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Effect of stiffness on the RC beam attached with external truss – a numerical analysis

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ABSTRACT

Reinforced Concrete (RC) structures get deteriorated due to numerous reasons like cracks, cover concrete spalling, large deflection, etc. The identified the factors responsible for these deteriorations are due to increasing load, rebar corrosion, earthquake occurrence, environmental effects and accidental impact on the structure. It is always preferable to strengthen the structures rather than rebuild them. Therefore, repair and rehabilitation have become an increasingly important challenge for the reinforced cement concrete structures in recent years. The tools such as STRAP, ETABS, ANSYS, and STAAD play pivotal role in the detailed analysis of RC structures. It was intended to model the stiffness of RC beam attached with external truss using STAAD Pro. The result indicates that the strengthening of RC beams with external truss could provide an appreciable increase in the stiffness of reinforced concrete beams. It is evident that the stiffness and strength of the beams strengthened with external truss substantially increased up to 4250 kN.m. Also the results of stiffness according to theoretical calculation were found to be almost similar to that of STAAD results.

Introduction

Reinforced concrete (RC) structures get damaged due to various reasons. The reasons could be like cracks, cover concrete spalling, large deflection, etc. Cairns & Rafeeqi [1] identified the factors responsible for these deteriorations are due to increasing load, rebar corrosion, earthquake occurrence, environmental effects and accidental impact on the structure. Greeshma, Jaya & Annilet [2] revealed that the reasons attributed for these damages were poor design and construction practices. It is always preferable to strengthen the structures rather than rebuild them. Therefore, repair and rehabilitation have become an increasingly important challenge for the reinforced cement concrete structures in recent years. It is necessary that repair techniques should be suitable in terms of cost effectiveness, easy and timely execution. There are different methods of structural strengthening techniques that have been developed over these years, such as external bonding of steel plates, glass fibre reinforced plastic (GFRP), fibre reinforced polymer (FRP) sheets, external prestressing, carbon fibre wrapping, external bar reinforcement, and very recently improved external (bars) reinforcement techniques as proposed by Hemaanitha & Kothandaraman [3]. The objective of this paper was to discuss the possibilities of modelling the stiffness of RC beams attached with external truss. To carry out the analytical investigations, the structure has been modelled using STAAD Pro.

Literature Review

The tools such as STRAP, ETABS, ANSYS, and STAAD are prevalently used for detailed analysis of RC structures. Many researches have been conducted to numerically analyse the RC beams based on the above tools. The opinions of many researchers prompt that STAAD gives better results compared to the other tools. As stated earlier by Hemaanitha & Kothandaraman [3], the emphasis laid here is on the studies related to the design of RCC structures using STAAD. Nag [4] outlined the benefits of using STAAD as forces and moments reduce the time and cost of engineering design and construction significantly. Lefas & Georgiannou [5] found that a single reinforced concrete ring beam supporting a 10mm deep excavation through conventional sheet piles provided an efficient temporary work structure. Al-Saidy et al. [6] proved that the grillage model using STAAD III provided results comparable with those from a more accurate three-dimensional finite element analysis. Al-Sarraf et al [7] suggested a procedure based the results of numerical analysis stating that it is an acceptable procedure which is adoptable to analyze bridge deck. Senthil Kumar, Murugesan & Thirugnanam [8] evaluated the test specimens to find out load-displacement relation, ductility, stiffness, load ratio and cracking pattern. On comparison, it was found that the behavior of exterior beam column joint was similar to that of experimental results. Prashanth et al [9] compared the results of a structure designed using STAAD and ETABS Software and found that STAAD Pro gives conservative design results comparatively. Agrawal, Kulkarni & Raut [10] reported that the increase in the opening percentage leads to a decrease on the lateral stiffness of in-filled frame. The study attempted by Sairaj and Padmanabham [11] with STRAP software to develop efficient geometric models for new constructions, and to provide necessary structural configuration against retrofitting of the existing structures, constructed in earthquake prone regions witnessed that braced frame models were efficient to show ductile performance of the structure. Madheswaran et al [12] investigated the behaviour of reinforced geopolymer concrete slab under repeated low velocity impact loading using ANSYS software for finite element modeling of slab. The analytical studies showed a pattern similar to that of experimental results. The authors emphasized that GPCC can be

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used in lieu of OPCC for structural components subjected to low velocity impact by proper design.

