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Rigid-flexible Coupling Modeling and Lifting Dynamic Load Analysis of Quayside Crane

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Abstract

In order to accurately describe and accurately calculate the dynamic response of quayside crane structure system under external excitation and the force of wire rope, it is necessary to establish a rigid-flexible coupling model of quayside crane to study the dynamic characteristics of quayside crane structure under different lifting weights. Based on SolidWorks, ADAMS and ANSYS to establish the virtual prototype model of the coupled shore bridge, shore bridge was established based on Adams/cable module main hoisting wire rope winding system, and respectively at 30t, 35t, 40t lifting weight as the research object, drive drum steel wire rope movement, through the simulation of the wire rope tension and lifting heavy lifting speed, get different shore bridge lifting load in lifting the change of dynamic load coefficient.

Keywords

Gantry Cranes; Rigid-flexible Coupling; Virtual Prototype; Lifting Dynamic Load.

1. Introduction

Quay bridge crane refers to a bridge crane which can reciprocate and move on the elevated structure track of the building through the running device at both ends of the bridge, so as to realize the material handling and transfer to the destination. The whole system of bridge crane mainly includes three parts: mechanical structure part, running part and electrical control system. This paper takes the mechanical structure part as the research object. Shore bridge main structure includes the following areas: main girder, former girders, car rail, door frame structure, and pull rod before and after the trapezoidal frame, car frame, cart frame and so on, and the interconnection between them, including weld connection and hinged connection and high strength bolt connection, in order to strengthen the bridge crane's overall rigidity, weld connections are preferred [1]. In this paper, taking the front girder of a quayside bridge as an example, the three-dimensional model of the front girder is established through SolidWorks, the three-dimensional model is meshed by ANSYS, and the MNF file is generated and imported into Adams to complete the establishment of the rigid-flexible coupling model. Finally, the dynamics simulation of the rigid-flexible coupling model is carried out, and the dynamic characteristics of the structure under different lifting weights are obtained through post-processing.

2. Establishment of virtual prototype model of quay bridge crane

2.1 Establishment of 3D model of quayside bridge

The front girder shall be of double-box welded construction and shall have sufficient torsional rigidity to avoid torsional deformation and overstress of the front girder due to landing of one end of the container. The inner and lower sides of the front girder are provided with the trolley rail bearing beam, which is made of T-shaped steel. The trolley track is a special heavy rail for quay bridge, and is fixed on the bearing rail beam with a track clamp device. In addition to the main girder and front girder

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hinged parts of the use of detachable hinge connection, other parts of the track with no seam form. The track of the front girder is provided with a track block to prevent the track from loosening and sliding when the front girder is lifted up[2]. The front end of the front part of the main beam and the rear end of the main beam is provided with a terminal fixed car stop, and the front part of the main beam is provided with a movable car stop, which can be automatically lowered when the front beam is lifted up, to ensure the safety of the car running.

In SolidWorks modeling should reflect the physical characteristics of the modeling, because the ANSYS model to beam, shell unit, and corresponding, the front beam solid model is composed of surface. The Angle steel is not added to the box beam for the time being, because the cross-sectional area of the Angle steel is too small and the adaptive mesh is too dense, which is not conducive to the overall calculation. The plate and beam coupling method can be used to add Angle steel in ANSYS. The tie rod is H-beam steel with regular section and can be completed independently in ANSYS.

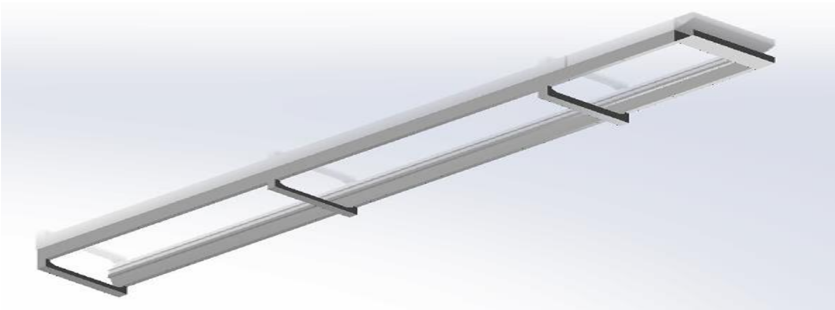

Figure 1. 3D solid model of front girder

Finally, with the actual drawings as a reference, SolidWorks is used to establish the front girder model of the quayside container crane, as shown in Figure 1. The established SolidWorks quayside bridge model is exported to x_t format to prepare for the next finite element analysis.

