Diploma Thesis

“Casing Design for Deep Wells in the Vienna Basin”

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I, the undersigned candidate, Dieter Kilian, hereby declare that this diploma thesis has been performed by myself using literature cited at the end of this thesis, according to the regulations of the Mining University Leoben Austria.

Leoben, 15.06.2007

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1 Abstract

Drilling deeper than 5000 meters is a challenge. The work reported here investigates construction designs for deep wells in the Vienna basin. The work is based on two wells drilled recently. These wells are Straßhof T4 and Straßhof T5. In this report both wells are analysed and different comparable factors are defined: well trajectory, temperature, casing design, pressure, geology, work time and costs. In this analysis the actual data of the drilled wells are compared with their planned data. Finally, a summary of the problems incurred during drilling is given. Based on data from these two wells, the casing loads calculation standards are compared with the recommended guidelines given by the “Wirtschaftsverband Erdöl- und Erdgasgewinnung (WEG)”. Therefore, the calculation of the important loads, tension, collapse and burst, are analysed well by well and section by section. After this, a third-party study made for OMV is checked and important findings are added to the work. Casing hangers and their residual loads are discussed based on this study, and the casing loads calculation spreadsheet reworked to include findings like temperature, safety factor, compression and biaxial loads.

Now conventional design alternatives have been created. Four commonly used diameter alternatives and two alternatives based on unconventional diameters with a tighter design were created. Also novel technologies have been investigated. Therefore, following technologies were found and described: expandable casing, liner hangers, monodiameter wells and expandables, as a contingency, monodiameter liners, casing while drilling, fibre glass casings and self expandable casing.

Some aspects of the completion were given. After this, the risk analysis and evaluation of cost were done. For the conventional alternatives, this is done in detail and for the novel technologies it is done in a more general way. Finally, a recommendation of a specific casing design for deep wells in the Vienna Basin is given.

2 Kurzfassung

Die folgende Arbeit hat das Ziel Designs für Bohrlochverrohrungen, basierend auf den beiden Bohrungen Straßhof T4 und T5, für das Wiener Becken zu untersuchen. Folgende Gruppen wurden deshalb definiert: Bohrlochverlauf, Temperatur, Bohrlochverrohrung, Druck, Geologie, Arbeitszeit und Kosten. Die Daten der abgeteuften Bohrungen wurden mit den Plandaten verglichen. Am Ende wurde eine Zusammenfassung der Bohrprobleme herausgegeben. Basierend darauf wurde die aktuelle Berechnung von Futterrohrbelastungen mit den WEG Richtlinie verglichen. Es wurden die Lasten Zug, Innen- und Aussendruck Bohrungs- und Sektionsweise analysiert. Danach wurden die Ergebnisse einer unabhängigen Studie der Arbeit beigefügt. Auf Grund dieser Studie wurden die resultierenden Lasten von Futterrohr-Hängern analysiert. Danach wurde das Futterrohrberechnungs-Excelfile in den Punkten Temperatur, Sicherheitsfaktoren, Druck- und Biaxiallasten überarbeitet.

Nun wurden konventionelle Designalternativen entwickelt. 4 mit regulärem Durchmesser und zwei mit einem engeren Design. Weiters wurden neue Technologien erarbeitet: Erweiterbare Futterrohre, Hänger und Notfallstrang, Eindurchmesser Liner und Bohrungen, Futterrohrbohren, Fiber Glas- und Selbsterweiterbare Futterrohre.

Einige Aspekte über Komplettierungen wurden herausgearbeitet, Risikoanalysen wurden gemacht und Kosten ermittelt. Am Ende wurde ein bestimmtes Verrohrungsschema empfohlen.

3 Introduction

To drill deeper than 5000 meter shows new challenges for drilling operations, especially for the well design. By drilling at this depth in certain areas, formations are reached that were never seen before. Of course, one of the main targets is to drill deeper and deeper, often in order to explore new geological formations. Therefore, because of the high uncertainty of the geology, the formation pressures and rock conditions are very high, even with investigation with seismic methods. As known, several problems can appear and this gives new challenges for well construction. It is very difficult to make an overall well design for the whole Vienna Basin, because the geology is very inhomogeneous. In this study, a common well construction and casing design for deep wells will be investigated and a recommendation in that area will be made.

The basis for the study is two already drilled wells with different designs. The first is Straßhof T4, which has a 4 section design. The second is Straßhof T5, which has a 4 section design with one contingency design. When comparing and analysing these two wells, there will be different and similar problems to be worked out. The current design practice at OMV-Austria will be compared to WEG Standards for Casing Design Calculations, which are relevant for casing design in Austria and Germany. The WEG Standards are not rules, which must be followed, rather guidelines which show the safest way to calculate loads on casing from a very general point of view. Due to kick tolerances and geology, the casing setting depths and the number of strings needed to reach the target depth, will be evaluated. Also different possible diameters, weights and qualities of the casing will be defined. Based upon these investigations, a set of conventional design alternatives will be found.

Also a set of design alternatives based on these novel technologies will be evaluated. All different alternatives will be cost evaluated because one of the main issues is to save money. Well design influences a lot of other things, like bit sizes, mud volume, cement volume, disposal volume of the cuttings and even with what rig the well could be drilled. To take everything into account, a complete well with every possible design has to be calculated. Therefore a common AFE calculation sheet used by OMV will be taken. Once we know how a design alternative influences our costs, it should be checked with risk analysis. Therefore, the first thing to find out is, what the general risks are. After that, special risks of the alternatives have to figure out. The probabilities will be based on the two wells which were looked at. Due to the fact that no risk analyses for drilling operations were made in OMV before, no reference data for the probabilities can be taken. The analysis will be done for both conventional and novel design alternatives. To compare all designs a decision tree is made so that finally a conclusion with a recommendation of an optimum well bore design for the deep wells in the Vienna Basin can be given.

4 Target – Actual – Comparison

4.1 General

First the two wells were compared by analysing how they were planned and how they are really drilled. The two wells were Straßhof T4 and Straßhof T5.Those two wells are the first wells of the field development of the Straßhof gas field. They are also the base for other field developments like in Ebenthal or Auersthal. They were taken because they are the last wells drilled in the depth of 4500 m and 5500 m and they were drilled with two different well designs. Straßhof T4 was drilled with four sections, whereas Straßhof T5 was drilled with four sections along with one contingency. There were several points that the author took a look at. The main points were as follows: Well trajectory, casing and setting depths, pressure (mud program), temperature regime and the geology.

4.2 Straßhof T4

4.2.1 General

Straßhof T4 is an appraisal/exploration well and shall test the primary appraisal target as a four-way-dip-closure of the Reyersdorfer Dolomite formation (gas) in North-West-direction (NW).

Spud in	09. February 2005
Rig Release	27.Apr.05
Planned TD	4320m MD
Actual TD	4516m MD
Total Days planned	67 days
Total Days actual	84 days
Planned AFE	EUR 5.859 Mio
AFE incl. increase	EUR 7.469 Mio
Total Cost	EUR 7.440 Mio

Table 1: Well Data [3]

The primary exploration target is the Perchtoldsdorfer Dolomite formation (gas) which was not drilled until just recently. A secondary target was the Bockfließ Stratums (oil). H_2S were expected in all three targets. [1] The main problems of that well were the overpressure in the dolomite and the capacity limitations of the rig. Because of this, the well path of 4300 m was limited. As said before, this well was drilled with a four section design.

4.2.2 Well Trajectory

The Straßhof T4 well was planned vertical until a kick off point (KOP) of 2230 m. Now the built up of the angle to an inclination of 34 ° with an azimuth of 143.6 ° was done. After this section, there was a tangent section planned to reach the target at a measured depth of 4300 m. The azimuth was necessary because of the dipping formation. The planned kick off point and the end of build were not reached. This was because of geology reasons. The inclination was not reached right away, so it was necessary to correct the angle at the beginning of the tangent section from 31.8 ° to 35.4 °. The planned inclination was finally missed only by 1.4 °. The azimuth was corrected to 162 ° and therefore, differs from the planned angle by 18.4 °.

4.2.3 Temperature

The chosen temperature gradient of 3 °C/100m is based on decades of experiences and is still correct. In this well, the bottom hole temperature was about 135 °C.

4.2.4 Casing Design

As said before, the well Straßhof T4 was planned with 4 sections without a contingency string. It has an 18 5/8” standpipe which is digging in. The casing string starts with a 13 3/8” surface casing down to 560 m followed by a 9 5/8” intermediate casing with a setting depth of 3015 m. After this point, a second intermediate casing performed as a 7” liner was planned to a depth of 3790 m. Finally, a 4 1/2” production liner string was planned to install. The setting depths were chosen due to geology and pressure predictions. The geology as well as the pressure prediction is based on reference wells. The steel quality and the nominal weight of the casing were chosen due to calculations of the predicted stress based on OMV standards. Further detailed explanations about OMV casing calculation standards are given in Chapter 4. Because of the uncertainty of the geology, prediction of the setting depths of the casing had to be adjusted to the new information of the formation.#

4.2.5 Pressure Regime (Mud Program)

The mud program, as it was planned, was quite suitable with some exceptions. At a measured depth of 4209 m and between 4237 m and 4268 m some fluid loss occurred. At the depths 3320 m and 4517 m, connection gas had been recognized and mud treatment was necessary. A kick appeared while running in the 4 1/2" liner had to be handled. It was done by well control operation and well fluid treatment. The problems had occurred because the well was drilled in an undifferentiated section of Lower Cretaceous, but this was one of the targets of this well. All problems were solved without any further incidents. [3], [4]

4.2.6 Geology

The geological data came from the reference wells Straßhof T2 and Bockflies 12. The Reyersdorfer Dolomite was hit at a measured depth (MD) of 3294 m which is 203 m underneath the predicted depth of 3081 m. The Main Dolomite was also found more than 200 m deeper than its prediction. The secondary target Bockflies stratums were found at a depth of 2881 m. Another target of this well was to investigate the Raetic scale of the Perchtholdsdorfer Dolomite, which was unfortunately not hit. [6]

4.2.7 Work Dissection

To split and to analyse the drilling time was primarily done to show the performance of the two projects. The Straßhof T4 well was planned for 1486 h (~ 62 days) with a measured depth of 4300 m. It was drilled in 1910 h (~85 days) down to the MD of 4514 m. This means that there was a time overrun of 20.3 % by a depth overrun of only 4,8 %. After about 1583 h (~66 days) the planned depth of 4300 m was reached, so at that point the project was already behind its plan.

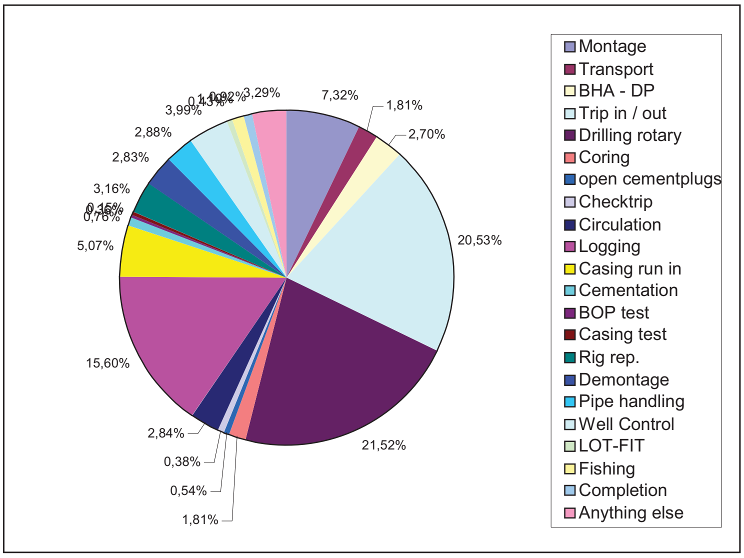


Diagram 1: Drilling Operation Time splitting in several Groups

More time was needed for defrost, longer tripping times and a very time consuming logging, not to mention the kick which had to be controlled. Overall, there were losses seen of 164 h. More details to the time losses can be found in the appendix. [2]

4.2.8 Cost

The planned costs where about of EUR 5.859 Mio and the final drilling costs where of EUR 7.440 Mio. The budget for that project was increased up to EUR 7.469 Mio. As it can be seen, the cost prediction until 3000 m was quite good. Afterwards, there was a longer non-drilling period. Therefore, the costs rose. After drilling faster and more cost efficient, it was finally possible to come back to the planned path

Target – Actual – Comparison

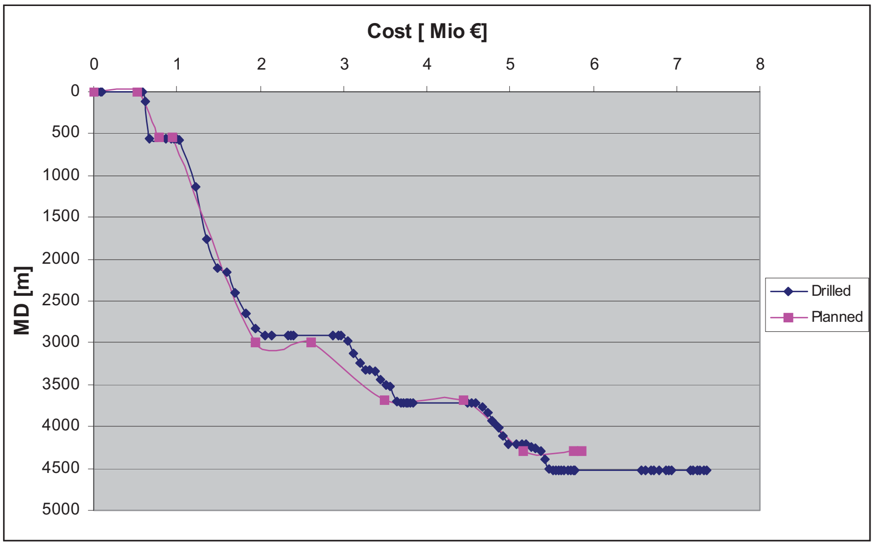


Table 2: Comparison of planned and drilled Well

The overall cost of EUR 7.440 Mio was about 25.6 % higher than the planned costs. [5]

4.2.9 Summary of Drilling Problems

17 1/2" Section and 12 1/4" Section: Because of the well known lithology and the vertical drilling path in the 17 1/2" and 12 1/4" section, there were no special drilling problems recognized. The final setting depth of the second section was reached in 8.5 days and the bottom hole assembly (BHA) was changed only once.

8 1/2" Section: Due to high trip, connection gas and the risk of H_2S, the mud weight was elevated up to 1.27 kg/l. After the weight corrections of the mud, there was very little mud loss. The gas flow was then under control. To compensate for the H_2S, further mud additives (Liquid Scavenger) were added.

6" Section: Because of high mud losses at a depth of 4208 m (100 m^3) two mud loss pills were pumped. The mud weight was then reduced to 1.15 kg/l. During running in the 4 1/2" liner, a kick occurred and the well was shut in. Well control operations were done. The operations were successful and the well was once again under control. In order to control the well, a mud weight correction was made up to 1.2 kg/l. [2]

4.3 Straßhof T5

4.3.1 General

The appraisal well Straßhof T5, is the vertical follow-up well of the exploration well Straßhof T4. It shall test, as a primary target, the Perchtoldsdorfer Dolomite in a deeper structural position. A secondary target is a 4-way-dip-closure of the Reyersdorfer Dolomite.

Spud in	10. December 2005
Rig Release	28. March 2006
Planned TD	5000 m MD
Actual TD	5435 m MD
Total Days planned	103 days
Total Days actual	109 days
Planned AFE	EUR 11.927 Mio
AFE incl. Increase	-
Total Cost	EUR 11.634 Mio

Table 3: Well Data [3]

The primary target will be drilled first in order to test and estimate its gas content as well as to establish the gas-water contact. If the primary target proves to have a gas bearing zone less than 100 m or it has to be drilled below the gas-water contact, the Straßhof T5 well will be plugged back and a sidetrack has to be made. [1]

4.3.2 Well Trajectory

The well was planned as a vertical well with the option of making a side track. The final depth was reached with 5435 m total vertical depth (TVD) and this was actually 435 m more than planned. After reaching the final depth, the main target was not reached because the target formation ended at a deeper position of the dipped formation and it was past. So the well had to be plugged back and a side track was made. Among other things, because this side track was still in progress while writing this work it will not be handled in this thesis.

4.3.3 Temperature

The chosen temperature gradient of 3 °C/100m is based on experiences of decades and is still correct. In this well the bottom hole temperature was about 163 °C.

4.3.4 Casing Design

The setting depths were chosen due to geology and pressure prediction of the formation drilled through. Because of the experience of Straßhof T4 it was decided to take a lower quality for the surface casing. As said already before, this well was planned with four sections and one contingency case. Having had a 30” standpipe, it was started with an 18 5/8” surface casing. After this, the first intermediate casing (with a size of 13 3/8”) was set and followed by a 9 5/8” casing which is the second intermediate casing. Finally a 7” production liner is the last string. If problems occur, a 4 1/2” contingency string can be performed as a liner. Because of uncertainties, it was necessary that the most casings, as you can see on the table, were set deeper than planned. The production casing was set at 5435 m, which is 435 m deeper than planned. For the 9 5/8” and the 7” string, the safety factors were already out bidden.

4.3.5 Pressure Regime (Mud Program)

Because of the experiences of the reference well, Straßhof T4, there were almost no problems according to the chosen predicted pressures. Only at the measured depths of 4630 m and 4639 m there was an inflow of formation fluids into the well recognized during flow check. The mud weight was conditioned, the inflow was stopped and no flow was seen after that. The mud weights seen during drilling are mostly in the suggested range. The formation pressure gradients are all much less than 1.2 kg/l. [3], [4]

4.3.6 Geology

The primary target was the Perchtoldsdorfer Dolomite. The secondary target was the Reyerdorfer Dolomite (Main Dolomite). The main target was found 432.3 m below its prediction depth at 4800.5 m and the secondary target was still 377 m below the prediction of 3245 m. The prediction of the formation, at a depth of 2774 m (Lower Cretaceous), was quite exact. Below that depth, the top depth of the formation and its prediction depth differ substantially. There are differences from 300 m up to 636 m. More details can be found in the appendix. [6]

4.3.7 Work Dissection

The work dissection is based on the daily drilling reports and some assumptions. The well, Straßhof T5, was planned for 2478 h (~ 103 days) with a measured depth of 5000 m. It was drilled in 2596 h (~109 days) down to a MD of 5435 m. This means that there was only a time overrun of 1.8 % by a depth overrun of 8.7 %. The planned MD of 5000 m was reached in about 2280 h (~95 days).

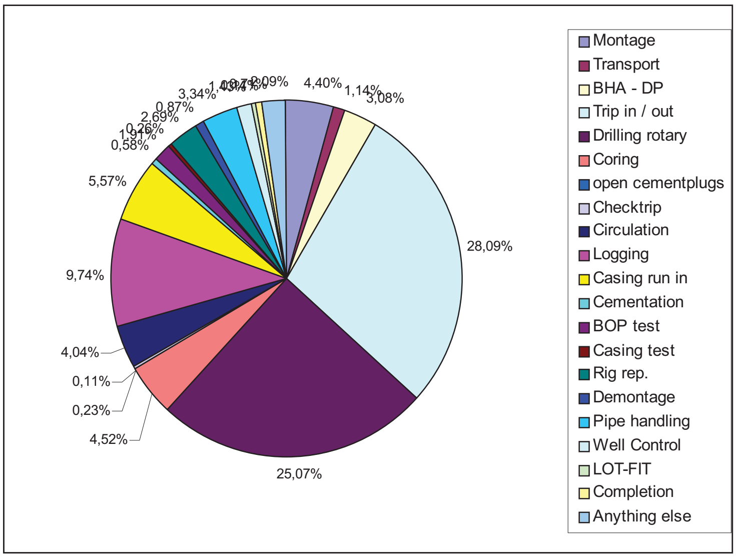


Diagram 2: Drilling Operation Time splitting in several Groups

Time was lost by a longer logging job, logging problems, wiper trips, problems during liner running and problems with the solids control equipment. Overall there were directly seen time losses of 365 h. [2]

4.3.8 Cost

The planned costs where about EUR 11.926.862 whereas the final drilling costs where EUR 11.633.641.97.

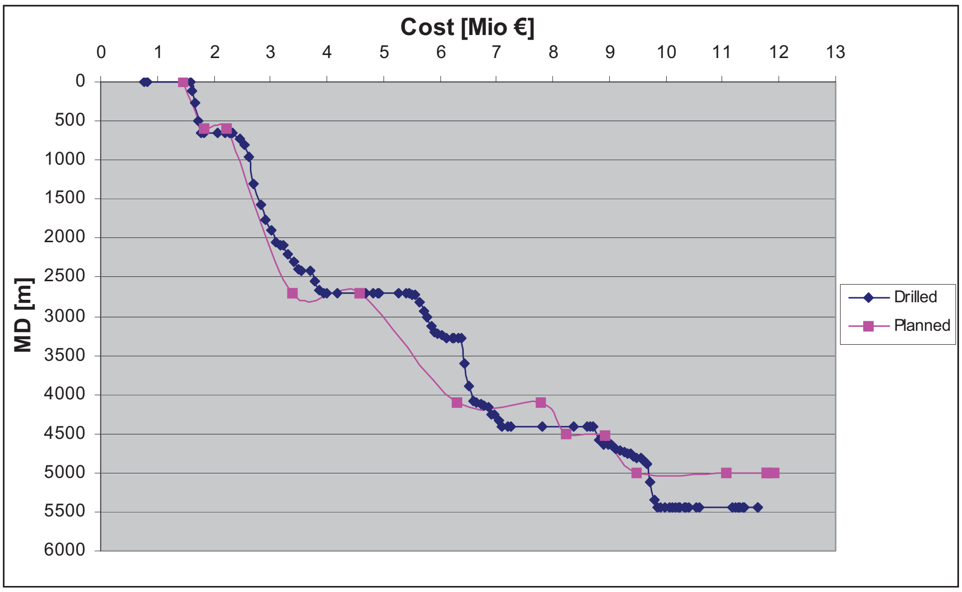


Table 4: Comparison of planned and drilled Well

Until a depth of 2000 m, the predicted costs were suitable. At a measured depth of 4500 m, the planned and the real costs were back on track. [5]

4.3.9 Summary of Drilling Problems

24" Section and 17 1/2" Section: In these sections, no problems due to formations occurred. The lithologies of these two sections are already well known. During the drilling of the first section, the gate valve was left open and the cellar had to be pumped empty. In the second section there were some problems with the drill pipe mesh. It was lost and had to be recovered. There were also some hole cleaning problems. It was necessary to circulate because of high cuttings output.

12 1/4" Section: This section was drilled without any problems and 1700 m were drilled in 10 days.

