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Innovative thin shell structure in space

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Abstract

Thin-walled shell structure may achieve such innovative structure enhancing better aesthetic view which should lead better performance in aspect of structural response; conducting accurate optimistic analysis and design for geo-strata of Earth or space objects. Nowadays, in developing countries for design of Stupa, Gumbaz and several dome structure simple spherical, parabolic three-dimensional structures are being rapidly analyzed and designed without proper analysis in which continuity of elastic theory enhancing member and bending forces developed within such structure should be considered. In this paper it is explained how the peak stress in intersecting line of several complex shell structures are being normalized and the continuity of elastic theory is maintained even though the structures are to be used in space purpose and will be constructed on the geo-strata of Lunar and Planetary objects. Those shell structures are not only in simple type like conventional dome structures; but also, innovative shell structures like Mongue's surfaces, Barrel Vaults, folded plate structures may be selected for space to resist pressure difference of internal and external environment in space, moon or any planet creating complex and aesthetic performance by humankind**.**

Thin-walled spatial structures used in various fields of technology are often combinations of sectors of thin shells and plates which may be connected at edge zones or may be intersected to each other along common intersecting line which will form its own continuity function. During analyze of various responses of connected structures, it is necessary to take into account the joint work of the sections of the structure, especially in the zone of intersection of the sections. At the same time, both two sectors or more than two sectors of thin shell may intersect in the intersection zone for covering large space consisting only peripheral stiff columns within shell structures. Intersecting sectors may be either of the same geometric shape or different depends upon designer in aesthetic sense, environment of space vacuum and geo-strata of space objects. The article provides study of innovative thin shell structure used in space which is found rarely

explained worldwide. An approach for analyzing connected or intersected thin shell structures based on the variation-difference method and the super element method is considered either using force or stiffness method to obtain optimization of structural parameters. The main aim of this paper is to focus on to conduct analysis of shell structure for Lunar surfaces or surfaces of other planetary objects which may resist extreme temperature, cosmic radiation and pressure difference. The boundary conditions for such shell structure are introduced as zero gravity, spring elements and assigned restrained in periphery of the shell must be matching with real features. This paper also motivates the structural engineers to develop innovative design of buildings, bridges and other monuments for future generations conducting construction of such shell structure in Earth and space as well.

Keywords: thin-walled spatial structures, connected thin shells, innovative, variation-difference method, shell structure in space

Introduction

Thin-walled spatial structures used in mechanical engineering, construction [1; 2], shipbuilding [3], rocketscience [4;5], aircraft industry [6] and other fields of technology, most often represent combinations of structures from sectors of shells and plates of the same [7-9] or various geometric shapes [10-12]. Many literatures on the analysis of shells are explained with analysis of shells of specific simple conventional shapes. In the literature on the analysis of combined structures, most works consider methods for calculating tanks and conjugate shells of revolution [13-18]. When designing combined shells of revolution, there is a problem of conjugated transition of the shell sectors, which provides a more correct shape and less concentration stresses in the contact zone or intersecting zone depending upon how the sector of shells are combined to each other [19]. Analytical error and issues arise in particular, when connecting cylindrical shells with different diameters. Super Element method, which appeared in the twentieth century allow to carry out analysis of the stress-strain state of complex spatial structures. However, FEM based software packages do not take into account geometric characteristics of the curved shells which may defined as Monge surfaces, which can lead to peak stress strain during analysis of shellsof complex geometric shapes to create innovative thin shell structure, including in the interface zones of the shell sectors of the spatial structure. Therefore, the development of alternative methods and programs for analysis of thin shell structure with complex geometry is main objective of this paper. Below is a method for calculating combined spatial structures based on the variation-difference method for analysis ofthin shell sector following rules of elastic theory related function of continuity along with geometric shapeof innovative thin shell structure. The method of super elements for the analysis of connected shell structures was explained but still to optimize analysis is necessary to follow rule of elastic theory. [20]

on the Lagrange principle - the minimum of the total strain energy. In FEM software systems, usually onlythe equation of the middle surface of the shell is used to break down the structure into final elements without taking into account the geometric characteristics of the surface.

The VRM Shell software package includes a library of curves, on the basis of which the shell sectors are formed and the coefficients and derivatives of the quadratic forms of the surface at the nodal points are calculated difference grid. The software package includes: analysis s of bending of plate shell and a planestress problem of elasticity theory in rectangular and polar coordinate systems, plate bending on curvilinear-trapezoidal plans (pseudo-polar coordinate system), analysis of cylindrical shells, shells of revolution, shells in the form of Joachimsthal surfaces, carved surfaces of Monge. Various line support conditions, edge zones are used, including elastic footings and elastic supports and considering with holesor without holes in shell surfaces Any types of loads over the shell structure directed to normal and tangentialsurfaces of shell structure, like nodal loads, distributed loads including moment, and self-weight of shell structure.

