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Structural and Dynamic Analysis of Sub-sea Diamond Miner MK II

Abstract

The Namibian Minerals Corporation (Namco) has had a sub-sea diamond miner operational for a number of years. Recently a second machine called the "sub-sea diamond miner MK II" was designed. This machine is to be operated from a ship that is currently being adapted for this purpose. For practical reasons the construction of a real prototype is not an option.
A *virtual* prototype was constructed by Delft University of Technology at the section of Dredging and Transport Technology (The Netherlands). With the help of Computer Aided Engineering (CAE) both the dynamic behaviour and the structural aspects were researched. Some problems in the design have been solved before the machine was actually constructed.

Introduction

The Namibian Minerals Corporation (Namco) has had a sub-sea diamond miner operational for a number of years. Recently a second machine called the "sub-sea diamond miner MK II" was designed.

This machine is to be operated from a ship that is currently being adapted for this purpose. The miner is also under construction. It will be equipped with a 1800 kW dredging pump that is connected to a 600 mm diameter discharge hose that in turn is connected with a processing plant on the ship. The machine is 18 metres long and weighs in at 160 tonnes.

Critical activities in the miner's operation cycle are the launch and recovery. During launch the machine is hoisted from the back of a ship by a synthetic cable. The ships motion and the water-induced forces working on the machine introduce large dynamic loads in the system.

Owing to the specific nature of the machine it is difficult to determine its characteristics. However, it is necessary to understand the working conditions of the machine in an early stage of the design phase in order to ensure correct operation. The behaviour of the new machine cannot be predicted directly from the existing one as the dimensions are considerably larger and dynamics were supposed to be more significant.

For practical reasons the construction of a real prototype is not an option. Namco decided that a *virtual* prototype had to be constructed by Delft University of Technology at the section of Dredging and Transport technology (The Netherlands). With the help of Computer Aided Engineering (CAE) both the dynamic behaviour and the structural aspects were researched.

The work was executed in close co-operation with Namco and their South African engineering counterpart Ingenio. As a result of this method of engineering some problems in the design have been solved before the machine was actually constructed.

Process of Virtual Prototyping

A virtual prototype is a computer model that represents the mechanical properties of a real system.
This enables the research of the machines behaviour in various operating circumstances.

In addition to the fact that building a virtual prototype is a time- and money-saving operation compared to constructing a real prototype, this approach has other advantages:
– It is possible to look at very extreme conditions, without endangering a costly machine or personnel.
– It would be very difficult to reflect the working conditions of a submerged machine in a normal prototyping phase.

The starting point was a 3D-CAD model that was deduced from the original 2D drawings. A 3D model gives good insight in the space frame structure of the diamond miner and was used to check the interference of geometry of the beam structures. From this model, both a Finite Element model (FEM) and a Multi-Body model have been derived, as illustrated in Figure 1.

Besides obvious influences such as applied forces and moments in the FEM analysis, the effects of water pressure and buoyancy have been accounted for.
A set of load cases was introduced to reflect mining conditions and the process of launching. These load cases were used to compare the results of the parties involved. By using two different modelling techniques (by TU Delft and Ingenio) this provided a means of validation of the models.

In the FEM model small deformations of the structure were the subject of attention (strength and stiffness).
In the Multi-Body model the focus was on large motions with respect to the dimensions of the system (dynamic behaviour of the machine). In order to represent the mechanical properties and external effects the following elements have been introduced in the Multi-Body model:
- water-related forces acting on the machine and discharge hose: viscous drag of the water, buoyancy and added mass as a result of machine movements;
- a hoisting system that consists of a cable, winch and wave compensator; and
- prescribed ship heave and pitch motion.

Some peculiarities in the cable force characteristics during the launching procedure have been communicated back to Namco. Load cell measurements on the existing machine under similar circumstances proved to display a similar trend. This gave a validation of the simulation results on the one hand, and cleared up some phenomena of the existing machine on the other.

Results

The three different models used for the study of the MK II have all led to improvements in the initial design.

3D-CAD
In the main frame the welding of several pipes would be difficult or even impossible. This was primarily the result of the large number of connecting pipes in some nodes and the complexity of the space structure.
In two-dimensional drawings it was not possible to perform these checks.

The machine was also researched for interference of elements as a result of the relative motion of the constituent parts. The main frame and inner yoke would have intersected at approximately 30 degrees swing angle (Figure 2). Both discoveries led to the redesign of the frame.

FEM
In addition to design changes in the main frame, which were mainly a result of high cable forces, some modifications on the boom were suggested.

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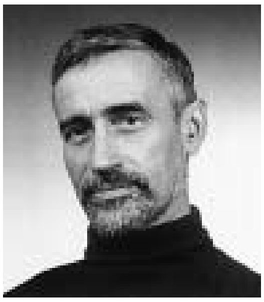
Professor W.J. Vlasblom graduated with a degree in Civil Engineering from Delft University of Technology in 1968. From 1968-1992 he worked for several international dredging companies. In 1992 he became Head, Production and Planning Department, Airport Platform Marine Contractors JV in Hong Kong. In 1994 he was appointed Professor at Delft University and is presently Chair of the Dredging Technology Department.