8 3/8" Section: In this section several problems happened. During flow check, gas peaks of up to 98 % were recognized so the mud was conditioned and weighted. This had to be done twice before the gas flow stopped. At the depths of 4815 m and 5113 m during run in the hole, reaming was necessary. At 5117 m the drill string stood off and the BHA got stuck. It had to be pulled with 245 t (~ 55 t over pull). At the total depth 5435 m there were also some problems. During a wiper trip, the BHA stood off and circulation had to be done. The same problem happened a second time, but was combined with a high cutting output (during tripping!). This probably happened because of caving caused by a weak formation. The mud was conditioned before logging. Finally, damage of the logging tool cost time yet again. [2]

5 Comparison OMV Casing Design Standard to WEG Guidelines

5.1 General

The design of casing is done due to the criteria of axial, collapse and burst loads. For the pipe strength, the values given by API Bul 5C2/ISO 10400 have to be used. Otherwise, according to the API Bul, 5 C3/ISO 10400 have to be calculated. If pipes are used which are not classified by the "American Petroleum Institute (API)", the pipe manufacturer has to put the calculation fundamentals at the companies disposal. The calculated or provided pipe strengths are minimum values. The pipe material based yield strength of the material is only valid for room temperature. Correlations due to the surrounding temperature had to be made. The WEG Guidelines are not for fibre glass strengthened synthetic (GFK) pipes. These strengths had to be found in other ways. [7]

At OMV the casing design calculations are done with an excel spreadsheet made by OMV itself. For the Straßhof T4 well, this sheet had not been used. It was done by an even easier method. Straßhof T5 shows the last casing design philosophy of the OMV, and there, the spreadsheet for the calculations had been used. In the following chapter, the casing load calculations were compared with the WEG standards. It will be shown if the method of the calculations is still appropriate. Then the casing calculation spread sheet has been renewed.

5.2 WEG Safety Factors

Collapse		1
Burst		1.1
Axial Pipe body Tension		1.25
Axial Pipe body Compression		1.1
Axial Couplings Tension	< 13 3/8"	1.6
	> 13 3/8"	1.8
Axial Couplings Compression		1.1
Triaxial		1.25

Table 5: Recommendation Safety Factors [7]

5.3 Surface Casing

5.3.1 Straßhof T4 (13 3/8")

5.3.1.1 Collapse

The used safety factor was 1.1. The one that the WEG recommended was 1.0. The calculation was based on the case "casing half empty". It simulates the case of fluid loss during drilling, resulting in a fluid level drop down to the half length of the first casing string. Outside, the casing is forced by G collapse which is equal to the formation pressure gradient and comes from experiences of reference wells in that certain area. The cementation process was taken into account. This is done by including the cementing pressure.

5.3.1.2 Burst

The used safety factor was 1.15. The one that the WEG recommended was only 1.1. The burst pressure was calculated at the well head by reducing the formation pressure of the hydrostatic weight of the gas column. The gradient of completion fluid and those of the fluid behind the pipe are equal.

5.3.1.3 Tension

The used safety factor was 1.25 and this corresponds with the recommendation of the WEG. The tension force was calculated by taking the weight in mud and adding the equivalent force of 100 bar pressurization (which comes from the cementing process). The loads during run in and movements during cementing are not taken into account. Pressure tests and ballooning were not taken into consideration as well. The threads, especially of the upper 100 m, should be checked for compressive strengths.

5.3.1.4 General

The casing shoe temperature in the upper section is 28.67 °C. The values of the material strength given by the manufacturer are under room temperature, which means 20 °C. So the in-situ temperature has nearly no influence on the strength of the material.

5.3.2 Straßhof T5 (18 5/8")

5.3.2.1 Collapse

The used safety factor was 1.0. This is corresponded with the recommendation of the WEG. The calculation was based on the case "casing half empty". Although the well has a greater diameter, it is the same case as used in Straßhof T4, but for the same volume of fluid loss the fall of the fluid level would be much less than for a smaller well. Outside, the casing is forced by G collapse which is equal to the formation pressure gradient. It also comes from experiences with other reference wells. The cementation process was taken into account. The pressure for designing the casing is taken at the casing shoe.

5.3.2.2 Burst

The used safety factor was 1.1, which corresponded with the recommendation of the WEG. In this well the burst pressure was calculated by combining two cases:

Case 1 assumes that 25 % of the well is filled with gas on the bottom and the other 75 % filled with normal mud.

Case 2 assumes that the well is filled with 50 % gas cut mud on the bottom and 50 % filled with gas. We then calculate the maximum burst pressure (bar) at the surface and at the casing shoe, for both cases and at the intersection point (mTVD). Compare all pressures with the cementing pump pressure and the highest value is the burst criteria for the casing design.

5.3.2.3 Tension

The used safety factor was 1.5. The one from the WEG recommendation was 1.25. The tension force was calculated by using the weight in mud and adding 50 bar pressurization, which is the equivalent force of the cementing process. The loads during run in and movements during cementing are not taken into account. Also pressure tests and ballooning were not taken into consideration. The threads especially of the upper 100 m should be checked for compressive strengths.

5.3.2.4 General

The casing shoe temperature in the upper section is 30 °C. The values of the material strength given by the manufacturer are under room temperature which means 20 °C. So the in-situ temperature has nearly no influence on the strength of the material.

5.4 First Intermediate Casing

5.4.1 Straßhof T4 (9 5/8”)

5.4.1.1 Collapse

The used safety factor was 1.1. The WEG recommendation was 1.0. The calculation was based on the case “casing half empty”. It simulates the case of a fluid loss during drilling, resulting in a fluid level drop down to the half length of the second casing string. Outside, the casing is forced by G collapse which is equal to the formation pressure gradient and comes from experiences from the reference wells. The cementation process was taken into account. This is done by including the cementing pressure.

5.4.1.2 Burst

The used safety factor was 1.15. The WEG recommendation was 1.1. The burst pressure was calculated at the well head by reducing the formation pressure of the hydrostatic weight of the gas column. The gradient of the completion fluid and those of the fluid behind the pipe are equal.

5.4.1.3 Tension

The used safety factor was 1.25. This corresponded with the recommendations of the WEG. The tension force was calculated by taking the weight in mud and adding the equivalent force of 150 bar pressurization (which comes from the cementing process). The loads during run in and movements during cementing are not taken into account. Also pressure tests and ballooning were not taken into consideration. The threads can be checked for compression due to upset loads. In wells with a very high build rates, abrasion and bending should taken into account.

5.4.1.4 General

The strength of the material will be reduced in higher temperatures. Until now, this was only included with temperatures above 150 °C. This level should be corrected to 100 °C. For this section, the temperature is 110.5 °C and that means a reduction of the yield strength of the casing of 7 % and is normally given by a correction factor which is 0.93 in this section.

5.4.2 Straßhof T5 (13 3/8”)

5.4.2.1 Collapse

The used safety factor was 1.0. This corresponded with the recommendations of the WEG. The calculation was based on the case “casing half empty”. It simulates the case of a fluid loss during drilling resulting in a fluid level drop to the half length of the second casing. Outside, the casing is forced by G collapse which is equal to the formation pressure gradient and comes from experiences from the reference wells. The cementation process was taken into account. The pressure is taken at the casing shoe.

5.4.2.2 Burst

The used safety factor was 1.1, which corresponded with the recommendations of the WEG. In this well the burst pressure was calculated by intersection of two cases:

Case 1 assumes that 25 % of the well is filled with gas on the bottom and 75 % filled with normal mud.

Case 2 assumes that the well is filled with 50 % gas cut mud on the bottom and 50 % filled with gas. We then calculate the maximum burst pressure at the surface, the casing shoe and at the intersection point. After comparing all pressures with the cementing pump pressure, we take the highest value and use it for the burst criteria for the casing design.

5.4.2.3 Tension

The used safety factor was 1.5. The WEG recommendation was 1.25. The tension force was calculated by taking the weight in air and adding the equivalent force of 80 bar pressurization (which comes from the cementing process). The loads during run in and movements during cementing are not taken into account. Also pressure tests were not taken into consideration. The threads can be checked for compression due to upset loads. In wells with a very high build rates abrasion and bending should taken into account.

5.4.2.4 General

For this section the temperature is 103 °C. By taking the corrected temperature level of 100 °C, we get a reduction of the yield strength of the casing of 6 % and it is normally given by a correction factor which is 0.94 in this section.

5.5 Second Intermediate Casing

5.5.1 Straßhof T5 (9 5/8")

5.5.1.1 Collapse

The used safety factor was 1.1. The WEG recommendation was 1.0. The calculation was based on the case "casing half empty". It simulates the case of a fluid loss during drilling resulting in a fluid level drop to the bottom hole. Outside, the casing is forced by G collapse with is equal to the formation pressure gradient and comes from experiences from the reference wells. The cementation process was taken into account. The pressure is at the casing shoe.

5.5.1.2 Burst

The used safety factor was 1.0. The WEG recommendation was 1.1. In this well, the burst pressure was calculated by the intersection of two cases:

Case 1 assumes that 25 % of well is filled with gas on the bottom and 75 % filled with normal mud.

Case 2 assumes that the well is filled with 50 % gas cut mud on the bottom and 50 % filled with gas. We then calculate the maximum burst pressure at the surface, the casing shoe and at the intersection point. We compare all the pressures with the cementing pump pressure and the highest value is the burst criteria for casing design.

5.5.1.3 Tension

The used safety factor was 1.5. The WEG recommendation was 1.25. The tension force was calculated by using the weight in air and adding 100 bar pressurization, which is the equivalent force of the cementing process. The loads during run in and movements during cementing are not taken into account. Also pressure tests were not taken into consideration. The threads can be checked for compression due to upset loads. In wells with a very high build rates abrasion and bending should taken into account.

5.5.1.4 General

For this section the temperature is 146.67 °C. When taking the corrected temperature level of 100 °C, we get a reduction of the yield strength of the casing of 10 % and it is normally given by a correction factor which is 0.9 in this section.

5.6 Production Liner

5.6.1 Straßhof T4 (7”)

5.6.1.1 Collapse

The used safety factor was 1.1. The WEG recommendation was 1.0. The calculation based on the case “casing completely empty”. It simulates the case of fluid loss during drilling, resulting in a fluid level drop to the bottom hole. Outside, the casing is forced by G collapse which is equal to the formation pressure gradient and comes from experiences from reference wells. The cementation process was taken into account. This is done by including the cementing pressure.

5.6.1.2 Burst

The used safety factor was 1.15. The WEG recommendation was 1.1. The base case for the calculation of the production casing is tubing leak at surface with packer. The burst pressure was calculated at the well head by reducing the formation pressure of the hydrostatic weight of the gas column. The gradient of the completion fluid and the fluid behind the pipe are equal.

5.6.1.3 Tension

The used safety factor was 1.25 and this corresponded with the recommendations of the WEG. Due to buoyancy, the weight in mud is zero, and the only load comes from the cementing process. Therefore, an equivalent load of the pressure at 200 bar was taken to calculate the axial force which acts on the liner. The loads during run in, movements during cementation and pressure test loads were not taken into account. The threads and the pipe body should be checked due to buoyancy and upset loads. In wells with a very high build rates, abrasion and bending should also be taken into account. To overcome the thermal expansion, the casing or liner has to be pre loaded. This additional load also has to be included in the calculation.

5.6.1.4 General

For this section the temperature is 136.33 °C. When taking the corrected temperature level of 100 °C, we get a 9 % reduction of the yield strength of the casing and it is normally given by a correction factor which is 0.91 in this section.

5.6.2 Straßhof T5 (7”)

5.6.2.1 Collapse

The used safety factor was 1.0. This corresponded with the recommendation of the WEG. The calculation was based on the case “casing completely empty”. It simulates the case of a fluid loss during drilling, resulting in a fluid level drop to the bottom of the hole. Outside, the casing is forced by G collapse with is equal to the formation pressure gradient and comes from experiences from reference wells. The cementation process was taken into account. This is done by including the cementing pressure.

5.6.2.2 Burst

The used safety factor was 1.0. The WEG recommendation was 1.1. For this section it is necessary to assume that the casing is filled fully with gas and the burst pressure at the casing shoe has to be calculated. Stimulation and work over loads like well killing, fracturing jobs, and completion without packer and so on, are included only by safety factors.

5.6.2.3 Tension

The used safety factor was 1.5. The WEG recommendation was 1.25. Only the weight in air is taken into account because it is the higher load. The equivalent load with a pressure of 100 bar was not taken to calculate the axial force. The loads during run in, movements during cementation and pressure test loads were not taken into account. The threads and the pipe body should be checked due to buoyancy and upset loads. In wells with a very high build rates, abrasion and bending should also be taken into account. To overcome the thermal expansion, the casing or liner has to be pre loaded. This additional load also has to be included in the calculation.

5.6.2.4 General

For this section the temperature is 176.67 °C. When taking the corrected temperature level of 100 °C, we get an 11 % reduction of the yield strength of the casing and it is normally given by a correction factor which is 0.89 in this section.

5.7 Production Liner

5.7.1 Straßhof T4 (4 1/2")

5.7.1.1 Collapse

The used safety factor was 1.1. The WEG recommendation was 1.0. The calculation was based on the case “casing completely empty”. It simulates the case of a fluid loss during drilling, resulting in a fluid level drop to the bottom of the hole. Outside, the casing is forced by G collapse with is equal to the formation pressure gradient and comes from experiences from reference wells. The cementation process was taken into account. This is done by including the cementing pressure.

5.7.1.2 Burst

The used safety factor was 1.15. The WEG recommendation was 1.1. The base case for calculating the production casing is leakage in the upper part of the tubing with packer. The burst pressure was calculated at the well head by reducing the formation pressure of the hydrostatic weight of the gas column. The gradient of completion fluid and the fluid behind the pipe are equal. Stimulation and work over loads like well killing, fracturing jobs, completion without packer and so on, are included only by safety factors.

5.7.1.3 Tension

The used safety factor was 1.25. This corresponded with the recommendations of the WEG. Due to buoyancy, the weight in mud is negative and the only load comes from the cementing process. Therefore, an equivalent load with the pressure of 200 bar was taken to calculate the axial force which acts on the liner. The loads during run, movements during cementation and pressure test loads were not taken into account. The threads and the pipe body should be checked due to buoyancy and upset loads. In wells with a very high build rates abrasion and bending should also taken into account. To overcome the thermal expansion the casing or liner has to be pre loaded. This additional load also has to be included in the calculation.

5.7.1.4 General

For this section the temperature is 146.47 °C. When taking the corrected temperature level of 100 °C, we get a 10 % reduction of the yield strength of the casing and it is normally given by a correction factor which is 0.9 in this section. [7], [8]

6 The Study “Safety Evaluation of wells for acid gas injection in den Reyerdorfer Dolomite” and resulting problems

The OMV Exploration Production Gmbh has given the commission for making a study about the safety evaluation of wells for acid gas injection in the Reyerdorfer Dolomite to “Untergrundspeicher- und Geotechnologie-Systeme (UGS GmbH) Mittenwalde/Mark”. The main target of this study was to check if the wells are suitable in terms of safety and technical issues for an acid gas injection. The wells are mainly old and abandoned with one exception. The well Straßhof T5, is the only actual well which was included in the study. Because this well is a reference well, of this work, it was the commission of the author of this work to check if the assumptions of UGS for this well were correct or if they have to rework it.

6.1 Study Description

Target of this study was to check 13 wells of the Straßhof field for their suitability for enhanced oil/gas recovery. By maintaining the pressure of acid gas injected, the production will be stabilized and the recovery effect will be raised. The content of this study is very wide in that it reaches from casing load calculation, cement bond strength, material strength, over corrosion, and even to gas specifications. Only the analyses of the well Straßhof T5 concerning this work will be explained in detail. The calculations were done in sections as usual. For Straßhof T5, the critical sections were the 18 5/8” surface casing and the 9 5/8” second intermediate casing. For the surface casing, one point was the compression load. The surface casing has to carry the loads of every string below. The casing was not checked if these setting loads caused any problems. Luckily, the strength of the casing was high enough to withstand the loads of the strings below. For the future, the compression load of the surface casing has to be taken into account.

Another point was the corrosion in the upper part of the surface casing. Corrosion is especially critical between the floor of the well cellar and the casing head, because this part is only covered with an extension of the conductor. For storage wells, the prediction will be done for 15 years operating. The time ranges from 2006 to 2021. The following corrosion numbers are based on experiences from other acid gas storage operations and are included in the calculations of the casing loads. The corrosion rate is the reduction of the wall thickness per year due to corrosion.

Case description	Reduction of the wall thickness
Surface Casing overlapped by Intermediate Casing	0.002 mm/a
Casing packet, Annulus filled with Inhibitor for: - low mineral fluids - for saturated fluids	0.006 mm/a 0.002 mm/a
Casing not packed to Tubing shoe	0.07 mm/a

Table 6: Corrosion Wear Numbers at Casing inside [10]

This corrosion rates are included in the load calculation as extensive erosion. The local weakening because of corrosion, work over or well treatment is not included in this study. The corrosion numbers are only for the overlapping casing sections. Table 4 and Table 5 show the corrosion numbers for inside and outside the casing. Both are given in millimetres per year.

Case description	Reduction of the wall thickness
Casing in Sweetwater containing Formation, Content of Oxygen not excluded (Transition zone of Conductor)	0.014 mm/a
Surface Casing overlapped by Intermediate Casing	0.002 mm/a
Casing in Formations with containing low mineral Formation water	0.006 mm/a
Casing in Formations with containing saturated mineral Formation water	0.002 mm/a

Table 7: Corrosion Wear Numbers at Casing outside [10]

For the outside of the casing at the transition between surface casing – bottom flange and bottom flange – cellar floor the wear number for oxygen containing fluids has to be taken. [10] This area is the most critical of the whole string. Even in wells without acid gas. So it is very important to protect this zone against corrosion. At OMV this part will be covered with two half shells of pipes which are welded together. This area should be additionally covered by corrosion prevention. This could be epoxy resin, or similar. Even a bandage soaked with grease like is often done in practice.

A much greater problem was the 9 5/8” second intermediate casing. UGS figured out that the casing will not withstand the loads in the slip landing area of the casing hanger. Because of the slips of a conventional casing hanger, it comes to a necking in this area which results in an additional load. This load has to be added to the tension load by calculating the Mises Stress.

By doing this they found out that the casing breaks if the casing sets in the slips. The fact was that the casing did not break. One point was that the reduced safety factor was 0.98 and the calculation of UGS which is based on a research of the “Technical University Freiberg” does not include plasticity of the material. This plasticity could approximately raise the safety factor by 0.2. [10] But the real mistake they made was that OMV has changed there casing hangers. UGS had not the information that the new casing hangers used by OMV have a different design so they took wrong assumptions. These new hangers have such a design, that the necking is reduced to a level wear a causes no problems anymore. For this well the limit with the old casing hangers was 242.5 metric tons and with the new system the limit was 451.4 metric tons.

6.2 Casing Hanger

OMV has used conventional AW casing hangers from Cameron, but now they are using so called “controlled friction” SB hanger also from Cameron. The big difference between those two hangers is the design. The AW hanger works with regular slips. Because of the wedge shape the axial load causes normal force between the inner slip and the casing. The normal force combined with the friction factor gives the friction force needed to hold the casing. But this normal force also causes the problem of necking the casing. The SB hanger has in comparison with the AW hanger, a certain design to limit this normal force. As said before for the Straßhof T5, the maximum setting load was 451,4 tons which is 80 % of the pipe body yield strength [13] of the 9 5/8” casing with a nominal weight of 53,5 lbs/ft and a steel grade of L80. Cameron gives the loads which can carry a hanger without deforming the casing in the percentage of the casing which is used. For the example of the Straßhof T5 a SB-3 casing hanger was used.

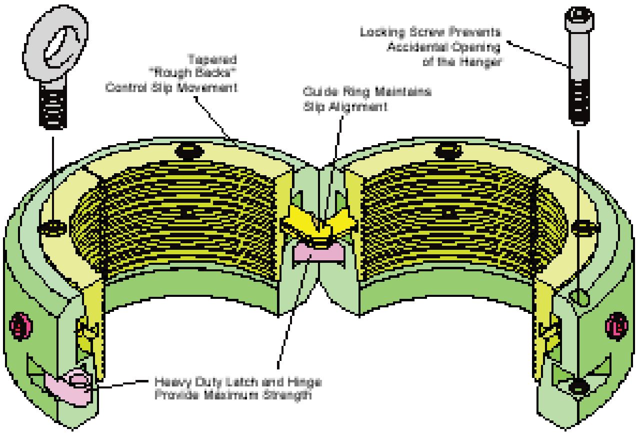


Figure 1: IC Casing Hanger [11]

Figure1 above shows an IC casing hanger which is quite similar to the AW hanger but only a newer model. [11] The IC casing hanger is a wrap around hanger in a slip style. It is made for shallow wells with lower casing loads which do not require an annulus seal prior to removing the blow-out preventer (BOP) and cutting the casing. The H packer is designed to be installed after slips are landed and the casing has been cut off and dressed. The H packer serves as the primary seal and protects the slips from test pressure.

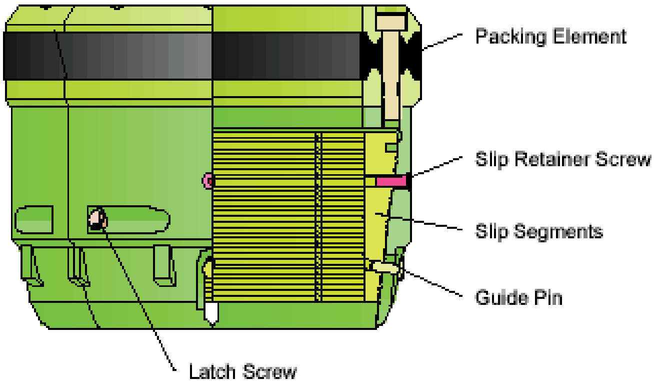


Figure 2: SB Casing Hanger [11]

As shown in Figure 2, the SB casing hanger is an automatic, weight set, slip style casing hanger. One of the main advantages is the test pressure load from the casing load. Separating those two allows the rated casing load capacity to be supported while maintaining a test pressure equal to the working pressure of the top flange of the head (up to the collapse rating of the casing). Another improvement is that the slip movement is limited. Therefore, the outer diameter (OD) of the slip segments have course, machined teeth, which aid in achieving high casing hang off weights. These teeth bite into the taper on the slip bowl and restrict excessive downward movement, which might impinge the casing.

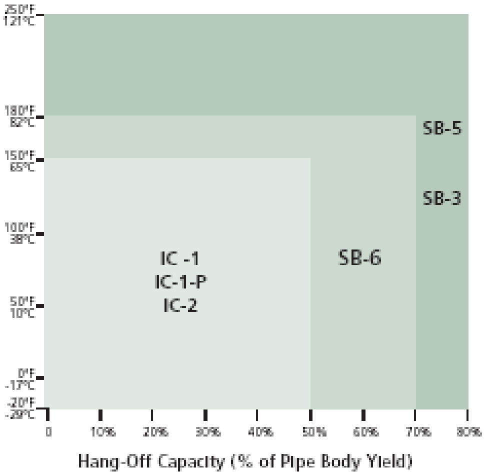


Diagram 3: Load Capacities of Hangers [12]

The diagram above shows the load capacities of different casing hangers in percentage of the pipe body yield of the casing. It can be seen that the IC hanger (as well as the AW hanger) are made for loads up to 50 % of the Yield whereas the SB casing hangers can carry up to 80 % of the pipe body yield. Also the temperature ranges for IC with maximum 65 °C are much lower than those from the SB hanger with 121 °C maximum temperature. [12]

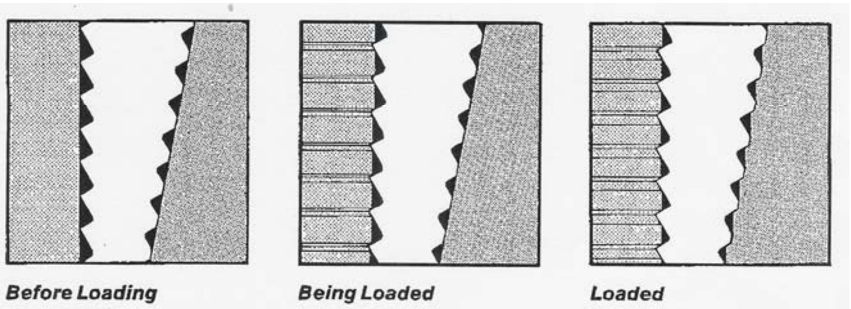


Figure 3: Loading Process of SB Casing Hanger [13]

Figure 3 shows the principle work of the controlled friction hanger. You can see a slip and how they work during the setting of the casing. **Before loading**: The slips are in position with no loading. **During loading**: The sharp inner teeth secure the casing. Slip and casing move down together. Dull back teeth initially slide down into the bowl with little friction. As movement continues, radial loading increases and the back teeth begin to form slight shoulders. Shoulders rapidly build friction until slip movement is stopped. **Loaded:** Slip movement has been stopped before inward movement damages casing. Dull back teeth rest secure on shoulders. The dangerous and costly casing bottlenecking is prevented for whole life time of the well. [13]

7 Casing Load Calculation Sheet

This excel spreadsheet is made by OMV and is used for the calculation of casing loads and to check if the chosen casings are suitable for these loads. For this, the calculation is done by sections and those are: surface casing, first intermediate casing, second intermediate casing and production liner or casing. This spreadsheet is used for several years and should be checked if it is still usable.

