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Study the Dynamic Response of the Stiffened Shallow Shell Subjected to Multiple Layers of Shock Waves

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Abstract*— *The ANSYS APDL programming and the results of calculating the stiffened shallow shell on elastic supports subjected to multiple layers of shock waves presented in the study. The program set up allows for the survey and evaluation of structural parameter and loads to the dynamic response of different types of shallow shell.

Keywords*— *Dynamic, Shell, shock wave, Elastic supports.

I. INTRODUCTION

The shell is used in many areas due to its good coverage and light weight. Some structures can be mentioned as: roof of the building, cover tunnel, engine cover, … Calculation of shell structure is influenced by different types of load are many scientists concerned. One of the types of high destructive load mentioned is the shock wave load [1,2,3,4,5]. In fact, when exposed to multiple layers of shock waves, the structural response is complex. To avoid the impact of impulse load, in some cases the elastic supports is used. In this paper, the problem of shallow shell structure with (or without) elastic supports subjected to multi layers of shock waves is investigated. The study results may give the readers a more complete vision on the response of the mentioned shell structure and may be used for reference in the its design.

II. PROBLEM MODELING

The Considering an eccentrically stiffened singly (or doubly) curved shell that is simply supported at the edges by elastic springs with stiffness k (Fig. 1). The shell is affected by multiple layers of shock waves p(t).

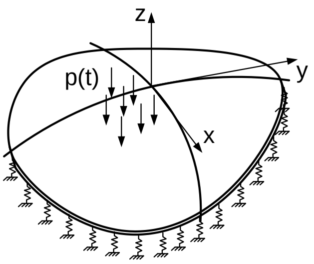

Fig. 1: Problem Model

For establishing an algorithm for the problem the following assumptions are used:

- The ribs and the shell material are homogeneous and isotropic;
- The shock-wave presssure is uniformly distributed on the shell surface.

III. TYPES OF ELEMENTS USED IN THE PROGRAM

To describe the bending shell, the SHELL63 element is used. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included [8].

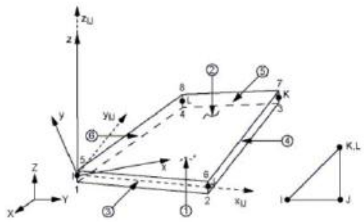

Fig. 2: SHELL63 Geometry

To describe the stiffener, 3-D Linear Finite Strain Beam (BEAM188) is used. BEAM188 is a linear (2-node) or a quadratic beam element in 3-D. It has six or seven degrees of freedom at each node, with the number of degrees of freedom depending on the value of KEYOPT(1). When KEYOPT(1) = 0 (the default), six degrees of freedom occur at each node. The eccentricity of the stiffener is described by the SECOFFSET command [8].

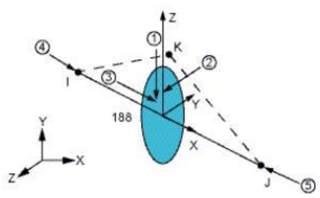

Fig. 3: BEAM188 Geometry

Elastic springs are described by the COMBIN14 element. With this type of element, the computational power of the

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program is extended to other types of viscoelastic pillows. In this case, the damping coefficient should be added when declaring the constants of the COMBIN14 element.

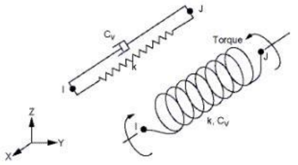

Fig. 4: COMBIN14 Geometry [8]

COMBIN14 has longitudinal or torsional capability in 1-D, 2-D, or 3-D applications. The longitudinal spring-damper option is a uniaxial tension-compression element with up to three degrees of freedom at each node: translations in the nodal x, y, and z directions. No bending or torsion is considered. The torsional spring-damper option is a purely rotational element with three degrees of freedom at each node: rotations about the nodal x, y, and z axes. No bending or axial loads are considered [8].

IV. GOVERNING EQUATIONS AND CALCULATION PROGRAM

The connection of the rib and the support elements into the flat shell elements is implemented by the direct stiffness method and the Skyline diagram is established by using the general algorithm of the FEM [6, 7, 8].

