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Design Optimization and Simulation Study of the Engine Transportation Metal Pallet for Stationary and Movable Condition

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Abstract

In transportation theory each and every equipment has its own importance. The main aim is only to be safe transport of finished goods. In the transportation many types of pallets are used. Generally the standard pallets are used in all the industry, because they are easily available and ordered from local market. The disposal of this standardize pallet is also easy. The engine transportation is the special case of transport when it comes to export of engines across countries. Before this type of design optimization it is needed to check with the all circumstance related to failures occurring while exporting the product across countries. The pallet design is optimized and simulated for the critical behavior of pallet. The design of pallet is simulated for the transportation and stationary (story building) condition with the aid of FEA analysis using analysis software.

Keywords: *Simulation, Design optimization, Engine metal pallet, and Transportation.*

1. Introduction

Packaging is one of the main parts of transportation of finished goods. The world becomes faster day by day and due to this time limitation all process to be completed within the customer time demand. In this process packaging is very important to contribute the safe dispatch. Internal and external transportations use different types of pallet like wooden, metal, plastic etc. In the transportation finished goods proper packaging is very important to prevent it from any types of damage the product. As for as the packaging concerned to be the safety transportation of engine packaging design consideration is required. It includes the packaging process and equipment.

In packaging, selection of proper pallet is also important. Olden day's many countries would use the wooden pallets for packaging. The wooden pallet is lighter in weight, easily available and manufactures with the less cost and has many more advantageous. Similarly plastic and metal pallet is alternative to wooden pallet.

Metal pallet is beneficial due to its high strength and suitable for heavy material transportation. We can design different types of engine pallets by make with slight changes in the metal pallet. Non similar shape of finished goods packaging is possible with this appropriate change. Metal pallets reused in many times, dismantle easily and recycled. It makes from the cold rolled sheet and standardizes sections that are easily available in market. The engine manufactures prefer special metal pallets for packaging. But in this process non standard sections are used. The proper design study is therefore required before finalizing the pallet manufacturing process. Metal pallet is subjected to under the stresses of compression and tension when the pallets move from one place to another place with the engines. The material selection with standard sections is depends upon the primary criteria of engine load. To keep a fine balancing between engine and pallet design optimization of weight is required. Normally the overall peripheral design of

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engine needs to be considered in designing of pallet for engine. In this paper, we will be dealing with soft validation design which the engine pallet makes, is easy to manufacture, assemble, and disassemble. We will go through these concepts.

2. Literature Review

Claudio Bernuzzi et al [1] part 1 deal with the selection of the method of analysis, i.e. 1st or 2nd order elastic analysis, depending on the rack deformability to horizontal loads. Internal forces and moments on members are significantly influenced by the effects of lateral displacements as well as by the type of the beam formulation adopted in the finite element analysis program. Static design rules currently adopt in Europe for steel storage pallet racks. No univocal rules are provided by the European rack code for routine design. The system length approach for buckling check leads to unsafe design. Improvements for the evaluation of the elastic critical load are urgently expected. Claudio Bernuzzi et al [2] theoretical Study of rack design and considers serviceability lateral displacements of the whole rack and both resistance and stability ultimate limit states for the uprights. Underline the weak points of the European rack standards and are of practical interest for structural engineers, stressing clearly when the recommended procedures fail, hence leading to an unsafe and uneconomic design.

Benoit P. Gilbert et al [3] improved the 2D model that was found to be accurately reproducing the bending moment distribution. The 3D advanced finite element analysis's improved the 2D model of steel drive-in racks. The effect of pallets on the bending moment distribution in the uprights is checked. The influence of the pallets on the capacity of the racks is investigated. This paper clarifies the loading scenario(s) governing the design. The strength of a device required to prevent the pallets from sliding is determined by them. Keshav K. Sangle et al [4] worked on the elastic stability analysis of cold-formed pallet rack structures with semi-rigid connections. With the help of experimental study & FEA is carried out on pallet rack structure. It also includes three dimensional finite element modeling and elastic buckling analysis. Original open upright sections are torsionally strengthened by external stiffeners. External stiffeners are found very useful for increasing the load carrying capacity. To calculate accurate buckling load, 3-D finite element modeling is recommended.

