Study of Transportation Fixture for an Road Load Conditions

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Abstract*—In machining fixtures, minimizing work-piece deformation due to clamping and cutting forces is essential to maintain the machining accuracy. The various methodology used for clamping operation used in different application by various authors are reviewed in this paper. The transportation fixture setup for component is done manually. For that more cycle time required for loading and unloading the material. So, there is need to develop system which can help in improving productivity and time. Fixtures reduce operation time and increases productivity and high quality of operation is possible. The objective of this project is to design the platform returnable fixture to hold the finished goods and to evaluate for a road load conditions during transportation from one place to another place. A study on detailed description of theoretical fixture design principles for a road load condition will be carried out and based on the literature review a design specifications will be arrived. Fixture design will be carried out in Pro-E and validate the design intend, FEA will be done using Hypermesh & Nastran tools. Design calculations, results obtained from the FEA and the projected benefits of this project including improved design with cost reduction is also presented.

Keywords*— Fixtures, productivity, FEA Introduction (Introduction to Transportation Fixtures).

I. INTRODUCTION

A. Introduction to Transportation Fixtures

Today, roadways are designed using engineering factors that establish the quantity, type and thickness of material that needs to be used to balance vehicle loads and roadway use. If money were not an issue, then building all roads to handle the heaviest legal loads would be the solution to accommodating freight on Minnesota roads. Our transportation system has developed over the last 100 years. During this time, truck sizes and weights have increased faster than roads have been improved. When most roads are reconstructed today, they are built to carry 10-ton loads. But, with limited available resource, the focus is on building a balanced system – the most-used roads carrying the heaviest loads need to be built to manage these loads. Our transportation system is comprised of many types of roads that are managed by varying levels of government. The following map shows how various levels of government work together to provide an effective transportation system.Workpiece location error is examined by considering the fixture geometric error and elastic deformation of the fixture and workpiece due to fixturing forces (Raghu and Melkote[1] 2005). The deformations at the contact points are obtained by solving a constrained optimization model and the experimental validation is also provided for several fixtureworkpiece variable levels using a 3-2-1 machining fixture. Kang and Peng[2] (2009) reported designing and fabricating fixtures can take up to 10-20% of the total cost of a manufacturing system and reviewed various approaches used in Computer-Aided Fixture Planning (CAFP). Wang et al[3](2010) presented a literature survey of computer aided fixture design and automation, including their approaches, requirements and working principles. Related to computer aided fixture design approaches, an interactive Computer Aided Fixture Design (CAFD) system using the Gauss Elimination Method for the design of a fixture to hold prismatic components during machining on a CNC machining centre is described by Krishnamachary and Reddy[5] (2005). Cecil (1995), Pehlivan et al[4] (2009) and Nee et al (1987) have reported the other feature-based methodologies in CAFD. Boyle et al[6] (2011) reviewed over seventy-five CAFD tools and approaches in terms of the fixture design phases and technology and reported two research issues that require further effort. The first is that current CAFD research is segmented in nature and there remains a need to provide more cohesive fixture design support. Secondly, a greater focus is 12 required on supporting the detailed design of a fixture’s physical structure. The general situation of research on agile fixture design is summarized and pointed out the achievements and deficiencies in the field of case-based agile fixture design (Li et al 2002). The automation of fixture design and integration of setup and fixture planning is discussed by Stampfer[7] (2009). Boonsuk and Frank[8] (2009) presented a methodology for the automated design of a fixturing system for a rapid machining process. An adaptive fixture design system with an evolutionary search algorithm has been developed by Fathianathan et al (2007)[9] to deal with the automatic design changes to meet the requirements of different domains. Armillotta et al[10] (2010) described the procedure for kinematic and tolerance analysis and demonstrated its significance on a sample case of fixture design. Kinematic analysis verifies that any relative motion between the part and the worktable is constrained and the tolerance analysis tests the robustness of part orientation with respect to manufacturing errors on datum surfaces. Luo et al (2011) developed a novel model for workpiece positioning analysis by using surface-to-surface signed distance function and a two-sided quadratic model for fixture locating analysis. This model has potential applications in fixture design, tolerance analysis and fault diagnosis. Studies related to fixture design show that fixture design has received considerable attention in recent years. However, little attention has been focused on the optimum fixture layout and clamping forces.

