ANALYSIS OF SHELL STRUCTURES IN NATURE

BY

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ABSTRAK

Sejak beberapa dekad yang lalu, pembangunan dalam kelompang nipis sebagai satu bentuk struktur telah menambahkan bab yang merangsang pada senibina semasa. Kelompang adalah struktur yang berkait rapat dengan bentuk, maka dengan itu pemilihan bentuk yang sesuai amatlah penting dalam memastikan penghasilan struktur yang mempunyai kecekapan yang tinggi tarafnya. Dengan pembangunan teknologi komputer dan juga perisisan komputer, stimulasi komputer telah berkembang ke tahap yang tertinggi. Analisis untuk struktur cengkerang boleh dilakukan dengan menggunakan kaedah elemen terhingga. Dalam kajian ini, satu siasatan ke atas kecekapan permukaan sejenis kekerang laut telah dijalankan. Disebabkan oleh tiada kajian yang telah dibuat sebelum ini dalam cubaan untuk menganalisis struktur cengkerang, kajian yang dijalankan ini adalah bertujuan untuk membandingkan kelebihan struktur dari segi kekuatan dan ketegaran bagi struktur cengkerang tersebut. Data permukaan cengkerang telah diperolehi dengan menggunakan kaedah "fringe projection". Berdasarkan data ini, model cengkerang telah di hasilkan dengan menggunakan perisian ADINA. Analisis statik di bawah tindakan berat sendiri telah dijalankan dengan menggunakan tebal permukaan yang berlainan. Melalui keputusan yang diperolehi, taburan momen lenturan, daya membran, tegasan ricih dan pesongan diteliti. Kajian ini menunjukkan bahawa kekuatan dan ketegaran bagi struktur cengkerang yang dihasilkan adalah baik dan boleh diterima dengan syarat bahan yang sesuai digunakan.

ABSTRACT

During the pass few decades, the development of shell structure in nature as a structural form has added an exciting chapter to contemporary architecture. As shells are form-active structure, proper choice of shape is very important in order to achieve high level of structural efficiency. With the development of computer technology and much computer software, computer stimulation has reached a high level of standard. The analysis of shell can be performed by using the finite element method. In this research, an investigation on the surface efficiency of selected seashell has been done. The data of seashell surface can be obtained by using "fringe projection" method. Static analysis under self-weight has been done with using different surface thicknesses. The model of the selected seashell can be generated by using finite element software ADINA. Since it is found that no research has been carried out in an attempt to investigate the structural efficiency of the seashell surface, this present research has been carried out with the objective to compare the structural advantages in term of strength and rigidity of the selected seashell. Through the analysis of the results, the distribution of bending moments, membrane forces, shear forces and vertical displacement can be examined. It has been found that the strength and rigidity of shell in the shape of seashell is quite good and acceptable as long as suitable material is used.

ACKNOWLEDGEMENTS

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CHAPTER 1:INTRODUCTION

1.1 Research Background

Shell is an inborn structure which exists widely in this world. Shell is one of the earliest structures which are used by human. There are many shell shaped inborn structures such as eggs, seashells, and human structures. The strength of certain structures is surprisingly special. As these structures are found in nature, there might be specific structural merits in terms of load carrying capacity such as the use of minimum material to carry maximum load. Engineers can learn from these inborn structures, understand their merits and perhaps apply them to the actual shell structures.

The beautiful form of shells shape can be found in nature. Since shells have both the characteristic of curvature and continuity, it may be advantageously used in structure such as arch structures used in bridge structure, dome roofs an also in membrane structure. The concept of resistance to loads through form from shell in nature can be borrowed and applied to the design of structurally efficient buildings. Before the shape in nature can be applied to engineering structure, the behavior of shells under load must be first understood.

In this study common shell structures in nature will be identified and analyzed. From the result of analysis, conclusions about structural merit of shell structure in nature can be drawn. Study on structural behavior in term of strength and stiffness will be carried out by using finite element analysis.

1.2 Shell Structures in Structural Engineering

In the past, human experimented with natural shell structures and developed studies in synthetic shell for the use in aerospace to construction fields. From 1886 to 1960, many papers had been published about shell and designs, analysis and failures. From 1900 to 1915, many papers were printed about technical development such as the strength of big tube which is supported by crutch (tunnel), stresses on curved tank base (storage tanks), stresses on tanks with cone-shaped base (water storage tanks), homogeny and structural dome (Fung *et. al,* 1974). In construction development, classic shapes shell structure is similar as dome roof. In technology applications and modern construction materials, engineers developed knowledge about dome action and build incredible structures like the Tacoma Dome (532 ft diameter) in Tacoma, Washington and Superdome (680 ft diameter) in New Orleans, Louisiana (Fung *et. al*, 1974).

1.3 Shell Structures in Nature

Natural shell structures that can be found in nature are shell structure created by natural forces, not man made. The word *shell* is an old one and is commonly used to describe the hard covering of eggs, seashells, tortoise, human skull etc.

During the past few decades, the development of thin shell as a structural form has added an exciting chapter to contemporary architecture. Shell are widely spread structures in nature which offer considerable advantages in the engineering aspects especially in the field of building construction. As these structures are found in nature, there might be specific structural merits in them.

Structural form plays important contribution in the development of several branches in engineering. Structure in natural shape such as sea-shells offers considerable advantages concerning static efficiency, economy and aesthetic value. Engineers can learn from them, understand their merits and perhaps apply them to actual shell structures.

1.4 Literature Review

Study of nature has formed a study area of its own. Having been in development for several billions years, only the most successful structural forms have survived. The study of natural forms especially the study of seashells has a long history, starting as early as 1900 until now (Jirapong K. *et. al*, 2002). Many of this researcher have outlined in a number of mathematical relationship that control the overall geometry of shells. As concerned by prior researchers, they were interested on the investigation of natural forms as starting point to generate the architecture forms. As documented by prior researchers, the seashell geometry can be expressed by four basic parameters which are influential on the shell form. The four parameters are, a) the shape of the aperture or the shape of shell section, b) the distance from the coiling axis to the centre of the shell section, c) the section radius and d) the vertical section between sections. The seashell shape can be reconstructed in a digital form with variations of the mathematical relationships among these four parameters. The result of a specific mathematical combination reflects the shell form for specific seashell specie. The concept of creating architectural form originating from seashell geometry can be accomplished by applying these parameters to an architectural form interpretive exploring process. The results are a family of architectural form based on one simple mathematical comprehensive relationship (Jirapong K. *et. al,* 2002).

