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Finite Element Analysis of Chassis Integrated Structure for Tractor Trolley in Agricultural Applications

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ABSTRACT:

This paper deals with the design evaluation of chassis integrated structure intended to carry tractor trolleys. This structure is either bolted along with tractor trailer chassis or attached to the trolley using special attachments. Such structure is located in between the trolley chassis and tractor trolley. The role of this structure is to provide a support to the trolley during transportation in agricultural terrains. This structure transmits and upholds the load variations during tractor travel in agricultural terrains. Present work deals with design evaluation of one such structure. In this work, the structure under consideration is designed to house and support one axle semi-trailer trolley. Locations of attachment of the structure to the chassis or trolley depend upon the weight and size restrictions mentioned in Indian Standards. Major design considerations for the structure include height of the semi-trailer trolley, nature of load or cargo placed inside the trolley, restrictions on axle load and tractor geometry parameters as departure angle & ground clearance. In order to evaluate structure characteristics of stress and deflection computer simulation is carried for the road-load conditions. Road profiles for structure simulation and analysis include typical Indian agricultural terrains comprising of black cotton soil and soil lumps.

KEYWORDS:

Semi-trailer; Tractor; Levelled base; Finite element analysis

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1. Introduction

Transportation is of paramount importance in a country's overall progress and growth. It is transportation which satisfies different requirements of a nation as raw material supplies, finished or final products delivery, supplying aids in areas suffered from natural calamities. Air, water and land are the traditional modes of transport. Road or non-guided ground transport is the most reliable and efficient medium as compared with air and water modes due to its less dependency on the surrounding environments. In a nation like India, where agriculture is the occupation of 75% of population, transportation is of great significance in agricultural sector and hence in development of economy. In old age agricultural activities like farm cultivation, supplies of farm requirements and deliveries of final crops to markets or industries were carried out with the help of animal-drawn vehicles prominently called bullock-carts. Land transport is the major mode of transport for all agricultural and allied activities. With the advancements in automobile sector, tractors have replaced traditional farm cultivation equipment.

Tractors with specific attachments play a major role in cultivation as well as in allied transport activities apparently in farm transports. Tractor is a versatile vehicle that satisfies needs of farmers ranging from farm cultivation to delivery of the harvest or final crop to market or industry as achieved with the help of specific attachments. Its contribution has increased agricultural productivity with reduction in numerous bottle-necks of farmers on all major transportation fronts. For vehicles employed in agricultural activities, the force needed to start, accelerate, turn or stop a vehicle depends on the frictional resistance between the tire and agricultural terrain and also on the soil quality. These forces are governed by co-efficient of friction generated due to tire-road interaction. However in hilly or sloppy terrains the tire-road contact is governed by angle of repose in addition to friction co-efficient. To adapt the varying soil nature in different regions the tires of tractor are provided with a wider base.

During travel on untarred village roads, the stability of combination of agricultural tractor fitted with semi-trailer depends on wheels and is further affected by load distribution on the semitrailer, height of load placed on the semi-trailer, shape and length of drawbar and semi-trailer dimensions. For agricultural operation and allied transportation activities, tractors need different design stipulations or sometimes a new design. Stability of tractors in agricultural terrains and on untarred roads is affected by strength and deformation characteristics of the road type and road profile, overall height of the combination of trailer and the transport commodity placed in the semi-trailer. For transport semi-trailers in which tipping action is mandatory, the stability of the tractor is predominantly governed by the tipping angles. Indian standards limit tipping angle for tractors between

42 to 50 degrees [1-2]. Tractor stability is influenced by levelled bases and road surfaces. For road surface with large unevenness, the tire-road co-efficient of friction (i.e. ratio of traction force to load) cannot be guaranteed and there is possibility of slip (less friction) or total vehicle immobilization (high friction).