2.2 The finite element model was established based on ANSYS

After reading the x_t format file through ANSYS interface, these surfaces and lines are given corresponding physical attributes, and the plate and beam coupling, meshing and other work is carried out, and then the finite element calculation model is established.

Shell 93 unit is used for the wing, web and partition of the box girder, and Beam 189 unit is used for the Angle steel. Compared with the whole beam element modeling, the beam-shell coupling modeling has the following advantages:

(1) It is more realistic to simulate thin plate beam element with shell element;

(2) Solve the problem of stress concentration, especially in the connection between box beam and box beam;

(3) The cross section characteristics of the beam with complex shape can be determined to improve the simulation accuracy.

Compared with shell element modeling, the beam shell element coupling model greatly reduces the number of element nodes, reduces the workload, and reduces the time of modal and static calculation. Boolean operation is carried out on the solid model in ANSYS, so that the intersection of surface and surface, and the intersection of surface and line produce dividing lines and divide the surface and line, and then the segmented surface and line are pasted together to use common nodes, and finally the beam element is established on the intersection line[3].

In ANSYS, the Boolean operation of the front girder model can avoid the cumbersome process of dividing and pasting, but there are special requirements for the divided surface and line: the intersecting line of the line or plane must run through the surface to be cut. In addition, after segmentation, each surface and line are divided into many parts, and their numbers can be found

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irregularly. In this case, the APDL parametric modeling of ANSYS can be used to classify and mesh lines and planes. In general, the Boolean operation has little effect on the mesh density and error, and can ensure the coordination of the two types of cells.

Since it is required to separate the faces where there are beam elements, the beam elements are established on the dividing line. Because the entity model is relatively large, if the graphical operation command provided by ANSYS is used, the workload will be very large, and it is easy to omit and misselect in the operation. In view of this situation, APDL parameterization language is used here to achieve modeling.

2.3 Flexible body transformation between ANSYS and ADAMS

In the front girder finite element calculation model, rigid points need to be generated to prepare for the interface points generated in ADAMS when the finite element calculation model is imported. After the finite element calculation model is imported into ADAMS, the flexible body model is generated. The interface point is the node where the force or constraint is applied on the flexible body component. Rigid region is a region that describes the connection between a master node and many slave nodes. The position relationship between master co-ownership and slave nodes is defined by the constraint equation written by the CERIG command, so that the slave node is limited in one direction or more directional degrees of freedom relative to the master node, or even completely fixed. Seven rigid points are set at the front girder. The rigid point is a Mass21 unit with negligible mass and great elastic modulus, which is rigidly coupled with the nearby nodes to generate a local rigid area, as shown in Figure 2.

