iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** IX **Month of publication:** September 2019

DOI: http://doi.org/10.22214/ijraset.2019.9077

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue IX, Sep 2019- Available at www.ijraset.com

Experimental Analysis of Trapezoidal Corrugated Web Beam with Stiffener with Hole for its Strength and Modes

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Abstract: ***Trapezoidal beam have been employed in building construction as floor joist & as arched roof girder of 90 feet span. Their use has been also expanded to many industrial & commercial structures., the advantages of Trapezoidal construction have been well recognized & they have been used extensively in Europe because of limited range of rolled wide flange sections available & the lower cost of labour. To govern lateral torsional buckling of web, shape of web can be changed in to trapezoidal or triangular sinusoidal to increase area of contact between web and flange. The project deals with modal analysis of I-section beam and also trapezoidal beam with circular opening having stiffener. Comparing the working frequencies of beam to avoid resonance with earthquake frequencies.***

Keywords: Finite element analysis, modal analysis, I-Section Beam, Trapezoidal Corrugated Web Beam

I. INTRODUCTION

The expanded beams have been widely used in the past in different countries of the world like the U.S.A, the U.K, Japan, Germany & other European countries for building, bridges, industrial structures & ship construction under various names, such as 'castellated' beam,'Serrated' cannels & angle & others. The idea of splitting & expanding beams to increase their sections modulus was first used, however, in about 1910, by H.F Horton of the Chicago Bridge & Iron Works. Castellated beam have been employed in building construction as floor joist & as arched roof girder of 90 feet span. Their use has been also expanded to many industrial & commercial structures. Since 1949, the advantages of castellated construction have been well recognized & they have been used extensively in Europe because of limited range of rolled wide flange sections available & the lower cost of labor. In United States, castellated beams have been used as floor joists, roof girders & in trailer & cranes. Also in 1952, the Texas State Highway Department adopted the castellated beam method for the two simple span bridge with span length of 100 feet & 65 feet respectively. In Zealand the castellated beams were used in 1956 for a three span continuous bridge over the Mangaturange stream. The concrete slab was placed on top. These beams also have been used in composite construction. An excellent example of modern composite construction is the twenty-one storied office building in Seattle named the Washington building. The beams were castellated & reinforcing bars bent & welded to the top flange. In short, castellated beams have been used in a wide variety of applications, such as roof beams & rafter in both simple span & cantilever construction, floor beams, tier building, rafter portions of rigid frames, pipe bridges, crane bridges, bog under frames, grift & other special applications.

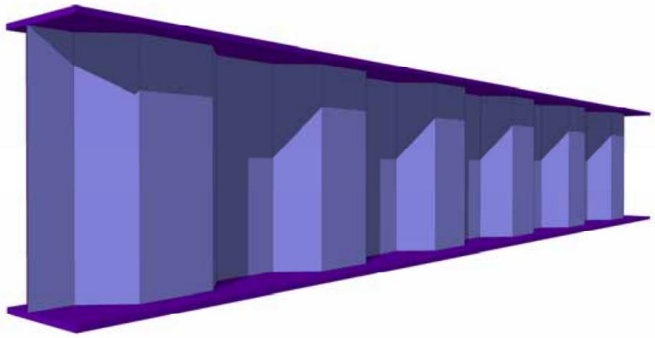

Fig.1. Trapezoidal Corrugated web Beam.

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II. METHODOLOGY

The design of selection of standard I- section beam as per BIS (808:1989) as shown in fig.1 To build up a 3-D solid model and perform stress analysis of I-section beam as per BIS (808:1989) by using FEA software, such as ANSYS.To perform vibration analysis of I-section beam as per BIS(808:1989) by using FEA software's such as ANSYS are also compared with theoretical calculation.To perform strength and modal analysis of modified I-section beam hole with stiffner by using FEA software's such as ANSYS. To perform strength and modal analysis of modified Trapezoidal corrugated web beam hole with stiffener by using FEA software's such as ANSYS. To perform the vibration analysis of modified Trapezoid corrugated web beam and modified I-section beam by using FFT analyzer as shown in fig.To compare and validate the result obtained by using software analysis with results obtained by experimental Analysis for vibration for modified Trapezoidal corrugated web beam and modified I-section beam.

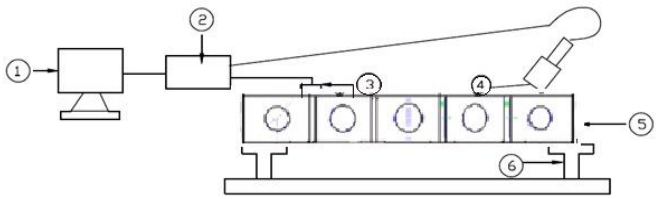

Fig.2. Proposed experimental set-up for vibration analysis
1. Computer, 2.Analyzer, 3.Accelerometer, 4.Hammer, 5.Test specimen, 6.Support

III.OBJECTIVES OF WORK

A. To Study Structural Behaviour of trapezoidal corrugated web Beam with stiffeners with hole and comparison with I- section beam with stiffener stiffeners with hole also find out working natural frequencies of both beams.
B. To improve the performance of trapezoidal castellated web beam hole with stiffener by transverse stiffeners.
C. To increase natural frequencies of I-section beam with change in web with hole and stiffener to avoid resonance with earthquake frequencies.

IV.PROBLEM DEFINITION

The failure modes comprise shear, flexural, lateral torsional buckling, rupture of welded joints and web post buckling failure modes were investigated by numerically experimentally & analytically. But detailed experimental work of beam with stiffeners for trapezoidal corrugated web beam was not carried out. Therefore in this project behaviour of trapezoidal castellated web beam with Stiffeners under loading and Vibration analysis are carried out experimentally.

V. LITERATURE REVIEW

The project deals with experimentation and analysis of Trapezoidal corrugated web beam hole with stiffener and I-section beam hole with stiffener so number of papers are available which describes the limitations of using I section beams, benefits of built up section, according effect, various shapes that can be used as web, design consideration in trapezoidal corrugated web and also effect of corrugation angle into strength of beam.

Khalid et.al,[1]The paper is devoted to the behavior of mild steel structural beams with corrugated web subjected to three-point bending. Semicircular web corrugation in the cross-sectional plane (horizontal) and across the span of the beam (vertical) were investigated each experimental and computationally using finite element technique. In the finite element analysis, test specimen was modeled using commercially available finite element software and a non-linear analysis was performed. This attributed to the increment of the second moment of area that has influence on the direct bending stresses.

Ngoc Duong Nguyen et.al.[2]--Moment modification factors of the I-girder with trapezoidal web corrugations subjected to concentrated load applied at different heights on the cross section and various end restraint conditions, are investigated. The moment modification factors are obtained by finite element buckling analyses. The new FEM program is developed by using beam elements and new general formulas of cross-section properties as well as a new warping constant of the I-girder with trapezoidal web corrugations.

