Weight Reduction, Modal Analysis and Testing of an Indian Railway Light Weight Bogie Bolster

[1]Dr. Sanjay Shukla, [2]Umesh Kumar, [3]Satish Kumar, [4]Parinay Gupta, [5]Anirudh Kumar, [6]Sanjay Kumar
[1,2,3]Senior. Section Engineer (Design), [4]Joint Director (Components Design),
[5]Director (Wagon Production), [6]Executive Director (Standards Wagon)
Wagon Directorate, Research Designs and Standards Organisation, Lucknow-226011, U.P. (India)

***Abstract* - Bolster used for three piece freight bogie is the central section that carries the weight of a freight vehicle under frame. Presently Ministry of Railways is planning to introduce light weight freight bogie for high speed freight trains to enhance better pay to tare ratio, resulting in increased throughput as well as to shrink the track forces significantly. Present study deals with weight reduction of an Indian Railways low height bogie bolster simultaneously enhancing the axle load from 22.9 to 25.0 ton. The cast steel bolster is modeled according to drawings using NX- 7.5, UGS software. Structural analysis is performed to locate the critical zones and surfaces with the help of Finite Element Method (FEM) using MSC FEA software for weight reduction. Load cases and boundary conditions are applied as per International standards Association of American Railroad (AAR specification M-202) [1]. The weight of the bolster has been reduced to approximately 13.30% through multiple iterations to modify the initial design. Fatigue strength is considered for weight reduction of the bolster with the help of transient analysis using the dynamic loading conditions extracting from Multi Body Dynamics (MBD) software and these results are verified by using Goodman diagram. Eigenvalues and eigenvectors are obtained from modal analysis of the bolster to compare the mode shapes of the initial and modified design. Further based on modified design parameters a prototype has been developed by Indian Railways for actual test and trial. The test bogie is fitted with GONDOLA freight vehicle. Test trials of modified bogie have been successfully completed by Testing Directorate of Research Designs and Standards Organisation (RDSO) with open wagon in East Coast Railway [2].**

***Index Terms*- Bolster, Finite element, Low Height Bogie, Modal Analysis, Throughput, Three Piece, Weight Reduction**

I. INTRODUCTION

Railway is most cost-effective, prompt and secure means of transportation. Indian Railway is endeavoring to increase the throughput by reducing the tare load at the same time enhancing the axle loads of freight stock to increase the revenue accruals. The weight of the bogie should be less for high speed operations. An attempt of design modification is performed by iterative evaluation and geometrical variation of the bolster design. The strength of the bolster and calculated by designers as per International Standard AAR M202 [1]. The actual performance of the bogie with freight vehicle car body is evaluated by the trials of prototype as per modified parameters on specified track conditions.

The cast steel bolster is made of AAR M-201grade B^+ class is considered for present study. Ribs plates are provided inside the hollow bolster to enhance the strength. A center pivot plate and two side bearer arrangements are provided to transfer the Traction/Braking and vertical loads respectively in service. Four pockets at each corner are designed to provide friction damping with wedge block and snubber spring. Eight lugs two at each corner are provided for controlling the lateral displacement during dynamic condition. The details of the bogie model and GONDOLA wagon are shown in Fig. 1 and 2 respectively.

A structural analysis of a Korean tilting train bogie bolster was performed by Kim et al. [3]. The static main service load case and dynamic tilting loads were investigated using FE and multi body dynamics environments respectively. The fatigue strength was performed up to $10 * 10^6$ cycles under tilting load condition and the stress values were verified on Goodman diagram. Li et al. [4] studied fatigue strength of subway vehicle bogie frame by rain-flow cycle counting method. Tang et al. [5] evaluated fatigue strength of DMU bogie frame with Goodman plots. Further modal analysis of the bogie frame was performed to determine practical operational constrains of the modal. Shukla et al. [6] optimized the weight of the Indian Railways freight bogie frame by evaluating the fatigue strength on Goodman diagram using dynamic loading conditions. Bubnov et al. [7] investigated casted bogie parts (bolster and side frame) strength using FE methods and modern computer technology for assessment of stress-strain state of three dimensional parts. The weight of Korean passenger bogie is reduced approximately up to 4.7% by Park et al. [8] using MBD modeling, Genetic algorithm and Goodman diagram.

