University of Southern Queensland

Faculty of Engineering and Surveying

Structural design, quotation and production support using parametric CAD tools and national/international standards for fluid storage systems.

A dissertation submitted by

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ABSTRACT

This dissertation is a documentation for the creation of a Structural design, quotation and production support system using parametric CAD tools and national and international standards for fluid storage systems. The project looks at establishing a parametric tool for bolted unanchored panel tanks with the use of SolidWorks's integrated program DriveWorksXpress. The object of which were to,

- Develop a feature based bill of materials
- Automate engineering and part drawings
- Provide an inlet/outlet orientation function
- Have a 3D representation of the tank

Methods for obtaining these objectives were to use MS Access to develop the bill of materials using a database aspect to retain inputted tank information and with DriveWorksXpress part dimensions could be captured and altered based on user input and standards that govern the construction and design of tanks. Results from which varied as issues arose with capability and programming requirements. Which leaves future work open to a variety of opportunities.

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ACKNOWLEDGEMENTS

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CHAPTER 1   INTRODUCTION

1.1   Introduction

The following report is researching "Structural design, quotation and production support using parametric CAD tools and national and international standards for fluid storage systems.'' The requirements for this project includes; the uses of CAD programs and Microsoft excel or access to automate the production of engineering drawings and quoting, thus reducing the time spent on the design and quoting phase of a project, which inadvertently reduces the cost.

The report will outline some of the major influences of why the development of such a program is important within the engineering industry and for the company that will be using the final product. A background on the literature of parametric design will be discussed in order to gain knowledge and techniques for the completion of the final project.

The overall aim of the project is to replace the existing EQS (Electronic Quotation System) program that is in place at Tyco pumps. The replacement is due to the updating of CAD software which no longer supports the original EQS program, in which the files have been encrypted so it is not possible to simply make changes to the EQS program to be able to support the new CAD software.

1.2   The Problem

The existing parametric tool that is being replaced is known as EQS (Electronic Quotation System). This program was developed within the Tyco Company to automate the quotation and design of their different panel tank departments. EQS has shown many glitches and is no longer supported by the new CAD software. Due to the inability to update the EQS program a similar system must be designed and put in place. The original EQS was developed through integrating AutoCAD and Microsoft Access. Microsoft Access was used to develop query based programming to filter out particular selections within the design of the tank and

exported those components to AutoCAD, which then automatically produced all detailed drawings for the quoted tank. Also, the creation of databases in Microsoft Access allows the program to easily quote a design, using an itemised database containing all necessary design components and cost. All of these program design functions are accessible within the program interface as well as other functions such as tank height, diameter and capacity. Other constraints are also selectable to ensure that the tank is designed to the required national and international standards.

The main reason why this software can no longer be used is due to upgrades in the in CAD software which no longer supports the original parametric tool. Also due to constraints and encrypted files the EQS program cannot simply be adjust to support the new CAD software. Therefore a completely new program is to be developed which use the new software and provides similar outputs as the original.

1.3   Project Objectives

The main objective of the project is to create a program with use of CAD software and Microsoft access to automate the design and quotation of engineering applications for fluid storage systems. In conjunction with Southern Cross Pumping Systems (the company for which the program is being designed for) a criteria was developed to establish the required outputs for the program. All outputs stay within the scope of the project and after the completion of each objective provide Southern Cross Pumping Systems with the ability to present a client with a quote and design in significantly less time.

The following is a list of the aims for the project "Structural design, quotation and production support using parametric CAD tools and national and international standards for fluid storage systems."

1. One of the developments of the parametric tool is creating the user-interface for which the foundation of this project is built. The interface is a platform that allows the user to make his/hers selection for the tank design with just a few clicks of the mouse. The reality is that the interface brings the relationship between the CAD software and Microsoft Access together, ensures that all design constraints are taken into consideration.

2. Development of a Bill of Materials (feature based) which is compliant with the standards when you select any two of the following - Tank diameter, Tank Height, Tank capacity. This BOM should also take into account the seismic region and wind region. It will be exported from the CAD software into Microsoft Word where a template will be used and the selected materials will be list with a product number, description and amount, to be used as an order form for the client's product.

3. From the produced BOM document, detailed drawings of all the components within the structural design of the panel tank will be produced automatically using the SolidWorks (CAD Software). These detailed drawing will go along with BOM to supply the manufacture details for the production of the components i.e. number of bolt holes in each panel and placement of selected inlet/outlet holes within particular panels.

4. Nozzle Selection; part of this product allows the user to select different nozzles for use with pumping systems. With the ability to select where they would like the position of the nozzles, the selected panels in the positioned area will then be updated in the detailed drawings to show the dimensions of the new nozzle fittings (time permits).

5. After the above are completed the final stage is to produce a 3D representation of the finished panel tank, with all considerations taking into account i.e. nozzle position, wind girders and the seismic area; giving the client a prototype view of the tank they are purchasing.

1.4   Closing Remarks

As discussed the goal of the project is to develop a structural design, quotation and production support program using parametric CAD tools and national and international standards for fluid storage systems in conjunction with Tyco pumping systems and the University of Southern Queensland.   The purpose for which is to replace an existing

parametric tool that has become redundant due software upgrades and standard changes within the company and industry. The parametric tool must be composed of similar traits that the pre-existing tool had which was, a user –inter face, automated engineering drawings, a bill of materials and nozzle selection. Additionally a 3D representation of the tank will also be constructed to give the client a perspective of what they are purchasing.

Equations from particular standard are used to define to dimensional relationships in the program which essentially allow the user to change aspects

CHAPTER 2   LITERATURE REVIEW

The content of this chapter is an overview of the available literature, standards and information on parametric design and fluid storage systems that will ultimately be used as a foundation throughout the development of this project. The aims of this chapter are to provide an overview of the history and development of CAD and parametric tools, recognize the need for integrated parametric tools for CAD programs and to establish an effective method for producing a parametric tool.

2.1   Computer Aided Design History

2.1.1 Introduction

CAD software, referred to as Computer Aided Design software and in the past as computer aided drawing and drafting software (CADD), refers to software programs that assist engineers and designers in a wide variety of industries to design and manufacture physical products ranging from buildings, bridges, roads, aircraft, ships and cars to digital cameras, mobile phones, TVs, clothes and of course computers. CAD software is often referred to as CAD CAM software ('CAM' Computer Aided Machining).

What is computer aided design? 'Computer aided design is the creation and manipulation of pictures (design prototypes) on a computer to assist the engineer in the design process' (Amirouche 1993, p22). Over the past quarter century CAD has developed into an essential tool for the technology, design and manufacturing industries. CAD revolves around three major characteristics hardware, software and users the blending of these attributes and the human ability to make decisions provides the optimum CAD system. As most people regard CAD solely as an electronic drafting board, its functions expand beyond drawing pictures. With the main functions primarily being design, analysis, and manufacturing there is also the expectation that an analysis of the object drawn with CAD can be made interactively on the screen where physical information can be extracted. For the engineering industry this would include the ability to do finite-element analysis, heat transfer analysis, stress analysis, dynamic simulation of mechanisms, and fluid dynamic analysis.

2.1.2 CAD History

In a sense CAD could be regarded as the evolution of computer graphical representation of information. It was essential created by the aerospace and automotive industries as a method for increasing the rate of technological development and reducing many tedious tasks of a designer. Early research in the development of computer aided design can be credited to Patrick Hanratty while working for General Motors Research Laboratory in the early 1960s.

However in the mid-1950s graphical representation in computers was being used by Air Defence Command and Control System. SAGE (Semi-Automatic Ground Environment) used computer graphics to change radar information into computer regenerated graphical pictures. It made use of a light pen, which the user was able to control and give the ability to choose information by pointing the pen at the appropriate area displayed on the CRT (Cathode-ray tube) (Figure 2.1).
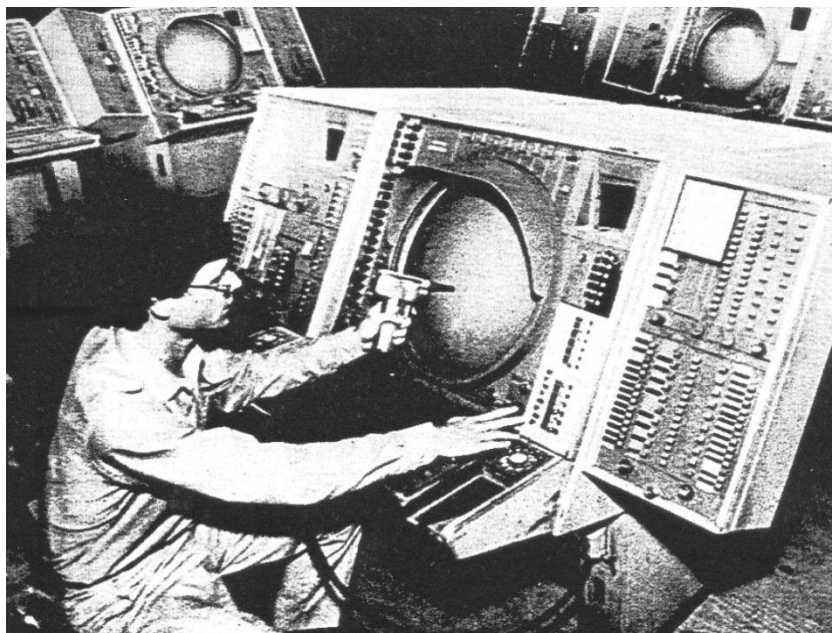
Figure 2.1 The SAGE digital computer used by the U.S Air force (F. AMIROUCHE 1993, p23)

A milestone in the development of computer graphics was the innovative production of a program called "*Sketch pad*" which was developed by Ivan Sutherland as part of his PhD thesis at MIT in the early 1960s, this then began laying the theoretical basis for computer graphics software. Sketch pad was especially innovative CAD software because the designer

interacted with the computer graphically by using a light pen to draw on the computer's monitor. The sketch pad consisted of a cathode-ray oscilloscope driven by a Lincoln TX-2 computer. Pictures could be displayed on the screen and manipulated by the user with the light pen. It is a tribute to Ivan Sutherland's ingenuity that even in 2004, when operations which took hours on 1960s computer technology, can now be executed in less than a millionth of a second and touch-sensitive TFT combination display/input devices are readily available, there is no leading CAD software that has yet incorporated such directness into its user interface (CADAZZ, 2004).

The use of the systems based on sketch pad has now become known as interactive graphics. The systems clearly showed the potential for a CRT as a designer's electronic drawing board with graphical operation such as scaling, translation, rotation, animation and simulation. That said in the early 1960s these new systems were very expensive and had a high maintenance cost, the only users of this system at the time were large industries that could justify their high cost. However, in the 1970s and 1980s, there vast improvements in computer hardware with faster processing speeds, larger memory and smaller sizes became widely available and affordable to various smaller industries.

First generation CAD software systems were classically 2D drafting applications developed by a manufacturer's internal IT groups (often collaborating with university researchers) and primarily intended to automate repetitive drafting tasks. As mentioned previously Dr Hanratty co-designed one such CAD system, named DAC (Design Automated by Computer) at General Motors Research Laboratories in the mid-1960s. Due to the lack of early computer graphics made the interpretation of computer designing strenuous on the design because first generation CAD programs used a numerical coding format i.e. binary code. It seemed there was a need to provide the designer with the means to communicate on a graphical scale with the computer in order to visually process the commands that are being sent to the computer.

Typical CAD programs that are used for general purpose i.e. engineering drawing (top, front and side views) use the Cartesian coordinates system to arrange the data inputted for display and visualisation. The Cartesian coordinate system uses the x, y and z axes to define the location and space that entities occupy. By manipulating the values in the arrays, which contain all points that the objects occupies, a designer can then scale (magnify or reduce), rotate about an axis and translate the object to another location in the same reference axis (Amirouche 1993, p22).

With the use of Cartesian coordinates early graphics programs model entities via wireframe drawings. Wireframe drawings are made up of lines, points and curves representing the outline of the object that the designer wishes to portray (Figure 2.2). When view a drawing of this standard it requires some imagination from the viewer to visualise the appearance of what is represented by the wireframe. As in most CAD programs such as AutoCAD there is a dominate function called the hatch function that allows the user to hide certain aspects of a drawing to enhance particular aspects and improve the drawing visually.
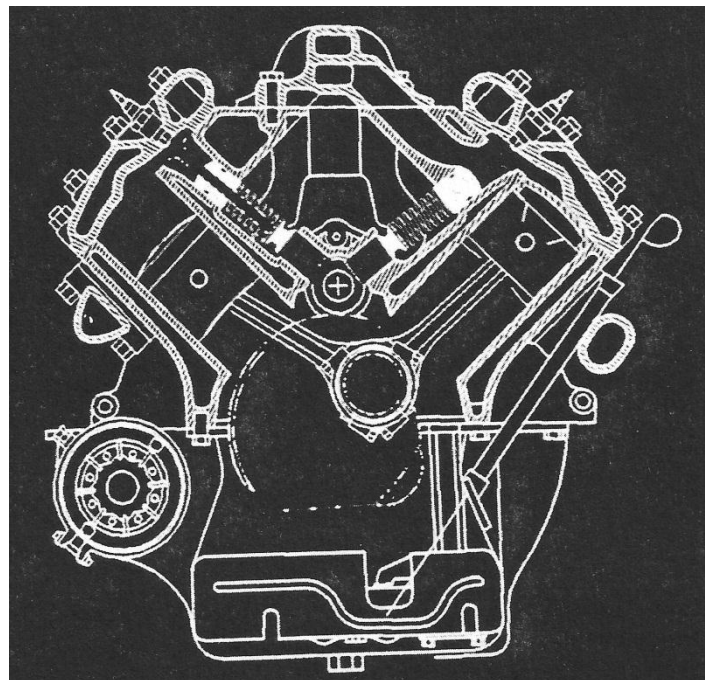
Figure 2.2 Wireframe Drawing (F. AMIROUCHE 1993, p23)

The advantage of a 2D drawing is that the object can be scaled to true size as long as the principle planes are parallel to the paper. The disadvantage is that with very complex drawings some details want be able to be seen due to the fixed planes of a 2D drawing.

Flashing into the 1990s saw the ever increasing demand for more dominate 3D capabilities. Pro/ENGINEER at the time was one of the leading developments within the industry, supplying more people with the ability to model in 3D then any other software. This sae new theories and algorithms evolve and integration of various elements of design and manufacturing was developed. The major research and development focus was to expand

CAD systems beyond three-dimensional geometric designs and provide more engineering applications.

The present day CAD/CAM development focuses on efficient and fast integration and automation of various elements of design and manufacturing along with the development of new algorithms. There are many commercial CAD/CAM packages available for direct usages that are user-friendly and very proficient.

2.1.3 Modelling Concepts

Within the design of a component, the process which takes place between conceptualisation and the final design isn't as easy as many believe it is. It consists of various amounts of steps, analysis and reiteration, with each process taking a substantial amount of time. An engineer's design or concepts in the past was usually a free hand interpretation without accurate dimensions. The engineer's vision become reality when people known as drafter, or designers where implemented to create what we know today as engineering drawings.

As mentioned before the use of wireframe drawings gave the designer a sense of perspective when designing an object. Shape and geometry have always been essential in the designing process. However the need for an accurate record of the geometry of a product was greatly intensified by the advent of modern industrial mass production in the early twentieth century. One key notion that arose from these turn of events was interchangability of parts, which required logical attention to the geometry and tolerances of the individual mechanisms to ensure that any components that were intended to work together can definitely be assembled successfully. To propagate the correct information needed for the geometric information, a number of systematic geometry presentation methods and conventions that now constitute engineering drafting methods today where developed (Shah & Mantyla 1995, p.23-4).

It was a consequence of need to link the various applications in design, analysis and manufacturing that utilise geometric information. Based on this view, geometric modelling can be characterised as follows; Geometric modelling studies computer based representation of geometry and related information needed for supporting various computer based application in engineering design, analysis and manufacturing along with other areas of simular requirements. This revolves around the study of certain aspects of the geometry such as data structures, algorithms and file formats for creating, representing, communicating and

manipulation of geometric information of physical parts and processes appearing in these applications and also related numerical and symbolic technical information.

Actual approaches to geometric modelling vary in the extent to which they are intended and capable of supporting the full range of geometric computations. In particular, some types of models are only intended to aid the production of human interpreted geometric representation, where others are intended to support automatic applications that can work with limited or no human guidance. There are three major types of geometric models graphical, surface and solid models. In actual CAD systems the originally distinct approaches to geometric modelling have continually converged. It can be stated that most feature models can be regarded as the recent stages in development.

Graphical models are used in the support generation of engineering drawings and illustrations to be interpreted by humans. To this day graphical models are still used within a large number of industries, using CAD systems based primarily on graphical models. Graphical models can be portrayed in the two-dimensional and three dimensional perspectives. From the modelling viewpoint two-dimensional models consist of graphical primitives such as lines, arcs, conics, text, symbols and other notations that are required to describe an engineering drawing. All primitives has a graphical attribute that controls how it is displayed and plotted, for example a line can appear as a dash, dotted-dash or solid, the line thickness is also consider as a graphical attribute. Multiple graphical primitives can also be combined to represent a symbol that has its own attributes i.e. local origin, and rotation around the origin. A complete engineering drawing can consist of multiple layers using these two-dimensional graphical primitive, the advantage is that each layer can be moved and displayed independently of each other. The approach is commonly used to separate basic geometric parts from construction elements, dimension lines and other supporting properties.

All graphical bases are created using construction techniques within the CAD drafting system. For instance a construction point may be created using a graphical pointer (mouse), typing coordinates (x,y,z) or by selecting the intersecting point of two lines. Lines can then be generated between give points or in parallel to an existing line. Some CAD systems provide associative graphical bases a capability that supports parametric design and drafting. Associative bases have two representations, a canonical representation that stores information on the primitive that in some suitable form for generating graphical output on display. For example a 'canonical representation of a circular arc could consist of a reference to the

underlying full circle and the starting and ending points of the arc' (Shah & Mantyla 1995, p.26). The associative representation is associated with storing a record of the construction technique used to create the drawing. In the case of the circular arc filet the associated representation could be; the arc is determined by the intersection of the lines already establish and the circle is generated by user input (diameter/radius) and the center point which would be a computation between the two lines. The benefit of this type of representation is that the construction history is fully captured and stored which therefore provides the designer with the ability to reiterate and possible redraw at a later time. As a result we have a unidirectional parametric graphical model.