Bentzione Pliacekos et al [5] worked on design improvements of automotive rack housing. With the help of product optimization and quasi-static nonlinear structural analysis identify the proposed design higher safety factor than current design. Total mass reduced 13% and total number of component reduced was 21%. This includes the material reduction, reduction of number of components, Manufacturing cost reduction etc. Lip H Teh et al [6] designed double-sided high-rise steel pallet rack frames and made analysis with the help of 3D linear buckling analyses, it demonstrated that the global buckling behavior of high-rise steel storage rack frames may not be revealed by 2D buckling analyses as 3D interaction modes are involved.

Soury et al [7] worked on the design, optimization and manufacturing of wood–plastic composite pallet. FEA and experimental method use for optimize the design of an I-shape profile with wood–plastic composite (WPC) pallet. Comparison of simulations and experimental results indicated that the given (WPC) design method is reasonably reliable. Godley et al [8] investigated the effects of looseness of bracing components in the cross-aisle direction on the ultimate load-carrying capacity of pallet rack frames. With the help of experimental load tests fully cyclic loading for determine the stiffness of the frame and also the effect of looseness in the connection. Yaman *et al* [9] studied on the manufacturer's mixed pallet design problem and formulate the problem as a mixed integer linear program. Use company data for conducting a computational study to investigate efficiency of the formulation and impact of mixed pallets on customer's total cost.

From the literature review it is seen that, when the stationary rack and pallets are under the loaded condition analyse forces of joints and columns. Also study and trail conducted on balancing of stationary rack and elastic limit deformation in columns.

It is seen that the maximum overall effect of these forces is taken or not is not cleared. Some of them have only considered the static loading forces. In static and transportation pallet load and their failure analysis are not justified. The practical testing is only done on the highest load condition. Both stationary and movable concept design failure soft validation analysis is not seen.

3. Pallet Design Requirement

Pallet design is completed with following design and peripheral requirements.

1. Standard material and easily available in the local market
2. Cost of the raw material and manufacturing process
3. Minimum weight of the pallet with proper strength
4. Manufacturing availability
5. Joints of pallet
6. Loads and stresses
7. Fork lifting provision in design
8. Engine mounting provision

After the all design consideration pallet design is made with two concept one with welded joint and another with bolted joints. Further the model is simulated for the CAE soft analysis.

3.1. Concepts Modelling

Two concepts are prepared, one is with the bolted concept and another is the welded joint concept. Bolted means all joints of the pallet is assembled with nut and bolts. Advantages of this type of pallet is when the engine mounting legs are damage in the handling process it can be removable and replaceable. Therefore it is beneficial for reuse more than one time. The main advantage is easy to assemble and disassemble of bolted pallet at both supplier and customer end. Less stack up of assembly size after dismantling the pallets. Another benefit is easy to manage with less space when condition in recycled transport. No need to cutting the pallet similar to the welding. Disadvantage is only the cost increased due to fasteners and chances of fastener getting loose in transportation.

Second concept is the welding concept. This concept is made to the minimum space requirement and the consideration with the container size in transportation. These types of pallet have better strength of joints. Major disadvantage is the mountings of engine legs are not replaceable when it gets damage and total pallet is needed to be scrapped.

4. Simulation for Concept Model

4.1. Consideration for Simulation

1. All analysis performed using thin shell elements.
2. All critical and near critical area should be documented prior to testing of prototypes to serve a guide for inspection.
3. Result expects it to be characterized by low frequencies, and comparatively low amplitudes.

4. It would be more concerned about shock due to the load being displaced due to large pitching and rolling of vessel, and then becoming suddenly stationary.
5. The frame has been designed to transport 4 engines at a time to the customer location via sea shipment.

4.2. FEA Perspective Validate the Frame Design

1. Stressed on frame/ channels owing to direct engine weight & at different G load per CTU packaging guidelines
2. Check for adequate bolted joints.
3. Model response of the assembly with hazardous frequency range for sea transportation.

The below table 1 is mentioned the specification for bolted concept model. In the same way in welded pallet only to reduce no of parts and all bolted joints converted to the welding thus no bolts required for the welding.

