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Research on Dynamic of Rubble Leveling Ship Based on Tremmie Pipe

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Abstract

The rubble leveling ship is an important marine engineering equipment for the construction of cross-sea bridges. The vibration of the rubble leveling operation will affect the accuracy of the rubble leveling ship. In order to explore the vibration of the tremmie pipe, the three-dimensional software SolidWorks was used to build a three-dimensional model, and the tremmie pipe was meshed with the finite element software ANSYS to generate a flexible body file, which was imported into ADAMS to construct a rigid-flexible coupling model. By applying assembly constraints, pipe end scraping force and external wave load, the dynamic simulation analysis of the model is carried out to obtain the pipe end displacement curve and acceleration curve. The analysis curve shows that the vibration of the pipe end of the tremmie pipe is more obvious when the wave load is applied.

Keywords

Rubble leveling ship, rigid-flexible coupling, wave load, ADAMS.

1. Introduction

With the continuous advancement of technology, the establishment of a cross-sea bridge has become an indispensable product in the new era. The rubble leveling technology of the submarine foundation bed of the cross-sea bridge has been studied as early as the 1960s, mainly concentrated in developed countries such as the United States and the United Kingdom [1]. China only started to study in this field in the middle and late 1970s. At this stage, the research started late, and the theoretical research is also lacking. However, recently, in 2017, the country's first world's largest rubble leveling ship (Jinping No. 1) completed the construction of the submarine foundation bed of the Hong Kong-Zhuhai-Macao Bridge [2].

From a global perspective, rubble leveling ships have been used in many fields in engineering, but the literature on dynamic response simulation in the relevant marine environment has not yet been retrieved, so many researches on the dynamic characteristics of these ships are not fully understood. In recent years, the virtual prototype has been widely used in the field of dynamics research by various industry research institutions due to its mature commercial use. Yang et al. [3] established an integrated model of mechanical system, hydraulic drive system and computer control system using ADAMS dynamics simulation software and Matlab / Simulink, and verified the validity of the built model through experiments. Li et al. [4] used ADAMS to establish a dynamic simulation model of a rigid-flexible coupled impact system, and Sun et al. [5] used ADAMS and AMESim to establish a virtual prototype model of the offshore wave compensation system.

In this paper, a virtual prototype model of a rubble leveling ship with flexible tremmie pipe was jointly established by SolidWorks and ADAMS, which is more conducive to the researchers' statics on the rubble leveling ship. Dynamic analysis and other related analysis can simulate the real motion environment, which provides a reliable simulation model for later theoretical calculation and optimization analysis.

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2. Rigid-flexible Coupling Theory

Rigid-flexible coupled multi-body dynamics system is a system composed of multiple rigid bodies and multiple flexible bodies connected in a specific system. It is a natural extension of the multi-rigid-body dynamic system. The dynamics of the rigid-flexible coupling system mainly studies the interaction between the elastic deformation generated by the internal or external forces of the system and the spatial motion within a specific range after the key components are flexible, and the dynamic effects caused by this relationship. This dynamic effect is an essential characteristic of a rigid-flexible coupled multi-body dynamics system, making it not only different from the multi-rigid body dynamics system, but also from the structural dynamics [6].

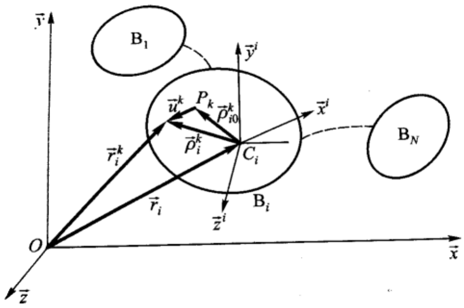

Figure 1. Multi-flexible body system in space motion

As shown in Figure 1, for a flexible body system composed of N flexible bodies, a common reference datum is defined for the system, denoted as $\vec{e}=\left(\vec{x} \quad \vec{y} \quad \vec{z}\right)^{\mathrm{T}}$, and the reference point is O. Take a point C_i on the flexible body $B_i=(i=1,\ldots,N)$ before deformation as a reference point to establish a floating reference, denoted as $\vec{e}^{\,i}=\left(\vec{x}^{\,i} \quad \vec{y}^{\,i} \quad \vec{z}^{\,i}\right)^{\mathrm{T}}$, the vector of C_i relative to datum O is denoted as $\vec{r}_i$, and the coordinate matrix in $\vec{e}$ is $r_i=\left(x_i \quad y_i \quad z_i\right)^{\mathrm{T}}$.