Three-dimensional graphical models are similar to two-dimensional in only difference is that the drawing is now defined in an additional space (a third coordinate). This means that all primitives now require more information on the plane they reside on. The result is a representation is a 3D model which described early as a wireframe. The usefulness of the wire frame representation is that various projects typically needed in engineering drawings can be drawn simply by using geometric transformations on the graphical primitives. This is why today most engineering drawings will be accompanied by an oblique or isometric representation of the object in question.
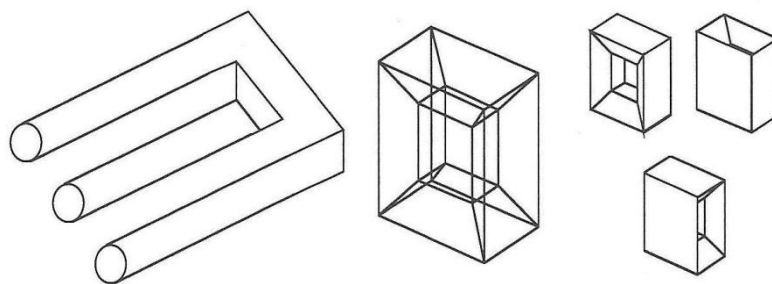

Figure 2.3 Problems that occur with graphical models (Shah & Mantyla, 1995)

A reason for this is that unfortunately while a three-dimensional representation provides with more of a perspective on the overall design in retrospect a 3D model is graphically deficient as lines can be left out and unnecessary elements maybe inserted (Figure 2.3). What's known

as a cross-sectional drawing can then be added to assist the observer in correctly establishing the detailed or other components that are required within the object. As graphical models are of limited utility, their main purpose is to support the creation of drawings and not to serve as generic models that can support several applications even though useful applications working on the basis of graphical models can and have been developed.

As we have found graphical models have the ability to capture simple geometric shapes that form the majority of geometric information that assists in the development of engineering drawings. However in some cases simple geometric models cannot be used as they fail to represent the overall geometry of the object. Some examples of such cases are where complex surfaces appear in forgings and castings, turbine blades, car bodies, air craft and ship hulls. To models these geometries, various manual methods of interpreting the above mentioned surfaces and curves were developed. With the advent for the need to automate these manual methods, computer based representation was formed. As we know it today, all CAD systems automate these option be it a spline curve or parametric curve. The automation is due to advanced algorithms that process and interprets the selection of the user and provides seamless results in the creation of surfaces and curves. Some of the function in CAD software that most would be familiar with would be extrude, sweep, bend and many more.

Today's dominating methods of modelling, especially for a mechanical component is solid modelling. Solid models are said to be the solution to the drawbacks of multiview orthographic drawings, wire frames and surface modellers. The first program that adopted this approach appear in the early 1970s (Bedworth, Heanderson & Wolfe, 1991). A solid modelling system is one that provides a complete, unambiguous description of a solid object. It can also be used in part as partial input data for program that provided finite element analysis; the output of such information can also be portrayed on the solid model its self with the use of colours. Solid Models also allow the creation of solid section views to show the interior of an object and can also be combined to other solid models to create assembly drawings. The advantage in this is that a designer doesn't have to complete a new drawing from scratch to display the overall component or the components that aren't visible. Figure 2.4 displays the typical drawings that can be generated with a solid modelling system.
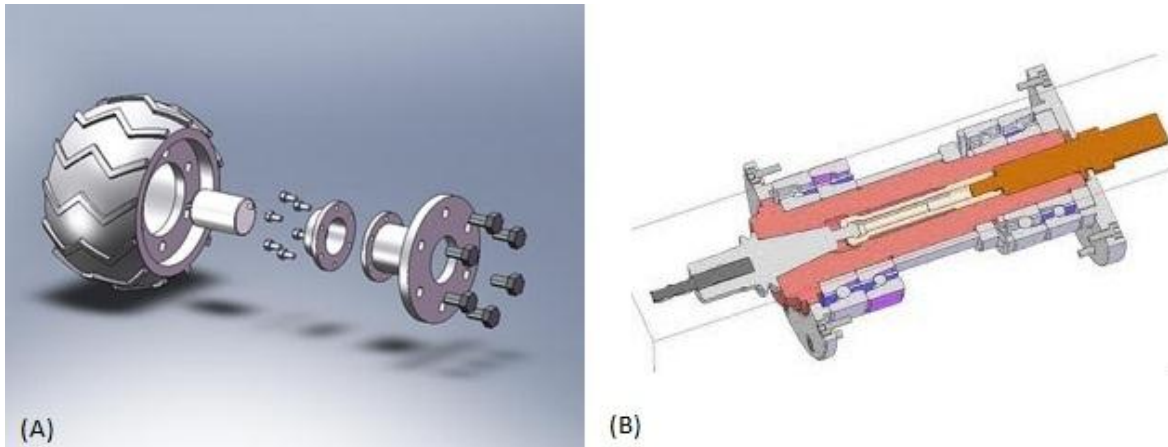
Figure 2.4 (A) Exploded solid model assembly(X Price Foundation 2010) (B) Solid model cross-sectional view (Jelsoft Enterprises Ltd 2010)

It can be seen that solid models resembles the geometry of surface models with the hidden lines removed. The main difference between solid models and wireframes can be seen with the limitations of wire frame models. A wire frame model fails to exhibit certain properties that are essential to the design. Properties are used to predict weight, moment of inertia and volume of the finished product. This is where solid models represent a more accurate picture of the designed parts, this is a necessity when designing objects with complex geometries.

2.2 Parametric Modelling

Parametric design is a modern approach to product modelling, which associates engineering knowledge with geometry and topology (mathematics concerned with spatial properties) in the product model by means of constraints. Together with the technique of feature based modelling, it has widely affected the development of new CAD-systems. Parametric design can be described as a process of designing in environment where design variations are effortless, thus replacing singularity with diversity in the design process. Parametric design is done with the aid of Parametric Models. A Parametric Model is a computer representation of a design constructed with geometrical entities that have attributes (properties) that are fixed and others that can vary. The variable attributes are also called parameters and the fixed attributes are said to be constrained. The designer changes the parameters in the Parametric Model to search for different alternative solutions to the problem at hand. The Parametric Model responds to the changes by adapting or reconfiguring to the new values of the parameters without erasing or redrawing.

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In parametric design, designers use declared parameters to define a form. This requires rigorous thinking in order to build a sophisticated geometrical structure embedded in a complex model that is flexible enough for doing variations. Therefore, the designer must anticipate which kinds of variations he wants to explore in order to determine the kinds of transformations the parametric model should do. This is a very difficult task due to the unpredictable nature of the design process.

Today's 3D CAD systems provide various powerful tools for the design of 3D objects. Techniques used for solid modelling are constructive geometry (CSG), sweeping to 2D shapes and other techniques like skinning and reconstruction of solids from projections. So called parametric and variational CAD systems are based mostly on feature approach for solids, defining a part as a structure of predefined objects called features.

The main aspects of modelling with constraints are structuring a solid model as a history of features, using topology objects and their geometric coordinates as parameters and applying constraints to these objects. In a CAD system, not only geometry of a product or part is of importance and must be modelled, but also parameters representing other product information like material properties or technology and manufacturing properties. This affects the constraints, which can be subdivided into geometric constraints and so called engineering constraints, relating geometric and other product properties.

In engineering constraints, parameters like dimensions, material strength and machining parameters such as cutting speed or feed-rate can be associated using arithmetical (functional) or logical expressions, thus adding engineering knowledge to the product description.

Modelling with constraints is especially suited for particular applications in computer-aided design. The definition of geometric shapes is strongly supported and can be performed easily. The variations of designed shapes or even parts of a shape are easy to define and calculate quickly. Furthermore the conceptual design phase and the modelling of catalogue parts (variants and standard parts) are efficiently supported. Based on a part's description by constraints, further applications like kinematic or dynamic simulations are also possible and even available in some present CAD systems

2.3   The need for Parametric Design

The need for parametric design is becoming an ever increasing necessity for businesses that produce components that only differ slightly i.e. height, width etc. The capability to reuse drawing and to produce new designs by simply changing the constraints save time and also increases the overall work output for a company, in the aspect that a drawing doesn't have to be reproduced due to one dimensional change. A quick change of the constraints/relationships that designer has implemented and the drawing is changed to suit the desired requirement.

Since all these parameters form a network of constraints, variations of parameter values directly lead to variations of shape by evaluation of this network. 'This is called bidirectional associativity between shape and dimension.' (Anderl & Mendgennd.) Within the design of this project parametric design is accentual due to the panel tanks only differing by way of height, diameter and volume. With these design constraint a parametric tool can be easily implemented to perform all duties automatically, by integrating programs such as Microsoft Access.

2.4   Fluid Storage System

This subsection outlines the typical fluid storage system that the parametric tool is to be created around. It will outline design standards, assembly methods and equations that will ultimately be used to construct the constraints of the parametric tool. As the main aspect of the project is to develop a parametric tool using CAD software the review of literature on the fluid storage system will not be as in-depth.

2.4.1 Types of fluid storage systems

As you could imagine there are a lot a different varieties of fluid storage systems and they are all constructed around the substance that is to be stored in them. Whether it is water, petroleum, slurry, oil or even gas in liquid form (LNG) the design and type of tank varies with the constraints of the fluid. The need for fluid storage is an ever increasing demand in particular industries such as oil refinement, community water, and in recent times coal seam gas. The properties of such liquids have made the construction and design of storage vary on a dramatic scale over years, with design spanning from vertical, horizontal, in ground, above ground, welded, bolted and riveted tanks.
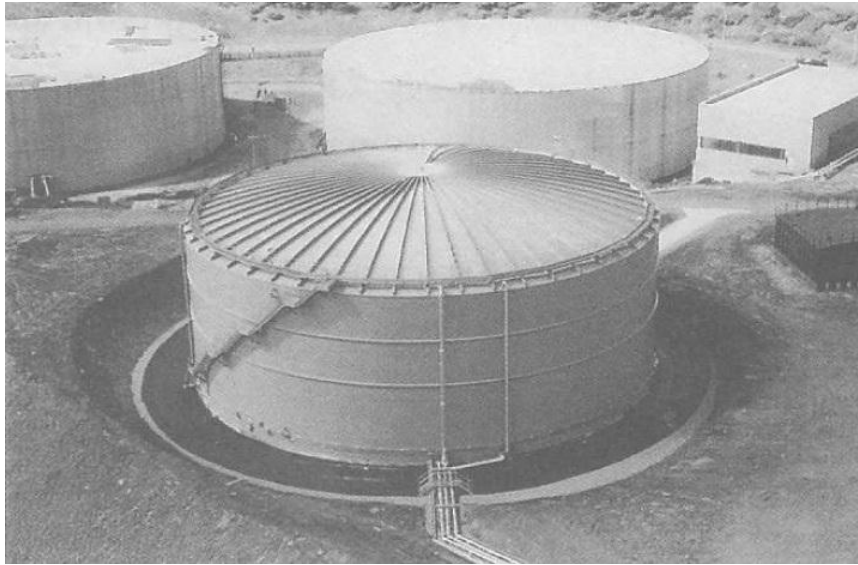
Figure 2.5 A 45 meter water tank (Long & Gardner 2004)

Figures 2.5 display a typical vertical tank configuration, and are the most widely used tanks in the industry today. In regards to construction and varieties of configuration for vertical tanks, the main aspect that is changed is the roof. Most common layouts are open, fixed and floating roofs which are used depending on the properties and form of the fluid. Open roofs are used for substances where evaporation is not an issue as it decrease expenses in the construction of the tank. Closed roofs are generally used for water storage and fluids that are affected by evaporation, decreasing evaporation can ultimately increase a company's profit margin. Floating roofs are essential for fluids such petroleum because of the fumes released by such fluid can be harmful and coarse catastrophic events like fires and explosions. A floating roof seals the fluid from releasing the fumes into the atmosphere and with proper ventilation the volatile fluid can be stabilised for storage.

Fluids that need to be pressurised (LNG, coal seam gas) are generally stored in horizontal tanks. Due to the compression the gas in liquid form occupies a lesser area. Also known as pressure vessels, these tanks are designed to with stand extremely high pressure and need to be designed on a very accurate scale. The use of pressure vessels provided and easy way to transport and store these types of liquid to the alternative of pipelining the liquid to its commercial and industrial outlets. Most of these tank can be viewed every day at fuel stations and on transporters i.e. trucks and trains. Figure 2.6 shows the uses of pressure vessels for storage.
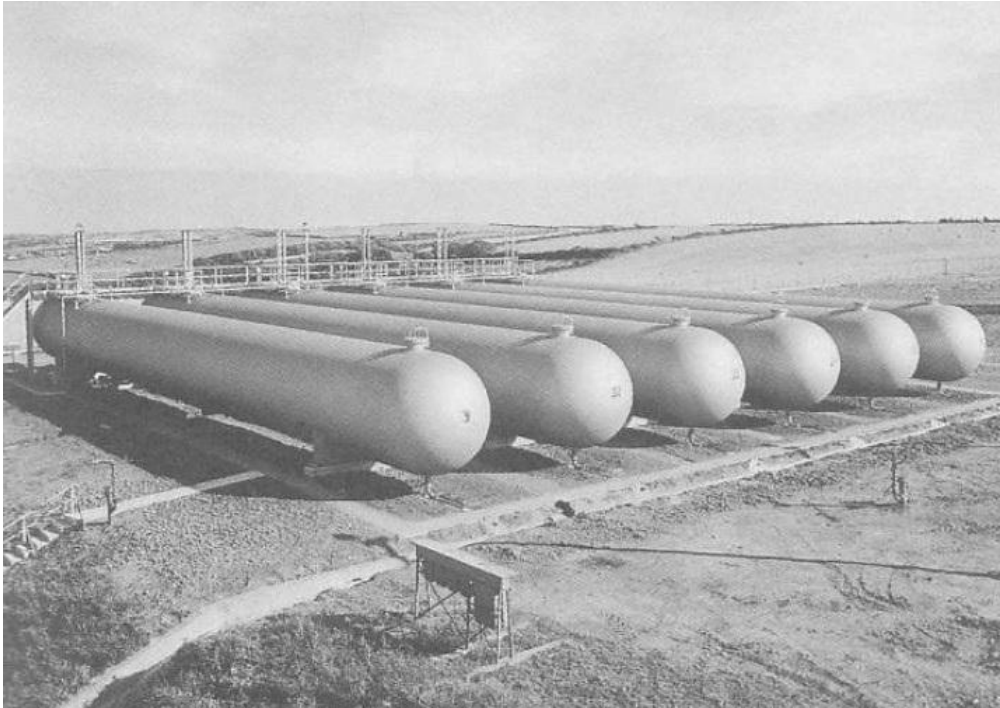
Figure 2.6 Liquid propane storage facility (Long & Gardner 2004)

Below ground tanks are the least common of all storage systems as there is usually more cost involved to do with excavating and subgrade work. In some cases there is no other option but to have the tank underground. Case included limited above ground space or where there are unacceptable risk/dangers i.e. airports and fuel station forecourts.

2.4.2 Construction and erection techniques

As with any construction work there are multiple of ways one can achieve a finished product and steel storage tanks are no exception. Public perception would have you believe that most tanks are actually constructed of site and then transported to the required location. With steel storage tanks this is certainly not the case. All tanks are constructed on site from the ground up or in some case the top down. Weld and riveted tanks are usually erected from the ground up with each course (the ring of panels that make a complete circle) welded or riveted together panel by panel. Once the course is complete they commence welding/riveting the next course.

This is accomplished with the use of scaffolding and cranes depending on the panel thickness. On the completion of the final course the tank liner is then attached and placed inside. A tank liner is only necessary for certain application of the tank i.e. water storage or for low corrosive fluids. If a liner is not required the inside of the tank will be coated with a wall sheet coating that is specific to the properties of the fluid that is to be stored.

Commonly bolted panel storage tanks are constructed at ground level for the entire erection from start to finish. This done with hydraulic jacks (Figure 2.7); the foundations are prepared and from then then first course is bolted together with the exemption of one panel to allow access into the interior of the tank. The roof is then constructed; this is still made possible without the use of scaffolding as the average height of a panel and therefore course is only 1.2 meters. The liner is then installed; the difference in tanks in shown here as the majority of bolted panel tanks can only support modest capacity and are therefore primarily used for water storage. Thus the liner is the cheapest option for corrosion proofing the interior of the tank.

Figure 2.7 Hydraulic jack used in construction (Tank Connections 2009)

When all of the initial setup is complete (first course, roof and liner) the hydraulics are then used to raise the structure to a height suitable for bolting the next course. This step is then completed until design height is reached. Then Advantage of the bolted panel storage tank for water storage purposes is that they quick and is to constructed and that they are essentially reusable in the fact that they can be disassembled and moved to a different location.

Along with erection techniques another key element is the orientation of the panels. There are two different ways that panels can be orientation and they are offset or parallel. Parallel is basically aligning the panel so that each is connected end by end; the next course is then aligned with the previous so that the weld or bolting lines run vertically up the entire tank. This can be observed in figure 2.7.

Offset orientation is usually only seen on bolt panel storage systems. Panels are offset in each course, by connecting the starting panel of the next course in the middle of a previous course panel (Figure 2.8).

Figure 2.8 Offset panel orientation (Tyco flow control 2009)
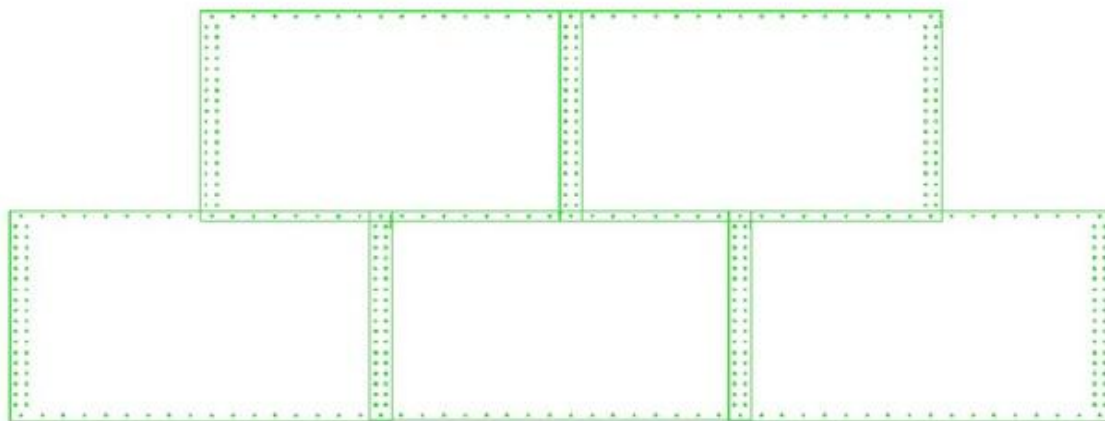
Figure 2.9 Offset bolt hole assembly

The many reason for most bolted panel tanks having to be offset is that due to the bolt assembly when constructing the tanks. If all panels were aligned on top of one another there would only be one bolt supporting the join of four panels. Figure 2.9 how the alignment is done and you can obverse that due to this arrangement the seams doesn't conflict with other panels. This also helps to keep the structural integrity of the tank and will not provide a localised area of failure.

