Design and Analysis of Modular Gridded Base Platform for the Static Structural Testing of Aerospace Structures[1]

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ABSTRACT

To qualify the design of aerospace structures, which are designed with minimum margin, it is necessary to subject them to static structural tests to reveal the real state of stress on flight structures under critical flight load conditions. This process build up confidence in the design methodology adopted and to validate the mathematical model used for simulations. In any space mission, safety holds utmost priority. Structural qualification tests are necessary to verify structural adequacy and to qualify the design. The primary objective of a structural qualification test is to assess the exact real performance of a structure and to validate its design. Static structural testing is a common method for verifying or ensuring that the realised structure has enough strength to withstand the loads for which it is designed. This study focus on the configuration and design of base platform. The base platform is intended to provide anchoring to the entire test rig assembly or to act as a foundation for distributing the moment and force reactions acting upon it. At present anchoring plates which are embedded in concrete strong floor is provided for mounting the test rigs. This set up requires reinforcement of the floor to certain depth and attracts major civil works. The proposed platform, which is a reinforced platform with gridded construction, is a replacement for the present set-up. Here we adopt the concept of modularity in configuration of the base platform. Hence the base platform is claimed as a modular gridded base platform with all the inherent features of modularity such as scalability, interchangeability and reconfigurability. In addition to the generation of a realisable configuration, this study expanse with the design of structural element and verification by Finite Element Method using Abaqus.

Keywords: *Aerospace structures; Modular gridded base platform; Static structural test; Structural qualification test*

INTRODUCTION

Aerospace structures are a class of lightweight structures used for aircrafts and spacecrafts which are normally subjected to cyclic loads. They are quite complex structures. The aerospace structures must be light but resistant, durable and the most importantly it should be safe. Among the many consequences, this statement means that, from a structural design point of view, such a system must be designed in order to accurately distribute the mass in the region where it is necessary, since any unjustified weight increment may lead to inefficiency [7]. To qualify the design of aerospace structures, which are designed with minimum margin, it is necessary to subject them to static structural tests to build up confidence in the design capability to withstand the expected flight loads. Design development tests are conducted early during the conceptual and preliminary design phase to establish the feasibility of a structural design

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approach, demonstrate the advantage of one design over another, identify failure modes, confirm analytical method or generate essential design data.

Qualification tests are conducted on flight quality hardware at specific load levels and for durations that exceed flight conditions to demonstrate that all structural design requirements have been achieved. And the margin evaluation tests are conducted after qualification test, to evaluate the actual margin available and the failure mode on the hardware, by increasing the loads up to destruction of the test hardware.

The entire load which is applied on the test article is being reacted on the base structure, where the test article is anchored. The loading portals which hold the load application lines also transfer their reactions to the base structure. Hence the base structure should be rigid enough with required strength to withstand high localized loads. Moreover, the base structure should not alter the natural response of the test article against load application. Hence, design of base structure or ground anchoring configuration holds utmost importance in the configuration of a proper test set-up. At present anchoring plates are used over the reinforced floors for providing anchoring to the test article and test rigs. In order to overcome the drawbacks of the present system a new base platform having modular gridded construction is introduced here.

OBJECTIVES

The main objective of the work carried out in this paper is to find out the best feasible solution for providing a rigid base support for a test rig assemblies as a superior alternative to conventional ground anchoring scheme.

The sub objectives and scope includes:

- To introduce the concept of modularity in base platform configuration
- Development of a complete portable assembly
- Design and use of FEM for static linear analysis

MODULAR GRIDDED BASE PLATFORM

Due to the variability in test requirements of hardware of small to large size with varying interfaces and complex requirements of loads to be simulated it is not possible to have a common test setup to cater to the test requirement of all hardware. Modular gridded base platform configuration consists of standard interchangeable modules for making test bed for different test rig assemblies. The main purpose of having a base platform is to support and anchor the test rigs. The requirement should also consider access for assembly, drainage for any accidental spill, load bearing and diffusion capability etc.

The conventional approach is the anchoring plates which are embedded in concrete strong floor, with threaded interface repeating in a pre-defined pattern or shall have T-slots are provided for mounting the test adaptor or the loading elements. This concept is replaced by the modular base platform, built-up of standard elements having flexibility to provide the required interface and with additional advantages. The modular gridded base platform consists of base plate, cross-plate, L-plate, long beam and short beam together to form the total assembly.