Structural analysis

The simply supported RCC beam with truss was analysed structurally using a simplified two dimension model on STAAD Pro V8i. It is obvious that STAAD is capable of producing reliable results and a proper tool for analysis and design. To demonstrate this fact, a validation run was carried out with the following specifications of the beam: Beam size = 0.250 X 0.150m; Length of the beam = 4m; E_c = 2e+007 kN/m^2; E_s = 2e+008 kN/m^2; A_{tie} = 0.0005 m^2; A_{strut} = 0.0005 m^2; θ=11.5; 15; and 19; and Length of the strut = 0.1l; 0.13l; and 0.16l.

The validation run in STAAD involved the analysis of an RC beam subjected to uniform distributed load (UDL). The comparison between the RC beam attached with external truss and the STAAD run was based on the determination of change in the θ and Length of the Strut (h) due to specified load. The following equation was arrived based on the matrix method to calculate stiffness:

$$Stiffness\,(k) = \left(1 - \frac{S_2}{y - s_3\,\sin\theta\cos\theta\;x}\right)S_2 \qquad \text{(eqn...1)}$$

$$x = 2\left(\frac{s_3\,\sin\theta\cos\theta}{s_1 + s_3\,\cos^2\theta}\right) \qquad \text{(eqn...2)}$$

$$y = 2s_3\sin^2\theta + s_2 \qquad \text{(eqn...3)}$$

Where,

$S_1=A_b\,E_b/L$

$S_2=A_s\,E_s/L$

$S_3=A_t\,E_t/L$

Modeling

STAAD – is equipped with a state of art of element based formulation. This includes plane stress, plate bending, deflection of elements with respect to element load specification uniform pressure on the load surface which can be applied in global or local directions. A 5-element model was adopted in STAAD for the analysis of simply supported RC beam. Fig. 1 illustrates the STAAD model for analysis of RC beam attached with an external truss. Here 1 and 2 are beam element while 3, 4, and 5 are the truss element. So the strut attached to the RC beam at the point acts as elastic support. The uniform distribution load is 75 kN/m.

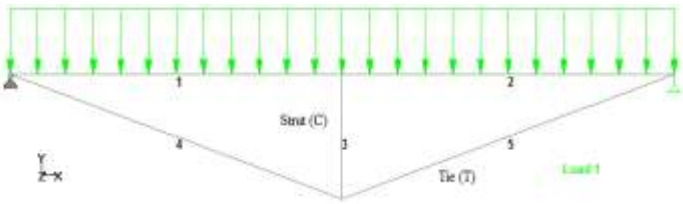

Fig. 1: STAAD model for the analysis of beam with external truss

Results and Discussion

Forces in External Truss

As indicated in Table 1, the analysis was carried out for 3 beams (A1, A2, and A3) of 250mm depth and reinforced with 12 mm dia bar from 150mm centre to centre. The result indicates that the axial thrust increased remarkably from 62 kN to 101 kN. A remarkable increase in force was noticed that 62 kN at 0.4 mm length of the strut increased to 101 kN at 0.65 mm length of the strut. Therefore, it is clear that the percentage of increase in axial thrust was depending upon the length of the strut placed at 0.4 mm, 0.5 mm and 0.65 mm respectively. The increase in axial thrust in the strut of the beams A1, A2, and A3 was 62 kN, 80 kN, and 101 kN respectively. The increase was observed in pull in each tie that went up to 82 kN. Axial thrust in the beams A1, A2, and A3 witnessed an increase of 154.7 kN, 159.29 kN, and 161 kN respectively. Thus, the results of STAAD clearly show that the greater increase in force could be achieved in the RC beams retrofitted with an external truss.

Stiffness of RC beam with Truss

An attempt was made to find out the stiffness of RC beam attached with external truss. The method of calculation for stiffness was derived in the following way: the stiffness for simply supported beam is calculated as the ratio of force to deflection at unit load (k1); and the stiffness for beam with external truss is also calculated as the ratio of force to deflection at unit load (k2). Therefore, the difference between k1 and k2 becomes the value of stiffness (k). The comparison of STAAD output with theoretical calculation has been illustrated in Table 2 and Fig. 2. The stiffness according to STAAD output increased from 1811 kN.m to 4250 kN.m. A remarkable increase in stiffness was noticed that 1811 kN at 0.4 mm length of the strut increased to 4250 kN at 0.65 mm length of the strut. Therefore, it is clear that the percentage of increase in stiffness was depending upon the length of the strut placed at 0.4 mm, 0.5 mm and 0.65 mm respectively. Based on the results of STAAD, it was observed that the greater in stiffness could be achieved in the beams retrofitted with external truss. On the other hand, the theoretical calculation resulted a meagre difference as compared to STAAD output witnessing an increase in stiffness from 1693 kN.m to 4357 kN.m. On comparison, it could be concluded that the results of stiffness according to theoretical calculation made based on the equations 1-3 were found to be almost similar to that of STAAD results.