How the loads are calculated is already shown in Chapter 3. For the surface casing the compression load due to the setting loads of the whole casing strings was added. This was easily done by summing up the setting loads of every casing below. The sum is the compression load acting on the surface casing.

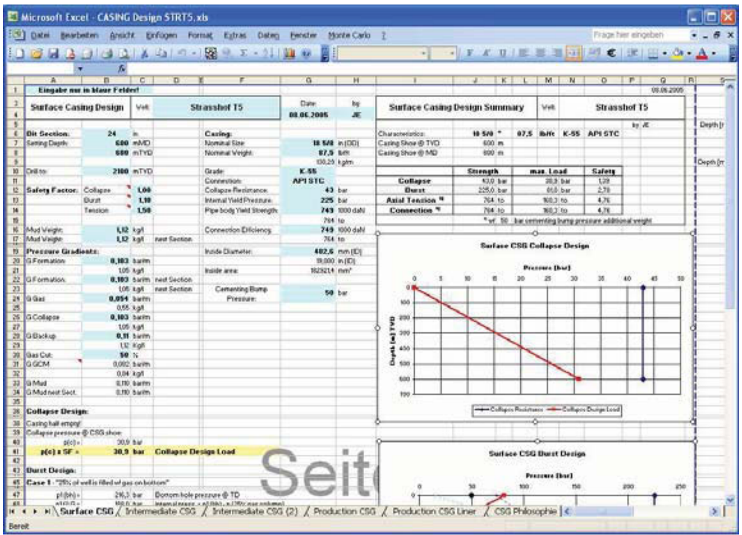


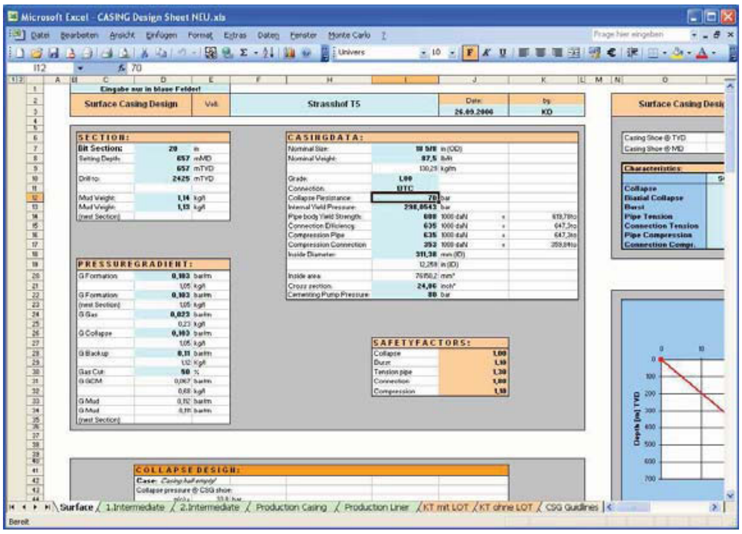
Figure 4: Old Casing design sheet (Straßhof T5) [9]

For the first and the second Intermediate and the production casing the reduction of the material strength, because of higher temperature, was included. Therefore, the limit temperature was 100 °C. The used reduction factor was taken from the WEG guidelines and are material dependent, which means for every Grade (J55, L80, C90, P110,…) there is a different correction. To get exact factors of the correction, (because the factors were only given from 100 °C to 250 °C in steps of 50 °C) an interpolation has been done.

The calculation of biaxial loads was also included. In this case the biaxial load means that the collapse resistance is reduced because of tension of the casing string. The used formula is taken from the drilling data handbook.

The biaxial loads as well as the collapse, burst, pipe and connection tension were calculated for every end point of the single pipe of the casing. This was done to get a base for the construction of a tapered string. If necessary, a better design of a tapered string can be easily refined. For example, instead of the single casing length (~ 12.5 m) it is possible to take a distance of one meter.

Instead of an overall safety factor for tension load, it is now differentiated between pipe and connection tension as well as compression for the surface casing. A safety factor of 1.3 for pipe and 1.6 for connection are used instead of a 1.5 overall safety factor. For surface casings which are bigger than 13 3/8” a connection safety factor of 1.8 is used.



Eingabe nur in blaue Felder!

Surface Casing Design	Well:	Strasshof T5	Date: 26.09.2006	by: KD

SECTION:

Bit Section:	20	in
Setting Depth:	657	mMD
	657	mTVD
Drill to:	2425	mTVD
Mud Weight:	1,14	kg/l
Mud Weight (next Section)	1,13	kg/l

CASINGDATA:

Nominal Size:	13 3/8	in (OD)
Nominal Weight:	87,5	lb/ft
	130,21	kg/m
Grade:	L80	
Connection:	BTC	
Collapse Resistance:	70	bar
Internal Yield Pressure:	298,0543	bar
Pipe body Yield Strength:	600	1000 daN
Connection Efficiency:	635	1000 daN
Compression Pipe:	635	1000 daN
Compression Connection:	392	1000 daN
Inside Diameter:	311,38	mm (ID)
	12,259	in (ID)
Inside area:	76150,2	mm²
Cross section:	24,06	inch²
Cementing Pump Pressure:	80	bar

PRESSUREGRADIENT:

G Formation:	0,103	bar/m
	1,05	kg/l
G Formation (next Section)	0,103	bar/m
	1,05	kg/l
G Gas	0,023	bar/m
	0,23	kg/l
G Collapse	0,103	bar/m
	1,05	kg/l
G Backup	0,11	bar/m
	1,12	Kg/l
Gas Cut	50	%
G GCM	0,067	bar/m
	0,68	kg/l
G Mud	0,112	bar/m
G Mud (next Section)	0,111	bar/m

SAFETYFACTORS:

Collapse	1,00
Burst	1,10
Tension pipe	1,30
Connection	1,80
Compression	1,10

Surface Casing Desi

Casing Shoe @ TVD
Casing Shoe @ MD

Characteristics:

- Collapse
- Biaxial Collapse
- Burst
- Pipe Tension
- Connection Tension
- Pipe Compression
- Connection Compr.

COLLAPSE DESIGN:

Case: Casing half empty!
Collapse pressure @ CSG shoe:

Figure 5: New casing design sheet

The already existing kick tolerance excel file was rework in that it is now possible to put the input data in SI units instead of field units. After this, the sheet was added to casing load sheet.

Finally, a new design for more clarity and better handling was made. To make working easier and faster instead of the input fields, kind of connection, steel grade, nominal weight, well and casing diameter, drop down menus were created.

8 Design Alternatives

8.1 Conventional Design Alternatives

8.1.1 General

First, it has to be explained what the conventional casing design alternatives are. So what does it mean, conventional? It is the constellation of drilling one section then setting a regular casing and continuing drilling with a smaller diameter. This will be done again and again until the planned depth is reached. Instead of run in a full casing to surface it is also possible to run in a liner. The combination of different casing sizes and kinds called design alternative. What conventional design alternatives are defined by the IADC. They are having made schemes for design alternatives. In addition it is to say that the delivery period for casing is about 10 – 12 week. So the decision for the right casing has to be done very early in the planning phase and therefore it should be made very carefully. The following chapter will describe six different alternatives to reach a total depth of 5500 m. These alternatives are based mainly on the well Straßhof T5 because it is the deeper well of the two which were analysed in the previous chapters.

8.1.2 Four Sections with one Contingency

The first alternative which has to be analysed is the already used, the so called “big alternative”. It is the alternative which was used in T5 and it is the safest way to drill a well to TVD. It consists of an 18 5/8” surface casing followed by a 13 3/8” intermediate casing. After this a 9 5/8” second intermediate casing and a 7” production liner is installed. This alternative has a contingency case. If necessary it a 4 1/2” liner can be installed.

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depth [m]
24	446.21	18 5/8	Surface Casing	~659
17 1/2	311.38	13 3/8	1. Intermediate Casing	~2719 - 2914
12 1/4	206.38	9 5/8	2. Intermediate Casing	~3860 - 4598
8 1/2	147.19	7	Production Liner	~5500
5 7/8	94.01	4 1/2	Contingency Liner	~5500

Table 8: Four sections with one contingency [4]

To create an alternative to the design shown in Table 6 the diameter of the surface casing can be changed. Instead of the 18 5/8” surface casing a 16” diameter casing can be installed. It reduces the bit size for drilling this section to 20”.The drift would be 382.6 mm, which is still enough to continue drilling with an 17 1/2 bit for the next section. [4]

8.1.3 Four Sections without Contingency

This alternative is the one which is used in the well Straßhof T4. It consists of a 13 3/8” surface casing followed by a 9 5/8” intermediate casing. After this, a 7” second intermediate casing and a 4 1/2” production liner was installed. This alternative has no contingency case. Due to the restriction of the OMV Production Department, which say that it is not recommended to get a smaller diameter than 4 1/2”. This means if any problems occur, it is not possible to continue drilling. If a side track has to be done or in the worst case, the well has to be abandoned and a new one has to be drilled.

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depth [m]
17 1/2	316.46	13 3/8	Surface Casing	~659 - 1036
12 1/4	218.41	9 5/8	1. Intermediate Casing	~2719 - 2914
8 1/2	149.33	7	2. Intermediate Casing	~3860 - 4598
5 7/8	94.01	4 1/2	Production Liner	~5500

Table 9: 4 sections without contingency [4]

The setting depths shown in Table 7 are based on the geology found in Straßhof T5. This is only an example of how to come down to 5500 m, because the geology in the whole Vienna Basin is very different. [4]

8.1.4 Three Sections with one Contingency

This alternative describes the absolute minimum due to the limit of well control. This design is only based on a kick scenario and the well control process. For this alternative, a specific example was taken. It is based on the pressure data, the formation integrity test and the leak off test of the T5. The first section for beginning is the production casing which is set at a depth of 5500 m. For the production section a formation fracturing gradient (G_{frac}) of 0.16 bar/m and a kick volume of 10 m³ was taken. The mud weight was chosen using 1.25 kg/l. By taking the minimum kick tolerance of 0.12 kg/l [31] into account, the setting depth of the intermediate casing has to be 2700m. For the next upward section, the same process was done, but the following data was used: G_{frac} of 0.15 bar/m, kick volume of 5 m^3 and mud weight of 1.13 kg/l. [2] With that data a setting depth of the surface casing was found at 1000 m

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depth [m]
17 1/2	316.46	13 3/8	Surface Casing	~659 - 1036
12 1/4	218.41	9 5/8	Intermediate Casing	~2500 - 3000
8 1/2	152.5	7	Production Liner	~5500
5 7/8	97.2	4 1/2	Contingency Liner	~5500

Table 10: 3 sections with one contingency

So as shown above in Table 8 the configuration of this alternative would be a 13 3/8” surface casing set at 1000 m followed by a 9 5/8” intermediate casing set at 2700 m. The 7” production liner would be set down to 5500 m. [24] A contingency case build as a 4 1/2” liner is included. Due to the geology in the past wells, this alternative is not realistic with regular drilling methods. The only drilling method which it is possible to go to that limit is the casing while drilling method. No further reflections will be taken on it.

8.1.5 Unconventional Diameter (Four Sections with one Contingency)

Unconventional diameters are those which are not much used in onshore operations in middle Europe. This is a much tighter version of the first design alternative. It starts with a 13 3/8” surface casing followed by a 10 3/4” intermediate casing. After this, an 8 5/8” second intermediate casing follows. Finally, a 6 5/8” production liner used to reach the target has to be installed. The contingency case would be a 4” liner. As said before, 4 1/2” would be the lower limit for the diameter, but because of the drift of 83.9 mm, this is still possible.

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depth [m]
17 1/2	316.46	13 3/8	Surface Casing	~659
12 3/8	244.5(S)	10 3/4	1. Intermediate Casing	~2719 - 2914
9 5/8	187.6	8 5/8	2. Intermediate Casing	~3860 - 4598
7 3/8	138.42	6 5/8	Production Liner	~5500
5 3/8	83.9	4	Contingency Liner	~5500

Table 11: Four sections with one contingency [14], [15], [16]

A common diameter for workover tools is 2 7/8” and that is equal to 73,025 mm. So it is possible to take a 4” liner but it is still unwanted. The only thing which would be necessary is a crossover from the liner top to the production tubing, because the tubing has a diameter of 4 1/2”. To overcome that problem, it is possible to drill the contingency with a 6” underreamer and run in a 4 1/2” Liner. A problem with this alternative is that with those diameters occur with the blow-out preventer and the well head. The problem occurs because the flanges of the casing head or spool and the BOP or well head have different punch circles. To overcome a crossover between the casing head or the spool and the BOP has to be used.

8.1.6 Unconventional Diameter (Four Sections with one Contingency & 9 5/8” Tie back liner)

The last casing design alternative is the most complex of all. This is the solution of the problem with the well head described in the point before. It is a combination of liner in the unconventional diameters and tie back liners to surface with common diameters connected with a crossover. The well starts with a very heavy 13 3/8” surface casing followed by a 10 3/4” intermediate liner. After this, an 8 5/8” liner with a 9 5/8” tie back as second intermediate casing has to be installed. Finally, a 6 5/8” production liner has to be run in. As a contingency, 4” liner is planned. It would also be possible to underream and install a 4 1/2” liner.

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depth [m]
17 1/2	309.65(S)	13 3/8	Surface Casing	~659
12 1/4	244.5(S)	10 3/4	1. Intermediate as Liner	~2719 - 2914
9 5/8	185.7	8 5/8	2. Intermediate as Liner	~3860 - 4598
9 5/8	206.38	9 5/8	Tie Back	~3860 - 4598
7 3/8	138.42	6 5/8	Production Liner	~5500
5 3/8	83.9	4	Contingency as Liner	~5500

Table 12: Four sections with one contingency & tie back with regular diameter [14], [15], [16]

Because of the small drift of the 13 3/8” surface casing, it is also possible to take a 14” casing. The special drift 322.3 mm and the bit size which can be used to drill the next section. It is a 12 5/8” instead of a 12 1/4”. This makes it easier to run in the liner, but it has the disadvantage that the problem with the blow-out preventer appears again. The same problem occurs after drilling when the well has to be completed, but this will be explained more in detail later.

8.1.7 Tapered String

A casing string is called a tapered string when the string of one section consists of more than one casing with different qualities or nominal weights. As already explained in a previous chapter, the calculation was done with the transformed calculation sheet. The calculation of the first time has shown that up to nine different qualities are possible for the conventional alternatives. Because a string composed of nine different qualities would give logistical problems, the number was limited to two. More numbers of casings would also give economical problems because of small amounts of ordering.

In general, it can be said that for the surface, first and second intermediate casing the tendency is that the loads are higher in the shallower part of the well and in the deeper part of the well the loads are lower. This results in the need of a higher load resistance in the lower part of the string and the lower load resistance in the upper part of the string. The production string, if it executed as casing to surface shows in the upper region the need of higher load resistance in the middle part a lower and in the lower part again a high load resistance. If the casing string is executed as a liner, the higher quality is needed in the lower part of the casing. This can be achieved either by taking higher steel quality casing or by using casing with higher nominal weight. Because of lower costs it is preferred to use casing with different nominal weight. When doing so, the inside diameter of the casing string becoming a stepped shape. Because this is unwanted for production strings a tapered string for this sections will not taken into account. The main target of a tapered string is to reduce the casing cost. The cost reduction of the calculated examples was about 5 % of the casing costs. So, there is a potential for reducing the costs and it has to decide from case to case if greater time expense is economical or not.

8.2 Design Alternatives considering Novel Technologies

8.2.1 Expandable Liner Hanger (VersaFlex® Liner Hanger System)

The VersaFlex® liner hanger system from Halliburton Company is a combination of liner hanger and packer which consists of an expandable solid body and a tie back receptacle. On the expandable body, several elastomers are attached. They are provided using a multidirectional sealing of the annular as well as the tension and compression load capacity.

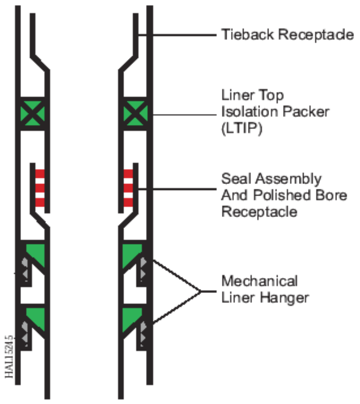


Figure 6: Regular Liner Hanger [17]

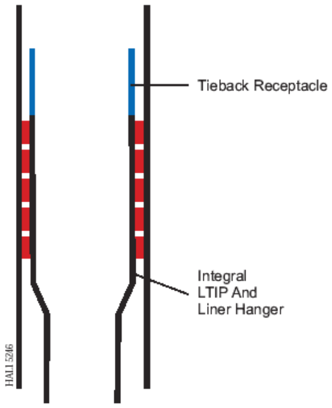


Figure 7: Expandable Liner Hanger [17]

It can be clearly seen on the figure above that the Versa Flex has a less complex design than a regular hanger. Due to that, the completion is also easier. Because of the use of several redundant sealing elements, the potential of leakage is also reduced. [17]

Combining this hanger with the conventional design alternatives shows several benefits. These benefits become even more important for the tight alternatives. The first is, there is no more top liner top isolation packer, which makes the whole installation less complex. Also, there is no more slip damage for casing support. The reduction of the outside diameter before setting makes it possible to run in the hole much faster which results in lower rig time and costs. The reduction of the run in diameter also reduces the risk of getting stuck. This is of special importance for the tight versions of the casing design. This hanger is field proven and has shown in hundreds of wells that it is a very good alternative to the regular liner hanger.

8.2.2 Expandable Casing

Expandable casings are solid steel pipes which are mechanically and hydraulically expanded after run in the well bore. The main reason for having expandable casings is to reduce well diameter while reducing the risk of getting stuck due to tight clearances. There is a limit of plastic deformation of the pipe without risking of pipe destruction. This limit is called “expansion ratio” and has a maximum of 30 %. [18] Another limit is the minimum clearance for cementation. The well diameter has to be 1” – 1 1/2” greater than the casing diameter. The working process of expandable casings is a little bit different than those with normal casings. After drilling, the first section with a regular bit, the casing has to be run in and cemented. An expansion of this section is also possible but not necessary. After this, the following sections follow the same principle shown in Figure 8:

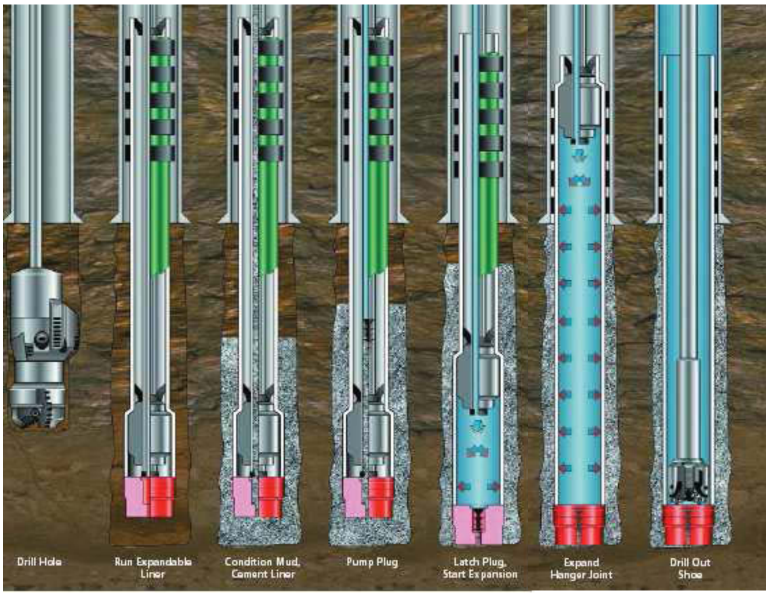


Figure 8: Process of inserting and enlarging of Expandable Casing [18]

The first process is to drill ahead of the first casing with a bicentered bit or an underreamer. The next process is to run in the expandable liner or casing on drill pipes or coil tubing. It has a shoe at the lower end to close the bottom of the casing. At the lower end inside the casing, the expanding plug is installed. The plug is connected to the drill pipes and the annulus between the expanding casing and the plug is sealed of. The plug has an opening at its lower side. The next step is to condition the mud and to cement the casing. After this is done, the expanding process can begin. Therefore, fluid is pumped inside the drill pipe down to the plug and out of the opening. The fluid can not move further and the pressure increases. As the pressure reaches the yield of the casing plug, it is forced upwards and the expansion starts. The expansion starts with the liner or casing. Finally, the liner hanger is expanded similarly to the expandable liner hanger system as explained in the previous chapter. The last process is to mill out the shoe. [18] Then drilling of the next section can begin. An example of a possible alternative is:

Bit size ["]	exp. Drift [mm]	Diameter ["]	exp. Diameter ["]	nom. Weight [lbs/ft]	Section	Setting Depth [m]
17 1/2	316.46	13 3/8	13 3/8	54.5	Surface Casing	~659
12 1/2	281.68	11 3/4	12 1/5	60	1. Intermediate Casing	~2719 - 2914
11	230.24	9 5/8	10 3/7	61.1	1. Intermediate Casing	~2719 - 2914
9	197.00	8 5/8	9	49	2. Intermediate Casing	~3860 - 4598
7 3/4	162.77	6 5/8	7 1/2	35	Production Liner	~5500
6 3/8	142.19	5	6 3/7	18	Production Liner	~5500
5 1/2	133.02	4 1/4	5 2/3	10.7	Contingency Liner	~5500

Table 13: Expandable Alternatives [19]

The table above shows the possible diameters, casing qualities and the resulting expanded diameters. It is only an approximation because the strength of the casing in its expanded position was not available and had to be calculated case by case from the supplying company. It can clearly be seen, that with the same surface casing diameter as those of the conventional four section alternative, it is possible to run eight sections and end up still with a diameter of 4 1/2”. In the case of four sections with one contingency, the last five diameters in the bold frame can be used. The reduction of the diameter is tremendous and will reduce the cost as well as the risk.

8.2.3 Monodiameter Wells

The monodiameter wells were not commercial until now, but they are promising great benefit. “Of all expandable applications to date, the monodiameter has the most potential to change the industry”, said Perry A. Fischer, editor of an SPE paper about monodiameter wells. It will take at least five years for commerciality of this technique.

To create a real monodiameter well, two expansions are needed. The first expansion is a bell-shaped (or flared) upper pipe. Into this bell shape a lower, subsequent pipe is expanded. The inner diameter of the bell is only slightly larger than that of the outer diameter of the lower pipe. Between the two pipes elastomerics, which act as hanger and sealing are squeezed in.

