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Appraisal Well Design in "X" Oil Field

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Abstract

The selection of casing depths and casing design are considered one of the most critical steps in the well construction process. Inaccurate selection of casing setting depths and casing design can result in many challenges, long time and hence high well costs.

"X" oil field was taken as a case study. There is only the exploration well X-1 drilled up to date. The 20″ surface casing was relatively long because it was set at the top of Dammam Formation. That means deep surface hole, long trip time, large amount of mud, long surface casing, large amount of cement and hence high cost. Also, Hartha Formation was not evaluated because it is isolated with the 13 3/8" & 9 5/8" casing and the perforation through two casing was not available. Another problem, the 9 5/8″ production casing damaged at the depth 32 m due to failure of tolerating the axial forces before or after the cement job.

All data was inputted into the Landmark software to simulate the well. It was found that the surface casing can be set at the top of Lower Faris Formation instead of Dammam Formation. Also, The Hartha Formation can be drilled in the 12 ¼ ″ hole and isolated by 9 5/8″ casing instead of drilling it in the 17 ½ ″ hole and isolating it by the 13 3/8″ casing. It was also found that the 9 5/8″ production casing can withstand all loads by selecting casing with higher weight.

The cost of the modified design was also checked to study the feasibility of the modified design. It was concluded that the modified design can save around 300,000 USD for each well comparing with the design of well X-1.

It is recommended to apply this design on the appraisal well to be drilled. If the design shows no problems, it can be considered the optimum design of appraisal and development wells to be drilled in the future. Also, the slim-hole design can be studied

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and an economic feasibility comparison can be made with the current and the proposed design in this study.

Keywords: Casing, Setting Depth, Design, Cost.

تصميم بئر تقييمي في حقل "X" النفطي

يعتبر اختيار أعماق البطانات وتصميمها من أهم الخطوات في عملية بناء البئر النفطية. أن الاختيار غير الدقيق لأعماق البطانات وتصميمها يمكن أن يؤدي إلى العديد من التحديات التي تستغرق زمن طويل لتجاوزها وبالتالي ارتفاع تكاليف الآبار.
تم أخذ حقل "X" النفطي كدراسة حالة. تم حفر بئر استكشافي واحد X-1 حتى الآن. كانت البطانة السطحية ″ 20 طويلة نسبيًا بسبب تثبيتها في الجزء العلوي من تكوين الدمام. وهذا يعني حفر مقطع سطحي عميق، ووقت السحب والتنزيل يكون طويلاً، زيادة كميات طين الحفر، بطانة سطحية طويلة، زيادة كميات السمنت، وبالتالي تكلفة عالية. بالاضافة الى ذلك، لم يتم تقييم تكوين الهارثة لأنه معزول ببطانتين 13 8/3" & 9 8/5" ولم تكن تقنية التثقيب خلال بطانتين متاحة. كذلك ظهرت مشكلة أخرى، البطانة الانتاجية 9 8/5" وجدت مقطوعة على عمق 32 متراً بسبب فشل تحمل قوى الشد المحوري قبل أو بعد عملية التسميت.
تم إدخال جميع البيانات في برنامج Landmark لمحاكاة البئر. وجد أن البطانة السطحية يمكن وضعها في أعلى تكوين الفارس الاسفل بدلاً من تكوين الدمام. أيضا، يمكن حفر تكوين الهارثة في المقطع 12 4/1" وعزله ببطانة 9 8/5" بدلاً من حفره في المقطع 17 2/1" وعزله ببطانة 13 8/3". وجد أيضاً أن البطانة الإنتاجية 9 8/5" يمكنها تحمل جميع الأحمال عن طريق اختيار البطانة ذات الوزن الأعلى.
كما تم تخمين تكلفة التصميم المعدل أيضاً لغرض دراسة جدوى التصميم المعدل. وجد أن التصميم الجديد يمكن أن يوفر حوالي 300000 دولار أمريكي لكل بئر مقارنةً بتصميم البئر X-1.
يوصى بتطبيق هذا التصميم على بئر التقييم التي سيتم حفرها. إذا لم يظهر التصميم أي مشاكل، فيمكن اعتباره التصميم الأمثل للآبار التقييمية والتطويرية التي سيتم حفرها في المستقبل. كذلك يمكن دراسة تصاميم تجاويف Slim-hole واجراء مقارنة اقتصادية بينها وبين التصميم الحالي والتصميم المقترح في هذه الدراسة.

1. Introduction

The Hole problems such as lost circulation, pipe sticking and/or well control problems occur during drilling troublesome formations. Inaccurate selection of casing setting depths makes the problems worse and more difficult to cure. For example, if the surface hole is relatively deep, that means long trip time to change the bit, increase number of bits to use, large amounts of drilling mud, long casing string and large amounts of cement. That leads to increase the risk of encountering the drilling problems and to increase the overall well cost [1].

The challenges come from the drilling operations in the "X" oil field, a new onshore oil field. The surface casing string was set few meters in Dammam Formation. In this well, the surface casing was relatively deep which may cause many challenges to be

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encountered while drilling and evaluation stages. The 9 5/8″ production casing had a damage problem which required work over operations. Hartha Formation is the last formation drilled in the 17 ½ " intermediate section in well X-1. Hartha Formation was isolated by 13 3/8" and 9 5/8" casing which made the evaluation of this formation difficult.

