Design of Flexible Jig for Leg Manufacturing on Jack-up Plateform

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Abstract. Due to various designs in racks and semicircle tubes, dedicated jigs are used in the manufacturing of most jack-up legs, which decreases the productivity. In this research, a new flexible jig system with jig and support column is designed to meet different production requirements of many jack-up platforms. Firstly, two kinds of adjustment bolts i.e. position bolts and angle bolts are designed for accurate positioning and attitude adjusting. Moreover, considering supporting height differences of the legs, an integrated mode of standard and specific components is adopted in construction of the support columns. By using of the new flexible jig, productivity of many jack-up platforms construction is greatly improved.

Keywords. jack-up plateform; flexible jig; leg manufacturing; flexible design

1. Introduction
In the construction process of the legs for jack-up¹, jigs are the necessary equipment. Jig can not only serve the leg as a supporting and positioning element in the construction process, but, more importantly, also can ensure the straightness of the leg²,³. At present typical structure of leg jig is mainly composed of jig foundation, jig and support column⁴. Because of varied type platform leg, rack plate, tube radius and weight of platform leg section are different. At all times, special jig is used in jack-up platform leg construction, that is to say, the jig leg is designed and manufactured for a particular platform size. When jack-up leg of other size is acquired to be manufactured, it is necessary to design a new special leg jig, which will lead to the waste of the original special jig and the increase of time and expense to construct the new jig.

Therefore, it is considerable to design a new flexible jig, which can meet the requirements to construct a common jack-up leg and can improve the versatility of a jig. It is significant to reduce time and expense to construct the new jig, and improve the efficiency of marine engineering construction.

The flexible jig design requires an adjustable diameter of leg tube ranging from 150 mm to 350 mm; the height of support column ranges from 7.5 m to 16 m. In this research, considering the characteristics during the building process of jack-up leg, a new flexible jig system with jig and support column is designed to meet different production requirements of many jack-up platforms, which is advanced comparing to existing special jig.
2. Flexible Jig structure research

It is primary to meet the functional requirements when designing a jig. In addition, simple facture process, low expense and better commonality is necessary. According to different requirements in construction of varied jack-up legs, small adjustments of jig can satisfy the operating requirement. When tube size changes, the rack plate can be still fixed in the designated position in a certain angle, and can support a certain weight load.

Taking expense and practicality into account, bolts are set on the jig. The bolts are used to adjust position of the tube and oblique angle of the rack plate. This study of jig structure can meet the requirements when the diameter of tube changes within a certain range. Preliminary research on jig size is based on the largest common tube diameter of jack-up legs. Overall outline drawing of jig corresponding the maximum and minimum diameter of tube can be seen in Fig.1 (a) and Fig.1 (b).

![Overall outline drawing of jig](image)

(a) maximum diameter of tube (b) minimum diameter of tube

The main function of the five bolts in Fig.1 is supporting and positioning, which can adjust deviation in different directions of the rack plate. In the building process of jack-up legs, the straightness of rack plate should be guaranteed. The angle between rack plate and horizontal direction is 60 degree to ensure that the three legs center surrounded is equilateral triangle. Horizontal bolt on the template can control the displacement in right-left direction of jack-up leg; the vertical bolt can control the displacement in up-down direction; the inclined bolt can simultaneously control both the displacement in right-left and up-down direction. Furthermore, vertical bolt and horizontal bolt also mainly bear the weight of jack-up leg. The displacement of inclined angle on the rack plate can be resolved by adjusting the angle bolt on the cover plate.

The position adjustment of inclined bolt on the jig template and angle bolt on the cover plate are based on change of leg size, to ensure that the inclined bolt working point is located in the center of the rack plate, and angle bolt can still play a nice regulating function. There exists backing plate between inclined bolt of jig and rack plate to avoid the working point of each inclined bolt on the template fall in the position beyond of the addendum, which leads to working point position is not stable. The backing plate can protect the rack plate from damage and fixed the position of inclined bolt. Due to the difficulty to guarantee the levelness of the ground, jig itself does not contact with the ground. It is convenient to find datum level to fix the seat bang on the ground, connecting with jig through the backing plate.

3. Support column structure research

At present, the sizes and weight of the most common jack-up legs are greatly different. Therefore, the support column not only requires an suitable adjustment range in height to match the range of the leg size, but also necessary strength and stability to satisfy the leg bearing requirements. The scheme requires that the height of the support column ranges from 7.5 m to 16 m. Furthermore, the support column needs to satisfy the support height, strength, stability and the convenience of construction.

