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DYNAMIC RESPONSE OF BOX-TYPE SONAR STRUCTURE

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Abstract

Emerging trends in hull-mounted submarine sonar systems call for compact modular structures. Typical configurations include linear, planar, cylindrical, and spherical. This paper examines a novel type of sonar structure. It is an open box-type, cuboidal in construction, with stiffened end-flanges and multiple openings for hydrophone fitment. The response of the structure to shock load was evaluated using numerical techniques and validated through experiments. Eight-noded linear solid finite elements were used for modeling. Eigen analysis was done using Lanczos method. Shock load dictated by Naval Shock Standards was applied in the longitudinal and transversal directions in the horizontal plane. Modal transient dynamic analysis was performed and the dynamic acceleration response obtained. Validation experiments were executed on “Impact Shock Test Machine” and response measured using accelerometers. The numerical and experimental results are in good agreement. It is observed that shock amplification is appreciable in transversal axis and negligible in longitudinal axis. This study aids sonar engineers in structural integrity issues associated with onboard installation.

1. INTRODUCTION

Underwater structures meant for defence applications are designed to withstand shock loads resulting from non-contact underwater explosion. As it is not possible to carry out underwater explosion test always, Naval Standards specify the severity of shock loads depending on the type of platform, mass of structure and position of structure in the platform. The sonar structure considered in this paper is also designed accordingly. However, in order to validate the design process, the sonar structure is subjected to testing on “Impact Shock Test Machine”.

The sonar structure is modeled using one of the standard commercial Finite Element Analysis software package namely NISA (Numerically Integrated elements for System Analysis) and analyzed for shock loads, simulating the actual boundary conditions and loading pattern. The dynamic response of the structure is obtained from the analysis.

The sonar structure is cuboidal in shape. The top and bottom ends are stiffened by end flanges. Gussets are provided to connect the structure with end flanges. The top and bottom sides are kept open. Due to this type of construction, the sonar structure is classified as box-type structure. The box-type sonar structure is shown in figure 1 and has dimensions of 900 mm × 300 mm × 650 mm. There are 27 holes of 36 mm diameter each on both the longitudinal sides for positioning of hydrophones. These holes have counterboring on the outer face and inner face. In addition to these, holes of smaller diameter are also provided on each of the longitudinal sides. The structure is made of stainless steel AISI 316L grade and weighs about 250 kilograms in air.

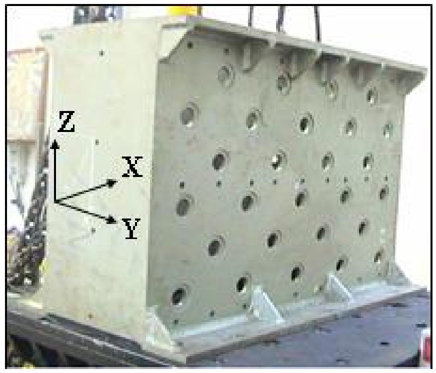

Figure 1. Box type sonar structure

To the best of knowledge of the authors, not much literature is available on the response of sonar structures, since the subject is generally classified in nature. Popplewell has studied the vibrations of box type structure and its response to traveling pressure wave utilizing finite elements [1],[2]. Ajith Kumar et al have evaluated the response of a typical stave structure to shock loading, considering it as a one dimensional structure [3]. Nandagopan et al have investigated the natural frequencies and mode shapes of clamped-free cylindrical sonar array structures using finite element method with 3D general shell elements [4].

2. FINITE ELEMENT ANALYSIS

The finite element package, NISA is used for the finite element modeling and analysis. The box type of sonar structure is modeled using 8-noded linear solid elements (NKTP=4). For the simplicity of modeling, the smaller diameter holes and the gussets are not considered for the finite element analysis. In the longitudinal sides of the structure, the counterboring holes on the outer and inner faces are also not modeled. Stainless steel is an isotropic material and its properties used in the analysis are: (i) Density, ρ = 7800 kg/m^3, (ii) Young's Modulus, E = 20,000 Mpa, and (iii) Poisson's Ratio, ν = 0.3.