All challenges were studied in this research and solutions have been recommended to drill the next appraisal well Da-2. Also, the estimated cost reduction will be shown in comparison with the design of the exploration well X-1.

1.1 Casing Seat Selection

The selection of casing setting depths is considered the first step of the casing design process. Incorrect selection of casing setting depths can preclude the well from achieving its objective. Casing seat selection is governed by the following parameters:

1. Formation pore pressure.
2. Formation fracture pressure.
3. Hole problems and wellbore stability considerations.
4. Kick tolerance requirements.
5. Experience in the region where drilling operations are carried out.
6. Corrosive zones.
7. Environmental considerations.
8. Regulations in which the field is located.
9. Company policy [2].

The casing setting depths are usually determined by two approaches:

1.1.1 Bottom-to-Top Approach

In this approach, the casing setting depths are selected by determining the depth of the production casing (or production liner), then the intermediate casing depth and after that the surface casing depth. The number of casing strings is governed by the depth of the well, the pore pressure gradient, the fracture pressure gradient, the kick tolerance and hole problems such as lost circulation, pipe sticking, wellbore stability. [3]

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1.1.2 Top-to-Bottom Approach

The setting depths of casing in this approach are determined starting from the surface casing to the production casing or the production liner. That means the depth of the surface hole is determined first and then the intermediate and production hole sections respectively.[3]

1.2 Selection of Casing Sizes

Once the number of casing strings and their setting depths are determined, the size of each casing string should be determined. Typically, it is recommended to start determining the size of the last casing string to be set on the bottom of the well. The size of the last casing string depends on the type of completion to be used. In addition, the casing program should allow for alternatives in case an uncontrollable problem is encountered and an additional casing string is required to isolate the problematic interval.[1]

1.3 Casing Design Criteria

Once the number of casing strings, setting depths and casing sizes are determined, the next step is to design each casing string based on the expected loads acting on each casing during various operations and service life. Basically, three types of loads are considered as follows:

1. Collapse:

Collapse loads are defined as the differential pressure in which the pressure outside the string exceeds the pressure inside the string. [3]

$$\text{Collapse pressure} = P_{out} - P_{in} \tag{1}$$

Where:

P_{out} : pressure outside casing (psi).

P_{in} : pressure inside casing (psi).

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2. Burst:

Burst loads are defined as the differential pressure in which the pressure inside the string exceeds the pressure outside the string. [3]

$$\text{Burst pressure} = P_{in} - P_{out} \quad (2)$$

3. Axial loads:

Axial loads causes tension or compression loads which mostly result from gravitational forces, frictional forces or changes in the pressure and temperature in the wellbore. In directional wells, there are also bending forces [4]. Also, bi-axial and tri-axial loads are taken into consideration.

1.4 Casing Specifications Selection

Once the maximum expected collapse and burst loadings are calculated and design lines are obtained, casing can be selected to approach the requirements of the design. Then, selected casing should be checked for axial, biaxial and tri-axial loads to ensure that it can withstand these loads during various stages. [5], [1]

In addition to design criteria, many considerations contribute to the selection of casing. The most important considerations are:

a) Grade and weight of casing.
b) Connection.
c) Cost should be kept as low as possible.
d) Current availability of casing.
e) Transportation.
f) Logistics issues. [5]

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2. Case Study

2.1 Field Data

"X" oil field is a new oil field located in Missan/Iraq. The field is operated by Missan oil company (MOC). One vertical well (X-1) was drilled in the field in 2012 by the Iraqi drilling company.

2.1.1 Lithological Column and Geological Description

The lithological column and geological interpretation are illustrated in Table (1).

2.1.2 Casing Program

Table (2) illustrates the casing strings used and their setting depths.[6]

2.1.3 Well Sketch

The well sketch is shown in Figure (1).

2.2 Casing Setting Depths and Design Problems in Da-1

The problems, challenges and their outcomes are explained in the following points:

1. The setting depth of 20″ surface casing is considered relatively deep. That means deep surface hole and hence long trip time, more bits to consume, large amounts of drilling mud, large amounts of cement, long casing string and high risk of casing sticking. All those challenges lead to high well cost.
2. A production casing 9 5/8″, 47 ppf, P-110, BTC has been used in X-1. Two stage cement job was achieved; the first stage was from the casing shoe depth 3912 m to the depth 3190 m. The second stage was achieved from 3190 m (D.V tool) to the top of cement (TOC) at 1750 m. A damage in this casing string occurred at the depth 32 m. The problem was identified while evaluation stage after perforating Yamamma Formation. The pressure in the annulus between 13 3/8″ intermediate casing and 9 5/8” production casing increased to the same value of the pressure inside the production casing which indicates that there is a leakage from the production casing to the annulus behind this casing. Then, 1.5 m^3 of mud were pumped to the annulus to make sure that there is a connection between the annulus and the production

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casing. The mud returned to the surface from inside the casing. The caliper log showed that the damage depth was at 30-32 m (no casing).