In order to satisfy 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. Unmanned vehicles are employed in hazardous environments to collect experimental data and even in war-head conditions. Study of levelled bases was further extended by Deulgaonkar [3]. In which they designed and developed a hydraulically levelled platform for 8×8 Tatra vehicles. Such platforms are utilized to provide a levelled base to the shelters that provide a closed environment to the sophisticated equipment, defence cargo and intelligent tracking systems used in war-head situations. The evaluation of the designed levelled base is done through finite element analysis and experimental strain measurement process. Experimental strain measurement is carried for variable speed and load conditions. This work is further extended by Deulgaonkar [4]. In which they developed a concept of gross section modulus for calculation of the stress and deflection values in the levelled base for different load conditions during vehicle operation with the aid of classical calculation method. They further devised a theoretical process for the evaluation of stress by using elementary shear force and bending moment diagrams. Theoretical calculations of section properties as centroidal distance, moment of inertia, co-ordinates of centroid of combination of constituents of levelled base are presented by Deulgaonkar et al [5].

Strain measurement for different vehicle speeds i.e. dynamic vehicle situations of an imitable platform is discussed by Deulgaonkar et al [6]. They proposed and validated a platform configuration for defence and commercial vehicles that led to significant improvements in stability and overall performance of shelter mounted vehicles. Height of the shelter is a major design attribute contributing to the overall magnitude of bending moment acting on the levelled bases. During transportation on rough roads and in cross country terrains varying magnitude of bending moment affects the lateral stability of the vehicle especially during turning. Levelled bases provide a significant amount of stability to the vehicle during such situations. Major design considerations for platform development are overall height and width of the vehicle, approach and departure angles [7-8].

2. Levelled base in agricultural transport

Indian Standard 9821 describes the terms needed for farm transportation. Agricultural trailer is rectangular boxed structure made of structural steel with one side open to place the agricultural produce and commodities necessary for production inputs. Trailers are classified broadly into four different types; balanced trailer, fixed platform trailer, semi-trailer and tipping platform trailer. Trailer dimensions include ground clearance, wheel base and wheel track. Loads of the trailers are described through axle load, gross load, payload and unladen mass. Dimensions of the balanced trailer are shown in Fig. 1. The semitrailer platform mounted on chassis includes two outer longitudinal members which are in a plane parallel to vehicle chassis and variable number of lateral or cross members are attached to form a ladder frame. This combination is directly integrated with the vehicle chassis using suitable number of U-bolts. Number of through U-bolts depends upon the clamping force needed to keep in the tact the semi-trailer and chassis assembly. Analysis of channel or C-sections for bending strength, load carrying capacity, manufacturability and ease of attachment of components makes it suitable for use in composition of the structure constituents [22].

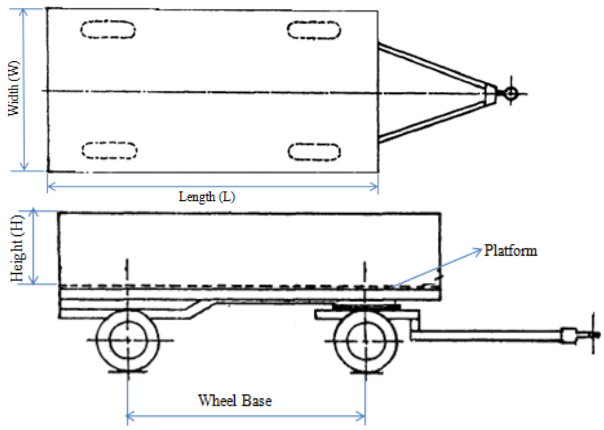

Fig. 1: Dimensions of balanced trailer

Dimensions of the channel section are selected from Indian Standard (IS) 808. Outer longitudinal member dimensions are rated as 125×75×5mm and those of lateral members are chosen as 150×100×8mm. To withstand the unevenness of vertical load arising during vehicle travel in agricultural and village road terrains, the lateral member dimensions are modified. A taper is provided on lower flange of cross member from outer longitudinal member to chassis. Theoretical design steps for the platform subjected to intense load as decision regarding material suitability, cross-section suitability for the individual components, evaluation of section properties of all components of the platform, calculation of gross section modulus of combined sections, elementary shear force and bending moment evaluation of static load on the platform, evaluation of static and dynamic stress values are discussed by Deulgaonkar et al [9]. The design constraints and their limiting dimensions are enlisted in Table 1. The magnitude of load to be applied on the finite element model of the platform-trolley combination is decided with the aid of Indian Standard for agricultural tractor-trailer (IS: 8213-2000) third revision.

