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Effect of Change in Geometry on Time Period of Lattice Parabolic Shells Using SAP2000 OAPI

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Abstract:
Nowadays, shell structures are frequently used in various areas and are preferred by architects and structural engineers due to its aesthetics and efficient load carrying capacities. Shell structures, especially lattice shell structures, are commonly used in airports, malls, train station and stadium where aesthetics and larger span are of prime importance. Theses lattice shell structures are formed by arranging the structural element in a triangulated form and held together by fixed nodes which prevent it from local buckling. Lattice Shells provide the benefit of thin shell structures, yet overcomes the difficulties of casting, i.e., they do not need complicated formworks.

1.Introduction

It is quite known that parabolic nature of two-dimensional structures such as parabolic arch require lower depth than circular arches under self-weight and external loading. F. Cedron et al [1] provided a approximate formula for the time period of lattice cylindrical shells, which related the geometrical parameters, material properties and loads with the time period. The parabolic nature of structure may be beneficial in case of lattice shell as well and hence this study aims to provide a detailed insight into the one of the key parameters of a structure. i.e., the time period of the parabolic lattice shells. A. Quansah et. al [2] carried out a parametric investigation of plane frame using SAP2000 OAPI and VBA in Excel which clearly demonstrated the power of programming in structural analysis. Parametric study is quite monotonous and are time consuming. Hence to overcome this Visual Basic for Application (VBA) in Excel was combined with SAP2000 Open Application Programming Interface (OAPI) to automatically perform the parametric study. The main objective of this study is to understand and develop a relationship between the geometrical parameters of the lattice parabolic shell with its time period using SAP2000 OAPI.

2. Arrangement of Structural Members

The arrangement of members in this study contains a three-way configuration of parabolic lattice shell i.e., it contains a parabolic arch, members along the longitudinal direction (similar to purlins in truss) and diagonal members (similar to truss roof bracing). Lattice shell have a pleasing aesthetic because of its curved structures and light scattering characteristics. For this a number of research has been done on thin shell and lattice shell structures, however very few discuss about the parabolic lattice shell. Hence, this paper studies and builds on the past works on shell with a particular focus on parabolic lattice shell.

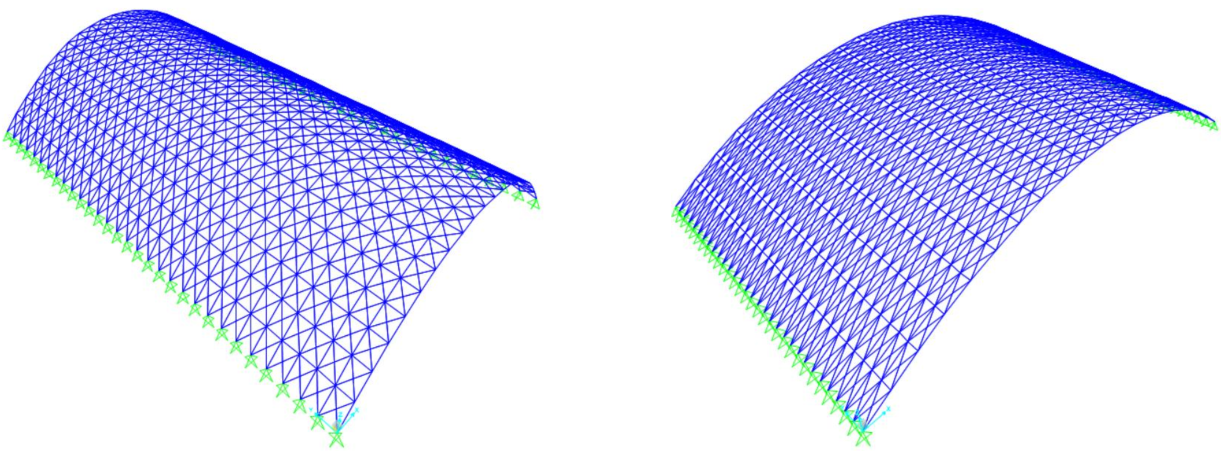
3. Methodology of Study

The geometry of parabolic lattice shell can be summarized by five variables: Rise (H), Span (B), Length (L), n_{long} (number of division along longitudinal direction) and n_{div}(number of division along span). In this study we have considered Span(B), Rise-Span Ratio (H/B), Length-Span Ratio (L/B), n_{long}, n_{div} as the geometrical parameters. The relation of time period of parabolic lattice shell with rise-span ratio, length-span ratio, applied load, support condition, ratio of number of division along longitudinal and transverse direction(n_{long}/n_{div}), ratio of number of division along longitudinal direction with length (n_{long}/L) and ratio of number of division along transverse direction with span (n_{div}/B) is determined and then studied to develop an empirical formula for time period. The material considered is mild steel (Fe250 as per Indian Standards).

