STRESS ANALYSIS OF ABOVEGROUND ATMOSPHERIC STORAGE TANK DUE TO EDGE SETTLEMENT

By

Norhafiza Binti Mohd Zukepeli

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

June 2010

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Stress Analysis of Aboveground Atmospheric Storage Tank Due to Edge Settlement

By

Norhafiza Binti Mohd Zukepeli

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Ir Dr Mokhtar Bin Che Ismail)
Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NORHAFIZA BINTI MOHD ZUKEPELI

ABSTRACT

Aboveground atmospheric storage tank is one of the important equipment in plant operation. One of the possible failures which normally overlooked is the failure of the tank due to settlement. The objective of this project is to conduct a deformation analysis based on bending moment theory and finite element analysis on deformation and bending moment distribution along section of bottom plate of aboveground storage tank that might occur during edge settlement. The results that represented the effect of edge settlement amplitude, plate thickness and foundation stiffness coefficient was generated. Using the used model, the prediction of relationship between settlement, foundation stiffness and plate thickness can be developed and future prevention of tank settlement may be applied. Comparison of the result with the API Standard 653 shows that the API Standard 653 which does not take into account of the effect of tank plate thickness, foundation stiffness, plate shell junction stiffness gives in general a conservative estimation of the allowable edge settlement limit. Using the model, for 7.5mm bottom plate thickness and 1m radial length the settlement limit is equals to 36mm which is about 20% more than the limit set by API Standard 653 for the same thickness and radial length which is 30.8mm.

ACKNOWLEDGEMENTS

First and foremost I would like to express my greatest praise and gratitude to Allah for His bounties, guidance and blessings throughout this project. With His greatest help, this project can be done even with full of hardness.

The gratitude also goes to everyone that given me all the greatest supports and guidance throughout the whole period of making this project successful especially my supervisor, Ir Dr Mokhtar Bin Che Ismail. With his trust, guidance and support, I am able to make this project possible. Apart from that, many thanks go to Dr Saravanan Karuppanan for helping me in giving advises and guide in using ANSYS software for design and simulation.

I would also like to acknowledge with much appreciation the crucial role of the evaluating lecturer, Ir Idris Bin Ibrahim and Mr Kamal Ariff Bin Zainal Abidin for their suggestion and recommendation to further improving my scope of project.

Also, thanks to my fellow colleagues for their helps and ideas throughout the completion of this study. Finally, a special thanks goes to my best friends and my parents for their endless support during the accomplishment of this project. Thank you all.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

1 INTRODUCTION

1.1 Background of study

1.1.1 General Overview of storage tank settlement

A storage tank is a container for holding liquid such as crude oil. Storage tanks are often cylindrical in shape, perpendicular to the ground with flat bottoms, and a fixed or floating roof. Design of vertical above ground atmospheric welded storage tanks shall conform to API standard 650. Tanks are relatively flexible structures and can tolerate a surprisingly large amount of settlement without showing any signs of distress. However, the flexibility of the tank itself is with limits. There are numerous example of tank failure resulted in tank settlement as for example, inoperative floating roofs, shells and piping bending damage. Tank settlement is resulted from hydrostatic pressure exerted to the wall and plate. Also, the characteristic of the soil condition and loading history can affect the differences in settlement modes of shell and bottom plate.

Settlements can cause tank failures and thus are of main concern to engineers. They are the result of localized and usually randomly distributed deformations and thus induce localized overstresses and radial distortions, known as ovality. Beyond permissible displacement limits the induced localized stresses can cause rupture and spillage of tank content, and an excessive ovality can cause a floating roof malfunction. If at any time settlement is deemed excessive, the tanks should be emptied and re-leveled. Re-leveling of a sizable tank is expensive and rather difficult to achieve. Thus, a decision to re-level a tank is a crucial one, and relies very much on the proper interpretation and evaluation of the monitored settlement data.

Assessment and monitoring of tank settlement has gradually gained greater importance in tank maintenance programs and is now a routine component of a most 10 yearly inspection, due to inclusion in the API standard 653 assessment requirements. Tank operators are realizing that the stress analysis associated with a settlement survey is as important information as that provided by an NDT survey in determining a tank's suitability for service. Generally, tank settlement of in service floating roof is conducted using Theodolite device which uses infrared measurement to come out with tank profile as stated in API 653 Appendix B. However the current method of accessing will not provide an accurate data for settlement. So, finite element analysis is chosen as the advance method to evaluate the allowable stress that can be exerted on the tank bottom.

This work focus on the analysis of the bottom plate out of plane tank settlement which is a major interest to engineers as it is frequently found in large storage tank. This type of settlement may lead to tank failure or cost for unnecessary repair if not evaluated properly.

1.2 Problem Statement

1.2.1 Problem Identification

Due to structural flexibility, a large is more likely to settle into a non-planar mode. This out of plane settlement can course tank failures and this becomes main concern for engineers. The settlement with beyond permissible limits, can cause rupture of tank and spillage of the content, it also might cause the floating roof malfunction together with another problems regarding the facilities used with the tank. Evaluation for maximum settlement amplitude and the decision to re-level the tank requires a precise stress analysis of the tank structure, especially for the area with noticeable deformations. In this case of study, the evaluations of the edge settlement become the main concern.

The API Standard 653 provides guidelines for measurement procedures of the settlements involve. However, API Standard 653 does not indicate the deformation and stress analysis procedure and the failure mode used in developing the curve for allowable settlement. It also does not shows the effects of the plate thickness and foundation shell flexibilities where these flexibilities tend to relax part of the stresses induced in the bottom plate by local settlements adjacent to the shell. This means that API Standard 653 is only provide a conservative estimation for the allowable edge settlement limit.

1.2.2 Significance of Project

Evaluation of the maximum allowable settlement amplitude, and consequently the decision on the fitness-to service and the choice of an appropriate repair procedure for a tank with a given deformation profile requires in general a rigorous stress analysis of the tank structure, specially for the areas of the tank with noticeable deformations

The Finite Element Analysis (FEA) modeling will be developed to evaluate tank settlements and provide solutions and recommendations to help maintain the integrity of tank structures based on API 653 Appendix B. The result of the assessment will be compared to the stress analysis result of the finite element method by using the ANSYS software. All the calculation used mainly based on all equations in API 653 standard. In this project, only edge settlement will be evaluated using ANSYS.

1.3 Objective

The objectives can be structured as follows:

- To do analysis on the edge settlement criteria using finite element analysis and compare the accuracy with the limit set by API Standard 653.
- To determine the stress affected by the difference in plate thickness and the crude level height to the settlement limits.

1.4 Scope of study

In determining the effects of soil settlement on storage tanks, it is common practice to monitor settlement of the tank bottom. In most cases, such a monitoring program is initiated during the construction and continued during hydrostatic testing and operations. During operations, settlement measurements should be taken at a planned frequency, based on an assessment of soil settlement predictions. For existing tanks that do not have initial settlement data, a program of settlement monitoring should be based on prior service history. In the present work, the Finite Element Analysis (FEA) simulation will be modeled to determine the stress associated with the settlement and the accurate prediction of tank remaining life.

1.5 Benefit and Feasibility of the Proposed Project

- Enable accurate prediction of future tank remaining life
- Prevent tank failure by accurately predicting its settlement profile
- Assist plant in developing tank mitigation plan
- Finite Element Analysis (FEA) stress analysis will determine there to focus inspection

CHAPTER 2

2 LITERATURE REVIEW

Many engineers incorrectly believe that settlement poses little threat to large, flexible storage tank. However, settlement has led to rupture of large tanks (Bell, 1980; Clarke, 1969; and Green and Hight, 1974). Disagreement existed among engineers, builders and regulators on limiting values of settlement.

2.1 General Description of Tank Settlement

The principal of tank settlement consist of settlements that relate to the tank shell and bottom plate. These settlements can be recorded by taking elevation measurements around the tank circumference and across the tank diameter. Figure 1 bellow shows recommended locations on a tank shell and bottom plate for settlement measurements. Data obtained from the measurement will be used to evaluate the tank structure. Additional settlement readings may be required to define depressions.

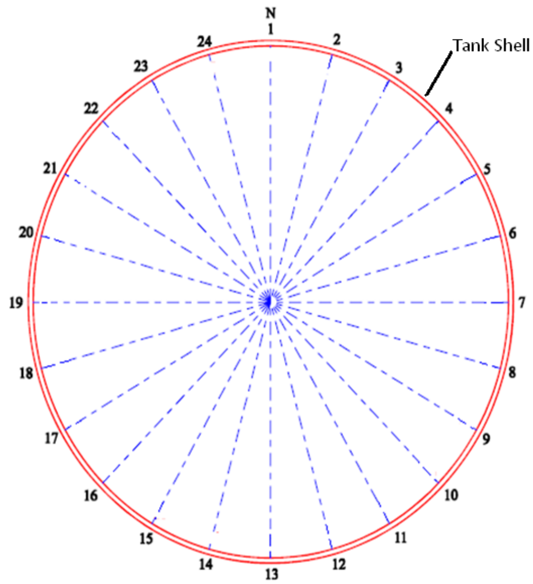


Figure 1: External measurement of shell settlement

2.2 Type of Settlement and Tank Failure Mechanics

Failure due to settling can be defined by the occurrences of these effects:

- Roof binding on floating roof tanks
- Damage or early worn out of floating roof seals
- Shell buckling in floating roof tanks
- Cracking of welds
- Loss of acceptable appearance
- Overstress of connected piping
- Accelerated corrosion due to drainage pattern changes outside the tank
- Inoperative or less effective drainage on the interior of the tank, especially where cone up or cone down or single slope bottoms are used
- Increased susceptibility to seismic damage as a result of distorted, overstressed or deformed bottoms
- Leaks in bottom or shells resulting from settling

The most serious failure mode results are leakage or loss of contents. The presence of even small crack in the tank bottom can pose a serious threat to the integrity of the tank. Several notable settlement failures that have occurred involved the following consequences:

- Development of an initial leak, caused by a crack in the tank bottom.
- Washout of foundation support immediately near the initial leak location. This causes the crack to grow due to the lack of support, and the leakage increases.
- The leak flow increases and the support under the tank is undermined to the point where the bottom separated from themselves or shell where the foundation has washed away**.**

Settlement of a tank is the result of either one, or a combination of the following settlement components which is:

1) Uniform settlement

For uniform settlement, the soil conditions are relatively uniform, and it is compressible. A storage tank under these conditions will slowly but uniformly sink downward. There is no significant problem with indefinite uniform settling. However there are two significant side effects resulted from this kind of settling which is:

1.1) Water ingress

Occurs when a depression or water trap is formed around the periphery of the tank where it meets the soil. When it rains or floods, moisture accumulates under the tank bottom near the shell or chime region and acts to corrode the bottom. Any moisture under the tank may condense but unable to escape to the atmosphere and may cause corrosion at the bottom.

1.2) Piping

Piping connected to the tank will eventually become overstressed by movement of the tank relative to the piping and its supports. It is possible to assess the degree of uniform settlement by simply monitoring the elevations at the base of the tank.

2) Rigid body tilting of a tank (planar tilt)

This type of settlement occurs when the tank rotates in a tilted plane. The tilt will cause an increase in the liquid level and, therefore, an increase in the hoop stress in the tank shell. Also, excessive tilting can cause binding of peripheral seals in a floating roof and inhibit roof travel. Often, planar tilt accompanies uniform settlement as well as the concern addressed for uniform settling there are several additional phenomena that occur as the tilt becomes severe.

Common phenomena that can be seen or measure after the tank experiences planar tilt settlement are:

2.1) Appearance

When the tank experiences even a small angle of tilt, the tank begins to look strange. This can be seen by anyone.

2.2) Hydrostatic Increase

The tilt will result in an increase in hydrostatic head as shown in Figure 2. The increase in hydrostatic head maybe estimated approximately by $D\,\Delta S/2$ where D is the tank diameter and ΔS is the high-to- low differences in tank bottom elevation. The effect is to increase the shell hoop stress slightly. Planar tilt can be accessed from an external tank inspection by taking elevation reading at several locations around the base of the tank.

2.3) Storage Capacity Reduced

Since the design liquid level is often just beneath the floating roof, the maximum liquid level and capacity may be reduced.

2.4) Ovalizing

If a tank tilts, the plan view will be will be an ellipse as shown in Figure 2. Since floating roof tanks have specific clearances and out-of-round tolerance for their rum seals to work properly, the possibility of planar tilt's causing seal problems exist. The amount of ovalizing can be estimated by $\Delta S = 2\sqrt{TR}$ *(*ΔS *= Maximum acceptable settlement, T = Radial tolerance on floating-roof tank shell, R = Tank radius)*

3) Out of plane settlement (differential settlement)

This settlement is due to the fact that a tank is a rather flexible structure. Chances are great that the tank shell will settle in a non-planar configuration, inducing additional stresses in the tank shell. The out-of-plane settlements at the bottom edge lead to a lack of circularity at the top of the tank, and in the case of a floating roof tank, the extent of the induced ovality may impede the proper functioning of the floating roof in such a way that releveling is required. This settlement may also cause flat spots to develop in the tank shell.

