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Design, Development, and Validation of a Vehicle-mounted Hydraulically-leveled Platform

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ABSTRACT

Hydraulically-leveled platforms are required, to provide a leveled base for accurate leveling of high-rise masts and other vehicle-mounted communication devices. Design, development, and validation of one such platform on an 8x8, high mobility, wheeled vehicle is presented. The platform is a welded structure, designed to accommodate two ISO type shelters, and the shelters are secured to the platform at their four ISO corners using special twist locks. The leveling of the platform is enabled by actuation of four hydraulic cylinders bolted to the vehicle chassis.

The concentrated type loading, resulting due to clearance maintained between the skids of shelters and the platform, and the loading pattern are the major design considerations. The other factors that have bearing on the design of platform include accommodation of variants of shelters, ease of operation of equipment mounted on the original chassis, and load distribution on axles, over-all height, ground clearance and departure angle of the integrated entity. Deflection and stress analysis of the platform structure using finite element analysis has been carried out for two types of shelter loadings. Limited track trials have been conducted at Vehicles Research & Development Establishment (VRDE) for assessment of structural integrity of the platform, and constructional and mobility aspects of platform-mounted-vehicle. Measurements of strain at critical locations, under-shelter loading, and while driving the vehicle at two different vehicle speeds on pave and cross-country tracks, have also been carried out for validation of design of platform. Details on problems faced during track trials, and the subsequent modifications carried out to the platform are also discussed.

Keywords: Hydraulically-leveled platform, ISO shelter, ISO corner, deflection, stress, strain gauge, accelerometer, data acquisition system

NOMENCLATURE

NCAT	National Center for Automotive Testing
FEA	Finite element analysis
PTO	Power take off
CM	Cross member
CM-R	Cross member rosette
ISO-F	ISO corner front
ISO-M	ISO corner middle
ISO-R	ISO corner rear
RLHC	Rear left hand corner of platform
RLHOH	Rear left hand overhang
LHCSM	Left hand C-section middle
LHCSF	Left hand C-section front
LHMC	Left hand middle chassis
RLHC	Rear left hand chassis
MFDD	Mean fully developed deceleration

1. INTODUCTION

Vehicle-mounted hydraulically-leveled platforms have been developed to meet the requirement of leveled base for masts and other vehicle-mounted communication devices while the vehicle is on rough/unpaved surfaces and when acted upon by aerodynamic moments generated by mast mounted on the platform. Hydraulically-leveled platform consists of platform structure, hydraulic actuators and hydraulic actuation system, which include hydraulic pump, reservoir, and valves. Figure 1 shows the platform developed along with its accessories including hydraulic actuation system as mounted on a 8x8 wheeled vehicle.

The process of design of platform started with analysis of requirement in terms of deflection level, loading pattern, and base vehicle details. There are a number of factors which effect the configuration and design of hydraulically-leveled platform other than the loading and specified deflection level. The constraints/parameters identified and their effects are given in Table 1.

The present work carried out includes evolution of platform configuration, analysis for various load conditions, and verification of suitability for variant shelter loading, track trials and measurement carried out for validation of platform design. The manufacturing aspects of platform are not detailed in this report.

2. CONFIGURATION OF THE PLATFORM

Firstly, the laden axle load distribution at the front and the rear have been found out based on the designated