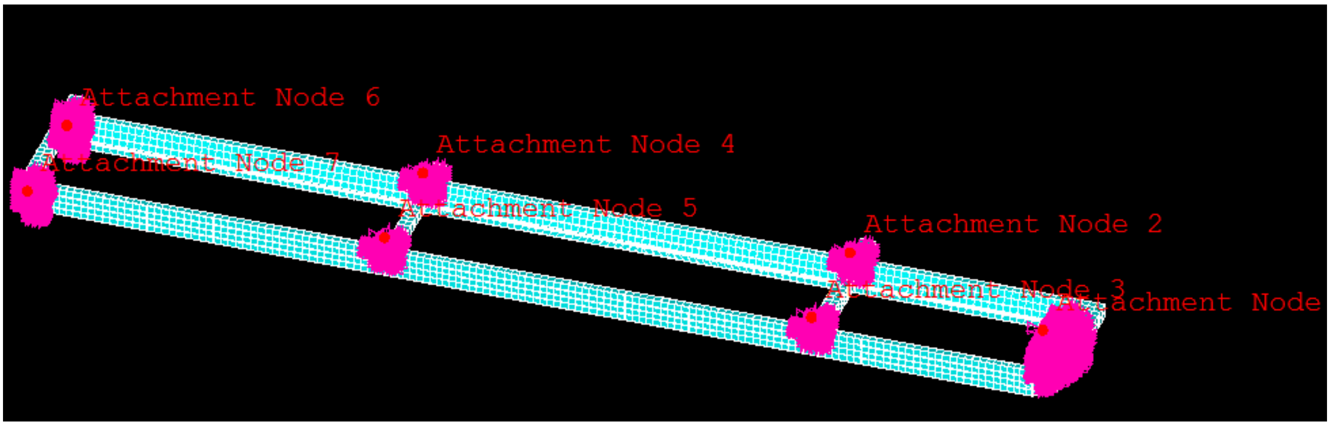

Figure 2. Finite element model drawing of front girder of quay bridge

After introducing a flexible part into the ADAMS model, it is necessary to establish the constraints between it and other flexible parts in the model or the ground, and these boundary conditions should be imposed on the interface points. These interface points are unit nodes with six degrees of freedom, which correspond to a constrained mode for each degree of freedom, that is, the static deformation of the object when unit displacement is applied on this degree of freedom and the displacement of other degree of freedom at other interface points is zero.

In this paper, the rigid point is taken as the interface point, and the rigid point and the surrounding slave nodes form a rigid region to disperse the forces on the rigid point and avoid large deformation at the constraint. Since all the forces are applied to the interface point, a large elastic modulus should be set at that point to prevent large strain.

After selecting the interface point, enter the output mode neutral file guide interface. At this time, you must specify the model unit, which will be saved in the mode neutral file. In this paper, the International System of Units (SI) is used[4]. The number of orthogonal modes extracted is also set in the guide interface. In order to ensure a sufficient number of orthogonal modes to ensure that the dynamic performance of the elastomer in the frequency range of interest is not distorted, 20 order

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orthogonal modes are extracted. This value will change after importing ADAMS, because ADAMS automatically adds interface point modes to the model. The specific calculation process is as follows:

Interface number *6+ number of orthogonal modes = total modes in ADAMS

The front girder has 7 interface points, and the user extracts 20 order orthogonal modes. When converted to ADAMNS, the flexible body will have mode 62.

2.4 The rigid-flexible coupling model of quayside bridge is established based on ADAMS

After generating the modal neutral file with MNF as suffix, it is imported into ADAMS/VIEW module to generate the flexible body model of front girder. The origin of the flexible body is placed on the origin of the global coordinate system and has no relationship with other parts. Some of its contents, such as modal composition, damping rate, inertial composition and initial conditions, can be reset to improve simulation efficiency. In the same way, the front tie rod and middle tie rod are endowed with physical attributes in the form of beam elements in ANSYS, and the modal neutral files are generated after mesh division, which are imported into ADAMS/VIEW module to generate flexible body. The next step is to complement the construction of trolley, pulley, wire rope, container and other components in ADAMS, and connect them with constraints and contacts provided by ADAMS/VIEW to generate a rigid-flexible coupling mechanical dynamics simulation model[5].

Macro command modeling and cable module are used to model the wire rope in quay crane and other lifting machinery. The macro command modeling is to simulate the flexible wire rope by connecting the multi-section rigid cylinder with the shaft sleeve force through the macro command operation mode. It can be used to establish the cable wire rope model, but is not applicable to the wire rope system with pulley block. In the Adams/Cable module, rope and pulley models can be quickly generated by successively inputting parameters of the rope system such as Anchor, Pulley and Cable. In the actual condition of the shore bridge, the actual length of the wire rope is hundreds of meters, and the working condition is complex, so it is not suitable to use the macro command modeling method to establish the rope, so the cable module is adopted in this paper to model, which can not only meet the calculation requirements, but also the calculation speed is faster.

The wire rope winding system was established based on the Adams/Cable module. The parameters of the wire rope system were set as follows: pulley diameter *1.0m*, pulley width *0.1m*, lifting drum diameter *1.5m*, wire rope diameter *28mm*, elastic modulus of wire rope *2.1e5MPa*, wire rope density *7805kg/m3*, and other parameters were set as the default parameters of ADAMS. As shown in Figure 3, the wire rope winding system of the main lifting mechanism is wound from the reel of the main lifting mechanism and wound along the following path: the main lifting reel → the tail pulley of the rear girder → the pulley of the main trolley frame → the upper pulley of the spinner → the pulley of the back trolley frame → the pulley at the end of the front girder.

