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Gradient Load Evaluation of Chassis Frame Mounted Specialised Structure Designed for Heavy Off-Road Vehicles

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ABSTRACT:

Chassis mounted structures provide a levelled base to the transport vehicles intended for on-road and off-road driving. These structures acts as cushioning elements to sophisticated cargos like intelligent tracking systems placed in shelters' closed environment. These structures need sufficient strength and rigidity to withstand the load variations arising from tire-road interactions during rough road travel. Such structures need special attention during the design phase itself in order to improve the specified payload carrying capacity with optimized dimensions. Present paper focuses on formulation of a specialized structure mounted on chassis intended to carry shelters. A scaled prototype is manufactured and tested for different grade-load combinations. This is done through experimental strain measurement and analysis of the results. The data is acquired for nine different load magnitudes and is categorised into three sets as low, moderate and high magnitudes. Interrelation between the stress/strain values acquired during each load and gradient state is developed. The structure behaviour is hypothesized through the gradient strain measurement outcomes. Major design concerns include the spacing & orientation of cross-members, load locations on the structure and the road profiles. Cross-country and rough road terrain behaviour of the structure is attempted in present work.

KEYWORDS:

Terrain vehicles; Structure design; intense loads; Levelled bases; Gradient loads

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1. Introduction

Transportation plays a vital role in nation's economic growth, progress and safety. On-road & off-road mode of transportation is considered to be the reliable mode of transport as it is less dependent on environmental conditions. Motor truck or truck forms an inseparable link for on-road and off road transportation. Selection of type of truck needs many considerations ranging from type of roads, commodities to be transported (solid, perishable &fluids), weight & volume of the commodity, conditions of road surfaces, grades and altitudes on which the vehicle is driven, loading and unloading costs involved, legal restrictions on weight and size of the vehicle, distance to be travelled, stop and go driving and many such known-unknown parameters. Levelled bases are needed for carriage of cargos which need special attention and care during their transportation, e.g. the tracking systems, high rise antennas and sophisticated computer equipments need to be placed in closed environment (shelters) when they are to be carried rough terrains during war-head conditions.

When a vehicle travels on a gradient road, the nature and distribution of forces/loads acting on the vehicle and other components are subjected to horizontal and vertical load components. On the gradient the stability of the vehicle primarily depends upon the coefficient of friction between the tires and the road surface. Also cargos like crude oil, petrol and liquefied petroleum gas needs closed environments for their transportation. Such transport applications needs levelled base and akin concern as failure of the shelter (container) endangers human life. The failure is likely to occur due to the unevenness in load arising for pits, bumps and allied road undulations during transportation. In case of petrol and allied commodities, road undulations may cause gas generation and increases pressure inside the closed environments. Use of efficiently designed chassis and chassis mounted structures ensures vehicle stability during on-road and off-road transportation.

In this regard work of Yu et al [3] is of significant importance. They developed a practical damage detection technique for frame structures based on finite element modal updating. They utilized an objective function that minimised experimental and analytical values of natural frequencies and mode shapes. Further the need of levelled bases for defence vehicles is identified by Senthilkumar et al [2]. They designed and developed a hydraulically levelled platform for Tatra 8x8 high mobility vehicle through vibration and strain measurement analysis at different vehicle speeds and road conditions. Deulgaonkar et al [13] carried mathematical modelling and formulation of chassis mounted structure with the use of classical shear force and bending moment analysis. They developed the concept of gross section modulus and utilized the same to evaluate the theoretical stress values for vehicle static and dynamic situations under intense load. They further carried finite element and experimental analysis of the same structure for static load condition.

A technique is developed by Tian et.al [04] to understand the dynamic behaviour of complex boxed structures such as truck cabins, air-craft cabins and transformer tanks. They classified the mode shapes of boxed structures by their symmetry properties and also investigated energy distributions in them. Finite element analysis method usage for vehicle frame/ sub-frame design is frequently attempted. Bum et al [7], attempted to overcome the meshing limitations involved in finite element analysis. They developed first order analysis method to surmount the limitations of computer aided design and engineering methods. Andjelic et.al [9] devised a method to optimise the channel section thin walled beams and their self weight. They developed a technique with area of channel section as objective function aiming to minimize area itself. However this method was limited due to its non-consideration of area moments of inertia and rotational moments of inertia.