To analyze a large number of models, SAP2000 OAPI (Open Application Programming Interface) is used along with Excel VBA (Visual Basic for Application). The code was written in Excel VBA that opens SAP2000, defines the material/ section, develops the model, applies the loads, runs the model, and retrieves time period of the model. In total 600 models were developed with the variables range as shown in the table below:

Table 1: Variable range for modelling in SAP2000

Variable	Range
Span	10m to 300m
Rise-Span ratio	0.1 to 0.5
Length- Span ratio	0.1 to 2
n_{long}	1 to 20
n_{div}	1 to 20
Applied Load on longitudinal member	0 to 4kN/m
Support Condition	Both End Hinged and Both End Fixed



Span, B	20m
Rise, H	6m
Length, L	30m
n_{long}	30
n_{div}	20

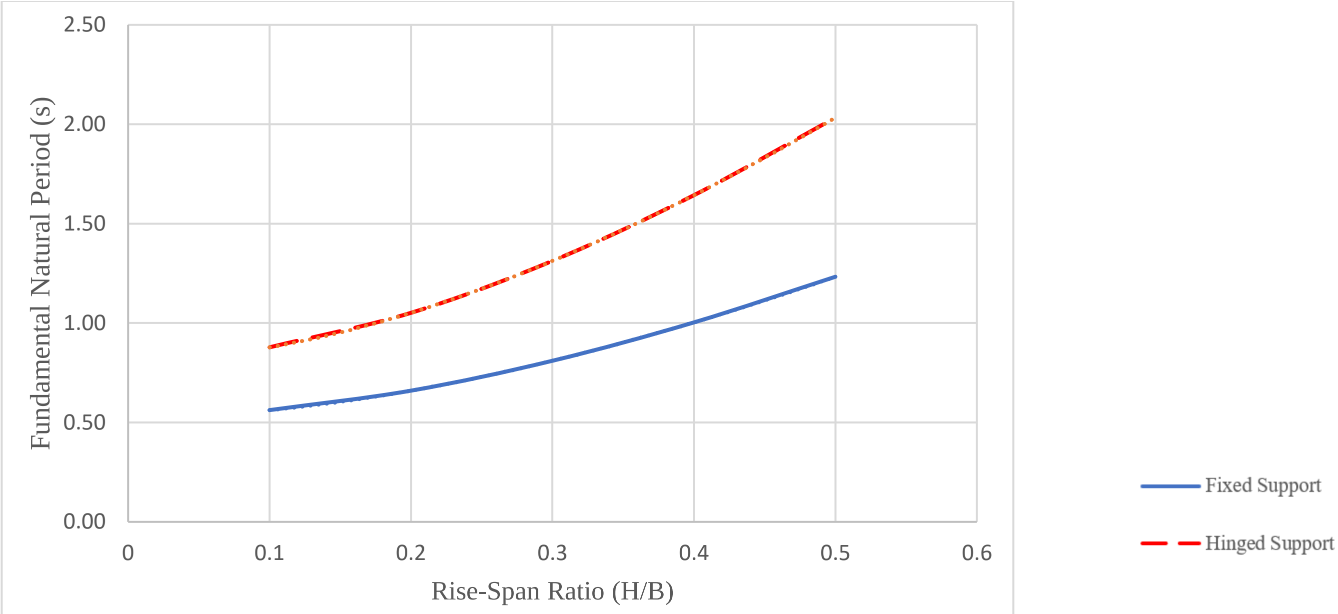
Span, B	50m
Rise, H	10m
Length, L	30m
n_{long}	30
n_{div}	20

Figure 1: Undeformed Shape of Lattice Shells

4. Results

4.1 Rise-Span Ratio (H/B)

The rise span ratio of the lattice parabolic shell was changed to determine its effect on time period. The graph below shows the results of the shell with a rise-span ratio varied from 0.1 to 0.5 with an increment of 0.1, a span of 50m, length-span ratio of 1, n_{long}= 10, n_{div}= 10 and load (q)= 20kN/m applied on the longitudinal members. The section size used in modelling is a square hollow section (SHS) with width, depth of 300mm and thickness of 12mm. Both hinged and fixed support condition were considered.