B. Fixtures

Fixtures have a much-wider scope of application than jigs. These work-holders are designed for applications where the cutting tools cannot be guided as easily as a drill. With fixtures, an edge finder, center finder, or gage blocks position the cutter. Examples of the more-common fixtures include milling fixtures, lathe fixtures, sawing fixtures, and grinding fixtures. Moreover, a fixture can be used in almost any operation that requires a precise relationship in the position of a tool to a work-piece. Fixtures are most often identified by the machine tool where they are used. Examples include mill fixtures or lathe fixtures. But the function of the fixture can also identify a fixture type. So can the basic construction of the tool. Thus, although a tool can be called simply a mill fixture, it could also be further defined as a straddle-milling, plate-type mill fixture. Moreover, a lathe fixture could also be defined as a radius-turning, angle-plate lathe fixture. The tool designer usually decides the specific identification of these tools. Fixtures are work holding devices designed to hold, locate and support work-pieces during manufacturing operations. Fixtures provide a means to reference and align the cutting tool to the work-piece but they do not guide the tool. Abbreviations and Acronyms

Fixturing devices include:

- Various standard clamps, chucks, and vises
- Metal plates containing dowel and/or tapped locating holes or key slots
- Dedicated fixtures with specific design and build requirements

C. Purpose

A fixture's primary purpose is to create a secure mounting point for a work-piece, allowing for support during operation and increased accuracy, precision, reliability, and interchangeability in the finished parts. It also serves to reduce working time by allowing quick set-up, and by smoothing the transition from part to part. It frequently reduces the complexity of a process, allowing for unskilled workers to perform it and effectively transferring the skill of the tool maker to the unskilled worker. Fixtures also allow for a higher degree of operator safety by reducing the concentration and effort required to hold a piece steady. Economically speaking the most valuable function of a fixture is to reduce labor costs. Without a fixture, operating a machine or process may require two or more operators; using a fixture can eliminate one of the operators by securing the work-piece.

D. Design

Fixtures must always be designed with economics in mind; the purpose of these devices is to reduce costs, and so they must be designed in such a way that the cost reduction outweighs the cost of implementing the fixture. It is usually better, from an economic standpoint, for a fixture to result in a small cost reduction for a process in constant use, than for a large cost reduction for a process used only occasionally. Number equations consecutively.Most fixtures have a solid component, affixed to the floor or to the body of the machine and considered immovable relative to the motion of the machining bit, and one or more movable components known as clamps. These clamps (which may be operated by many different mechanical means) allow work-pieces to be easily placed in the machine or removed, and yet stay secure during operation. Many are also adjustable, allowing for work-pieces of different sizes to be used for different operations. Fixtures may also be designed for very general or simple uses. These multi-use fixtures tend to be very simple themselves, often relying on the precision and ingenuity of the operator, as well as surfaces and components already present in the workshop, to provide the same benefits of a specially-designed fixture. Examples include workshop vises, adjustable clamps, and improvised devices such as weights and furniture. Each component of a fixture is designed for one of two purposes: location or support.

E. Transportation and Handling Loads

Structural design criteria described herein establishes the minimum requirements of design of platform as per the standards. The basic input information furnished in Project specification is to be complied with. The design criteria those relate to functional requirements of components, principles of design and those directly applicable to design /concept shall be followed as a mandatory requirement. The objective of this project was to research technologies to improve and speed fixture designs for the Road load conditions. Inadequate assessment of transportation and handling loads can lead to local damage to the fixture caused by insufficient load bearing on the handling fixture or it can lead to fatigue failure caused by accumulated damage from cyclic loads. This monograph is concerned with the generation and presentation of criteria and recommended practices for the prediction and verification of transportation and handling loads for vehicle structure and for monitoring these loads during transportation and handling of the fixture on the vehicle. Elements of the transportation and handling systems and the forcing functions and associated loads are described. The forcing functions for common carriers and typical handling devices are assessed throughout the monograph and references for descriptions of the functions are cited from the limited amount of available literature. The magnitude of transportation and handling loads is influenced by such factors as the transportation and handling medium; type of handling fixture, transport vehicle speed, types of terrain, weather and the dynamics of the transportation modes or handling devices and rotations of the transporter or handling device. Thus, these factors must be considered when predicting the loads for each proposed transportation and handling system and its operation. When estimates of allowable loads are available, an initial selection is made of transportation and handling system which it is roughly estimated does not generate loads that exceed the allowable loads nor appreciably affect the vehicle's fatigue life. After this initial selection, the loads imposed on the vehicle by the selected transportation and handling system are predicated through the analytical methods. Few of the Platforms fixture design are as shown below:

Platform Fixture Transportation   Work-Piece clamped in a platform fixture

Figure 1.1 platform fixture transportation with the truck

II. PROBLEM DEFINATION

Table 2.1- Single Stack Platform Returnable Fixture

Medium/mode	Longitudinal load factors, g	Lateral load factors, g	Vertical load factors, g
Water	±0.5	±2.5	+2.5
Air	±3.0	±1.5	±3.0
Ground			
Truck	±3.5	±2.0	+6.0
Rail (humping shocks)	±6.0 to ±30.0	±2.0 to ±5.0	+4.0 to +15.0
Rail (rolling)	±0.25 to ±3.0	±0.25 to ±0.75	+0.2 to +3.0
Slow-moving dolly	±1.0	±0.75	+2.0

During the transportation and handling loads by road ways the dynamic load response and transfer characteristics of the entire moving system come into picture, forcing functions generated by the transportation or handling medium (e.g., the road profile) coupled with the velocity of the moving system. The sources of excitation for road transporters can be categorized as both internal and external. However, internal excitations, the vibrations caused by the engine, transmission and drive assembly, wheel unbalance, and shimmy, can be limited to low levels by careful design and maintenance of the transport vehicle. Other external excitations result from the road profile and are assumed to consist of a washboard course and individual bumps, stopping, turning, docking, and wind loadings. The effect of these loading conditions must be minimized to avoid effect to the finished products which is resting on the platform truck during transportation.

