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Design Evaluation of Chassis Mounted Platform for Off-Road Wheeled Heavy Vehicles

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ABSTRACT:

Chassis mounted platform is an intermediate component between vehicle chassis and shelter, and acts as a levelled base for shelters. Platform transfers & sustains unevenness in load arising from the road or soil irregularities during vehicle travel in rough terrains. Present work deals with development, evaluation and improvement of one such platform. 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 the shelter. Major design modifications of the platform include nature & pattern of load, flange orientations of channel sections, span between webs of adjacent channels, axle load distribution and vehicle geometry constraints as ground clearance & departure angle. Hand calculations, computer aided design and finite element analysis are carried to evaluate the stress and deflection for different platform configurations. Road profiles for platform analysis include rough road and cross-country terrains. Experimental strain measurement at critical locations on the platform is carried out to evaluate the performance of the platform under specified load-speed conditions. Mathematical relation between experimental stress values and strain gauge locations on the platform is developed for different load magnitudes and loading patterns.

KEYWORDS:

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

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1. Introduction

Off-road transportation is of paramount importance in regards with agriculture, military, construction and other transport situations. Its contribution has a vital role in agricultural productivity, security, safety, and infrastructural enhancement. Road or non-guided ground transport with considerations of legal restrictions on the overall dimensions, payload capacities, nature of cargo intended for transport, environmental and geographical considerations, is the most reliable and efficient medium as compared with air and water modes due to its lesser dependency on the surrounding environments. Motor truck is an indispensible medium for on-road and off-road transport situations. In certain situations e.g., warhead conditions, off-road transport becomes a mandate mode for transportation over other modes in regards with the unfavourable environment circumstances.

For off-road vehicles, the force required to start, accelerate, turn or stop a vehicle depends on the frictional resistance between the tire and road surface. These forces are governed by the coefficient of friction generated due to tire-road interaction. During off-road travel, stability of the vehicle is contributed by vertical load, tire inflation pressure, surface friction and speed, slip angle and tire type. For off-road transportation, vehicles need different design considerations or sometimes totally a new design. Unlike the commercial transport vehicles, designer of off-road vehicle has to begin his work from the consideration that where the vehicle will operate. Strength and deformation characteristics of the road type and road profile influences the off-road vehicle design and over all stability of vehicles that carry trailers and containers of considerable height. Levelled base and road surface has direct influence on the vehicle stability. However for rough terrain, vehicle stability is much affected and the cargo is more likely subjected to damage unless special care is taken. For road surface with large unevenness, the tire-road coefficient of friction cannot be guaranteed and there is possibility of slip (less friction) or total vehicle immobilization (high friction).

To cater the need of providing wireless communications, monotonous data collection, video coverage of experimentation site and other similar applications concept of unmanned vehicle mobile instrumentation platform were developed. Unmanned vehicle systems facilitate less or no human intervention while entering into dangerous environments. Gombar [1] has worked on the development of mobile instrumentation platform for unmanned vehicles. Vehicle stability of troop trucks on which containers are mounted is affected by height of the shelter, nature and the location of cargo placed inside the shelter.

Shelter is needed to isolate the cargo from the effects of surrounding environments, especially in case of intelligent tracking systems used in military applications where accuracy of the tracking system is affected by varying weather conditions. Such shelters require a levelled base to sustain the load variation during off-road travel. In this regard, Senthilkumar et al [2], attempted design and evaluation of levelled base for high-rise antennas, tracking and communication devices for 8x8 wheeled vehicle with the aid of finite element analysis and experimental strain measurement techniques. Experimental strain measurements include computation of static and dynamic strain values. Deulgaonkar et al [3] used concept of combined section modulus for calculating the stress and deflection values in platform for different load conditions during vehicle operation and also suggested a theoretical method to evaluate stress with the use of conventional shear force and bending moment diagrams. They proposed and validated a platform configuration for defence that led to significant improvements in stability and overall performance of shelter mounted vehicles.

