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DESIGN AND ANALYSIS OF STRUCTURAL FRAME AND LOADING BEAM FOR MULTI AXIAL LOAD APPLICATIONS

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ABSTRACT

Full-scale and section level tests, on tests articles such as full-scale airframes and its sections are to be carried out using structural frame and loading beam. The test article experiences various loads such as aerodynamic, inertial, launch and handling loads during its development process. The structural loads experienced by test article during above-mentioned conditions may be summarized into axial load, bending moment, external pressure and thermal loads etc. Test article experiences axial loads during generator firing phase. Test article also experiences axial loads due to inertial effect of section ahead of individual sections. Airframe sections experience bending Moment due to maneuvering, handling and combined effect of aerodynamic & inertial loads during the flight. The present work is confined to design and analysis of structural frame and loading beam to simulate Bending Moment, Axial load and External pressure on airframes.

Structural frame is designed for maximum Bending Moments of 5676kgf-m (M_X) & 12000kgf-m (M_Y), maximum axial Load of 90000kgf and maximum external pressure of 10kg/cm^2. Axial load, B.M and external pressure are applied in different combinations for ten different load cases. The structural frame is designed and analyzed with beams and plates made of structural steel material. The test article will be fixed firmly on the structural frame as cantilever during section level tests, to simulate bending moments M_X & M_Y, Axial load and External pressure simultaneously depending upon the load case. The Structural Frame will be grouted near one end of the trench of loading beam. The loading beam is used for mounting hydraulic actuators for application of loads to simulate bending moment. The test article will be supported at two locations as simply supported beam for carrying out full-scale test. Point loads will be applied at appropriate locations along the tests article length to simulate bending moments during full-scale tests. Hydraulic actuators of required capacities will be mounted on the loading beam, which is grounded firmly in a trench using foundation bolts, to apply necessary point loads. Loading beam is designed for a central load of 25-tons applied between two adjacent grouting considering as fixed beam. Structural frame is designed and analyzed for ten different load cases having maximum bending moments of 5676kgf-m (M_X) & 12000kgf-m (M_X), axial load of 90000kgf and external pressure of 10kg/cm^2 and loading beam is designed and analyzed for 25 tons. Design and analysis are carried out using Finite Element Package ANSYS 10.0.

INTRODUCTION

Test article experiences various loads such as aerodynamic, inertial, launch and handling loads during its development process. The structural loads experienced by test article during above-mentioned conditions may be summarized into axial load, bending moment, external pressure and thermal loads etc. Test articles experience axial loads when gas generators are fired. Test article also experiences axial loads due to inertial effect of sections ahead of individual sections. Airframe sections experience bending Moment due to maneuvering, handling and combined effect of aerodynamic & inertial loads during the flight. Full-scale and section level tests, on tests articles such as full-scale airframes and its sections are to be carried out using Structural frame and loading beam. The present work is confined to design and analysis of Structural frame and loading beam to simulate Bending Moments M_X and M_Y simultaneously.

Each and every section of an Airframe is designed for withstanding their critical load conditions. The design of each component is to be proved by simulating the respective critical load conditions. A Structural frame is necessary for holding test article (section level) in cantilever mode and to apply bending moments using actuators mounted on loading beam. Ten different load cases involving different bending moments are considered for the design and analysis of Structural frame. Structural frame is designed for maximum Bending Moments of 5676kgf-m (M_X) & 12000kgf-m (M_Y), maximum axial Load of 90000kgf and maximum external pressure of 10kg/cm^2. Axial load, B.M and external pressure are applied in different combinations for ten different load cases which are given in chapter-4. And also the overall airframe (full-scale airframe) is also to be proved for its own critical loading conditions. The test article will be supported on two reaction points as simply supported beam for carrying out full-scale test. Point loads will be applied at appropriate locations along the tests article length to simulate bending moment during full-scale test. A loading beam is necessary for mounting hydraulic actuators and support frames during the test. Loading beam is designed for a central load of 25-tons applied between two adjacent grouting considering as fixed beam. The structural frame and loading beam shall be positioned as per the assembly.

