

Effect of Touchdown Trench Modelling on SCR Fatigue Life

G. Hu¹, C. Shi^{2, 3}, and Y. Zhao²

¹ Dalian Maritime University, Dalian, China

² School of Petroleum Engineering, China University of Petroleum, Qingdao, China

E-mail: shichen2004@hotmail.com

Abstract. Touchdown zone (TDZ) is one of the most critical fatigue hot spot for a Steel Catenary Riser (SCR). In current industry practice, a flat profile is always used when modelling the seabed surface. However, survey data shows that trenches are formed at SCR touch down zone after riser installation. It is important to understand the impact of trench modelling for fatigue life at TDZ. This paper presents a SCR TDZ fatigue life comparison between a flat and trenched seabed profile using Finite Element Analysis (FEA) models based on linear soil stiffness. The trenched seabed is modelled in its assumed equilibrium condition using an analytical equation derived from non-linear hysteretic analysis in the literature. Further analyses are conducted for more parameters. The objective of this study is to determine if a linear seabed model with trenched profile can improve TDZ fatigue life of an SCR when compared to an SCR on a flat seabed surface.

1. Introduction

Steel Catenary Riser (SCR) is one of the most widely used riser concepts in deepwater for its simplicity. A general SCR configuration is illustrated in Figure 1. One of the most critical fatigue hot spot for a SCR is touchdown zone (TDZ)[1]. Understanding SCR's touchdown zone fatigue performance under environmental loading and host vessel motion can be very challenging. One of the challenges is the modelling of riser interaction with seabed. Current industry practice typically uses a flat seabed surface assumption when conducting SCR analyses[2]. This approach is considered to be conservative and it is believed that incorporating a trenched profile into an FEA model can help improve TDZ fatigue life[3]. However, very limited studies have shown the actual impact of seabed trench modelling on SCR fatigue life at TDZ. One of the reasons is that implementing trench profile in the FEA model can be very challenging.

In this study, a SCR model on a seabed with trench profile is developed. And the fatigue results based on this model is compared to the one with flat seabed. The trench theory, field data, design parameters, model development, and fatigue results are presented in the following sections, followed by conclusions.

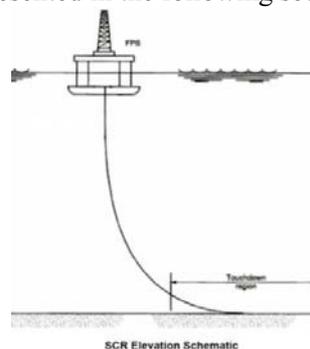


Figure 1. Typical SCR Layout Showing the Touchdown Zone

³ Any correspondence should be addressed to the author (C. Shi, shichen2004@hotmail.com)

2. Trench Theory in Literature

A theoretical trench shape includes a few key points [4]:

- Touchdown Point (TDP), where the SCR reaches the nominal level of the seabed;
- Trench Bottom Point (TBP), where the trench reaches its maximum depth;
- Trench Surface Point (TSP), where the SCR reaches essentially the zero gradient towards the anchored end of the riser.

A theoretical trench shape schematic is shown in Figure 2.

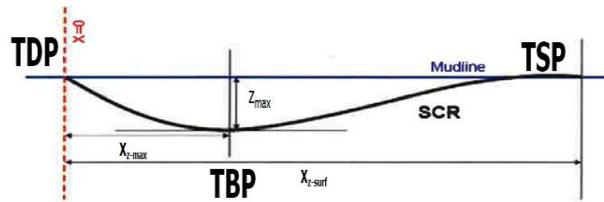


Figure 2. Theoretical Trench Shape [4]

Shiri [4] concluded a mathematical equation to approximate the SCR trench profile based on SCR trench development simulation on hysteretic non-linear seabed for a range of cycles, as shown in Figure 3. A quadratic exponential equation is used to mirror the Abaqus model at 1,000 cycles, as shown in Figure 4.

