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Analysis of Stress and Deflection Patterns in Railroad Ties Subjected to Static and Dynamic Loads

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Abstract: A railroad tie, cross tie, or sleeper is a rectangular object used as a base for railroad tracks. Traditionally, ties have been made of wood, later steel has also been used and concrete is now widely used along with composite materials. To determine the various stresses in the ties due to static and dynamic loads, the finite element method is used which is accurate and time saving. The FEM has developed simultaneously with the increasing use of high speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. The systematic generality of the finite element procedure makes it a powerful and versatile tool for a wide range of problems. In this project, the finite element analysis software such as ANSYS R11.0 is used to carry out the stress analysis. In this work, 3D analysis is used to carry out a railroad tie made of steel and composite materials under static and dynamic loads. A detailed model of the tie is created using ANSYS geometric modeling options. Due to static loading the stress distributions and deflections are investigated. The plots of distribution of stress is depicted with the results and their influence on the tie is discussed. Further modal, harmonic and transient analysis is performed to obtain dynamic stability. The analysis suggests that composite ties can be used instead of steel ties and stress in the ties can further be reduced by increasing the thickness of composite ties and can have greater life. But the major problem with composites is higher initial cost.

Keywords: Composite, concrete, Deformation, Harmonic and Railroad tie

I. INTRODUCTION

A railroad tie, cross tie, or railway sleeper is a rectangular object used as a base for railroad tracks. Sleepers are members generally laid transverse to the rails, on which the rails are supported and fixed, to transfer the loads from rails to the ballast and sub grade, and to hold the rails to the correct gauge. Traditionally, ties have been made of wood. Later steel ties were developed, but concrete is now widely used. Composite ties are currently used as well, however far less than concrete ties. Ties are normally laid on top of track ballast, which supports and holds them in place, and provides drainage and flexibility. Heavy crushed stone is the normal material for the ballast, but on lines with lower speeds and weight, sand, gravel, and even ash from the fires of coal-fired steam locomotives have been used. They are laid across the grade at intervals of about two feet. The steel rails are then laid atop the ties, perpendicular to them. If the ties are wood, then cleats are laid down and spikes driven through them into the ties to clamp down the rails. The rails are held on wooden ties with rail spikes. For concrete ties, steel clips (for example the Pandrol clip) are often used to fasten the rails. After this is done, additional ballast is then added to fill the spaces between and around the ties to anchor them in place. The ties then act as anchors and spacers for the rails, while providing a slight amount of give to accommodate weather and settling. The ties are "floating" in the top of the ballast. Failure of a single tie is generally insignificant to the usability and safety of the rails. A datenail was implemented and coded by the railroads to identify the age of the railroad tie (that was usually laid down in sections) by hammering it into the railroad tie after installation for maintenance purposes. A typical mile of rail contains approximately 3,000 ties.

Concrete ties have become more common mainly due to greater economy and better support of the rails under heavy traffic. As concrete technology developed in the 19th century, concrete established its place as a versatile building material and could be adapted to meet the requirements of railway industry. Due to research carried out on French and other European railways, the modern concrete tie was developed. Heavier rail sections and long welded rails were also being produced, requiring higher-quality ties. These conditions spurred the development of concrete ties in France, Germany and Britain, where the technology was perfected.

Fig 1 Mounting and hangers

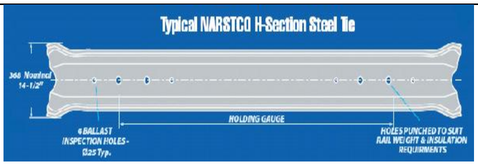

Fig 2 H-section steel tie

II. METHODOLOGY

Table 1 Material properties of the steel

Material	Young's modulus	Poisson's ratio
Steel	2.1e5N/mm2	.3

Table 2 Material properties of carbon epoxy:

Elastic Constraint	Property(GPa)
EXY	181
EYZ	10.3
EXZ	10.3
PRXY	.28
PRYZ	.28
PRXZ	.28
GXY	7.17
GYZ	7.17
GXZ	7.17

Static analysis of the hh10 tie and hh12 tie

In the modelling of the HH10 tie, the steps in the preprocessor are followed and the coordinates taken.