The dynamic load of shock is given in standard sine wave form with peak acceleration 48 g and duration 40 milliseconds (full sine wave), as per Naval Standards. To carry out the experiment using the Impact Shock Test Machine, intermediate structures are designed for interfacing the sonar structure with the Impact Shock Test Machine. Hence in the finite element analysis also, the intermediate structures are modeled along with the sonar structure.

Initially eigen analysis was carried out using the Sparse solver [5]. The eigen value extraction technique used was the Lanczos method. Consistent mass matrix formulation was utilized for the analysis. Then modal transient dynamic analysis was carried out to find out the response to the shock load. The response of the structure is measured at a point at the centre of the topmost surface (the point where accelerometer is placed during the experimental evaluation).

2.1 Transient Analysis – Transversal Axis

The box-type sonar structure and the interface fixtures were modeled using solid elements as shown in figure 2. There were a total of 18264 nodes and 12498 elements in the finite element model. The boundary conditions were constituted by fully restraining the nodes on the side of the fixture that was connected to the shock test machine by means of bolts.

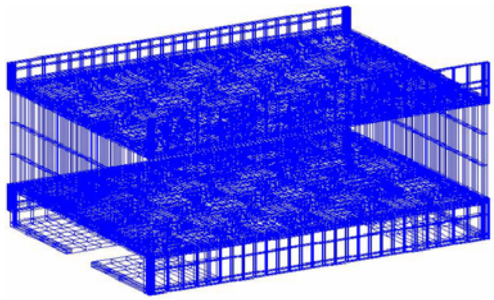

Figure 2. Finite element model - transversal axis.

The eigen analysis was carried out for the first 70 modes. The total time taken for computation was 19.24 minutes and the total disk space used was 323.13 MB. The natural mode shapes for the first six modes are shown in the figure 3.

