Ocean Engineering 83 (2014) 63–75

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Dynamic response analysis of heavy load lifting operation in shipyard using multi-cranes

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ARTICLE INFO

Article history:
Received 20 September 2013
Accepted 16 March 2014
Available online 9 April 2014

Keywords:
Dynamic response analysis
Multi-body system
Multi-crane
Hydrodynamic force

ABSTRACT

To increase the lifting capacity and minimize the cost and time for building a ship and offshore structure, block lifting with multi-cranes becomes more and more important. In this paper, therefore, dynamic response analysis of the multi-cranes is performed for block lifting operation. By this simulation, one can confirm the dynamic effects, such as dynamic motion and load, to prevent fatal accidents during the multi-crane operation.

There are several types of crane and the crane systems consist of several rigid bodies. These rigid bodies are connected with various types of joints and wire rope, and the crane system is called as multibody system. To carry out the dynamic simulation of the crane system, therefore, the program for dynamic analysis of multibody system is developed.

Among the several types of the cranes, the floating crane is operated on the sea water. Therefore, the developed program includes the function for calculating the hydrostatic and hydrodynamic forces. Using the dynamics simulation program developed in this paper, a dynamic response simulation of several cases of block lifting with multi-cranes are carried out, and the simulation results are validated by comparing them with the measured data from the shipyard.

1. Introduction

Recently, the shipyard has been manufacturing the ship blocks as large as possible for minimize the building cost and time. But weight of these blocks often exceeds the lifting capability of the crane. Thus to solve this problem, the shipyard has started to use multiple cranes to lift the heavy loads.

Fig. 1 shows various situations using the multi-crane. Fig. 1 (a) shows operation of block turnover using 2 goliath cranes, which is one of the most important equipment in shipyard, Fig. 1(b) shows launching a ship, which is built outside dock, to the ocean using 2 floating cranes which can generally transport the blocks heavier than the ones carried by goliath crane, and Fig. 1(c) shows transportation of the blocks to the dock using 2 Jib cranes. These transporting operations are more dangerous than using single crane, thus it is important to have simulations to insure the safety of the operation in advance.

The crane systems in Fig. 1 are all multi-body system which the multiple rigid bodies are jointed together, therefore the shipyard recently want to use the general analysis program for its dynamic response analysis. But the disadvantage of using the general analysis program for dynamic response of multi-body system is that it is difficult to consider its exact fluid dynamic, in specific, it's hard to analyze its hydrostatic and hydrodynamic force.

In a case of floating cranes for example, the crane is constantly experiencing hydrodynamic forces during the lifting operation. Therefore in this paper, the kernels are developed that can analyze the dynamic response of the multi-body system and calculate the hydrostatic, hydrodynamic, and wind forces.

In this paper, the research about the commercial kernel of dynamic analysis for multi-body system is discussed first. Then, the kernel of dynamic analysis developed in this research is discussed, and the developed kernel for determining external forces is discussed. After that, the result of simulation for dynamic response analysis of multi-crane using the developed program will be discussed, and lastly the conclusion and further plan for the research will be considered.

2. Related works

2.1. Dynamic analysis kernel

ADAMS (Automatic Dynamic Analysis of Mechanical Systems) is a software system that consists of a number of integrated programs that aid an engineer in performing three-dimensional

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http://dx.doi.org/10.1016/j.oceaneng.2014.03.026
0029-8018/

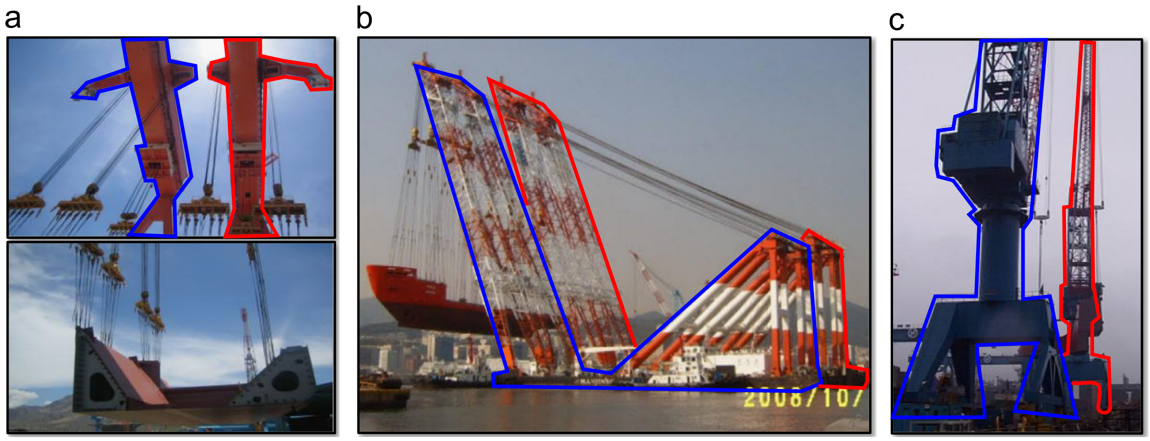

Fig. 1. Various cases of heavy load transportation using multi-crane in the shipbuilding industry: (a) two goliath cranes (b) two floating cranes and (c) two jib cranes.