The long beam is made up of a standard section of ISNPB (Indian Standard Narrow Parallel Beam). The total length of the beam is 5730mm and a depth of 610mm. The built-up section is made after welding top and bottom together by a 45mm MS face plate and also they are stiffened by gussets. The short beam is a standard section of ISNPB built-up section. The total length of the beam is 920mm and a depth of 610mm. It is also made up by welding MS cover plate at top and bottom. The figures below show the 3D model of long beam and short beam.

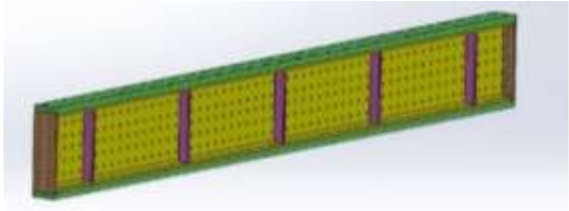


Fig 1 Long beam

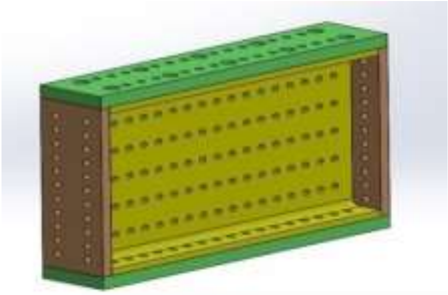


Fig 2 Short beam

Similarly, the L plate is used at the four corners. It has a thickness of 20mm and 22 mm diameter holes are provided with a pitch of 50mm. And the cross- plates are used to interconnect the beams. They also have a thickness of 40mm and are having the bolt diameter of 22mm with a pitch of 50mm. The base-plate is a square plate of one side 1190mm and having a total thickness of 80mm. it is designed in such a way that it can accommodate any components. It consists of bolt hole of diameter 22mm at four sides and 45mm diameter holes for accommodating the testing components. Fig 3 shows the 3D view of L plate, cross plate and base plate.

For the validation of this project, the test set-up of this assembly consists of test adaptors and the base beams. These loading beam assemblies are made of Standard Modular Sections. Mild steel adaptor is used at top with loading locations. These MS adaptors provide proper load diffusion. The loading locations are arranged equi-spaced over the top flange of this MS adaptor and are designed in such a way that the concentrated loads acting at discrete locations on the fore end of these adaptors would distribute properly along it's whole length and reaches the aft end, thus keeping the load distribution uniform. M20 (12.9 class) fasteners are used in this assembly of modular platform

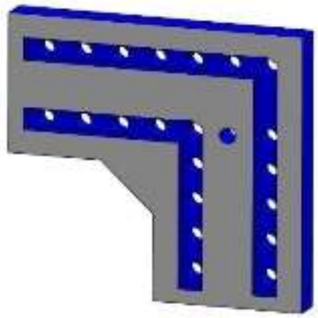


Fig 3 L plate

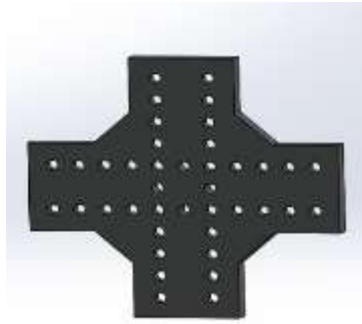


Fig 4 Cross plate

Fig 5 Base plate

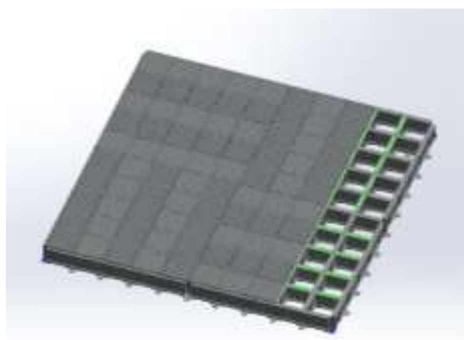


Fig 6 Final Assembly

MATERIALS

The material properties of the support structure elements used for the design are given below in table 1.

Table 1 Material properties of Mild Steel

Mild steel	
Yield Strength	240 N/mm^2
Ultimate Strength	420 N/mm^2
Bearing Strength	420 N/mm^2
Shear Strength	120 N/mm^2

FINITE ELEMENT ANALYSIS OF STRUCTURES

Finite element analysis (FEA) is a numerical method for the analysis of field problems. It is an approximate method for the solution of differential equations. Structural analysis, heat transfer mechanism, fluid mechanics, etc. are examples of field problems. For the problems involving complicated geometries, loading and material properties, it is generally not possible to obtain an analytical solution. Hence, we need to rely on numerical methods such as FEA for acceptable solutions.

