

SEISMIC ANALYSES OF SHELL SUPPORTED BRIDGE

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Abstract— This paper demonstrates the performance of shell supported bridge structure resting on different soil conditions when subjected to seismic analysis using ANSYS 15. As a part of the bridge, shells use all the modes of structural action available to beams, struts, arches, cables and plates. This paper provides a comparative study on the effects of structural configuration on static and seismic analyses of pedestrian shell supported bridge resting on pile foundation. The modelling of bridge is prepared on Auto cad 3D software and was analysed as FEM model using static structural analyses, Modal Analyses and response spectrum analyses. The parameters considered in the study are thickness of the shell, different soil and contact conditions and their effect on stress as well as deformation behaviour of structure under static and seismic loading.

Keywords— Shell supported Bridge, Anticlastic Shell, ANSYS 15, Response spectrum analyses, Pile Foundation

INTRODUCTION

The introductions of the concrete shell have made tremendous change in the field of construction. Shells are most commonly seen as domes, but may also the form of ellipsoid or cylindrical sections or a combination. The shells are commonly used are roots, nowadays for sports buildings or storage facilities. Anticlastic shells or hyper shells are shell capable of taking large compressive loads. The advantage of shell structures is that they bring down the dead load and material cost and that it has higher load carrying capacity. The disadvantage lies in higher cost of foam work and labour.

The confidence in shell structures over the years has led to shells being used to support bridge deck. The Musmeci Shell supported bridge in Potenza, Italy is an example of a shell supported bridge of an anticlastic shell. Even though shell sections are thin they have great strength derived from the shape rather than the mass. During earthquakes great damage is known to occur. Though shell type bridges are very promising due to their overall performances, use of shell supported bridges with confidence requires an detailed investigation of its performance.

SHELLS BRIDGES AND EARTHQUAKES

The concept of shell supported bridge is a recent innovation. The improved building terminology in structural concrete and steel work has led designers to use different topology of steel supported bridges. In shell supported bridges the bridge deck slab is supported by the concrete shell with beam stillness provided below the bridge deck slab. Such bridges have generally been found satisfactory under the usual loading.

When the soil conditions are not suitable for providing foundation, deep foundations such as piles, piers etc are adopted as foundations for bridges. Bridges supported on deep foundation need to be analyzed for soil structure interaction effects. Such shell supported bridges as mentioned above needs studies to ascertain their safety during an earthquake. Earthquakes such as The Great Hanshin earthquake is an example of the destructive force of an earthquake. The bridge has to be safe from damage, if it is to be adopted.

A. Scope of the Work

The scope of the research work conducted as a part of this project work is as follows;

1. To studying the role of stillness of bridge support by shell structure under static, Modal and seismic analyses by conducting analyses of three different thickness of shells.
2. To evaluate the effects of soil structure interaction on the pile supported Shell supported bridge by conducting different analyses in two types of soils with smooth and bonded contact condition.

3. To understand the behavior of a shell supported bridge resting on pile foundation and to evaluate the relative influence of each component the following analyses were performed separately.
 - Static structural analyses shell supported bridge structure
 - Static structural analyses shell supported bridge and pile foundation
 - Model analyses – shell supported bridge structure
 - Model analyses – shell supported bridge and pile foundation
 - R S A of shell supported bridge structure along x, y and z axis.
 - R S A of shell supported bridge and pile foundation.

B. Objective of the Work

This project work aims at considering the static and dynamic response of a Shell supported bridge. Shells of different stiffness are considered in the analyses. The seismic analyses of a shell supporting bridge structure resting on pile foundation considering the soil structure interaction is envisaged. The static analyses, model analyses and response spectrum in different soil condition and the influence of all these on the structural behaviour of a shell supported bridge resting on the pile is planned.

C. Methodology

This work studies the seismic performance of shell supported bridge using Finite Element Methods (FEM). In order to understand the relative role of this shell supported bridge deck, pile and soil structure interaction, each part is modelled separately and analysed statically and dynamically. The investigation is conducted using the FEM Software ANSYS version 15. The response spectrum of Savannah River Site Disaggregated Seismic Spectra is used for the seismic analyses. The Shell supported bridge was modelled using AUTOCAD, modal, static and response spectrum analyses were conducted to obtain the response of various parameters studied.