Jae-Yueloh et.al.[3]--Various types of composite members have been developed to utilize the combined advantages of existing reinforced concrete and steel structures, and to actively improve ductility and serviceability of structural members. One of them is the hybrid-type steel beam, in which the pre-stressing method is applied to a steel beam. Introducing pre-stress to the existing I-shaped steel beam, however, results in a very low pre-stress efficiency due to the large axial stiffness of the section.

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LincyPabraham et.al. [4]This paper deals with the investigation on Behaviour of encased cold formed built up I-section with trapezoidal corrugated web and encased cold formed built up I-section with plane web, under two point loading by varying height to thickness ratio of the beam specimen. The experimental results of encased trapezoidal corrugated web and that of plane web are compared and the behaviour and failure modes are discussed. Encasing the corrugated web of steel beam with concrete could improve the resistance to transverse deflections.

Magnucka et.al.[5]--Devoted to the mathematical modeling of transverse shearing effect for sandwich beams with sinusoidal corrugated cores. Bending and buckling problem of two sandwich beam are found out by theoretical.

Pankaj Kumar et.al.[6]--Beams under study include cantilever, simply supported and fixed beam. Mode shapes and natural frequencies of these three types of beams are obtained using theoretical analysis, simulation in ANSYS and experiment using FFT analyzer. Finally natural frequencies obtained from simulations and experiments are compared with theoretical values of natural frequencies. The mode shapes obtained from simulations and experiments are matching closely with analytical ones.

Bureau of Indian Standards[7] -IS808:1989(Reaffirmed 1999)This normal covers the nominal dimensions, mass and sectional properties of hot rolled sloping flange beams and column sections, sloping and parallel rim channel sections and equal and unequal leg angle sections. The Indian Standard IS 1852: 1985 'Rolled and cutting tolerances for hot rolled steel products (fourth revision)' are necessary adjunct to this standards.

VI. STIFFNER

Stiffeners are those structural components which are used to strengthen shear & moment resistance of steel plates along the longitudinal & transvers or/and along the edge of opening, but if castellated beams are subjected to concentric loading in such beam prove to be inappropriate. In such cases castellated beams must be reinforced at the places where these load concentrations occur.

VII. DESIGN AND CONSIDERATION PARAMETER

From bureau of Indian standard I section beam is selected which is MB100.then for calculated is various parameters like mass, volume, area. These are as follows.

Standard Beam Dimensions (I section)

D- Depth of the beam=100mm

b - Flange Width of beam, column or channel section=50mm

tw - Web thickness of beam=4mm

tf -Flange Thickness of beam=6mm

Density of Structural Steel=8050kg/mm^3

Poisons ratio-0.26

Y- Young's modulus of structural steel=200GPa

G- Modulus of Rigidity=75GPa

L- Length of the Beam=1000mm

a- Sectional area of beam=882.4mm^2

V- Volume= 882.4* 103mm^3

M- Mass of the beam=7.1 kg/m

• Area, Volume and Mass are calculated by Following Equations

• Area=[Dt + 2TB]

• Volume =[Dt + 2TB]*L

• Mass=[Dt+2TB]*L*Density.

For our project analysis, we have used castellated web beam with circular opening. So our modified shape of beam as follows

1) Dimensions of I-section beam

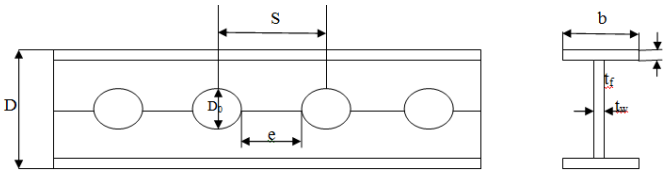

Fig.3. Typical cross section of the beam

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Various dimensional parameters involved in the castellated beam with hexagonal openings (Fig.1.4) are defined as given below:
Do = Depth of opening provided=50mm
D = Overall depth of the beam=100mm
e = Clear distance between two opening=200mm
b = Width of flange of I beam=50mm
t_f = Thickness of flange of I beam =6mm
t_w = Thickness of web of I beam=4mm

2) Dimensions of Trapezoidal Corrugated web be Beam

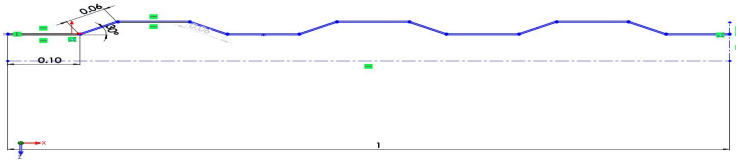

Fig.4. Top view of trapezoidal corrugated web

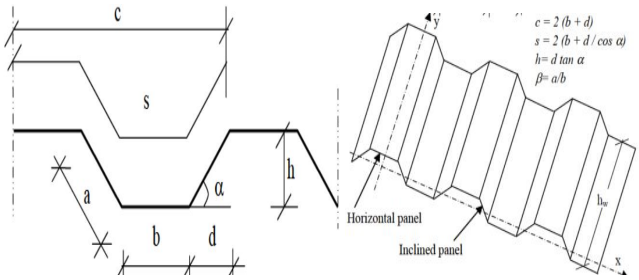

Fig.5. Terminology trapezoidal corrugated web

b=100mm. $\alpha=30^0$ a=60mm.
Depth of opening provided= Do =50mm
Overall depth of the beam=D =100mm
Clear distance between two opening=e =200mm
Width of flange of I beam=b =50mm
Thickness of flange of I beam =tf =6mm
Thickness of web of I beam=tw =4mm