The time period of the lattice shell increase with the increase of H/B ratio in a curved pattern. This was consistent with the previous studies for solid shell structures, the larger the rise of the shell, the more flexible it becomes laterally, as the slope of the members near the support tends to become more vertical. The curve rises at a relatively high rate for shells with fixed ends as compared to hinged ends indicating that fixed ends magnify the effect of rise-span ratio.

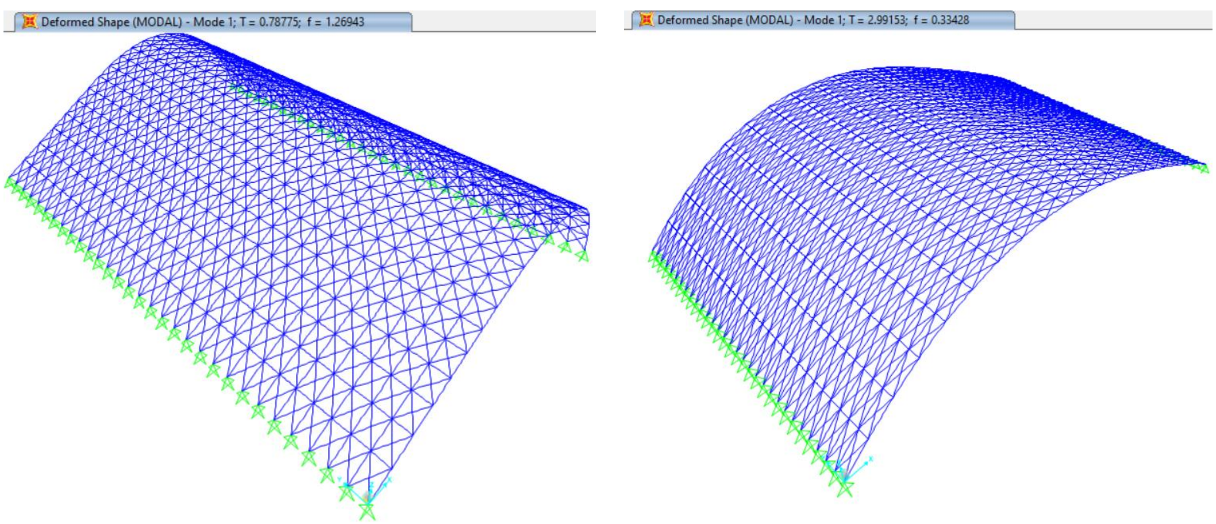
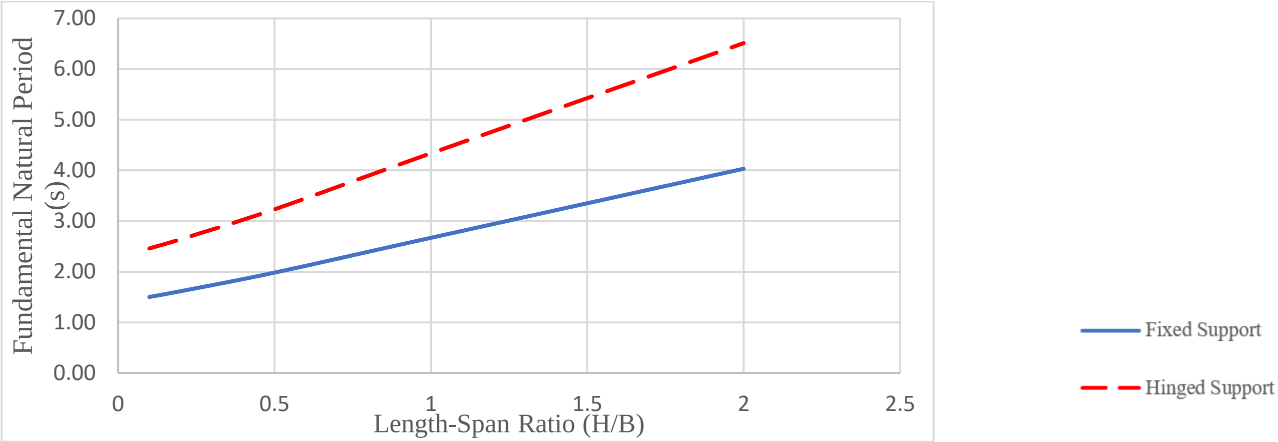


