Analysis of stepped beam with multiple transverse cracks*

Gobika Shree N[1], Suresh Kumar J[2]
[1](Structural engineering, Anna University regional campus, coimbatore, India, ngobikashreecivil@gmail.com)
[2](Assistant professor,Anna University regional campus, coimbatore, India)

Abstract*—The stepped beam is an example of non-prismatic beams.This paper presents analysis of stepped beam using Ansys software.The concept aims to implement non-prismatic beams which is safe and economical under various analysis.Stepped beams provides stress concentration at the joint and requires an adequate detailing for such joint in order to avoid premature failure.Although,fiber reinforced polymer(FRP) material are widely used for strengthening and retrofitting of concrete structures and bridgesIn this paper hybrid fiber reinforced concrete stepped beam are used for analysis.CPRP strips are used in this project for retrofitting the defected beams.Stepped beams mainly avoids catastrophic failures.Vibration analysis for natural frequency and transverse crack detection are made with multiple cracks using fracture mechanism.Also deflection tests are processed in Ansys modeling of entire building with stepped beams,results in safe and economical benefits.Finally flextural performance of stepped beam and CFRP strengthening beam configuration along with seismic analys is proposed .

Keywords—stepped beam,fracture mechanism,catastrophic failure,CFRP strengthening

1. INTRODUCTION

The stepped beam is an example of an non-prismatic beams that can be used to support a split-level floor.As height of the building increases it has more chance to collapse,Stepped beams if provided,can transfer load to adjacent section and the chance of deflection or collapse get reduced.This application is commonly used in theaters and in private housing for aesthetic reasons.The stepped beams provides additional need for reinforcement detailing to fulfill the stress concentration at the stepped joints.

The well-known advantage of fibre-reinforced polymer composite over other materials make good choice for civil engineering applications.Here the combination of steel fibers and glass fibers are used in the optimistic ranges to result the stepped beam structure durable and economical.These materials can be designed and used in the form of laminates,rods,dry fibers sheets adhesively bonded to concrete.

Several studies were conducted in order to identify the methods of preventing premature failure with the aim of improving the load carrying capacity and ductility of RC beams. Researchers studied the use of end anchorage techniques, such as U-strape,L-shape jackets, and steel clamps, for preventing premature failure of RC beam strengthened with FRP or CFRP sheets.

Ductility may be broadly defined as the ability of the structure to undergo inelastic deformation beyond the initial yield deformation with no decrease in the load resistance.Toughness of the system can be defined as the maximum energy that can be sustained by the system up to failure.It can be used as an indicator for the ductility where higher toughness means higher dissipation of energy,until the failure occurred leading to higher ductility.The toughness can be defined as the area under the load-deflection curve.

The crack detection has importance for structural health monitoring applications because fracture in a structure can be harmful because static dynamic loadings.In the last two decades a lot of research effort has been devoted to developing an effective method of approach for crack detection in structures. Early crack detection plays a very important role for ensuring safety and reliability of in-service structures.

Finally, the project implements the usage of various non-prismatic beams,haunched beams, pavilions etc.Stepped beams of various cross sections are used widely and majorly used in long span constructions, composite bridge structures ,auditoriums and many other structures for its aesthetic and design purpose.

A. Physical parameters affecting dynamic characteristics of cracked structures

The dynamic response of a structure is normally determined by the physical properties, boundary conditions and the material properties. The changes in dynamic characteristics of structures are caused by their variations. The presence of a crack in structures also modifies its dynamic behavior. The following properties of the crack influence the dynamic response of the structure.

- Depth of crack
- Location of crack
- Orientation of crack
- Number of cracks

B. Fracture mechanics theory

Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials Fracture mechanics is a field that tells us about the capacity of cracks and the crack propagation law. Its job is to examine the situation of stress and strain near the tip of the crack, master crack propagation law subjected load, and understand the loading capacity of bodies with fractures, thereby, suggesting anti-crack design solutions to ensure the construction is safe.

