SOFTWARE DEVELOPMENT FOR WELL PLANNING

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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SOFTWARE DEVELOPMENT FOR WELL PLANNING

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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การออกแบบทิศทางหลุมเจาะและการใช้ท่อกรุเป็นหนึ่งในงานหลักในปฏิบัติการการขุดเจาะปิโตรเลียม การออกแบบทิศทางของหลุมเจาะและการใช้ท่อกรุที่ถูกต้องและเหมาะสมไม่เพียงส่งผลต่อการประหยัดงบประมาณเท่านั้นแต่ยังส่งผลต่อความปลอดภัยอีกด้วย ซอฟแวร์คอมพิวเตอร์นี้ได้ถูกพัฒนาขึ้นด้วยโปรแกรมไมโครซอฟท์วิชวลเบสิกและออโตแคดและให้ชื่อว่า WPD โปรแกรม WPD สามารถใช้งานได้ดีและมีความถูกต้องเมื่อเปรียบเทียบกับผลการคำนวณและออกแบบทิศทางของหลุมเจาะกับการคำนวณด้วยมือ WPD สามารถช่วยในการออกแบบและเลือกใช้ท่อกรุโดยวิธีใช้กราฟช่วยได้อีกด้วย นอกจากนี้การศึกษาครั้งนี้ยังได้จัดทำฐานข้อมูลของท่อกรุขนาดต่างๆ ตามมาตรฐานของ API ไว้ในรูปแบบดิจิตัลซึ่งเป็นประโยชน์และสะดวกต่อการใช้งานไว้อีกด้วย

สาขาวิชา <u>เทคโนโลยีธรณี</u> ลายมือชื่อนักศึกษา____________________

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WARUT SIRICHOAR : SOFTWARE DEVELOPMENT FOR WELL PLANNING. THESIS ADVISOR : ASST. PROF. AKKHAPUN WANNAKOMOL, Ph.D., 175 PP.

WELL PLANNING / WELL PATH DESIGN / CASING DESIGN / DRILLING OPERATION

Well path and casing design are one of the main tasks in petroleum drilling operation. An accurate and suitable well path and casing design are not only resulted in budget saving, but also in safety operation. This computer software has been developed on Microsoft Visual Basic and AutoCAD program, named WPD. WPD software work well and has a good accuracy when compared the calculation results with those of manual calculations. WPD can help in casing design and casing selection by graphical method as well. Moreover this study has been generated various casing size databases according to the API standard in digital format, which is very useful and convenient for using.

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Academic Year 2015 Advisor's Signature_________________

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Warut Sirichoat

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SYMBOLS AND ABBREVIATIONS

PDC	=	Polycryterized diamond compact
KOP	=	Kick off point
BOPE	=	Blow-out prevention equipment
API	=	American Petroleum Institute
d_o	=	Pipe outside diameter (in.)
t	=	Wall thickness (in.)
σ_y	=	Minimum yield strength of pipe (psi)
σ_{ya}	=	Yield strength of axial stress equivalent grade (psi)
σ_a	=	Axial stress-tension is positive (psi)
A_{ip}	=	Cross-sectional area of the pipe wall under the last per thread
L_e	=	Engaged thread length (in^2)
σ_{up}	=	Minimum ultimate strength of pipe (psi)
A_p	=	Cross-sectional area of plain-end pipe (in.^{2})
A_c	=	Cross-sectional area of coupling (in.^{2})
σ_{uc}	=	Minimum ultimate strength of coupling (psi)
W_{pe}	=	Plain-end weight (lb/ft)
W_n	=	Nominal weight (lb/ft)
P_c	=	Collapse pressure due to mud weight (psi)

SYMBOLS AND ABBREVIATIONS (Continued)

ρ_m	=	Mud weight (ppg)
D	=	Depth (ft)
DST	=	Drill stem testing
P_b	=	Burst pressure at the casing shoe (psi)
P_f	=	Formation pressure from next depth (psi)
TD	=	Total depth (ft)
CSD	=	Casing setting depth (ft)
SF	=	Safety factor
G_f	=	Formation fluid gradient (psi/ft)
ρ_m	=	Mud gradient (psi/ft)
BF	=	Bending force (lb_f)
D_{OD}	=	Nominal outside diameter (in)
W_{cs}	=	Weight of casing per unit length
θ	=	Angle of deviation (degrees)
F_s	=	Shock load (lb_f)
W_{cs}	=	Cross-section area of casing
q	=	Rate of inclination angle buildup (degrees/ft)
CAD	=	Computer – aided design
CADD	=	Computer-Aided Design and Drafting
VB	=	Visual basic
RAD	=	Rapid application development

CHAPTER I

INTRODUCTION

1.1 Background and rationale

Well path and casing design is one of the main tasks in petroleum drilling operation. An accurate and suitable well path and casing design not only resulted in budget saving, but also resulted in safety. Therefore, both well path and casing design must be done effectively to reach those two objectives.

1.2 Research objectives

The main objective of this study is to develop a computer software for well planning design, including well path and casing design.

1.3 Research methodology

The research methodology of the study is depicted in Figure 1.1, including literature review, required data collecting and analyses, computer software writing and developing, developed software testing, simulating and analyses, results conclusions, discussions, and thesis writing.

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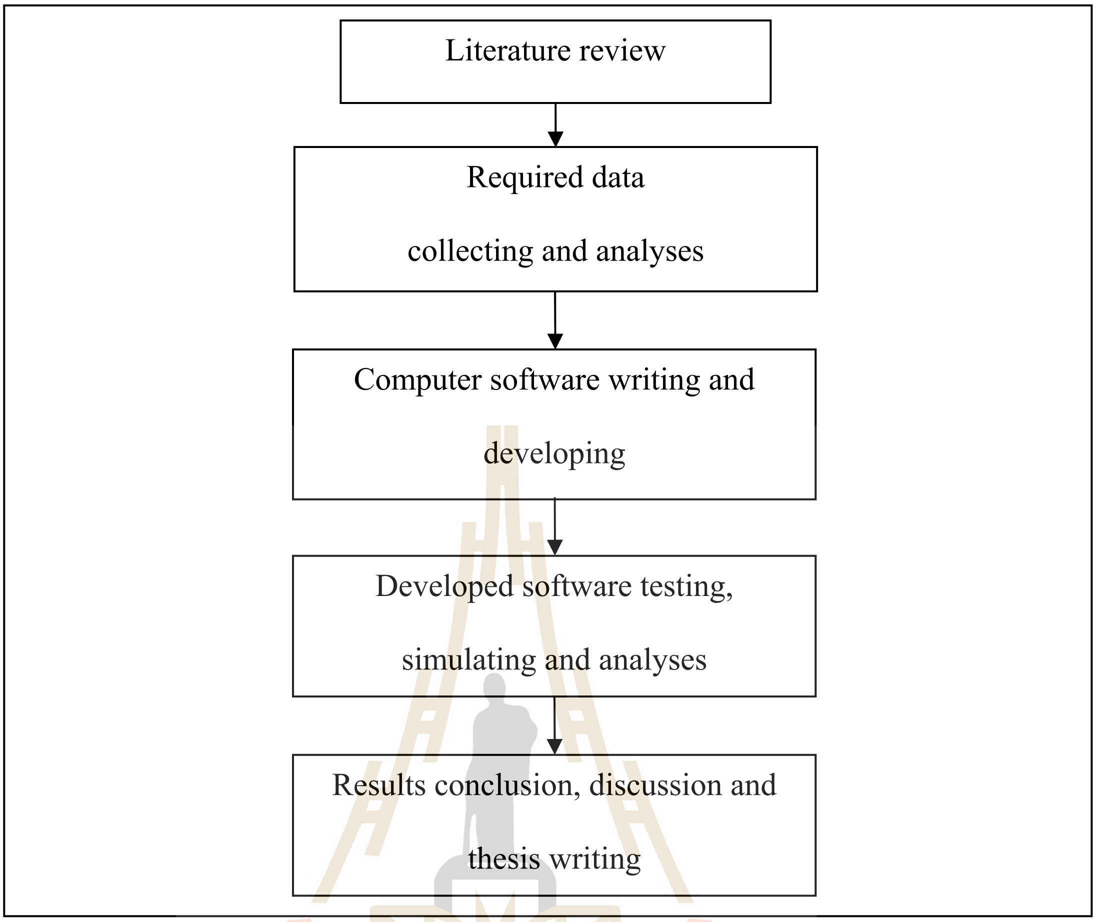


Figure 1.1 Flowchart showing steps of work of the study.

1.3.1 Literature review

Literature review had been carried out to study the previous researches on related subjects. The sources of information were from internet, text books, journals and conference papers. A summary of the literature review which are given in the thesis are as follows;

– Well planning

– Well path design

– Casing design

– Other similar commercial software

1.3.2 Required data collecting and analyses

In this part relevant and required data had been collected, analyzed and prepared for well planning computer software writing and developing in the next step.

1.3.3 Software design

Results from calculation and design had been sent and linked to AutoCAD software for the graphical displaying purpose.

1.3.4 Software developing and testing

The developed software had been tested, simulated and analyzed for checking its performance and accuracy.

1.3.5 Conclusions, discussions and thesis writing

Results from software developing had been concluded, discussed and prepared for the thesis writing and examination.

1.4 Scope and limitations

The study had been scoped mainly only on well path and casing design and the computer software had been developed on Microsoft Visual Basic 2010 software and AutoCAD 2012.

Some required parameters had been assumed for the calculation purposes if they were unavailable.

1.5 Expected results

The expected result is a usable, accurate and has user-friendly tools computer software that can be used for well path and casing design graphically.

1.6 Thesis contents

This thesis is divided into five chapters. The first chapter includes background and rationale, research objectives, research methodology, scope and limitations, and expected results. Chapter II presents results of the literature review which are necessary for improving the computer software developing for well planning. Chapter III presents data acquisition and data preparation, describes software developing and software testing steps. Chapter IV presents results and discussions of the study. Chapter V presents conclusions and recommendations for further studies, respectively. Appendix A presents the parameters for collapse pressure calculation and minimum performance properties of API casing and grade.

CHAPTER II

LITERATURE REVIEW

This chapter summarizes the results of literature review which are helpful for the well planning, well path, and casing design software developing. Some related literatures reviews of relevant subjects are summarized as below.

2.1 Well planning

Drilling or digging for oil has occurred in one way or another for hundreds of years. The Chinese, for instance, invented a bamboo rig to obtain oil and gas for lighting and cooking. In 1859, oil came spurting out of the ground from a well 69.5 feet deep in Titusville, Pennsylvania. Colonel Drake had just gone down in oil prospecting history. But although this initiated industrial oil well drilling, a large number of wells had been drilled long before to produce water, brine and even naphtha for caulking boats, and for lighting and medicinal purposes.

By the name of a well (borehole) is meant a cylindrical mine opening made too small forman's access there to, the diameter of the opening being many times less than its length. The beginning of the well is called its mouth, collar or well-head, the cylindrical surface is termed the wall or hole shaft (bore), and its floor the bottom hole. The distance from the mouth to the bottom hole along the axis of the borehole shaft is the length of the well, while the projection of its axis onto the vertical plane represents the depth of the well. The wells are sunk as straight, slanted or horizontal boreholes. As regards their purpose, boreholes drilled for geological exploration of the region, search for prospecting and exploitation of deposits are classified into key or stratigraphic, extension or-outpost, structure-exploratory, reconnaissance, prospecting production and special boreholes.

Structure-exploratory boreholes serve the purpose of a thorough investigation into the structures encountered in drilling of key and extension holes and of drawing up a program for exploratory-prospecting drilling into these structures. The results of the structure-exploratory drilling and of geophysical investigations are utilized in studying the mode of occurrence, determining the age and physical properties of the rocks making up the column, precisely marking the reference or key horizons, and in compiling structural (subsurface) maps.

Producing wells are drilled into a completely prospected deposit developed for exploitation. The category of producing wells includes not only the wells through which oil or gas is recovered (producing wells proper), but also the wells which help to effectively develop the defining more exactly the reservoir behavior (drive) and the extent of possible recovery of oil from individual sections of the pool, ascertaining and accurately delimiting the boundaries of producing fields.

Injection wells serve the purpose of edge and inter-field boundary injection of gas or air into the producing reservoir in order in the formation pressure. Observation wells are put down to affect a regular control over changes in the pressure, over the position of the water-oil, gas-water and gas-oil contacts during the operation of the reservoir.

Well planning is perhaps the most demanding aspect of drilling engineering. It requires the integration of engineering principles, corporate or personal philosophies, and experience factors. Although well planning methods and practices may vary within the drilling industry, the end result should be a safely drilled, minimum-cost hole that satisfies the reservoir engineer's requirements for oil/gas production.

The skilled well planners normally have three common traits. They are experienced drilling personnel who understand how all aspects of the drilling operation must be integrated smoothly. They utilize available engineering tools, such as computers and third-party recommendations, to guide the development of the well plan. And they usually have an investigative characteristic that drives them to research and review every aspect of the plan in an effort to isolate and remove potential problem areas.

2.1.1 Drilling methods in oil industry

Rocks can be broken up by applying mechanical, thermal, pyhsico-chemical, electric-spark and other methods. Practical applications in industry have found, however, only methods involving mechanical disintegration of the rock, the others continuing so far to be at the stage of development.

In oil industry, mechanical drilling is affected by employing percussive (cable-tool) drilling and rotary drilling methods. Cable-tool drilling has been abandoned about 30 years ago, and no longer employed, with some minor exceptions. However, this method is still used for coal and ore mining industries, geological engineering, and in drilling of wells for water. Different drilling techniques are used in oil industry. Early days, cable-tool drilling was the major method. Recently, rotary drilling systems are widely used. For the last two decades, downhole motor systems are preferred as directional and horizontal drilling needs are increasing. Cable-tool drilling will be emphasized in the next chapter, and the rest of the course will be focused on rotary drilling technique.

2.1.2 Auger drilling

In order to start an oil well drilling operation, hydraulic hammering or auger drilling techniques are used for the conductor casing installations. Auger drilling can be a best solution for dump leaching where dumps are in thickness of 30-60 ft or a bit more, and being in the dump site for long period of time. This kinds of dumps may be squeezed and show some difficulties to passage of leach solutions. Portable auger drills can drill fast and adequate sizes of holes which leach solutions can be poured or dumped in. Drill string components of an auger drilling system are composed of bits, augers and universal joints and subs. Augers are usually 5 to 20 ft long. Hexagonal, circular or hollow augers are available. Rotation of an auger system is achieved by using a top drive system or a bevel gear. Load on the bit is determined from cable feed, chain feed, hydraulic feed or combination of these. Cuttings are removed mechanically.

2.1.3 Cable tool drilling

The first oil well in the United States was drilled with cable tools in 1859 to a depth of 65feet. This was the historic Drake well located near Titusville, Pennsylvania; it is credited with having started the American petroleum industry. The cable tool (also called churn or percussion) drilling method, however, did not originate in this country, but is believed to have been employed first by the early Chinese in the drilling of brine wells. In this method, drilling is accomplished by the pounding action of a steel bit which is alternately raised by a steel cable and allowed to fall, delivering sharp, successive blows to the bottom of the hole. This principle is the same as that employed in drilling through concrete with an air hammer, or in driving a nail through a board. The original percussion drilling apparatus consisted of a spring pole anchored into the ground at an angle, with the bit suspended from the free end by a rope. To impart the necessary reciprocating action to the bit, the Chinese employed a number of men who alternately jumped on and off the spring pole beam from a ramp. Many early brine wells in the United States were drilled in the same manner, except that the spring pole was equipped with stir ups where two or three men stood and literally kicked the well down. As more and deeper wells began to be drilled efforts were made to improve the drilling equipment. Steam engines began to be used; walking beams replaced the spring pole; steecables replaced manila ropes; and other improvements followed. Although the modern cable tool rig is a far cry from the ancient Chinese model, the changes have been in materials and equipment, for the basic operating principle is unchanged problems previously unsolved except by rig floor trial and error. Further field verification of the theory is needed; such experiments could possibly aid the economic application of cable tools.

2.1.4 Rotary drilling system

Making a hole for the recovery of underground oil and gas is a process which requires two major constituents man-power, and hardware systems. The man power includes a drilling engineering group and a rig operator group. The first provides engineering support for optimum drilling operations, including rig selection, design of mud program, casing and cement programs, hydraulic program, drill bit program, drillstring program and well control program. After drilling begins, the daily operations are handled by a rig operator group which consists of a tool pusher and several drilling crews. The hardware systems which make up a rotary drilling rig are :

1. Power generation system,
2. Hoisting system,

3. Drilling fluid circulation system,

4. Rotary system,

5. Well blowout control system, and

6. Drilling data acquisition system and monitoring system.

Basic principles of rotary drilling are the rotary method uses tricone-type toothed bits or one-piece bits such as diamond or PDC bits. While the bit is being rotated, a force is applied to it by a weight. The advantage is that a fluid can be pumped continuously through the bit, which is crushing the rock formation, and carry cuttings up out of the hole to the surface with the rising fluid flow. The rotary drilling rig is the apparatus required to fulfill the following three functions:

- Put weight on the bit
- Rotate the bit
- Circulate a fluid

It is the drill collars, screwed onto the bottom of the drillpipe assembly just above the bit, that provide the necessary weight, and prevent buckling of the drillpipes above them. Drill collars, along with drillpipe and bit all make up the drillstring, which is rotated by the rotary table and the kelly. The drillstring component parts are hollow down the middle so that the drilling fluid can be circulated down to the bit. A fluid-tight rotary joint, the swivel, is located at the top of the kelly and provides a connection between the mud pump discharge line and the inside of the drillstring. A hoisting system is required to support the weight of the drillstring, lower it into the hole and pull it out. This is the function of the derrick, the hook and the drawworks.

The drilling rig is complete with facilities to treat the drilling fluid when it gets back to the surface, a storage area for tubular goods, shelters and offices on site. In addition, when a well is being drilled, it is regularly cased. It is lined with steel pipe, or casing, which is lowered into the hole under its own weight in smaller and smaller diameters as the hole gets deeper. The first length of pipe is run in as soon as the bit has drilled the surface formation and is then cemented in the hole. A casing housing is connected to the top of the surface casing. All the following lengths of pipe are hung on the casing housing and cemented at the base to the walls of the hole. After the first drilling phase is cased, drilling will be resumed with a bit with a diameter smaller than the inside diameter of the casing string that was run in and cemented. The deeper the borehole gets and the more casings are set in the well, the smaller the diameter of the bit must be. The casing housing also serves to hold the safety equipment, such as blowout preventers.

2.2 Directional drilling

Directional drilling is much more than simply selecting a well path and hole angle. It includes selecting the most appropriate survey techniques, defining the best control tools, researching applicable government regulations, and gathering pertinent geological data. In addition, the directional program may alter or affect the casing and cement program, hydraulics, centralization and completion techniques.

Controlled directional drilling is to process of deviating a well-bore along a predetermined course to a target whose location is given as lateral distance from the vertical. This definition is the basis for all controlled directional drilling, whether to maintain the well-bore as nearly vertical as possible or as a planned deviation from the vertical. Vertical drilling, although considered fundamental in most areas, can be very difficult to achieve in some regions due to steeply dipping formations.

2.2.1 Inaccessible locations

Quite often, a target pay zone lies vertically beneath the surface location that is impractical as a rig site. Common examples include a residential locations, riverbeds, mountains, harbors, and roads. In these cases, a rig site is selected and the well is drilled directionally into the target zone.

2.2.2 Multiple wells drilling from a single site

Perhaps the most common application for directional drilling is associated with offshore production platforms (Figure 2.1). It is more economical, in most cases, to drill a number of directional wells from a single platform than to build individual platforms from vertical well.

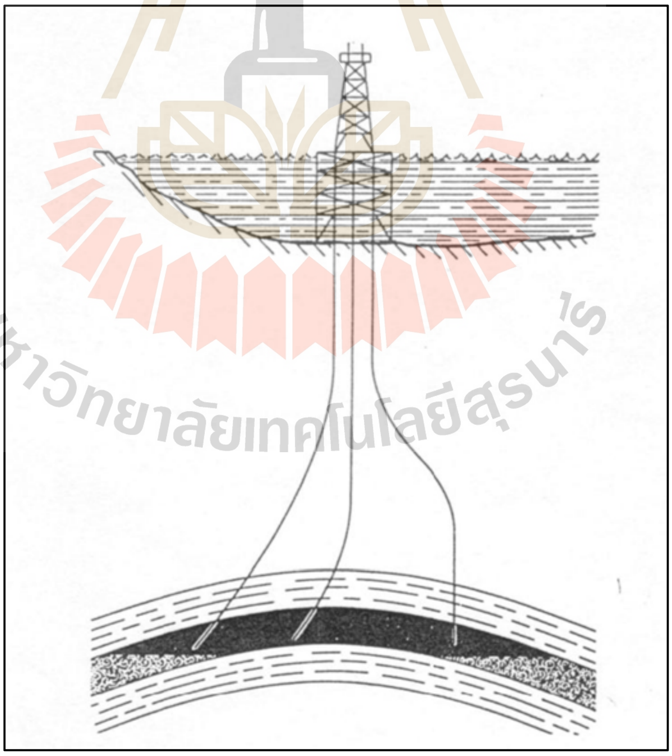


Figure 2.1 Directional drilling from an offshore platform (after http://users.metu.edu. tr/kok/ index.html, nd)

2.2.3 Sidetracks

A frequently occurring cause for directional drilling is sidetracking. The primary purpose is to deviate the well bore around and away from an obstruction in the original well bore, such as stuck drill string. Generally sidetracking cannot be defines as controlled directional drilling because it does not have a predetermined target.

2.2.4 Relief well drilling

Possibly the most spectacular application of directional drilling is a relief well to intersect a blowout well near the bottom so that mud and water can be pumped into the blowout well (Figure 2.2). Directional control in this type of drilling is stringent due to the extreme accuracy required to locate and intersect the blowout well. Quite often, special logging tools are required in locating the blowout well.

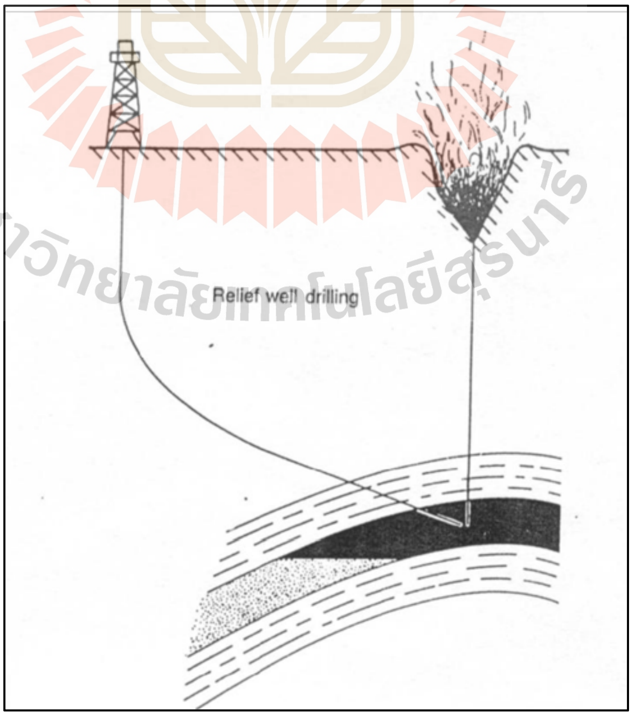


Figure 2.2 Relief well drilling (after after http://users.metu.edu. tr/kok/ index.html, nd)

2.2.5 Multiple targets

Geologist may define multiple targets for a prospect that cannot be drilled with a vertical well. It may be necessary to drill through one target and alter the direction of the well to reach the next target. The targets may be in two-dimensional plane such that the drift angle must be altered. Other cases may involve three-dimensional planning such that the inclination and azimuth must be changed.

2.2.6 Design considerations

Assuming that a target and rig site has been selected, the directional planning consideration is as follows:

-lateral, or horizontal, displacement from the target to a vertical line from the rig site,

- Kick off point (KOP)
- Desired build angle rate
- Final drift angle
- Plan type, straight kick vs. S curve

If an S curve is selected as the plan type the engineer must also select a drop angle rate and a depth at which the hole must return to vertical (Figure 2.3).

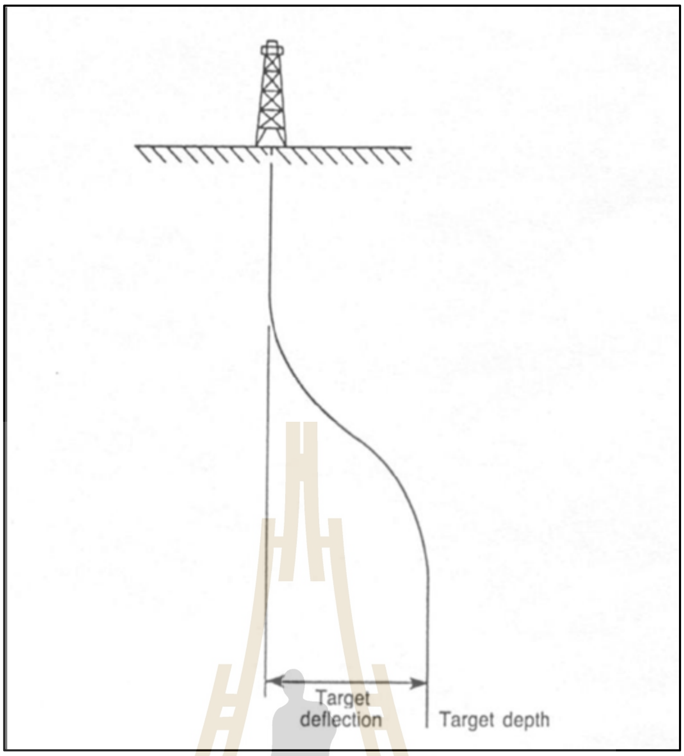


Figure 2.3 S-type kick (after http://users.metu.edu. tr/kok/ index.html, nd)

2.2.7 Drift or inclination angle

The drift, or inclination, of the well bore is the angle, measured in degrees, between the actual well path, or some depth and a vertical line below the rig site (Figure 2.4). This measurement is independent of the azimuth or course heading. Typically this value will range from 15° to 35°. The minimum acceptable drift angle of approximately 12° – 15° is desired by many industry personnel. Drift angles less than this range are slightly more difficult to control. In other words, it is usually easier to control a 20° well than a 10° well. Although wells have been drilled in the 70° – 80° range, common upper restraints are 45° – 48°. Hole angles greater than 45° – 48° begin to encounter problems such as increased torque and drag as well as pump down requirements for some logging operations. Many operators establish 35° as the upper limit. The typical planning procedure is to establish minimum and maximum acceptable drift angles and KOP (kick off point).