A. Aim and Objective of paper

The aim of this research is to design, analyze and validate the platform returnable fixture for the following conditions:

- Load Case-1: A study will be carried out to evaluate the structural strength and stiffness of the platform returnable fixture by doing the modal analysis. The structure should have fundamental natural frequency greater than 12Hz.
- Load Case-2: A study will be carried out to evaluate the structural strength of the platform returnable fixture for the road load conditions for transportation in a truck.

The objectives of this research is as follow

- To review the literature on existing Platform fixture design for different application.
- To arrive at design specification & guidelines based on application
- To perform FE Analysis for the single stack and for the four stack model to meet the design specifications.

B. Methodology to meet the objectives

- Literature review of structural members used in different types of Platform fixture design and its application were carried out by referring reviewed journals, books, manuals and related documents.
- Based on application and reviewed literature design specifications were arrived.
- Geometrical modeling of Platform fixture will be created using Pro-e Software
- Finite element model was created using the Hypermesh Software.
- Structural analysis performed using Nastran Software
- Design calculation has been carried out to evaluate the Stress criteria.

III. GEOMETRICAL MODELING

In this chapter geometric modelling, design assumption, material properties considered is as discussed below: Increasingly intensive global competition in manufacturing and changing consumer demand are resulting in a trend towards greater product variety and innovation, shorter product life-cycle, lower unit cost, higher product quality, and short lead-time. Evolving from such a trend, both `markets pull' and `technological push' are forcing towards greater flexibility. In this research the design evaluation of fixtures for holding prismatic work pieces and to calculate the structural stiffness of the foam material to withstand the weight of the assembly. This formulation of the fixturing design problem takes into account deflection of the work-piece subjected to assembly for road load conditions. Using the minimization of the work piece deflection at selected points as the design criterion, the design problem is determining the positions of the fixture supports with the foam material in between the work piece to avoid the scratch. The Finite Element Method is used for calculating deflections that are the basis for the design objective function. Preparation of the CAD Model and its assumptions are detailed below

Design assumptions considered for the platform returnable fixture are

- The main application of the returnable fixture design is to hold the finished goods and to evaluate for a road load conditions during transportation from one place to another place.
- The design of all structure shall accommodate the forces imposed during transportation.
- The main intent is to validate the structural strength for the inertial loads
- To calculate the structural stiffness of the foam material used in between the work-piece, one above the other.
- Replace-ability, reusability and discard-ability of the fixture
- Standardization of fixtures and fixturing principles

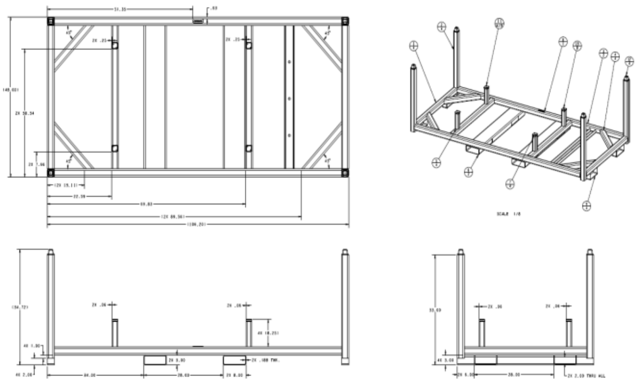

Figure3.1-Frame Work of the Platform returnable fixture design

A. Material properties

The material properties used for the fixture design is ASTM A36 and its mechanical properties is as shown below:

Table3.1: Specifications of ASTM A36 steel

Physical Properties	Metric	English
Density	7.85 g/cc	0.284 lb/in³
Mechanical Properties	**Metric**	**English**
Tensile Strength, Ultimate	400 - 550 MPa	58000 - 79800 psi
Tensile Strength, Yield	250 MPa	36300 psi
Elongation at Break	20 %	20 %
	23 %	23 %
Modulus of Elasticity	200 GPa	29000 ksi
Bulk Modulus	160 GPa	23200 ksi
Poissons Ratio	0.26	0.26
Shear Modulus	79.3 GPa	11500 ksi
Component Elements Properties	**Metric**	**English**
Carbon, C	0.25 - 0.29 %	0.25 - 0.29 %
Copper, Cu	0.20 %	0.20 %
Iron, Fe	98 %	98 %
Manganese, Mn	1.03 %	1.03 %
Phosphorous, P	<= 0.040 %	<= 0.040 %
Silicon, Si	0.28 %	0.28 %
Sulfur, S	<= 0.050 %	<= 0.050 %

IV. FINITE ELEMENT MODELING

The finite element is a mathematical method for solving ordinary & partial differential equations, because of its numerical method it has an ability to solve complex problems which are represented in the form of differential equation. These types of equations occur naturally in all fields of the physical science & application wise it is limitless as concern the solution of practical design problems. Commonly FEA is described as a discretization technique.