Figure 2: Deformed Shape of Lattice Shells

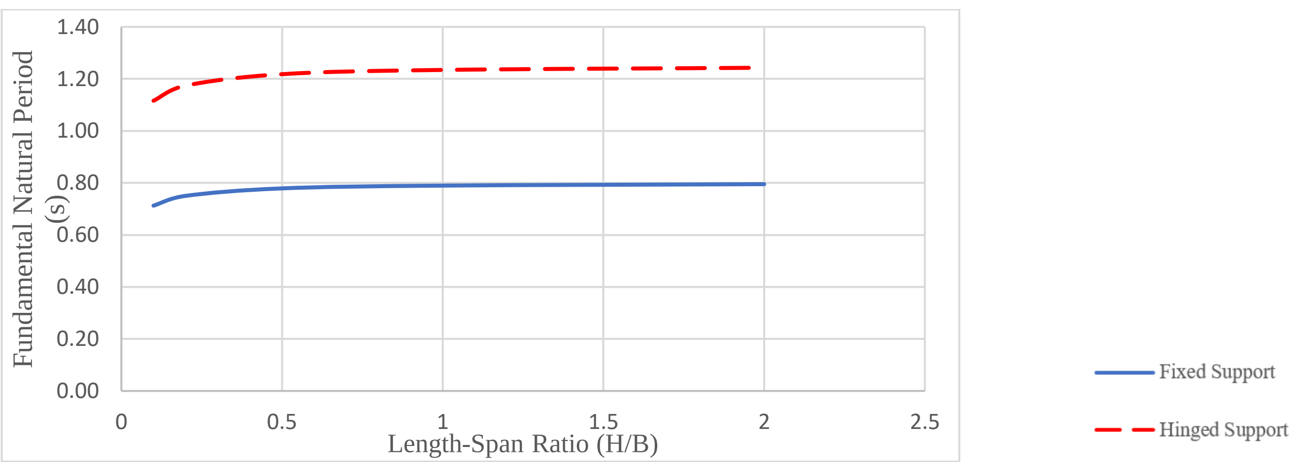
4.2 Length-Span Ratio (L/B)

The length span ratio of the lattice parabolic shell was changed to determine its effect on time period. The graph below shows the result with length-span ratio varied from 0.1 to 2 with a span of 100m, rise-span ratio of 0.3, n_{long}= 10, n_{div}= 10 and load (q)= 10kN/m applied on the longitudinal members. The section size used in modelling is a square hollow section (SHS) with width, depth of 300mm and thickness of 12mm. Both hinged and fixed support condition were considered.



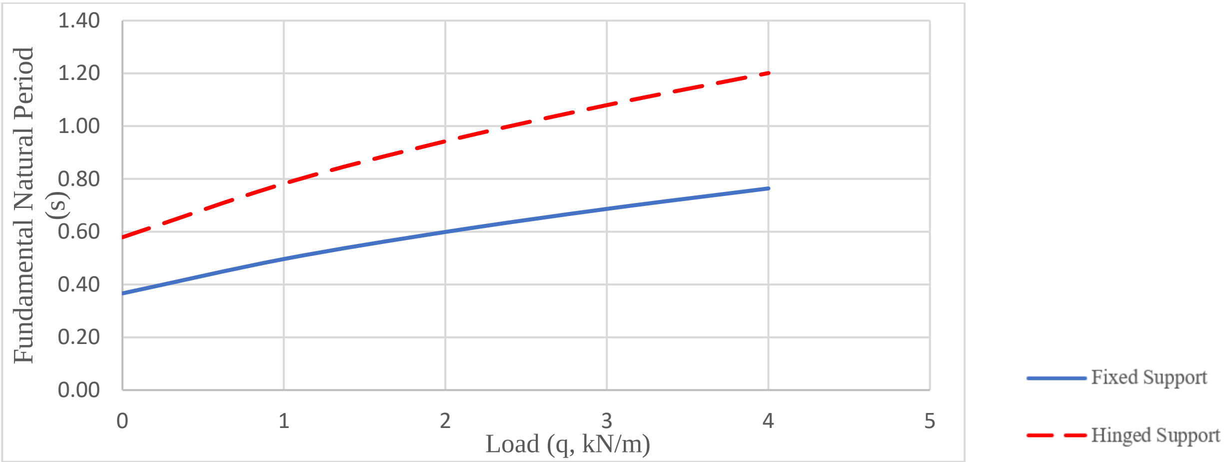
The time period of the lattice shell increase with the increase of L/B ratio in a linear pattern. The increase in length-span ratio increases the longitudinal stiffness of the shell, yet this also increases mass of the shell. The curve rises at a relatively high rate for shells with fixed ends as compared to hinged ends indicating that fixed ends magnify the effect of length-span ratio.