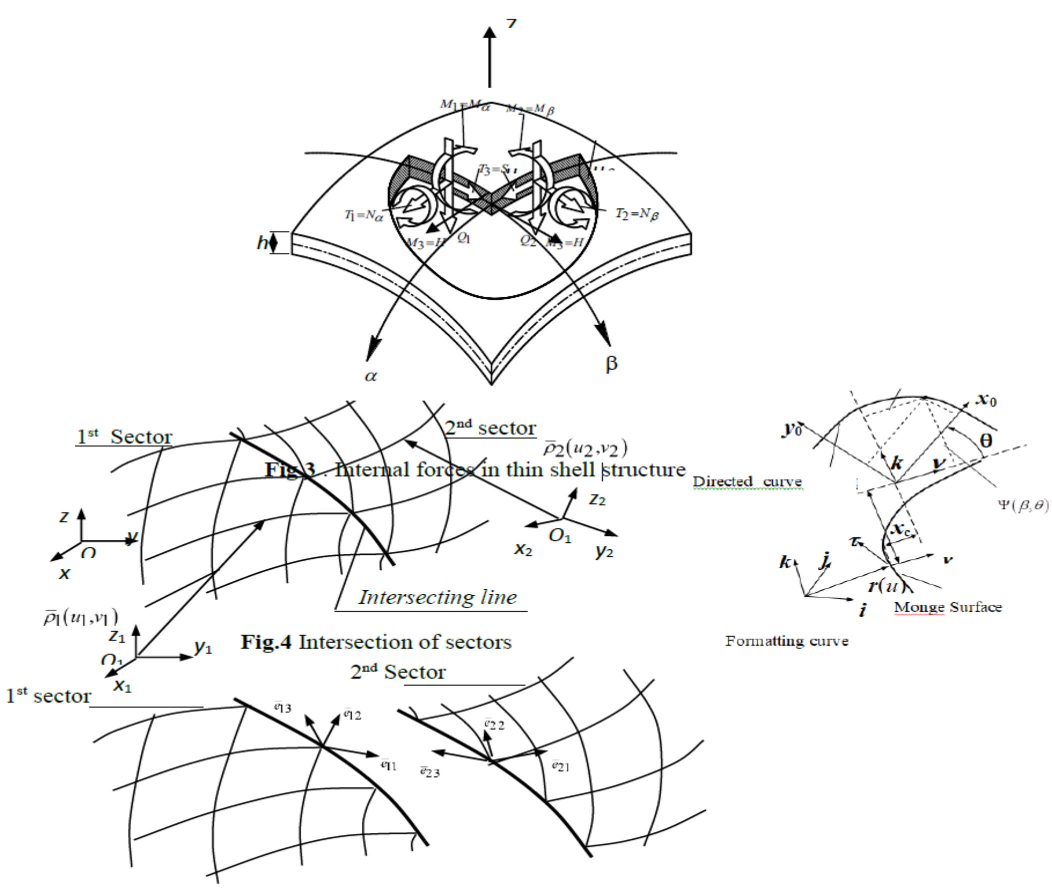

Fig.1: Orthos of sectors of shell

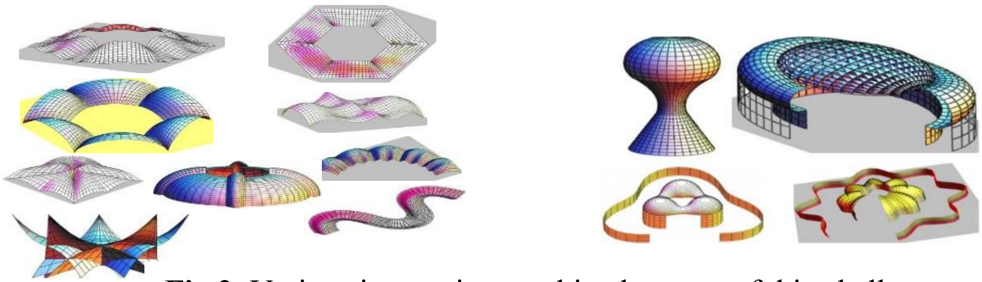

Fig.2: Various innovative combined sectors of thin shellstructure

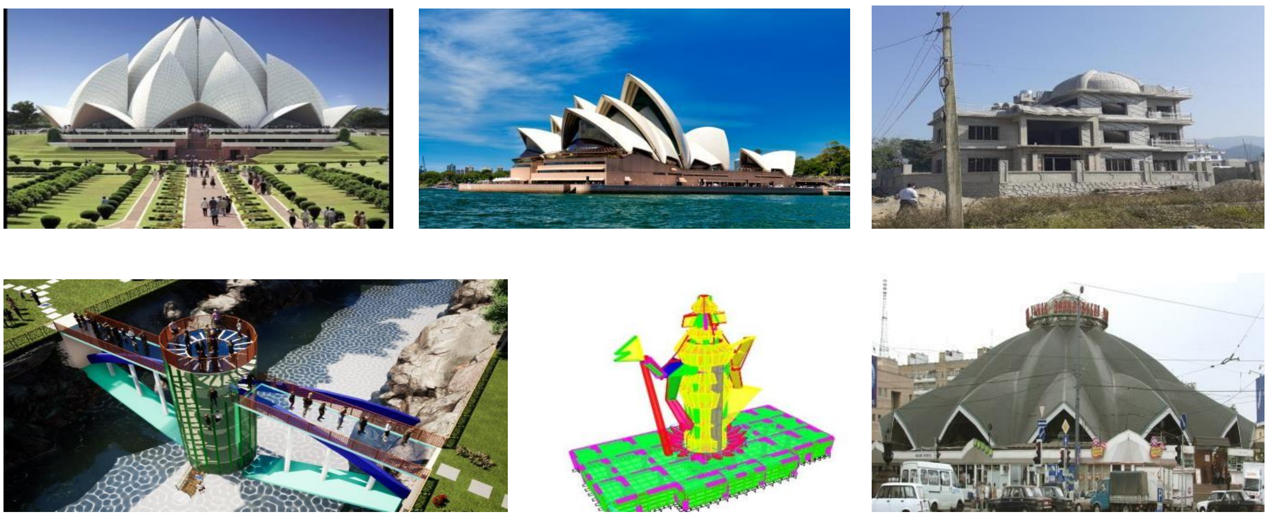

Fig.3: Various innovative combined sectors of real thin shell structures

Methods

The super element method is based on the method of forces [20]. Each sector of the combined spatial structure is calculated on the basis of the VRM Shell program for the load acting on the sector and unit forces at the grid nodes considering specially 4th degree of redundancies at the intersection lines of the sectors. From conditions for equality of nodal displacements of sectors of thin shell structures at grid nodeson lines intersections in the global coordinate system [22], nodal efforts. Next, the stresses and strains in the shell sectors are summarized from the action of the load and nodal forces in the zone of suppression of the sectors. At dividing the structure into sectors, some sectors may not have supports in all or some directions. To stabilize such sectors conditional elastic foundations are introduced. For conditional spring stiffness coefficients of the elastic foundation, small values are set so that the elastic foundation had no significant effect on the stress-strain sector status pretending zero stiffness as in the case of cantilever thin shell structure.

For analysis of thin shell structure two variants of interface of sectors are possible:

1. Sectors of thin shell structure with various geometrical structure are interfaced on a line, a being commoncoordinate line of both shells. Such analysis is possible, in particular, at formation of sectors of thin shellsin the form of cyclic, irregular or carved surfaces of Monge, revolution of shell and also interface of sometypes of cylindrical of various diameters. Analysis of designs from replicated sectors of shell of innovative structure is also possible.

2. Solving system of the algebraic equations (10), we define unknown forces in units on a line of interface ofsectors. Further each sectors pays off independently on action of the loading, acting on a sectors and systemof efforts in units on a line of interface of sectors.