3. Workover operations were achieved to solve the problem as follows:
   a) Plugging the well by cement plug from 1004 m to 1105 m.
   b) Deactivating the secondary seals of 13 5/8" Flange.
   c) Nippling down tubing head (7 1/16") and casing spool (13 5/8” *5000 psi *11”*10000 psi) then releasing 9 5/8" casing hanger and pulling the cut casing out of the hole.
   d) RIH fishing tool (spear) with left threaded drill pipe to depth 32 m and backing off 9 5/8" casing to depth 229 m.
   e) D.V was made up with 9 5/8" casing and RIH and connected with casing in well at depth 229 m.
   f) Landing new hanger of 9 5/8"casing.
   g) Opening the D.V and pumping cement slurry behind 9 5/8" casing through the D.V from depth 229 m to surface then closing the D.V by 1000 psi. [6]

2.3 Evaluation of Hartha Formation

After completing the drilling operations, the evaluation of the formations was started to determine the pay zones in the field. Evaluation of Yammama, Nhr Umr, Mishrif, Khasib and Sadi formations were successfully achieved. While, the evaluation of Hartha formation (2133.5 m to 2148 m) was canceled due to inability to perforate two casing (13 3/8" & 9 5/8”) because Hartha formation was the last formation drilled in the first intermediate hole section (17 ½") whereas the other formations has been drilled in the second intermediate hole section (12 ¼ ") and isolated by one casing only (9 5/8") Figure (2). [6]

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Table (1): Lithological column and geological description of X-1

Formation	Top of Formation (m MSL)	Lithology
Alluvium	Surface	Claystone
Upper Faris	150	Claystone, Sand and Gypsum
Lower Faris	750	Anhydrite, Clay, Marl & limestone
Ghar	1110	Sand, Clay
Dammam	1230	Dolomite & Limestone
Rus	1400	Dolomite & Anhydrite
Umm Eradhuma	1405	Dolomite, Limestone & Marl
Tayarat	1855	Dolomite, Limestone & Arg.
Shiranish	1970	Limestone & Marl.
Hartha	2095	Dolomite, Limestone, Marl & Shale.
Sadi	2275	Limestone.
Tanuma	2365	Shale, Marl & Limestone.
Khassib	2415	Limestone, Shale.
Mishrif	2485	Limestone.
Rumaila	2720	Limestone.
Ahmadi	2760	Shale & Limestone.
Maudud	2920	Limestone.
Nahr Umar	3110	Sandstone & Shale.
Shuaiba	3330	Limestone & Dolomite.
Zubair	3495	Sandstone & Shale.
Ratawi	3835	Limestone.
Yamama	3950	Limestone
Sulay	4250	Limestone

Table (2): Casing program of well X-1 [6]

Hole Size (inches)	Casing Size (inches)	Casing Type	Casing Grade	Casing Weight (ppf)	Connection	Casing Depth (m)
36	30	CP	K-55	280		50
26	20	Surface	K-55	133	BTC	1247
17 ½	13 3/8	Intermediate	N-80	72	BTC	2299
12 ¼	9 5/8	Production	P-110	47	BTC	3912
8 ½	7	Production Liner	C-95	32	BTC	4212

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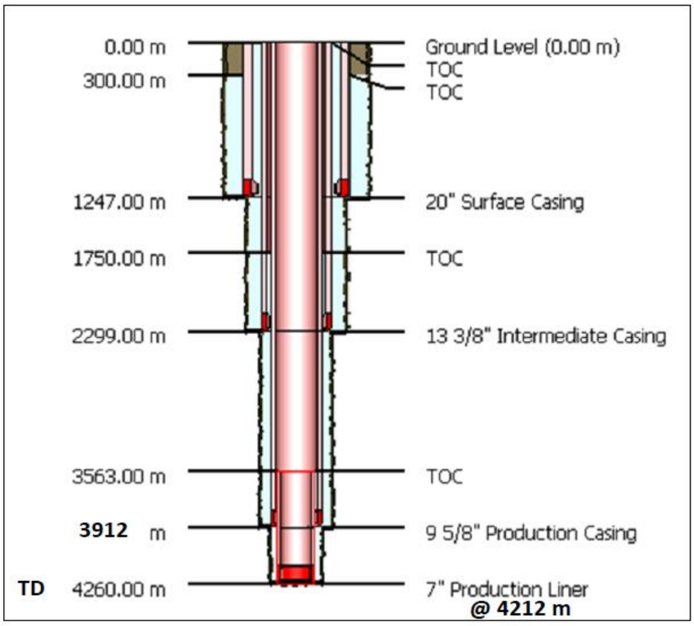

Fig. (1): Well sketch of well X-1 [6]