Because the support column can be used in different heights within a certain range, a multi-connecting way is adopted. At the preliminary stage, a series of sleeves in different heights are connected to constitute a support column. However, when bearing heavy weight, this connecting way
is unable to ensure the security of the connection between the sleeves, then the stability of the column mentioned above is a critical problem to solve. As a result, the improved project choose the column with the joist steel section. Flange connections are applied between columns, solving the problem of the security and stability.

There are different heights of the column for different types of platform. In order to avoid the specificity of the support column, try to use more common parts to fit different height of support column, in which way, small changes can meet the column height requirements. According to the stability of the support column after loading, its section dimension is determined, and then its strength should be checked.

The support column is consist of specific top part, a series of different sizes of standard parts, such as 1 m, 2 m, 5 m, and specific bottom components. The main part of the standard and specific parts is made of H section steel. There exist flange with unified type at the end connection. There are grooves corresponding the jack-up size above the top specific part, and there exists a base plate at the bottom of the support column, which is convenient for leveling of datum level. According to the height requirement of support column for jack-up leg, the combination schemes of the height for support column is shown in Table 1.

**Table 1. Different combination scheme of height for support column**

| Support height of composite /m | The number of 1m standard parts | The number of 2m standard parts | The number of 5m standard parts | The height of specific part/m | The height of specific bottom part/m |
|--------------------------------|--------------------------------|--------------------------------|--------------------------------|-------------------------------|------------------------------------|
| 7.5                           | 1                              | 0                              | 1                              | 1                            | 0.5                               |
| 8.5                           | 0                              | 1                              | 1                              | 1                            | 0.5                               |
| 9.5                           | 1                              | 1                              | 1                              | 1                            | 0.5                               |
| 10.5                          | 0                              | 2                              | 1                              | 1                            | 0.5                               |
| 11.5                          | 0                              | 0                              | 2                              | 1                            | 0.5                               |
| 12.5                          | 1                              | 0                              | 2                              | 1                            | 0.5                               |
| 13.5                          | 0                              | 1                              | 2                              | 1                            | 0.5                               |
| 14.5                          | 1                              | 1                              | 2                              | 1                            | 0.5                               |
| 15.5                          | 0                              | 2                              | 2                              | 1                            | 0.5                               |
| 16.5                          | 1                              | 2                              | 2                              | 1                            | 0.5                               |

In the support column scheme, the standard parts should be connected with flange as much as possible, to recycle the standard parts and extend its life. The specific bottom part are used to protect the standard parts. Because the bottom part needs to be connected with the base plate, welding fixed and removed after use may lead to abrasion and damage. Small parts if abraded or damaged can be replaced with lower expense.

There are only a few combinations of special sizes in Table 1. In the actual manufacturing, the height of the special bottom part can be adjusted to meet requirements for different heights of the jack-up leg.

The overall outfitting drawing of support column is shown in Fig.2, which shows the position of jig and support column in the working status. Fig.3 shows the connection between special top part and top leg, namely Detail 1 in Fig.2. Because it is not easy to guarantee the levelness and straightness of the rack plate after hanging the top leg to the top of support column, the top rack plate can be adjusted by the adjustable bolts at the top specific part.
4. Design of bolt and support column on flexible jig

Possible damage of jig is the failure of screw pairs of force bolts and the instability of support column after jig structure was determined. Therefore, the following work are bolt design and strength check of support column based on these two forms of damage.

4.1. Design of bolts

This research applies the finite element analysis software ANSYS to establish finite element model of platform leg section\(^5\). The force of every adjustment bolt on the jig can be calculated according to the weight of jack-up leg. Further bolt design base on the force results calculated.

Jack-up leg section finite element model was established according to 300 feet jack-up leg size as shown in Figure 4. All beam element type choose BEAM188. Considering bolt mainly bear compressive stress, its unit type select LINK8. The model bear the gravity of jack-up leg section, which calculated the force of every bolt and support column.

Calculate the force of each bolt in the condition where it may occur failure mostly possibly, that is to say to calculate the maximum possible force of every bolt. For example: there are only vertical bolt on the jig contact with tube and inclined bolt do not participate in the load-bearing. At this time the vertical bolt bear the largest force. Through calculated the maximum force was 149380N and make this force as the design allowable load of vertical bolt.

Design screw pairs, including type of screw pairs, materials and the calculation of screw pairs in the reference to Mechanical Design Handbook\(^6\). The following are the steps to design a vertical bolt as an example.

The type of thread choose trapezoidal thread; bolt choose 45 steel quenching and tempering, nut choose 45 steel quenching and tempering.

