

Subsea Equipment Decommissioning Using Fiber Rope

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Abstract. A comparative study of lifting lines for subsea equipment decommissioning was conducted to evaluate the applicability of fiber ropes. Generally, conventional steel wire ropes are used for subsea equipment decommissioning operations, but there are some disadvantages in using steel wires as the lifting lines at deepwater depth. To overcome the disadvantages, fiber ropes are proposed for using as lifting lines. The comparative methods to evaluate the performance of both lifting lines include three sections of calculations, payload capacity, and horizontal offset due to current, critical length of lifting line. Moreover, dynamic analysis using Orcaflex was performed to compare the dynamic forces occurring in the lifting lines during subsea equipment decommissioning. The results showed that the fiber ropes had advantages in payload capacity, critical length of lifting line and lower dynamic forces occurred compared to the steel wire ropes at deepwater depth.

1 Introduction

Many subsea fields are currently in operation, and an increasing number of subsea equipment such as a tree, manifold, and pipeline have or will reach their end of the service life in the near future, which may consider being decommissioned. According to Oil & Gas UK, across the North Sea, not only a total number of 1,832 wells are estimated to be plugged and abandoned, also 12,000 mattresses and 65,000 tons of subsea structures will be decommissioned from 2016 to 2025 [1].

Conventional steel wire ropes have been typically used as lifting lines to install, operate, and decommission the subsea equipment. However, the steel wire ropes have some disadvantages such as a heavy self-weight, and resonance problem that may occur more frequently at deepwater depth. To overcome these drawbacks, a new installation method has been proposed in the field of subsea installations, which is fiber ropes can be used as lifting line for ultra-deepwater installation, and can be substituted for the conventional steel wire rope [2], and in two-fall system using fiber ropes [3]. In addition, some subsea industries are also researching and developing several fiber rope cranes to extend its

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applicability into subsea operations [4], the Trident fiber rope crane from NOV, Deepwater technology using HMPE rope from Dyneema [5].

The main objective of this study is to do the comparative study of two lifting lines, steel wire ropes and fiber ropes to evaluate the applicability of fiber ropes during subsea equipment decommissioning. The applicability of the fiber rope in the field of subsea installation has been proven through some subsea projects, however the topic related utilizing the fiber rope in subsea decommissioning activities has not been discussed.

2 Methodology

To compare the lifting lines, three sections of calculations and the dynamic analysis using Orcaflex was conducted.

- Payload capacity calculation is to compare the lifting capability of the lifting lines at different water depths
- Horizontal offset due to current is to estimate roughly the operational risk and positioning problem.
- Critical length of lifting line is to find out where the resonance effects occurs in the lifting lines
- Dynamic analysis using Orcaflex is to compare the dynamic forces that occur at each water depth on the lifting lines

A typical subsea lifting for decommissioning can be divided into four main phases, On-bottom, Lifting up, Splash zone, and In-air. In this study, only lifting up stage which is the most stable and predictable was considered to focus on the purpose of this study.

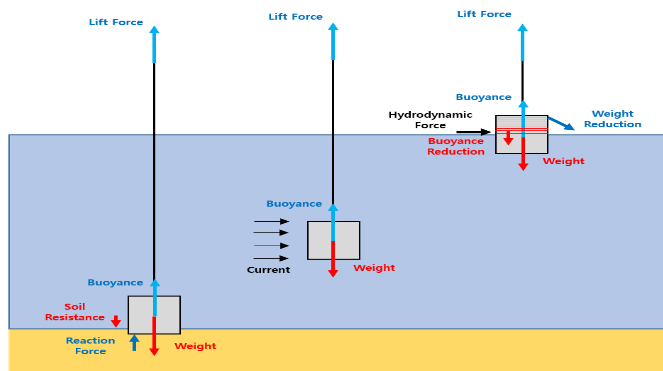


Fig. 1. Four main phases for subsea equipment decommissioning.

2.1 Payload capacity

To calculate the payload capacity of the lifting lines, the specification for fiber ropes is based on the Skandi santos project, which is 88 mm, braid optimized for bending rope from Puget Sound/Cortland companies. For the specification of wire ropes used in the calculation, non-rotating 35xK19S compacted steel developed by Kiswire are selected. Table 1 shows the specifications of the lifting lines used in the payload calculation. These two lifting lines have the same safety working load (SWL) at in air phases, 126 tons.