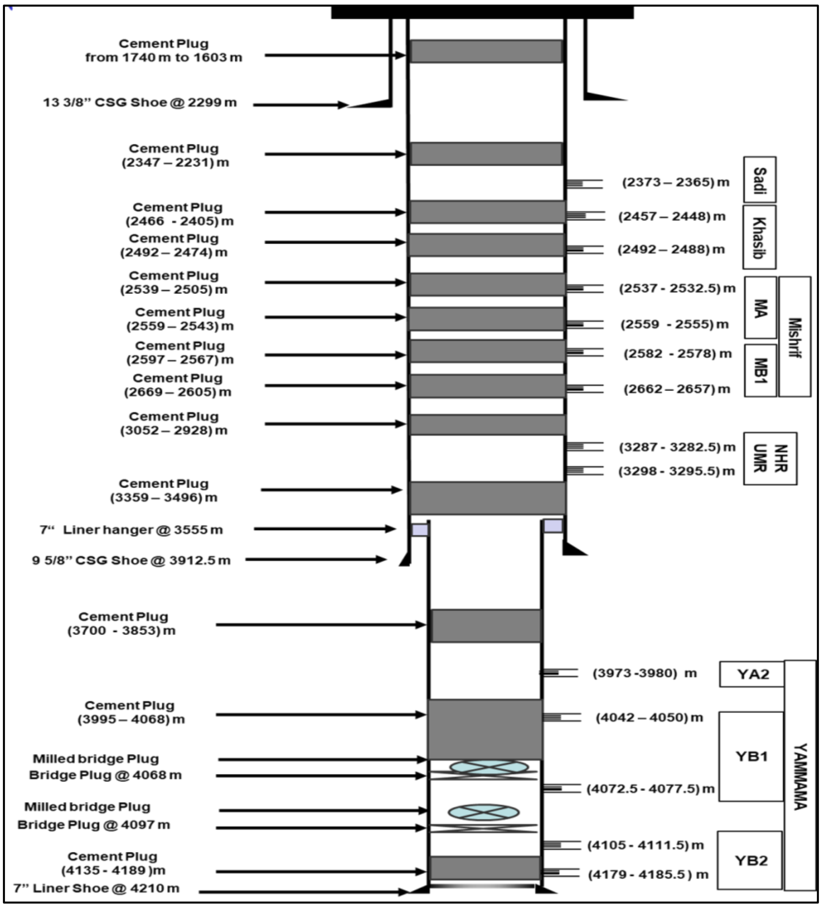

Fig. (2): Final well status of well X-1 [6]

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3. Results and Discussion

3.1 Casing Setting Depths

The design limitations include the following points:

a) Overbalance margin.

b) Differential sticking limit.

c) Stability minimum mud weight.

d) Kick tolerance consecration.

The design was based on the analysis method (Bottom Up Design and Up Down Design), Figure (3).

The Landmark software provides the least design costs (depending on the prices of raw steel and the cost of drilling one foot) or the smallest hole sizes and casing sizes. In case of cost details are not available, the design will be from the largest size to the smallest size. Figure (4) illustrates the possible hole and casing sizes, where dark shapes give the hole size and the white shapes give the casing sizes that are possible to run in hole.

