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Development and Validation of Chassis Mounted Platform Design for Heavy Vehicles

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ABSTRACT:

Hand calculations, finite element (FE) analysis and experimental validation of chassis mounted platform design for defence and commercial off-road vehicles have been attempted in this work. The work was commenced with the thorough study of platform configuration, loading pattern, platform mount location & configuration on the vehicle chassis and relevant vehicle characteristics. Calculation of section modulus, shear force and bending moment of various structural members under specified loading has been carried out before proceeding with the FE modeling and analysis of platform. FE model of the chassis mounted platform has been made using shell elements and the boundary conditions have been imposed based on the loading pattern with an assumption of rigid vehicle chassis. Static and gradient analyses of the platform have been carried out for full scale and reduced scale prototype FE models. Experimental strain measurement at critical locations under different static and gradient loads has been carried out for design validation of chassis mounted platform using the scaled prototype. Close correlation has been found between the experimental stress values and FE stress analysis results for static and gradient load conditions. From the entire load tests conducted, it is observed that the strain values in rear portion are less as compared with those in front and mid portions of the platform in-spite of the rear overhang provision.

KEYWORDS:

Off-road vehicles; Chassis mounted platform; Finite element analysis; Prototype; Strain measurement

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1. Introduction

Transportation system is a significant element in economic growth, progress, safety and other aspects of nation's development. Various modes of transport such as air, water and road ways exist since the transportation system evolved. Road transportation is most significant and reliable mode of transport as it is independent or less dependent of environmental conditions as compared with air and water modes of transport. The motor truck industry has continued to advance vehicle design and performance. Motor truck is vital, valuable and efficient link in coordinating other transport services such as rail, road, ships, air lines and pipe lines. Many factors are responsible for selecting the vehicle type. The cargo to be transported must be known and factors such as nature of cargo (solid, perishable or fluid), weight and volume of cargo, expectancy of stop-go driving, diminishing load, distance to be travelled, light, route, condition of road surface, traffic, grades and altitudes, legal restrictions on weight and size of vehicle, loading and unloading cost and operational cost must be accounted for deciding the correct type of chassis and vehicle body.

Failure of any of the components mounted on the chassis frame assembly is always the foremost apprehension for researchers. In this regard, Yu et al. [1] devised a practical damage detection technique for frame structures. This technique is based on finite element (FE) model updating. They defined an objective function by the use of which, the discrepancies between the experimental and analytical values of natural frequencies and mode shapes are minimized, which augmented the reliability of this method. For defence and commercial transportation trucks the elementary need to provide a levelled base for mounting the high rise antennas, tracking and communication devices is attempted by Senthilkumar et al. [2]. Dynamic vibration and strain measurement on the platform at various locations for pavement roads and cross-country terrains at 20 km/h vehicle speed is undertaken.

A procedure to estimate variant load cases using FE analysis is formulated and auxiliary experimentation process is avoided. In order to enhance the strength and stiffness of the chassis frame, the longitudinal channels of the chassis are boxed. When the vehicle travels in a terrain, it is subjected to random vibrations which results in complex stresses in chassis and its mounted structures and further damages the cargo in the containers and/or causes discomfort to the occupants. The vibration response of such boxed structures is of concern for vehicle durability and stability during dynamic conditions. In this regard, work of Lin et al. [3] to understand the vibration characteristics of a box-type structure using FE method is useful. Threaded fasteners such as U-bolts and clamps are used to attach different components and mountings to the chassis frames. These fasteners are frequently subjected to vibrations in vehicle dynamic environment. Due to random and repeated cyclic nature of vibrations in case of off-road vehicles, these fasteners are subjected to complex stresses and get loosened. Nassar et al. [4] developed a mathematical model for studying the vibration induced loosening of threaded fasteners that are subjected to harmonic excitation. These parameters give rise to provide a levelled base, referred as chassis mounted platform, for containers for road and off-road vehicles.