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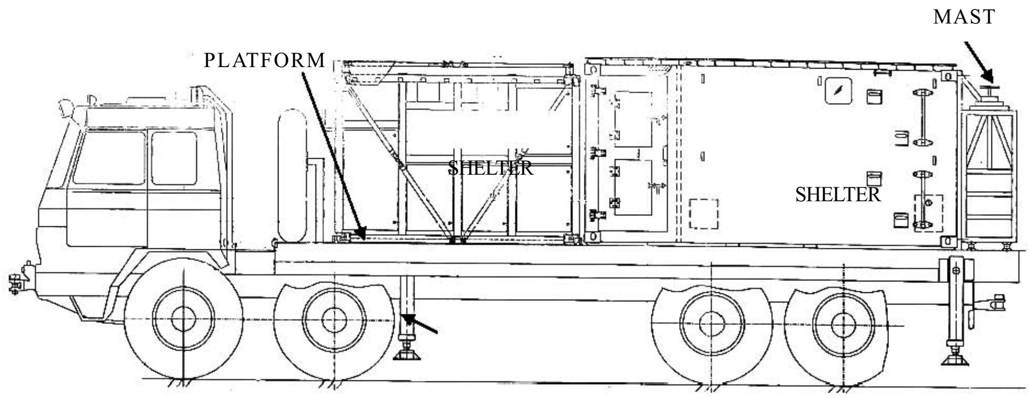
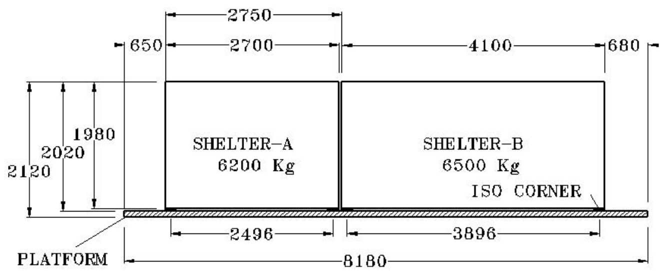
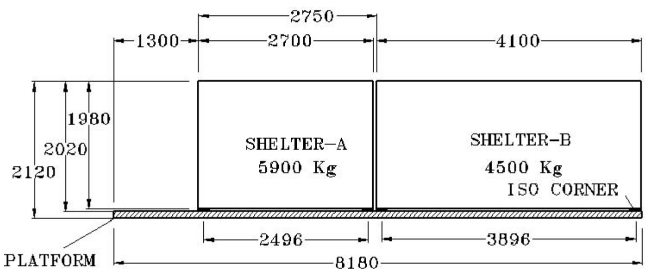


Figure 1. Hydraulically-leveled platform, and shelters as mounted on 8 x 8 vehicle.

weight and positions of equipment inside the shelter, bare shelter weight and its position on platform and, estimated platform weight and its position on vehicle chassis. Possible modifications have been made to positions of shelter, and equipment inside the shelter to maintain the original laden axle load distribution ratio. Two types of shelter loading combinations (Type-I and Type-II) considered in the present work are given in Fig. 2. Figure 3 shows hydrulic actuator as bolted to vehicle chasis and the hydraulic circuit of levelling system is shown in Fig. 4. After finalisation of axle load distribution and thorough study of various constraints listed in Table 1, a preliminary layout and configuration has been worked out. The configuration has been refined and finalised using FE carried out. The platform configuration evolved for the intended application is depicted in Fig 5.



(a) TYPE - I LOADING ON PLATFORM



(b) TYPE - II LOADING ON PLATFORM

Figure 2. Shelter loadings on platform.

Table 1. Design constraints and their effects

Design constraints/ parameters	Effect on design of platform
Over-all height of vehicle Shelter height Chassis height from ground	These factors pose restriction to the height of the platform and determine the space for platform.
Over-all length	Extension of vehicle chassis for accommodation of longer shelters would increase the rear over hang.
Departure and ramp angle	The positions of the actuators bolted to the chassis, and mounting of other accessories in between front and rear wheel stations redefine the departure angle and ramp angle of original vehicle respectively.
Weight of shelters Loading type (UDL/ concentrated) Shelter mounting locations	These parameters largely account for the magnitude of stress, configuration of longitudinal and cross members and their dimensions and positions.
Limit specified on weight of platform	Demands feasible weight reduction measures of platform and its accessories
Axle load distribution	Demands changes in location of equipment mounted inside the shelters.
Specified deflection limit platform	Effects the size of members at and their location
Operation of original vehicle-mounted equipment	Poses problem in working out the configuration of platform. Sufficient space needs to be ensured for effective use/ operation of this equipment.
Bump clearance	Defines the space between tyres and platform member above it. Reduction in this clearance would limit the articulation and cross country mobility.

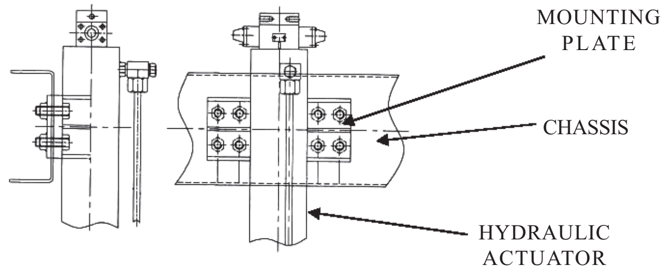


Figure 3. Hydraulic actuator as bolted to vehicle chassis.