Differential settlement as might be expected is more serious nature that uniform and planar settlement because deflection of the structure on a local scale is involved which reduces high local stresses. Differential edge settlement results in two main problems:

3.1) Ovalizing

The differential settlement that occurs in the tank bottom near the shell produces the out-of-roundness in the top of tanks which are not restricted in movement (for fixed roof tank). One of the most noticeable and serious problems with differential edge settlement in the bottoms of floating roof tanks is in the operation of the floating roof, Because the floating roof seals have specific tolerance limits between the edge of the roof and tank shell, ovalizing can interfere with the operation or even destroy the seal itself.

3.2) Shell stress due to differential shell settlement

Non planar differential settlement may result in high shell stresses being generated. These high stresses are generated near the tank and may result in buckling of the upper courses.

4) Edge settlement

Edge settlement occurs in the bottom plates near the shell. It occurs when the tank shell settles sharply around the periphery, resulting in deformation of the bottom plate near the shell-to-bottom corner junction. It is almost impossible to determine the condition of this type of settlement from the exterior of the tank. However, from the inside, this is one of the most prominent and obvious type of settling. It is usually can be seen with the naked eye. The allowable edge settlement limit is given by the formula of B = 0.0308R. Where B is allowable edge settlement and R is the distance between shells and start of edge settlement.

This project focus on the analysis of the bottom plate out of plane edge settlement which is major interest as it is frequently found in large storage tanks and can lead to tank failure or costly unnecessary repair if not evaluated properly. The edge settlement developed when tank shell settles sharply around the periphery leading usually to excessive and localized bottom plate deformations near the plate shell-junction as shown in figure 2.

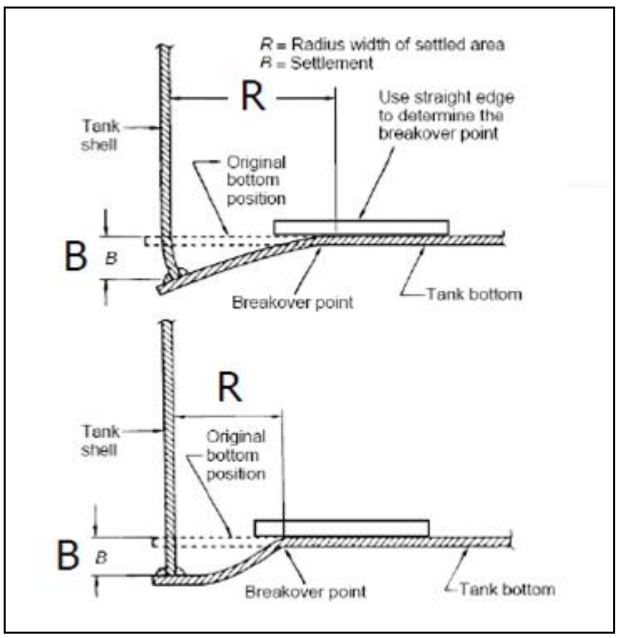


Figure 2: Tank Edge Settlement

(API Standard 653)

Measurement taken when the bottom is not in contact with the soil or foundation under the tank can overestimate edge settlement significantly. If the measured settlement is near the maximum allowable settlement, repeating the measurement with the bottom forced down to the soil should be considered. The API Standard 653 provides guidelines for measurement procedure of the localized depression edge settlement and recommends using the following criterion on evaluating the allowable edge settlement deflection limit:

$$\frac{B}{R} \leq 0.03083$$

Where:

B = Plate edge maximum deflection

R = Radial length of the plate settled area

The API standard 653 also provides 2 graphs for evaluation B for different values of tank diameters in cases where the area of the localized edge includes floor lap-welds approximately parallel to the shell (B_{ew}) (figure 3) and another for edge settled area with no floor welds or any floor butt-weld or lap-welds in the floor that approximately perpendicular to the shell (B_e)(figure 4). Since B_{ew} is more conservative than B_e, the simplest approach is to initially evaluate measured settlement B against B_{ew} for all settle area. The API Standard 653 indicates that these curves which were developed for a plate of ¼ inch in thickness maybe used with reasonable accuracy for the thickness range of 5/16 to 3/8 inches and it also provides an interpolation formula for evaluation B for the cases which the area of the localized edge settlement has weld at an arbitrary angle to the shell. However it does not include the deformation analysis procedure and the failure mode used in developing these curve, not do these curves show the effect of plate thickness and the foundation and shell flexibilities where these flexibilities tend to relax part of the stresses induced in the bottom plate by local settlement adjacent to the shell.

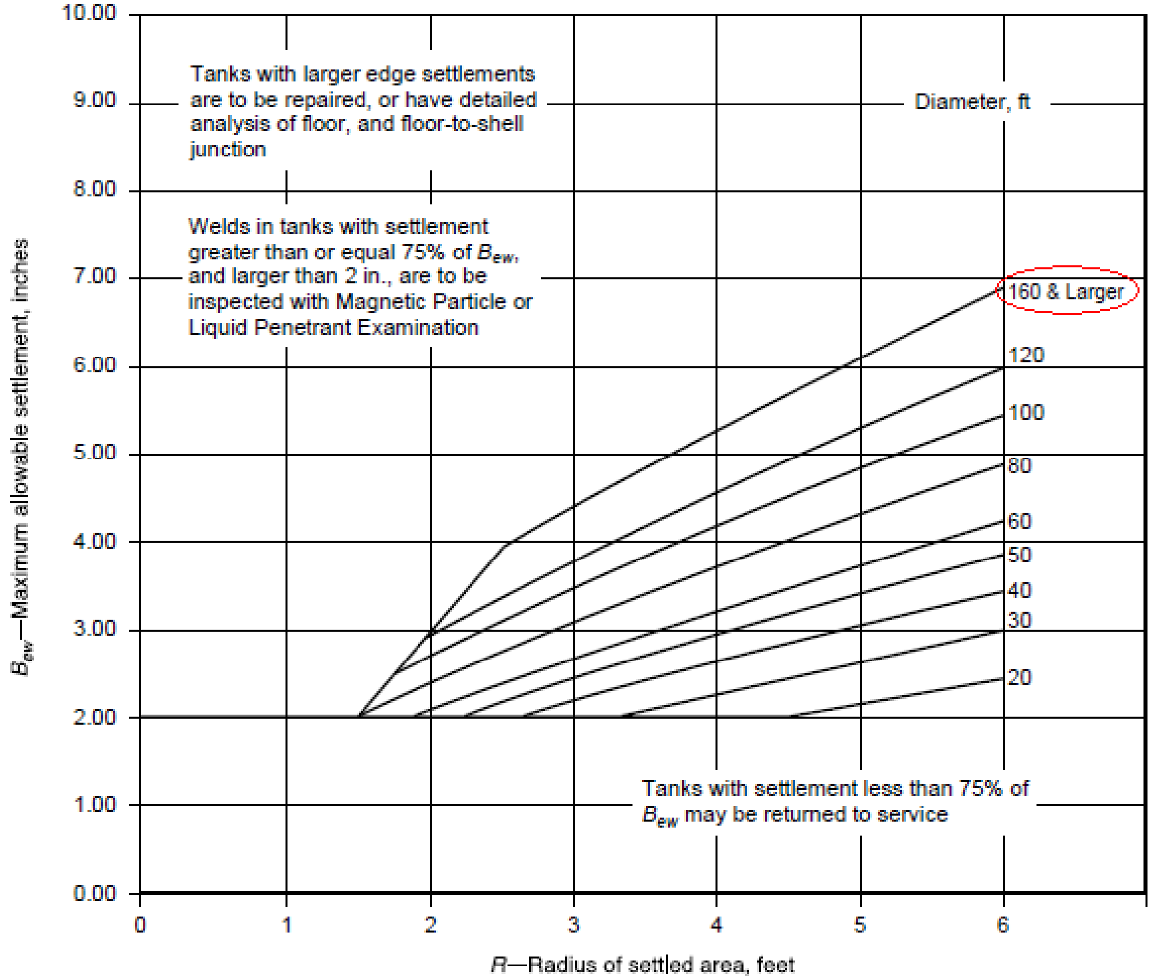


Figure 3: Maximum Allowable Edge Settlement for Areas with Bottom Lap Welds Approximately Parallel to the Shell

(API Standard 653)

According to the tank diameter, the curve that should be used is for 160ft and above, since the tank diameter is 233.6 feet. Using this curve, the radius of settled area and maximum allowable settlement can be predicted. To read this graph, the tank diameter has to be known and the radius of settlement together with its maximum allowable settlement is interpolated using the diameter curve. Value of settlement more than as stated on the table for any radius of settlement, may result in damages and has to be repaired. It will provide information for future used in finite element analysis.

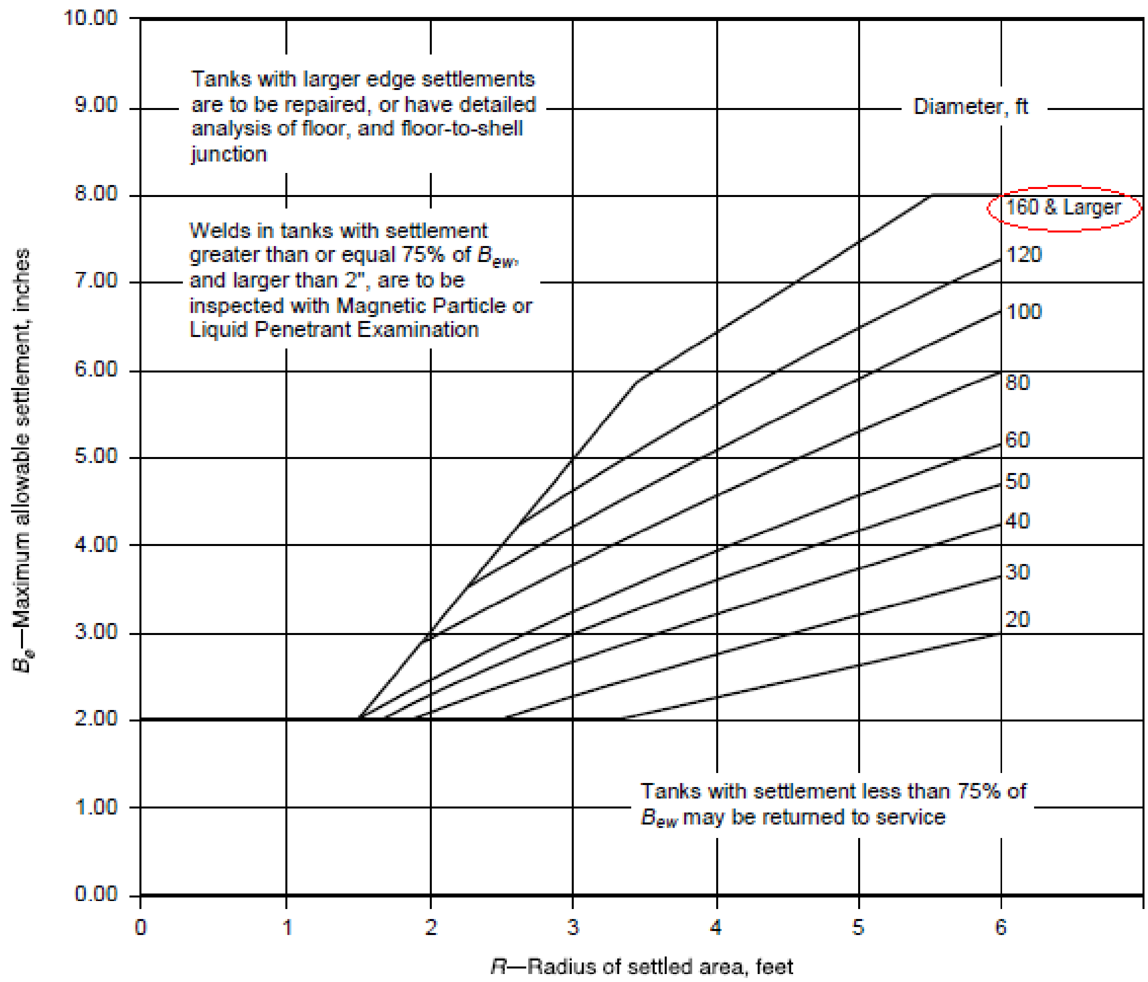


Figure 4: Maximum Allowable Edge Settlement for Areas with Bottom Lap Welds Approximately Perpendicular to the shell

(API Standard 653)

According to M.N Hamdan in a journal entitle ‘A simplified analysis of edge settlement of a large aboveground liquid storage tank’, had refers to a beam model theory to simplify the analysis of edge settlement. The localized edge settlement of a uniform bottom plate resting on elastic foundation with stiffness K_f per unit area with settlement extending over a plate section of radial length R and having maximum settlement, B at the plate edge is analyzed by considering a unit width radial strip of length R.