FINITE ELEMENT MODELLING OF SHELL SUPPORTED BRIDGE

In this project a finite element model of a shell supported bridge resting on pile foundation and surrounding soil is subjected in to static, modal and dynamic analyses. Details of geometry a finite model of Shell supported bridge, foundation and soil, material models, material properties, contact options and seismic data adopted are elaborated.

A. Shell Supported Bridge Model

The Shell supported bridge consists of an anticlastic shell which supports the deck slab of the bridge. The dimensions of the Shell supported bridge considered in this study were fixed with reference to the design of [13]. Figure 1. shows typical Shell supported bridge geometry.



Fig..1 Shell-supported bridges [13]

The shell supported bridge of a typical type was modelled as a part of optimisation technique by [13]. It consists of different boundary conditions and the following data as given below.

- Uniformly distributed load of 4 kN/m²
- Dimension the deck slab = 40 m x 6 m
- Height of 7 m from the bottom level which supports the deck and 5.5 m to the bottom shell.
- Thickness of deck = 0.15 m
- The thickness of the shell varies from 150 mm to 400 mm

As a part of this project 3 different models are developed for the different analyses. The 3 different models having shell thickness of 150 mm, 200 mm, and 320 mm with a deck slab of thickness 150 mm each. The shell structure was modelled using the Solid works and Auto Cad 2015 software's with appropriate boundary conditions provided by [13]. Meshing was carried out using quadrilateral and mapped mesh elements. The concrete element used here is solid 186. Figure 2 show the three model of bridge used

in this study. The different models were prepared for analysis in ANSYS. The concrete element type used in these analyses is solid186.

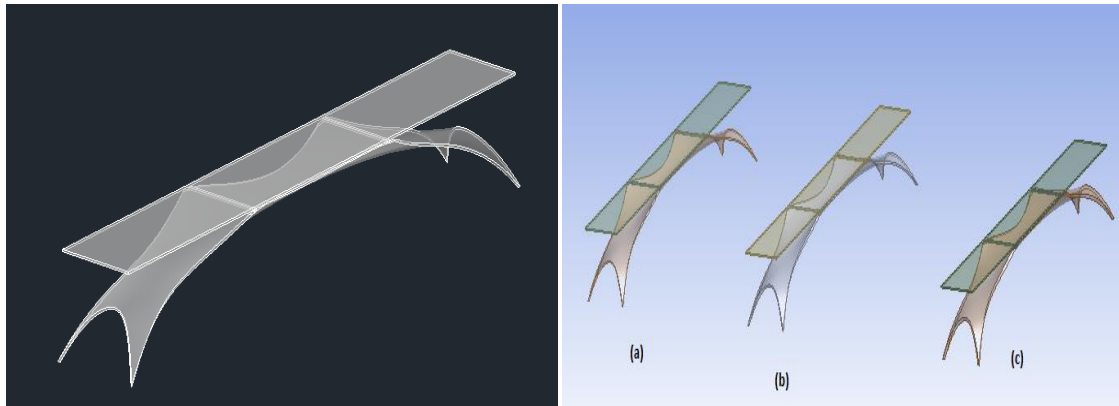


Fig. 2 Shell supported bridge of shell thickness (a) 150 mm, (b) 200 mm, (c) 320 mm

The details of the Shell supported bridge used in this study are given in table I. For seismic analyses of bridge the entire structure has to be considered. A combination of 3 piles with soil block is modelled with the Shell supported bridge.

Table I Dimension Details of Shell supported bridge

Thickness of the shell (m)	Span of bridge (m)	Width of bridge (m)	Height of bridge from bottom level (m)	Head level from the bottom portion of shell (m)	Size of beam stiffeners along the width
0.15	40	6	7	5.5	0.15 x 0.25
0.2	40	6	7	5.5	0.15 x 0.25
0.32	40	6	7	5.5	0.15 x 0.25

MODELLING OF PILE FOUNDATION AND SOIL GEOMETRY

The report of soil investigation carried out for design of pile foundation for the pedestrian bridge by [2] is taken. The end bearing piles are selected from the corresponding bore-log given in the same reference. From the data a group of 3 pile was designed using IS 2911 and IS 456. Figure 3 shows the shell supported bridge with piles. Figure 4 shows the shell supported bridge with piles and soil. Table II gives details of the pile foundation.