Table 1. Detail Specification of Metal Pallet

Metal pallet specification	
L X W X H of single rack	1135.5 X 1135.5 X 801
Number of parts	12
Material of beam	Steel ASTM A1008 (CR)
Yield strength	240 Mpa
Module of elasticity	2.1e5 Mpa
Poisson's ratio	0.3
Density	7850 kg/m3
Metal rack weight	48 kg
Engine weight	95 kg
No of bolts	20 Nos.
Application	Stationary as well as transportation

4.3. Assumptions

Few assumptions are required for this FEA analysis is given below

1. The weld material at several welded contact points is not considered in the analysis & a node to node (or bonded) connectivity is assumed at welded components.
2. Effect of fastening of two palettes (by rope, etc) is not considered, merely a placement of one on top of another.
3. Analysis carried out by assuming relevant point mass of individual engines & upper palette at respective centre of gravity.
4. A co-efficient of damping of 5% has been assumed for PSD analysis results.
5. It is assumed that the welding is perfect without discrepancies. Hence structural strength will greatly depend of quality of welds owing to elimination of bolted joints.

6. The inner square sectioned vertical bar is assumed to have a perfectly flat face in contact with the bottom support cup so as to avoid any leveling problems at the top palette.

4.4. Meshing Details

1. All components were meshed in workbench as shell elements (except the engine legs and mounting pads).
2. A point mass was used to represent the engine and palette assembly at respective centre of gravity.

4.4.1. Loads & Boundary Conditions: Table 2 is show that the load boundary condition of pallet that used for analysis. In real practice it is not feasible to each point of the column faces is manufactured completely flat and complete contact with ground because of manufacturing and assembly limitation.

Table 2. Load and Boundary Conditions

Analysis intent	Load applied	Constraint
Pothole/Handling stock	2G Load applied in the vertical direction	Fixed at faces touching the ground
Stacking check	Thrice the mass applied on the top flat resting faces	Fixed at faces touching the ground
Vehicle braking/ Cornering check	1/2 G Load applied in all horizontal directions	Fixed at faces touching the ground
Base random vibration check	Input as per the PSD provided in vertical direction	Fixed at faces touching the ground
Forklift supporting check	2G Load applied in the vertical direction	Fixed at surface likely to touch forklift arms.

4.4.2 Mass Calculations: Before the analysis of model table 3 shows the assembly weight calculated according to the each component density.

Table 3. Mass of Single Pallet

	Mass (in kg)
Engine (4 nos.)	380
Pallet frame	48
Total	**428**

4.4.3 Meshing- Quality Checks: Mesh sizes would be controlled in workbench and would be kept sufficiently fine so that the mesh represents all the curves & bends to the best detailed level.

4.5. Bolted Concept Analysis

This concept checks with in analysis for the stationary stacking and movable condition effects.

For stacking, consider the three storey level weight.

FEM model: 3 X (Mass of palette assembly)

[F = 428*3*9.81 = 12596 N]

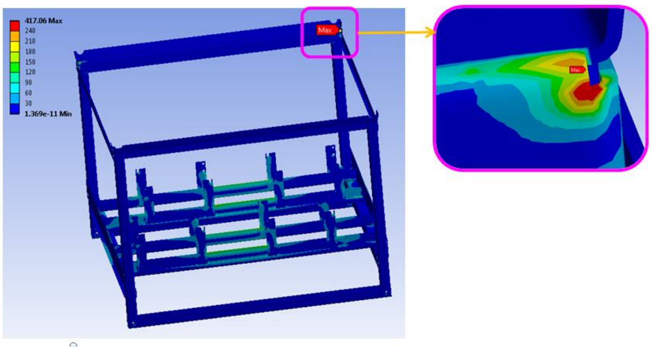

Figure 1. High Stress in the Top Corner of Pattern

Figure 1 shows the high stresses form in the top corner of pallet structure at an all the Pothole/Handling stock analysis, stacking analysis, forklift supporting check (short side), forklift supporting check (long side).

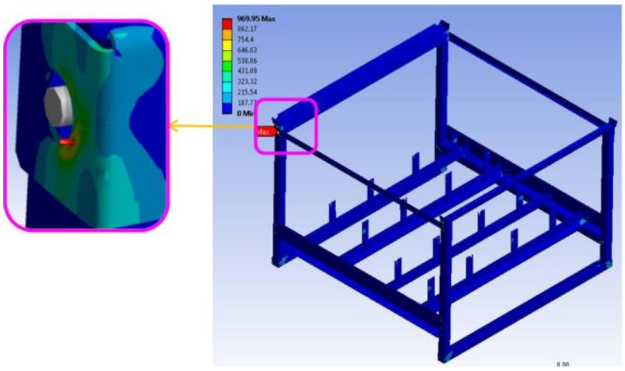

Figure 2. Vehicle Braking / Cornering Check Analysis

And figure 2 shows the top bolting corner high stresses are produced when consider the vehicle braking / Cornering checking.