The configuration of the flexible body B_i is determined by the displacement coordinate matrix $\vec{r}_i$ of the floating datum point, the attitude coordinate matrix π_i of the floating datum about the common datum, and the modal coordinate matrix a_i of the flexible body B_i, which constitute the configuration coordinate matrix of the flexible body B_i, which is denoted as

$$q_i=\left(r_i^{\mathrm{T}} \quad \pi_i^{\mathrm{T}} \quad a_i^{\mathrm{T}}\right)^{\mathrm{T}} \quad (i=1,\ldots,N) \tag{1}$$

These N matrices constitute the coordinate array of the flexible multi-body system, which is denoted as

$$q=\left(q_1^{\mathrm{T}} \ldots q_N^{\mathrm{T}}\right)^{\mathrm{T}} \tag{2}$$

Let P_k be an arbitrary point on the flexible body B_i, $\vec{r}_i^{\,k}$ is the vector radius of point P_k relative to datum O, $\vec{\rho}_i^{\,k}$ be the vector radius of P_k relative to C_i, and $\vec{u}_i^{\,k}$ be the deformation displacement vector

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$$\vec{r}_i^{\,k} = \vec{r}_i + \vec{\rho}_i^{\,k}, \vec{p}_i^{\,k} = \vec{\rho}_{i0}^{\,k} + \vec{u}_i^{\,k} \tag{3}$$

Find the first derivative of equation (3) with respect to time, we get

$$\dot{\vec{r}}_i^{\,k} = \dot{\vec{r}}_i + \vec{\omega}_i \times \vec{\rho}_i^{\,k} + \overset{\circ}{\vec{u}}{}_i^{k} = \dot{\vec{r}}_i - \vec{\rho}_i^{\,k} \times \vec{\omega}_i + \overset{\circ}{\vec{u}}{}_i^{k} \tag{4}$$

Where $\overset{\circ}{\vec{u}}{}_i^{k}$ is the derivative of the deformation displacement vector with respect to time on the floating reference.
Find the second derivative of equation (3) with respect to time, we get

$$\ddot{\vec{r}}_i^{\,k} = \ddot{\vec{r}}_i - \vec{\rho}_i^{\,k} \times \dot{\vec{\omega}}_i + \vec{\omega}_i \times \left(\vec{\omega}_i \times \vec{\rho}_i^{\,k}\right) + 2\vec{\omega}_i \times \overset{\circ}{\vec{u}}{}_i^{k} + \overset{\circ\circ}{\vec{u}}{}_i^{k} \tag{5}$$

3. Simplification of Rigid Body Model

Rubble leveling ship is a large offshore equipment, mainly composed of hull, cart, cage, trolley, etc. Due to its large size and complicated internal structure, in the process of model building, the three-dimensional model is established with the help of three-dimensional modeling software SolidWorks. The internal complex structure is appropriately optimized and adjusted, and each sub-assembly model as shown in the figure is established, and the .x_t file is exported. As shown in figure 2:

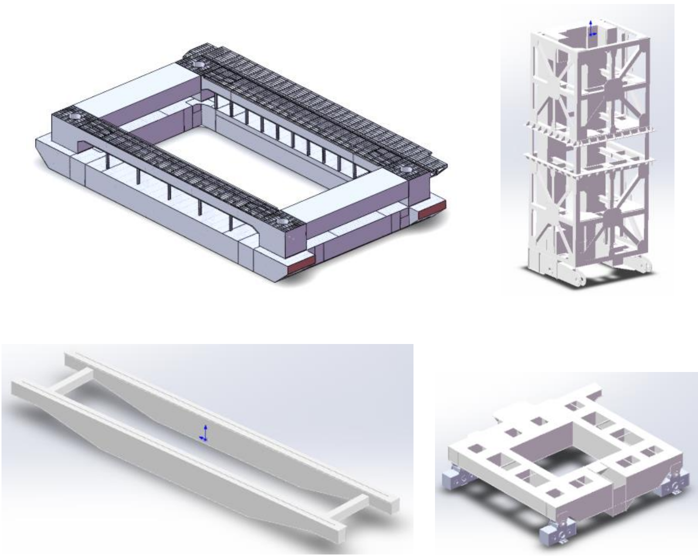

Figure 2. Rigid body model created by SolidWorks

4. Flexibility of the Throwing Pipe

In this paper, the tremmie pipe was meshed in the ANSYS-APDL environment, which is selected by solid185 unit, and the material properties and real constants are set to mesh the tremmie pipe freely. The rigid area method is adopted, and the modal neutral file available for ADAMS is generated by the mass21 unit, and four external connection nodes are defined. The four external nodes correspond to the four rigid areas, as shown in Figure 3:

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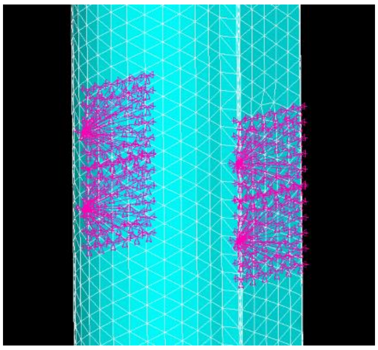

Figure 3. Finite element model of the tremmie pipe

5. Dynamic Simulation of Rubble Leveling Ship Based on Flexible Tremmie Pipe

Import the flexible tremmie pipe .mnf file into ADAMS, and import the .x_t rigid body file generated by SolidWorks, complete the assembly of the rigid body and the flexible body model, and apply the constraints and driving between the members [7]. The virtual prototype model of the rigid-flexible coupling of the rubble leveling ship is shown in Figure 4.

ADAMS establishes the corresponding dynamics of solving equations based on constraints and driving. The system of constraints equations is as follows:

$$\begin{cases} \dfrac{d}{dt}\left(\dfrac{\partial P_{xi}}{\partial x_i}\right)-\dfrac{\partial P}{\partial x_i}+\sum\limits_{i=1}^{n}\dfrac{\partial \Gamma_i}{\partial x_i}\gamma = F_x \\ \dfrac{d}{dt}\left(\dfrac{\partial P_{yi}}{\partial y_i}\right)-\dfrac{\partial P}{\partial x_i}+\sum\limits_{i=1}^{n}\dfrac{\partial \Gamma_i}{\partial y_i}\gamma = F_y \\ \dfrac{d}{dt}\left(\dfrac{\partial P_{zi}}{\partial z_i}\right)-\dfrac{\partial P}{\partial x_i}+\sum\limits_{i=1}^{n}\dfrac{\partial \Gamma_i}{\partial z_i}\gamma = F_z \end{cases} \quad (6)$$

In the formula: x_i, y_i, z_i are the generalized coordinates of the rubble leveling ship; P_{xi}, P_{yi}, P_{zi} are the kinetic energy of the rubble leveling ship along the three coordinate axes; P is the total kinetic energy of the rubble leveling ship; Γ_i is the constraint of the rubble leveling ship; F_x, F_y, F_z are the external forces on the riprap.

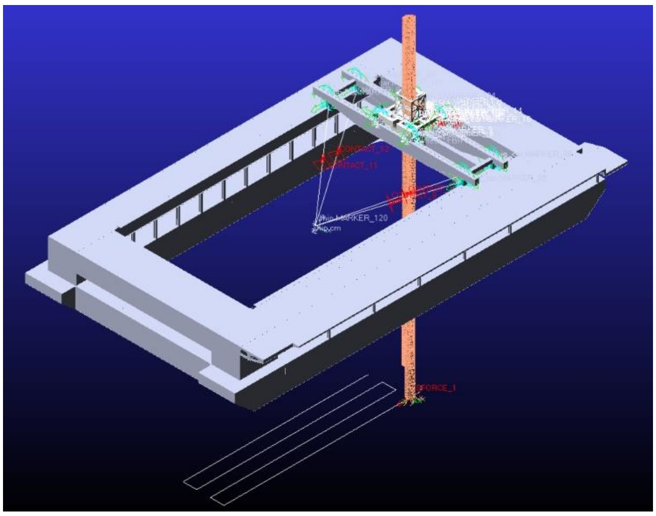

Figure 4. The virtual prototype model of the rubble leveling ship

5.1. Application of Scraping Force at the End of Tremmie Pipe

In the process of rubble leveling operation, the paved stone will produce a scraping force opposite to the direction of movement of the pipe end when the tremmie pipe is continuously moving forward. The data of this part of the scraping force is calculated by the simulation of the rubble leveling in the discrete computing software EDEM.

Here, when the cart is running at a constant speed of 2.5m / min and the stone cushion is 30cm high, the scraping force curve of the pipe end is shown in Figure 5.

