction or during its lifespan (Sri Harsha 2019).

Praneeth proposed a shear strength equation and compared with ACI 318-14 equation and existing shear strength expression. A total of 111 deep beams data have been taken to know the unknown parameters. The results states that proposed equation is the best fitted equation to determine the shear strength of deep beams (Praneeth 2019). Apart from shear failure, another major failure in deep beams is diagonal cracking which increases with the increase in the shear to dept ratio. So, the importance of shear reinforcement in the middle region is much more which will improve the shear strength (Sri Harsha and Poluraju 2019). The crack width of deep beams decreased with increase in the percentage of shear reinforcement and detailed investigation showed that horizontal web reinforcement had more effect over vertical web reinforcement in the deep beams (Sri Harsha and Poluraju 2021).

Research Significance

Since, the deep beams primarily fail in shear, the aim of this study is to increase the shear strength of deep beams by enhancing the shear reinforcement wherever required. The reinforcement is provided in the form of vertical web reinforcement and horizontal web reinforcement through out the deep beam.

Experimental Program

The experimental program consists of six deep beams reinforced horizontally and vertically by varying the percentages of horizontal and vertical reinforcement as shown in table 1. The length, width and depth of deep is 1500mm, 250mm and 800mm respectively and kept constant for all deep beams. The length to depth ratio is maintained as 1.875 and shear span to depth ratio is maintained as 0.9375. The grade of concrete used is M35 and High yield strength deformed bars HYSD 500 were used as tension reinforcement and web reinforcement. 12 mm diameter bars and 16 mm diameter bars are used as vertical reinforcement and tension reinforcement respectively. All the six specimens were tested under loading frame of capacity 2000 kN and surface LVDT's were used to measure deflection and micrometers were used to measure crack widths.

Table 1. Cross Section and Percentage of Horizontal and Vertical Shear Reinforcement of Deep Beams

S. No	Beam Id	L (mm)	B (mm)	D (mm)	l/d	a/d	ρh%	ρv%
1	1D800	1500	250	800	1.875	0.9375	0.45	
2	2D800	1500	250	800	1.875	0.9375	0.5	0.4
3	3D800	1500	250	800	1.875	0.9375	0.55	
4	4D800	1500	250	800	1.875	0.9375	0.45	
5	5D800	1500	250	800	1.875	0.9375	0.5	0.6
6	6D800	1500	250	800	1.875	0.9375	0.55	

In Table 1, the first number in beam id indicates the number of specimen and letter D indicates deep beam and last three digits indicate the depth of deep beam. The percentage of horizontal reinforcement is varied in between 0.45-0.55 with an increment of 0.05. The percentage of vertical reinforcement is varied in two percentages i.e., 0.4% and 0.6% of total gross area of deep beam. Figure.1 shows the reinforcement details and cross section details of all the six specimens.