The limiting dimensions of the platform trolley as per IS 8213-2000 are 5000×2500 mm^2 for 5 tonne load carrying capacity of the agricultural tractor, with an average load of 0.004 N/mm^2. Experimental and finite element analysis outcomes of a steel prototype with dimensions 1500×1000mm^2 are discussed by Deulgaonkar et al [10], same dimensions of prototype are employed to avoid the experimentation phase. Further the average proportionate load for the reduced dimensions of prototype is 6000N based on the same 0.004 N/mm^2 load carrying capacity.

Table 1: Design constraints and limiting dimensions

Parameter	Dimension	Remark
Trailer width	Upto 2500mm	--
Trailer length	Upto 5000mm	Trailer capacity 5 tonnes
Trailer length	Upto 6700mm	Trailer capacity more than 5 tonnes
Trailer height (Tires inflated)	1500mm	Distance between ground and lowest portion of the trailer
Trailer height (Tires inflated)	2200mm	Distance between ground and topmost portion of the trailer
Front overhang	800mm	Balanced trailer
Ground clearance	300mm	--
Tipping angle	42° to 50°	Tipping type trailer
Wheel track	1500 to 1700mm	--

3. Computer aided modelling of trailer

Computer simulation of the trailer and integrated platform is carried to understand and estimate the behavior of the platform-trolley combination under load. As platform-trolley is presumed to be a welded structure and expected to behave as a single entity when subjected to actual load situations, it needs to be modelled as one single entity. Dimensional considerations of the platform-trolley combination decide the type of computer modelling technique to be employed. The computer aided model, dimensional and other details of the platform-trolley combination are shown in Fig. 2. Dimensional details of the platform-trolley combination are depicted in Fig. 3.

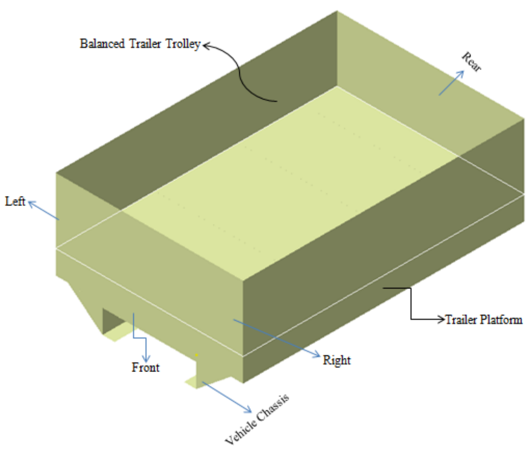

Fig. 2: Details of chassis mounted platform and trolley

Present platform-trolley combination is a structure whose length is dominant over the individual member thickness and therefore surface modelling technique is employed for preparation of computer model of the platform-trolley combination. The software employed for simulation is CATIA V5 R19 considering its surface modelling capabilities. With the limiting dimensions and design constraints mentioned in Table 1, a prototype of the platform-trolley combination is made. This computer model is further verified for interconnection between platform surfaces and coincidence of edges at corners. This model is saved in IGES (Initial Graphics Exchange Specifications) format in order to export the same in analysis software environment for finite element modelling.