Lee (2001) has carried out analysis on egg shell by using the finite element software Staad-Pro. In his research, Staad-Pro had been used to model eggshell. At first, the raw data of egg surface is measured in the laboratory. Coordinates of the egg surface is then calculated and transferred into software Staad-Pro to be used as input for geometry of model. With the eggshell modeled in the computer and by applying different conditions such as loading condition, boundary condition and types of material, the variance of the behavior of eggshell under different situation in term of force, stress, moment and displacement have been studied. The locations where the critical force and displacement occur have also been studied. It was found that shell with egg surface is able to withstand its self-weight with stress level far below the allowable values. Maximum displacement taking place in the structure is very small and can be neglected practically.

Voon (2004) have also carried out the analysis of egg shell by using finite element method. In his research, comparison among model of egg shell, elliptical and spherical shell surfaces have been made. The research has been carried out in an attempt to investigate the structural efficiency of the chicken egg shell surface. Comparison of structural merits (strength and rigidity) of chicken egg shell with shells shapes of ellipsoid and sphere have been made. From the analysis results, the distribution of bending moments, membrane forces, shear forces and the vertical displacement are obtained. It has been found that the strength and rigidity of shell in the shape of chicken egg is not as good as that in the form of ellipsoid and sphere. However, the difference is found to be not very significant.

There are many shape of shell structure can be found in nature. Due to this fact, Ong (2003) had come out with the comparative study on load carrying characteristic of arches in the form of logarithmic, Archimedes' and golden proportion spirals. According to this study, the research has been carried out in order to investigate and compare the load carrying characteristic of arches in the form of three spiral curves, i.e. logarithmic spiral, Archimedes' spiral and golden proportion spiral by using commercial finite element software ANSYS. The arch models are generated with the same properties such as span length and height, material type, section used, element type, boundary conditions and load type to simplify the comparison. This research focuses on linear static analysis and the analysis result such as stresses and deformation are investigated. Analysis results show that Archimedes' spiral is the most suitable shape to be used as arch structure, followed by logarithmic spiral and golden proportion spiral. It is found that in Archimedes' spiral form arch, the majority of loading in the arch rib is transferred by means of in-planes forces or axial compression action compared to logarithmic spiral form arch and golden proportion spiral form arch. The majority of loading in the golden proportion spiral form arch is transferred by means of bending action rather than axial action. The load transferring characteristic for logarithmic spiral form arch is in the intermediate stage which means that load transfer by the combination of both bending and in-plane action.

As can be seen from the previous works mentioned above, study of shell-like shape in nature will provide us with information on strength and stiffness of those structures. Armed with that information, a better understanding of the behavior of those structures in nature can be achieved. With such better understanding idea from nature especially the shape in nature could then be applied to engineering practice, especially in roof structures design. There is a lot to be studied about shell-like shapes in nature. This study is carried out as a continuation of effort to gain understanding of the structural merits of shell-like shapes in nature.

1.5 Research Objectives

Some of the most sophisticated and efficient structures come from the concept of shell-like structures in nature. This research has been carried out with the following two main objectives:

i) To investigate the load carrying characteristic of the surface of a kind of seashell under its self-weight.

ii) To make conclusions about the effectiveness of the selected shell in term of its stiffness and strength.

1.6 Layout of Dissertation

Chapter 1 presents the project background, a survey of shell structures found in nature and structural engineering and literature review. It also contains the research objectives and research approach.

Chapter 2 presents the methodology of the research. The basic concept of how to measure the surface of the selected seashell is explained. This is then followed by a description on the process to generate the FE model of shell structure.

Chapter 3 shows the results and the ensuing discussions of all numerical examples.

Conclusions of the research project are presented in Chapter 4. Recommendations for future works which related to this research project are also outlined in this chapter.

CHAPTER 2: METHODOLOGY

This chapter will describe how to do the measurement on the surface of the seashell and how to generate a model of the seashell by using finite element software ADINA. This research begins with identify suitable shell structure in nature. A seashell has been chosen because of its curvature which is suitable for application to arch structures. The next step is to do the measurement of surface of shell structure identified to generate the Cartesian coordinates of the selected shell. These coordinates are then transferred to the finite element method (FEM) based computer packages to generate the model of the selected shell. Finite element (FE) software used is ADINA. The type of the analysis to be considered in this research study is limited to static analysis. Finally, the conclusion about structural merits of the shell structure will be achieved.

2.1 Seashell Surface Measurement

This part will describe how to get the data to representing the coordinates for the seashell surface. For this seashell measurement, the method that has been used is called "Fringe Projection Method" or also can be called as "Structured Lighting Method". This method is a non-contacting method where there is no contact had been made to measure the surface of the seashell sample. This method has its own advantages because the experimental design and the technique of analysis are simple. By using this method, no costly optical instrument is required. If using this method, the information can be extracted from a single fringe pattern and also better contrast fringes for automatic analysis can be obtained.

This method is using a digital camera as can be shown in Figure 2.1, a slide projector as shown in Figure 2.2 and a whiteboard which is used as screen as shown in Figure 2.3 below. Figure 2.4 shows the equipment set up for "Structured Lighting Method" which is used to determine the surface measurement.