Table 3 Geometric points of HH10 tie and HH12 tie

HH10 tie			**HH12 tie**		
Keypoint	**x-coordinate**	**y-coordinate**	**Key point**	**x-coordinate**	**y-coordinate**
1	150	120	1	150	122
2	233	120	2	229	122
3	275	62	3	272	64
4	288	20	4	287	21
5	300	16	5	300	18
6	300	9	6	300	12
7	290	0	7	289	0
8	267	56	8	257	68
9	230	110	9	225	110
10	150	110	10	150	110

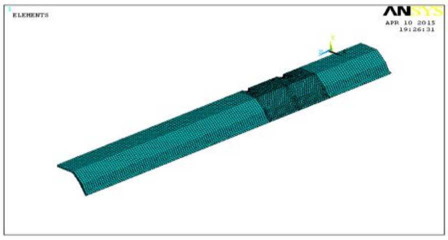

Fig 3 meshed elements of the HH10 tie.

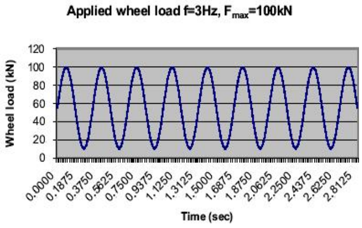

Fig 4 Transient load definition for 3Hz

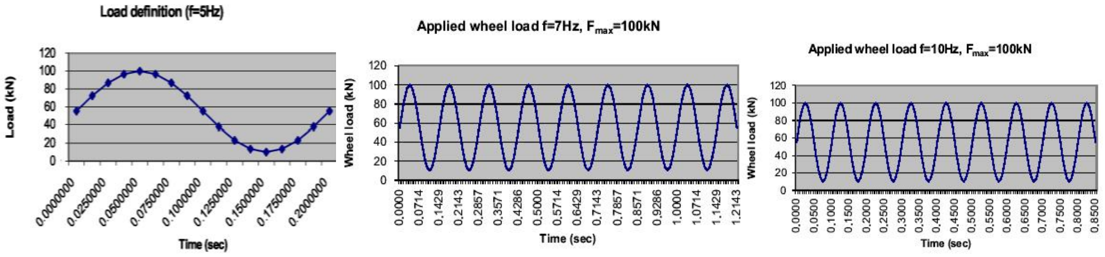

Fig.5 Transient Load Definition for 5Hz, 7Hz and 10Hz

STATIC ANALYSIS OF 12mm COMPOSITE TIE

Table 4 Geometric points of 12mm composite tie

Key point	x-coordinate	y-coordinate
1	150	122
2	229	122
3	272	64
4	287	21
5	300	18
6	300	12
7	289	0
8	257	68
9	225	110
10	150	110

III. RESULTS AND DISCUSSIONS

This chapter deals with the presentation of results obtained and a brief discussion of what has been achieved. The results obtained due to static and dynamic loads on the tie made of both steel and composite materials are incorporated.

Static analysis of railroad tie

Three models of railroad ties are created with different materials.

Steel tie of thicknesses 10mm, 12mm and Composite tie of thickness 12mm

All these models are subjected to same meshing and loading conditions. Same analysis procedure is followed for all the three of them. Stresses and deflections are determined for all the ties under static loading. The following table represents the results regarding the stresses of maximum stresses and deflections induced in various ties.

Table 5 Representing Maximum stresses and deflections induced in the tie

Type of railroad tie	Steel 10mm thickness	Steel 12mm thickness	Composite 12mm thickness
Maximum stress (MPa)	82.069	70.451	68.609
Maximum Deflection(mm)	5.223	4.014	2.414

The results regarding the stresses of maximum stresses and deflections induced in various ties are as follows.