W.J. Vlasblom

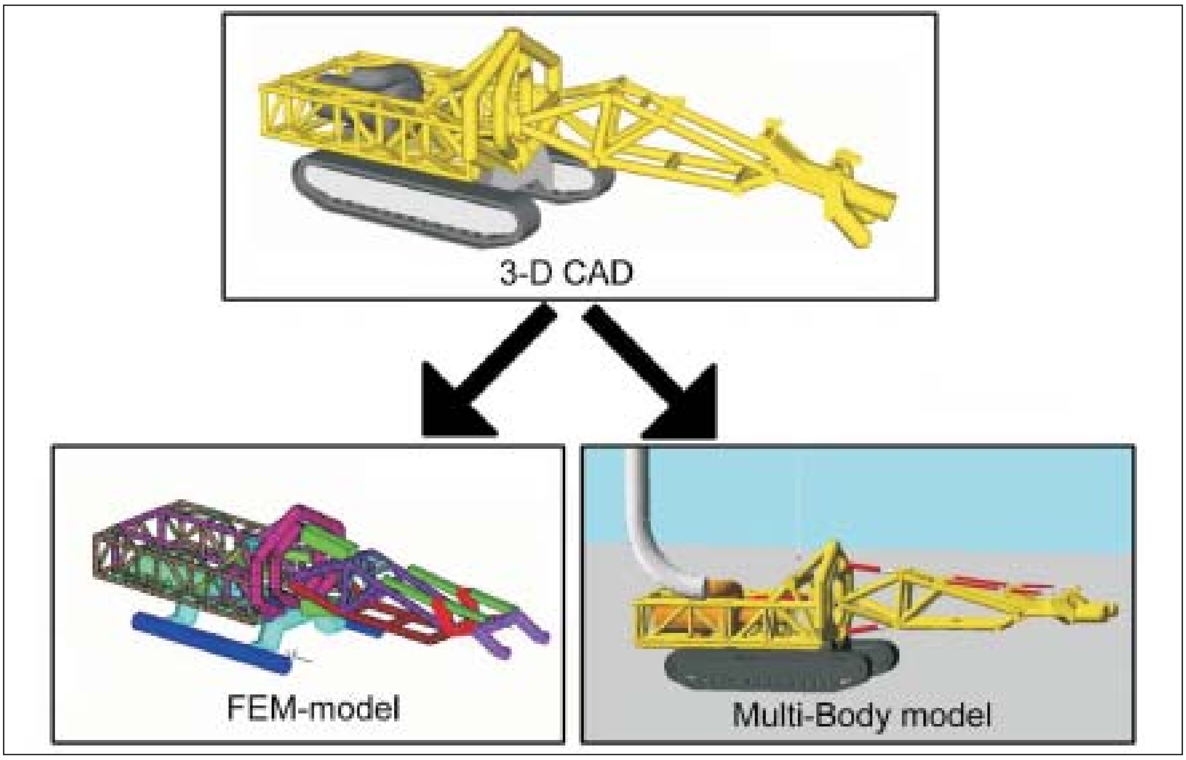
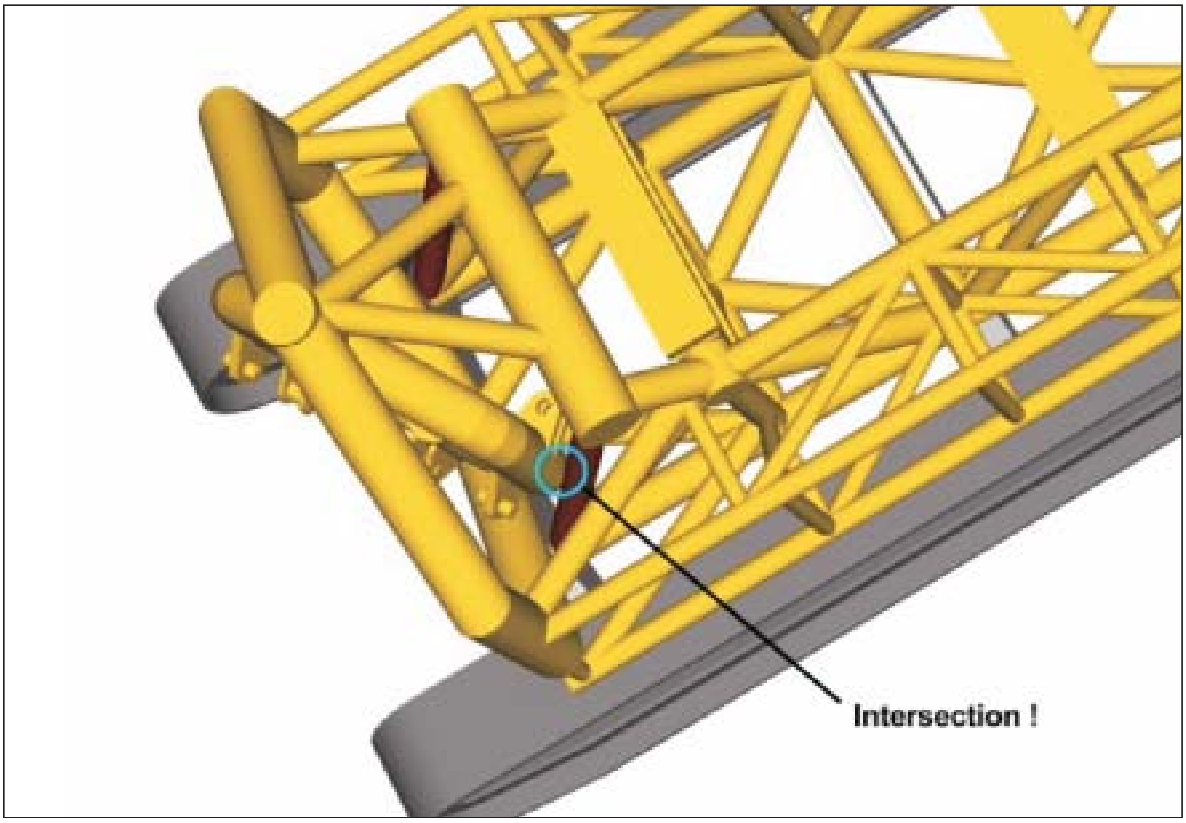