A. Discretization of Returnable Fixture

The FE mathematical model of the Returnable Fixture and its structural members was generated using Hypermesh as a preprocessor tool. To develop a finite element model, it involves certain steps & mesh requirement as mentioned below:

- Defining the geometric domain of the problem.
- Defining the element connectivity’s
- Defining the element type to be used.
- Defining the material properties
- Defining the physical constraints (boundary conditions).
- Defining the loadings.

B. Defining the element connectivity. (Mesh the model)

The returnable fixture consists of square and rectangular tubes, Flat bars, stacking cup. The cross sections used are geometrically linear. Hence, first order 2D Pshell and 3D Psolid elements i.e., CTRIA3, CQUAD4 and CTETRA elements are used for Finite element analysis without compromising the accuracy of the results.

C. Defining the Physical Boundary Conditions

The model is assumed to be fixed at the large end of the connecting rod. These boundary conditions will not influence the stress near the small end due to interference. Location of the boundary conditions is shown in the picture below. The fixture consists of the four vertical legs connected with the horizontal members, which are constrained in all degrees of freedom. The constrained region of fixture is as shown in the figure below:

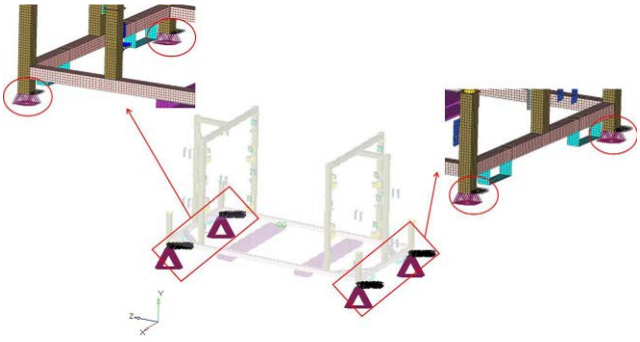

Figure 4.1-Boundary Conditions

V. PROBLEM SOLVING

A. Idealization of loading and boundary condition of Returnable Fixture

- Returnable fixture and work-piece are modeled using shell and solid elements to simulate the realistic condition.
- The vertical square tubes at the bottom are constrained, as it is will be rest on the truck.
- A modal analysis will be carried out to obtain the frequency levels and mode shapes to evaluate the structural stiffness.
- A complete structural will be evaluated for the road load condition for transportation mode for a four stack model.
- The stress and displacement obtained will be detailed
- As the work-piece seats one above the other and in between foam blocks will be placed for the support. So structural stiffness of the same will be evaluated.
- A supporting parts seat on the base frame is constrained in all degrees of freedom to replicate the realistic scenario.

B. Baseline Modal Analysis of the Returnable Fixture

In the constrained modal analysis the first mode shape is called as the fundament natural frequency. From the above figure we can observe that 1st mode obtained is 9.407 Hz, which is called as a fundament resonance frequency of a system. The mode shapes obtained at different modes are as tabulated in the above figure. The behavior of the first mode shape observed is a lateral bending. Hence the obtained natural frequency is less than the required frequency of 12Hz. Therefore a design optimization is required to meet the design specs.

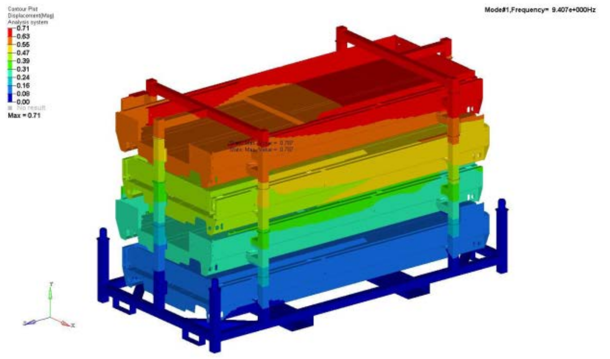

Figure5.1: Mode Shape-1 Fundamental natural frequency of the system

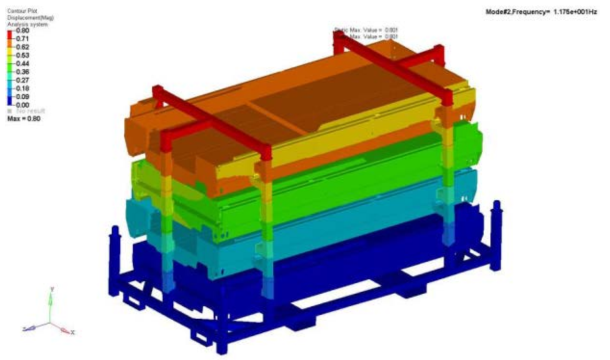

Figure5.2: Mode Shape-2 of the Returnable fixture

The behavior of the second mode shape observed is a longitudinal bending of 11.75 Hz.