Results of stresses induced and deflections of hh10 tie under static loading

Fig shows the pattern of the longitudinal stress on the tie loaded by an axle load of 200 KN. Maximum value of the longitudinal stress: 45.827MPa for compression; 34.629 MPa for tension.

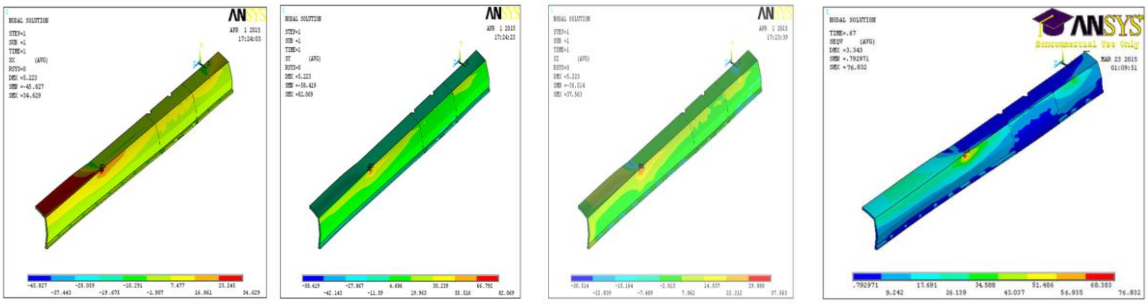

Fig.6 Variation of Stress in X,Y,Z directions of HH10 Tie, MPa & Vonmises stress variation at time 0.67sec in steel 10mm tie (3 Hz), MPa

Fig shows the pattern of the transverse stress on the HH10 tie loaded by an axle load of 200KN.Maximum value of the transverse stress: 82.069MPa for tension; 58.419 MPa for compression. Fig shows the pattern of the lateral stress on the HH10 tie loaded by an axle load of 200KN.Maximum value of the lateral stress:37.563MPa for tension; 30.514 MPa for compression.**F**ig shows the variation of Vonmises stress on the HH10 steel tie when loaded with fig at an accumulated time of 0.67 sec, maximum value of the stress is 76.832MPa.

RESULTS OF TRANSIENT ANALYSIS OF THE HH10 TIE

Table 6 shows values of variables on Transient analysis of HH10 steel tie when dynamic assessments are carried out

Frequency (Hz)	Name	Node	Result item	Max	Frequency (Hz)	Name	Node	Result item	Max
3	UX-2	9840	X-comp. of disp.	16.21	7	UX-2	9840	X-comp. of disp.	16.85
3	UY-3	9840	Y- comp. of disp.	0	7	UY-3	9840	Y- comp. of disp.	0
3	UZ-4	9840	Z- comp. of disp.	24.36	7	UZ-4	9840	Z- comp. of disp.	24.71
3	SX-5	9840	X-comp. of stress	42.25	7	SX-5	9840	X-comp. of stress	42.89
3	SY-6	9840	Y-comp. of stress	11.25	7	SY-6	9840	Y-comp. of stress	11.76
3	SZ-7	9840	Z-comp. of stress	55.15	7	SZ-7	9840	Z-comp. of stress	55.45
3	SEQV	9840	Vonmises stress	76.83	7	SEQV	9840	Vonmises stress	84.79
5	UX-2	9840	X-comp. of disp.	16.51	10	UX-2	9840	X-comp. of disp.	17.19
5	UY-3	9840	Y-comp. of disp.	0	10	UY-3	9840	Y-comp. of disp.	0
5	UZ-4	9840	Z-comp. of disp.	24.65	10	UZ-4	9840	Z-comp. of disp.	25.12
5	SX-5	9840	X-comp. of stress	42.38	10	SX-5	9840	X-comp. of stress	43.1
5	SY-6	9840	Y-comp. of stress	11.46	10	SY-6	9840	Y-comp. of stress	12.25
5	SZ-7	9840	Z-comp. of stress	55.23	10	SZ-7	9840	Z-comp. of stress	55.6
5	SEQV	9840	Vonmises stress	80.25	10	SEQV	9840	Vonmises stress	89.95