OBJECTIVES AND METHODOLOGY

The main objective of this project is to carry out design and analysis of Structural frame and Loading beam for carry out full-scale and section level tests. The Structural frame is a steel structure constructed out of I-beams and plates. The main function of Structural frame is to hold the test article in cantilever mode, and to take-up the reaction forces generated due to simulation of axial force and bending moment. The typical FE model of structural Frame is given in Figure.2. Loading beam is for supporting full-scale test article in simply supported condition and to hold hydraulic actuators for load application. The Loading beam will take up the reaction forces generated at two supporters and actuator points. The Loading beam is also be used for mounting actuators for section level tests, where the test article mounted in cantilever mode. The design of loading beam is carried out using conventional formulas. The detailed analysis of the beam and Structural frame is carried out using Finite Element Package `ANSYS 10.0`.

DESIGN AND ANALYSIS OF STRUCTURAL FRAME

INTRODUCTION

The Structural Frame is a structure which holds test article in cantilever mode during section level tests. The details of design and analysis of Structural Frame are presented below.

SPECIFICATION

Specifications for the design of structural frame for simulating axial load and bending moment simultaneously on test article are listed below,

1. The structural frame shall hold Test Article in cantilever mode, such that the axis of the article shall be 1.6 m above the ground level.
2. The size of the frame shall not exceed 4m x 4m in width and height.

3. A circular hole of diameter 300mm to be provided on interface plate, which holds test article, for the entry of the actuator rod and other linkages.
4. The structural frame shall be designed to withstand the test loads with the deflection not more than 5 mm.
5. Load cases to be considered for the design of structural frame are given below.

Case-1		**Case-2**	
Lateral force (F_{Y1})	4500 kg f	Lateral force (F_{Y5})	5400 kg f
Lateral force (F_{Y2}	2000 kg f	Lateral force (F_{Y6})	5400 kg f
Lateral force (F_{Y3})	8000 kg f		
Lateral force (F_{Y4})	5400 kg f		

Material	UTS Kg/mm^2	0.2% PS Kg/mm^2	Young's Modulus Kg/mm^2	% Of Elongation
Plates: Steel - 20M055 (IS: 2041)	48	28	21000	20
Beams: Structural Steel - Sts42	41	24	21000	23

FE MODEL OF LOADING BEAM

Finite Element Analysis of loading beam has been carried to find the deflection and stresses induced under the applied loads and boundary conditions using ANSYS 10.0 software. Sheets of 12 mm thick, of loading beam are modeled as areas. Area, which is idealizing top flange, bottom flange, web and side plates are split at an interval of 500mm where cross stiffeners of 12mm thick are welded.. Each sheet of 12mm thick is idealized using shell-93 element. The overall FE model of loading beam is analyzed for the boundary conditions. The real constants taken for individual sheets of loading beam are given below.

- Top Flange thickness: 12 mm , Bottom flange thickness: 12 mm ,
- Bottom interface plate thickness: 30 mm, Bottom interface plate plus bottom flange: 42 mm.
- Web thickness: 12mm. Side plate thickness: 12 mm.

DESCRIPTION OF STRUCTURAL FRAME

The Structural Frame is an assembly of front frame, rear frame, interface plate, actuator mounting plate, inclined and vertical beams and horizontal connecting beams.

Front frame

Front frame is used to hold test article on interface plate in cantilever mode during axial load and bending moment application. It consists of a an interface plate of 1.8 m x 1.5 m x 80 mm with the center hole of 300mm.The interface plate is connected to four vertical I-Beams of ISMB-250 by means of M16 Fasteners at a pitch of 80 mm. Assembly of vertical beams and interface plate using fasteners enable the interface plate be detached at any time from structural frame, if necessary. The plate consists of 32 nos. of M12 tapped holes on 620 mm pitch circle diameter (PCD) for assembling test article. Horizontal and inclined beams of four numbers each, of ISMB-250 are fixed to the plate by means of M16 fasteners. All the beam members are fixed to the ground with sufficient number of foundation bolts.

Rear Frame

It used to fix the actuator to apply the compressive load on the test article. It consists of actuator plate of 1m x 1m x 50mm and supported by two vertical I-Beams of ISMB-250.The plate is fixed to the vertical members, by means of M16 fasteners at a pitch of 80mm.The base of actuator is fixed to this plate. Horizontal and inclined I-beams of ISMB-250 further reinforce the plate to reduce the deflection and the stress levels on the rear frame.