Fig. 3 Shell supported bridge with pile foundation modelled in Autocad 2015

Table II Dimension Details of pile

Diameter of pile	0.85m
Length of pile	8.8m
Depth including pile cap	10.2m

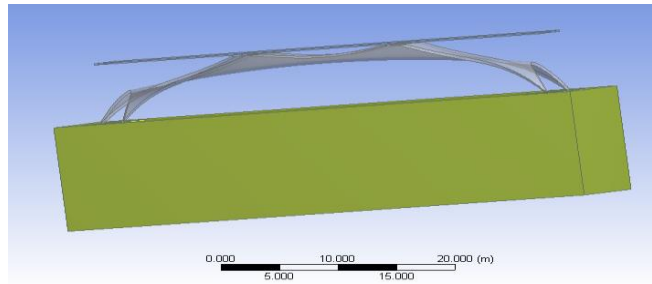


Fig. 4 Shell supported bridge with soil block modelled in AUTOCAD 2015

The thickness of soil below the pile tip is ten times the pile diameter from the pile tip and five times pile diameter from pile cap end [21]. The size of soil was restricted to small size in order to control number of nodes or elements. Since the structure is large in size, so the system needs more time and it requires more memory space. In order to overcome this issue an inflation layer was created between the pile and soil layer. Thus increasing the mesh size of the soil block and providing an inflation layer at the contact region enhances better soil structure interaction.

PROPERTIES USED FOR SHELL STRUCTURES AND SOIL.

Concrete is defined as multi-linear isotropic material. The plasticity model for concrete is based on the flow theory of plasticity, Von Mises yield criterion, isotropic hardening and associated flow rule. For concrete in compression, the ANSYS program requires the yield and ultimate strength of the material property to properly model concrete. The multi-linear isotropic material uses the Von Mises failure criterion to define the failure of the concrete [5]. The structures assigned for M30 grade concrete properties as tabulated in table III. The material properties adopted for soil in the present study are given in table IV

Table III Properties of concrete

SI No.	Concrete properties	Value
1	Modulus of Elasticity, E_c	2.238×10^7 kN/m ²
2	Poisson's Ratio, ν	0.17
3	Density	24 kN/m ³
4	Tensile ultimate strength	2.9×10^3 2.9kN/m ²
5	Compressive ultimate strength	3×10^4 kN/m ²

Table IV Properties of Soil

SI No.	Properties	Homogeneous soil condition	
		Loose sand	Medium clay
1	Modulus of Elasticity, E_s , (kN/m ²)	24×10^3	15×10^3
2	Poisson's Ratio, ν	0.3	0.45
3	Density (kN/m ³)	18	20
4	Cohesion(kN/m ²)	0	35
5	Angle of Internal Friction	30°	0

SEISMIC SPECTRUM ANALYSIS

For engineering design of earthquake-resistant structures, response spectra serve the function of characterizing ground motions as a function of period or frequency. These motions then provide the input parameters that are used in the analyses of structural response. Because they use the maximum response, the response spectra are an inherently conservative design tool. Response spectra are described in terms of amplitude, duration, and frequency content, and these are related to source parameters, travel path, and site conditions. Studies by a number of investigators have shown by statistical analyses that for different magnitudes the response spectrum values are different for differing periods. The spectrum analysis is mainly done in bridges. The savannah river site disaggregated seismic spectrum was mainly done in shantou bay bridge and tiger gate bridge. This response spectrum analyses can

bring out the dynamic behaviour of the structure [22]. The data consist of a maximum acceleration of 0.358 m/s^2 with a maximum frequency up to 50 hz (figure 5).

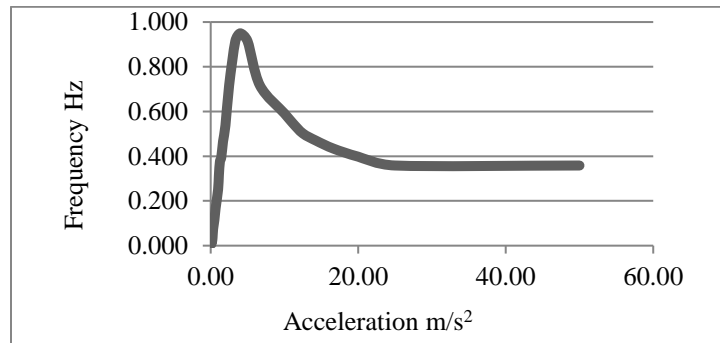


Fig. 5 Acceleration frequency spectrum of Savannah River site disaggregated seismic spectrum.

