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Finite Element Analysis and Experimental Simulation of Chassis Mounted Platform for Off-Road Wheeled Combat and Transport Utility Vehicles

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ABSTRACT:

Chassis mounted platform is an intermediate component between vehicle chassis and chassis mounted shelter, and is intended to act as a levelled base for shelters. Shelters in combat vehicles provide a closed stipulated environment to computerized tracking systems, sophisticated defense combat equipments to suit the operational and environmental requirements during warhead situations. Platform carries transfers & sustains unevenness in load arising from the road or soil irregularities during off-road vehicle travel. Present work deals with development, evaluation and improvement of one such platform for 8x8 vehicles. In this work, the platform under consideration is designed to accommodate two shelters, each being secured to the platform using standard twist locking arrangements. Securing locations are dependent on the size & weight of the commodity to be placed inside shelter. Major design ruminations of the platform include nature & pattern of load, flange orientations of channel sections, span between webs of consecutive channels, axle load distribution and vehicle geometry constraints as ground clearance & departure angle. Finite element analysis is carried out in to order evaluate stress and deflection in the present platform configuration. Experimental strain measurement at critical locations on the platform is carried at Automotive Research Association of India (ARAI) to evaluate the performance of the platform under specified load-speed conditions. Relation between experimental stress values and strain gauge locations on the platform is assessed for different load magnitudes.

KEYWORDS:

Terrain vehicles; Off-road vehicle mobility; Terra mechanics; Levelled base

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1. Introduction & literature review

Off-road transportation is of principal significance in regards with military, construction, agriculture and other transport circumstances. Off-road vehicle's contribution in agricultural productivity, defence, safety, and infrastructural enhancement for a nation is of vital importance. Road or non-guided ground transport with deliberations of lawful precincts on the payload carrying capacities, overall dimensions of the vehicle, type and nature of cargo to be transported, environmental and geographical considerations, is the most efficient as well as trustworthy transport mode as compared with air and water modes, due to its less dependency on the surrounding environments. Motor truck is an inseparable medium for on-road and off-road transport situations. In certain situations e.g., warhead conditions, off-road transport becomes a mandate mode of transportation over other modes in regards with the unfavourable environment circumstances.

Combat vehicles which carry tracking systems, sophisticated electronic equipments and computer hardware with modernized operating systems are temperature dependent and require certain set of operating parameters to be maintained. Hence such components are placed in a closed environment i.e. in a shelter or container to provide the set of operating parameters especially during off-road travel situations e.g. in hilly regions, forest areas or regions which suffer from frequent snow-fall. For off-road vehicles, the frictional resistance offered by the road surface to tire motion i.e. magnitude of friction coefficient between tire and road surface decides the force and power requirements needed for different vehicle operations like starting, speeding-up, turning or stopping of the vehicle. During off-road travel, the steadiness of the wheeled vehicle over rough terrain surface is contributed by type of tire; slip angle, vertical load exerted by the chassis mountings, tire inflation pressure, lateral forces, cornering effects during vehicle turning and gradient angle.

For off-road vehicle operation, different vehicle design considerations or occasionally a new design is needed. Contrasting to the commercial transport vehicle, off-road vehicle designer has to begin design work from the contemplation that where the vehicle is being intended to be driven. The stability of combat vehicles and off-road vehicle designs that carry shelters of considerable height are governed by strength and deformation characteristics of the road surface, soil quality and vegetation. Levelled base below the shelter and road surface beneath tires influences the vehicle stability. However for off-road terrains in which the vehicle is subjected to random load inputs both from ground and vehicle mountings, its stability is affected to an accountable level, hence the modernized electronic warfare equipments, cargo/commodities are more likely subjected to damage unless special care is taken. For off-roads and rough terrains, the ratio of traction force to load is totally unpredictable which may result in slipping of the vehicle due to less friction or total vehicle immobilization due to high friction.