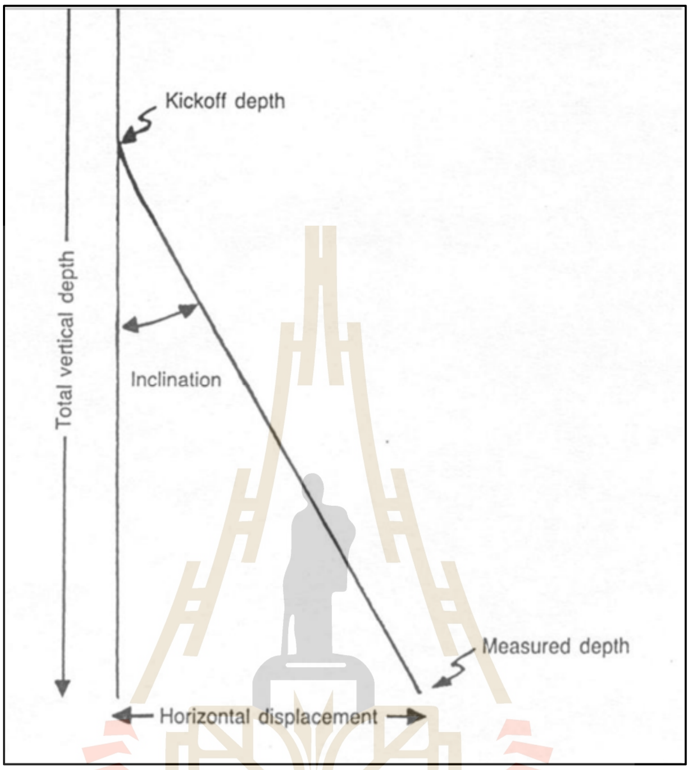


Figure 2.4 Directional planning considerations (after http://users.metu.edu. tr/kok/ index.html, nd)

2.2.8 Kick off Point (KOP)

The Kick off point (KOP) is the depth at which the well bore path will be intentionally diverted from the vertical position. The KOP is usually selected in soft, shallow formations where directional drilling is easier. In addition, the KOP is often selected so the final angle build-up can be achieved prior to setting surface casing. This approach minimises key-seat problems in the hole section. The KOP affects the final inclination angle.

2.3 Casing design

Casing string is mainly designed considering the pressure exerted from formation and/or from hydrothermal fluid within the well. In this paper casing designing is based on both temperature and different pressures. Regulatory requirements in the drilling permit will determine other aspects of the casing design and blow-out prevention equipment (BOPE). A typical specification is that surface casing is at least 10% of the total depth and that one-third of the hole be behind casing at any given time. Once the minimum required depth is reached, casing will normally be run unless the formation is particularly fractured and broken. It is important to have competent rock at the casing shoe, as it is normally required to do a pressure test by drilling out the shoe into a new formation, then applying a pressure gradient above hydrostatic pressure to the wellbore. This procedure evaluates the well's ability to withstand high pressures without breaking down the formation or the cement around the casing and is the basis for establishing the temperature to which the well can be drilled without setting another casing string. Clearly, if there is not competent rock around the shoe, the wellbore will not be able to withstand a high pressure gradient and the ability to advance the well to the desired depth/temperature will be compromised. If the minimum casing depth is reached and there is no competent rock, it is often desirable or necessary to continue drilling until a better formation is found (Finger et al., 1999).

Loads on casing in a well may be of various types and occur during the running of the casing, cementing, drilling and after completion of the well. These loads may occur both in the axial direction of the casing or in the redial direction, inwards or outwards.

Of the various possible load combinations acting on the casing string, the most critical seem to be caused by pressure and thermal expansion (Karlsson, 1978).

Collapse and burst pressures which are important load on casing are explained in detail in the following sections.

Casing string design and selection is one of the most important aspects of the properly prepared well design. The functions of casing are:

1. To protect the hole against caving in of the formations into the hole

2. To isolate porous media with different fluid, pressure regimes from contaminating the pay zone

3. To prevent contamination of near surface fresh water zones

4. To provide a passage for production tubing and other downhole equipment

5. To provide a suitable connection for the wellhead equipment

6. To provide exact dimensions of the hole to facilitate the running of testing and completion equipment

Different types of casing schemes are used depending on well type, formation drilled, and well depth. In this section the design considerations for conductor pipe, surface casing, intermediate casing, production casing, and liner casing are discussed. Casing strength properties such as yield strength, collapse strength, and burst strength are presented. Examples of some typical casing programs are illustrated in Figure 2.5.

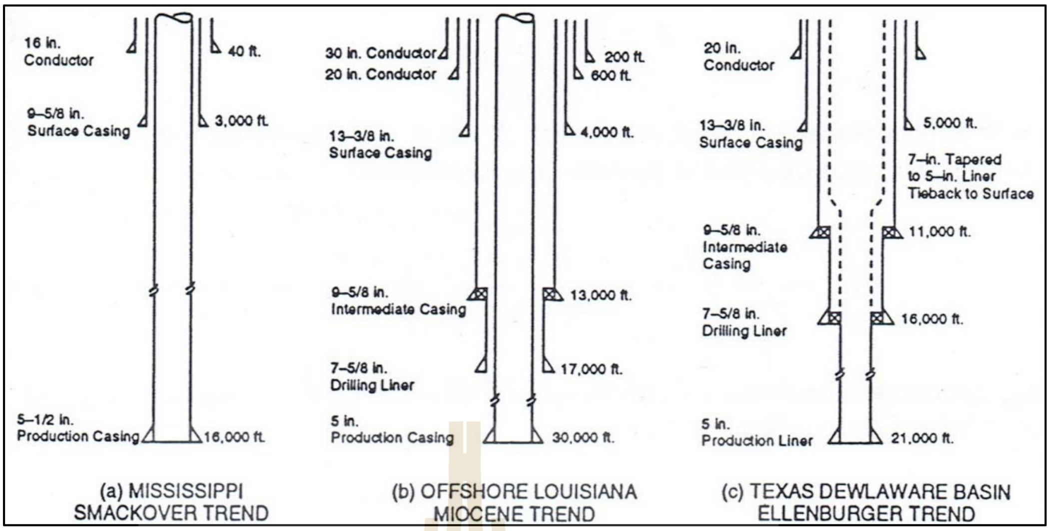


Figure 2.5 Example of casing program (after SPE, 1986)

An appropriate casing design exercise involves careful determination of factors that influence internationally by the petroleum industry (API) has provided bulletins casing failure under various conditions and selecting the most suitable, safe, and economical casing string on the recommended minimum performance properties and equations for the computation of these properties. A casing is specified by its

1. Outside diameter and wall thickness
2. Weight per unit length
3. Type of coupling
4. Length of joint
5. Grade of steel

For the identification of casing API has designated grades to identify the strength characteristics. The grade code consists of an arbitrary letter code followed by a number the number designates the minimum yield strength of the steel in thousands of psi. Besides the API recommended grades, there are many non-API grades also widely used by the industry. These non-API grades are used for special applications that require very high tensile strength, collapse resistance, or high-strength steels that are more resistant to corrosive environment.

The minimum performance properties of casing are given in Table A3 (Appendix A). The equations used to calculate the related properties are as follows.

Yield-strength collapse pressure equations

$$p_y = 2\sigma_y \left[\frac{d_o/t-1}{(d_o/t)^2}\right] \tag{2.1}$$

Where

d_o= pipe outside diameter (in.)

t = wall thickness (in.)

σ_y = minimum yield strength of pipe (psi)

Equation 2.1 is valid up the (d_o/t) values calculated by the following equation

$$(d_o/t)_{yp} = \frac{\sqrt{(F_A-2)^2+8(F_B+F_C/\sigma_y)+[F_A-2]}}{2(F_B+F_C/\sigma_y)} \tag{2.2}$$

Where $(d_o/t)_{yp}$ = (d_o/t) intersection between yield-strength collapse and plastic collapse F_A, F_B, F_C are correlation coefficients given in Table A1 (Appendix A)

Plastic collapse-pressure equation

$$p_P = \sigma_y\left(\frac{F_A}{d_o/t} - F_B\right) - F_C \tag{2.3}$$

The plastic collapse pressure equation is applicable for d_o/t values ranging from $(d_o/t)_{yp}$ to $(d_o/t)_{pT}$ from the following equation

$$(d_o/t)_{pT} = \frac{\sigma_y(F_A-F_F)}{F_C+\sigma_y(F_B-F_G)} \tag{2.4}$$

Where F_F and F_G are correlation coefficients given in Table A1 (Appendix A)

Transition collapse-pressure equation

$$p_T = \sigma_y \left(\frac{F}{d_o/t} - F_G\right) \tag{2.5}$$

Equation 2.5 is applicable for d_o/t value ranging from $(d_o/t)_{pT}$ to $(d_o/t)_{TE}$ given by the following equation

$$(d_o/t)_{TE} = \frac{2+F_B/F_A}{3F_B/F_A} \tag{2.6}$$

Elastic collapse-pressure equation

$$p_E = \frac{49.95\times10^6}{(d_o/t)[(d_o/t)-1]^2} \tag{2.7}$$

The applicable (d_o/t) range for elastic collapse is shown in Table A2 (Appendix A). The subscripts p_T and TE denote transition pressure and elastic transition, respectively.

$$\sigma_{ya} = \left[\sqrt{1 - 0.75(\sigma_a - \sigma_y)^2} - 0.05[\sigma_a/\sigma_y]\right]\sigma_y \tag{2.8}$$

Where

σ_{ya} = yield strength of axial stress equivalent grade (psi)

σ_a = axial stress-tension is positive (psi)

σ_y = minimum yield strength of pipe (psi)

The correlation coefficients F_A, F_B, F_C, F_F and F_G given in Table A1 (Appendix A) are calculated using the following equations.

$$F_A = (2.8762) + (0.10679\times10^{-5}\sigma_y) + (0.21301\times10^{-10}\sigma_y^2) - (0.53132\times10^{-16}\sigma_y^3) \tag{2.9}$$

$$F_B = (0.026233) + (0.50609\times10^{-6}\sigma_y) \tag{2.10}$$

$$F_C = (-465.93) + (0.030867\sigma_y) - (0.140483\times10^{-7}\sigma_y^2) - (0.36989\times10^{-13}\sigma_y^3) \tag{2.11}$$

$$F_F = \frac{46.95\times10^6(3F_B/F_A/2+F_B/F_A)^3}{\sigma_y(3F_B/F_A/2+F_B/F_A-F_B/F_A)(1-3F_B/F_A/2+F_B/F_A)^2} \quad (2.12)$$

$$F_G = \frac{F_F F_B}{F_A} \quad (2.13)$$

Pipe-body yield strength

$$W_p = 0.7854(d_o^2 - d_i^2)\sigma_y \quad (2.14)$$

Round-thread casing joint strength-short and long threads and couplings

Lesser of

$$W_j = 0.95A_{ip}\sigma_{up} \quad (2.15)$$

And

$$W_j = 0.95A_{ip}L_e\left(\frac{0.74d_o^{-0.59}\sigma_{up}}{0.5L_e+0.141d_o} + \frac{\sigma_y}{L_e+0.141d_o}\right) \quad (2.16)$$

Where

A_{ip} = cross-sectional area of the pipe wall under the last per thread $0.7854[(d_o - 0.1425)^2 - d_i^2]$ for eight round threads (psi)

L_e = engaged thread length (in^2)

σ_{up} = minimum ultimate strength of pipe (psi)

Lesser of

$$W_j = 0.95A_p[1.008 - 0.0396(1.083 - \sigma_y/\sigma_{up}d_o)] \quad (2.17)$$

And

$$W_j = 0.95A_c\sigma_{uc} \quad (2.18)$$

Where

A_p = cross-sectional area of plain-end pipe (in.^{2})

A_c = cross-sectional area of coupling (in.^{2})

σ_{uc} = minimum ultimate strength of coupling (psi)

Note that the casing types are normally identified by their nominal weight (lb/ft) given by the following equation. Nominal weight (W_n) are based on a 20-ft length of threaded and coupled casing joint.

$$W_n = 10.68(d_o - t)t + 0.0722d_o^2 \quad (2.19)$$

The plain-end weight (W_{pe}) is the weight of the casing joint without the inclusion of threads and couplings.

$$W_{pe} = 10.68(d_o - t)t \quad (2.20)$$

2.4 General casing design criteria

Casing design in general is influenced by

- Loading conditions during drilling and protection
- The strength properties of the formation at casing shoe
- The degree of deterioration to which the casing will be subjected
- The availability of casing

Casing string are usually designed for

1. Burst pressure
2. Collapse pressure
3. Tension load
4. Biaxial effect

1. The burst pressure is based on the maximum formation pressure anticipated during the drilling of the next hole section. Burst pressure is the highest at the top and least at the casing shoe. In production casing the burst pressure will reverse if the production tubing leaks gas to the casing

2. The collapse pressure is due to the column of mud in the hole which acts on the outside of the casing. Collapse pressure is highest the bottom and zero at the top. The collapse pressure should never exceed the collapse resistance of the casing

3. Tensile forces in casing are due to its own weight, bending forces, and shock loading. The topmost joint carries the total weight of the string below it; therefore this uppermost joint is considered the weakest in tension.

4. Casing carrying inner strings are subjected to compression load, i.e., production casing are free from these loads.

5. The combination of stresses due to the weight of the casing and external pressures are referred to as biaxial stresses. These stresses will reduce the collapse resistance of the casing.

The casing may also be subjected to other loads such as

- Bending with tongs
- Slip crushing
- Corrosion and fatigue
- Wear due to running wireline tools and drillstring assembly, which could be very severe in deviated and doglegged holes.

To obtain the most economical design, casing strings consist of multiple sections of different steel grades, wall thickness, and coupling types. Such a casing string is called a combination string.

Because of the uncertainties in determining the actual loadings and also because of the change in casing properties with time, a safety factor is used to allow for such uncertainties. Safety factors commonly used in the design of casing string are the followings.

Collapse strength	0.85 – 1.125
Joint strength	1.60 – 1.80
Plain-end yield strength	1.25
Internal yield pressure	1.0

2.4.1 Collapse pressure calculation

Collapse pressure (P_c) may be defined as the external pressure required causing yielding of drill pipe or casing. In normal drilling operations the mud columns inside and outside the drill pipe are both equal in height and are of the same density. This results in zero differential pressure across the pipe body and, in turn, zero collapse pressure on the drill pipe. In some cases, as in drill stem testing (DST), the drill pipe is run partially full, to reduce the hydrostatic pressure exerted against the formation. This is done to encourage formation fluids to flow into the well bore, which is the object of the test. Once the well flows, the collapsing effects are small, as the drill pipe is now full of fluids. The collapse pressure can be calculated by following equation.

$$P_c = 0.052\rho_m D \tag{2.21}$$

Where

P_c = Collapse pressure due to mud weight (psi)

ρ_m = Mud weight (ppg)

D = Depth (ft)

2.4.2 Burst pressure calculation

Burst pressure (P_b) is an internal pressure from fluids within the casing. Maximum burst pressure is usually occurred when a well is shut and full of gas, or under compressed air, and commonly used to stimulate the well to start flowing. The burst resistance to casings is defined by following equations (API and ISO standards; Rath, 2005):

$$P_b = [Internal\ Pressure] - [External\ Pressure]$$

$$P_b = \left[P_f - (TD - CSD)G_f\right] - [CSD(0.052\rho_m)] \quad (2.22)$$

$$Burst\ at\ surface = p_f - (TD \times G_f) \quad (2.23)$$

Where

P_b = Burst pressure at the casing shoe (psi)

P_f = Formation pressure from next depth (psi)

TD = Total depth (ft)

CSD = Casing setting depth (ft)

SF = Safety factor (generally 1.5-10.1 for bursting pressure)

G_f = Formation fluid gradient (psi/ft)

$0.052\rho_m$ = Mud gradient (psi/ft)

2.4.3 Tension effect

The tension load can be evaluated after the weight, grades and section lengths have been established from the collapse designs. Buoyancy is included in the tension evaluation due to the manner in which biaxial stresses alter the collapse properties of the pipe. Since the string is designed with a maximum load concept, it is important that buoyancy should be included in the design.

$$Total\ Tensile\ Load\ at\ Each\ Joint = Buoyancy + BF + F_s \quad (2.24)$$

$$BF = 63D_{OD}W_{CS}\theta \quad (2.25)$$

$$F_s = 3200W_{CS} \quad (2.26)$$

Where

BF = Bending force (lb_f)

D_{OD} = Nominal outside diameter (in)

W_{CS} = 3.46 A_{CS} (lb/ft)

= Weight of casing per unit length

θ = Angle of deviation (degrees)

F_s = Shock load (lb_f)

A_{CS} = Cross-section area of casing (in^2)

2.5 Casing setting depths

Casing setting depths are to be established following the determination of the pore pressure and fracture pressure profiles for a particular well. For exploration wells, the well data is to be based upon the best available data. Once these two pressure profiles have been defined, selection of casing setting depths is usually a routine procedure. In addition, offset well data is to be closely scrutinized for problematic intervals that may be encountered in the planned well. Information of particular interest would be

– Zones of whole mud losses and the loss mechanism (e.g. permeability, natural or induced fractures, depleted pore pressure),

– Tight hole sections, suggesting fluid sensitive shale or overpressure,

– Zones susceptible to differential sticking, and

– Intervals of high formation gas that may impact successful primary cementing.

The principal purpose of casing is to ensure the integrity of the well during drilling and production. The selection of casing setting depths is critical for casing off troublesome formations, containing pressure, or protecting fresh water formations.

Casing design evolves from completion requirements, as the completion equipment dictates the size of the production casing or liner. Casing sizes at necessary depths up hole escalate as needed for clearance. Tubular strengths are selected as the well conditions dictate, and materials are selected to resist corrosion. Wellhead and blowout-prevention systems must be compatible with the tubular in pressure rating and material.

Prior to designing casing strings, the engineer must study pressure requirements and prepare a mud-density schedule. A plot of fracture gradient versus depth should be prepared, although in some instances knowledge of the fracture gradients at the casing depths under study is sufficient. Leak off data on new wells is particularly valuable. Hole problems must be thoroughly identified and the need to design for acid gases or other corrosion problems evaluated.

2.5.1 Conductor casing

Conductor casing setting depth is usually shallow (80 to 150 ft.) and selected so that drilling fluid may be circulated to the mud pits while drilling the surface hole. The casing seat must be in an impermeable formation with sufficient fracturing resistance to allow fluid to circulate to the surface. With subsea wellheads, no attempt is made to circulate through the conductor string to the surface. It is set deep enough to assist in stabilizing. Large sizes (usually 16 to 30 in.) are required as necessary to accommodate subsequently required strings.

2.5.2 Surface casing

Surface casing setting depth should be in an impermeable section below fresh-water formations. In some instances, near-surface gravel or shallow gas may need to be cased off. The depth should be great enough to provide a fracture gradient sufficient to allow drilling to the next casing setting point and to provide reasonable assurance that broaching to the surface does not occur in event of closure on a kick. In hard-rock areas the string may be relatively shallow (300 to 800 ft.), but in soft-rock areas deeper strings are necessary. Surface casing setting depths are often specified by government regulatory bodies to protect fresh-water sands.

2.5.3 Intermediate or protective string

A protective string may be necessary to case off lost circulation, salt beds, or sloughing shales. In cases of pressure reversals with depth, protective casing may be set to allow reduction of mud density. The most predominant use is to protect normally pressured formations from the effects of increased mud density needed in deeper drilling.

2.5.4 Liner

A liner is often economically attractive in deep wells as opposed to setting a full casing string. This decision must be carefully considered because the intermediate string must be designed with a burst requirement suitable for the depth of the liner. This increases the cost of the intermediate string. Also, the possibility of continuing wear of the intermediate string must be evaluated. If there is to be a production liner, then either the production liner or the drilling liner should be tied back to the surface as production casing. If the drilling liner is to be tied back it is usually best to do so before drilling hole for the production liner. By doing so, the intermediate casing can be designed for a lower burst requirement, resulting in considerable savings. Also, any wear in the intermediate string is covered up prior to drilling the production interval.

2.5.5 Production string

Whether production casing or liner is set, the depth is determined by the geological objective. Depths may have to be altered accordingly if the well runs higher or lower than the geologic prognosis. The objective and method of identifying the correct depth should be stated.

2.6 Major types of wellbore trajectories

The first step in planning any directional well is to define the bottomhole target to be reached and the surface location from where it has to reach. Then the second step is to design the wellbore path, or trajectory, between the surface location and the bottomhole target. The designed trajectory will show the planned true vertical depth (TVD), the horizontal departure from the vertical section, the inclination angle buildup, and the kick-off point, etc.

In general the following three main types of directional wellbore trajectories can be drilled to hit the target. These types are schematically illustrated in Figure 2.6

1. Buildup-and-hold trajectory, showing in Figure 2.6(a)
2. Buildup-and-hold-and-drop (S) trajectory, showing in Figure 2.6(b) and Figure 2.6(c)
3. Buildup-hold-partial drop-and hold (modified S) trajectory, Figure 2.6(d)

The Type 1 directional well is deviated from the vertical hole at shallow depth and the inclination is locked in until the target is intersected. This type is useful for wells requiring large lateral displacement. With the S-shape trajectory the wellbore intersects the target vertically while with the modified-S type the wellbore penetrates the target at an inclination angle less than the maximum used in the hold section. For well planning some rule of thumbs are:

1. The buildup-and-hold type is less expensive and easier and easier to drill than the other two types.
2. For a certain true vertical depth and target departure, a higher kick-off point results in smaller slant angles, less buildup footage, and overall hole as compared to using deeper kick-off point.
3. For slant angles smaller than 15°, directional control is difficult.

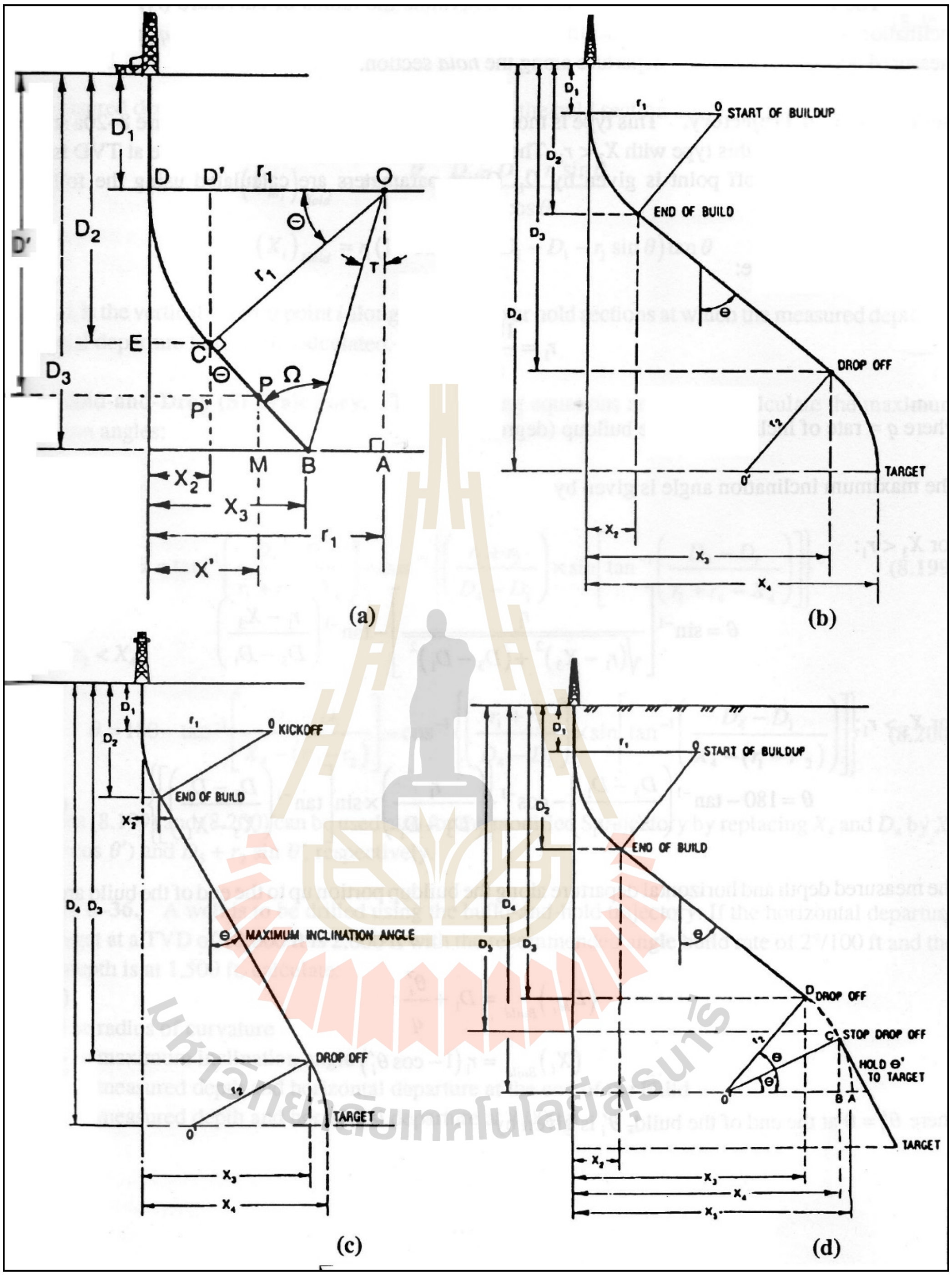


Figure 2.6 Typical wellbore trajectories (after Bourgoyne et al., 1986)

The following equations can be used to determine the radius of curvature (r_1), the maximum inclination angle (θ), the measured depth and horizontal departure along the buildup portion, and the measured depth and horizontal departure along the hold section.

2.6.1 Build-and-Hold Trajectory

This type most commonly used in the industry. Figure 2.6 (a) shows a wellbore trajectory of this type with $X_3 < r_1$. The TVD is given by D_3 and the departure at TVD is given by X_3 while the kick-off point is given by D_1. Other parameters are calculated using the following equation.

The radius of curvature:

$$r_1 = \frac{180}{\pi}\left(\frac{1}{q}\right) \quad (2.27)$$

Where

q = Rate of inclination angle buildup (degrees/ft).

The maximum inclination angle is given by

For $X_3 < r_1$:

$$\theta = sin^{-1}\left[\frac{r_1}{\sqrt{(r_1 - X_3)^2 + (D_3 - D_1)^2}}\right] - tan^{-1}\left(\frac{r_1 - X_3}{D_3 - D_1}\right) \quad (2.28)$$

For $X_3 > r_1$:

$$\theta = 180 - tan^{-1}\left(\frac{D_3 - D_1}{X_3 - r_1}\right) - cos^{-1}\left\{\left(\frac{r_1}{D_3 - D_1}\right) \times \sin\left[tan^{-1}\left(\frac{D_3 - D_1}{X_3 - X_1}\right)\right]\right\} \quad (2.29)$$

The measured depth and horizontal departure the buildup portion up to the end of the build are given by

$$\left(D_{M_i}\right)_{Build} = D_1 + \frac{\theta_i'}{q} \quad (2.30)$$

$$(X_i)_{Build} = r_1(1 - cos\theta_i') \quad (2.31)$$

Where

$$\theta_i' = \theta \text{ at the end of the build, } \theta_i' \text{ is given by}$$

$$\theta_i' = sin^{-1}\left(\frac{D_i}{D_1 + r_1}\right) \tag{2.32}$$

The measured depth and the horizontal departure along the hold section are given by

$$\left(D_{M_i}\right)_{Hold} = D_1 + \frac{\theta}{q} + \frac{D_i - D_1 - r_1 sin\theta}{cos\theta} \tag{2.33}$$

$$(X_i)_{Hold} = r_1(1 - cos\theta) + (D_i - D_1 - r_1 sin\theta)tan\theta \tag{2.34}$$

Where D_i is the vertical depth at point *i* along the buildup or hold sections at which the measured depth and horizontal departure have to be calculated.

