Development of analysis software for deepwater risers

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Abstract. Analysis software for deepwater riser system was developed based on theoretical research. The software consists of riser joint database module and analysis module. The analysis module was developed with the capability to conduct both static and dynamic analysis under loading due to currents, vessel offsets, waves and wave-induced vessel motions. The results of analysis were compared with those of ABAQUS under the same conditions. The comparison showed that the developed software was in good agreement with ABAQUS.

1. Introduction
In deepwater floating platform or ship operations such as drilling, oil production and deep-sea mining, riser is an important and weak link in the whole system, and its correct use is directly related to the smooth completion of the operation and even the safety of the whole system. Using special software to analyze the riser system is of great significance to reduce the risk of riser system failure during operation. In view of the lack of special analysis software for riser system at present, in order to facilitate engineering application, we developed analysis software for deepwater risers based on Windows.

The software was developed on the platform of VC++ and MATLAB, and the solver was designed based on finite element theory. It can be used for analysis and design of deepwater riser system.

2. Module Composition and Workflow

2.1. Module Composition and Functions
The software consists of the following core modules:
- Riser joint database module
- Analysis module

The analysis module was developed with the capability to conduct both the static and dynamic analysis. The static analysis module can predict the riser response under loading due to currents and vessel offsets. The dynamic analysis module accounts for the combined loading due to waves, wave-induced vessel motions and current loading.

2.2. Overall workflow
The overall workflow of the software is given in Figure 1.
3. Riser Joint Database Module
A database for deepwater risers is created for a certain vessel. Riser joints data including:\(^1-^4\):

- Joint type (slick, buoyant)
- Material
- Outer and inner diameters of joints structural wall
- Wall thickness
- Length of joint
- Joint peripheral lines dimensions
- Drag diameter of riser joint
- Second moment of area of joints structural wall
- Joint weight in air and in water, including contribution from internal fluid, buoyancy and peripheral lines
- Coefficient of drag to be used in analysis

4. Analysis Module
Analysis module include both riser static and dynamic analysis to provide riser operational guidance. Existing commercial riser analysis packages are both complex and costly. Typical commercial software available introduces complexity with multiple features such as 3D analysis for various riser types that is not required for the intended purpose and thereby increase the computation time defeating the purpose. Thus an easy to use and cost effective program which can be run was proposed to conduct riser analysis.

The following simplifications were proposed for the analysis:

- Conduct analysis in 2D
- Simplified static analysis using current loading

4.1. Governing equation
The governing equation for a dynamic analysis can be written as\(^5\):

\[
M\ddot{\delta} + C\dot{\delta} + K\delta = F
\] (1)

In the formula, \(C\) is the overall damping matrix; \(M\) is the overall mass matrix; \(K\) is the overall stiffness matrix; \(\delta\) is the overall displacement matrix (vector) for riser system; \(F\) is the overall load matrix.

For static analysis the force balance equation is described as follows\(^6-^7\):

\[
K\delta = F
\] (2)
The tangent stiffness matrix is used to solve the geometric nonlinearity of plane beam element. The tangent stiffness matrix of plane beam element is as follows:

\[ K_T = K_E + K_G \]  

(3)

In the formula, \( K_E \) is the element linear stiffness matrix and \( K_G \) is the element geometric stiffness matrix.

\[
K_E = \begin{bmatrix}
\frac{EA}{L} & 0 & 0 & -\frac{EA}{L} & 0 & 0 \\
\frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & -\frac{12EI}{L^3} & \frac{6EI}{L^2} & \frac{2EI}{L} \\
\frac{4EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{2EI}{L} & \frac{4EI}{L} & \frac{6EI}{L^2} \\
\frac{EA}{L} & 0 & 0 & \alpha & 0 & 0 \\
\end{bmatrix}
\]

Symmetry

(4)

Flexible joint element is defined by rotational stiffness. Assuming that the rotational stiffness of flexible joint is equal, the element stiffness matrix in its overall coordinate system is as follows:

\[
K_E = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
\frac{EA}{L} & 0 & 0 & -\frac{EA}{L} & 0 & -\alpha \\
\alpha & 0 & 0 & -\alpha & 0 & 0 \\
0 & 0 & 0 & \alpha & 0 & \frac{EA}{L} \\
\end{bmatrix}
\]

Symmetry

(5)