3. On offered algorithm of analysis of thin shells using method of super elements the program in language FORTRAN has been realized and test analysis s of various analysis and designs are adopted. The analysis results show good convergence at comparison with known decisions in the literature those used FEM.

The Matrix for Mongue surface to change in global to local coordinates as follow;

$$\{\gamma_0\}=\begin{Bmatrix}(i\cdot e_1) & (j\cdot e_1) & (k\cdot e_1)\\ (i\cdot e_2) & (j\cdot e_2) & (k\cdot e_2)\\ (i\cdot e_3) & (j\cdot e_3) & (k\cdot e_3)\end{Bmatrix}=\begin{Bmatrix}\frac{x'_H}{s'_H} & \frac{y'_H}{s'_H} & 0\\ -\frac{\dot{\varphi}\cdot y'_H}{s'_H\cdot\dot{s}_0} & \frac{\dot{\varphi}\cdot x'_H}{s'_H\cdot\dot{s}_0} & \frac{\dot{\psi}}{\dot{s}_0}\\ \frac{\dot{\psi}\cdot y'_H}{s'_H\cdot\dot{s}_0} & -\frac{\dot{\psi}\cdot x'_H}{s'_H\cdot\dot{s}_0} & \frac{\dot{\varphi}}{\dot{s}_0}\end{Bmatrix}$$

$$P_\alpha=\{\gamma\}_0\left(\{\gamma\}_H P\right)=\{\gamma\}_H\{\gamma\}_H P=\{\gamma km\}P$$

$$\{\gamma km\}=\{\gamma\}_H\{\gamma\}_H$$

$$\{\gamma\}_H=\begin{Bmatrix}\cos\omega & \sin\omega & 0\\ -\sin\omega & \cos\omega & 0\\ 0 & 0 & 1\end{Bmatrix}$$

The matrix of transformation of one local systems of coordinates in global is defined by system directing cosines or scalar products ortho of two systems which will lead easy to transform the local coordinates into any form of three-dimensional coordinates for space structure in static as well as in dynamic sense.

$$[Cs]=\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix}, \qquad (1)$$

If projections of a vector in the first system of coordinates $-P_{1i}$ multiplying a matrix of transformation on a vector it is received its decomposition in global system of coordinates –

$$\overline{P} = P_{11}\cdot\overline{e}_{11} + P_{12}\cdot\overline{e}_{12} + P_{13}\cdot\overline{e}_{13} = P_{21}\cdot\overline{e}_{21} + P_{22}\cdot\overline{e}_{22} + P_{23}\cdot\overline{e}_{23};$$

$$\left\{P_{zi}\right\} = \begin{Bmatrix} P_{z1} \\ P_{z2} \\ P_{z3} \end{Bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \cdot \begin{Bmatrix} P_{11} \\ P_{12} \\ P_{13} \end{Bmatrix} = \left[Cs\right]\cdot\left\{P_{1i}\right\}; \qquad (2)$$

$$\left\{P_{zi}\right\} = \begin{Bmatrix} P_{z1} \\ P_{z2} \\ P_{z3} \end{Bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \cdot \begin{Bmatrix} P_{21} \\ P_{22} \\ P_{23} \end{Bmatrix} = \left[Cs\right]\cdot\left\{P_{2i}\right\}. \qquad (3)$$