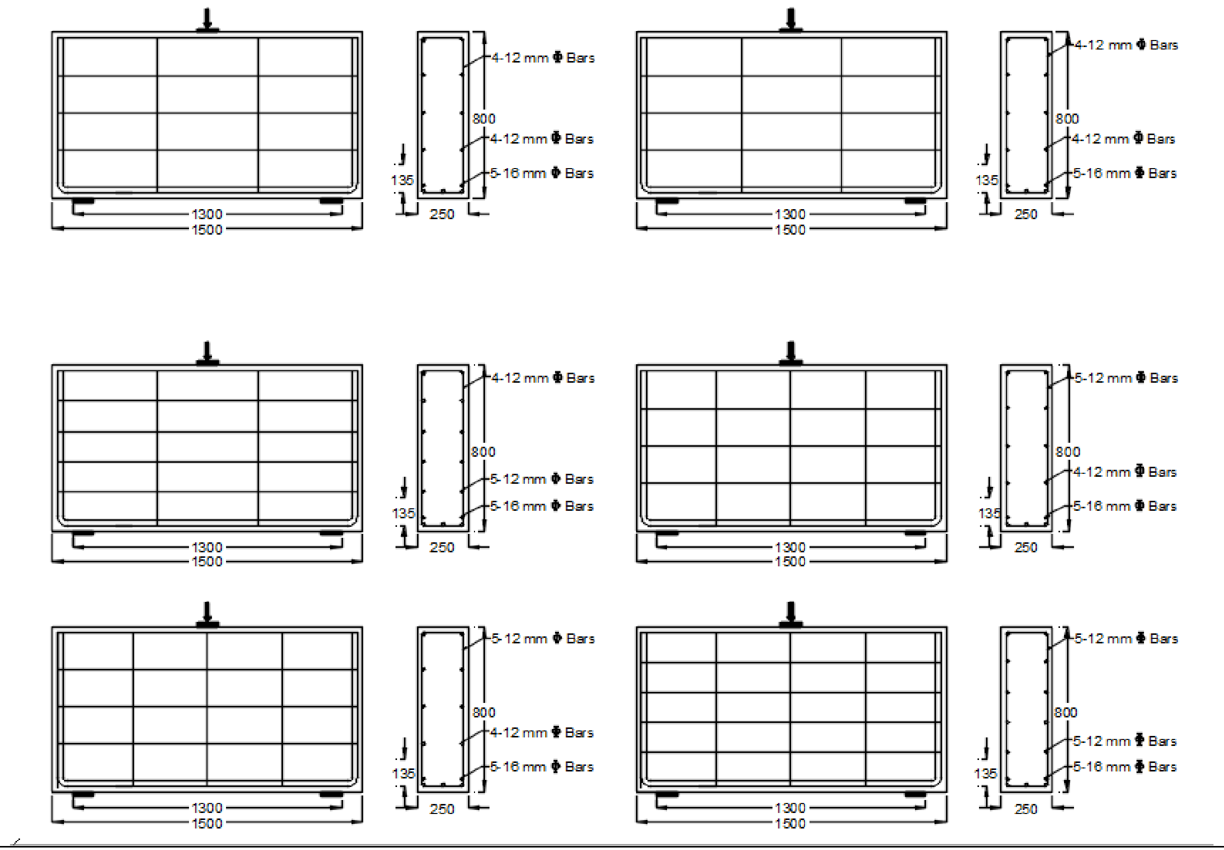


Figure.1 Reinforcement details and cross section details of deep beams

Finite Element Analysis

The deep beams were analyzed analytically in Abaqus software to know the shear strength and the experimental results are validated with analytical results. The type of element used is solid 65 with closed box form and size of mesh used is 10 mm for accuracy. Parameters like S Mises, U Magnitude, Damage Compression, Damage Tension were calculated to know the maximum deflection and shear failure criteria.

Figure 2 shows the magnitude and formation of S Mises in Abaqus for all the six deep beams. It was observed clearly in the figure that the shear failure has propagated to the top in an inclined way from the two supports reaching to the point of application of load at the centre.