Table 1. Specification for lifting lines in payload capacity

| | Fiber rope | Wire rope |
|-------------------------|-------------------------|--------------------------------------|
| Type | 12 x 12 strand BOB rope | Non-rotating 35xK19s compacted steel |
| Size [mm] | 88 | 67 |
| MBL [ton] | 567 | 391 |
| Safety factor | 4.5 | 3.1 |
| SWL [ton] | 126 | 126 |
| Mass in air [kg/m] | 6.931 | 22.59 |
| Submerged weight [kg/m] | 0.87 | 19.92 |

The fiber ropes have minimum ultimate strength of 567 tons and the safety factor of 4.5. The safety factor for fiber ropes is higher than the safety factor for steel wire rope due to the lack of field experiences. The wire rope has the has the MBL of 391 tons with the safety factor of 3.1 which is the minimum recommended value from DNV-OS-H205 [6]. The sling capacity “Minimum breaking load” is checked as following equation.

$$F_{sling} < \frac{MBL_{sling}}{\gamma_{sf}} \tag{1}$$

Where F_{sling} is the sling capacity and γ_{sf} is the safety factor for lifting lines.

For subsea installation case, the payload capacity is reduced steadily because of the self-weight of the lifting line, so this is called “Reduced payload capacity”. However, the payload capacity is increased for the case of subsea decommissioning operations because of lifting up from the seabed, so it can be called “Increased payload capacity”. The payload capacity can be obtained as following equation.

$$\text{Payload capacity} = \text{SWL} - (M_{submerged} * L_{line}) \tag{2}$$

Where SWL is the safety working load of lifting line, $M_{submerged}$ is the submerged weight of lifting line, and L_{line} is the length of lifting line.

2.2 Horizontal offset

For subsea lifting operation, the horizontal offset due to current is the important factor, especially for subsea installation cases because one of the most important operations for subsea installation is that positioning the objects on the place where you want to install. Therefore, it is necessary to predict the horizontal offset due to current in advance in order to prevent a large horizontal distance occurs.

In the case of subsea equipment decommissioning, the positioning operations is not required. If the horizontal offset is large during subsea equipment decommissioning, there is a bad influence on the several things such as vessel’s motion and it may follow to increase the risk of the operation, however the effect of horizontal offset is less important than the field of subsea installation.

DNV-RP-H103 provides the theory of the horizontal offset, and the horizontal offset of a lifted object subjected to a uniform current [7], which can be expressed as Fig. 2 and Eq. 3.

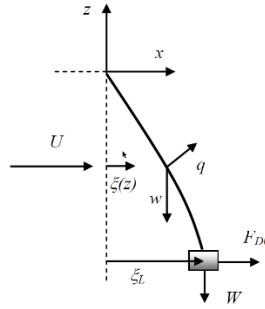


Fig. 2. Horizontal offset due to current

Where q is the drag force on lifting lines, F_{D0} is the drag force on lifted object, w is the submerged weight of lifting line, W is the submerged weight of lifted object, U is the current velocity, $\xi(z)$ is the horizontal offset at an arbitrary water depth z , and ξ_L is the horizontal offset of the lifted object.

$$\xi_L = L \left(\frac{q}{w} k - \lambda \right) \ln \left(\frac{k}{k+1} \right) + \frac{qL}{w} \quad (3)$$

$$k = \frac{W}{wL} \quad (4)$$

$$\lambda = \frac{F_{D0}}{wL} \quad (5)$$

$$q = \frac{1}{2} \rho_{sw} C_{Dn} D_c U^2 \quad (6)$$

$$F_{D0} = \frac{1}{2} \rho_{sw} C_{Dx} A_x U^2 \quad (7)$$

$$W = F_G - F_B \quad (8)$$

Where D_c is the diameter for lifting line, λ is the ratio between the drag on lifted object and weight of the lifting line, k is the ratio between the weight of lifted object and weight of the lifting line, C_{Dn} is the drag coefficient for normal flow past lifting line, A_x is the projected area of lifted object in x -direction, C_{Dx} is the drag coefficient for flow past lifted object in x -direction.

In the calculation, the decommission of subsea tree and manifold using fiber and wire ropes are considered. We assumed that subsea tree has the dimension $6 \times 6 \times 7$ m weighting 70 tons and the manifold has the dimension $9 \times 7 \times 5$ m weighting 115 tons. The submerged weight of subsea structures and lifting lines can be shown in (Table 2 and 3).

