Strength check for production riser during dry tree unit coil tubing operations under different environmental conditions

Fei Fu\textsuperscript{1,2,3}, Jianxing Yu\textsuperscript{2}, Zhanbin Meng\textsuperscript{2} and Xiangxi Han\textsuperscript{2}

\textsuperscript{1}Jimei University, Xiamen 361021, China
\textsuperscript{2}Beibu Gulf University, Guangxi 535011, China
\textsuperscript{3}E-mail: fufei201916@163.com

Abstract. In this paper, we introduce the modelling, loads, result evaluation method and boundary for production riser strength analysis. We investigated the different result evaluation method and different boundary condition based on a real project. The strength checks for the riser coil tubing stack up system in different environmental conditions was performed by SACS Software, calculate the most critical members UC and the maximum loads at critical flange locations of the riser during the whole dry tree unit coil tubing operations. According to the corresponding specification, the analysis results show that all the values of UC less than 1 and the project meet design requirements.

1. Introduction

Nowadays, Floating Production Storage and Offloading System (FPSO) has been widely used in offshore oil production. Dry Tree Unit (DTU) collects well production fluids, which are transferred to the FPSO for processing by way of mid-water fluid transfer lines. Before install a new production riser, strength check for the riser coil tubing stack up system during dry tree unit coil tubing operations under different environmental conditions should be performed.

The riser coil tubing stack up system includes gooseneck, HR 660 injector, side door stripper assembly, cromar subs, cross X-over, flange riser spider frame, BOP, flow cross, and tubing spool assembly. There are some problems to await to settle in the dry tree unit coil tubing operations, such as complicated application technology, high production cost, easily affected by environment, and so on. Engineering safety and process reliability will be important factors to consider. Therefore, if we can establish an accurate analytical model to assess the risk of understrength and local buckling instability, it will provide theoretical basis for the safety evaluation of dry tree unit coil tubing operations.

In this paper, we use an example to describe the loads, result evaluation method and boundary condition for strength check of production riser.

2. Loads and environmental conditions

The exploitation of offshore oil and gas is influenced by water depth, offshore distance, wave, current and wind conditions. The forces applied on production riser include dead loads and live loads, dead loads consist of the dead weight of the structure and the fixed weight of the equipment, live loads include environmental load and operation load. The environmental loading consists of wave, current and wind loading. Extreme operating conditions should be avoided to ensure projects can be carried through safely and smoothly. The basic loads applied on production riser during dry tree unit coil tubing operation are summarized in Table 1.
Table 1. Basic load case summary.

| Item          | Data                          | Other/Comments                                                                                                                                 |
|---------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| System Weight | Component weight              | Consider the weight of all major components. Dry: Include tubing + connections, production fluids, clamps, control lines. Normal: multiply a factor of 1.55. Accident: multiply a factor of 2.0. Allowance for friction. When feeding in treat as accidental case. |
| PR Completion | PR Completion                 |                                                                                                                                               |
| Applied Loads | coil tubing pipe load in hole |                                                                                                                                               |
| Lateral       | for 1 yr storm: 0.12g         | for 10 yr storm: 0.18g                                                                                                                      |
| accelerations | for Hs = 0m: 0.0g             | for Hs = 2m: 0.065g                                                                                                                         |
| Wind loads    | 1 year Wind velocity (3 second gust) | 10 year Wind velocity (3 second gust)                                                                                                       |

3. Method comparison on engineering application

If production risers are top tensioned by production riser tensioners, the vertical loads of each riser (including surface equipment weights) are transferred on to the production riser tensioner through a load ring. The coil tubing howitzer riser joint from the coil tubing unit to the coil tubing BOP assembly are treated as overhanging beam and the riser string from the tree to the tensioner load ring are treated as a simple beam. The top end of the beam is subjected to an external axial load, a transverse force, and a bending moment, which will produce buckling tendencies. The top end (top of injector) is also loaded by the inner tubing weight. The tubing weight will increase the total axial stress in the outer casing, but will not produce buckling tendencies as the inner tubing is well centralized.

For buckling check [1-3], we build a SACS model (called Model 1) with all loads except coil tubing axial loads. The effective length factor K is 1.0 and 2 for members below spider frame and above spider frame, respectively. Then build another model for yield strength check (called Model 2) with only coil tubing axial loads. The effective length factor K for all members is 0.001. In order to get the member stress unity check, there are two methods for engineering application:

a) Method 1: Get axial stresses and bending stresses from Model 1 and Model 2 and then calculate the Combine UC by the following formula:

\[
Combine\ UC = \frac{f_a}{F_a} + \frac{f_b}{F_b} + \frac{f_{ai}}{0.6F_y}
\]

where

- \(f_a\) = members’ axial stress from Model 1, ksi,
- \(F_a\) = the allowable axial stress, ksi
- \(f_b\) = members’ bending stress from Model 1, ksi,
- \(F_b\) = the allowable bending stress, ksi
- \(f_{ai}\) = members’ axial stress from Model 2, ksi,
- \(F_y\) = yield strength, ksi.

b) Method 2: Get values of UC1 from Model 1 and values of UC2 from Model 2, combined UC = UC1 + UC2.