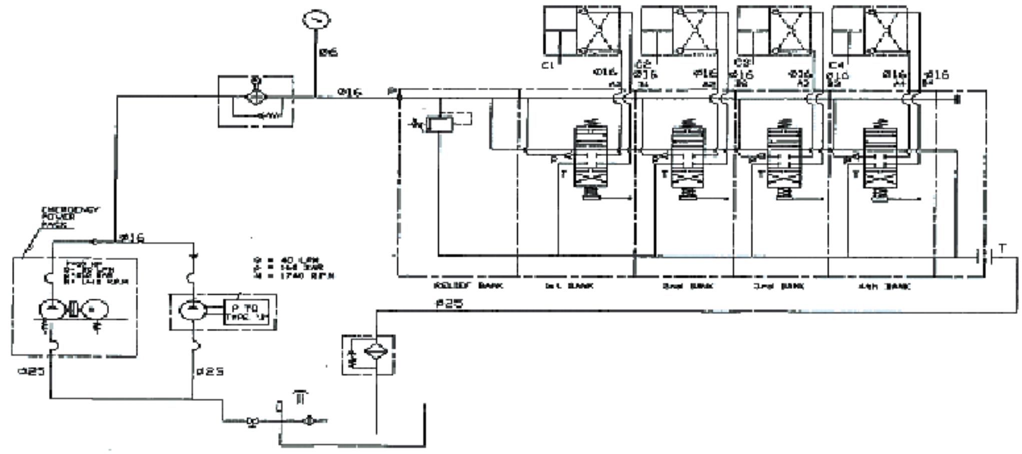


Figure 4. Hydraulic circuit of leveling system.

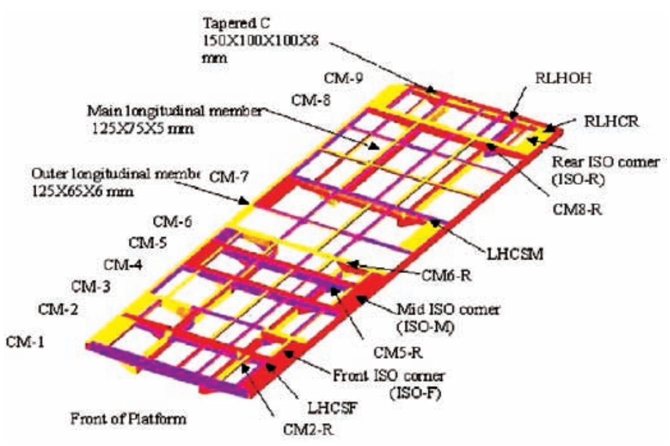


Figure 5. Platform configuration along with locations of strain gauges and accelerometers.

The platform consists of two main longitudinal members in the centre of the platform for mounting it on the vehicle chassis. It also consists of nine cross members located appropriately along the length of the platform to carry the shelter loads, which are concentrated at six locations. The main longitudinal members are box sections having dimension of 125 X 75 X 5 mm and the cross members are tapered C-sections of dimension 150 X 100 X 100 X 8 mm. The cross members are connected by box type outer longitudinal members of dimension 125 X 65 X 6 mm. Two cross members, one at the middle of the platform and the other one at front have been made discontinuous for easy operation of original vehicle equipment mounted on chassis such as crane winch, etc. Gusset plates are welded at the intersections of main longitudinal and cross members to minimise the deflection of the cross members. Plates of thickness of 8 mm have been welded at ISO corner locations of shelters over a required length for accommodating shelters of varying length. The platform is provided with four hydraulic actuators welded to the chassis for leveling purpose.

3. ANALYSIS AND VALIDATION OF PLATFORM STRUCTURE FOR DEFLECTION AND STRESS

3.1 Finite Element Analysis of the Platform

3.1.1Modelling and Meshing

Surface modelling of the platform was carried out considering the whole platform as single entity, and a thin shell (2-D) element was used for meshing of the platform. The platform was primarily meshed using quadrilateral elements, and triangular elements were used to mesh the triangular gusset geometries. The meshed model consists of 42835 nodes, and 36638 quadrilateral and 9567 triangular elements. The meshed model with the load applied for Type-I loading with mast moment is shown in Fig. 6.