Beermann [4] has evaluated joint deformations in commercial truck chassis frames by using flexibility coefficients to determine the torsion stresses in joints of frames. Stresses in joints for fluctuating loads are also found out. Hermann et al [6] devised a structural analysis procedure using shock spectra loading. This process has been used as a design tool for truck trailer mounted refrigeration unit frames. With the aid of finite element model, the stresses in the frames are computed. They used a static equivalent load method for which the peak acceleration value was multiplied by 1.5 to account for dynamic amplification. Design and finite element considerations included governing codes, non-structural components (covers, control panel, etc.), boundary conditions, container construction, load criterion, shock and vibration load criteria, load criteria for containers on ships, mathematical modeling of dynamic load methods, comparison of methods and results. They found that there was good agreement of experimental and analysis results and the variation of the results in some areas of the frame were due to increased stiffness by addition of stiffeners and gusset plates and others due to pre-stressing in components during assembly.

2. Platform stress evaluation using hand calculations

The chassis mounted platform consists of two outer Longitudinal Members (LMs) which are in a plane parallel to vehicle chassis and eight to ten or variable number of lateral or Cross Members (CMs) welded to the outer LMs to form a ladder frame. Two central members, with same cross-sectional dimensions as outer LMs, called as main longitudinal members, are welded to this frame. These main longitudinal members are either continuous or discontinuous and run over chassis length. The platform is bolted to vehicle chassis through U-bolts [5-8]. From the comparative analysis of C, I and T sections with regards with their bending strengths, load carrying capacities, manufacturability and ease of attachment, the cross-section of all members is arrived.

Dimensions of the channel section are selected from Indian Standard (IS) 808. Dimensions of outer LMs are selected as 125x75x5mm and those of lateral or CMs are selected as 150x100x8mm. To withstand the load unevenness arising from vehicle travel in off-road terrains, the CMs dimensions are customized. A taper of 1:5.72 is provided on lower flange of the CMs from outer LMs to chassis or main longitudinal member. For mounting of shelters on the platform, steel plates of 5mm thickness are welded at front, mid and rear of the platform. These load locations are termed as ISO corners. The gross or combined section at fixed portion consists of a combination of vehicle chassis, main longitudinal member and the portion of tapered CM resting on main longitudinal member [3]. General view of chassis mounted platform is shown in Fig. 1.

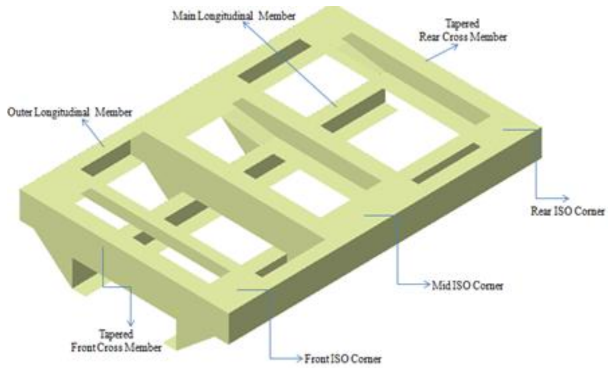

Fig. 1: Chassis mounted platform

From ISO corners, the shelter weight gets transferred towards the vehicle chassis via tapered cross members. Cantilever behaviour is observed in the portion between outer LMs and chassis, maximum bending moment being at the fixed chassis section. Platform design steps such as material selection, selection of cross-section for platform constituents, calculation of section properties for individual and combined sections, calculation of section modulus of combined sections, shear force and bending moment calculations for static load case, theoretical evaluation of static and dynamic stress values for static load case on the platform are discussed by Deulgaonkar et al [3]. Adopting the values of gross section modulus of the combined sections from [3], theoretical stress for braking and gradient load situations is calculated. To evaluate the maximum bending moment, classical beam theory is employed. In order to presume support reactions, rule 93 of central motor vehicles rules is adopted and wheel base is assumed as 5.8m.

The stability of the vehicle on the gradient primarily depends upon the coefficient of friction between the tires and the road surface. When a vehicle with this chassis integrated platform is required to travel on a gradient road, the rearmost cross member is subjected to maximum stress as the major component of load gets transferred to the rear section. During gradient travel, the loads acting on the structure gets resolved into two components as sine and cosine of the gradient angle. Theoretical evaluation of horizontal component is cumbersome in terms of evaluating shear force and bending moment values [9-13]. This cosine component generates and axial force on the whole vehicle and its components are taken care by the tractive force and gradient resistance required for moving the vehicle on gradient uphill direction. Separate construction of thrust diagram is considered for oblique loads. The maximum gradient angle as per the literature for Indian roads is 30°. Hence gradient analysis for two values of 15° and 30° is undertaken. A component of magnitude $W\sin\theta$ is considered to act at each ISO loading corner, where θ is the angle of inclination. The shear force and bending moment diagrams for gradient loads at 15° & 30° on platform are shown in Fig. 2 and 3 respectively.