The model used which representing the deformed strip, is assumed to have thickness of t, cross-sectional area flexural rigidity EI in unit width, resting on elastic foundation of stiffness K_f and subjected to uniform liquid pressure, P. At the breakover point (i.e x = 0) the beam vertical deflection y and bending moment M are assumed zero [malhotra and Veletsos, 1994]. At the connecting end to the shell, the beam is assumed to be elastically constrained against both rotation and axial displacement by a torsional stiffness, K_r and translational stiffness, K_t of linear spring. These end springs are assumed to be induced by a linear elastic and infinite long cylindrical shell subjected at it base, due to hydrostatic loading, to an axisymmetric bending moment, M_a and transverse shear force, $N_{a,}$ where M_a, N_a and the spring coefficient K_r and K_t.(Timoshinko and Woinowsky-Krieger,1984). The beam model can be specified as figure 5 below:

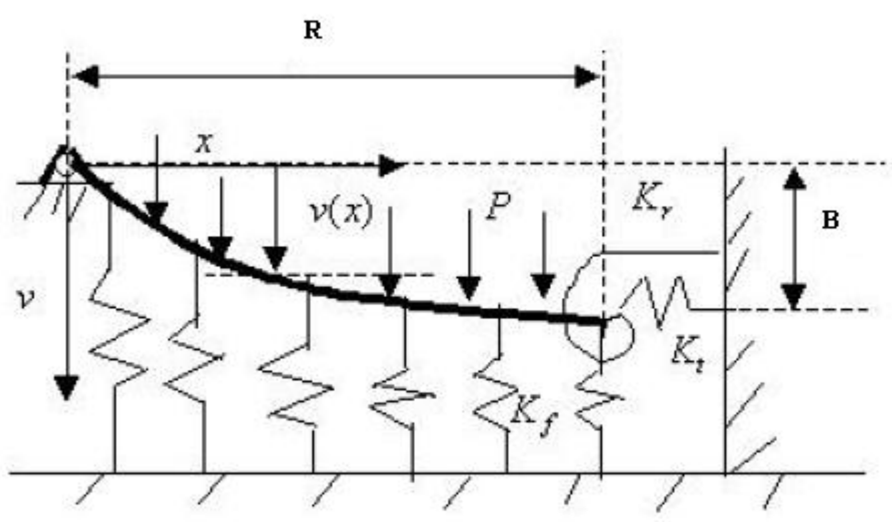


Figure 5: Edge Settlement Beam Model

(M.N Hamdan)

$$K_r = \frac{E\ {t_s}^2\ (t_s/r)^2}{2[3(1-\mu^2)]^{3/4}}$$

……… (1.a)

$$K_t = \frac{E(t_s/r)^{3/2}}{[3(1-\mu^2)]^{3/2}}$$

……… (1.b)

$$M_a = \left(1 - \frac{1}{\beta h}\right)\frac{\gamma r h t_s}{\sqrt{12(1-\mu^2)}}$$

……… (1.c)

$$N_a = \frac{\gamma r h t_s}{\sqrt{12(1-\mu^2)}}\left(2\beta - \frac{1}{r}\right)$$

.... (1.d)

Where;

$$\beta = \left(\frac{3(1-\mu^2)}{r^2 {t_s}^2}\right)^{1/4}$$

E = Young's Modulus

t_s = Shell wall thickness

r = Tank radius

h = liquid Height

γ = liquid specific weight

μ = Poisson's Ratio

Using Euler-Bernoulli beam bending theory, the deflection, v of the above described beam in the presence of constant axial force N may be described by the following linear ordinary linear equation:

$$EI\frac{d^4v}{dx^4} - N\frac{d^2v}{dx^2} + K_f v = P$$

This can be written in the following form:

$$\frac{d^4v}{d\xi^4} - K_1\frac{d^2v}{d\xi^2} + K_2 v = q$$

……… (2)

Where:

$$\xi = \frac{x}{R}$$

$$K_1 = \frac{NR^2}{EI}$$

$$K_2 = \frac{K_f R^4}{EI}$$

$$q = \frac{PR^4}{EI}$$

Based on the assumption made, the four boundary condition associated with the above equation may be specified as:

At $x = 0: v = 0 \; and \; \frac{d^2v}{d\xi^2} = 0$

…….(3-a, b)

At $\xi = 0: v = B \; and$

……… (3-c)

$$M = EI\frac{d^2v}{d\xi^2} = \begin{cases} -\frac{K_r}{R}\frac{dv}{d\xi} + M_a \; for \; M(1) \le M_y \\ -M_y \qquad for \; M(1) \le M_y \end{cases}$$

……… (3-d)

Where M_y is yielding moment at beam shell junction (i.e at $\xi = 1$).

$$M_y = \frac{\sigma_y t^2}{12}$$

……… (3-e)

Using this condition, it was assumed that the shell thickness is greater than the plate thickness so that the yielding at the plate junction is initiated in the beam and not in shell. Therefore, M_y in equation (3-d) will be taken to be beam yield moment. In addition to the above four boundary condition, this following equation is obtained by assuming the beam to be inextensible and has zero horizontal displacement when $\xi = 0$, will be used in determine the unknown axial force N in equation (2):

$$N = -K_t U + N_a = -\frac{K_r}{2}\int_0^1 \left(\frac{dv}{dx}\right)^2 dx + N_a$$

……… (4)

Where $U = \frac{1}{2l}\int_0^1 \left(\frac{dv}{d\xi}\right)^2 d\xi$ is the axial shortening of the bent inextensible beam model in equation (2) – (4).

The beam deflection, v(ξ) can be described by equation:

$$v(\xi) = \frac{P}{K_f} e^{-a\xi}\left[A_1 \cos(b\xi) + A_2 \sin(b\xi)\right] + e^{-a\xi}\left[A_3 \cos(b\xi) + A_4 \sin(b\xi)\right]$$

……… (5)

Substituting equation (5) into equation (3), noting that the beam bending moment is given by $M(\xi) = \frac{EI}{R^2}\frac{d^2 v}{d\xi^2}$ leads to following express for the constant A_i,i =1,…4:

$$A_1 = \frac{-P}{K_f} - A_3$$

……… (6-a)

$$A_2 = A_4 + \frac{b^2 - a^2}{2ab}\frac{P}{K_f}$$

……… (6-b)

$$A_3 = \frac{F_1 C_4 - F_2 C_2}{\Delta}$$

……… (6-c)

$$A_4 = \frac{F_2 C_1 - F_1 C_3}{\Delta}$$

……… (6-d)

Where

$$\Delta = C_1 C_4 - C_2 C_3,$$

$$F_2 = e^a \left(B - \frac{P}{K_f}\right) + \frac{P}{K_f}(\cos b + \frac{a^2 - b^2}{2ab}\sin b)$$

$$F_2 = \frac{P}{K_f}\left[\frac{(a^2 - b^2)^2}{2a}\sin b\right] - \frac{R^2 M_y e^a}{EI}$$

$Where: C_1 = (e^{2a} - 1)\cos b$

$C_2 = (e^{2a} + 1)\sin b$

$C_3 = (a^2 - b^2)(e^{2a} - 1)\cos b - 2ab(1 + e^{2a})\sin b$

$C_4 = (a^2 - b^2)(e^{2a} + 1)\sin b + 2ab(e^{2a} - 1)\cos b$

These equations define the close form of solutions for the coefficients A_i,i =1,…4 for the beam deflection in equation 5. Using equation (5) and (6), substitute $\frac{dv}{d\xi}$ into equation (4) to solve axial force N. This method will lead to complicated equation and hard to solve. To avoid this difficulties, an approximation t the unknown axial force N is obtain by assuming the v(ξ) profile may be approximated as:

$$v(\xi) = \ Bsin\left(\frac{\pi\xi}{2}\right)$$

……… (7)

Substitute this equation into equation (4):

$$N = \frac{-\pi^2 B^2 K_r}{16R} + N_a$$

……… (8)

Finally, using equation (5) the equation for bending moment distribution M(ξ) along the beam can be expressed as:

$$M(\xi) = \frac{EI}{R^2}\frac{d^2 v}{d\xi^2}$$

……… (9)

CHAPTER 3

3 METHODOLOGY

3.1 Procedure Identification

3.1.1 Project Initiation

The project begins with collecting information related to common settlement in industries. It further continues with designing tank storage using ANSYS software. The project will be continued by solve the modelled storage tank in ANSYS. The resulted stress from the solution will be compared with the analytical calculation method. If the result is failed to achieve maximum edge settlement allow, the design process will be repeated until it reaches the objective to determine the maximum stress exert on the tank bottom plate.

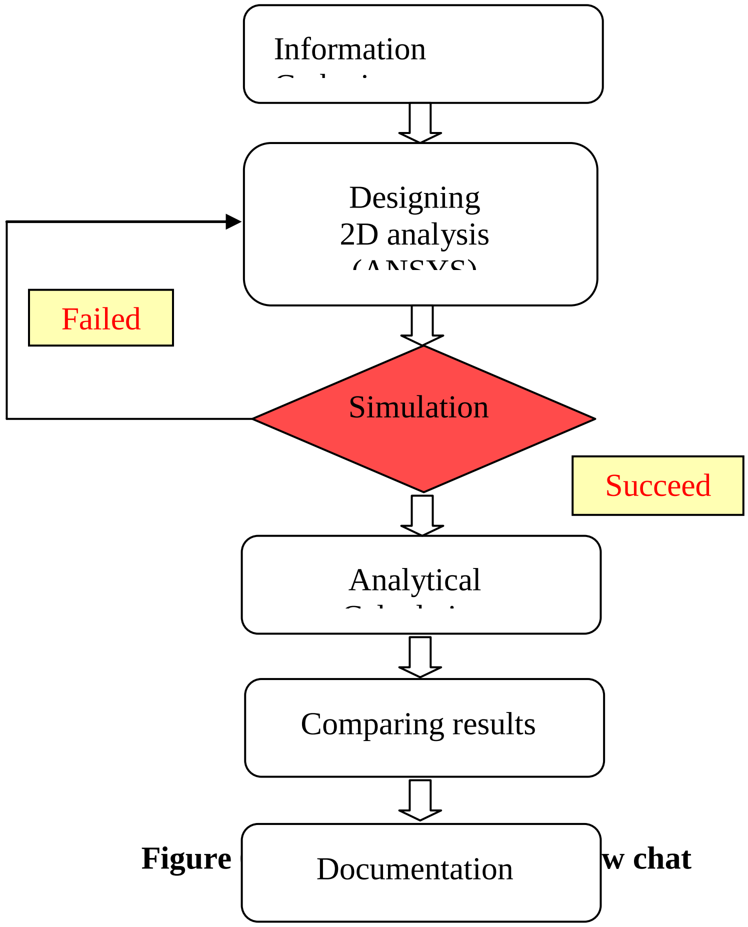


Figure **w chat**

3.2 Tools

3.2.1 ANSYS

The software used to accomplish this project is ANSYS, to develop a finite element analysis model and simulation. ANSYS is general-purpose finite element computer program that contains more than 100,000 lines codes. ANSYS is capable of performing static, dynamic, heat transfer, fluid flow and electromagnetism analysis. ANSYS is the most suitable software when dealing with finite element analysis modelling. Within the objective of this project, structural analysis is the best option.

There are 3 basics phase in ANSYS which are:

1) Preprocessing Phase
   - Creating and discrete the solution domain into finite element; which is subdivides the problem into nodes and elements.
   - Assume a shape function to present the physical behaviour of an element; that is, a continuous function to represent the physical behaviour of an element
   - Develop equation for an element.
   - Assemble the element to present the entire problem.
   - Apply boundary conditions, initial condition, and loading.

2) Solution Phase
   - Solve a set of linear or nonlinear algebraic equations simultaneously to obtain nodal result, such as displacement values at different nodes.

3) Postprocessing Phase
   - Obtain other important information such as principal stresses.

The same approach using this method. The bottom plate of the tank is design as a beam. All the boundary conditions will be applied on the beam and the result is evaluated.

Pre-processing: Defining the Problem

1) **Giving title**

   Utility Menu > File > Change Title ...
   /title, Storage tank

2) **Open preprocessor menu**

   ANSYS Main Menu > Preprocessor

3) **Create Areas**

Preprocessor > Modeling > Create > Areas > Rectangle > By Dimensions

The value is depending on the analysis we want to deal with. Since storage tank is very big, a portion which is close to the settled area is taken so that the result can clearly be visualized.