2.4.3 Materials

As one can imagine fluid storage tanks are under immense hydrostatic pressure and environmental loads. Therefore there is great importance in material selection and use. The type of tanks described in previous sections involves the use a panel to provide the profile and liquid containment for the system. With any construct the entire operation must to conform to appropriate national and international standards were needed. In most cases panels are fabricated form stainless steel sheet metal. The metal is hot rolled and formed to the diameter require to produce a course of panels that much the diameter of the tank. Panels are produced from stainless steel due to its corrosion prevention properties.

Care as to be taken when fabricating these panels, to not comprise the mechanical properties of the metal. Usually the purchaser or manufacture of the panels will have a third part to come and inspect the panels to be complete sure that there are no faults in the material before transported to the construction site, this is general practise for most companies in a lot of industries.

Mentioned previously in this section was the criterion for panel width, height and thickness. Common practise is to fix one of these variables as it will make fabrication less tedious and calculation for panel requirements a lot easier. Panel thickness which is described in the standard subsection of this chapter is controlled by a standard and can sometimes vary as the height on each course of the tank rises.

Basic roof materials are composed of C-purlins, brackets and roof sheeting. These components are primarily for tanks that contain none corrosive or flammable liquids. For any other types of fluid a floating roof is constructed. Floating roofs require many more design requirements as they need to create a seal around the inner diameter of the tank. Pressures are also increase when using floating roof as the liquid is compressed slightly to allow the roof to float.

To ensure structural integrity it is important that all components of the tank are fabricated from the same material as the panels if they are required to be attached to a panel. Things like manholes, wind girds, inlet/outlet fittings, bolts and ladders support if made for carbon steel and welded or bolted to a panel that is stainless steel can disrupted the properties of the steel and compromise the entire structure.

2.5   NATIONAL/INTERNATIONAL STANDARDS

This subsection will outline the Australian and American standards that are used in the construction and design of a fluid storage system. The use of standards within this project is very important as they are the basis of all the rules that allow the automation of assemblies, part and engineering drawings (list of standards located in appendix F).

As well as outlining the standards that were used, a detailed summary of the standard and the sections that are applicable to this project will also be discussed.

2.5.1 AWWA D103-97

This particular standard is from the American Water Works Association (AWWA). It covers factory-coated bolted steel tanks for water storage and is based on the accumulative knowledge and experience of manufactures of bolted steel tanks. Due to the absence of an Australian standard solely for bolted panel tanks. YT tanks a division of Tyco Pumping Systems has opted to use this American standard as it has very comprehensive information which in this case is more suited to the application.

The standard outlines all the aspects to do with the general construct of a panel tank. However it is only need used for the following attributes.

- Sheet metal thickness
- Design loads
- Manhole construction
- Wind Girder placement
- Pipe connections

All other requirements will incorporate the Australian standards and will be addressed later on in the chapter. Note all units are in imperial as this is an American standard located in appendix C is a list of conversions that transform all imperial measurements to metric. Also

all equation within this subsection are cited from the American Water Works Association standard D103-97

2.5.1.1 2. Sheet metal thickness

In the design of the tank shell, the hydrostatic water pressure towards the bottom ring of the tanks plates can shall be assumed to act undiminished on the entire area of the bottom ring. Therefore the tensile stress governs the thickness of the cylindrical shell plates stressed by the contents of the tank, so plate thickness can be calculated by the formula (AWWA D103-97);

$$t = \frac{2.6HSDG}{f_t(S-d)} \tag{2.1}$$

where t =   shell plate thickness, in inches.

H =   height of liquid from the top capacity line to the bottom of the shell being designed.

S =   bolt spacing in line perpendicular to the line of stress, in inches.

D =   tank diameter, in feet.

G =   specific gravity of liquid (water 1.0).

f_t =   allowable tensile stress, in pounds per square inch.

d =   bolt hole diameter, in inches.

As most of these parameters are set as per the clients request the formula can be solved once ft is established. Explained above f_t is the allowable tensile stresses on the net section of a bolted connect and is calculated by.

$$f_t = 0.40F_u \tag{2.2}$$

Or

$$f_t = 0.6F_y(1.0 - 0.9r + \frac{3rd}{s}) \leq 0.6F_y \tag{2.3}$$

where
f_t =   allowable tensile stress, in pounds per square inch.

F_u =   published ultimate strength of the sheet material, pounds per square inch.

F_y =   published yield strength yield strength of the sheet material, pounds per square inch.

r =   force transmitted by the bolt/s at the section considered, divided by the tensile force in the member at the section. If less than 0.2 can be considered 0.

d =   diameter of bolt/s, in inches.

s =   bolt spacing, in inches.

The sheet material in use has been selected by the company and is AS3678 grade 300. All variables are now defined and can be used to find the sheet thickness. H in equation 4.1 must be looped when creating the rule that defines the thickness as each sheet is 1200mm in height and the thickness of each ring will change as the tank is erected.

2.5.1.2   Manhole construction

Bolted panel tanks must be constructed with one manhole, unless otherwise specified and will be placed in the first ring of the tanks shell at a location to be designated by the purchaser. In tanks with one manhole, a sheet opposite the manhole may be removed for more ventilation, if required for inspection and re-coating. To comply with workplace health and safety any manhole covers that weighs over 22.7 kilograms a hinge or davit shall be provided.

The sizing and shape of the manhole shall comply with the AWWA D103-87 standard which suggests the following layouts. Manholes maybe either circular, 610mm in diameter; square, 610mm × 610mm; or elliptical 457mm × 558.8mm, minimum size. Flush rectangular manholes with a minimum of 610mm in the short direction and a maximum length in the long direction of 1219mm are also acceptable. Cut-outs for all rectangular manholes are also required to have a minimum radius of 152mm around all corners.

Reinforcing the shell plate where the manhole is located is essential so that, the new addition to the tank doesn't compromise the structural integrity of the tank. Hence all portions of the manhole, including the bolting, the cover, and reinforcement of the neck, are to be designed to withstand the weight and pressure of the tank contents. The standard states that all welded or bolted connections greater than 101.6mm in diameter in the tank shell and other locations that are subjected to hydrostatic pressure, where the thickness were established in accordance with the design criteria as given in Sec 4.1.1, shall be reinforced. Reinforcing solution may

be the flange of a fitting, an additional ring of metal, a thicker plater, or any combination of these (AWWA D103-97).

2.5.1.3   Wind girders

Wind girders are a form of stabilising the tank. In most cases where the tank has a roof, intermediate girders are not essential. However in tanks that don't have a roof or are of an excessive height intermediate wind girders are uses to minimise localised buckling of the tank. In order to establish whether or not a girder is required in a design the following formula is used.

$$h = \frac{10.625(10)^6 t}{P(D/t)^{1.5}} \tag{2.4}$$

where h =   vertical distance between the intermediate wind girder and the top of the tank.

P =   wind pressure, in pounds per square foot. This is assumed to be 18 unless the wind velocity is specified to be greater than 100mph.

D =   tank diameter, in feet.

t =   average tank thickness for the vertical height.

In the case that the wind velocity does exceed 100mph in the specified zone of tank erection then the value for P is calculated by the formula.

$$P = 18 \left(\frac{wind\ velocity, in\ mph}{100} \right)^2 \tag{2.5}$$

All calculations made for the winder girders should be based on the average shell thickness obtain using equation 4.1 for the overall all height of the tank. If the vertical distance h between the intermediate wind girder and the top of the tank is calculated to be greater then the overall height of the tank, then no intermediate wind girder is required. After establishing the location of the first wind girder (if required), the procedure can be repeated for additional wind girders, using the previous intermediate wind girder as the top of the tank (AWWA D103-97).

2.5.1.4   Pipe Connections

All pipes shall be sized as per purchasers request. However overflow and inlet holes and pipes are standard with the overall design of the tank. There are two types of over flow pipes stub and to ground overflow pipes, the stub pipe requires that it protrudes at least 304.8mm beyond the tank shell. If the overflow to ground is required, it should be brought down the outside of the tank shell and supported at proper intervals with suitable braketing to insure structual integrety. The overflow and intake pipes should have a capacity at least equal to the pumping rate as specidied by the purchaser.

Table 2.1 Flange sizing (AWWA D103-97)

Size (mm)	50.8	76.2	101.6	152.4	203.2
Diameter of bolt circle	101.6	136.5	161.9	228.6	285.8
Number of bolts	101.6	101.6	127	152.4	203.2
Diameter of bolts	12.7	15.9	15.9	15.9	15.9
Diameter of bolt holes	15.9	19.1	19.1	19.1	19.1
Minimum thread length, Y	22.2	30.2	33.3	39.7	44.5
Depth of counter bore	8	9	10	12	14
Outside diameter of flange, O	130.2	168.3	196.9	266.7	323.94

As discuss previously if there is any alteration to any of the shell panel they will require reinforcing. An easy option for reinforcing when it comes to pipe connects is the use of flanges. Table 1 outlines the sizes and requirements when using flanges for pipe connections, figure 1 identifies the areas in which the dimensions from table 1 are used.
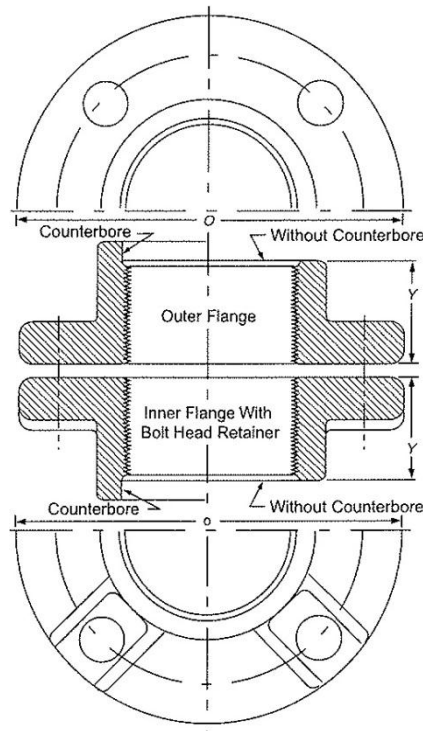
Figure 2.10 Flange layout (AWWA D103-97)

2.5.1.5   Seismic Requirements

The designs of most flat bottom ground supported tanks recognise the reduction in seismic load due to the sloshing of the contained liquid. This design procedure is recognised as the effective-mass method. Within in the design of such tanks they can either be anchored or un-anchored depending on client's request. However anchored tanks are susceptible to tearing of the shell if the anchorage is not designed properly, care must be taken to ensure that the anchor-bolt attachment is stronger than the anchor bolt itself. Experience shows that properly designed anchored tanks have greater reserve strength to seismic loads than that of un-anchored tanks. The anchorage should be designed such that the bolts yield before the shell attachment fails, seismic resistance for an un-anchored tank relates to the height to diameter ratio.

The following design loads are based on consistent probability of seismic disturbance in Australia. As stated above the effective-mass procedure considers two response modes of the tank and contents. The first is the high frequency amplified response to lateral ground motion of the tank shell and roof together with a portion of liquid that moves in unison with the shell. Second the low frequency amplified response of a portion of the liquid contents in the

fundamental sloshing mode. The design requires the determination of the hydrodynamic mass associated with each mode and the lateral force and overturning moment applied to the shell resulting from the response of the masses to lateral ground motion (AWWA D103-97).

Equations that govern the design loads are listed below .First it must be noted that if an unanchored tank design is used, the maximum thickened bottom annulus width used to resist overturning shall be limited to seven.

The base shear and overturning moment due to seismic forces applied to the bottom of the shell shall be determined in accordance with the following formulas.

Base shear:

$$V_{ACT} = \frac{18ZI}{R_w}[0.14(W_s + W_r + W_1) + SC_1W_2] \tag{2.6}$$

Overturning moment:

$$M = \frac{18ZI}{R_w}[0.14(W_sX_s + W_rH_t + W_1X_1) + SW_2X_2C_1] \tag{2.7}$$

where

V_{ACT}	=	actual lateral shear, pounds	
M	=	overturning moment applied to the bottom of tank Shell.	
Z	=	zone coefficient from appendix B	
I	=	use factor	
R_W	=	force reduction coefficient, table 2	
W_s	=	total weight of tank shell bottom and significant appurtenances in pounds	
X_s	=	height from the bottom of the tank to the centre of gravity of the shell, in feet	
W_r	=	total weight of the tank roof plus permanent loads if any, in pounds	
H_t	=	total height of tank, in feet	
W_1	=	weight of effective mass of tank contents that moves in unison with the tank shell	
X_1	=	height from the bottom of the tank to the centroid of lateral seismic force applied to W_1, in feet	
S	=	site amplification factor, assumed to be 1.5 unless otherwise stated	
W_2	=	weight of effective mass of the first mode sloshing contents of the tank, in pounds	
X_2	=	height from the bottom of the tank shell to the	

centroid of lateral seismic force applied to W_2, in feet.

The value Z zone seismic coefficients are given on geographical maps located in the appendices there are maps for each state and territories of Australia. Areas that do not fall on a reading are to be given the value that is closest.

Table 2.2 Force reduction coefficient (AWWA D103-97)

Structure	Force Reduction Coefficient R_w
Anchored flat-bottom tank	4.5
Unanchored flat-bottom tank	3.5

Table 2.3 Site amplification factor S (AWWA D103-97)

	Soil Profile Type			
Site Amplification	A	B	C	D
Factor	1.0	1.2	1.5	2.0

The following is an explanation for the determination of the site amplification factor, which shall be supplied by the purchaser. Site effects on tank response shall be established based on the following four soil profiles factors.

Table 2.4 Soil profile type (AWWA D103-97)

Profile type A	Rock of any characteristic, either shale-like or crystalline in nature. Such material may be characterised by a shear wave velocity greater than 760 m/s.
	Stiff soil conditions where the soil profile is less than 61m and the soil types overlying

	rock are stable deposits of sands, gravels, or stiff clays.
Profile type B	Soil has a profile with deep, cohesionless or stiff clay conditions, including sites where the soil depth exceeds 61m and the soil types overlying rock are stable deposits of sands, gravels and stiff clays
Profile type C	A profile with soft to medium stiff clays and sands characterised by 9.1m or more of soft to medium stiff clays with or without intervening layers of sand or other cohesionless soils.
Profile type D	A profile containing more than 12.2m of soft clay characterised by a shear wave velocity less than 152.4m/s.

*In locations where the soil profile type is not known due to insufficient details in determining the soil profile type, soil profile type C should be assumed.

Table 2.5 Use factor I (AWWA D103-97)

1.25	Sole supply Fire protection Multiple supply and fire protection
1.0	Multiple supply and no fire protection

*An *I* of 1.25 should be used unless other wised specified by the purchaser.

As C_1 is controlled by the first mode sloshing wave period (T_w), therefore T_w must be calculated prior to the calculation of C_1.

$$T_w = K_p D^{\frac{1}{2}} \tag{2.8}$$

where

T_w	=	first mode sloshing wave period, in seconds
K_p	=	factor from figure 2 for the ratio of tank diameter, in feet, to maximum depth of water, in feet, D/H.
D	=	tank diameter, in feet.
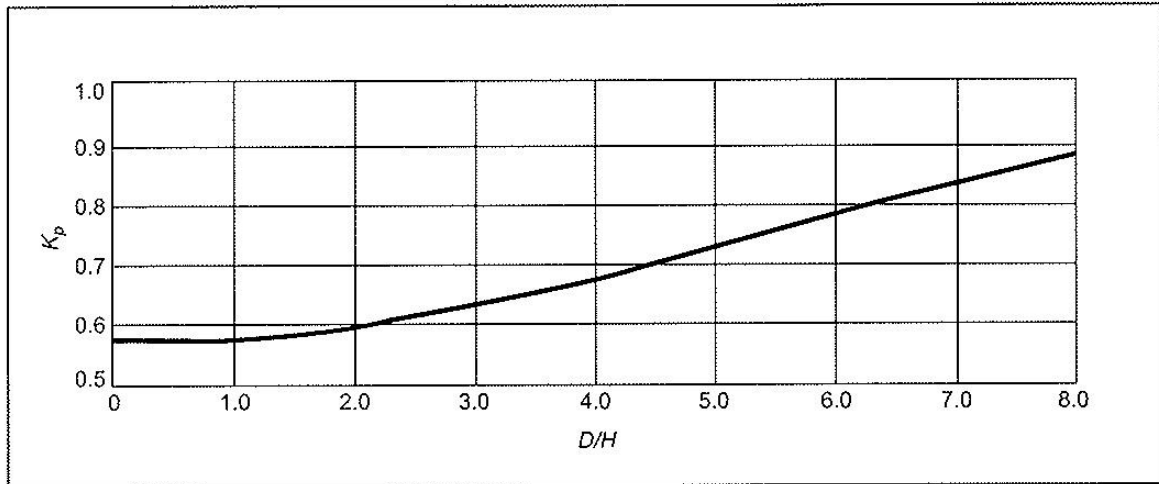
Figure 2.11 Curve for obtaining factor K_p for the ratio D/H (AWWA D103-97)

Now C_1 can be obtained, however there are two conditions which must be accounted for when establishing a value for C_1.

For the condition where $T_w \geq 4.5$ seconds

$$C_1 = \frac{0.75}{(T_w)^2}$$ (2.9a)

For the condition where $T_w < 4.5$ seconds

$$C_1 = \frac{1}{6T_w}$$ (2.9b)

The overturning moment determined by this formula is that applied to the bottom of the shell only. The tank foundation is subject to an additional overturning moment due to lateral displacement of the tank contents. This may need to be considered in the design of some foundations, such as pile supported concrete slabs, however this aspect is out of the scope of the project as the seismic consideration is only for the design of the tank structure itself (AWWA D103-97).

The effective of the tank contents that moves in unison with the tank shell W_1 and the weight of the effective mass of the first mode sloshing contents W_2 may be determined by multiplying W_t by the ratios W_1/W_T and W_2/W_T respectively. The ratios can be obtained from Figure 4.3 for the ratio H/D.