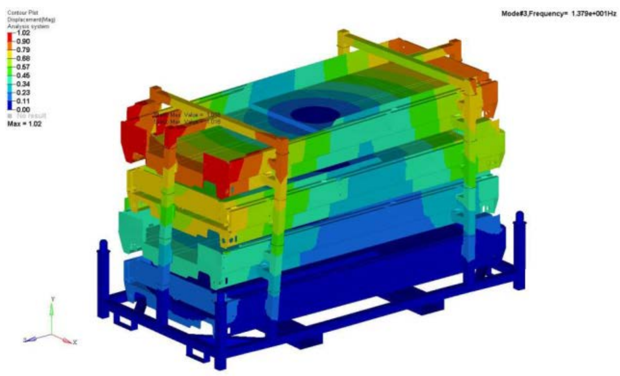

Figure5.3: Mode Shape-3 of the Returnable fixture

The behavior of the third mode shape observed is a twisting mode of 13.79 Hz.

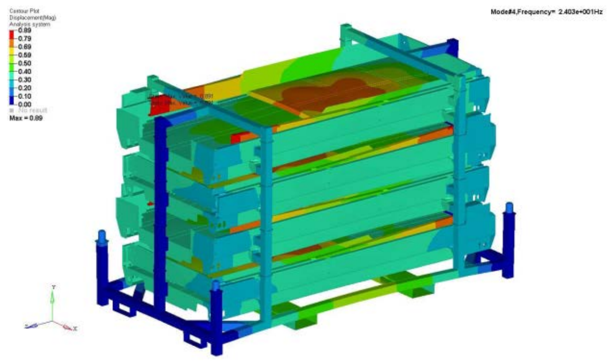

Figure5.4: Mode Shape-4 of the Returnable fixture

The behavior of the fourth mode shape observed is a vertical bending of 24.03 Hz.

C. Baseline Static Structural Analysis of Four stack returnable fixture for a Road load conditions.

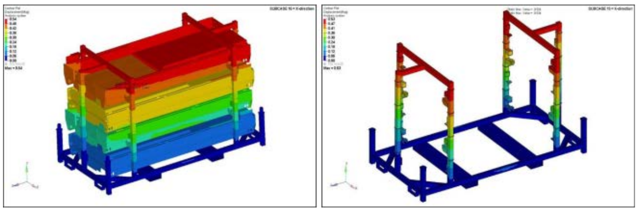

Figure5.5: Baseline Model Displacement Plot for Road Load condition for 3.5G along X-direction

The maximum displacement observed is 0.54 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.53 inch for a 3.5G loading condition along X-direction.

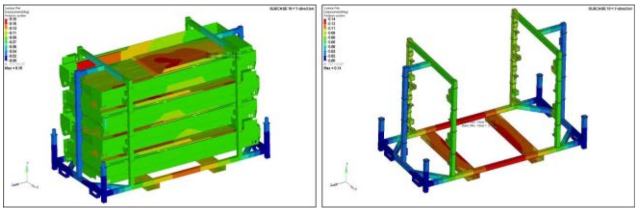

Figure5.6: Baseline Model Displacement Plot for Road Load condition for 6G along Y-direction

The maximum displacement observed is 0.16 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.14 inch for a 6G loading condition along Y-direction.

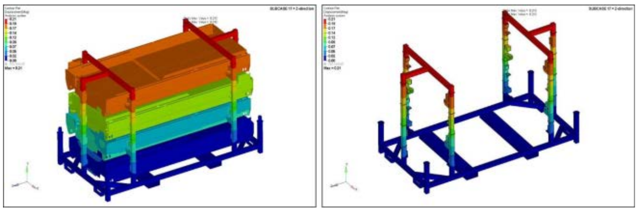

Figure5.7: Baseline Model Displacement Plot for Road Load condition for 2G along Z-direction

The maximum displacement observed is 0.21 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.21 inch for a 2G loading condition along Z-direction.

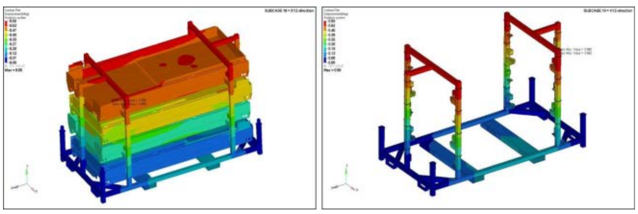

Figure5.8: Baseline Model Displacement Plot for Road Load condition for Combination loads along XYZ direction

The maximum displacement observed is 0.6 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.58 inch for a combination loading along XYZ directions.