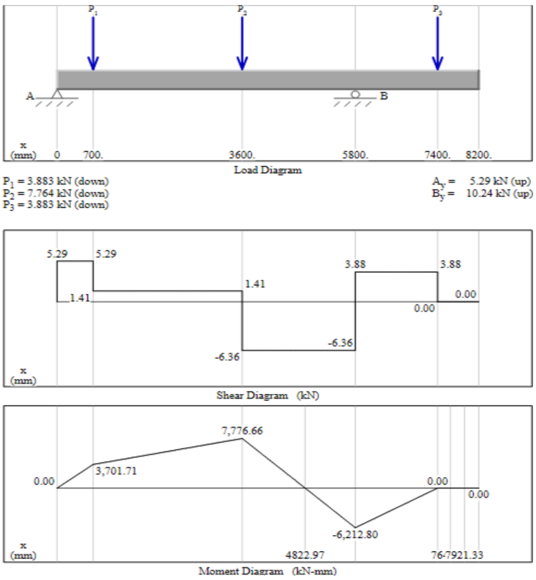

Fig. 2: Shear force and bending moment diagram for 15° gradient load on platform

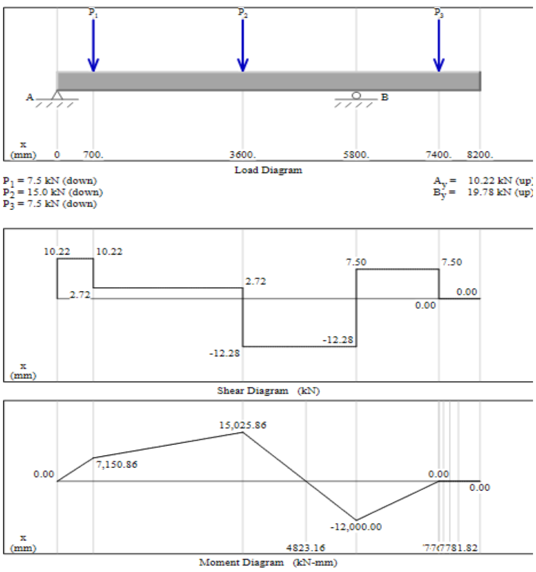

Fig. 3: Shear force and bending moment diagram for 30° gradient load on platform

During braking action, major component of load is transferred to the front axle which changes the weight distribution on the platform. During braking a horizontal load in addition to vertical load acts on the platform. Efficient braking system needs many design considerations such as laden and unladen vehicle mass, wheelbase, height of centre of gravity when laden and unladen, maximum vehicle speed, and road condition, coefficient of friction between road and tires, rates of deceleration. Keeping these parameters at average optimum values, a braking efficiency of 50% is assumed. Major component of load gets transferred to the front axle. Hence, front cross-member is subjected to maximum stress. The shear force and bending moment diagram for braking load is shown in Fig. 4. The maximum value of bending moment for gradient and braking load conditions on the platform are observed at mid portion of the platform. The magnitudes of maximum bending moments are summarized in Table 1.