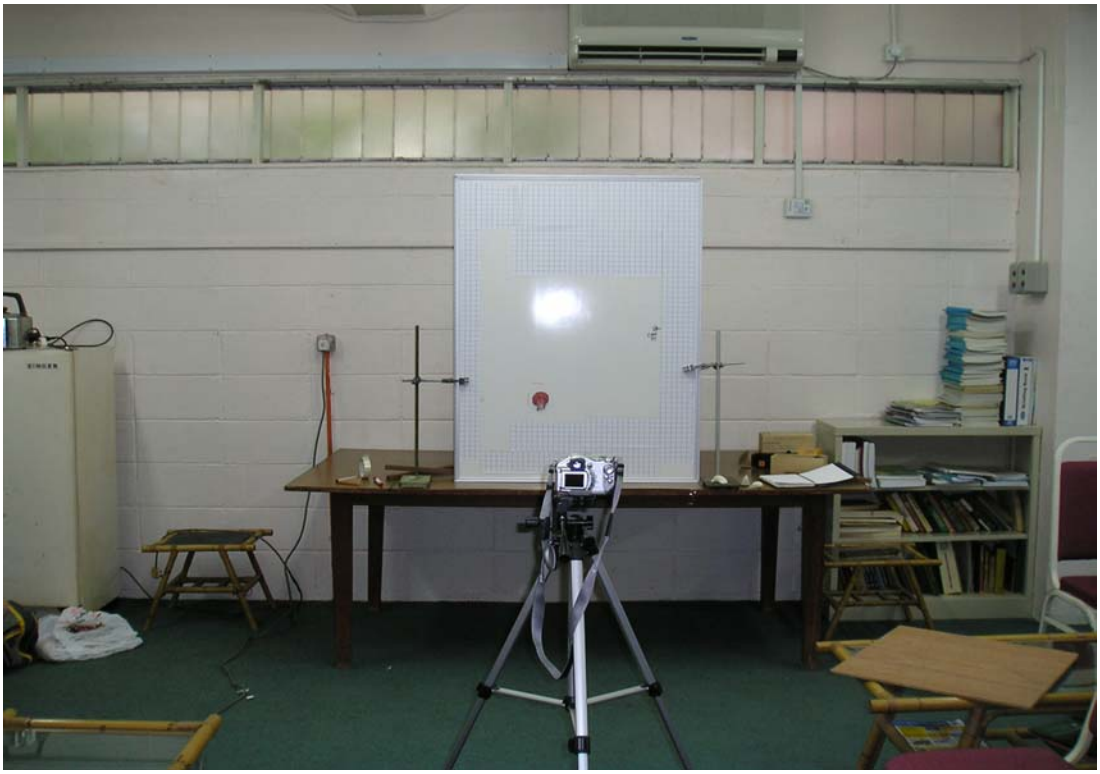


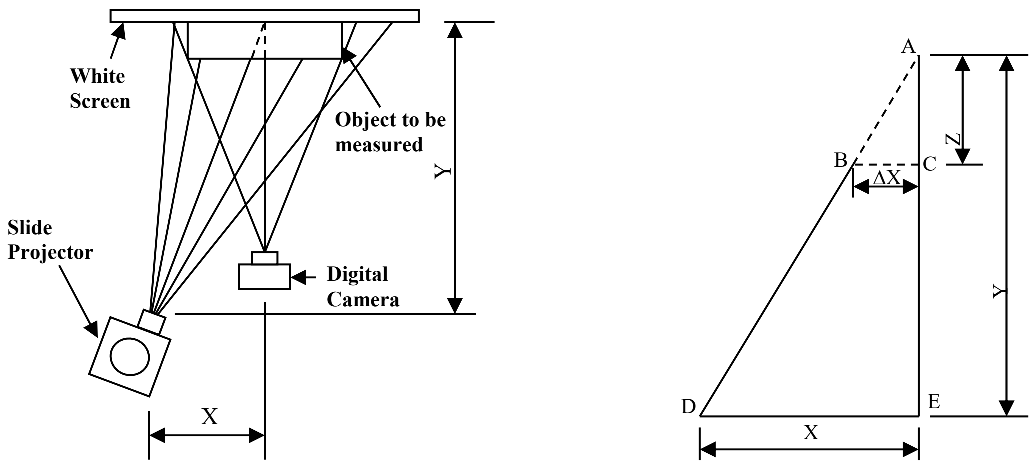
Figure 2.1: Digital Camera used in the Structured Lighting Method

Figure 2.2: Projector used in the Structured Lighting Method

Figure 2.3: Whiteboard which is used as screen in the Structured Lighting Method

Figure 2.4: Equipment setup for Structured Lighting Method

In this method the principle that had been used is by using triangulation principle. Image of projection of a set of parallel fringe pattern on object has to be first captured. Based on this captured image, calibration process is then carried out. After that, coordinates of the surface to be measured are then obtained by using of suitable image processing software such as Microsoft Photo Editor and Photoshop. The principle of this method is shown in Figure 2.5 below:



$$Z = \Delta X \tan \theta$$
$$\tan \theta = Y/X$$

Figure 2.5: The principle of Structured Lighting Method

As an example to explain how to get the calibration of the object measured, a PVC pipe with diameter D = 110 mm is used as can be shown in Figure 2.6. The objective is to obtain factor in the form of:

- mm/pixel in x-direction
- mm/pixel in y-direction

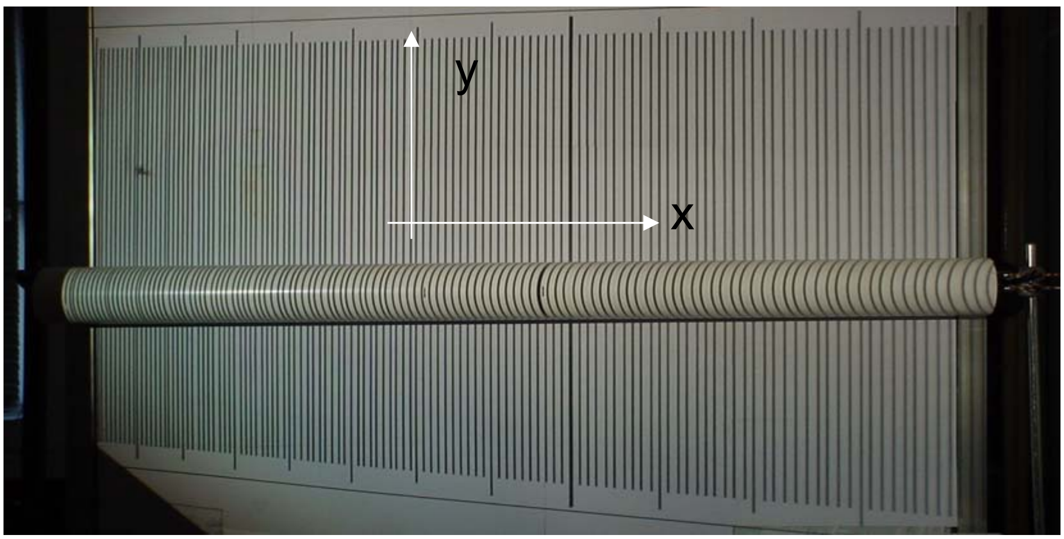


Figure 2.6: Calibration to obtain factor in the form of mm/pixels

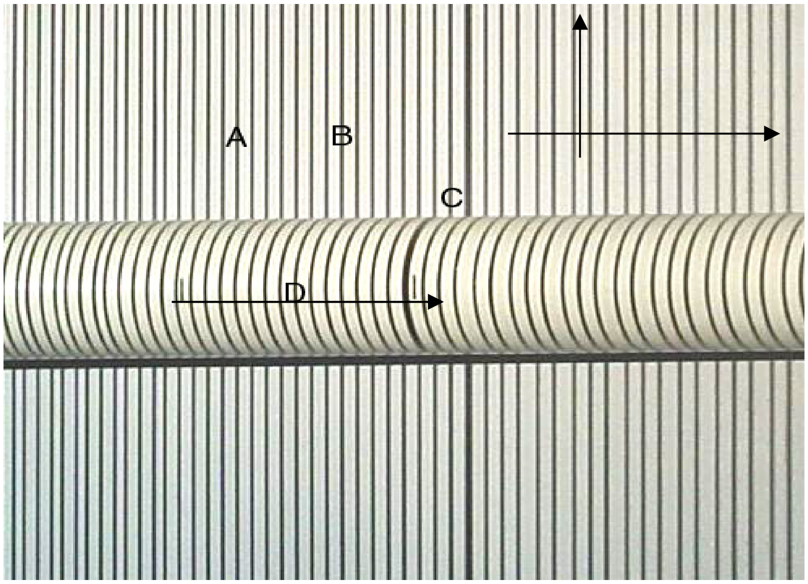


Figure 2.7: Calibration for factor in x-direction

For factor in x-direction, the distance A-B, say L mm (known priori = 100 mm) is first obtained as can be shown in Figure 2.7. Next, by using image processing software such as Adobe Photoshop, the distance A-B, say P in pixel is measured. The scaling factor in x-direction is: X-scale = L/P mm/pixel.

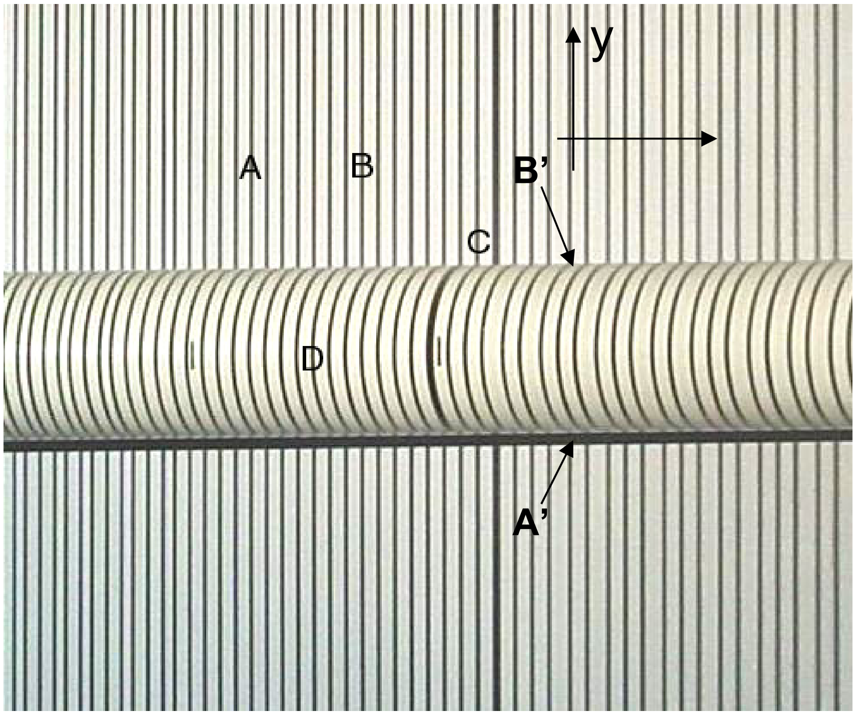


Figure 2.8: Calibration for factor in y-direction

For factor in y-direction, the distance of A’-B’, say L’ mm (known a priori = diameter of pipe = 110 mm) is first measured as can be shown in Figure 2.8. Next, by using image processing software such as Adobe Photoshop, the distance of A’-B’, say P’ in pixel is measured. The scaling factor for y-direction is: Y-scale = L’/P’ mm/pixel.