Table 4. Stress Analysis Result of Bolted Concept Model

Sr. No.	Analysis Intent	Analysis Type	Load	Stress (MPa)
1	Pothole/Handling stock	Structural	2G Load applied in the vertical direction	417.06
2	Stacking check	Structural	Thrice the Mass applied on the top flat resting faces	622.30
3	Vehicle braking/ Cornering check	Structural	1/2 G Load applied in all horizontal directions	969.95
4a	Forklift supporting check (short side)	Structural	2G Load applied in the vertical direction	425.43
4b	Forklift supporting check (long side)	Structural	2G Load applied in the vertical direction	435.78

After the first bolted analysis followings are the main observations are founds.

1. High stresses are observed at bends on upper supports, owing to sharp corners.
2. These stresses are above the yield point of steel (240 MPa).
3. A smoother profile and thicker section would help eliminate these stresses.
4. Design is sturdy but it cannot be holds 4 engines and a higher mass of the pallet above.

The design is deemed unsafe under the given set of loading conditions owing to the high stresses seen at top supports

4.6 Welded Concept Analysis

4.6.1. Pothole/Handling Stock Analysis: This type of analysis is required for internal handling of the pallet stack. Below figure is the displacement and stress plot for the 2 level stacks. For choosing the storey level of the internal stack is depending on the industrial fork truck vertical transport limit.

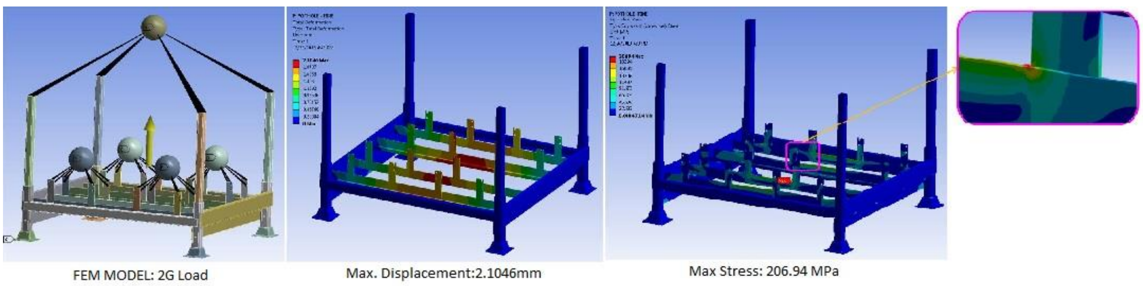

Figure 3. Displacement Plot and Stress Plot

4.6.2 Stacking Analysis: In the industrial racking all joints is attached with each other, and the load of the product is equally distributed all over joints. Therefore each member of rack is supported to each other and balances the load equally. Since the effect of loading is minimized on all joints and reduce the high level of stresses in the each corner and joints. This stacking analysis related to the welding pallet up to 5 storey level stack up. If the pallets are stored on 5 level benefits is to required minimum space inside the storage area.

FEM model: 5 * (Mass of palette assembly)

[F = 428*5*9.81 = 21000 N]