We use the same model to calculate the value of UC, the results are shown in Table 2. Compare the two results, we came to the conclusion that the value of combined UC of most components are similar, but the difference values of most critical members’ combined UC are too big to ignored. In order to ensure the safety of the project, we recommend Method 2 would be a more rational way.
Table 2. Member stress unity check in different methods.

| Member | Method 1 | Method 2 | Difference |
|--------|----------|----------|------------|
|        | fa       | Fa       | fb         | Fb         | fai      | 0.6*      | Combined UC1 | UC1 | UC2 | Combined UC2 | Difference value |
| 1      | -0.3     | 1.79     | -13.9     | 56.25      | -0.38    | 45        | 0.42        | 0.42 | 0.01 | 0.43      | 0.01 |
| 2      | -0.75    | 1.07     | -41.9     | 56.25      | -0.96    | 45        | 1.47        | 2.83 | 0.02 | 2.85      | 1.38 |
| 3      | -0.16    | 2.72     | -6.12     | 56.25      | -0.21    | 45        | 0.17        | 0.17 | 0    | 0.17      | 0.00 |
| 4      | -0.11    | 2.72     | -3.65     | 56.25      | -0.21    | 45        | 0.11        | 0.11 | 0    | 0.11      | 0.00 |
| 5      | -0.11    | 2.74     | -3.46     | 56.25      | -0.2     | 45        | 0.11        | 0.1  | 0    | 0.1       | -0.01|
| 6      | -0.18    | 9.12     | -6.6      | 56.25      | -0.38    | 45        | 0.15        | 0.14 | 0.01 | 0.15      | 0.00 |
| 7      | -0.45    | 5.45     | -19.8     | 56.25      | -0.96    | 45        | 0.46        | 0.43 | 0.02 | 0.45      | -0.01|
| 8      | -0.1     | 2.72     | -2.86     | 56.25      | -0.21    | 45        | 0.09        | 0.09 | 0    | 0.09      | 0.00 |
| 9      | -0.09    | 2.61     | -2.8      | 56.25      | -0.2     | 45        | 0.09        | 0.08 | 0    | 0.08      | -0.01|
| 10     | -0.74    | 1.15     | -40.6     | 56.25      | -0.96    | 45        | 1.39        | 2.38 | 0.02 | 2.4       | 1.01 |
| 11     | -0.29    | 1.92     | -13.2     | 56.25      | -0.38    | 45        | 0.39        | 0.39 | 0.01 | 0.4       | 0.01 |
| 12     | -0.16    | 2.74     | -5.82     | 56.25      | -0.2     | 45        | 0.17        | 0.16 | 0    | 0.16      | -0.01|
| 13     | -0.21    | 4.95     | -8.45     | 56.25      | -0.38    | 45        | 0.20        | 0.19 | 0.01 | 0.2       | 0.00 |
| 14     | -0.53    | 2.96     | -25.4     | 56.25      | -0.96    | 45        | 0.65        | 0.65 | 0.02 | 0.67      | 0.02 |
| 15     | -0.11    | 2.72     | -3.69     | 56.25      | -0.21    | 45        | 0.11        | 0.11 | 0    | 0.11      | 0.00 |
| 16     | -0.24    | 24.9     | 0.18      | 56.25      | -0.22    | 45        | 0.02        | 0.01 | 0    | 0.01      | -0.01|

4. Structural strength calculation example

4.1. SACS model

The analysis is performed using SACS Software, most components of the production riser stack up system (Figure 1) are modeled, as shown in Figure 2. There are one 6 ft flange riser at top and two 15 ft flange risers welded together with cut off a pair of necks.

**Figure 1.** Coiled tubing technology was applied in Gulf of Mexico[4].

**Figure 2.** The model of riser coil tubing stack up system.
4.2. Load case
Each main load case considered 2 positions - normal position, upstroke position (5.5 ft). Two options have the same components and spider elevation. Each position combined with four lateral inertial load cases (max. lateral accelerations of 0.0g, 0.065g, 0.12g, and 0.18g respect to Hs=0.0 m, Hs=2.0 m, 1 year wave condition and 10 years wave condition). Also wind loads (3 second gust, 31.853 knots and 40.226 knots for 1 year and 10 years, respectively) are combined with correspondent inertial loads. The coil tubing pipe max overpull load is 32.596 kips and the coil tubing max side pull tension load is 1.894 kips. The load combination is shown in Table 3.