Table 1
Comparison of the features of the developed dynamics kernel in this study with commercial dynamics kernel.

	This study	ADAMS	ODE	RecurDyn
Multi-body formulation	Recursive formulation	Augmented formulation	Augmented formulation	Recursive formulation
Various joints	○	○	○	○
Flexible body	x	○	x	○
Hydrostatic force	○	Δ	Δ	Δ
Linearized hydrodynamic force	○	Δ	Δ	Δ

*○: Supported; Δ: Can be only interfaced by the developer of the dynamics kernel).

kinematic and dynamic analysis of mechanical systems (Orlandea et al., 1977 and Schiehlen, 1990). ADAMS generates equations of motion for multi-body systems using augmented formulation. The user can define any multi-body system composed of several rigid and flexible bodies that are interconnected by joints. ADAMS supplies various types of joints, such as fixed, revolute, and spherical joints. Various external forces can also be applied to the multi-body systems, but the hydrostatic and hydrodynamic forces, which are the dominant forces exerted on the floating platform, cannot be handled by ADAMS.

ODE (Open Dynamics Engine) is an open-source library for simulating multi-body dynamics (Smith, 2006). Similar to ADAMS, ODE derives equations of motion for multi-body systems using augmented formulation. ODE can treat only rigid bodies, however, not flexible bodies. Moreover, ODE cannot handle hydrostatic and hydrodynamic forces.

RecurDyn (FunctionBay, 2011) is a three-dimensional simulation software that combines dynamic response analysis and finite element analysis tools for multi-body systems. It is 2 to 20 times faster than other dynamic solutions because of its advanced fully recursive formulation. Various joints and external forces can also be applied to the multi-body systems, but RecurDyn cannot handle hydrostatic and hydrodynamic forces.

Of course, it is possible to interface these general programs with hydrodynamics using user-subroutine. For example, Jonkman (2009) developed a module called "HydroDyn" for calculating hydrodynamic force in time domain and interface it with other program. For calculating hydrodynamic force in time domain, Jonkman transforms the analysis results from "WAMIT", which is a commercial program for calculating hydrodynamic force in frequency domain, into time domain using Cummins equation. In other words, the analysis results from "WAMIT" are required to use "Hydrodyn". In our research, to make the developed kernel independent from any other programs, 3D Rankine panel method is applied for direct calculation of hydrodynamic force in time domain. To interface 3D Rankine panel method with the existing programs of dynamic response analysis for multi-body, input of hydrodynamic force is not enough. To increase numerical stability, it is required to modify the mass and inertia of the floating body using added mass, which is the one of the calculated properties using the module for calculating the hydrodynamic force. Therefore it is not easy to interface the module for calculating the hydrodynamic force with other commercial programs. Moreover, as mentioned above, to make the developed kernel independent from any other programs, the functions for analyzing dynamic response of multi-body and calculating hydrostatic and dynamic force are integrated together.

This study presents the development of a dynamics kernel for the dynamic analysis of offshore structures such as semi-submersible drilling rig or drill ship. The equations of motion for multi-body systems were derived using recursive formulation. Moreover, the external force calculation module can generate hydrostatic force by considering the nonlinear effects and the linearized hydrodynamic force as external forces.

Table 1 shows the features of the different dynamics kernels that were compared in this study.

2.2. Study about floating cranes

MOSES (Multi-Operational Structural Engineering Simulator) is simulation software that can analyze the movement of a single body in fluid by applying hydrostatic force and hydrodynamic force. With this software, the multi-body system that is connected in restrictive condition cannot be simulated because connective relation between the bodies is not supported, but simulation that considers hydrostatic force and hydrodynamic force from external force is possible. Thus, it is often used for ocean shipyard simulation for floating single body.

According to Cha et al. (2010), the related works about floating cranes are analyzed as following. Chang et al. (1986), Jiang (1991), and Schellin et al. (1993), Ellermann et al. (2002) does not consider the full-degree-of-freedom of the floating cranes and cargo.