2.6.2 Build-Hold-and-Drop (S) Trajectory

The following equations are used to calculate the maximum inclination angles:

For $r_1 + r_2 > X_4$:

$$\theta = tan^{-1}\left(\frac{D_4 - D_1}{r_1 + r_2 - X_4}\right) - cos^{-1}\left\{\left(\frac{r_1 + r_2}{D_4 + D_1}\right) \times \sin\left[tan^{-1}\left(\frac{D_4 - D_1}{r_1 + r_2 - X_4}\right)\right]\right\} \tag{2.35}$$

For $r_1 + r_2 < X_4$:

$$\theta = 180 - tan^{-1}\left[\frac{D_4 - D_1}{X_4 - (r_1 - r_2)}\right]$$

$$-cos^{-1}\left\{\left(\frac{r_1 + r_2}{D_4 - D_1}\right) \times \sin\left[tan^{-1}\left(\frac{D_4 - D_1}{X_4 - (r_1 - r_2)}\right)\right]\right\} \tag{2.36}$$

2.6.3 Buildup-hold-partial drop-and hold (modified S) trajectory

Equation (2.34) and (2.35) can be used also for the modified S trajectory by replacing X_4 and D_4 by

$$X_4 = X_5 + r_2(1 - \cos\theta') \tag{2.37}$$

$$D_4 = D_5 + r_2 \sin\theta' \tag{2.38}$$

2.7 Graphical method for casing design

Graphical method of casing design is the most widely used method for selecting proper weights, grades, and section lengths of casing. The burst, collapse, and tension loads are represented by a graph of depth versus pressure. Strength values of the available casing grades in collapse and burst are plotted as vertical lines on this graph. Collapse, burst, and fracture gradient lines are also plotted on this graph.

2.8 Computer-Aided Design (CAD)

2.8.1 Introduction to CAD

As our society moves away from this century of automation through information base systems and into the new millennia, education must change at a faster pace (Merickel, 1990). Because of the rapid influx of technological innovations, computer technology has had a pronounced effect on nearly every facet of society especially industry and education (Wang, 1993). Computer-Aided Design (CAD) is especially undergoing rapid growth and change (Goss, 1990).

The use of Computer-Aided Design and Drafting (CADD) in technology with increased competitiveness and improved quality and efficiency has proliferated throughout the drafting industry (Wang, 1993). Drafting is a fundamental communication technique used in the construction industry to visually demonstrate, exemplify or elucidate projects (Hales, 1991). Consequently, competitive companies and institutions that use drafting as a form of communication have been watching the growing field of CADD looking for a CADD system that will best fulfill their needs. However, some organizations have been unwilling to implement the use of a CADD system, which raises concerns regarding the following:

1. Difficulties in estimating the rate of return on the relatively high initial capital costs involved in setting up CADD workstations.

2. Training employees in the use o f a CADD workstation.

3. Upgrading software.

4. Providing upgrade training for the operators.

With these difficulties, companies cannot afford to ignore the challenge of technological change (Beatty, 1986).

Gow's (1991) prediction that CADD would replace traditional drafting in many diverse industries and that the changeover from traditional drafting to CADD would reach the 90% to 100% level has come to pass. Consequently, university/college programs are utilizing computer graphics and computer applications in an effort to keep pace with advancing technology. However, as software upgrades and revisions are produced, drafting technology educators must adjust the CADD curriculum to encompass new developments in the field (Diez, 1990; Pedras and Hoggard, 1985).

2.8.2 History of CAD

Byles (1985) indicated that CAD had its beginnings in the mid 1950s through a consortium of aerospace companies called the Aircraft Industries Association. Engineers at General Motors used the program tool generated by Aircraft Industries Association to create CAD batch language for producing loft lines. He further pointed out that the next generation of CAD software did not appear until CAD systems became commercially available during the late 1960s. Jefferis and Jones (1994) wrote that computers started becoming available to large firms that could afford their hefty price tags in the early 1980s. While mechanical and electrical engineering firms started using CAD, architects did not because computers could not produce drawings with an artistic flair. However, by the mid 1980s, prices had dropped and programs had been developed that could produce drawings with enough artistic flair to satisfy many architectural firms. Consequently, by the late 80s many architects had discovered that computers would have a place in their office.

Bertoline (1985) reported that since in the late 70s there has been a dramatic increase in the number of CAD systems on the market and in the number of industries using them. No one event produced this increase in CAD, but there are a number of important reasons. Contributing to the increased use of CAD by industry are the rapid developments in the microcomputer due to improved microprocessor technology, the dropping cost of memory, and the increased number of venders supplying CAD. Another major reason for the growth in CAD is competition among rival companies both in the United States and abroad. Industries are finding that CAD must be used in order to remain competitive in such fields as electronics. The decrease in turnaround time in design and increases in productivity are two ways that CAD can make a company more competitive. CAD is and will continue to be the most productive method for drafter-designers to perform their job.

Eiteljorg (1996) agreed with Bertoline in that, with the advent of IBM's AT desktop computer system in the early 1980s, software packages designed to run on these systems came into being. AutoCAD was one such software package. Later, as computer technology became increasingly sophisticated, more powerful computer processing hardware was created permitting the development of complicated functions within AutoCAD that were not possible in earlier versions of the software package. When major changes in features and operation of AutoCAD were produced, a new revision of the software was presented to the public.

Wang (1993) indicated that there were three approaches to teaching CAD, each requiring its own set of competencies. The first approach was in regard to programming, concentrating on data structures and the design of user interfaces. The second approach concerned the mathematical principles used in representation of curves and surfaces. The last approach was based on current CAD systems and the need to provide appropriate training on that system. According to Michell and Ligget (1986), this approach would be the most desired methodology for operators of CAD, CAD educators, and CAD system venders.

Wang (1993) further pointed out that a competent CAD operator must be able to effectively use the working commands of a CAD system as well as customize the CAD working environment by developing macros for later use allowing increased productivity of the system. Developing macros is a process by which an operator would link several AutoCAD commands together under a new command name. In order to accomplish this, a clear understanding of the AutoCAD command structure would be required.

In addition, Flechsig and Seamans (1987) pointed out that the purpose of each computer aided drafting class was to teach students to select, modify, and apply the computer commands necessary to draw the required assignment.

In petroleum industry CAD is widely used in various ways, e.g. in surface and subsurface geological mapping, reservoir modeling, well planning, etc.

2.9 Visual basic .NET

2.9.1 Introduction to Visual Basic

One tool that has stood the test of time and continues to receive updates is Visual Basic (VB). The popularity behind this software product is based on the fact that it is developed as a Rapid Application Development (RAD) tool. This allows users of almost any learning ability to easily create graphical interfaces quickly and without needing an absolute knowledge of how these interfaces are intrinsically created. Code snippets of any size can be provided describing the actions that need to be taken using various predefined events. This will enable the VB application to manipulate the graphical interface as well as perform various specialized functions.

2.9.2 Background of Visual Basic

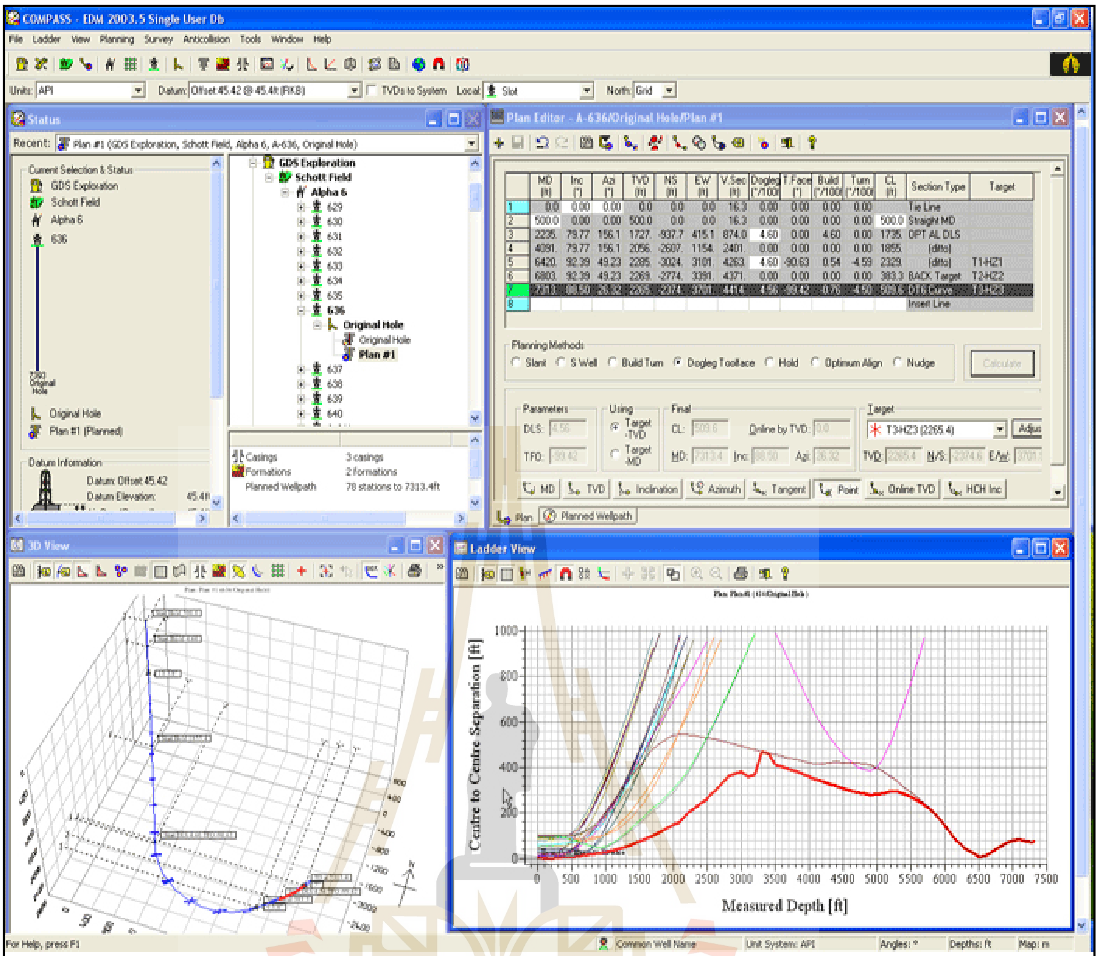
Visual Basic's first inception came about in 1987 and was developed as a concept shell software known as "Tripod" in direct resistance to Microsoft's current shell product of the time. Since then, it moved forward with a larger development team two years later bearing the name "Ruby" and was purchased by Microsoft in 1990. From there, the original shell backend was removed and replaced with QuickBasic (Cooper Interaction Design, 1996). In 1991, it heralded an official version 1 release at a Trade Show in Atlanta, Georgia. At this point, it had a leg up on the other programming languages providing a simple to design user interface, an event-based programming model, and extensibility via its VBX plug-ins (Spencer, 2001). However, it was not easy to use and not widely accepted as a development platform (Lambert, 2008). Other notable languages that were more established during this time included: Structured Query Language (SQL), variations of C, Perl, Pascal, Ada, Fortran, and Cobol to name a few. VB version 2 improved on its usability programming environment making it both easier and faster (Max Visual Basic, n.d.), as well as the ability to use Object Linking and Embedding (OLE) via a component. VB version 3 came in two flavors-Standard and Professional-which set the stage for its licensing model. It also was the first to include accessibility to Microsoft Jet Databases as well as other databases. VB version 4 was the first foray into the 32-bit processors' realm with the inclusion of 16 and 32 bit executables, the first use of the ActiveX control model, non-GUI class creation, and the introduction of the Remote Data Objects (RDO) library for building client/server applications. VB version 5 was only released in 32-bit form but included cross compatibility with version 4 by allowing project files that could be directly opened by its predecessor so that developers could continue to create 16-bit applications. It also included the ability to compile to native code as well as create custom user controls. VB version 6, released in 1998, was bundled with other coding tools inside a package known as Visual Studio (VS). It improved on its predecessor in many ways including, the introduction of Active Data Objects (ADO) and the added ability to create web-based applications. This is the last in the binary executable line and the most popular of the series at the time of this writing (Microsoft, n.d.).

2.10 Commercial software for well planning in the market

There are some commercial softwares for analyzing multi linear regression analysis. This study introduces the COMPASS™ directional well planning software. This software is the industry's premiere application for directional path planning, survey data management, plotting and anti-collision analysis. It is designed for both oil companies and directional drilling contractors, improves safety, efficiency, and cost effectiveness of directional well programs. COMPASS™ includes user-friendly tools such as multiple 2D and 3D planning methods, torque/drag, cost and re-entry optimization, plotting, survey data analysis, and driller's target generation.

COMPASS™ is deployed on Landmark's Engineer's Data Model™ (EDM) enabling users to improve data consistency and reduce planning cycle times by sharing common data. Automatic updates and notifications ensure that all users are always aware when changes occur and engineering results are updated in real time.

COMPASS™ is an integral part of collaborative planning in multi-discipline asset team environments. Integration with OpenWorks™ ensures that geoscientists and engineers recognize trajectory changes made by the other discipline. Each member of the team can immediately provide the feedback required to achieve both engineering and subsurface objectives. Example of COMPASS™ feature is showed in Figure 2.7



COMPASS plan editor with three live graphic views

Figure 2.7 Some features of Compass Directional Well Planning Software (after Halliburton, 2011)

CHAPTER III

METHODOLOGY

3.1 Software developing concepts

In this study are computer software was developed for two main objectives: 1) casing design and casing selection, and 2) wellbore trajectory design and well planning. Therefore the developed software was designed and developed into two main modules in order to meet objectives of the study.

The first module consists of pressure and load calculation, results of pressure and load calculation display, and casing selection part, respectively. In pressure and load calculation part, collapse pressure, burst pressure, and tension effect are calculated according to the mentioned concepts and equations in chapter 2. Result from the first part will be then depicted in form of graph between depth and pressure. After the correlation of pressure and depth had been established and displayed in the second part, casings can be selected in order to meet the calculated pressure and load in the third part, respectively.

The second module consists of wellbore trajectory and well planning assisting part. Results from the first module, including pressure and load, and selected casing will be used for wellbore trajectory design which are displayed in from of picture. In this module well trajectory pattern, kick off point, vertical depth, measured depth, radius of curvature, and horizontal departure from rig location can be adjusted to meet the user satisfaction.

The developed software had been created on the basis of high results accuracy and user friendly. Some unavailable data had been assumed according to the general practice and API specifications.

3.2 Software developing

This topic describes the concept and steps used in the software development for well planning and casing design under various geological conditions and petroleum engineering requirements. The software hereafter is called WPD. The proposed system is based on the known analytical solutions and theories, but does not based on the heuristic knowledge, inference procedure and experience of well planning expert backed up by the rationale and logic. The concepts and steps include problem analysis, flowchart developing, programming, software testing, conclusion and discussion, respectively.

3.2.1 Problem analysis

Problem analysis is a primary step for a computer software development which identifies statement of problem, solution, procedure and result. The problem analysis can be divided into five sub-topics as software requirement, input data, output, variable declaration, and procedure, respectively.

3.2.1.1 Software requirement

The primary requirement of a computer software consist of software display details, basic facilities design, and necessary information that can be save and print in terms of file and documents.

3.2.1.2 Input data

The WPD software records all required input parameters in SQL server in the software file folder of drive C. The WPD then calculates the pressure and load used in the casing design, and calculate inclination angle, radius of curvature, depth, horizontal departure used in wellbore trajectories. All required parameters are input to WPD through three pages, Parameter view page, Casing section view page, and Wellbore trajectories design view page.

In Parameter view page the required data parameters are assigned, including collapse pressure data, burst pressure data, and casing outside diameter data. After raw data or calculated data have been input, all input data then are displayed in form of panel display on the Data view page automatically.

3.2.1.3 Output

After the calculation processes have been completed, results of the calculation are sent to the panel display. The casing selection page has 2 parts; 1) graphs showing the relationship between collapse pressure, burst pressure and depth each input parameter, and 2) API Casing tables. The Wellbore trajectories page shows equation, wellbore type and wellbore trajectories graphically. Moreover, there is a Report button to report output data in form of Microsoft Office Word files and AutoCAD file.

3.2.1.4 Variable declaration

Input parameters, output data, calculation, and processing symbols used in this developed software are declared and listed in Chapter 4.

3.2.2 Flowchart

This part shows and explains the flowchart of WPD software developing. The main process includes data input, input checking, calculation, data base in SQL server linking, and output checking. These components sometimes work concurrently. The system uses forward chaining strategy. The input data are compiled and subjected to rules and conditions to obtain specific answers. This approach is appropriate general data because the WPD records various data and be designed to simply use.

A main flowchart was developed for description compiling process of WPD as showed in Figure 3.1. The details of sub-flowchart 1 are presented in Figure 3.2.

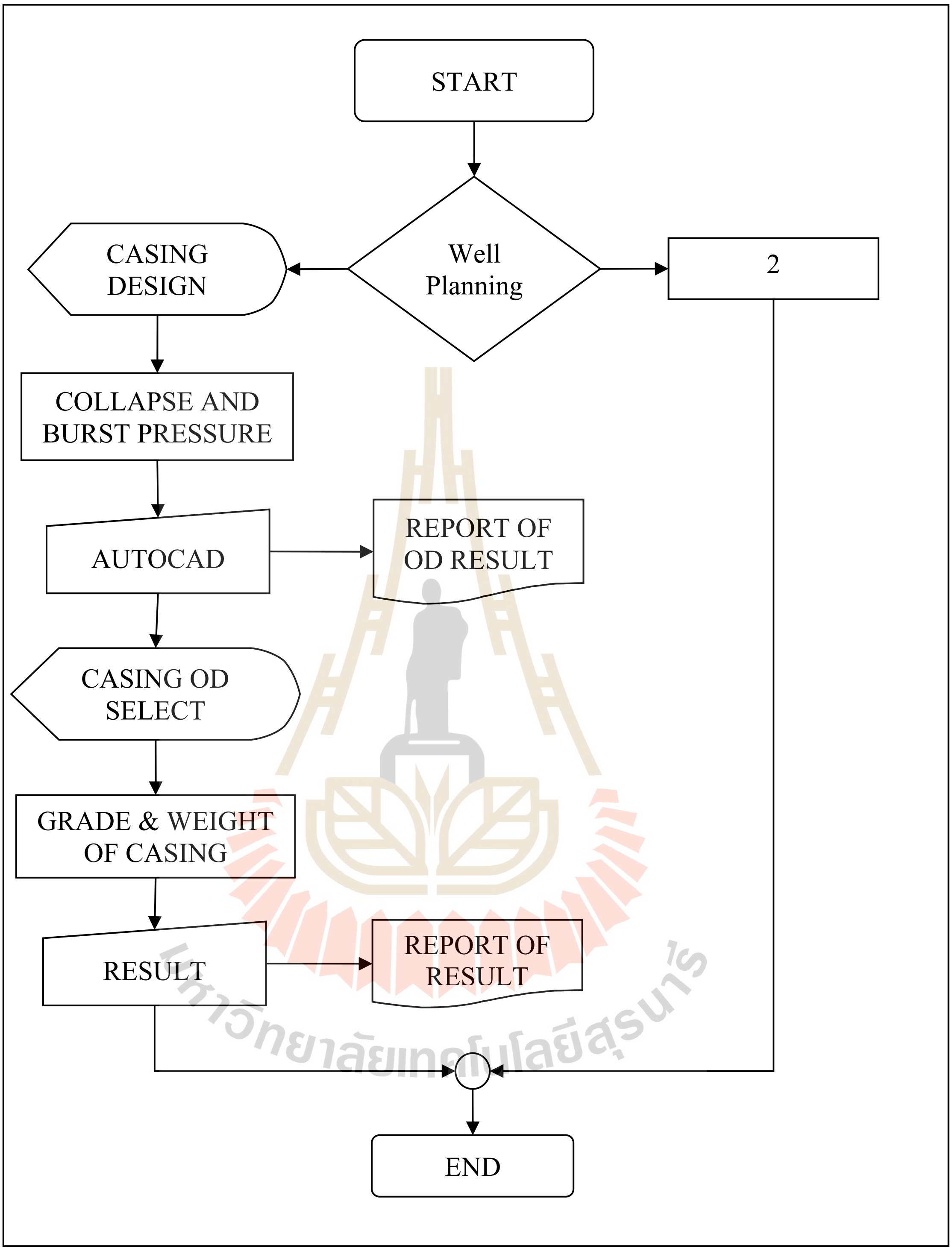


Figure 3.1 The main WPD software working flowchart

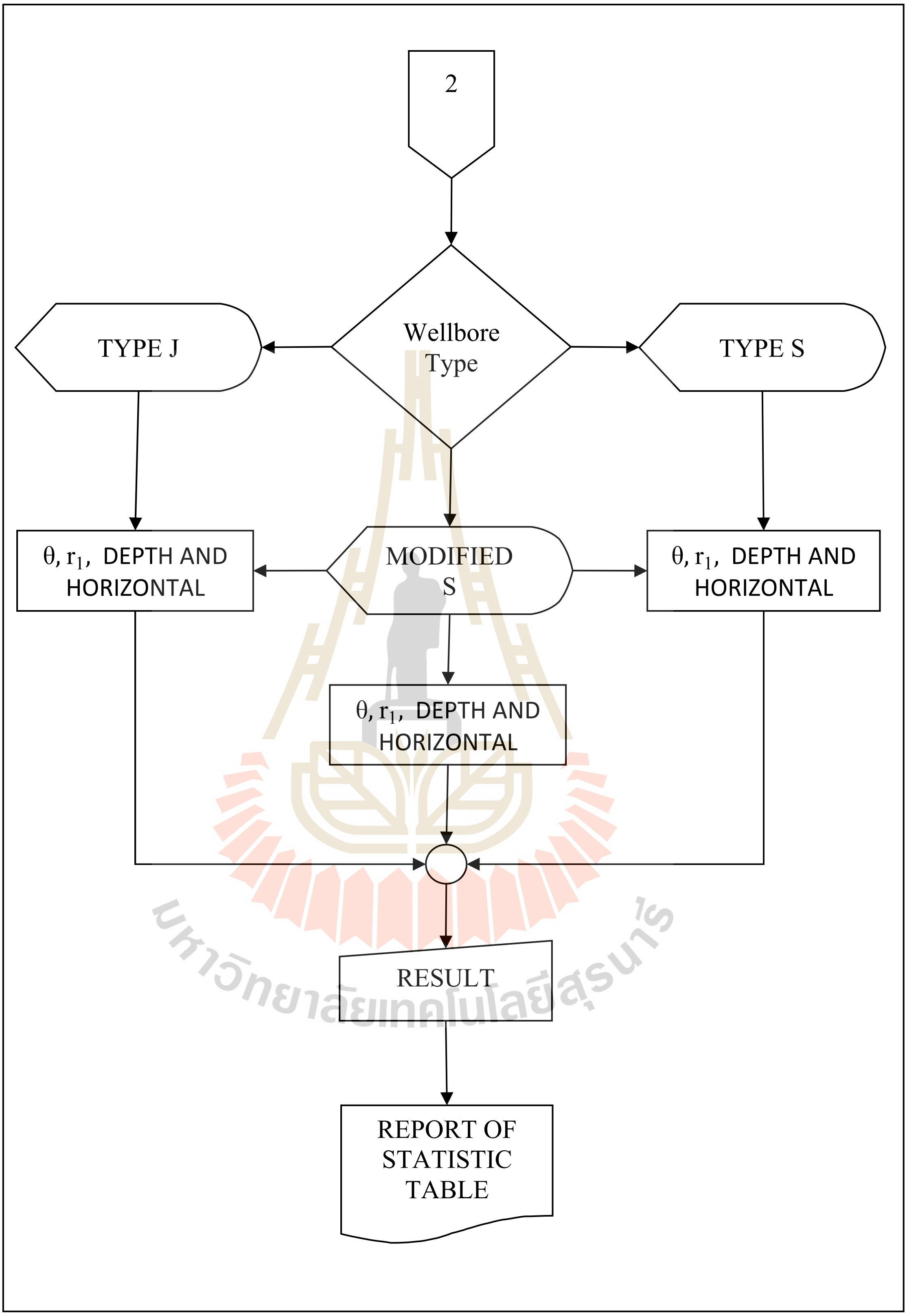


Figure 3.2 The WPD software sub-flowchart part 1

3.2.3 WPD Software

Source codes of WPD software both for the main menu and sub-menu in each module following the flowchart structure are presented in Appendix B.

3.2.4 Software system development

The WPD software system development can be divided to into three phases; 1) system shell development, 2) system control development and 3) data base system development, respectively. In general, the system shell is used as the software structure. The system control directs the paths and flows of the software. The data base stores the rules and conditions of statistic theories.

3.2.4.1 System shell

The WPD was developed on Microsoft Visual Basic .NET software. The advantages of Microsoft Visual Basic .NET are 1) equipped with GUI-Graphical User Interface, 2) ease of application,3) quick construction, 4) supporting the management data base system, and 5) compile of complex calculation.

3.2.4.2 System control

The main processes for control functions are the decision making, iteration, array and procedure. The main structures of software developments are as follows.

(1) Decision structures

- Two-way decision making; “if…Then…Else”
- More than two-way decision making; “Select…Case”

(2) Iteration structures

- Known number of interaction; “For…Next”
- Unknown number of interaction; “While…When”

- Unknown number of interaction and go out from iteration; “Do/While…Unit/Loop”

(3) Array and Dynamic.

- Array structures are parts of permanent and non permanent storage data that are used for calculation.

(4) Procedure structure; include

- Sub software (sub routine)
- Function (sub function)

3.2.4.3 Data base system

The input data have been compiled and stored in form of Microsoft Access. They can be searched by Data Query Language (SQL) and data control which are contained in Microsoft Visual Basic.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 WPD working produce

This part demonstrates procedures to use the WPD software. Main page of WPD software (Figure 4.1) shows three buttons. Upper, middle, and lower button on the main page are pressure caculation, casing selection, and wellbore trajectory design commands respectively. Step by step for using this software will be described as follows.