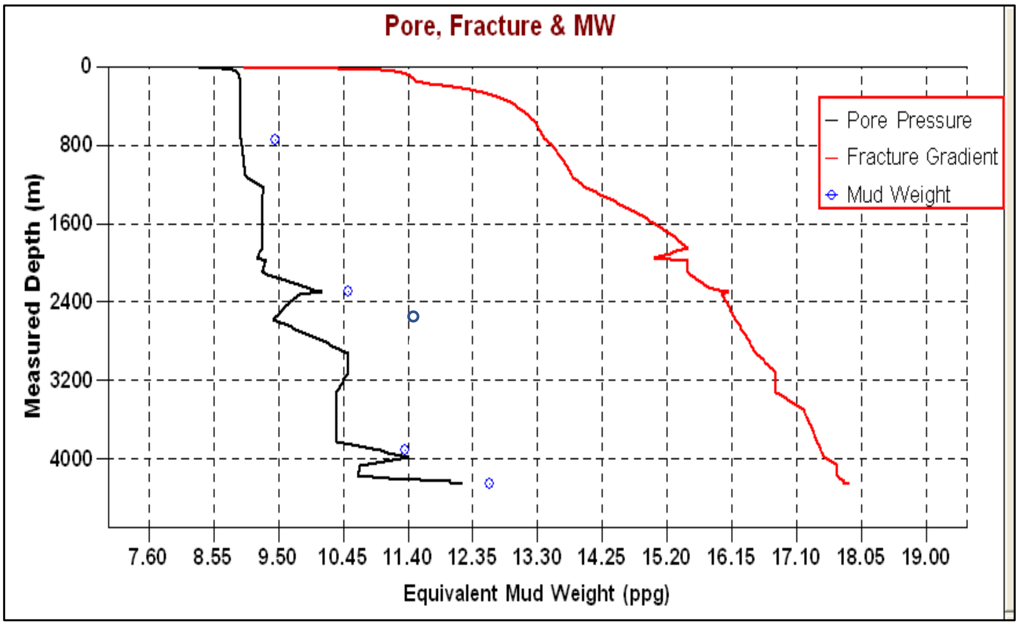

Fig. (3): Pressure profile and setting depths

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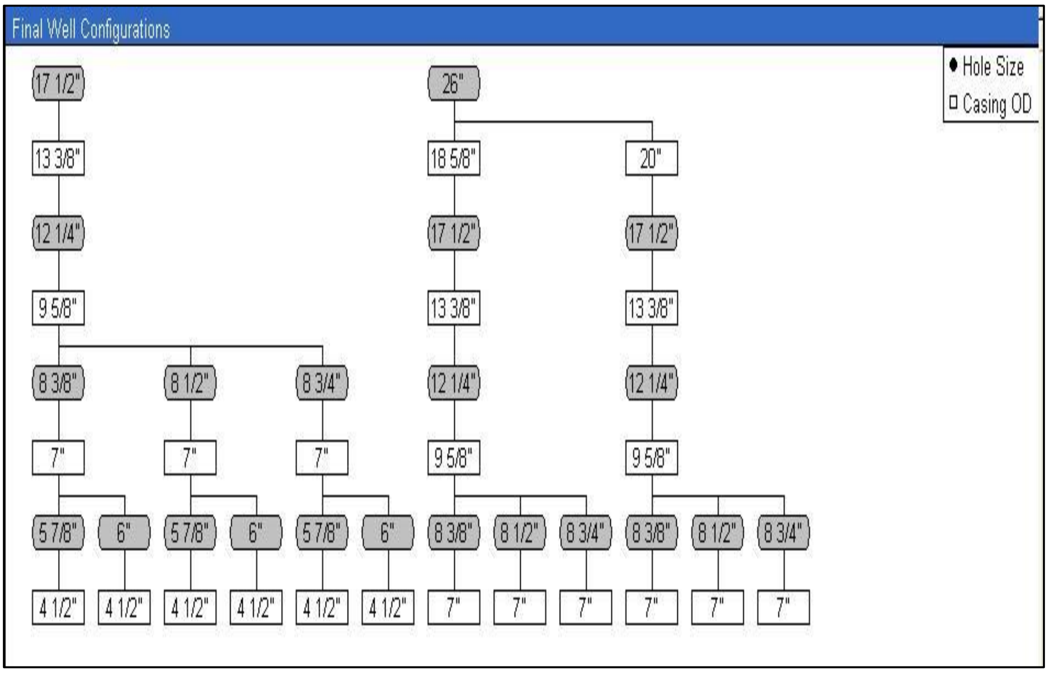

Fig. (4): The possible hole and casing sizes of appraisal well in "X" oil field

The 20" surface casing and the 13 3/8" intermediate casing setting depths have been changed by using the Landmark/ Casing seat as follows:

3.1.1 Proposed 20" Surface Casing Setting Depth

The main changes are explained as follows:

1. The casing setting depth of the 20″ surface casing is at 750 m (top of Lower Faris) in Anhydrite formation instead of setting that casing at 1247 m (top of Dammam formation), Table (3).
2. The casing setting depths and the comparison of the well sketches are shown in Figures (5 & 6) respectively.
3. It should be mentioned that the 20″ surface casing can be set at the same depth as in X-1 (at 1247 m) in case that Dammam is a thief zone. In case of no lost circulation is encountered, the 20″ surface casing can be set at 750 m.

The design limitations are due to increase the hydrostatic pressure of mud with adding ECD, which can fracture the formation at some depth, and the limitations related to the influx volume (40 bbl as a worst case) require running casing. But, if the surface casing setting depth is less than 750 m, then the software will add one more casing string due to

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exceeding the maximum value of the kick tolerance which had been previously determined.

3.1.2 Proposed 13 3/8" Intermediate Casing Setting Depth

It was found that the casing seat can be at (+/-) 2000 m through Shiranish formation (Table 3). The latest formation is a competent formation which makes it suitable for setting the 13 3/8" intermediate casing string. When cementing the 13 3/8" casing, the most competent lithology must be selected for setting the casing and the casing must be raised around 5 m to be set at a strong cement structure. Due to changing the setting depth of the 13 3/8" intermediate casing, Hartha formation will be drilled in 12 ¼" the second intermediate hole section. In this case the cementing of the 9 5/8" casing that is run through the 12 ¼" hole must be two-stage cementing. The TOC of the first stage is at 1850 m. This will reduce the hydrostatic pressure that is exerted on Hartha formation. Based on this scenario, the cementing of the 13 3/8" casing will be one stage instead of two-stage.

3.1.3 The 9 5/8" Production Casing Setting Depth

No change in setting depth is proposed, but the TOC should be at 538 m to tolerate the loads without failure. The length of the production casing can be either from the surface to the total depth or a production liner. In case of using a 7″ production liner, the 9 5/8″ will be considered as a production casing.

Table (3): The first suggested design

	OD (in)	Hole Size (in)	Shoe Depth (m)	TOC
1	20	26	750	295.9
2	13 3/8	17.5	2000	451.7
3	9 5/8	12.25	3912	539.4
4	7	8.5	4260	744.7

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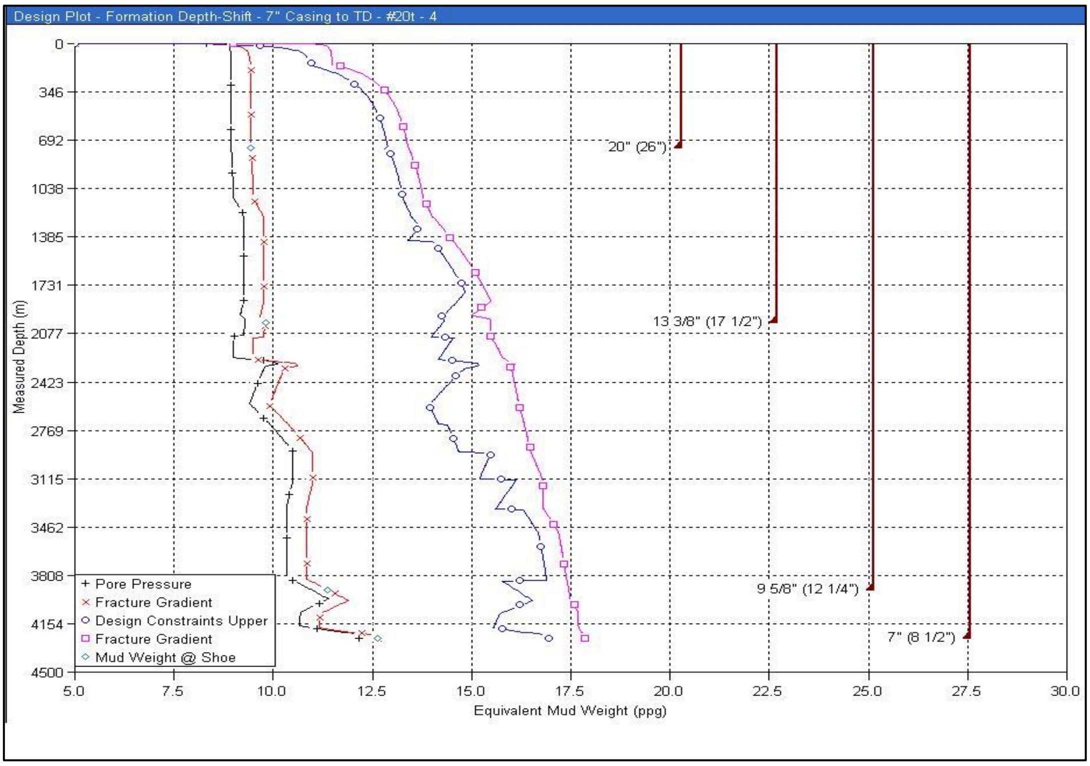