For analysis of crossed sectors of thin shells, we shall apply a method of forces. Dismembering sectors on a line of interface, equal and opposite nature of unit vectors will be introduced in each grid- nodes of shell surface. A condition mutual works on a line of crossing and a perpendicular in a plane normal moment will be introduced into a line of crossing sectors, in case of their rigid interface. At hinged connection on a line of crossing only unit forces will be considered.

Also to adopt force methods for unknown redundancies per node of grid shell we introduce units vectors on a line of the crossing of sectors shells in a direction of the local system of coordinates of the first sectors and the moment

$$Z_m = X_{1,k}; \quad Z_{m+1} = X_{2,k}; \quad Z_{m+2} = X_{3,k}; \quad Z_{m+4} = M_{n,k}, \qquad (4)$$

Where k – number of unit on a line of crossing, k = 0, 1, … Kyз; m = 4□(k - 1); (k - 1); Kuz – quantity of units on a line of crossing; - effort in k-th unit in a direction of i-th orthos - the moment in a plane normal to a line of crossing. in k-th unit.

The first and second sectors pays off on individual forces in a direction on a combination of projections of individual forces in global system of coordinates in units and the individual moment in normal to a line of crossing of a plane.

$$\overline{Z}_{k+i} = 1 \quad \rightarrow \quad \alpha_{i1(k)}\cdot\overline{e}_{21(k)} + \alpha_{i2(k)}\cdot\overline{e}_{22(k)} + \alpha_{i1(k)}\cdot\overline{e}_{21(k)} \qquad (5)$$

Here k – number of unit on a line of crossing.

As a result of analysis s receive systems of Rotation and corners of turn in units in a plane, normal to a line of crossing from all individual efforts

$$\delta_{(t)mn} = \delta_{(t)\,in}^{(k)}, \qquad (6)$$

Where t = 1, 2 - number of a sectors; k - number of unit on a line of crossing of sectors; i = 1,2,3 – number of orthos in local system of coordinates in which direction moving is calculated; i = 4 - a corner of turn in a plane normal to a line of crossing; ; $m = 4\text{x}(k - 1)$ - a serial number of moving on a line of crossing of sectors; n – number of individual effort from which action moving is calculated.

Besides Rotation and in units of sectors on a line of crossing from the loading operating within the limits of a sectors are to be calculated.

$$\delta'_{(t)\,mn} = \sum_{l=1}^{3} \alpha_{i\,l(k)} \cdot \delta_{(t)\,l\,n}^{(k)}, \quad m = 4\times(k - 1) + i, \quad i = 1,2,3. \qquad (7)$$

Similarly, from loading in the second sectors.

$$\Delta'_{(t)\,m\,P} = \sum_{l=1}^{3} \alpha_{i\,l(k)} \cdot \Delta_{(t)\,l\,P}^{(k)}. \qquad (8)$$

For a corner of turn around of a normal to a line of crossing (i =4)

$$\delta'_{(t)\,mn} = \delta_{(t)\,4,n}^{(k)}, \quad m = 4\times(k - 1) + 4. \qquad (9)$$

Then, conditions of mutual work of rotation on a line of interface of sectors will enter the name in the form of:

$$\sum_{n=1}^{4\times K} \left\{\delta'_{(1)mn} - \delta'_{(2)mn}\right\} \cdot Z_n + \Delta'_{(1)\,mP} + \Delta'_{(2)\,mP} = 0,.\ m = ,2,\ldots 4 \cdot K_{y3} \qquad (10)$$

Solving system of the algebraic equations (10), we define unknown forces in units on a line of interface of sectors. Further each sectors pays off independently on action of the loading, acting on a sectors and system of efforts in units on a line of interface of sectors.

On offered algorithm of analysis of thin shells using method of super elements the program in language FORTRAN has been realized and test analysis s of various analysis and designs are adopted. The analysis results show good convergence at comparison with known decisions in the literature those used FEM. Analysis of structure in Space shall be focused mainly into pressure difference between normal internal pressure and zero pressure on outer layer of thin shell structure (23). As per situation and environments of objects in space thin shell structures shall be designed and constructed into form of intersected and connected thin shell plates with curved shell structures. In fig 4 to 7 the various complex shapes of shell structure are illustrated to construct on surface of planetary objects and in space as well.