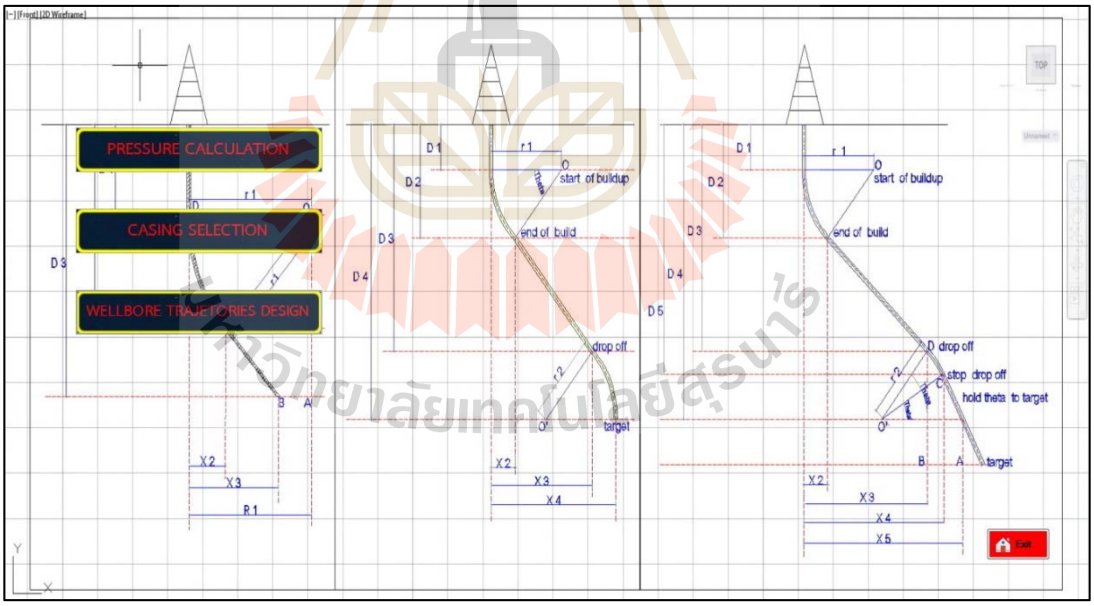


Figure 4.1 Main page of the WPD software

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Step 1

In Parameter view page (Figure 4.2) user input required data for the collapse pressure and burst pressure calculation, then click calculate button to calculate the collapse and burst pressure. User can change or clear data by clicking the clear button below input data box

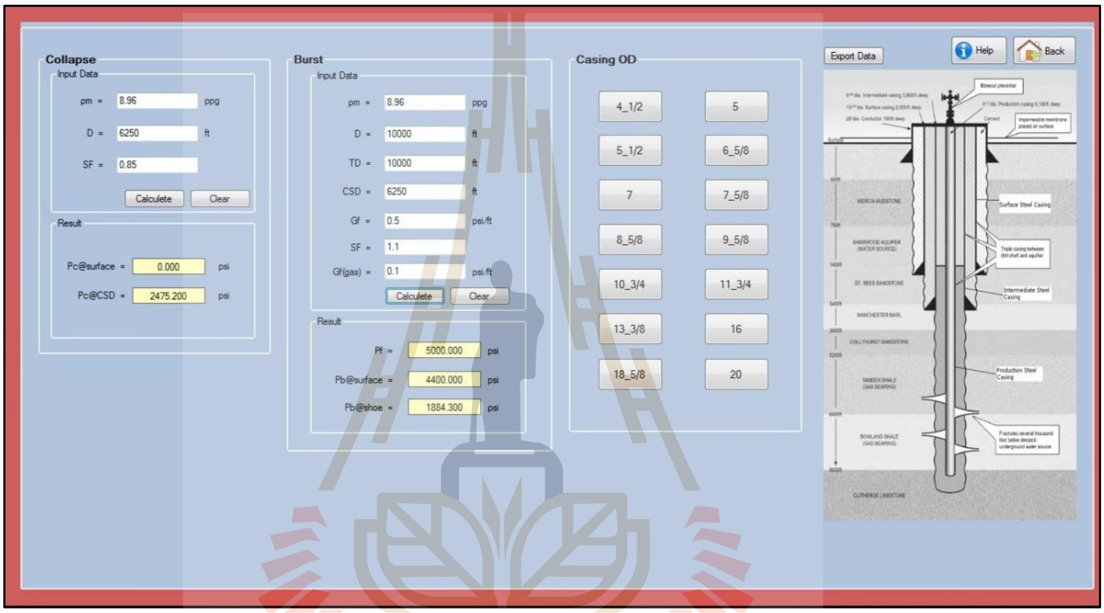

Figure 4.2 Parameter view page of the WPD software

After the results of the collapse pressure and burst pressure are displayed. Select the satisfied casing outside diameter from the casing OD field where user can select casing outside diameter sizes from the given list of OD. Then the selected casing is displayed graphically as showed in Figure 4.3.

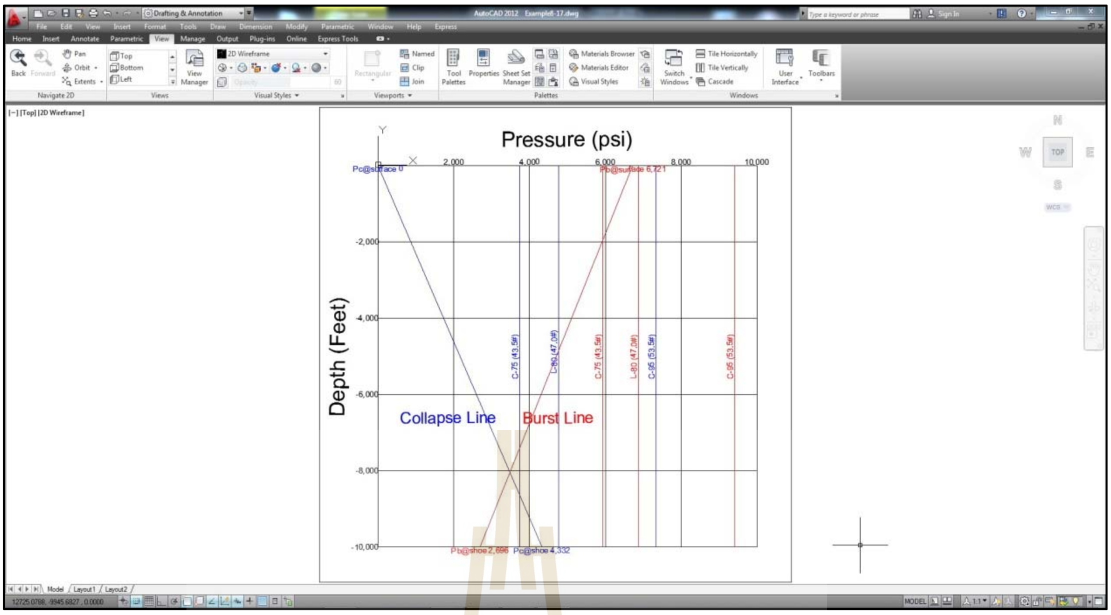

Figure 4.3 Graphically display of casing outside diameter on AutoCAD program

Step 2

In casing selection page (Figure 4.4) user can fill in the details of the casing, depth, and size of required casing. User can also select grade of casing to be used in the borehole at the required depth from the table on the left of the page. The full table can be opened using the open file button. Data is then sent and displayed in Microsoft Office Excel file. Tension load can be calculated in the tension field by filling in required data. User can report the input data by clicking the Export data view button to report data in form of the Microsoft Office Word file.

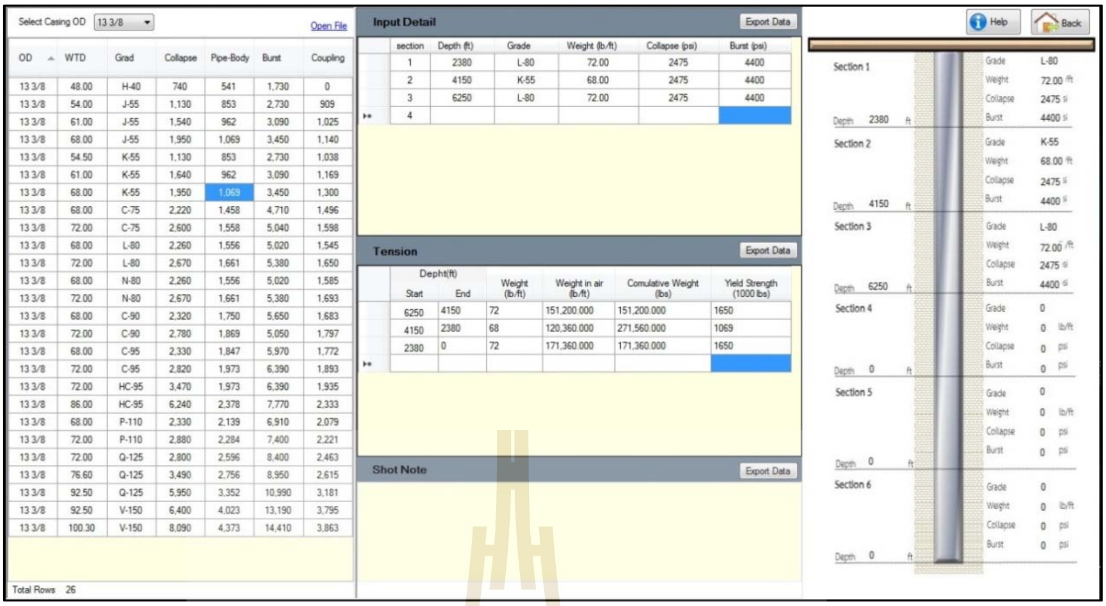

Figure 4.4 Casing selection page view in the WPD software

Step 3

In Wellbore trajectories view page user can choose wellbore trajectories from 3 standard templates, including build-and-hold trajectory (Type J) (Figure 4.5), Build-and-hold-and-drop trajectory (Type S) (Figure 4.6), and Build-and-hold and partial drop trajectory (Modified S) (Figure 4.7). User can also input required data to calculate the radius of curvature, maximum inclination angle, depth, and horizontal departure along the buildup portion up to the end of the build. The value and wellbore type design of the drill holes are displayed beside. Users can perform detailed design wellbore trajectory graphically through AutoCAD by clicking open file button as depicted in Figure 4.8.

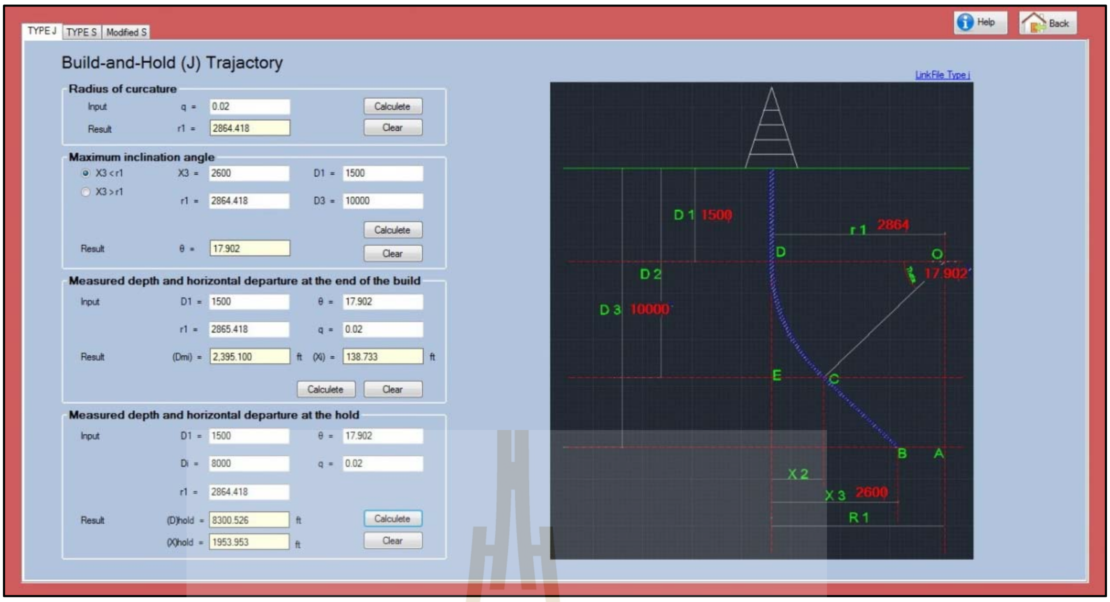

Figure 4.5 Wellbore design for Build-and-hold trajectory (Type J) on Data View page of the WPD software

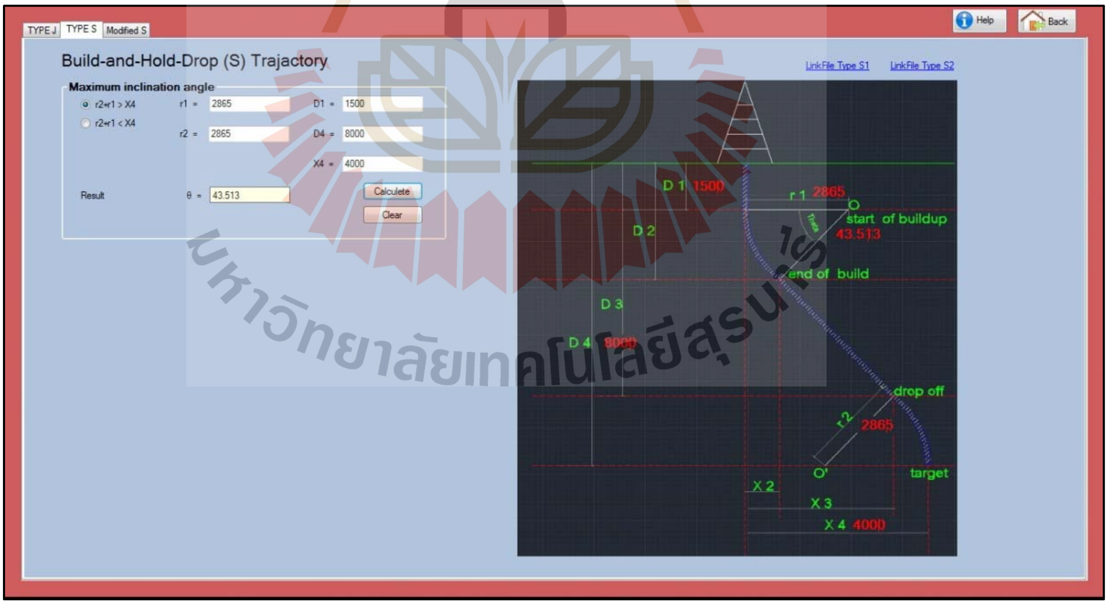

Figure 4.6 Wellbore design for Build-and-hold-and-drop trajectory (Type S) on Data View page of the WPD software

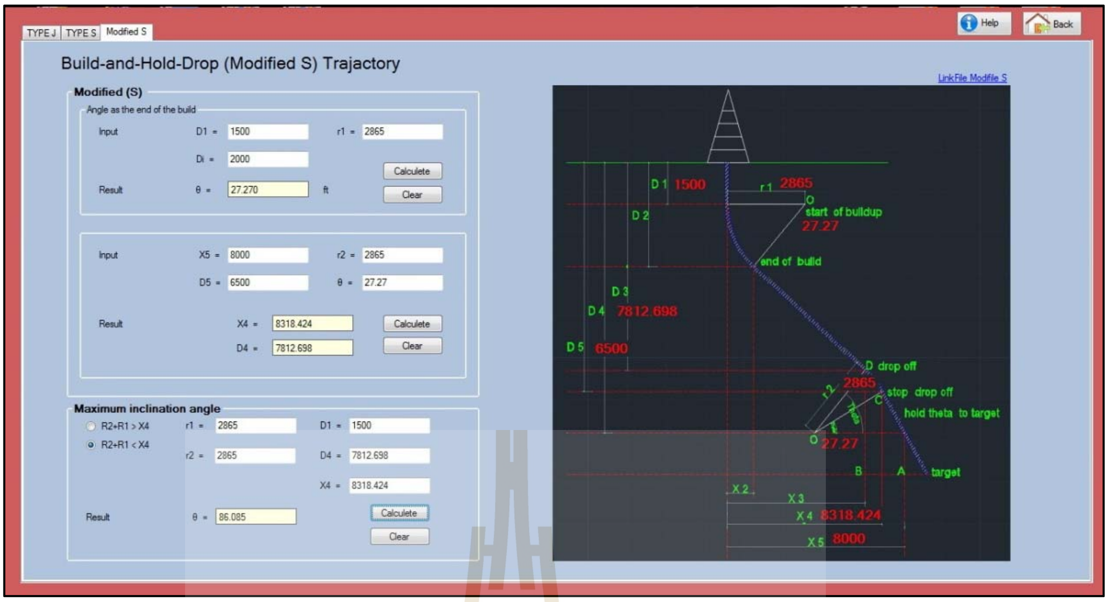

Figure 4.7 Wellbore design for Build-and-hold and partial drop trajectory (Modified S) on Data View page of the WPD software

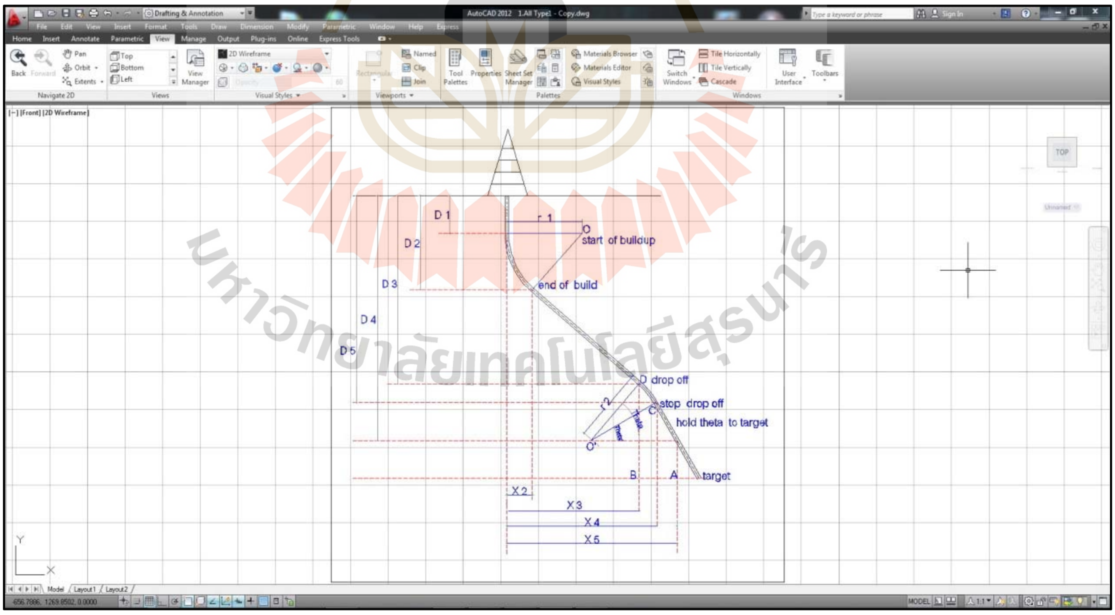

Figure 4.8 Designed wellbore trajectory view page on AutoCAD program

WPD software has a help section for user and can be achieved by clicking Help button (Figure 4.9). In this section user can find some hints for any question concerned with the software and it also has some statistics theory in brief as a user guide.

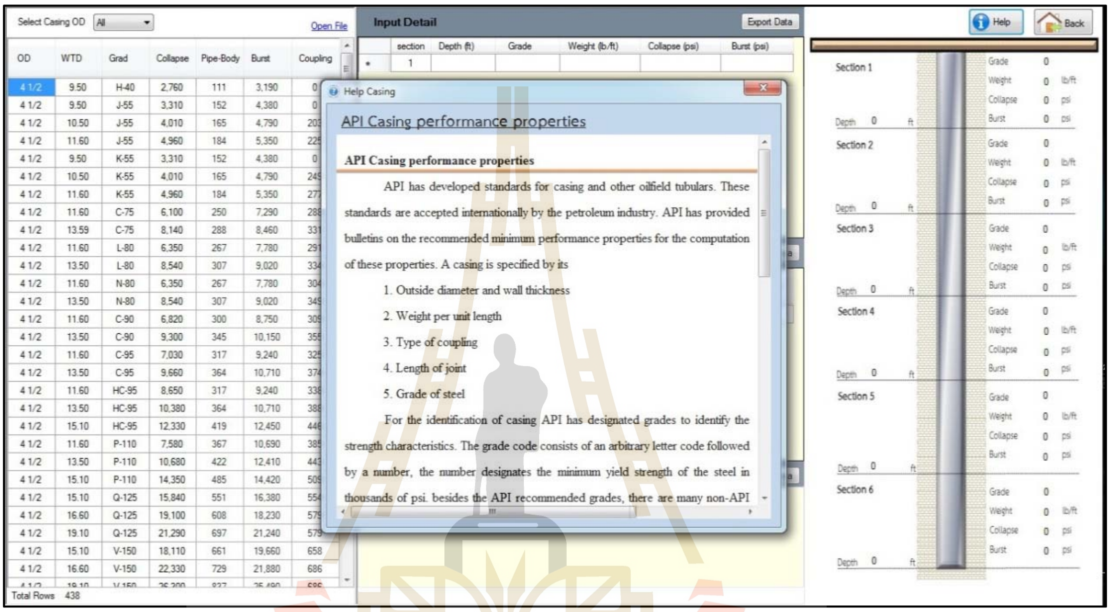

Figure 4.9 Help view page of the WPD software showing software handling, calculation and statistic theories

4.2 WPD results examination

To examine the efficiency and accuracy of the P_c, P_b calculated from WPD software, these P_c, P_b were compared to P_c, P_b which were calculated from the manual conventional method as presented in example 1 through example 3(example were picked up from Mian, 1992). Comparison results are summarized and presented in Table 4.6 and it is indicated that, P_c, P_b calculated from WPD software was reliable and can be compared to the manual calculation P_c, P_b.

Example 1: Design a 20-in. conductor pipe for a 26-in. hole with the casing to set at 400 ft. The casing head housing will be installed on the conductor pipe. The mud program calls for using mud weights of 8.69 ppg to drill the conductor hole and 8.96 ppg to drill the next 17-$^1/_2$ in. hole section from 400 to 6,250 ft. The design safety factors are

(a) Collapse = 0.85

(b) Burst = 1.1

(c) Tension = 1.8

Solution: Assume that no gas kick is expected this shallow depth, assume water kick in which formation gradient is 0.465 psi/ft.

(a) Collapse:

p_c at surface = 0

Using Equations (2.21)

p_c at CSD = $0.052\rho_m D$

p_c at CSD = $0.052 \times 8.69 \times 400 \times 0.85$

p_c at CSD = 153.639 psi

(b) Burst

Using Equations (2.23)

$p_f = G_f \times D$

$p_f = 0.465 \times 6{,}250$

p_f = 2,906.25 psi

Using Equations (2.22)

$$p_b \text{ at shoe} = \left[p_f - (TD - CSD)G_f\right] - \left[CSD(0.052 \times \rho_m)\right]$$

p_b at shoe = $\{[2{,}906.25 - (6{,}250 - 400)0.465]$

$- [400(0.052 \times 8.69)]\} \times 1.1$

p_b at shoe = 5.773 psi

p_b at surface = $p_f - (TD \times G_f)$

p_b at surface = $2{,}906.25 - (6{,}250 \times 0.465)$

p_b at surface = 0 psi

That if a gas kick had been considered instead of the saltwater kick, the burst pressure at the surface and the shoe would have been higher.

The casing selection is made by simply comparing the strength properties of available casing Table A3 (Appendix A) with the existing pressure. All the available grades satisfy the above requirements. Hence select J-55, 94 lb/ft casing having collapse 520 psi, burst 2,110 psi, and yield strength 1,480,000 lbs.

Example 2: For the well in Example 1, design a 13-$^3/_8$ in. intermediate casing to a depth of 6,250 ft. The next hole will drilled to depth of 10,000 ft with 9.8 ppg mud

Solution:

(a) Collapse:

p_c at surface = 0

Using Equations (2.21)

p_c at CSD = $0.052\rho_m D$

p_c at CSD = $[0.052 \times 8.96 \times 6{,}250] \times 0.85$

p_c at CSD = 2,745.2 psi

Draw the collapse line as show in Figure 4.10. From Table A3 (Appendix A), for 13-$^{3}/_{8}$ in. casing available K-55, 54.5 lb/ft (LTC); K-55, 68 lb/ft (BTS); and L-80, 72 lb/ft (BTS). Plot the collapse resistance values for these grades of casing as show in Figure 4.10. The formation fluid gradient from 6,250 ft to 10,000 ft is 0.5 psi/ft. Assume the invading fluid to be gas with 0.1 psi/ft gradient.

(b) Burst

Using Equations (2.23)

$$p_f = G_f \times D$$

$$p_f = 0.50 \times 10{,}000$$

$$p_f = 5{,}000 \text{ psi}$$

Using Equations (2.22)

$$p_b \text{ at shoe} = \left[p_f - (TD - CSD)G_f\right] - \left[CSD(0.052 \times \rho_m)\right]$$

$$p_b \text{ at shoe} = \{[5{,}000 - (10{,}000 - 6{,}250)0.1]$$

$$- [6{,}250(0.052 \times 8.96)]\} \times 1.1$$

$$p_b \text{ at shoe} = 1{,}884.3 \text{ psi}$$

$$p_b \text{ at surface} = p_f - (TD - CSD)G_f$$

$$p_b \text{ at surface} = \left[5{,}000 - (10{,}000 - 0) \times 0.1\right] \times 1.1$$

$$p_b \text{ at surface} = 4{,}400 \text{ psi}$$

Draw the burst line between 1,884.3 and 4,400 psi as show in Figure 4.10

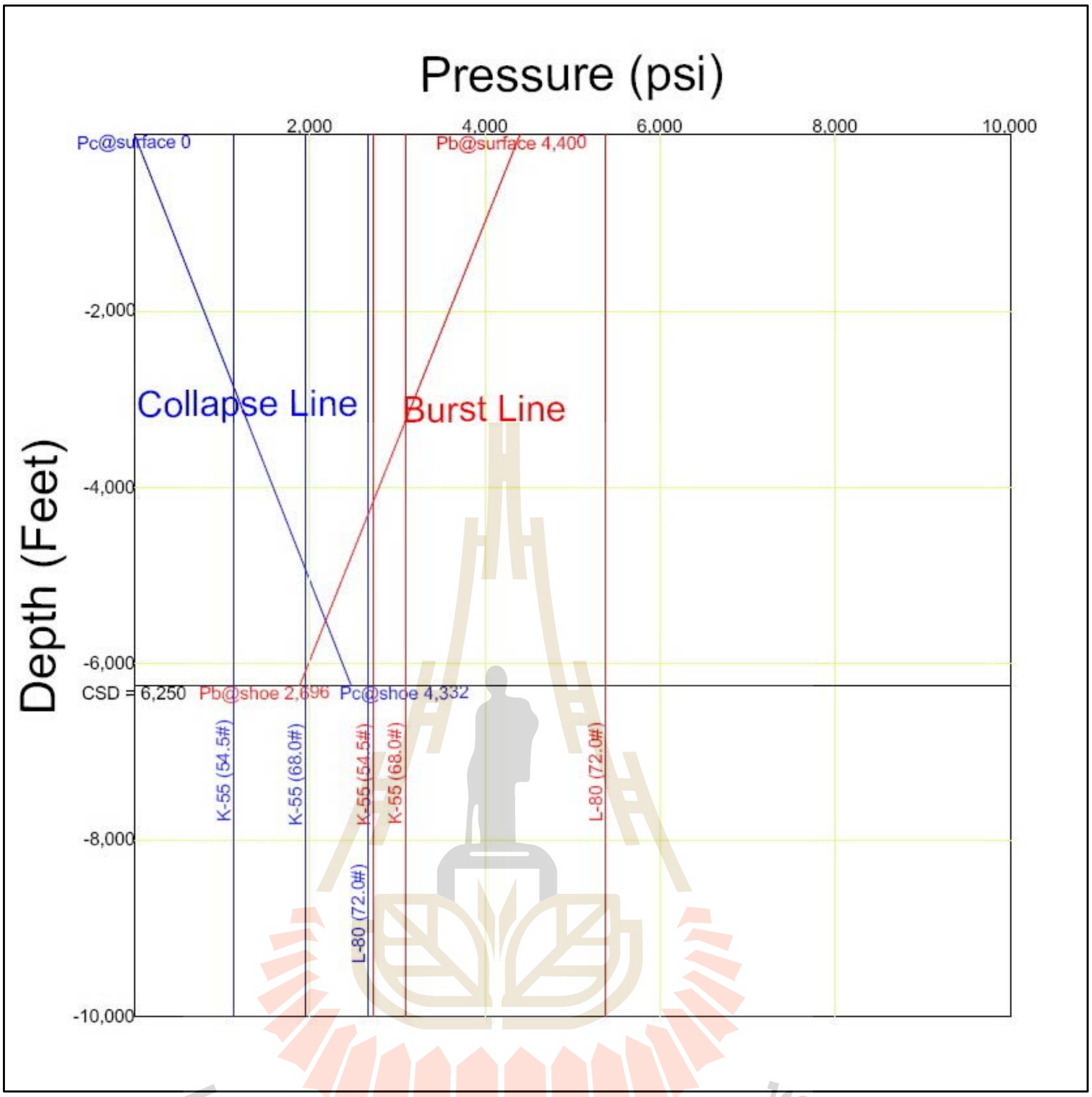

Figure 4.10 13-$^{3}/_{8}$ Casing design for Example 2

Based on combined collapse and burst satisfaction, Casing selection are depicted in Table 4.1.