Fig. (5): Casing setting depth with pore pressure and fracture pressure gradients

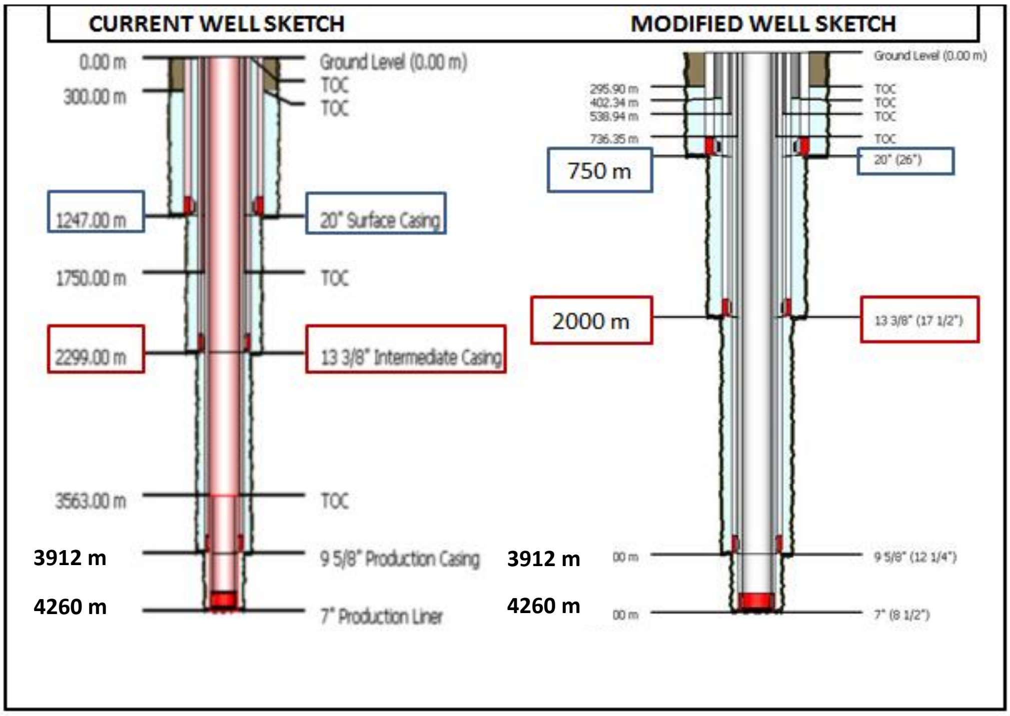

Fig. (6): Comparison between the current and the proposed well sketches.

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3.2 Casing Design and Stress Check

After determining the depth of each hole section, casing setting depths, hole sizes and casing sizes, the next step is determining the casing grade, weight and coupling that can tolerate the loads applied on the casing. Safety factors are taken into account in the design process. The loads are simulated in the Landmark/Stress check as follows:

1. For Collapse Loads, all assumptions are shown in Figure (7).
2. For burst loads design, all assumptions are shown in Figure (8).
3. The other forces such as axial forces, tri-axial forces and the compression forces are considered after the casing selection in order to check the tolerance of the selected casing to those forces.

Based on the assumption mentioned in Figures (7 & 8), the casing specifications were determined as shown in Table (4). It was found that:

a) All the design factor values for all loads are acceptable according to the basics of design.
b) All couplings are BTC.
c) In case of setting the surface casing at the top of Dammam formation (+/- 1247 m), the casing specification 20″, K-55, 147 ppf, BTC will be the best option to use.
d) The damage of the 9 5/8″ production casing that occurred in X-1 can be avoided by selecting casing with higher weight. The proposed casing to be used is 9 5/8″, 53.5 ppf, P-110, BTC instead of using 9 5/8″, 47 ppf, P-110, BTC to avoid problems that may be encountered due to collapse and/or tension failure.