Transient Analysis Results of 10mm Steel Tie At 3Hz

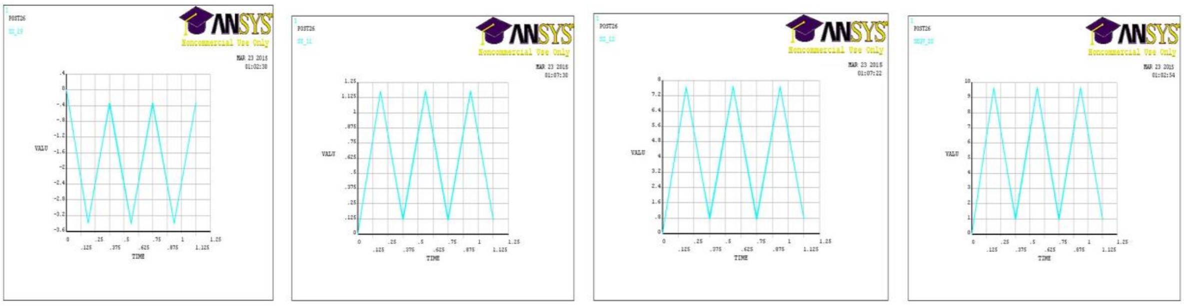

Fig 7 shows the variation of stress in X,Y,Z-direction at a frequency of 3Hz & variation of vonmises stress at a frequency of 3Hz

Transient analysis results of 10mm steel tie at 10Hz

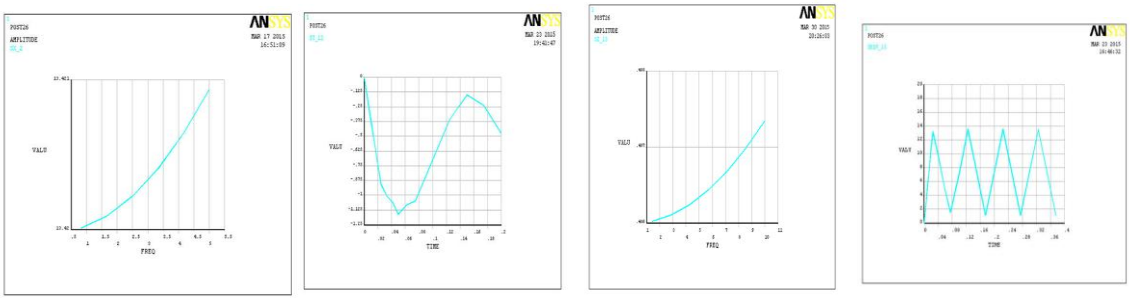

Fig 8 shows the variation of stress in X,Y,Z-direction at a frequency of 10Hz &variation of von-mises stress at a frequency of 10Hz

RESULTS OF STRESSES INDUCED AND DEFLECTIONS OF HH12 TIE UNDER STATIC LOADING

Fig shows the pattern of the longitudinal stress on the HH12 steel tie loaded by an axle load of 200KN.Maximum value of the longitudinal stress:30.77MPa for tension; 36.434 MPa for compression.

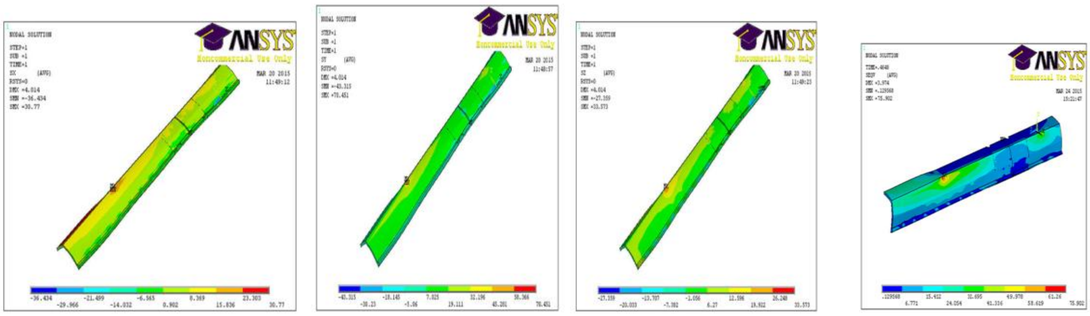

Fig.9 Stress in X,Y,Z directions of HH12 Tie, MPa & Vonmises stress variation at time .4648 sec in steel 12mm tie (3 Hz), MPa