After connecting the element matrices and the element vectors in to the global ones the differential equation describing the oscillation of the stiffened shell may be written in the form:

$$[M]\{\ddot{q}\}+[C]\{\dot{q}\}+[K]\{q\}=\{F\}, \qquad (*)$$

where:

$[M]=\sum_e[M_s^e]+\sum_e[M_b^e]$ - the overall mass matrix ($[M_s^e]$ - the element mass matrix of shell element, $[M_b^e]$ - the element mass matrix of beam element);

$[K]=\sum_e[K_s^e]+\sum_e[K_b^e]+\sum_e[K_{sp}^e]$ - the overall stiffness matrix ($[K_s^e],[K_b^e],[K_{sp}^e]$ - the element stiffness matrix of shell element, beam element and combin14 element respectively);

$\{F\}=\sum_e\{F_s^e\}+\sum_e\{F_b^e\}$ - the overall load vector;

$[C]=a_R[M]+b_R[K]$ - the overall damping matrix, where α_R, β_R are Rayleigh damping coefficients [7,8].

Solution of equation (*) provided by the algorithm of calculator in ANSYS software. Depending on the choice of linear or nonlinear solvers, the Newmark's direct integration algorithm is used or combined using the Newton-Raphson iteration method.

A program to calculate the stiffened shallow shell subjected to multiple layers of shock waves on ANSYS APDL language written called Shallow_shell_multishock_waves (SSMW). The program includes the following modules:
- Modul 1: Import_data.mac;
- Modul 2: Model_building.mac;
- Modul 3: Loading_and_solving.mac;
- Modul 4: Export_ result.mac.

Within the scope of the study, the calculation program was designed to calculate two types of shell: shallow cylindrycal shell and doubly curved shell.

V. NUMERICAL RESULTS AND DISCUSSION

1. Problem 1

Consider an eccentrically stiffened shallow cylindrical shell whose plan view is a rectangular, a = 2.0m, b = 1.0m, the radius of curvature R = 1.6m, the thickness h = 0.025m. Shell material has an elastic modulus E_s = 2.1×10^{11}N/m^2, poisson coefficient ν_s = 0.3, specific weight ρ_s = 7850kg/m^3. Four edges of shell are supported by elastic springs with stiffness k = 3.10^4 kN/m. The eccentric ribs of the shell has h_r = 0.03m, b_r = 0.01m, the ribs in the directions are 6 (6 ribs parallel to the generating line, 6 ribs perpendicular to the generating line). The ribbed material has E_r = 2.5×10^{11}N/m^2, ν_r = 0.3, ρ_r = 7500kg/m^3.

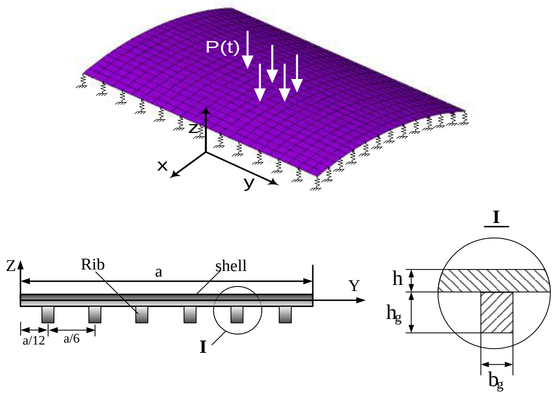

Fig. 5: Model of problem 1

The working load is two shock waves acting on the shell $p(t)=p_{max}F(t)$, with: p_{max1} = p_{max2} = 3.10^4 N/m^2,

$F(t)=\begin{cases}1-\dfrac{t}{\tau}: & 0\le t\le\tau\\ 0: & t>\tau\end{cases}$, τ_1 = τ_2 = 0.05s, time difference between wave layers: $\Delta\tau$ = 0.02s.

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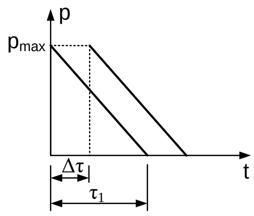

Fig. 6: Variation law of the load

Using the SSMW program, the author solved the problem with the calculating time t_{cal} = 0.16s, integral time step Δt =0.0005s. Resulting in stress and vertical displacement at the center of the shell, as shown in Table 1 and Figures 7, 8, 9.

Table.1: The maximum value of the quantity calculated in problem 1

	w_{max} [cm]	σ_x^{max} [N/m^2]	σ_y^{max} [N/m^2]
SSMW	0.0115	3.5977×10^6	1.5273×10^6