4) **Define the Type of Element**

Preprocessor > Element Type > Add/Edit/Delete...

For this problem we will use the PLANE2 (Structural, Solid, Quad 4node182) element. This element has 2 degrees of freedom (translation along the X and Y axes).

5) **Define Element Material Properties**

Preprocessor > Material Props > Material Models > Structural > Linear > Elastic > Isotropic

In the window that appears, enter the following geometric properties for steel:

a. Young's modulus EX: 210e9
b. Poisson's Ratio PRXY: 0.29

6) **Define Mesh Size**

Preprocessor > Meshing > Size Cntrls > ManualSize > Areas > All Areas

7) **Mesh the frame**

Preprocessor > Meshing > Mesh > Areas > Free > click 'Pick All'

Solution Phase: Assigning Loads and Solving

1. **Define Analysis Type**

   Solution > Analysis Type > New Analysis > Static

2. **Apply Constraints**

   Solution > Define Loads > Apply > Structural > Displacement > On Nodes

   The nodes selected are based on the value of radial length of the plate settled area.

3. **Apply Loads**

   Solution > Define Loads > Apply > Structural > Force/Moment > On nodes
   The force resulted from the weight of the tank wall is defined here.

   Solution > Define Loads > Apply > Structural > Pressure > On Lines
   Hydrostatic pressure inside the tank is defined on the upper line of the beam.

4. **Solve the System**

   Solution > Solve > Current LS

Post-processing: Viewing the Results

General Postproc > Plot Results > Contour Plot > Nodal Solu

3.2.2 CATIA P3 V5R14

Apart from ANSYS, CATIA P3 V5R14 has also been used for designing the actual tank storage. CATIA is an integrated software of Computer Aided Engineering (CAD) to develop 3D modelling shape in simulate the real model of thank storage. The software is used because of this software made the designing of a storage tank become simpler. This approach is at first time used as a trial to design storage tank, but after having difficulties on importing CATIA V5 data to ANSYS, so the trial failed.

CHAPTER 4

4 RESULT AND DISCUSSION

4.1 Result

For this project, the specification obtained from the tank actual drawing and specification. Bellow is the tank specification that has been gathered.

Tank specification:

Diameter, D: 71.2 m

Height, h: 21.0 m

Material: mild carbon steel (ASTM A537 CL 2)

Young modulus, E: 210GPa

Density, ρ: 7.85 g/cm^3

Poison ratio, μ: 0.29

Thickness of the tank is vary for each height

Crude specification:

Density: 0.86 g/cm^3

Specific Weight, γ: 862 N/m^3

Maximum crude inside the tank: 19.8m

4.1.1 Calculation

Pressure Inside

$$P = P_{atm} + \rho g h$$

$$= 101kPa + \left(860\ {}^{kg}/_{m^3}\right)\left(9.81\ {}^{m}/_{s^2}\right)(21m)$$

<u>P = 278 kPa</u>

Tank Shell Volume

Table 1: Tank Shell Volume

t_s (thickness)	R(Outer radius)	r (Radius with thickness	V (Volume of hollow cylinder)
0.0301	35.6	35.5699	20.19
0.0245	35.6	35.5755	16.43
0.0203	35.6	35.5797	13.62
0.0161	35.6	35.5839	10.80
0.0119	35.6	35.5881	7.98
0.01	35.6	35.59	6.71
0.01	35.6	35.59	6.71
		Total	**82.45**

Weight of tank shell

Mass $=\rho V$

$$= \left(7850\ {}^{kg}/_{m^3}\right)(82.45m^3)$$

= <u>647232.5 kg</u>

Weight = mass x gravitational acceleration

= (647231.5kg)(9.81m/s^2)

= <u>6349341.02 N</u>

Tank Volume

Table 2: Tank inner volume

Height	r (radius)	Volume
3	35.5699	11924.4
6	35.5755	23856.3
9	35.5797	35792.9
12	35.5839	47735.1
15	35.5881	59683.0
18	35.59	71627.3
21	35.59	83565.1
	Total	**334184.2**

Weight of crude inside

Mass $=(\rho V)_{liquid}$

$$= \left(860\, {}^{kg}\!/_{m^3}\right)(334184.2 m^3)$$

= 287398240 kg

Weight = mass x gravitational acceleration

= (287398240kg)(9.81m/s^2)

=2819376734 N

Hoop Stress

The hoop stress can be expressed as:

$$\sigma_h = \frac{PD}{2t}$$

$$= \frac{(278 \text{ kPa})(71.2)}{2(0.0075)}$$

= 1.31 GPa

Longitudinal Stress

The longitudinal stress can be expressed as:

$$\sigma_L = \frac{PD}{4t}$$

$$= \frac{(278KPa)(71.2m)}{4(0.0075)}$$

= 659.8 MPa

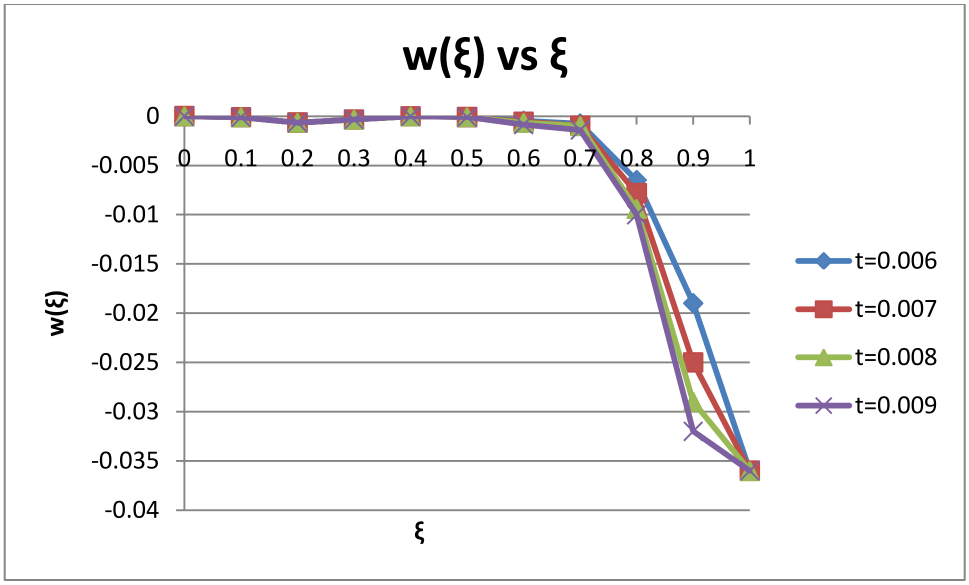
According to equation (5) and (9), the behavior of deflection configuration v(ξ) and bending moment M(ξ) of the beam model as figure 5. The variation of edge settlement, B, radial length, R and foundation elastic stiffness, K_f will be examined using these equations. Since the beam deflection v(ξ) is positive when downward, so for better visualization purpose, it is better to use w(ξ) = -v(ξ). The result also presented behavior of bending moment ratio $M(\xi)/M_y$ where M_y can be calculated using equation (3-e). Using this method, it is expected that maximum edge settlement, B can be determined, by using parameters bellow or above the allowable limits the examine the corresponding plot of the ratio $M(\xi)/M_y$ versus ξ. If at any one or more of the beam interior points, ($\xi<1$) the ratio $M(\xi)/M_y$ will be more than 1, which means yielding has occurred at the interior point of the beam and the edge settlement amplitude, B is above allowable limit. When the ratio of $M(\xi)/M_y$ is bellow than 1 for every $\xi<1$, it is considered that the settlement is bellow the allowable limits even if yielding takes place at the shell beam junction ($\xi=1$, $M(1)=M_y$).

The calculated table bellow is for plate thickness t= 0.075, K_f = $3x10^7 N/m^3$, B = 0.036m and h=21m.

Table 3: Example of calculated M(ξ)/My

My	B	ξ	v(ξ)	M(ξ)/My
9656.25	0.036	0.0	0.000	0.000
9656.25	0.036	0.1	0.006	-0.120
9656.25	0.036	0.2	0.011	-0.118
9656.25	0.036	0.3	0.016	-0.050
9656.25	0.036	0.4	0.021	-0.031
9656.25	0.036	0.5	0.025	0.070
9656.25	0.036	0.6	0.029	0.450
9656.25	0.036	0.7	0.032	0.781
9656.25	0.036	0.8	0.034	0.978
9656.25	0.036	0.9	0.036	0.910
9656.25	0.036	1.0	0.036	-1.000

For the first evaluation, the effect of plate thickness is evaluated with constant foundation stiffness, Kf, settlement, B and the height of crude level inside the tank, h. Taken K_f=$3x10^7 N/m^3$, B=0.036 and h=21m. As can see in the graph, the thicker the thickness, the lower value for the $M(\xi)/M_y$ which means that the harder for the tank to settled is beyond the allowable limits even if yielding takes place at the shell beam junction.



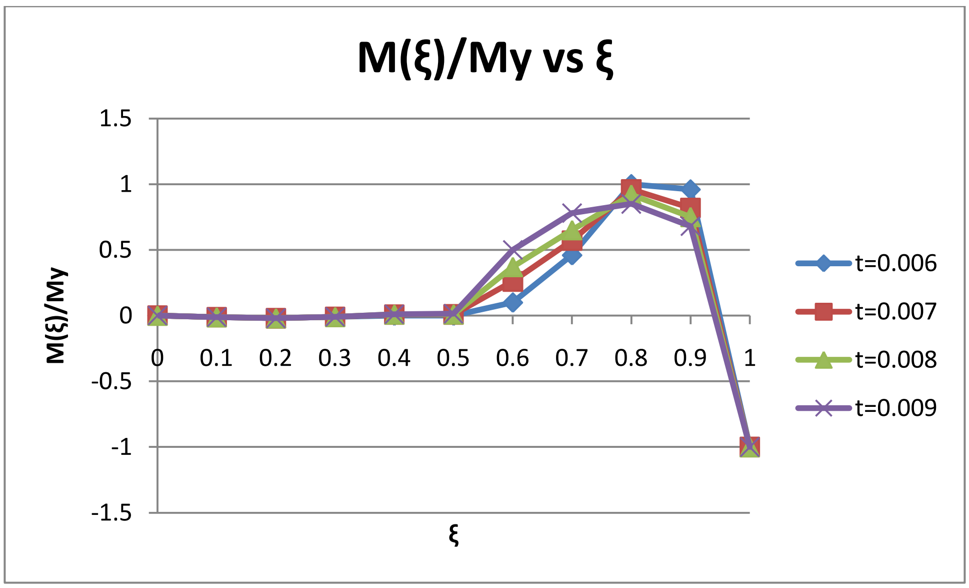
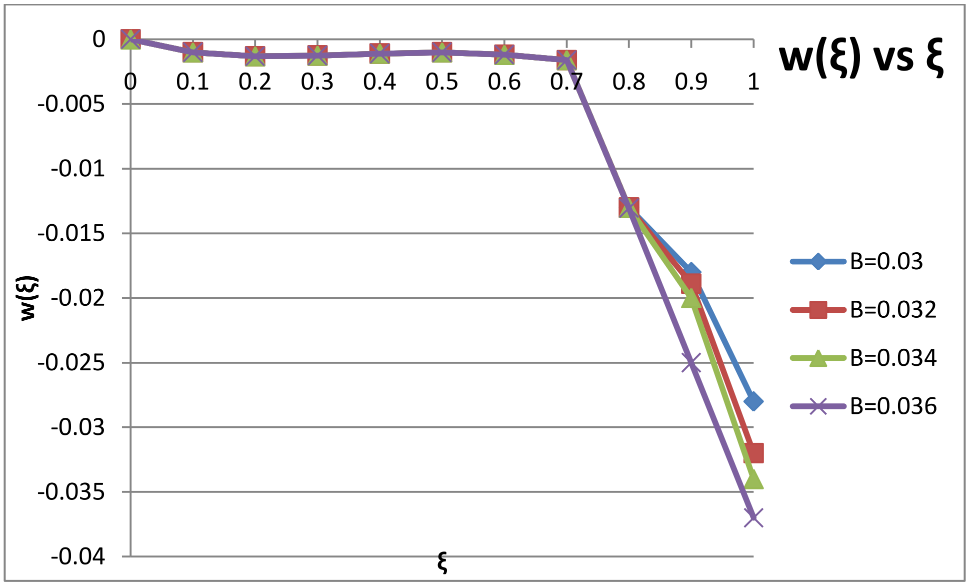


Figure 7: Effect of the plate thickness, t

The second evaluation is based on the effect of the settlement, B with constant foundation stiffness, K_f, thickness, t and the height of crude level inside the tank, h. Taken $K_f=3x10^7 N/m^3$, t=0.0075 and h=21m.