Fig shows the pattern of the transverse stress on the HH12 steel tie loaded by an axle load of 200KN.Maximum value of the transverse stress:70.451 MPa for tension; 43.315 MPa for compression. Fig shows the pattern of the lateral stress on the HH12 steel tie loaded by an axle load of 200KN.Maximum value of the transverse stress:33.573MPa for tension; 27.359 MPa for compression. **F**ig shows the variation of vonmises stress on the HH12 steel tie when loaded with fig at an accumulated time of 0.4648 sec & maximum value of the stress is 75.902 MPa.

RESULTS OF TRANSIENT ANALYSIS OF HH12 STEEL TIE

Table shows the values of variables in transient analysis on HH12 steel tie with axle load varying

Table 7 Variables in Transient Analysis on HH12 Steel & HH12 Steel

Frequency (Hz)	Name	Node	Result item	Max	Frequency (Hz)	Name	Node	Result item	Max
3	UX-2	10058	X-comp. of disp.	13.24	7	UX-2	10058	X-comp. of disp.	13.73
3	UY-3	10058	Y- comp. of disp.	0	7	UY-3	10058	Y- comp. of disp.	0
3	UZ-4	10058	Z- comp. of disp.	22.42	7	UZ-4	10058	Z- comp. of disp.	22.45
3	SX-5	10058	X-comp. of stress	39.51	7	SX-5	10058	X-comp. of stress	39.52
3	SY-6	10058	Y-comp. of stress	9.73	7	SY-6	10058	Y-comp. of stress	9.73
3	SZ-7	10058	Z-comp. of stress	52.27	7	SZ-7	10058	Z-comp. of stress	52.27
3	SEQV	10058	Vonmises stress	75.90	7	SEQV	10058	Vonmises stress	82.5
5	UX-2	10058	X-comp. of disp.	13.62	10	UX-2	10058	X-comp. of disp.	14.27
5	UY-3	10058	Y-comp. of disp.	0	10	UY-3	10058	Y-comp. of disp.	0
5	UZ-4	10058	Z-comp. of disp.	22.42	10	UZ-4	10058	Z-comp. of disp.	23.25
5	SX-5	10058	X-comp. of stress	39.51	10	SX-5	10058	X-comp. of stress	39.52
5	SY-6	10058	Y-comp. of stress	9.75	10	SY-6	10058	Y-comp. of stress	10.23
5	SZ-7	10058	Z-comp. of stress	52.27	10	SZ-7	10058	Z-comp. of stress	52.27

5	SEQV	10058	Vonmises stress	78.8	10	SEQV	10058	Vonmises stress	86.75

Transient analysis results of 12mm steel tie at 3Hz

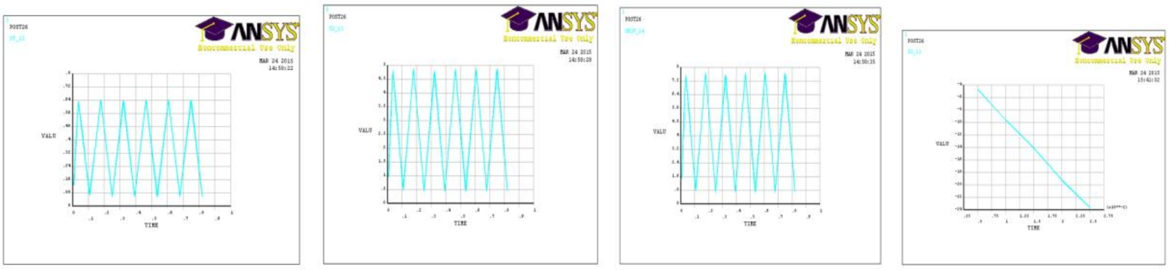

Fig 10 shows the variation of stress in x,y,z-direction & vonmises stress at a frequency of 3Hzwhen the axle load varies as shown in fig