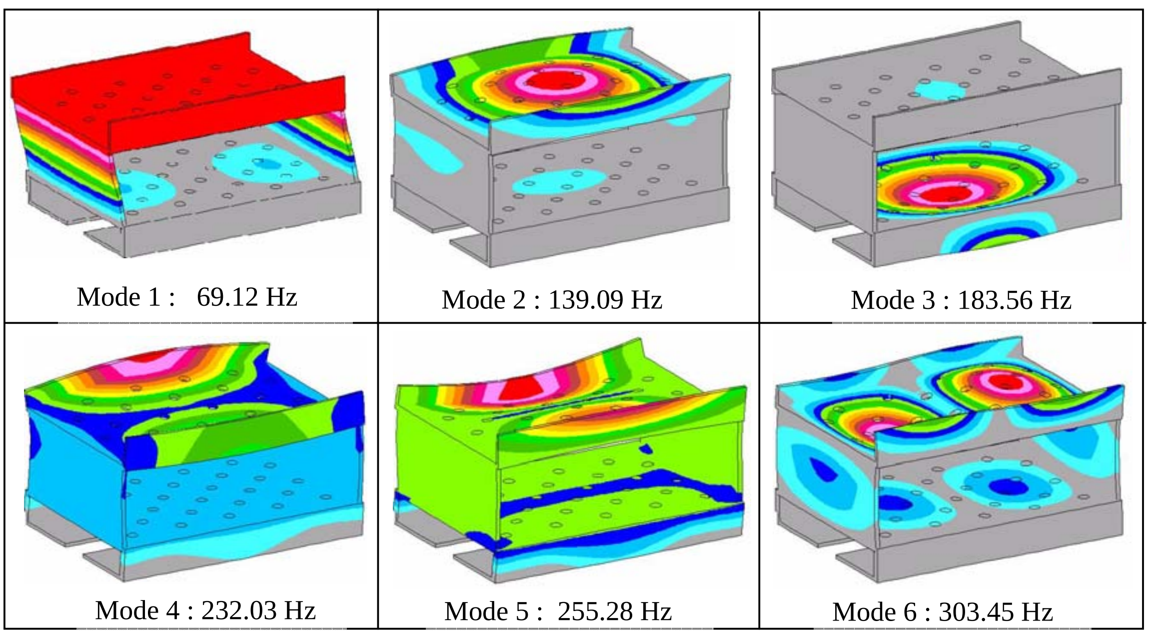

Figure 3. Structural mode shapes – transversal axis

The structure along with the fixtures is then subjected to modal transient dynamic analysis to simulate the impact test. The time dependent input excitation is given as a discrete sine function with peak amplitude of 48 ‘g’. The duration of the excitation is 40 milliseconds (for full sine pulse), which is attained in 20 time steps. All the 70 modes obtained as per the eigen analysis were taken into account while performing the shock analysis. The total computation time taken for the analysis is 6.569 seconds and the total disk space used was

150.95 MB. The response of the structure in terms of acceleration is plotted in figure 4, where X-axis indicates the time in seconds and Y-axis the acceleration in mm/s^2.

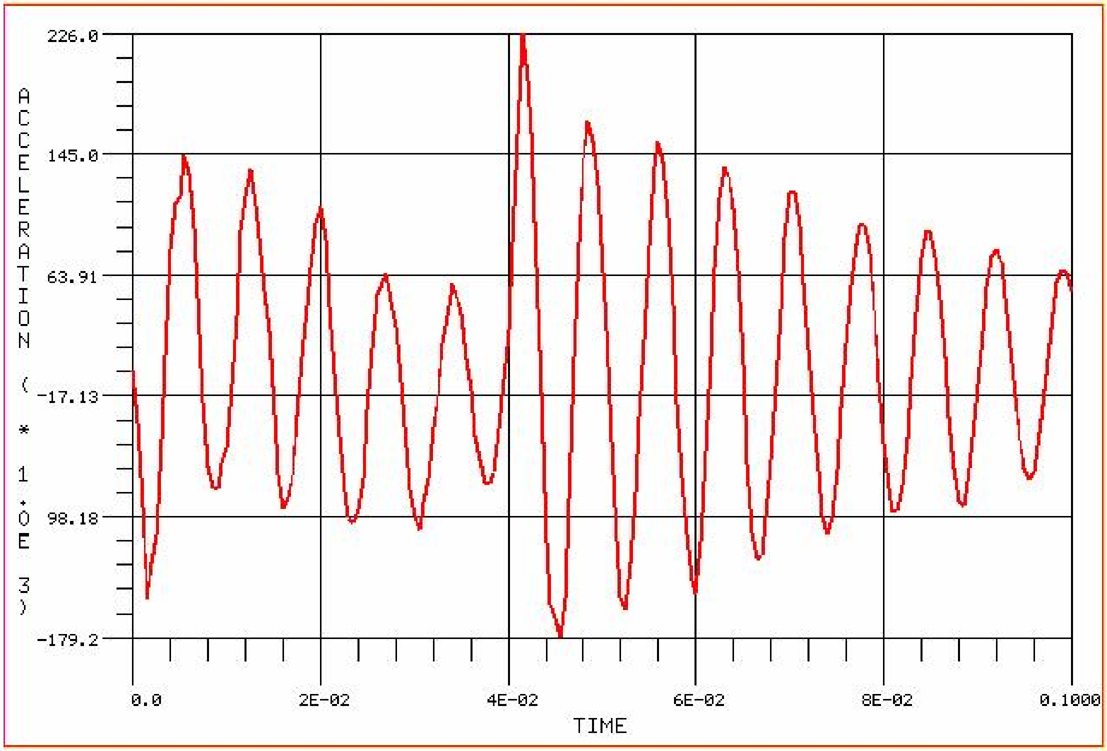

Fig. 4. Response of box type sonar structure fixed in transversal axis

2.2 Transient Analysis – Longitudinal Axis

The box type sonar structure and the interface fixtures were modeled using solid elements. The realistic plot of the model is shown in figure 5. There were a total of 18238 nodes and 12492 elements in the finite element model. The boundary conditions were constituted by fully restraining the nodes on the side of the fixture that was bolted to the shock test machine.