C. Analysis using Ansys software

ANSYS structural mechanics solutions offer best-in-class simulation tools for product design and optimization that increase productivity, minimize physical prototyping and help deliver better and innovative products in less time. These solutions tackle real-world analysis problems by making product development less costly and more reliable. A broad spectrum of capabilities cover a range of analysis types, elements, contact, materials, equation solvers, and coupled physics capability all targeted toward understanding and solving complex design problems.

D. Free vibration analysis of stepped beams

This paper involved Ansys modeling of the stepped beam with and without cracks for initial free vibration analysis as shown Fig(1) & fig (2).

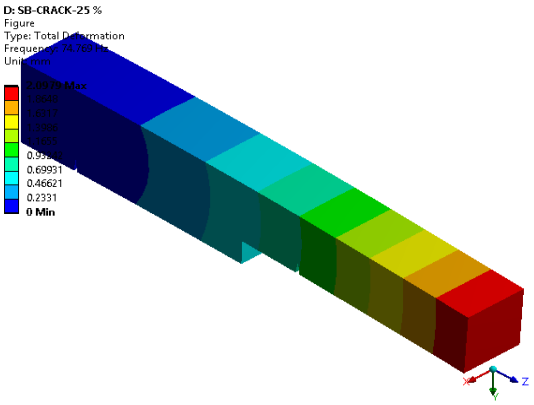

Fig 1 Stepped beam with cracks

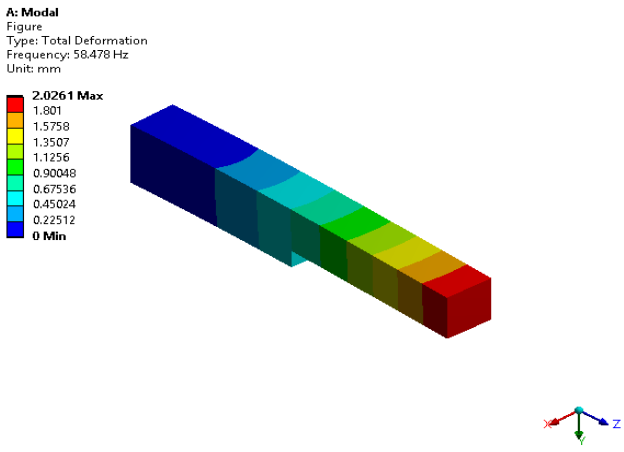

Fig2 Stepped beam without cracks

The crack cause reduction of natural frequency.The presence of cracks weakens the beam from the point of view of reduction in natural frequency.Frequency reduction variation is significant that crack is closer to the free end.If closer to 4th natural frequency that crack closer to fixed end of the beam.

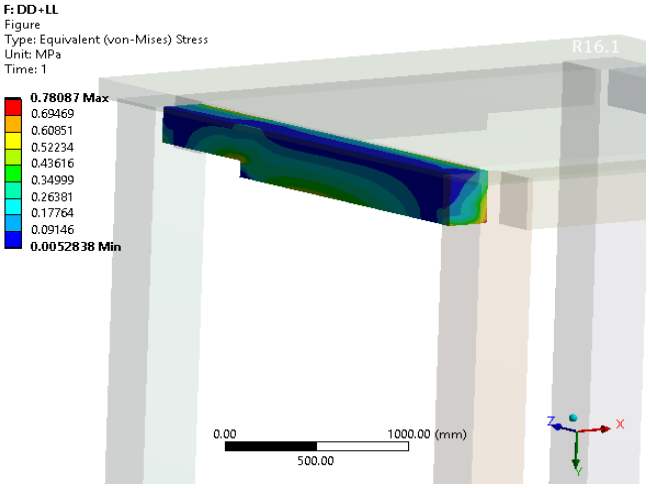

Fig 3 Stepped beam in simple frame

2. STEPPED BEAM DEFLECTION ANALYSIS

The deflection test with LL+DL combinations were given and the results shows that stepped beam resists similar to normal beams and with detailing stepped beam have less deflection compared to the conventional type beams.these are shown in fig (2)