Assembly

The front and rear frames are joined together by means of four horizontal build up I-Beams of ISMB-250 to form the total structural frame. The interface plate is further supported by four inclined I-beams and four vertical beams of ISMB-250. The assembly of front and rear frames along with inclined and horizontal beams is taken. The distance between the front and rear frames is maintained as 2 m to accommodate actuator and other linkages.

FE MODEL OF STRUCTURAL FRAME

Finite Element Analysis of the structural frame has been carried to find the deflection and stresses induced under the applied loads and boundary conditions using ANSYS 10.0 software. Vertical, inclined and horizontal beams are modeled as lines and the interface plate and actuator plate are modeled as areas. Area, which is idealizing interface plate, is split in to two areas by a circle of 620 mm diameter. This circle is divided into 32 parts to have 32 key points at 620 mm PCD to apply structural loads. The solid model of structural frame is shown in Figure.2. The plates are idealized using shell-93 element and all beam members are idealized using 3D beam element, beam-4. The real constants taken for beams and plates during analysis of structural frame are given below.

- Front Interface plate thickness: 80 mm , Back plate thickness: 50 mm
- I-Beams ISMB-250 (Vertical Beams) ,Area: 6750 mm^2

I_{yy}: 21579167 mm^4, I_{zz}: 84592667 mm^4, I -Beams ISMB-250 (Inclined Beams)

Area: 6750 mm^2, I_{yy}: 21579167 mm^4, I_{zz}: 84592667 mm^4

- I -Beams ISMB-250 (Horizontal Beams)

Area: 10750 mm^2, I_{yy}: 88164500 mm^4, I_{zz}: 105426001 mm^4

Boundary conditions: All the grounded ends of the vertical beam and inclined beam members are constrained completely in all degrees of freedom.

LOADS: The axial load and bending moment are applied on interface plate as point loads, at 32 key points. The axial load is distributed equally on all 32 key points at 620mm PCD. The bending moment is converted into equivalent point loads and the point loads are applied on 32 key points of 620mm PCD. The point loads of axial force and bending moment are superimposed to apply axial load and bending moment simultaneously. The loads applied on each key point for four different load cases are given below.

Case-1

The loads to be applied on test article for case-1 are,

Lateral force (F_{Y1}) = 4500 kg f,
Lateral force (F_{Y2}) = 2000 kg f
Lateral force (F_{Y3}) = 8000kgf
Lateral force (F_{Y4}) =5400 kg f

The above loads are acting on test article as shown in Figure-1a. The lateral forces, $\mathbf{F_{Y1}}$, $\mathbf{F_{Y2}}$, $\mathbf{F_{Y3}}$ and $\mathbf{F_{Y4}}$ are acting at distance of 4150mm, 2979mm, 1725mm and 675mm respectively from the fixing point (from interface plate) as lateral loads applied on a cantilever. The above loads induce a bending moment **(M_Y)** on test article**.** The effect of bending moment **(M_Y)** is converted into equivalent point loads acting at key points of PCD 620mm circle. The calculation is done based on unit distance method. The following calculations are carried out to find out the equivalent point loads.

Bending Moment, M_Y =2562000 kgf-mm, PCD of the circle = 620mm, Radius of the circle,
R=310 mm
Number of key points = 32

Angular pitch = $\theta = 360^0/32 = 11.25^0$

Force variation (Harmonic) = $F*\cos\theta$

Where, F = Max. Force / Alliterate (To be computed)

Force at location-1 (Key point-1), $F_1 = F \cos 0^0$, Force at location-2 (Key point-2), $F_2 = F \cos 11.25^0$

Force at i^{th} location, $F_i = F \cos (i-1)\ 11.25$ (i = 1 to 32) , Arm distance, $r_i = R*\cos (i-1)\ 11.25^0$ (i = 1 to 32)

The above forces are acting in Z-direction of FE model. Forces F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_{26}, F_{27}, F_{28}, F_{29}, F_{30}, F_{31}, and F_{32} act in positive Z-direction and forces F_{10}, F_11, F_{12}, F_{13}, F_{14}, F_{15}, F_{16}, F_{17}, F_{18}, F_{19}, F_{20}, F_{21}, F_{22}, F_{23} and F_{24} act in negative Z direction. (Y-Y is taken as Neutral plane).