A solid model of the cast steel low height bolster working with 22.9 ton axle load bogie is developed in NX-7.5 UGS interface [9]. Model is solid meshed in MSC FEA software [10]. Load cases and boundary conditions as per AAR M-202 are applied on FE meshed model to locate the critical areas and surfaces. Multiple iterations have been performed to reduce the weight of the bolster and evaluate its performance by enhancing axle load capacity up to 25 ton. The Fatigue strength of the modified bolster design is evaluated with the help of transient analysis using the dynamic load cases extracting from MBD freight vehicle model Shukla et al. [11]. The results of the transient analysis are verified on Goodman diagram. Eigenvectors have been compared by performing modal analysis of Initial and modified design. Based on modified design a prototype of bogie has been developed and the bogie is fitted with GONDOLA wagon. The wagon has qualified the specified trail standards.

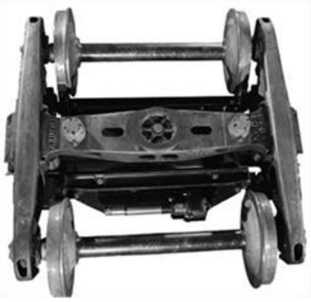

Fig. 1: Light weight Bogie

Fig. 2: Light weight Bogie

II. FINITE ELEMENT ANALYSIS

A full scale solid model of the low height cast steel bolster is developed excluding small hole and curves in NX-7.5 UGS software as shown in Fig. 3. Material properties of the AAR M-201 grade B^+ class cast steel bolster is given in Table 1. One end of the meshed bolster model is constrained Longitudinal, Lateral and Vertical and the other end is only constrained in longitudinal and vertical direction, the motion along the track is longitudinal direction. Indian Railway in service load cases and boundary conditions for 25 ton axle load capacity are calculated as per AAR Specification M-202 are shown from Figs. 4 to 10. Vertical load cases load cases 2, 6 and 7 as shown in Figs. 4, 8 and 9 are due to gross load at various loading condition on central pivot. Load coming on side bearers due to rolling of vehicle in motion are defined in load cases 3 and 5 as shown in Figs. 5 and 7. Transverse load cases 1 and 4 are generated during Tractions and braking of freight vehicle as shown in Fig. 3 and 6. Structural analysis of the bolster model systematically applying above given seven load cases is performed in MSC FEA interface explained in next sub section.

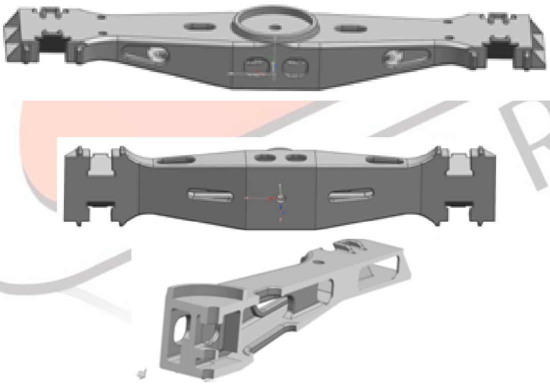

Fig. 3: Initial bolster model with.

Table 1: Material Properties

Property	Value	Value
Yield Stress	344.40	MPa
Ultimate Stress	551.04	Mpa
Endurance Limits	220.42	Mpa
Young Modulus	210.00	GPa
Density	7850.00	Kg/m^3
Poisson’s Ratio	0.30	--

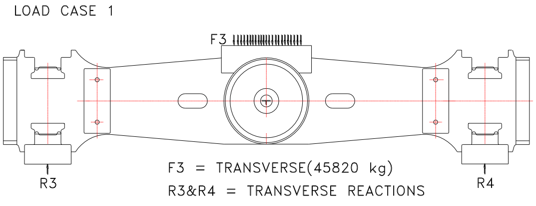

Fig. 4: Load case 01 in transverse direction.

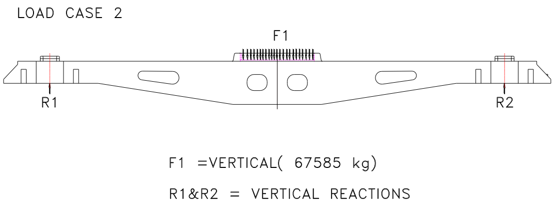

Fig. 5: Load case 02 in Vertical direction.

