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Casing Collapse and Salt Creeping for an Iraqi Oil Field: Implications for Mitigation

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Abstract

Casing collapse is considered one of the costliest problems that occurs in the oil industry, and it happens when the stresses or loads exceed the casing collapse resistance or due to casing wear and corrosion or salt creeping. For X oil field, located in Iraq's southern east, a casing collapse phenomenon has been exposed in four wells, including well X-1, and the salt creeping may be the main reason because the collapsed casing section is encountered by a salt formation that may be creeping under compression. In this paper, Lower-Fars's formation had been specified as the high-pressure salt formation that causes this problem according to the analysis of the provided data that included the depths of the collapse, log data and the final geological report. A new suggested casing design had been suggested by using pore pressure, fracture pressure, and horizontal stresses that were estimated by interactive petrophysics software from the well log data. The proposed and current casing designs were Simulated using Landmark-stress check software, and the proposed casing design indicates changing the grade from (L-80, 47 ppf) to (N-80, 53 ppf), which prevents the problem from recurring when drilling new wells in the same field as well as the proposed casing design can be economically considered feasible.

Keywords: Casing Collapse, Salt Creeping, Horizontal Stresses, Landmark software, Pore Pressure, Fracture Pressure, Lower fars formation, IP software.

تأثير المتغيرات الجيوميكانيكة على الزحف الملحي وانهيار البطانة في الآبار النفطية

الخلاصة:

يعتبر انهيار البطانة من أكثر المشاكل تكلفة في الصناعة النفطية، ويحدث عندما تزيد الضغوط أو الأجهادات عن ضغط انهيار البطانة، بسبب تآكل البطانة أو بسبب الزحف الملحي. حقل (X) النفطي الواقع في جنوب شرق العراق، تتكرر ظاهرة انهيار البطانة ضمن اربعة آبار من بينها البئر (X-1)، وقد يكون زحف الملح هو السبب الرئيسي لأن جزء البطانة المنهار يقابل تكوين ملحي ومن الممكن ان يكون قد زحف تحت تأثير الضغوط .في هذا البحث تم تحديد تكوين فارس السفلي على أنه تكوين ملحي

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عالي الضغط ومسبب هذه المشكلة، وفقا لتحليل بيانات مجسات الابار والتي شملت أعماق انهيار البطانة وبيانات المجسات والتقرير الجيولوجي النهائي. تم اقتراح تصميم بطانة جديد مقترح باستخدام ضغط المسام وضغط الكسر والأجهادات الأفقية التي تم تقديرها بواسطة برنامج (Ip Software)، تمت محاكاة تصميمات البطانة المقترحة والحالية باستخدام برنامج لاندمارك ويشير تصميم البطانة المقترح إلى تغيير نوع البطانة من (L-80 47 ppf) الى (N-80 53 ppf) يمنع تكرار مشكلة الزحف الملحي عند حفر آبار جديدة في نفس الحقل كما أنها التصميم المقترح ذو جدوى اقتصادية.

1. Introduction:

Salt can be defined as one of the most crucial formations that plays an important role in oil and gas trapping because it behaves as a ductile material, it can move and cause deformation to the nearby sediments, creating hydrocarbon traps, it also acts as a seal formation because it is impermeable to hydrocarbons. The Salt formation can creep or have a deformation. This ability is unique and at the same time problematic characteristic of salt. If sediments show little resistance, the salt rises, creating a characteristic dome, pillows and wedges that truncate upturned sedimentary layers [1].