The limiting factor in terms of pipe size is the overlapping area. The bell shaped upper pipe reaches the limit of 30 %.

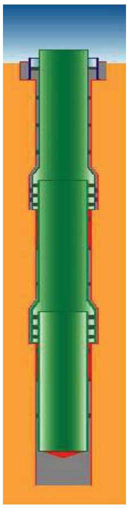


Figure 9: Monodiameter Well [21]

Expanding 9 5/8” x 11 3/4” pipe results in a 10.4” inner diameter. This leads to an expansion rate of 17 %, whereas the bell must be expanded by 24 %, which is well within expansion ratio limit. This makes 9 5/8” x 11 3/4” pipe to a practical monodiameter size.

Now the expanding of a 5 1/2” x 7” pipe results in a 6.1” inner diameter. This leads to an expansion rate of 25 %, whereas the bell must be expanded by 42 %, which exceeds the expansion ratio limit. For monodiameter applications, the smallest diameter which can expand in a bell is 7 5/8” x 9 5/8” pipe, which results in an 8” inner diameter. This leads to an expansion rate of 19 %, whereas the bell must expand 29 %.

For the cementing of the bell lies another problem. As already explained the borehole has to be 1” – 1,5” larger than the bell in order to give enough space for the cement to travel. For example, the already explained 9 5/8” x 11 3/4” monodiameter liner creates a 10.4” inner diameter and a bell outer diameter of 11.8”. With a cement clearance of 1.5”, it requires a hole size of 13.4”. This means that a bit would have to increase from 10.4” to 13.4”. This is an increase of 127 %. This can usually be achieved by underreamers and bicentered bits, but special adjustments may have to be made. [20]

8.2.4 Expandable Casing as Contingency

8.2.4.1 Expandable Liner

The idea of using expandable liners as contingency is not new but it is an ideal way to combine the lowering of the risk with the reduction of the diameter.

The following two examples are based upon the *MetalSkin* series from Weatherford Company. The first is a regular expandable liner system and the second is a monodiameter liner system. Both systems are already in use although the monodiameter liner system is quite new.

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depht [m]
17 1/2	316.46	13 3/8	Surface Casing	~659 - 1036
12 1/4	218.41	9 5/8	1. Intermediate Casing	~2719 - 2914
8 1/2	149.33	7	2. Intermediate Casing	~3860 - 4598
6 3/8	104.78	5 8/9	Contingency Liner	-
5	95.25	4 1/2	Production Liner	~5500

Table 14: Alternative 1

The table above shows the first of two examples of an expandable liner as a contingency. It can be seen that the contingency has to be installed in between and not at the end as it normally should. This is because of the small clearances and the fact that it is not wanted to get smaller diameter than 4 1/2”. So this Alternative is only a contingency case, if the accident happens before the 4 1/2” liner is set. If no problems occur it has to be dismissed. If an installation is necessary, because of small clearances, the section after the expandable casing has to be drilling with bicentered bits or underreamers. This has to be done to achieve the minimum diameter to guarantee the setting and the cementation of the next casing without problems.

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depht [m]
17 1/2	316.46	13 3/8	Surface Casing	~659
12 1/2	218.41	9 5/8	1. Intermediate Casing	~2719 - 2914
8 1/2	199.41	8 1/4	Contingency	~5200 and below
7 6/7	149.33	7	Casing - Liner	
5 3/8	95.25	4 1/2	Casing - Liner	~5200 and below

Table 15: Alternative 2

In Table13 the second alternative is shown. Here the contingency has to be set even one section earlier than in alternative 1. Even if no problems occur, for safety reasons, the expandable casing has to be installed. This means that the expandable casing is not a real contingency string. In both alternatives, the diameters of the contingency are those of the already expanded liners, so it can be seen that this alternative is not the ideal case. It is however, still thinkable. [22]

8.2.4.2 Monodiameter liner

The monodiameter liner is the newest development of expandable casings and in comparison to the complete monodiameter well, it is already economical. As a planned liner it can be installed instead of any regular casing string in the well. The example below is showing what the well construction can look like and how it raises the ending diameter compared to a normal casing string.

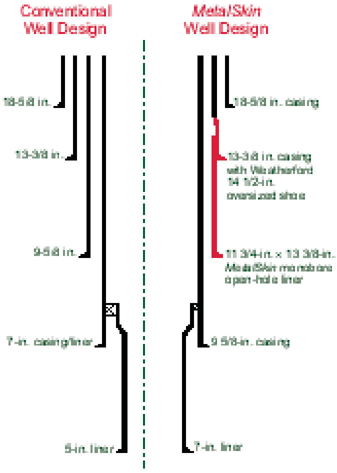
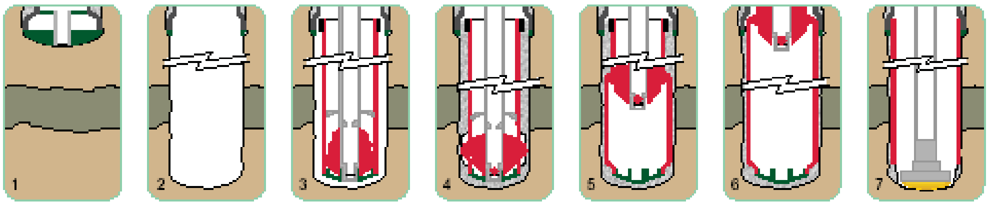


Figure 10: Comparison Expandable vs. Regular [22]

In terms of creating a backup as a contingency it is best to install the expandable liner at the end as the last casing string. Therefore, the penultimate casing string has to have an oversized shoe. This bell shaped shoe is either created before run in the hole or has to be created down-hole. In the system of Weatherford, the oversized shoe is already a part of the casing. [22]



Install base casing with oversized shoe.

Drill out shoe, and underream hole section.

Run in hole with monobore open-hole liner system.

Cement well (if required), assemble cone and initiate expansion.

Expand monobore shoe extension system.

Expand liner hanger.

Drill out shoe.

Figure 11: Running Process of Monodiameter Liner [22]

The figure above shows the installation and running process of the monodiameter liner. It has the same principle as the expandable casing described in the previous chapter.

With the expandable casings as well as the monodiameter casing it is no longer necessary to cement the casing to fix the string. Even the hydraulic separation between the casing and the formation behind the casing can be achieved. This is done with elastomerics which are squeezed between the casing and the formation. [22] All in all, for creating a contingency case, the monodiameter liner shows the best capability.

8.2.5 Casing while Drilling

One of the newest technologies in the oil- and gas industry is casing drilling. As the name says it is a combination of drilling the well by using the casing instead of the drill string and cases it simultaneous. This means that no more drill pipes are used for drilling the well. The borehole is cased after drilled down with the same casing. There are a lot of different configurations of drilling with casing, but there are two main technologies used for casing drilling:

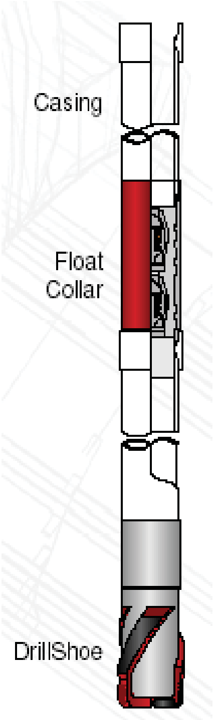


Figure 12: Rotational Drilling [23]

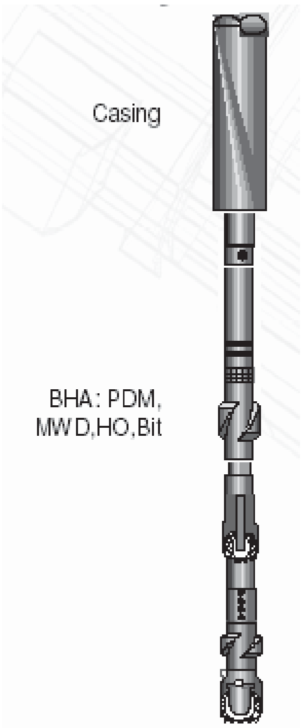


Figure 13: Drilling with Down-Hole Motor [23

The **first configuration** showed in figure 12 uses the casing for transmitting the weight and the rotary torque to the bit. The bit as well as the valve assembly has to be drillable. The valves run in the hole with the first casing. The casing is rotated during drilling and it is connected to the top drive via spear assembly which provides the transmission of the torque. After reaching the planned depth the casing can cemented immediately without additional trip.

The **second configuration** shown in figure 13 consists of a bottom-hole assembly with a down-hole motor (e.g. positive displacement motor – PDM), a drill bit, and a hole opener. This assembly is latched to the tool joint of the first casing. The casing can either run in sliding or in rotational mode. After reaching the planned depth the assembly has to be recovered. This is done by a special retrieval tool. Before cementation can start a valve assembly has to be installed.

Also, a big difference between the first and the second configuration is that with wireline retrievable BHA, some alterations have to be done and some additional units have to be installed. The crown block and the travelling block have to be split for installing a wireline winch. Wireline BOPs and additional solid control equipment have to be installed. Also, a top drive is required. With a rotary casing system no additional installations have to made, but drillable bottom-hole assemblies and bits have to be used. [23]

Due to the fact that the casing is always on bottom, problems due to geology can be eliminated. As shown in the previous chapter of the regular alternatives, the so called "mini" alternative is the suitable once for casing drilling. The following configuration can be implemented:

Bit size ["]	Drift [mm]	Diameter ["]	Section	Setting Depth [m]
17 1/2	316.46	13 3/8	Surface Casing	1000
12 1/4	218.41	9 5/8	Intermediate Casing	2700
8 1/2	152.5	7	Casing - Liner - Tie Back	5500
5 7/8	97.2	4 1/2	Contingency Casing - Liner - Tie Back	5500

Table 16: Example of Casing While Drilling Configuration

It can be seen that with this configuration, casing while drilling if well handled has the potential to save money while reducing the risk. Detailed explanations to the last two points will be given in the next chapters.

8.2.6 Fibre Glass Casing

The idea for using a fibre glass casing is to reduce the weight of the string. The specific gravity of fibre glass is 1.8 kg/l. Compared to the specific gravity of steel, which is about 7.8 kg/l this is very low. The fibre glass has an advantage. It is much more resistant against corrosive fluids and gases. So it may be able to be used for C_{O2} injection wells or for H_2S wells.

These casings are made out of premium fibre glass soaked and covered from aromatic amine cured epoxy. The pressure ratings are up to 17.2 MPa and the maximum temperature is 100 °C.

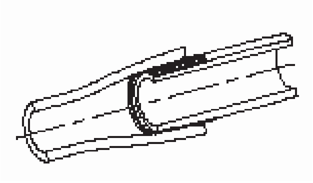


Figure 14: Integral joint [25]

The threads are regular API threads. There are the same different types of threads then those of regular steel casings. The difference is that the threads are not made out of steel but they are moulded with epoxy, graphite and ceramic. They are compatible with API steel threads. The thread

and wrench damage is lower and the chemical resistance is higher. The diameter ranges from 1 1/2” to 9 5/8”. Because of this, this kind of casing can only be used in parts of the well in the lower sections. In the upper sections the diameter is too small.
The main applications for fibre glass casings and tubing are:

- Disposal or injection tubing to depths of 3.000 m
- Production tubing
- Cemented casing or liners
- Chemical waste disposal
- Geothermal
- Slotted production liners and pre-packed screens
- Observation well casing
- Open hole casing or liner

Because of the low pressure resistance and the fact that only casings with small diameters are available until now, fibre glass casings are not very suitable for deep wells. Nevertheless, it could be an alternative for shallower oil or gas wells up to a depth of 1500 m or for injection wells up to a depth of 3000 m. [25]
For this usage it shows some benefit. The corrosion caused by C_{O2}, H_{2S} & salt water is under control. Also the casings have improved flow efficiency. They are easily drilled up and they show excellent logging characteristics.

8.2.7 Self Expandable Casing

Current expandable tubular technologies based on the plastically deformation of the tubular. A basic problem with the deformation of steel is that this process results in shrinkage in the other dimensions. It also causes irregularities in the chemistry and the wall thickness. Combining this with inhomogeneous borehole conditions this result in a reduction of the possible tubular expansion.
Another point is that current expandable tubular technology is not possible for slimhole drilling by coiled tubing because the initial pressure needed to expand the tubing would be too high.

The development of the self expandable casing is still in the project phase. The planned end of the project is 2008.

Figure 15: Structure of the self expandable casing [26]

The expandable casing consists of volumetrically adjustable cells in honeycomb structures, which are compressed to reduce the outside diameter. The metallurgical bonds between various interior "cellspring" surfaces hold the reduced size temporarily in place. Those bonds are removed as soon the casing is in the well bore. This is done either by chemicals or by mechanical activation. After this activation the casing recovers nearly to its original dimension. The structure is shown in Figure 6.

The project began 2005 with a selection of the best of several design concepts. This concept was optimized and a prototype was planned. The design is capable of 200 % expansion and indefinite pressure capacity. The next step is the optimization and completion of the design and a construction of a prototype. This project is developing an expandable casing that consists of pre-stressed cells that eliminate shrinkage and don't require pressure for deployment. After this the prototype is tested in the laboratory, a final test in a section of a real well has to be made. [26]

Figure 16: Cross section thought a self expandable casing [26]

Design Alternatives

One of the main promised advantages is to reduce drilling risks and improve economics throughout exploration and production. Self-expanding technology allows reduction of hole volume, increased inside diameter production tubing, shortened field schedules, and minimized drill site footprint. The technology is well-suited for drilling and casing micro holes with tight annular spaces.

9 Completion Aspects

In case of an open hole completion the final diameter has nearly no restrictions. Only minimum diameter from the production side is required. Also for gravel pack installation it is cheaper to have a smaller diameter due to the need of less gravel pack material. Another point is that a well with a smaller diameter is more stable than a bigger one.

With the “big alternative” (four sections with one contingency) we have an 18 5/8” surface casing. For that dimension an 11” christmas tree is needed to complete the well. With the “small alternative” (four sections without contingency) we have a 13 3/8” surface casing. For that dimension a 7 1/16” christmas tree is needed to complete the well. Only wireline retrievable big diameter subsurface safety valves (SSSV) are possible in a 7” tie back liner to surface. Tubing retrievable SSSV is better because of it’s bigger outside diameter.

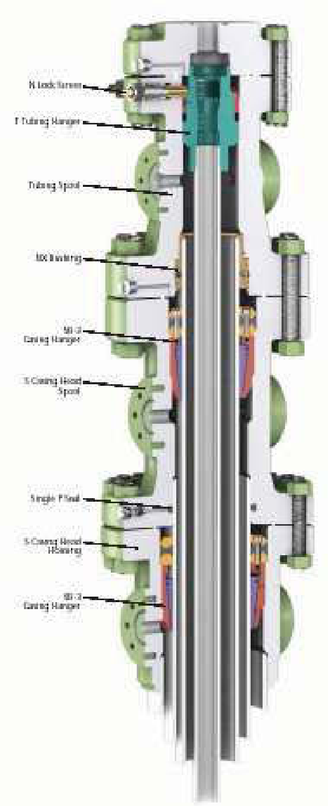


Figure 17: Cameron S wellhead system [12]

The connection from the first casing (surface casing) to the casing head shown in the figure above has to be checked for compression load and its safety factor during the lifetime of the well. This should include corrosion outside as well as inside the casing. In terms of production, it is better to end up with a 41/2” diameter liner because the tubing also has a 4 1/2” diameter and it is good for the oil or gas flow to have a so called monobore well. For work over operations, this is not very good. Here, it is better to end up with a 7” diameter casing to have “more space” to work. The diameter of the most workover tools is 2 7/8” and with a 4 1/2” liner the clearance starts to get very small. The clearance is about 4/5”. By ending up with the contingency case of the tight alternative this clearance is only about 2/5”. This influences not the cost but it makes it easier for handling. For stimulation it is better to have a smaller diameter because less expensive fracturing-fluid is necessary.

10 Risk Analysis

10.1 General Risks

There are four main parts of the drilling operation of a well where problems can occur:

- Drilling operation
- During run in and pull out
- During casing run
- During logging

10.1.1 Drilling Operation

While drilling in an unexpected high pressure formation, an inflow from the formation is possible. This can even result in a kick and a well control problem.

By drilling in a high fractured formation, fluid loss is often a big problem. When fluid loss is not handled fast enough, the bottom-hole pressure will be reduced and it can result in a kick.

Drilling through unexpected under-hydrostatic zones has the same effect as drilling in fractured formations.

10.1.2 Run In/Pull Out, Casing Run and Logging

The biggest problem of these three steps of drilling a well is time. Formations like shale become unstable when they are exposed too long to the drilling mud. This means that in these formations, the length of one section is also limited by time of open hole. This problem gets even bigger in depleted reservoirs. The pore pressure of the reservoir fluid (which helps too hold the formation stable) is missing and this make the problem even worst.

Also problems can appear by drilling through plastic formation like plastic shale or salt. If the open hole time is too long, these formations can deform the borehole or close it. This can result in sticking of logging tools or the drill string.

10.2 Geological Problems

10.2.1 Surface Casing Section (between 500 m – 700 m)

No problems have to be taken into consideration. The final depth of this section had to be, because of safety reasons, above the first hydrocarbon layer. The corresponding formation would be the Lower Pannon.

10.2.2 First Intermediate Casing Section (~ 3200 m Top Reyersdorfer Dolomite)

Some losses in the Aderklaaer stratums have been recognized in the past. But in this formation, the losses are sporadic and not predictable. Sometimes there are losses and sometimes not, but they have to be taken into account. Also, a smaller problem at the observed wells was the borehole stability of the well. After some days the well starts to close and reaming was necessary. This was mainly in the Ottnang and the Karpat with a corresponding depth of 2100 m – 2300 m and between 2700 m – 2914 m.

10.2.3 Second Intermediate Casing Section (~ 4500 m Neokom)

The main problem was the H_2S content in the Reyersdorfer Dolomite and the overpressure of this formation. Important for the setting depth in this section, was the fact that below the Reyersdorfer Dolomite the Hierlatz/Hornstein Lime follows. This is a formation were mud losses can occur and a combination with the over pressured Reyerdorfer Dolomite would give big problems.

10.2.4 Production Casing Section (~5200 m Top Noric Dolomite)

This is the section were the most problems had been appeared. The first problems were losses in the Hornstein/Hierlatz Lime. The next, was the over-hydrostatic pressure regime of the Perchtoldsdorfer Dolomite. A combination of both cases is the real problem in this section. Another problem was an instable layer between the Raetic and the Noric Dolomite. Fall back can happen in this formation. [6]

10.3 Technical Problems and Risks of Conventional Design Alternatives

For all design alternatives a risk analysis was made. Therefore the daily drilling reports were analysed and problems occurred during drilling operation were pointed out. Then the solution and its additional time requirements were reported. After this the loss of money based on the rig day rate was calculated. As soon this was done the probability that this problem would happen in the future was calculated. It was based on the two reference wells. The assumption was made, that if an accident happened at no well the probability for the future is 0 %. If an accident happened at one well, the probability would be 50 %. If it happened at both wells, the probability is 100 %. For a better refinement, instead of 0 %, 15 % was used and 90 % instead of 100 %. As the probability was now available, a probability waited risk was calculated. The probabilities of problems are from the reference wells Straßhof T4 and T5. The occurred problems are taken from the daily drilling reports. It can clearly be seen, because only two reference wells where taken into account, that this method is very rough and inexact, but it gets better if more reference wells are involved. This method was done with no computerized model but by hand. For the future a model should be useful.

Section ["]	Work	Problems	Solving Action	Timeloss [h]	Moneyloss [€]	Probability [%]	Problem cost x Probability
12 1/4"	Drilling	inflow	mud weighted	10	17.989,20	50	8994,60
		mud losses	reduce MW, pump pill	10	17.989,20	50	8994,60
		H2S-Content in the Reyersdorfer Dol.	special coring threatment, safety,	3	5.396,76	15	809,51
		over-hydrostatic pressure Regime	mud conditioning	2	3.597,84	15	539,68
	Logging	Logging tool Stand off during run in	ram down, run out, wiper trip, reaming	13	23.385,96	15	3507,89
		Logging tool stuck	over pull, pump pill	50	89.946,01	15	13491,90
		Logging tool Failure	additional round trip, tool repair	13	23.385,96	50	11692,98
9 5/8"	2. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate, reaming	20	35.978,40	15	5396,76
		Casing stuck	overpull, pump pill, circulate and rotate	6	10.793,52	15	1619,03
		incorrect setting depth	------	3	5.396,76	90	4857,08
		Depth Prediction	------	3	5.396,76	90	4857,08
	Cementation	Cementing problems	recementation,	5,5	9.894,06	15	1484,11

Table 17: Risk Analysis Sheet

The table above shows the analysis sheet for one section of the well. It also can be seen that the drilling process is split in four groups: drilling, logging, casing or liner installation and cementation. This analysis sheet does not include side tracking or abandon the well. [2], [4]

10.3.1 Four Sections with one Contingency

Of all variants, this is the safest. It has the same risks than the other alternatives but with a lower consequence. (in terms of money) By including one contingency string, it is possible to react if one of the problems discussed before occurs and an additional casing string has to be set. Also, due to its greater clearance between every casing string, the wellbore and the casing itself, makes it easier to handle casing run tripping or logging. For reaching a depth of 5500 m under those geological conditions, four sections with one contingency is a very good way to bring down the well. If greater depths should be reached, a furthermore section has to be planned or at least one or more additional contingency case. From the risk analysis, this design alternative has a waited value of EUR 410.585. The case of a 16” surface casing section has a little bit higher risk. The value is about EUR 410.734. This comes from the smaller clearances between wellbore, casing and the casing of the next section. The probability that a problem would occur is higher than with an 18 5/8” casing section.

10.3.2 Four Sections without Contingency

This is a more unsafe method to drill a well down to 5500 m. Due to its design there is nearly no more leeway for greater problems. This means that the risks are the same than in the previous design but , because of the missing contingency, the consequences are much higher. For solving “daily problems”, this alternative is even better than the previous. Due to its smaller and “lighter” design, problems are solved faster and therefore cheaper than a design with greater diameters. The risk of getting stuck with a logging tool is higher because of the small clearance. The log has a diameter of 5 7/16” and the well a diameter of 6 1/2”. So it is clear that the waited risk with a value of EUR 314.978 is smaller than the one before.

If a bigger problem occurs which would lead to the necessity of a contingency, this design has only two options. The first would be to make a side track. The second would be to abandon the well and drill a new one. The side track has a risk value of EUR 795.401. If this number is added to the first value the new value would be EUR 1.110.379 which is significantly higher than those of the first design alternative.

10.3.3 Unconventional Diameter (Four Sections with one Contingency)

This design alternative, in principal, is the same as the first. It also has one contingency case for bigger problems, but the whole well design has smaller diameters. The design has smaller clearances and is, all in all, a much tighter design. Because of this the risk of getting stuck with a drill bit, bottom-hole assembly, casing or logging tool is much higher. The value of the risk is EUR 423.228. If the contingency case has to be used, an additional problem could be the 4" liner diameter. For work over, the tighter clearance between the inside diameter of the liner with 3 1/3" and the diameter of the work over tool of 2 7/8", could be a problem. Another problem could be the availability of drill bits, BHA or special tools. If problems occur and the drilling assembly or other parameters have to be changed it is may be not possible to do this in a acceptable time, because of longer delivery times of necessary tools. The same problem can appear. For example, a fishing job is needed, which is normally at short notice. Then it may need several days or longer before the right tool is on the well site. All those things have to be taken into account when deciding for that design.