Therefore :

$$W_T = 62.4GH\left(\frac{\pi D^2}{4}\right) = 49GHD^2 \qquad (2.10)$$

where D =   tank diameter, in feet
                   H =   maximum depth of water in the tank, in feet
                   G =   specific gravity (1.0 for water)
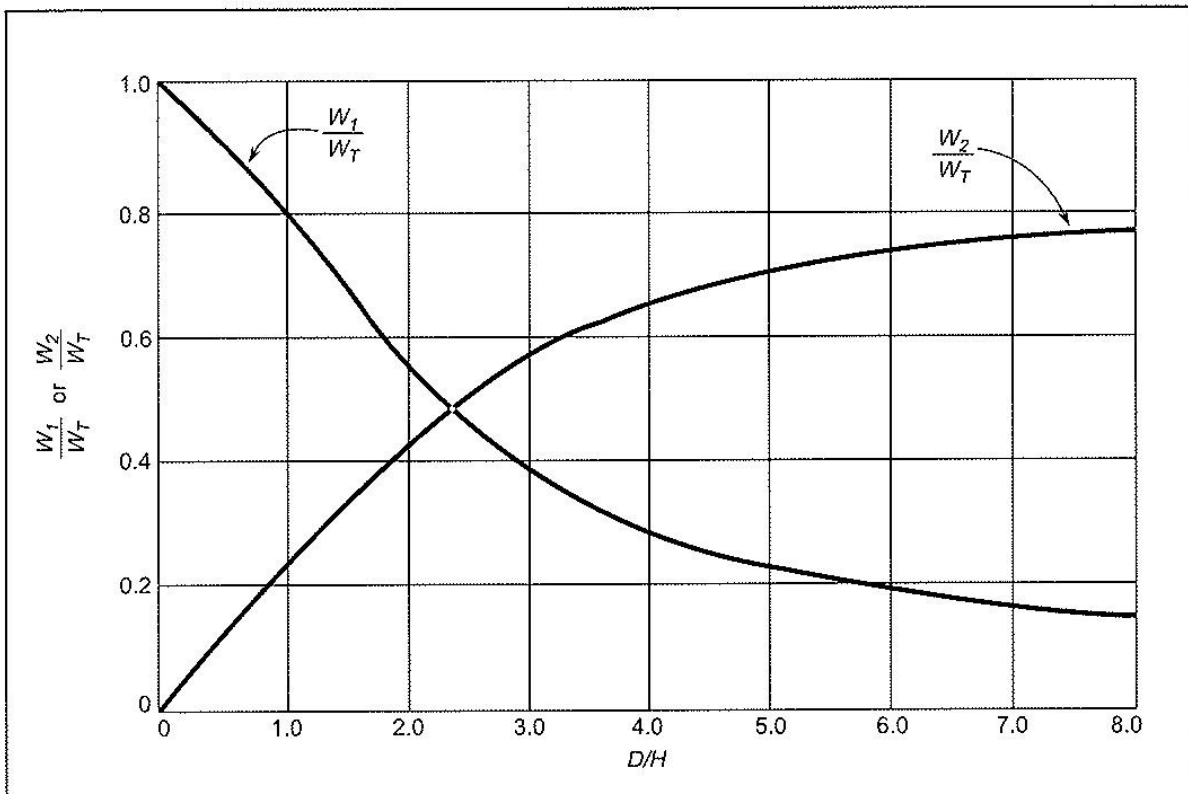
Figure 2.12 Curves for obtaining factors W1/WT and W2/WT for the ratio D/H (AWWA D103-97)

As for the heights X_1 and X_2, from the bottom of the tank shell to the centroids of the lateral seismic forces applied to W_1 and W_2, may be determined by multiplying H by the ratios X_1/H and X_2/H, respectively. These ratios can be obtained from Figure 4.4 for the ratio D/H.
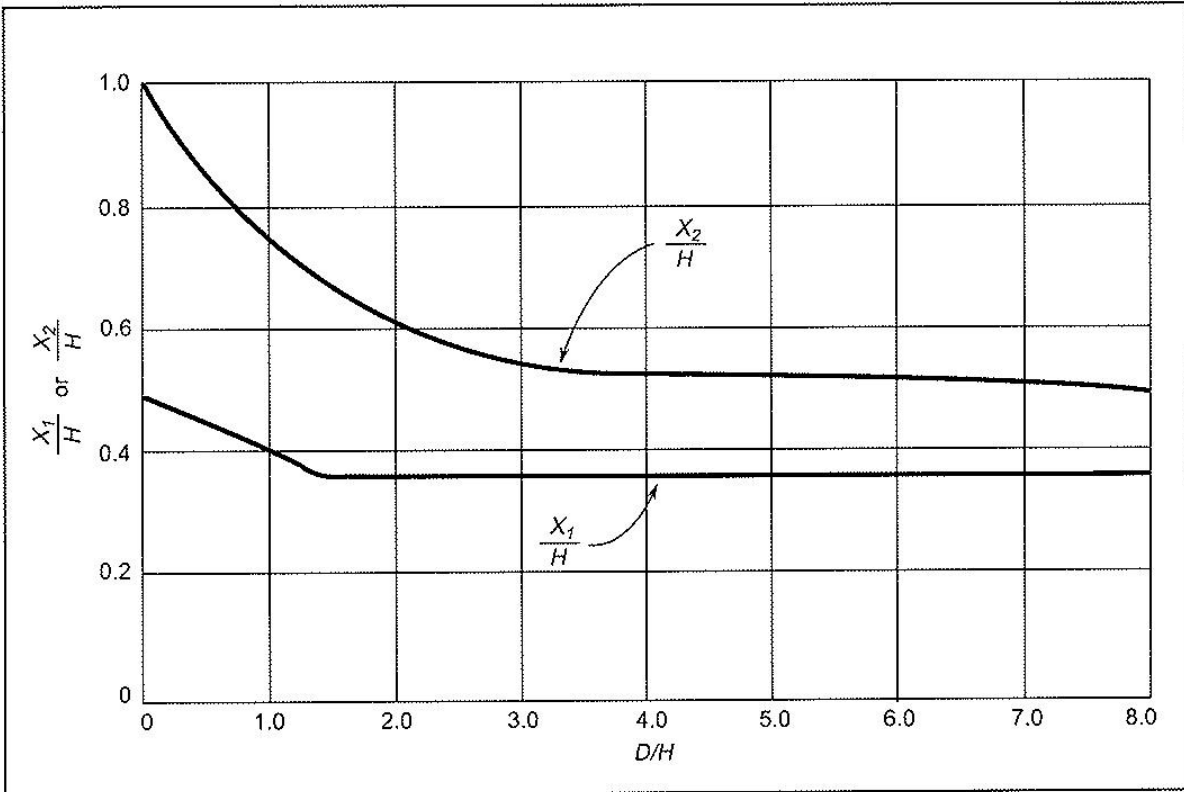
Figure 2.13 Curves for obtaining factors X1/H and X2/H for the ratio D/H (AWWA D103-97)

Resistance to the overturning moment at the bottom of the shell may be provided by the weight of the tank shell, weight of the roof reaction on shell and by the weight of a portion of the tank contents adjacent to the shell for unanchored tanks or by anchorage of the tank shell. For unanchored tanks the portion of the contents that may be used to resist the overturning moment is dependent on the width of the bottom annulus. The annulus may be a separate ring or an extension of the bottom plate if the required thickness does not exceed the bottom thickness. The weight of the bottom annulus that lifts off the foundation is calculated by the following formula (AWWA D103-97).

$$w_L = 7.9 t_b \sqrt{\sigma_y HG} \leq 1.28 HDG \qquad (2.11)$$

where w_L = maximum weight of thank contents per foot of shell circumference that may be used to resist the shell overturning moment, in pounds per foot

t_b = thickness of bottom annulus, in inches

σ_y	=	minimum specified yield strength of bottom annulus, in psi
H	=	maximum depth of water, in feet
G	=	specific gravity (1.0 for water)
D	=	tank diameter, in feet

The maximum longitudinal shell compression stress at the bottom of the shell when there is no uplift is determined by the formula below. Uplift meaning that the tanks bottom shell course remains on the ground when the moment is in effect. It can be assumed that anchored tanks always fall in this category because of the anchorage points located on the bottom shell course.

$$\sigma_c = \left(w_t + \frac{1.273M}{D^2}\right)\frac{1}{12t_s} \tag{2.12}$$

These terms have already been defined throughout the chapter.

Whether or not there is uplift can be determined when the resulting quantity from equation 4.13. There is no uplift when the equation is equal to or less than 0.785.

$$\frac{M}{D^2(w_t + w_L)} \leq 0.785 \tag{2.13}$$

However the maximum longitudinal shell compression stress at the bottom of the shell when there is uplift is determined by the formula.

$$\sigma_c = \left[\frac{w_t + w_L}{0.6070 - 0.18667\left(\frac{M}{D^2(w_t + w_L)}\right)^{2.3}} - w_L\right]\frac{1}{12t_s} \tag{2.14}$$

There is up lift when equation 4.15 yields a quantity greater than 0.785 but equal to or less than 1.54. If the equation yields a quantity greater then 1.54, then the bottom annulus must be thickened or be anchored.

$$0.785 < \frac{M}{D^2(w_t + W_L)} \leq 1.54 \qquad (2.15)$$

$$w_t = \frac{W_s}{\pi D} + w_{rs} \qquad (2.16)$$

where σ_c =   maximum longitudinal shell compression strength, psi

           t_s =   thickness of bottom shell course, in inches

           w_t =   weight of the tank shell and portion of the roof reacting to the tank shell, in pounds per foot of shell circumference

           w_{rs} =   roof load acting on shell, in pounds per foot of shell circumference

As the maximum longitudinal shell compression strength has been derived the earthquake allowable stress needs to be accessed to determine whether the annulus (bottom shell course) can with stand seismic reactions. The following formulas are for both anchored and unanchored tanks.

For unanchored tanks:

$$\sigma_e = 1.333 \left(f_s + \frac{\Delta\sigma_{cr}}{2} \right) \qquad (2.17)$$

For anchored tanks:

$$\sigma_e = 1.333 f_s \qquad (2.18)$$

where σ_e =   earthquake allowable stress, in psi

           f_s =   allowable compressive stress, in psi, equation 4.19

           $\Delta\sigma_{cr}$ =   critical buckling stress increase due to pressure, in

psi, equation 4.20

$$f_s = 15000 \left(\frac{2}{3}\right)\left(100\frac{t}{R}\right) \times [2 - \left(\frac{2}{3}\right)\left(100\frac{t}{R}\right) \le 15000 \qquad (2.19)$$

$$\Delta\sigma_{cr} = \frac{\Delta C_c E t}{R} \qquad (2.20)$$

where ΔC_c = pressure stabilising buckling coefficient Figure 4.5
E = Modulus of elasticity taken as 29000000 psi
t = thickness of the plate under consideration, in inches
R = radius of the tank, in inches

The definitions for the symbols used in Figure 9 are as follows:

ΔC_c = pressure stabilizing buckling coefficient
P = hydrostatic pressure at point under consideration in pounds per square inch
E = the modulus of elasticity
R = the radius of tank, in inches
t = the thickness of the plate under consideration
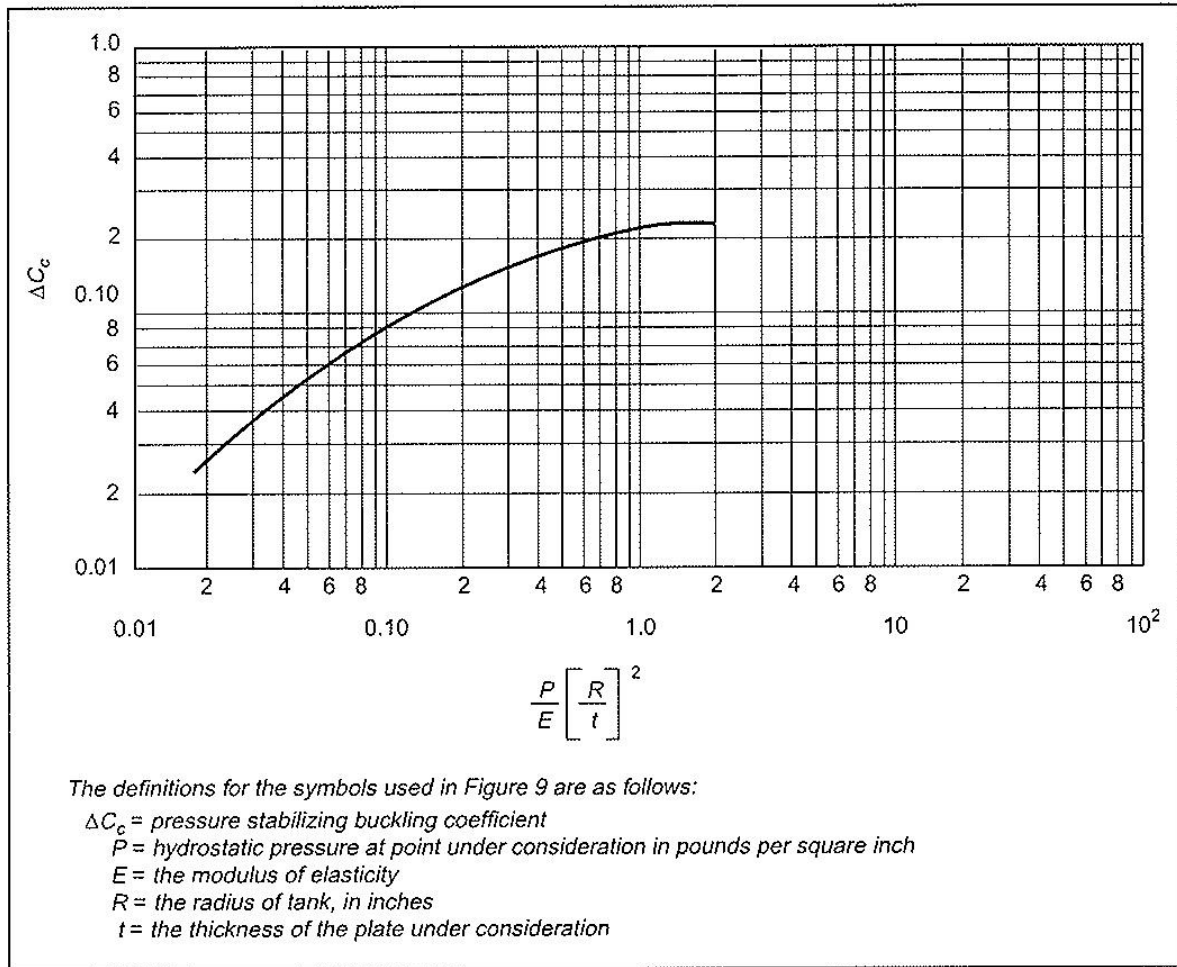
Figure 2.14 Increase in axial-compressive buckling-stress coefficient of cylinders due to internal pressure (AWWA D103-97)

To concluded it must be seen that to determine whether the tank can withstand seismic activity is by comparing the values calculated for σ_c and σ_e. The earthquake allowable stress (σ_e) must be greater than the maximum longitudinal compression strength (σ_c), if σ_c is greater than the tank may require anchorage (if not already) or the bottom annulus thickness must be increase and values recalculated until σ_e is the greater value.

2.5.1.6 Freeboard and Overflow

The freeboard is driven by what's known as the sloshing mode, created by seismic activity and wind loads. Calculation of the wave height can provide an outline for which the freeboard and over flow must be set under.

$$d = 7.53D \left[\frac{ZIC_1S}{R_w} \right] \qquad (2.21)$$

where d = wave height created by seismic occurrences

All another variables have been defined previously in this chapter.

CHAPTER 3   DESIGN METHODOLOGY AND OVERVIEW

The following chapter will outline the steps and procedures used in compiling and developing the parametric CAD tool for fluid storage systems. The contents will outline step by step the approach that was taken to develop each requirement of the objectives list in section 1.4 of the introductory chapter. It incorporates information from the standards discussed in section 2.5 to provided parametric constraints on the drawings that are required to be automated within the program. Note that all methods of the design are following contractual standards for unanchored bolted panel tanks.

3.1   User-Interface

The two main parts of the program are to automate engineering drawings and to export a bill of materials to a printable word document. These two operations through trial and error have been found to be easier if they are completed as separate entities and then brought together via another operation. The CAD parametric tool use an internal program within SolidWorks (the CAD program) called DriveWorksXpress. This program allows the developer to create a form for data entries which is filled with the required information from the user.
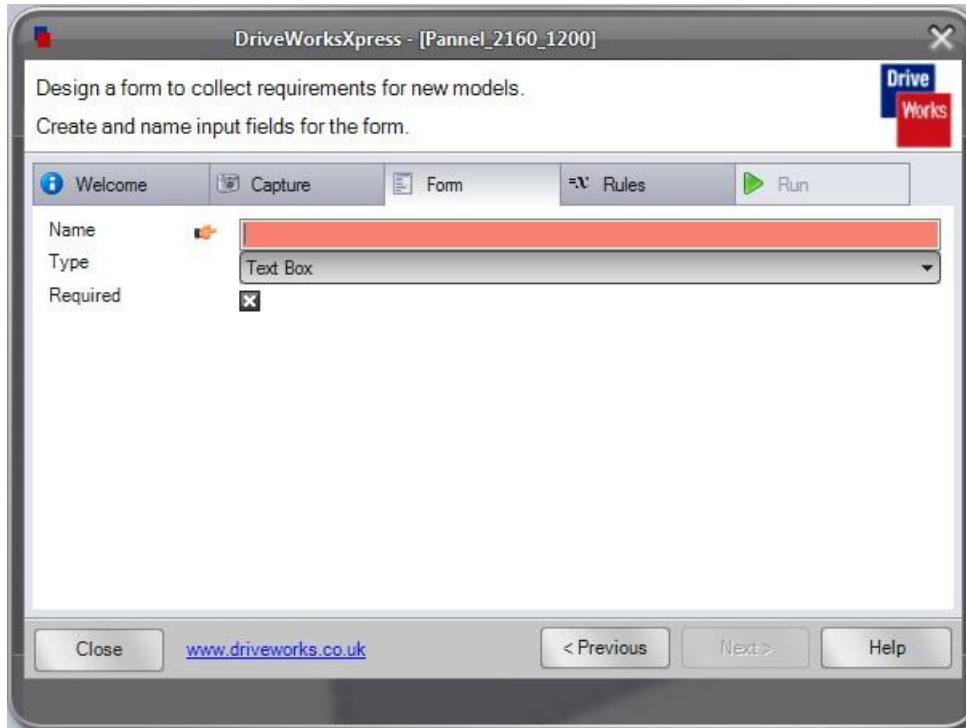
Figure 3.1 DriveWorkXpress form creation