Table 2. Specification for subsea structures in horizontal offset

| Structure | Size [m] | Weight in air [tons] | Submerged weight [tons] |
|-------------|-----------|----------------------|-------------------------|
| Subsea tree | 6 x 6 x 7 | 70 | 60.9 |
| Manifold | 9 x 7 x 5 | 115 | 100.1 |

Table 3. Specification for lifting lines in horizontal offset

| Line type | Size [mm] | Weight in air [kg/m] | Submerged weight [kg/m] |
|------------|-----------|----------------------|-------------------------|
| Wire rope | 95 | 45.24 | 39.9 |
| Fiber rope | 88 | 6.931 | 0.87 |

The uniform current of 0.6 m/s and the subsea equipment are located at a water depth of 3000 m are assumed. The length of the lifting lines is same to the water depth. According to DNV-RP-H103 and DNV-RP-E301, the drag coefficient for flow past the wire rope and the fiber rope were referred to. The related parameter can be seen in Table 4 and 5.

Table 4. Parameter for horizontal offset calculation in the case of subsea tree

| Subsea tree | Fiber rope | Wire rope |
|--|------------|-----------|
| Drag coefficient for normal flow to lifting line (C_{Dn}) | 1.8 | 1.8 |
| Drag coefficient for flow to x-direction of lifted object (C_{Dx}) | 1.16 | 1.16 |
| Ration between the weight of the lifted object and lifting line (k) | 23.35 | 0.509 |
| Current velocity (U_c) [m/s] | 0.6 | 0.6 |
| Lifting line diameter (D_c) [m] | 0.088 | 0.0953 |
| Drag force on lifting line per unit length (q) [N/m] | 29.225 | 31.65 |
| Drag force on lifted object (F_{D0}) [N] | 8989 | 8989 |
| Ratio between the drag force on the lifted object and lifting line (λ) | 0.351 | 0.00766 |

Table 5. Parameter for horizontal offset calculation, in the case of manifold

| Manifold | Fiber rope | Wire rope |
|--|------------|-----------|
| Drag coefficient for normal flow to lifting line (C_{Dn}) | 1.8 | 1.8 |
| Drag coefficient for flow to x-direction of lifted object (C_{Dx}) | 1.16 | 1.16 |
| Ration between the weight of the lifted object and lifting line (k) | 38.37 | 0.837 |
| Current velocity (U_c) [m/s] | 0.6 | 0.6 |
| Lifting line diameter (D_c) [m] | 0.088 | 0.0953 |
| Drag force on lifting line per unit length (q) [N/m] | 29.225 | 31.65 |
| Drag force on lifted object (F_{D0}) [N] | 13480 | 13480 |
| Ratio between the drag force on the lifted object and lifting line (λ) | 0.527 | 0.011 |

2.3 Critical length of lifting line

The critical length of lifting line means that finding out the estimated point where the resonance will occur in the lifting line during the operations. The method to calculate the critical length of lifting line is that the natural period of the lifting line system which is the function of line length, compares to the crane tip motion transfer function which is the response amplitude operator of crane tip as presented in Fig. 3

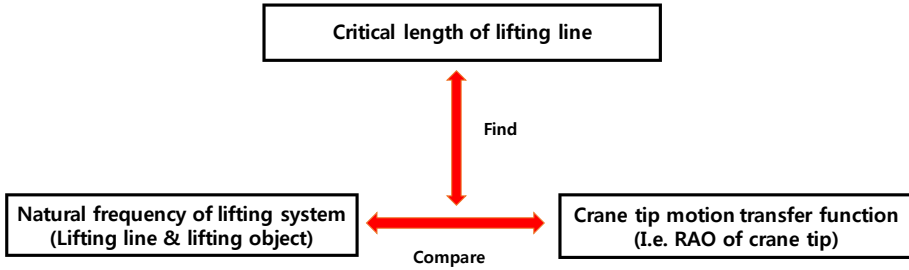


Fig. 3. Method for finding out critical length of lifting line

2.3.1 Crane tip motion transfer function

The vertical crane tip motion can be same as the RAO curve for the crane tip because the motion of lifting vessel has the linear relationship where the motion at a point is linearly transferred to another point [8]. The dynamic analysis tool for offshore system, Orcaflex, is used to obtain RAO curve for the crane tip as presented in Fig. 4. For the lifting vessel in this study, the standard vessel which is similar size and motion with oil tanker was used. In this study, the pitch and roll motion of the vessel are neglected because the lifting line is located at a midship to minimize the pitch, and vessel heading is set to 0° to minimize the roll motion. Thus, the vertical crane tip motion can be easily obtained since it is equal to the heave RAO as presented in Eq. 9.