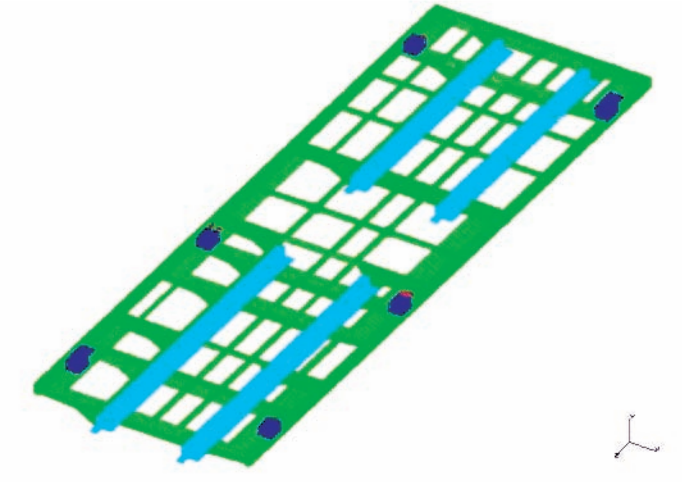


Figure 6. FE model constraints: Type-I (shelter loading with mast moment).

3.1.2 Static Analysis Under Shelter Loading

In this analysis of the platform, the vehicle-chassis is assumed to be rigid and the main longitudinal members of the platform completely rest on chassis. Nodes on the bottom surface of the main longitudinal member are constrained in all six degrees of freedom (DOFs) to simulate the assumption. The boundary conditions imposed on these nodes are $X=Y=Z=0$ (translational DOF), rx, ry, and $rz=0$ (rotational DOF). The loads are applied at six locations representing the ISO corner locations of shelters on the platform. Static analysis of the platform was carried out for 50 per cent and 100 per cent load magnitudes for both Type-I and Type-II loadings.

3.1.3 Static Analysis Under Shelter Loading with Mast Moment

Magnitude of force transferred to the shelter from the mounting of mast bolted to the shelter and in turn to the platform was calculated based on mast moment generated at the specified operational wind speed of 90 km/h. Two masts, which were supported by brackets bolted to the shelter, were located at front left corner of shelter-A and rear right corner of shelter-B. Calculated force of 35000 N was applied at right rear most and left front ISO corner

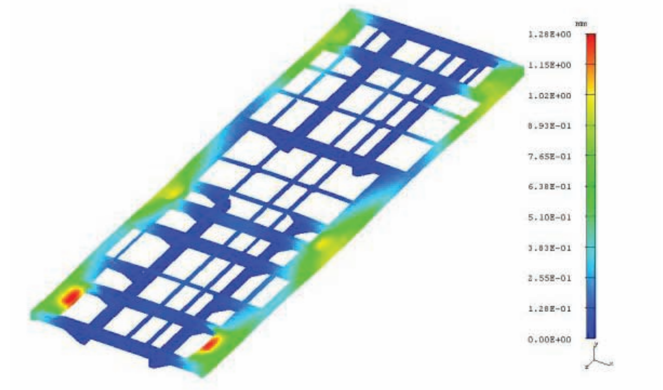


Figure 7. Deflection: Type-I loading.

Table 2. Deflection results (values in mm)

	Type-I FEA	Experimental	Type-II FEA	Location
Static-SW	0.69	Less than	0.52	ISO-F
	0.9	2 mm	1.5	ISO-M
	0.82		0.6	ISO-R
Static-SW	0.86	---	-----	ISO-F
Wind	0.92	------	----	ISO-M
moment	0.96			ISO-R

Table 3. Stress results (static test), Type-I loading

Location	Stress (Von-mises) kg/mm²	
	FEA	Experimental
CM2-R	1.87	1.24
CM5-R	3.56	3.18
CM6-R	2.14	2.38
CM8-R	3.67	3.37

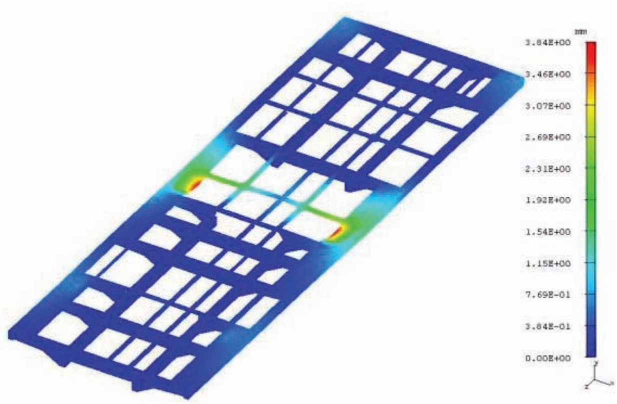


Figure 8. Deflection: Type-II loading.