D. Baseline Model Von-misses stress

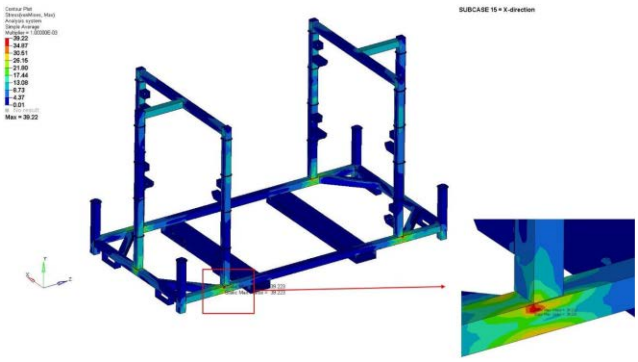

Figure5.9: Baseline Model Von-misses stress Plot for 3.5G along X-direction

The overall von-misses stress observed in platform returnable fixture for a 3.5G loading condition along longitudinal X-direction is 39.22 ksi. The material yield strength is 80 ksi and the obtained FOS is 2.03.

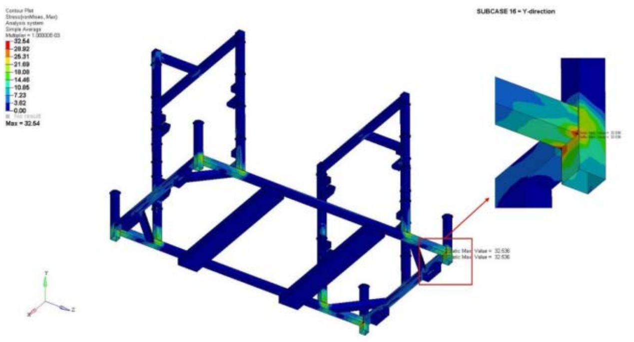

Figure5.9: Baseline Model Von-misses stress Plot for 6G along Y-direction

The overall von-misses stress observed in platform returnable fixture for a 6G loading condition along longitudinal Y-direction is 32.54 ksi. The material yield strength is 80 ksi and the obtained FOS is 2.45.

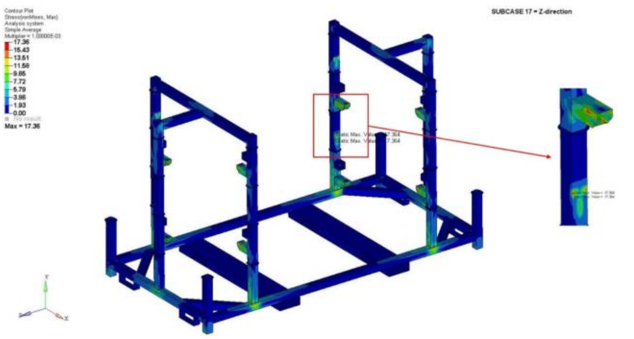

Figure5.10: Baseline Model Von-misses stress Plot for 2G along Z-direction

The overall von-misses stress observed in platform returnable fixture for a 2G loading condition along longitudinal Z-direction is 17.36 ksi. The material yield strength is 80 ksi and the obtained FOS is 4.60.

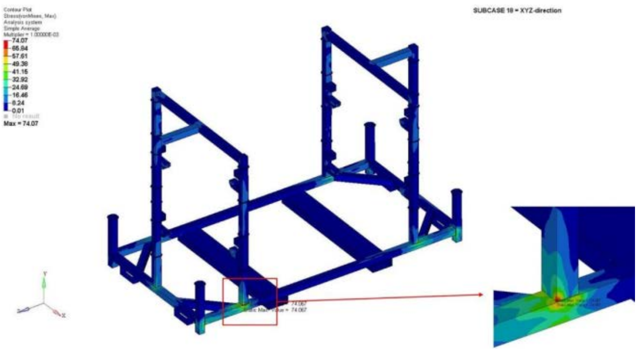

Figure5.11: Baseline Model Von-misses stress Plot for along XYZ directions

The overall von-misses stress observed in platform returnable fixture for a combination of loading condition along XYZ-direction is 74.07 ksi. The material yield strength is 80 ksi and the obtained FOS is 1.08.

E. Static Structural Analysis of Four stack Modified Returnable fixture for a Road load conditions.

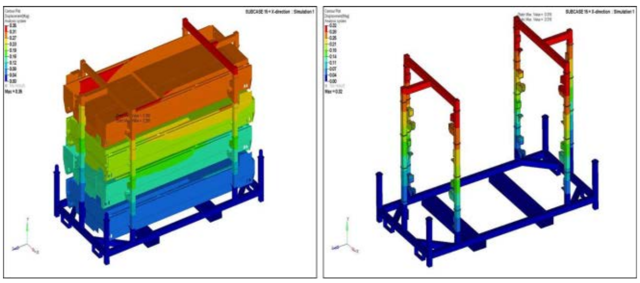

Figure5.12: Modified Model Displacement Plot for Road Load condition for 3.5G along X-direction

The maximum displacement observed is 0.35 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.32 inch for a 3.5G loading condition along X-direction.