However, the effect of Length-span ratio on time period seems to diminish when we keep the spacing between each arch constant. The graph below shows L/B ratio vs Time period for a shell with span 20m, rise-span ratio of 0.3, n_{div}= 5 and load (q)= 3kN/m applied on the longitudinal members. The section size used in modelling is a square hollow section (SHS) with width, depth of 100mm and thickness of 4mm. Again, both hinged and fixed support condition were considered. This time the number of longitudinal division (n_{long}) was changed such that the spacing between each arch remain constant, i.e. spacing= 2m. The graph shows a nearly horizontal curve indicating a little or no dependence between the variables. As the spacing between the arch remains the same, the stiffness and the mass changes linearly as the Length-span ratio changes. This causes the ratio of stiffness and mass to remain almost constant causing little change in time period of lattice parabolic shell.



4.3 Applied Load (q)

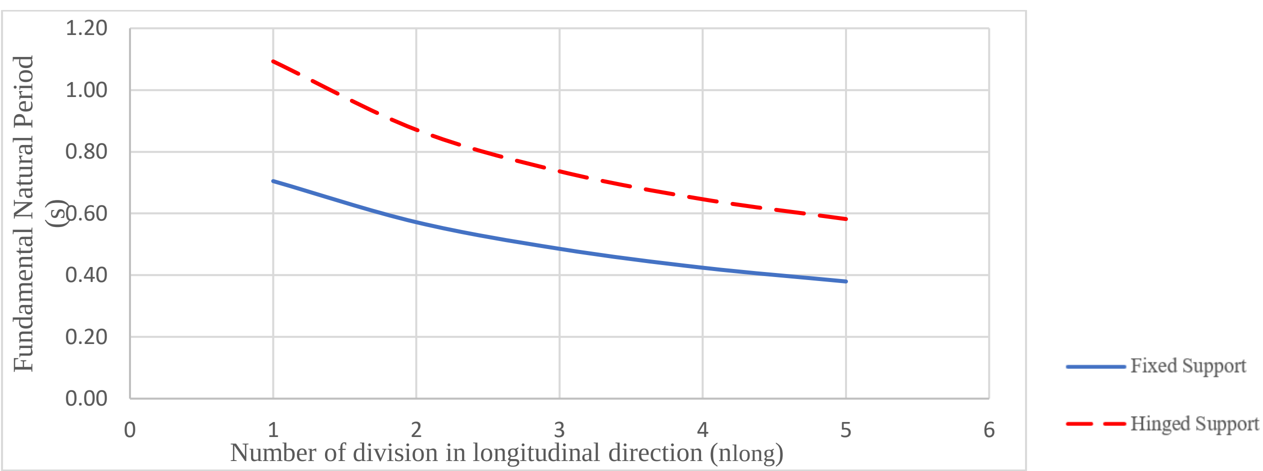
The loads were applied on the longitudinal members of lattice shell as similar to the purlins of truss. The load on the shell and the support condition were changed to assess its influence on the time period. The applied load was varied from 0 to 4 kN/m on the longitudinal members. The graph below shows the result of a shell with a span of 15m, rise-span ratio of 0.5, n_{long}= 10, n_{div}= 5 and length-span ratio= 1.The section size used in modelling is a square hollow section (SHS) with width, depth of 100mm and thickness of 4mm. Both hinged and fixed support condition were considered.