Linear static analysis

Linear static analysis is performed to predict the response of a structure under prescribed boundary conditions and time independent applied loads. The responses will be generally displacement, stress, strains, reactions, moments and energy. The basic equation for linear static analysis may be written in the form

[K] {u} = {p} -----------------(I)

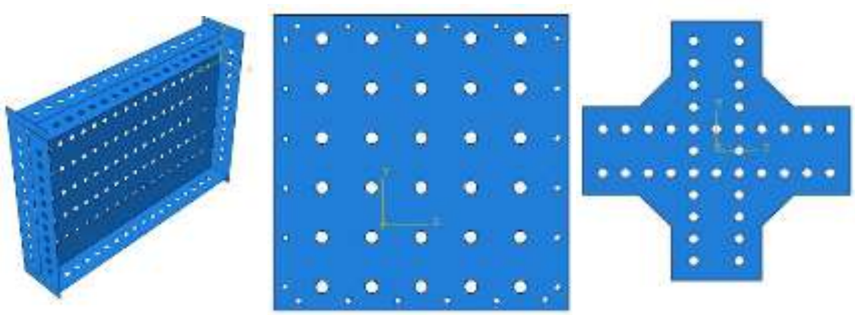
Where, [K] is linear static stiffness matrix for the structure

{u} is the nodal displacement vector which is unknown

{p} is the load vector

Finite Element Modeling

As the elements to be modeled were massive solid structures, in order to reduce the computational expense of analyzing the actual complete solid model, mid-surface modeling technique was adapted. This technique allowed creation of simplified shell representation of solid models of the test elements. The total assembly was also modeled as mid-surface geometry and was discretized using shell elements itself. The bending response in thin sections of models can be better accounted by mid-surface models than a solid model. Also, it results in reduction in time solver. And as part of validation of this project a MS adaptor and base beams are also modeled. The MS adaptor is a cylindrical shell of 2742mm diameter and 16mm thick, which is made of mild steel (MS). This MS adaptor rest on 8 bottom beams of 4m length and is made up of ISNPB 450 built up section. This bottom beam is anchored to the gridded platform by using bolts.



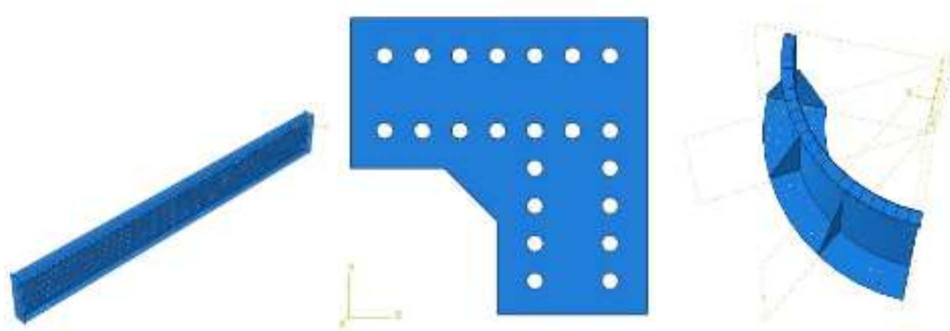


Fig 5 FE model of elements

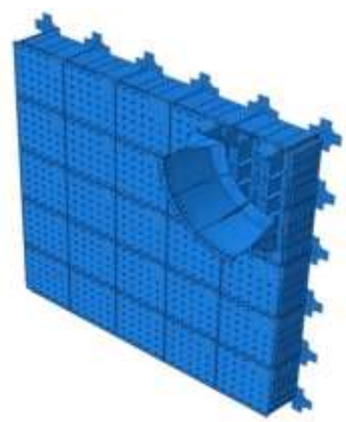


Fig 6 FE model of entire assembly

Meshed models

Mesh convergence study was conducted in order to verify the mesh. In the mesh convergence study, maximum Von Mises stress and the displacement of each element were the parameters considered. The Von Mises stress was found to be fluctuating in the mesh convergence study. But as with refinement from coarser to finer, it is found to be decreasing and converged to a particular value. From the analysis carried out the stress was found to be converged at mesh size 15. So, the mesh size of 15 was selected for all the elements and analysis were carried out.