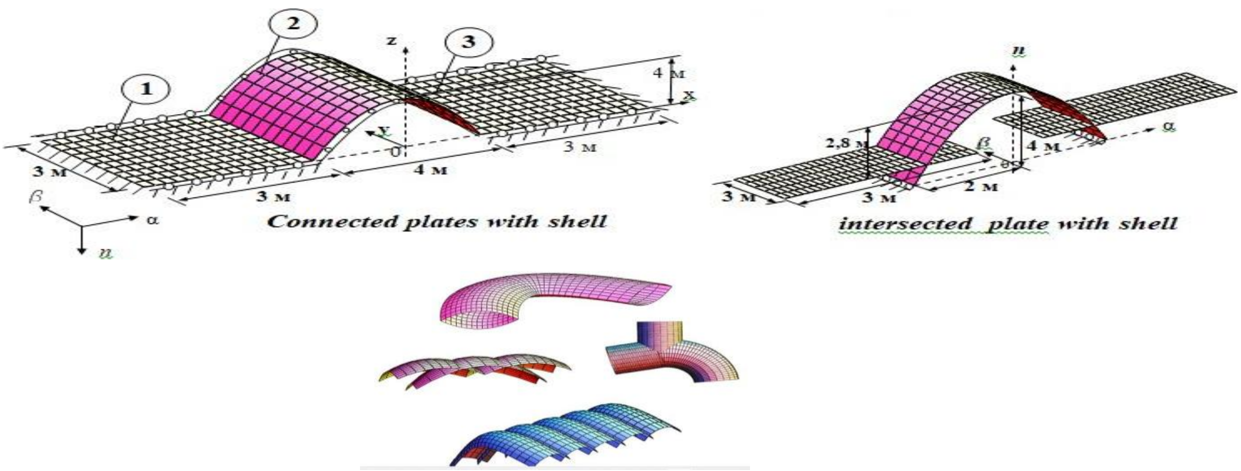

Fig.4: various types of formation of innovative shell structure

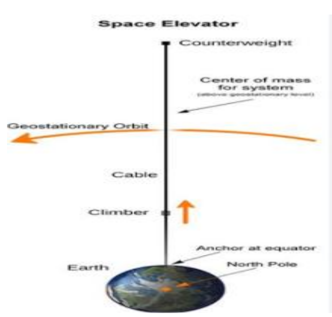

Fig.5: Space Elevator

Fig.6: Lunar structure as thin shell

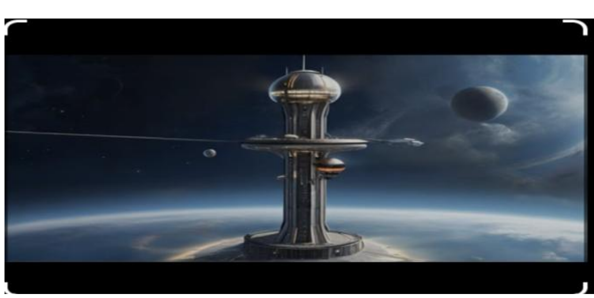

Fig.7 a: Space elevator source: Projects/ NCSS

Fig.7 b: Mars colonies as thin shell structure as

At the stage of end of analysis, the developed module of the program in FORTRAN complex realizing calculation of crossed sectors of thin shell structures by a method of Super elements and test calculationsare adopted. In particular, calculation of the Parabolic-sinusoidal wave carved innovative thin shell structure is divided into two sectors. Results were compared to calculation of the whole sectors. Results ofcalculations have completely coincided.

On fig. 8 and 9 the design of the thin shell structures, consisting of 4 consistently connected sectors with a mediancarved parabolic-sine wave surface variable Gausses curvature with positive and negative radii is formed. The design may not be presented by performing uniform continuous surface, and will be analysed as a setof crossed sectors of thin shell structures.

Results and discussion

Sectors of an thin shell structures with a symmetric directed parabola – of size -15m to 15m and a sinusoidalcurve forming within the limits of two half waves - 0 to 16 m. as shown in fig 6.

The all properties are kept as concrete shell structure with thickness of 10 cm. For Planetary objects the thickness will vary from 1.5 cm to 10 cm as per environments leading minimization of materials during cast in-situ of the surface of the objects. The foundation for such thin structure will be chosen as deep and stiff foundation for stability of thin shell structure.

Results of calculations: rotations (slope); tangential efforts, S; bending and twisting the moments M, T are presented.