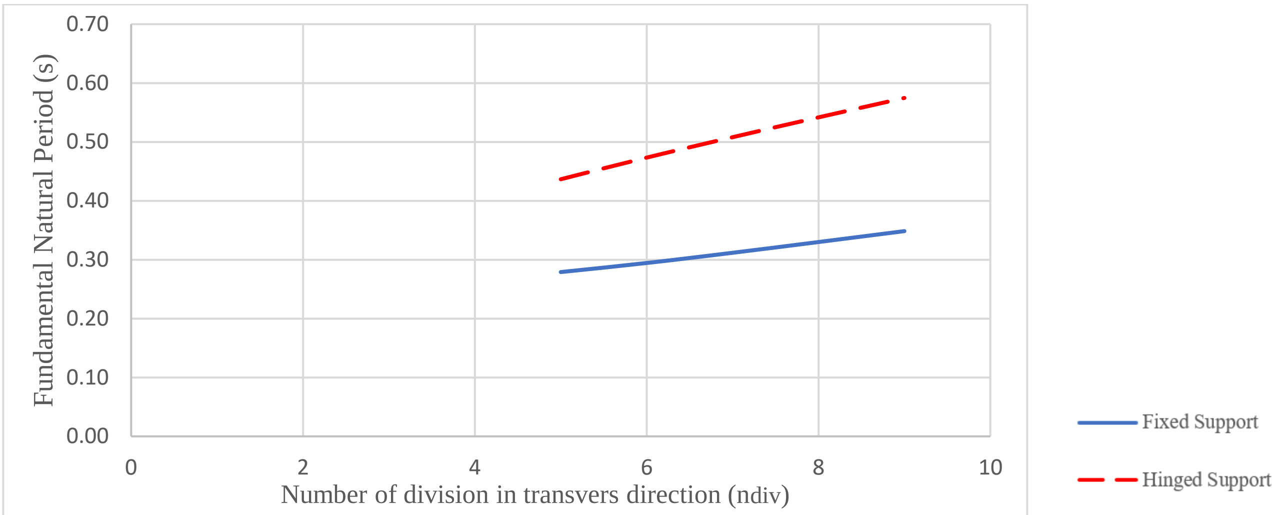


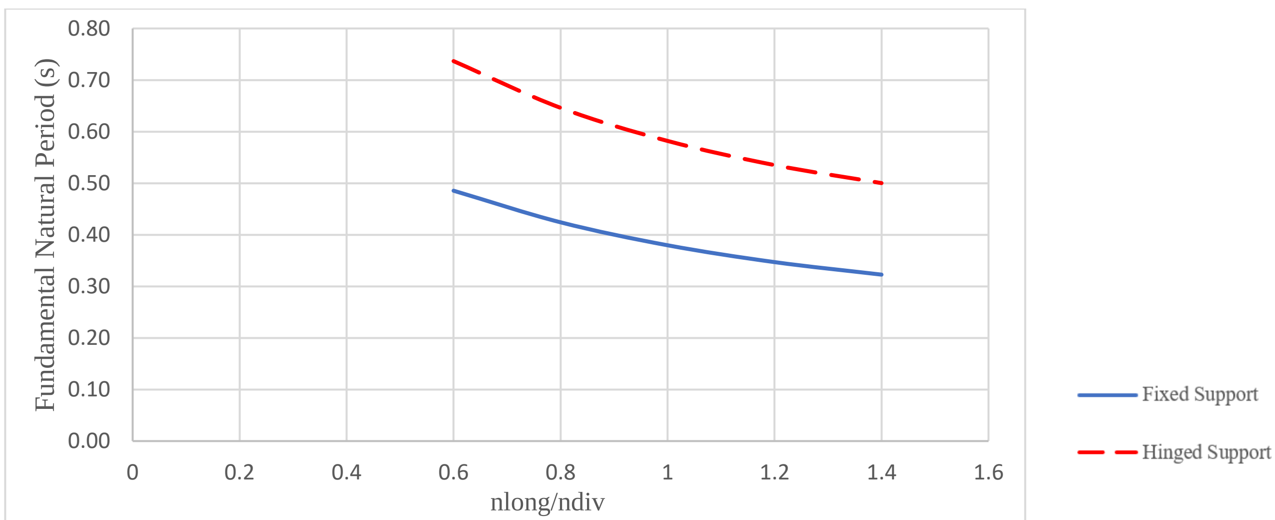
The time period of the lattice shell increase with the increase of load. The relationship was expected as the increase in applied load has a direct effect on the overall mass of the shell which in turn affects the time period. The time period increases proportionally with the square root of the mass.

4.4 Number of divisions along the longitudinal and transverse direction (n_{long} and n_{div}

The number of divisions along the longitudinal and transverse direction were varied to assess its influence on the time period. Firstly, n_{div} was taken constant and was assigned a value of 5 to see the effect of n_{long} on time period. The second time, n_{long} was fixed and a value of 10 was assigned on it to see the effect of n_{div} on time period. The graph below shows the result of a lattice parabolic shell having a span of 12m, rise-span ratio of 0.5, length-span ratio of 2, applied load= 0kN/mother section size used in modelling is a square hollow section (SHS) with width, depth of 100mm and thickness of 4mm. Both hinged and fixed support condition were considered.







From the graphs shown above, we can see that the increase in n_{long} seemed to decrease in time period, increase in n_{div} increased the time period. The combination of both, i.e. the increase in ratio of n_{long}/n_{div} decreased the time period of the shell.