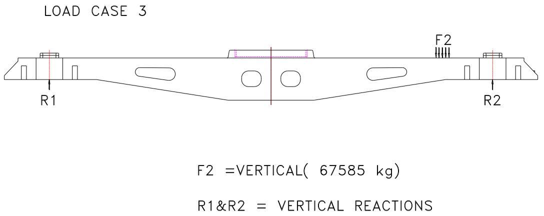

Fig. 6: Load case 03 in vertical direction.

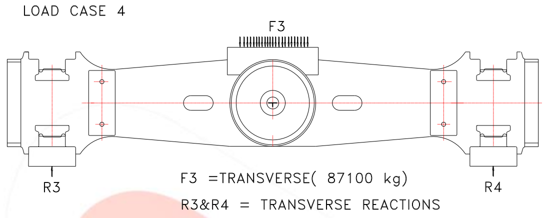

Fig. 7: Load case 04 in transverse direction.

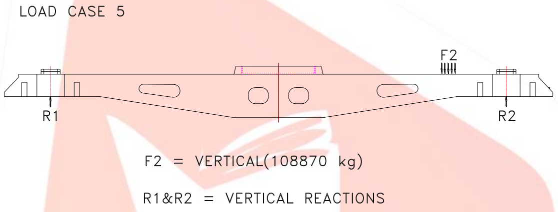

Fig. 8: Load case 05 in vertical direction.

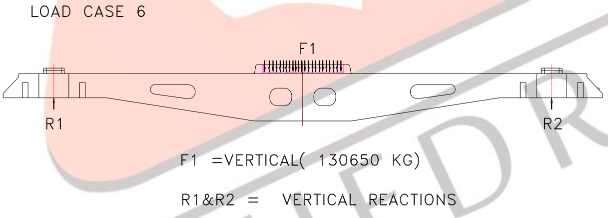

Fig. 9: Load case 06 in vertical direction.

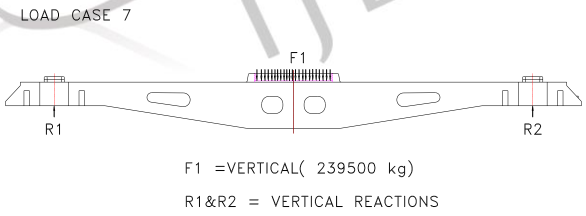

Fig. 10: Load case 07 in vertical direction.

III. STRUCTURAL ANALYSIS

Structural analysis of the initial and modified bolster design is performed applying load cases and boundary conditions as per AAR M-202. Thickness of the bolster top, bottom, side wall and inner ribs are considered for weight reduction. The areas and surfaces are selected from the results of structural analysis of initial bolster design by FEM. The stress and deflection plots of initial bolster design applying load cases 4, 5 and 7 are shown from Figs. 11 to 13. The design of bolster is modified by regular regress cycle of geometric modification followed by FEM and comparing the results with initial one. An attempt is made through modifying surfaces thickness, size and location of holes in geometry to reduce the weight of the bolster. Approximately 13.30% weight of modified design is reduced in comparison to initial one as given in Fig 14. Subsequently modified bolster design is verified by the same load and boundary conditions. The stress and deflection plots of same load cases are shown from Figs. 15 to 17. The detailed results of all seven load cases are listed in Table 2.

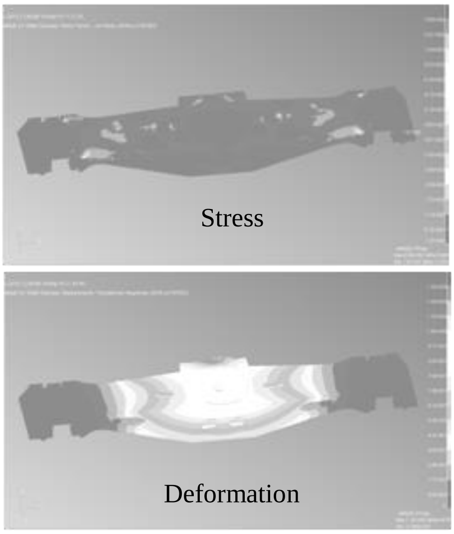

Fig. 11: Initial design plots (Load case 04).