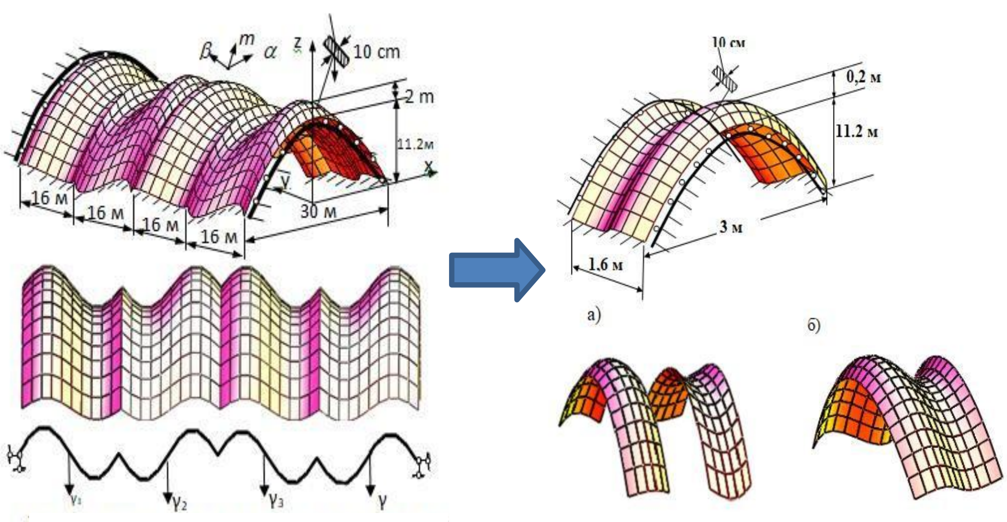

Fig.8 a: Parabolic sinusoidal thin shell structure in Planetary surface resisting self-weight

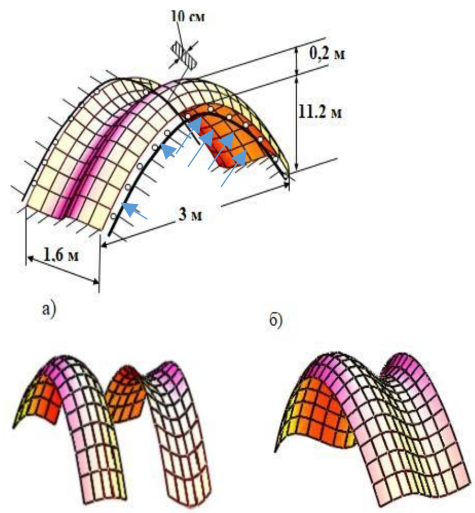

Fig.8 b: Parabolic sinusoidal thin shell structure in Planetary surface resisting Intense internal pressure

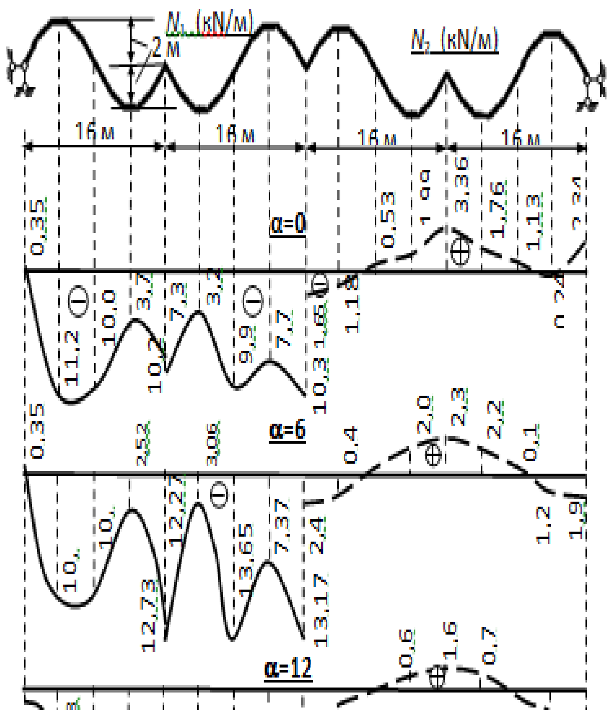

Fig.8 c: Axial force (N)

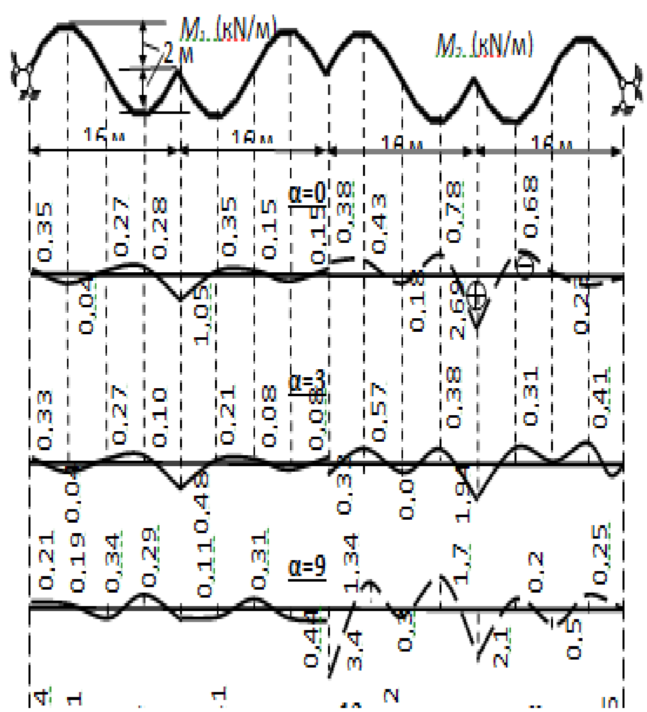

Fig.8 d: Bending Moment (M)