RESULTS AND DISCUSSIONS

The result of static analyses, modal analyses and dynamic analyses of Shell supported bridge are discussed. The static analysis is done in order to determine the deformation characteristics and stress generated on the Shell supported bridge. In this, static analyses is done on varying the thickness of the shells of thickness of 150 mm, 200 mm, and 320 mm. Modal analyses is the study of the dynamic properties of structures under vibration excitation. The modal analysis is done in order to determine the natural frequency of the particular structure. Dynamic characteristic of the bridge are investigated by using the response spectrum analyses. The seismic behaviour of the Shell supported bridge is conducted to check whether any possibilities for resonance conditions and to determine the strength and performance of anticlastic shells. Also the analyses were done based on the varying soil properties such as cohesive and cohesion-less soil and the varying interface roughness such as bonded and smooth contact to simulate the two extreme possibilities of contact. The following five cases were subjected to static, modal and dynamic analyses.

- 1) Shell supported bridge, 2) Shell supported bridge with pile foundation with bonded contact in loose sand, 3) Shell supported bridge with pile foundation with smooth contact in loose sand, 4) Shell supported bridge with pile foundation with bonded contact in medium clay, 5) Shell supported bridge with pile foundation with smooth contact in medium clay.

A. Static Analyses Of Shell Supported Bridge

Nonlinear static analyses were done on the Shell supported bridge. The analysis was performed on the bridge without soil, and the structure with pile foundation in different soil conditions. This was done in order to determine the behaviour of the structure. The load was applied on to the top of the deck surface. The standard earth gravity was also considered in the case of bridge with soil block. The boundary conditions were appropriately provided. The X, Y, Z directions in analysis is such that Y is vertical and X and Z are horizontal.

- Deformation of Shell supported bridge

The analyses were done under the static load of 4 kN/m^2 throughout the deck surface. The load from the deck slab is directly transferred through the beam stiffeners provided on the upper support of the shell. Static analyses of Shell supported bridge along with pile foundation in soil block were also done. The static load of 4 kN/m^2 along with the standard gravity load is applied. The analyses were done based on the varying soil properties such as cohesive and cohesion-less soil and the varying interface roughness such as bonded and smooth contact. The entire structure (i.e., bridge, pile foundation) is merged to a single body. The deformation of shell supported bridge under static analysis is given in table V

Table V deformation of Shell supported bridge under static analyses

Thickness of Shell supported bridge (m)	Deformation (m)
0.15	0.01002
0.2	0.00928
0.32	0.00455

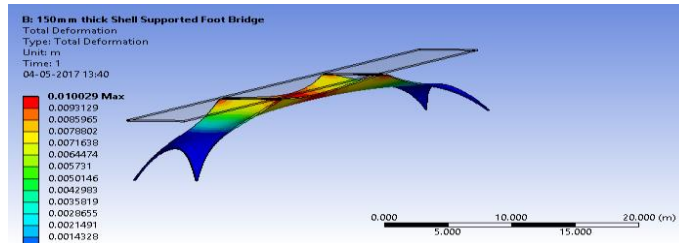


Fig. 6 Maximum deformation in Shell supported bridge of thickness 0.15m

- Deformation of shell supported bridge resting in soil.

From the above result it is found that the deformations of the shells are within the permissible deformation in the case of Shell supported bridge without foundation and soil. When the shell thickness increase the deformation decreases. The deformation of 0.15 m thick shell is within the permissible limit. Table VI shows the deformation of shell supported footbridge with pile foundation in different soil conditions while figure 6 shows the deformation on the structure.

Table VI Deformation of Shell supported bridge with pile foundation in different soil conditions

Thickness of Shell supported bridge shell (m)	Deformation under static load (m)			
	Loose sand		Medium clay	
	Bonded	Smooth	Bonded	Smooth
0.15	0.001214	0.0187	0.001581	0.02382
0.2	0.001242	0.01771	0.00161	0.02219
0.32	0.001298	0.01739	0.00165	0.02333

The result obtained in the bridge along with the pile foundation in different soil condition shows that the deformation is more in soil with smooth contact than the soil with bonded contact. In Figure 7 the deformation of the entire structure is represented. The deformation occurring is the settlement of the soil. Deformation obtained in different soil is shown in the figure 8.