The salt formation plays important role in the generating of some types of traps for oil and gas, also causes many serious problems in the drilling and completion processes such loss circulation, well bore instability and casing deformation. This formation acts as a visco-plastic material, which deform if it is subjected to high pressures [2]. This type of salt formation deformation is known a creeping deformation which is normally happened when the salt formation is disturbed. The salt starts to creep as soon as the salt formation is penetrated because of the instability of this formation and the subjected stresses [3]. Casing collapse is a phenomenon that can occur in oil and gas wells, particularly in salt formations. It occurs when the casing deforms or collapsed under the loads and stresses and it experiences during drilling and production. This can lead to problems, including the well's failure and reduced production. Casing collapse against salt formations can be particularly challenging to prevent and mitigate due to the high deformability and low strength of salt, as well as the corrosive environment. One of the most used tools to evaluate the casing loads and select the optimum casing design regarding the geomechanical variables is the landmark software that provide graphical design tools and algorithms that automatically can generate minimum-cost solutions for minimizing the cost of well tubular. Stress Check casing design software is one of the software that belongs to the landmark group that enables quick, systematic, and accurate valuation of casing wear limits, and can automatically create the minimum cost design, It provides comprehensive tri-axial and working-stress design for burst, collapse, and axial installation, and service-life loads to maximize the use of the most cost-effective casing for each particular

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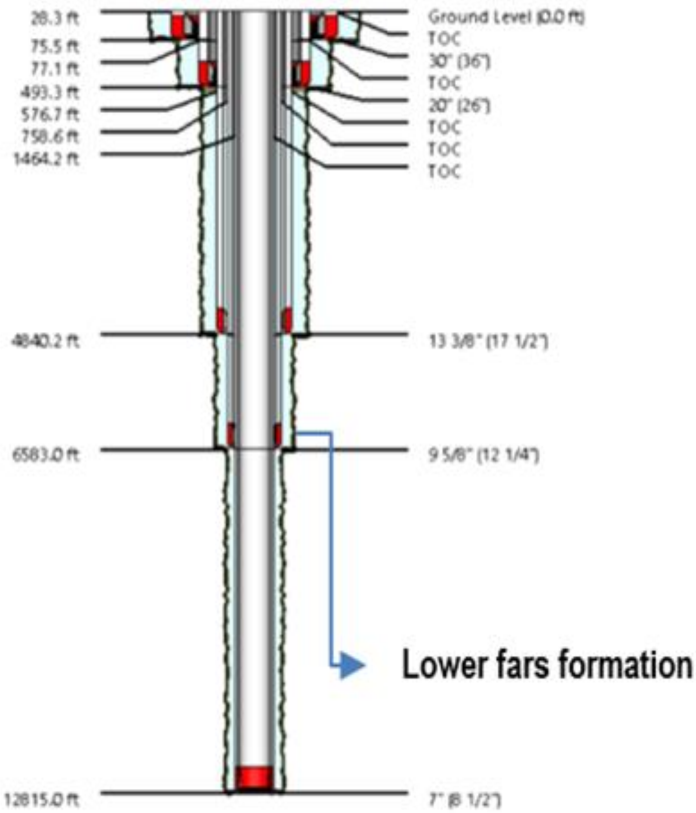
situation. In this article the focus will be on the effect of loads from geomechanical parameters acting on casing 95/8 set in a salt formation named lower fars based on a real case study for the oil field called X [4], [5].

1.1 Obtainable Data for X-1 Well

A schematic well property for X-1, located in an X oil field in the south east of Iraq field is addressed in Figure (1) and it showed that the casing 95/8 set at lower fars formation (salt formation) that causes the collapse of the casing [6].

The analyzed data from the well's logs, final geological reports, completion and workover reports, final well reports, and other data are summarized in Table (1)[7].



Formation		Age of Formation	TVD (m)
Upper Fars		Tertiary	11.6
Lower Fars	MB5		1374
	MB4		1607
	MB3		1735
	MB2		1885
	MB1		1903
Jeribe/Euphrates			1919.67
Upper kirkuk			1926.4
Middle kirkuk			2082
Lower kirkuk			2184
Jaddala			2260
Aaliji			2460
Shiranish		Upper Cretaceous	2495
Hartha			2559
Sadi	Sadi A		2611
	Sadi B		2663.6
Tanuma			2735
khasib	Khasib A		2748.8
	Khasib B		2809.75
Mishrif	Mishrif A	Lower Cretaceous	2835
	Mishrif B1		2866
	Mishrif B2		2980
	Mishrif C1		3029
	Mishrif C2		3110
	Mishrif C3		3170
Rumaila			3230
Ahmadi			3277
Mauddud			3303
Nahr Umr	Nahr Umr A		3465
	Nahr Umr B		3649
Shuaiba			3706
TD in shuaiba			3740
Total Depth			3740

Fig. (1) X well sketch with geological column, [8],[9].