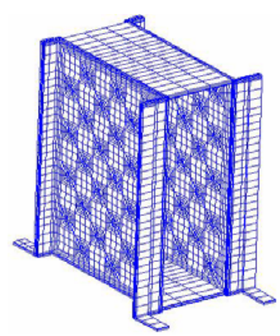

Figure 5. Finite element model – longitudinal axis

The eigen analysis was carried out for the first 70 modes. The total time taken for computation was 14.12 minutes and the total disk space used was 451.52 MB. The natural mode shapes for the first six modes are shown in figure 6.

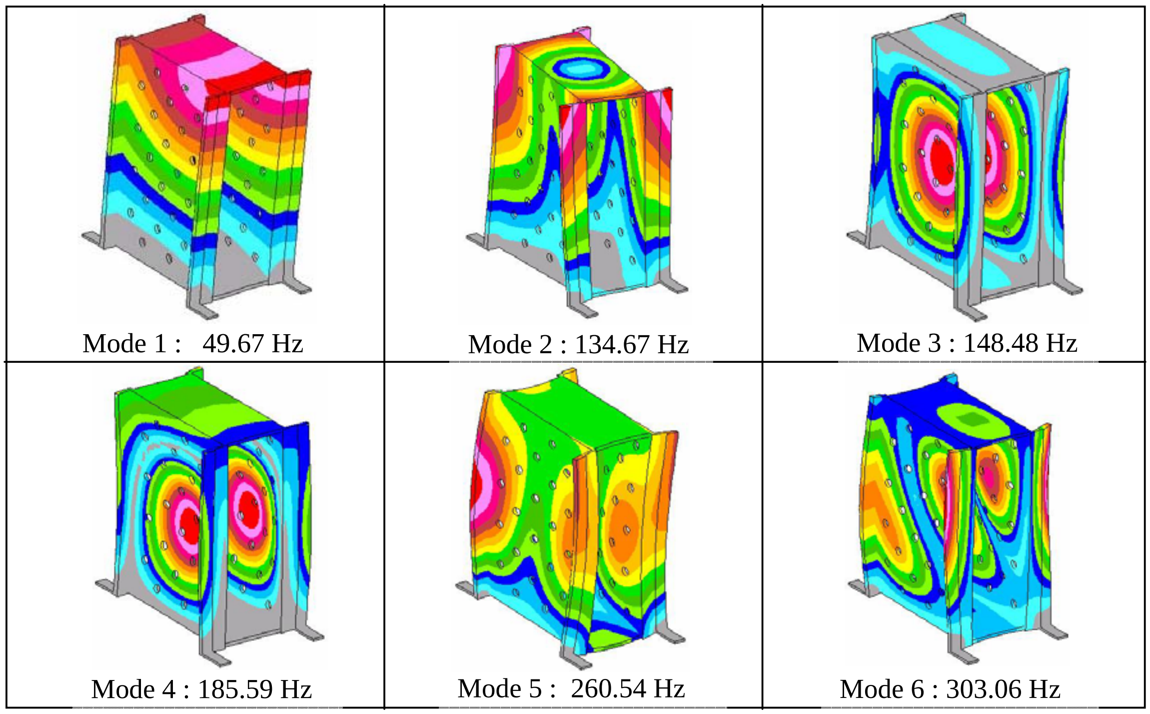

Figure 6. Structural mode shapes – longitudinal axis

The structure along with the fixtures is then subjected to modal transient dynamic analysis with the same input excitation as in the earlier case. The total computation time taken for the analysis is 3.234 seconds and the total disk space used was 149.69 MB. The response of the structure in terms of acceleration is plotted in figure 7, where X-axis indicates the time in seconds and Y-axis the acceleration in mm/s^2.