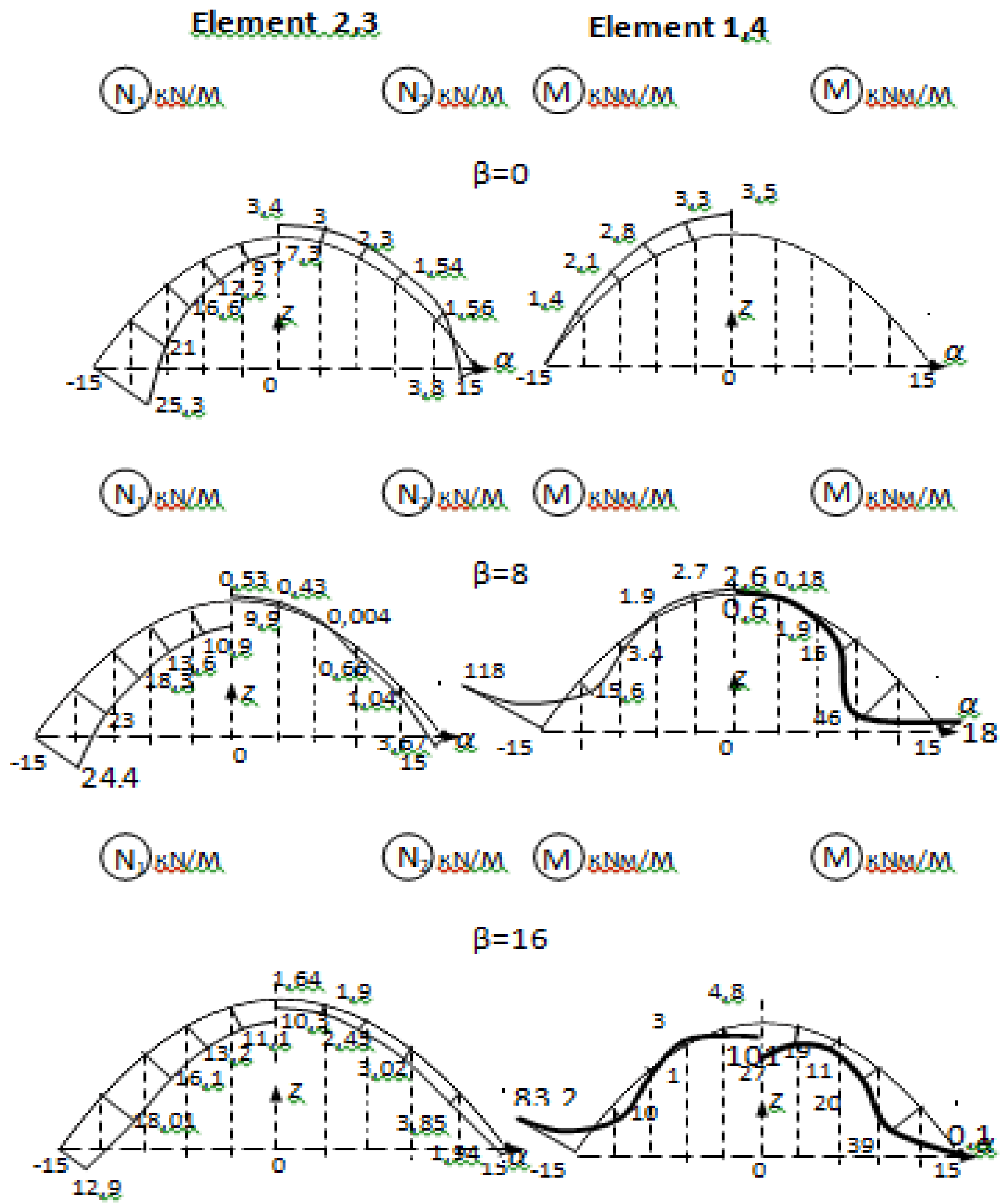

Fig.9: N and M along X direction of Module

Table 1. Analysis of Global Element 1, 4

Section	α	N_α [кN/м]	N_β [кN/м]	M_α [кN·м/м]	M_β [кN·м/м]
$\beta=0$	-15	0	0	0	0
	-12	-0,854E+00	-0,569E+01	-0,137E-02	-0,648E-07
	-9	-0,656E+00	-0,437E+01	-0,211E-02	-0,157E-06
	-6	-0,285E+00	-0,190E+00	-0,279E-02	-0,318E-06
	-3	0,150E+00	0,100E+00	-0,331E-02	-0,525E-06
	0	0,351E+00	0,234E+00	-0,351E-02	-0,634E-06
$\beta=4$	-15	-0,689E+01	-0,103E+01	0,286E-02	0,430E-03
	-12	-0,377E+01	-0,173E+01	-0,309E-02	-0,152E-01
	-9	-0,622E+01	-0,165E+01	-0,194E-02	-0,151E-01
	-6	-0,879E+01	-0,122E+01	-0,825E-03	-0,898E-02
	-3	-0,106E+02	-0,581E+00	-0,352E-03	-0,410E-02
	0	-0,112E+02	-0,248E+00	-0,284E-03	-0.954EE-03
$\beta=8$	-15	-0,237E+02	-0,355E+01	-0,118E+00	-0,178E-01
	-12	-0,227E+02	-0,112E+01	0,156E-01	0,461E-01
	-9	-0,182E+02	-0,692E+00	0,342E-02	0,147E-01
	-6	-0,136E+02	0,153E+00	-0,191E-02	0,193E-02
	-3	-0,109E+02	0,897E+00	-0,272E-02	-0,185E-03
	0	-0,100E+02	0,113E+01	-0,268E-02	-0,597E-03
$\beta=12$	-15	-0,232E+02	-0,348E+01	-0,142E-01	-0,213E-02
	-12	-0,141E+02	0,771E+00	-0,447E-02	-0,187E-01
	-9	-0,547E+01	0,166E+01	-0,294E-02	-0,194E-01
	-6	-0,252E+01	0,222E+01	0,149E-02	-0,532E-02
	-3	-0,316E+01	0,202E+01	-0,381E-05	-0,315E-02
	0	-0,375E+01	0,176E+01	-0,332E-02	-0,680E-02
$\beta=16$	-15	-0,253E+02	-0,380E+01	-0,832E-01	0,113E-03
	-12	-0,209E+02	0,156E+01	0,101E-01	0,395E-01
	-9	-0,166E+02	0,154E+01	0,106E-01	0,201E-01
	-6	-0,122E+02	0,231E+01	-0,294E-02	0,110E-01
	-3	-0,901E+01	0,304E+01	0,483E-02	0,194E-01
	0	-0,733E+01	0,336E+01	0,104E-01	0,269E-01