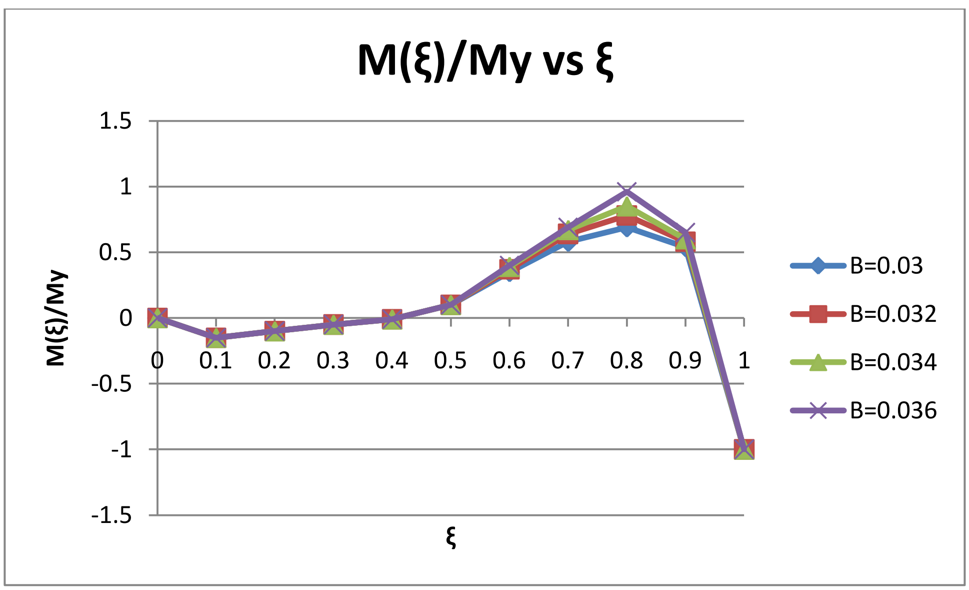
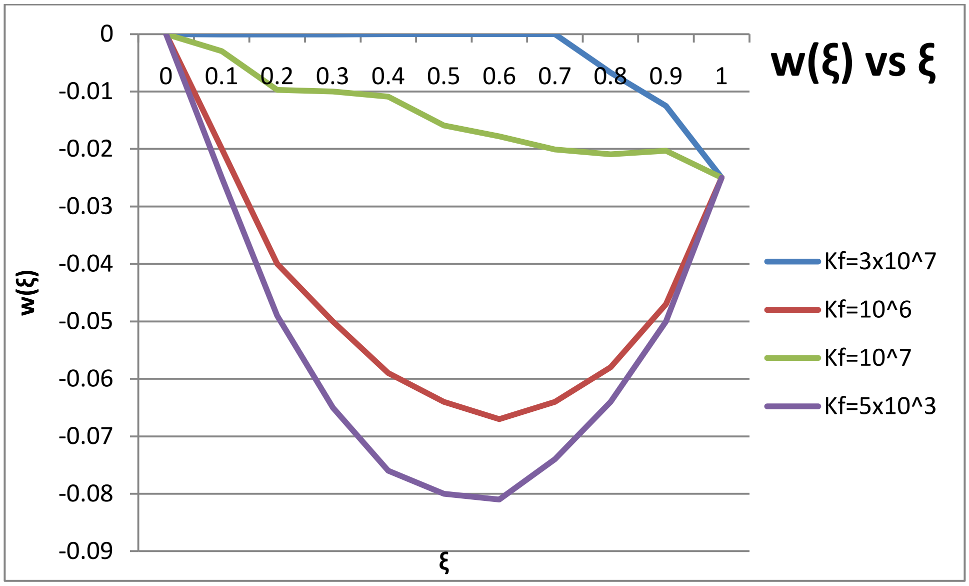


Figure 8: Effect of edge settlement, B

The effect of foundation stiffness K_f for Settlement, B = 0.025m, t=7.5 mm and h=21m.



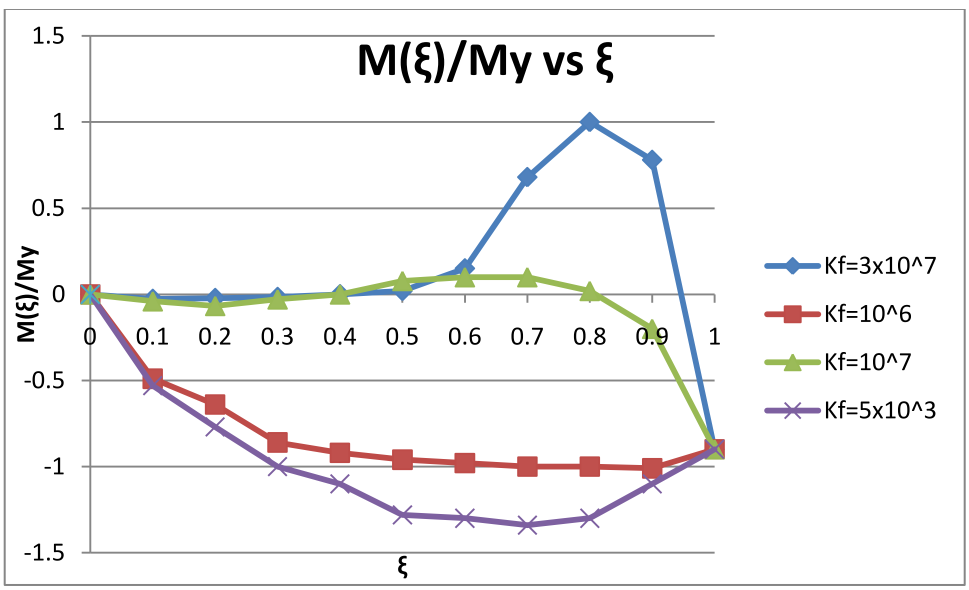
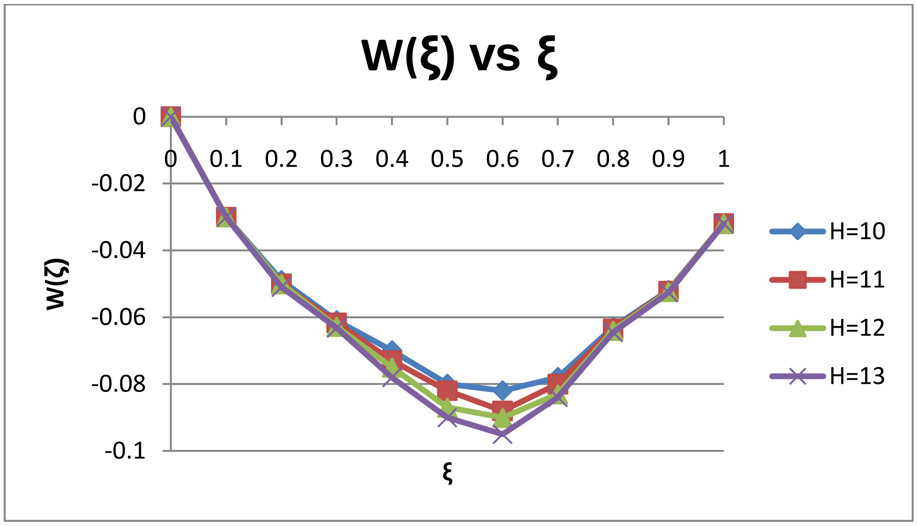


Figure 9: Effect of foundation stiffness, K_f

The effect of crude level height for Settlement, B = 0.03m, t=7.5 mm and $K_f=7x10^3$



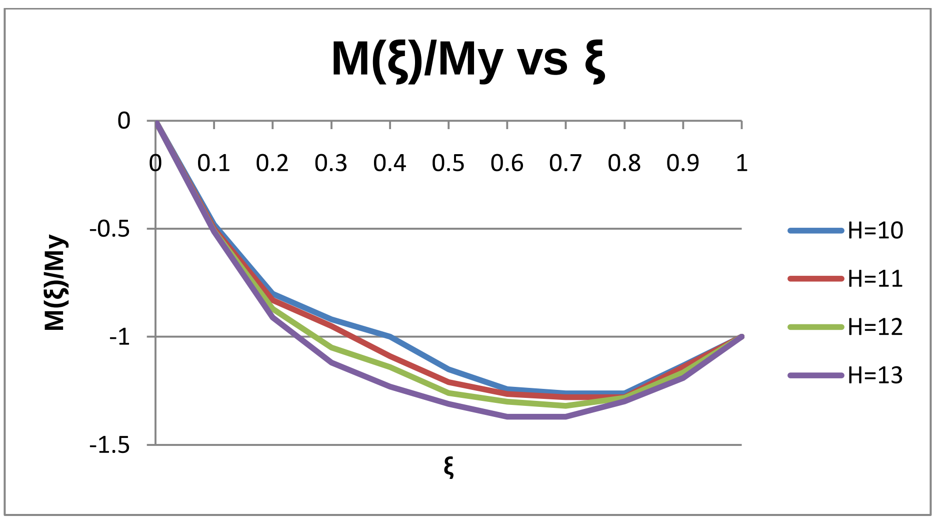


Figure 10: Effect of the crude level height, h

4.1.2 Stress Analysis Using ANSYS

Based on figure 3 and 4, a table is made to determine the allowable settlement for areas with both bottom lap weld parallel and perpendicular to the shell. Using equation for edge settlement, B=0.0308R, the value for settlement for each radius were calculated. Based on the figure 3 and 4, tank with radius more than 6ft, exceed the limits for allowable settlement and need to be repaired, or have detailed analysis of floor, and floor-to-shell junction.

Table 4: Correlations between allowable settlements with radius of settled area

R (ft)	B_{ew}	B_e	B(inches)
0.0	2.0	2.0	0.0
1.0	2.0	2.0	0.4
2.0	3.0	3.0	0.7
3.0	4.4	5.0	1.1
4.0	5.2	6.4	1.5
5.0	6.1	7.5	1.9
6.0	6.9	8.0	2.2
7.0	7.8	8.0	2.6

To be repaired/detailed analysis

Based on the value given, the stress is then calculated using ANSYS. There are several things that might be considered to develop an ANSYS model such as the uniform hydrostatic pressure on the inner side of the tank wall and plate, and the weight of the tank wall. Since the tank wall has different thickness, so the weight is based on weight for each thickness. Using this finite element analysis, the foundation stiffness is ignored. There are 2 boundary conditions used for this model which are the pressure boundaries that exerted on the tank wall and wall boundary. It is important to specify the correct boundary condition to get the correct result. In order to make sure that the tank fix at one place, some constrain has to be considered. The bottom plate has been constrained so that the tank has it base in ANSYS and not just floating in space.

For this FEA, some assumptions have been made for some value to be entered during the analysis. The material properties for the tank storage are elastic modulus E=210 GPa ($210x10^9$ N/m^3), Poisson's ratio=0.29 and Yield Strength=330MPa ($330x10^6$ N/m^2). The geometric modeling was performed using mm as units of length, so a consistent set of units is used. Results calculated with these inputs will have displacements in m and stresses in N/m^2. The tank storage is assumed using the element types of PLANE 182 (Structural, Solid, Quad 4node 182). Then the storage tank model is meshed, apply boundary condition and constrain and next the pressure on the wall and the force caused by the wall weight has been applied. As calculated, the pressure exert on the tank wall is 278KPa. Then the radius of settled area is set on the tank plate.

The behavior of stress when different radial length but with constant thickness of the wall tank, t_s and height of crude level, h, it can be defined in the ANSYS model which the result is as below. The radial length used is R_1=1.2m, R_2=1.5m and R_3=1.8m. For the first model when R is 1.2 m the maximum stress exerted is on the bending section of the plate, which the maximum value of the stress is 10.1GPa. For R is 1.5m the maximum stress exerted is 25.5GPa and for R is 1.8 which is the maximum radial length that tank can sustain before rupture, the stress is 61.8GPa.