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Table (1) Field Data for Well X-1 [10].

Data	Well Name :X-1
Total depth (m)	3909
Well type	Vertical
Lower-Fars formation (top-bottom) (m)	1700-2015
9 $^{5/8}$ casing seat (top- bottom) (m)	1521-2015
Current casing type	L-80 , 47 ppf
Mud weight in lower fars formation (gm/cc)	1.6-1.8

2. Geomechanical Variables Estimation Methods

Geomechanical variables such as pore pressure, fracture pressure, and overburden gradient are crucial for understanding the subsurface loads on the casing and evaluating the risk of casing collapse [11], [12].

These variables can be estimated by analyzing large amounts of data, including log data, using many correlations like the Eaton, Terzaghi and Belloti methods. Estimating these variables correctly is crucial for determining the cause of the collapse, identifying any potential risk factors and acting loads, which can help prevent future incidents. These variables are used as the main input parameters in landmark software to estimate the loads on casing [13-15].

2.1. Overburden Pressure Calculations

The overburden pressure, also known as the vertical stress, is the pressure exerted by the weight of the rocks above the wellbore [6]. Salt formations, due to their unique properties, are susceptible to a phenomenon known as "salt creeping," which occurs when the salt is deformed by the overburden pressure. This can lead to changes in the shape and structure of the salt formation over time. As depicted in Figure (2), the overburden pressure is typically increased with depth without any significant deviation in the curve. The data presented in Figure (2) is specific to well X-1.

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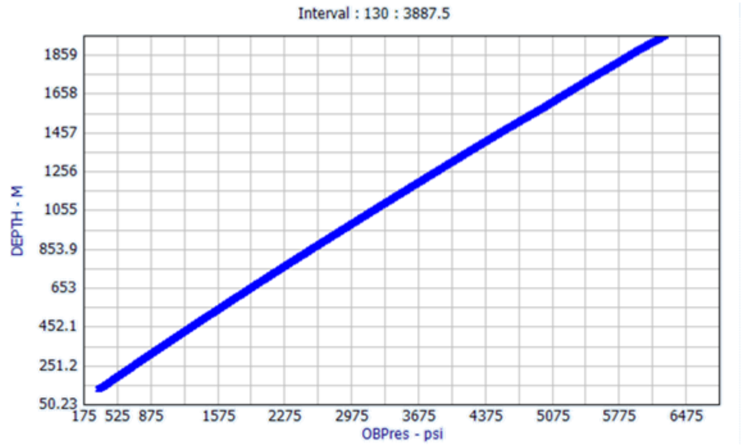

Fig. (2): Overburden Pressure Vs Depth for Well X-1.

2.2. Pore Pressure Calculations

Accurate pore pressure and formation pressure calculations are of paramount importance within the petroleum industry [8]. The elevation of pore pressure can result in a corresponding increase in the stress on the wellbore and its associated casing, thereby increasing the susceptibility of the well to collapse and salt creeping. Salt formations, due to their unique geomechanical properties, are particularly sensitive to variations in pore pressure. When the pore pressure exceeds the rock strength, it can induce salt flow and subsequent deformation, thereby compromising the structural integrity of the wellbore and increasing the likelihood of casing collapse. To accurately determine the pore pressure profile of well X-1, the Eaton method was employed. The data presented in Figure (3) illustrates a notable decrease in pore pressure within the salt formation (depth interval 1700-1900 m), which is a common occurrence in salt formations due to the lack of fluids in the formation's pores.