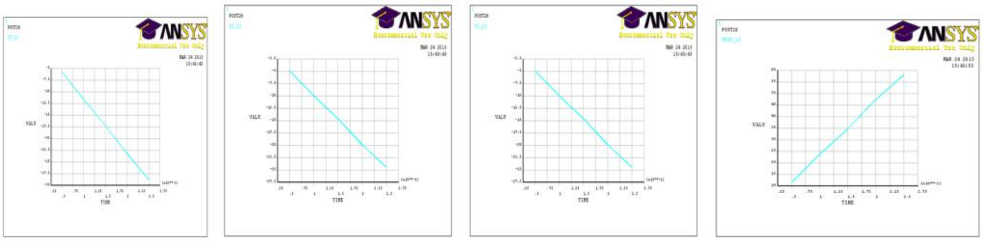

Fig 11 shows the variation of stress in x, y,z-direction & vonmises stress at a frequency of 10Hz when the axle load varies as shown in fig.

RESULTS OF STRESSES AND DEFLECTIONS OF 12mm COMPOSITE TIE UNDER STATIC LOADING

Fig shows the pattern of the longitudinal stress on the HH12 composite tie loaded by an axle load of 200KN.Maximum value of the longitudinal stress: 27.099MPa for tension; 29.942 MPa for compression.

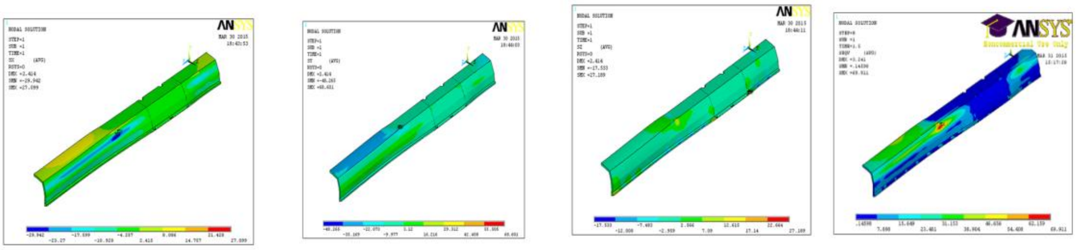

Fig.12 Stress in x,y,z-direction & Vonmises stress variation at time 1.5sec of 12mm composite tie, MPa

Fig shows the pattern of the transverse stress on the HH12 composite tie loaded by an axle load of 200KN.Maximum value of the transverse stress:68.601 MPa for tension; 48.265MPa for compression. Fig shows the pattern of the lateral stress on the HH12 composite tie loaded by an axle load of 200KN.Maximum value of the lateral stress:27.189MPa for tension; 17.533MPa for compression. **F**ig shows the variation of vonmises stress on the HH12 Composite tie when loaded with fig at an accumulated time of 1.5 sec & maximum value of the stress is 69.911 MPa

Table 8 Transient analysis results of 12mm composite tie. Transient analysis results of 12mm composite tie

Frequency (Hz)	Name	Node	Result item	Max
3	UX-2	9713	X-comp. of disp.	5.47
3	UY-3	9713	Y- comp. of disp.	0
3	UZ-4	9713	Z- comp. of disp.	9.01
3	SX-5	9713	X-comp. of stress	41.25
3	SY-6	9713	Y-comp. of stress	64.42
3	SZ-7	9713	Z-comp. of stress	45.28
3	SEQV	9713	Vonmises stress	69.91