The element geometric stiffness matrix is determined by the local effective tension of riser. The geometric stiffness matrix of the two-dimensional beam element in the global coordinate system is as follows:

\[
K_G = \frac{T}{L} \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
\frac{6}{5} & \frac{L}{10} & \frac{5}{L} & -\frac{6}{5} & \frac{6}{10} & \frac{L}{L^2} \\
\frac{2L^2}{15} & 0 & \frac{10}{L} & -\frac{6}{5} & \frac{6}{10} & \frac{L}{30} \\
\frac{10}{15} & 0 & 0 & -\frac{L}{10} & \frac{L}{3} & 0 \\
\frac{6}{5} & 0 & 0 & \frac{L}{10} & 2L^2 & \frac{10}{15} \\
\end{bmatrix}
\]

(6)

In the formula, \( A \) is the cross section area of the unit; \( E \) is the elastic modulus of the unit material; \( I \) is the inertia moment of the unit; \( L \) is the unit length; \( T \) is the unit tension.

4.2. Convergence Criteria

The end of iteration needs to be judged according to the corresponding convergence criteria. Common convergence criteria are displacement convergence criterion and equilibrium convergence criterion.
The displacement convergence criterion uses the ratio of the root mean square value of displacement difference obtained by two adjacent iterations to the root mean square value of displacement obtained by the previous iteration to judge the degree of convergence.

\[ C_1 = \left( \frac{\sum_{n=1}^{N} (\delta_{n+1} - \delta_n)^2}{\sum_{n=1}^{N} \delta_n^2} \right)^{1/2} \]  

(7)

In the formula, \( \delta_n \) refers to the displacement obtained by the \( n \)th iteration.

The equilibrium convergence criterion uses the ratio of the root mean square value of unbalanced force obtained by single iteration to the root mean square value of external load to judge the degree of convergence.

\[ C_2 = \left( \frac{\sum_{n=1}^{N} (K\delta_n - F_n)^2}{\sum_{n=1}^{N} F_n^2} \right)^{1/2} \]  

(8)

In the formula, \( F_n \) is the load matrix used in the \( n \)th iteration, \( (K\delta_n - F_n) \) is the unbalanced force of the \( n \)th iteration.

4.3. Analysis Flowcharts

The flowcharts for performing the static and dynamic analyses are illustrated Figure 2 and Figure 3 respectively.

- **Determine element stiffness matrix, \( K_e \)**
- **Determine element force matrix, \( F_e \)**
- **Assemble \( K_e \) to form global stiffness matrix, \( K \)**
- **Assemble \( F_e \) to form global force matrix, \( F \)**
- **Apply boundary conditions**
- **Solve Morison’s equation for unknown \( d \): \( d = K^{-1}F \)**
- **Immediate output results:**
  - Static nodal displacement
  - Static nodal rotation
- **Further calculations to determine:**
  - Riser displacements
  - Flex-joint angles
  - Riser bending moment
  - Riser von Mises stress

Figure 2. Static analysis flowchart.
Solve equations for unknown $d$

Further calculations to determine:
- Riser displacements
- Riser bending moments
- Riser von Mises stress

Form global stiffness matrix
Form global mass matrix
Form global damping matrix $C$
Form global dynamic force matrix $F$

Make initial guess

Apply dynamic boundary conditions

Next iteration

Recalculate dynamic$(F, C)$

Check convergence

Immediate output results:
- nodal displacements
- nodal rotations

Further calculations to determine:
- Riser displacements
- Riser bending moments
- Riser von Mises stress

Figure 3. Dynamic analysis flowchart.

5. Validation
Parametric analysis was conducted to validate the analysis module of the software. The comparisons of the key analysis results including riser bending moment and von Mises stress were made between the analysis module and the benchmarking tool ABAQUS.

Plots of bending moment and von Mises stress comparisons between the analysis module and ABAQUS are presented in Figure 4 and Figure 5.
Figure 4. Bending moment comparison.

Figure 5. Von Mises stress comparison.

6. Conclusions
Based on the requirement of professional analysis software for deepwater riser operation, analysis software for deepwater risers was developed. Modular method was used during the development, and scientific computing software MATLAB was used for the solver development.

The software consists of riser joint database module and analysis module. The analysis module was developed with the capability to conduct both static and dynamic analysis under loading due to through currents, vessel offsets, waves and wave-induced vessel motions.

The riser finite element solver was designed based on the finite element analysis theory. The results of analysis were compared with those of ABAQUS software under the same conditions. The results showed that the developed software was in good agreement with those of commercial software.

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