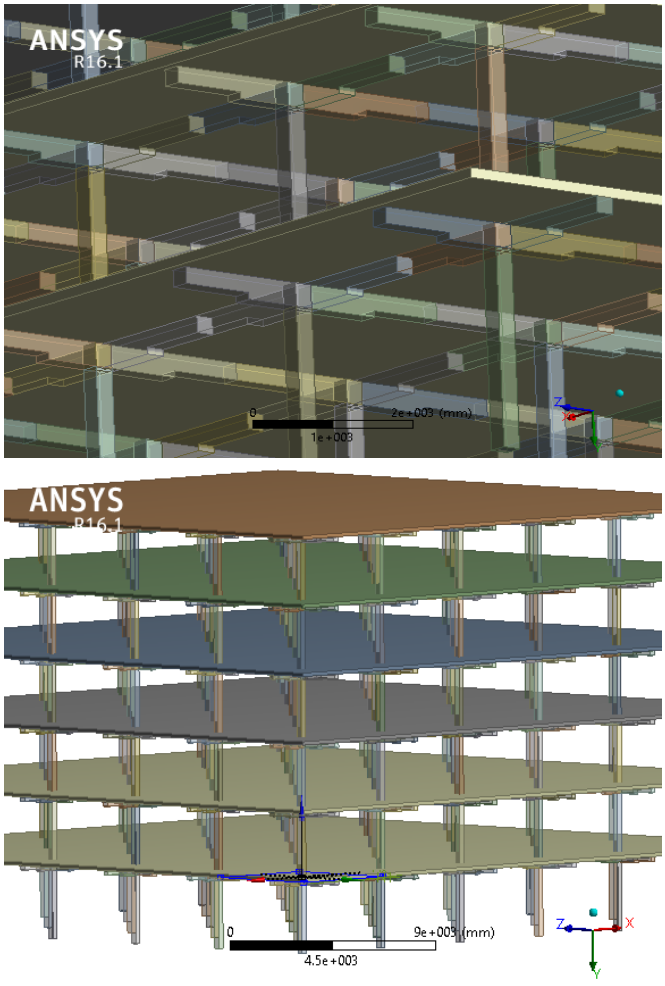

Fig 4 Deflection test on stepped beam in frame structures

A. *CFRP warping*

The stepped beam with traverse cracks are retrofitted with 1mm thickness of caebon-fiber-reinforced polymers,accordance with ACI 440.2R-08 recommendationsThe stiffness of the defected stepped beam ids sustained after retroffitting.Fig(4) shows the stepped beam with CFRP wraping respectively.

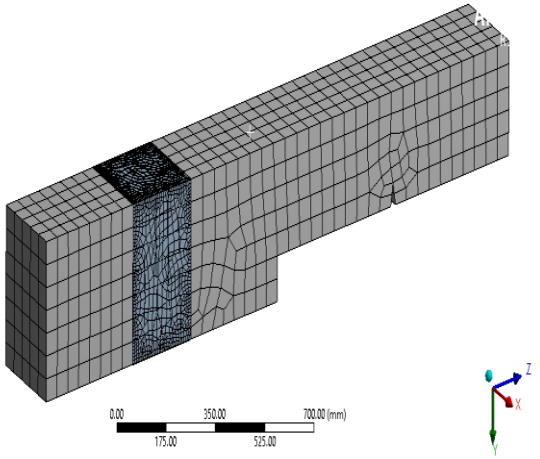

Fig 6 stepped beam with CFRP wraping

TABLE I. MECHANICAL PROPERTIES OF CFRP MATERIAL

CRITERIA	CFRP STRIPS	CFRP SHEETS
Tensile strenggth (Mpa)	2800	3500
Modulus of elasticity (Gpa)	165	230