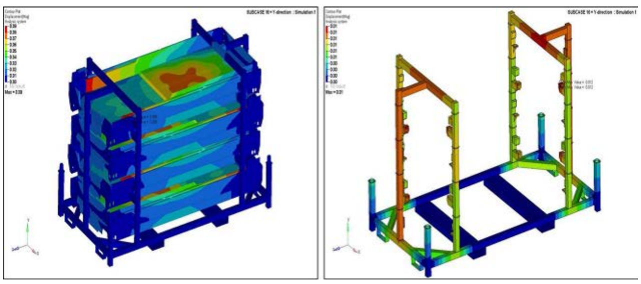

Figure5.13: Modified Model Displacement Plot for Road Load condition for 6G along Y-direction

The maximum displacement observed is 0.09 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.01 inch for a 6G loading condition along Y-direction.

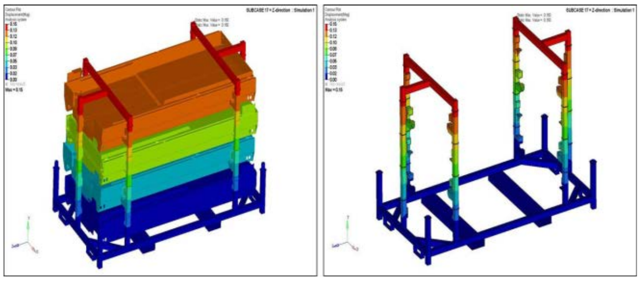

Figure5.14: Modified Model Displacement Plot for Road Load condition for 2G along Z-direction

The maximum displacement observed is 0.15 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.15 inch for a 2G loading condition along Z-direction.

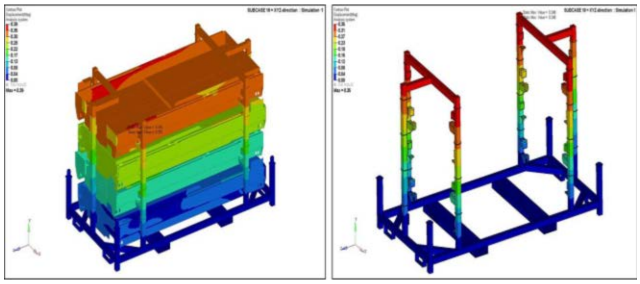

Figure5.15: Modified Model Displacement Plot for Road Load condition for Combination loads along XYZ direction

The maximum displacement observed is 0.39 inch in the platform returnable fixture assembly and the max displacement observed in the fixture only is 0.35 inch for a combination loading along XYZ directions.

F. Modified Model Von-misses stress

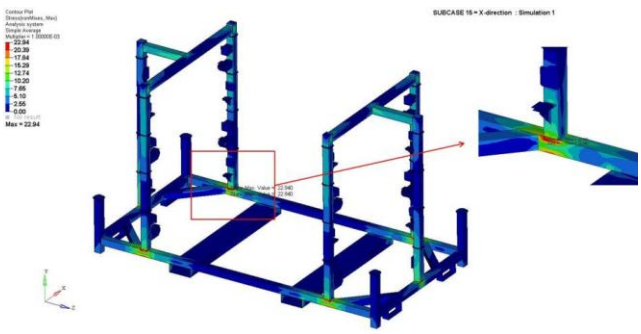

Figure5.16: Baseline Model Von-misses stress Plot for 3.5G along X-direction

The overall von-misses stress observed in platform returnable fixture for a 3.5G loading condition along longitudinal X-direction is 22.94 ksi. The material yield strength is 80 ksi and the obtained FOS is 3.49.

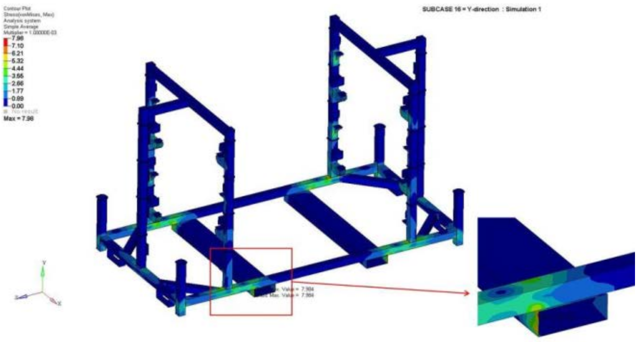

Figure5.17: Modified Model Von-misses stress Plot for 6G along Y-direction

The overall von-misses stress observed in platform returnable fixture for a 6G loading condition along longitudinal Y-direction is 7.98 ksi. The material yield strength is 80 ksi and the obtained FOS is 10.03.