In applications involving video coverage of experimentation sites, monotonous & repetitive data collection, wireless communications, hazardous chemical environments, collection of data in explosion environments the concept of unmanned vehicle mobile instrumentation platform is practiced. Such unmanned vehicle systems assists while working into dangerous environments with the possibility of less or sometimes no human intervention [1]. Development of a mobile instrumentation platform system for providing flexibility and functionality necessary to assist in the development of network-centric systems is carried. This mobile instrumentation platform is able to withstand and work in environments of heavy rain, can sustain wind forces upto 30 miles per hour, ice, sand, salt water, mud and temperature ranges between -20°F to 120°F [2]. Geometry of combat and transport utility vehicles used in warhead situations is not regular or uniform to suit the requirements of housing needed for arms & ammunitions, tactical weapons and tracking systems with high rise antennas.

Stability of such vehicles in off-road situations becomes critical parameter to deal with. Centre of gravity of the overall vehicle configuration significantly influences vehicle stability. Centre of gravity in these vehicles is decided by parameters like overall dimensions of shelter, nature of cargo placed inside the shelter, shelter height, location and placement of cargo inside the shelter. Shelter acts as a mobile room for high precision ballistic software electronic equipments, rugged military computers, communications equipment & peripherals and also provides the required set of operating temperature-pressure conditions to intelligent tracking systems used in military applications where accuracy of the tracking system is affected by varying weather conditions. Such shelters are placed on a levelled base or platform attached over vehicle chassis to sustain the load/moment variation during off-road travel. Deulgaonkar et al [8], has carried design evaluation of levelled base of 8x8 wheeled with the aid of finite element analysis and experimental strain measurement technique.

They developed a hydraulically levelled platform for high-rise antennas and tracking & communication devices. In this research the platform design validation has been carried with the comparison of simulation and experimental results. This work was further extended and they carried design, development and validation of a different configuration of chassis mounted structure in three research phases [3]. In first phase of their research, calculation of section properties of platform constituents was carried using classical method and development of the concept of combined or gross section modulus was carried. With the use of this gross section modulus, calculation of theoretical stress values for static and dynamic vehicle operating situations was carried out. Concrete mathematical model to carry stress analysis of braking, stationery and gradient load considerations on the chassis mounted platform was established. In further research stages they carried finite element analysis and experimentation to evaluate the design.

The platform configuration in their work sufficed the need of levelled base for defence and commercial vehicles and led to improvements in stability and performance of shelter mounted vehicles [4]. Deformation in joints due to torsional and fluctuating loads induced in chassis frame of a commercial truck has been evaluated with the use of flexibility coefficients [5]. Formulation of a structural analysis process with the use of shock spectra loading is carried and has been utilized as a powerful design tool for commercial trucks and trailers mounted with refrigeration unit frames [6]. The stresses in the chassis frames are computed with the aid of finite element model. They used static equivalent load method which included the use of peak acceleration value multiplied by 1.5 in order to account for dynamic amplification. Design and finite element concerns in their research included the non-structural components, boundary conditions, governing codes, shock and vibration load criteria, container construction, load criterion, mathematical modeling of dynamic load methods, load criteria for containers on ships, comparison of methods and results [7]. They found good agreement between experimental and analysis results. Also in some areas of the frame, variations of the results were due to increased stiffness by addition of stiffener and gusset plates and other due to pre-stressing of the components during assemblage.

2. Chassis mounted platform

Chassis mounted platform or structure caters the need of levelled bases for combat and transport utility vehicles during warhead and unfavourable environmental situations. The chassis mounted platform is a rectangular structure consisting of longitudinal and cross members as constituents. Longitudinal direction of the platform is the direction parallel to the plane of vehicle chassis and cross or lateral direction is the direction perpendicular to plane of vehicle chassis. For the platform configuration in present work, the limiting dimensions of length and width are 8000mm and 2000mm respectively. Two channel or C-section members of 8000mm length are termed as outer longitudinal members (OLMs) which are in a plane parallel to vehicle chassis. The orientation of flange portions of these OLMs is parallel to chassis frame longitudinal C-sections and are 2000mm distance apart. Eight (or sometimes ten) cross members (CMs) are placed over the length of OLMs. These longitudinal and cross members are joined together by using oxy-acetylene welding process and forms a geometry similar to ladder frame.