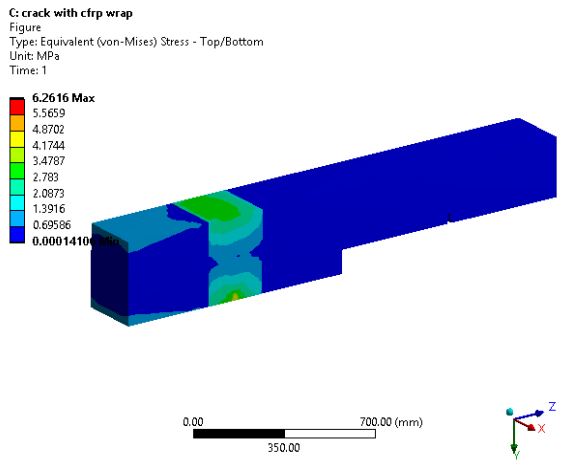

Fig 7 Stepped beam with CFRP warping stiffness analysis

3 LATERAL LOAD ANALYSIS OF STEPPED BEAM

The stepped beam is modeled for G+4 bays and tested for its seismic resistance ,assuming ZONE II.The results gave drastic successful results compared to the same structure with conventional type beams.This proved that stepped beams resistance more stress induced on it and the structure is protected from premature failures.The analysis is made for ground floor,middle and top floors and the complete lateral load reistance is predicted.The results shows about 9.4% of reduce in stress induced in stepped beams.Fig (8) and fig (9) stepped beam lateral load resistance analysis.

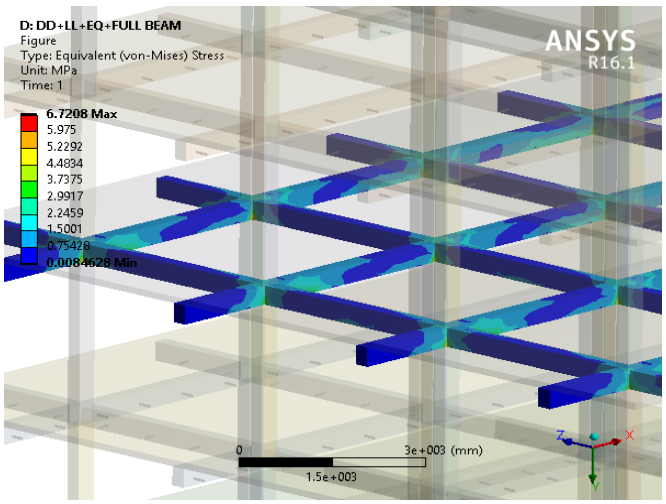

Fig 8 normal beam lateral load analysis

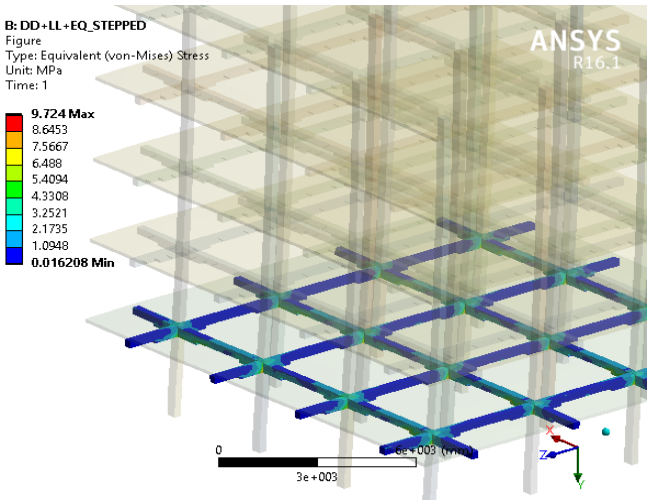

Fig 9 stepped beam lateral load resistance analysis

4 HYBRID FIBRE REINFORCED CONCRETE STEPPED BEAM ANALYSIS

On analysis of hybrid reinforced concrete stepped beam which is the combination of steel and glass fibres the deflection and natural frequency test shows good results compared to normal rcc stepped beam.

The variation in the material is the trail method of using stepped beam in the construction field.Finally the analysis are carried out and it is observed that stepped beam with cracks can withstand stress more effectively than the normal convensional stepped beams due to action of fibers respectively.Fig (10) and Fig (11) shows the deflection and vibration analysis of the fibre reinforced concrete stepped beams.