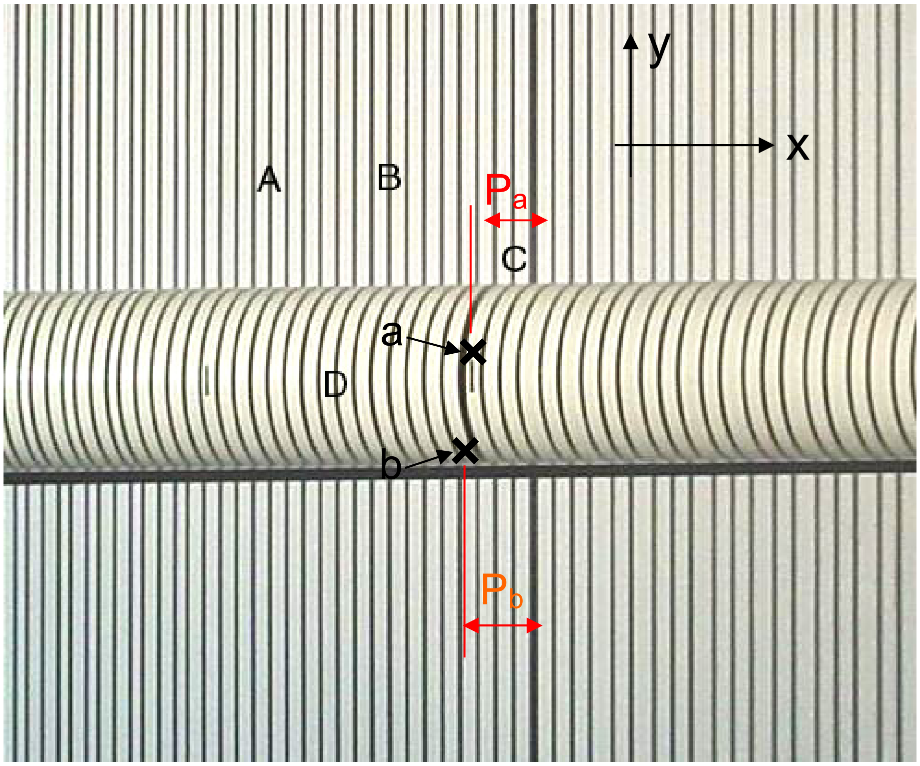


Figure 2.9: Calibration to get the z-direction coordinate

In order to get the coordinate for z-direction, a computation had to be made. Figure 2.9 shows the calibration to get the coordinate in z-direction. Pa is the distance from screen to point a in pixel and Pb is the distance from screen to the point b in pixel. Za is the coordinate of point a in z-direction and Zb is the coordinate of point b in z-direction. The example of the computation is:

1. Za =Pa x scale x tan θ
2. Zb =Pb x scale x tan θ

Figure2.10 shows the image of the seashell without using image processing software and Figure 2.11 shows the image of the seashell by using the image processing software. In this research, image processing software Adobe Photoshop CS has been used.

Figure 2.10: Seashell picture without using image processing software

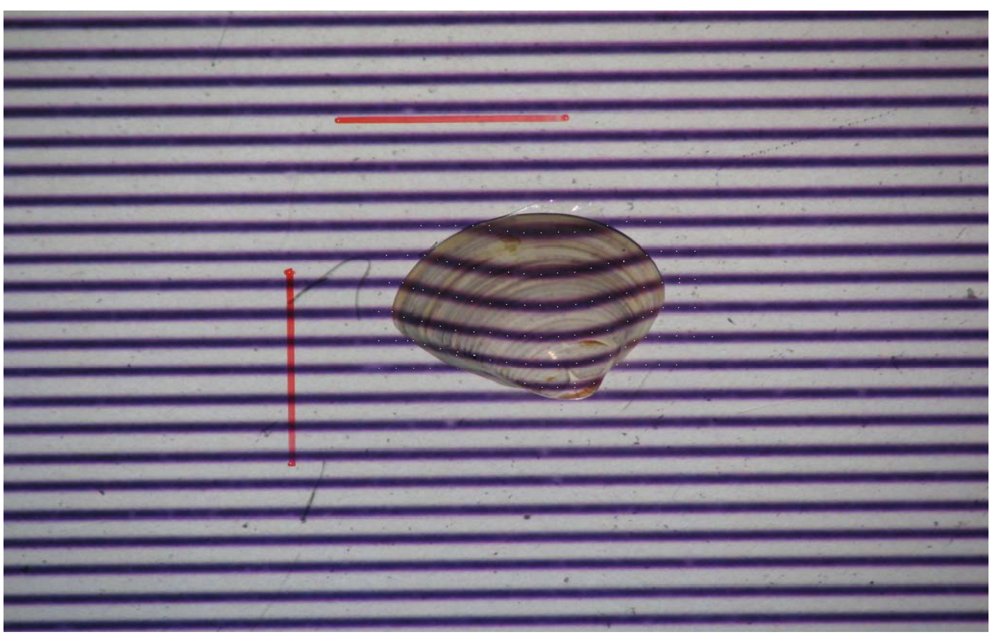


Figure 2.11: Seashell picture by using image processing software

2.2 Generation of Seashell Surface

Since seashell surface is kind of curved surface which can not be derived using mathematical equation, the measurement data of seashell surface must first had to be known. The acquisition of data of seashell surface can be done by using the method that had been explained in section 2.1 above. After the measurement of the seashell surface, by using the finite element software ADINA, the process of generating the model of seashell surface is given as shown below:

a. By using the data from the measurement using "Structured Lighting Method", all the data is input into ADINA, as shown in Figure 2.12 and Figure 2.13. Figure 2.14 shows the generated coordinates of the seashell.