Figure 3.1 displays the beginnings of a form using DriveWorksXpress. The name of the field is place in the highlighted area i.e. Product number. Then in case of a numerical field the type selection will have to be changed to numerical text box. To ensure that the correct data is put in to each required field a minimum and a maximum value range can be put in (Figure 3.2). Once all necessary fields have been entered for that particular form entry, click next and move on to a new form field.
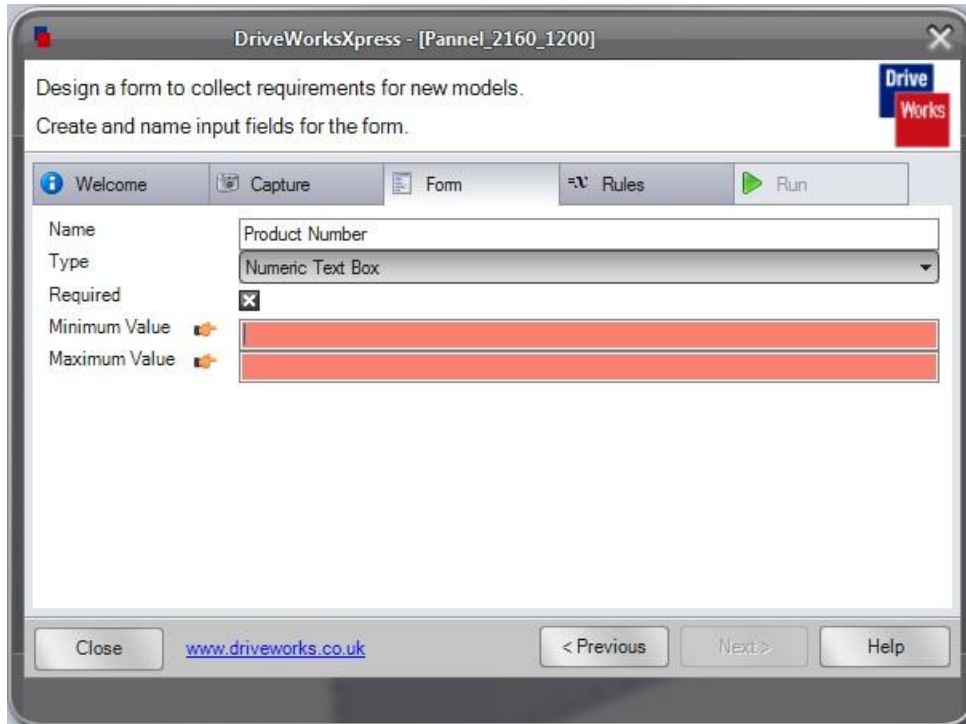
Figure 3.2 Filtering form data entries

After next is clicked from the above described operations a dialog box appears (Figure 3.3). Within this area selections can be made to develop another form entry or edit and delete previous ones. Testing on already established form items can also be done to see whether or not all fields are working as desired.
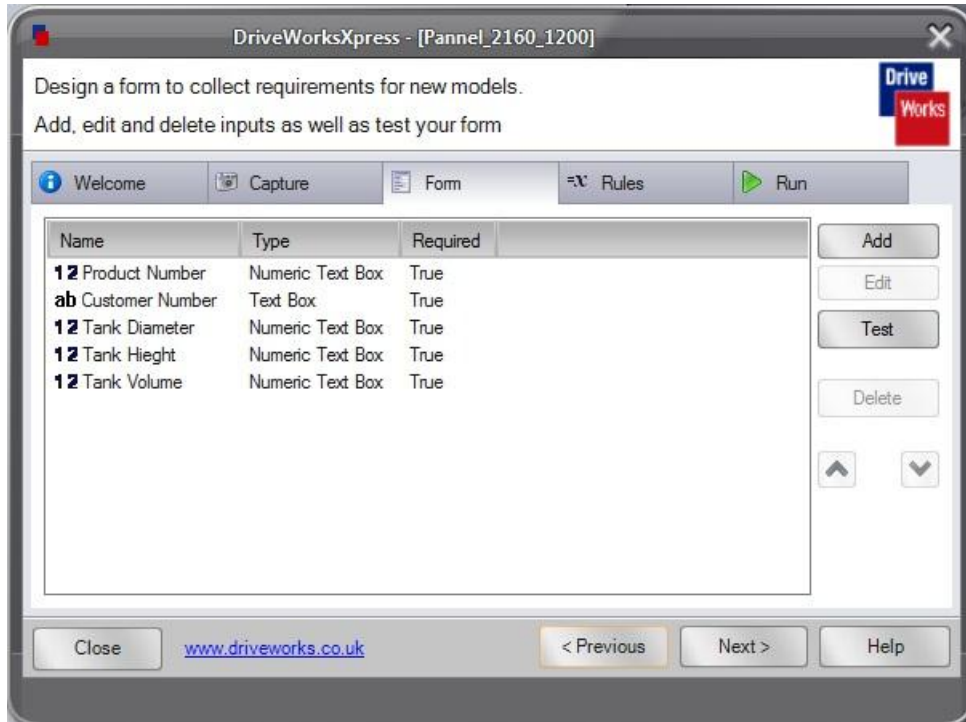
Figure 3.3 Dialog box for editing forms
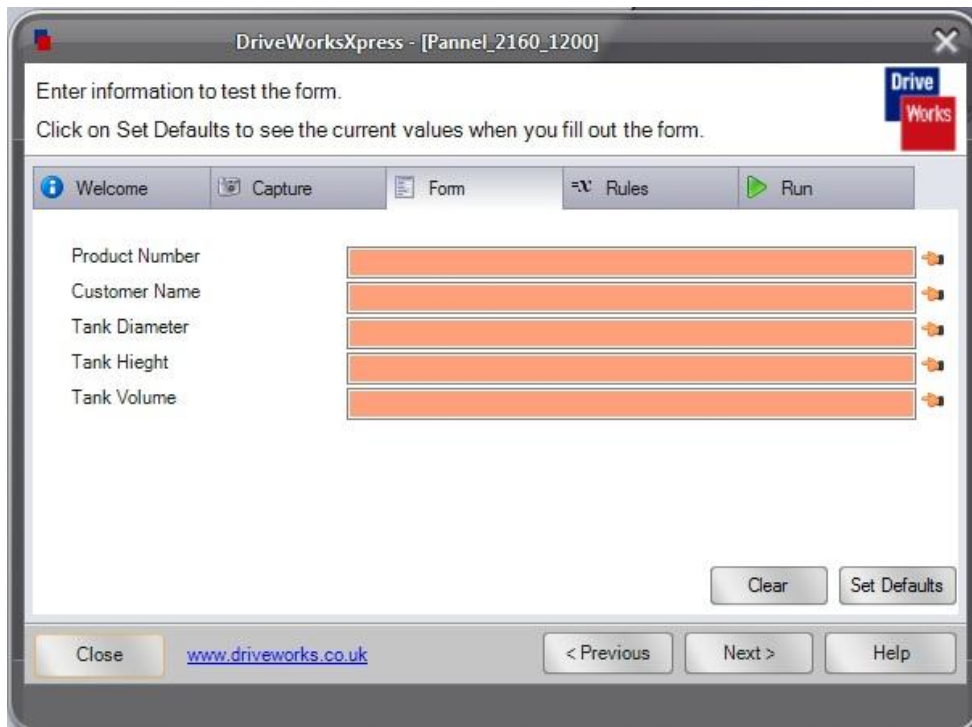
Figure 3.4 Completed Form

Figure 3.4 showcase the possible finished form, from what was entered in the previous steps discussed above. Access to the form is through SolidWorks.exe file, this file extension opens the SolidWorks CAD program. DriveWorksXpress can be found in the tools menu. From there DriveWorksXpress open on the most recently active database, which can be changed by checking the add/change option in the start-up menu. If changing the directory is not required the form, and the option to run drawing automation is accomplished by selecting run on the DriveWorksXpress inter-face, which then takes you to the form you constructed, ready for data entry.

Acquiring the bill of materials follows a similar approach however it uses Microsoft Access to create the form based interface. An advantage of using Microsoft access is that all data entered into the form through the inter-face will be save on the one file. Data basing all entries will allow user to revisit previous orders and submit new ones via the same program.

Microsoft access forms require a different approach to that of DriveWorksXpress. A form has to be link to a table, so before the form can be created a table must be constructed. The form isn't essential for the program to work, however it decrease data corruption as it only displays one record at a time. Whereas tables display all the submitted records within the database, this is why a form becomes the interface for data input.

The table is created by opening Microsoft Access and opening the create tab. The tab then displays a number of option, the one used was create table in design view. When displayed (Figure 3.5) the design view allow you to enter fields and set indexing options. It wise to set these indexing options, as it will control the data that is entered and stop corruption that could potentially ruin the database. After the table is constructed, the form can now be produced.
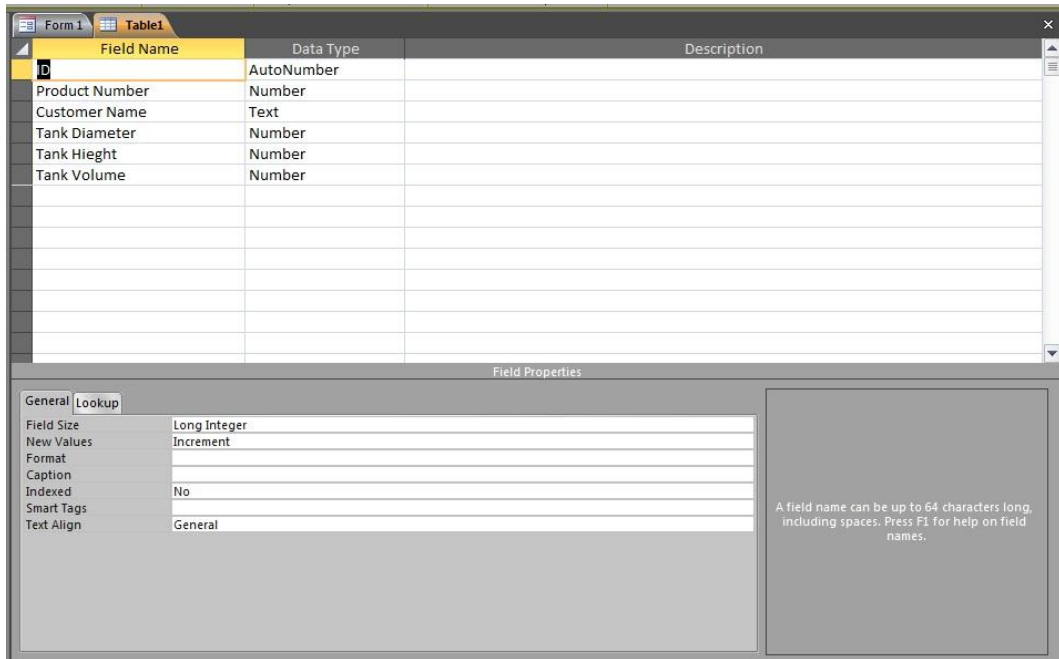
Figure 3.5 Table Creation Microsoft Access

To store the data entered in to the form in the table, labels and text box created on the form have to the table. Using form design wizard within Microsoft Access is an easy way to establish these required links. The form is thus designed and created using the fields that were used in the table. Forms are constructed this way as there are simply there to aid the user in enter data into tables. Figure 3.6 provides an example of the use of fields from the tables in developing a sufficient form for data entry.

Figure 3.6 Bill of materials (BOM) inter-face

An addition to the form fields is the use of buttons and other automotive functions. These functions give the form an inter-face feel, as seen in Figure 3.6 there are two buttons. The

functions of these buttons allow the user to save entries made within the form fields, which will then transfer that data to the required table's thus allowing user to revisit entries if required at a later stage. Buttons that will also be required are, view bill of materials, find previous record and delete/edit record. It is important that several operations are available on the form, because once complete the only thing that can be accessed by users is the interface. This is done to keep the integrity of the program and to stop users from trying to adjust features that are automated by code which could potentially affect the operation of the database.

3.1.1 Interface justification

It was found more beneficial to construct two separate data entry point arranged as form interfaces, because it was found that DriveWorksXpress wasn't capable of convert form entries to a bill of materials report. That is why Microsoft Access is used as it is capable of constructing multiple tables, forms and reports that can be exported to word documents. A down side to this is that if multiple records and reports are required the operation will get very repetitive.

3.2   Bill of Material Development

The bill of materials is designed in conjunction with the interface (form) that was developed in Microsoft access. It is important to note that the bill of materials in this case is just the sum of all required features that make up the tank (panels, connects, etc.). From records input through the inter face a report is generate using Microsoft Access. The report uses fields from the form and carries then over to the report.

Bill Of Materials		
Product Number 6510		Customer Name Jane Citizin
Tank Diameter (m) Tank Hieght (m)		Capacity (m^3)
7 9		346

Figure 3.7 Feilds carried over from interface

Figure 3.7 shows the uses of fields from the form and table that have carried over. Details like capacity are calculated using the tank diameter and fluid height. Fluid height is the maximum height that the fluid can reach within the tank, thus the remainder is the freeboard. Freeboard is calculated by using equations from section 2.5.1.6 in chapter 2.

The remainder of the bill of materials is also calculated using records inputs that are called from the table once entered. The below figure shows an example of a table produced in the report for the BOM. It outlines features need and there quantities. Product titles remain constant across all reports, the change is in the quantity column where each individual value is calculated, and an example of this is with the panel quantity. The number of panels is calculating by obtaining the total circumference of the tank and dividing it by the panel length (2160) this then equates to the number of panel that make up the tank circumference. As for the number of panels to create the height this is simply tank height divided by panel width (1200), times both values together and the quantity is created. The overall figure is then rounded to ensure full panel output. All other quantities are calculate with a similar approach or are directly filled from the form.

$$Qty = \left(\frac{tank\ circumference}{2160}\right) \times \left(\frac{tankheight}{1200}\right) \quad\quad (3.1)$$

Tank Products	Qty
2160 x 1200 Tank Panels	92
Inlet/outlet Panels	1
Wind Girders	1
Manholes	2
Pipe Connections	1
Ladders	2

Figure 3.8 BOM feature quanity for tank

3.3 Automation of Part and Engineering Drawings

Outline in the introductory chapter automation of part and engineering drawings is the main attribute for the parametric CAD tool. Automation is developed through SolidWorks and its add-on program DriveWorksXpress. The following will outline the methods adopted to establish relationship, capture dimension and feature that control the outcome of the parts. Ultimately with the use of records entered into the form discussed in section 3.1 rules are established regarding what actually needs to change in the drawing, then the drawing well be automatically manipulated to represent the new criteria.

Step one was to redraw all engineering drawings that were develop in AutoCAD (software program) into SolidWorks as part drawings, part drawing are a vital part to the development of the automation as they are also used in the 3D assembly (discussed later on in the section). Engineering drawing was then made with relative easy as they are produced from the part drawing with all dimensions and features carried over.

After drawings are developed DriveWorksXpress can be accessed, when start a new program you are required to select the drawing that you wish to control. This is done in the capture tab of the program. Select all drawing that are required including, part, assembly and engineering drawings. Once that is complete, all driven dimension and feature from the part and assembly drawings are to be captured. There is no need to capture any features in the engineering drawings as the will update with the alteration of the part drawing.
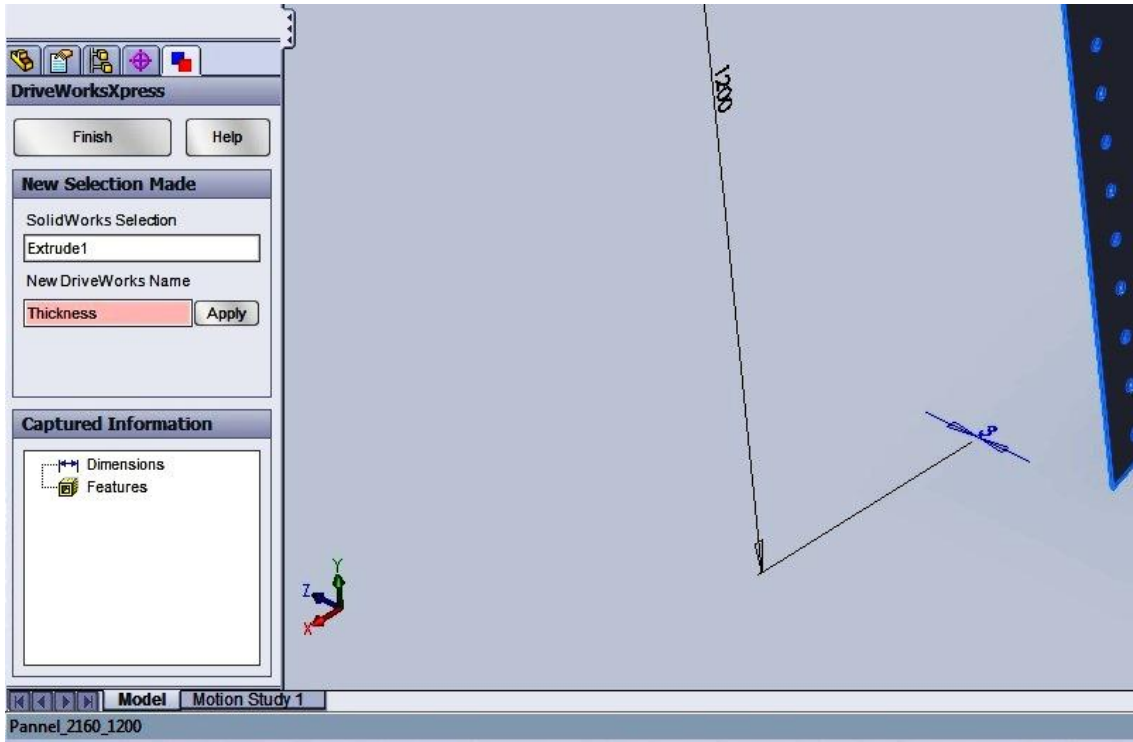
Figure 3.9 Capturing drawing deminsions

Figure 3.7 gives an example of capturing the dimensions for a 2160×1200 panel. As you can see all the dimensions from the drawing are displayed, to select a dimension that you wish to drive in DriveWorksXpress select the feature, whether it be a sketch, extrusion or hole. For the example in Figure 3.7 the extrusion feature is selected and the dimension that drives it is then highlighted in blue. From the navigation plane that is displayed in the program under the section "New Selection Made" it shows the corresponding SolidWorks selection. To develop a rule with that dimension it's required that you label it with a name to be called in DriveWorksXpress.

 Once all features are captured, rules must be establish to drive the drawing automation form input data that was record on the form previously developed (section 3.1). The method used to create rules was to use the governing equations with the standards that are required when constructing bolted panel tanks. In the case of the 2160×1200 panel the thickness is governed by equations 4.1 and 4.2/4.3 (section 2.5.1.1). The following array of figure will display how those equations are then used to drive the dimension to automate a new drawing based on design variations such as tank height and diameter.