$$\text{Vertical crane tip motion} = RAO_{Heave} \tag{9}$$

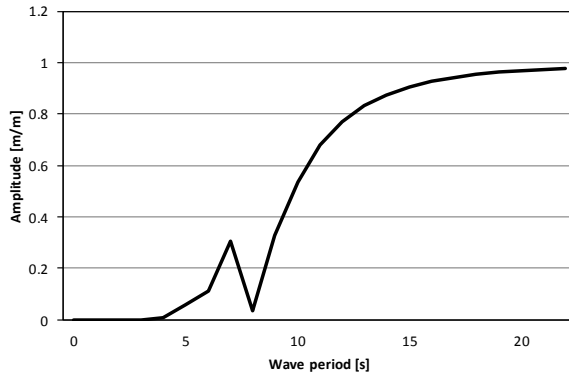


Fig. 4. RAO curve for the crane tip

2.3.2 Natural frequency of lifting system

B. Tormod [9] introduced the equation to calculate natural frequency of lifting system as expressed in Eq. 10.

$$T_0 = 2\pi \sqrt{\frac{M' + \frac{mL}{3}}{K_E}} \tag{10}$$

$$K_E = \frac{EA}{L} \tag{11}$$

Where T_0 is the natural frequency of lifting system, M' is the weight of lifting object in air and added mass in z-direction, m is the weight of lifting line in air per unit length, L is the length of lifting line, K_E is the stiffness of lifting system, and EA is the axial stiffness of the lifting line.

Table 6. Parameter for natural frequency of lifting system

| Parameter | Fiber rope | Wire rope |
|--------------------------------------|-------------------------|-----------------------|
| Cable stiffness (EA)[N] | 148.3 * 10 ⁶ | 511 * 10 ⁶ |
| Weight in air per unit length [kg/m] | 6.931 | 45.24 |
| Line outer diameter (D_c)[m] | 0.087 | 0.0816 |

2.4 Dynamic analysis

The nonlinear time domain simulation was performed to investigate dynamic response of the lifting up stage from 2950 to 500 m with 500 interval using Orcaflex software. The applicability of this numerical simulation tool to offshore pipeline, riser, cable, etc. Have been verified by many researchers [10-14]. The dynamic force will differently occur if the lifting line types are different with different water depth. The simulation time is set to 1800 second at each depth of 500 m interval. The vessel heading is set to 0° and the environmental heading is set to 180°, therefore roll motion is minimized as shown in Fig. 5.

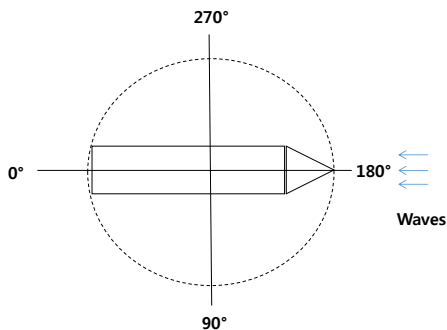


Fig. 5. Vessel and environmental heading for dynamic analysis

2.4.1 Dynamic acceptance criteria

DNV-RP-H103 provides accept criteria for dynamic force occurring during lifting. Two accept criteria are defined to calculate the acceptance criteria. The result of the dynamic analysis should satisfy these two accept criteria. In the second criteria, slack sling occurs when the dynamic forces exceeds the static weight of the lifting object, but, applying 10% margin to the start of slack sling. The formulas for the two criteria are shown in Eq. 12 and 13.

Criteria 1

$$F_{\max_dynamic} = SWL_{line} - F_{static} \tag{12}$$

Criteria 2

$$F_{\max_dynamic} = 0.9 * M_{sub_object} \tag{13}$$

Where $F_{\max_dynamic}$ is the maximum allowable dynamic force, SWL_{line} is the safety working load of lifting line, F_{static} is the static force in lifting line, and M_{sub_object} is the submerged weight of lifting line.