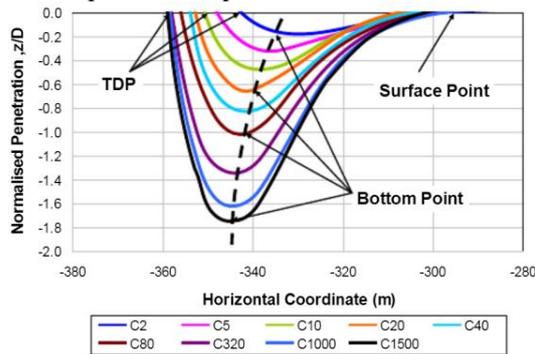


Figure 3. Gradual Displacement of Trench Key Points with Trench Deepening [4]

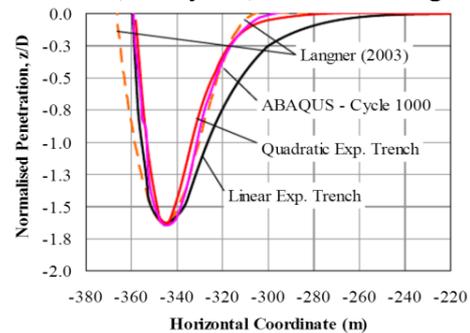


Figure 4. SCR Trench Mathematical Approximation [4]

The quadratic exponential approximation is given as follows:

$$z = -z_{max} \left[\left(\frac{x}{X_{z-max}} \right) e^{\left(1 - \frac{x}{X_{z-max}} \right)} \right]^2 \quad (2)$$

Where:

- x – Horizontal distance from the TDP;
- z – Vertical distance below the mudline;
- z_{max} – Maximum trench depth (i.e. TBP);
- X_{z-max} – Horizontal distance from the TDP corresponding to the maximum trench depth.

Shiri [4] assumes the TSP is located where z falls to 1% of z_{max} , therefore, the relative distance from the TDP to the TSP may be approximated as follows:

$$X_{z-max} = \frac{1}{5} * X_{z-surf} \quad (3)$$

One consequence of using the analytically derived trench seabed profile in a global FEA model is that inconsistencies between the riser's natural catenary and the seabed may be present, leading to varying stress ranges in the TDZ, as shown in Figure 5 [4].

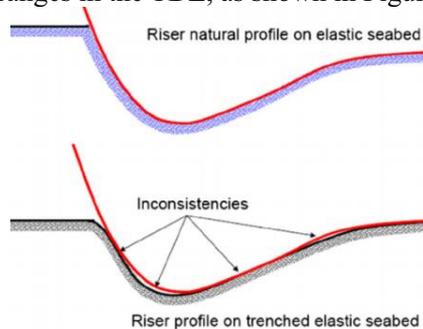


Figure 5. Riser-trench Contact Geometry with Various Trench Locations [4]

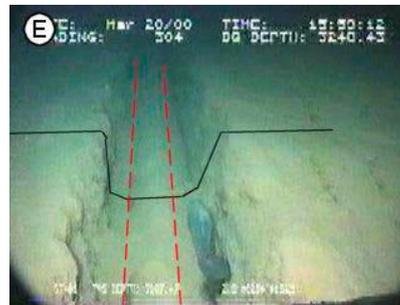


Figure 6. Gas Export SCR TDZ Trench in the GoM [5]

3. Field Data

Gulf of Mexico (GoM) has the most SCR application in the world, relevant survey data in GoM is reviewed to determine appropriate trench dimensions. Bridge's study [5] presents field data in the GoM that is utilized in this study to determine approximate trench sizes for modelling purposes. A trench from a 12.75 inch gas export SCR in the Allegheny field in the GoM seven months after installation is shown in Figure 6 [5]. The survey showed that the trench is approximately four diameters in depth and 60m long [5]. Dimensions in this range are considered for this study.