Table 4.1 Casing selection for example 2

Depth	Grade & Weight	Weight in air, 1000 lb
0 - 2,380	L-80, 72 lb/ft	171.360
2,380 - 4,150	K-55, 68 lb/ft	120.360
4,150 - 6,250	L-80, 72 lb/ft	151.200
	Total weight in air	442.90

(c) Tension

If bending and shock loading is ignored, the selection obtained above can be checked for tension by comparing the weight in air carried by each section with its yield strength. The values of yield strength are obtained from Table A3 as the lowest value of either the body (Column 12) or coupling (Column22) yield strength.

Table 4.2 Tension load for example 2

Weight of Section (1,000 lbs)	Cumulative Weight (1,000 lbs)	Yield Strength (1,000 lbs)	Safety Factor
151.200	151.200	1,650	1,650/151.20 = 10.91
120.360	271.560	1,069	1,069/271.56 = 3.94
171.360	442.920	1,650	1,650/442.92 = 3.73

Since all the safety factors exceed 1.8, the casing selection satisfies tension requirement.

Example 3: Using the data of Example 1 and Example 2, design a 9- $^5/_8$ in. casing string to a casing setting depth of 10,000 ft. The casing will be subjected, in the event of kick, to formation pressure of 0.57 psi/ft from the next hole drilled to 13,000 ft. The mud weight to be used to drill the hole to 13,000 ft is 11.5 ppg. The casings available are given below. The hole experiences a maximum dogleg of 3°/100 ft.

Table 4.3 Available casing for example 3

Grade	Weight (lb/ft)	Collapse (psi)	Burst (psi)
C-75	43.5	3,750	5,930
L-80	47.0	4,750	6,870
C-95	53.5	7,330	9,410

Solution:

(a) Collapse:

p_c at surface = 0

Using Equations (2.21)

p_c at CSD = $0.052\rho_m D$

p_c at CSD = $[0.052 \times 9.8 \times 10{,}000] \times 0.85$

p_c at CSD = 4,331.6 psi

(b) Burst

Using Equations (2.23)

$p_f = G_f \times D$

$p_f = 0.57 \times 13{,}000$

$p_f = 7{,}410$ psi

Using Equations (2.22)

p_b at shoe $= [p_f - (TD - CSD)G_f] - [CSD(0.052 \times \rho_m)]$

p_b at shoe $= \{[7{,}410 - (13{,}000 - 10{,}000)0.1]$

$-[10{,}000(0.052 \times 8.96)]\} \times 1.1$

p_b at shoe $= 2{,}695.88$ psi

p_b at surface $= p_f - (TD - CSD)G_f$

p_b at surface $= [7{,}410 - (13{,}000 - 0) \times 0.1] \times 1.1$

p_b at surface $= 6{,}721$ psi

The collapse and burst lines for this 9- $^5/_8$ in. casing design are show in Figure 4.11. The casing selection is as follows:

Table 4.4 Casing selection for example 3

Depth	Grade and Weight
0 - 1,750	L-80, 47.0 lb/ft
1,750 - 9,100	C-75, 43.5 lb/ft
9,100 - 10,000	L-80, 47.0 lb/ft

The selected casing should be checked for tension by considering the total tensile forces resulting from casing buoyant weight, bending force, and shock loading.

Table 4.5 Tension load for example 3

Depth	Grade and Weight (lb/ft)	Weight in Air (1,000 lbs)	Cumulative Weight (1,000 lbs)
9,100 - 10,000	L-80, 47.0	42.30	42.30
1,750 - 9,100	C-75, 43.5	319.73	362.03
0 - 1,750	L-80, 47.0	82.25	444.28
Total weight in air		444.28	

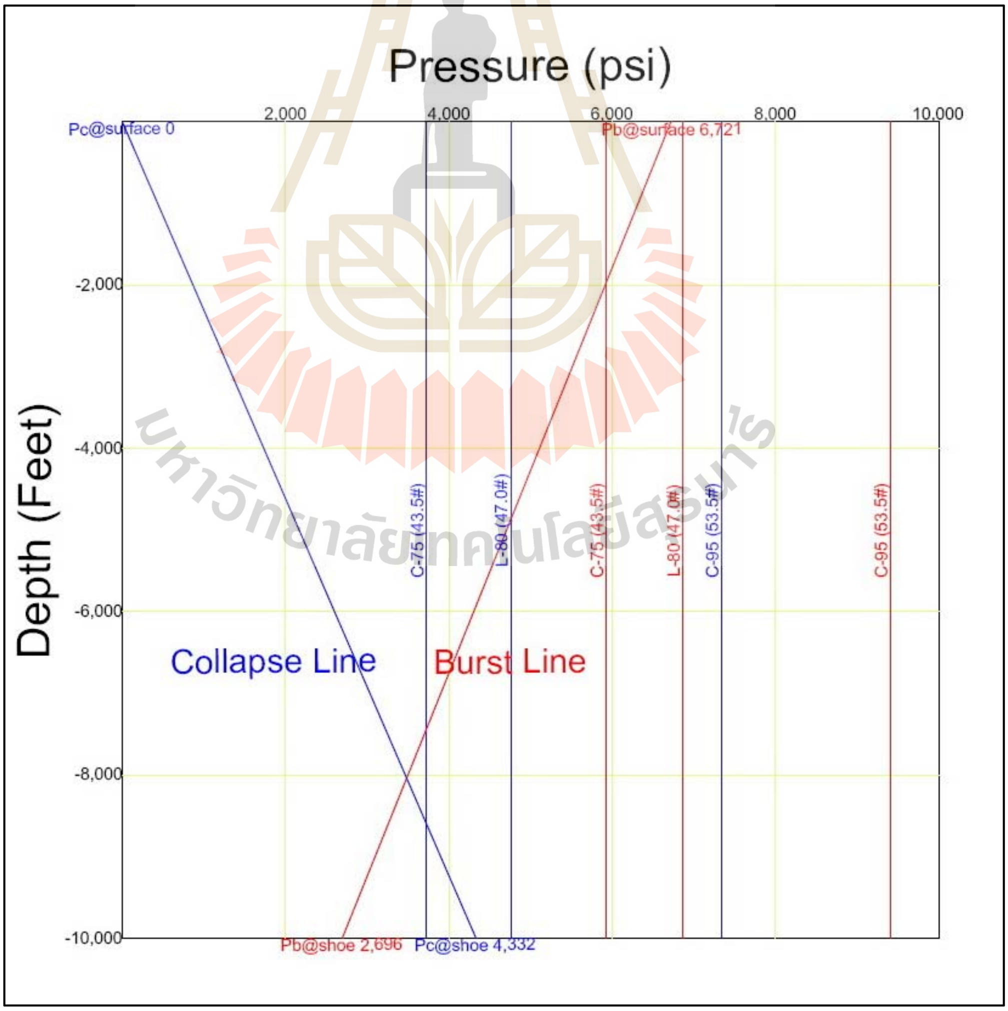

Figure 4.11 9- $^{5}/_{8}$ Casing design for Example 3

Table 4.6 Comparison of casing design between manual calculation and WPD software

		From Conventional Calculate (psi)	From WPD Software (psi)	Differentiated Percent
Example 1	P_c @ CSD	153.64	153.639	0.001
	p_f	2,906.25	2,906.250	0.000
	p_b @ surface	0.00	0.00	0.000
	p_b @ shoe	5.77	5.773	0.052
Example 2	P_c @ CSD	2,475.20	2,475.200	0.000
	p_f	5,000.00	5,000.000	0.000
	p_b @ surface	4,400.00	4,400.00	0.000
	p_b @ shoe	1,884.30	1,884.300	0.000
Example 3	P_c @ CSD	4,331.60	4,331.600	0.000
	p_f	7,410.00	7,410.000	0.000
	p_b @ surface	6,721.00	6,721.000	0.000
	p_b @ shoe	2,695.88	2,695.880	0.000
Average				0.004

Radius of curvature, maximum inclination angle, measured depth and horizontal departure at the end of build calculated from WPD software were compared to results from manual calculation as presented in example 4 through example 8 (examples were picked up from Mian, 1992). Comparison results are summarized and presented in Table 4.11 and it is also indicated that these results are reliable and can be compared to the manual calculation as well.

Therefore, this can be assured that the software algorithm is correct and effective.

Example 4: A well is to be drilled using the build-and-hold (Type J) trajectory. If the horizontal departure to the target at a TVD of 10,000 ft is 2,600 ft with the recommended angle rate of 2°/100 ft and the kickoff depth is at 1,500 ft.

Solution:

(a) The radius of curvature

Using Equations (2.27)

$$r_1 = \frac{180}{\pi}\left(\frac{1}{q}\right)$$

$$r_1 = \frac{180}{\pi}\left(\frac{1}{2/100}\right)$$

$$r_1 = 2{,}865 \text{ ft}$$

(b) The maximum inclination angle

Using Equations (2.28)

$$\theta = \sin^{-1}\left[\frac{r_1}{\sqrt{(r_1 - X_3)^2 + (D_3 - D_1)^2}}\right] - \tan^{-1}\left(\frac{r_1 - X_3}{D_3 - D_1}\right)$$

$$\theta = \sin^{-1}\left[\frac{2{,}865}{\sqrt{(2{,}865 - 2{,}600)^2 + (10{,}000 - 1{,}500)^2}}\right]$$

$$- \tan^{-1}\left(\frac{2{,}865 - 2{,}600}{10{,}000 - 1{,}500}\right)$$

$$\theta = \sin^{-1}(0.3369) - \tan^{-1}(0.0312)$$

$$\theta = 17.901°$$

(c) The measured depth and horizontal departure at the end of the build

Using Equations (2.30)

$$(D_{M_i})_{Build} = D_1 + \frac{\theta_i'}{q}$$

$$(D_{M_i})_{Build} = 1500 + \frac{17.9}{2/100}$$

$$(D_{M_i})_{Build} = 2{,}395 \text{ ft}$$

Using Equations (2.31)

$$(X_i)_{Build} = r_1(1 - \cos\theta_i')$$

$$(X_i)_{Build} = 2{,}865(1 - \cos 17.9)$$

$$(X_i)_{Build} = 138.68 \text{ ft}$$

(d) The measured depth and horizontal departure at 8,000 ft

Using Equations (2.33)

$$(D_{M_i})_{Hold} = D_1 + \frac{\theta}{q} + \frac{D_i - D_1 - r_1\sin\theta}{\cos\theta}$$

$$(D_{M_i})_{Hold} = 1{,}500 + \frac{17.9}{2/100} + \frac{8{,}000 - 1{,}500 - 2{,}865\sin 17.9}{\cos 17.9}$$

$$(D_{M_i})_{Hold} = 8{,}300.271 \text{ ft}$$

Using Equations (2.34)

$$(X_i)_{Hold} = r_1(1 - \cos\theta) + (D_i - D_1 - r_1\sin\theta)\tan\theta$$

$$(X_i)_{Hold} = 2{,}865(1 - \cos 17.9) + (8{,}000 - 1{,}500 - 2{,}865\sin 17.9)\tan 17.9$$

$$(X_i)_{Hold} = 1{,}953.706 \text{ ft}$$

Example 5: A well is to be drilled using the build-and-hold (Type J) trajectory. If the horizontal departure to the target at a TVD of 10,000 ft is 3,000 ft with the recommended angle rate of 2°/100 ft and the kickoff depth is at 1,500 ft.

Solution:

(a) The radius of curvature

Using Equations (2.27)

$$r_1 = \frac{180}{\pi}\left(\frac{1}{q}\right)$$

$$r_1 = \frac{180}{\pi}\left(\frac{1}{2/100}\right)$$

$$r_1 = 2{,}865 \text{ ft}$$

(b) The maximum inclination angle

Using Equations (2.29)

$$\theta = 180 - \tan^{-1}\left(\frac{D_3 - D_1}{X_3 - r_1}\right) - \cos^{-1}\left\{\left(\frac{r_1}{D_3 - D_1}\right) \times \sin\left[\tan^{-1}\left(\frac{D_3 - D_1}{X_3 - X_1}\right)\right]\right\}$$

$$\theta = 180 - \tan^{-1}\left(\frac{10{,}000 - 1{,}500}{3{,}000 - 2{,}865}\right)$$

$$- \cos^{-1}\left\{\left(\frac{2{,}865}{10{,}000 - 1{,}500}\right) \times \sin\left[\tan^{-1}\left(\frac{10{,}000 - 1{,}500}{3{,}000 - 0}\right)\right]\right\}$$

$$\theta = 19.439°$$

(c) The measured depth and horizontal departure at the end of the build

Using Equations (2.30)

$$(D_{M_i})_{Build} = D_1 + \frac{\theta_i'}{q}$$

$$(D_{M_i})_{Build} = 1500 + \frac{19.439}{2/100}$$

$$(D_{M_i})_{Build} = 2{,}471.95 \text{ ft}$$

Using Equations (2.31)

$$(X_i)_{Build} = r_1(1 - \cos\theta_i')$$

$$(X_i)_{Build} = 2,865(1 - \cos 19.439)$$

$$(X_i)_{Build} = 163.315 \text{ ft}$$

(d) the measured depth an horizontal departure at 8,000 ft

Using Equations (2.33)

$$(D_{M_i})_{Hold} = D_1 + \frac{\theta}{q} + \frac{D_i - D_1 - r_1\sin\theta}{\cos\theta}$$

$$(D_{M_i})_{Hold} = 1,500 + \frac{19.439}{2/100} + \frac{8,000 - 1,500 - 2,865\sin 19.439}{\cos 19.439}$$

$$(D_{M_i})_{Hold} = 8,353.753 \text{ ft}$$

Using Equations (2.34)

$$(X_i)_{Hold} = r_1(1 - \cos\theta) + (D_i - D_1 - r_1\sin\theta)\tan\theta$$

$$(X_i)_{Hold} = 2,865(1 - \cos 19.439)$$

$$+ (8,000 - 1,500 - 2,865\sin 19.439)\tan 19.439$$

$$(X_i)_{Hold} = 2,120.797 \text{ ft}$$

Example 6: A well is to be drilled using the build-hold-and-drop (Type S) trajectory. Calculate radius of curvature. Wellbore trajectories data are given in Table 4.7.

Table 4.7 Wellbore trajectories data for calculation in example 6

Variable	Distance
D_1	1,500 ft
D_4	8,000 ft
r_1	2,865 ft
r_2	2,865 ft
X_4	4,000 ft

Solution:

Using Equations (2.35)

$$\theta = \tan^{-1}\left(\frac{D_4 - D_1}{r_1 + r_2 - X_4}\right) - \cos^{-1}\left\{\left(\frac{r_1 + r_2}{D_4 + D_1}\right) \times \sin\left[\tan^{-1}\left(\frac{D_4 - D_1}{r_1 + r_2 - X_4}\right)\right]\right\}$$

$$\theta = \tan^{-1}\left(\frac{8,000 - 1,500}{2,865 + 2,865 - 4,000}\right)$$

$$- \cos^{-1}\left\{\left(\frac{2,865 + 2,865}{8,000 + 1,500}\right) \times \sin\left[\tan^{-1}\left(\frac{8,000 - 1,500}{2,865 + 2,865 - 4,000}\right)\right]\right\}$$

$$\theta = 43.513°$$

Example 7: A well is to be drilled using the build-hold-and-drop (Type S) trajectory. Calculate radius of curvature. Wellbore trajectories data are given in Table 4.8.

Table 4.8 Wellbore trajectories data for calculation in example 7

Variable	Distance
D_1	1,500 ft
D_4	8,000 ft
r_1	2,865 ft
r_2	2,865 ft
X_4	6,000 ft

Solution:

Using Equations (2.36)

$$\theta = 180 - \tan^{-1}\left[\frac{D_4 - D_1}{X_4 - (r_1 - r_2)}\right]$$

$$- \cos^{-1}\left\{\left(\frac{r_1 + r_2}{D_4 - D_1}\right) \times \sin\left[\tan^{-1}\left(\frac{D_4 - D_1}{X_4 - (r_1 - r_2)}\right)\right]\right\}$$

$$\theta = 180 - \tan^{-1}\left[\frac{8{,}000 - 1{,}500}{6{,}000 - (2{,}865 - 2{,}865)}\right]$$

$$- \cos^{-1}\left\{\left(\frac{2{,}865 + 2{,}865}{8{,}000 - 1{,}500}\right) \times \sin\left[\tan^{-1}\left(\frac{8{,}000 - 1{,}500}{6{,}000 - (2{,}865 - 2{,}865)}\right)\right]\right\}$$

$$\theta = 83.082°$$

Example 8: A well is to be drilled using the build-hold-partial drop-and-hold (Type modified S) trajectory. Calculate radius of curvature. Wellbore trajectories data are given in Table 4.9.

Table 4.9 Wellbore trajectories data for calculation in example 8

Variable	Distance
D_1	1,500 ft
D_5	6,500 ft
D_i	2,000 ft
r_1	2,865 ft
r_2	2,865 ft
X_5	8,000 ft

Solution:

Using Equations (2.32)

$$\theta_i' = \sin^{-1}\left(\frac{D_i}{D_1 + r_1}\right)$$

$$\theta_i' = \sin^{-1}\left(\frac{2,000}{1,500 + 2,865}\right)$$

$$\theta_i' = 27.27°$$

Using Equations (2.37)

$$X_4 = X_5 + r_2\left(1 - \cos\theta'\right)$$

$$X_4 = 8,000 + 2,865(1 - \cos 27.27)$$

$$X_4 = 8,318.424 \text{ ft}$$

Using Equations (2.38)

$D_4 = D_5 + r_2 \sin\theta'$

$D_4 = 6{,}500 + 2{,}865\sin 27.27$

$D_4 = 7{,}812.698$

Using Equations (2.36)

$$\theta = 180 - \tan^{-1}\left[\frac{D_4 - D_1}{X_4 - (r_1 - r_2)}\right]$$

$$- \cos^{-1}\left\{\left(\frac{r_1 + r_2}{D_4 - D_1}\right) \times \sin\left[\tan^{-1}\left(\frac{D_4 - D_1}{X_4 - (r_1 - r_2)}\right)\right]\right\}$$

$$\theta = 180 - \tan^{-1}\left[\frac{7{,}812.698 - 1{,}500}{8{,}318.424 - (2{,}865 - 2{,}865)}\right]$$

$$- \cos^{-1}\left\{\left(\frac{2{,}865 + 2{,}865}{7{,}812.698 - 1{,}500}\right) \times \sin\left[\tan^{-1}\left(\frac{7{,}812.698 - 1{,}500}{8{,}318 - (2{,}865 - 2{,}865)}\right)\right]\right\}$$

$\theta = 86.085°$

Example 9: A well is to be drilled using the build-hold-partial drop-and-hold (Type modified S) trajectory. Calculate radius of curvature. Wellbore trajectories data are given in Table 4.110.

Table 4.10 Wellbore trajectories data for calculation in example 9

Variable	Distance
D_1	1,500 ft
D_5	6,500 ft
D_i	2,000 ft
r_1	2,865 ft
r_2	2,865 ft
X_5	5,000 ft

Solution:

Using Equations (2.32)

$$\theta_i' = \sin^{-1}\left(\frac{D_i}{D_1 + r_1}\right)$$

$$\theta_i' = \sin^{-1}\left(\frac{2{,}000}{1{,}500 + 2{,}865}\right)$$

$$\theta_i' = 27.27°$$

Using Equations (2.37)

$$X_4 = X_5 + r_2\left(1 - \cos\theta'\right)$$

$$X_4 = 5{,}000 + 2{,}865(1 - \cos 27.27)$$

$$X_4 = 5{,}318.424 \text{ ft}$$

Using Equations (2.38)

$$D_4 = D_5 + r_2 \sin\theta'$$

$$D_4 = 6{,}500 + 2{,}865 \sin 27.27$$

$$D_4 = 7{,}812.698 \text{ ft}$$

Using Equations (2.35)

$$\theta = \tan^{-1}\left(\frac{D_4 - D_1}{r_1 + r_2 - X_4}\right) - \cos^{-1}\left\{\left(\frac{r_1 + r_2}{D_4 + D_1}\right) \times \sin\left[\tan^{-1}\left(\frac{D_4 - D_1}{r_1 + r_2 - X_4}\right)\right]\right\}$$

$$\theta = \tan^{-1}\left(\frac{7{,}812.698 - 1{,}500}{2{,}865 + 2{,}865 - 5{,}318.424}\right)$$

$$- \cos^{-1}\left\{\left(\frac{2{,}865 + 2{,}865}{7{,}812.698 - 1{,}500}\right) \times \sin\left[\tan^{-1}\left(\frac{7{,}812.698 - 1{,}500}{2{,}865 + 2{,}865 - 5{,}318.424}\right)\right]\right\}$$

$$\theta = 61.2°$$

Table 4.11 Comparison of wellbore trajectories design between manual calculation and WPD software

		From Conventional Calculate (psi)	**From WPD Software (psi)**	**Differentiated Percent**
Example 4	Radius of curvature (r_1)	2,864.79 ft	2,864.418 ft	0.013
	Inclination angle (θ)	17.90°	17.902°	0.011
	$(D_{mi})_{Build}$	2,395.00 ft	2395.100 ft	0.004
	$(X_i)_{Build}$	138.68 ft	138.685 ft	0.004
	$(D_{mi})_{Hold}$	8,300.27 ft	8,300.526 ft	0.003
	$(X_i)_{Hold}$	1,953.71 ft	1,953.953 ft	0.012
Example 5	Radius of curvature (r_1)	2,864.79 ft	2,864.418 ft	0.013
	Inclination angle (θ)	19.44°	19.442°	0.010
	$(D_{mi})_{Build}$	2,471.95 ft	2472.100 ft	0.006
	$(X_i)_{Build}$	163.32 ft	163.389 ft	0.042
	$(D_{mi})_{Hold}$	8,353.75 ft	8,353.753 ft	0.001
	$(X_i)_{Hold}$	2,120.80	2,121.160 ft	0.017
Example 6	Inclination angle (θ)	43.51°	43.513°	0.007
Example 7	Inclination angle (θ)	83.08°	83.082°	0.002
Example 8	Inclination angle (θ)	86.08°	86.085°	0.006
Example 9	Inclination angle (θ)	61.20°	61.30°	0.163
	Average			0.020

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

WPD software had been developed for casing design and selection, and wellbore trajectory design assistance. Therefore, WPD consists of two main modules: 1) casing design and casing selection module, and 2) wellbore trajectory design module. In casing design and casing selection module the collapse pressure, burst pressure, and tension load are calculated using conventional equations and displayed in form of graph which can be used for casing selection in the next step. In wellbore trajectory design module user can choose the trajectory path form the three standard trajectory templates as J, S, and modified S type. Result from the first module will be used as essential data, e.g. casing size and grade, in this step

To examine the efficiency and accuracy of WPD, results from WPD calculations were compared to the results from manual calculations. Comparison results indicated that results of WPD and manual calculation were not different. This can be assured that the WPD software can be used effectively with a satisfied accuracy. Moreover, this study also generated the API casing properties in from of digital database as presented in Appendix B.

Though this developed program may have some limitations and cannot compared to the commercial software in the market, WPD required only Microsoft Visual Basic and AutoCAD which are easily to find out and widely available in the market. Result from WPD calculation and design can be saved, printed out, and displayed in form of Microsoft Word file that user can be used and printed out easily.

5.2 Recommendations

This study has many limitations: 1) the unit of program is only in English – US unit, other units must be converted to this unit before using WPD, 2) the graphically results displayed in AutoCAD are limited only in two – dimensional (2D) that sometimes it is not convenient, and 3) data used in WPD calculation and design are only from a few text books, therefore, the results of calculations and design may be restricted.

For further development, this program needs some functions to convert the unit of required data or support other data unit. Three – dimensional (3D) display may need to add – in this program for more convenient to use. If available, actual raw data should be used with this program to examine the efficiency and the accuracy of it calculation. Some commercial database software in the market, e.g. Microsoft Access, should be used and add – in this program for more convenient in data management.