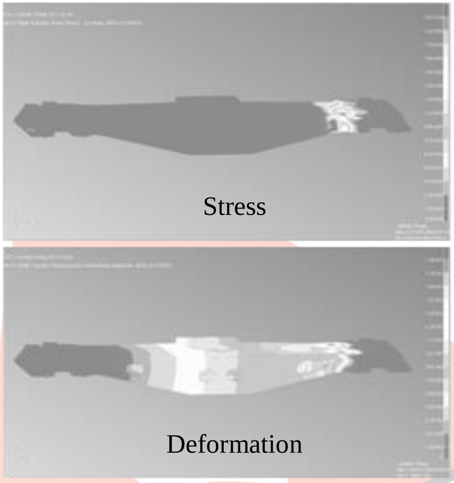

Fig. 12: Initial design plots (Load case 05).

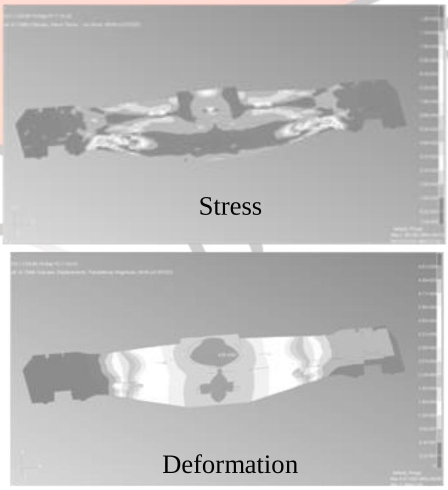

Fig. 13: Initial design plots (Load case 07).

Fig. 14: Modified bolster solid model.

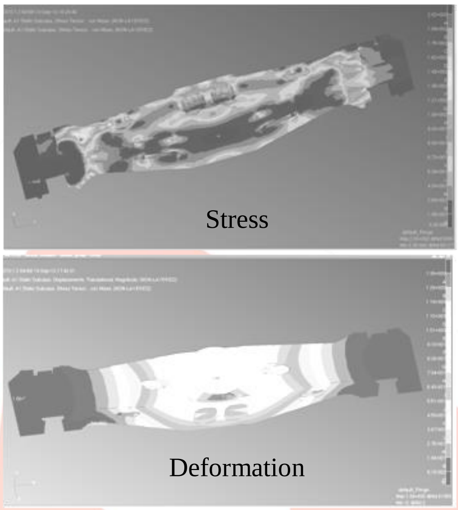

Fig. 15: Modified design plots (Load case 04).

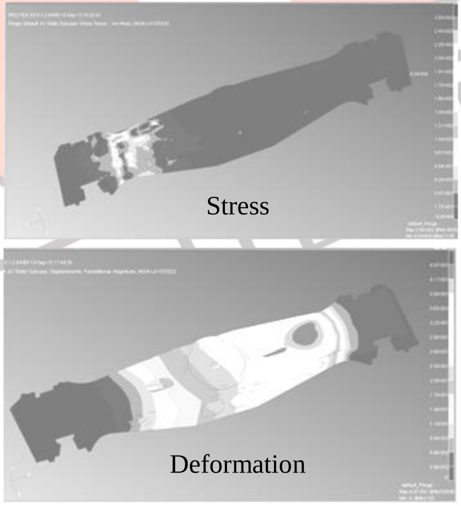

Fig. 16: Modified design plots (Load case 05).

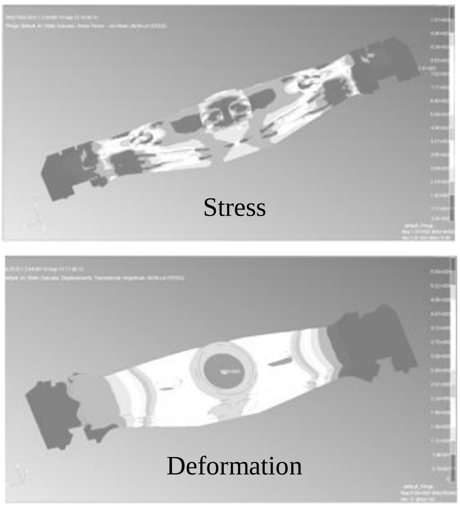

Fig. 17: Modified design plots (Load case 07).