To obtain the dynamic stress/strain history and distribution of vehicle frame the work of Kim et al [10] is significant. They carried dynamic stress analysis of vehicle frame using non-linear finite element analysis and used a virtual proving ground approach that is capable of producing all the results with one model, one program and one process. Transport bus finite element idealization for dynamic stress and vibration response is carried by Sujatha et.al [22]. They used the random road undulations as input to finite element model of bus and evaluated the acceleration and stress response. They further carried experimental measurement of road undulations for good roads, roads of medium ride quality and bad roads. The vehicle speeds were 30, 60 and 72km/hr. Design of chassis mounted structures includes considerations of wheel base, braking or stopping distance, turning radius, approach & departure angles, break-over angle, ramp angle, sprung & un-sprung mass locations on vehicle chassis, front and rear overhang distances, structure mounting style on chassis.

2. Description of chassis mounted structure for gradient load analysis

The chassis mounted structure is a combination of longitudinal and cross members. It consists of two Longitudinal Members (LMs) that are in a parallel plane to vehicle chassis and eight or more number of Cross Members (CMs). These longitudinal and lateral members are welded to each other and a ladder framed structure in plan view is formed. In present work the cross-members are given a taper on bottom flange to relive the deflection of longitudinal members [15]. For mounting of this combination on vehicle chassis frame, two longitudinal members (called as main longitudinal members) are welded to the central portion of the structure with their flange portions facing towards each other. These main longitudinal members are spaced exactly equal to the chassis frame spacing on the transport vehicle. Main longitudinal members may be continuous or discontinuous depending on the application/design, and placed over chassis frame length. With the aid of through U-bolts, the structure is bolted with vehicle chassis frame [17]. Decision regarding the cross-section of the structure members is made through the comparison of C, I and T sections in respect of their individual section properties, combined section modulus, load carrying capacity, ease of attachment of components and manufacturability of the selected section.

Indian Standard (IS) 808 reveals the standard dimensions of channel sections and hence used in deciding the longitudinal and cross member dimensions of the structure. Dimensions of LMs are decided as 125x75x5mm along with the length of 1500mm and those of CMs are 150x100x8mm along with the length of 1000mm. These longitudinal and cross members are welded to each other using oxy-acetylene welding technique. This welded combination when subjected to range of loads will act as a single entity [18-20]. The cross member dimensions are customized in order to ensure sufficient bending strength against the load. Taper of 5.72° is provided on lower flange portion of the lateral members over the length from longitudinal member to chassis frame. Steel plates of 5mm thickness and of suitable length are welded at front, mid and rear portions of the structure. These locations are termed as ISO corners and are the corners at which the load is applied. The nomenclature stated in above analysis and other details are shown in Fig. 1.

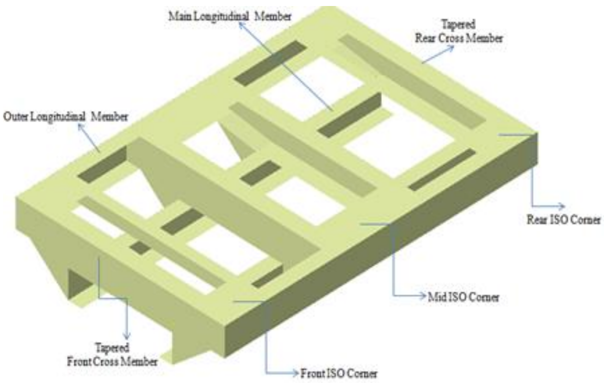


Fig. 1: Platform constituents

3. Gradient strain measurement (uphill travel) of the chassis mounted structure

Gradient strain measurement on the chassis mounted structure is carried to evaluate the strength of the structure for a range of grade-load combinations. When the vehicle travels over a gradient (uphill condition) the major component of load is transferred to the rear ISO corners and the rear overhung cross member is subjected to severe stresses [16]. During gradient uphill travel, the intense loads acting on the structure are resolved into sine and cosine components of the gradient angle which the road makes with the horizontal plane. The cosine component generates an axial thrust on the structure at each load location. This cosine component is balanced by the tractive forces and gradient resistance needed to move the vehicle on gradient in uphill direction. Construction of thrust diagram is into practice for oblique loads. The maximum gradient angle which the present literature reveals for Indian roads is 30°. This test is performed for gradient angles of 0° to 25° of structure inclination [17].