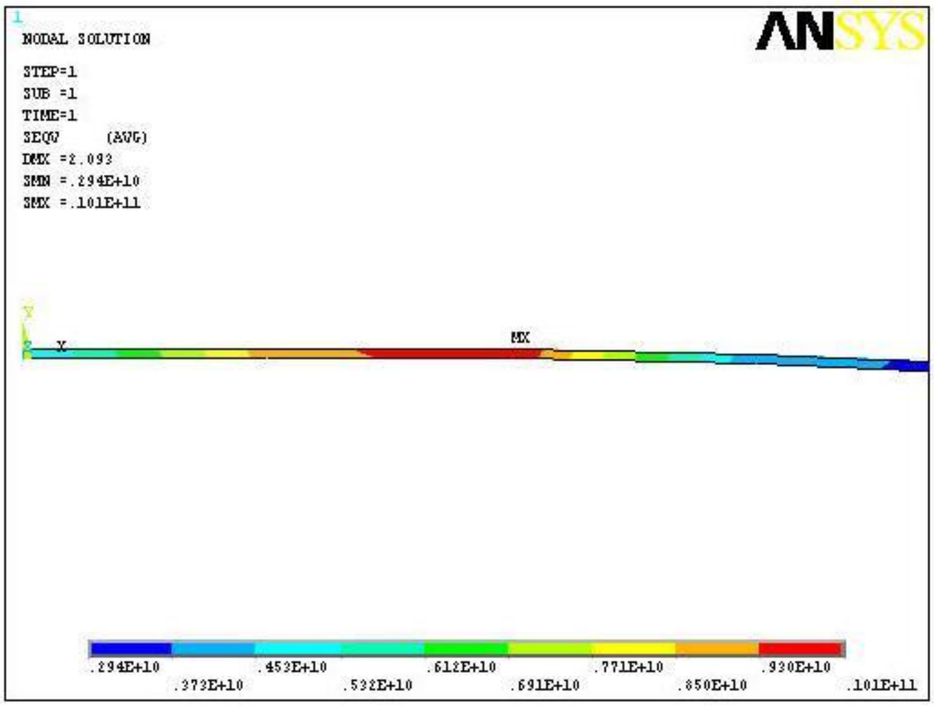


Figure 11: Stress analysis when R=1.2m

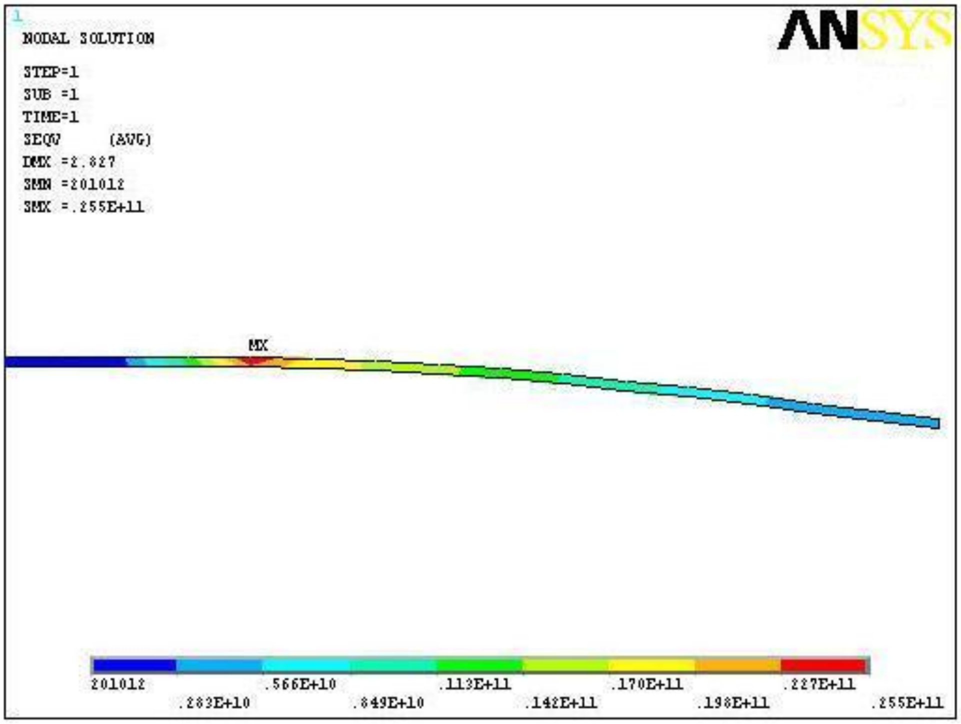


Figure 12: Stress analysis when R= 1.5m

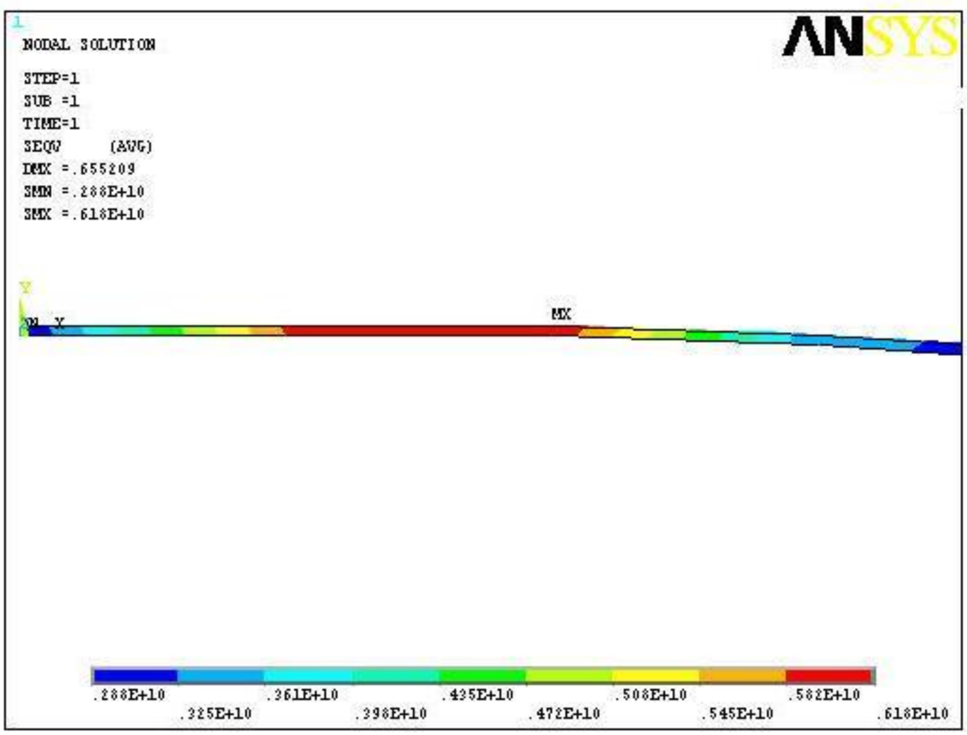


Figure 13: Stress analysis when R=1.8m

For the second model, thickness of the shell variation is used. Variation in thickness will leads to variation in weight of the tank wall that exerted on the bottom plate of the tank. The radial length, R and crude level height, h has to be considered constant. When the thickness, t_s is 0.01m, the weight of the tank wall is 10.8x10^6 N. The maximum stress exerted is on the bending section of the plate will be 3.55GPa. For thickness, t_s is 0.02m the maximum stress exerted is 7GPa and for thickness, t_s is 0.03m the stress is 10.5GPa.

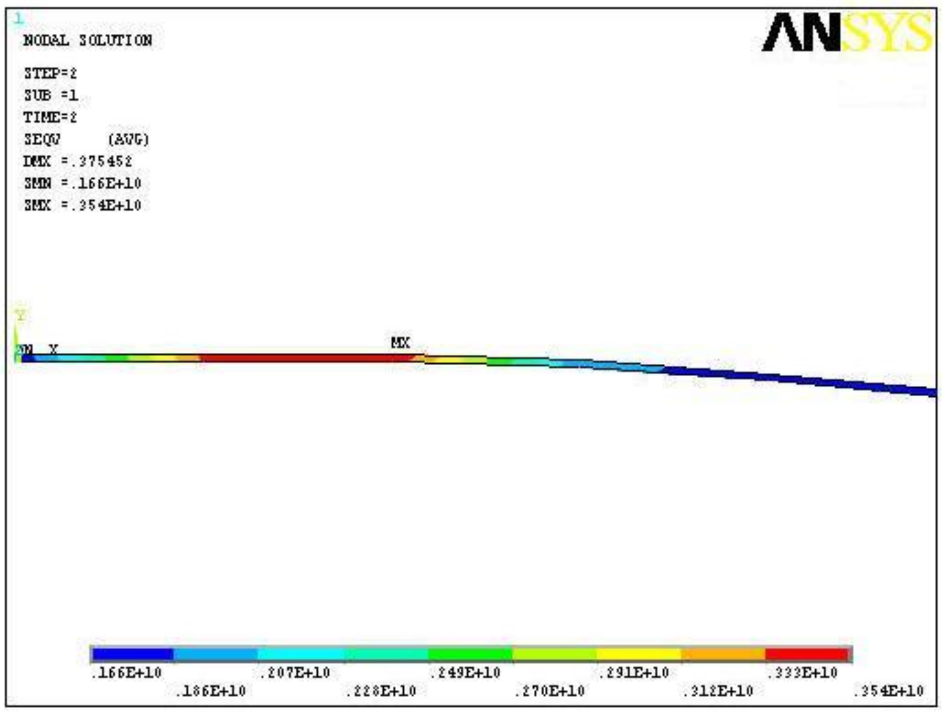


Figure 14: Stress analysis when t_s=0.01m

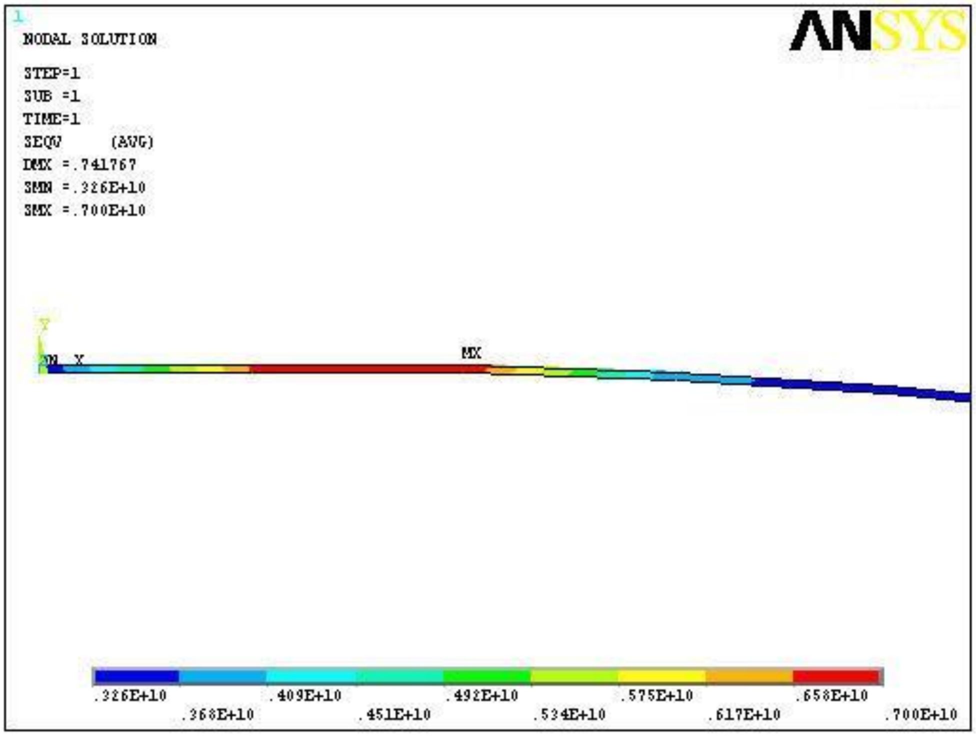


Figure 15: Stress analysis when t_s=0.03

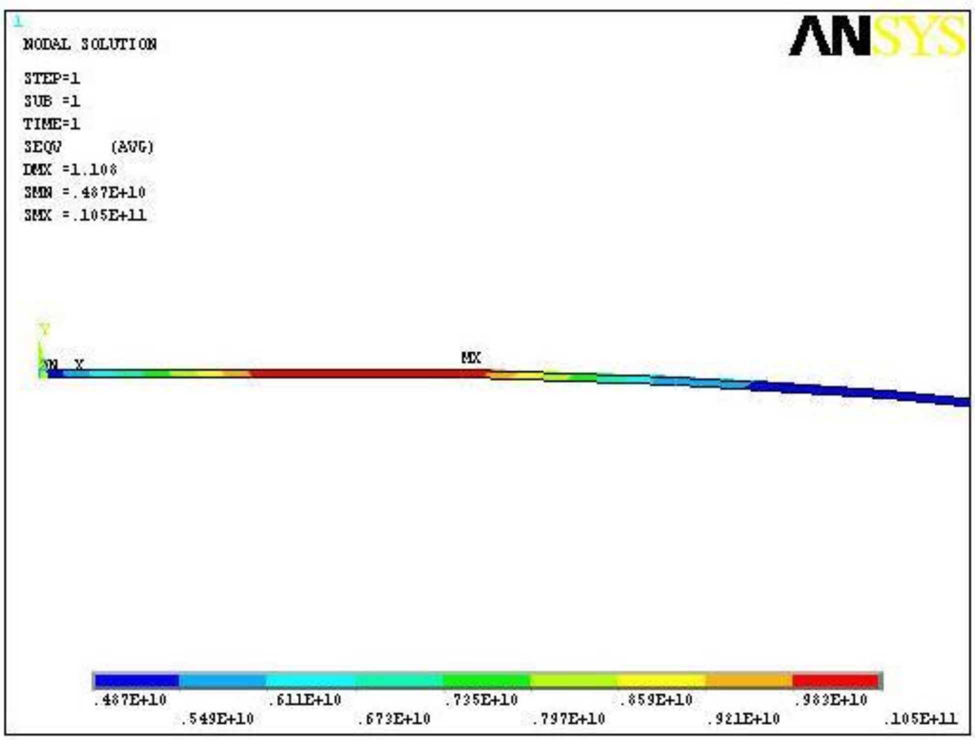


Figure 16: Stress analysis when t_s=0.01m

For the last model using finite element analysis, it concern about the variation of the pressure inside the tank which caused by the variation of the water height. Now the radial length, R and thickness are as the constant value. When the water height is 10m, the pressure inside the tank is 84.5KPa and the maximum stress exerted is 6.07GPa. Then the water height is increased to 15m, the pressure also increases to 126KPa and the maximum stress has become 6.09GPa. Using the maximum water level which is 19.8m the pressure has become 167KPa and the stress is slightly increase to 6.10GPa