10.3.4 Unconventional Diameter (Four Sections with one Contingency & 9 5/8" Tie back liner)

The casing design is the same as the previous, with some small differences as those discussed in the chapter before. Besides the problems of the previous alternative, due to the installation of a tie back liner, additional problems appear. This means because of a more complex run in procedure of the liner and the tie back liner, the risk is much higher than with those of a run in a casing. Another problem is the smaller clearances between the greater outside diameter tie back liner and the previous casing. Therefore the risk number is higher than EUR 456.923.

10.4 Risks and Limitations of Design Alternatives considering Novel Technologies

10.4.1 Expandable Alternatives

Due to the similarities of the different alternatives using solid expandable technology, the problems and risks are quite the same. Always a big problem has been the sealing of the connections. This comes special in appearance if gas tight connections are demanded. Due to new technologies which achieve gas tightness, this problem is not that dangerous anymore, but it is still something to keep an eye on. Another big problem is the strength of the expanded casing. Because of expanding the steel pipe to a bigger inner diameter, the wall thickness is reduced by 1 – 1.5 mm, depending on the expansion ration. The result is now a casing with a bigger diameter and smaller wall thickness. In other words, we create a casing with the same nominal weight, but with a bigger diameter than before expansion. For example, in the previous alternative, a base casing with a diameter of 5” and a nominal weight of 17 lbs/ft was used. After expansion, the diameter was 5 8/9” with the same nominal weight. It can clearly be seen that the difference is quite big. So this means that this has to be included when planning the well. A great problem can occur if the expansion of the hanger, at any cause, can not be completed. Then the risk is very high that the liner falls down the wellbore. The result is that the liner may buckle and due to the cementation, it is may not be possible to fish it out and straighten it again. If the sealing is damaged during run in hole additional problems appear if the annulus between the expanded hanger and the previous casing can not be sealed off.

A further problem can appear if there is fluid loss during the expansion process, because then the casing is not expandable anymore. Therefore, a hydraulic jack as a back up system has to be installed.

In terms of safety, it has to be said that the use of high pressure of more than 700 bar is very important. The safety surface equipment has to be adequate and the people who are working on the rig have to be instructed of the special dangers during the job. To counteract that problem the self expandable casing would be a good alternative for the future. The monodiameter well system still has too many uncertainties for a realistic alternative, but it is the optimum and the best way of well construction until now.

All in all the expandable reduces the technical risks like BHA, logging and casing stick or stand off. Also, liner setting problems and problems with the liner hanger are reduced.

10.4.2 Casing while Drilling

The following analyses are based on the TESCO Drilling System already shown. Generally, it can be said that casing while drilling reduces the risk dramatically. It reduces the well control problems like lost circulation or kick to a minimum. The risk of hole problems, water hazards and fall back of or unstable formations is also reduced. Because casing is covering the formation during the drilling process, the destruction of the formation and the formation of wash out is reduced. It also makes it easier to drill trough depleted reservoirs. Because the casing is always at the depth of the BHA, problem with stuck pipe or differential pipe sticking are nearly eliminated. It makes it possible to get the casing always to its planned depth. The risk of time delayed changes in the shape of the wellbore or closure of it can be counteracted, because the cementing has to begin almost immediately upon reaching TD. There are also some risks which come with the design. Due to smaller clearances the cutting output can be a problem. This leads to possible stuck. Also the directional drilling is a very big problem and challenge the drilling companies. In spite of all the positive things, there are several limitations. Drilling with casing requires bits which are small enough to pass trough the casing but they should be able to drill a hole large enough for the casing outside diameter. This makes it necessary to use underreamers in combination with a smaller diameter bit or bicentred bits.

BHA change: The change of bottomhole assemblies or bits is done by wireline which can have problems. Because with casing drilling the well is cased during drilling uncased openhole sections do not exists. Therefore regular logging trips are not possible. It is possible to pull the casing and to log at the bottom but this seams to not be a very good solution. It would be better to use logging while drilling (LWD) cased hole logs. Other formation evaluation tools like core barrels or testing equipment are installed with wireline and latched to the casing.

The connections of a casing normally are not made to resist high torque or tension and compression loads. They are also not made to withstand high buckling loads. This means that by using casing while drilling the torque, bit weight and the buckling should kept as low as possible.

After drilling the section the BHA is removed with wireline. The problem is now that the casing did not have a float collar for landing the cement plug. To solve that problem the displacement plug has to be landed and latched to the casing. After the cement job is finished the plug and the cement below has to be drilled away.

11 Costs and Benefits

11.1 General

A drilling project doesn't have the target to get out the highest revenues of a project, but it has the duty to control the costs and to work as much economic as possible. The following costs are examples based on the AFE calculations of one of the reference well of this work Straßhof T5. The overall cost of a well is composed of several single costs. There costs are influenced by time, which is based on the well plan. One of the most important factors thereby, is the well diameter. The following analysis of the costs of the different variants will show which part of the costs mainly influences the overall cost of the project. Therefore, five well diameter sensitive parts of the costs are emphasized out: casing costs, bit costs, mud costs, cement costs and cutting disposal costs.

Cost changes for different completions, like wellhead sizes, due to different diameters are not taken into account, but an eye needs to be kept on it in the praxis. The following costs of the conventional alternatives are based on the alternative four sections with one contingency. As this alternative is the most expensive one during the following alternatives the cost differential (Δ Cost [€]) will be given.

11.2 Conventional Design Alternatives

11.2.1 Four Sections with one Contingency

As said in the chapter before, this is the safest variant, but it is also the most expensive one. Roughly, it can be said that the greater the diameter of a well, the greater the costs. By starting with a diameter of 18 5/8", this variant has the biggest diameters of all. As a consequence of that this alternative has the highest costs.

Cost category	Cost [€]
Casing costs	2.746.192
Bit costs	450.000
Mud costs	936.811
Cement costs	476.695
Cutting disposal costs	225.984
Rig + Additional costs	7.474.371
Overall costs	12.310.053

Table 18: Cost of Casing Design Alternative

The table above shows how the costs are distributed. It can be seen that the casing costs are more than 20 % of the overall cost. This means that there influence on the overall cost is very great, and so it makes sense to try to reduce casing costs. This can only be done by reducing the diameter of the casing. Another big block is the mud costs (there are about 8 % of the whole costs).

By reducing the Surface Casing diameter from 18 5/8" to 16" it is possible to reduce the cost by EUR 136.193.

Cost category	Cost [€]	Δ Cost [€]
Casing costs	2.659.543	86.649
Bit costs	447.000	3.000
Mud costs	910.534	26.277
Cement costs	473.184	3.511
Cutting disposal costs	209.228	16.756
Rig + Additional costs	7.947.082	-
Overall costs	12.173.860	136.193

Table 19: Cost of Casing Design Alternative

The main costs which influence the reduction are the casing costs, mud and cutting disposal costs. The bit and cement costs haven not changed significantly.

11.2.2 Four Sections without Contingency

In contribution to the first variant, this is the cheapest one. The overall costs are about 26 % less than those of the alternative before. The casing costs are the biggest block in the table below.

Cost category	Cost [€]	Δ Cost [€]
Casing costs	1.582.461	1.163.731
Bit costs	304.000	146.000
Mud costs	602.655	334.156
Cement costs	293.823	182.872
Cutting disposal costs	113.696	112.288
Rig + Additional costs	6.098.206	1.376.165
Overall costs	8.994.841	3.315.212

Table 20: Cost of Casing Design Alternative

In the table above the reduced costs due to the smaller design can be seen. The listed factors above are 58 % of the overall cost differential. The rest mainly comes from the reduced drilling rig costs and due to the reduced drilling time. Another smaller part comes from the fact that this variant, because of its smaller and lighter casing strings, can be drilled with a smaller rig. The smaller rig has smaller day rates than a bigger rig. This variant has definitely got the advantage of a lot lower costs.

11.2.3 Unconventional Diameter (Four Sections with one Contingency)

This design alternative was invented to reduced cost by reducing the diameter. As explained in the previous chapters this variant is the same as the first one with the difference of smaller diameters of the sections. This reduces the costs by EUR 788.824 which is 6.4 %.

Cost category	Cost [€]	Δ Cost [€]
Casing costs	2.326.416	419.776
Bit costs	376.000	74.000
Mud costs	892.847	43.964
Cement costs	232.618	244.077
Cutting disposal costs	197.120	28.864
Rig + Additional costs	7.496.228	21.857
Overall costs	11.521.229	788.824

Table 21: Cost of Casing Design Alternative

As seen in the table more than the half of the cost reduction comes from lower casing costs. The second biggest part is the reduced cementing costs. This comes from the smaller clearance between the casing and the wellbore, and between casing and the casing of the previous section. Not included are the costs of different drilling and cementing equipment and casing setting tools. This could raise the cost again.

11.2.4 Unconventional Diameter (Four Sections with one Contingency & 9 5/8” Tie back liner)

This alternative was created to overcome eventual additional cost due to the necessity of a different BOP stacks as well as a well head. The case is based on the previous case and so are the costs. Although the tie back liner has greater diameters, the costs are quite similar to the previous case. This comes from the reduced cementing costs. Because of the smaller clearance between the greater diameter tie back liner and the previous casing less cement volume is needed.

Cost category	Cost [€]	∆ Cost [€]
Casing costs	2.373.964	372.228
Bit costs	376.000	74.000
Mud costs	895.297	41.514
Cement costs	225.118	251.577
Cutting disposal costs	197.120	28.864
Rig + Additional costs	7.496.228	21.857
Overall costs	11.563.727	746.326

Table 22: Cost of Casing Design Alternative

The table shows the reduced cementing costs. The casing costs are higher than in the alternative before. This is because the used tie back liner is more expensive than those with a smaller diameter. A small reduction in the casing costs is that the 10 3/4” casing is made as liner without tie back.

11.3 Design Alternatives considering Novel Technologies

11.3.1 Expandable Alternatives

Besides the already explained risks reduction the expandable casings shows several other benefits. The first and most obvious is that due to expanding the casing after installation a greater clearance during run in the casing can be achieved. Due to that several problems can be reduced or even eliminated. Because of greater clearance the pressure loss in the annulus between the casing outside and the wellbore is reduced. Therefore, problems with equivalent circulation density (ECD) and differential pipe sticking are minimized. Also, the run in speed can be greater with this configuration and risk of a stuck pipe and fishing or lost tools is reduced.

In terms of a liner in the area of the hanger, the possible leak paths are eliminated by multiple packing elements. Trough these packing elements the stress on the previous casing is evenly distributed. Because of the missing external elements like the regular hanger-packer-assembly, a faster run in and a better circulation rate can be achieved. [17]

By the use of a monodiameter liner, there are some extra advantages for the well construction. It is possible to have an extra string without loosing any hole size. It can be used as contingency to overcome lost circulation or over-pressured zones as well as for regular liner installations. If a monodiameter well could be achieved all those benefits would be multiplied. [22]

In general it can be said that expandable casings leads to fewer cuttings, reduced mud and cement, smaller surface string, drilling smaller holes with higher ROP and the potential for the use of smaller rigs.

The benefits from expandable casings and single diameter wells are all good, but the most important is time. Reducing the drilling time not only reduces the costs. As the drilling period of the well is finished as earlier oil can get out of the well. Also construction costs can be reduced due to slimmer well design.

Examples of the past showing that by using expandable, the following cost reductions can be achieved:

Advantages	[%]
reduction in casing costs	20
reduction in cementing costs	60
increase in ROP	40
reduction in bit costs	25
reduction in hole cleaning time	50

Table 23: Possible Cost Reduction [30]

With monodiameter liner or even hole wells, the cost savings can be even higher. Smaller boreholes could save as much as 59 % for cuttings disposal, 38 % for casing weight, 42 % less cement and 44 % less drilling fluid volume. [20] The examples show only approximations, but it can clearly be seen that the potential for cost savings is quite high. For detailed cost prediction the individual case has to be analysed.

11.3.2 Casing while Drilling

When comparing casing while drilling operations to regular drilling operations, one finds that there are several benefits which can be pointed out. The main is that because of drilling and casing at the same time, it reduces drilling time by eliminating the flat spots in the drilling curve which lowers the costs. Because the casing is always on or near bottom, as already explained, several trip related or unexpected problems are reduced which lower the cost as well. Also no contingency string is necessary. This leads to a smaller diameter well design as a consequence of that to smaller "foot prints" at surface. This also causes a reduction in mud cost, cutting disposal and cement costs. Because the casing is used instead of the drill pipes, no rental costs of the drill pipes and collars are needed which reduce the rental costs. With this method it is not necessary to use double or triple masts which make rig movement easier. Also the lower maintenance and fuel cost as well as less wear and tear of the drilling unit makes this system also beneficial. [27], [28]

Casing drilling wireline winch	384.600
Split crown block	115.400
Split travelling block	115.400
Wireline BOPs	38.500
Solid control equipment	65.400
Rig day rate (8 days)	162.400
Total	801.600

Table 24: Additional Costs for Conversion [27]

A lot of points are shown which reduce the costs, but one point has to be added to that discussion. For casing while drilling, a normal rig has to be adapted. A wireline winch has to be installed as well as a BOP for the wireline. Also the crown and the travelling block have to be split. In the case that it is a rig with no top drive, a top drive has to be installed as well. The table above shows the costs for the additional installation including the day rate of the rig during the conversion work. It can be seen that the costs are quite a lot, but the cost reduction is still very high.

Well name	time [d]	Rig dayrate [€/d]	Rig Costs [€]	problem [%]	problem [d]	problem cost [€]
Straßhof T4	84	46970,4	3.945.513,60	6,43	5,40	253.697
Straßhof T5	109	39272,16	4.280.665,44	2,80	3,05	119.859

Table 25: Problem Costs

Examples of 57 drilled wells in south Texas show that a reduction of the problem costs down to 3 % is possible. Of course this value is a very theoretical and it has no to be take too serious, but it shows that a reduction in the costs due to problem is possible. In the case of the two reference wells this would mean for T4, a reduction from EUR 253.697 to EUR 7.610 and for T5 from ~EUR 120000 down to ~ EUR 4.0. The same example of Texas shows that the average drilling time was about half of drilling conventional. The reduction for T4 would be EUR 1.972.756.8 and for T5 EUR 2.140.332.72. Based upon the example of Texas, the approximated costs for the Straßhof T4 project would be about EUR 6.022.757.57 which is a cost reduction of 33.04 %. For the Straßhof T5 project the costs would be about EUR 10.179.004.41 which is a cost reduction of 17.31 %. It can clearly be seen that the cost factor is quite important for this system.

12 Conclusion

There are a lot of alternatives discussed in this work and even more exist. To give a recommendation of a concrete design alternative for the whole Vienna Basin is not easy. Every single alternative of the six conventional design alternatives have advantages and disadvantages and a change to a different casing design can bring additional problems not discussed in this work. It has however, been shown that four sections with one contingency are necessary. Therefore, the recommended casing design alternative is the second unconventional diameter alternative with the 9 5/8” tie back liner, which shows the best possibility to save costs and drill the well as safe as possible. Due to its liner configuration, the change of surface equipment like BOPs and well heads is not that big when using casing to surface. If casing to surface is necessary the Tie back liner with regular diameter shows the best way to use.

Further the implementation of a risk analysis tool for drilling operations is recommended. With this, the contingency string could eventually be dismissed in certain cases. There are several programs on the market like Osprey, P1, UNRiskIT or RiskAMP. Non of them were used during this work.

From the novel technologies the monodiameter liner as contingency shows great potential for cost savings. Also the casing while drilling could save costs while lowering the risk. The exact cost and the adaptability of both systems should be checked out more in detail with the service companies. Then maybe, for a shallower well with less section this technology can be used.

The monodiameter well as well as the self expandable casing should be watched and the capability for the future should kept in mind.

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Conversion Factors

inch	=	mm	25,4
lbs/ft	=	kg/m	1,488278
kg/l	=	bar/m	0,1
MPa	=	bar	10
10^3 daN	=	t	1,019368

Abbreviations

AFE	
API Bul 5C2/C3	Guidelines for Casing Load Calculation by American Petroleum Institute
BHA	Bottom Hole Assembly
BOP	Blowout Preventer
BTC	Buttress Thread Connection
DP	Drillpipes
ECD	Equivalent Circulation Density
EOB	End of Built
FIT	Formation Integrity Test
G	Gravity
GFK	Fibre Glass Strengthened Synthetics
G_{frac}	Fracture Gradient
HO	Hole Opener
ISO	International Standardization Organisation
KOP	Kick off Point
LOT	Leak off Test
LTC	Long Thread Connection
LWD	Logging While Drilling
MD	Measured Depth
MW	Mud weight

MWD	Measuring While Drilling
NW	North-West
OD	Outer Diameter
SG	Specific Gravity
SPE	Society of Petroleum Engineers
SSSV	Sub Surface Safety Valve
STC	Short Thread Connection
PDM	Progressive Displacement Motor
TD	Total Depth
TU	Technical University
TVD	Total Vertical Depth
UGS	Untergrundspeicher- und Geotechnologie-Systeme
VAGT	Vallourec Gas Tight
WEG	Wirtschafsverband Erdöl - und Erdgasgewinnung

Appendix

Target – Actual – Comparison

Straßhof T4

Well Trajectory

The well Straßhof T4 was planned vertical until a KOP of 2230 m and than built up to an inclination of 34 ° with an azimuth of 143.6 °. After this section, there was a tangent section planned to reach the target at a measured depth of 4300 m. The azimuth was necessary because of the dipped formation. To ensure that the drilled well has a rectangular position to the inclined formation the planned angle of 34 ° has to be hold.

	Plan			Done		
	MD [m]	Inclination [°]	Azimuth [°]	MD [m]	Inclination [°]	Azimuth [°]
KOP1	2230.0	0	143.6	1800.0	0	162.0
EOB1	2688.0	34.0	143.6	2308.0	31.8	162.0
9 5/8	2970.0	34.0	143.6	2910.0	31.8	162.0
Correction	-	-	-	3330.0	35.4	162.0
7	3790.0	34.0	143.6	3750.0	35.4	162.0
MD	4300.0	34.0	143.6	4514.0	35.4	162.0

Table 26: Well Plan

As shown in table 1, the planned kicks off point as well as the end of build were not reached. This was because of geology reasons. The table above also shows that the inclination was not reached right away. That meant that it was necessary to correct the angle at the beginning of the tangent section from 31.8 to 35.4 °. The planned inclination was finally missed by only 1.4 °. The azimuth was corrected to 162 °, so it differs from the planned angle by 18.4 °. The geology differs quite a lot from there predictions. Especially, the top depths of the formation are different, but this will be explained more in detail afterwards.

Casing Design

As said before, the well Straßhof T4 was planned with 4 sections without a contingency string. It has an 18 5/8” standpipe which is dug in. The casing string starts with a 13 3/8” surface casing down to 560 m, followed by a 9 5/8” intermediate casing with a setting depth of 3015 m. After this point, a second intermediate casing performed as a 7” liner was planned to a depth of 3790 m. Finally, a 4 1/2” production liner string was planned to install. The setting depths are based on the geology and the pressure predictions for the occurring formations. The steel quality and the nominal weight of the casing were chosen due to calculations of the predicted stress based on OMV standards. Further detailed explanations about OMV casing calculation standards are given in chapter 5.

	Plan			Done		
	Section ["]	MD [m]	nom. weight [lbs/ft]	MD [m]	nom. weight [lbs/ft]	qual. / thread
Standpipe	18 5/8	8.0	-	8.00	-	-
Surface Casing	13 3/8	560.0	54.5	553.8	54.5	L-80 / BTC
Interm. Casing	9 5/8	3015.0	47.0	2907.6	47.0	L-80 / BTC
Liner	7	3790.0	29.0	-	-	L-80 / BTC
Tie-Back Liner	7	-	-	3707.6	29.0	L-80 / VAGT
Liner	4 1/2	4300.0	13.5	4514.0	13.5	L-80 / VAGT

Table 27: Casing Program

As you can see on the table there are differences between the planned and the actual setting depths. The differences may come from uncertainties from the prediction of geological layers where we want to set the casing. Because the pressure of the occurring kick was to high for the 9 5/8” section a 7 “ tie back liner had to be installed.

Pressure Regime (Mud Program)

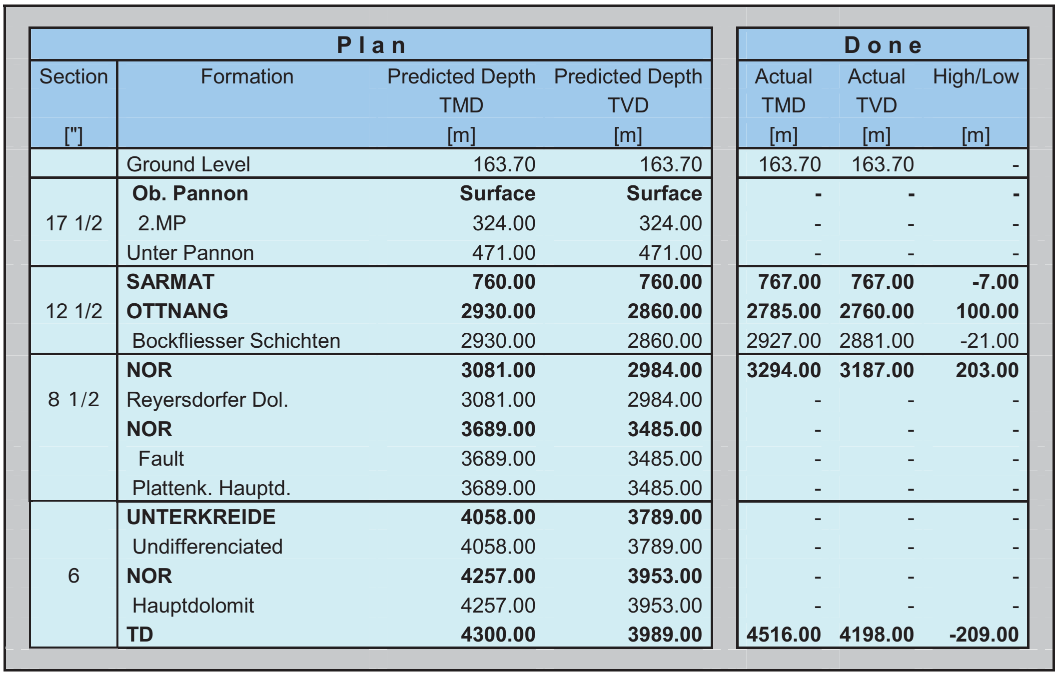
The mud program as it was planned was quite suitable with some exceptions. At a measured depth of 4209 m and between 4237 m and 4268 m, some fluid losses occurred. At the depths 3320 m and 4517 m, connection gas had been recognized and mud treatment was necessary. A kick while run in the 4 1/2” liner had to be handled. It was done by well control operations and well fluid treatment. The problems had occurred because the well was drilled in an undifferentiated section of Lower Cretaceous, but reaching this formation was one of the targets and part of the planning. All problems were solved with out any further accidents.