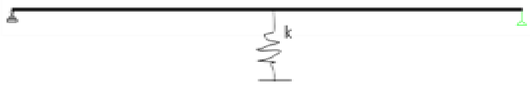

Fig. 2: Analogy of Truss

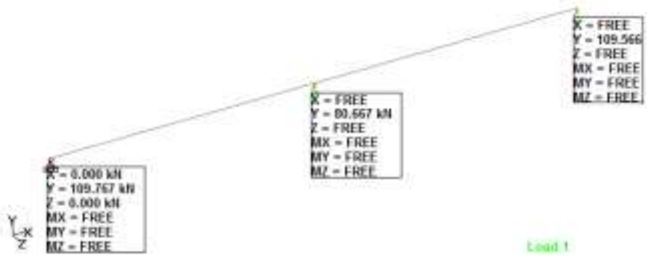

Fig. 3: Screenshot of STAAD output

Forces in External Truss with Stiffness

The result of force in external truss without stiffness was compared with the force in external truss with stiffness. As shown in Table 3, it was found that the stiffness increased from 1811 kN.m to 4250 kN.m. The percentage of increase in stiffness was due to variations in length of the strut located at 0.4mm, 0.5mm and 0.65mm respectively. The increase in axial thrust in the strut of the beams A1, A2, and A3 was 62 kN, 80 kN, and 101 kN respectively. A considerable amount of increase was observed in pull in each tie that went up to 82 kN. The increase in stiffness for A1, A2, and A3 was found to be 1811 kN.m, 2746 kN.m, and 4250 kN.m respectively. The axial thrust in the beams A1, A2, and A3 witnessed an increase of 154.7 kN, 159.29 kN, and 161 kN respectively. On comparison, it was found that the results of force in external truss without stiffness are similar to the result of the beam tested with stiffness.

Table 1: The results of forces in external truss

Spec. Ref.	Beam Depth (mm)	Effective Depth of Bonded bar (mm)	Bonded Reinforcement		Length of the strut h (mm)	Axial Thrust in the Strut (kN)	Pull in each tie (kN)	Axial Thrust in the Beam (kN)
			No.	Dia.				
A1	250	219	2	12mm	0.4	62	78.9	154.7
A2	250	219	2	12mm	0.5	80	80	159.29
A3	250	219	2	12mm	0.65	101	82	161

Table 2: Comparison of STAAD output with theoretical calculation

Spec. Ref.	Beam Depth (mm)	Effective Depth of Bonded bar (mm)	Bonded Reinforcement		Length of the strut h (mm)	STAAD (k) kN/m	Theor Calc. (k) kN/m
			No.	Dia.			
A1	250	219	2	12mm	0.4	1811	1693
A2	250	219	2	12mm	0.5	2746	2854
A3	250	219	2	12mm	0.65	4250	4357

Table 3: The results of force in external truss with stiffness

Spec. Ref.	Beam Depth (mm)	Effective Depth of Bonded bar (mm)	Bonded Reinforcement		Effective Depth of external truss h (mm)	Stiffness (kN.m)	Axial Thrust in the Strut (kN)	Pull in each tie (kN)	Axial Thrust in the Beam (kN)
			No.	Dia.					
A1	250	219	2	12mm	0.4	1811	62	78.9	154.7
A2	250	219	2	12mm	0.5	2746	80	80.6	159.29
A3	250	219	2	12mm	0.65	4250	101	82	161

Conclusion

The numerical analysis carried out to examine the effect of stiffness on the RC beam attached with external truss using STAAD Pro lead the following conclusion:

- the strengthening of RC beams with external truss can provide an appreciable increase in the stiffness of reinforced concrete beams. It is evident that the stiffness and strength of the beams strengthened with external truss substantially increased up to 4250 kN.m.
- the results of stiffness according to theoretical calculation were found to be almost similar to that of STAAD results.
- the results of force in external truss without stiffness are similar to the result of the beam tested with stiffness

It is therefore suggested that an extensive programme of work to examine the stiffness of simply supported beams strengthened by attaching a simple truss externally may be executed.

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Notation and units

A_s = area of strut (mm^2)

A_t = area of tie (mm^2)

b=- breadth of the beam (mm)

d = effective depth of beam (mm)

E_c = elastic modulus of concrete (MPa)

E_s = elastic modulus of steel (MPa)
f_{ck} = compressive strength of concrete (MPa)
h = Length of the strut
l = Length of the beam (mm)
θ = gradient of the external steel rod
s_1 = stiffness of beam (kN/m)
s_2 = stiffness of strut (kN/m)
s_3 = stiffness of tie (kN/m)