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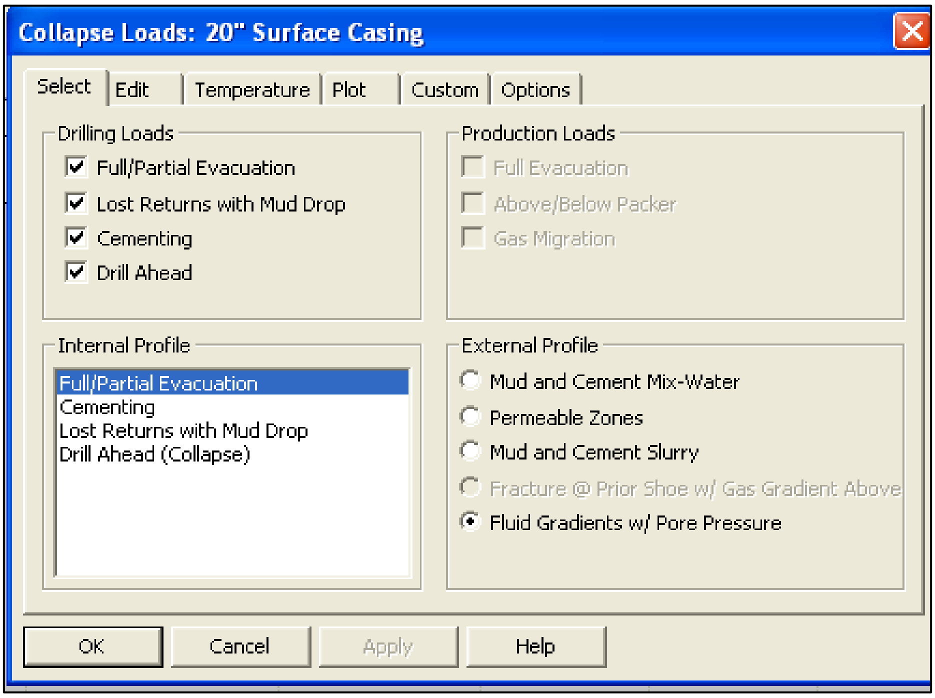

Fig. (7): Collapse loads scenarios

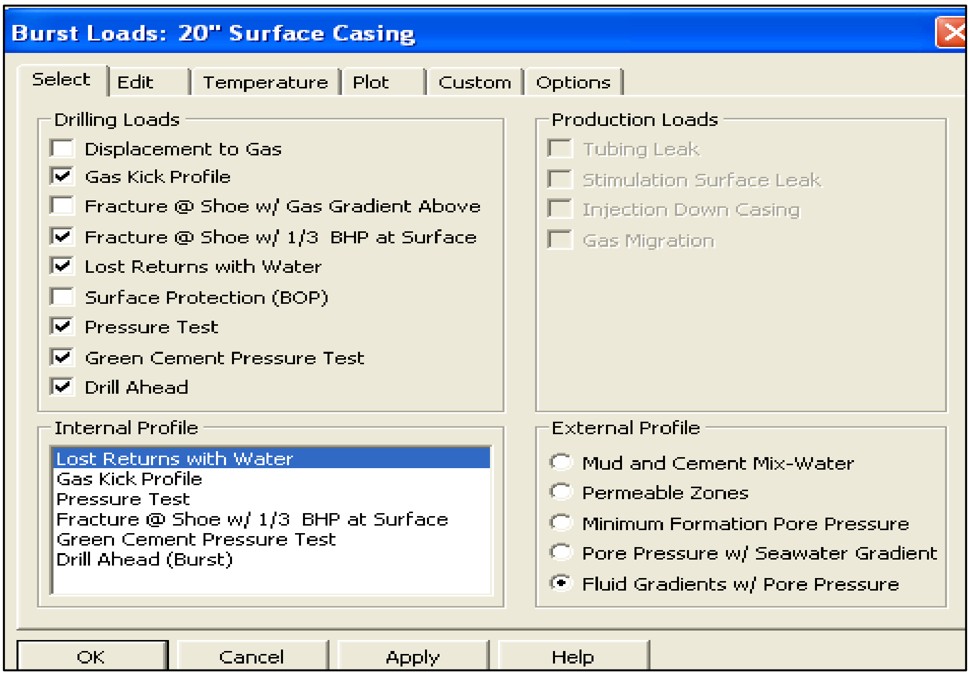

Fig. (8): Scenarios of burst loads

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Table (4): The casing specifications

	OD/Weight/Grade	Connection	MD Interval (m)	Minimum Safety Factors			
				Burst	Collapse	Axial	Triaxial
1	20", 133 ppf, K55	BTC, K-55	0 - 750	1.12	1.4	3.47	1.82
2	13 3/8", 72 ppf, P-110	BTC, P-110	0 - 2000	1.13	1.3	2.75	1.99
3	9 5/8", 53.5 ppf, P-110	BTC, P-110	0 - 3912	1.53	1.48	1.98	1.97

3.3 Economic Feasibility

The most important benefit obtained from the design modification must be the overall cost reduction resulting from consuming time and materials. The challenges of getting the well cost details of well X-1 led the research team to use the cost of other wells from another field in the same governorate “Missan”. The cost data of the bits was neglected because it was assumed that the same type of bits used in X-1 will be used while drilling the next wells. Time saving is not easy to be estimated at this stage because the wells are either exploration wells or appraisal wells.

3.3.1 Casing Cost

The casing cost was got from MOC. Some casing grades or weights costs were not available, therefore the same cost of the closest casing grades and weights to the required casing grades and weights has been assumed. Table (5) shows the expected cost saving related the casing by applying the modified design.

3.3.2 Cementing Cost

The cementing cost data was obtained from some wells in Amara oil field. Table (6) illustrates the cost reduction related to cement.