Plan					Done			
Section ["]	MD [m]	Condition	SG [kg/l]	H_2S	MD [m]	Condition	SG [kg/l]	H_2S
17 1/2	8.0 – 560.0	hydr.	1.05 – 1.12	no	8.0 – 553.8	hydr.	1.06	no
12 1/2	560.0 – 1930.0	hydr.	1.05 – 1.12	no	553.8 – 1120.0	hydr.	1.08	no
12 1/2	1930.0 – 2110.0	underhydr.	1.05 – 1.12	no	1120.0 – 1930.0	hydr.	1.11	no
12 1/2	2110.0 – 3015.0	hydr.	1.05 – 1.12	no	1930.0 – 2110.0	underhydr.	1.08	no
12 1/2	-	-	-	-	2110.0 – 2907.5	hydr.	1.08	no
8 1/2	3015.0 – 3790.0	overhydr.	1.12 – 1.25	yes	2907.5 – 3238.0	overhydr.	1.18	yes
8 1/2	-	-	-	-	3238.0 – 3707.6	overhydr.	1.27	yes
6	3790.0 – 4300.0	overhydr.	1.20 – 1.30	yes	3707.6 – 4514.0	overhydr.	1.16	yes

Table 28: Formation/Mud Pressure

Geology

The geological data came from the reference wells Straßhof T2 and Bockflies 12. The primary targets were the Reyerdorfer Dolomite and the Hauptdolomit and the secondary target was the Bockflies Schichten. The Reyersdorfer Dolomite was hit by a MD of 3294 m which is 203 m under the predicted depth of 3081 m. The Hauptdolomit was found more than 200 m deeper than its prediction. The secondary target Bockflies Schichten was found only 21 m above its predicted depth at 2881 m.



Plan				Done		
Section ["]	Formation	Predicted Depth TMD [m]	Predicted Depth TVD [m]	Actual TMD [m]	Actual TVD [m]	High/Low [m]
	Ground Level	163.70	163.70	163.70	163.70	-
17 1/2	**Ob. Pannon**	**Surface**	**Surface**	**-**	**-**	**-**
	2.MP	324.00	324.00	-	-	-
	Unter Pannon	471.00	471.00	-	-	-
12 1/2	**SARMAT**	**760.00**	**760.00**	**767.00**	**767.00**	**-7.00**
	OTTNANG	**2930.00**	**2860.00**	**2785.00**	**2760.00**	**100.00**
	Bockfliesser Schichten	2930.00	2860.00	2927.00	2881.00	-21.00
8 1/2	**NOR**	**3081.00**	**2984.00**	**3294.00**	**3187.00**	**203.00**
	Reyersdorfer Dol.	3081.00	2984.00	-	-	-
	NOR	**3689.00**	**3485.00**	-	-	-
	Fault	3689.00	3485.00	-	-	-
	Plattenk. Hauptd.	3689.00	3485.00	-	-	-
6	**UNTERKREIDE**	**4058.00**	**3789.00**	-	-	-
	Undifferenciated	4058.00	3789.00	-	-	-
	NOR	**4257.00**	**3953.00**	-	-	-
	Hauptdolomit	4257.00	3953.00	-	-	-
	TD	**4300.00**	**3989.00**	**4516.00**	**4198.00**	**-209.00**

Table 29: Formation Characterization

It can be seen on the table above that from the surface to the Bockfliess Schichten the formation prediction was quite good. Below this, the difference between real top depths and the predicted depths got bigger and bigger. One of the main reasons could be that the formation had a greater slope than the geologist had thought. Another reason is that one of the targets of this well was to investigate the Raetic scale of the Perchtholdsdorfer Dolomite, which was unfortunately not found.

Cost

The planned costs where in a range of EUR 5.859 Mio and the final drilling costs where EUR 7.440 Mio. The budget for that project had to be increased up to EUR 7.469 Mio. As it can be seen the cost prediction until 3000 m was quite good. Then there was a longer non-drilling time so that the costs rose. By drilling faster and more cost efficient it was finally possible to drill the well with in the planned cost. The overall cost of EUR 7.440 Mio was about 25,6 % higher than the planned costs.

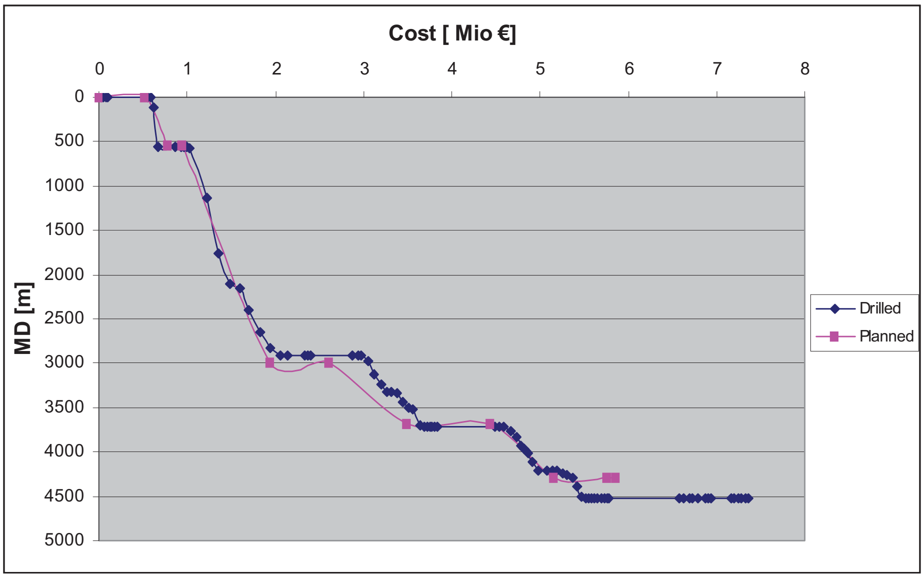


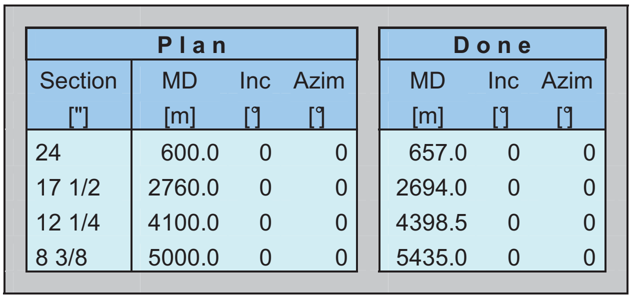
Diagram 4: Comparison of planned and drilled Well

The diagram shows a cost versus measured depth curve. It can be seen in which section the drilling costs were higher than the planned once. There are several factors which influenced the cost rise. The logging operation needed much more time than it was planned (+EUR 159.000) and some additional logging and coring operations had to be done (+EUR 50.000).Also the needed cementation volume was higher (+EUR 20.000) and price increments of the casing (+EUR 35.000) had to be included. Finally some well control problems and even a kick in the last section had to be handled. Because of all that problems and the fact that the well was drilled 216 m deeper than planned 23 days of more rig time has to be added (~EUR 529.000). Due to all this facts the planned AFE had to be overworked and a new higher AFE had to be made.

Straßhof T5

Well trajectory

Due to the fact the well was planned as a vertical well with options of making a side track, the well path was quite simple. The well was drilled more or less vertical, so the plan could be realized. The final depth was reached and then some. After reaching the final depth, the main target was not reached and so the well has to be plugged back and a side track was made.



Plan				Done		
Section ["]	MD [m]	Inc [°]	Azim [°]	MD [m]	Inc [°]	Azim [°]
24	600.0	0	0	657.0	0	0
17 1/2	2760.0	0	0	2694.0	0	0
12 1/4	4100.0	0	0	4398.5	0	0
8 3/8	5000.0	0	0	5435.0	0	0

Table 30: Well Trajectory

As you can see on the table after the 12 1/4” section we were already nearly 200 m away from the planned depth. The final depth was reached with 5435 m TVD and this was even 435 m more than planned.

Casing Design

The setting depths were chosen due to geology and pressure predictions of the formation drilled through. The quality and the nominal weight of the casing needed were calculated with OMV standards by predicted stress on the casing. Because of the experience of Straßhof T4, it was decided to take a lower quality for the conductor. As said before, this well was planned with 4 sections and one contingency case. This so called” big design “was made because of the greater depth. By having a 30” standpipe we start with a 18 5/8” surface casing, after this, the first intermediate casing with a size of 13 3/8” was set, followed by a 9 5/8”, which is the second intermediate casing. If everything runs perfect, as it never does, a 7” production liner would be the last string. If problems occur, a 4 1/2” contingency string performed as a liner is held back.

Plan				Done		
	Casing ["]	MD [m]	nom. weight [lbs/ft]	MD [m]	nom. weight [lbs/ft]	qual. / thread
Conductor	30	8.0	-		-	-
Surf. Casing	18 5/8	600.0	87.5	657.0	87.5	K-55 / BTC
1. Int.Casing	13 3/8	2760.0	77.0	2694.0	77.0	L-80 / BTC
2. Int.Casing	9 5/8	4100.0	53.5	4398.5	53.5	L-80 / VAGT
Prod.Casing	7	5000.0	32.0	5435.0	32.0	L-80 / VAGT

Table 31: Casing Program

Because of uncertainties it was necessary to set the surface casing 66 m higher than planned. Every other casing, as you can see on the table above, was set deeper than planned. The production casing was set at 5435 m which is 435 m deeper than planned. The much greater depth was a very critical factor in terms of the stresses which were acting upon the casing. For the 9 5/8" and the 7" string, the safety factors were already out bidden.

Pressure Regime (Mud Program)

Because of the experiences of the reference well Straßhof T4, there were nearly no problems according to the chosen predicted pressures. Only during flow checks at the measured depths of 4630 m and 4639 m an inflow of formation fluids was recognized. The mud weight was conditioned, the inflow was stopped and no flow was seen anymore.

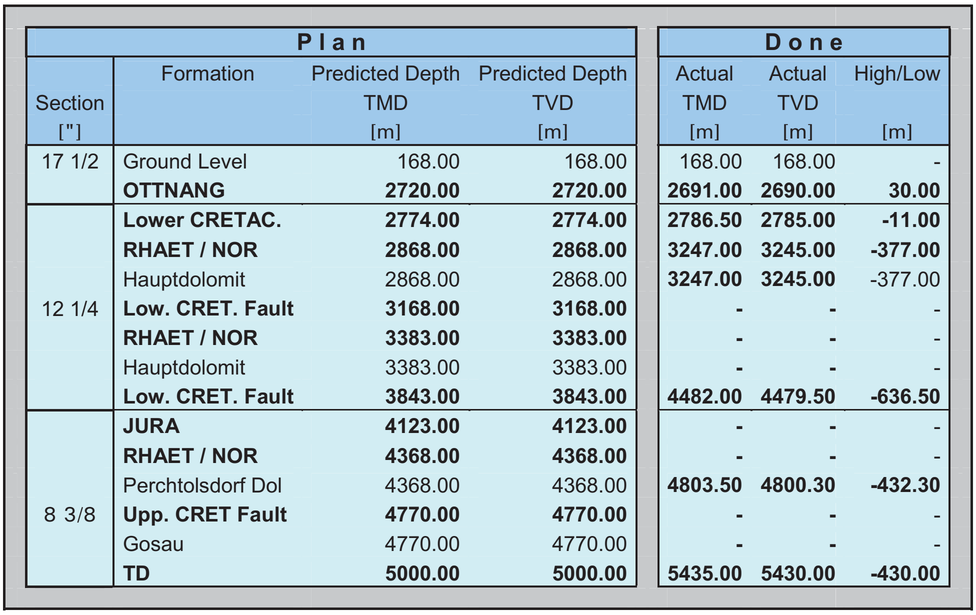
Plan					Done			
Section ["]	MD [m]	Condition	SG [kg/l]	H_2S	MD [m]	Condition	SG [kg/l]	H_2S
24	80 – 600.0	Hydrostat.	1.05 – 1.10	no	8.0 – 657.0	Hydr.	1.10	no
17 1/2	600.0 – 1781.0	Hydrostat.	1.05 – 1.10	no	657.0 – 2694.0	Hydr.	1.10	no
17 1/2	1781.0 – 1823.0	underhydrost.	1.05 – 1.10	no	-	-	-	-
17 1/2	1823.0 – 2760.0	Hydrostat.	1.05 – 1.13	no	-	-	-	-
12 1/4	2760.0 – 2868.0	Overhydrost.	1.12 – 1.25	no	2694.0 – 4398.5	Hydr.	1.10	no
12 1/4	2868.0 – 3843.0	Overhydrost.	1.12 – 1.25	yes	-	-	-	-
12 1/4	3843.0 – 4100.0	Overhydrost.	1.12 – 1.25	yes	-	-	-	-
8 3/8	4100.0 – 5000.0	Overhydrost.	1.12 – 1.3	yes	4398.5 – 4630.0	Overhydr.	1.12	yes
8 3/8	-	-	-	-	4630.0 – 4639.0	Overhydr.	1.14	yes
8 3/8	-	-	-	-	4639.0 – 5435.0	Overhydr.	1.17	yes

Table 32: Mud/Formation Pressure

On the table above, the predicted and the real pressures can be seen. It can be seen that the mud weights during drilling were mostly in the suggested range. The table also shows that the formation pressure gradients were all much under 1.2 kg/l.

Geology

The primary target was the Perchtoldsdorfer Dolomite. The secondary target was the Reyerdorfer Dolomite (Main Dolomite). The main target was found 432.3 m below its prediction depth at 4800.5 m and the secondary target was still 377 m below the prediction at 3245 m.



Plan				Done		
Section ["]	Formation	Predicted Depth TMD [m]	Predicted Depth TVD [m]	Actual TMD [m]	Actual TVD [m]	High/Low [m]
17 1/2	Ground Level	168.00	168.00	168.00	168.00	-
	OTTNANG	**2720.00**	**2720.00**	**2691.00**	**2690.00**	**30.00**
12 1/4	**Lower CRETAC.**	**2774.00**	**2774.00**	**2786.50**	**2785.00**	**-11.00**
	RHAET / NOR	**2868.00**	**2868.00**	**3247.00**	**3245.00**	**-377.00**
	Hauptdolomit	2868.00	2868.00	**3247.00**	**3245.00**	-377.00
	Low. CRET. Fault	**3168.00**	**3168.00**	**-**	**-**	-
	RHAET / NOR	**3383.00**	**3383.00**	**-**	**-**	-
	Hauptdolomit	3383.00	3383.00	**-**	**-**	-
	Low. CRET. Fault	**3843.00**	**3843.00**	**4482.00**	**4479.50**	**-636.50**
8 3/8	**JURA**	**4123.00**	**4123.00**	**-**	**-**	-
	RHAET / NOR	**4368.00**	**4368.00**	**-**	**-**	-
	Perchtolsdorf Dol	4368.00	4368.00	**4803.50**	**4800.30**	**-432.30**
	Upp. CRET Fault	**4770.00**	**4770.00**	**-**	**-**	-
	Gosau	4770.00	4770.00	**-**	**-**	-
	TD	**5000.00**	**5000.00**	**5435.00**	**5430.00**	**-430.00**

Table 33: Formation Characterization

As the table above shows, there was no great difference between the formation top depths of the real and the predicted formations until a depth of 2774 m (Lower Cretaceous). Below that depth, the top depth of the formation and its prediction differs very much. There are differences from 300 m up to 636 m.

Cost

The planned costs where ranging about EUR 11.926.862 and the final drilling costs where EUR 11.633.641. The final costs are dated until 28.February 2006 with is the finishing date of the vertical well. After that a side track was made, but this is not part of this analysis. The costs due to time losses because of wiper trips, logging problems with solid control equipment and top drive, were nearly equalized by a good drilling performance. This means, that the expenditures of the project were nearly the same as planned.

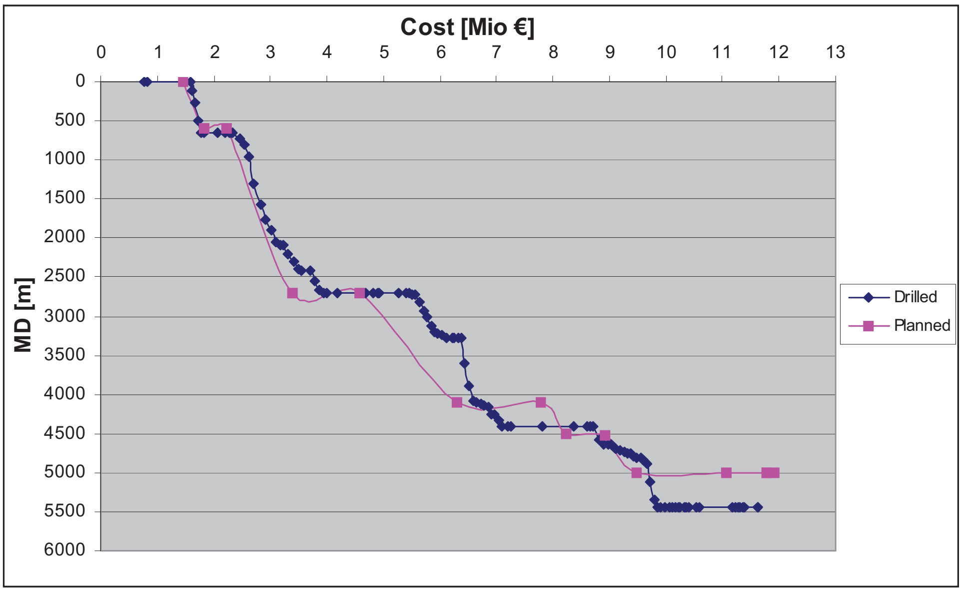


Diagram 5: Comparison of planned and drilled Well

The diagram shows that, until a depth of 2000 m, the predicted costs were suitable. Then, when following the line downwards, one sees that the planned AFE line and the real cost line sometimes cross each other. At a measured depth of 4500 m the planned and the real costs were practically the same again.

Work Time Splitting

General

To split and to analyse the drilling time was primary done to show the performance of the two projects. Another point was to find out the difference between the small and the big well design. The following two diagrams show a splitting of the working time needed to drill the wells Straßhof T4 and Straßhof T5 to there final depths. It is based on the daily drilling reports and some assumptions. There are 22 groups listed next to the diagram

Straßhof T4

The well Straßhof T4 was planned for 1486 h (~ 62 days) with a measured depth of 4300 m. It was drilled in 1910 h (~85 days) down to the MD of 4514 m. This means that there was a time overrun of 20.3 % by a depth overrun of only 4.8 %. After about 1583 h (~66 days) the planned depth of 4300 m was reached. So at that point, the project was already behind schedule. More time was needed for defrost, longer tripping times and a very time consuming leak off test. Another big problem was the logging. It was planned for 20 h and was finally done in 130 h. The more time was needed for an additional trip due to a damaged logging tool and some additional log points. Not to mention, a kick of 37 h to get back well control. To sum it up, there was 23 days more rig time needed, due to smaller problems and the fact that the drilling path was about 216 m longer than planned.

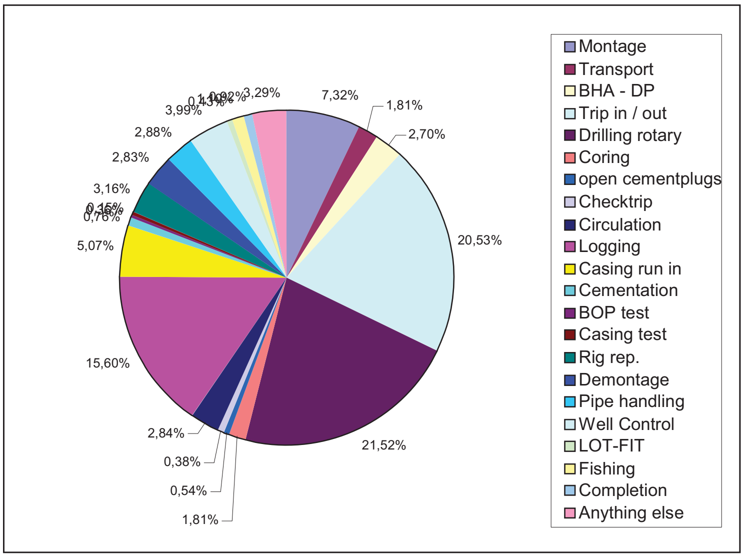


Diagram 6: Drilling Operation Time splitting in several Groups

The biggest "pieces of the cake", were luckily the net drilling time (21.52 %) and tripping (20.53 %). Another big block in this well was the logging work. This was because of big problems with the logging company and due to the fact that this well was the first drilled in a new formation (Perchtoldsdorfer Dolomite). Therefore, the amount information needed was much higher than in the wells drilled after that well. The lost time due to problems, was about 6.43 % of the overall time.

Straßhof T5

The well Straßhof T5 was planned for 2478 h (~ 103 days) with a measured depth of 5000 m. It was drilled in 2596 h (~109 days) down to a MD of 5435 m. This means that there was only a time overrun of 1.8 % by a depth overrun of 8.7 %. The planned MD of 5000 m was reached in about 2280 h (~95 days) which means the drilling crew drilled faster than planned. Time was lost by additional logging time (99 h) and some logging problems (57 h). Also, two wiper trips where needed (90 h) and the liner installation needed more time than it was planned (56 h), There where also some problems with the solids control equipment (45 h) and the top drive while running the casing (8 h). All these problems had no effect on the planned overall time, because the predicted drilling time was higher than the real.

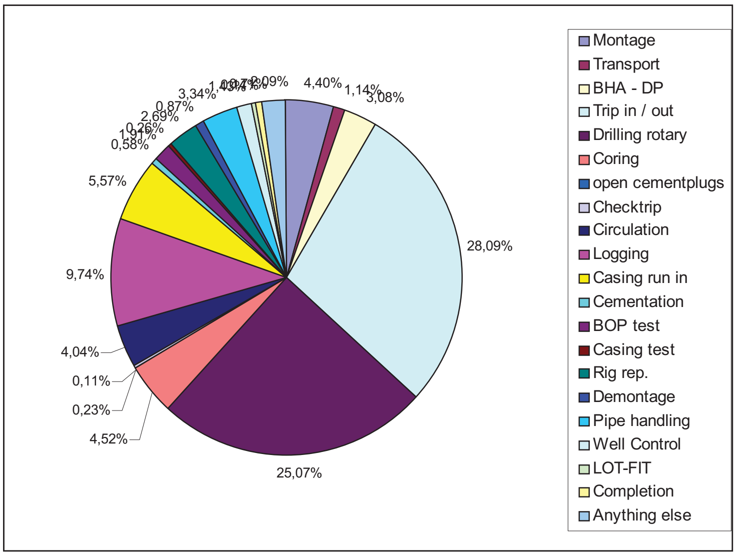


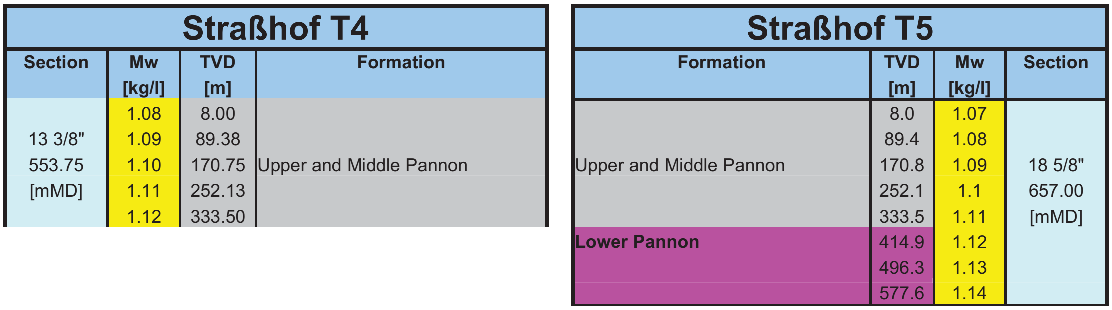
Diagram 7: Operation Time splitted in several Groups

The biggest “pieces of the cake”, were luckily the net drilling time (25.07 %) and tripping (28.09 %). Still a big block in this well is the logging work (9.74 %) and the coring (4.52 %) due to the fact that this well was the second drilled in a new formation (Perchtoldsdorfer Dolomite), but rather in a deeper position. Therefore, the information quantity needed was still high. The lost time due to problems was about 2.8 % of the overall time.