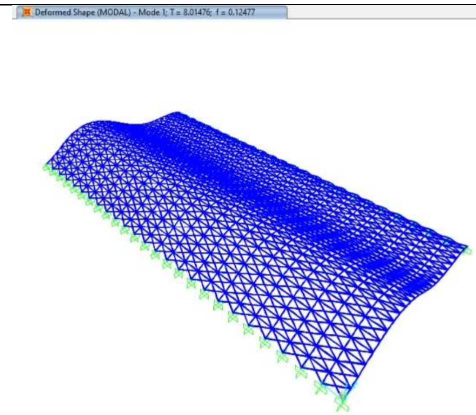
4.5 Support Condition

Two support condition were considered separately, i.e., once both ends were fixed and in the next case both ends were hinged. The graphs above showed that in comparison to hinged support, fixed support decreased the time period of the lattice shell.

4.6 Shell Deformation

The first modal time period is very important in design and hence only the first modal time period was considered in this research. The first modal deformation on all shell showed a lateral movement along the arch of the shell implying that the deformation at the lowest energy would be along the lateral direction. This deformation has been shown below for a shell with span of 50m, variable rise span ratio, length of 100, load applied= 3kN/m, n_{long} of 25 n_{div} of 25 and fixed support at both ends.

Table 2: Modal deformation of shell of span 50m, length 100m, n_{long} 25, n_{div} 25

<table>
<tr><td>Span= 50m
Rise= 5m
Length= 100m
n_{long}=25
n_{ldiv}=25
Load applied on longitudinal member= 3kN/m
Both Ends Fixed</td><td>
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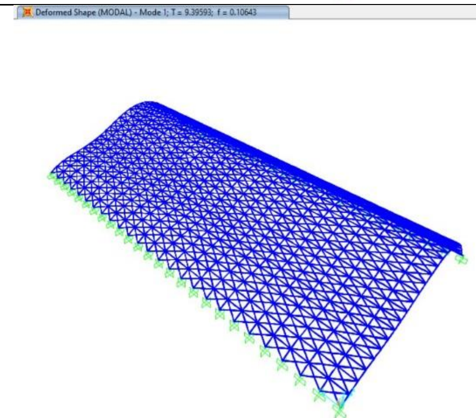
Load applied on longitudinal member= 3kN/m
Both Ends Fixed</td><td>
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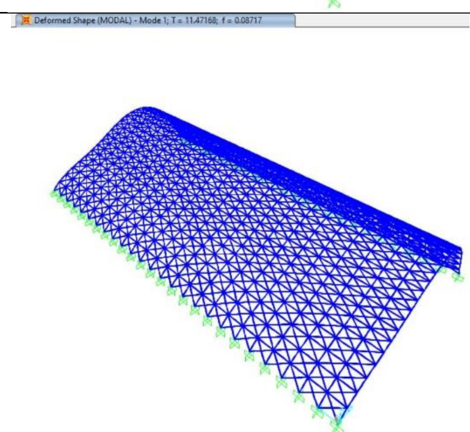
Load applied on longitudinal member= 3kN/m
Both Ends Fixed</td><td>
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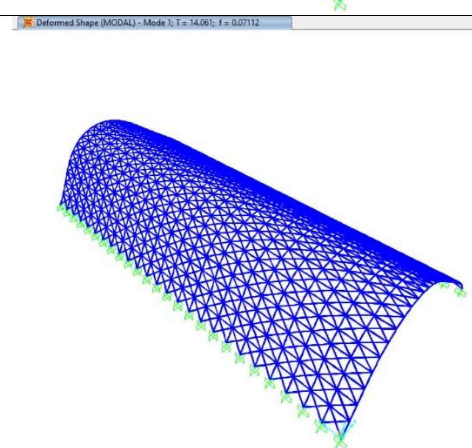
<tr><td>Span= 50m
Rise= 20m
Length= 100m
n_{long}=25
n_{ldiv}=25
Load applied on longitudinal member= 3kN/m
Both Ends Fixed</td><td>
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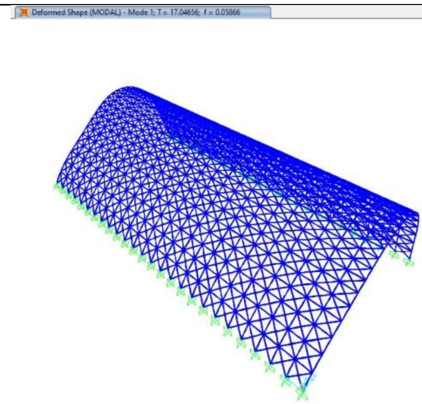
Span= 50m Rise= 25m Length= 100m n_{long}=25 n_{ldiv}=25 Load applied on longitudinal member= 3kN/m Both Ends Fixed	

5. Discussion

From this study we observed that each variables have some degree of effect on the time period of the lattice parabolic shell. The time period seems to have a parabolic relationship with the rise-span ratio, load applied and the ratio of number of longitudinal divisions with the number of transverse divisions of the lattice shell. A linear relationship was observed with the length-span ratio.