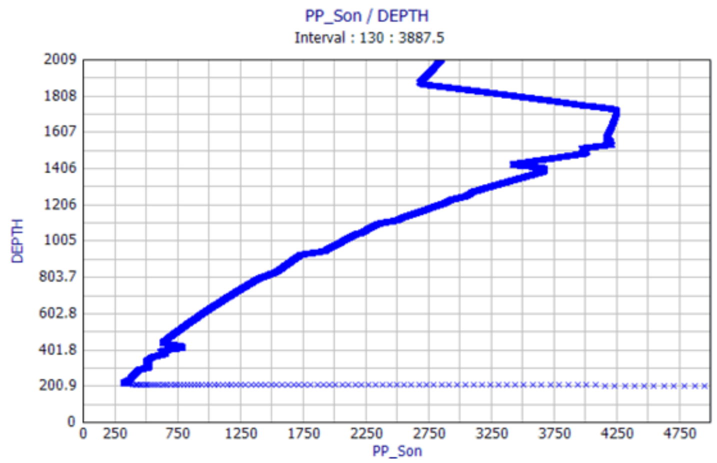

Fig. (3): Pore Pressure Vs Depth for Well X-1.

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2.3. Fracture Pressure Calculations

The Eaton method is a technique used to estimate the fracture pressure of a wellbore. This method utilizes data from a sonic log to estimate fracture pressure. By assuming that rock strength is proportional to the compressional wave velocity of the rock, as measured by the sonic log, the Eaton method can provide a reliable estimate of the fracture gradient. Figure (4) illustrates the relationship between fracture pressure and depth for well X-1, which shows a decrease in fracture pressure in the salt formation (depth interval 1506-1707) due to its ductile nature. This is a normal occurrence in salt formations, as they tend to be more malleable and can easily deform, leading to a decrease in fracture pressure, for pore pressure and fracture pressure validation the mud window in checked according to the calculated results and also its showed a good matching as shown in Figure (4).

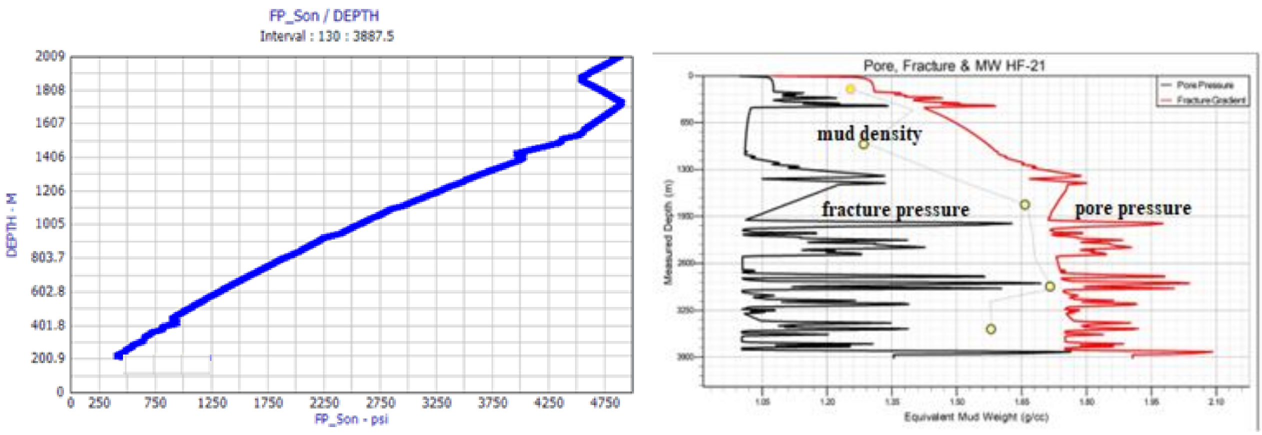

Fig. (4): Fracture Pressure Vs Depth for Well X-1 and Mud window.

2.4. Horizontal Stress Calculations

Eaton method can be used to calculate horizontal stress from a sonic log by measuring the travel time of a sonic pulse through the rock, determining the elastic modulus and Poisson's ratio, and using these values and the density of the rock to calculate the horizontal stress [9]. This method is commonly used in the oil and gas industry to assess stress conditions in a wellbore and design casing and cementing plans. Figure (5) shows the maximum horizontal stress vs. depth for well X-1. A sudden increase in maximum horizontal stress in the lower Fars formation (depth interval 1506-2001) observed in Figure (5), and this is normal because of the ductile nature of salt under compression. The identified parameters will be utilized to calculate the total loads exerted on the casing, which will be classified as external loads. This will be further discussed in the subsequent paragraph.