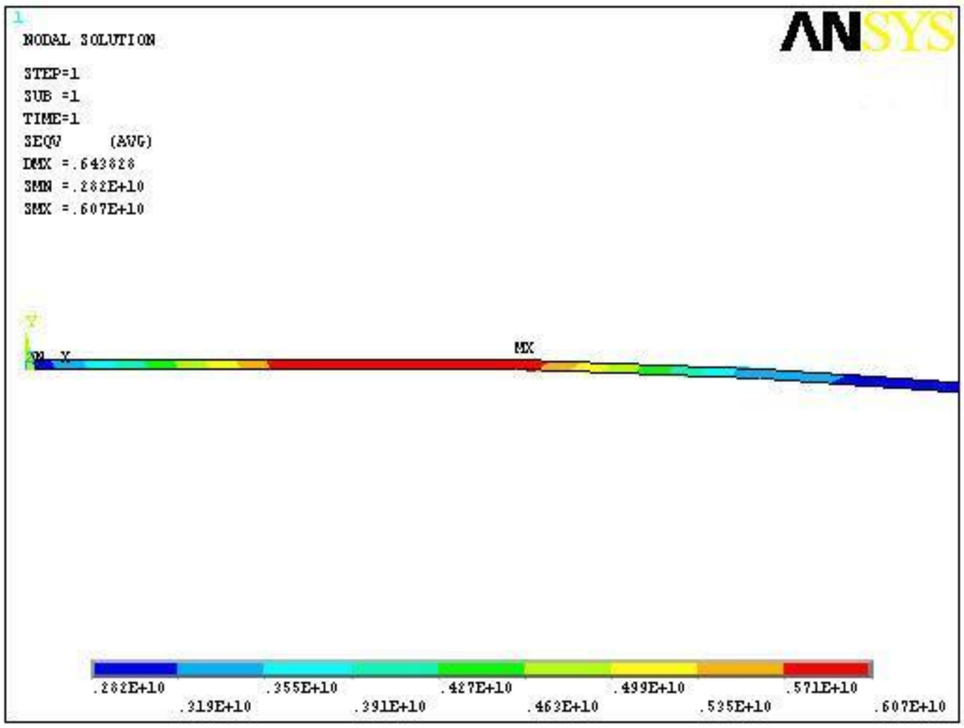


Figure 17: Stress analysis when h=10m

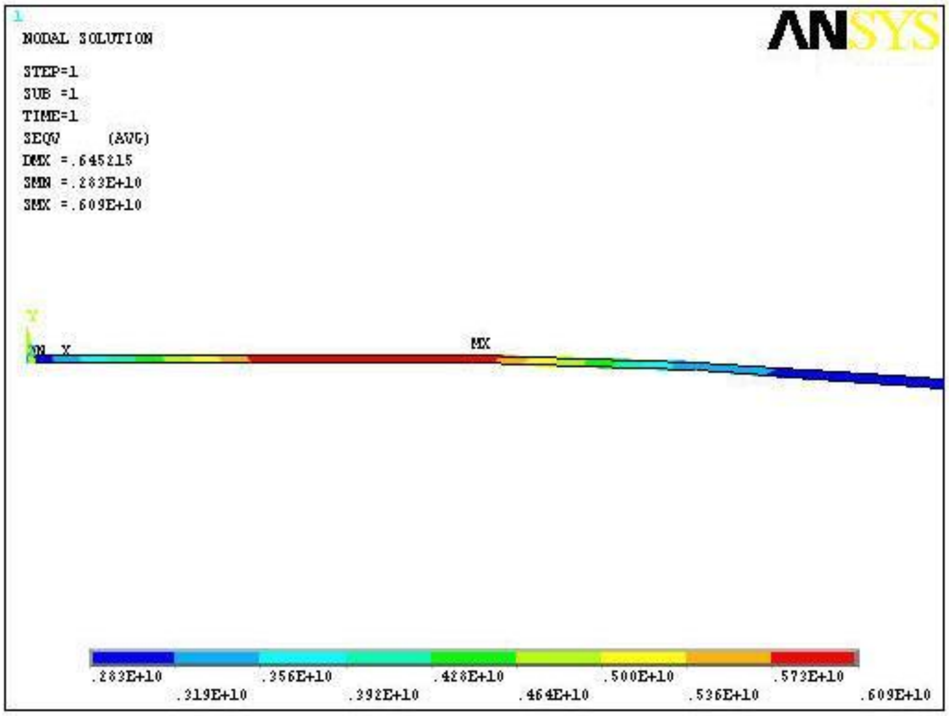


Figure18: Stress analysis when h=15m

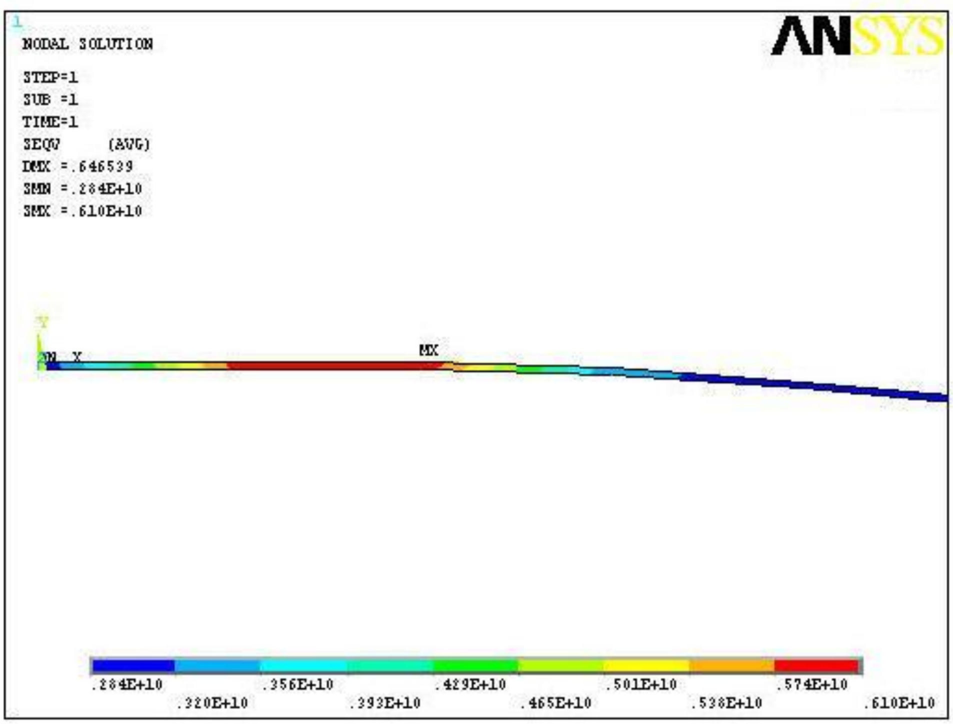


Figure 19: Stress analysis when h=19.8m

Many of the current development and investigations on the tank settlement prediction are focused in the attempt to develop a better method that provides a close prediction of tank settlement before the settlement occurs. Although much effort has been put in this field, the available information on the efficiency of all this methods with respect to allowable tank settlement is still inadequate. Studies done each and every settlement will prove to be a key area of scientific application in the future decades.

From the study, it was found that many different parameters that may cause settlement, in this case, edge settlement. Instead of the hydrostatic pressure exerted to the tank wall and plate, the plate thickness and foundation elastic stiffness coefficient have significant effect on the edge settlement, deflection configuration and associated moment distribution. The effect of the tank height on the edge settlement allowable limit, deflection configuration and moment distribution have only little affect but only if the foundation is relatively soft or highly rigid. The results presented in this work indicate that evaluation of the edge settlement allowable maximum amplitude using the API Standard 653 is in general fairly conservative.

The evaluation of the permissible edge settlement limit using the above API Standard 653 relation is, depending on system parameters, in many cases fairly conservative. For example, if thickness, t= 7.5mm and the radial length is 1m. The settlement limit 36mm which is about 20% more than the limit set by API Standard 653, B= 30.8mm, which using the equation of B=0.03083R. Using finite element analysis, it shows that the stress become higher when the parameters being increase but it did not shows much effect for hydrostatic pressure on the wall. It is shows that the pressure is not have significant effect for the settlement but the thickness of the wall, thickness of the bottom plate and the foundation stiffness that affect the settlement the most.

CHAPTER 5

5 CONCLUSION AND RECOMMENDATION

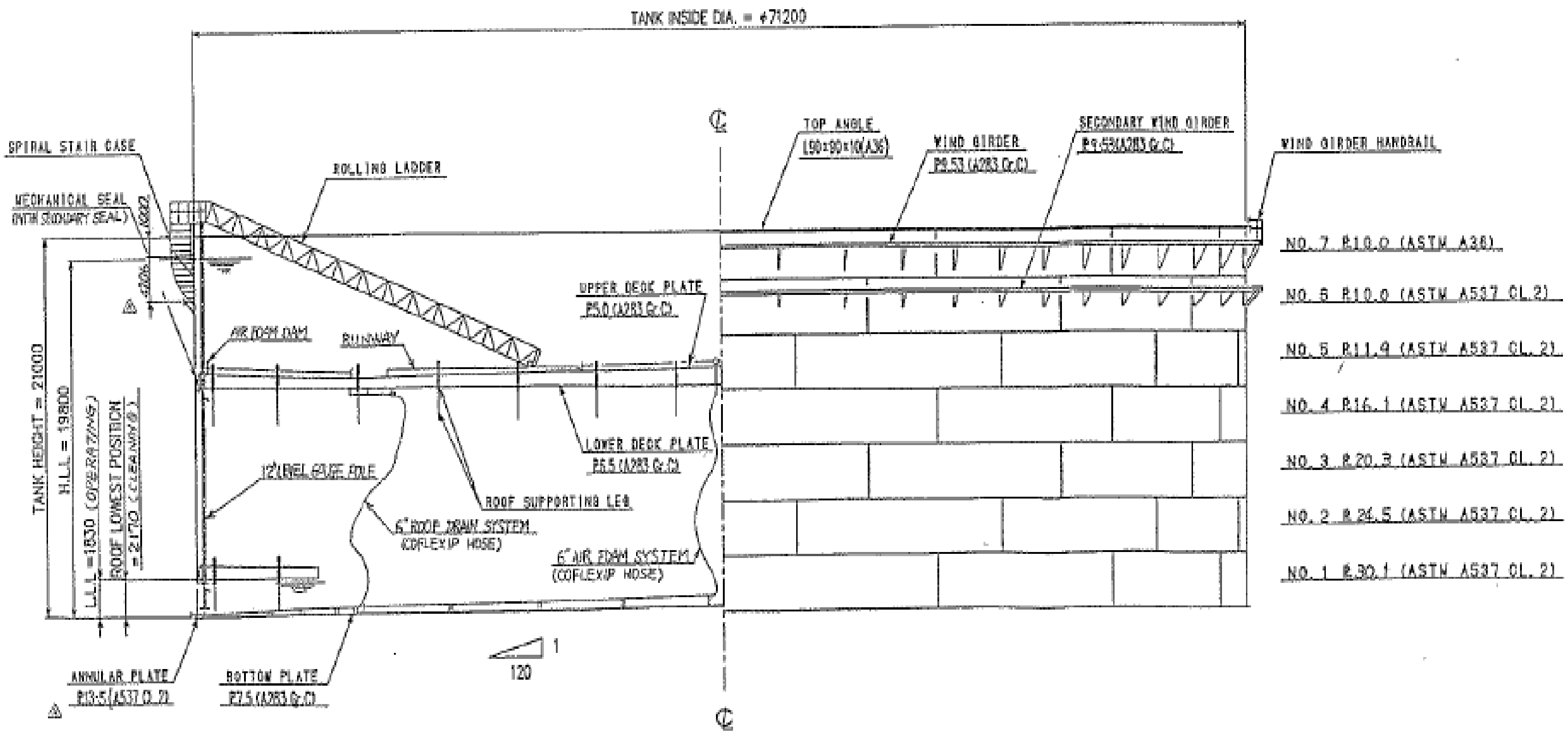
The edge settlement deformation along bottom plate section analysis has been calculated using both bending moment theory calculation and finite element analysis method. The result shows that the tank with greater shell thickness will have greater stress exerted on the tank bottom plate thickness, which means that higher chances for edge settlement to be happened. For example, when the shell thickness is 0.01m, the stress exerted becomes 3.55GPa and the value becomes higher when the shell thickness gets larger. The effect of height did not show any significant changes to the stress on the tank bottom plate.