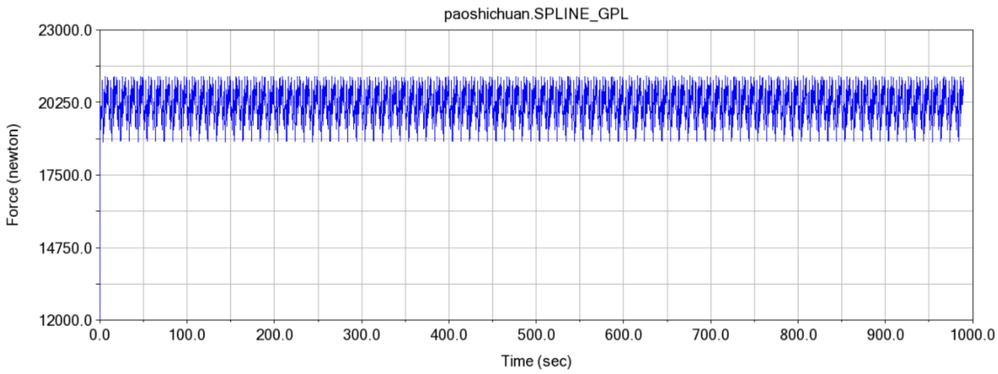

Figure 5. Scraping force curve of pipe end

5.2. Application of Wave Load

In the process of rubble leveling operation, the depth of the rock-throwing pipe can reach up to a water depth of about 60 meters when the tremmie pipe is continuously moving forward.

As the depth continues to increase, the force of the ocean on moving objects continues to increase, and the maximum load has a great relationship with the working depth. As the depth continues to increase, the force of the ocean on moving objects continues to increase, the maximum load has a great relationship with the working depth.

The offshore engineering structure analysis and design software SACS is used to analyze and calculate the force of the tremmie pipe. Consider the calculated length of the stone throwing pipe is 60 meters, including 20 meters above the water and 40 meters below the water, the outer diameter of the tremmie pipe is 1.524m, and the wall thickness is 20mm.

The results of environmental forces on the pipeline at a ship speed of 2.5m / min are shown in Table 1.

Table 1. Environmental forces on pipelines at a speed of 2.5m / min

Speed(m/min)	Wind force (KN)	Maximum wave force (KN)	Minimum wave force (KN)
2.5	0.136	4.305	0.393

5.3. Dynamic Characteristics of the Flexible Tremmie Pipe Driven By the Cart at A Constant Speed

The ADAMS / Solver module is an ADAMS solver module that provides various mathematical model solution options. For the Kinetic differential equation of rigid-flexible coupling, different integration algorithms need to be selected according to the actual model.

GSTIFF [8] is the most stable integration solver officially provided by ADAMS. I3 integration equation is selected. The I3 integral format is as follows:

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$$\left.\begin{array}{l} \dot{P}-\partial T/\partial q+\Phi_q^T\lambda+H^TF=0 \\ P=\partial T/\partial \dot{q} \\ u=\dot{q} \\ \Phi(q,t)=0 \\ F=f(u,q,t) \end{array}\right\} \tag{7}$$

As shown in Table 1, the information of the 10 nodes of the maximum stress of the stone tremmie pipe during the simulation operation can clearly see the coordinate position, number and stress of each node. This provides a great reference value for judging the fragile part of the tremmie pipe.

VON MISES Hot Spots for FLEX_PIPE_1 Date= 2019-10-08 00:47:21						
Model= .paoshichuan1008		Analysis= Last_Run	Time = 0 to 990 sec			
Top 10 Hot Spots			Abs	Radius= 0 meter		
Hot Spot	Stress	Node	Time	Location wrt LPRF (meter)		
#	(newton/meter**2)	id	(sec)	X	Y	Z
1	4.46179e+08	63942	886.05	-0.927978	15.3734	-0.0594209
2	4.16688e+08	32075	885.741	-0.46	16.745	-0.87
3	3.81336e+08	24414	885.741	0.44	16.74	-0.87
4	3.81103e+08	63941	886.05	-0.928008	15.4306	-0.0594599
5	3.80794e+08	49643	886.05	-0.921606	15.276	-0.0551896
6	3.73208e+08	16677	886.05	-0.93754	15.314	-0.0521704
7	3.70112e+08	64043	886.05	-0.926715	15.2143	-0.0580338
8	3.66918e+08	32137	885.741	-0.46	18.745	-0.87
9	3.48516e+08	30606	644.226	0.46	18.745	-0.87
10	3.40317e+08	49681	886.05	-0.921606	15.288	-0.0551896

Figure 6. Information of the 10 nodes of the tremmie pipe maximum stress

During the process of rubble leveling at the speed of 2.5m / min, the displacement curve of the node number 163 of the pipe end of the tremmie pipe is shown in Figure 7, and the vertical velocity curve of the tremmie pipe end is shown in Figure 8. The red curve indicates the effect of only the scraping force, and the blue curve indicates the effect of the wave load and the scraping force.