Table 2: Structural Analysis results

Load Case.	Von – mises stress (MPa)		Maximum deflection (mm)	
	Initial design	Optimized design	Initial design	Optimized design
1	148	143	0.8	0.8
2	142	138	1.1	1.1
3	222	164	0.5	0.6
4	281	271	1.5	1.6
5	358	263	0.9	0.9
6	274	266	2.2	2.2
7	503	488	4	4.1

IV. FATIGUE STRENGTH

Fatigue strength of the modified design is verified by performing transient analysis applying dynamic rail wheel contact vertical and lateral forces importing from a 70 degree of freedom MBD freight vehicle model in VI/Rail interface Shukla et al. [11] as shown in Figs. 18-19. The values of critical stress from transient analysis using dynamic load cases are shown in Fig. 20. The time dependent stress plots of modified bolster critical zone in Rib, Top, Bottom and side plate surfaces are shown from Figs 21 to 24. The values of mean stress and stress amplitude of modified design of bolster are verified by Goodman diagram (Fig. 25).

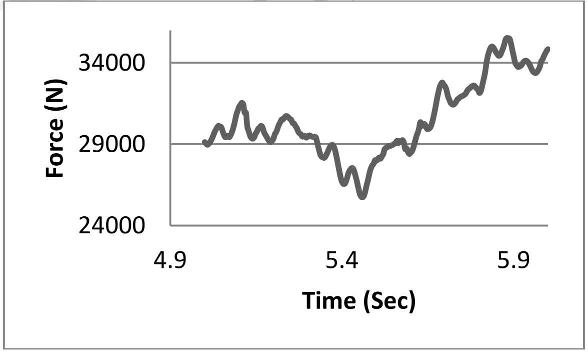

Fig. 18: Vertical forces at wheel rail interaction