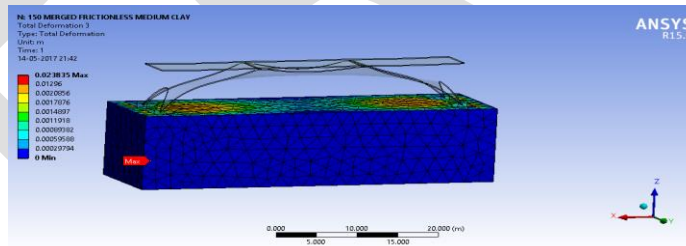


Fig. 7 Maximum deformation in Shell supported bridge with pile foundation of thickness 0.15m

The deformation of shell supported bridge obtained in soil and that without soil is plotted on a graph of deformation vs thickness (Fig 8). It is found that the maximum deformation is shown in medium clay with smooth contact. The soil with smooth contact shows maximum deformation than with bonded contact. In the case of shell supported bridge without soil the maximum deformation is obtained in shell supported bridge with thickness 0.15 m.

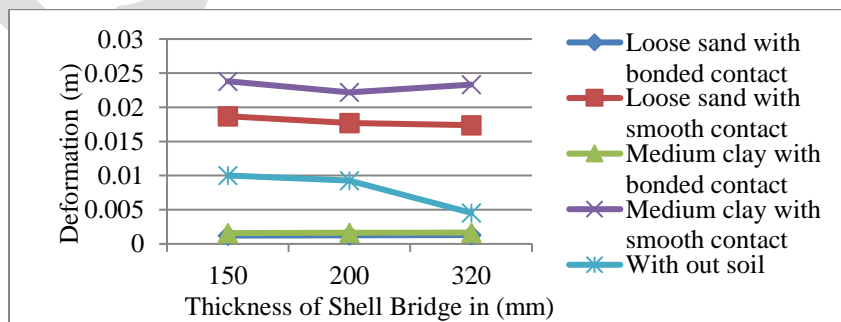


Fig. 8 Deformation of Shell supported bridge with soil and without soil

- Stress in Shell supported bridge

The stresses that developed due to the same static load of 4 kN/m² on the Shell supported bridge are shown in the table VII. This study is to determine the stress developed in the shell. The characteristic cylindrical strength was 30000 kN/m². The structure will be safe if the stresses developed are within this range. The table VII shows the stress developed on the shell supported bridge.

Table VII Stress on shell supported bridge

Thickness of Shell supported bridge (m)	Stress (kN/m ²)
0.15	25292
0.2	19200
0.32	17628

From the above result the stress is found to be more in bridge with 0.15 m thick shell. The maximum stress is obtained at the upper support of the shell. It can be seen that the stress obtained here does not exceeded the actual strength of the concrete. So the structure is safe.

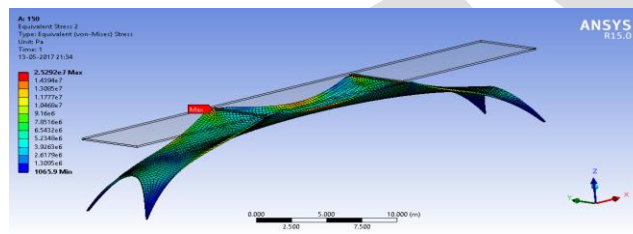


Fig 9 Maximum stress developed in Shell supported bridge of thickness 0.15m

- Shell supported bridge resting in soil

The case of the Shell supported bridge with pile and soil block standard earth gravity is considered. The table VIII shows the result of Stresses on shell supported bridge with pile foundation in different soil block. The table VIII shows the static analyses result of bridge with pile foundation embedded in the soil block. The above result shows the variation of stress in soil with bonded and smooth contact.. From the above result it is found that the stresses obtained in smooth contact are greater than that of stresses obtained in bonded contact. The stress is found to be more in the shell with thickness 0.15 m. The maximum stress is found to be at the centre of the shell. These stresses are developed due to the settlement of the supports or foundation.