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APPENDIX A

PATAMETERS FOR COLLAPSE PRESSURE CALCULATION AND PROPERTIES OF CASING

Table A1. Empirical coefficients used for collapse-pressure calculation (after API Bulletin, 1989)

Grade	F_A	F_B	F_C	F_F	F_G
H-40	2.950	0.0465	754	2.063	0.0325
H-50	2.976	0.0515	1,056	2.003	0.0347
J-K 55 & D	2.991	0.0541	1,206	1.989	0.0360
J-K 60 & D	3.005	0.0566	1,356	1.983	0.0373
J-K 70 & D	3.037	0.0617	1,656	1.984	0.0403
C-75 & E	3.054	0.0642	1,806	1.990	0.0418
L-80 & N-80	3.071	0.0667	1,955	1.998	0.0131
C-90	3.106	0.0718	2,254	2.017	0.0466
C-95	3.124	0.0743	2,404	2.029	0.0482
C-100	3.143	0.0768	2,553	2.040	0.0499
P-105	3.162	0.0794	2,702	2.053	0.0515
P-110	3.181	0.0819	2,852	2.066	0.0532
P-120	3.219	0.0870	3,151	2.092	0.0565
P-125	3.239	0.0895	3,301	2.106	0.0582
P-130	3.258	0.0920	3,451	2.119	0.0599
P-135	3.278	0.0946	3,601	2.133	0.0615
P-140	3.297	0.0971	3,751	2.146	0.0632
P-150	3.336	0.1021	4,053	2.174	0.0666
P-155	3.356	0.1047	4,204	2.188	0.0683
P-160	3.375	0.1072	4,356	2.202	0.0700
P-170	3.412	0.1123	4,660	2.231	0.0734
P-180	3.449	0.1173	4,966	2.261	0.0769

Grade without letter are non-API Grades

Table A2. Range of d_e/t for various collapse-pressure regions when axial stress is zero (after API Bulletin, 1989)

Grade	Yield Strength Collapse ≤	Plastic Collapse	Transition Collapse	Elastic Collapse ≥
H-40	16.40	16.40 – 27.01	27.01 – 42.64	42.64
H-50	15.24	15.24 – 25.63	25.63 – 38.83	38.83
J-K 55 & D	14.81	14.81 – 25.01	25.01 – 37.21	37.21
J-K 60 & D	14.44	14.44 – 24.42	24.42 – 35.73	35.73
J-K 70 & D	13.85	13.85 – 23.38	23.38 – 33.17	33.17
C-75 & E	13.60	13.60 – 22.91	22.91 – 32.05	32.05
L-80 & N-80	13.38	13.38 – 22.47	22.47 – 31.02	31.02
C-90	13.01	13.01 – 21.69	21.69 – 29.18	29.18
C-95	12.85	12.85 – 21.33	21.33 – 28.36	28.36
C-100	12.70	12.70 – 21.00	21.00 – 27.60	27.60
P-105	12.57	12.57 – 20.70	20.70 – 26.89	26.89
P-110	12.44	12.44 – 20.41	20.41 – 26.22	26.22
P-120	12.21	12.21 – 19.88	19.88 – 25.01	25.01
P-125	12.11	12.11 – 19.63	19.63 – 24.46	24.46
P-130	12.02	12.02 – 19.40	19.40 – 23.94	23.94
P-135	11.92	11.92 – 19.18	19.18 – 23.44	23.44
P-140	11.84	11.84 – 18.97	18.97 – 22.98	22.98
P-150	11.67	11.67 – 18.57	18.57 – 22.11	22.11
P-155	11.59	11.59 – 18.37	18.37 – 21.70	21.70
P-160	11.52	11.52 – 18.19	18.19 – 21.32	21.32
P-170	11.37	11.37 – 17.82	17.82 – 20.60	20.60
P-180	11.23	11.23 – 17.47	17.47 – 19.93	19.93

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
4 ½	9.50	H-40	0.205	4.090	3.965	5.000				2,760	111
	9.50	J-55	0.205	4.090	3.965	5.000				3,310	152
	10.50	J-55	0.224	4.052	3.927	5.000	4.875			4,010	165
	11.60	J-55	0.250	4.000	3.875	5.000	4.875			4,960	184
	9.50	K-55	0.205	4.090	3.965	5.000				3,310	152
	10.50	K-55	0.224	4.052	3.927	5.000	4.875			4,010	165
	11.60	K-55	0.250	4.000	3.875	5.000	4.875			4,960	184
	11.60	C-75	0.250	4.000	3.875	5.000	4.875			6,100	250
	13.59	C-75	0.290	3.920	3.875	5.000	4.875			8,140	288
	11.60	L-80	0.250	4.000	3.875	5.000	4.875			6,350	267

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
3,190	3,190						77							
4,380	4,380						101							
4,790	4,790		4,790	4,790	4,790	4,790	132		203	203	203	203		
5,350	5,350	5,350	5,350	5,350	5,350	5,350	154	162	225	225	225	225		
4,380	4,380						112							
4,790	4,790		4,790	4,790	4,790	4,790	146		249	249	249	249		
5,350	5,350	5,350	5,350	5,350	5,350	5,350	170	180	277	277	277	277		
7,290		7,290		7,290				212	288		288			
8,460		8,460		7,490				257	331		320			
7,780		7,780	7,780	7,780	7,780	7,780		212	291		291			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
4 ½	13.50	L-80	0.290	3.920	3.795	5.000	4.875			8,540	307
	11.60	N-80	0.250	4.000	3.875	5.000	4.875			6,350	267
	13.50	N-80	0.290	3.920	3.795	5.000	4.875			8,540	307
	11.60	C-90	0.250	4.000	3.875	5.000	4.875			6,820	300
	13.50	C-90	0.290	3.920	3.795	5.000	4.875			9,300	345
	11.60	C-95	0.250	4.000	3.875	5.000	4.875			7,030	317
	13.50	C-95	0.290	3.920	3.795	5.000	4.875			9,660	364
*	11.60	HC-95	0.250	4.000	3.875	5.000	4.875			8,650	317
*	13.50	HC-95	0.290	3.920	3.795	5.000	4.875			10,380	364
*	15.10	HC-95	0.337	3.826	3.701	5.000	4.875			12,330	419

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
9,020		9,020	9,020	9,020	7,990	9,020		257	334		320			
7,780		7,780	7,780	7,780	7,780	7,780		223	304	304	304	304		
9,020		9,020	9,020	9,020	7,990	9,020		270	349	349	337	349		
8,750		8,750	8,750		8,750			223	309		309			
10,150		10,150	10,150		9,000			270	355		337			
9,240		9,240	9,240		9,240			234	325	325	325			
10,710		10,710	10,710		9,490			284	374	374	353			
9,240		9,240	9,240	9,240	9,240	9,240		245	338	338	338	338		
10,710		10,710	10,710	10,710	9,500	10,710		297	388	388	370	388		
12,450		12,450	11,630	12,450	9,500	11,000		357	446	446	370	421		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	11.60	P-110	0.250	4.000	3.875	5.000	4.875			7,580	367
	13.50	P-110	0.290	3.920	3.795	5.000	4.875			10,680	422
	15.10	P-110	0.337	3.826	3.701	5.000	4.875			14,350	485
	15.10	Q-125	0.337	3.826	3.701	5.000	4.875			15,840	551
*	16.60	Q-125	0.375	3.750	3.625	5.000	4.875			19,100	608
*	19.10	Q-125	0.437	3.626	3.501	5.000	4.875			21,290	697
*	15.10	V-150	0.337	3.826	3.701	5.000	4.875			18,110	661
*	16.60	V-150	0.375	3.750	3.625	5.000	4.875			22,330	729
*	19.10	V-150	0.437	3.626	3.501	5.000	4.875			26,300	837

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
Plain End or Extreme Line	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
10,690		10,690	10,690	10,690	10,690	10,690		279	385	385	385	385		
12,410		12,410	12,410	12,410	10,990	12,410		338	443	443	421	443		
14,420		14,420	13,460	14,420	10,990	13,910		406	509	509	421	509		
16,380		16,380	15,300		12,490			438	554					
18,230		16,650	15,300	18,230	12,490	14,980		496	579	911	454	539		
21,240		16,650	15,300	18,370	12,490	14,980		588	579	686	45	539		
19,660		19,660	18,360		14,980			519	658		539			
21,880		19,980	18,360		14,980			588	686		539			
25,490		19,980	18,360		14,980			697	686		539			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
5	11.50	J-55	0.220	4.560	4.435	5.563				3,060	182
	13.00	J-55	0.253	4.494	4.369	5.563	5.375			4,140	208
	15.00	J-55	0.296	4.408	4.283	5.563	5.375	4.151	5.360	5,560	241
	11.50	K-55	0.220	4.560	4.435	5.563				3,060	182
	13.00	K-55	0.253	4.494	4.369	5.563	5.375			4,140	208
	15.00	K-55	0.296	4.408	4.283	5.563	5.375	4.151	5.360	5,560	241
	15.00	C-75	0.296	4.408	4.283	5.563	5.375	4.151	5.360	6,940	328
	18.00	C-75	0.362	4.276	4.151	5.563	5.375	4.151	5.360	9,960	396
	21.40	C-75	0.437	4.126	4.001	5.563	5.375			11,970	470
	23.20	C-75	0.478	4.044	3.919	5.563	5.375			12,970	509

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
4,240	4,240						133							
4,870	4,870	4,870	4,870	4,870	4,870	4,870	169	182	252	252	252	252		
5,700	5,700	5,700	5,700	5,700	5,700	5,700	207	223	293	293	287	293	328	
4,240	4,240						147							
4,870	4,870	4,870	4,870	4,870	4,870	4,870	186	201	309	309	309	309		
5,700	5,700	5,700	5,700	5,700	5,130	5,700	228	246	359	359	359	359	416	
7,770		7,770	7,770		6,990			295	375		364		416	
9,500		9,500	9,290		6,990			376	452		364		416	
11,470		10,140	9,290		6,990			466	510		364			
12,550		10,140	9,290		7,000			513	510		364			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	24.10	C-75	0.500	4.000	3.875	5.563	5.375			13,500	530
	15.00	L-80	0.296	4.408	7.483	5.563	5.375	4.151	5.360	7,250	350
	18.00	L-80	0.362	4.276	4.151	5.563	5.375	4.151	5.360	10,500	422
	21.40	L-80	0.437	4.126	4.001	5.563	5.375			12,760	501
	23.20	L-80	0.478	4.044	3.919	5.563	5.375			13,830	543
	24.10	L-80	0.500	4.000	3.875	5.563	5.375			14,400	566
	15.00	N-80	0.296	4.408	4.283	5.563	5.375	4.151	5.360	7,250	350
	18.00	N-80	0.362	4.276	4.151	5.563	5.375	4.151	5.360	10,500	422
	21.40	N-80	0.437	4.126	4.001	5.563	5.375			12,760	501
	23.20	N-80	0.478	4.044	3.919	5.563	5.375			13,830	543

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
13,130		10,140	9,290		6,990			538	510		364			
8,290		8,290	8,290	8,290	7,460	8,290		295	379		364		416	
10,140		10,140	9,910	10,140	7,460	10,140		376	457		364		416	
12,240		10,810	9,910		7,460			466	510		364			
13,380		10,810	9,910		7,460			513	510		364			
14,000		10,810	9,910		7,460			538	510		364			
8,290		8,290	8,290	8,290	7,460	8,290		311	396	396	383	396	437	
10,140		10,140	9,910	10,140	7,460	10,140		396	477	477	383	477	469	
12,240		10,810	9,910	12,240	7,460	10,250		490	537	566	383	479		
13,380		10,810	9,910	13,380	7,460	10,250		540	537	614	383	479		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	24.10	N-80	0.500	4.000	3.875	5.563	5.375			14,400	566
	15.00	C-90	0.296	4.408	4.283	5.563	5.375	4.151	5.366	7,840	394
	18.00	C-90	0.362	4.276	4.151	5.563	5.375	4.151	5.366	11,530	475
	21.40	C-90	0.437	4.126	4.001	5.563	5.375			14,360	564
	23.20	C-90	0.478	4.044	3.919	5.563	5.375			15,560	611
	24.10	C-90	0.500	4.000	3.875	5.563	5.375			16,200	636
	15.00	C-95	0.296	4.408	4.283	5.563	5.375	4.151	5.360	8,110	416
	18.00	C-95	0.362	4.276	4.151	5.563	5.375	4.151	5.360	12,030	501
	21.40	C-95	0.437	4.126	4.001	5.563	5.375			15,160	595
	23.20	C-95	0.478	4.044	3.919	5.563	5.375			16,430	645

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread							
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
14,000		10,810	9,910	13,620	7,460	10,250		567	537	639	383	479		
9,320		9,320	9,320		8,400			311	404		383		430	
11,400		11,400	11,150		8,400			396	487		383		469	
13,770		12,170	11,150		8,400			490	537		383			
15,060		12,170	11,150		8,400			540	537		383			
15,750		12,170	11,150		8,400			567	537		383			
9,840		9,840	9,840		8,850			326	424		402		459	
12,040		12,040	11,770		8,850			416	512		402		493	
14,530		12,840	11,770		8,850			515	563		402			
15,890		12,850	11,770		8,860			567	563		402			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	24.10	C-95	0.500	4.000	3.875	5.563	5.375			17,100	672
*	15.00	HC-95	0.296	4.408	4.283	5.563	5.375			9,380	416
*	18.00	HC-95	0.362	4.276	4.151	5.563	5.375			11,880	501
*	23.20	HC-95	0.478	4.044	3.919	5.563	5.375			15,820	645
	15.00	P-110	0.296	4.408	4.283	5.563	5.375	4.151	5.360	8,850	481
	18.00	P-110	0.362	4.276	4.151	5.563	5.375	4.151	5.360	13,470	580
	21.40	P-110	0.437	4.126	4.001	5.563	5.375			17,550	689
	23.20	P-110	0.478	4.044	3.919	5.563	5.375			19,020	747
	24.10	P-110	0.500	4.000	3.875	5.563	5.375			19,800	778
	15.00	Q-125	0.296	4.408	4.283	5.563	5.375			9,480	547

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
16,630		12,850	11,770		8,850			595	563		402			
9,840		9,840	9,840	9,840	8,860	9,840		342	441	441	422	441		
12,040		12,040	11,770	12,040	8,860	10,260		436	532	532	422	479		
15,890		12,850	11,770	13,630	8,860	10,260		594	591	671	422	479		
11,400		11,400	11,400	11,400	10,250	11,400		388	503	503	479	503	547	
13,940		13,940	13,620	13,940	10,250	13,940		495	606	606	479	606	587	
16,820		14,870	13,620	16,820	10,250	13,980		613	671	720	479	613		
18,400		14,880	13,630	18,400	10,260	13,990		675	671	780	479	613		
19,250		14,880	13,620	18,580	10,250	13,980		708	671	812	479	613		
12,950		12,950	12,950					420	548					

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	18.00	Q-125	0.362	4.276	4.151	5.563	5.375			14,830	659
	23.20	Q-125	0.478	4.044	3.919	5.563	5.375			21,620	849
	24.10	Q-125	0.500	4.000	3.875	5.563				22,500	884
*	15.00	V-150	0.296	4.408	4.283	5.563	5.375			10,250	656
*	18.00	V-150	0.362	4.276	4.151	5.563	5.375			16,860	791
*	23.20	V-150	0.478	4.044	3.919	5.563	5.375			25,940	1,019
5 1/2	14.00	H-40	0.244	5.012	4.887	6.050				2,620	161
	14.00	J-55	0.244	5.012	4.887	6.050				3,120	222
	15.50	J-55	0.275	4.950	4.825	6.050	5.875	4.653	5.860	4,040	248
	17.00	J-55	0.304	4.892	4.767	6.050	5.875	4.653	5.860	4,910	273

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
15,840		15,840	15,490					535	661					
20,910		16,000	15,490					729	725					
21,880		16,000	15,490					765	725					
15,540		15,540	15,540		13,990			497	651		613			
19,100		16,000	18,590		13,990			634	785		613			
25,090		16,000	18,590		13,990			864	859		613			
3,110	3,110						130							
4,270	4,270						172							
4,810	4,810	4,810	4,810	4,810	4,730	4,810	202	217	300	300	300	300	339	339
5,320	5,320	5,320	5,320	5,320	4,730	5,320	229	247	329	329	318	329	372	372

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	14.00	K-55	0.244	5.012	4.887	6.050				3,120	222
	15.50	K-55	0.275	4.950	4.825	6.050	5.875	4.653	5.860	4,040	248
	17.00	K-55	0.304	4.892	4.767	6.050	5.875	4.653	5.860	4,910	273
	17.00	C-75	0.304	4.892	4.767	6.050	5.875	4.653	5.860	6,040	372
	20.00	C-75	0.361	4.778	4.653	6.050	5.875	4.653	5.860	8,410	437
	23.00	C-75	0.415	4.670	4.545	6.050	5.875	4.545	5.860	10,470	497
	17.00	L-80	0.304	4.892	4.767	6.050	5.875	4.653	5.860	6,280	397
	20.00	L-80	0.361	4.778	4.653	6.050	5.875	4.653	5.860	8,830	466
	23.00	L-80	0.415	4.670	4.545	6.050	5.875	4.545	5.860	11,160	530
	17.00	N-80	0.304	4.892	4.767	6.050	5.875	4.653	5.860	6,280	397

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
4,270	4,270						189							
4,810	4,810	4,810	4,810	4,810	4,730	4,810	222	239	366	366	366	366	429	429
5,320	5,320	5,320	5,320	5,320	4,730	5,320	252	272	402	402	402	402	471	471
7,250		7,250	7,250		6,450			327	423		403		471	471
8,610		8,610	8,430		6,450			403	497		403		497	479
9,900		9,260	8,430		6,450			473	550		403		549	479
7,740		7,740	7,740	7,740	6,880	7,740		338	428		403		471	471
9,190		9,190	8,990	9,190	6,880	9,190		416	503		403		497	479
10,560		9,880	8,990	10,560	6,880	9,460		489	550		403		549	479
7,740		7,740	7,740	7,740	6,880	7,740		348	446	446	424	446	496	496

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	20.00	N-80	0.361	4.778	4.653	6.050	5.875	4.653	5.860	8,830	466
	23.00	N-80	0.415	4.670	4.545	6.050	5.875	4.545	5.860	11,160	530
	17.00	C-90	0.304	4.892	4.767	6.050	5.875	4.653	5.860	6,740	447
	20.00	C-90	0.361	4.778	4.653	6.050	5.875	4.653	5.860	9,630	525
	23.00	C-90	0.415	4.670	4.545	6.050	5.875	4.545	5.860	12,380	597
	26.00	C-90	0.476	4.548	4.423	6.050	5.875			14,240	676
	35.00	C-90	0.650	4.200	4.075	6.050	5.875			18,760	891
	17.00	C-95	0.304	4.892	4.767	6.050	5.875	4.653	5.860	6,940	471
	20.00	C-95	0.361	4.778	4.653	6.050	5.875	4.653	5.860	10,010	554
	23.00	C-95	0.415	4.670	4.545	6.050	5.875	4.545	5.860	12,940	630

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread		Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long					Standard Joint	Optional Joint
9,190		9,190	8,990	9,190	6,880	9,190		428	524	524	424	524	523	504
10,560		9,880	8,990	10,560	6,880	9,460		502	579	596	424	530	577	504
8,710		8,710	8,710		7,740			356	456		424		496	496
10,340		10,340	10,120		7,740			438	536		424		523	504
11,880		11,110	10,120		7,740			514	580		424		577	504
13,630		11,110	10,120		7,740			598	580		424			
18,610		11,110	10,120		7,740			614	580		424			
9,190		9,190	9,190		8,170			374	480		445		521	521
10,910		10,910	10,680		8,170			460	563		445		549	530
12,540		11,730	10,680		8,170			540	608		445		606	530

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	17.00	HC-95	0.304	4.892	4.767	6.050	5.875			8,580	471
*	20.00	HC-95	0.361	4.778	4.653	6.050	5.875			10,630	554
*	23.00	HC-95	0.415	4.670	4.545	6.050	5.875			12,450	630
	17.00	P-110	0.304	4.892	4.767	6.050	5.875	4.653	5.860	7,480	546
	20.00	P-110	0.361	4.778	4.653	6.050	5.875	4.653	5.860	11,100	641
	23.00	P-110	0.415	4.670	4.545	6.050	5.875	4.545	5.860	14,540	729
*	17.00	Q-125	0.304	4.892	4.767	6.050	5.875			7,890	620
*	20.00	Q-125	0.360	4.778	4.653	6.050	5.875			12,080	729
	23.00	Q-125	0.415	4.670	4.545	6.050	5.875			16,070	829
*	26.80	Q-125	0.500	4.500	4.375	6.050	5.875			20,660	982

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread Short	Round Thread Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Round Thread Short	Round Thread Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
9,190		9,190	9,190	9,190	8,170	9,190		392	498	498	466	498		
10,910		10,910	10,680	10,910	8,170	9,460		482	585	585	466	530		
12,540		11,730	10,680	12,370	8,170	9,460		566	638	665	466	530		
10,640		10,640	10,640	10,640	9,460	10,640		445	568	568	530	568	620	620
12,640		12,640	12,360	12,640	9,460	11,880		548	667	667	530	667	654	630
14,520		13,160	12,360	14,520	9,460	11,880		643	724	759	530	668	722	630
12,090		12,090	12,090	12,090	10,770	12,090		481	620	620	573	620		
14,360		14,360	14,360	14,070	10,770	12,920		592	728	728	573	679		
16,510		16,510	15,210	14,070	10,770	12,920		694	783	828	573	679		
19,890		19,890	15,210	14,070	10,770	12,920		842	783	928	573	679		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	20.00	V-150	0.361	4.778	4.653	6.050	5.875			13,460	874
*	23.00	V-150	0.415	4.670	4.545	6.050	5.875			18,390	995
*	26.80	V-150	0.500	4.500	4.375	6.050	5.875			24,790	1,178
6 5/8	20.00	H-40	0.288	6.049	5.924	7.390				2,520	229
	20.00	J-55	0.288	6.049	5.924	7.390	7.000			2,970	315
	24.00	J-55	0.352	5.921	5.796	7.390	7.000	5.730	7.000	4,560	382
	20.00	K-55	0.288	6.049	5.924	7.390	7.000			2,970	315
	24.00	K-55	0.352	5.921	5.796	7.390	7.000	5.730	7.000	4,560	382
	24.00	C-75	0.352	5.921	5.796	7.390	7.000	5.730	7.000	5,550	520
	28.00	C-75	0.417	5.791	5.666	7.390	7.000	5.666	7.000	7,790	610

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
17,230		17,230	16,880		12,920			701	865		678			
19,810		18,250	16,880		12,920			823	928		678			
23,860		18,250	16,880		12,920			998	928		678			
3,040	3,040						184							
4,180	4,180	4,180	4,180	4,180	4,060	4,180	245	266	374	374	374	374		
5,110	5,110	5,110	5,110	5,110	4,060	5,110	314	340	453	453	390	453	477	477
4,180	4,180	4,180	4,180	4,180	4,060	4,180	267	290	453	453	453	453		
5,110	5,110	5,110	5,110	5,110	4,060	5,110	342	372	548	548	494	520	605	605
6,970		6,970	6,970		5,540			453	583		494		605	605
8,263		8,263	8,263		5,540			552	683		494		648	644

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	32.00	C-75	0.475	5.675	5.550	7.390	7.000	5.550	7.000	9,800	688
	24.00	L-80	0.352	5.921	5.796	7.390	7.000	5.730	7.000	5,760	555
	28.00	L-80	0.417	5.791	5.666	7.390	7.000	5.666	7.000	8,170	651
	32.00	L-80	0.475	5.675	5.550	7.390	7.000	5.550	7.000	10,320	734
	24.00	N-80	0.352	5.921	5.796	7.390	7.000	5.730	7.000	5,760	555
	28.00	N-80	0.417	5.791	5.666	7.390	7.000	5.666	7.000	8,170	651
	32.00	N-80	0.475	5.675	5.550	7.390	7.000	5.550	7.000	10,320	734
	24.00	C-90	0.352	5.921	5.796	7.390	7.000	5.730	7.000	6,140	624
	28.00	C-90	0.417	5.791	5.666	7.390	7.000	5.666	7.000	8,880	732
	32.00	C-90	0.475	5.675	5.550	7.390	7.000	5.550	7.000	11,330	826

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread		Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long					Standard Joint	Optional Joint
9,410		9,410	9,200		5,540			638	771		494		717	644
7,440		7,440	7,440		5,910			473	592		494		605	605
8,810		8,810	8,810		5,910			576	693		494		648	644
10,040		10,040	9,820		5,910			666	783		494		717	644
7,440		7,440	7,440	7,440	5,910	7,440		481	615	615	520	615	637	637
8,810		8,810	8,810	8,810	5,910	8,120		586	721	721	520	650	682	678
10,040		10,040	9,820	10,040	9,910	8,120		677	814	814	520	650	755	678
8,370		8,370	8,370		6,650			520	633		520		637	637
9,910		9,910	9,910		6,650			633	742		520		682	678
11,290		11,290	11,050		6,650			732	837		520		755	678

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	24.00	C-95	0.352	5.921	5.796	7.390	7.000	5.730	7.000	6,310	659
	28.00	C-95	0.417	5.791	5.666	7.390	7.000	5.666	7.000	9,220	773
	32.00	C-95	0.475	5.675	5.550	7.390	7.000	5.550	7.000	11,810	872
	24.00	P-110	0.352	5.921	5.796	7.390	7.000	5.730	7.000	6,730	763
	28.00	P-110	0.417	5.791	5.666	7.390	7.000	5.666	7.000	10,160	895
	32.00	P-110	0.475	5.675	5.550	7.390	7.000	5.550	7.000	13,220	1,009
*	24.00	Q-125	0.352	5.921	5.796	7.390	7.000			7,020	867
*	28.00	Q-125	0.417	5.791	5.666	7.390	7.000			10,990	1,017
*	32.00	Q-125	0.475	5.675	5.550	7.390	7.000			14,530	1,147
*	24.00	V-150	0.350	5.921	5.796	7.390	7.000			7,340	1,041

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread Short	Round Thread Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Round Thread Short	Round Thread Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
8,830		8,830	8,830		7,020			546	665		546		668	668
10,460		10,460	10,460		7,020			665	780		546		716	712
11,920		11,830	11,660		7,020			769	880		546		793	712
10,230		10,230	10,230	10,230	8,120	8,310		641	786	786	650	786	796	796
12,120		11,830	12,120	12,120	8,120	8,310		781	992	992	650	832	852	848
13,800		11,830	13,500	13,800	8,120	8,310		904	1,040	1,040	650	832	944	848
11,620		11,620	11,620		8,310			702	860		702			
13,770		11,830	13,770		8,310			855	1,008		702			
15,680		11,830	14,780		8,310			989	1,138					
13,950		11,830	13,950		8,310			831	1,023		832			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	28.00	V-150	0.417	5.791	5.666	7.390	7.000			12,120	1,220
*	32.00	V-150	0.475	5.675	5.550	7.390	7.000			16,500	1,317
7	17.00	H-40	0.231	6.538	6.413	7.656				1,420	196
	20.00	H-40	0.272	6.456	6.331	7.656				1,970	230
	20.00	J-55	0.272	6.456	6.331	7.656				2,270	316
	23.00	J-55	0.317	6.366	6.241	7.656	7.375	6.151	7.390	3,270	366
	26.00	J-55	0.362	6.276	6.151	7.656	7.375	6.151	7.390	4,320	415
	20.00	K-55	0.272	6.456	6.331	7.656				2,270	316
	23.00	K-55	0.317	6.366	6.241	7.656	7.375	6.151	7.390	3,270	366
	26.00	K-55	0.362	6.276	6.151	7.656	7.375	6.151	7.390	4,320	415

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
Plain End or Extreme Line	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
16,520		11,830	14,780		8,310			1,013	1,199		832			
18,820		11,830	14,780		8,310			1,172	1,353		832			
2,310	2,310						122							
2,720	2,720						176							
3,740	3,740						234							
4,360	4,360	4,360	4,360	4,360	3,950	4,360	284	313	432	432	421	432	499	499
4,980	4,980	4,980	4,980	4,980	3,950	4,980	334	367	490	490	421	490	506	506
3,740	3,740						254							
4,360	4,360	4,360	4,360	4,360	3,950	4,360	309	341	522	522	522	522	632	632
4,980	4,980	4,980	4,980	4,980	3,950	4,980	364	401	592	592	533	561	641	641