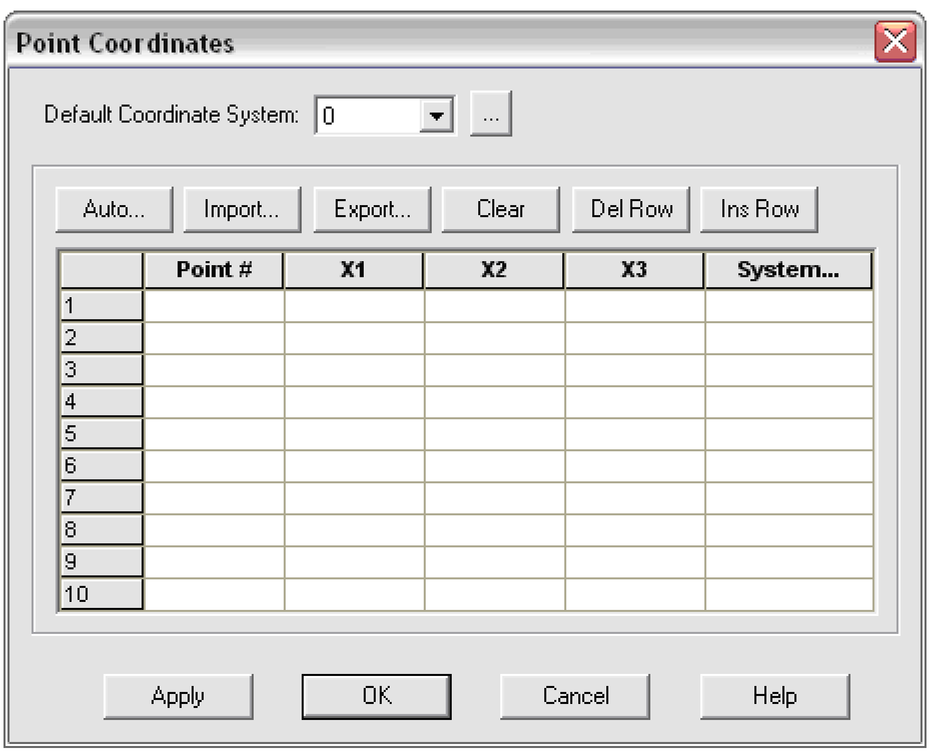


Figure 2.12: Input of measurement data into FEM software ADINA

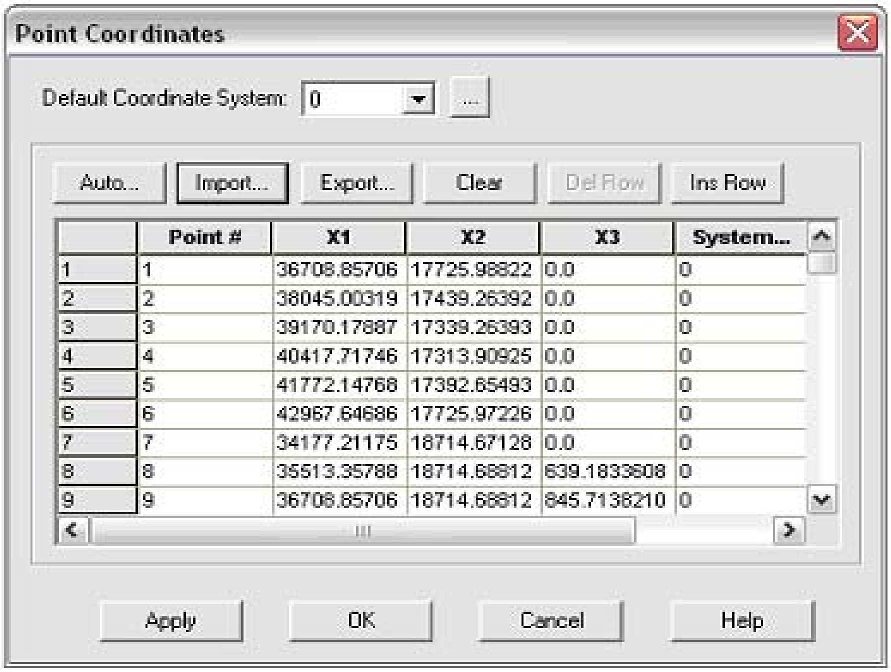


Figure 2.13: Point coordinates of the seashell

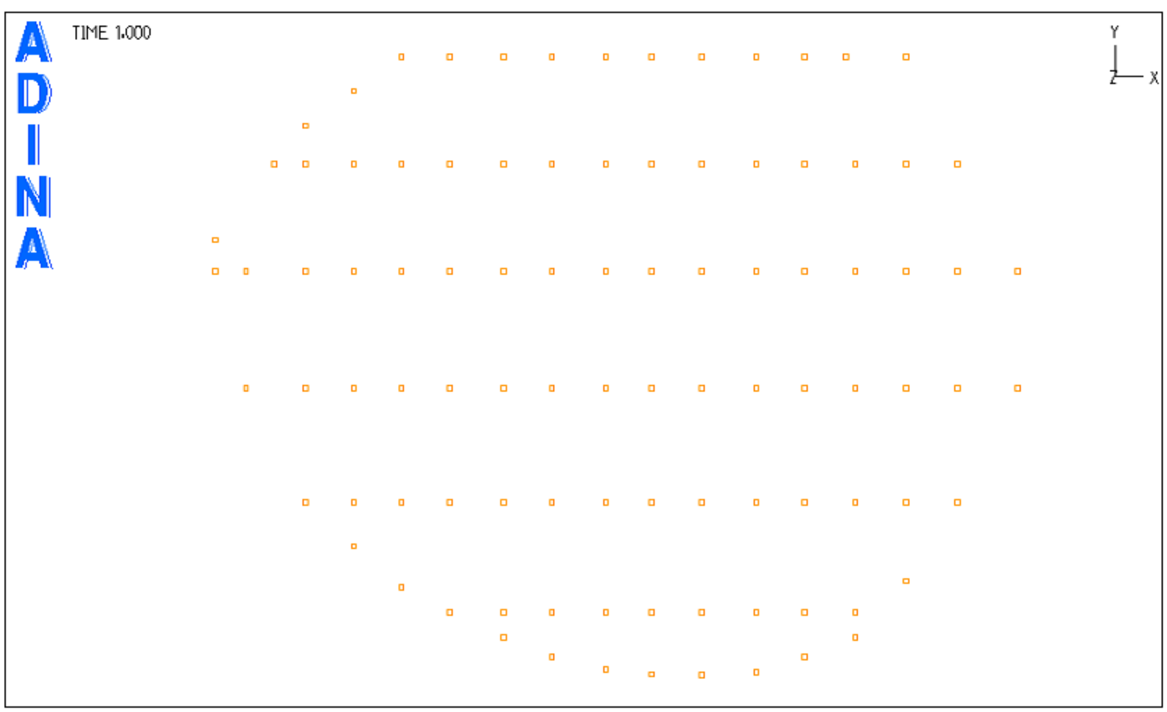


Figure 2.14: The generated coordinates of seashell surface

b. Generation of the surface of the seashell surface is next carried out. The surface has been made by using the point which had been generated before. It has to be made sure that the direction of point taking is in counter-clockwise direction as shown in Figure 2.15. The generated surface is next checked in different view angle as shown in Figure 2.16.