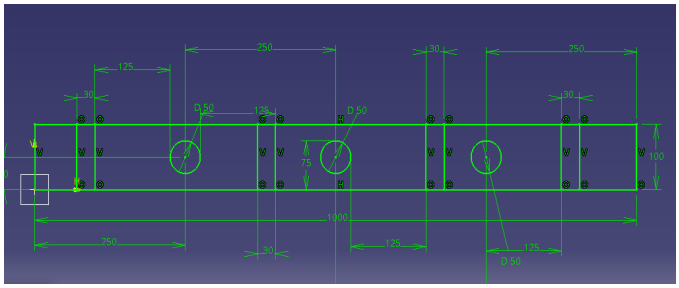

Fig.6. Front view of web for the I-section and Trapezoidal section

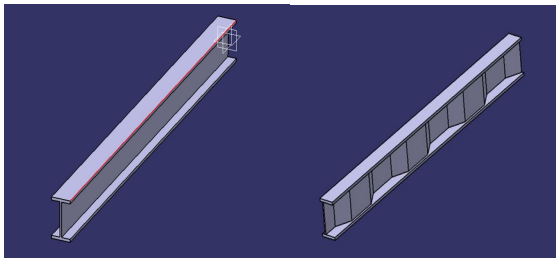

Fig.7. Cad Model of I Section & Trapezoidal Section Beam

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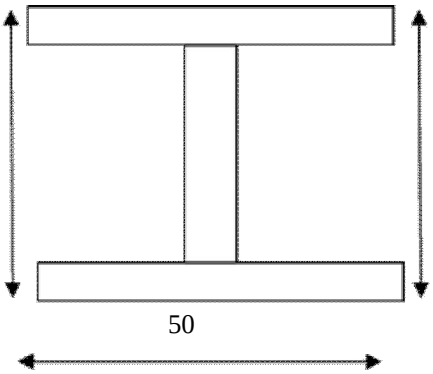
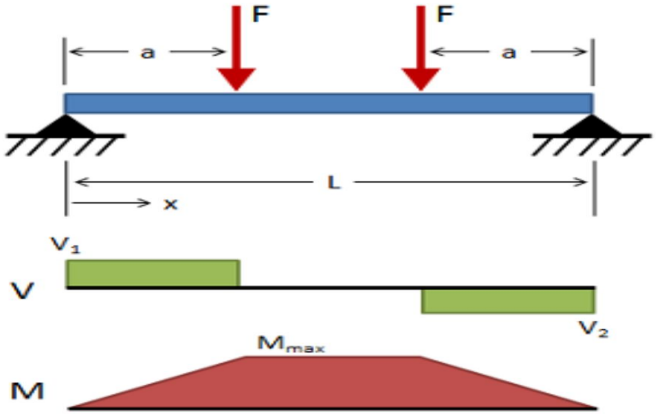
This is the cad model of I-Section of beam and corrugated web beam this is not modified and optimized without stiffener structure of beam. They are used in regular manner.

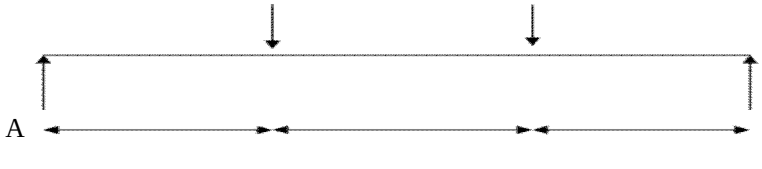
3) Theoretical Stress calculation for I-Section Beam



A1=50×6=300mm2
A2=4×88=352 mm2
A3=50×6=300 mm2
To find the moment of inertia about X-X axis, we have to divide area A1, A2, A3
By using parallel axis theorem
Ixx=I1+I2+I3
=[(Ixx1+A1h12) + (Ixx2+A2h22) + (Ixx3+A3h32)]
=[(b1d13/12)+A1h12+(b2d23/12)+A2h22+(b3d33/12)+A3h32]
= [(50×63/12)+300×(50-3)2+(4×883)/12+(50×63)/12+300(50-32)]
=663600+209683.69+663600
=1536883.69mm4
Ixx=1.5368 $\times 10^6 mm^4$



Simply supported I-section beam, two point loading with shear force and bending moment



Beam span under loading

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To find reaction at support

RA+RB=20+20=40KN ……1)

Taking moment about 'A'

RB ×1=20 ×1/3+20 ×2/3

RB=20KN

RA=20KN……Putting in case

a) Shear force diagram

At point 'B' Before=0

After=-20KN

At point 'D' Before=-20KN

After=20-20=0

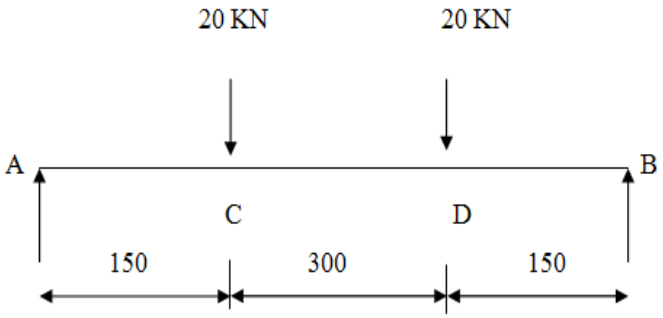
At point 'C' Before=-20-20=0KN

After=20-20+20=20

At point 'A' Before=20-20+20=20

After=20-20+20-20=0

To find maximum bending moment



Beam span under loading

About point B=Bending moment is zero

About point D=20 ×0.150=3 KNm

About point C=20 ×0.450-20 ×0.150=6 KNm

About point A =20 ×0.6 - 20 ×0.150 - 20 ×0.450=0 KNm

M/I = σb/y

Y=Distance of Extreme flange from neutral axis,

Y=50

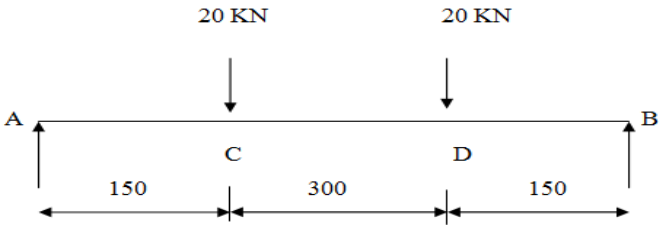
M/I = σb/y

σb = (M/I) ×y

σb= (6) $\times 10^6$ × 50/ (1.5368 $\times 10^6$)

σb=195.21 N/mm^2

To find the deflection of Beam



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Deflection:

$$\delta = -\frac{Fx}{6EI}\left(3aL - 3a^2 - x^2\right) \qquad (0 \le x \le a)$$

$$\delta = -\frac{Fa}{6EI}\left(3Lx - 3x^2 - a^2\right) \qquad (a \le x \le L - a)$$

$$\delta_{max} = \frac{Fa}{24EI}\left(3L^2 - 4a^2\right) \qquad @\ x = L/2$$

Maximum deflection occurs at mid-point of beam so at a = 0.3 m

$$\Delta = \frac{10 \times 1000 \times 0.3(3 \times 0.6 \times 0.6 - 4 \times 0.3 \times 0.3)}{24 \times 2 \times 1011 \times 1.5368 \times 10 - 6}$$

δ= 10000×0.3×0.72/7376640

= 0.002968 m

= 2.9 mm

4) Theoretical Natural Frequencies Calculation

a) To find the natural frequencies of I-section beam Formula for natural frequency –

$\omega n = \beta^2 \sqrt{\frac{EI}{pA}} = (\beta l)^2 \sqrt{\frac{EI}{pAl4}}$

ωn- Natural Frequency

I-section beam and Trapezoidal corrugated web beam both are cantilever supported and impacting Hammer on it, Natural frequency are taken.

By using theory of cantilever condition

$\beta_1 l$=1.875, $\beta_2 l$=4.694, $\beta_3 l$=7.