5	UX-2	9713	X-comp. of disp.	5.69
5	UY-3	9713	Y-comp. of disp.	0
5	UZ-4	9713	Z-comp. of disp.	11.61
5	SX-5	9713	X-comp. of stress	51.44
5	SY-6	9713	Y-comp. of stress	50.02
5	SZ-7	9713	Z-comp. of stress	57.89
5	SEQV	9713	Vonmises stress	71.65

Frequency (Hz)	**Name**	**Node**	**Result item**	**Max**
7	UX-2	9713	X-comp. of disp.	5.82
7	UY-3	9713	Y- comp. of disp.	0
7	UZ-4	9713	Z- comp. of disp.	12.75
7	SX-5	9713	X-comp. of stress	41.58
7	SY-6	9713	Y-comp. of stress	64.14
7	SZ-7	9713	Z-comp. of stress	48.85
7	SEQV	9713	Vonmises stress	73.24
10	UX-2	9713	X-comp. of disp.	5.99
10	UY-3	9713	Y-comp. of disp.	0
10	UZ-4	9713	Z-comp. of disp.	13.83
10	SX-5	9713	X-comp. of stress	34.83
10	SY-6	9713	Y-comp. of stress	38.08
10	SZ-7	9713	Z-comp. of stress	60.5
10	SEQV	9713	Vonmises stress	75.45

Transient analysis results of 12mm composite tie at 3Hz

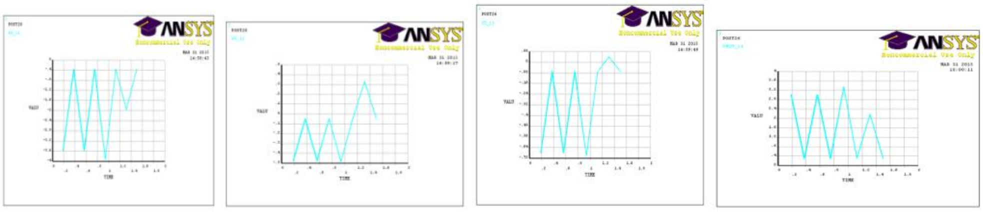

Fig 13 shows the variation of stress in x,y,z-direction & vonmises stress at a frequency of 3Hz when the axle load

Transient analysis results of 12mm composite tie at 10Hz

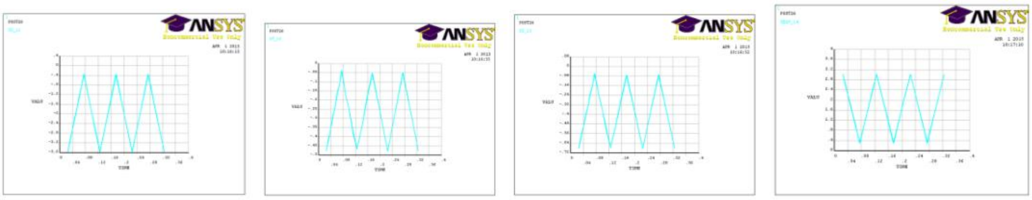

Fig 14 shows the variation of stress in x,y,z-direction & vonmises stress at a frequency of 10Hz when the axle load varies as shown in fig

Graphs shows the variation between HH10steel,HH12steel and Laminated composite ties in various aspects

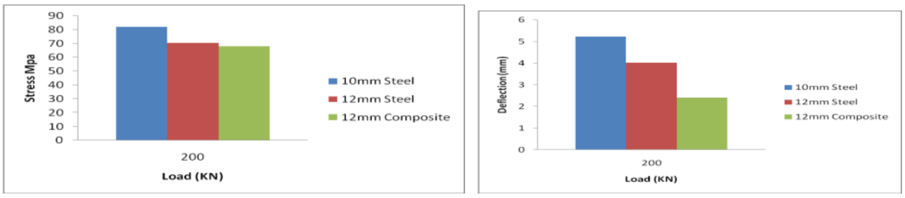

Fig 15 shows the variation of maximum stresses maximum deflections of steel and composite tie under static loading