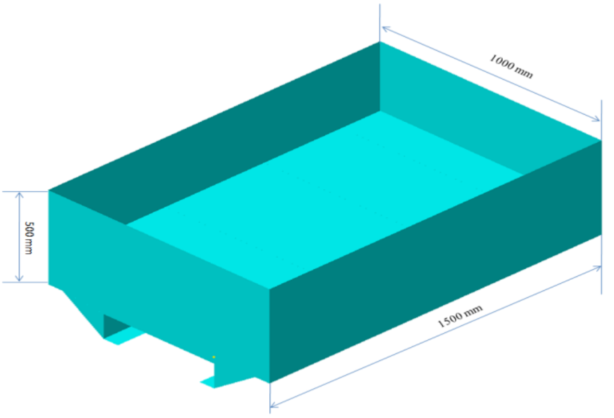

Fig. 3: Dimensional details of prototype of platform-trolley combination

In next phase of research, finite element analysis of the platform-trolley combination is carried. To simulate the practical or actual load situations to which the platform-trolley combination is subjected, concise understanding of the loading environment through which the platform-trolley combination has to undergo is the fundamental prerequisite [11-14]. Other vital considerations for platform-trolley simulation are material and its physical properties, attachment of platform trolley-combination to vehicle chassis which decides the constraints and further boundary conditions for finite element analysis. Every finite element analysis process possesses three fundamental steps viz. pre-processing or modelling, analysis and post-processing.

During pre-processing phase of platform-trolley combination, geometry of combination along with loads, constraints and mechanical properties are formulated. This includes surface model of the preparation of the platform-trolley combination, meshing of the same and application of loads and constraints. Present platform-trolley combination is structural welded and bolted steel structure. Element selection being crucial step during finite element analysis is given important concern. Present structure is a combination length-width dimensions in which length is dominant over individual thickness that corresponds to plane stress situation in finite element terms. Shell element which resembles plane stress situation is selected for meshing [15]. A quad-tri element shape combination is used while meshing complex regions. Major elements for meshing comprise of quadrilateral shape. Steel material properties as Young's Modulus: 210GPa, Poisson's ratio as 0.3 and density of 7850kg/m^3 are assigned to the elements [18].

Node to node and element to element connectivity are ensured for proper load transfer in all regions of the platform-trolley combination. Meshed platform-trolley model is further verified for possible meshing errors such as aspect ratio, warpage, skewness interior angle, and taper before proceeding for application of boundary conditions. The meshed model is shown in Fig. 4. A uniformly distributed load of 6000N on the prototype combination is applied and nodes on the bottom surface of chassis flange are applied constraints. All the degrees of freedom of the bottom nodes are arrested based on the presumption that chassis is rigid [19]. Intense loads in downward direction are applied over the nodes of platform trolley-combination. The meshed model of the structure along with these boundary conditions is shown in Fig. 5.