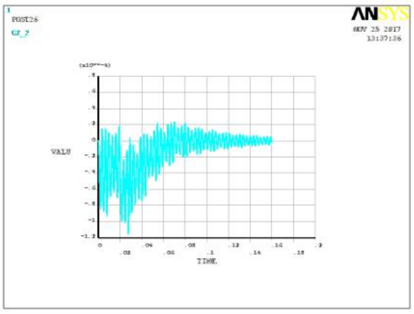

Fig. 7: Vertical displacement response w at center point

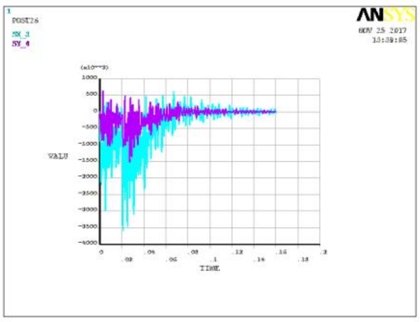

Fig. 8: Stress response σ_x, σ_y at center point

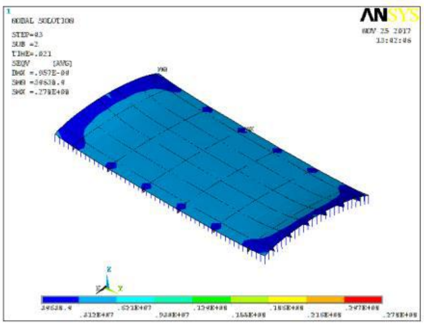

Fig. 9: Field of von mises stress of the shell at time t = 0.021s

Comment: With the given set of data, the maximum dynamic response values of the system reached at the time of two waves of simultaneous effects (time t = 0.021s). At center point, the stress σ_x^{max} is greater than the stress σ_y^{max}.

2. Problem 2

Considering the shallow cylindrical shell whose plan view is a rectangular, generating line's length *a* = 2.0m, opening angle of the shell θ = 40^o, the radius of curvature is R = 2.0m, h = 0.02m, E_s = 2.2×10^{11}N/m^2, ν_s = 0.31, ρ_s = 7800kg/m^3. The eccentrically ribbed shell with h_r = 0.03m, b_r = 0.01m, the shell with 4 ribs is parallel to the generating line, 6 ribs is perpendicular to the generating line, the ribs are equispaced. E_r = 2.4×10^{11}N/m^2, ν_r = 0.3, ρ_r = 7000kg/m^3. The mentioned shell has a round hole in the middle position, with d = 0.2 m (fig. 10). The load acting and the boundary are the same as Problem 1.

Vertical displacement and stress at point A, field of von mises stress of the shell and the overall transposition field of the structure at time t = 0.021s are shown in Figure 11, 12, 13, 14 and table 2.

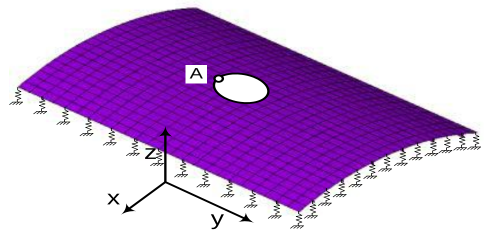

Fig. 10: Model of problem 2

Table.2: The maximum value of the quantity calculated in problem 2

	w^{Amax}[cm]	σ_x^{Amax} [N/m^2]	σ_y^{Amax} [N/m^2]
SSMW	0.0178	24.502×10^6	3.669×10^6