To integrate this combination with the vehicle chassis, two central members known as main longitudinal members (MLMs) are welded to this frame. These MLMs are continuous or discontinuous and are placed over the length of vehicle chassis frame. With the use of suitable number of through U-bolts, this platform is then mounted or integrated with chassis frame through bolting process. Stress concentration on the MLMs and chassis frame caused due to holes needed to accommodate the through U-bolts is neglected. For selection of dimensions of the platform constituents Indian Standard (IS) 808 is used. Dimensions of OLMs are selected as 125 x 75 x5mm and those of lateral or CMs are selected as 150 x100 x 8mm. These dimensions are slightly modified by providing a taper of 5.72° on the lower flanges of all cross members; hence these cross members are called as tapered cross members (TCMs). Due to taper provided in the portion between the chassis and OLMs, cantilever effect is generated during working situations of the platform.

This assists in uniform load distribution and enhances vehicle stability. Steel plates of 5mm thickness and arbitrary length are welded at front, mid and rear portions on the platform for shelter mounting. These plates act as base plates for the shelter, and hence are called as load locations, load corners or ISO corners. Stiffener or gusset plates are welded at base portion of CMs and MLMs. Fig. 1 shows full scale platform model with all platform constituents.

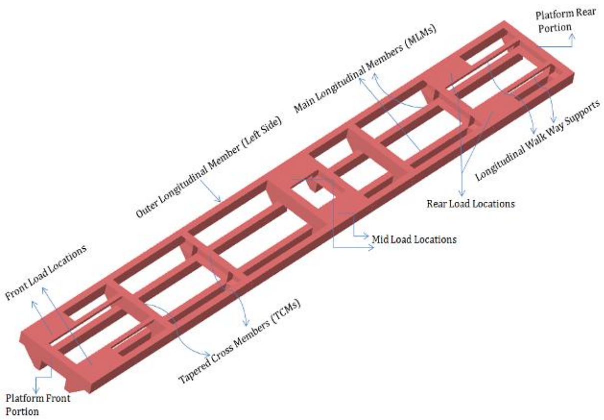

Fig. 1: Full scale platform model with all constituents

Fig. 2 depicts the tapered portion between MLMs & OLMs and triangular gusset plates. The platform is placed over vehicle chassis in symmetrical manner with respect to its width dimension i.e. 2000mm and is also loaded symmetrically at six load locations. The six load locations on the platform are shown in Fig. 1. The length to width ratio of the platform is 4:1 (8000mm length and 2000mm width). Over the length of 8000 mm nine different load patterns are formulated. Shelter dimensions and loading details of first type of load pattern are shown in Fig. 3. The load transfer process on the platform is described with the help of block diagram shown in Fig. 4. During the load transfer process the platform acts as single entity to withstand the load exerted by the shelter. Fundamental steps for the platform design include material selection, deciding the cross-section for platform members and evaluation of section properties of individual & combined sections, shear force and bending moment evaluation, theoretical stress evaluation for vehicle stationery load condition [9]. With the aid of gross section modulus concept, theoretical stress for evaluation for static and dynamic load conditions like braking and gradient vehicle travel has been attempted by Deulgaonkar et.al. [10].

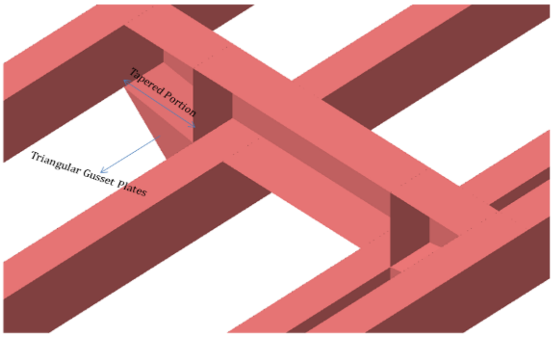

Fig. 2: Tapered portion and triangular gusset plates of platform

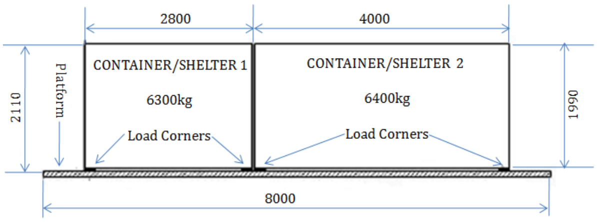

Fig. 3: Dimensional details of platform and platform mounted shelters (dimensions in mm)