Chassis mounted platforms are integrated with additional longitudinal members which are clamped to chassis using U-bolts. The nature and type of load acting on the platform primarily depends upon the containers and nature of cargos placed inside them. The aerodynamic forces acting on the walls of containers generate a drag depending upon the coefficient of friction and the atmospheric conditions. These aerodynamic forces also contribute to generate additional moments at the mounting locations on the platform. These moments are taken care by these levelled bases provided in addition to chassis frame. A detailed study and analysis of forces and moments in static & dynamic conditions acting on these platforms is necessary at the earlier stages of vehicle design. Twist locks are provided to hold the containers safely and rigidly on the platform of the vehicle or on the base of trailer. The twist lock locations on the platform, the load pattern inside the containers, load intensity, location of centre of gravity, the wheel base, self-weight of the platform, axle load distribution, approach and departure angles, ramp angle of the vehicle, trailer length, front & rear overhangs, vehicle width or height form the most important deign constraints of the chassis mounted platform [5-12].

2. Design development

Design considerations of platform and individual components include material selection for the platform, physical and chemical properties of the material, manufacturability of the material, environment in which the platform is used, distribution of forces (predictable & momentary), nature of load (intense load as considered in present analysis) acting on the platform, magnitude of load to which the component is subjected, magnitude of factor of safety, strength and rigidity. Material selected for the platform and its components is 0.2% low carbon steel with yield strength of 250 MPa and elastic modulus of 200 GPa. This material is selected due to its suitability for the present design requirements such as elasticity, machinability, weldability and formability. The key components of the platform are main and outer longitudinal members (LMs) and cross-members (CMs). A different type of combination of LMs and CMs in platform design is formulated. The judgment concerning the assortment of type of cross section for the LMs and CMs is made by the investigation of present sections accessible as per Indian Standard 808, 1989. The assessment of various sections is presented Table 1.

Table 1: Comparison of various cross-sections

Parameters	C Section	I Section	T Section
Bending strength	High	Low	Medium
Attachment of components	Easy	Difficult	Difficult
Load carrying capacity	Low	High	Medium
Manufacturing	Easy	Complex	Moderate
Cost	Low	High	Medium

The main LM is bolted to the chassis and the base of CM. The gross section of the platform as viewed from the front of the vehicle is shown in Fig. 1. Further detailed analysis of section properties such as moment of inertia, positions of centroid, section modulus are carried for each member. In order to theoretically compute the permissible stress in the platform, a gross section modulus is calculated. Section modulus is defined as the ratio of moment of inertia of the section about an axis passing through the centroid to the distance of most distant fiber from the neutral axis. The calculated gross section modulus from the bottom, top, left and right faces of the combined section are 580899, 621790, 303712 and 1240512 mm^3 respectively.

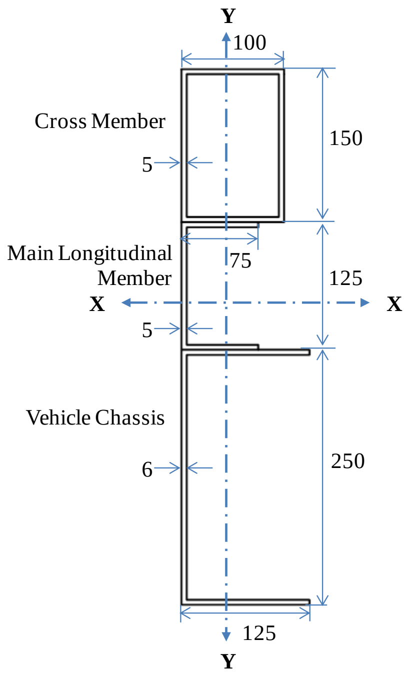

Fig. 1: Combined cross section of chassis, main LM and CM

The shear force and bending moment due to self-weight of the chassis mounted platform for vehicle stationary condition is determined using classical beam analysis. For evaluation of maximum bending moment, the wheel base of VNN Tatra 8x8 truck is taken as a reference along with rule 93 of central motor vehicle rules. The wheel base of the platform is 5.8m.The centre of the platform is subjected to twice the magnitude of load at front and rear corners. The constructed shear force and bending moment diagram is shown in Fig. 2. The maximum bending moment that occurs at the mid portion of the platform is 30052 kN-mm. The static stress values are calculated as the ratio of maximum bending moment and extreme fibre section modulus. In order to evaluate the performance of platform in vehicle moving conditions a dynamic factor is to be considered.