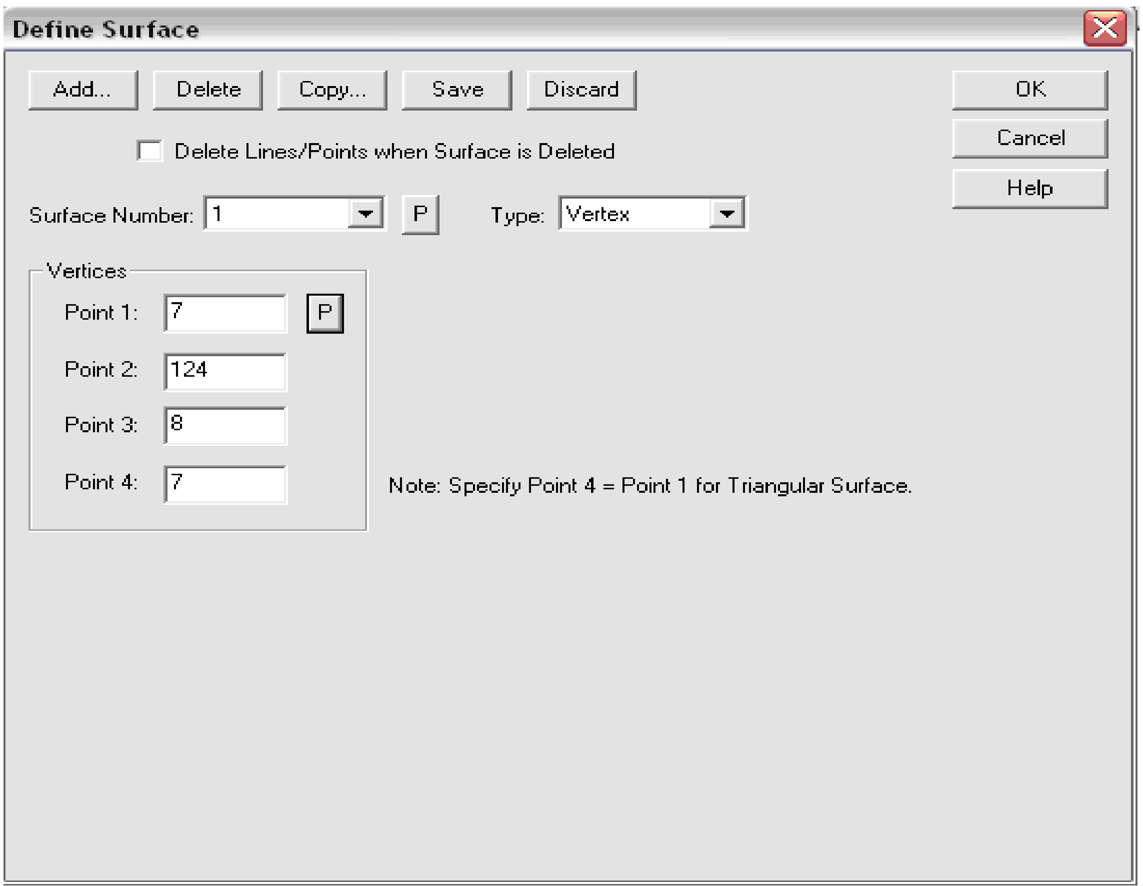


Figure 2.15: Point numbering direction: counter-clockwise

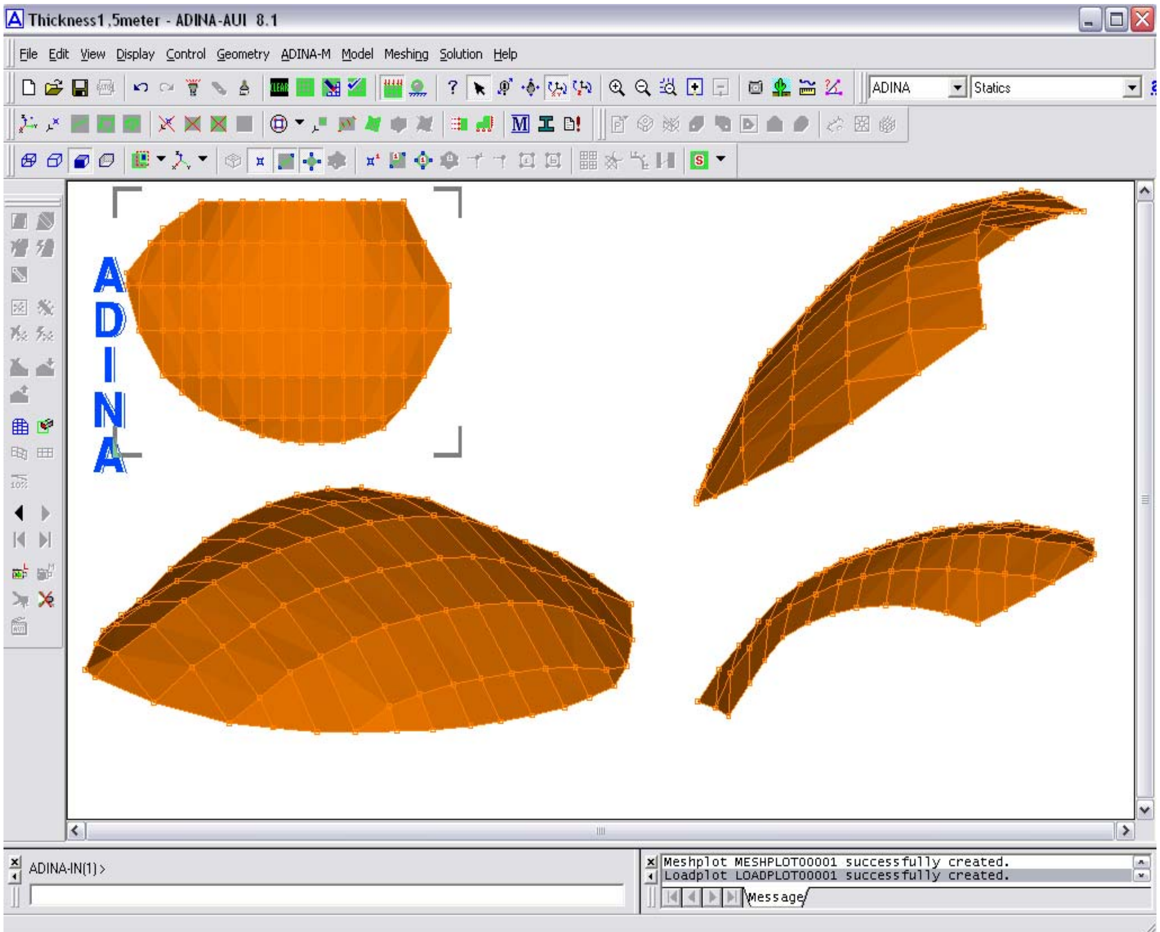


Figure 2.16: Generated surface in different angle of view

c. After the surface has been generated, the surface thickness is then defined. In this research, there are 3 different thicknesses that had been used. There are 350 mm, 500 mm and 1000 mm. Definition of surface thickness is shown in Figure 2.17 below:

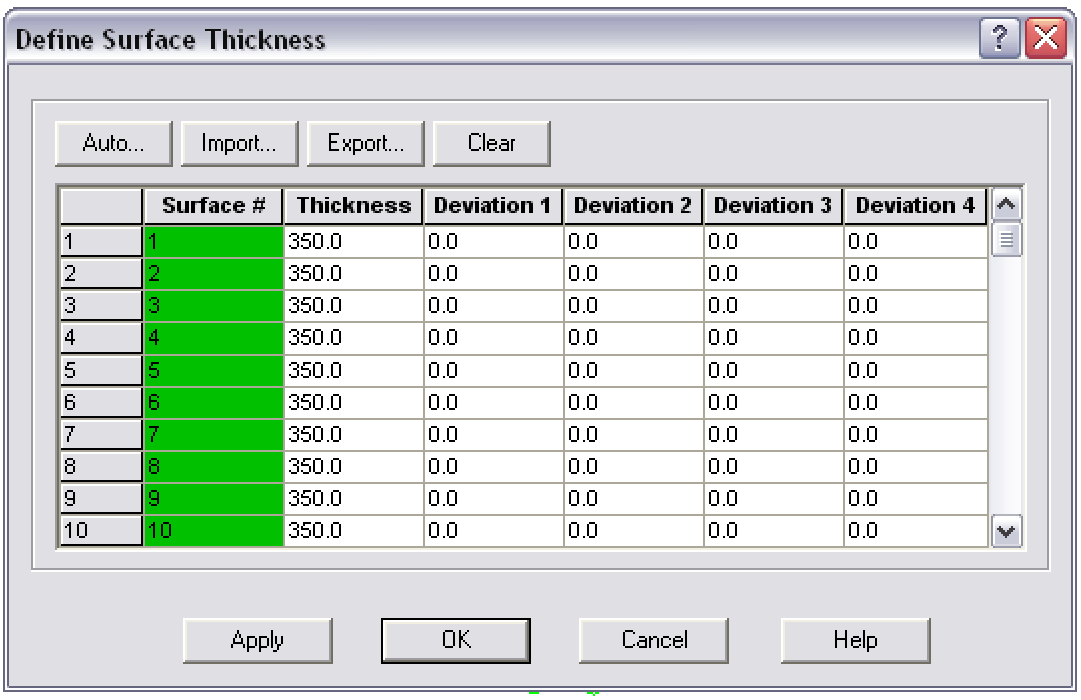


Figure 2.17: Definition of surface thickness

2.3 Boundary Condition and Loading Condition

All the boundary conditions for the model are set to be pinned type support along the boundary as shown in Figure 