Tendon analysis on tension leg platform

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Abstract. Tension Leg Platform is one kind of compliant structure using a moored tendon fixed to the sea bottom, which is suitable for deep water. The characteristic of TLP is different from the fixed jacket type, where the TLP has a flexible response to external forces. The objective of the present study is to analyze TLP’s behavior in terms of stress and deflection. The calculation is done using the finite element method through SACS software. The result obtained by the finite element method is presented in terms of stress and deflection.

1. Introduction
Tension Leg Platform (TLP) is one of the flexible structure that can move based on the acting force. Unlike jacket structure, TLP is very useful, especially for deep water, the exploration and exploitation may be conducted for this reason. Besides, the TLP structure must be evaluated for the structural design in terms of stress and deflection of the tendons.

The offshore structures like the Tension Leg Platform have been studied by some researches. Yu [1] focuses on a series of mooring analyses for a TLP with TTRs when its tendons fail to get the subsequent behaviors of the platform and mooring system response, including remanent tendons and risers. Tabeshpour [2] deals with the effect of damage tendon condition of TLP on behavior and tensions of tendons in a wave frequency range. Equilibrium of TLP is studied, and the stiffness matrix of TLP is derived in tendon damage condition. Xia [3] focuses on high-precision diving and leveling control of an underwater tension leg platform, which uses hydraulic winches as the actuation mechanism. Kim [4] presented a multi-objective optimization of the TLP by the SA method is applied to minimize both the heave response and the total weight of the hull and tendons. Eldin [5] conducted the sensitivity analysis on the seismic life-cycle cost of a fixed-steel offshore platform structure. The sensitivity analysis was performed using different methods such as tornado diagram analysis, first-order second moment, and Latin hypercube sampling. Gude [6] presented a method for risk assessment and inspection plan development as part of the risk-based structural integrity management of the offshore jacket platform. Muis Alie [7] analyze the effect of symmetrical and unsymmetrical configuration shapes on buckling and fatigue strength analysis of the fixed offshore platform. Two models of the fixed offshore structure were taken to be analyzed with the same dimension but different configuration shapes. The numerical calculation was performed to investigate the buckling and fatigue strength of both structures. Hezarjaribi [8] performed the nonlinear response of jacket-type platforms against extreme waves that were examined utilizing sensitivity analyses. Muis Alie [9] discussed the configuration effect of fixed offshore structure with symmetrical and unsymmetrical shape toward buckling failure. Two kinds of the offshore structure were analyzed. The numerical analysis was adopted to calculate buckling failure under axial and lateral load.
The objective of the present study is to analyze the tendons characteristic of the Tension Leg Platform (TLP) in terms of stress and deflection. The calculation is done using the finite element method through SACS software. The result obtained by the finite element method is also presented in this study.

2. Methodology
The wave load acts where the structure in the vertical direction can be determined by the following equations.

\[ F = F_D + F_I \]  \hspace{1cm} (1)

\[ F_D = \frac{\rho C_D D}{2k} (\omega H)^2 \left( \frac{\sinh^2 ky}{\sin^2 kh} + \frac{2ky}{\sin^2 kh} \right) \cos \omega t \cos \omega t \]  \hspace{1cm} (2)

\[ F_I = \frac{\rho C_I l}{2k} \frac{\pi D^2}{4} \omega^2 H \frac{\sinh ky}{\sinh kh} \sin \omega t \]  \hspace{1cm} (3)

Where

- \( F_D \) : Drag force
- \( F_I \) : Inertia force
- \( C_D \) : Drag coefficient
- \( C_I \) : Inertia coefficient
- \( D \) : Pile diameter
- \( \omega \) : Angular velocity
- \( H \) : Wave height
- \( k \) : Wave number
- \( y \) : Distance
- \( h \) : Water depth

**Figure 1.** Wave load distribution
The calculation of beam deflection with some condition related to the asymmetrical load distribution and support condition, the following equations are used. Generally, the beam deflection can be determined by using the formula,

$$E I \frac{\partial^2 y}{\partial x^2} = M$$  \hspace{1cm} (4)

Where $E$, $I$ and $M$ are young’s modulus, inertia, and moment, respectively.

The analytical method is also performed, for the axial load is applied on the jacket leg structure, and it is calculated by using the following formula,

$$\sigma = \frac{F}{A}$$  \hspace{1cm} (5)

where $F$ and $A$ are the axial force and cross sectional area, respectively. The stress-strain is also represented by the following formula,

$$\sigma = E \varepsilon$$  \hspace{1cm} (6)

The young’s modulus $E$ and strain $\varepsilon$ are expressed by the relationship form the Hooke’s law. The equation (7) can be modified to obtain the strain as,

$$\varepsilon = \frac{\sigma}{E}$$  \hspace{1cm} (7)

The combined axial stress and bending stress are determined by the following equation considering the influence of the reduction factor. The combined axial and bending stress in equation (8) is called interaction ratio (IR) and the value should be less than 1 [10]. In this case, the reduction factor $c_m$ may be taken from 0.40 to 0.85.

$$\frac{f_a}{F_a} + \frac{c_m \sqrt{f_{ba}^2 + f_{by}^2}}{F_b \left(1 - \frac{f_a}{f_e}\right)} \leq 1$$  \hspace{1cm} (8)

where

- $f_a$ : axial column buckling stress \hspace{1cm} (N/m$^2$)
- $F_a$ : axial column allowable buckling stress \hspace{1cm} (N/m$^2$)
- $f_{ba}$ : major bending stress \hspace{1cm} (N/m$^2$)
- $f_{by}$ : minor bending stress \hspace{1cm} (N/m$^2$)
- $c_m$ : reduction factor
- $F_b$ : allowable bending stress \hspace{1cm} (N/m$^2$)
3. Results and discussion

The hull of the TLP structure is steel, with one column having the diameter is 26 m, the depth of the column and draft is 38 m and 32 m, respectively. The elastic modulus, yield strength, and ultimate tensile strength are $210 \times 10^3 \text{ N/mm}^2$, 690 N/mm$^2$, and 938 N/mm$^2$. The TLP structure is modeled using the finite element method, as shown in figure 2.

![Figure 2. TLP structure](image)

![Figure 3. Deflection-IR relationship](image)

![Figure 4. Deflection of TLP structure](image)
Figure 3 shows the relationship between deflection and interaction ratio (IR). The deflection is plotted in x, y, and z-direction. The deflections and interaction ratios are small. The interaction ratio is the combination between the axial and bending stress acting on each elements of the tendons. Figure 4 shows the deflection of the TLP structure. The tendons are deflected according to wave force.

4. Conclusion
The analysis of tendons of the Tension Leg Platform (TLP) has been conducted using the finite element method. It is found that the deflections are small in any direction. The interaction ratios for the combination between axial and bending stress are small for each element of tendons.

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