The sectional properties of Beam—

E--- 200 GPA.

p—8050 kg/m3

For I-section Beam---

I— 1.5368 * 106 mm4

A— 952mm2

L----1000mm.

$\sqrt{\frac{EI}{pAl4}}$ = (2*10^11 *1.5368*10^-6/8050*952*10^-6*1^4)$^{0.5}$

= 196.95

$\omega n = (\beta l)^2 \sqrt{\frac{EI}{pAl4}}$

For 1st mode $\beta_1 l$=1.875, for second mode $\beta_2 l$=4.694,

By using above values

ωn_1= 692.40 rad/s so f=110.25 Hz, ωn_2 =4339.52 rad/s so f=691.12 Hz

Modified Cad Model of I-Beam and Corrugated Trapezoidal Web Beam

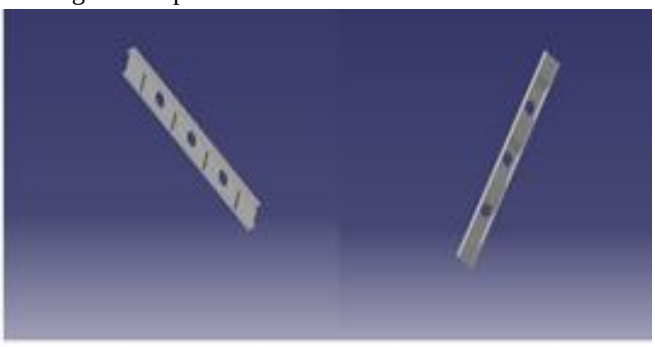

Fig. 8. Cad Model

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VIII. SIMULATION WORK

Modal Analysis -: Modal analysis is that the method of determinant the inherent dynamic characteristics of a system in kinds of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior. The developed mathematical model is referred to as the modal model of the system and therefore the information for the characteristics are referred to as its modal information. The dynamics of a structure are physically decomposed the frequency and position. This is clearly evidenced by the analytical resolution of partial differential equations of continuous systems such as beams and strings. Modal analysis is predicated upon the actual fact that the vibration response of a linear time-invariant dynamic system may be expressed as the linear combination of a collection of easy harmonic .

Modal analysis of without Hole and with hole stiffener of I-section And trapezoidal Corrugated web Beam :-

1) Modal Analysis I- Beam Without Hole and Stiffner

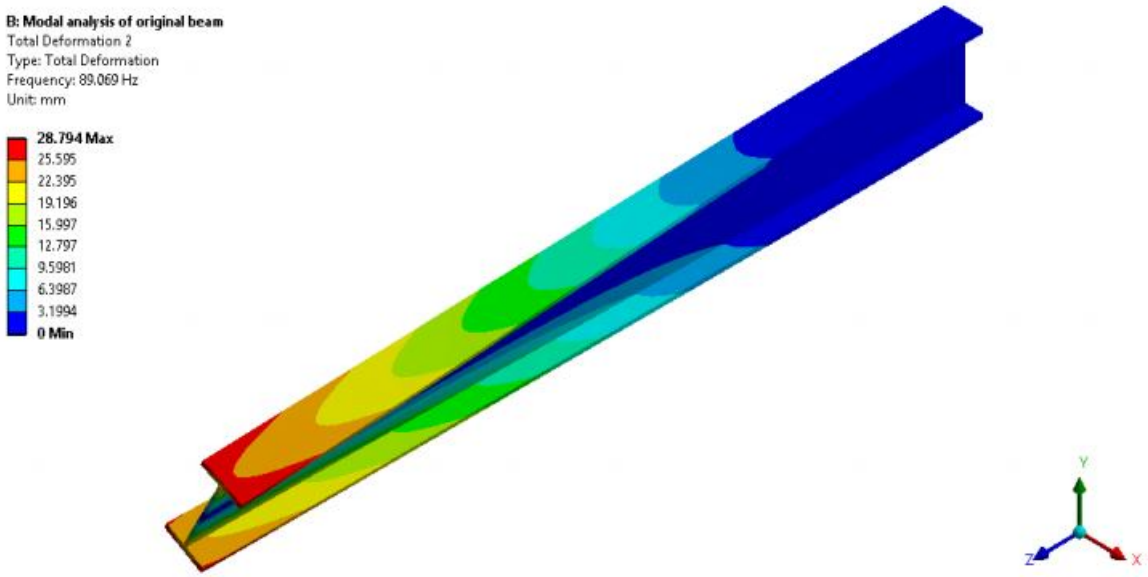

Fig.9. 1st Natural frequency 89.06 Hz

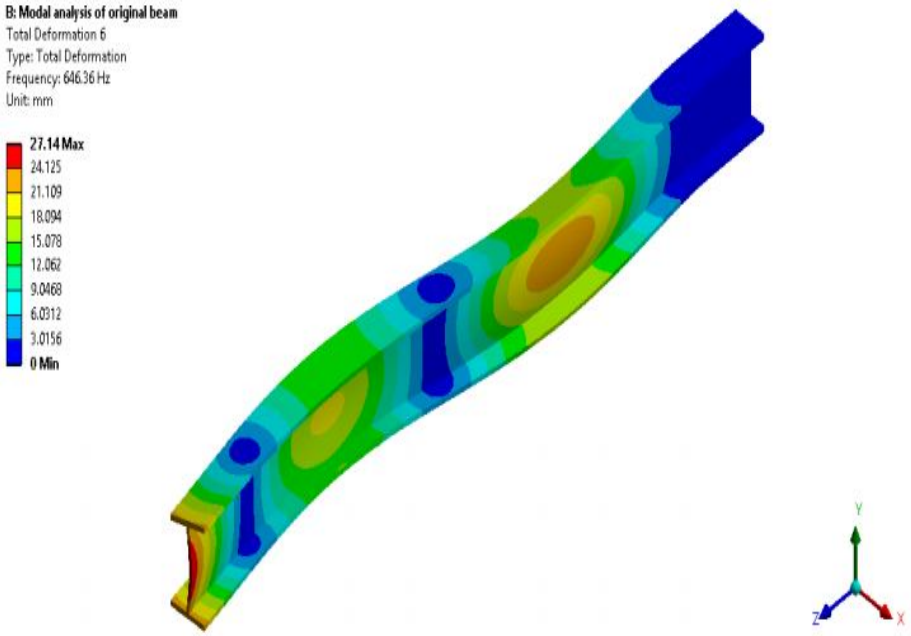

Fig.10. 2nd Natural frequency 646.36 Hz

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2) Modal Analysis I-Beam with Hole And Stiffener