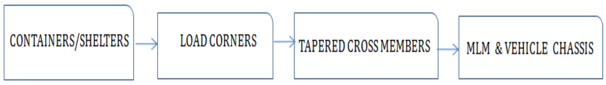

Fig. 4: Block diagram of load transfer process from shelter to vehicle chassis

3. Computer aided modelling and finite element analysis

Limiting dimensions of platform are decided using central motor vehicle rules as per the vehicle configurations. Before the actual computer model preparation, decision regarding type of computer modeling technique is significant step as this decides further finite element analysis inputs. The prepared computer model is required to meet all the operational requisites of the platform and also must identify every detailed aspect of the platform geometry [11]. Surface modeling technique is used to prepare the computer model of the platform accounting the dimensional features and operational requirements. This decision is due to the fact that lengths of OLMs, TCMs are far more dominant over their individual thickness and the operational requisite of platform to behave as a single entity. All the platform constituents are welded to form a chassis sub-frame and behaves as a single entity under the action of shelter load. Using surface simulation software (geometric modeler) CATIA V5 due to the platform model is prepared.

Two computer models of the platform are prepared viz, one with full scale and the other with reduced scale. Finite element analysis of both full scale and reduced scale platform models is carried; results of finite element analysis are further verified with the experimentation of manufactured prototype of platform model [12]. The computer aided surface model of the platform with overall dimensions is depicted in Fig. 5 and that of the platform prototype is shown in Fig. 6.