3 Result

3.1 Payload capacity

Subsea equipment decommission starts from the seabed and the operating water depth decreases slightly according to the payout rate of lifting lines. Both lifting ropes had the same SWL of 126 tons but the payload capacity for wire ropes was significantly decreased to 66 tons at 3000 m. The reduction ratio for the wire rope is 47.6%. However, only a small decrease, 123 tons, was shown for fiber ropes which reduction ratio is 2.4%.

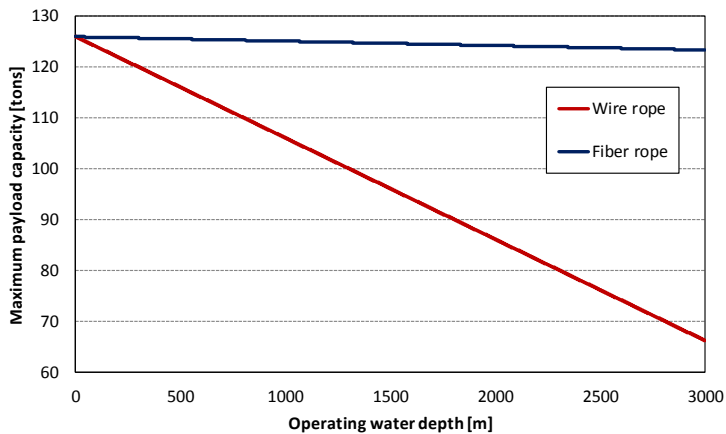


Fig. 6. Result for maximum payload capacity at different water depth.

Since the payload capacity reduced significantly at 3000 m, the wire size must be increased to decommission the object weighting over 66 tons. The payload capacity was calculated with increasing the size to satisfy the 126 tons of SWL of wire ropes at 3000m.

To satisfy the SWL of 126 tons, the wire size should be increased from 67 to 97 mm, also the weight of the wire is increased to 45.24 kg/m, which are seen in Fig. 7.

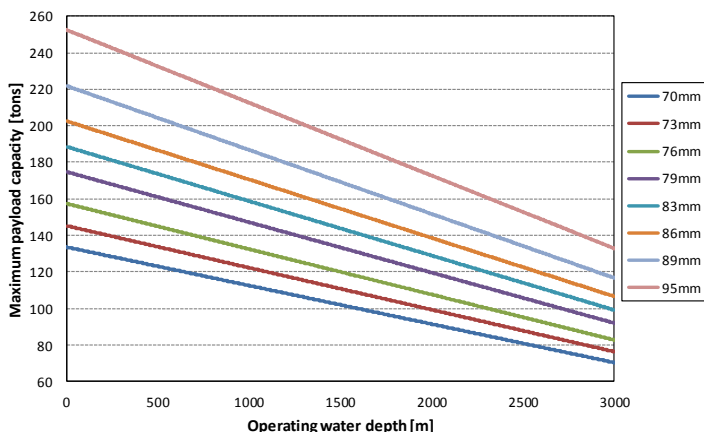


Fig. 7. Increasing size of wire rope.

3.2 Horizontal offset

Maximum horizontal offset for fiber ropes is significantly higher than that of wire ropes, which the comparative ratio is 51% for subsea tree and 64% for manifold as shown in Table 7. Since the submerged weight of fiber ropes is lighter, the lifting line will be more affected by the current force and the horizontal movement will increase.

Also, the submerged weight of the lifting object significantly affects on the horizontal offset. Since the weight of the manifold is 45 tons heavier than the subsea tree, the horizontal offset of the manifold showed lower values.

Table 7. Result for maximum horizontal offset

| Structure to be decommissioned | Max. horizontal offset Fiber rope [m] | Max. horizontal offset Wire rope [m] | Comparative ratio [%] |
|--------------------------------|---------------------------------------|--------------------------------------|-----------------------|
| Subsea tree | 258 | 133 | 51 |
| Manifold | 6172 | 110 | 64 |

3.3 Critical length of lifting line

The vertical crane tip motion transfer function has the peak at 6.5 second of wave periods. It means that the resonance is most likely to occur at the operating water depth where the natural frequency of the lifting lines taht approaches 6.5 seconds. The water depths corresponding to 6.5 seconds are summarized in Table 8.

Table 8. Result for critical length of lifting line

| Lifting line | Subsea structure | Critical length of lifting line [m] |
|--------------|------------------|-------------------------------------|
| Wire rope | Subsea tree | 2145 |
| | Manifold | 1760 |
| Fiber rope | Subsea tree | 705 |
| | Manifold | 555 |

The tendency of this result is that the resonance occurs more at deepwater when using wire ropes, however the resonance occur more at shallow water when using fiber ropes. This implies that the fiber ropes have advantages in deepwater operations because of less dynamic forces occurring at deepwater.