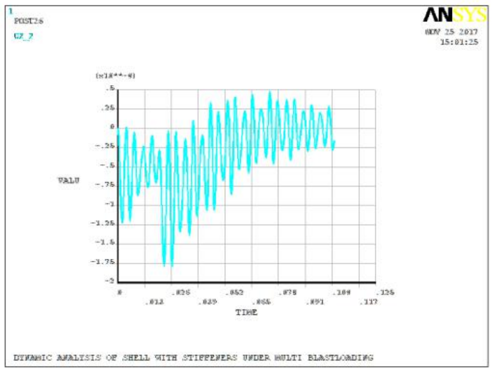

Fig. 11: Vertical displacement response w at point A

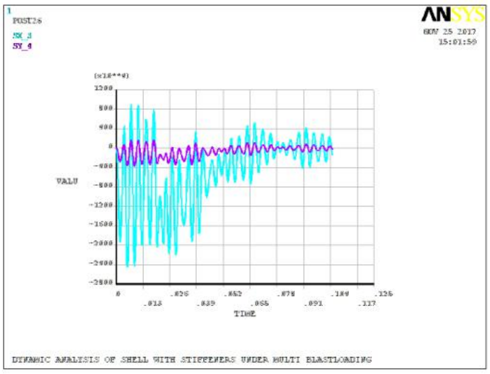

Fig. 12: Stress response σ_x, σ_y at point A

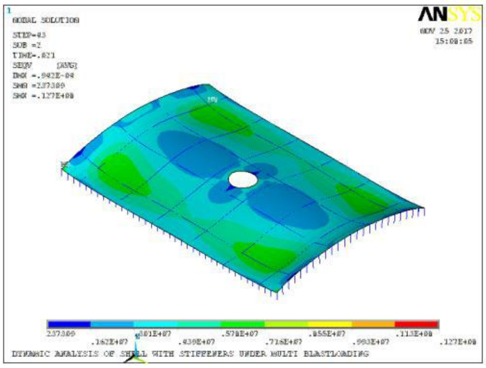

Fig. 13: Field of von mises stress of the shell at time t = 0.021s

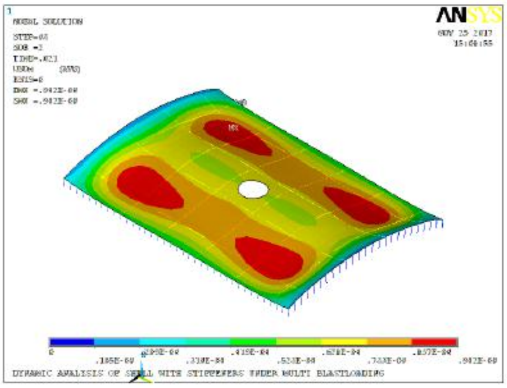

Fig. 14: The overall transposition field of the structure at time t = 0.021s

Comment: Immediately after the second wave appeared, the vertical displacement of the point A increases quite a lot, which represents the great influence of the second wave on the structure. At the time t = 0.021s, the shell appeared four symmetrical areas through the center with relatively large stress and displacement responses compared to the other positions. This is due to the reduction in the pressure applied to the position at the center of the cover.

3. Problem 3

Considering the doubly curved shell whose plan view is a rectangular, a = 1.5m, b = 1.0m, R_1 = 2.0m, R_2 = -4.0m, the thickness h = 0.005m. Shell material has $E_s = 2.1\times10^{11}$ N/m^2, ν_s = 0.31, ρ_s = 7800kg/m^3 (fig. 15). The load acting is the same as Problem 1.

Vertical displacement and stress at center point, field of von mises stress of the shell and the overall transposition field of the structure at time t = 0.025s are shown in Figure 16, 17, 18, 19 and table 3.

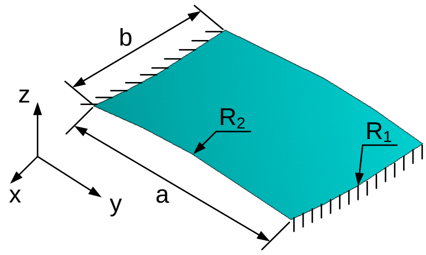

Fig. 15: Model of problem 3

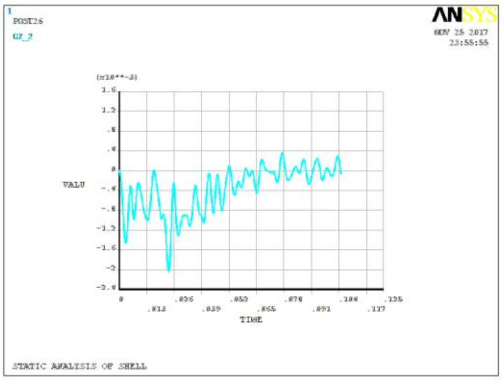

Fig. 16: Vertical displacement response w at center point

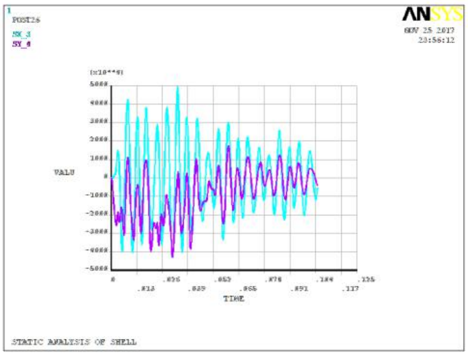

Fig. 17: Stress response σ_x, σ_y at center point

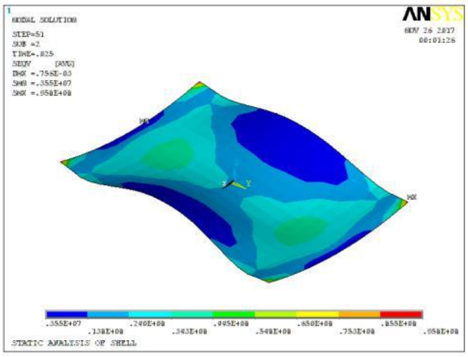

Fig. 18: Field of von mises stress of the shell at time t = 0.025s

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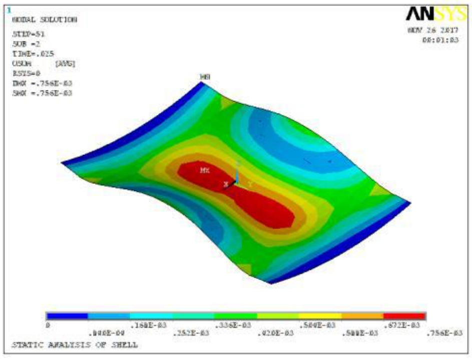