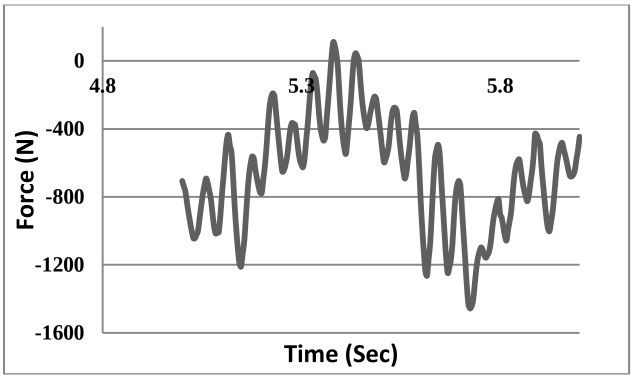

Fig. 19: Lateral forces at wheel rail interaction

Fig. 20: Stress plots performing transition analysis

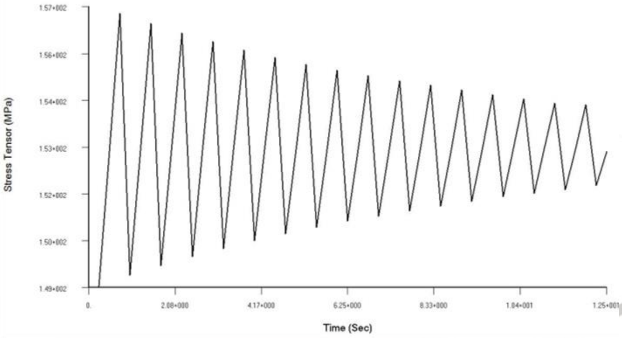

Fig. 21: Plots of Node No.9176 of Rib plate

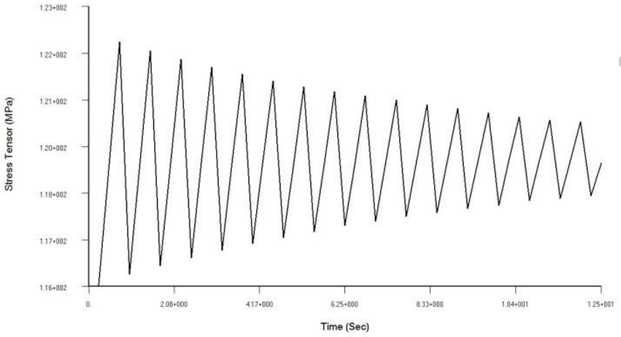

Fig. 22: Plots of Node No.52588 of Top plate

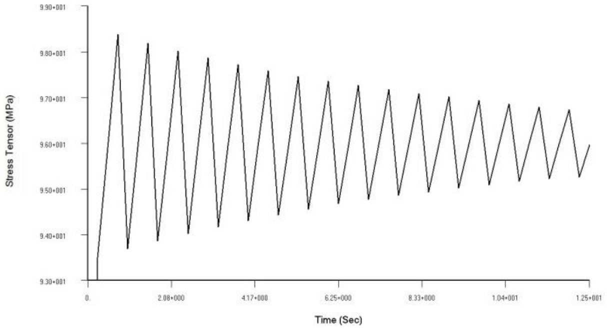

Fig. 23: Plots of node No. 66775 of Bottom plate

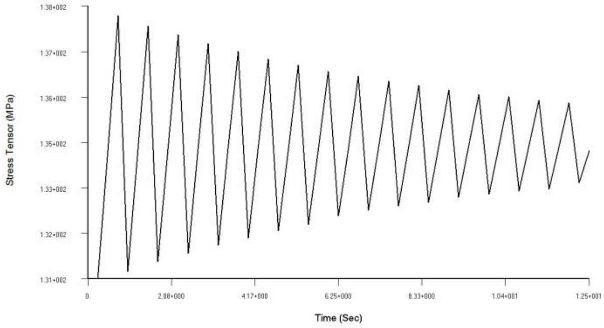

Fig. 24: Plots of node No. 46397 of side plate

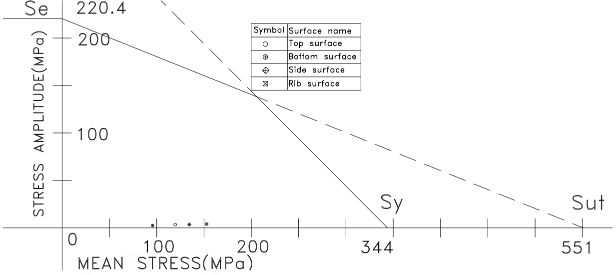

Fig. 25: Goodman diagram for fatigue strength

V. MODAL ANALYSIS

Finite element analysis of the verified bolster design has been carried out to study the topological effect of weight reduction on eigenvalues and eigenvectors. The first five eigenvectors of initial and modified bolster design has been extracted to compare the mode shapes of FE model as shown from Figs 26 to 30. The natural frequencies are matched against each other as listed in Table 3.