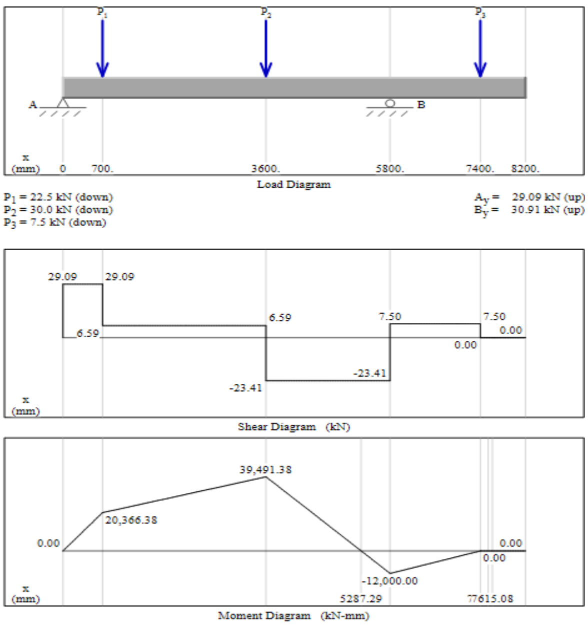

Fig. 4: Shear force and bending moment diagram for braking load on platform

Table 1: Summary of maximum bending moments for gradient and braking loads

Load Condition	Maximum bending moment location	Magnitude of bending moment BM (N-mm)
15^0 Gradient	Middle portion of platform	7776.66
30^0 gradient	Middle portion of platform	15025.86
Braking	Middle portion of platform	39491.38

Static stress values are estimated using the ratio of maximum bending moment to section modulus. Theoretical estimation of dynamic stress values needs to account for predictable and unpredictable factors arising from off-road vehicle travel leading to variation in load distribution on the platform. From the available literature, the dynamic performance is evaluated by relating the static stress times dynamic factor as $\leq 2/3^{rd}$ of yield stress. A value of 1.5 is considered for dynamic factor accounting the various predictable and unpredictable loads on the platform. The results for 15° and 30° gradient and braking load conditions are summarized in Table 2, 3 and 4 respectively.

Table 2: Summary of static and dynamic stress values for 15° gradient loads on platform

Face	Z (mm^3)	BM (N-mm)	2/3*Yield Stress (MPa)	Static Stress (MPa)	Dynamic Stress (MPa)
Bottom	580899	7776.66	166.67	13.38	20.08
Top	621790	7776.66	166.67	12.50	18.75
Left	303712	7776.66	166.67	25.60	38.40
Right	1240512	7776.66	166.67	6.26	9.42

Table 3: Summary of static and dynamic stress values for 30° gradient loads on platform

Face	Z (mm^3)	BM (N-mm)	2/3*Yield Stress (MPa)	Static Stress (MPa)	Dynamic Stress (MPa)
Bottom	580899	15025.86	166.67	25.86	38.79
Top	621790	15025.86	166.67	24.16	36.24
Left	303712	15025.86	166.67	49.47	74.21
Right	1240512	15025.86	166.67	12.11	18.16

Table 4: Summary of static and dynamic stress values for braking loads on platform

Face	Z (mm3)	BM (N-mm)	2/3*Yield Stress (MPa)	Static Stress (MPa)	Dynamic Stress (MPa)
Bottom	580899	39491.38	166.67	67.98	101.97
Top	621790	39491.38	166.67	63.51	95.26
Left	303712	39491.38	166.67	130.02	195.04
Right	1240512	39491.38	166.67	31.83	47.75

3. Experimental stress analysis of platform

Theoretical stress evaluation for different loading conditions on the platform provides a set of stress values that guides the further design evaluation process. In order to predict the platform behaviour and to establish an interrelation between stress values at different locations on the platform, experimental strain measurement is undertaken. The experimentation process is carried on a scaled prototype of 1500x1000mm [15-17]. For experimental assessment of stress, strain measurement is carried using linear and rosette strain gauges. To specify the strain gauge (SG) locations on the platform, geometric nomenclature needed to identify the platform details is shown in Fig. 5.