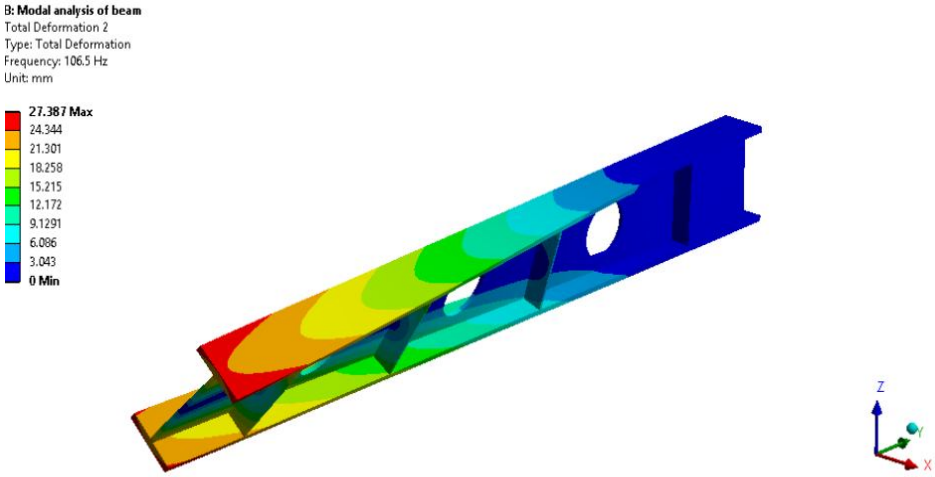

Fig.11.1st Natural frequency 106.5 Hz

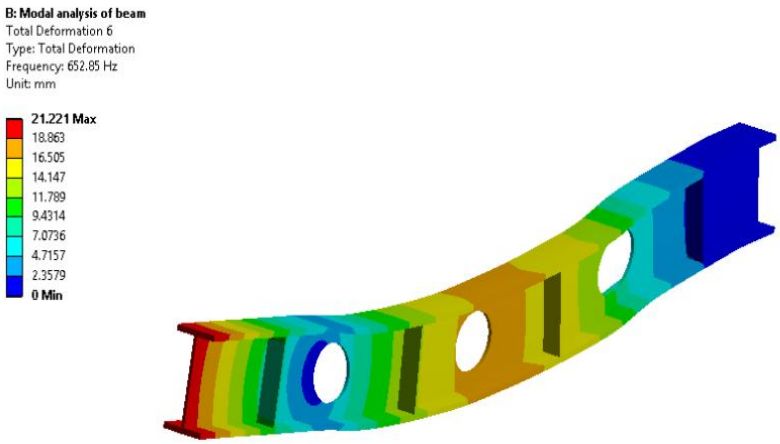

Fig.12. 2nd Natural frequency 652.85 Hz

3) Modal analysis of Trapezoidal beam hole with Stiffener

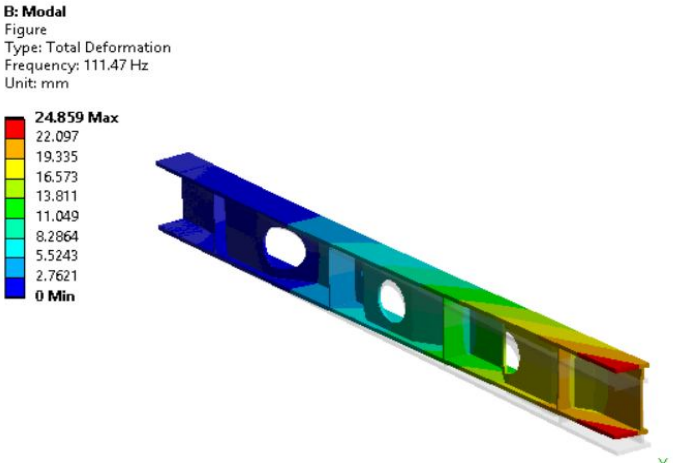

Fig.13.1st Natural frequency 111.47 Hz

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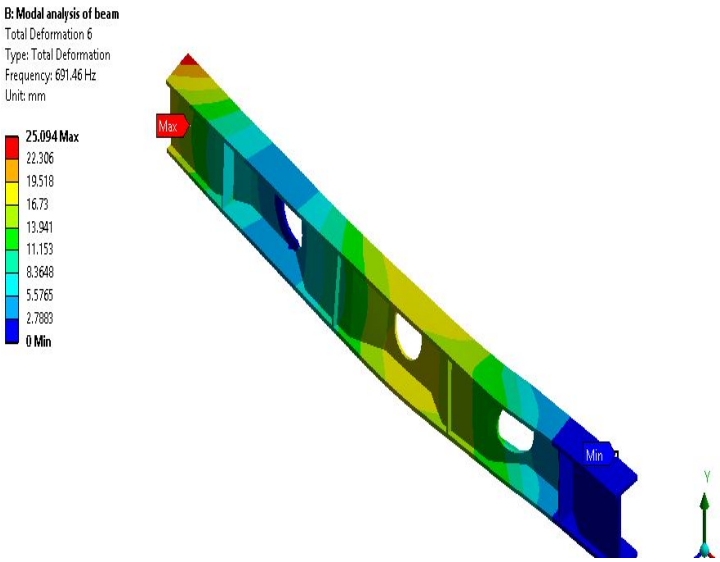

Fig.14. 2nd Natural frequency 691.094

4) Strength Analysis of I-Section Beam: The model of I-section beam and Trapezoidal beam is prepared in solid works and catia as mentioned dimension in above and saved. Strength analysis is carrying out to find out the load carrying capacity of beams and stress induced at critical location in ANSYS software.

Following steps are performed on the ANSYS

a) Preference: A static structural analysis gives the deflection, stresses, strains, and forces in structures or elements caused due to loads.

b) Pre-processor: A) Element type- Solid 185 is used for 3-D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node.

c) Material Properties: Material properties are entered for structural steel (A36).

Fig.14.Mesh Model of I-Section Beam

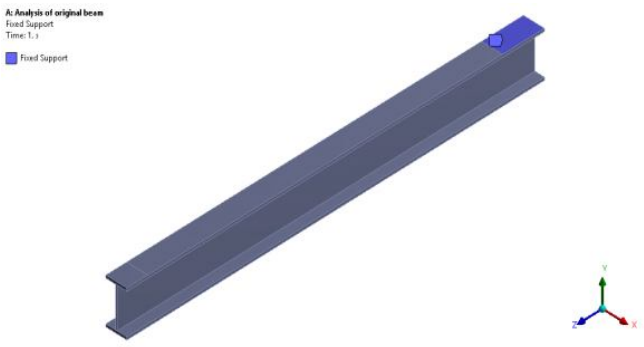

Fig.15. Boundary condition Model

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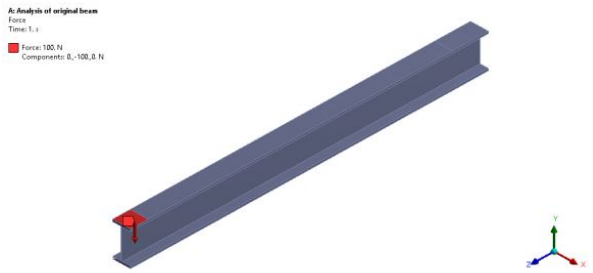