3.4 Dynamic analysis

3.4.1 Dynamic force in lifting line – subsea tree

Maximum dynamic force can be calculated by a maximum effective tension in lifting line minus a static tension in lifting line. The results of the dynamic analysis are shown in Fig. 8 and 9.

As a result, both ropes have no weather limitation for the lifting up operation. It is seen that when using wire ropes, more dynamic force occurring at deepwater, but the dynamic force occurring at shallow water when using fiber ropes.

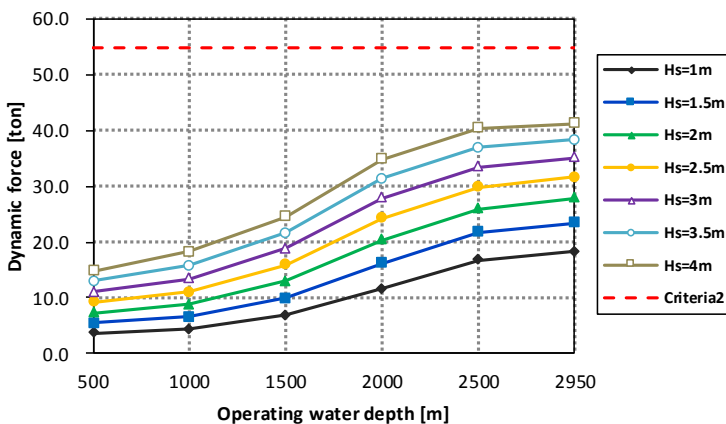


Fig. 8. Result for maximum dynamic force in wire rope during subsea tree decommissioning

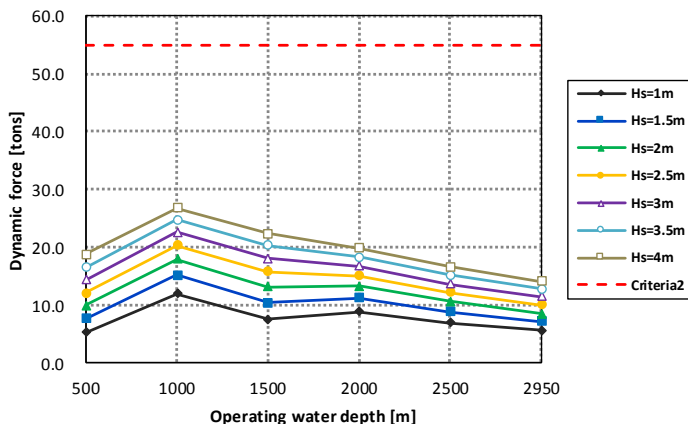


Fig. 9. Result for maximum dynamic force in fiber rope during subsea tree decommissioning

From Table 9, the positive values in the comparative ratio are a measure of how much more dynamic force is occurred when using wire ropes, conversely the negative values are a measure of how much more dynamic force occurred when using fiber ropes. Until 1000m of water depth, it is seen that more dynamic force occurred in the fiber ropes, and the dynamic force more occurred in the wire ropes from 1500 to 2950 m.

Table 9. Comparative ratio for maximum dynamic force at different water depth

| Operating water depth [m] | | 500 | 1000 | 1500 | 2000 | 2500 | 2950 |
|---------------------------|------------|------|------|------|------|------|------|
| Dynamic force [tons] | Fiber rope | 18.8 | 26.8 | 22.4 | 19.9 | 16.6 | 14.1 |
| | Wire rope | 14.9 | 18.3 | 24.5 | 34.8 | 40.4 | 41.2 |
| Comparative ratio [%] | | 26 | 46 | -8 | -74 | -143 | -192 |

3.4.2 Dynamic force in lifting line – manifold

The results for the manifold decommission are expressed in Fig. 10 and 11. It is seen that wire ropes can only be used as lifting lines when the significant wave height is less than 2m, but the fiber rope can only be used when the it is less than 2.5m. Thus, Using wire ropes has stricter weather limitation than using fiber ropes, also there is the same tendency that the more dynamic force occurring at deepwater when using wire ropes, but more dynamic force occurring at shallow water when using fiber ropes.