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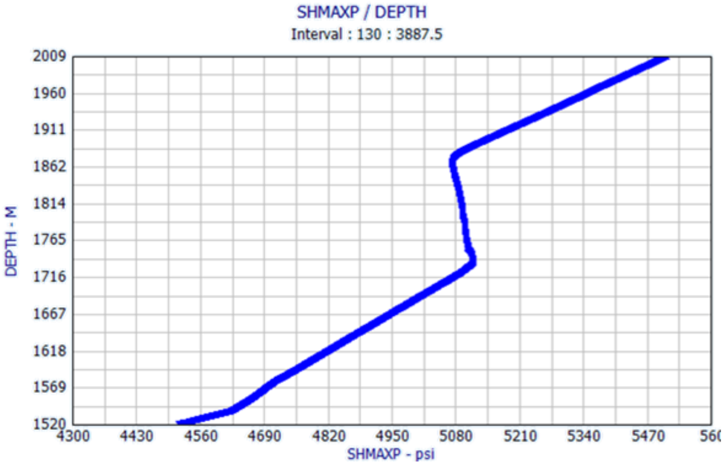

Fig. (5): Max. Horizontal Stress Vs Depth for Well X-1.

3. Results and Discussion:

3.1. Casing Design Evaluation and Geomechanical parameters

The landmark-stress check software allows the analysis and simulation of overburden pressure, pore pressure, fracture pressure, and horizontal stress loads to understand their effect on casing collapse risk. Failure to properly handle these loads can lead to deformation and failure. The software facilitates the identification of potential risks and the implementation of preventative measures to ensure well safety through the use of API Bulletin 5C3, "Formulas and Calculations for Casing Properties," to determine the total loads. In the following paragraphs, the geomechanical data for well X-1 will be utilized as the primary inputs for the stress check-landmark software in order to evaluate the current casing design and suggest a new casing grade to handle the acting loads.

3.2. Input Data for Landmark Software

The main data used to calculate the loads in landmark- stress check software is pore pressure, fracture pressure and overburden pressure as shown in Figures (6) and (7). These loads combined and simulated with max. Horizontal stress to calculate the real loads acting on casing 95/8 or any desired depth.

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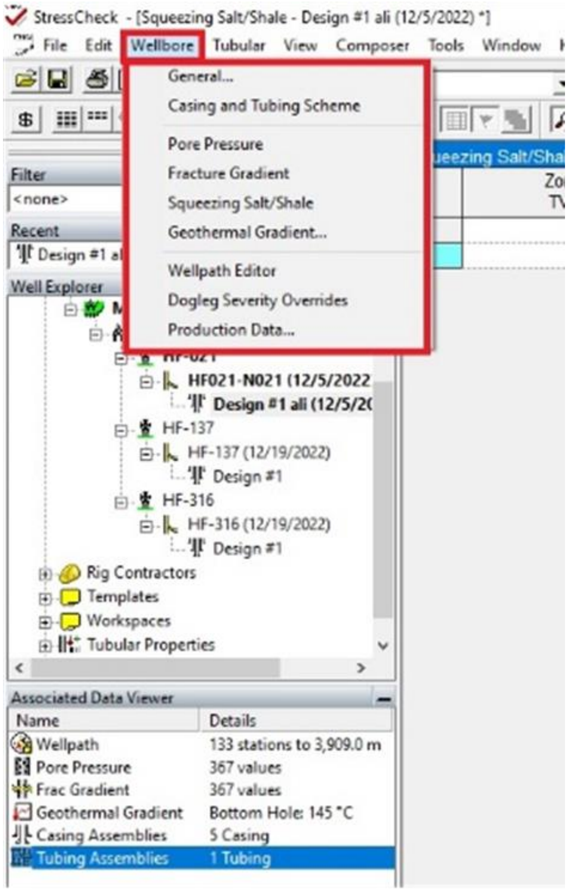

Fig. (6): The Main Entry Interface for the Landmark Stress Check Software.