Table 3. Load combination.

| Load Case | Load case Description | Inertial Loads | Wind Loads (speed) | Other Loads |
|-----------|-----------------------|----------------|-------------------|-------------|
| LC1       | coil tubing stuck in gooseneck | 1) Hs = 0m | coil tubing pipe max overpull load (32.596 kips) | + max upstroke (5.5 ft) and downstroke (5 ft) condition. |
| LC2       |                        | 2) Hs = 2.0 m |                   |             |
| LC3       |                        | 3) Hs = 1 yr | 31.853 knots      |             |
| LC4       |                        | 4) Hs = 10 yr<sup>(a)</sup> | 40.266 knots      |             |

Note: (a) Under 10 years wave conditions, no coil tubing max side pull tension loads will apply to the gooseneck.

4.3. Boundary condition
The dry tree unit tubing will laterally support by the spider, TTR deck and tension load ring, vertically only supported by the tension load ring. The spider frame is lateral restrained by four vertical pipes located at corners, and is vertical supported at four points located at middle edges of the spider frame. The middle vertical supports are design with two options:

a) Boundary condition 1: The spider frame is simply sit on the Spar upper deck, i.e. move upwards only, realized by compression only dummy members.

b) Boundary condition 2: The spider frame is simply hold by bolts on the Spar upper deck.

The boundaries and restraints at the spider frame of Boundary condition 2 was shown in Figure 3.
The howitzer riser joint through the middle sleeve of the spider frame and is lateral restrained by two dummy wishbone members located at the top end and bottom end of the middle sleeve.

4.4. Summary of results
The model and analysis results have been carefully examined and verified before any results are considered useable. These include the checking of loading point, load combinations value, boundaries for each member, etc. Based on above method, post-process the results, we can get the maximum resultant moment and the maximum force in different load case, as shown in Figure 4 and Figure 5.

![Figure 4](image1.png)

(a) **Figure 4.** The maximum resultant moment (in-kips) in different load case; (a) Boundary condition 1; (b) Boundary condition 2.

![Figure 5](image2.png)

(b) **Figure 5.** The maximum force (kips) at top of tree in different load case; (a) Boundary condition 1; (b) Boundary condition 2.

| Boundary condition | Position | Max Member Combined UC | Load condition                   | OK or Not |
|--------------------|----------|------------------------|----------------------------------|-----------|
| 1                  | Normal Stoke | 0.63                    | Max overpull, 1 Year Strom       | OK        |
|                    | UP Stoke   | 0.63                    | Max overpull, 1 Year Strom       | OK        |
| 2                  | Normal Stoke | 0.63                    | Max overpull, 1 Year Strom       | OK        |
|                    | UP Stoke   | 0.63                    | Max overpull, 1 Year Strom       | OK        |
Table 5. Maximum loads at critical flange locations.

| Point | Normal Elevation (ft) | Max. Moment (kip-in) | Load Case | Flange Description |
|-------|-----------------------|----------------------|-----------|--------------------|
| 0034  | 108.863               | 765.479              | up stroke & 1 year wave &wind | Cromar sub |
| 0027  | 101.363               | 1048.816             | up stroke & 1 year wave &wind | 5 5K API 17D |

Maximum UC and maximum loads among all load cases are shown in Table 4 and Table 5, respectively. The locations of the most critical members’ UC and maximum loads are shown in Figure 6 and Figure 7.

Figure 6. Maximum UC location.  
Figure 7. Flange joint location.

5. Conclusions
The results of the stack up analyses suggests that this production riser has adequate strength to withstand coil tubing pipe loads, coil tubing reel tension loads under design environmental conditions. The maximum utilization ratio at flange neck is 0.63, thus the crossovers and howitzer risers meet the API requirements for member strength check. Also the flange integrities except one flange can sustain the design loads (maximum bending moment and internal pressure of 1000 psi) and meet the ASME Boiler and Pressure Vessel Code requirements [5].

Acknowledgements
This project was supported by the Guangxi Natural Science Foundation (No. 2018GXNSFBA281138, 2019GXNSFAA185044).

References
[1] American Petroleum Institute. Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platform-Working Stress Design: API RP 2A-WSD[S]. Washington: API Publishing Services, 2007
[3] American Institute of Steel Construction Inc. Specification for Structural Steel Buildings-Allowable Stress Design and Plastic Design: AISC 335[S]. Chicago: Illinois 60601-1802, 1989

[4] Chen Qianrong 2017 Research on the Mechanics of Sidetracking Operations in the Deep Sea based on Coiled Tubing Technology[D]. China university of petroleum (Beijing)

[5] ASME Boiler and Pressure Vessel Code, BPVC-II Materials Part D Properties (Metric)[S]