By equating these forces to the Bending Moment, M_Y

Bending Moment, $M_Y = \sum Fi\ ri = 2562000 = F \times R \times \sum \cos^2 ((i-1) \times 11.25^0)$

From above equation, F = 516.53 kgf

$F_1 = -F_{17} = 516.5$ kgf, $F_2 = -F_{16} = -F_{18} = F_{32} = 506.6$ kg f, $F_3 = -F_{15} = -F_{19} = F_{31} = 477.2$ kgf

$F4 = -F14 = -F_{20} = F_{30} = 429.5$ kg f, $F_5 = -F_{13} = -F_{21} = F_{29} = 365.2$ kgf

$F_6 = -F_{12} = -F_{22} = F_{28} = 287.0$ kg f, $F_7 = -F_{11} = -F_{23} = F_{27} = 197.7$ kgf

$F_8 = -F_{10} = -F_{24} = F_{26} = 100.8$ kg f, $F_9 = F_{25} = 0$ kgf

The above loads are applied on FE model at corresponding key points (32 Nos.) on 620mm circle. The loads applied on 32 key points as point loads are given in Table-1.

Case- 2

The loads to be applied on test article for case-2 are,

Lateral force (F_{Y5}) = 5400 kgf

Lateral force (F_{Y6}) = 5400 kg f

The above loads are acting on test article as shown in Figure-1b. The lateral forces $\mathbf{F_{Y5}}$ and $\mathbf{F_{Y6}}$ are acting at distance of 4064mm and 3475mm respectively from the fixing point (from interface plate) as lateral loads applied on a cantilever. The above loads induce a bending moment **(M_Y).** The effect of bending moment **(M_Y)** is converted into equivalent point loads acting at key points of PCD 620mm circle. The calculation is done based on unit distance method. The following calculations are carried out to find out the equivalent point loads.

Bending Moment M_Y = 3180600 kgf- mm, PCD of the circle = 620mm

Radius of the circle R= 620/2 = 310mm, Number of key points = 32

Angular pitch = θ = $360^0/32$ = $11.25^{0,}$ Force variation (Harmonic) = F*Cos θ

Where F = Max. Force / Alliterate (To be computed), Force at location-1 (Key point-1) F1 = F Cos 0^0

Force at location-2 (Key point-2) F2 = F Cos 11.25^0, Force at i^{th} location Fi = F Cos (i-1) 11.25 (i = 1 to 32)

Arm distance ri = R*Cos (i - 1) 11.25^0 (i = 1 to 32)

The above forces acting are in Z Direction. Forces F1, F2, F3, F4, F5, F6, F7, F8, F26, F27, F28, F29, F30, F31, and F32 act in positive Z direction and forces F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F21, F22, and F23 act in negative Z direction. (Y-Y is taken as Neutral plane).

By equating these forces to the Bending Moment M_Y,

Bending Moment M_Y =$\sum$ Fi ri = 3180600 = F x R x $\sum$ Cos^2 ((i - 1) x 11.25^0)

From above equation, F =641.25Kgf (by considering the factor of safety 1.1)

Then, F1 = -F17 = 641.25kg f, F2 = - F16 = - F18 = F32 =628.93Kgf

F3 = - F15 = - F19 = F31 =592.44 Kg f, F4 = - F14 = - F 20 = F30 = 533.18Kgf

F5 = - F13 = - F 21 = F29 = 453.43Kg f , F6 = - F12 = - F22 = F28 =356.26Kgf

F7 = - F11 = - F23 = F27 = 245.40Kg f , F8 = - F10 = - F24 = F26 =450.2 Kgf , F_9 = F_{25} = 0 kgf

The above loads are applied on FE model at corresponding key points (32 Nos.) on 620mm circle. The loads applied on 32 key points as point loads are given in Table-2.