Pore Pressure

	Vertical Depth (m)	Pore Pressure/EMW (psia)	Pore Pressure/EMW (g/cc)
1	4.20	-14.70	0.998
2	220.98	323.60	1.076
3	230.97	349.80	1.110
4	240.95	377.90	1.146
5	250.93	386.20	1.123
6	260.91	392.40	1.097
7	270.89	419.00	1.126
8	280.88	429.70	1.112
9	290.86	439.20	1.097
10	300.84	500.20	1.203

Fracture Gradient

	Vertical Depth (m)	Fracture Pressure/EMW (psia)	Fracture Pressure/EMW (g/cc)
1	4.20	-14.70	1.078
2	220.98	396.80	1.309
3	230.97	425.40	1.340
4	240.95	455.00	1.371
5	250.93	472.40	1.365
6	260.91	488.90	1.357
7	270.89	517.70	1.382
8	280.88	537.20	1.381
9	290.86	555.90	1.379
10	300.84	605.60	1.450

Squeezing Salt/Shale

	Zone Top TVD (m)	Base TVD (m)	Overburden Pressure at Top (psia)	Overburden Pressure at Top (g/cc)	Overburden Pressure at Base (psia)	Overburden Pressure at Base (g/cc)
1	1520.00	2006.00	4725.50	2.193	6409.20	2.251
2						

Fig. (7): Pore, Fracture and overburden pressure Inputs for Landmark- Stress Check Software

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3.3. Current Casing Design Based on Collapse Loads

The casing design plot for collapse characterizes the actual and design load lines as a function of depth for all selected and custom collapse cases. The design load line is used for interactive graphical design and visual comparison of the current-string API collapse rating with the design collapse loads. The design load line for collapse represents the maximum design collapse pressure as a function of depth based on consideration of all load cases (calculated by Barlow's law) for the current casing. When analyzing the current casing design and the actual loads acting on casing 95/8 by simulating the current used casing grade in X oil field (L-80, 47 ppf), a failure in casing 95/8 to handle the loads is shown in Figure 8 because the current casing can handle loads of about 4739 psi and the loads as shown in the black line in Figure 8 reach about 5790 psi, therefore a new casing design needed to be achieved and it will be presented in the next paragraph.

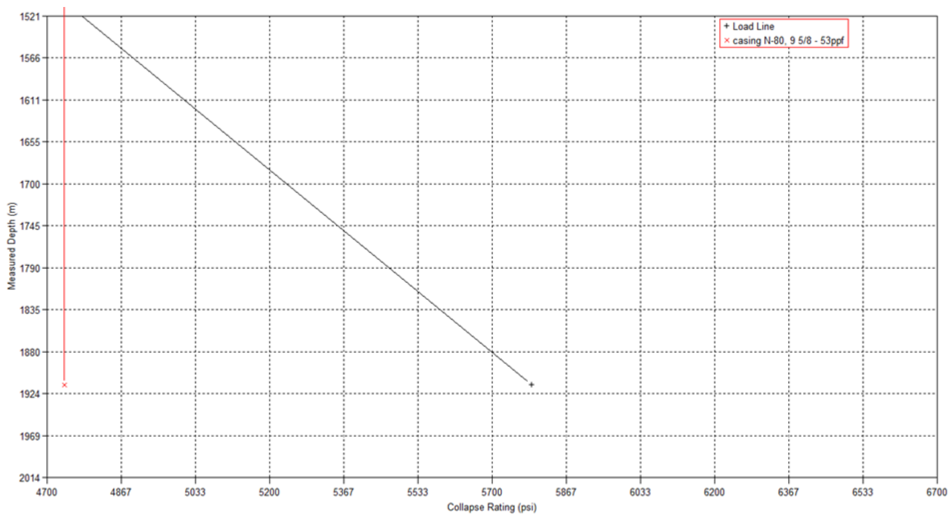

Fig. (8): Current Casing Grade Vs Load Line for Collapse Design for Well X-1.