4. Design Parameters

This study is conducted for a South China Sea field in approximately 1,000 meter water depth using a semi-submersible vessel. Regular wave analysis is performed using a high probability low amplitude seastate of the type that dominates the fatigue damage at the TDZ. The vessel's response to waves is extracted by its response amplitude operator (RAO) and applied to the riser models in OrcaFlex.

The hang-off angles considered is 11 degrees from the vertical for both flat and trenched seabed models. SCR properties are listed in Table 1 and relevant environmental data is detailed in Table 2. The API X' fatigue curve with an SCF of 1.1 is chosen for this study[6].

Table 1. SCR Model Design Data

Parameter	Value
OD, in. (m)	10.75 (0.273)
ID, in. (m)	7.75 (0.197)
Wall Thickness, in. (m)	1.50 (0.038)
Internal Fluid Density, lb/ft ³ (kg/m ³)	10 (160)
Internal Pressure at Water Surface, psi (MPa)	500 (3.45)
Hang-off Angles (°)	11
Material	X65
Yield Strength, ksi (MPa)	65.3 (450)

Table 2. Environmental Data

Parameter	Value
Water Depth (m)	1,015
Hs (m)	1.8
Tp (sec)	7.5
Wave Type	Regular

5. Model Development

Analysis is carried out using the non-linear time domain finite element analysis program OrcaFlex [7]. The models are constructed with equivalent single string elements. The properties of the strings are captured using general pipe element.

Details of the seabed parameters are given in Table 3. Trench lengths considered are based on survey data and also by the hang-off angle which determines how the SCR’s natural catenary would lay in the trench. The SCR model in the trenched TDZ for both soil stiffness values considered is shown in Figure 7. The green line is the SCR and the orange line is the seabed. The vertical lines represent the SCR nodes, where white indicates contact and green indicates a gap between the SCR and seabed. Contact discontinuities are present between the SCR and seabed when the larger seabed stiffness is used, but no discontinuities are present for the smaller seabed stiffness. Another representation of the SCR in the trenched profile is shown in Figure 8. The SCR model resting on the flat seabed surface for both seabed stiffness values is shown in Figure 9, where no contact discontinuities are present.

Table 3. Seabed Properties

Seabed Profile Type	Seabed Soil Stiffness (kN/m/m ²)	Trench Length from TDP to TSP (m)	Trench Depth
Flat	60	N/A	N/A
	120		
Trenched	60	100	3*OD
	120	100	