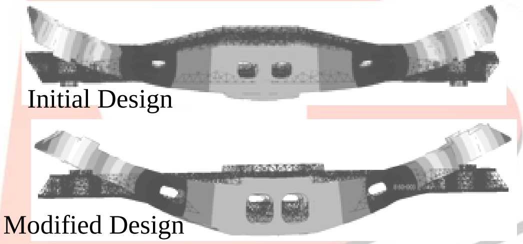

Fig. 26: First Mode shape

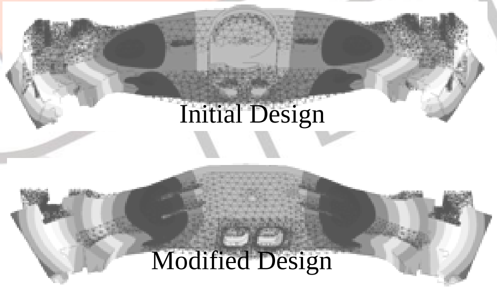

Fig. 27: Second Mode shape

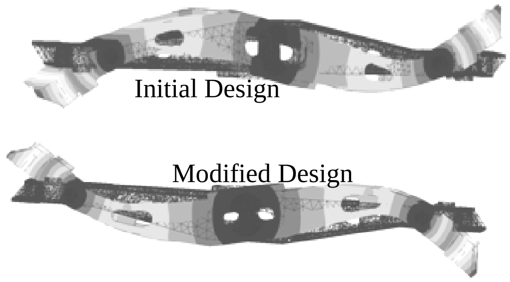

Fig. 28: Third Mode shape

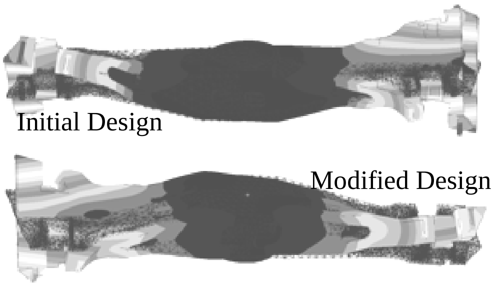

Fig. 29: Fourth Mode shape

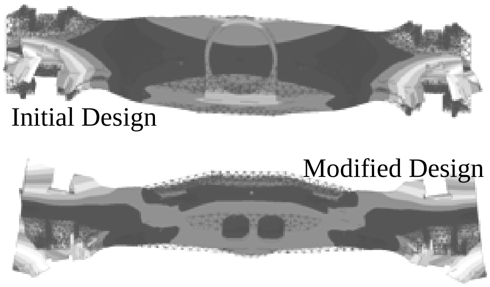

Fig. 30: Fifth Mode shape

Table 3: Natural frequency of initial and modified bolster design

Mode No.	Natural Frequency of Initial bolster design	Natural Frequency of modified bolster design	Remarks
1	217.76	218.57	Longitudinal
2	322.83	306.55	Lateral
3	372.28	376.38	Longitudinal
4	416.61	417.04	Torsion
5	502.19	526.46	Torsion

VI. FIELD TRIALS

The Detailed Oscillation trial runs of “GONDOLA 25t” wagon fitted with modified light weight bogie are conducted between CTC-PRDP sections of East Coast Railway in KUR Division on tangent-track, station yard, Curve (1.750-2.20)-2.10 & Curve (1.00-1.50)-1.50 in empty and loaded (79.50MT 298 nos. of PSC-12 (S/H), concrete sleeper are loaded in GONDOLA car body to simulate 25t of axle load conditions) [2]. The instrumented bogie having modified design is shown in Fig. 31. The performance of assessment of modified bogie bolster is based on the third Report of the Standing Criteria Committee of Research Designs and Standards Organisations, Lucknow. The maximum values of Stability parameter for lateral force (Hy_{2m}) in Empty and loaded condition are 1.12 t and 5.38 t respectively with in permissible limits.

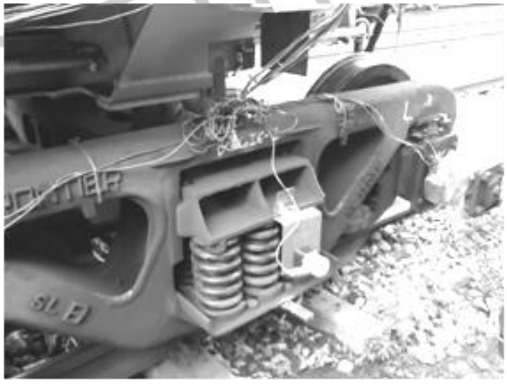

Fig. 31: Instrumented modified design bogie

VII. CONCLUSION

The Finite Element Methods are used to perform structural analysis of the bogie. Structural strength of the three piece freight bogie is estimated to identify the critical zone and surfaces for weight reduction applying in service load cases and boundary conditions as per international standards design specifications, AAR M-202. The structural strength of the cast steel three piece bogie bolster of 22.9 ton is evaluated initially to mark the area for weight reduction. The bolster design is modified by stepwise geometrical variation in design to enhance its capacity from 22.9 ton to 25.0 ton axle load. The weight of the modified design is around 13.30% less than initial one. Dynamic loadings extracted from MBD interface are used in FE environment to extract the time dependent stress values from modified bolster surfaces and ribs. The Fatigue strength of the modified bogie bolster is verified putting above stress values on Goodman diagram. The mode shape analysis is performed to validate the Eigenvector of initial and modified design. The modified bogie is fitted with GONDOLA 25t car body. An oscillation trial is conducted to assess the running conditions as per RDSO third criteria committee. The results of the trials are within permissible limits.

VIII. ACKNOWLEDGEMENTS

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