Formation Comparison

General

In this chapter the formation of the two wells are compared. This will be done by comparing the real lithologies which were found. Also, the setting depths of different casings were analysed. The corresponding pressures were also included in this part of the work. This comparison will show how different or equal, in terms of the geology, those two wells are. And it is a good example for the difficulties of well design. Even these two wells are very close to one another and nevertheless, the formation was different.

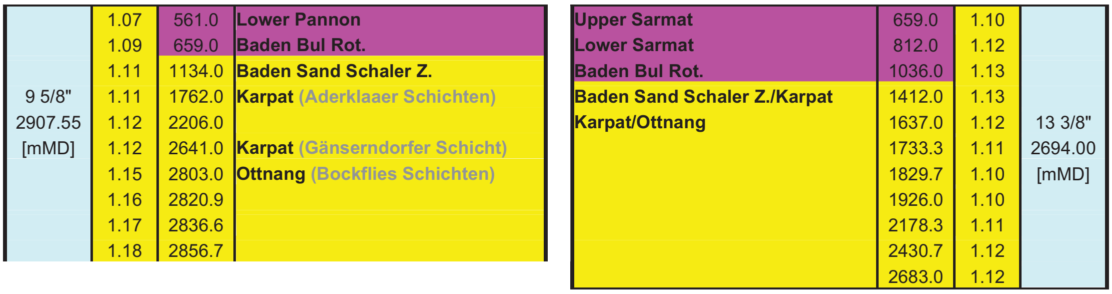


Straßhof T4			
Section	**Mw [kg/l]**	**TVD [m]**	**Formation**
13 3/8" 553.75 [mMD]	1.08	8.00	Upper and Middle Pannon
	1.09	89.38	
	1.10	170.75	
	1.11	252.13	
	1.12	333.50	

Straßhof T5			
Formation	**TVD [m]**	**Mw [kg/l]**	**Section**
Upper and Middle Pannon	8.0	1.07	18 5/8" 657.00 [mMD]
	89.4	1.08	
	170.8	1.09	
	252.1	1.1	
	333.5	1.11	
Lower Pannon	414.9	1.12	
	496.3	1.13	
	577.6	1.14	

Table 34 : Surface Section

The table above shows that the differences in the depths already begin with the Upper Pannon. This is a result of the fact that the Lower Pannon rises upward, so that the top of T5 is higher than at the one of T4. In the Straßhof T5, the Sarmat formation appears. This formation may be forces the Pannon formation upwards. The formation pressures for this section are quite similar.

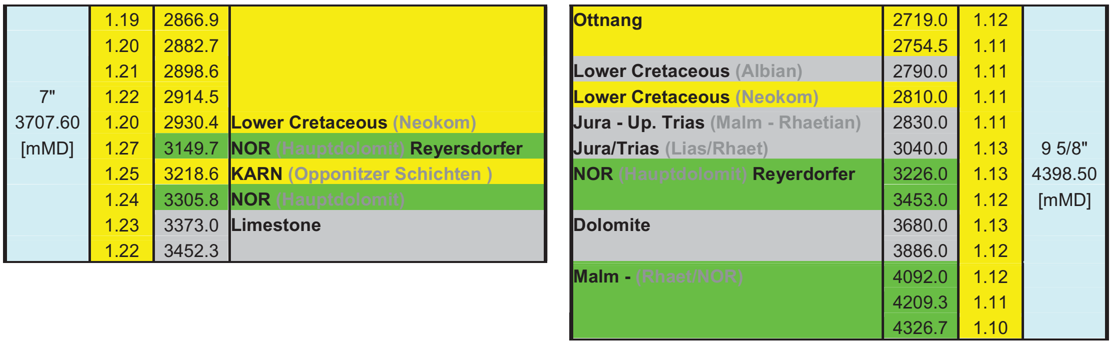


9 5/8" 2907.55 [mMD]	1.07	561.0	**Lower Pannon**
	1.09	659.0	**Baden Bul Rot.**
	1.11	1134.0	**Baden Sand Schaler Z.**
	1.11	1762.0	**Karpat** (Aderklaaer Schichten)
	1.12	2206.0	
	1.12	2641.0	**Karpat** (Gänserndorfer Schicht)
	1.15	2803.0	**Ottnang** (Bockflies Schichten)
	1.16	2820.9	
	1.17	2836.6	
	1.18	2856.7	

Upper Sarmat	659.0	1.10	13 3/8" 2694.00 [mMD]
Lower Sarmat	812.0	1.12	
Baden Bul Rot.	1036.0	1.13	
Baden Sand Schaler Z./Karpat	1412.0	1.13	
Karpat/Ottnang	1637.0	1.12	
	1733.3	1.11	
	1829.7	1.10	
	1926.0	1.10	
	2178.3	1.11	
	2430.7	1.12	
	2683.0	1.12	

Table 35: First Intermediate Section

Table 35 shows the Sarmat explained above. It is also shown that top depth of the Baden Bul. Rot. formation at the well T5 is significant deeper than it is at the position of the well Straßhof T4. After this, the top depths were greater at the well T4. The formation pressures for both wells are quite the same.

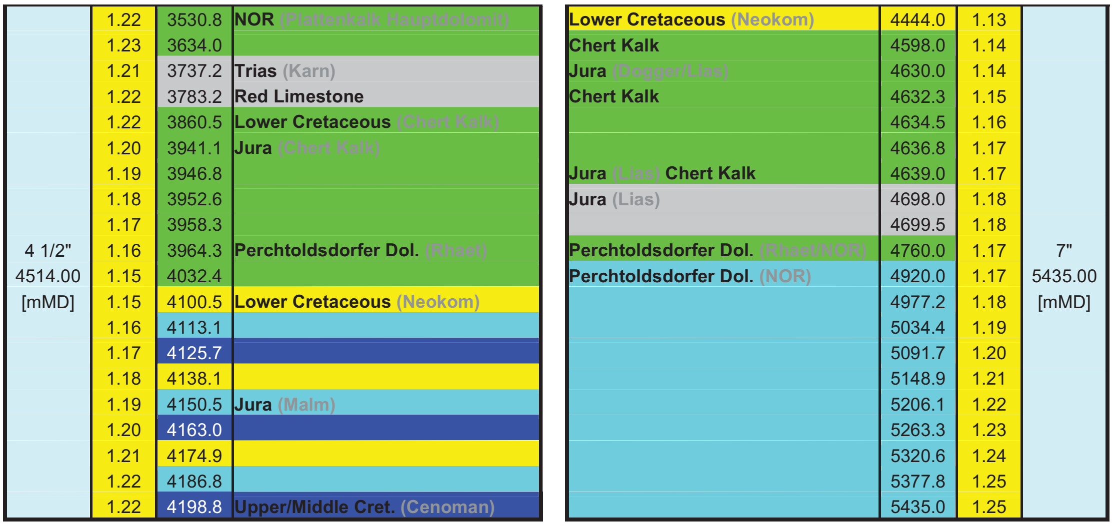


7" 3707.60 [mMD]	1.19	2866.9	
	1.20	2882.7	
	1.21	2898.6	
	1.22	2914.5	
	1.20	2930.4	**Lower Cretaceous** (Neokom)
	1.27	3149.7	**NOR** (Hauptdolomit) **Reyersdorfer**
	1.25	3218.6	**KARN** (Opponitzer Schichten)
	1.24	3305.8	**NOR** (Hauptdolomit)
	1.23	3373.0	**Limestone**
	1.22	3452.3	

Ottnang	2719.0	1.12	9 5/8" 4398.50 [mMD]
	2754.5	1.11	
Lower Cretaceous (Albian)	2790.0	1.11	
Lower Cretaceous (Neokom)	2810.0	1.11	
Jura - Up. Trias (Malm - Rhaetian)	2830.0	1.11	
Jura/Trias (Lias/Rhaet)	3040.0	1.13	
NOR (Hauptdolomit) **Reyerdorfer**	3226.0	1.13	
	3453.0	1.12	
Dolomite	3680.0	1.13	
	3886.0	1.12	
Malm - (Rhaet/NOR)	4092.0	1.12	
	4209.3	1.11	
	4326.7	1.10	

Table 36: Second Intermediate Section

As it is shown in table 36, the difference in depths continuous until the Reyersdorfer Dolomite is reached. After that it changes and the top depths of Straßhof T5 are now greater. The formation pressure of the well T4 is now significantly higher than those of the T5.



4 1/2" 4514.00 [mMD]	1.22	3530.8	**NOR** (Plattenkalk Hauptdolomit)
	1.23	3634.0	
	1.21	3737.2	**Trias** (Karn)
	1.22	3783.2	**Red Limestone**
	1.22	3860.5	**Lower Cretaceous** (Chert Kalk)
	1.20	3941.1	**Jura** (Chert Kalk)
	1.19	3946.8	
	1.18	3952.6	
	1.17	3958.3	
	1.16	3964.3	**Perchtoldsdorfer Dol.** (Rhaet)
	1.15	4032.4	
	1.15	4100.5	**Lower Cretaceous** (Neokom)
	1.16	4113.1	
	1.17	4125.7	
	1.18	4138.1	
	1.19	4150.5	**Jura** (Malm)
	1.20	4163.0	
	1.21	4174.9	
	1.22	4186.8	
	1.22	4198.8	**Upper/Middle Cret.** (Cenoman)

Lower Cretaceous (Neokom)	4444.0	1.13	7" 5435.00 [mMD]
Chert Kalk	4598.0	1.14	
Jura (Dogger/Lias)	4630.0	1.14	
Chert Kalk	4632.3	1.15	
	4634.5	1.16	
	4636.8	1.17	
Jura (Lias) **Chert Kalk**	4639.0	1.17	
Jura (Lias)	4698.0	1.18	
	4699.5	1.18	
Perchtoldsdorfer Dol. (Rhaet/NOR)	4760.0	1.17	
Perchtoldsdorfer Dol. (NOR)	4920.0	1.17	
	4977.2	1.18	
	5034.4	1.19	
	5091.7	1.20	
	5148.9	1.21	
	5206.1	1.22	
	5263.3	1.23	
	5320.6	1.24	
	5377.8	1.25	
	5435.0	1.25	

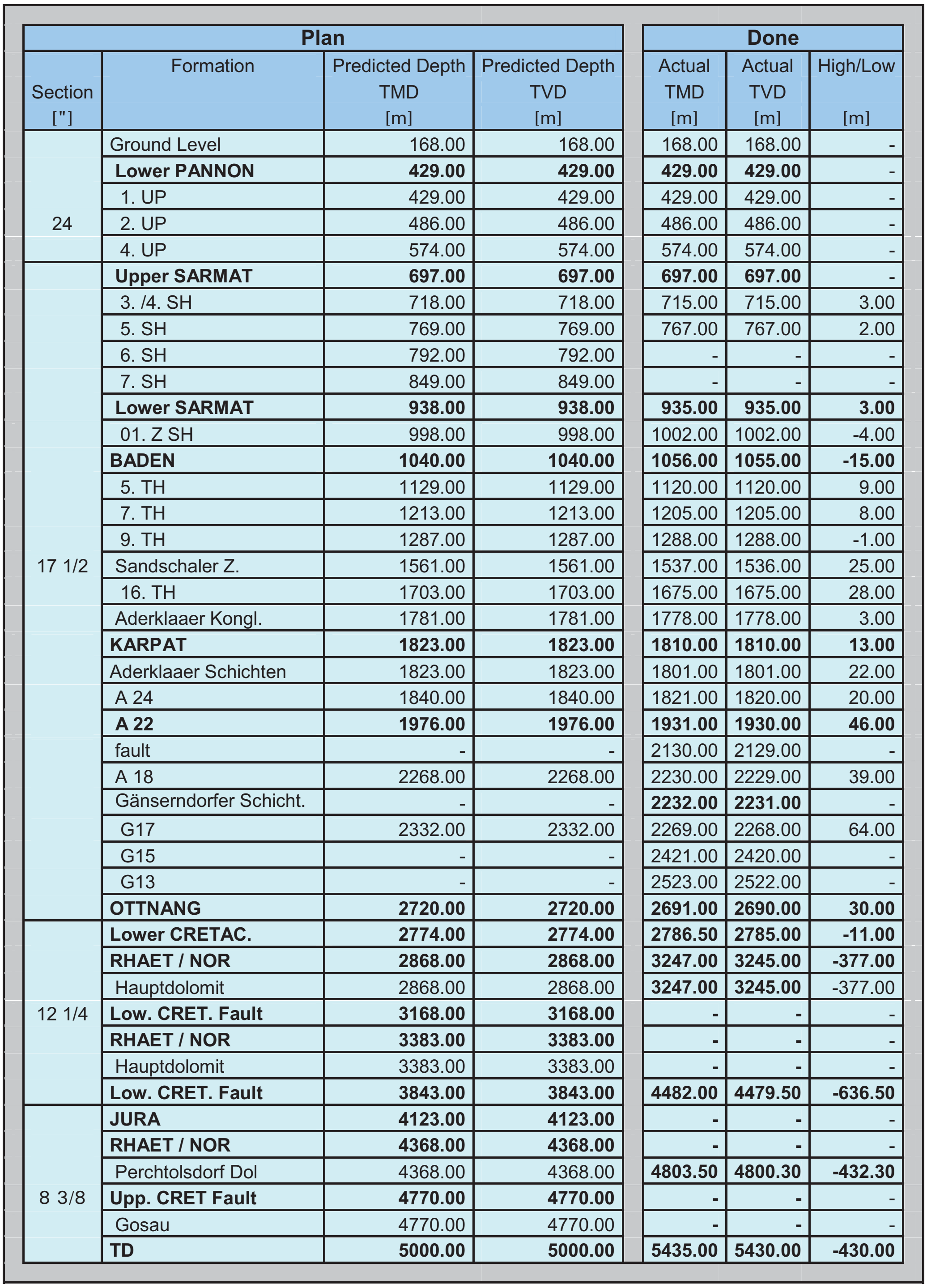
Table 37: Production section

The table 37 shows that the difference in the formation depths continuous and gets even bigger. It can also be seen that although the well Straßhof T4 was deep enough it didn't hit the Noric part of the Perchtoldsdorfer Dolomite formation. The well Straßhof T5 had the right position and so it hit the formation. This is because the Perchtoldorfer Dolomite is split in the Noric and in the Raetic part and some deeper parts not reached yet. These parts are not layer but they are formed as plates and the position of the T4 was at the end of the Noric plate so it was not hit. Due to the greater depth (~ 5500 m) and the more actual casing design calculation of Straßhof T5, all further alternatives and cost calculations are based on this well.

Formations which were found in both wells are: Pannon, Baden(Sandschaler), Karpat, Ottnang, Reyersdorfer Dolomite(Noric), Chert Kalk(Jura, Lower Cretatious), Perchtoldsdorfer Dolomite(Raetic).

Plan				Done		
Section ['']	Formation	Predicted Depth TMD [m]	Predicted Depth TVD [m]	Actual TMD [m]	Actual TVD [m]	High/Low [m]
	Ground Level	163.70	163.70	163.70	163.70	-
17 1/2	**Ob. Pannon**	**Surface**	**Surface**	**-**	**-**	**-**
	2.MP	324.00	324.00	-	-	-
	Unter Pannon	471.00	471.00	-	-	-
12 1/2	**SARMAT**	**760.00**	**760.00**	**767.00**	**767.00**	**-7.00**
	Ober Sarmat	760.00	760.00	-	-	-
	3. /4. SH	760.00	760.00	-	-	-
	Unter Sarmat	960.00	960.00	973.00	973.00	-13.00
	BADEN	**1076.00**	**1076.00**	**1108.00**	**1108.00**	**-32.00**
	Bulim.-Rot.Zone	1076.00	1076.00	1108.00	1108.00	-32.00
	8.TH	1230.00	1230.00	1300.00	1300.00	-70.00
	9.TH	1275.00	1275.00	-	-	-
	Sandschaler Zone	1610.00	1610.00	1615.00	1615.00	-5.00
	Obere Lageniden Zone	1840.00	1840.00	1840.00	1840.00	-
	KARPAT	**1930.00**	**1930.00**	**1930.5**	**1930.00**	-
	Aderklaaer Kongl.	1930.00	1930.00	1930.5	1930.00	-
	Aderklaaer Schichten	2110.00	2110.00	2073.00	2071.00	39.00
	Gaenserndorfer Schicht.	2736.00	2700.00	2654.00	2640.00	60.00
	OTTNANG	**2930.00**	**2860.00**	**2785.00**	**2760.00**	**100.00**
	Bockfliesser Schichten	2930.00	2860.00	2927.00	2881.00	-21.00
8 1/2	**NOR**	**3081.00**	**2984.00**	**3294.00**	**3187.00**	**203.00**
	Reyersdorfer Dol.	3081.00	2984.00	-	-	-
	KARN	**3321.00**	**3182.00**	-	-	-
	Opponitzer Schichten	3321.00	3182.00	-	-	-
	Lunzer Schichten	3385.00	3235.00	-	-	-
	LADIN	**3533.00**	**3357.00**	-	-	-
	Partnach Schichten	3533.00	3357.00	-	-	-
	Reiflinger Schichten	3580.00	3395.00	-	-	-
	Reiflinger Schichten	3580.00	3395.00	-	-	-
	ANIS	**3628.00**	**3435.00**	-	-	-
	Gutensteiner Schichten	3628.00	3435.00	-	-	-
	NOR	**3689.00**	**3485.00**	-	-	-
	Fault	3689.00	3485.00	-	-	-
	Plattenk. Hauptd.	3689.00	3485.00	-	-	-
6	**OBERKREIDE**	**3792.00**	**3570.00**	-	-	-
	Fault	3792.00	3570.00	-	-	-
	GOSAU	3792.00	3570.00	-	-	-
	UNTERKREIDE	**4058.00**	**3789.00**	-	-	-
	Undifferenciated	4058.00	3789.00	-	-	-
	NOR	**4257.00**	**3953.00**	-	-	-
	Hauptdolomit	4257.00	3953.00	-	-	-
	TD	**4300.00**	**3989.00**	**4516.00**	**4198.00**	**-209.00**

Table 38: Formation Comparison Predicted vs. Actual Straßhof T4



Plan				Done		
Section ["]	Formation	Predicted Depth TMD [m]	Predicted Depth TVD [m]	Actual TMD [m]	Actual TVD [m]	High/Low [m]
24	Ground Level	168.00	168.00	168.00	168.00	-
	Lower PANNON	**429.00**	**429.00**	**429.00**	**429.00**	-
	1. UP	429.00	429.00	429.00	429.00	-
	2. UP	486.00	486.00	486.00	486.00	-
	4. UP	574.00	574.00	574.00	574.00	-
17 1/2	**Upper SARMAT**	**697.00**	**697.00**	**697.00**	**697.00**	-
	3. /4. SH	718.00	718.00	715.00	715.00	3.00
	5. SH	769.00	769.00	767.00	767.00	2.00
	6. SH	792.00	792.00	-	-	-
	7. SH	849.00	849.00	-	-	-
	Lower SARMAT	**938.00**	**938.00**	**935.00**	**935.00**	**3.00**
	01. Z SH	998.00	998.00	1002.00	1002.00	-4.00
	BADEN	**1040.00**	**1040.00**	**1056.00**	**1055.00**	**-15.00**
	5. TH	1129.00	1129.00	1120.00	1120.00	9.00
	7. TH	1213.00	1213.00	1205.00	1205.00	8.00
	9. TH	1287.00	1287.00	1288.00	1288.00	-1.00
	Sandschaler Z.	1561.00	1561.00	1537.00	1536.00	25.00
	16. TH	1703.00	1703.00	1675.00	1675.00	28.00
	Aderklaaer Kongl.	1781.00	1781.00	1778.00	1778.00	3.00
	KARPAT	**1823.00**	**1823.00**	**1810.00**	**1810.00**	**13.00**
	Aderklaaer Schichten	1823.00	1823.00	1801.00	1801.00	22.00
	A 24	1840.00	1840.00	1821.00	1820.00	20.00
	A 22	**1976.00**	**1976.00**	**1931.00**	**1930.00**	**46.00**
	fault	-	-	2130.00	2129.00	-
	A 18	2268.00	2268.00	2230.00	2229.00	39.00
	Gänserndorfer Schicht.	-	-	**2232.00**	**2231.00**	-
	G17	2332.00	2332.00	2269.00	2268.00	64.00
	G15	-	-	2421.00	2420.00	-
	G13	-	-	2523.00	2522.00	-
	OTTNANG	**2720.00**	**2720.00**	**2691.00**	**2690.00**	**30.00**
12 1/4	**Lower CRETAC.**	**2774.00**	**2774.00**	**2786.50**	**2785.00**	**-11.00**
	RHAET / NOR	**2868.00**	**2868.00**	**3247.00**	**3245.00**	**-377.00**
	Hauptdolomit	2868.00	2868.00	**3247.00**	**3245.00**	-377.00
	Low. CRET. Fault	**3168.00**	**3168.00**	-	-	-
	RHAET / NOR	**3383.00**	**3383.00**	-	-	-
	Hauptdolomit	3383.00	3383.00	-	-	-
	Low. CRET. Fault	**3843.00**	**3843.00**	**4482.00**	**4479.50**	**-636.50**
8 3/8	**JURA**	**4123.00**	**4123.00**	-	-	-
	RHAET / NOR	**4368.00**	**4368.00**	-	-	-
	Perchtolsdorf Dol	4368.00	4368.00	**4803.50**	**4800.30**	**-432.30**
	Upp. CRET Fault	**4770.00**	**4770.00**	-	-	-
	Gosau	4770.00	4770.00	-	-	-
	TD	**5000.00**	**5000.00**	**5435.00**	**5430.00**	**-430.00**