In order to create an intense load at each loading (ISO) corner, a dummy frame is manufactured and welded on the structure in such a way that, when the structure is loaded, the intense nature of loading is achieved as stated in the hypothesis. Fly-ash bricks, each brick weighing 3.5kg are used as a loading material. To experimentally simulate the container effect, a sieve/mesh is wrapped around the additional welded frame. Wooden plates of 6mm thickness are used to provide a base on the dummy structure. As fly-ash bricks are utilized for as loading material, the height of the brick layer placed on the sieve was the major constraint for load magnitudes. While loading the structure, bricks is kept in such a way that equal load is transferred at each ISO corner. The angle meter is used to check the gradient, while the screw-jack is operated using tommy bar is employed to provide gradient. The experimentation process is carried out in gradient loading on the platform for three load sets as low (100kg, 200kg & 500kg), moderate (600kg, 800kg &1000kg) and high (1200kg, 1400kg & 1500kg) load magnitudes. The experimental setup for the gradient strain measurement is shown in Fig. 2.

Fig. 2: Experimental setup for gradient load strain measurement

Ten channel strain indicator is used for acquisition of experimental data. Linear and rosette gauges are used for strain measurement. Linear gauges are located on longitudinal members of the platform adjacent to the loading corners and rosette locations are selected at the mid-portions of the cross-members. Five linear gauges and two rosette gauges are used. The nomenclature for strain gauging on the structure and gauge numbering on abscissa used for graphical representation is described in Table 1 and strain gauge locations are depicted in Fig. 3.

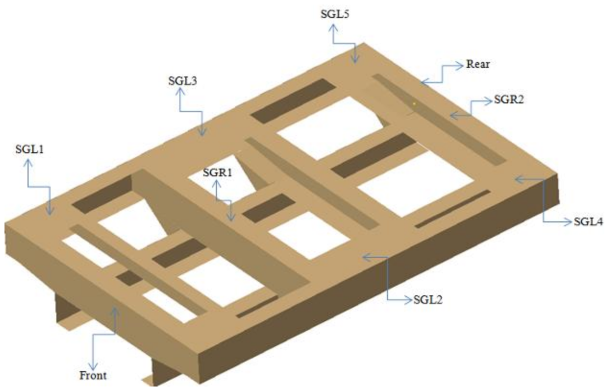


Fig. 3: Positions of linear and rosette strain gauges on the structure

Table 1: Strain gauge nomenclature for gradient strain measurement

Type of strain gauge	SG#	Location of gauge on structure	Abscissa notation
Linear	SGL1	Strain gauge on front left iso corner	1
Linear	SGL2	Strain gauge on mid right iso corner	2
Linear	SGL3	Strain gauge on mid left iso corner	4
Linear	SGL4	Strain gauge on rear right iso corner	5
Linear	SGL5	Strain gauge on rear left iso corner	7
Rosette	SGR1	Strain gauge at mid of third cross-member	3
Rosette	SGR2	Strain gauge on mid of rear cross-member	6

4. Strain data acquisition and analysis of experimental results

As in experimentation process there are no assumptions; direct outcomes are obtained. From the experimental strain values obtained at prescribed strain gauge locations, platform behaviour for different grade-load combinations is predicted. Strain gauge locations are plotted on abscissa as 1 to 7 and corresponding strain values are plotted on ordinate. The strain measurement is carried for three different load sets as mentioned in above sections as low, medium and high magnitudes. The gauge resistance of each strain gauge is 120Ω. As there are nine different load values; single value form each load set is presented. The data acquired is in micro-strain units. The data acquired for 100kg, 600kg and 1200kg loads is discussed. The strain values acquired during gradient strain measurement for 100, 600 & 1200kg are given in Tables 2, 3 & 4 respectively.