Table 2. Analysis of Global Element 2, 3

Section	α	N_α [кN/м]	N_β [кN/м]	M_α [кN·м/м]	M_β [кN·м/м]
$\beta = 0$	-15	-0,253E+02	-0,380E+01	-0,832E-01	0,113E-03
	-12	-0,209E+02	0,156E+01	0,101E-01	0,395E-01
	-9	-0,166E+02	0,154E+01	0,106E-01	0,201E-01
	-6	-0,127E+02	0,230E+01	-0,294E-02	0,110E-01
	-3	-0,983E+01	0,302E+01	0,465E-02	0,194E-01
	0	-0,831E+01	0,334E+01	0,102E-01	0,269E-01
$\beta = 4$	-15	-0,242E+02	-0,363E+01	-0,145E-01	-0,218E-02
	-12	-0,153E+02	0,671E+00	-0,411E-02	-0,169E-01
	-9	-0,664E+01	0,149E+01	-0,264E-02	-0,175E-01
	-6	-0,306E+01	0,209E+01	0,150E-03	-0,490E-02
	-3	-0,292E+02	0,211E+01	-0,769E-04	-0,379E-02
	0	-0,317E+02	0,199E+01	-0,339E-02	-0.781E-02
$\beta = 8$	-15	-0,244E+02	-0,367E+01	-0,106E+00	-0,159E-01
	-12	-0,229E+02	-0,104E+01	0,138E-01	0,408E-01
	-9	-0,182E+02	-0,658E+00	0,299E-02	0,132E-01
	-6	-0,136E+02	0,365E+00	-0,175E-02	0,218E-02
	-3	-0,109E+02	0,435E+00	-0,218E-02	-0,479E-03
	0	-0,990E+02	0,526E+00	-0,188E-02	-0,201E-03
$\beta = 12$	-15	-0,106E+01	-0,160E+01	0,511E-02	0,767E-03
	-12	-0,607E+01	-0,155E+00	-0,258E-02	-0,117E-01
	-9	-0,673E+01	-0,159E+01	-0,179E-02	-0,139E-01
	-6	-0,737E+01	-0,148E+01	0,950E-02	-0,952E-02
	-3	-0,767E+01	-0,128E+01	-0,583E-05	-0,568E-02
	0	-0,770E+01	-0,118E+01	-0,523E-02	-0,430E-02
$\beta = 16$	-15	-0,129E+02	-0,194E+01	-0,144E-00	0,188E-03
	-12	-0,180E+02	-0,385E+01	0,129E-01	0,649E-01
	-9	-0,161E+02	0,301E+01	0,441E-02	0,314E-01
	-6	-0,131E+02	0,245E+01	0,702E-03	0,102E-01
	-3	-0,110E+02	0,190E+01	0,827E-03	-0,333E-03
	0	-0,103E+02	0,165E+01	0,147E-02	-0,381E-03

Conclusion

The Paper describes a method for Analysis shells of complex shape based on vibrational-difference method to create innovative thin shell structure- in the base the software package "VRM Shell" and leading continuity fully following theory of elasticity which will be sever used in space elevator suspending structure and as well as on Geo- surface of moon or mars. The analysis of combined spatial structures – software Global Comb Shell complex in FORTRAN using Geometric Characteristics middle surfaces of complex shell s allows to obtain more reliable results of the analysis of the stress-strain state of spatial structures specially in intersection of two sectors of shell structures. The operation of software systems was checked by comparison with the analysis of available analytical solutions and with analysis that carried out by FEM software packages. The analysis showed reliable accuracy when compared with analytical solutions and close results with used FEM tools. The structural performance of thin shell structure for any type of loadings seen realistic and accurate as enhanced following theory of elasticity unlike framed structures which need resist sever bending stress mainly for surface of planetary objects. Thin shell structures in planetary objects shall be chosen observing their light weight having small thickness

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