Table VIII Stress on shell supported bridge with pile foundation in different soil

Thickness of Shell supported bridge shell.	Stress under static load (kN/m ²)			
	Loose sand		Medium clay	
	Bonded	Smooth	Bonded	Smooth
0.15	8510.9	8926.6	8516.2	9287.1
0.2	7038	7341.76	7189.3	7541.55
0.32	5446.2	6681.4	5217.2	6121.2

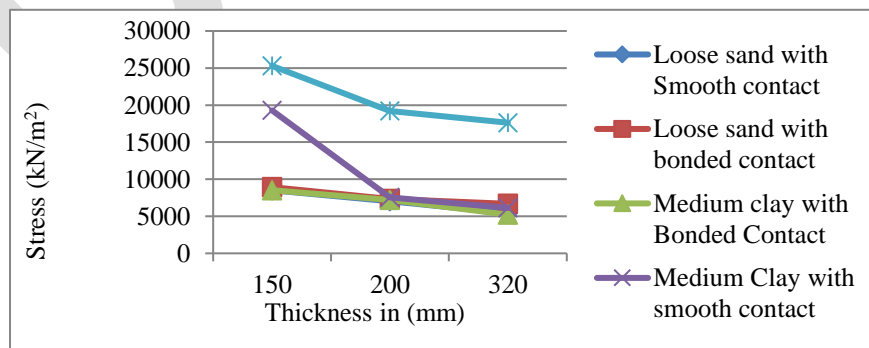


Fig. 10 Stress in Shell supported bridge with pile foundation in different soil and that with shell supported bridge only.

The maximum stress is obtained in the shell supported bridge without soil. The maximum stress is obtained in 0.15 m thick shell. From the figure 12 the stresses are found to be less in shell supported bridge with soil. In the case of shell supported bridge with soil, maximum stress is obtained in the soil with smooth contact than that with the bonded contact. It is because the less amount of friction between the soil and concrete.

B. Modal analyses of shell supported bridge

The modal analysis of Shell supported bridge is performed in order to determine the natural frequency of the bridge. The modal analysis is carried out on bridge only and with bridge cum foundation-soil system. The result of the analyses is shown in the table IX. This analysis was conducted to check the possibility of resonance which will occur when the natural frequency of the system is equal to the exciting frequency of the earthquake.

Table IX Frequency of Shell supported bridge

Thickness of Shell supported bridge (m)	Frequency (hz) of Shell supported bridge	Frequency (hz) of Shell supported bridge with pile foundation in soil block			
		Loose sand		Medium clay	
		Bonded	Smooth	Bonded	Smooth
0.15	1.6321	0.68677	0.68644	0.68647	0.6863
0.2	1.6601	0.89584	0.89353	0.89585	0.89341
0.32	1.8394	1.2958	1.2889	1.2936	1.2873

The results of modal analyses showed that the frequency of structure with bonded contact is having higher frequency than that of smooth contact. The frequency of the 0.2 m thick shell is taken for the validation purpose. The frequency value obtained from the modal analyses is not within the range of excited frequency. Hence there is no possibility for resonance conditions. So the structure is safe.

C. Seismic analyses of shell supported bridge

The response spectrum analyses (RSA) of the Shell supported bridge is done using the details of Savannah river site disaggregated seismic spectrum explained in previous section. The analyses are done with bridge without soil and bridge with pile foundation embedded in a soil block with the parameters bonded and smooth contact in loose sand and medium clay. The deformation and the stress developed due to this excited vibration on the structure are discussed in this section.

- Deformation of Shell supported bridge from response spectrum analyses

The maximum deformation obtained from the response spectrum analyses is shown in the table X. The response spectrum analyses is performed in x, y and z axis. The standard earth gravity is considered.

Table X Deformation of Shell supported bridge

Thickness of shell (m)	Deformation of the Shell supported bridge (m)		
	Along X-axis	Along Y-axis	Along Z-axis
0.15	0.02905	0.06831	0.01516
0.2	0.00702	0.03414	0.00969
0.32	0.00335	0.00909	0.00729

The above result shows the response spectrum analyses of shell supported bridge only. The maximum deformation s obtained along the Y-axis. Figure 11 illustrate the typical deformed contour plots of shell supported bridge for shell thickness 0.15 m.

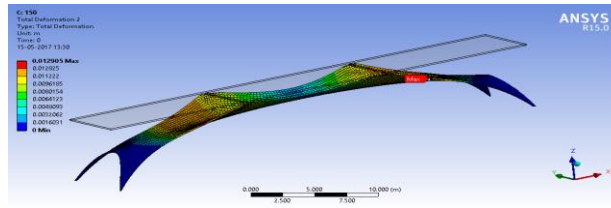


Fig. 11 Deformation of bridge with 0.15 m thickness obtained from RSA along X-axis

The maximum deformations along X-axis and Y-axis are found to be at the edges and curves of the shell. In the case of Z-axis the deformation is found to be at the centre of the anticlastic shell. These deformations are within the limit. Hence the structure is safe. The table XI shows the result for bridge with the combination of foundation and soil. The foundation is consists of three piles.