3.3.3 Drilling Fluids Cost

The cost data related to drilling mud of X-1 is available and it’s obtained from MOC. Table (7) gives the details of the expected reduction in mud consumption and hence cost.

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The calculations based on the price of ton of material. It should noticed that 1 bag of material is equal to 25 Kg.

3.3.4 Overall Cost Reduction

Based on the costs that have been taken into consideration, the total cost to be reduced from drilling one well is around 300,000 USD.

Table (5): Casing costs

Casing Size (inch)	Casing Grade	Casing Weight (ppf)	Casing Depth (m) in Da-1	Cost per Meter ($/m)	Cost ($) of Casing in Da-1	Proposed Casing Grade	Proposed Casing Weight (ppf)	Proposed Casing Depth (m)	Cost per Meter ($/m)	New Cost ($)	Diff. in Cost ($)
20	K-55	133	1247	400	498,800	K-55	133	750	400	300,000	**198,800**
13 3/8	N-80	72	2299	170	390,830	P-110	72	2000	170	340,000	**50,830**
9 5/8	P-110	47	3912	80	312,960	P-110	53.5	3912	92	359,904	**- 46,944**
Total Cost Reduction of Casing ($)											**202,686**

Table (6): Cementing costs

Hole Size (inch)	Casing Size (inch)	Interval to be cemented (m)		Quantity (Ton)	Cost ($/Ton)	Cost ($)	Proposed Interval to be cemented (m)		Quantity (Ton)	New Cost ($)
26	20		1247	231.7	343	79,473		750	139.4	47,814
17 ½	13 3/8	1st stage	2299-1983	27	343	9,261		750-402	145.8	50,010
		2nd stage	1983-surface	215.3	343	73,848				
12 ¼	9 5/8	1st stage	3912-3190	26.4	343	9,055	1st stage	3912-2000	70	24,010
		2nd stage	3190-1750	60.4	343	20,717	2nd stage	2000-538	62.1	21,300
Total Cost ($)						**192,354**				**143,134**
Cementing Cost Reduction ($) = 49,220										

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Table (7): Mud Costs

Hole Size (inch)	Mud Material	Mud Consumption in Da-1	Expected Consumption due to proposed design	Diff. in consumption	Diff. Weight (Ton) or (m^3 for crude oil)	Price ($/ton) or ($/m^3 for crude oil)	Diff. in Cost ($)
26	Bentonite (ton)	167	100	67	67	225	**15,075**
	soda ash (bag)	246	148	98	2.5	800	**2,000**
	starch (bag)	384	231	153	3.8	790	**3,002**
	caustic soda (bag)	202	121	81	2	700	**1,400**
	CMC HV (bag)	58	35	23	0.58	2775	**1,610**
	Lignosulphonate (bag)	232	140	92	2.3	2000	**4,600**
	Lignite (bag)	184	111	73	1.8	860	**1,548**
	Crude oil (m3)	12	7	5	5	420	**2100**
17 ½	Bentonite (ton)	68	59	9	9	225	**2025**
	Barite (ton)	134.5	117	17	17	250	**4250**
	soda ash (bag)	133	116	17	0.43	800	**344**
	starch (bag)	190	165	25	0.62	790	**490**
	caustic soda (bag)	229	199	30	0.75	700	**525**
	CMC HV (bag)	609	530	79	1.98	2775	**5495**
	Sodium Becarbonate (bag)	18	16	2	0.06	700	**42**
	Lignosulphonate (bag)	117	102	15	0.38	2000	**760**
	Lignite (bag)	35	30	5	0.11	860	**95**
	Crude oil (m3)	69	60	9	9	420	**3780**
Total Cost Reduction of Mud ($)							**49,141**

4. <u>Conclusions</u>

1. The optimum well design plays a key role of saving cost because the materials used especially casing, mud and cement are too expensive. Those materials can be reduced as well as time consumed to solve some problems related the incorrect well design.
2. Damage of the 9 5/8″, 47 ppf, P-110, BTC production casing probably occurred after the 2nd stage of cementing and the casing damage was at the depth 32 m in the pipe body (not in the couplings).

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3. Failure of 9 5/8″, 47 ppf, P-110, BTC production casing happened because the selected casing couldn't withstand the axial force and the selected TOC (1750 m) made the risk of failure much higher than the case of selecting shallower TOC.
4. Hartha Formation was drilled in the first intermediate hole section (17 ½"). Based on that, the formation is isolated by two casing (13 3/8" and 9 5/8"). That made the evaluation of Hartha Formation is difficult due to the technique of perforation through two casing or open hole DST was not available. Changing the 13 3/8" intermediate casing setting depth to be shorter facilitates to evaluate Hartha Formation by perforating one casing (9 5/8").
5. If the modified well design is achieved successfully while drilling the appraisal well, the cost of each well may reduce about 300,000 USD in comparison with well X-1. Hence, drilling only 20 development wells in the future can save about 6 million USD.

Nomenclature and Abbreviations:

Pout: Pressure outside casing

Pin: Pressure inside casing

MOC: Missan Oil Company

BTC: Buttress thread coupling

D.V: Differential valve

TOC: Top of cement

RIH: Run in hole

ECD: Equivalent circulating density

BHP: Bottom hole pressure

OD: Outside diameter

MD: Measured depth

Ppf: Pound per foot

Psi: Pound per square inch

m: meter

Kg: Kilogram

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