The maximum value of dynamic factor to account for longitudinal loads, lateral loads, torsion loads, momentary loads which arises due to pot holes, bumps, road un-evenness etc. in addition to bending loads from vehicle design is taken as 1.5 [13-19]. The dynamic performance is assessed by a condition of 1.5 * static stress should be less than or equal to 2/3rd of yield strength. A summary of computed stress values for the four extreme faces of the combined section is given in Table 2.

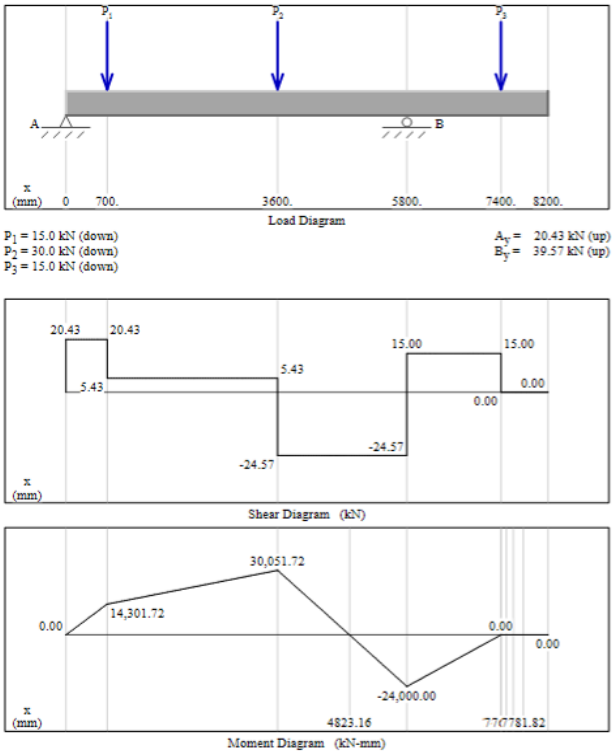

Fig. 2: Shear force & bending moment diagram of vehicle platform in stationary condition

Table 2: Summary of theoretical stress values for the platform

Face	Yield stress (MPa)	2/3 Yield stress (MPa)	Static stress (MPa)	Dynamic stress (MPa)
Bottom	250	166.7	51.7	77.6
Top	250	166.7	48.3	72.5
Left	250	166.7	98.9	148.4
Right	250	166.7	24.3	36.3

3. Detailed design

In order to advance from mathematical design and analysis procedure of the platform to computer aided design (CAD) and FE analysis, the designer must be aware of the associated aspects of vehicle design that has direct or indirect effect on the vehicle performance. The chassis frame encompasses two LMs and eight lateral channel sections as shown in Fig. 3. The density and elastic modulus of platform material (steel) is 7850 kg/m^3 and 210 GPa respectively. LMs are named as right and left longitudinal members when viewing from the vehicle front side and abbreviated as LMR and LML respectively. The LMs' channel section dimensions are standard over its 8m length. In order to locate the front, mid and rear ISO corners on the LMR & LML, the corners at CM and LM are abbreviated as LMR-F, LMR-M, LMR-R, LML-F, LML-M and LML-R. These main LMs are either continuous or discontinuous and are mounted on vehicle chassis with suitable number of U-bolts at suitable locations over the length of chassis.

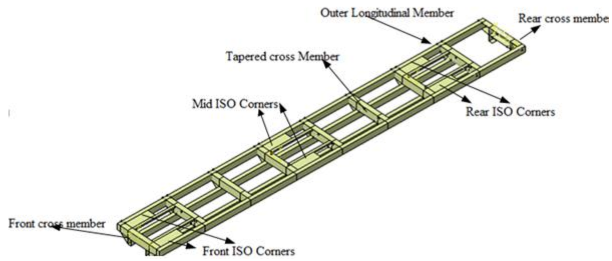

Fig. 3: CAD model of full-scale platform

The dimensions of the lateral channel sections are customized for intense loading and are given a taper angle of 5.72° centrally over 1m length. The outer LMs C-section is 125x75x6 mm. The tapered CMs C-section is 150x100x8 mm. All CMs are equi-distanced by 1m from the front cross member and are numbered sequentially from front to rear of the vehicle where 1st CM being the one immediately after the front wheels. The CMs are either continuous or discontinuous depending upon the nature of cargo transported or the locations of other various components of the load carrying vehicles. Further, the LMs and CMs of the incorporated platform are oriented such that their combination provides an immense stability against dynamic load conditions to the transportation system. This orientation is judged through FE analysis. In order to strengthen the platform, triangular gusset plates of 5mm thickness are welded to the platform at the CM and main LM intersections. At each CM, four gusset plates are welded. Small walkway supports of channel or angle section are used as per the platform load requirements.