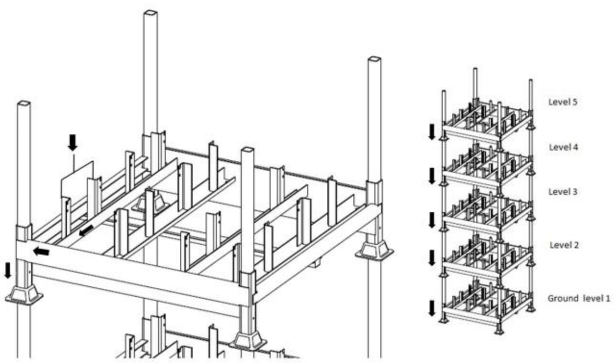

Figure 4. Storey Level Load Distribution from Engine Mounting Legs

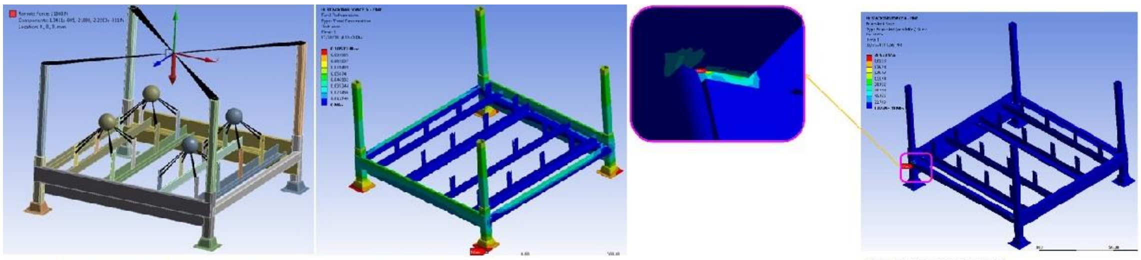

Figure 5. Displacement Plot and Stress Plot

In figure 4 how to load transfer in each column at an 5 storey levels are shown.

4.6.2. Vehicle Braking / Cornering check: This analysis is required when the final product transport outside from the industry like sea shipment and on road by trucks.

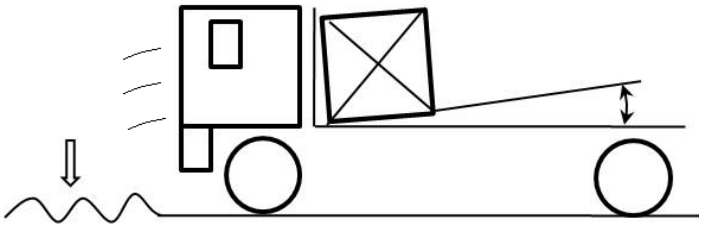

Figure 6. Vehicle Braking

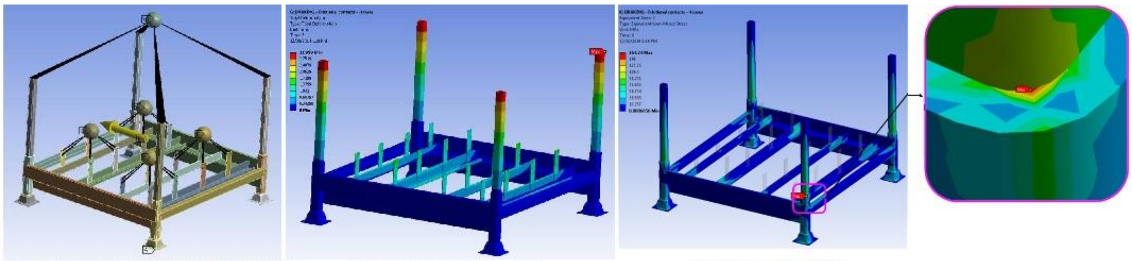

Figure 7. Displacement Plot and Stress Plot

Above figure 6 is to explain the condition of when the suddenly break applied on the vehicle. Product can chance to move the direction of both angular upward and parallel to the velocity of vehicle. Due to this reason all joints and corners are need to check with FEA analysis.

4.6.3. Forklift Supporting Check: All industry internal transportation manual forks or the fork trucks are used. Loaded pallets lift by the help of forks.

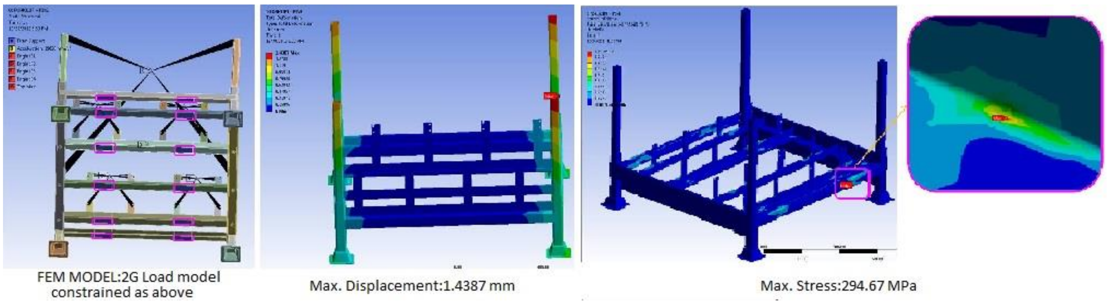

Figure 8. Displacement Plot and Stress Plot

In above figure 8 FEM model with 2 levels stack check with stress and displacement analysis.