References

1. American Petroleum Institute Publication, Third Edition 2001,"API Standard 653", Washington DC, USA
2. Presentation Slides by Steven L Braune, Tank Industry Consultants, "Edge Bottom Settlement", Indianapolis, Indiana
3. ASME SEC II A SA-283 SA-283M, "Specification for Low and Intermediate Tensile Strength Carbon Steel Plates"
4. McGraw-Hill Engineering Book, Philip E. Mayers, 1997, "Above Ground Storage Tank", Washington DC, USA
5. Allen Marr, Jose A. Ramos and T. William Lambe, 1982, "Criteria for Settlement of Tanks"
6. Mechanical Engineering Department, KFUPM, 2002, M. N. Hamdan, "A Simplified Analysis of Edge Settlement of a Large Aboveground Liquid Storage Tank", Dhahran
7. International Institute of Earthquake Engineering and Seismology, Masoud Nourali Aharia, Sassan Eshghi, Mohsen Ghafory Ashtianya, 1997, "The Tapered Beam Model for Bottom Plate Uplift Analysis of Unanchored Cylindrical Steel Storage Tanks", Tehran
8. PERTONAS Technical Standards, PTS 34.51.01.31, 1992, "Standard Vertical Tanks Selection, Design and Fabrication"
9. Department of Civil Engineering and Surveying University of Puerto Rico, Luis A. GODOY, Genock PORTELA, Eduardo M. SOSA, Luis E. SUAREZ, Juan C. VIRELLA, and Raúl ZAPATA, "Damage Due to Buckling in Aboveground Storage Tanks", Puerto Rico
10. University of Alberta, ANSYS tutorials: http://www.mece.ualberta.ca/tutorials/ansys
11. Kent L. Lawrence, ANSYS Tutorial Release 9.0, Mechanical and Aerospace Engineering, University of Texas at Arlington

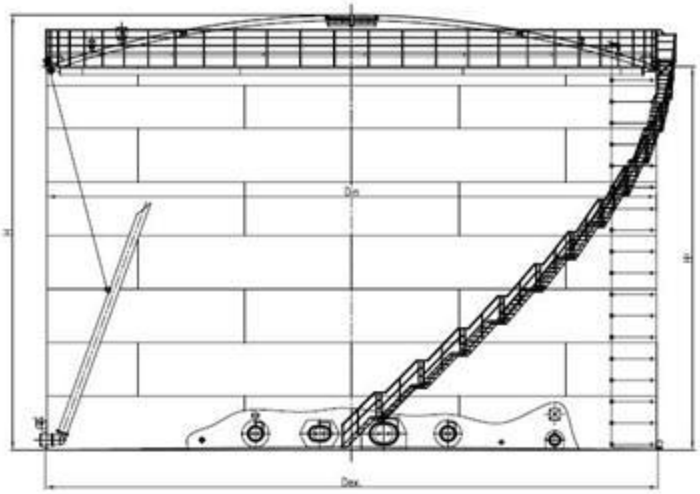
APPENDICES

APPENDIX I



General Assembly of Tank Storage

APPENDIX II



Full assembly of storage tank

External measurement of shell settlement in progress (photo 1-5)

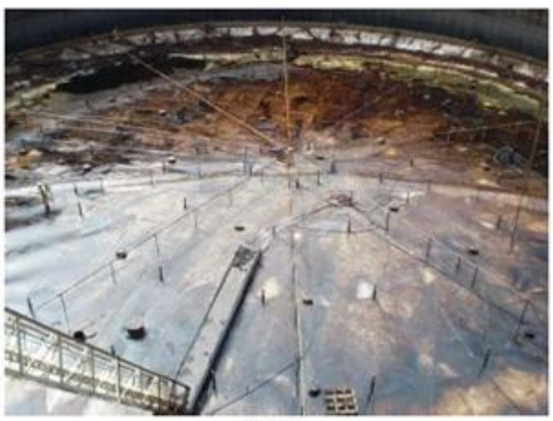


Photo 1

Photo 3

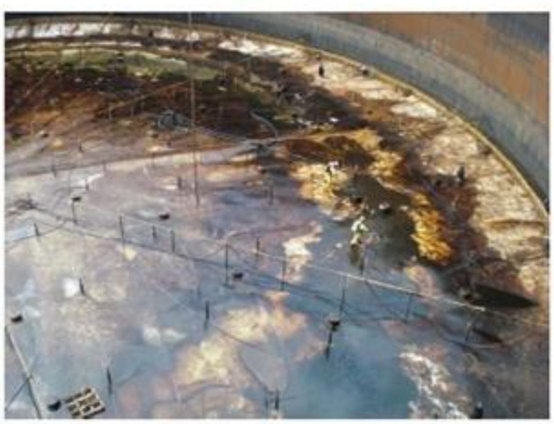


Photo 2

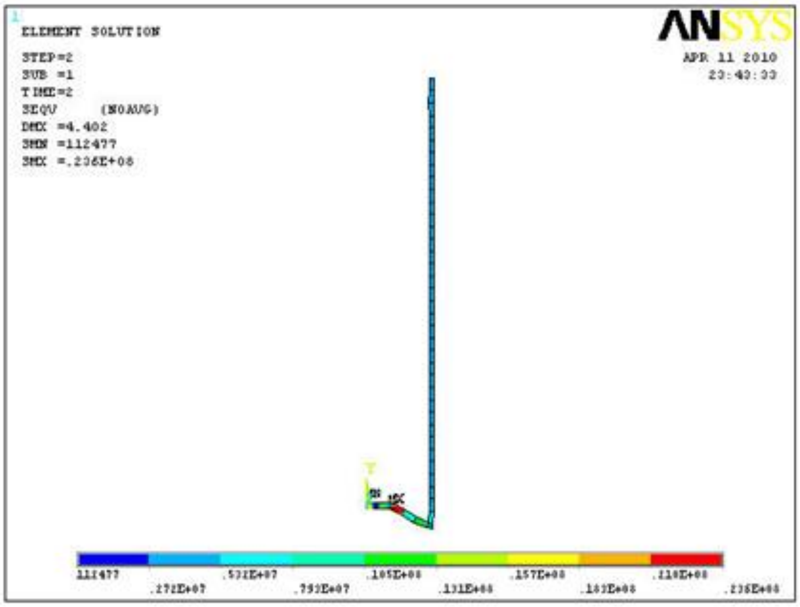
Photo 4

APPENDIX III

Problem occurs during ANSYS simulation

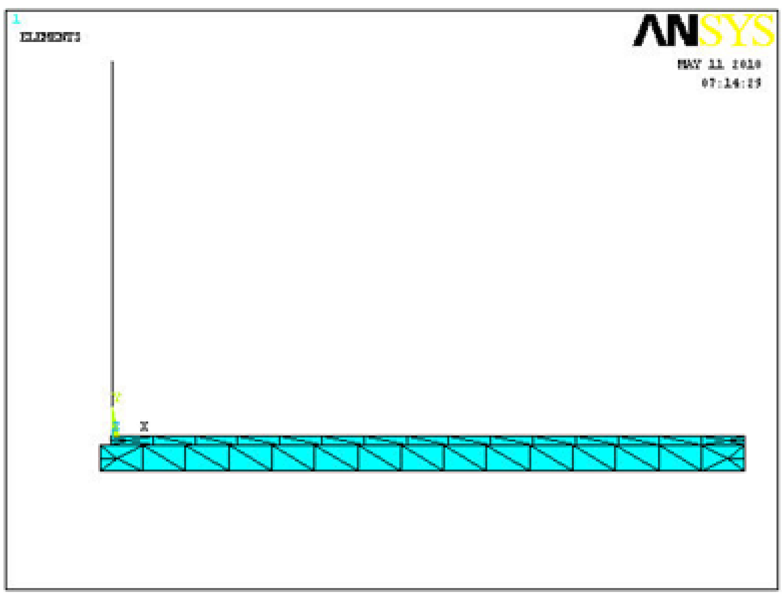
1) First time modeling

- wrong dimension used since the actual dimension is not given



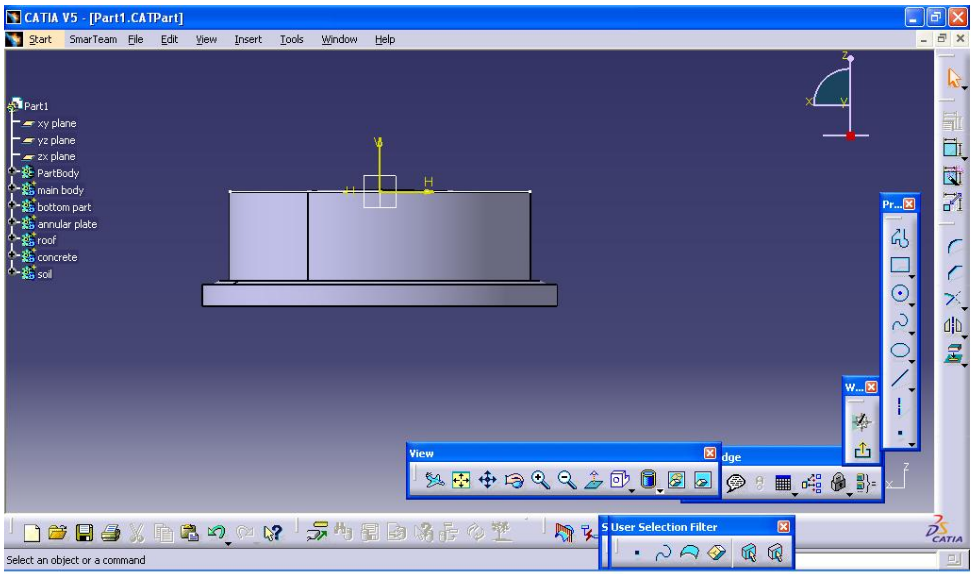
2) **Second time modeling**

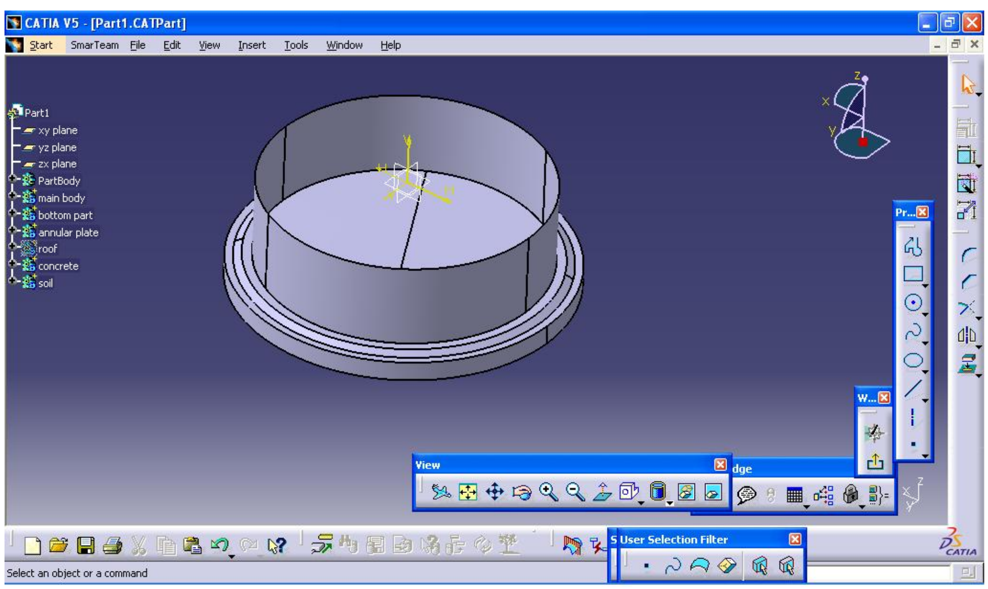
- Asked by Dr Saravanan to include the concrete base and the soil properties
- Failed as it can’t be solve, so many error messages appear



3) Third times modeling

- Tried to use CATIA and export in ANSYS after received actual design, since the thickness of every height is different and the tank bottom is design as slightly curved
- Failed to meshed and solve





4) The last try

- Consult with supervisor about the problems and a new design has to be developed but simpler than before.
- Used as current design