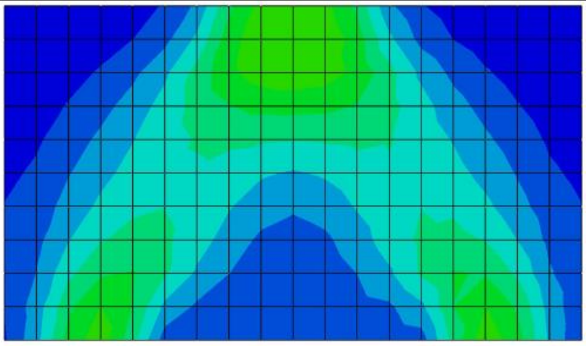
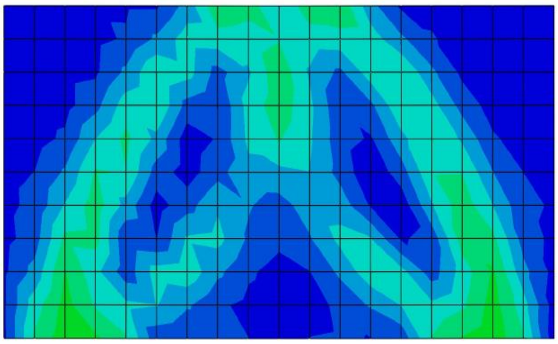
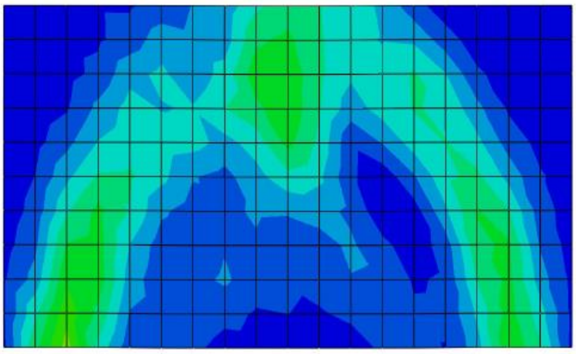
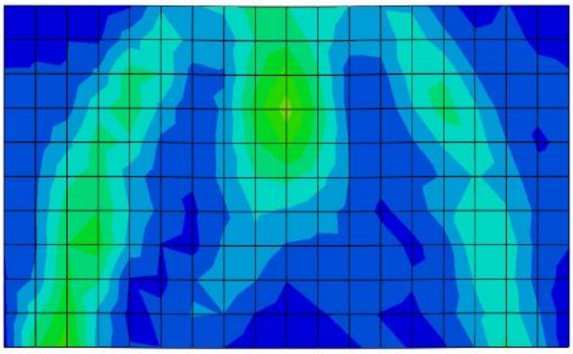
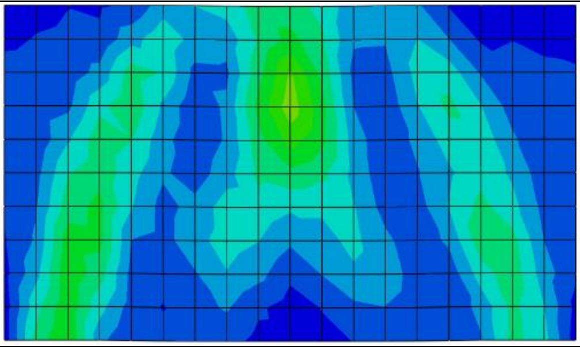
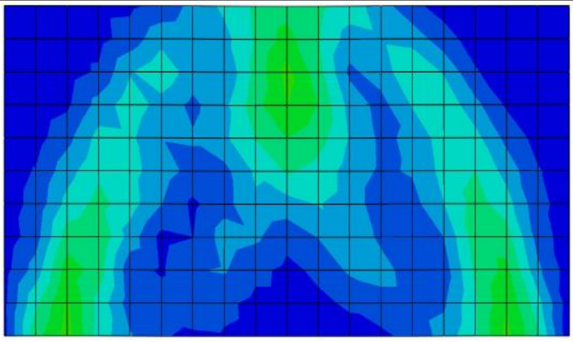
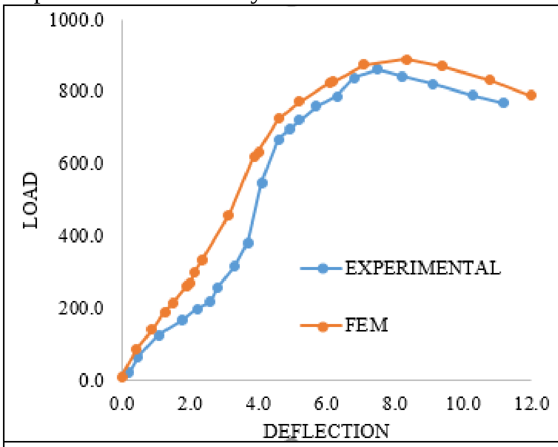
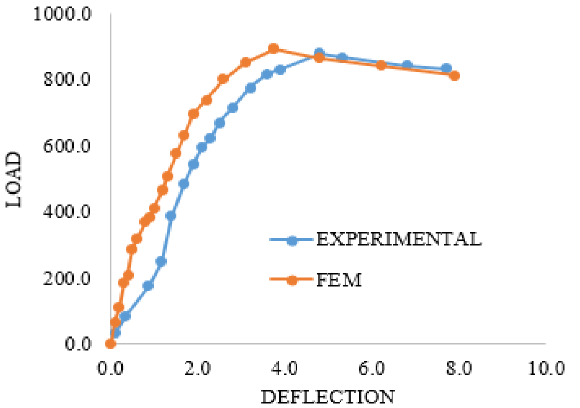
	
1D 800	**2D 800**
	
3D 800	**4D 800**
	
5D 800	**6D 800**

Figure.2 Formation of S Mises in Abaqus

Results and Discussions

Figure 3 shows the comparison of Load vs deflection for all the six deep beams individually. The ultimate load in each case is varied in between the range of 861.7kN to 978.4kN. The maximum deflection in each case is varied in between the range of 7.7 mm to 11.2 mm. The first crack started in between the range of 160kN to 175kN for all deep beams.