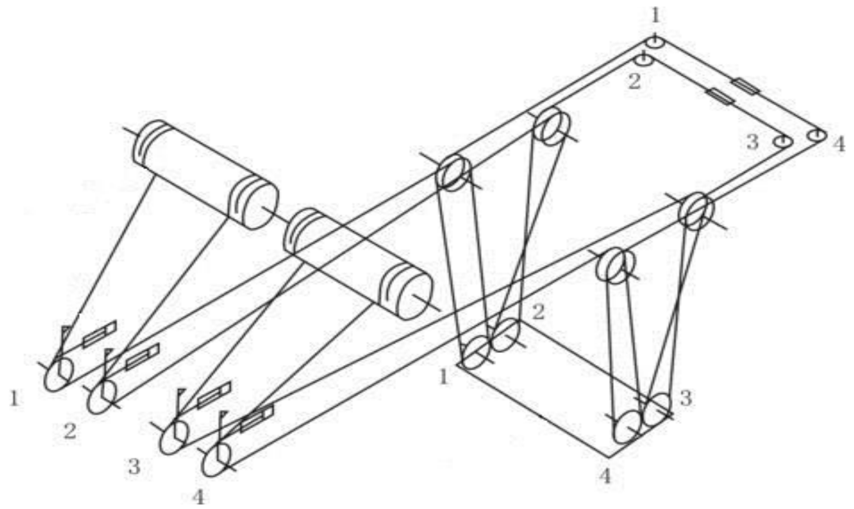

Figure 3. Main hoisting winding system

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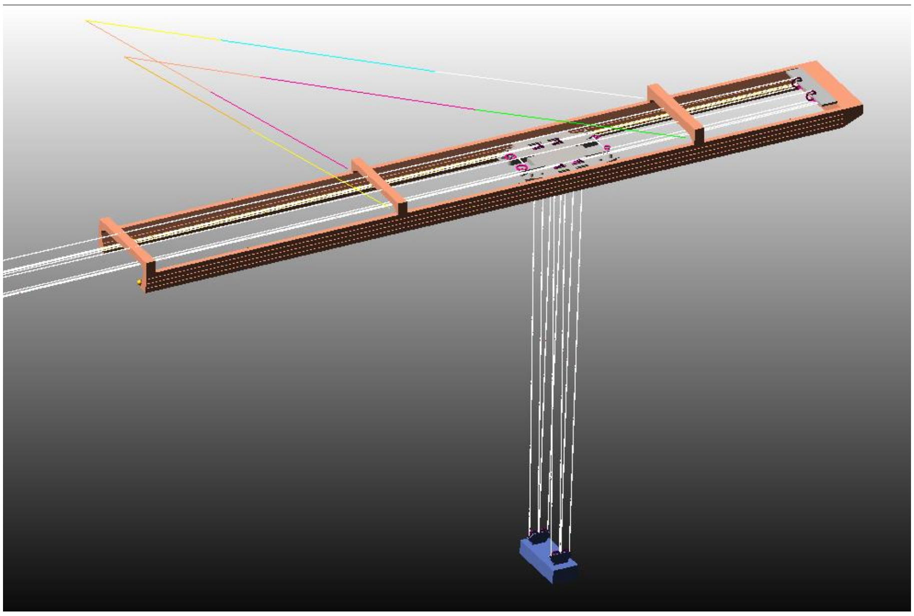

Figure 4. Rigid-flexible coupling model of front girder hoisting

By means of constraints, the rigid parts and flexible parts are connected together, thus generating the rigid-flexible optimum model for the front girder hoisting. As shown in Figure 4. Before lifting off the ground, the wire rope gradually tightens, and under the tightening tension, the front girder will bend downwards. Taking this phenomenon into account, during the modeling, the wire rope is relaxed before the lifting begins. After the lifting begins, the wire rope will show elastic characteristics, gradually tighten, straighten, slightly vibrate, gradually lift the lifting weight off the ground, and the front girder will also bend down under the tightening force.

3. Multi-tonnage simulation and the study of hoisting dynamic load coefficient

In China's crane design code, the recommended parameters of dynamic load coefficient under various working conditions are shown in Table 1. The calculation method of dynamic load coefficient is the direct reference data in the form of table according to different load state levels and different hoisting levels of the crane, and it is a linear function of stable hoisting speed.

$$\varphi_2 = \varphi_{2\min} + \beta_2 v_q \tag{1}$$

Wherein, φ_2 is the lifting dynamic load coefficient, φ_{2min} is the minimum value of lifting dynamic load coefficient corresponding to different lifting state levels, β_2 is the coefficient set according to different lifting state levels, v_q is the steady lifting speed (unit is *m/s*).