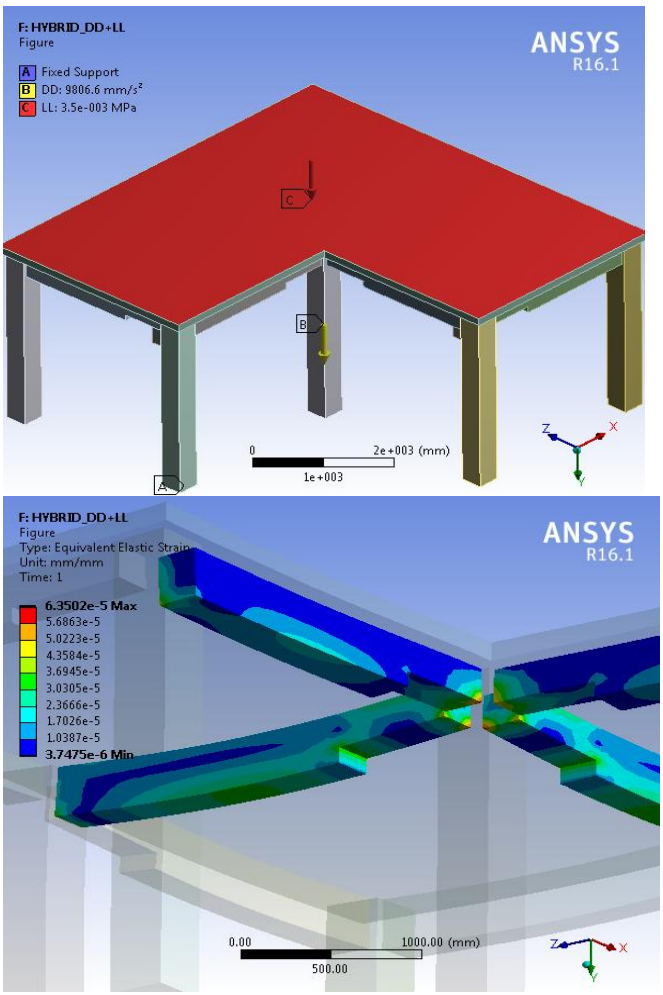

Fig 10 Analysis of the hybrid fibre reinforced concrete stepped beams for deflection

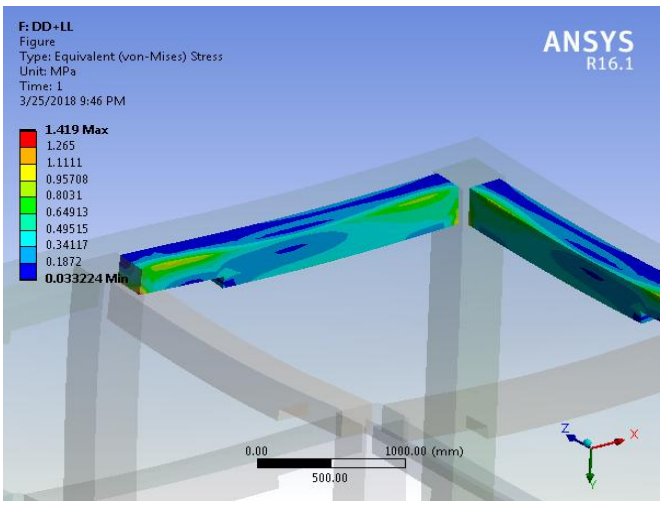

Fig 11 Natural frequency analysis of the hybrid fibre reinforced concrete stepped beams for deflection

5 RESULT AND DISCUSSION

The stepped beam is analyzed with various models for criteria includes deflection ,free vibration,lateral load resistance, economical factors ,stress ,and stiffness analysis.

The results from the analysis are highly positive when compared to the conventional type beams.