As per the dimensions obtained from the mathematical analysis, CAD model of the platform is prepared using CATIA. The individual members of the structure are joined by oxy-acetylene welding process and then the whole combination of the LMs and CMs is again welded to main LMs which are of 125x75x5 mm. This combination of longitudinal, lateral and main channel sections is then incorporated with chassis using U-bolts. The rear portion of the incorporated frame is overhanging, due to wheel base of the transport truck. Hence one or two CMs of the incorporated platform are overhanging at the rear. Plates of 5mm thickness are welded at 6 locations to form ISO corners. These plates are located at front & rear ends, and at mid portions of the chassis mounted platform as shown in Fig. 3. As the platform is welded entity, it will behave as a single component during static and dynamic loading [20-24].

A scaled prototype of chassis mounted platform of dimensions 1500x1000 mm is manufactured for detailed analysis and testing in laboratory. This prototype is manufactured keeping all the design constraints and design requirements same as that of full scale platform. This scaled prototype model replicates the dimensions, orientations and positions of CMs in full-scale platform configuration. CAD model of this scaled prototype is shown in Fig. 4.

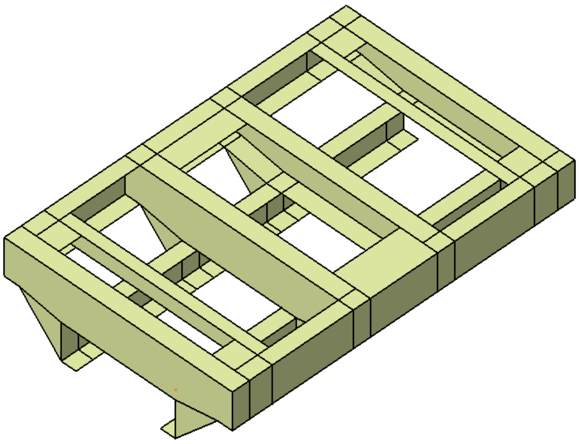

Fig. 4: CAD model of scaled prototype platform

4. FE modelling and analysis

The FE modeling and analysis of the chassis mounted platform is carried out using HyperMesh and ANSYS software. For meshing the platform, a two dimensional thin shell (shell 43) element is used. The platform is primarily meshed using quadrilateral elements. Triangular elements are used to mesh the triangular gusset geometries. Though quadrilateral and triangular elements are used, combination of physical properties and connectivity is ensured to get better results. In the analysis of the platform, the vehicle-chassis is assumed to be rigid and the main LM of the platform rests on chassis. To simulate this boundary condition, the nodes on the bottom surface of the main LM are constrained in all degrees of freedom such that TX=TY=TZ=0, Rx, Ry & Rz =0. FE analyses of the full-scale and reduced scale prototype are carried for static, braking, gradient and vertical acceleration cases. The FE mesh of the reduced scale prototype model is shown in Fig. 5.

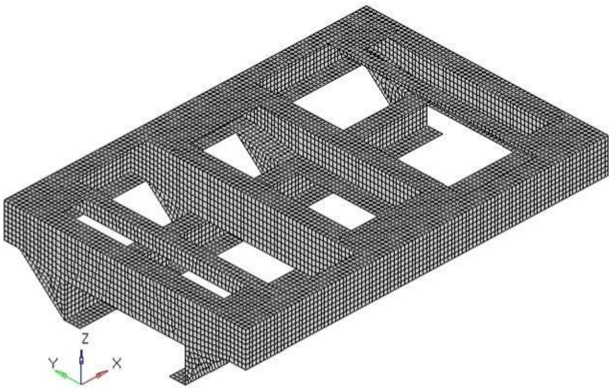

Fig. 5: FE mesh of reduced scale prototype platform

The full-scale and reduced scale prototype FE models are solved for stress and deflection at various locations on the platform. The stress and deflection plots for 1400kg load on the platform are shown in Figs. 6 - 9. Same stress patterns are observed in full scale and the reduced scale prototype models of the chassis mounted platform at front mid and rear portions. For the prototype, the maximum value of deformation at mid portion of the structure correlates well with the deformation value of full-scale model. A summary of peak stress and displacement from reduced scale prototype model analysis is given in Table 3.