3.4. Collapse Design for Suggested Casing

In order to design a new casing and prevent collapse, a thorough study of geomechanical parameters and loads was conducted. The primary issue identified was instability and deformation in the presence of salt formation due to overburden pressure. The current casing design was found to have an average collapse pressure of 4739 psi, as illustrated in Figure (8). This is significantly lower than the estimated acting loads. As a result, N-80 (weight 53) ppf casing grade was proposed as the optimal selection, as shown in Figure (9). This grade can safely handle higher loads, reaching up to 6600 psi, compared to the L-80 casing grade used in the current design, as demonstrated in Figure 9. Additionally, the proposed design is more cost-effective than the current one, as outlined

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in Table (2). The suggested design also meets the safety standards outlined in API, as detailed in Table (3). For validation of the results presented in this paper, in the next paragraph a comparison will be made with a previous study addressing the same issue of casing design in the presence of salt formation in the same field.

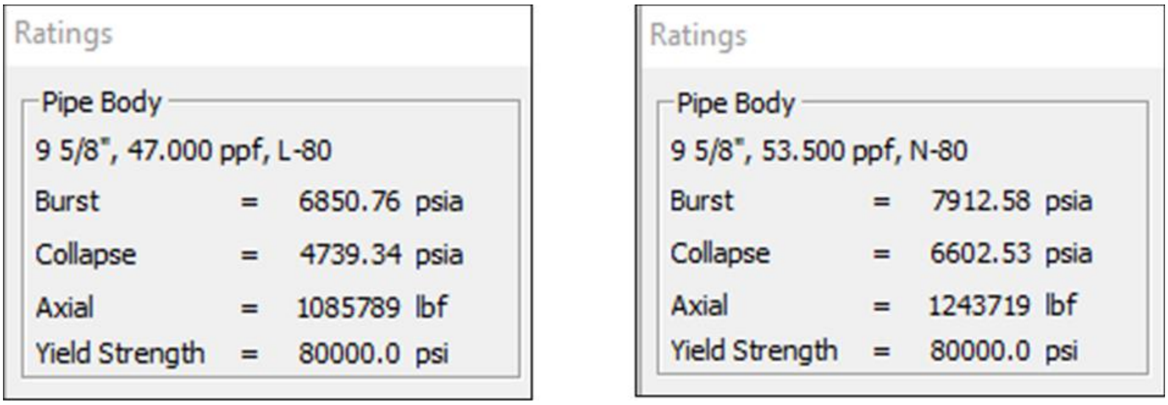

Fig. (9): Casing Ratings Comparison: Current Casing Design (Left) and the Suggested Casing Design (Right).

Table (2): Casing Design Cost for both Current and Suggested Casing Design.

Casing design	Cost in $
Current casing design (L-80 47 ppf)	600,000
Suggested casing collapse (N-80 53 ppf)	572,000

Table (3) Safety Factors Comparison between Current and Suggested Casing Design.

Casing	Safety Factors (%)			
	Burst	Collapse	Axial	Triaxial
Current design 9 5/8", 47.000 ppf, L-80	1.10	**0.82**	3.41	1.04
Suggested design 9 5/8", 53.500 ppf, N-80	2.14	**1.13**	5.01	1.21

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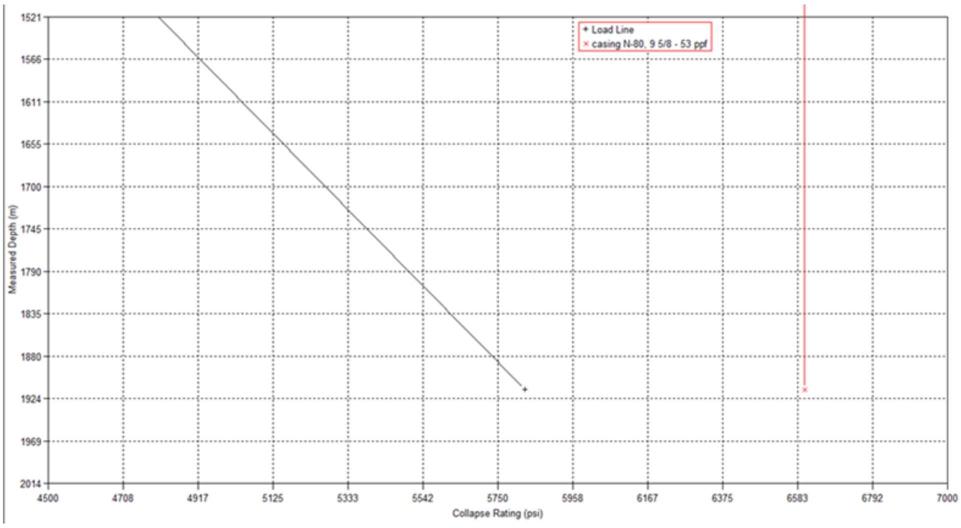