57
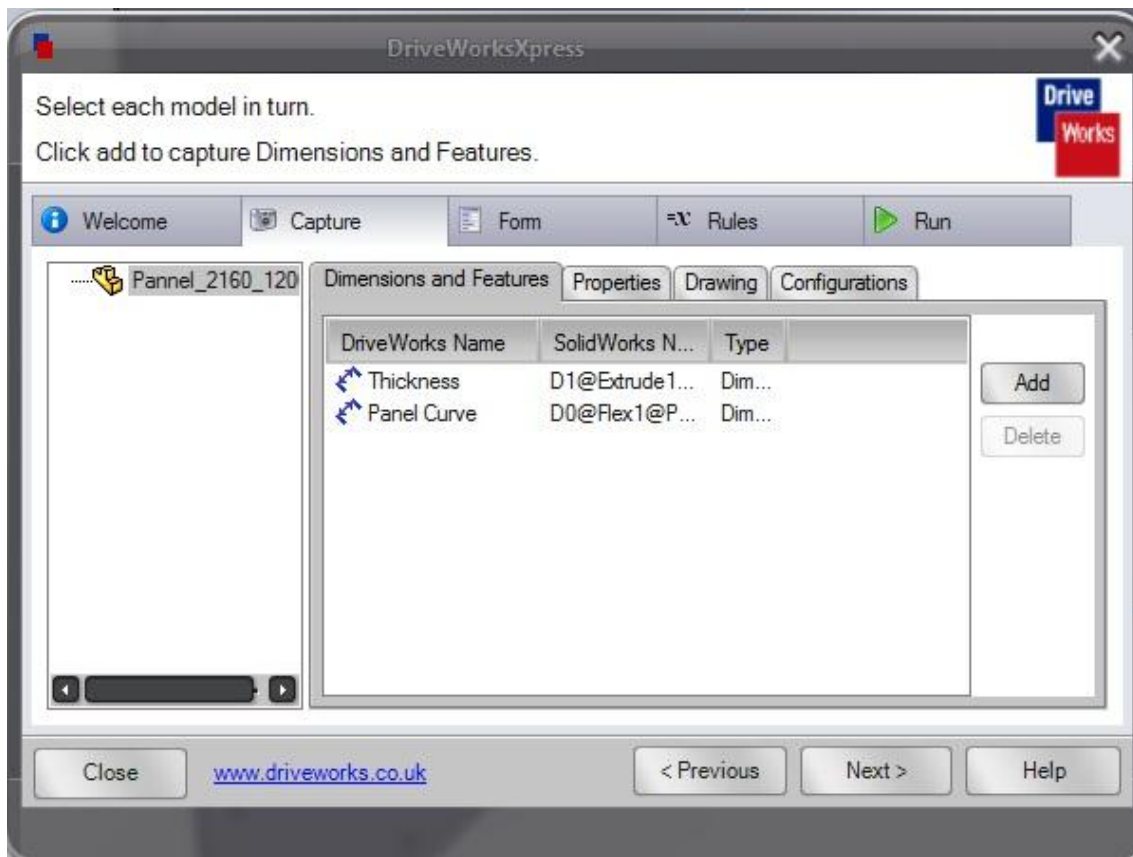
Figure 3.10 Captuer features

Figure 3.8 shows the dimensions captured for the panel generation. Important features for the panel are thickness and panel curve. Length and width are neglected as they are set parameters and don't change with tank size.
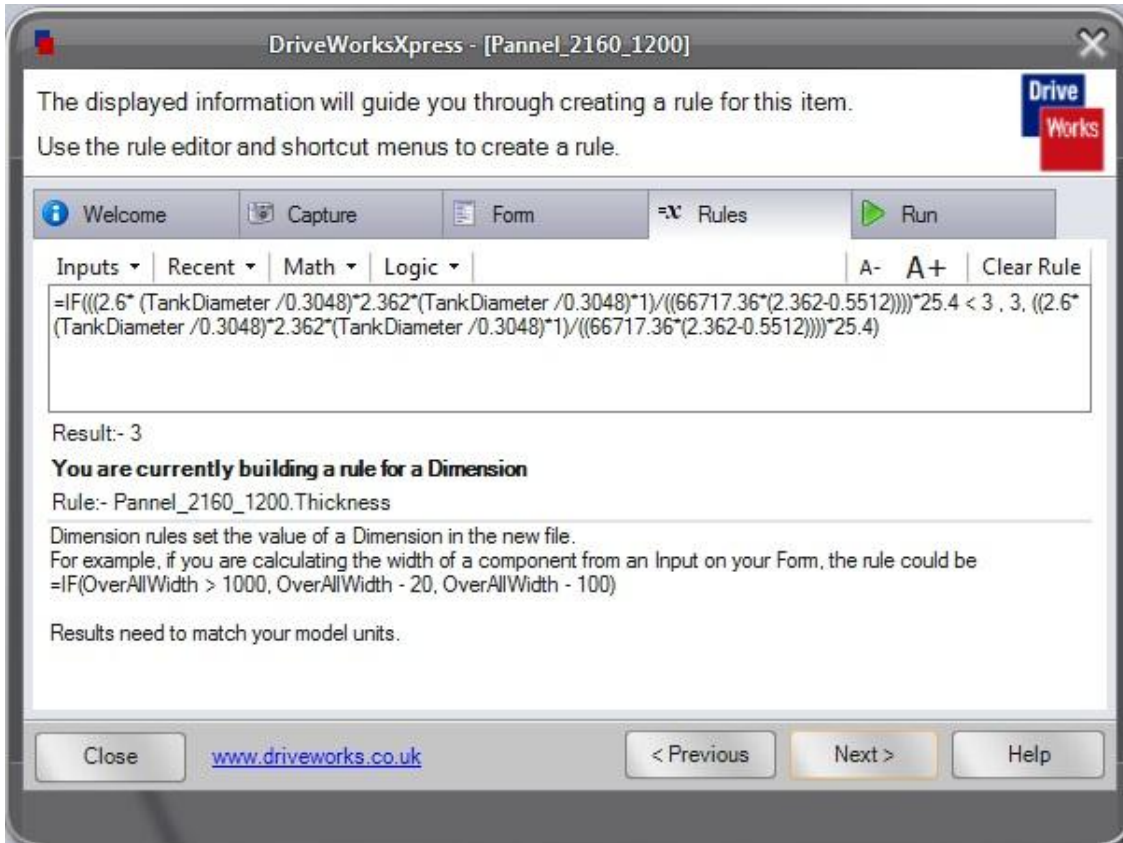
Figure 3.11 Generating rules

Figure 3.9 shows how the equation from the standard is adapted into the rule to evaluate the thickness of the panel. Because panels start with a minimum thickness of three millimetres a rule is put in place. The rule states if the equation is less than three make the dimension three; else use the value that is generated in the equation. Figure 3.9 displays this rule and the equation has been altered to metric measurements as it's from an American standard.

The panels curve rule was also made from the basic equations of an arc. The curve is changed based on the tank radius and the amount of panels that make up the circumference of the tank. So the equation generates the arc angle for the panel. This is simply;

$$\theta = \frac{Panel\ Lenght \times 360}{Tank\ Radius \times 2\pi} \qquad\qquad (3.2)$$

After the rules are complete the model is ready to run and the drawings will be reproduced in the background with their new dimensions. All part and engineering drawings are done this way with the exception that different rules control different features and it all comes down to what features where captured in the begin steps. The result section will give more information on each part, the methods simply carry over.

3.4   Nozzle Positioning

Nozzle positioning takes a similar approach to part drawings. However instead of solely capturing a dimensional constraint, it's required also to capture the entire feature that generates the hole in the panel for pipe connections. All tanks are required to have an inlet, outlet and if there is a roof an overflow pipe. Depending on how the tank supplies water and is filled the location of these nozzles may vary. To make it simpler the inlet is in a fixed position and all other connections are orientated from that point. The adjustments for the other nozzles are based on angle and height. Angle is referring to position in degrees from the outlet; 0-360 degrees. However to ensure structural integrity of the tank, all holes that are to be cut into the panels should be positioned somewhat in the centre of the panels.
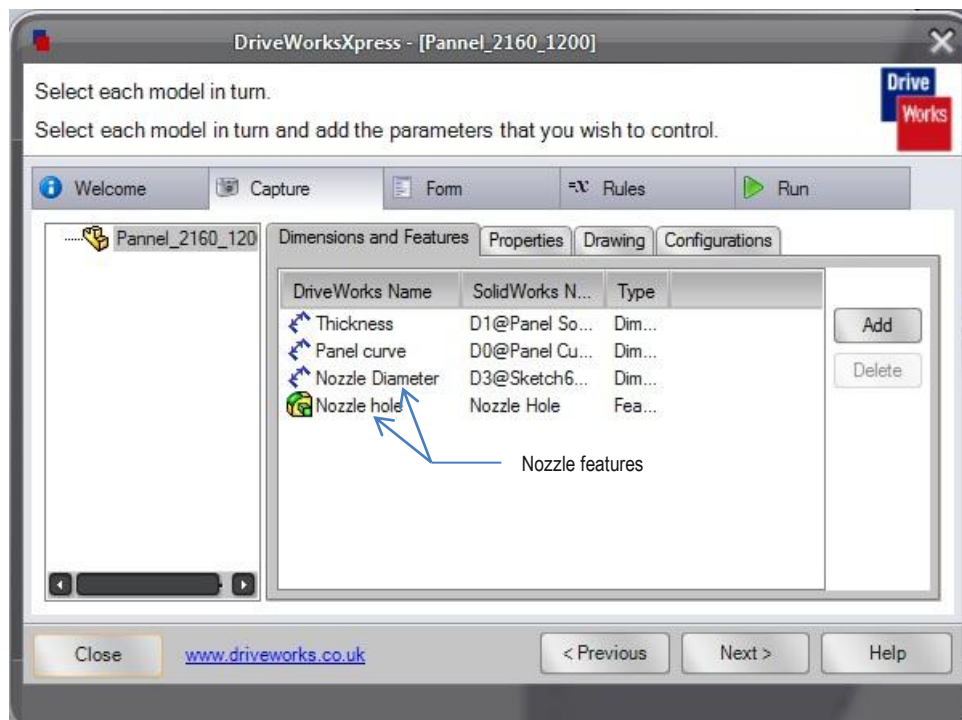
Figure 3.12 Nozzle features

60

Following the same concept as sections 3.3, in the capture tab add the features that controls the nozzle (Figure 3.10). To alter the diameter of the nozzle a rule must be made, this is done by matching the number submit in the form and applying it to the dimension (Figure 3.11)
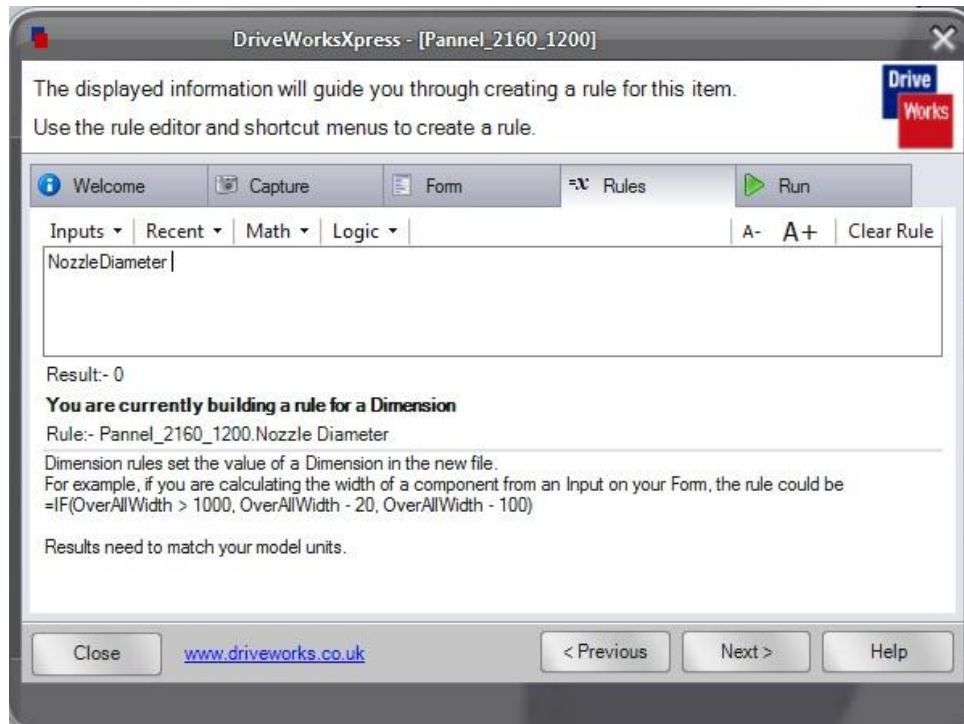
Figure 3.13 Nozzle dimension rule

Using the DriveWorksXpress rule creator the nozzle diameter is linked to the form input by selecting the input drop down box (Figure 3.11) and selecting the nozzle diameter input relationship is now made.

If the nozzle is not required then the feature that controls the extrusion to cut through the panel can be suppressed. Suppressing the detail doesn't delete it, as all drawings are regenerated from an original the detail should never be deleted, it may be required and a different design. Figure 3.12 shows the rule developed to supress the nozzle feature on the panel if it is not required.
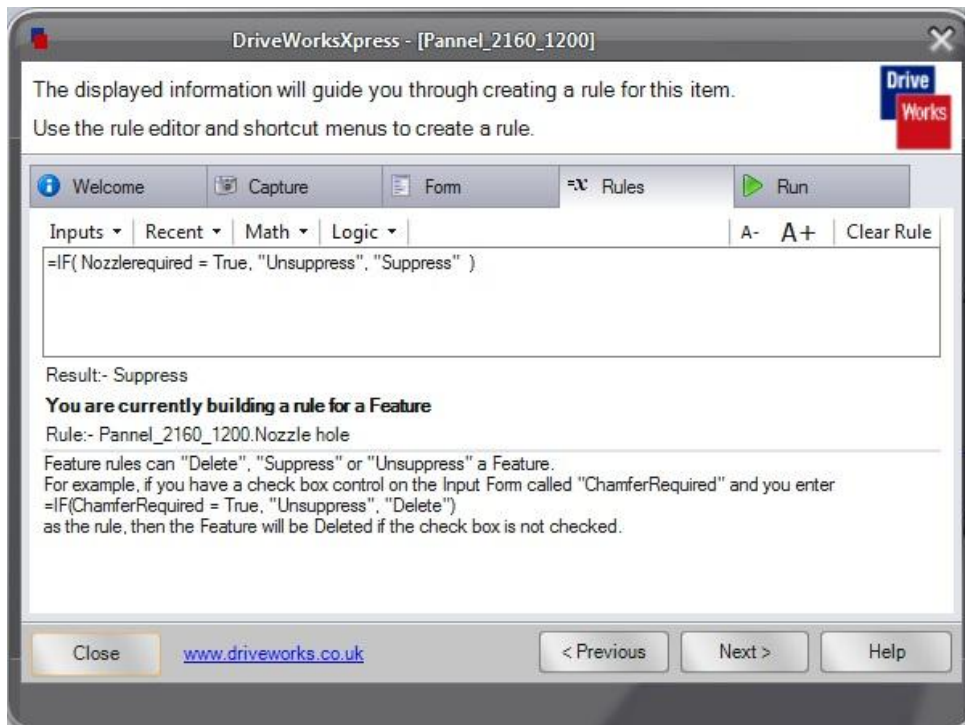
Figure 3.14 Nozzle feature suppression

As you can see to distinguish whether or not the nozzle is required is inputted on the form, by using a check box. The rule is then made by an IF statement, by saying if the box is checked then unsuppressed the feature if not then suppress it.

Height variation in the tank and orientation of the nozzles means that all panels will have the hole feature within it geometry. According to where the client wants the nozzle will mean whether the feature is displayed or not. This will incorporate the above rule, however it will not have to be entered in several times as there is only a single panel drawing that makes up the shell of the tank.

3.5 3D Representation

To drive the 3D representation the tank the complete assembly of the tank has to be constructed with each individual part drawing. This ensures that all rules developed carry over to the full assembly. It was found that to represent varying heights in the tank small assemblies of shell courses had to be constructed and then imported into the main assembly. This was necessary so that large sections of the tank could suppressed in courses instead of individual panels at a time.

The roof of the tank (if required) is self-supporting and is always connected to the first course of the tank shell. So there should be no alter (Suppressing) of that course. Stated by was that the assembly is derived from the part drawings so the main aspect for the 3D representation is height and diameter. Diameter is control be the curve place on the panel as discussed in section 3.3, therefore there is no need to capture that overall dimension when setting rules. The only capturing required for the assembly is each individual course assembly.

The panel height is known (1200mm), so the overall height of the tank can be divided by the panel height to work out the number of course required to suffice the tank height requirement. In order to achieve this, the overall assembly has to be first created with the maximum number of course (21 courses = 25m tank height). This is so the course can be suppressed according to height.

CHAPTER 4   RESULTS AND DISCUSSION

This chapter outlines the outputs gained from the developed parametric tool. This will include segments of codes, drawings and screen shots. Also a short comparison between the products developed in this project and the existing program that was in place at Tyco pumping systems.

4.1   Bill of Materials and Interfaces

As described in the methodology the interfaces where created through the development of forms within two separate programs (MS Access and SolidWorks) this was due to compatibility issues with the two programs. The interfaces were reasonably easy to construct as they just consists of labels, text boxes and buttons. Some validation input codes were necessary to ensure that the correct data was entered into the forms. An example of this is would be to place a minimum and maximum value rule that constrains the input to that value range. These typical constraints were used for values like tank height, diameter and wind and seismic regions.