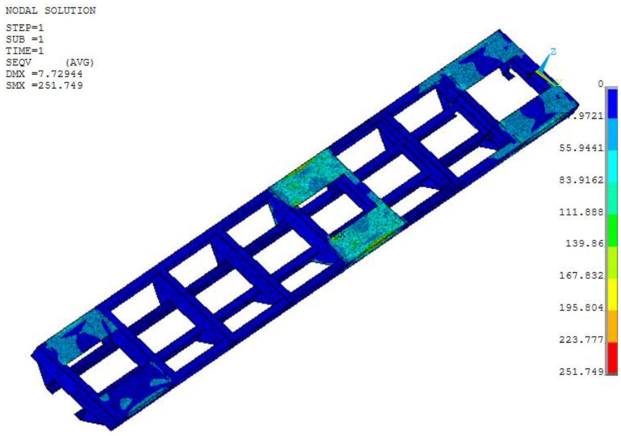

Fig. 6: Stress plot for 1400kg load applied to full-scale model

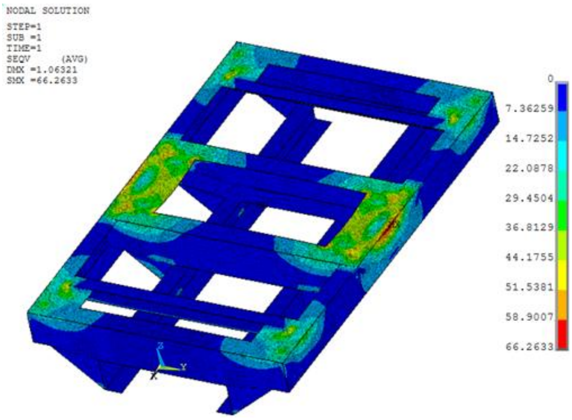

Fig. 7: Stress plot for 1400kg load applied to prototype model

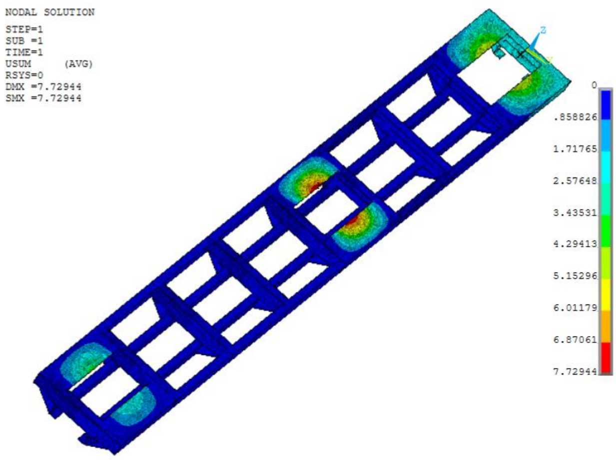

Fig. 8: Deflection plot for 1400kg load applied to full-scale model

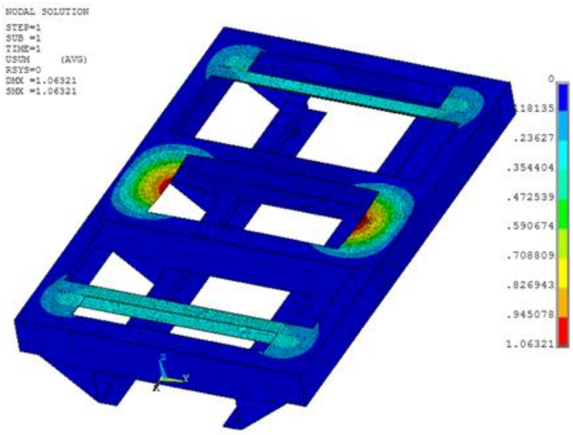

Fig. 9: Deflection plot for 1400kg load applied to prototype model

Table 3: Results summary of reduced scale prototype model

Load case	Stress (MPa)	Deformation (mm)	Location
Static load	45.0	1.72	Mid portion of the platform
15° Gradient load	32.8	0.23	Rear CM
30° Gradient load	38.3	0.25	Rear CM