	
1D 800	**2D 800**

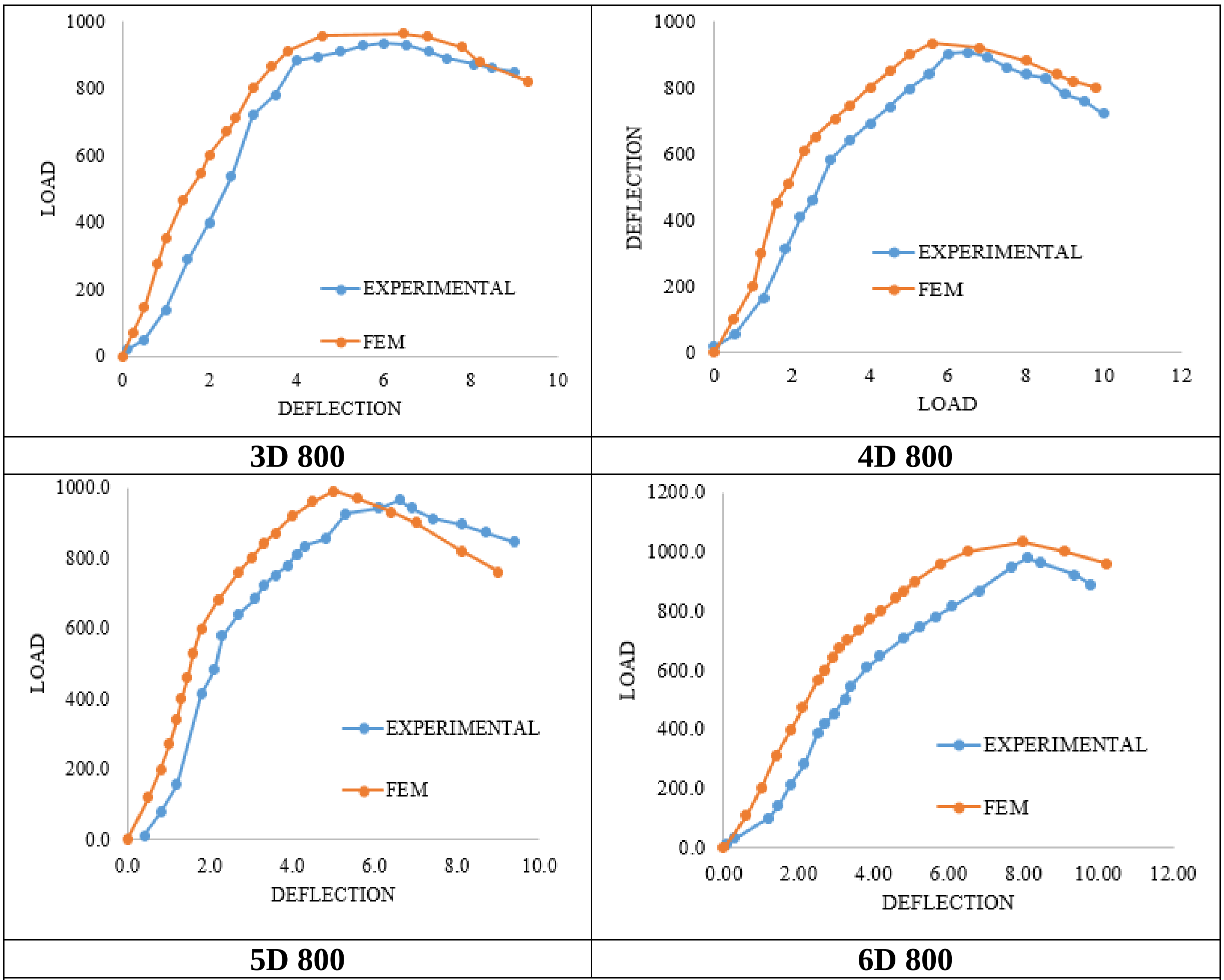


Figure.3 Load vs Deflection of deep beams

Comparison of Experimental vs Analytical results

Table 2 shows the comparison of ultimate loads of each deep beam between experimentally investigated and analytical analysis in abaqus using FEM. Both the results were found to meet to a similar scale equal to 1.0 based on the percentage table. In fact, FE model gave higher results compared to experimental values. Figure 4 represents the bar graph showing the variation of ultimate loads between the two results.

Table 2 Comparison of ultimate loads between experimental and FE Modal results

S.NO	SPECIMEN	VUEXP (KN)	VUFEM (KN)	VUEXP / VUFEM %
1	1D 800	861.7	889	96.93
2	2D 800	878.4	892	98.48
3	3D 800	934	963	96.99
4	4D 800	905	932	97.10
5	5D 800	966.3	990	97.61
6	6D 800	978.4	1033	94.71

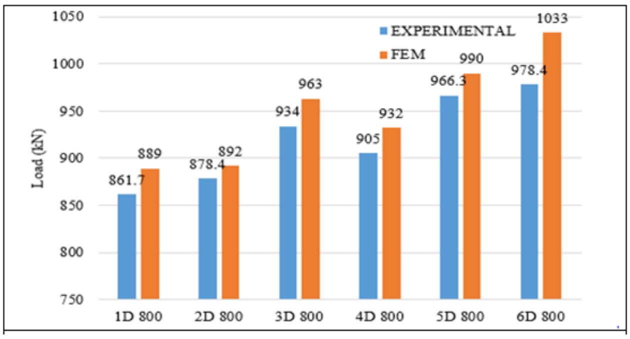


Figure.4 Comparison of ultimate loads between experimental and FE Modal results

Table 3 shows the comparison of ultimate deflection of each deep beam between experimentally investigated and analytical analysis in abaqus using FEM. Both the results were found to meet to a similar scale equal to 1.0 based on the percentage table. In fact, FE model gave higher results in few cases and experimental results gave higher results in few cases. Figure 5 represents the bar graph showing the variation of ultimate loads between the two results.