As the rise-span ratio was increased, the time period seemed to increase. This may be because as the rise span ratio was increased, the height of the shell increases which in turn decreases the stiffness of the shell and results into a longer duration. The curve shows that rise-span ratio has a significant effect on the time period. It is clear that larger time period which might affect the stability of the shell hence, a lower value or rise-span ratio is recommended considering the time period of lattice parabolic shell.

In the case of length-span ratio, considering all other variables fixed, the time period of the shell increased as the length-span ratio is increased. This is due to the increase in mass with the fixed value of stiffness of the lattice shell. As the length-span ratio is the only variable being changed, the number of divisions along the length is fixed which keeps the number of support fixed and in turn keeps the stiffness constant. If we increase the length-span ratio keeping the spacing of the support constant (i.e the number of divisions along the longitudinal direction changes with the length), the effect of length-span ratio on the time period seems to diminish.

As the number of divisions in the longitudinal direction was increased, the time period is decreased. This is related with the stiffness and mass of the lattice shell. As the number of divisions in longitudinal direction is increased, there will be more supports and more members connected with the supports resulting in the increase in stiffness as well as the increase in mass. However, the increase in mass is not as significant as the increase in stiffness and hence we observe a decrease in time period. With the increase in number of divisions in transverse direction, the time period seemed to increase. This is because as the number of divisions in transverse direction is increase, the mass of the shell is increased while the stiffness of the shell remains the same causing the increase in time period.

The time period increased with the increase in load applied and decrease when the hinged support was replaced by fixed support. This is clear as the time period is directly related with the mass and the load applied on the shell, while we all know that members connected with fixed support have higher stiffness. The results however made it clear that the time period when the support are fixed is nearly equal to 60% of the time period when the support are hinged. The calculation of time period and its relationship with the load applied and support conditions helped in validating the works performed in this research. Higher time period relates to greater deformation; hence it is recommended that for shorter deformation fixed support is suitable.

6. Approximate Formula for Time Period

A simple formula can provide a reliable estimate for the time period which is suitable of initial analysis or design phase, hence an attempt has been made to develop a relation of time period based upon the

Rise-span ratio, length-span ratio and n_{long}/n_{div} as shown below:

$$T= \quad S\, C_0\, C_1\, (C_2\, C_3\, C_4)^{0.12}$$

Where, S= 1 for Hinged support and 0.6 for fixed support

Co= Coefficient related to span and rise= $(B^2+H^2)^{0.5}$

C_1= Coefficient depending upon the Area A, Poisson's ratio v, density of the material ρ, Young's Modulus E and Moment of Inertia of the member

I= $\sqrt{\frac{3A(1-v^2)\rho}{EI}}$, A,E, I and ρ all are in m, kg, N,

C_2= Coefficient related to Rise and Span= $(H/B)^4$

C_3= Coefficient related to Length and Span= L/B

C_4= Coefficient related to n_{long} and n_{div} =$(n_{long}/n_{div})^{0.8}$

7. Conclusions

The dynamic behavior of lattice parabolic shell are not well studied. A parametric study of these shell has been performed with variables as rise-span ratio, length- span ratio and ratio of number of longitudinal divisions by number of transverse divisions. A program in Excel was developed using Visual Basic for Application (VBA) to perform theses analysis in SAP2000. The program saved a significant amount of time and provided sufficient data for parametric analysis and the development of an approximate formula. The following conclusions were drawn from this research for the time period of lattice parabolic steel shells:

i) A parabolic relation was found between time period and rise span ratio,

ii) The time period when the supports are fixed is nearly equal to 60% of time period when the supports are hinged.

iii) A linear relation was found with length-span ratio,

iv) A parabolic relation was found with the number of longitudinal divisions and the number of transverse divisions of the lattice shell,

v) A simple approximate formula was developed to obtain the time period based upon these variables.

$$T= C_0\, C_1\, (C_2\, C_3\, C_4)^{0.12}$$

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