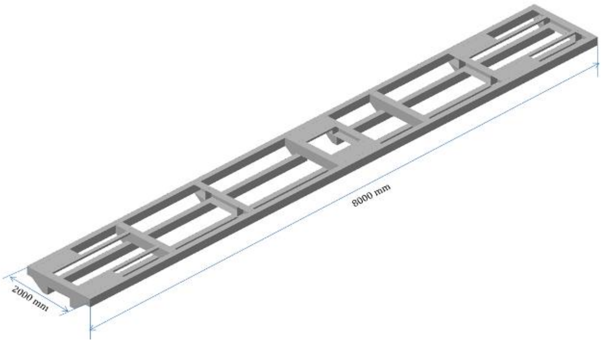

Fig. 5: Surface model of the platform (full scale) with overall dimensions

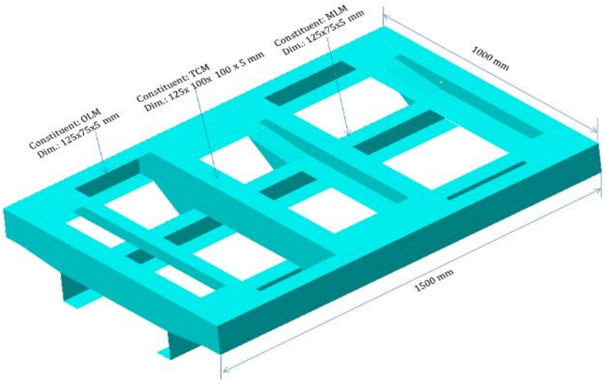

Fig. 6: Detailed dimensions of platform prototype

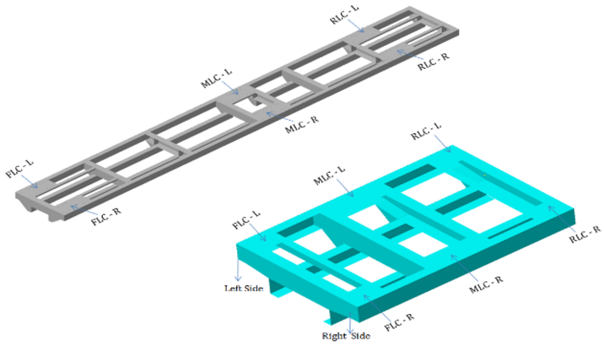

Fig. 7: Load locations on platform and prototype

With the completion of preparation of geometric model of the platform and before proceeding for the linear elastic finite element analysis process the load application and constraints application locations on the platform are identified. The loads are applied at front, mid and rear load locations and constraints are applied to MLMs. The terminology used for load location identification and application on the platform and its prototype is shown in Fig. 7. Errors in interconnectivity of geometric model are verified and necessary corrections are made, which is a prerequisite for pre-processing phase in finite element analysis. Pre-processing phase in finite element analysis includes development of finite element model of the platform [13]. Element selection for platform constituents has been done by accounting the complexities in geometries of platform after welding, variations in cross-sections, profiles and geometries of all attachments and constituents. Two dimensional quadrilateral shell elements are selected to simulate the platform behaviour under different load situations to which the platform is subjected.

All the constituents of the platform are of structural steel material. Hence, the material properties assigned to the elements are 0.3 for Poisson's ratio, density of 7850kg/m^3 and Modulus of elasticity as 200 GPa. Intense loads are applied over the nodes on selected area of load locations [14]. Quads are the dominant elements employed to mesh the platform while triangular shell elements are employed to mesh triangular gusset geometries. Node to node coincidence and common nodes at all the continuous and discontinuous of the platform sections is ensured for proper element connectivity. Proper element connectivity is a prerequisite of efficient load transfer in finite element analysis. All shell elements (quads & trias) are assigned a thickness of 5mm [15]. This meshed model is further verified for meshing errors like aspect ratio, warpage, skewness, interior angle and taper before application of boundary conditions on the platform. The meshed model of the platform and zoomed mesh are shown in Figs. 8 & 9 respectively.

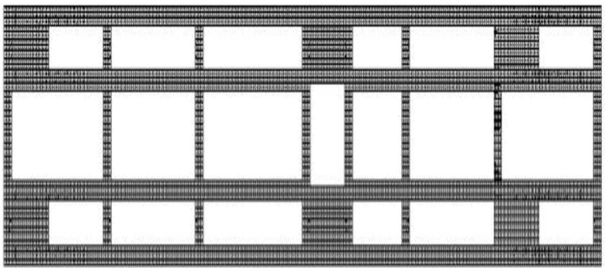

Fig. 8: Meshed model of the platform

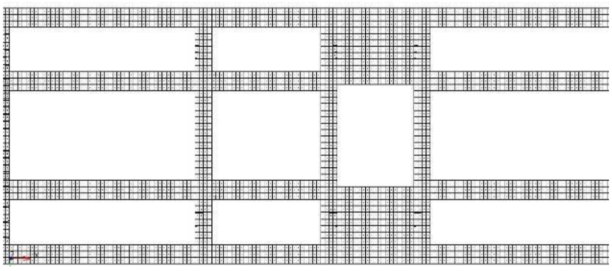

Fig. 9: Meshed model of the platform zoomed mesh

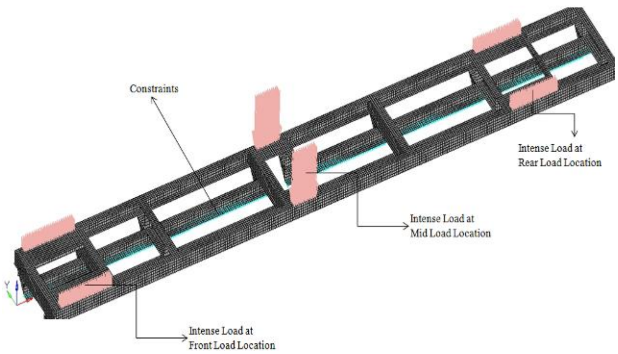

Fig. 10: Boundary conditions (loads & constraints) applied on the platform model

Imposing boundary conditions on the meshed model is the key task to be carried in platform analysis. Vehicle chassis is the foundation on which the longitudinal member is placed and integrated using through U-bolts. Therefore constraints are applied on the lower flange of the main longitudinal member [16]. The degrees of freedom of the nodes on the lower flange portion of main longitudinal member are arrested. Intense loads are applied at front; mid and rear load locations on the platform. Distribution of load magnitude is done according to number of nodes distributed over each load location [17]. Boundary conditions and loads applied on the meshed model are shown in Fig. 10. Stresses and deflections are evaluated from this and are shown in Figs. 11 & 12 respectively.