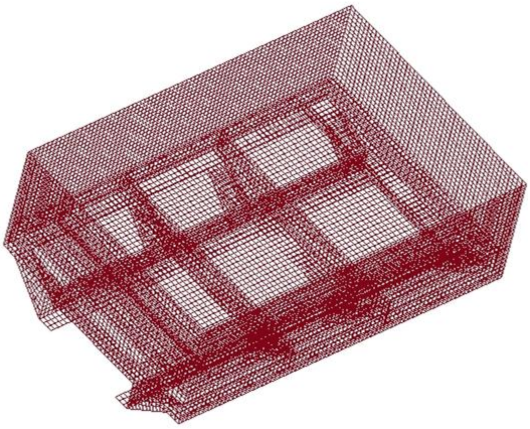

Fig. 4: Meshed model of platform-trolley combination

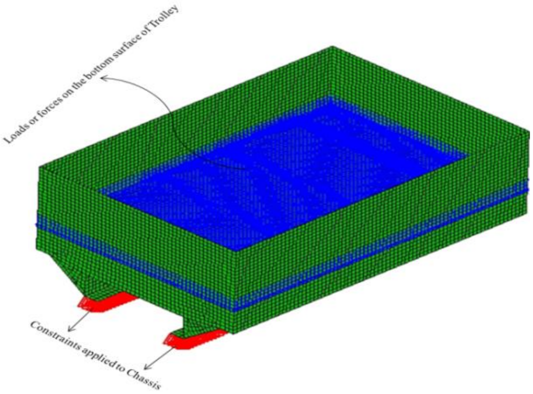

Fig. 5: Loads and boundary conditions applied to platform-trolley

The second step in the finite element analysis procedure is to solve (analysis) phase. In this stage matrix (stiffness, force & displacement) equations are generated for the applied set of boundary conditions i.e. for loads and constraints at each element and these are further assembled for the entire elements of the platform-trolley combination. These equations are solved for deflection and are utilized to evaluate stress, strain and reaction values at critical locations. This process is done with the aid of solver and all the calculations are done at the background of computer [21]. Final post-processing step that includes interpretation of results is very crucial to determine the critically stressed locations on the platform-trolley combination structure. From the stress and displacement plots shown in Fig. 6 and Fig.7, the critical stress areas are identified. Although load is uniformly distributed over the entire trolley surface intact with platform, major stress portions include mid, front and rear at the centroidal locations. Present results are converged at the element dimension of 20mm [20]. Convergence of displacement results is observed at 20mm which is observed after carrying analysis for element dimensions ranging from 5mm to 15mm in steps of 5mm each.

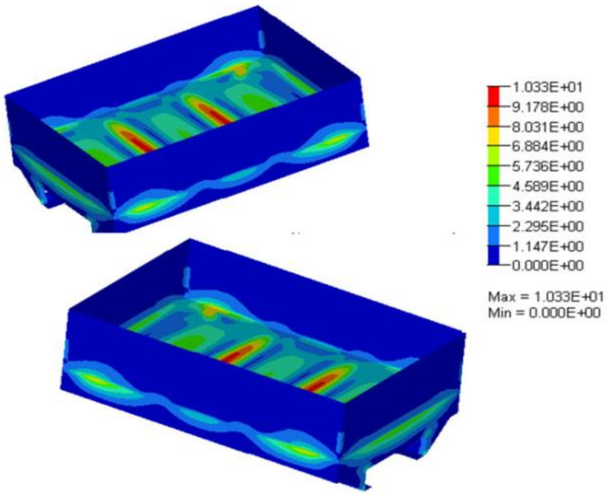

Fig. 6: Stress plot for platform-trolley combination

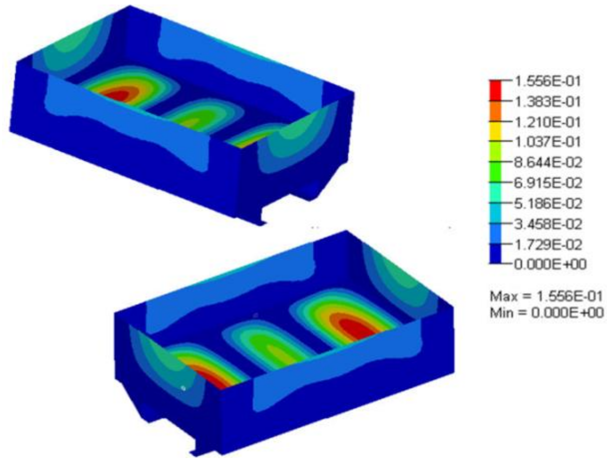

Fig. 7: Displacement plot for platform-trolley combination

4. Conclusions

The commencement of simulation work of the platform-trolley design evaluation includes consideration for factors as agricultural terrain and untarred road profiles, unevenness in load arising from tire-road interaction during agricultural and related transport operations, effect of heap (commodity) height placed in the trolley and magnitude of bending moment generated about the centre of gravity of the tractor-trolley combination in addition to design parameters that include overall height, bump clearance, cornering effect, ground clearance etc. From the stress pattern observed, it is inferred that there is uniform distribution of load over the entire surface of the trolley which is attributed to the design of supporting platform along with trolley.

Maximum magnitude of Von-Mises stress is observed at the mid portion of the trolley-platform combination and its magnitude is 10.325MPa. This magnitude is very low when extrapolated with the true scale loading of 5 tonnes. Maximum displacement is observed in front and rear overhang portions of the structure. This is attributed to the locations of cross-members on the platform beneath trolley. The magnitude observed is 0.15mm at both front and rear portions. The stress and deflection at other locations are well within limits of the material yield strength. With the aid of these finite element analysis results, the behaviour of trolley-platform combination is devised and understood. As the same combination is used for agricultural transportation it is obvious that such trolleys are always overloaded. Present research provides a levelled base for the agricultural produce to be transported with extravagant load carrying capacity and to withstand rough usage.

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