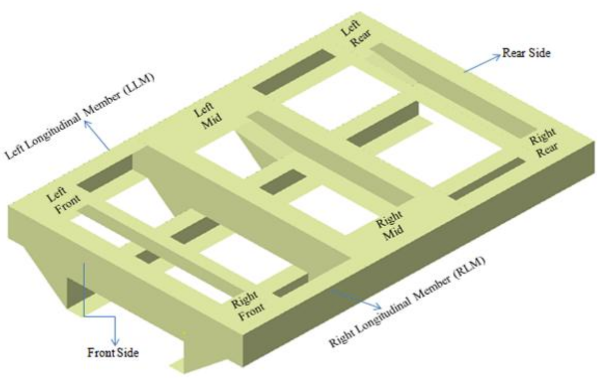

Fig. 5: Detailed nomenclature of platform

Sixteen channels, 4 linear and 4 tri-axial rosette (0, 45, 90 degrees) gauges are used to acquire the strain signals with a sampling rate of 25 samples/sec/channel. Resistance of strain gauge is 350 ohm and the gauge factor is 2.1. The strain measurement is carried out for the load values of 400kg, 900kg, 1400kg, 1500kg and 1600kg respectively. With the present design and load pattern, stress and deflection levels in the rear overhang portion of the platform are considerably reduced. During 400kg load test four steel blocks each of weight 100kg are placed on the front and rear corners and no load is applied at the mid of the platform. During 900kg load test, a steel block of 500kg is placed at the middle right portion of the platform in addition to the 400kg weight placed in 400kg test and there is no load at the left mid portion of the structure. This is similar to the phenomenon occurring during abrupt loading and unloading of the structures. During 1400kg load test, additional steel block of 500kg is placed in the left mid portion symmetric to the 500kg block in earlier 900kg load test. The 1500kg load test is conducted by adding two 50kg blocks at two front (left & right) corners. During 1600kg load test two blocks, each of weight 50kg, are placed on the rear (left & right) corners [18-21]. The load distribution on the platform for each load case is given in Table 5.The locations of linear strain gauges (SG1 to SG4) & rosette gauges (SG5 to SG8) and the data acquisition system used in strain measurement process are shown in Fig. 6.

Table 5: Distribution of load on the platform for each load case

Load in kg						
Right Front	Left Front	Right Rear	Rear left	Right Mid	Left Mid	Total weight
100	100	100	100	0	0	400
100	100	100	100	500	0	900
100	100	100	100	500	500	1400
150	150	100	100	500	500	1500
150	150	150	150	500	500	1600

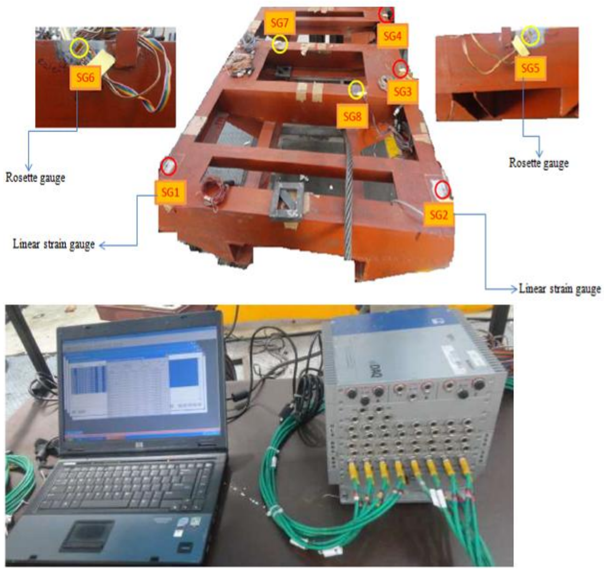

Fig. 6: Strain gauge locations and data acquisition system used for strain measurement

The experimentation is carried at Automotive Research Association of India, Pune. Data is acquired in micro-strain units and further using rosette reduction techniques, the stress values at every strain gauge location are computed. Typical load distribution on platform during one of the test condition is shown in Fig. 7. The stress distribution on the platform for the considered load cases is given in Table 6.

Fig. 7: Load distribution on the platform during experimentation

Table 6: Distribution of stress values on the platform

Load	Stress Values (MPa) on Platform							
(kg)	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
900	0.21	3.78	8.19	1.89	23.30	2.15	3.59	15.71
1400	0.84	3.99	7.98	1.47	22.25	25.85	17.72	16.31
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

4. Analysis of theoretical and experimental results

4.1. Theoretical results analysis

From the gross section modulus of the combined section, static and dynamic stress values are calculated. Graphical representation and comparison of these theoretical stress values is shown in Fig. 8. Position of section modulus (bottom, top, left, right) is represented on abscissa and stress values are represented on ordinate.