Fig.16. Load Application model

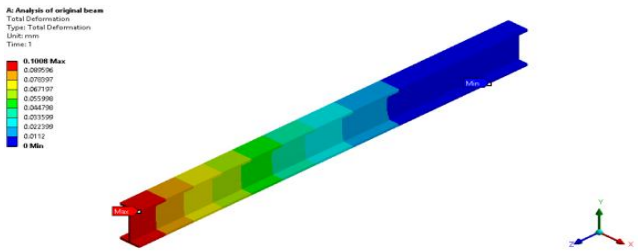

Fig.17. 0.1008 mm Deflection of beam at 100N

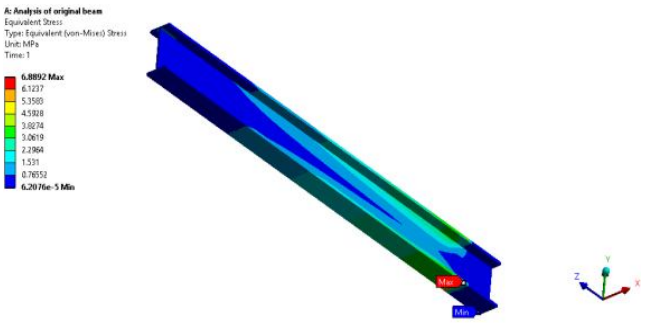

Fig.18. 6.8892MPa Von-Mises stress

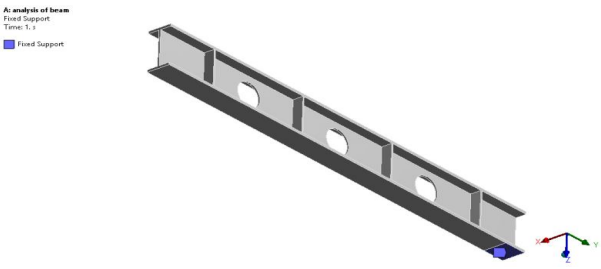

Fig.19. Boundary condition of modified I-section beam

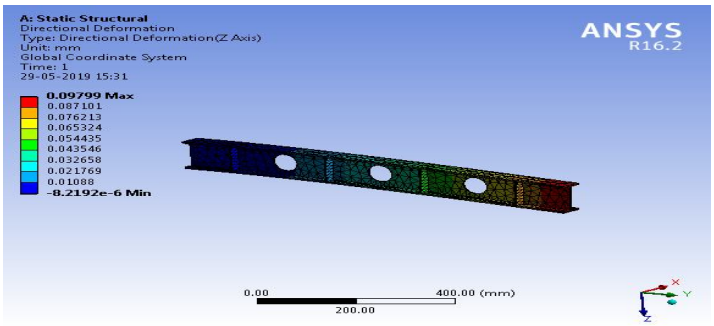

Fig.20. 0.09799 mm Deformation of Modified I-section beam

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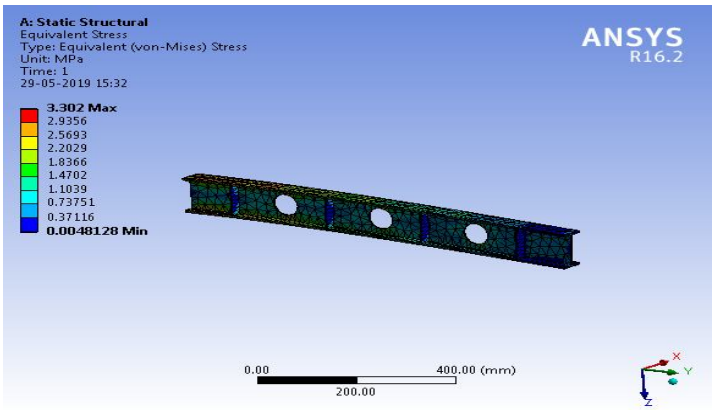

Fig.21. 3.302 MPa Von-Mises stress in modified I-section beam

5) Stress Analysis of Trapezoidal Beam

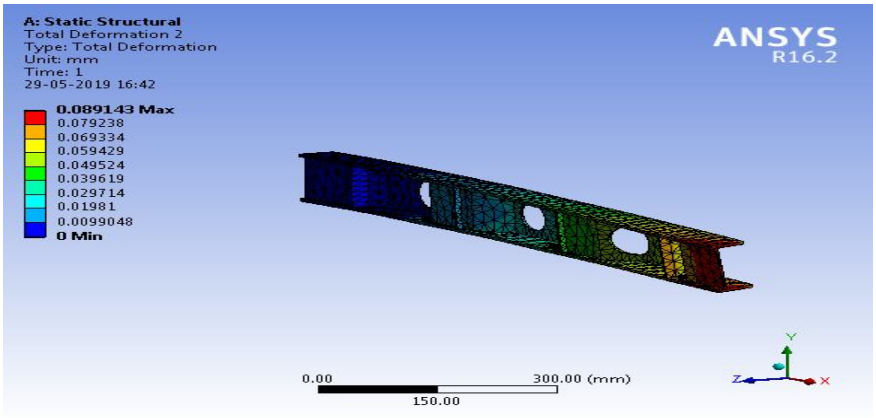

Fig.22. 0.0891mm Deformation of Modified Trapezoidal beam at 100N

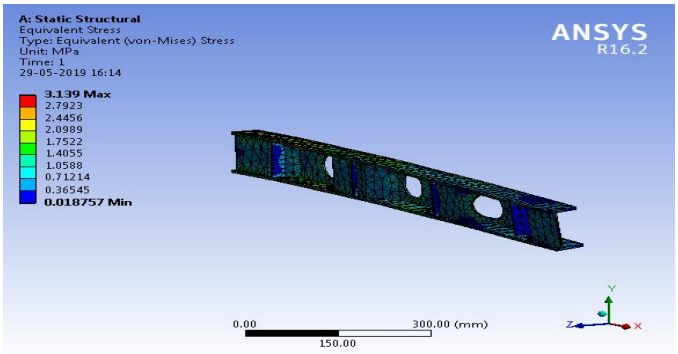

Fig.23. 3.139 MPa Von-Mises stress in Trapezoidal beam

IX. EXPERIMENTAL INVESTIGATION

Vibration Measurement System:-Motion of the vibrating body is converted into an electrical signal by the vibration transducer .In general a transducer is a device that transforms the signal changes in mechanical quantities(such as displacement, velocity, acceleration, force) changes into electrical quantities (such as voltage, current).Since the output signal conversion instrument is utilized to amplify the desired price. The output from the signal conversion instrument can be presented on display unit for visual inspection, or by recorder by recording device or stored in a computer for later use. Depending upon the quantity measured vibration measuring device is termed a Vibrometer, a velocity meter, an accelerometer, a phase meter, or a frequency meter. The following consideration usually dictates the kind of measuring device to be used in a vibration test.