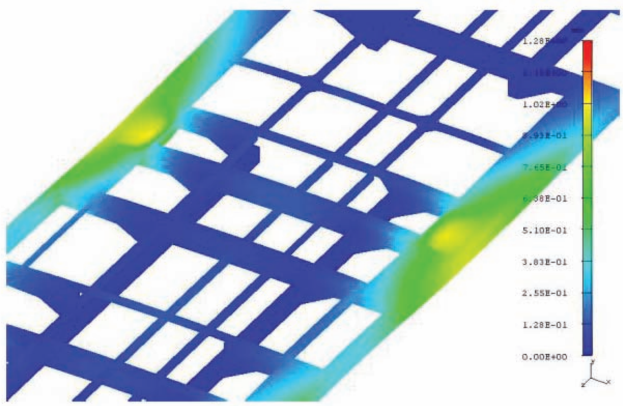


Figure 9. Deflection plot zoomed: Mid type-1.

Table 4. Stress values (static test with mast moment), Type-I loading

Location	Stress (Von-mises) kg/mm^2 (FEA)
CM2-R	2.0
CM5-R	3.52
CM6-R	2.17
CM8-R	4.0

Table 5. Comparison of dynamic and static strain components (pave track-20 km/h)

Location	Dynamic strain ($\mu\varepsilon$) at elements of Rosettes			Static strain ($\mu\varepsilon$) at elements of Rosettes		
	A	B	C	A	B	C
CM2-R	8.4	22.7	14.0	37	83	35
CM5-R	7.4	20.1	7.69	89	254	80
CM6-R	11	6.5	7.7	153	131	-65
CM8-R	8.2	18.3	17.2	92	248	96

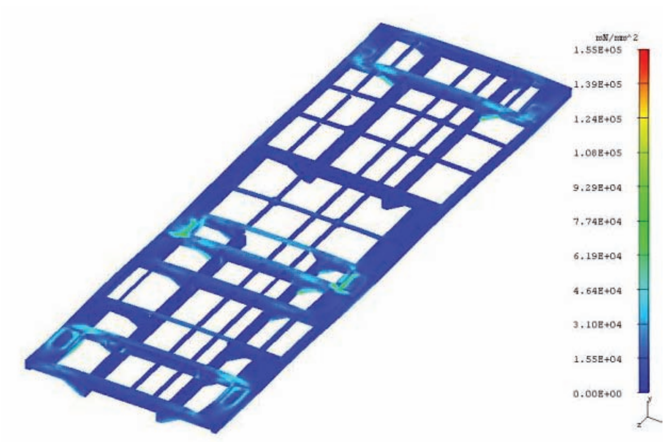


Figure 10. Stress: Type-I loading.

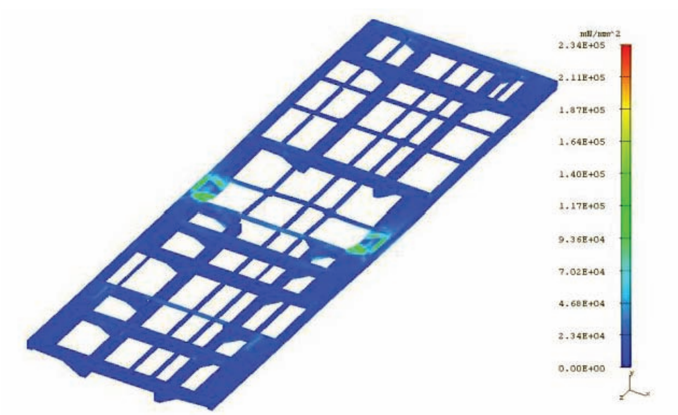


Figure 11. Stress: Type-II loading.