Table 1. Coefficients *β2 φ2min*

Lifting status level	*β2*	*φ2min*
HC1	0.17	1.05
HC2	0.34	1.10
HC3	0.51	1.15
HC4	0.68	1.20

When we are in the crane design calculation, for the lifting dynamic load coefficient value, can not be regarded as the same or must comply with the problem. In the actual design calculation, we should learn and apply it flexibly. In combination with previous practical cases and relevant work experience, we should properly revise the lifting dynamic load coefficient that has been calculated in accordance with the design specification [6].

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3.1 Simulation results of 30t quayside crane

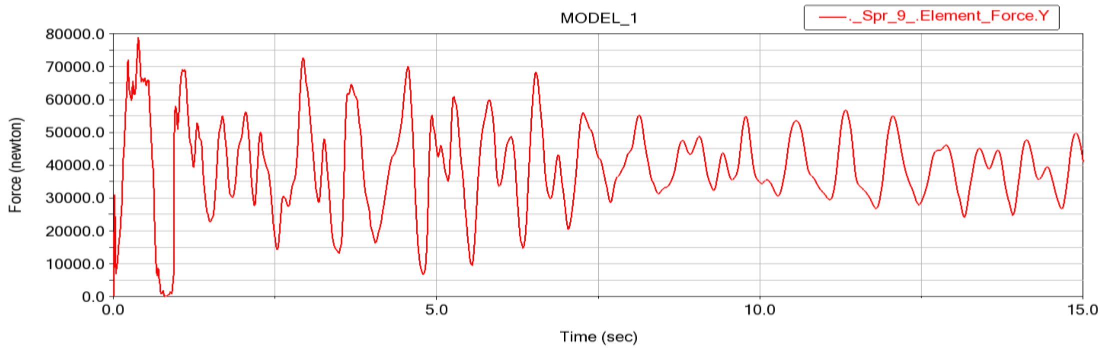

Figure 5. The force of rope with 30 tons

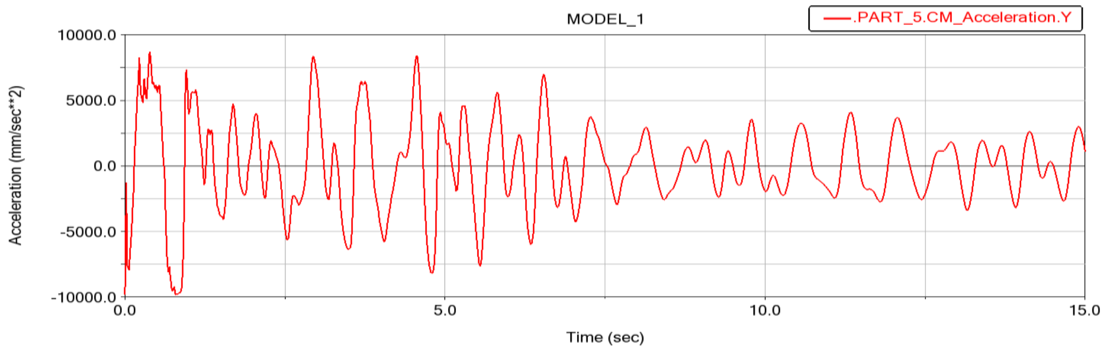

Figure 6. The acceleration curve of 30 tons

According to the design specification of a bridge crane with rated lifting weight of 30t, the lifting state level of the crane is HC_3. Formula (1) and Table 1 show that: when the hoisted object is 30t and the steady lifting speed is 0.14m/s, the calculated dynamic load coefficient is:

$$\varphi_{230} = \varphi_{2\min} + \beta_2 v_q = 1.15 + 0.51 \times 0.14 = 1.2214$$

According to Fig. 5, when the hoisted object is 30t and the steady lifting speed is 0.14m/s, the maximum force of the wire rope is 77800N, and the actual dynamic load coefficient is:

$$\varphi_{2300} = \frac{F_{\max}}{mg} = \frac{77800 \times 8}{30 \times 1000 \times 9.8} = 2.117$$