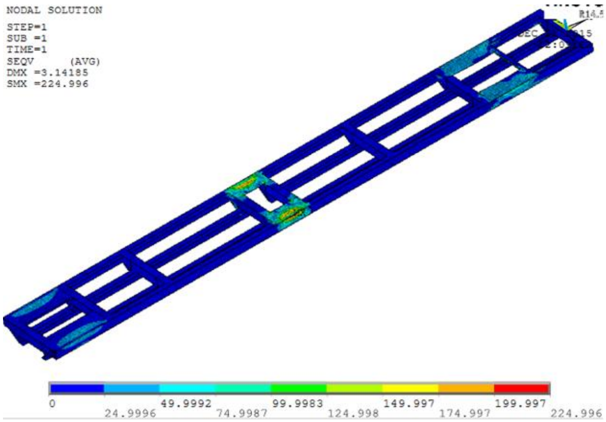

Fig. 11: Stress plot for the platform

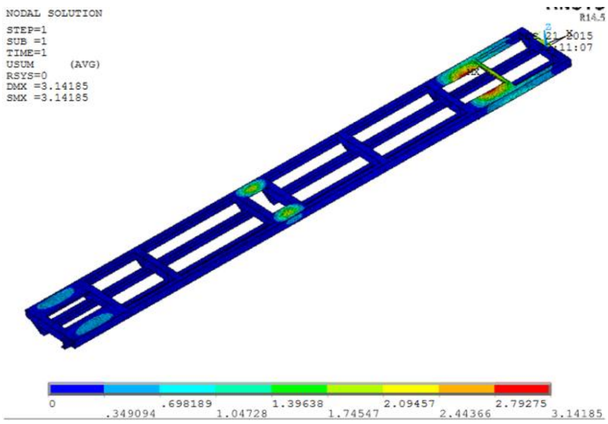

Fig. 12: Deflection plot for the platform

4. Experimental stress analysis of platform

Outcomes of finite element analysis of the platform are stress values at stipulated load locations and the stress distribution in adjacent members which are in vicinity of the load locations. During the finite element analysis process, though all operational requirements are kept in close correlation with the actual situations to which the platform is subjected, clamping elements like U-bolts, small holes made to accommodate these bolts and changes in material properties after welding process are shortfalls of computer aided modeling. The contribution of these to the platform behaviour under loading situation is predicted further with the experimentation process. For experimentation process a scaled prototype of platform with overall dimensions of 1500 x 1000mm is manufactured [18]. Strain measurement is carried at critical locations observed from finite element analysis. Four linear and four rosette strain gages are employed in experimentation. The strain gauge (SG) numbering and their locations on the platform prototype are shown in Fig. 13. Table 1 shows the details of strain gage numbering and their locations on the platform.

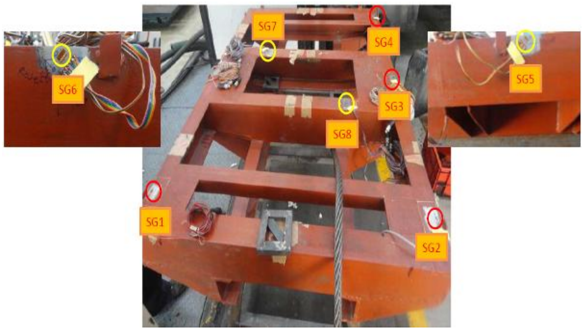

Fig. 13: Strain gauge locations for strain measurement

Sixteen channels (4 linear and 4 tri-axial rosettes 0 – 45 - 90 degrees gauges) are used to acquire strain signals with a sampling rate of 25 samples/sec/channel. Resistance of strain gauge is 350ohm and the gauge factor is 2.1. The strain measurement is carried for loads ranging from 400kg to 1600kg [19]. The load distribution on the platform for each experimentation case is given in Table 2. This experimentation is carried under different load sets mentioned in Table 2. Experimentation data is acquired in micro-strain units by using the data acquisition system shown in Fig. 14. Using rosette reduction technique stress values at every strain gauge location are calculated. The stress values at selected load locations on the platform for each load case are given in Table 3.