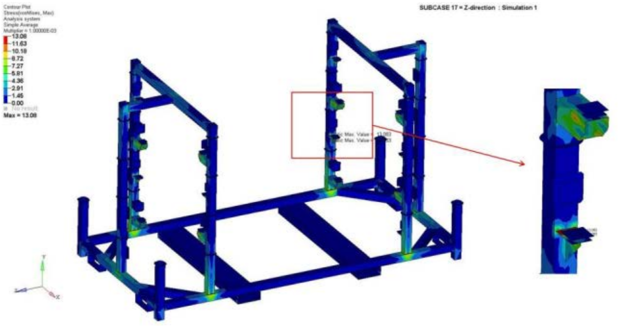

Figure5.18: Modified Model Von-misses stress Plot for 2G along Z-direction

The overall von-misses stress observed in platform returnable fixture for a 2G loading condition along longitudinal Z-direction is 13.08 ksi. The material yield strength is 80 ksi and the obtained FOS is 6.12.

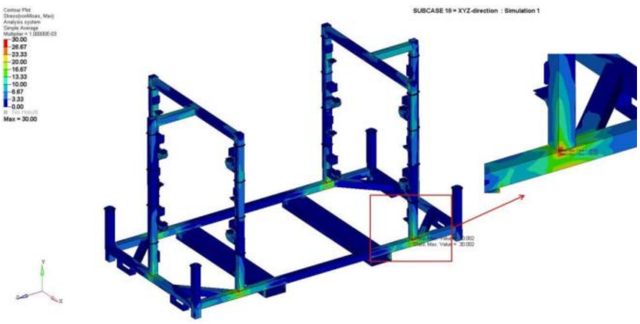

Figure5.19: Modified Model Von-misses stress Plot for along XYZ directions

The overall von-misses stress observed in platform returnable fixture for a combination of loading condition along XYZ-direction is 30 ksi. The material yield strength is 80 ksi and the obtained FOS is 2.67.

VI. CONCLUSION

Modified model has be carried out for the FE modelling and assigned the variable thickness to carry out the modal analysis and static structural analysis for the road load conditions and the obtained results are as discussed below:

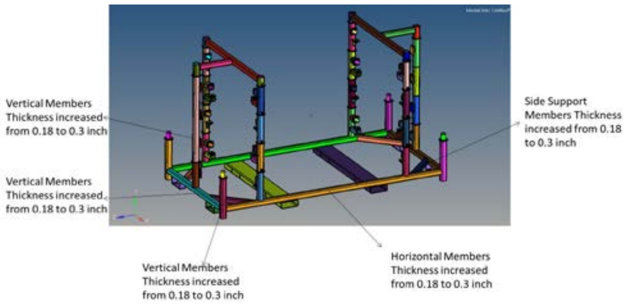

Figure5.20: Modified model of the Platform Returnable fixture

The monograph of the paper is particularly concerned with the assessment of loads acting on the returnable fixture during transportation and handling. A detail study on modal analysis shows the structural stiffness and its mode shapes, the fundamental frequency observed for the baseline model is 9.407 Hz whereas the modified design has 12.01 Hz, which meets the design parameters and shows the structural adequacy of the optimized model.

Table6.1-comparison of baseline and modified design of platform returnable fixture

Sl. No	Description	Baseline Model								
		Material Yield Strenght (ksi)	3.5G along X-direction	FOS	2G along Y-direction	FOS	6G along Z-direction	FOS	Combination of Loads along XYZ	FOS
1	Overall Displacement Plot (inch)	80	0.54		0.16		0.21		0.6	
2	Displacement Level on fixture (inch)		0.53		0.14		0.21		0.58	
3	Overall Stress Plot (ksi)		50.37	**1.59**	32.54	**2.46**	23.72	**3.37**	74.07	**1.08**
4	Stress on Fixture (ksi)		**39.22**	**2.04**	**32.54**	**2.46**	**17.36**	**4.61**	**74.07**	**1.08**

Sl. No	Description	Modified Model								
		Material Yield Strenght (ksi)	3.5G along X-direction	FOS	2G along Y-direction	FOS	6G along Z-direction	FOS	Combination of Loads along XYZ	FOS
1	Overall Displacement Plot (inch)	80	0.54		0.16		0.21		0.6	
2	Displacement Level on fixture (inch)		0.53		0.14		0.21		0.58	
3	Overall Stress Plot (ksi)		36.86	**2.17**	12.73	**6.28**	17.14	**4.67**	45.39	**1.76**
4	Stress on Fixture (ksi)		**22.94**	**3.49**	**7.98**	**10.03**	**13.08**	**6.12**	**30**	**2.67**

Future course of project is to study the transportation loads acting on fixture under the pavement and the terrain road, where the load acting are sinusoidal with respect to time and even fatigue life cycle of the fixture is also very important, which give the life cycle of the fixture design.

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