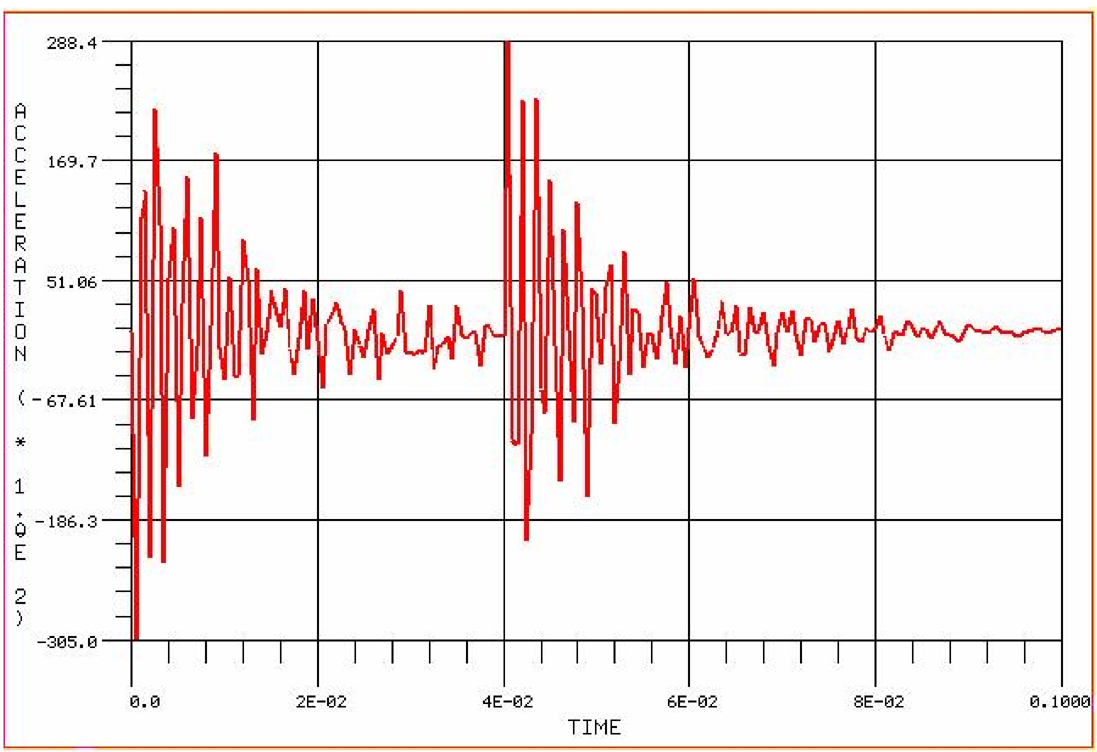

Figure 7. Response of box type sonar structure fixed in longitudinal axis

2.3 Results

It can be observed from figure 4 that for the shock in the transversal axis, the structure experienced a relative shock acceleration of the order of 226 m/s^2 in one direction and 179.2 m/s^2 in the opposite direction. This amounts to a shock amplification of the order of 48.04 % and 38.1 % respectively. From figure 7, it is seen that for the longitudinal axis, the relative acceleration was less and was of the order of 28.84 m/s^2 and 30.5 m/s^2 in either directions, thereby amounting to a shock amplification of 6.13 % and 6.48 %.

3. EXPERIMENTAL SHOCK TESTING

The machine used for the test is 886 MTS Impact Shock Test Machine shown in fig.8. This machine has the facility to input user defined shock pulse. The shock load applied for the experiment was half sine pulse as the machine doesn't have the facility to simulate a full sine wave. The structure was mounted over the shock test machine in both the axes perpendicular to its axis of fitment on the platform.

Figure 8. 886 MTS Impact Shock Test Machine

The experimental setup consists of the box type sonar structure, the shock testing machine and the fixtures for fixing the sonar structure on the shock machine table. The actual mounting of the structure on the shock machine for testing in the transversal and longitudinal axes are depicted in fig.9 and fig.10.