Basic assumption in experimental analysis

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A. The structure is assumed to be linear i.e. the response of the structure to any combination of forces, simultaneously applied, is the sum of the individual responses to each of the forces acting alone.

B. The structure is time invariant, i.e. the parameters that are to be determined are constants. In general, a system which is time invariant has components that's mass, stiffness, or damping depend on factors that are not measured or not included in the model.

C. The structure obeys Maxwell's reciprocity, i.e. a force applied at degree of freedom p causes a response at degree of freedom q that is the same as the response at degree of freedom p caused by a similar force applied at degree of freedom q.

D. The structure is observable; i. e. the input output measurements that are created enough information to get an adequate behavioural model of the structure.

1) FFT Analyzer

Top side connectors

Side connectors

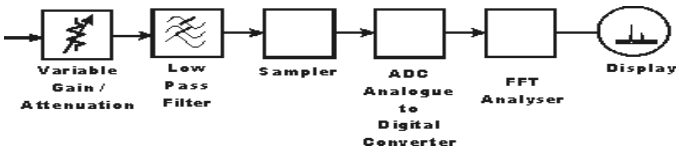

Fig.24. FFT Analyzer Block Diagram

Following apparatus will be used to perform the real experiment:

a) Impact Hammer

b) Accelerometer

c) Multi-channel Vibration Analyzer (DEWESoft-DEWE-43)

d) A PC or a Laptop loaded with software for modal analysis.

e) Test-specimen (A cantilever held in a fixture)

f) Power supply for the PC and vibration analyzer, connecting cables for the impact hammer and accelerometer, fasteners and spanner to fix the specimen in the fixture, and adhesive/wax to fix the accelerometer).

2) Actual Setup FFT Analyzer

Fig.25. Experimental Testing of Modified I-section Beam

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Fig.26. Experimental Testing of Trapezoidal corrugated web Beam

X. RESULT ANALYSIS

A. *Modal Analysis*

1) Modal analysis done by ANSYS software of I-section and modified I-section under same boundary condition as cantilever beam and following results are observed

Table .1. Modal analysis of I-section and Modified I- section

Natural frequency	I-section	Modified I-section
1st	89.06	106.5
2nd	646.36	652.85

Natural frequency of modified I-section beam is increased by 10% as comparison with I-section beam by using ANSYS results.

2) Modal analysis done by ANSYS software of modified I-section and Trapezoidal corrugated web beam hole with stiffener under same boundary condition as cantilever beam and following results are observed

Table 2. Modal analysis of Modified I- section andTrapezoidal corrugated web beam

Natural frequency	Modified I-section	Trapezoidal corrugated web beam
1st	106.50	111.47
2nd	652.85	691.094

Natural frequency of Trapezoidal corrugated web beam is increased by 4% as comparison with Modified I-section beam by using ANSYS results.

B. *Strength Analysis*

1) By using Ansys software I-section and modified I-section loaded with same boundary condition as cantilever beam at 100N and following results are observed

Table .3.Strength analysis of I- section and Modified I- section

Sr. No	I-section	Modified I-section
Von-Mises Stress in MPa	6.88	3.3020
Deflection in mm	0.1008	0.0979

Deflection observed in I-section beam is 3% more than modified

I-section beam and Von-Mises stress observed in I-section beam is 35% more than Modified I-section beam at 100N by using ANSYS results.

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2) By using Ansys software modified I-section and Trapezoidal corrugated web with hole with stiffener loaded with same boundary condition as cantilever beam at 100N and following results are observed

Table .4.Strength analysis of Modified I- section and Trapezoidal corrugated web

Sr. No	Modified I-section	Trapezoidal web beam
Von-Mises Stress in MPa	3.3020	3.139
Deflection in mm	0.0979	0.0891

XI. EXPERIMENTAL RESULT ANALYSIS

By using FFT software both beam modified I-section and Trapezoidal corrugated web beam hole with stiffener under same boundary condition as cantilever beam tested Experimentally and following results are observed

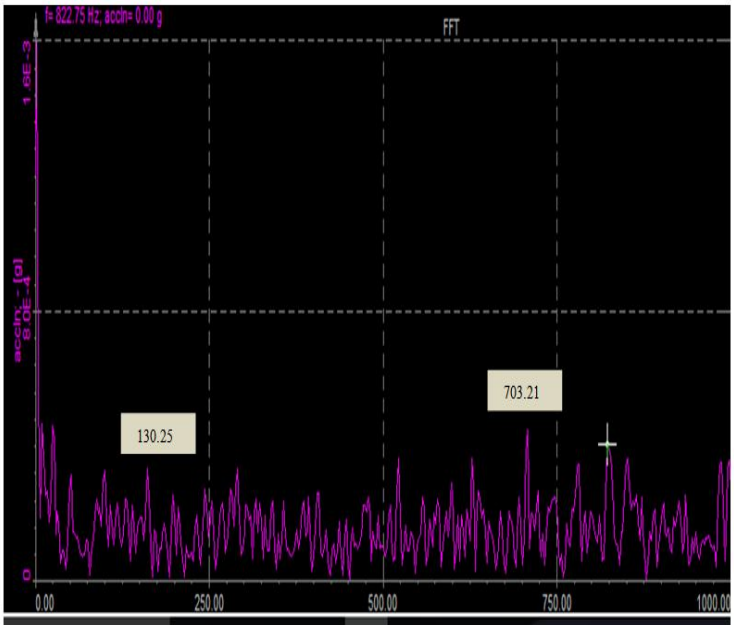

Fig.27.FFT Graph of Modified I-section beam

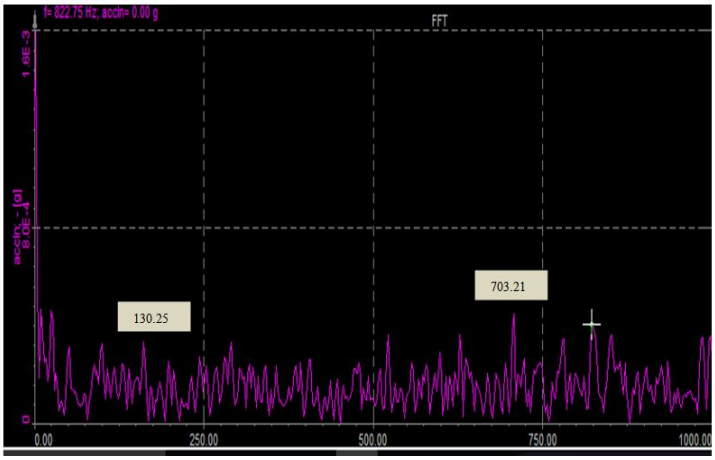

Fig.28. FFT Graph of Trapezoidal corrugated web beam

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Table.5. Natural Frequency of Trapezoidal corrugated web
And Modified I-section By FFT

Natural frequency in Hz	Modified I-section	Trapezoidal corrugated web beam
1st	128.2	130.25
2nd	665.5	703.21

Natural frequency of Trapezoidal corrugated web beam is increased by 5% as comparison with Modified I-section beam by using Experimental result analysis by FFT

XII. RESULTS & DISCUSSION

Table.6. Comparing the variation in natural frequencies of modified I-section beam by FEA and Experimental result.