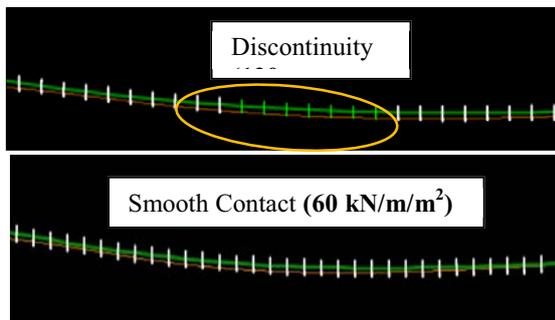


Figure 7. SCR TDZ, Trenched Seabed Profile

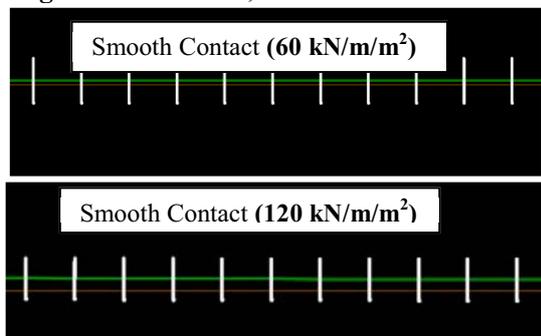


Figure 9. SCR TDZ, Flat Seabed Profile

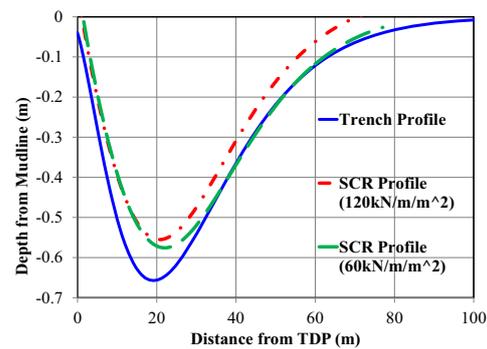


Figure 8. SCR TDZ, Trenched Seabed Profile

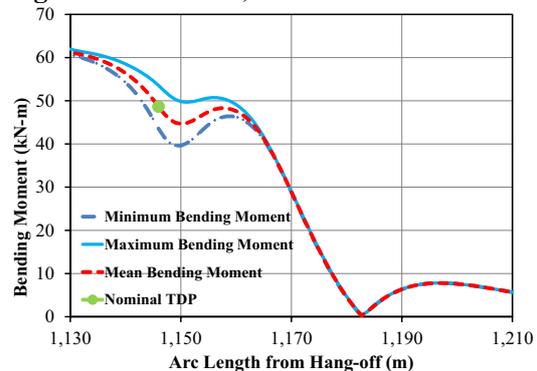


Figure 10. Bending Moment Envelope, Trenched Seabed Profile, 120 kN/m/m²

6. Analysis Results

Results are given in this section considering flat and trenched seabed surfaces for both soil stiffness values. The bending moment envelope for the trenched and flat seabed profiles using soil stiffness of 120 kN/m² is shown in Figure 10 and Figure 11, respectively. The bending moment envelope for the trenched and flat seabed profiles using soil stiffness of 60 kN/m² is shown in Figure 12 and Figure 13, respectively. It can be seen that the trenched profile experiences a larger bending moment envelope than the flat seabed profile for both soil stiffness values analyzed. The trenched profile is experiencing a larger bending moment range due to the following: (a) The shape of the SCR in the global model is slightly inconsistent with the analytically derived shape in the TDZ; and (b) Although the SCR shows continuous contact in the TDZ with the smaller soil stiffness, the gradient of seabed resistance is high near the location along the SCR with the lowest fatigue life (see Figure 14).

A stress range comparison between the trenched and flat seabed profiles is given in Table 4. The stress ranges given are at the most damaging location along the SCR, which occur just beyond the nominal TDP. A larger stress range is experienced for the trenched SCR profile when compared to a flat seabed.

Larger stress ranges experienced by the SCR in a trenched seabed profile lead to lower fatigue life, as detailed in Table 5. The fatigue life for an SCR in a trenched profile has decreased by 27% and 31% for the two seabed stiffness values considered when compared to a flat seabed surface, respectively. As expected, the fatigue life reduction increased more when using the larger seabed stiffness.