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	23.00	C-75	0.317	6.366	6.241	7.656	7.375	6.151	7.390	3,750	499
	26.00	C-75	0.362	6.276	6.151	7.656	7.375	6.151	7.390	5,220	566
	29.00	C-75	0.408	6.184	6.059	7.656	7.375	6.059	7.390	6,730	634
	32.00	C-75	0.453	6.094	5.969	7.656	7.375	5.969	7.390	8,200	699
	35.00	C-75	0.498	6.004	5.879	7.656	7.375	5.879	7.530	9,670	763
	38.00	C-75	0.540	5.920	5.795	7.656	7.375	5.795	7.530	10,680	822
	23.00	L-80	0.317	6.366	6.241	7.656	7.375	6.151	7.390	3,830	532
	26.00	L-80	0.362	6.276	6.151	7.656	7.375	6.151	7.390	5,410	604
	29.00	L-80	0.408	6.184	6.059	7.656	7.375	6.059	7.390	7,020	676
	32.00	L-80	0.453	6.094	5.969	7.656	7.375	5.969	7.390	8,610	745

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
5,940		5,940	5,940		5,380			416	557		533		632	632
6,790		6,790	6,790		5,380			489	631		533		641	641
7,650		7,650	7,650		5,380			562	707		533		685	674
8,490		8,490	7,930		5,380			633	779		533		761	674
9,340		8,660	7,930		5,380			703	833		533		850	761
10,120		8,660	7,930		5,380			767	833		533		917	761
6,340		6,340	6,340	6,340	5,740	6,340		435	565		533		632	632
7,240		7,240	7,240	7,240	5,740	7,240		511	641		533		641	641
8,160		8,160	8,160	8,160	5,740	7,890		587	718		533		685	674
9,060		9,060	8,460	9,060	5,740	7,890		661	791		533		761	674

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	35.00	L-80	0.498	6.004	5.879	7.656	7.375	5.879	7.530	10,180	814
	38.00	L-80	0.540	5.920	5.795	7.656	7.375	5.795	7.530	11,390	877
	23.00	N-80	0.317	6.366	6.241	7.656	7.375	6.151	7.390	3,830	532
	26.00	N-80	0.362	6.276	6.151	7.656	7.375	6.151	7.390	5,410	604
	29.00	N-80	0.408	6.184	6.059	7.656	7.375	6.059	7.390	7,020	676
	32.00	N-80	0.453	6.094	5.969	7.656	7.375	5.969	7.390	8,610	745
	35.00	N-80	0.498	6.004	5.879	7.656	7.375	5.879	7.530	10,180	814
	38.00	N-80	0.540	5.920	5.795	7.656	7.375	5.795	7.530	11,390	877
	23.00	C-90	0.317	6.366	6.241	7.656	7.375	6.151	7.390	4,030	599
	26.00	C-90	0.362	6.276	6.151	7.656	7.375	6.151	7.390	5,740	679

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread		Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long						
9,060		9,240	8,460	9,060	5,740	7,890		734	833		533		850	761
10,800		9,240	8,460	10,800	5,740	7,890		801	833		533		917	761
6,340		6,340	6,340	6,340	5,740	6,340		442	588	588	561	588	666	666
7,240		7,240	7,240	7,240	5,740	7,240		519	667	667	561	667	675	675
8,160		8,160	8,160	8,160	5,740	7,890		597	746	746	561	702	721	709
9,060		9,060	8,460	9,060	5,740	7,890		672	823	823	561	702	801	709
9,960		9,240	8,460	9,060	5,740	7,890		746	876	898	561	702	895	801
10,800		9,240	8,460	10,800	5,740	7,890		814	876	968	561	702	965	801
7,130		7,130	7,130		6,450			447	605		561		666	666
8,150		8,150	8,150		6,450			563	687		561		575	675

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	29.00	C-90	0.408	6.184	6.059	7.656	7.375	6.059	7.390	7,580	760
	32.00	C-90	0.453	6.094	5.969	7.656	7.375	5.969	7.390	9,380	839
	35.00	C-90	0.498	6.004	5.879	7.656	7.375	5.879	7.530	11,170	915
	38.00	C-90	0.540	5.920	5.795	7.656	7.375	5.795	7.530	12,820	986
	23.00	C-95	0.317	6.366	6.241	7.656	7.375	6.151	7.390	4,140	632
	26.00	C-95	0.362	6.276	6.151	7.656	7.375	6.151	7.390	5,880	717
	29.00	C-95	0.408	6.184	6.059	7.656	7.375	6.059	7.390	7,830	803
	32.00	C-95	0.453	6.094	5.969	7.656	7.375	5.969	7.390	9,750	885
	35.00	C-95	0.498	6.004	5.879	7.656	7.375	5.879	7.530	11,650	966
	38.00	C-95	0.540	5.920	5.795	7.656	7.375	5.795	7.530	13,440	1,041

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
			Buttress Thread				Threaded and Coupled							
									Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread Short	Round Thread Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Round Thread Short	Round Thread Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
9,180		9,180	9,180		6,450			648	768		561		721	709
10,190		9,520	9,520		6,450			729	847		561		801	709
11,210		9,520	9,520		6,450			809	876		561		895	801
12,150		9,520	9,520		6,450			883	876		561		965	801
7,530		7,530	7,530		6,810			505	636		589		699	699
8,600		8,600	8,600		6,810			593	722		589		709	709
9,690		9,520	9,690		6,810			683	808		589		757	744
10,760		9,520	10,050		6,810			768	891		589		841	744
11,830		9,520	10,050		6,810			853	920		589		940	841
12,820		9,520	10,050		6,810			931	920		589		1,013	841

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	23.00	HC-95	0.317	6.366	6.241	7.656	7.375			5,650	632
*	26.00	HC-95	0.362	6.276	6.151	7.656	7.375			7,800	717
*	29.00	HC-95	0.408	6.184	6.059	7.656	7.375			9,200	803
*	32.00	HC-95	0.453	6.094	5.969	7.656	7.375			10,400	885
*	35.00	HC-95	0.498	6.004	5.879	7.656	7.375			11,600	966
*	38.00	HC-95	0.540	5.920	5.795	7.656	7.375			12,700	1,041
	26.00	P-110	0.362	6.276	6.151	7.656	7.375	6.151	7.390	6,230	830
	29.00	P-110	0.408	6.184	6.059	7.656	7.375	6.059	7.390	8,530	929
	32.00	P-110	0.453	6.094	5.969	7.656	7.375	5.969	7.390	10,780	1,025
	35.00	P-110	0.498	6.004	5.879	7.656	7.375	5.879	7.530	13,020	1,119

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
7,530		7,530	7,530	7,530	6,810	7,480		512	659	659	617	659		
8,600		8,600	8,600	8,600	6,810	7,480		602	747	747	617	701		
9,690		9,520	9,690	9,690	6,810	7,480		692	836	836	617	701		
10,760		9,520	10,050	10,760	6,810	7,480		779	922	922	617	701		
11,830		9,520	10,050	11,630	6,810	7,480		865	964	1,007	617	701		
12,830		9,520	10,050	11,630	6,810	7,480		944	964	1,085	617	701		
9,960		9,520	9,960	9,960	7,480	7,480		693	853	853	702	853	844	844
11,220		9,520	11,220	11,220	7,480	7,480		797	955	955	702	898	902	886
12,460		9,520	11,640	11,790	7,480	7,480		897	1,053	1,053	702	898	1,002	886
13,700		9,520	11,640	11,790	7,480	7,480		996	1,096	1,150	702	898	1,118	1,002

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	38.00	P-110	0.540	5.920	5.795	7.656	7.375	5.795	7.530	15,140	1,205
*	29.00	Q-125	0.408	6.184	6.059	7.656	7.375			9,100	1,056
*	32.00	Q-125	0.453	6.094	5.969	7.656	7.375			11,720	1,165
	35.00	Q-125	0.498	6.004	5.879	7.656	7.375			14,310	1,272
	38.00	Q-125	0.540	5.920	5.795	7.656	7.375			16,750	1,370
*	42.70	Q-125	0.625	5.750	5.625	7.656	7.375			20,330	1,565
*	29.00	V-150	0.408	6.184	6.059	7.656	7.375			9,790	1,267
*	32.00	V-150	0.453	6.094	5.969	7.656	7.375			13,020	1,388
*	35.00	V-150	0.498	6.004	5.879	7.656	7.375			16,220	1,526
*	38.00	V-150	0.540	5.920	5.795	7.656	7.375			19,240	1,644

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
14,850		9,520	11,640	11,790	7,480	7,480		1,087	1,096	1,239	702	898	1,207	1,002
12,750		9,520	11,790		7,480			885	1,045		757			
14,160		9,520	11,790		7,480			996	1,183		757			
15,560		9,520	11,790		7,480			1,106	1,183		757			
16,880		9,520	11,790		7,480				1,207	1,183		757		
19,530		9,520	11,790		7,480			1,277	1,183		757			
15,300		9,520	11,790		7,480			1,049	1,243		898			
16,990		9,520	11,790		7,480			1,180	1,402		898			
18,680		9,520	11,790		7,480			1,310	1,402		898			
20,250		9,520	11,790		7,480			1,430	1,402		898			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	42.70	V-150	0.625	5.750	5.625	7.656	7.375			24,390	1,878
7 5/8	24.00	H-40	0.300	7.025	6.900	8.500				2,030	276
	26.40	J-55	0.328	6.969	6.844	8.500	8.125	6.750	8.010	2,890	414
	26.40	K-55	0.328	6.969	6.844	8.500	8.125	6.750	8.010	2,890	414
	26.40	C-75	3.280	6.969	6.844	8.500	8.125	6.750	8.010	3,280	564
	29.70	C-75	0.375	6.875	6.750	8.500	8.125	6.750	8.010	4,650	641
	33.70	C-75	0.430	6.765	6.640	8.500	8.125	6.640	8.010	6,300	729
	39.00	C-75	0.500	6.625	6.500	8.500	8.125	6.500	8.010	8,400	839
	42.80	C-75	0.562	6.501	6.376	8.500	8.125			10,240	935
	45.30	C-75	0.595	6.435	6.310	8.500	8.125			10,790	986

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
23,440		9,520	11,790		7,480			1,514	1,402		898			
2,750	2,750						212							
4,140	4,140	4,140	4,140	4,140	4,140	4,140	315	346	483	483	483	483	553	553
4,140	4,140	4,140	4,140	4,140	4,140	4,140	342	377	581	58	581	581	700	700
5,650		5,650	5,650		5,650			461	624		624		700	700
6,450		6,450	6,450		6,140			542	709		709		700	700
7,400		7,400	7,400		6,140			635	806		735		766	744
8,610		8,610	8,610		6,140			751	929		735		851	744
9,670		9,670	9,190		6,140			852	1,035		735			
10,240		9,840	9,180		6,140			905	1,090		764			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	47.10	C-75	0.625	6.375	6.250	8.500	8.125			11,290	1,031
	26.40	L-80	0.328	6.969	6.844	8.500	8.125	6.750	8.010	3,400	602
	29.70	L-80	0.375	6.875	6.750	8.500	8.125	6.750	8.010	4,790	683
	33.70	L-80	0.430	6.765	6.640	8.500	8.125	6.640	8.010	6,560	778
	39.00	L-80	0.500	6.625	6.500	8.500	8.125	6.500	8.010	8,820	895
	42.80	L-80	0.562	6.501	6.376	8.500	8.125			10,810	998
	45.30	L-80	0.595	6.435	6.310	8.500	8.125			1,151	1,051
	47.10	L-80	0.625	6.375	6.250	8.500	8.125			12,040	1,100
	26.40	N-80	0.328	6.969	6.844	8.500	8.125	6.750	8.010	3,400	602
	29.70	N-80	0.375	6.875	6.750	8.500	8.125	6.750	8.010	4,790	683

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
10,760		9,840	9,190		6,140			953	1,140		735			
6,020		6,020	6,020	6,020	6,020	6,020		482	635		635		700	700
6,890		6,890	6,890	6,890	6,550	6,890		566	721		721		700	700
7,900		7,900	7,900	7,900	6,550	7,900		664	820		735		766	744
9,180		9,180	9,180	9,180	6,550	9,000		786	745		735		851	744
10,320		10,320	9,790		6,550			892	1,053		735			
10,920		10,500	9,790		6,550			947	1,109		764			
11,480		10,490	9,790		6,550			997	1,160		735			
6,020		6,020	6,020	6,020	6,020	6,020		490	659	659	659	659	737	737
6,890		6,890	6,890	6,890	6,550	6,890		575	749	749	749	749	737	737

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	33.70	N-80	0.430	6.765	6.640	8.500	8.125	6.640	8.010	6,560	778
	39.00	N-80	0.500	6.625	6.500	8.500	8.125	6.500	8.010	8,820	895
	42.80	N-80	0.562	6.501	6.376	8.500	8.125			10,810	998
	45.30	N-80	0.595	6.435	6.310	8.500	8.125			11,510	1,051
	47.10	N-80	0.625	6.375	6.250	8.500	8.125			12,040	1,100
	26.40	C-90	0.328	6.969	6.844	8.500	8.125	6.750	8.010	3,610	677
	29.70	C-90	0.375	6.875	6.750	8.500	8.125	6.750	8.010	5,040	769
	33.70	C-90	0.430	6.765	6.640	8.500	8.125	6.640	8.010	7,050	875
	39.00	C-90	0.500	6.625	6.500	8.500	8.125	6.500	8.010	9,620	1,007
	42.80	C-90	0.562	6.501	6.376	8.500	8.125			11,890	1,122

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
7,900		7,900	7,900	7,900	6,550	7,900		674	852	852	773	852	806	784
9,180		9,180	9,180	9,180	6,550	9,000		798	981	981	773	967	896	784
10,320		10,320	9,790	10,320	6,550	9,000		905	1,093	1,093	773	967		
10,920		10,500	9,790	10,920	6,550	8,030		962	1,152	1,152	804	1,005		
11,480		10,490	9,790	11,480	6,550			1,013	1,205	1,204	773	967		
6,780		6,780	6,780		6,780			532	681		681		737	737
7,750		7,750	7,750		7,370			625	773		773		737	737
8,880		8,880	8,880		7,370			733	880		804		806	784
10,330		10,330	10,330		7,370			867	1,013		804		896	784
11,610		11,610	11,020		7,370			984	1,129		804			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	45.30	C-90	0.595	6.435	6.310	8.500	8.125			12,950	1,183
	47.10	C-90	0.625	6.375	6.250	8.500	8.125			13,540	1,273
	26.40	C-95	0.328	6.969	6.844	8.500	8.125	6.750	8.010	3,710	714
	29.70	C-95	0.375	6.875	6.750	8.500	8.125	6.750	8.010	5,140	811
	33.70	C-95	0.430	6.765	6.640	8.500	8.125	6.640	8.010	7,280	923
	39.00	C-95	0.500	6.625	6.500	8.500	8.125	6.500	8.010	10,000	1,063
	42.80	C-95	0.562	6.501	6.376	8.500	8.125			12,410	1,185
	45.30	C-95	0.595	6.435	6.310	8.500	8.125			13,660	1,248
	47.10	C-95	0.625	6.375	6.250	8.500	8.125			14,300	1,306
*	26.40	HC-95	0.328	6.969	6.844	8.500	8.125			4,850	714

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
12,290		11,800	11,020		7,370			1,045	1,189		804			
12,910		11,800	11,020		7,370			1,100	1,239		804			
7,150		7,150	7,150		7,150			560	716		716		774	774
8,180		8,180	8,180		7,780			659	813		812		774	774
9,380		9,380	9,380		7,780			772	925		812		846	823
10,900		10,900	10,900		7,780			914	1,065		812		941	823
12,250		11,800	11,620		7,780			1,037	1,187		812			
12,970		11,800	11,630		7,780			1,101	1,251		854			
13,630		11,800	11,620		7,780			1,159	1,300		812			
7,150		7,150	7,150	7,150	7,150	7,150		568	740	740	740	740		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
*	29.70	HC-95	0.375	6.875	6.750	8.500	8.125			7,150	811
*	33.70	HC-95	0.430	6.765	6.640	8.500	8.125			8,800	923
*	39.00	HC-95	0.500	6.625	6.500	8.500	8.125			10,600	1,063
*	45.30	HC-95	0.595	6.435	6.310	8.500	8.125			12,900	1,248
	29.70	P-110	0.375	6.875	6.750	8.500	8.125	6.750	8.010	5,350	940
	33.70	P-110	0.430	6.765	6.640	8.500	8.125	6.640	8.010	7,870	1,069
	39.00	P-110	0.500	6.625	6.500	8.500	8.125	6.500	8.010	11,080	1,231
	42.80	P-110	0.562	6.501	6.376	8.500	8.125			13,920	1,372
	45.30	P-110	0.595	6.435	6.310	8.500	8.125			15,430	1,446
	47.10	P-110	0.625	6.375	6.250	8.500	8.125			16,550	1,512

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread		Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long					Standard Joint	Optional Joint
8,180		8,180	8,180	8,180	7,780	8,030		668	841	841	814	814		
9,380		9,380	9,380	9,380	7,780	8,030		783	957	957	885	957		
10,900		10,900	10,900	10,900	7,780	8,030		926	1,101	1,101	885	1,005		
12,970		11,800	11,630	12,680	7,780	8,030		1,116	1,293	1,293	885	1,005		
9,470		9,470	9,470	9,470	9,000	9,470		769	960	960	960	960	922	922
10,860		10,860	10,860	10,860	9,000	10,860		901	1,093	1,093	967	1,093	1,008	979
12,620		11,800	12,620	12,620	8,030	8,030		1,066	1,258	1,258	967	1,237	1,120	979
14,190		11,800	12,680	12,680	8,030	8,030		1,210	1,402	1,402	967	1,237		
15,020		11,800	12,680	12,680	8,030	8,030		1,285	1,477	1,477	1,005	1,287		
15,780		11,800	12,680	12,680	8,030	8,030		1,353	1,545	1,545	967	1,237		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			**Extreme Line**			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
*	29.70	Q-125	0.375	6.875	6.750	8.500	8.125			5,670	1,068
*	33.70	Q-125	0.430	6.765	6.640	8.500	8.125			8,350	1,215
	39.00	Q-125	0.500	6.625	6.500	8.500	8.125			12,060	1,399
	42.80	Q-125	0.562	6.501	6.376	8.500	8.125			15,350	1,559
	45.30	Q-125	0.595	6.435	6.310	8.500	8.125			17,090	1,643
	47.10	Q-125	0.625	6.375	6.250	8.500				18,700	1,718
*	29.70	V-150	0.375	6.875	6.750	8.500	8.125			6,060	1,282
*	33.70	V-150	0.430	6.765	6.640	8.500	8.125			8,850	1,458
*	39.00	V-150	0.500	6.625	6.500	8.500	8.125			13,440	1,679
*	45.30	V-150	0.595	6.435	6.310	8.500	8.125			19,660	1,971

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread							
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
10,760		10,760	10,760		8,030			861	1,052		1,052			
12,340		11,800	12,340		8,030			1,009	1,197		1,086			
14,340		11,800	12,680		8,030			1,194	1,379		1,086			
16,120		11,800	12,680					1,355	1,536					
17,070		11,800	12,680		8,030			1,439	1,619		1,086			
17,930		11,800	12,680					1,515	1,673					
12,910		11,800	12,680		8,030			1,030	1,252		1,252			
17,800		11,800	12,680		8,030			1,207	1,424		1,287			
17,210		11,800	12,680		8,030			1,428	1,640		1,287			
20,480		11,800	12,680		8,030			1,721	1,926		1,287			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
8 5/8	28.00	H-40	0.304	8.017	7.892	9.625				1,610	318
	32.00	H-40	0.352	7.921	7.796	9.625				2,200	366
	24.00	J-55	0.264	8.097	7.972	9.625				1,370	381
	32.00	J-55	0.352	7.921	7.796	9.625	9.125	7.700	9.120	2,530	503
	36.00	J-55	0.400	7.825	7.700	9.625	9.125	7.700	9.120	3,450	568
	24.00	K-55	0.264	8.097	7.972	9.625				1,370	381
	32.00	K-55	0.352	7.921	7.796	9.625	9.125	7.700	9.120	2,530	503
	36.00	K-55	0.400	7.825	7.700	9.625	9.125	7.700	9.120	3,450	568
	36.00	C-75	0.400	7.825	7.700	9.625	9.125	7.700	9.120	4,000	755
	40.00	C-75	0.450	7.725	7.600	9.625	9.125	7.600	9.120	5,330	867

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
2,470	2,470						233							
2,860	2,860						279							
2,950	2,950						244							
3,930	3,930	3,930	3,930	3,930	3,930	3,930	372	417	579	579	579	579	686	686
4,460	4,460	4,460	4,460	4,460	4,460	4,460	434	486	654	654	654	654	688	688
2,950	2,950						263							
3,930	3,930	3,930	3,930	3,930	3,930	3,930	402	452	690	690	690	690	869	869
4,460	4,460	4,460	4,460	4,460	4,460	4,460	468	526	780	780	780	780	871	871
6,090		6,090	6,090		5,530			648	847		839		871	871
6,850		6,850	6,850		5,530			742	947		839		942	886

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	44.00	C-75	0.500	7.625	7.500	9.625	9.125	7.500	9.120	6,660	957
	49.00	C-75	0.557	7.511	7.386	9.625	9.125	7.386	9.120	8,180	1,059
	36.00	L-80	0.400	7.825	7.700	9.625	9.125	7.700	9.120	4,100	827
	40.00	L-80	0.450	7.725	7.600	9.625	9.125	7.600	9.120	5,520	925
	44.00	L-80	0.500	7.625	7.500	9.625	9.125	7.500	9.120	6,950	1,021
	49.00	L-80	0.557	7.511	7.386	9.625	9.125	7.386	9.120	8,580	1,129
	36.00	N-80	0.400	7.825	7.770	9.625	9.125	7.700	9.120	4,100	827
	40.00	N-80	0.450	7.725	7.600	9.625	9.125	7.600	9.120	5,520	925
	44.00	N-80	0.500	7.625	7.500	9.625	9.125	7.500	9.120	6,950	1,021
	49.00	N-80	0.557	7.511	7.386	9.625	9.125	7.386	9.120	8,580	1,129

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
7,610		7,610	7,610		5,530			834	1,046		839		1,007	886
8,480		8,480	8,480		5,530			939	1,157		839		1,007	886
6,490		6,490	6,490	6,490	5,900	6,490		678	864		839		871	871
7,300		7,300	7,300	7,300	5,900	7,300		776	966		839		942	886
8,120		8,120	8,120	8,120	5,900	8,110		874	1,066		839		1,007	886
9,040		9,040	9,040	9,040	5,900	8,110		983	1,180		839		1,007	886
6,490		6,490	6,490	6,490	5,900	6,340		688	895	895	883	895	917	917
7,300		7,300	7,300	7,300	5,900	6,340		788	1,001	1,001	883	1,001	992	932
8,120		8,120	8,120	8,120	5,900	6,340		887	1,105	1,105	883	1,103	1,060	932
9,040		9,040	9,040	9,040	5,900	6,340		997	1,222	1,222	883	1,103	1,060	932

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled						
								Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	36.00	C-90	0.400	7.825	7.700	9.625	9.125	7.700	9.120	4,250	930
	40.00	C-90	0.450	7.725	7.600	9.625	9.125	7.600	9.120	5,870	1,040
	44.00	C-90	0.500	7.625	7.500	9.625	9.125	7.500	9.120	7,490	1,149
	49.00	C-90	0.557	7.511	7.386	9.625	9.125	7.386	9.120	9,340	1,271
	36.00	C-95	0.400	7.825	7.700	9.625	9.125	7.700	9.120	4,350	982
	40.00	C-95	0.450	7.725	7.600	9.625	9.125	7.600	9.120	6,020	1,098
	44.00	C-95	0.500	7.625	7.500	9.625	9.125	7.500	9.120	7,740	1,212
	49.00	C-95	0.557	7.511	7.386	9.625	9.125	7.386	9.120	9,710	1,341
*	36.00	HC-95	0.400	7.825	7.700	9.625	9.125			6,060	982
*	40.00	HC-95	0.450	7.725	7.600	9.625	9.125			7,900	1,098

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength (1,000 lbf)**							
Internal Pressure Resistance † (psi)							**Threaded and Coupled**							
			Buttress Thread						**Buttress Thread**					
			Regular Coupling		**Special Clearance Coupling**								**Extreme Line**	
Plain End or Extreme Line	**Round Thread**						**Round Thread**		**Regular Coupling**	**Regular Coupling Higher Grade[1]**	**Special Clearance Coupling**	**Special Clearance Coupling Higher Grade[1]**		
	Short	**Long**	**Same Grade**	**Higher Grade**	**Same Grade**	**Higher Grade**	**Short**	**Long**					**Standard Joint**	**Optional Joint**
7,300		7,300	7,300					749	928		883		917	917
8,220		8,220	8,220		6,340			858	1,038		883		992	992
9,130		9,130	9,130		6,340			965	1,146		883		1,060	932
10,170		10,170	10,170		6,340			1,085	1,268		883		1,060	932
7,710		7,710	7,710		6,340			789	976		927		963	963
8,670		8,670	8,670		6,340			904	1,092		927		1,042	979
9,640		9,640	9,640		6,340			1,017	1,206		927		1,113	979
10,740		10,380	10,740		6,340			1,114	1,334		927		1,113	979
7,710		7,710	7,710	7,710	6,340	6,340		800	1,008	1,008	971	1,008		
8,670		8,670	8,670	8,670	6,340	6,340		916	1,127	1,127	971	1,104		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	44.00	HC-95	0.500	7.625	7.500	9.625	9.125			9,100	1,212
*	49.00	HC-95	0.557	7.511	7.386	9.625	9.125			10,400	1,341
	40.00	P-110	0.450	7.725	7.600	9.625	9.125	7.600	9.120	6,390	1,271
	44.00	P-110	0.500	7.625	7.500	9.625	9.125	7.500	9.120	8,420	1,404
	49.00	P-110	0.557	7.511	7.386	9.625	9.125	7.386	9.120	10,740	1,553
*	40.00	Q-125	0.450	7.725	7.600	9.625	9.125			6,630	1,445
*	44.00	Q-125	0.500	7.625	7.500	9.625	9.125			8,980	1,595
	49.00	Q-125	0.557	7.511	7.386	9.625	9.125			11,660	1,765
*	44.00	V-150	0.500	7.625	7.500	9.625	9.125			9,640	1,914
*	49.00	V-150	0.557	7.511	7.386	9.625	9.125			12,950	2,118