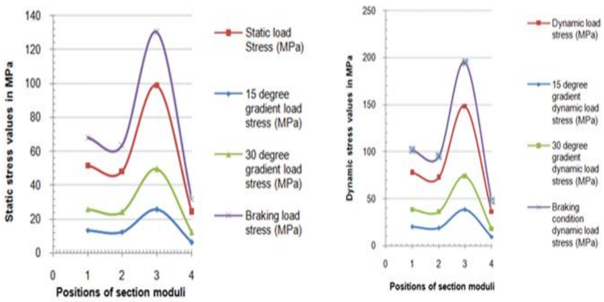

Fig. 8: Comparison of static & dynamic theoretical stress values

The following observations are made from Fig. 8:

i. It is observed that stress pattern is similar for static and dynamic conditions.

ii. The stress values in dynamic situations being greater than static conditions, on enlarged scale the curves show same stress pattern for all loading conditions.

iii. Stress magnitude is greater when calculated from the left side of the combined section i.e., at point 3 on abscissa.

iv. It is also observed from ordinate values corresponding to points 3 and 4 on abscissa that gradient load case of 15 degree reflects low stress magnitudes and braking load shows highest stress magnitudes in static and dynamic situations as compared with other load cases.

v. Right side consideration of section modulus value for evaluation of stress on abscissa gives the lowest stress value as seen from point 4 on abscissa and this is used in present combination of chassis; main longitudinal member and cross-member.

vi. For the evaluation of stress values, section modulus considered from top shows less stress magnitude as compared with the bottom, as observed from points 1 & 2 on abscissa, the corresponding value of stress is lower at point 2 than at point 1.

vii. Comparing the ordinate values corresponding to points 1 & 2 on abscissa, a difference of 6.57% is observed for all the load cases.

viii. Comparing the ordinate values corresponding to points 3 & 4 on abscissa, a notable difference of 66.67% is observed for all load cases. This change is due to the orientation of main longitudinal and cross-member combination.

4.2. Experimental results analysis

From the analysis of experimental stress values an attempt is made to establish mathematical relation between the stress values obtained at prescribed strain gauge locations. The variation of stress for the considered load cases are shown in Fig. 9 to 10. Strain gauge locations i.e. SG1 to SG8 are plotted on abscissa and corresponding stress values are plotted on abscissa. A third order polynomial equation displayed on each figure mathematically predicts the platform behaviour.

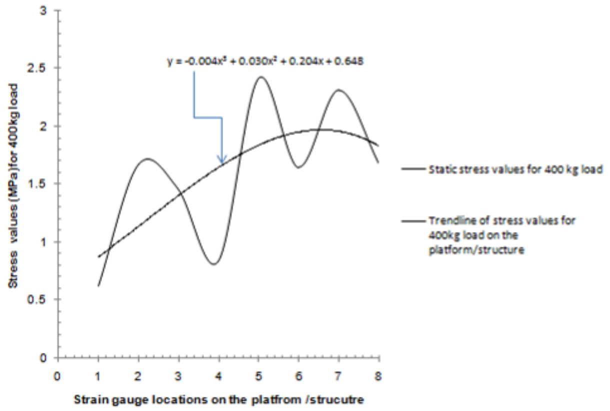

Fig. 9: Variation of stress on platform for 400kg load test

The following inferences are made based on Fig. 9:

i. Low values of stress are observed.

ii. Along with front and rear portions of the platform, stresses are also observed in the mid portion of the platform, though no load is applied at this location.

iii. The stress at the mid portion of the platform is 57.14% greater than the stress magnitude at rear portion, comparing the stress at points 3 & 4.

iv. The stress value in outer right longitudinal member where tri-axial rosette is pasted possesses highest magnitude of stress than any other location. This is observed at point 5 on the abscissa.

v. Outer portion of third cross-member is subjected to stress due to load application in rear portion. This is attributed to the rear overhang of the structure.

vi. The stress in front portion is 50% more than the stress magnitude at rear portion of the structure.

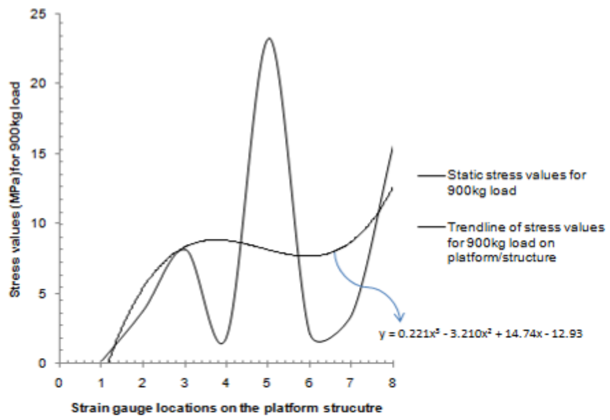

Fig. 10: Variation of stress on platform for 900kg load test

Based on the graphical representation of the stress curve in Fig. 10, the following observations are made:

i. The ratio of front and rear corner stress values is same (50%) as observed in earlier 400kg load test with higher magnitudes of stresses. This is observed from ordinate values at 2 & 4 corresponding locations on abscissa.
ii. The stress in the mid portion of the structure is 23.07% greater than rear location.
iii. Highest stress magnitude peak is observed at the outer right longitudinal member mid-portion (right mid) where a load block of 500kg is placed. This peak is attributed to sudden unsymmetrical load application on the structure. This is indicated by point 5 on abscissa.
iv. The outer portion of the second cross-member in immediate connection with right outer longitudinal member is subjected to more stress than corresponding location on left side. This is attributed to the cantilever behaviour of the cross-member subjected to intense load at the end. This behaviour is in agreement with the hypothesis that load is transferred from outer longitudinal member to cross member.

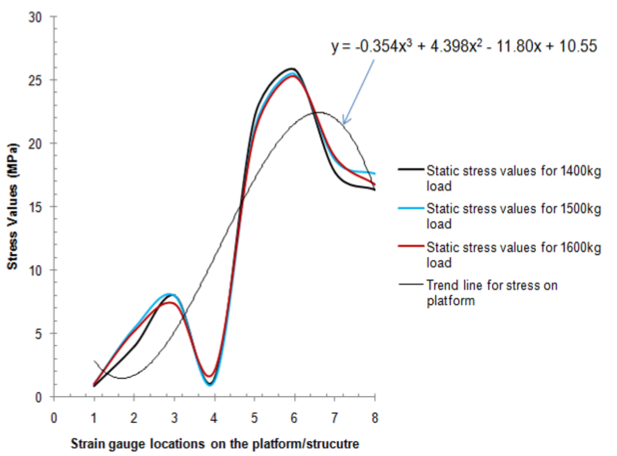

Fig. 11: Variation of stress on platform for 1400, 1500 and 1600kg load tests

Based on the graphical representation of stress values in Fig. 11, the following inferences are made;

i. The variation of stress in front, mid and rear portions of the platform, is observed to follow a similar pattern with reduced or enlarged scales corresponding to the load magnitudes applied.
ii. For the three load tests, the average stress magnitudes in the front portion of the structure are 33.67% greater than that in rear portion. This is depicted from the peaks and ordinate values at locations 2 & 4 on abscissa.
iii. For loads of higher magnitude, the stress values show slight increase in rear portion of the platform as observed from the lift of curve for load of 1600kg.
iv. Highest magnitude of stress is observed at the mid-portion of right and left outer longitudinal member as observed from the peaks corresponding to points 5 & 6 on abscissa.

5. Conclusions

The theoretical and experimental work on platform design evaluation includes considerations of off-road and cross-country road profiles, unevenness in load resulting from tire-road interaction during off-road travel, shelter height and its effect on the magnitude of bending moment generated about the centre of gravity of platform and the vehicle, stability of vehicle during unsymmetrical load on the platform and allied aspects of vehicle design and stability. From the experimental stress analysis of platform for different load magnitudes and load patterns, a mathematical relation between load locations and corresponding stress values is developed. The mathematical relations presented in earlier sections depict the mathematical behaviour of chassis mounted platform. Stress magnitudes in rear portion of the platform are less in comparison with those in front and mid portion in spite of the rear overhang provided. This design overcomes the conventional limitation that a rear member subjects to higher magnitudes of stress levels than those of front and mid sections.

Close correlation has been found between the experimental stress values and finite element stress analysis at static and gradient load conditions. The static and dynamic component of strain values have been found lesser in comparison with the similar platforms. The lower levels of dynamic strain could be correlated to the increase in ratio of sprung mass to unsprung mass, resulted due to higher payload put on the vehicle. This is attributed to present arrangement of longitudinal and cross-members. Lower stress magnitudes in rear portion of platform indicate efficient load transfer from rear to mid and front portions. This attribute of present platform can be utilized for off-road vehicles which carry high rise antennas, tracking systems and sophisticated cargo and need a levelled base during operation.

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