The use of hybrid fibre reinforced concrete stepped beam satisfies the above mentioned criteria better than reinforced concrete structures .The retrofitting method for defected stepped beam shows that the stepped beam possess stiffness after cracks.

The innovation concept of using stepped beam in the building is henceforth practically economical and safe is analysed in this paper.

6 CONCLUSION

Based on the studies and analysis of stepped beam with and without transverse cracks the following conclusions are being derived respectively.

- The weight of the full conventional type beam is 549 tons and the stepped beam is 529 tones.Hence the stepped beams provide 3.6% economical convenience .
- The lateral load resistance of the stepped beam is 10.01% higher than normal beams designed in ZONE II.It proves that stepped beam resists seismic force and can be used in any zones.
- The deflection of stepped beam in rcc and hybrid fiber reinforced concrete structure gave good stiffness and the implementation of non-prismatic beam is practically possible in construction is clear in the Ansys analysis.
- Moreover the stepped beam can be casted in any construction material and shapes, for further investigation on this paper.
- The stepped beams in this paper are analysed for different works like individual stepped beams,stepped beams in simple frame,hybrid fibre reinforced concrete stepped beam,G+4 bays with stepped beam analysis are effectively made for betterness.
- The retrofitting method adoped for defected stepped beam with 1mm thickness of CFRP sheet shows that the catastrophic failures are arrested .Thus the paper is made to impact the stepped beam and other non-prismatic beams in construction for above mensioned merits and aesthetic prospects respectively.

REFERENCES

[1] Dynamic Behavior of a Double-Cracked Beam," Proceedings of the 14th International Saavedra P. N., and Cuitino L. A. (2001), "Crack detection and vibration behavior of cracked beams", Computers and structures, 79, 1451-1459.

[2] Shen M. H., and Pierre C. (1986), "Modes of free vibrations of cracked beams", 1-46.

[3] Shifrin E. I., and Rutolo R. (1999),"Natural frequencies of a beam with an arbitrary number of cracks", Journal of Sound and Vibration, 222(3), 409-423.

[4] Subramaniam G., and Balasubramanian T. S. (1987), "Beneficial effects of steps on the free vibration characteristics of beams", Journal of sound and vibration, 118(3), 555-560.

[5] Xinwei W., and Yongliang W. (2013), "Free vibration analysis of multiple-stepped beams." Applied Mathematics and Computation, 219, 5802–5810.

[6] Zheng D. Y., and Kessissoglou N. J. K. (2004), "Free Vibrational Analysis of Cracked beam by finite element method", Journal of Sound and Vibration, 273, 457-475.
[7] Jang S. K. and C. W. Bert. Free vibration of stepped beams: exact and numerical solutions. Journal of Sound and Vibration, 130(2):342–346, 1989.
[8] IS 456:2000, Indian Standard Plain and Reinforced Concrete - Code for Practice.
[9] SP16:1980, Design Aids for Reinforced Concrete to IS 456.
Bureau of Indian Standards, 1987, IS: 875, (part II).
[10] Ehsan A, Sobuz HR, Sutan NM. Flexural performance of CFRP strengthened RCbeams with different degrees of strengthening schemes. Int J Phys Sci 2012;6:2229–38.
[11] Murali G, Pannirselvam N. Flexural strengthening of reinforced concrete beams using fiber reinforced polymer laminate: a review. ARPN J Eng Appl Sci 2011;6:41–7.
[12] American Concrete Institute (ACI). Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures. ACI
440.2 R-08, Farmington Hills, Mich.; 2008.
[13] Bilal S, Amal Y, Hage A, Harajli MH. Effect of fiber-reinforced polymer confinement on bond strength of reinforcement in beam anchorage specimens. J Compos Constr 2005;9:44–51.
[14] Sarah L, James O, Oguzhan B. Design considerations of carbon fiber anchors. J Compos Constr 2008;12:608–16.
[15] Hussein M. Strengthening of non-prismatic continuous reinforced concrete beams using CFRP. In: 14th International conference on structural faults and repair, Edinburgh, Scotland, UK; 3–5 July, 2012.