Table XI Deformation of Shell supported bridge with pile foundation and soil

Thickness of shell (m)	Deformation (m) in loose sand		Deformation (m) in medium clay	
	Bonded contact	Smooth contact	Bonded contact	Smooth contact
0.15	0.012835	0.013289	0.049361	0.04943
0.2	0.013308	0.013808	0.014554	0.014638
0.32	0.014274	0.014974	0.01415	0.01425

From the results it can be seen that with bonded contact and smooth contact in sand, the settlement is low, but with bonded and smooth contact in clay the settlement is high. It is also clear that the smooth contact show poor performance than bonded contact.

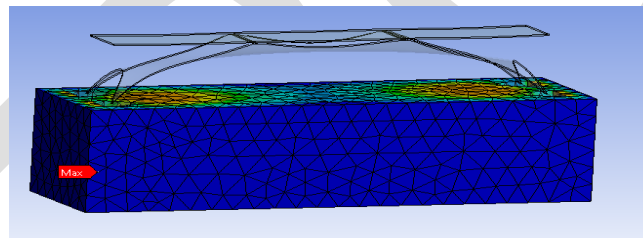


Fig. 12 The visualization of deformation in soil under RSA

The settlement is more found to be in soil with smooth contact than the bonded contact. This happens as the bridge can undergo settlement easily under smooth condition without any resistances. The maximum deformation is found to be in bridge with shell thickness 0.15 in medium clay with smooth contact. While comparing the deformations with shell supported bridge alone and shell supported bridge with soil, the maximum deformation is found to be at medium clay soil and thickness of 0.15 m shows maximum deformation. The deformation is more in smooth contact than in bonded contact cases.

- Stress in Shell supported bridge from response spectrum analyses

The maximum stress obtained from the response spectrum analyses is shown in the table XII and XIV. The response spectrum analysis of Shell supported bridge alone is done in X, Y and Z axis. The result shows that RSA along Z-axis shows higher stress than the other axis except in the case of 0.15 m thick shell. The stress is found to be more in Y-axis than Z-axis.

Table XII Stress developed in Shell supported bridge

Thickness of shell (m)	Stress developed on the Shell supported bridge (kN/m ²)		
	Along X-axis	Along Y-axis	Along Z-axis
0.15	9864.5	22034	21606
0.2	6135	15883	17868
0.32	2957	6251.6	7848.4

The other two models show better result than the 0.15 m. The stress is found to be more in Y-axis than Z-axis. The other two models show better result than the 0.15 m. The figure 13 shows the stress developed in 0.15m from response spectrum analyses along X, Y and Z-axis. Figure14 shows the stresses on the shell structure and the piles.

Table XIV Stress in Shell supported bridge along with foundation and soil

Thickness of shell (m)	Stress in loose sand (kN/m ²)		Stress in medium clay (kN/m ²)	
	Bonded contact	Smooth contact	Bonded contact	Smooth contact
0.15	1664.5	1222.2	1933.6	1648.3
0.2	1158.9	1039.7	1680.2	1439.7
0.32	8459.6	6397.2	4380.3	1811.4