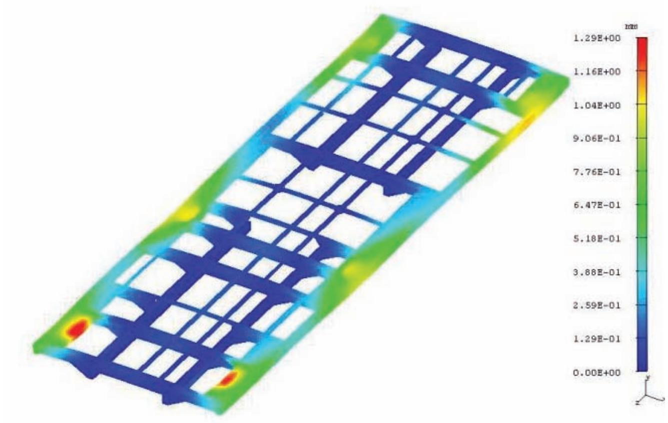


Figure 12. Deflection: Type-I with mast moment.

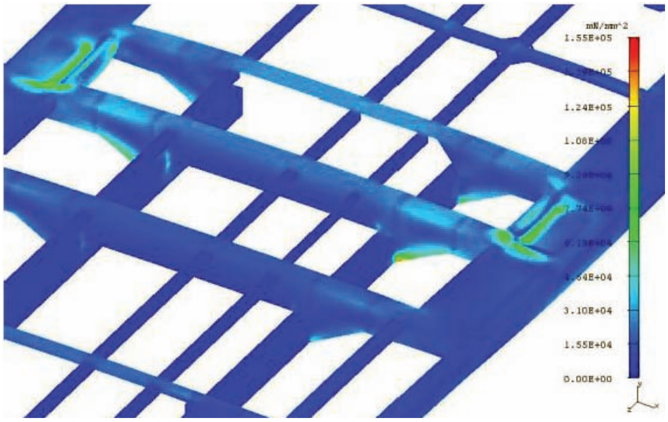


Figure 13. Stress: Type-I mid zoomed view.

locations in longitudinal direction in addition to the shelter loading already applied on the platform. Then the model has been solved for deflection and stress.

3.2 Strain Measurement

Static and dynamic strain measurements werw carried out to find the magnitudes of stress at selected locations. Static measurement was done at 50 per cent and 100 per cent design load conditions of Type-I loading. The loading pattern of actual loading condition was followed while placing the dummy loads on the platform. Dynamic measurement was carried out while driving the vehicle on pave and cross-country tracks at NCAT, VRDE. The measurements was conducted at constant vehicle speed (s) on selected portions of tracks, which exhibit approximately uniform characteristics throughout the selected length. The measurement of dynamic strain has been carried out with zero static reference. The data acquisition system used and the strain gauges pasted on cross members CM-5 and CM-6 are shown in Figs 14-15.

3.3 Vibration Measurement

Vibration measurement was conducted at constant speed(s) of 15km/h and 20 km/h on pave track and 20 kmph on cross-

Figure 14. Data acquisition system-Wavebook 512 with strain gauge module WBK-16.

Figurs 15. Location of strain gauges on CM-5 and CM-6.

country track. The sections of roads were selected such that these exhibited approximately uniform characteristics over the selected length. The vibration levels measured in terms of g–rms at selected locations on chassis and platform are given in Tables 7 and 8. Location of an accelerometer on chassis is shown in Fig. 16. Vibration measurement on the chassis was carried out with a view to validate the experimental dynamic strain values. However, since the magnitude of dynamic strain components were found not contributing to the resultant stress values, the random PSD analysis was not carried out. The PSD spectras obtained at rear and middle of chassis are given in Figs.17and 18.

3.4 Selected Results and Inference

The deflection, strain, and stress values obtained from the afore-mentioned FEA and experimental methods are given in Tables 2 to 7. The deflection and stress plots are given in Fig. 7 to 13. The effect of load pattern is clearly visualised from the deflection and stress plots. The deflection and stress are found to concentrate around the members, which are bearing the load.