Fig 7 Meshed model of entire assembly

Boundary condition, Loads applied and Interactions on models

At first, the structural strength of each component is analyzed. For that, fixed boundary condition is given to individual components and particular loads are applied to it. Also, fixed boundary conditions were applied to the entire assembly model. That is the linear displacements and rotation along the three axes is restrained. Therefore it can be seen as an encastre (U1=U2=U3=UR1=UR2=UR3=0). Here, in this work a quadrant portion is taken for analysis. So, for a symmetric boundary condition is also used here. And, while stacking these elements for the assembly, they are supposed to be placed with a minimum gap considering their mid surface thickness. Thus, in order to provide connections between them, these should be provided with some sort of contact interactions. Here in this project, contact pairs were provided by tie constraints. A tie constrain is a constrain that provides the ties to up or hold together two separate individual surfaces, so that there comes no relative motion between both the surfaces. And a tension force of 2800kN and a compression force of –3000kN were given for the analysis.

FINITE ELEMENT ANALYSIS

The Linear static analysis was carried out on the Finite Element Models. The detailed mesh statistics, boundary conditions and loads applied on each model are explained in above section

Finite element results of components

The von- Mises stresses of individual structures for the applied load are found out and are shown in fig. The stress components S11 (Local 11 direct stress), S22(Local 22 direct stress) and S12 (Local 12 shear stress) of each components are noted. For shell, plane stress and membrane elements only the in-plane tensor components 11, 22, and 12 are noted using Abaqus/Standard. The S33, out-of-plane direct stress component or the stress in thickness direction will be zero as all are shell elements. The maximum von-Mises stress of 44.75 N/mm^2 was observed for the L-plate. The peak value was observed near a bolt hole. For the cross plate, the maximum VM stress was observed as 87.28N/mm^2 and it was observed near the bottom bolt hole. As for base plate the maximum stress was found at middle bolt hole near the load is applied. And the maximum VM stress value observed at the particular location was 101.6 N/mm^2 In the case of short beam, the maximum stress obtained was 48.86 N/mm2 and for long beam it is 197.4 N/mm^2 .