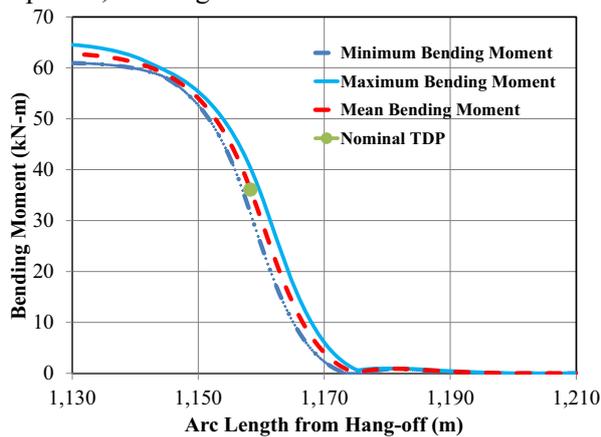


Figure 11. Bending Moment Envelope, Flat Seabed Profile, 120 kN/m²

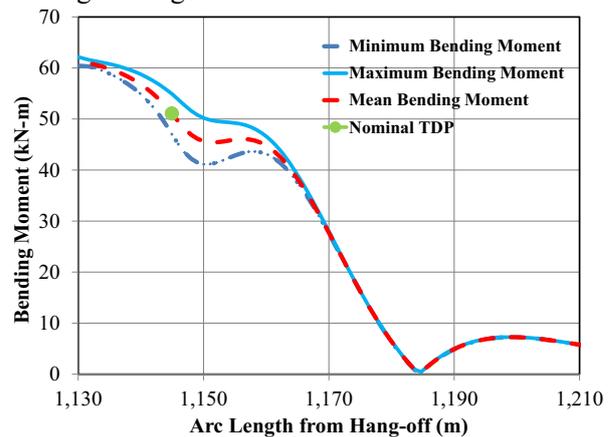


Figure 12. Bending Moment Envelope, Trenched Seabed Profile, 60 kN/m²

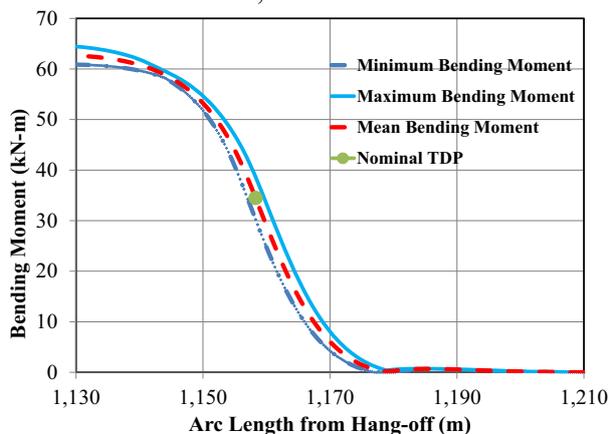


Figure 13. Bending Moment Envelope, Flat Seabed Profile, 60 kN/m²

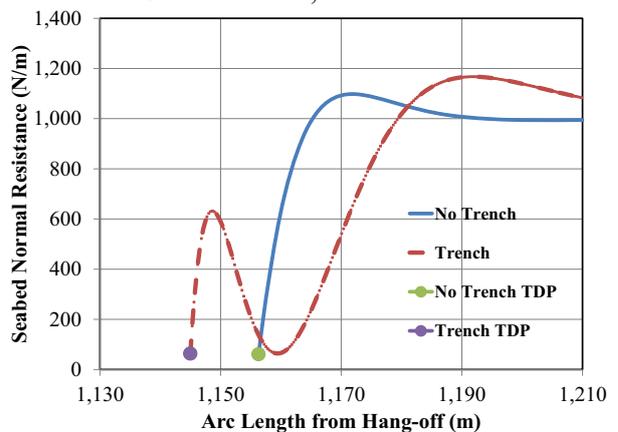


Figure 14. Seabed Normal Resistance, 60 kN/m²

Table 4. Axial Stress Range Comparison

Seabed Soil Stiffness (kN/m/m ²)	Stress Range (MPa)		Difference (MPa)
	Trenched Seabed	Flat Seabed	
60	14.28	12.94	1.34
120	16.57	15.19	1.38

Table 5. Fatigue Life Comparison

Seabed Soil Stiffness (kN/m/m ²)	Fatigue Life (Year)		Difference (%)
	Trenched Seabed	Flat Seabed	
60	266	367	-27
120	156	225	-31