Table 3. Comparison of ultimate deflection between experimental and FE Modal results

S.NO	SPECIMEN	VUEXP (MM)	VUFEM (MM)	VUEXP /VUFEM %
1	1D 800	11.2	11.98	93.49
2	2D 800	7.7	7.9	97.47
3	3D 800	9.02	9.3	96.99
4	4D 800	10	9.8	102.04
5	5D 800	9.4	9	104.44
6	6D 800	9.78	10.2	95.88

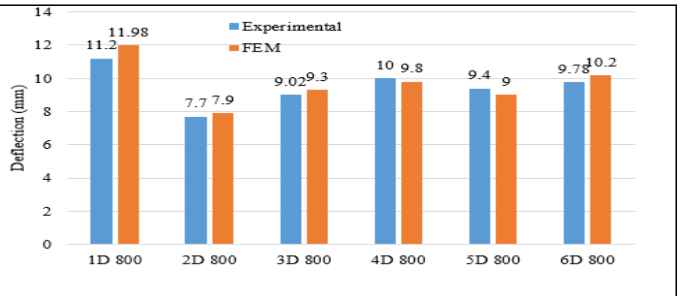


Figure 5 Comparison of ultimate deflection between experimental and FE Modal results

Figure 5 Comparison of ultimate deflection between experimental and FE Modal results

Conclusions

Six deep beams were investigated experimentally and analytically, and the following conclusions were drawn. Shear strength of deep beams increased with the increase in the percentage of web reinforcement. The ability to carry heavier loads increased with the increase in shear reinforcement. Experimental investigation proved that deep beams could carry load up to 1000 kN for a web reinforcement percentage of 0.55% of total gross area. It is proved that shear failure is the primary failure in deep beams and most of them failed in shear. In addition to shear failure, diagonal tension and diagonal compression failures also occurred in deep beams. The deflection of deep beams decreased with increase in the shear reinforcement of deep beams.

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

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