Table 39: Formation Comparison Predicted vs. Actual Straßhof T5

Straßhof T4				Straßhof T5			
Section	Mw [kg/l]	TVD [m]	Formation	Formation	TVD [m]	Mw [kg/l]	Section
13 3/8" 553.8 [mMD]	1.08	8.00			8.0	1.07	18 5/8" 657.0 [mMD]
	1.09	89.38			89.4	1.08	
	1.10	170.75			170.8	1.09	
	1.11	252.13			252.1	1.1	
	1.12	333.50			333.5	1.11	
9 5/8" 2907.6 [mMD]	1.07	561.0	Lower Pannon	Lower Pannon	414.9	1.12	
	1.09	659.0	Baden Bul Rot.		496.3	1.13	
	1.11	1134.0	Baden Sand Schaler Z.		577.6	1.14	
	1.11	1762.0	Karpat (Aderklaaer Schichten)	Upper Sarmat	659.0	1.10	13 3/8" 2694.0 [mMD]
	1.12	2206.0		Lower Sarmat	812.0	1.12	
	1.12	2641.0	Karpat (Gänserndorfer Schicht)	Baden Bul Rot.	1036.0	1.13	
	1.15	2803.0	Ottnang (Bockflies Schichten)	Baden Sand Schaler Z./Karpat	1412.0	1.13	
	1.16	2820.9		Karpat / Ottnang	1637.0	1.12	
	1.17	2836.6			1733.3	1.11	
	1.18	2856.7			1829.7	1.10	
7" 3707.6 [mMD]	1.19	2866.9			1926.0	1.10	
	1.20	2882.7			2178.3	1.11	
	1.21	2898.6			2430.7	1.12	
	1.22	2914.5			2683.0	1.12	
	1.20	2930.4	Lower Cret.?(Neokom)	Ottnang	2719.0	1.12	9 5/8" 4398.5 [mMD]
	1.27	3149.7	NOR (Hauptdolomit) Reyersdorfer		2754.5	1.11	
	1.25	3218.6	KARN (Opponitzer Schichten ?)	Lower Cretaceous (Albian)	2790.0	1.11	
	1.24	3305.8	NOR (Hauptdolomit)	Lower Cretaceous?(Neokom)	2810.0	1.11	
	1.23	3373.0	Limestone	Jura - Up. Trias(Malm - Rhaetian)	2830.0	1.11	
	1.22	3452.3		Jura/Trias (Lias / Rhaet)?	3040.0	1.13	
4 1/2" 4514.0 [mMD]	1.22	3530.8	NOR (Plattenkalk Hauptdolomit?)	NOR (Hauptdolomit) Reyerdorfer	3226.0	1.13	
	1.23	3634.0			3453.0	1.12	
	1.21	3737.2	Trias (Karn) ?	Dolomite	3680.0	1.13	
	1.22	3783.2	Red Limestone		3886.0	1.12	
	1.22	3860.5	Lower Cretaceous? (Chert Kalk)	Malm - (Rhaet/NOR)	4092.0	1.12	
	1.20	3941.1	Jura? (Chert Kalk)		4209.3	1.11	
	1.19	3946.8			4326.7	1.10	
	1.18	3952.6		Lower Cretaceous ?(Neokom)	4444.0	1.13	7" 5435.0 [mMD]
	1.17	3958.3		Chert Kalk	4598.0	1.14	
	1.16	3964.3	Perchtoldsdorfer Dol.(Rhaet)	Jura (Dogger / Lias)	4630.0	1.14	
	1.15	4032.4		Chert Kalk	4632.3	1.15	
	1.15	4100.5	Lower Cretaceous?(Neokom)		4634.5	1.16	
	1.16	4113.1			4636.8	1.17	
	1.17	4125.7		Jura (Lias) Chert Kalk	4639.0	1.17	
	1.18	4138.1		Jura (Lias)	4698.0	1.18	
	1.19	4150.5	Jura (Malm)		4699.5	1.18	
	1.20	4163.0		Perchtoldsdorfer Dol.(Rhaet/NOR)	4760.0	1.17	
	1.21	4174.9		Perchtoldsdorfer Dol.(NOR)	4920.0	1.17	
	1.22	4186.8			4977.2	1.18	
	1.22	4198.8	Upper /Middle Cret.		5034.4	1.19	
					5091.7	1.20	
					5148.9	1.21	
					5206.1	1.22	
					5263.3	1.23	
					5320.6	1.24	
					5377.8	1.25	
					5435.0	1.25	

Table 40: Formation Comparison Straßhof T4 vs. Straßhof T5

Section ["]	Work	Possible Problems	Solving Action	Timeloss [h]	Moneyloss [€]	Probability [%]	Problem cost x Probability
24"	Drilling	inflow	mud weighted	6	7.464,66	15	1119,70
		mud losses	reduce mud weight, pump pill	8	9.952,88	15	1492,93
		- " - , Differential pipe sticking	reduce mud weight, pump pill	24	29.858,64	15	4478,80
		Hole cleaning Problems	mud conditioning, adjust mud flow	6	7.464,66	15	1119,70
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	11.196,99	15	1679,55
		Logging tool stuck	over pull, pump pill	40	49.764,41	15	7464,66
		Logging tool Failure	addditional round trip, tool repair	7,5	9.330,83	15	1399,62
18 5/8"	Surface Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	5	6.220,55	15	933,08
		Casing stuck	overpull, pump pill, circulate and	7	8.708,77	15	1306,32
		Casing not set at the correct Depht	------	2	2.488,22	15	373,23
	Cementation	Problems with Cementation	recementation,	2,5	3.110,28	15	466,54
17 1/2"	Drilling	Hole cleaning Problems	mud conditioning, adjust mud flow	6	11.761,86	50	5880,93
		inflow	mud weighted	6	11.761,86	50	5880,93
		Losses in Aderklaaer Schichten	reduce mud weight, pump pill	6	11.761,86	50	5880,93
		2100m-2300m Open-Hole Section	reaming	22	43.126,82	50	21563,41
		– Borehole Stability					0,00
		BHA Stuck		7	13.722,17	15	2058,33
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	17.642,79	15	2646,42
		Logging tool stuck	over pull, pump pill	43	84.293,34	15	12644,00
		Logging tool Failure	addditional round trip, tool repair	9	17.642,79	15	2646,42
13 3/8"	1. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	15	29.404,65	15	4410,70
		Casing stuck	overpull, pump pill, circulate and	20	39.206,20	15	5880,93
		Casing not set at the correct Depht	------	2,5	4.900,78	90	4410,70
	Cementation	Problems with Cementation	recementation,	3,5	6.861,09	15	1029,16
12 1/4"	Drilling	inflow	mud weighted	10	17.989,20	50	8994,60
		mud losses	reduce mud weight, pump pill	10	17.989,20	50	8994,60
		H2S-Content in the Reyersdorfer	special coring threatment, safety,	3	5.396,76	15	809,51
		– over-hydrostatic pressure	mud conditioning	2	3.597,84	15	539,68
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	13	23.385,96	15	3507,89
		Logging tool stuck	over pull, pump pill	50	89.946,01	15	13491,90
		Logging tool Failure	addditional round trip, tool repair	13	23.385,96	50	11692,98
9 5/8"	2. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	20	35.978,40	15	5396,76
		Casing stuck	overpull, pump pill, circulate and	6	10.793,52	15	1619,03
		Casing not set at the correct Depht	------	3	5.396,76	90	4857,08
		Depth Prediction of the Geology	------	3	5.396,76	90	4857,08
	Cementation	Problems with Cementation	recementation,	5,5	9.894,06	15	1484,11
8 1/2"	Drilling	BHA stuck		7	12.474,35	50	6237,18
		inflow	mud weighted	5	8.910,25	90	8019,23
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.692,30	50	5346,15
		Instable Layer between Rhaet und	mud conditioning, adjust mud flow	5	8.910,25	90	8019,23
		NOR (Fall Back)					0,00
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol. + Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.730,75	15	4009,61
		Logging tool stuck	over pull, pump pill	50	89.102,51	15	13365,38
		Logging tool Failure	addditional round trip, tool repair	15	26.730,75	90	24057,68
7"	Production Casing / Liner Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.551,25	15	6682,69
		Casing stuck	overpull, pump pill, circulate and	6	10.692,30	15	1603,85
		Casing not set at the correct Depht	------	3,5	6.237,18	90	5613,46
		Depth Prediction of the Geology	------	3,5	6.237,18	90	5613,46
	Cementation	Problems with Cementation	recementation,	6,5	11.583,33	15	1737,50
6"	Drilling	BHA stuck		7		50	0,00
		inflow	mud weighted	6	10.572,31	90	9515,08
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	15	3964,62
		Logging tool stuck	over pull, pump pill	55	96.912,83	15	14536,92
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
4 1/2"	Contingency as Liner or Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	15	6607,69
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	15	1585,85
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
Sumtotal				914,5	**1.515.780,06**		**432.568,07**

Table 41: Risk Analysis: Four Sections with one Contingency

Section ["]	Work	Possible Problems	Solving Action	Timeloss [h]	Moneyloss [€]	Probability [%]	Problem cost x Probability
20"	Drilling	inflow	mud weighted	6	7.464,66	15	1119,70
		mud losses	reduce mud weight, pump pill	8	9.952,88	15	1492,93
		- " - , Differential pipe sticking	reduce mud weight, pump pill	24	29.858,64	15	4478,80
		Hole cleaning Problems	mud conditioning, adjust mud flow	6	7.464,66	15	1119,70
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	11.196,99	15	1679,55
		Logging tool stuck	over pull, pump pill	40	49.764,41	15	7464,66
		Logging tool Failure	addditional round trip, tool repair	7,5	9.330,83	15	1399,62
16"	Surface Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	5	6.220,55	16	995,29
		Casing stuck	overpull, pump pill, circulate and	7	8.708,77	16	1393,40
		Casing not set at the correct Depht	------	2	2.488,22	15	373,23
	Cementation	Problems with Cementation	recementation,	2,5	3.110,28	15	466,54
17 1/2"	Drilling	Hole cleaning Problems	mud conditioning, adjust mud flow	6	11.761,86	50	5880,93
		inflow	mud weighted	6	11.761,86	50	5880,93
		Losses in Aderklaaer Schichten	reduce mud weight, pump pill	6	11.761,86	50	5880,93
		2100m-2300m Open-Hole Section	reaming	22	43.126,82	50	21563,41
		– Borehole Stability					0,00
		BHA Stuck		7	13.722,17	15	2058,33
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	17.642,79	15	2646,42
		Logging tool stuck	over pull, pump pill	43	84.293,34	15	12644,00
		Logging tool Failure	addditional round trip, tool repair	9	17.642,79	15	2646,42
13 3/8"	1. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	15	29.404,65	15	4410,70
		Casing stuck	overpull, pump pill, circulate and	20	39.206,20	15	5880,93
		Casing not set at the correct Depht	------	2,5	4.900,78	90	4410,70
	Cementation	Problems with Cementation	recementation,	3,5	6.861,09	15	1029,16
12 1/4"	Drilling	inflow	mud weighted	10	17.989,20	50	8994,60
		mud losses	reduce mud weight, pump pill	10	17.989,20	50	8994,60
		H2S-Content in the Reyersdorfer	special coring threatment, safety,	3	5.396,76	15	809,51
		– over-hydrostatic pressure	mud conditioning	2	3.597,84	15	539,68
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	13	23.385,96	15	3507,89
		Logging tool stuck	over pull, pump pill	50	89.946,01	15	13491,90
		Logging tool Failure	addditional round trip, tool repair	13	23.385,96	50	11692,98
9 5/8"	2. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	20	35.978,40	15	5396,76
		Casing stuck	overpull, pump pill, circulate and	6	10.793,52	15	1619,03
		Casing not set at the correct Depht	------	3	5.396,76	90	4857,08
		Depth Prediction of the Geology	------	3	5.396,76	90	4857,08
	Cementation	Problems with Cementation	recementation,	5,5	9.894,06	15	1484,11
8 1/2"	Drilling	BHA stuck		7	12.474,35	50	6237,18
		inflow	mud weighted	5	8.910,25	90	8019,23
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.692,30	50	5346,15
		Instable Layer between Rhaet und	mud conditioning, adjust mud flow	5	8.910,25	90	8019,23
		NOR (Fall Back)					0,00
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol. + Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.730,75	15	4009,61
		Logging tool stuck	over pull, pump pill	50	89.102,51	15	13365,38
		Logging tool Failure	addditional round trip, tool repair	15	26.730,75	90	24057,68
7"	Production Casing / Liner Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.551,25	15	6682,69
		Casing stuck	overpull, pump pill, circulate and	6	10.692,30	15	1603,85
		Casing not set at the correct Depht	------	3,5	6.237,18	90	5613,46
		Depth Prediction of the Geology	------	3,5	6.237,18	90	5613,46
	Cementation	Problems with Cementation	recementation,	6,5	11.583,33	15	1737,50
6"	Drilling	BHA stuck		7		50	0,00
		inflow	mud weighted	6	10.572,31	90	9515,08
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	15	3964,62
		Logging tool stuck	over pull, pump pill	55	96.912,83	15	14536,92
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
4 1/2"	Contingency as Liner or Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	15	6607,69
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	15	1585,85
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
Sumtotal				914,5	**1.515.780,06**		**432.568,07**

Table 42: Risk Analysis: Four Sections with one Contingency 16”

Section ["]	Work	Possible Problems	Solving Action	Timeloss [h]	Problem cost [€]	Probability [%]	Problem cost x Probability
17 1/2"	Drilling	inflow	mud weighted	6	7.464,66	15	1119,70
		mud losses	reduce mud weight, pump pill	8	9.952,88	15	1492,93
		- " - , Differential pipe sticking	reduce mud weight, pump pill	24	29.858,64	15	4478,80
		Hole cleaning Problems	mud conditioning, adjust mud flow	6	7.464,66	15	1119,70
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	11.196,99	15	1679,55
		Logging tool stuck	over pull, pump pill	40	49.764,41	15	7464,66
		Logging tool Failure	addditional round trip, tool repair	7,5	9.330,83	15	1399,62
13 3/8"	Surface Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	5	6.220,55	15	933,08
		Casing stuck	overpull, pump pill, circulate and	7	8.708,77	15	1306,32
		Casing not set at the correct Depht	------	2	2.488,22	15	373,23
	Cementation	Problems with Cementation	recementation,	2,5	3.110,28	15	466,54
12 1/4"	Drilling	Hole cleaning Problems	mud conditioning, adjust mud flow	6	11.761,86	50	5880,93
		inflow	mud weighted	6	11.761,86	50	5880,93
		Losses in Aderklaaer Schichten	reduce mud weight, pump pill	6	11.761,86	50	5880,93
		2100m-2300m Open-Hole Section	reaming	22	43.126,82	50	21563,41
		– Borehole Stability					0,00
		BHA Stuck		7	13.722,17	15	2058,33
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	17.642,79	15	2646,42
		Logging tool stuck	over pull, pump pill	43	84.293,34	15	12644,00
		Logging tool Failure	addditional round trip, tool repair	9	17.642,79	15	2646,42
9 5/8"	1. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	15	29.404,65	15	4410,70
		Casing stuck	overpull, pump pill, circulate and	20	39.206,20	15	5880,93
		Casing not set at the correct Depht	------	2,5	4.900,78	90	4410,70
		Depth Prediction of the Geology	------	2,5	4.497,30	90	4047,57
	Cementation	Problems with Cementation	recementation,	5,5	9.894,06	15	1484,11
8 1/2"	Drilling	inflow	mud weighted	10	17.989,20	50	8994,60
		mud losses	reduce mud weight, pump pill	10	17.989,20	50	8994,60
		H2S-Content in the Reyersdorfer	special coring threatment, safety,	3	5.396,76	15	809,51
		– over-hydrostatic pressure	mud conditioning	2	3.597,84	15	539,68
7"	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	13	23.385,96	15	3507,89
		Logging tool stuck	over pull, pump pill	50	89.946,01	15	13491,90
		Logging tool Failure	addditional round trip, tool repair	13	23.385,96	50	11692,98
	2. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	20	35.978,40	15	5396,76
		Casing stuck	overpull, pump pill, circulate and	6	10.793,52	15	1619,03
		Casing not set at the correct Depht	------	3	5.396,76	90	4857,08
		Depth Prediction of the Geology	------	3	5.396,76	90	4857,08
	Cementation	Problems with Cementation	recementation,	5,5	9.894,06	15	1484,11
6"	Drilling	BHA stuck		7	12.334,36	50	6167,18
		inflow	mud weighted	5	8.810,26	90	7929,23
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, shut in the well, circulate	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk	out, mud conditioning				0,00
		-> Kick!		38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	30	7929,23
		Logging tool stuck	over pull, pump pill	55	96.912,83	30	29073,85
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
4 1/2"	Production Casing / Liner Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	20	8810,26
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	20	2114,46
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
Sumtotal				601,5	1.036.790,34		**314.978,39**

Table 43: Risk Analysis: Four Sections without Contingency

Section	Work	Possible Problems	Solving Action	Timeloss [h]	Problem cost [€]	Probability [%]	Problem cost x Probability
17 1/2"	Drilling	inflow	mud weighted	6	7.464,66	15	1119,70
		mud losses	reduce mud weight, pump pill	8	9.952,88	15	1492,93
		- " - , Differential pipe sticking	reduce mud weight, pump pill	24	29.858,64	15	4478,80
		Hole cleaning Problems	mud conditioning, adjust mud flow	6	7.464,66	15	1119,70
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	11.196,99	15	1679,55
		Logging tool stuck	over pull, pump pill	40	49.764,41	15	7464,66
		Logging tool Failure	addditional round trip, tool repair	7,5	9.330,83	15	1399,62
13 5/8"	Surface Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	5	6.220,55	15	933,08
		Casing stuck	overpull, pump pill, circulate and	7	8.708,77	15	1306,32
		Casing not set at the correct Depht	------	2	2.488,22	15	373,23
	Cementation	Problems with Cementation	recementation,	2,5	3.110,28	15	466,54
12 5/8"	Drilling	Hole cleaning Problems	mud conditioning, adjust mud flow	6	11761,86	50	5880,93
		inflow	mud weighted	6	11761,86	50	5880,93
		Losses in Aderklaaer Schichten	reduce mud weight, pump pill	6	11761,86	50	5880,93
		2100m-2300m Open-Hole Section	reaming	22	43126,82	50	21563,41
		– Borehole Stability					0,00
		BHA Stuck		10	19603,10	15	2940,47
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	17642,79	15	2646,42
		Logging tool stuck	over pull, pump pill	43	84293,34	15	12644,00
		Logging tool Failure	addditional round trip, tool repair	9	17642,79	15	2646,42
10 3/4"	1. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	15	29404,65	22	6469,02
		Casing stuck	overpull, pump pill, circulate and	20	39206,20	22	8625,36
		Casing not set at the correct Depht	------	2,5	4900,78	90	4410,70
	Cementation	Problems with Cementation	recementation,	3,5	6861,09	15	1029,16
9 5/8"	Drilling	inflow	mud weighted	10	17989,20	50	8994,60
		mud losses	reduce mud weight, pump pill	10	17989,20	50	8994,60
		H2S-Content in the Reyersdorfer	special coring threatment, safety,	3	5396,76	15	809,51
		– over-hydrostatic pressure	mud conditioning	2	3597,84	15	539,68
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	13	23385,96	15	3507,89
		Logging tool stuck	over pull, pump pill	50	89946,01	15	13491,90
		Logging tool Failure	addditional round trip, tool repair	13	23385,96	50	11692,98
8 5/8"	2. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	20	35978,40	20	7195,68
		Casing stuck	overpull, pump pill, circulate and	6	10793,52	20	2158,70
		Casing not set at the correct Depht	------	3	5396,76	90	4857,08
		Depth Prediction of the Geology	------	3	5396,76	90	4857,08
	Cementation	Problems with Cementation	recementation,	5,5	9894,06	15	1484,11
7 3/8"	Drilling	BHA stuck		10	17.620,51	50	8810,26
		inflow	mud weighted	6	10.572,31	90	9515,08
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	15	3964,62
		Logging tool stuck	over pull, pump pill	55	96.912,83	15	14536,92
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
6 5/8"	Production Casing / Liner Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	18	7929,23
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	18	1903,02
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
5 3/8"	Drilling	BHA stuck		10	17.620,51	50	8810,26
		inflow	mud weighted	5	8.810,26	90	7929,23
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	15	3964,62
		Logging tool stuck	over pull, pump pill	55	96.912,83	15	14536,92
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
4"	Contingency as Liner or Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	18	7929,23
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	18	1903,02
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
Sumtotal				811,5	1404867,21		433.646,99

Table 44: Risk Analysis: Unconventional Diameter: Four sections with one contingency

Section	Work	Possible Problems	Solving Action	Timeloss [h]	Problem cost [€]	Probability [%]	Problem cost x Probability
17 1/2"	Drilling	inflow	mud weighted	6	7.464,66	15	1119,70
		mud losses	reduce mud weight, pump pill	8	9.952,88	15	1492,93
		- " - , Differential pipe sticking	reduce mud weight, pump pill	24	29.858,64	15	4478,80
		Hole cleaning Problems	mud conditioning, adjust mud flow	6	7.464,66	15	1119,70
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	11.196,99	15	1679,55
		Logging tool stuck	over pull, pump pill	40	49.764,41	15	7464,66
		Logging tool Failure	addditional round trip, tool repair	7,5	9.330,83	15	1399,62
13 5/8"	Surface Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	5	6.220,55	15	933,08
		Casing stuck	overpull, pump pill, circulate and	7	8.708,77	15	1306,32
		Casing not set at the correct Depht	------	2	2.488,22	15	373,23
	Cementation	Problems with Cementation	recementation,	2,5	3.110,28	15	466,54
12 5/8"	Drilling	Hole cleaning Problems	mud conditioning, adjust mud flow	6	11761,86	50	5880,93
		inflow	mud weighted	6	11761,86	50	5880,93
		Losses in Aderklaaer Schichten	reduce mud weight, pump pill	6	11761,86	50	5880,93
		2100m-2300m Open-Hole Section	reaming	22	43126,82	50	21563,41
		– Borehole Stability					0,00
		BHA Stuck		10	19603,10	15	2940,47
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	9	17642,79	15	2646,42
		Logging tool stuck	over pull, pump pill	43	84293,34	15	12644,00
		Logging tool Failure	addditional round trip, tool repair	9	17642,79	15	2646,42
10 3/4"	1. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	15	29404,65	44	12938,05
		Casing stuck	overpull, pump pill, circulate and	20	39206,20	44	17250,73
		Casing not set at the correct Depht	------	2,5	4900,78	90	4410,70
	Cementation	Problems with Cementation	recementation,	3,5	6861,09	15	1029,16
9 5/8"	Drilling	inflow	mud weighted	10	17989,20	50	8994,60
		mud losses	reduce mud weight, pump pill	10	17989,20	50	8994,60
		H2S-Content in the Reyersdorfer	special coring threatment, safety,	3	5396,76	15	809,51
		– over-hydrostatic pressure	mud conditioning	2	3597,84	15	539,68
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	13	23385,96	15	3507,89
		Logging tool stuck	over pull, pump pill	50	89946,01	15	13491,90
		Logging tool Failure	addditional round trip, tool repair	13	23385,96	50	11692,98
8 5/8"	2. Intermediate Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	20	35978,40	40	14391,36
		Casing stuck	overpull, pump pill, circulate and	6	10793,52	40	4317,41
		Casing not set at the correct Depht	------	3	5396,76	90	4857,08
		Depth Prediction of the Geology	------	3	5396,76	90	4857,08
	Cementation	Problems with Cementation	recementation,	5,5	9894,06	15	1484,11
7 3/8"	Drilling	BHA stuck		10	17.620,51	50	8810,26
		inflow	mud weighted	6	10.572,31	90	9515,08
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	15	3964,62
		Logging tool stuck	over pull, pump pill	55	96.912,83	15	14536,92
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
6 5/8"	Production Casing / Liner Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	36	15858,46
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	36	3806,03
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
5 3/8"	Drilling	BHA stuck		10	17.620,51	50	8810,26
		inflow	mud weighted	5	8.810,26	90	7929,23
		Losses in Hornstein/Hierlatzkalk	reduce mud weight, pump pill	6	10.572,31	50	5286,15
		Instable Layer between Rhaet &	mud conditioning, adjust mud flow	5	8.810,26	90	7929,23
		Overpressure in the Perchtoldsd.	pump pill, mud conditioning	8	14.256,40	15	2138,46
		Dol.+ Losses in the Hornsteinkalk					0,00
		-> Kick!	shut in the well, circulate, mud	38	66957,9532	50	33478,98
	Logging	Logging tool Stand off during run in	ram down ?, run out, wiper trip,	15	26.430,77	15	3964,62
		Logging tool stuck	over pull, pump pill	55	96.912,83	15	14536,92
		Logging tool Failure	addditional round trip, tool repair	15	26.430,77	90	23787,69
4"	Contingency as Liner or Casing Installation	Casing Stand off during run in	ram down, circulate and rotate,	25	44.051,29	36	15858,46
		Casing stuck	overpull, pump pill, circulate and	6	10.572,31	36	3806,03
		Casing not set at the correct Depht	------	3,5	6.167,18	90	5550,46
		Depth Prediction of the Geology	------	3,5	6.167,18	90	5550,46
	Cementation	Problems with Cementation	recementation,	6,5	11.453,33	15	1718,00
Sumtotal				811,5	1404867,21		477.760,26

Table 45: Risk Analysis: Unconventional Diameter: Four sections with one contingency & tie back with regular diameter