4.6.4. Random Vibration Analysis - (1% Damping and 5% Damping): This type of analysis is also required because the chance of the vibration in vehicle breaking and sea shipment.

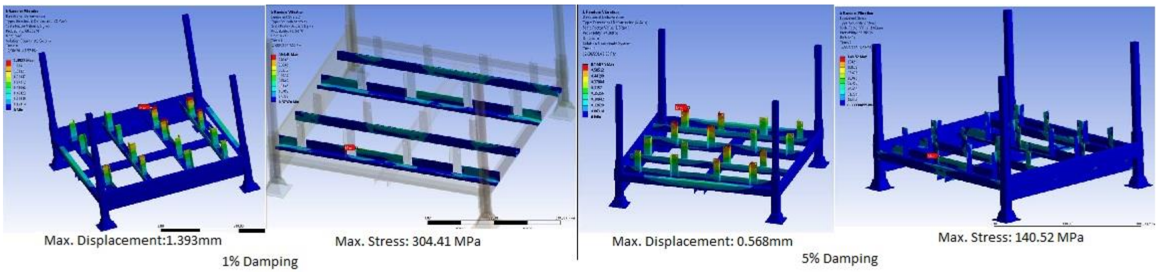

Figure 9. Displacement Plot and Stress Plot

On the above figure pallet analyzes and check with 1% and 5% damping analysis. In the standards cargo truck container bottom platform is make from the wooden. Due to this absorb the vehicle vibration in transportation.

Table 5. Stress Analysis Result of Welded Concept Model

Sr. No.	Analysis Intent	Analysis Type	Load	Deformation	Stress	frequency
				(mm)	(MPa)	(Hz)
1	Modal analysis	Modal	-	-	-	7.9421
2	Pothole/ Handling stock	Structural	2G Load applied in the vertical direction	2.1046	206.94	-
3	Stacking check	Structural	Four times the mass applied on the top square faces.	0.10573	204.73	-
4	Vehicle braking/ Cornering check	Structural	1/2 G Load applied in all horizontal directions	3.096	164.24	-
5	Forklift supporting	Structural	2G Load applied in the vertical direction	1.4387	294.67	-

	check						
6	Base random vibration check	Random vibration	Input as per the standard PSD in vertical direction	At 1% damping	1.3927	304.91	-
				At 5% damping	0.568	140.52	-

5. Results & Discussion

The table no. 4 shows the analysis result of bolted joint pallet design. The stresses produced at the all condition for pothole analysis, stacking analysis, forklift supporting analysis and vehicle braking analysis are seen very high. The 3 storey level stacking analysis is also not seen fulfilling the transport and the stationary application requirement.

The analysis results of pallet design with welded joint are seen in table no.5. The stresses seen under the all intend condition are within safe limit of acceptance criteria of material. The 3 storey level stacking analysis is also seen fulfilling the transport and the stationary application requirement. To further strengthen the weld joint design following changes are done

1. Increase thickness of bottom cups.
2. Introduce guide member into cups for more stability against wobbling of upper pallet.
3. Increase thickness of transverse members
4. Replace current engine legs with an L-shaped member instead of current design.
5. Additional C-member below all engine carrying cross-members.

6. Conclusions

The design optimization and simulation of engine pallet design mainly shows below points

1. The welded joint pallet simulation for engine transportation in stationary and movable condition shows the stress level within the acceptable limits.
2. The welded joint pallet design is finalized as it has more advantage in terms of structural stability, load carrying capacity and very reliable in export shipment.
3. The welded joint pallet design has also shown good stability in road and sea transportation.
4. The bolted design concepts has a high stresses at joints hence it cannot be selected
5. The bolted joint pallet design concept has not been selected mainly due to higher stress level and it is more prone for fastener loosening at the time of actual shipment.
6. All the designs intend considered for design of pallet meets the acceptance criteria and are under safe working condition.

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