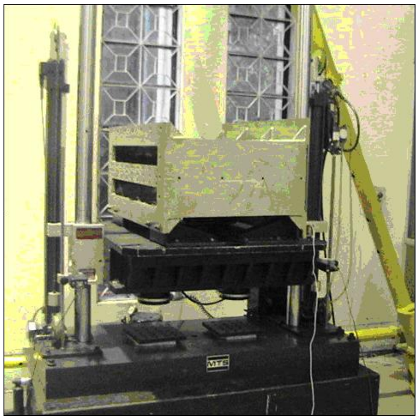

Figure. 9. Shock test in the transversal axis

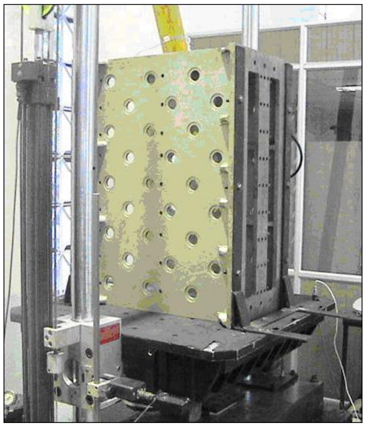

Figure 10. Shock test in the longitudinal axis

The sonar structure is properly bolted on to the machine table using the fixtures specially made for this purpose. After presetting the machine to the required height and fixing the required programmers, the structure is made to drop down by gravity. Two accelerometers, one fixed on the structure and the second on the machine table pass on the required data to a computer, which then plots the response. The output from the accelerometer fixed on the machine table is taken as the input pulse to the sonar structure. The output from the accelerometer fixed on the sonar structure at the centre of the topmost surface is taken as the response of the structure.

3.1 Results

The values of the input pulse to the sonar structure as well as the response of the structure for the different axes of impact are given in table 1. It can be seen that in the longitudinal axis, the shock is transmitted almost fully, the amplification or loss by 2 to 3 % being negligible. This is as expected since no shock mounts were used and the structure was rigidly fixed to the machine table. However in the transversal axis, the shock is transmitted with amplification of 24 to 35%.

Table 1. Results of the Experiment

Trial No.	Axis of Impact	Input		Response		Amplification (%)
		Peak Acceleration (g)	Time Duration (ms)	Peak Acceleration (g)	Time Duration (ms)	
1	Transversal	46.7	21.76	62.8	16.02	34.48
2		48.7	21.64	60.4	15.83	24.02
3		46.8	22.03	61.6	16.48	31.62
4	Longitudinal	50.1	21.49	49.1	18.6	-2
5		50.9	21.64	52.4	20.37	2.95
6		50.2	21.68	51.4	20.64	2.39

4. CONCLUSION

The dynamic response of the box type sonar structure was evaluated from finite element analysis as well as from experimentation on Impact Shock Test Machine. A comparison of the results of the finite element analysis and the experiment is presented in table 2.

Table 2. Comparison of results of finite element analysis and experiment

AXIS OF IMPACT	**MAXIMUM AMPLIFICATION OF SHOCK LOAD (g)**	
	Finite Element analysis	**Experiment**
Transversal	48.04 % to 38.1%	24.02 % to 34.48 %
Longitudinal	6.13 % to 6.48 %	-2 % to 2.95 %

It can be seen that input shock load is transmitted fully to the structure. Both experiment and finite element analysis show that there is an appreciable amplification of shock load in the transversal axis. On the other hand, the amplification of shock in the longitudinal axis is negligible. The experiment thus validates the results of the finite element analysis.

Although the finite element analysis and experiment are in close agreement, the difference in the numerical values can be attributed to the fact that the analysis was carried out on an idealized model, where the effects of gussets, smaller diameter holes and counterboring on faces were not accounted for.

The study gives useful insight to sonar engineers for installation of sonar structures onboard platforms in ways optimum for mitigating the effects of underwater explosion.

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