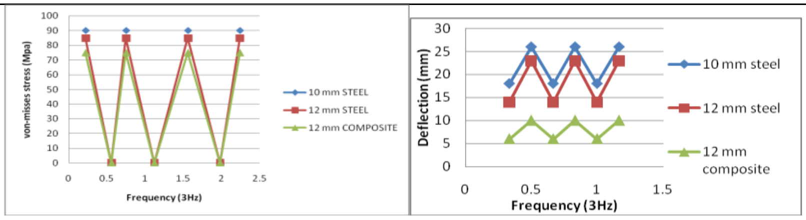

Fig16 shows the variation of von-misses stress variation of deflections in steel and composite tie at a frequency of 3Hz

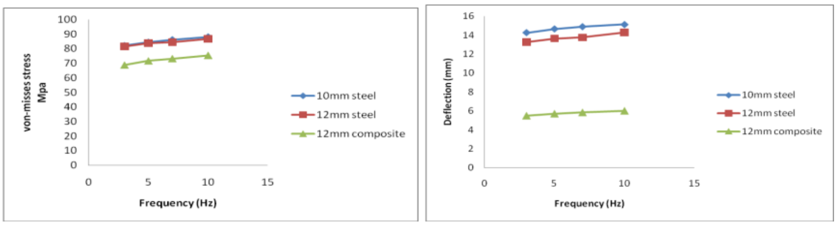

Fig 17 shows the variation of von-misses stress variation of deflections in steel and composite tie at the different frequencies (Hz)

IV. RESULTS OF MODAL ANALYSIS

Using Lanczo's method with consistent mass the natural frequencies for the tie made of steel and composite are shown in table

Table 9 Modal Analysis

S.No	Steel		Composite 12mm thick
	10mm thick	12mm thick	
1	278.73	279.23	282.36
2	308.35	351.84	354.25
3	445.25	465.16	477.80
4	558.46	560.65	612.37
5	678.85	680.22	688.04
6	738.33	775.89	822.93
7	868.05	799.52	1046.2
8	883.47	999.68	1100.6
9	1030.8	1108.9	1255.8

V. CONCLUSIONS

The solid and finite element models of steel and composite railroad ties have been generated successfully. The effect of thickness in steel and composite ties on the stresses and deflections has been established. From the results obtained, it is concluded that the values of these stresses and deflection decrease by increasing the thickness. The effect of type of material in railroad ties on the stresses and deflections has been established. From the results obtained, it is concluded that the values of these stresses and deflection decrease by changing the material in composite ties. The maximum stresses induced in 10mm steel tie,12mm steel tie and 12mm composite tie are found to be 82.069Mpa,70.4Mpa,68.6Mpa and corresponding deflections induced are found to be 5.223 mm,4.014 mm and 2.414mm respectively. From the static analysis, it is observed that the maximum stress induced is less in composite ties of 12mm thickness when compared to steel ties of 10mm and 12mm thickness at same loading conditions. The maximum stress in composite ties is found out to be 681.6 MPa and the maximum deflection in composite tie is less than the steel tie. Hence the composite tie is more stable due to its rigidity and strength and is best suitable than steel ties due to its long life as per design point of view and they have very less wear and tear and no corrosion. From the modal analysis, it is concluded that the natural frequencies are high in the composite ties when compared to steel ties. From the dynamic analysis, it is observed that the stresses in longitudinal direction are more when compared to transverse and lateral directions. The stresses and deflection in longitudinal direction are more in steel ties when compared to composite ties at same loading conditions. From the above results it can be concluded that under the same load the composite tie is the best as per the strength criteria. Hence the composite ties will be alternate material for the tie.

CONTRIBUTION

This work contributes the modeling aspects of railroad ties, also an exact stress analysis is performed and the results obtained are quite similar for the assumed set of conditions.

FUTURE SCOPE OF THE WORK

The present work is carried out by modeling the steel and composite ties. Future endeavors may look for a model with different materials of varying thickness and different cross-sections which can give more information regarding the railroad ties.

Future study may include more parameters and various other loading conditions that might affect the stresses and deflections in railroad ties.

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