Figure 4.1 Final MS Access interface

Figure 4.1 shows the final design of the MS Access interface, the interface place all the variables entered into a database table. This allows users to revisit any previous entered information designs for clients.
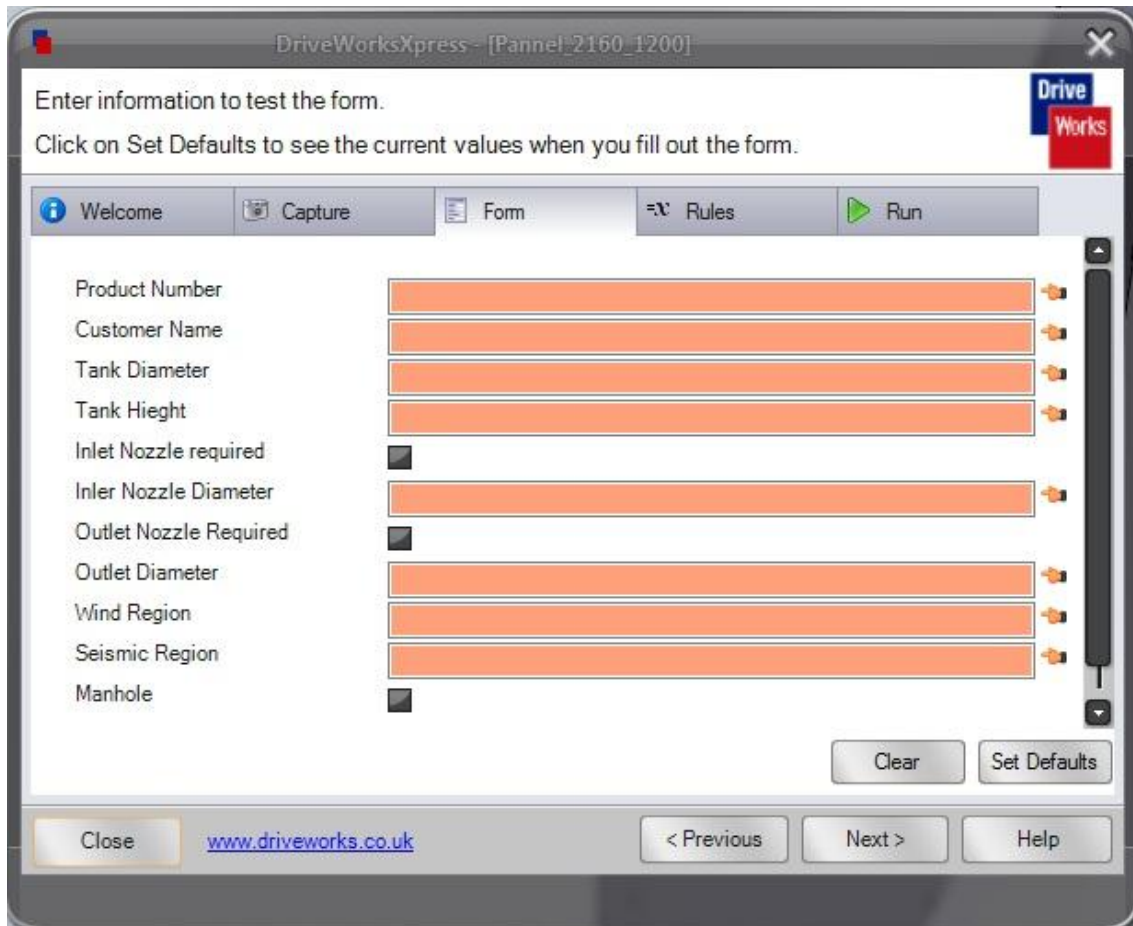
Figure 4.2 SolidWorks Form

The above figure is from the form generated to run the automation of part and engineering drawings similar to that of the MS Access form; its primary operation is to drive the rules that configure the drawings.

The bill of materials was roughly complete. Problems arose with some of the equations as they required variables that had to be read from graphs within the standard. Unfortunately this restricted output to the bill of materials and it became more of a components guide that should be used in conjunction with engineering drawings. It outlines the following;

- Number of panels that are required to construct the tanks shell

- Number of panels that require holes for the nozzles
- Winder Girders required if any
- Number of manholes required
- Number of Pipe connections/flanges need to reinforce panels with holes
- Number of ladders specified by purchaser

This help designers compare the outputs from the drawing and makes sure all drawings are accounted for. The screen shot of the bill of materials is located in appendix D and is accompanied with the codes made to produce the quantities.

4.2   Engineering Drawings and 3D Representation

The automation of engineering drawing was developed through the CAD program SolidWorks in conjunction with an in built program called DriveWorksXpress. All dimensions that drive that outcome of each individual part are captured and assigned a name. The name is then given a rule which in turn drives the feature or dimension to the specified value based on inputs into a form. General drawing outputs are displayed in appendix E accompanied with form inputs and codes.

In programing sense some aspects were very difficult to control and honestly surpass my knowledge of programing. This made some drawing difficult to automate; nozzle positioning was one of these difficulties. The positioning system for the nozzles was extremely difficult, it may have been limitations in the software but it was not possible to complete. Therefore inlet/outlet nozzle where set to a default position at the top above the freeboard and at the bottom attached to the last course.

The wind girders also fell under this category as there position on the tank was governed in the 3D representation and it was failing to mate to the required bolt seam. The height of the wind girder if required was governed by equations 2.4and essentially has to be pace on the closest bolt seam to that height which was within the ability of the program. However when trying to mate the girder to the required panel holes the drawing failed and the program omits failed features from the outputs. Given more time I think this could be fixed.

The 3D representation was the same as the wind girders, mating procedures for the assembly drawing (3D representation) are a very dominate feature. And because the tank shell is made from essential the one component the panel, with varying thicknesses and bends, when the

panel dimension were altered the outcome of the assembly became a scatter of panels in no way representing a tank like shape. Even with the use of the suppressing method described in the methodology 3D representation just could not be obtained.

4.3 Product Comparison

A short product comparison can be observed between the parametric tool developed within the scope of this project and the once operational tool that was already in place at Tyco Pumping Systems.

The original program labelled EQS used a similar approach to that of this project. The EQS program used a 97 version of MS Access and was developed as a user-interface. It used a switch board (Figure 4.3) to allow the users to navigate between a design mode and quotes list.
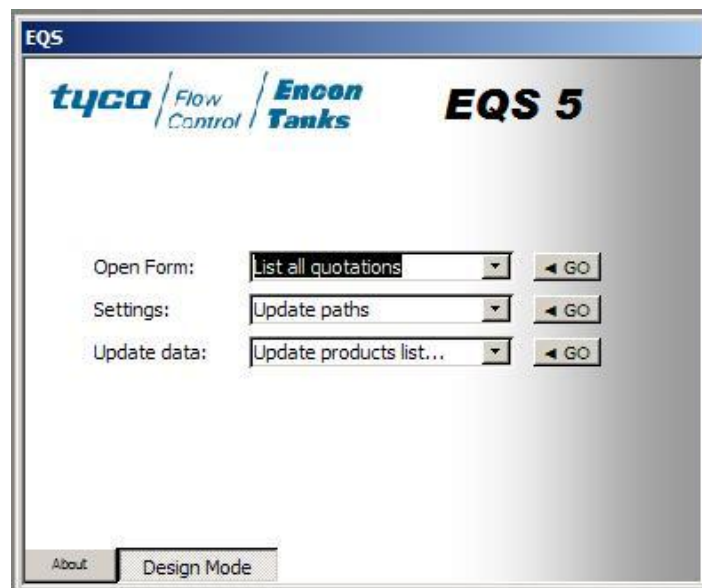
Figure 4.3 EQS switch board

When design mode was selected the user was taken to a form that outlined all previous quotes. This presented the user with the decision of amending a previous design or compiling another design (Figure 4.4).

Figure 4.4 Form navigation

When an item was selected the user was then navigated to a design interface (Figure 4.5).

Figure 4.5 Design interface

This is where all design constraint are to be entered. Has you can see in the design area (neglect costing at bottom) the form is similar to that within this project. Both have input areas where design constraints are entered such as tank height, diameter, seismic region, wind region and manholes etc. This difference is that all fittings are completed within in this form also, under the tab fittings. This is where all aspects of the fittings are inputted and exported to the CAD program.

The difference is software is great the EQS program uses AutoCAD, where this project uses SolidWorks. AutoCAD is more of a standard engineering drawing tool all though it does have some 3D capabilities. SolidWorks is primarily a part modelling and 3D assemblies program.

From the form within the EQS program information is then exported to AutoCAD, via windows command screen. After you closing EQS AutoCAD is open and the file containing input information is enter into the command menu and all drawings are generated. Some information has to be reiterated (same the program outlined in this project), and from my knowledge of EQS most drawings are called from a directory and have their dimensions overridden to coincide with the need required dimensions of the new designed tank.

Although this is a good approach the difference between programs is that the parametric tool within this project involved 3D part drawings that where driven by code and equations with in the standard to alter their dimensions in the part drawing and transfer that to the engineering drawings.

CHAPTER 5 CONCLUSION

The overall outline of this project has been followed and that means that the tank components where designed in conjunction with relevant standards to ensure that structural integrity and operational sufficiency if designs in this project where used in the construction of a bolted unanchored panel tank for water storage.

It should be noted that all equation and ideas that were used from the standards are not an exact design and construction standard but more a guide to the development of bolted storage systems. The results of the project weren't as desirable as first intended, but given the time frame I think it's a big step for the development of a parametric tool using SolidWorks. A reason as to why the results aren't as expected I think is because of the shear amount a parts that go into the design of the tanks coinciding with the capability issues with DriveWorksXpress. Given a larger time frame it's not a unrealistic vision to think that program would come together and suffice all requirements set in the objects.

5.1   Future Work

To develop this parametric tool further it's recommend that the objectives be split into two different possible projects for future work. The first being further development on the bill of materials and looking at ways to automatically read values from a graph, so that critically equations can be used. Furthermore costing's could also added to the bill to provide a more automative quoting support.

Secondly would be further development in DriveWorksXpress to refine the codes so that 3D representation can be achieved and also more comprehensive engineering drawing output.

Also I found that DriveWorks can be upgrade from Xpress to Pro and the details are promising. Pro allows the development of BOM's and other reports from the SolidWorks interface solely, so that would be another avenue to take for future work.

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Appendix A Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **David Slack - Smith**

TOPIC: **Structural design, quotation and production support using parametric CAD tools and national/international standards for fluid storage systems.**

SUPERVISOR: Dr. Harry Ku

ENROLMENT: ENG4111 – S1, 2009;
ENG4112 – S2, 2009

PROJECT AIM: To improve the current process and tools used for the design, quotation and production support of fluid storage tanks, by using tools that integrate with parametric CAD to achieve the proposed improvements.

PROGRAMME: **Issue A, 24th March 2009**

1. Literature review

2. Development of a Bill of Materials (feature based) which is compliant with the standard when you select any two of the following - Tank diameter, Tank Height, Tank capacity. This BOM should also take into account the seismic region and wind region the user selects and the overflow and freeboard conditions needed.

3. Part Drawings - Drawings automatically generated for each distinct component in the BOM (except items like nuts and bolts etc)

4. Assembly Drawings - Assembly General Arrangement automatically generated from part drawings.

5. Nozzle Selection - Nozzle size and positioning (size, height and polar position) entered into a table which then adds necessary parts to the BOM, creates part drawings for these and updates the assembly drawings (time permits).

AGREED:

_____ (student)   _____ (Supervisor)

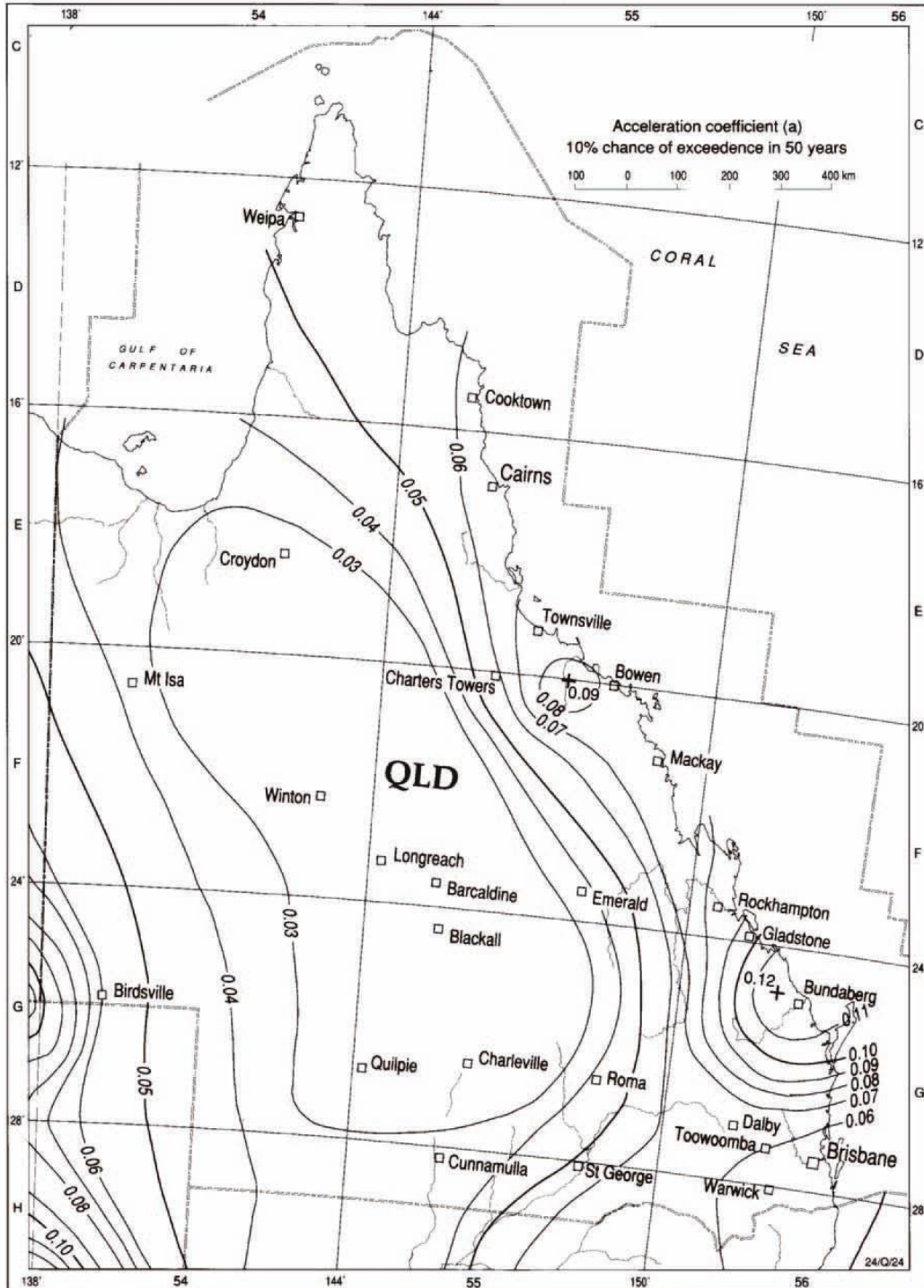(Date)___/___/__   (Date) ___/___/__

Appendix B Zone Coefficients

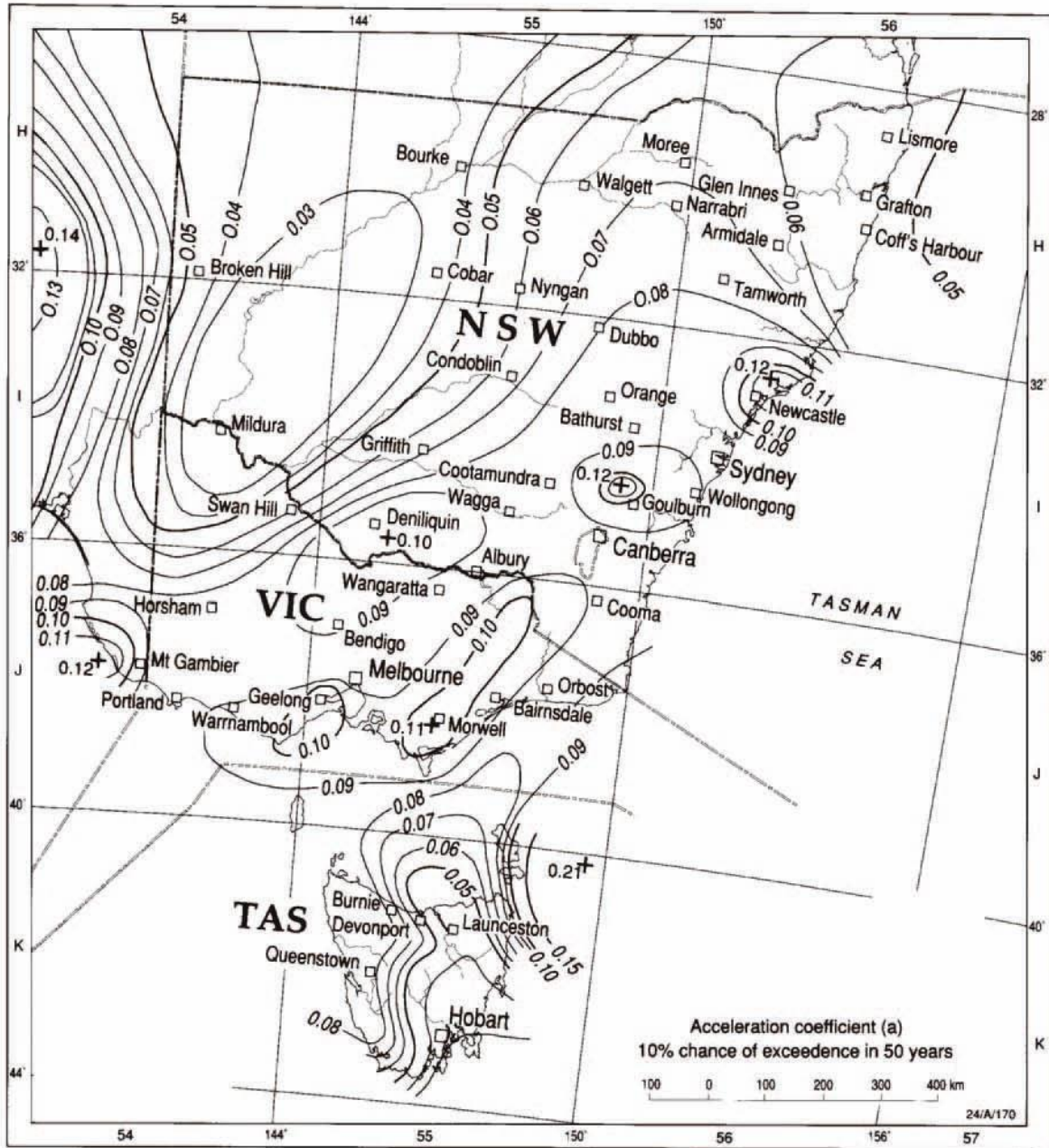**Figure A.1: Queensland seismic zones**

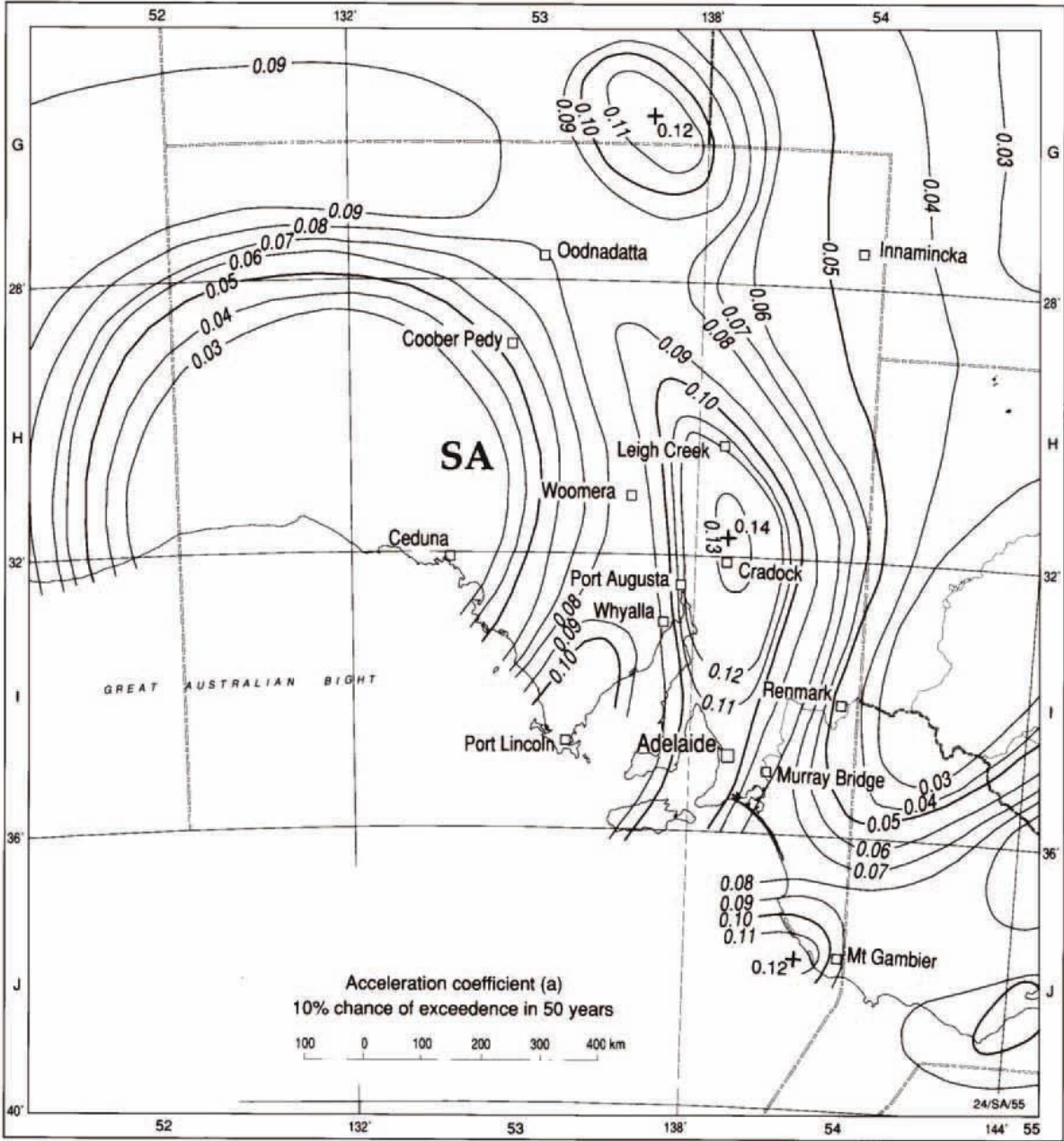**Figure A.2: New South Whales, Victoria and Tasmania seismic zones**
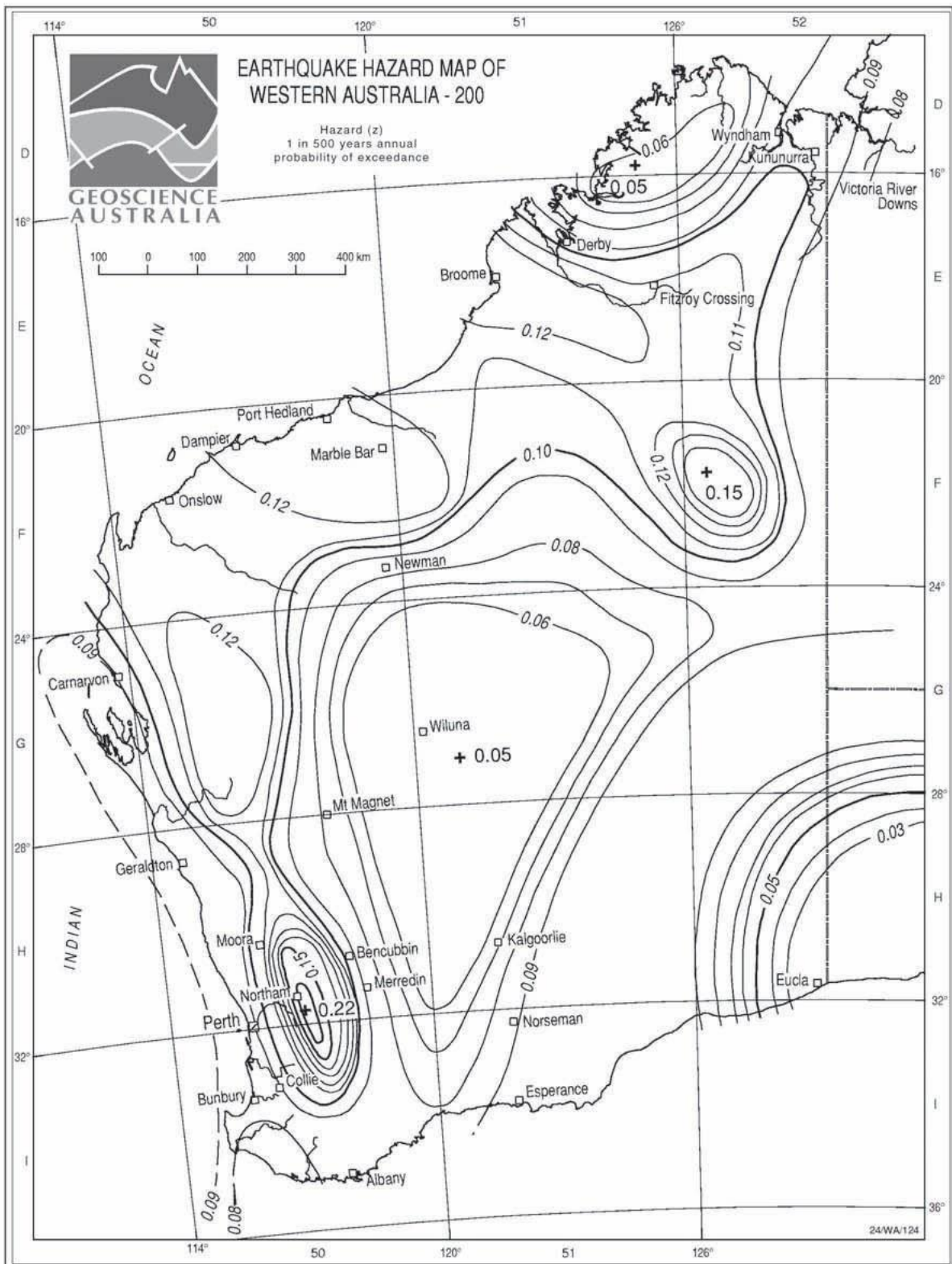
Figure A.3: South Australia seismic zones
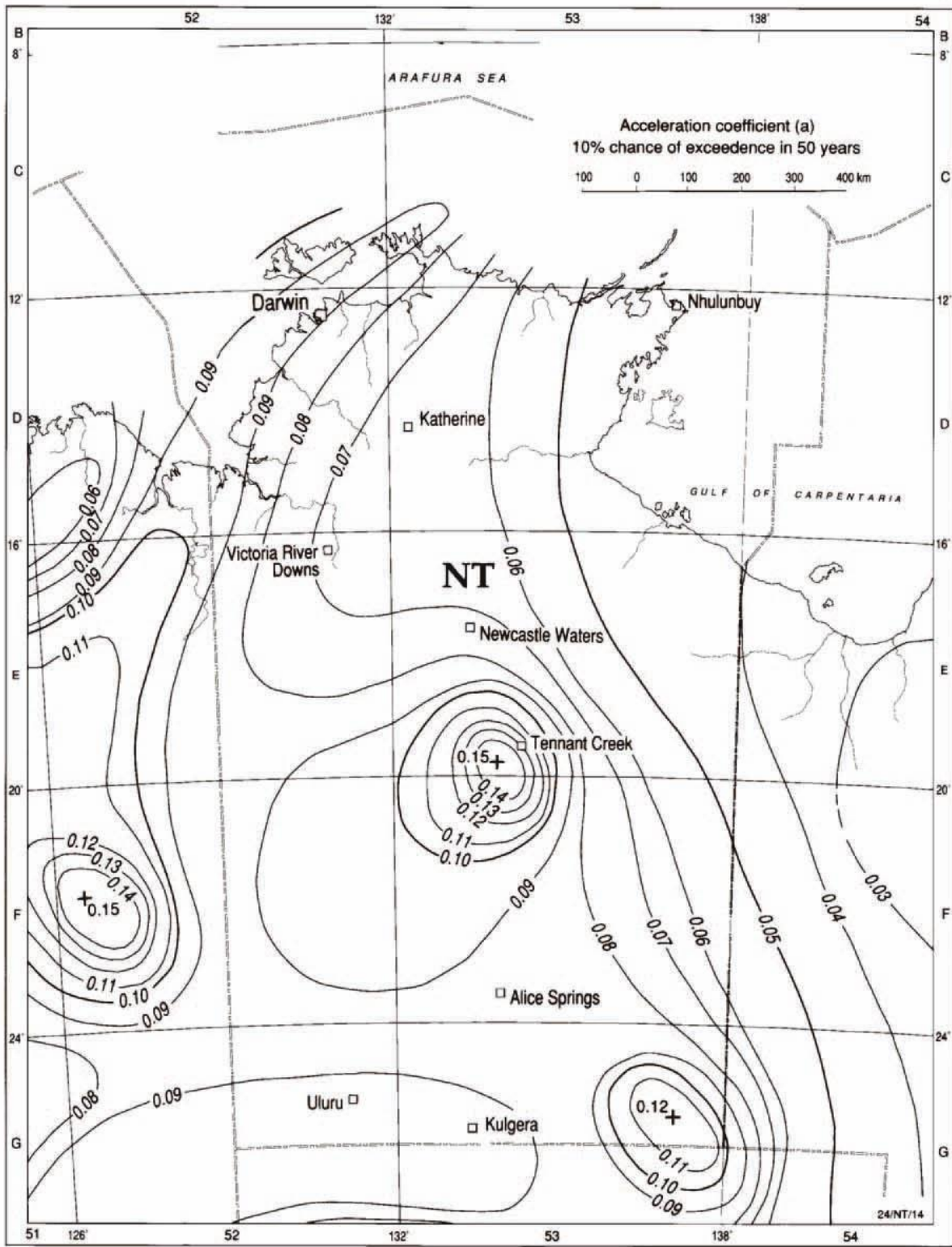
Figure A.4: Western Australia seismic zones

Figure A.5: Northern Territory seismic zones

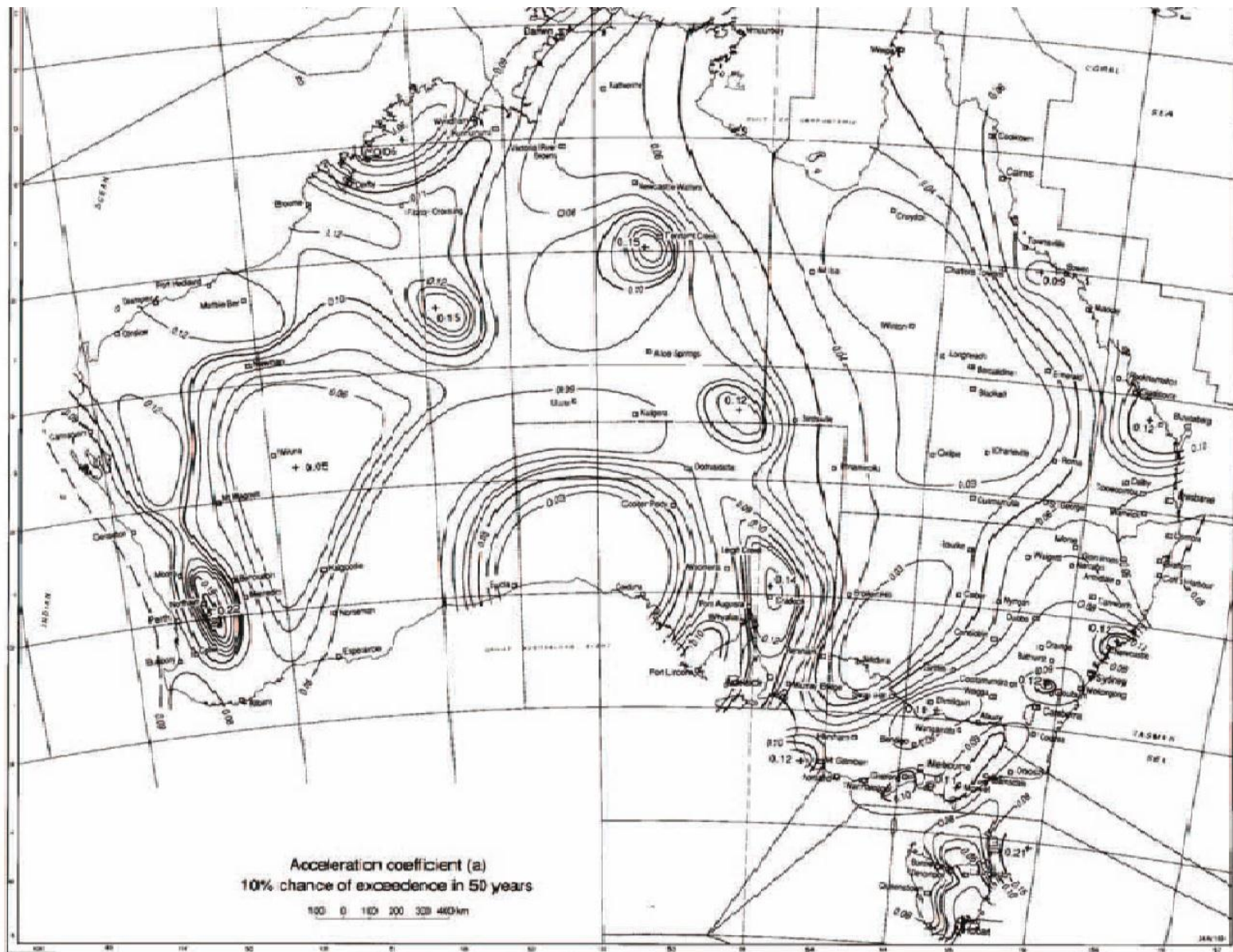**Figure A.6: Australia seismic zones**

Appendix C Unit Conversion

Property	To Convert US From	To Metric (IS) Units	Multiply by
Area	Square inch	Millimetre squared	$6.451600 \times 10^{+02}$
	Square foot	Metre squared	9.290304×10^{-02}
Force	Pound-force	Newton	$4.44822 \times 10^{+00}$
Force/Area	Pound-force/foot squared	Newton/metre squared	$4.188026 \times 10^{+01}$
Impact Strength	Foot-pound force	Joule	$1.355818 \times 10^{+00}$
Linear Dimension	Inch	Millimetre	$2.540000 \times 10^{+01}$
	Foot	millimetre	$3.048000 \times 10^{+02}$
Mass/Volume	Pound-mass/cubic foot	Kilograms/cubic metre	$1.601846 \times 10^{+01}$
Temperature	Degrees Fahrenheit	Degrees Celsius	$°C = (°F - 32)/1.8$
Tensile Strength	Pounds per square inch	Pascal	$6.894757 \times 10^{+03}$
Velocity	Miles per hour	Metres per second	4.470400×10^{-01}
Volume	Gallon	Metre cubed	3.785412×10^{-03}

Appendix D Bill of Materials

Bill Of Materials

Product Number	6510	**Customer Name**	Jane Citizin

Tank Diameter (m)	Tank Hieght (m)	Capacity (m^3)
7	9	346

Tank Products	Qty
2160 x 1200 Tank Panels	81
Inlet/outlet Panels	1
Wind Girders	1
Manholes	2
Pipe Connections	1
Ladders	2

2160 x 1200 tank panels

Round(((3.14*[Tank Diameter])/2.16)*Round(([Tank Hieght]/1.2)))

Inlet/outlet Panels

=IIf([Inlet]=True,1,0)+IIf([outlet]=True,1,0)

Wind Girders (equations 2.4&2.1)

=IIf(((((10.625*(10^6)*([Panel thickness]/25.4))/(18*(([Tank Diameter]*0.3048)/([Panel thickness]/25.4)^1.5)))/0.3048)>[Tank Diameter],0,1)

Manholes

=[Manholes]

Pipe Connections

=IIf([Inlet]=True,1,0)+IIf([outlet]=True,1,0)

Ladders

=[Ladder]

Capacity

Round((3.14*([Tank Diameter]^2)/4)*([Tank Hieght]-((7.53*([Tank Diameter]*0.3048))*((0.06*1*(0.75/(0.6*(([Tank Diameter]*0.3048)^2)))*1.5)/3.5)*0.0254)))

[Panel Thickness]

IIf(((((2.6*([Tank Hieght]*0.3048)*4.72*([Tank Diameter]*0.3048)*1)/(66717.342*(4.72-0.55)))*25.4)<3,3,(((2.6*([Tank Hieght]*0.3048)*4.72*([Tank Diameter]*0.3048)*1)/(66717.342*(4.72-0.55)))*25.4))

Note all inputs marked by [] are either inputs from the interface or calculated table values (code is shown where applicable).

Appendix E Drawing Outputs

The drawing displayed here were output when the following was entered in the design form.

Tank Diameter	7
Tank Height	12
Inlet Required	Yes
Inlet Diameter	300
Outlet Required	Yes
Outlet Diameter	150
Wind Region	18 (Default)
Seismic Region	0.06
Manhole	Yes

Also note that drawing borders and title blocks have been removed as the conflicted with formatting. Also dimensions are not set in the correct format the are a default SolidWorks setting.

Appendix F Standard List

Standard	Service
AWWA D103-87	Basis for tank structural design. Tanks designed by certified engineer. Design certificate will be supplied for each tank type
AS 1170.4 / NZS 4219	Seismic requirements (Tanks are ideal in a seismic area as they can withstand an excessive amount of movement without leakage)
AS 1170.2 / NZS 4203	Roof design
AS 4100	Material for base and roof angle ring
AS 1657	Ladder and platform design
AS 2129	Table E Flanges
ASTM A 234	Elbows
AS 1163	Piping
AS 1554.1	Welding
AS/NZS 1167.2	Filler wire
AS3500	Plumbing code and disinfection
AS 4680	Hot Dip Galvanising of components
AS 3566.1:2002	Screw fastener manufacturing
AS 3566.2 2002	Screw fastener plating
AS 1111	Galvanised bolts
AS 1112	Galvanised nuts
AS 1237	Galvanised washers
AS 1252	8.8 hi tensile bolt assembly
AS 4020	Liner potability
AS 1365	Wall sheet material
AS 1397	Wall sheet coating
AS 3600	Concrete work
AS 1302, AS 1303, AS 1304	Concrete reinforcement
AS 1509	Formwork
ASTM D 5199 ASTM D 751 ASTM D 5884-95 ASTM D 1204 ASTM D 413 ASTM D 4833-88 ASTM D2136-94	Liner