Fig. 19: The overall transposition field of the structure at time t = 0.025s

Table.3: The maximum value of the quantity calculated in problem 3

	w^{max}[cm]	σ_x^{max} [N/m^2]	σ_y^{max} [N/m^2]
SSMW	0.0204	49.535×10^6	42.782×10^6

Comment: Like the results of the problem 1 and problem 2, the maximum dynamic response values at point A of the structure reached at the time of two waves of simultaneous effects.

4. Problem 4

The parameters of the model are similar to the parameters in problem 3. The difference is that the shell has a square hole (a_1 x a_1) in the middle position, with a_1 = 0.2 m.

Table.4: The maximum value of the quantity calculated in problem 4

	w^{Amax}[cm]	σ_x^{Amax} [N/m^2]	σ_y^{Amax} [N/m^2]
SSMW	0.0126	7.348×10^6	71.405×10^6

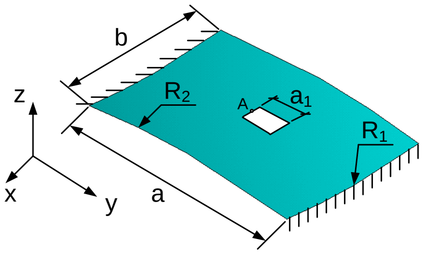

Fig. 20: Model of problem 4

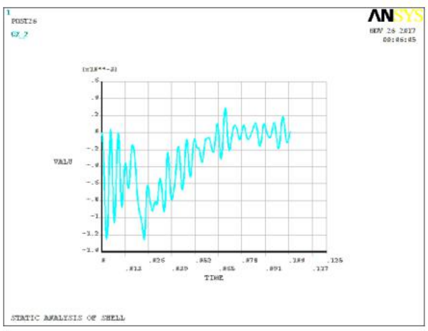

Fig. 21: Vertical displacement response w at point A

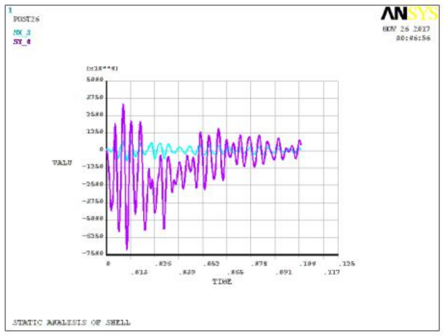

Fig. 22: Stress response σ_x, σ_y at point A

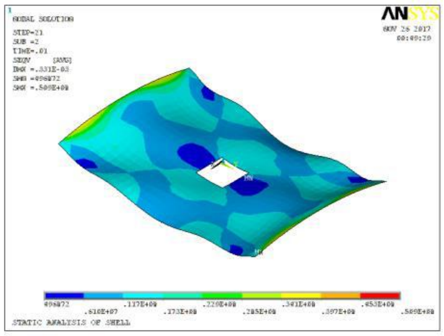

Fig. 23: Field of von mises stress of the shell at time t = 0.01s

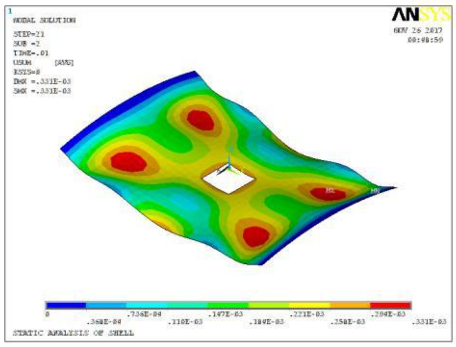

Fig. 24: The overall transposition field of the structure at time t = 0.01s

Comment: Compared to the result at the midpoint of the shell in Problem 3, the maximum value of the stress response at point A (*σ_y^{max}*) is much greater, this shows that the more susceptible to damage of the structure when there is a defect on its.

VI. CONCLUSION

In this study, using the ANSYS APDL programming language, a program has been established that allows for solving many different problem classes. The paper focuses on solving the problem of calculating the shell structure with one or two curvature with or without holes, which is affected by the impulse load system. The results show the complex response of the structure when multiple layers of shock wave load are applied. Solving different problem classes demonstrates the ability of the program.

The results of the study may be good references when calculating, designing the same structural.

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