3.2 Simulation results of 35t quayside crane

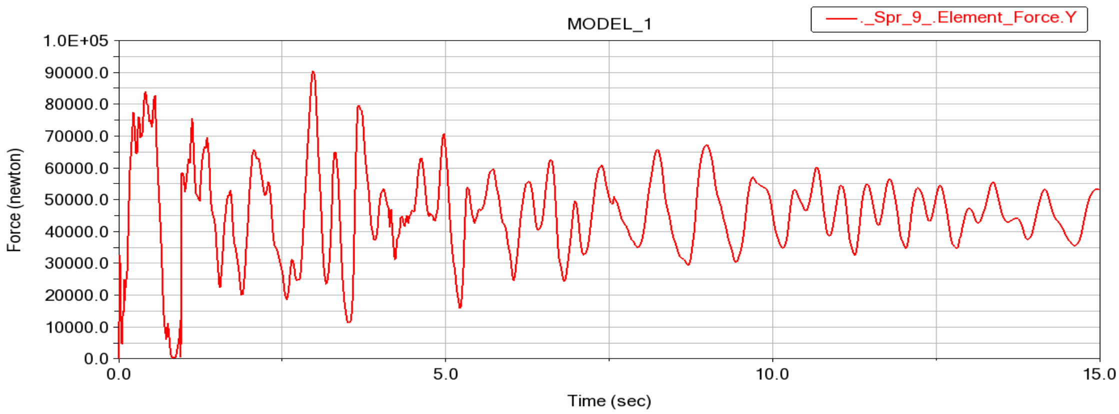

Figure 7. The force of rope with 35 tons

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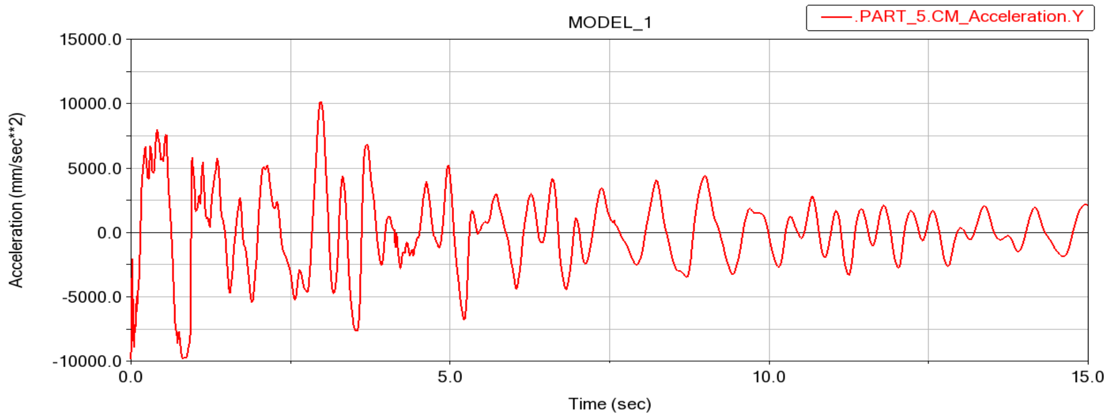

Figure 8. The acceleration curve of 35 tons

According to the design specification of a bridge crane with rated lifting weight of 35t, the lifting state level of the crane is HC_3. Formula (1) and Table 1 show that: when the hoisted object is 35t and the steady lifting speed is 0.11m/s, the calculated dynamic load coefficient is:

$$\varphi_{235} = \varphi_{2\min} + \beta_2 v_q = 1.15 + 0.51 \times 0.11 = 1.2061$$

According to Fig. 7, when the hoisted object is 10t and the steady lifting speed is 0.11m/s, the maximum force of the wire rope is 90000N, and the actual dynamic load coefficient is:

$$\varphi_{2350} = \frac{F_{\max}}{mg} = \frac{90000 \times 8}{35 \times 1000 \times 9.8} = 2.0991$$