Table 2: Strain values for 100kg gradient load on the structure

θ° inclination	Strain Values in(µe) Units						
	SGL1	SGL2	SGL3	SGL4	SGL5	SGR1	SGR2
00	4.5	6	1.5	0	0	6	0
04	24	34.5	7.5	22.5	1.5	115.5	1.5
05	24	34.5	7.5	22.5	1.5	115.5	1.5
06	24	34.5	7.5	22.5	3	114	1.5
08	24	34.5	7.5	24	3	114	1.5
10	24	34.5	7.5	24	3	114	1.5
13	24	34.5	6	24	1.5	115.5	1.5
15	24	34.5	6	24	1.5	114	3
16	24	34.5	6	24	1.5	114	3
18	24	34.5	6	24	1.5	114	1.5
19	24	34.5	4.5	24	1.5	112.5	3
20	24	36	6	24	1.5	112.5	3
21	24	34.5	4.5	24	1.5	112.5	3
22	24	34.5	4.5	24	1.5	112.5	3
23	24	36	3	24	1.5	111	3
25	24	36	4.5	24	1.5	112.5	3

4.1. Gradient strain measurement on structure

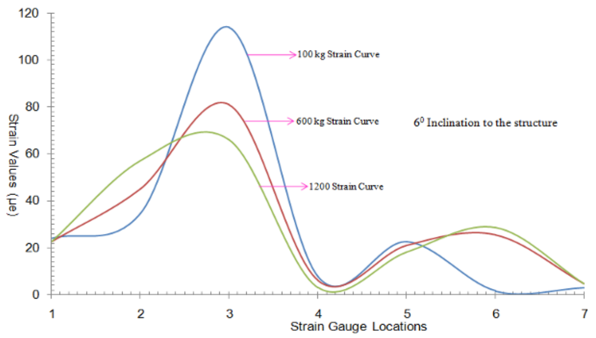
The strain response of the structure for six degree, fifteen degree and twenty degree inclination is graphically depicted in graph 1, graph 2 and graph 3 respectively. Position of strain gauges on the structure and its representation on abscissa is described in Table 1.

Table 3: Strain Values for 600kg gradient load on the structure

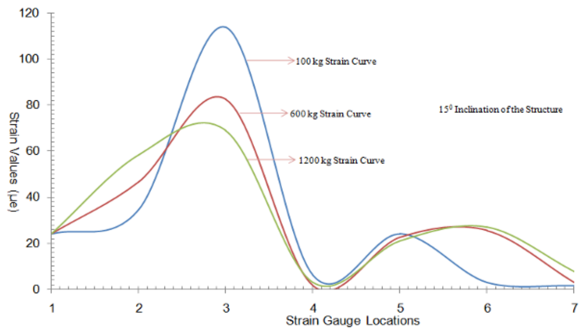
θ°	Strain Values in(µe) Units						
inclination	SGL1	SGL2	SGL3	SGL4	SGL5	SGR1	SGR2
00	1.5	22.5	7.5	0	6	21	1.5
04	21	43.5	6	21	3	81	25.5
05	25.5	43.5	6	21	4.5	81	25.5
06	22.5	45	6	21	4.5	81	25.5
08	22.5	45	4.5	21	4.5	81	25.5
10	22.5	45	3	22.5	4.5	81	25.5
13	24	45	1.5	22.5	3	82.5	25.5
15	24	46.5	1.5	22.5	3	82.5	25.5
16	24	46.5	0	22.5	3	82.5	27
18	24	46.5	0	22.5	3	82.5	25.5
19	24	46.5	0	22.5	3	82.5	27
20	24	48	0	22.5	1.5	82.5	27
21	24	46.5	0	22.5	3	84	27