According to design of the wear resistance, the pitch diameter of strew thread diameter was calculated as follows.
\[ d_2 \geq 0.8 \sqrt{\frac{F_a}{\psi \cdot [p]}} = 0.8 \sqrt{\frac{149380}{1.8 \times 10}} = 73 \text{mm} \] (1)

Where \(d_2\) is the pitch diameter of strew thread, \(F_a\) is the force on the bolt, \(\psi\) is the ratio of the whole length of nut \(H\) and the pitch diameter of strew thread \(d_2\), take as 1.8. \([p]\) is the allowable pressure of thread surface, take as 10 MPa.

According to national standard GB/T 5796.3-2005 of the trapezoidal thread standard, take thread parameters as follows:

Pitch \(P = 10 \text{mm}\), normal diameter \(d = 80 \text{mm}\), pitch diameter \(d_2 = 75 \text{mm}\), minor diameter \(d_1 = 69 \text{mm}\).

Nut parameters:
- nominal diameter \(D = 80 \text{mm}\), pitch diameter \(D_2 = 75 \text{mm}\), minor diameter \(D_1 = 81 \text{mm}\),
- Height of nut \(H = \psi d_2 = 1.8 \times 75 = 135 \text{mm}\).
- Rotary joint ring number of strew thread \(z = \frac{H}{P} = 13.5\), take integer \(z = 14\). Height of nut \(H = Pz = 140 \text{mm}\), Working height of strew thread \(h = 0.5P = 5 \text{mm}\).

According to bolt thread and nut thread parameter above calculated check wear resistance, self lock, and check the strength of bolt and screw thread and bolt pressure stability. All checked results should meet the requirements.

4.2 Design of support column

The maximum force of standoffs calculated by the finite element model was approximately 150000N. Simplify support column as slender rod and check its stability and strength with Euler’s formula based on the simplify.

Stability check should satisfy the condition as follows:\(^8\)

\[ F_a \leq \frac{F_{cr}}{S} \] (2)

Where \(F_{cr}\) is the critical load, \(S\) is safety coefficient of stability check, Usually take \(S = 2.5 \sim 4\). Take main support column as 55a joist steel. Its section area is 134.185 cm\(^2\), principal moment of inertia is 62900 cm\(^4\), radius of inertia \(i = 21.6 \text{cm}\). Compliance calculation formula

\[ \lambda = \frac{EI}{i^2} = \frac{2 \times 15.5 \times 100}{21.6} = 143.5 \] (3)

Due to \(\lambda = 143.5 > 100\), critical load is determined by Euler’s formula.

\[ F_{cr} = \frac{\pi^2 EI}{(\mu L)^2} \] (4)

Where \(\mu\) is the length factor. When one end of rod is fixed, the other is free, take it as 2. \(L\) is the length of slender rod, 15.5 m. \(E\) is elastic modulus, 211 GPa, \(I\) is the slender rod’s section moment of inertia.

We can get critical load of support column \(F_{cr}\) is 1363043N after take these data to formula. Take safety coefficient of stability check \(S\) as 4, \(\frac{F_{cr}}{S} = 340761 \text{N}\). That is to say, if occur instability, the force at the top of support column at least is 340761 N.

According to finite element model calculation of the whole jack-up leg, the maximum force of support column is about 150000 N. It is less than critical load, so the support column will not occur instability.
Stress calculation formula

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

Put data into the formula and get stress of support column section. \( \sigma = 11.2 \text{MPa} \)

Support column strength requirements

\[ \sigma < [\sigma] = \frac{\sigma_s}{S} \]  \hspace{1cm} (6)

Where \( \sigma_s \) is yield strength of material, low carbon steel take as \( 235 \text{MPa} \). \( S \) is safety coefficient of strength check, take as 2. \([\sigma]\) is allowable stress.

The allowable stress is \( 117.5 \text{MPa} \) after calculated. \( \sigma = 11.2 \text{MPa} < [\sigma] = 117.5 \text{MPa} \). So the strength of support column meet the design requirements.

5. Conclusions

This paper has conducted research on flexible jig for leg manufacturing of jack-up. The new flexible jig satisfies the condition that adjustable diameter of leg tube ranges from 150 mm to 350 mm, and the height of support column ranges from 7.5 m to 16 m. A new flexible jig is designed by using jig and the support column for preliminary positioning of jack-up leg. The position bolts and angle bolts setted on the jig can be used for accurate positioning and the adjustment of oblique angle, to meet the requirements of tube size and the straightness of leg manufacturing for different types of jack-up legs. Moreover, considering supporting height differences of the legs, an integrated mode of standard and specific components is adopted in the construction of the support columns.

The flexible jig designed in this study can satisfy the varied requirements of jack-up leg manufacturing and the convenience of construction, reduce the production time and the construction cost of jig, and improve the construction efficiency of marine engineering. It is a great improvement comparing with existing special jig.

6. References

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