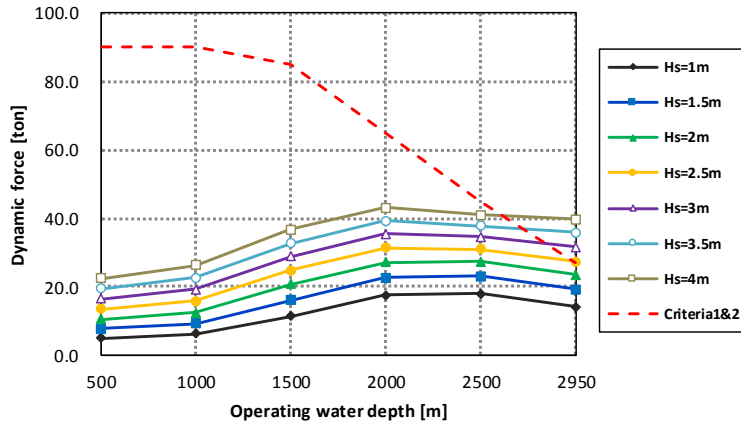


Fig. 10. Result for maximum dynamic force in wire rope during manifold decommissioning

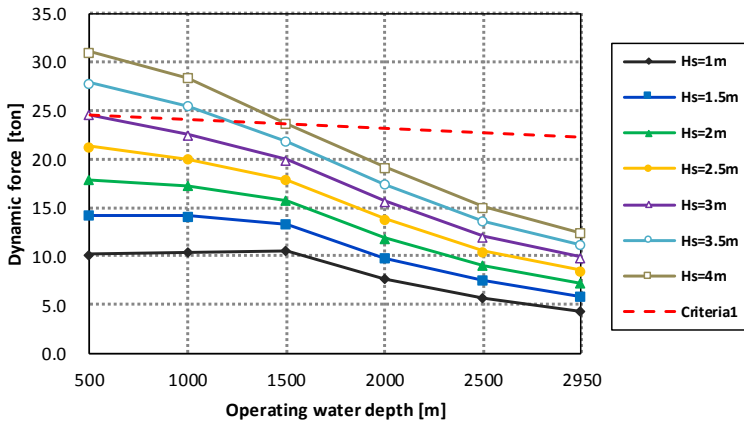


Fig. 11. Result for maximum dynamic force in fiber rope during manifold decommissioning

From Table 10, there is the same tendency as the results of the subsea tree decommissioning.

Table 10. Comparative ratio for maximum dynamic force at different water depth

| Operating water depth [m] | | 500 | 1000 | 1500 | 2000 | 2500 | 2950 |
|---------------------------|------------|------|------|------|------|------|------|
| Dynamic force [tons] | Fiber rope | 31 | 28.3 | 23.7 | 19.1 | 15.1 | 12.4 |
| | Wire rope | 22.5 | 26.3 | 36.6 | 43.1 | 41 | 39.6 |
| Comparative ratio [%] | | 39 | 7 | -54 | -125 | -171 | -219 |

4 Conclusions

This study was conducted to compare fiber ropes and wire ropes as lifting lines for subsea equipment decommissioning, and to assess the applicability of fiber ropes in the lifting for subsea decommissioning field. Payload capacity, horizontal offset due to current, critical length of lifting line, dynamic analysis were conducted.

Using fiber ropes showed an advantage in the payload capacity due to the light self-weight, which brings great benefits for deepwater operations. Also, Using fiber ropes had a disadvantage in the horizontal offset. However, since there is no need for positioning problem in the decommissioning operations, a large problem does not occur even if a large horizontal offset is generated. The dynamic force occurred more at deepwater depth when using wire ropes, and at shallow water when using fiber ropes. This tendency was identified in the result of the critical length of lifting line and dynamic analysis. Thus, when using fiber ropes, there is the great benefit for deepwater operations as less dynamic force occurs.

All the results showed a significant benefit for deepwater operations, and a sufficient possibility and benefit in the subsea equipment decommissioning with using fiber ropes, especially deepwater decommissioning.

Table 11. Summarized results for comparative study

| | Fiber rope | Wire rope |
|----------------------------------|---------------|--------------|
| Payload capacity | Advantage | Disadvantage |
| Horizontal offset due to current | Disadvantage | Advantage |
| Critical length of lifting line | Shallow water | Deepwater |
| Dynamic force | Shallow water | Deepwater |
| Weather limitation | Less strict | More strict |

Acknowledgements

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