RESULTS AND DISCUSSIONS

STRUCTURAL FRAME

The stress analysis on the FE model of the structural frame is carried out with the imposed loads and boundary conditions. The objective of performing FE analysis is to find out stress and deflections on structural frame under applied load conditions. And also the stresses and deflections obtained from the analysis for case-1, case-2, case-3 case-4, case-5, case-6, case-7, case-8 and case -9 and case-10 are plotted and enclosed in this report. The details of von-misses stresses and deflections for all the load cases are given below.

Case-1: The overall FE model of structural frame is shown in Figure-2 and the Von-misses stress plot of structural frame is shown in Figure-7. The maximum von-misses stress for case-I on structural frame is 0.868 kg/mm^2. And the maximum deflection of the structural frame is 0.06mm. The FE model of horizontal beams is shown in Figure-3 and the Von-misses stress plot of horizontal beams is shown in Figure-8. The maximum von-misses stress for the case-I on horizontal beams is 0.41 kg/mm^2. And the deflection of the horizontal beams is 0.054mm. The FE model of vertical and inclined beams is shown in Figure-4 and the Von-misses stress plot of vertical and inclined beams is shown in Figure-9. The maximum von-misses stress for the case-I on vertical and inclined beams is 0.868 kg/mm^2. And the maximum deflection of the vertical and inclined beams is 0.06mm. The FE model of interface plate is shown in Figure-5 and the Von-misses stress plot of interface plate is shown in Figure-10. The maximum von-misses stress for the case-I on interface plate is 0.711 kg/mm2. And the maximum deflection of the interface plate is 0.06mm. The FE model of actuator mounting plate is analyzed and the Von-misses stress plot of actuator mounting plate is calculated. The maximum von-misses stress for the case-I on actuator mounting plate is 0.711 kg/mm^2. And the deflection of the actuator mounting plate is 0.06mm. The maximum von-misses stress and deflections obtained from analysis of all members of structural frame are given in Table.

Factor of safety: Factor of safety of stresses obtained from the analysis is calculated on Ultimate strength of the material (UTS). The factor of safety is the ratio of UTS and maximum working stress and the details are as follows. The factor safety obtained for case-1 is 27.65.

Case-2: The overall FE model of structural frame is shown in Figure-2 and the Von-misses stress plot of structural frame is shown in Figure-12. The maximum von-misses stress for the case-2 on structural frame is 0.928 kg/mm^2. And the maximum deflection of the structural frame is 0.067mm. The FE model of horizontal beams is analyzed and the Von-misses stress plot of horizontal beams is calculated. The maximum von-misses stress for the case-2 on horizontal beams is 0.44 kg/mm^2. And the maximum deflection of the horizontal beams is 0.057mm.

The maximum von-misses stress for the case-2 on vertical and inclined beams is 0.928 kg/mm^2. And the maximum deflection of the vertical and inclined beams is 0.067mm. The FE model of interface plate is shown in Figure-5 and the Von-misses stress plot of interface plate is shown in Figure-15. The maximum von-misses stress for the case-2 on interface plate is 0.759kg/mm^2. And the maximum deflection of the interface plate is 0.067mm. The maximum von-misses stress for the case-2 on actuator mounting plate is 0.759 kg/mm^2. And the maximum deflection of the actuator mounting plate is 0.067mm. The maximum von-misses stress and deflections obtained from analysis of all members of Structural frame

Factor of safety: Factor of safety of stresses obtained from the analysis is calculated on Ultimate strength of the material (UTS). The factor of safety is the ratio of UTS and maximum working stress and the details are as follows. The factor safety obtained for case-2 is 25.86.

CONCLUSIONS

The design of structural frame and loading beam is carried out using FEM software Ansys 10.0 and found to be adequate for carrying out structural tests, since the maximum von-misses stresses obtained from analysis are well within yield strength of the material. Maximum deflection obtained from analysis is also well within allowable limits. Hence the structural frame and loading beam can be realized and erected for carrying out ten different structural tests and full scale test.