Fig. (9): Suggested Casing Grade Vs Load Line for Collapse Design for Well X-1

3.5 Discussion

In the analysis of well X-1, it was observed that the results did not include shear sonic logs, which are crucial for determining the properties of the rocks. To compensate for this, the Eaton method was employed to estimate shear sonic values from sonic logs, however, this approach resulted in a loss of accuracy. Furthermore, the density log was utilized to provide insight into the fluids present in the rocks and the rock's density relative to similar rocks in its hard state. The Bellotti et al method correlation was found to be the most accurate method for density estimation when compared to other wells drilled in the same formation. Additionally, the overburden gradient was observed to exhibit a gradual decrease in pressure with depth, with the exception of saline regions where an increase in pressure was observed.

Pore pressure was calculated using both sonic and resistivity logs, in addition to temperature data. The values obtained from resistivity logs were found to be higher than those obtained from sonic logs. It is worth noting that most analytical stress models for salt loading are based on limited or incomplete data and do not account for non-salt loading or pipe defects. These limitations make it challenging to predict the behavior of the formation beyond the yield point.

The horizontal stress for the formation was found to exceed 5000 psi. Salt creep can lead to significant collapse problems or well integrity incidents, as was recorded in five wells out of a few tens of historical wells in field X. These problematic wells possess distinct pressure regimes, salt thicknesses, and top of reservoir depths, and are located in proximity to successfully drilled wells with similar subsurface and stress conditions. Therefore, it is unlikely that the recorded collapse incidents are related to specific geological settings or tectonic changes.

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Casing collapse was observed in wells with 9 5/8" and the beginning of 7" overlap, which is likely due to non-uniform loading caused by salt creep. As a result, the casing design was changed from L-80 weight 47 ppf to N-80 weight 53 ppf, as it is able to handle more stress. A cost comparison (as illustrated in Table (2)) of the designs revealed that the suggested design is economically profitable, despite the current design failing with the collapse design. The optimized design with higher weight succeeded in the collapse design with lower cost.

4. Conclusions

Based on analyzing the well data, it was observed that the casing shoe was seated at the end of the salt formation (end of Lower Fars, MB2), despite it being classified as an abnormal pressure formation. Furthermore, the absence of temperature tests for each layer of the lithological column, as well as leak off tests, which are essential in accurately obtaining overburden pressure, pore pressure and fracture pressure, was also noted. These tests are also crucial in matching the data obtained with the geomechanical variables estimated by IP software. In the salt formation, the results obtained from the Eaton's method and the adapted Eaton's method were found to be highly consistent. To mitigate the impact of salt creeping on the 9⅝ inch casing, a change in casing grade to N-80 (53 ppf) and an increase in the casing design safety factor for collapse and burst load cases were proposed. The results showed that the current casing grade was unable to withstand the stress estimated by IP software. The proposed casing design was found to be more capable of handling the stress from the salt formation, and was also more cost-effective compared to the current design.

Nomenclatures

API:	American Petroleum Institute	OWC:	Oil Water Contact
DDR:	Daily Drilling Report	PF:	Fracture Pressure
DF:	Design Factor	PP:	Pore Pressure
DP:	Drilling Program	SBT:	Shoe Bond Test
FWR:	Final Well Report	SLB:	Schlumberger
IP:	Interactive petrophysics	TD:	Total Depth
KPI:	Key Performance Indicator	TVD:	True Vertical Depth
MD:	Measure Depth		

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