Table 4: Strain values for 1200kg gradient load on the structure

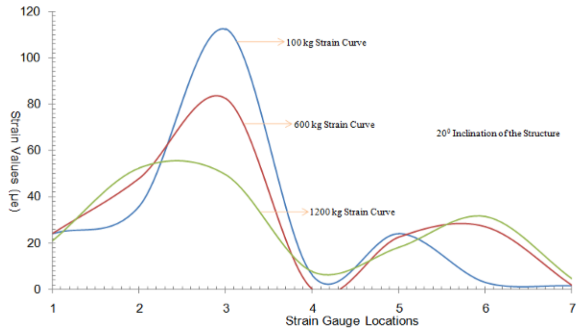
θ°	Strain values in(µe) Units						
inclination	SGL1	SGL2	SGL 3	SGL4	SGL 5	SGR1	SGR2
05	25.5	72	3	24	3	124.5	4.5
06	22.5	57	3	18	4.5	66	28.5
08	21	55.5	1.5	18	4.5	66	27
10	22.5	57	0	19.5	4.5	67.5	27
13	24	57	1.5	21	3	67.5	27
15	24	58.5	3	21	7.5	69	27
16	25.5	58.5	3	21	3	69	28.5
18	25.5	60	4.5	22.5	3	70.5	28.5
19	25.5	60	6	22.5	1.5	70.5	28.5
20	21	52.5	7.5	18	4.5	49.5	31.5



Graph 1: Comparison of strain values for six degree (6°) inclination of the structure



Graph 2: Comparison of strain values for fifteen degree (15°) inclination of the structure



Graph 3: Comparison of strain values for twenty degree (20°) inclination of the structure

The graphs are plotted for three inclination angles 6°, 15°, and 20°. The initial load magnitudes of the said three load sets are selected i.e. 100kg, 600kg &1200kg. Following points are observed at 6° inclination of the structure from graph 1

1) The values of strain at SGL1 i.e. at front portion of the structure for all the three loads are in interval of 22.5 to 25 micro-strains. This is observed on ordinate at corresponding point 1 on abscissa. This variation in strain values is due to small magnitude of gradient angle.
2) At SGL2 there is considerable variation in strain values corresponding to each load considered. A scatter or separation in strain curves is observed between points 1 & 2 on abscissa. Variation in strain values is observed at the mid-right ISO corner on the structure at which load magnitude is greater due to transfer of load from front portion of the structure.
3) At the mid portion of the structure where SGR1 is located, highest magnitudes of strain values are observed. This is due to efficient load transfer from the outer longitudinal member through cross-member mid-portions on gradient conditions. This is observed at point 3 on abscissa.
4) At point 4 on abscissa (i.e. SGL3) corresponding to mid-left ISO corner on the structure lowest magnitudes of strain values are observed for all inclinations and load conditions on the structure as seen from the drop in curvature of the graph.
5) The points 5, 6 & 7 (i.e. at SGL4, SGR2 & SGL5) on abscissa represent the rear portion strain value distribution on the structure. Slight variation in strain values is observed at point 5 on abscissa from the graph. Decrease in strain values is observed in the rear portion of the structure i.e. at SGR2 & SGL5 gauge locations.

As observed from graphs 2 & 3 the curves follow similar nature for 15° and 20° inclinations of the structure as observed for 6°. Similar conclusions can be drawn from the remaining two graphs (i.e. graph 2 & graph 3) as deduced for 6° inclination of structure. Proportionate increase in strain values is observed with the increase in gradient angle, however the curves follow a similar pattern for as observed for small gradient angles. This indicates efficient design of the structure.

5. Conclusions

Experimental strain measurement on the chassis frame mounted structure for gradient load conditions has been carried for three load sets. This work has been commenced with the findings of response of structure to grade-load combinations. Efficient load transfer process is observed from outer longitudinal member to main longitudinal member through cross-members. Strain values in mid portion of the structure are more as compared with front and even for rear portions. This is due to formulated design, that for inclined position of the structure low strain values are observed in rear portions. The strain values at the rear portion of the structure are 18.45% less as compared with those in front and mid portions respectively.

From the trend line of strain curves for stipulated load-grade combination a three degree polynomial equation can be deduced relating the abscissa and ordinate. The equation $y = 1.00x^3 - 13.25x^2 + 46.61x - 7.07$ represents a curve obtained for 20° and 1200kg load-grade combination. This equation governs the strain values on the platform in front, mid and rear portions of the structure at the selected gauge locations. With the aid of this gradient strain measurement similar equations for curves of different grade-load combinations can be deduced. Less strain magnitudes for inclined position of the structure in mid and rear portions as observed signify proficient load transfer from rear and front to mid portions. This aspect of present chassis mounted structure when utilized for off-road vehicles intended for carrying high-rise antennas, computer-tracking systems & cargo that need closed environment for operation increases the reliability of these applications.

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