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AF =0 kgf		B.M = 3180600 kgf-m		Radius = 310 mm	
		Fi=641.25kgf			
Key point	Load (AF)	Cos(i-1)*11.25	Square (C3)	Fi	Total Load (kgf)
1	0	1	1	641.25	**641.3**
2	0	0.98078528	0.961939766	628.93	**628.9**
3	0	0.923879533	0.853553391	592.44	**592.4**
4	0	0.831469612	0.691341716	533.18	**533.2**
5	0	0.707106781	0.5	453.43	**453.4**
6	0	0.555570233	0.308658284	356.26	**356.3**
7	0	0.382683432	0.146446609	245.40	**245.4**
8	0	0.195090322	0.038060234	125.10	**125.1**
9	0	6.12574E-17	3.75247E-33	0.00	**0.0**
10	0	-0.195090322	0.038060234	-125.10	**-125.1**
11	0	-0.382683432	0.146446609	-245.40	**-245.4**
12	0	-0.555570233	0.308658284	-356.26	**-356.3**
13	0	-0.707106781	0.5	-453.43	**-453.4**
14	0	-0.831469612	0.691341716	-533.18	**-533.2**
15	0	-0.923879533	0.853553391	-592.44	**-592.4**
16	0	-0.98078528	0.961939766	-628.93	**-628.9**
17	0	-1	1	-641.25	**-641.3**
18	0	-0.98078528	0.961939766	-628.93	**-628.9**

19	0	-0.923879533	0.853553391	-592.44	**-592.4**
20	0	-0.831469612	0.691341716	-533.18	**-533.2**
21	0	-0.707106781	0.5	-453.43	**-453.4**
22	0	-0.555570233	0.308658284	-356.26	**-356.3**
23	0	-0.382683432	0.146446609	-245.40	**-245.4**
24	0	-0.195090322	0.038060234	-125.10	**-125.1**
25	0	-1.83772E-16	3.37722E-32	0.00	**0.0**
26	0	0.195090322	0.038060234	125.10	**125.1**
27	0	0.382683432	0.146446609	245.40	**245.4**
28	0	0.555570233	0.308658284	356.26	**356.3**
29	0	0.707106781	0.5	453.43	**453.4**
30	0	0.831469612	0.691341716	533.18	**533.2**

Table-2 Loads applied on 32 key points for Case-2

AF =0 kgf		B.M = 2562000 kgf--m		Radius = 310 mm	
		Fi=516.16 kgf			
Key point	Load (AF)	Cos (i-1)*11.25	Square (C3)	Fi	Total Load (kgf)
1	0	1	1	516.53	**516.5**
2	0	0.98078528	0.96193977	506.61	**506.6**
3	0	0.923879533	0.85355339	477.21	**477.2**
4	0	0.831469612	0.69134172	429.48	**429.5**
5	0	0.707106781	0.5	365.24	**365.2**
6	0	0.555570233	0.30865828	286.97	**287.0**
7	0	0.382683432	0.14644661	197.67	**197.7**
8	0	0.195090322	0.03806023	100.77	**100.8**
9	0	6.12574E-17	3.7525E-33	0.00	**0.0**
10	0	-0.195090322	0.03806023	-100.77	**-100.8**
11	0	-0.382683432	0.14644661	-197.67	**-197.7**
12	0	-0.555570233	0.30865828	-286.97	**-287.0**
13	0	-0.707106781	0.5	-365.24	**-365.2**
14	0	-0.831469612	0.69134172	-429.48	**-429.5**
15	0	-0.923879533	0.85355339	-477.21	**-477.2**
16	0	-0.98078528	0.96193977	-506.61	**-506.6**
17	0	-1	1	-516.53	**-516.5**
18	0	-0.98078528	0.96193977	-506.61	**-506.6**
19	0	-0.923879533	0.85355339	-477.21	**-477.2**
20	0	-0.831469612	0.69134172	-429.48	**-429.5**
21	0	-0.707106781	0.5	-365.24	**-365.2**
22	0	-0.555570233	0.30865828	-286.97	**-287.0**
23	0	-0.382683432	0.14644661	-197.67	**-197.7**
24	0	-0.195090322	0.03806023	-100.77	**-100.8**
25	0	-1.83772E-16	3.3772E-32	0.00	**0.0**
26	0	0.195090322	0.03806023	100.77	**100.8**
27	0	0.382683432	0.14644661	197.67	**197.7**
28	0	0.555570233	0.30865828	286.97	**287.0**
29	0	0.707106781	0.5	365.24	**365.2**
30	0	0.831469612	0.69134172	429.48	**429.5**

Table-1 Loads applied on 32 key points for Case