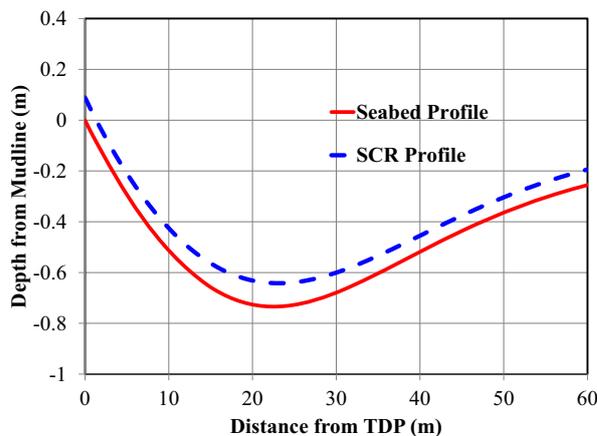
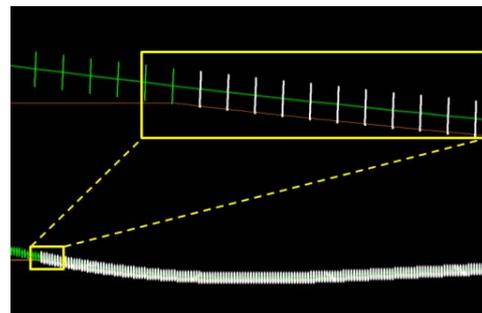
7. Parametric Analysis Results

7.1. Refined Trenched Seabed Profile

In this analysis, trenched seabed profile is refined to closely match riser configuration. The SCR's TDZ global coordinates from the analytical trenched seabed profile are used as the new seabed coordinates in the TDP to TSP region. This approach helps reduce discontinuities between the SCR and seabed, and also reduce seabed contact force in the touchdown region.

The soil stiffness considered for this analysis is 120 kN/m². The refined SCR profile is shown in Figure 15. There is a smooth transition between the SCR's natural catenary and TDP as well as complete contact between the SCR and seabed, as illustrated in Figure 16. Refining the TDZ has reduced the seabed resistance gradient when compared to the analytical trench, as shown in Figure 17.

The bending moment envelope for the refined trench profile is shown in Figure 18. The max bending range has reduced when compared to Figure 10. However, the bending moment range for the refined trench still exceeds the flat seabed configuration when compared to Figure 11. Implementing a refined trench has reduced the stress range when compared to an analytical trench, as detailed in Table 6. However, the stress range is still higher than the flat seabed. The fatigue life improves by approximately 28% when compared to the analytical trench, but falls short of the flat seabed fatigue life by 3.9%, as given in Table 7 and Table 8, respectively.

**Figure 15.** SCR Refined TDZ, 120 kN/m²**Figure 16.** SCR Refined TDZ without Contact Discontinuity, 120 kN/m²

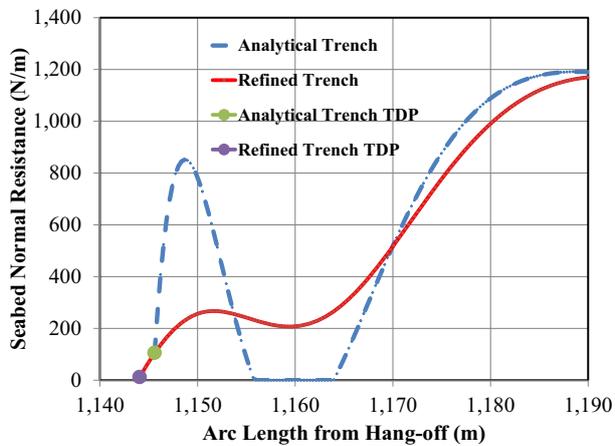


Figure 17. Seabed Normal Resistance Comparison, 120kN/m/m²

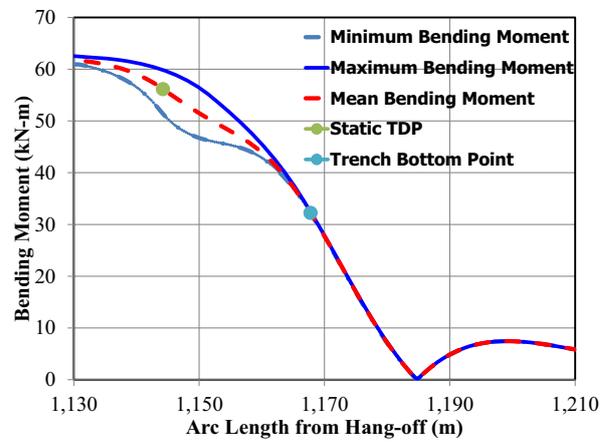


Figure 18. Bending Moment Envelope for Refined Seabed Profile, 120 kN/m/m²

Table 6. Axial Stress Range Comparison, Refined vs Analytical Trench

Seabed Soil Stiffness (kN/m/m ²)	Stress Range (MPa)		Difference (MPa)
	Refined Trench Seabed Profile	Analytical Trench Seabed Profile	
120	15.31	16.47	-1.16