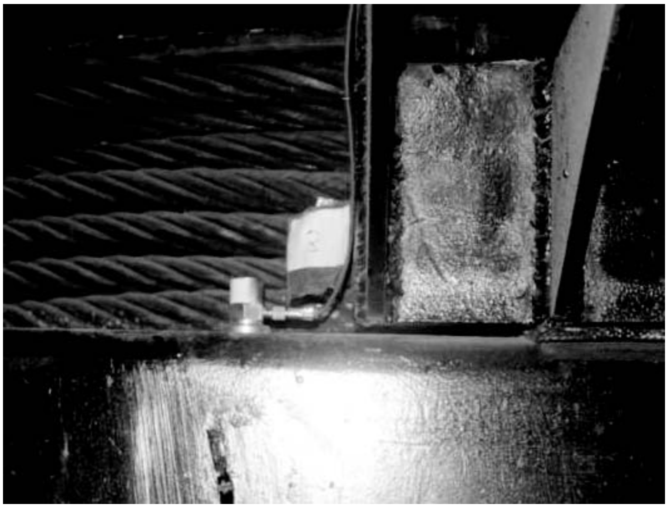


Figure 16. Location of an accelerometer on vehicle chassis.

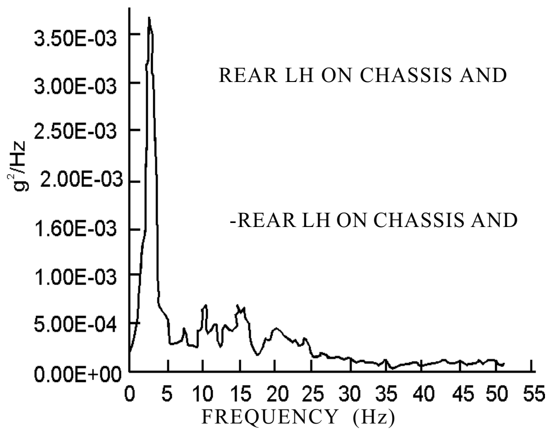


Figure 17. PSD spectra (Rear LH on chassis end).

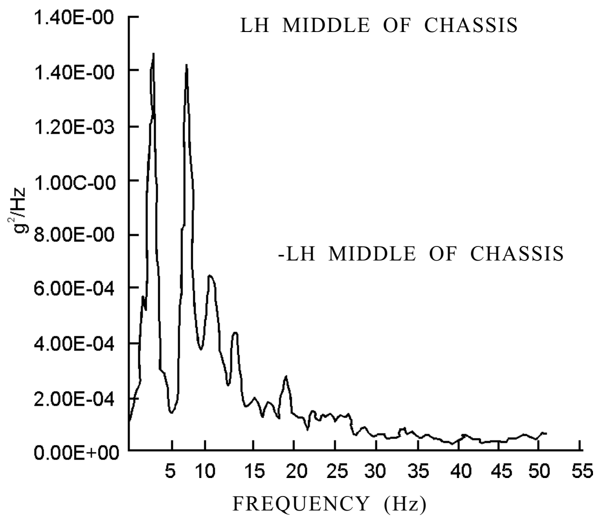


Figure 18. PSD spectra (LH middle of chassis).

The deflection was found more at ISO corner locations. It was maximum at mid ISO corner locations. The deflection of 0.9 mm in Type I loading and 1.5 mm in Type-II are found

Table 6. Dynamic stress values

Location	Dynamic stress (von-mises) (kg/mm^2) Experimental
CM2-R	1.298
CM5-R	3.194
CM6-R	2.387
CM8-R	3.400

3.5 Vibration Results

Table 7. Vibration acceleration on pave track at 20 km/h

Location		Vibration (g-rms) Sections of pave track		
		A	B	C
	RLHCR	0.216	0.235	0.307
Platform	RLHOH	0.203	0.227	0.307
	LHCSM	0.160	0.164	0.155
	LHCSF	0.170	0.181	0.165
Chassis	RLHC	0.219	0.255	0.38
	LHMC	0.142	0.152	0.224

Table 8. Vibration acceleration values on cross-country track

Location		Vibration (g-rms) Sections of cross country-track		
		A	B	C
	RLHCR	0.1431	0.154	0.122
Platform	RLHOH	0.148	0.158	0.142
	LHCSM	0.122	0.1	0.088
	LHCSF	0.122	0.114	0.102
Chassis	RLHC	0.278	0.245	0.222
	LHMC	0.127	0.13	0.118

within the specified limit of 3.0 mm.

The stress was found higher at cross members, which bear the load at ISO blocks. The values obtained from FEA and experimental measurements are comparable.