Table 1: Strain gauge numbering and locations on the platform

Strain gage no.	Type of gage	Strain gage location on the platform prototype
SG1	Linear	On longitudinal member of front load corner left
SG2	Linear	On longitudinal member of front load corner right
SG3	Linear	On longitudinal member of middle load corner right
SG4	Linear	On longitudinal member of rear load corner right
SG5	Rosette	On outer longitudinal member web portion middle load corner right
SG6	Rosette	On outer longitudinal member web portion middle load corner left
SG7	Rosette	On flange portion of third cross member near mid load corner left
SG8	Rosette	On flange portion of second cross member near mid load corner right

Table 2: Load distribution during experimentation on the platform

Load case	FLC-R	FLC-L	RLC-R	RLC-L	MLC-R	MLC-L	Total weight
Load distribution in kg							
01	100	100	100	100	000	000	400
02	100	100	100	100	500	000	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

Fig. 14: Platform under load and data acquisition system

Table 3: Stress values at each strain gauge location on the platform

Load (kg)	Stress values (MPa) on the platform							
	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8
400	0.63	1.68	1.47	0.84	2.42	1.65	2.32	1.68
1500	1.05	5.46	7.98	1.26	21.26	25.49	18.71	17.62
1600	1.05	5.25	7.35	2.1	20.96	25.27	18.90	16.77

5. Comparison of Finite element analysis and experimental outcomes

Comparing the finite element analysis and experimental results helps in validating the design configuration of chassis mounted platform. Comparison of the stress values for two major load cases of 1500kg and 1600kg is made and is shown in Table 4.

Table 4: Finite element and experimental analysis results

Strain gauge	1500kg load (stress values MPa)		1600kg load (stress values MPa)	
	FEA stress	Experimental stress	FEA stress	Experimental stress
SG1	2.73	1.05	2.94	1.05
SG2	4.41	5.46	5.88	5.25
SG3	8.81	7.98	7.32	7.35
SG4	2.15	1.26	1.47	2.1
SG5	18.69	21.21	19.32	21.0
SG6	26.67	25.41	26.95	25.2
SG7	17.38	18.69	20.37	18.9
SG8	18.95	17.64	16.38	16.8

Following conclusions are drawn based on the outcomes;

a) The stress values obtained at front, mid and rear load locations on longitudinal portions of the platform by experimental technique and finite element analysis process are in close co-relation. Comparison of stress values at locations SG1, SG2 and SG3 depict the same.

b) A difference of 4.59% is observed between the experimental and finite element analysis values. This difference is due to holes made to accommodate U-bolts, changes in the material properties in vicinity of welded areas due to high temperature during welding process, pre-stressing of the platform members accounted shape complexity of individual members.

c) The maximum value of tri-axial stress is 25.41MPa on the web portion at mid load location i.e. at SG6, due to greater magnitude of load.

d) Effective load transfer is observed with increases in load magnitude. Decrease in stress values is observed with the increase in load magnitude.

6. Conclusions

From the comparison of finite element and experimental analysis of platform for various load magnitudes, a close co-relation is observed between the stress values at critical load location on the platform. Lower magnitude of stresses is observed in rear portions than front and mid portions even though rear overhang provided. Lower deflection values are observed in rear portion due to efficient load transfer. This attribute is useful platforms on off-road vehicles that carry tracking systems, sophisticated cargo and high rise antennas that need a levelled base for efficient operating of such systems on off-road terrains. Further employment of such levelled bases reduces the operational errors and damage to the cargo inside the shelter. Design constraints for chassis mounted platform include material selection considerations, legal restrictions for vehicle dimensions, location and size of the shelters, payload carrying capacity and the nature of cargo carried in shelter. Major contributing factors for the platform stability are centre of gravity location of vehicle & platform, approach angle, departure angle and the permissible deflection level. With the present combination of longitudinal and cross members the deflection level in the rear overhang portions of the platform are reduced.

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