3.3 Simulation results of 40t quayside crane

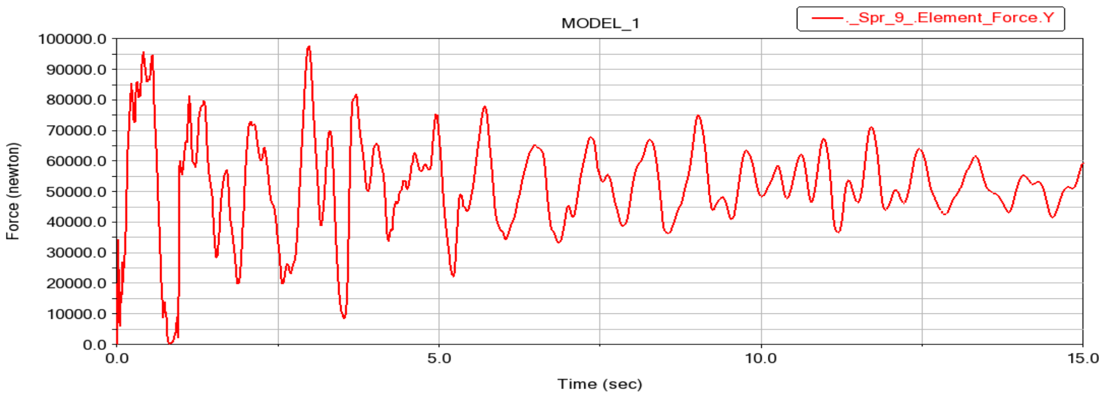

Figure 9. The force of rope with 40 tons

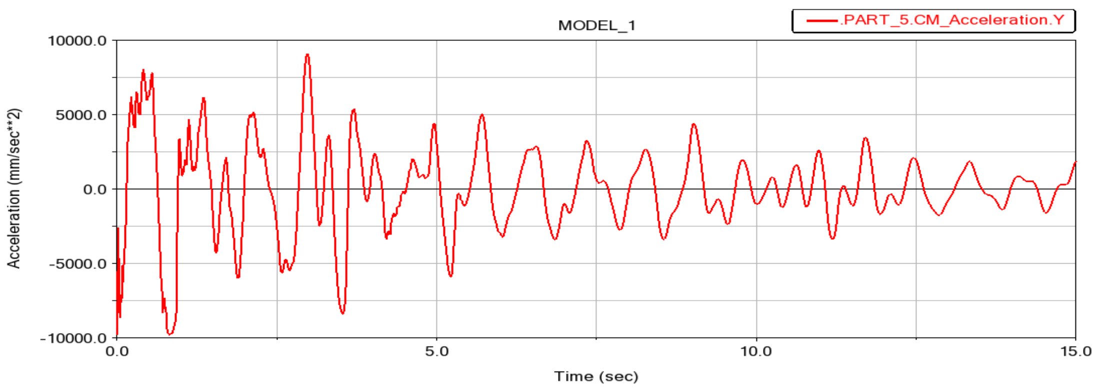

Figure 10. The acceleration curve of 40 tons

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According to the design specification of a bridge crane with rated lifting weight of 40t, the lifting state level of the crane is HC_3. Formula (1) and Table 1 show that: when the hoisted object is 40t and the steady lifting speed is 0.09m/s, the calculated dynamic load coefficient is:

$$\varphi_{240} = \varphi_{2\min} + \beta_2 v_q = 1.15 + 0.51 \times 0.09 = 1.1959$$

According to Fig. 9, when the hoisted object is 40t and the steady lifting speed is 0.09m/s, the maximum force of the wire rope is 97000N, and the actual dynamic load coefficient is:

$$\varphi_{2400} = \frac{F_{\max}}{mg} = \frac{97000 \times 8}{40 \times 1000 \times 9.8} = 1.9796$$

4. Conclusion

In this paper, the front girder of the quayside container crane is taken as the research object, and the rigid-flexible coupling model of the front girder of the quayside crane is established through SolidWorks, ANSYS and ADAMS, and the lifting weight of 30t, 35t and 40t is taken as the research object to get the change of the dynamic load coefficient of the lifting when the quayside crane is hoisted under different loads. It can be seen from the video of the simulation process that the flexible steel wire rope gradually straightens, vibrates, bends and deforms in the lifting process, and these actions will have an impact on the dynamic characteristics of the structural model of the bridge. If the static analysis method is used to analyze the quayside bridge, it is difficult to realize these actions. The dynamic simulation can well simulate this process, and then get more accurate results. It can be seen from the simulation results that there is a big difference between the actual dynamic load coefficient and the calculated dynamic load coefficient when a certain initial speed of the drum is directly given to drive the lifting load up. Moreover, when the tonnage of the crane is smaller and the rated lifting speed is larger, the difference between the dynamic load coefficient of the lifting is larger. In this simulation, non-frequency conversion speed control is adopted, and frequency conversion speed control can be considered to reduce the lifting dynamic load coefficient.

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