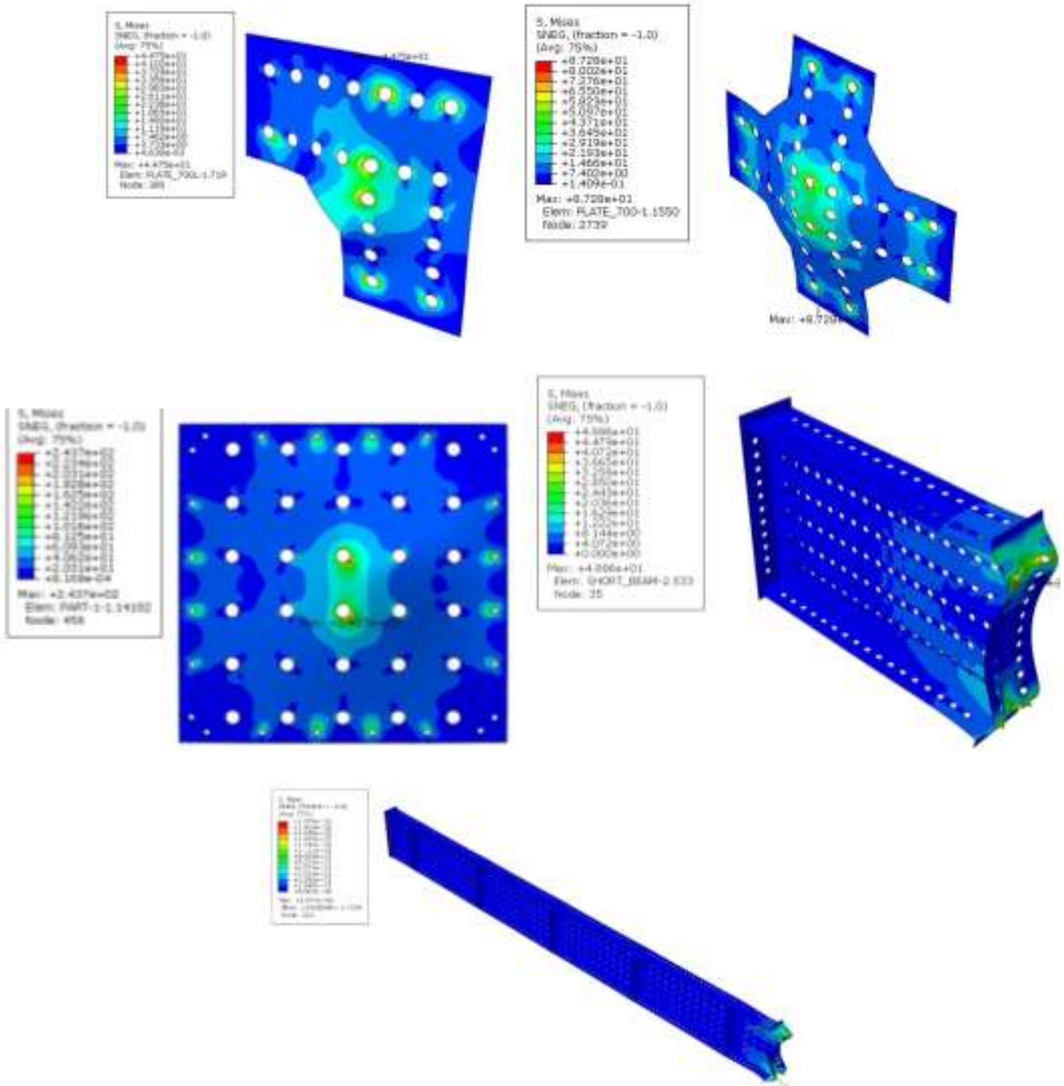


Fig 8 VM Stress contour on each element

All these values were less than 240 N/mm^2, that is all the values are less than yield stress/ allowable stress. So it is safe.

The consolidated stress values of all individual structural elements are provided in table 2.

Table 2 Stresses of individual structural elements

Sl No	***Structural element***	***S11 (N/mm^2)***	***S22 (N/mm^2)***	***S12 (N/mm^2)***	***von Mises stress (N/mm^2)***
1	L plate	30.58	40.94	16.12	44.75
2	Cross plate	59.62	65.6	33.05	87.28
3	Base plate	161.4	175.1	762.2	101.6
4	Long beam	92.16	91.17	60.06	197.4
5	Short beam	22.6	47.01	17.92	48.86

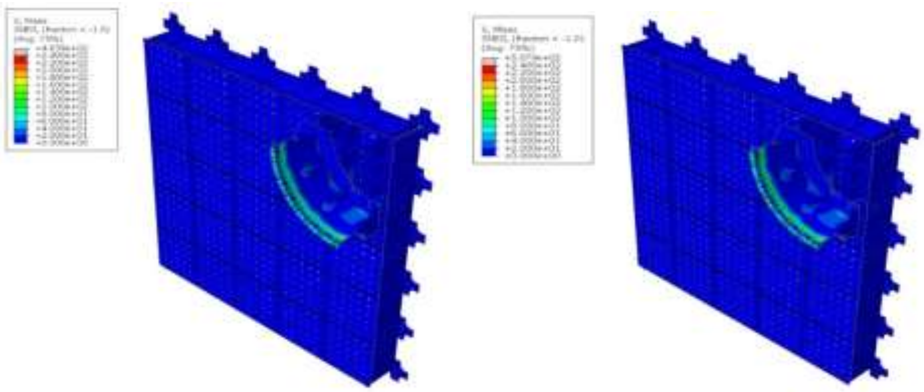


Fig 9 (a) VM stress on assembly for tension load (b) VM stress on assembly for compression load

The objective of this project was to make a gridded test platform with strength and stiffness to withstand the static structural loads from aerospace structures and to make a modular gridded test bed platform using standard section and to standardize the platform. The consolidated margin of safety (MOS) of all components is shown in table3. And as in the case of whole assembly, when tension force is applied, the maximum value obtained was 154.6 N/mm^2 and in case of compression it was 120 N/mm^2. Hence, there margin of safety is greater than zero, it is considered as safe.

Table 3 Stress values and Margin of safety of each components.

Sl No	*Components*	*Stress (N/mm^2)*	*Yield Stress (N/mm^2)*	*MOS*
1	L plate	44.75	240	4.363
2	Cross plate	87.28	240	1.749
3	Base plate	101.6	240	1.36
4	Long beam	197.4	240	0.215
5	Short beam	48.86	240	3.911
6	Assembly- Tension	154.6	240	0.552
7	Assembly- Compression	120	240	1

CONCLUSION

A modular gridded base platform has been configured as a superior for the present test rig ground anchoring scheme. The margin of safety of each component was calculated. Through detailed finite element simulation using ABAQUS, it was found that the proposed configuration is safe by design.

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