Table 7. Fatigue Life Comparison, Refined vs Analytical Trench

Seabed Soil Stiffness (kN/m/m ²)	Fatigue Life (Year)		Difference (%)
	Refined Trenched Seabed Profile	Analytical Trench Seabed Profile	
120	218	157	28%

Table 8. Fatigue Life Comparison, Refined vs Flat Seabed

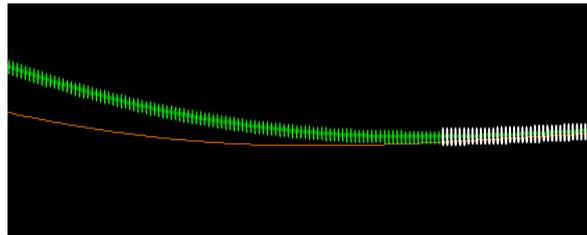
Seabed Soil Stiffness (kN/m/m ²)	Fatigue Life (Year)		Difference (%)
	Refined Trench Seabed Profile	Flat Seabed Profile	
120	218	227	-3.90

7.2. Vessel Offsets with Refined Seabed Profile

Based on the SCR configuration in the refined trench profile, 1% near and far vessel offsets are considered to determine effects on TDZ fatigue. Fatigue lives considering vessel offsets are given in Table 9. A lower fatigue life than nominal is observed for near vessel offset because the SCR is being forced into the trench, hence increasing the curvature in the touchdown region. A higher fatigue life is observed for far vessel offset when compared to a flat seabed. However, this is not representative of a trench in equilibrium conditions because the SCR is lifted from the trench, as shown in Figure 19.

Table 9. Fatigue Life Comparison, Refined vs Flat Seabed, Vessel Offsets

Seabed Type	Fatigue Life (Years)		
	Far Vessel Offset	Nominal Vessel Location	Near Vessel Offset
Refined Trench	290	218	169
Flat	248	227	218

**Figure 19.** Far Offset TDZ Arrangement, Refined Seabed Profile, 120 kN/m/m²

8. Conclusions

A linear seabed model that implements an analytical equilibrium trench in an SCR's TDZ derived from non-linear hysteretic model is presented. The stress range, seabed resistance, as well as fatigue life of the SCR in a trenched seabed profile is compared to an SCR on a flat seabed profile. Parametric analyses are also performed by refining the trench profile and applying vessel offsets.

Based on the analysis results presented above, it is found from this study that an SCR's TDZ fatigue life does not improve when implementing an analytically derived trenched seabed. The fatigue life in the touchdown region does not improve when implementing an artificial trench due to the following:

(a) Discontinuity between the SCR and seabed arise which lead to contradictory stresses and large seabed shear gradients; and (b) The gradient of seabed resistance is high near the hot spot of SCR touchdown zone.

It is also observed that vessel offset has significant impact on the fatigue life when trench is modelled. The impact from the vessel offset should be considered as in real life there always be some extent of vessel offset.

Interpreting SCR TDZ soil interaction in analysis models is still very challenging as the modelling of exact profile of an SCR trench in equilibrium conditions is extremely difficult. It is recommended to monitor a full-scale SCR and measure stress response in the TDZ to further understand the trench effect. The data could be used to confirm the results of small scale tests and improve modeling of the TDZ in SCRs. Additionally, further research and field surveys should be conducted to explore the nature and mechanisms of trenching below an SCR.

9. References

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Acknowledgements

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