CM behaviour of the platform is similar to behaviour of a cantilever beam subjected to intense load at free end as observed from the stress pattern at mid CMs. Due to symmetric load application on the selected ISO corners of the platform, the stress pattern observed is also symmetric. The load transfer process [25-27] is observed to take place from outer LM to CM and then from CM to main LM. The load magnitude at the mid portion of the platform is twice the load magnitude as compared with front and rear of the platform. Hence, the stress values observed at the mid portion of the platform are greater than the front and rear portions. Gusset plates used at the main LM and CM intersections also share some part of the load and takes part in the load transfer process. These plates strengthen the structure and enhance the load carrying capacity of the structure.

5. Strain measurement on the prototype

The strain measurement is of vital importance in design validation of chassis mounted platform meant for special and commercial applications. As there are no assumptions involved in the experimentation procedure, the strain measurement provides actual strain values. Locations for strain measurement have been selected on the basis of FE analysis. Strain measurement locations are mainly at the CM and outer LM intersections. Linear (uni-axial) strain gauges are used on the LMs at front, mid and rear ISO corners. The gauge factor and resistance is 2.1 and 350 ohm respectively. The strain gauges are sequentially numbered as SG1 – SG8 from front side of prototype. The locations of affixed linear and rosette gauges on the chassis mounted platform prototype are shown in Figs. 10-12 and given in Table 4.

Fig. 10: Strain gauge locations on the chassis mounted platform

Table 4: Strain gauge numbering and their locations

Strain gauge #	Type	Location
SG1	Linear	LML-F
SG2	Linear	LMR-F
SG3	Linear	LMR-M
SG4	Linear	LMR-R
SG5	Rosette	LMR-M
SG6	Rosette	LML-M
SG7	Rosette	3rd CM
SG8	Rosette	2nd CM

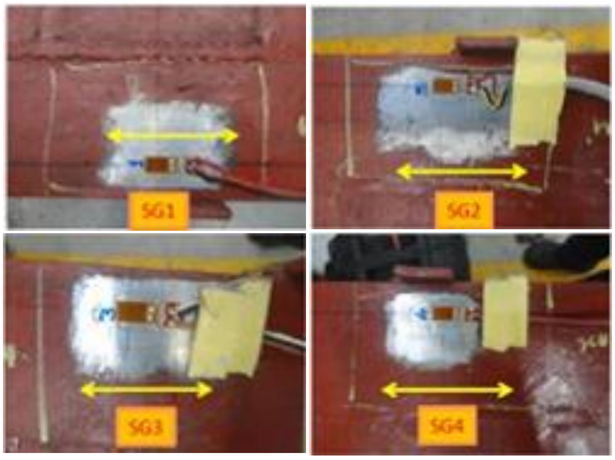

Fig. 11: Linear gauges installed on the platform

Fig. 12: Rosette gauges installed on the platform

Strain measurements have been carried on the prototype platform for static and gradient loads. Sixteen (4 for linear gauge and 12 for rosette) strain channels are used simultaneously with a sample rate of 25 samples/sec/channel for strain measurement at the loading conditions as given in Table 5. This test is conducted at Automotive Research Association of India, Pune. The strain measurement data is acquired while loading the platform and then while unloading the platform. The acquired strain values in micro-strain (μe) units are given in Table 6. Comparing the strain values obtained at front and rear linear gauge locations, it is found that rear part of the platform is subjected to more stress than front portion. This is due to presence of rear overhang in the platform. From the measured strain values, the stress magnitudes are calculated and given in Table 7. For rosettes - SG5 to SG8, resultant stress values which are obtained after using rosette reduction technique [28, 29] are used. The 2nd CM of the prototype is subjected to a maximum stress value of 25.66 MPa.