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
Plain End or Extreme Line	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread		Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Extreme Line	
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long					Standard Joint	Optional Joint
9,640		9,640	9,640	9,640	6,340	6,340		1,030	1,244	1,244	971	1,104		
10,740		10,380	10,740	10,740	6,340	6,340		1,159	1,377	1,377	971	1,104		
10,040		10,040	10,040	10,040	6,340	6,340		1,055	1,288	1,288	1,103	1,288	1,240	1,165
11,160		10,380	11,160	11,160	6,340	6,340		1,186	1,423	1,423	1,103	1,412	1,326	1,165
12,430		10,380	11,230	11,230	6,340	6,340		1,335	1,574	1,574	1,103	1,412	1,326	1,165
11,410		10,380	11,230		6,340			1,182	1,415		1,192			
12,680		10,380	11,230		6,340			1,330	1,562		1,192			
14,130		10,380	11,230		6,340			1,496	1,728					
15,220		10,380	11,230		6,340			1,591	1,859		1,413			
16,950		10,380	11,230		6,340			1,789	2,056		1,413			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
9 5/8	32.30	H-40	0.312	9.001	8.845	10.625				1,370	365
	36.00	H-40	0.352	8.921	8.765	10.625				1,720	410
	36.00	J-55	0.352	8.921	8.765	10.625	10.125			2,020	564
	40.00	J-55	0.395	8.835	8.679	10.625	10.125	8.599	10.100	2,570	630
	36.00	K-55	0.352	8.921	8.765	10.625	10.125			2,020	564
	40.00	K-55	0.395	8.835	8.679	10.625	10.125	8.599	10.100	2,570	630
	40.00	C-75	0.395	8.835	8.679	10.625	10.125	8.599	10.100	2,990	859
	43.50	C-75	0.435	8.755	8.599	10.625	10.125	8.599	10.100	3,730	942
	47.00	C-75	0.472	8.681	8.525	10.625	10.125	8.525	10.100	4,610	1,018
	53.50	C-75	0.545	8.535	8.379	10.625	10.125	8.379	10.100	6,350	1,166

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
2,270	2,270						254							
2,560	2,560						294							
3,520	3,520	3,520	3,520	3,520	3,520	3,520	394	453	639	639	639	639		
3,950	3,950	3,950	3,950	3,950	3,660	3,950	452	520	714	714	714	714	770	770
3,520	3,520	3,520	3,520	3,520	3,520	3,520	423	489	755	755	755	755		
3,950	3,950	3,950	3,950	3,950	3,660	3,950	486	561	843	843	843	843	975	975
5,390		5,390	5,390		4,990			694	926		926		975	975
5,930		5,930	5,930		4,990			776	1,016		934		975	975
6,440		6,440	6,440		4,990			852	1,098		934		1,032	1,032
7,430		7,430	7,430		4,990			999	1,257		934		1,173	1,053

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	40.00	L-80	0.395	8.835	8.679	10.625	10.125	8.599	10.100	3,090	916
	43.50	L-80	0.435	8.755	8.599	10.625	10.125	8.599	10.100	3,810	1,005
	47.00	L-80	0.472	8.681	8.525	10.625	10.125	8.525	10.100	4,760	1,086
	53.50	L-80	0.545	8.535	8.379	10.625	10.125	8.379	10.100	6,620	1,244
	40.00	N-80	0.395	8.835	8.679	10.625	10.125	8.599	10.100	3,090	916
	43.50	N-80	0.435	8.755	8.599	10.625	10.125	8.599	10.100	3,810	1,005
	47.00	N-80	0.472	8.681	8.525	10.625	10.125	8.525	10.100	4,760	1,086
	53.50	N-80	0.545	8.535	8.379	10.625	10.125	8.379	10.100	6,620	1,244
	40.00	C-90	0.395	8.835	8.679	10.625	10.125	8.599	10.100	3,250	1,031
	43.50	C-90	0.435	8.755	8.599	10.625	10.125	8.599	10.100	4,010	1,130

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
Plain End or Extreme Line	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
5,750		5,750	5,750		5,140			727	947		934		975	975
6,330		6,330	6,330		5,140			813	1,038		934		975	975
6,870		6,870	6,870		5,140			893	1,122		934		1,032	1,032
7,930		7,930	7,930		5,140			1,047	1,286		934		1,173	1,053
5,750		5,750	5,750	5,750	5,140	5,140		737	979	979	979	979	1,027	1,027
6,330		6,330	6,330	6,330	5,140	5,140		825	1,074	1,074	983		1,027	1,027
6,870		6,870	6,870	6,870	5,140	5,140		905	1,161	1,161	983		1,027	1,027
7,930		7,930	7,930	7,930	5,140	5,140		1,062	1,329	1,329	983		1,027	1,027
6,460		6,460	6,460		5,140			804	1,021		983		1,086	1,085
7,120		7,130	7,130		5,140			899	1,119		983		1,235	1,109

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			**Extreme Line**			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	47.00	C-90	0.472	8.611	8.525	10.625	10.125	8.525	10.100	5,000	1,221
	53.50	C-90	0.545	8.535	8.379	10.625	10.125	8.379	10.100	7,120	1,399
	40.00	C-95	0.395	8.835	8.679	10.625	10.125	8.599	10.100	3,320	1,088
	43.50	C-95	0.435	8.755	8.599	10.625	10.125	8.599	10.100	4,120	1,193
	47.00	C-95	0.472	8.681	8.525	10.625	10.125	8.525	10.100	5,090	1,289
	53.50	C-95	0.545	8.535	8.379	10.625	10.125	8.379	10.100	7,340	1,477
*	40.00	HC-95	0.395	8.835	8.679	10.625	10.125			4,230	1,088
*	43.50	HC-95	0.435	8.755	8.599	10.625	10.125			5,600	1,193
*	47.00	HC-95	0.472	8.681	8.525	10.625	10.125			7,100	1,289
*	53.50	HC-95	0.545	8.535	8.379	10.625	10.125			8,850	1,477

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
Plain End or Extreme Line	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
7,720		7,720	7,720		5,140			987	1,210		983		1,027	1,027
8,920		8,460	8,920		5,140			1,157	1,386		983		1,027	1,027
6,820		6,820	6,820		5,140			847	1,074		1,032		1,086	1,086
7,510		7,510	7,510		5,140			948	1,178		1,032		1,235	1,109
8,150		8,150	8,150		5,140			1,040	1,273		1,032		1,078	1,078
9,410		8,460	8,460		5,140			1,220	1,458		1,032		1,078	1,078
6,820		6,820	6,820	6,280	5,140	5,140		858	1,106	1,106	1,082	1,106	1,141	1,141
7,510		7,510	7,510	7,510	5,140	5,140		959	1,213	1,213	1,082	1,213	1,297	1,164
8,150		8,150	8,150	8,150	5,140	5,140		1,053	1,311	1,311	1,082	1,229		
9,410		8,460	9,160	9,160	5,140	5,140		1,235	1,502	1,502	1,082	1,229		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
*	58.40	HC-95	0.595	8.435	8.279	10.625	10.125			9,950	1,604
*	61.10	HC-95	0.625	8.375	8.219	10.625	10.125			10,500	1,679
	43.50	P-110	0.435	8.755	8.599	10.625	10.125	8.599	10.100	4,420	1,381
	47.00	P-110	0.472	8.681	8.525	10.625	10.125	8.525	10.100	5,300	1,493
	53.50	P-110	0.545	8.535	8.379	10.625	10.125	8.379	10.100	7,950	1,710
	47.00	Q-125	0.472	8.681	8.525	10.625				5,640	1,697
	53.50	Q-125	0.545	8.535	8.379	10.625				8,440	1,943
*	58.40	Q-125	0.595	8.435	8.279	10.625	10.125			10,530	2,110
*	61.10	Q-125	0.625	8.375	8.219	10.625	10.125			11,800	2,209
*	53.50	V-150	0.545	8.535	8.379	10.625	10.125			8,960	2,332

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
10,280		8,460	9,160	9,160	5,140	5,140		1,357	1,631	1,631	1,082	1,229		
10,800		8,460	9,160	9,160	5,140	5,140		1,430	1,707	1,707	1,082	1,229		
8,700		8,700	8,700	8,700	5,140	5,140		1,106	1,388	1,388	1,229	1,388	1,283	1,283
9,440		9,440	9,160	9,160	5,140	5,140		1,213	1,500	1,500	1,229	1,500	1,358	1,358
10,900		9,670	9,160	9,160	5,140	5,140		1,422	1,718	1,718	1,229	1,573	1,544	1,386
10,730		9,670	9,160		5,140			1,361	1,650					
12,390		9,670	9,160		5,140			1,595	1,890					
13,520		9,670	9,160		5,140			1,754	2,052		1,328			
14,200		9,670	9,160		5,140			1,848	2,149		1,328			
12,390		9,670	9,160		5,140			1,595	2,251		1,574			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	58.40	V-150	0.595	8.435	8.279	10.625	10.125			11,560	7,532
*	61.10	V-150	0.625	8.375	8.219	10.625	10.125			13,120	2,651
*	70.30	V-150	0.734	8.157	8.001	10.625	10.125			18,800	3,075
10 3/4	32.75	H-40	0.279	10.192	10.036	11.750				840	367
	40.50	H-40	0.350	10.050	9.894	11.750				1,390	457
	40.50	J-55	0.350	10.050	9.894	11.750	11.250			1,580	629
	45.50	J-55	0.400	9.950	9.794	11.750	11.250	9.794	11.460	2,090	715
	51.00	J-55	0.450	9.850	9.694	11.750	11.250	9.694	11.460	2,700	801
	40.50	K-55	0.350	10.050	9.894	11.750	11.250			1,580	629
	45.50	K-55	0.400	9.950	9.794	11.750	11.250	9.794	11.430	2,090	715

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
Plain End or Extreme Line	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
13,520		9,670	9,160		5,140			1,754	2,444		1,574			
14,200		9,670	9,160		5,140			1,848	2,559		1,574			
16,680		9,670	9,160		5,140			2,185	2,812		1,574			
1,820	1,820						205							
2,280	2,280						314							
3,130	3,130		3,130	3,130	3,130	3,130	420		700	700	700	700		
3,580	3,580		3,580	3,580	3,290	3,580	493		796	796	796	796	975	
4,030	4,030		4,030	4,030	3,290	4,030	565		891	891	822	891	1,092	
3,130	3,130		3,130	3,130	3,130	3,130	450		819	819	819	819		
3,580	3,580		3,580	3,580	3,290	3,580	518		931	931	931	931	1,236	

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	51.00	K-55	0.450	9.850	9.694	11.750	11.250	9.694	11.460	2,700	801
	51.00	C-75	0.450	9.850	9.694	11.750	11.250	9.694	11.460	3,110	1,092
	55.50	C-75	0.495	9.760	9.604	11.750	11.250	9.694	11.460	3,920	1,196
	51.00	L-80	0.450	9.850	9.694	11.750	11.250	9.694	11.460	3,220	1,165
	55.50	L-80	0.495	9.760	9.604	11.750	11.250	9.694	11.460	4,020	1,276
	51.00	N-80	0.450	9.850	9.694	11.750	11.250	9.694	11.460	3,220	1,165
	55.50	N-80	0.495	9.760	9.604	11.750	11.250	9.694	11.460	4,020	1,276
	51.00	C-90	0.450	9.850	9.694	11.750	11.250	9.694	11.460	3,400	1,310
	55.50	C-90	0.495	9.760	9.604	11.750	11.250	9.694	11.460	4,160	1,435
	51.00	C-95	0.450	9.850	9.694	11.750	11.250	9.694	11.460	3,480	1,383

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
4,030	4,030		4,030	4,030	3,290	4,030	606		1,043	1,043	1,041	1,043	1,383	
5,490	5,490		5,490		4,150		756		1,160		1,041		13,830	
6,040	6,040		6,040		4,150		843		1,271		1,041		1,151	
5,860	5,860		5,860		4,150		794		1,190		1,041		1,383	
6,450	6,450		6,450		4,150		884		1,303		1,041		1,515	
5,860	5,860		5,860	5,860	4,150	4,150	804		1,288	1,228	1,096	1,228	1,456	
6,450	6,450		6,450	6,450	4,150	4,150	895		1,345	1,345	1,096	1,345	1,595	
6,590	6,590		6,590		4,150		692		1,287		1,112		1,456	
7,250	6,880		7,250		4,150		771		1,409		1,112		1,595	
6,960	6,880		6,960		4,150		927		1,354		1,151		1,529	

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	55.50	C-95	0.495	9.760	9.604	11.750	11.250	9.604	11.460	4,290	1,515
*	51.00	HC-95	0.450	9.850	9.694	11.750	11.250			4,460	1,383
*	55.50	HC-95	0.495	9.760	9.604	11.750	11.250			5,950	1,515
*	60.70	HC-95	0.545	9.660	9.504	11.750	11.250			7,550	1,660
*	65.70	HC-95	0.595	9.560	9.404	11.750	11.250			8,640	1,830
*	71.10	HC-95	0.650	9.450	9.294	11.750	11.250			9,600	1,959
	51.00	P-110	0.450	9.850	9.694	11.750	11.250	9.694	11.460	3,660	1,602
	55.50	P-110	0.495	9.760	9.604	11.750	11.250	9.604	11.460	4,610	1,754
	60.70	P-110	0.545	7.660	9.504	11.750	11.250	9.504	11.460	5,880	1,922
	65.70	P-110	0.595	9.560	9.404	11.750	11.250			7,500	2,088

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
7,660	6,880		7,450		4,150		1,032		1,483		1,151		1,675	
6,960	6,880		6,960	6,960	4,150	4,150	737		1,392	1,392	1,223	1,389		
7,660	6,880		7,450	7,450	4,150	4,150	821		1,524	1,524	1,223	1,389		
8,430	6,880		7,450	7,450	4,150	4,150	914		1,670	1,670	1,223	1,389		
9,200	6,880		7,450	7,450	4,150	4,150	1,005		1,814	1,814	1,223	1,389		
10,050	6,880		7,450	7,450	4,150	4,150	1,105		1,971	1,971	1,223	1,389		
8,060	7,860		7,450	7,450	4,150	4,150	1,080		1,594	1,594	1,370	1,594	1,820	
8,860	7,860		7,450	7,450	4,150	4,150	1,203		1,745	1,745	1,370	1,745	1,993	
9,760	7,860		7,450	7,450	4,150	4,150	1,338		1,912	1,912	1,370	1,754	2,000	
10,650	7,860		7,450	7,450	4,150	4,150	1,472		2,077	2,077	1,370	1,754		

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	55.50	Q-125	0.495	9.760	9.604	11.750	11.250			4,850	1,993
	60.70	Q-125	0.545	9.660	9.504	11.750	11.250			6,070	2,184
	65.70	Q-125	0.595	9.560	9.404	11.750	11.250			7,920	2,373
*	71.10	Q-125	0.650	9.450	9.294	11.750	11.250			9,990	2,573
*	73.20	Q-125	0.672	9.406	9.250	11.750	11.250			10,810	2,660
*	79.20	Q-125	0.734	9.282	9.126	11.750	11.250			13,150	2,887
	60.70	V-150	0.545	9.660	9.504	11.750	11.250			6,550	2,621
*	65.70	V-150	0.595	9.560	9.404	11.750	11.250			8,320	2,847
*	71.10	V-150	0.650	9.450	9.294	11.750	11.250			10,880	3,094
*	73.20	V-150	0.672	9.406	9.250	11.750	11.250			11,900	3,191

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
10,070	7,860		7,450		4,150		1,351		1,925		1,501			
11,090	7,860		7,450				1,503		2,109		1,501			
12,110	7,860		7,450				1,653		2,291		1,501			
13,230	7,860		7,450		4,150		1,817		2,489		1,501			
13,670	7,860		7,450		4,150		1,882		2,568		1,501			
14,940	7,860		7,450		4,150		2,063		2,639		1,501			
13,310	7,860		7,450		4,150		1,798		2,513		1,779			
14,530	7,860		7,450		4,150		1,918		2,730		1,779			
15,870	7,860		7,450		4,150		2,174		2,966		1,779			
16,410	7,860		7,450		4,150		2,252		3,060		1,779			

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
*	79.20	V-150	0.734	9.282	9.126	11.750	11.250			14,790	3,464
11 3/4	42.00	H-40	0.333	11.084	10.928	12.750				1,070	478
	47.00	J-55	0.375	11.000	10.844	12.750				1,510	737
	54.00	J-55	0.435	10.880	10.724	12.750				2,070	850
	60.00	J-55	0.489	10.772	10.616	12.750				2,660	952
	47.00	K-55	0.375	11.000	10.844	12.750				1,510	737
	54.00	K-55	0.435	10.880	10.724	12.750				2,070	850
	60.00	K-55	0.489	10.772	10.616	12.750				2,660	952
	60.00	C-75	0.489	10.772	10.616	12.750				3,070	1,298
	60.00	L-80	0.489	10.772	10.616	12.750				3,180	1,384

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
17,290	7,860		7,450		4,150		2,469		3,127		1,779			
1,980	1,980						307							
3,070	3,070		3,070	3,070			477		807	807				
3,560	3,560		3,560	3,560			568		931	931				
4,010	4,010		4,010	4,010			649		1,042	1,042				
3,070	3,070		3,070	3,070			509		935	935				
3,560	3,560		3,560	3,560			606		1,079	1,079				
4,010	4,010		4,010	4,010			693		1,208	1,208				
5,460	5,460		5,460				869		1,361					
5,830	5,820		5,830				913		1,399					

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	60.00	N-80	0.489	10.772	10.616	12.750				3,180	1,384
	60.00	C-90	0.489	10.772	10.616	12.750				3,360	1,557
	60.00	C-95	0.489	10.772	10.616	12.750				3,440	1,644
*	60.00	HC-95	0.489	10.772	10.616	12.750				4,410	1,644
	60.00	P-110	0.489	10.772	10.616	12.750				3,610	1,903
	60.00	Q-125	0.489	10.772	10.616	12.750				3,680	2,162
*	66.70	Q-125	0.547	10.656	10.500	12.750				4,980	2,407
*	66.70	V-150	0.547	10.656	10.500	12.750				5,200	2,888
13 3/8	48.00	H-40	0.330	12.715	12.559	14.375				740	541
	54.00	J-55	0.380	12.615	12.459	14.375				1,130	853

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
5,830	5,820		5,830				924		1,440	1,440				
6,550	5,820		6,300				1,011		1,517					
6,920	5,820		6,300				1,066		1,596					
6,920	5,820		6,300				1,078		1,638					
8,010	5,820		6,300	6,300			1,242		1,877	1,877				
9,100	6,650		6,300				1,395		2,074					
10,180	6,650		6,300				1,582		2,308					
12,220	6,650		6,300				1,893		2,752					
1,730	1,730						322							
2,730	2,730		2,730	2,730			514		909	909				

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	61.00	J-55	0.430	12.515	12.359	14.375				1,540	962
	68.00	J-55	0.480	12.415	12.259	14.375				1,950	1,069
	54.50	K-55	0.380	12.615	12.459	14.375				1,130	853
	61.00	K-55	0.430	12.515	12.359	14.375				1,640	962
	68.00	K-55	0.480	12.415	12.259	14.375				1,950	1,069
	68.00	C-75	0.480	12.415	12.259	14.375				2,220	1,458
	72.00	C-75	0.514	12.347	12.191	14.375				2,600	1,558
	68.00	L-80	0.480	12.347	12.259	14.375				2,260	1,556
	72.00	L-80	0.514	12.347	12.191	14.375				2,670	1,661
	68.00	N-80	0.480	12.415	12.259	14.375				2,260	1,556

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread Short	Round Thread Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Round Thread Short	Round Thread Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
3,090	3,090		3,090	3,090			595		1,025	1,025				
3,450	3,450		3,450	3,450			675		1,140	1,140				
2,730	2,730		2,730	2,730			547		1,038	1,038				
3,090	3,090		3,090	3,090			633		1,169	1,169				
3,450	3,450		3,450	3,450			718		1,300	1,300				
4,710	4,550		4,710				905		1,496					
5,040	4,550		4,930				978		1,598					
5,020	4,550		4,930				952		1,545					
5,380	4,550		4,930				1,029		1,650					
5,020	4,550		4,930	4,930			963		1,585	1,585				

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	72.00	N-80	0.514	12.347	12.191	14.375				2,670	1,661
	68.00	C-90	0.480	12.415	12.259	14.375				2,320	1,750
	72.00	C-90	0.514	12.347	12.191	14.375				2,780	1,869
	68.00	C-95	0.480	12.415	12.259	14.375				2,330	1,847
	72.00	C-95	0.514	12.347	12.191	14.375				2,820	1,973
*	72.00	HC-95	0.514	12.347	12.191	14.375				3,470	1,973
*	86.00	HC-95	0.625	12.125	11.969	14.375				6,240	2,378
	68.00	P-110	0.480	12.415	12.259	14.375				2,330	2,139
	72.00	P-110	0.514	12.347	12.191	14.375				2,880	2,284
	72.00	Q-125	0.514	12.347	12.191	14.375				2,800	2,596

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Internal Pressure Resistance † (psi)							Joint Strength** (1,000 lbf)							
			Buttress Thread				Threaded and Coupled							
									Buttress Thread					
	Round Thread		Regular Coupling		Special Clearance Coupling		Round Thread						Extreme Line	
Plain End or Extreme Line	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling	Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]	Standard Joint	Optional Joint
5,380	4,550		4,930	4,930			1,040		1,693	1,693				
5,650	4,550		4,930				1,057		1,683					
5,050	4,550		4,930				1,142		1,797					
5,970	4,550		4,930				1,114		1,772					
6,390	4,550		4,930				1,204		1,893					
6,390	4,550		4,930				1,215		1,935					
7,770	4,550		4,930				1,507		2,333					
6,910	4,550		4,930	4,930			1,297		2,079	2,079				
7,400	4,550		4,930	4,930			1,402		2,221	2,221				
8,400	4,550		4,930				1,576		2,463					

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
*	76.60	Q-125	0.547	12.281	12.125	14.375				3,490	2,756
*	92.50	Q-125	0.672	12.031	11.875	14.375				5,950	3,352
*	92.50	V-150	0.672	12.031	11.875	14.375				6,400	4,023
*	100.30	V-150	0.734	11.907	11.751	14.375				8,090	4,373
16	65.00	H-40	0.375	15.250	15.062	17.000				630	736
	75.00	J-55	0.438	15.124	14.936	17.000				1,020	1,178
	84.00	J-55	0.495	15.010	14.822	17.000				1,410	1,326
	75.00	K-55	0.438	15.124	14.936	17.000				1,020	1,178
	84.00	K-55	0.495	15.010	14.822	17.000				1,410	1,326
18 5/8	87.50	H-40	0.435	17.755	17.567	20.000				630*	994

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
8,950	4,550		4,930				1,690		2,615					
10,990	4,550		4,930				2,113		3,181					
13,190	4,550		4,930				2,529		3,795					
14,410	4,550		4,930				2,776		3,863					
1,640	1,640						439							
2,630	2,630		2,630	2,630			710		1,200	1,200				
2,980	2,980		2,980	2,980			817		1,351	1,351				
2,630	2,630		2,630	2,630			752		1,331	1,331				
2,980	2,980		2,980	2,980			865		1,499	1,499				
1,630	1,630						559							

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			Extreme Line			
OD (in.)	Nominal Weight, Threads and Coupling (lbm/ft)	Grade	Wall Thickness (in.)	ID (in.)	Drift Diameter (in.)	OD of Coupling (in.)	OD Special Clearance Coupling (in.)	Drift Diameter (in.)	OD of Box Powertight (in.)	Collapse Resistance (psi)	Pipe-Body Yield Strength (1,000 lbf)
	87.50	J-55	0.435	17.755	17.567	20.000				630*	1,367
	87.50	K-55	0.435	17.755	17.567	20.000				630*	1,367
20	94.00	H-40	0.438	19.124	18.936	21.000				520*	1,077
	94.00	J-55	0.438	19.124	18.936	21.000				520*	1,480
	106.50	J-55	0.500	19.000	18.812	21.000				770*	1,685
	133.00	J-55	0.635	18.730	18.542	21.000				1,500	2,125

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
							Joint Strength** (1,000 lbf)							
Internal Pressure Resistance † (psi)							Threaded and Coupled							
			Buttress Thread						Buttress Thread					
			Regular Coupling		Special Clearance Coupling								Extreme Line	
Plain End or Extreme Line	Round Thread						Round Thread			Regular Coupling Higher Grade[1]	Special Clearance Coupling	Special Clearance Coupling Higher Grade[1]		
	Short	Long	Same Grade	Higher Grade	Same Grade	Higher Grade	Short	Long	Regular Coupling				Standard Joint	Optional Joint
2,250	2,250		2,250	2,250			754		1,329	1,329				
2,250	2,250		2,250	2,250			794		1,427	1,427				
1,530	1,530	1,530					581							
2,110	2,110	2,110	2,110	2,110			784	907	1,402	1,402				
2,410	2,400	2,400	2,320	2,320			913	1,057	1,960	1,960				
3,060	2,400	2,400	2,320	2,320			1,192	1,380	2,012	2,012				

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
					Threaded and Coupled			**Extreme Line**			
OD (in.)	**Nominal Weight, Threads and Coupling (lbm/ft)**	**Grade**	**Wall Thickness (in.)**	**ID (in.)**	**Drift Diameter (in.)**	**OD of Coupling (in.)**	**OD Special Clearance Coupling (in.)**	**Drift Diameter (in.)**	**OD of Box Powertight (in.)**	**Collapse Resistance (psi)**	**Pipe-Body Yield Strength (1,000 lbf)**
	94.00	K-55	0.438	19.124	18.936	21.000				520*	1,480
	106.50	K-55	0.500	19.000	18.812	21.000				770*	1,685
	133.00	K-55	0.635	18.730	18.542	21.000				1,500	2,125

* Non-API weights and grades.

Table A3. Minimum performance properties of casing (after SPE Petroleum Engineering Handbook, 1987) (Continued)

13 Plain End or Extreme Line	14 Internal Pressure Resistance † (psi) – Round Thread – Short	15 Round Thread – Long	16 Buttress Thread – Regular Coupling – Same Grade	17 Buttress Thread – Regular Coupling – Higher Grade	18 Buttress Thread – Special Clearance Coupling – Same Grade	19 Buttress Thread – Special Clearance Coupling – Higher Grade	20 Joint Strength** (1,000 lbf) – Threaded and Coupled – Round Thread – Short	21 Round Thread – Long	22 Buttress Thread – Regular Coupling	23 Buttress Thread – Regular Coupling Higher Grade[1]	24 Buttress Thread – Special Clearance Coupling	25 Buttress Thread – Special Clearance Coupling Higher Grade[1]	26 Extreme Line – Standard Joint	27 Extreme Line – Optional Joint
2,110	2,110	2,110	2,110	2,110			784	907	1,402	1,402				
2,410	2,400	2,400	2,320	2,320			913	1,057	1,960	1,960				
3,060	2,400	2,400	2,320	2,320			1,192	1,380	2,012	2,012				

** Some joint strengths listed in Col 20 through 27 are greater than the corresponding pipe body yield strength listed in Col 12.

* Internal pressure resistance is the lowest of the internal yield pressure of the pipe, the internal yield pressure of the coupling, or the internal pressure leak resistance at the E_1 or E plane.

† For P-110 casing the next higher grade is 150YS a non-API steel grade having a minimum yield strength of 150,000 psi.

BIOGRAPHY

Mr. Warut Sirichoat was born on the 22nd of July 1986 in Nakorn Ratchasima province, Thailand. He earned his high school diploma in Science-Math from Nangrong School in 2004 and received his Bachelor's Degree in Engineering (Geotechnology) from Suranaree University of Technology (SUT) in 2008. For his post-graduate, he worked as geologist about 2 years. In 2011, he returned to study with a Master's degree in the Petroleum Engineering Program, Institute of Engineering, SUT. During graduation, 2011-2015, he was a part time worker in position of laboratory assistant, teaching assistant and research assistant of SUT. His strong background is in drilling engineering, well logging and reservoir management.