The dynamic stress values were calculated based on rectangular rosette reduction technique. It is evident from Tables 3 and 6 that the contribution of dynamic strain to the resultant stress is less significant.

4. HYDRAULIC AND LEVELING SYSTEM

The hydraulic system provided consists of four hydraulic cylinders bolted to the vehicle chassis, PTO driven pump, auxiliary electrical motor-driven pump and a mobile block consisting of 6/3 spring centred, manually-operated control valves. During operation, the normally retracted cylinders are extended to the ground and extended further till the tires leave the ground and the platform is leveled. Since the suspension and tyre do not bear any load, the motion of platform is completely arrested. Details on mounting of hydraulic cylinder are given in Fig. 3. The circuit indicating various components of the hydraulic system is given in Fig. 4. The design of hydraulic system has been adapted based on platforms developed earlier under the same project. The dimensions of mounting plates used for bolting of hydraulic cylinders and design of elephant foots (base platform for cylinders) have been optimised using FEA. The actuation system has been checked for the operating pressure, leveling of platform to the required accuracy, stroke length, and operation on dc motor and also for creep. The creep in terms of variation in stroke length of actuators measured has been found within the limit of $\pm$ 4 mm (16 h)

Table 9. Track trial results

Parameters	Results/observation	
FAW/RAW(Laden) ratio	0.769	
Departure angle (deg)	21	
Ramp angle (deg)	23	
Rear overhang (mm)	1940	
Ground clearance (mm)	330	
Clearance circle Dia		
Right lock (m)	30.92	
Left lock (m)	31.79	
Gradeabilty (deg)	15	
Parking brake effectiveness on gradient	15 deg	
Braking	Engine connected	Engine disconnected
Test speed (km/h)	60.30	50.6
Stopping distance (m)	32.43	22.83
MFDD (m/s^2)	5.04 5.25	
Safe turning speed		
Left lock (km/h)	29	
Right lock (km/h)	24	
Articulation successfully 200 tried out mm	without fouling	
Running on various tracks		
Pave track: 50 km		
100mm Corrugated track: 04 passes		
Pothole track: 04 passes		
High speed track: 50 km		
Cross country track: 50 km		

5. LIMITED TRACK TRIALS

A limited trial programme was formulated to assess: (a) structural integrity of the platform along with its accessories, and (b) effect on the mobility aspects of vehicle. The trial results/observations are given in Table 9. Photographs showing few trial views are given in Figs 19-21.

Figure 19. Loaded platform as per type-I loading.

Figure 20. Safe turning speed test on steering pad.

Figure 21. Gradient climbing.

6. CONCLUSIONS

The methodology adapted for development of hydraulically-leveled platform involved various steps including (a) Identification of design constraints, (b) analysis of loading type and its pattern, vehicle axle load distribution and possible reconfiguration, (c) evolvement of preliminary platform configuration, (d) FEA analysis for deflection and stress under various loading conditions and refinement of design, (e) strain measurement and comparison with FEA values, and (f) limited technical trials to assess the structural integrity of platform and mobility aspects of platform mounted vehicle.

The point loading type and its pattern effected the design configuration of the platform to a larger extent. The positions of cross members and length of ISO corner mounting plates have been worked out to cater to two type of loading patterns and minor changes in positions of shelters.

FEA has been used for analysing the platform design evolved for Type-I shelter loading and refinement of platform to limit the defection within the specified values. The FEA has been of great use in visualising the incremental change in deflection and stress levels due to minor modifications such as increase in dimensions of gussets under cross members.

Experimental strain and deflection measurement conducted has been used for validation of FE model for Type-I shelter loading. Limited track trials conducted, served as a means for proving the structural integrity of platform and the mobility aspects of platform-mounted vehicle. The problems observed during trials have been useful in further perfecting platform design.

The FE model of the platform after validation has been used for analysis of platform under Type-II loading. The greater utility of validated FE model can now be extended for new shelter variants.

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Mr M. Chidanand obtained Diploma in Mechanical Engineering from Govt Polytechnic, Bellary, in 1980. He joined VRDE, Ahmednagar, in 1982 and worked in areas including development of vehicle-mounted hydraulically-leveled platforms and shelters and, hydraulic systems such as brake, steering and ramp for light tracked vehicles. Presently, he is involved in testing and evaluation of vehicles at National Centre for Automotive Testing (NCAT), VRDE.

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