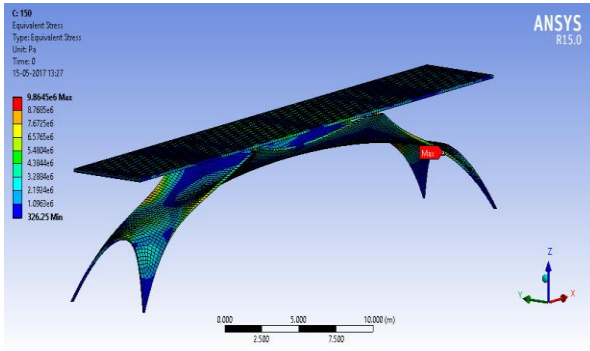


Fig. 13 Stress developed in 0.15m thick shell from RSA along X-axis

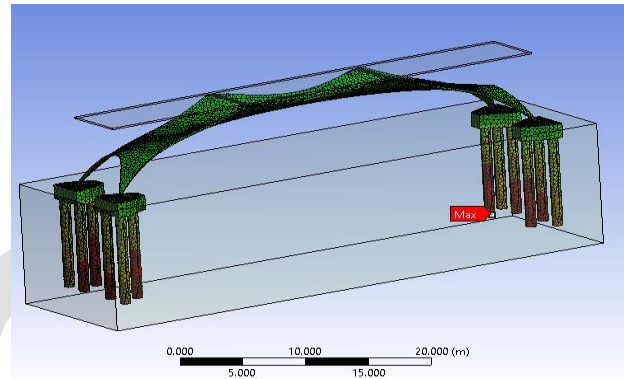


Fig. 14 Stress developed on the pile supporting bridge

From the table XIV it is found that the stress is more in the bonded contact than in the smooth contact. Among the shell of three thicknesses, 0.32 m thick shell show greater stress in bonded contact. The stress developed in 0.2 m thick shell is lesser than that of 0.15 m. from this it can be conclude that the performance of 0.2 m thick shell is comparatively better than the other two. The figure 15 shows a comparison of stress obtained from response spectrum analyses of shell supported bridge with and without soil. The maximum stress is obtained on 0.15 m thick shell supported bridge without soil. On the other hand shell supported bridge with soil, 0.32 m thick shell supported bridge shows higher stress. The stress is more in soil with bonded contact.

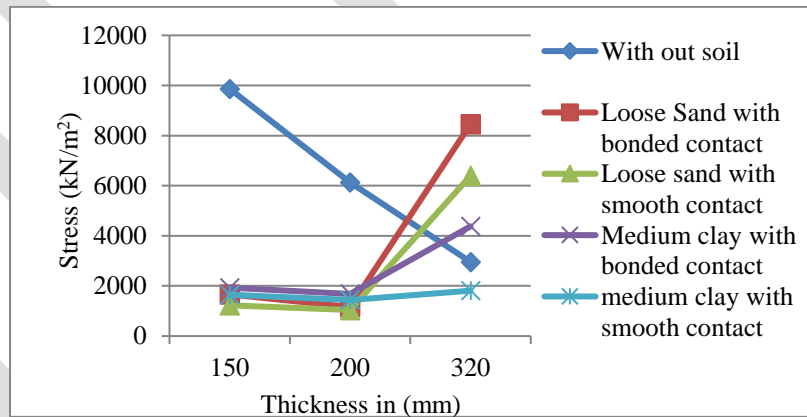


Fig. 15 Stress developed in Shell supported bridge with and without soil.

This projects the importance of the soil structure interaction analysis in estimating the deformation and stress behaviour of shell supported bridge structures.

CONCLUSION

The conclusions of this study cannot be generalised as they are applicable only to the specific data used in this study. Modal analyses of shell supported bridge is done in order to determine the natural frequency, and to compare it with the Savannah River site earthquake data. It can be concluded that no resonance take place in the shell supported bridge. From the static analysis of shell supported bridge without the foundation or soil shows that as the thickness of the shell increased the deformation or settlement of the bridge decreased. However when foundation and soil are taken in to account this is not always true. In shell supported bridge without soil, the maximum deformation is seen in shell supported bridge of shell thickness 0.15 m. In shell supported bridge with foundation cum soil system with different contact interface (bonded and smooth), maximum deformation is found to be in soil with smooth contact. 14. In shell supported bridge without soil, the maximum stress is seen in shell supported bridge of shell thickness 0.15 m. In case of Shell Bridge without soil as the shell thickness increase 0.15 m to 0.2 m (25 % increased) stress decreased by 24%. When the shell thickness increased from 0.2 m to 0.32 m (37.5 % increased), the deformation decreased by 8.1 %. In shell supported bridge with foundation cum soil system with different contact interface (bonded and smooth), maximum stress is seen in soil with smooth contact than that of bonded. From seismic analysis (response spectrum analysis) it is found that the deformation is in shell supported bridge with shell thickness 0.15 m. The deformation decrease with increase in the shell thickness. By varying the thickness of the shell of shell supported bridge 0.15 m, 0.2 m, 0.32 m the percentage difference in stresses between bonded and smooth contact in loose sand are 26.57 %, 10.28 %, 24.3 % respectively. By varying the thickness of the shell of shell supported bridge 0.15 m, 0.2 m, 0.32 m the percentage difference in stresses between bonded and smooth contact in medium clay are 14.7 %, 14.3 %, 58.6 % respectively. The following are the common conclusions,

- The bonded contact shows good soil structure interaction
- The deformation decrease with increase in the thickness of shell.
- Stresses are more in shell supported bridge with shell thickness 0.15 m

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