Table 5: Prototype platform loads for static strain measurement

Test	Load in kg						
case	LMR-F	LML-F	LMR-R	LML-R	LMR-M	LML-M	Total
01	100	100	100	100	0	0	400
02	100	100	100	100	500	0	900
03	100	100	100	100	500	500	1400
04	150	150	100	100	500	500	1500
05	150	150	150	150	500	500	1600

Table 6: Measured strain (με) while loading the prototype

Strain gauge	Load (kg) on chassis mounted platform prototype					
	0	400	900	1400	1500	1600
SG1	0	-3	1	-4	-5	-5
SG2	0	-8	-18	-19	-26	-25
SG3	0	7	-39	-38	-38	-35
SG4	0	-4	-9	7	-6	-10
SG5-A	0	3	-28	-28	29	-28
SG5-B	0	0	63	60	55	56
SG5-C	0	8	107	102	98	96
SG6-A	0	6	6	-31	-32	-30
SG6-B	0	6	9	50	52	52
SG6-C	0	-3	-3	123	121	120
SG7-A	0	-5	-6	7	3	2
SG7-B	0	4	4	-28	-29	-27
SG7-C	0	11	17	46	52	55
SG8-A	0	-5	10	8	5	4
SG8-B	0	1	-35	-33	-34	-33
SG8-C	0	8	29	35	42	40

The exterior portion of the second cross-member where rosette – SG6 is pasted is subjected to a stress value of 25.85 MPa for a load of 1400 kg while loading the chassis mounted platform. While unloading the structure, a stress value of 25.21 MPa is observed at the middle portion of the second CM. Strain gauge rosettes mounted on the web portion of the outer LMs at middle of the platform for static load test showed stress magnitudes of 20.96 MPa and 25.27 MPa respectively for 1600 kg. Occurrence of stresses in the web at the mid portion of the outer LMs indicates that the major component of load is sustained by the structure itself. Comparing the stress values of front and rear portions for static loading and unloading of the platform, it is found that rear portion experiences 13.2% and 31.8% more stress respectively than the front and mid portion of the platform for 1500 kg load.

Table 7: Stress values (MPa) from measured strain while loading the chassis mounted platform at all gauge locations

Strain gauge	Weight (kg) on chassis mounted platform prototype					
	0	400	900	1400	1500	1600
SG1	0	0.63	0.21	0.84	1.05	1.05
SG2	0	1.68	3.78	3.99	5.46	5.25
SG3	0	1.47	8.19	7.98	7.98	7.35
SG4	0	0.84	1.89	1.47	1.26	2.1
SG5	0	2.42	23.30	22.25	21.26	20.96
SG6	0	1.65	2.15	25.85	25.49	25.27
SG7	0	2.32	3.59	17.72	18.71	18.90
SG8	0	1.68	15.71	16.31	17.62	16.77

6. Conclusions

The work was commenced with the thorough study of platform configuration, loading pattern, platform-mounting style on the vehicle chassis including mounting locations and the relevant vehicle characteristics. Calculation of section modulus, bending moment and shear force of various structural members under specified loading conditions has been carried out before proceeding with the FE modeling and analysis of platform. With the aid of maximum bending moment and section moduli, theoretical stress values are found out. Though theoretical implications have many limitations, stress values devised by other advanced methods are in good agreement.

FE model has been made using shell element and the boundary conditions have been imposed based on the loading pattern with an assumption of rigid chassis. Analysis of the platform has been carried out for full scale and reduced scale prototype FE models. While reducing the scale, detailed study of the dimensional parameters in order to maintain the similarity between model and prototype is carried. Critical gradiant and static load combinations are identified.

Experimental strain measurement at critical locations under different load magnitudes has been carried out for design validation of chassis mounted platform using a manufactured prototype platform. Static strain for various load combinations on the ISO corners has been measured prevailing to the actual mounting and un-mounting of cargo in the containers. Close correlation has been found between experimental stress values and FE analysis results. The static and dynamic component of strain values have been found less in comparison with the similar platforms. From the entire load tests conducted, it is observed that strain values in rear portion are lower than those in front and mid portions in-spite of the rear overhung provided. This results into an efficient load transfer from rear portion of the structure to front and mid portions, which is beneficial for the vehicle stability during turning around curved roads.

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