It can be clearly seen from Figure 7 that due to the periodic effect of the wave load, the fluctuation of the blue curve is greater than the curve, and the change frequency is relatively smaller than the red curve.

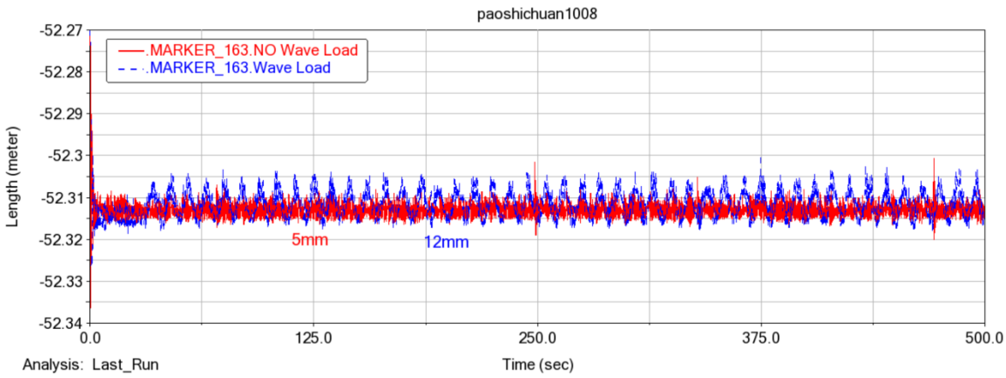

Figure 7. Displacement curve of the pipe end

It can be clearly seen from Figure 8 that under the effect of wave load, the acceleration of the blue curve is significantly greater than that of the red curve, and the acceleration change evaluation rate is also higher than that of the red curve.

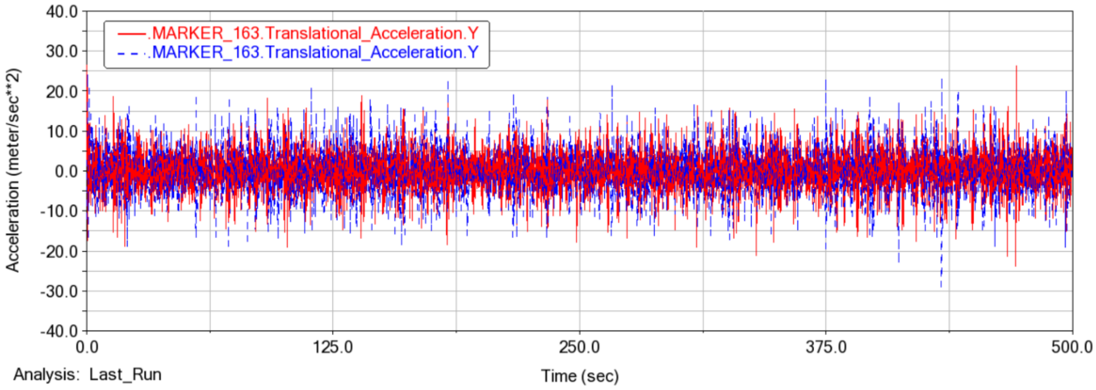

Figure 8. Vertical velocity curve of the tremmie pipe end

It can be concluded from the above that there is obvious vibration at the tremmie pipe end, and the acceleration curve changes positively and negatively around the zero position. From the simulation results, it can be seen that under the influence of the scraping force, the tremmie pipe has obvious vibration in the vertical direction. Compared with the case where there is no wave load, this phenomenon is more obvious after applying the wave load.

6. Conclusion

Without considering the electric control and under the action of external scraping force and wave load, the rigid-flexible coupling simulation of the rubble leveling ship of the flexible tremmie pipe can show that there is obvious vibration at the end of the tremmie pipe. The vibration of the tremmie pipe directly affects the accuracy of the rubble leveling operation, which becomes more obvious under the influence of the wave load and the effect is remarkable. Therefore, the design manufacturer should optimize the design of the tremmie pipe from the perspective of design structure or electrical control. Since the model rubble leveling ship is very large, resulting in a flexible body simulation is quite cumbersome and complex, so we only take into account the flexible tremmie pipe, further research can be targeted flexible processing of other components.

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