Results	1st Natural Frequency in Hz	2nd Natural Frequency in Hz
FEA	128.2	130.25
Experimental	665.5	703.21

Variation in natural frequencies of modified I-section beam by FEA and experimental results 10% which is in acceptable range.Variation may present due to boundry condition applied in FEA and Experimentation are not equal.

Table.7. Comparing the variation in natural frequencies of Trapezoidal corrugated web beam by FEA and Experimental result.

Results	1st Natural Frequency in Hz	2nd Natural Frequency in Hz
FEA	111.47	691.09
Experimental	130.25	703.21

Variation in natural frequencies of modified I-section beam by FEA and experimental results 8% which is in acceptable range.Variation may present due to boundry condition applied in FEA and Experimentation are not equal.

XIII. CONCLUSION

By using theory of deflection of beam the deflection is directly proportional to square of length beam and inversely proportional to moment of Inertia. The length of Trapezoidal web increases which bears most of compressive stress which resists the deflection of beam. The shear stress are dependent upon the area of contact between the flange and web, for trapezoidal beam more area of contact is present as compare to I-section beam. Experimental results of FFT are with some variation matching with the FEM hence we can replace modified I-section beam with Trapezoidal corrugated web beam hole with stiffener. The Natural frequencies of Trapezoidal corrugated web beam with hole with stiffener increases as compared to natural frequencies of modified I-section beam to avoid resonance with earthquake frequencies.

XIV. ACKNOWLEDGMENT

It is indeed a great pleasure and moment of immense satisfaction for me to present a Project report on“Experimental Analysis Of Trapezoidal Corrugated web beam with stiffner for its strength and modes” amongst a wide panorama that provided us inspiring guidance and encouragement, I take the opportunity to thanks to thanks those who gave us their indebted assistance. I wish to extend my cordial gratitude with profound thanks to our internal guide Prof. M. M. Joshi It was his inspiration and encouragement which helped us in completing my work. I am also thankful to Prof. S. M. Jadhav, PG Co-ordinator for his overwhelming support and invaluable guidance. My sincere thanks and deep gratitude to Head of Department, Prof. D. H. Burande and other faculty members; but also to all those individuals involved both directly and indirectly for their help in all aspect of the Project. At last but not least I express my sincere thanks to the Institute’s Principal Dr. Y. P. Reddy, for providing us infrastructure and technical environment.

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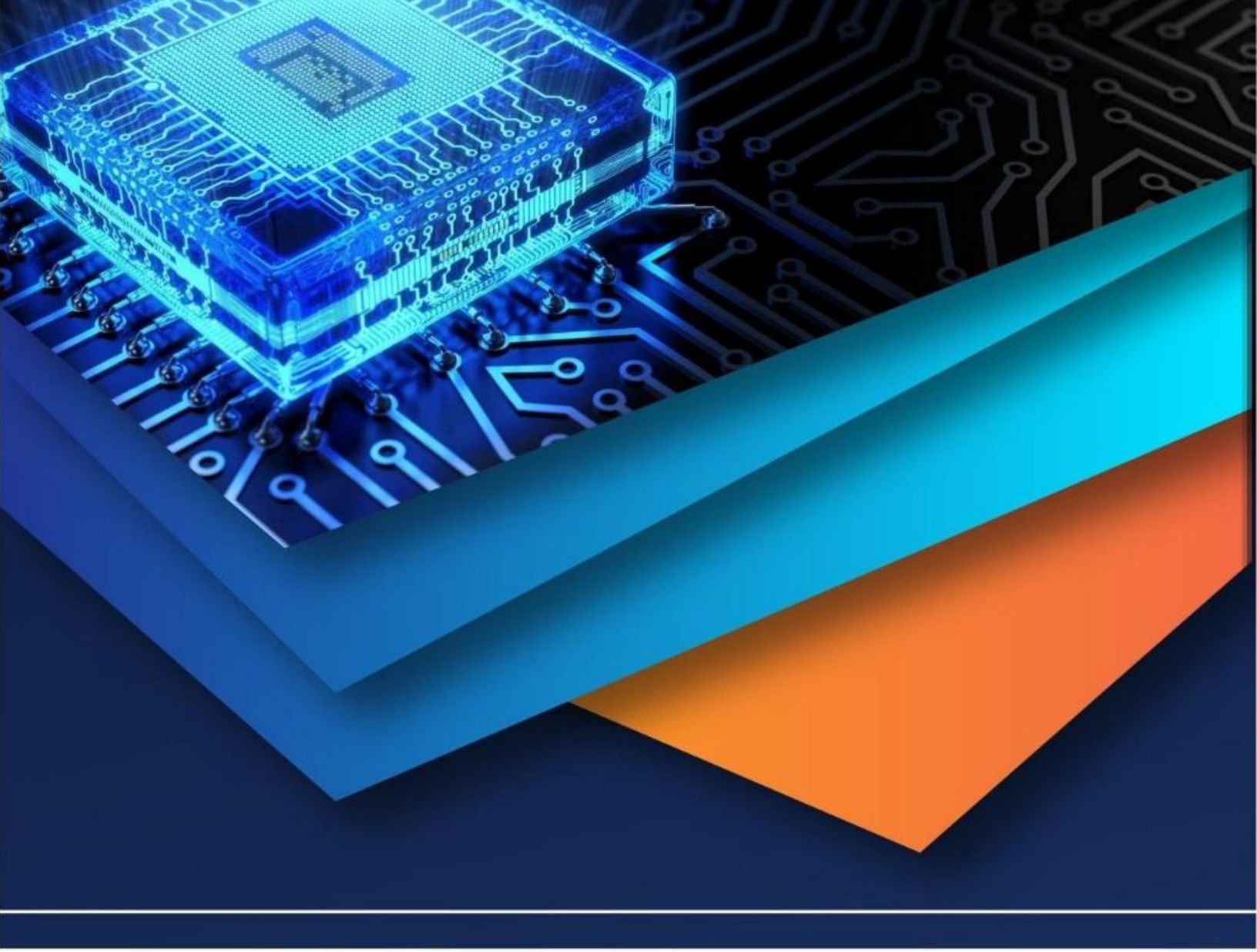

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