2.18. Hence, the degree of freedom for translations in the x, y and z directions are constrained. After that, the fixity condition is applied to the nodes that had been determined as shown in Figure 2.19.

One of the objectives of the research is to compare the strength and the rigidity of the seashell surface under self-weight. Self-weight can be created in software ADINA by applying the mass proportional type loading in the z-direction as shown in Figure 2.20. The application of load is to the analysis model as shown in Figure 2.21 and the generated boundary condition of the seashell model is shown in Figure 2.22.

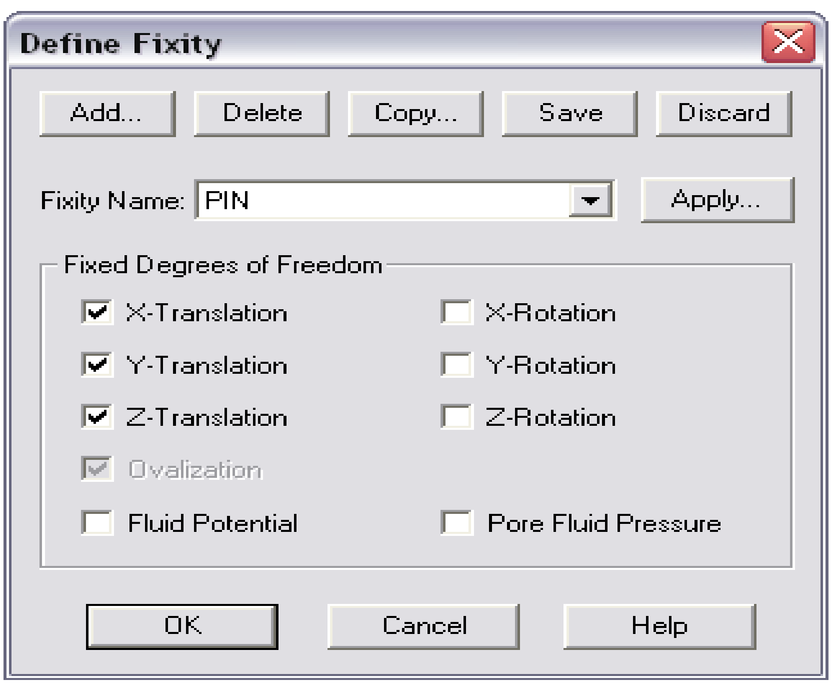


Figure 2.18: Definition of support condition