Figure 1. Conversion from 3D CAD-model to FEM and Multi-Body models.

Figure 2. Intersection of inner yoke and main frame at approx. 30 degree swing angle.



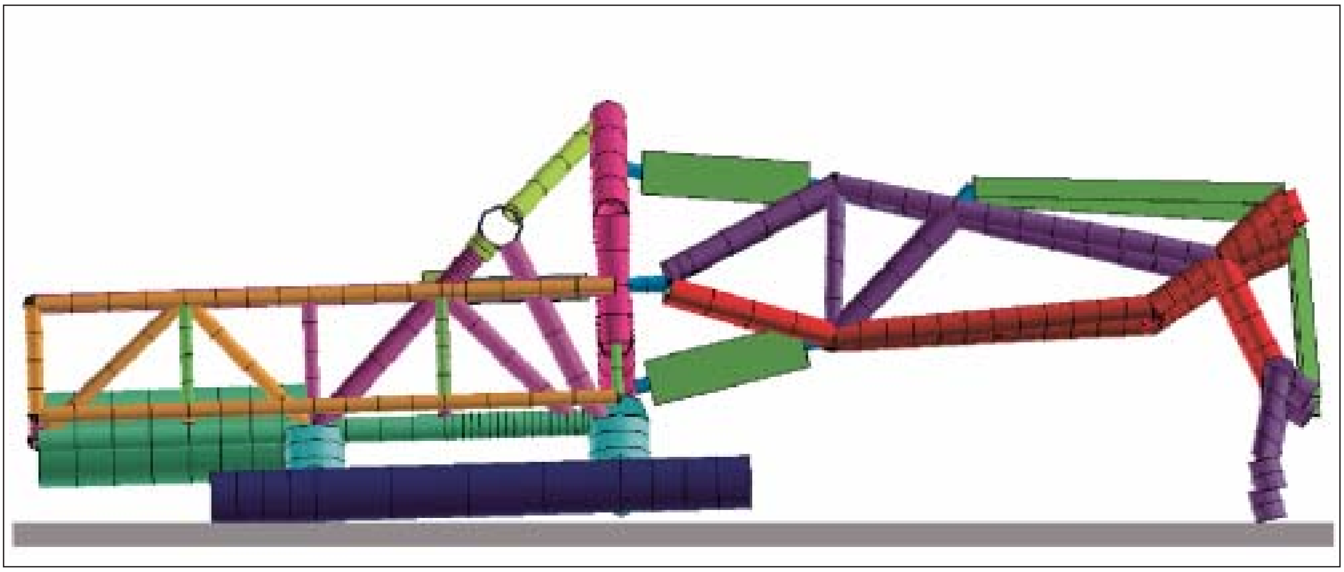


Figure 3. Machine "push up" with the boom.

The most critical load case for the boom results from a rescue type of operation. When the tracks lose grip, the machine can do a "push up" with the boom. Balancing on the back of the tracks and the suction nozzle, the boom is forced in a rotation so that the machine can correct course (Figure 3).

In order reduce the bending moments in the longitudinals in this situation additional elements have been proposed (Figure 4).

Multi-Body

As a result of the buoyancy force of the discharge hose acting on the machine the static pitch angle is dependent of the water depth. The effect of this is demonstrated in Figure 5, where 100 m and 200 m *static* angles of the machine are displayed.

Because of the ship's motion the machine will have an additional dynamic rotation.

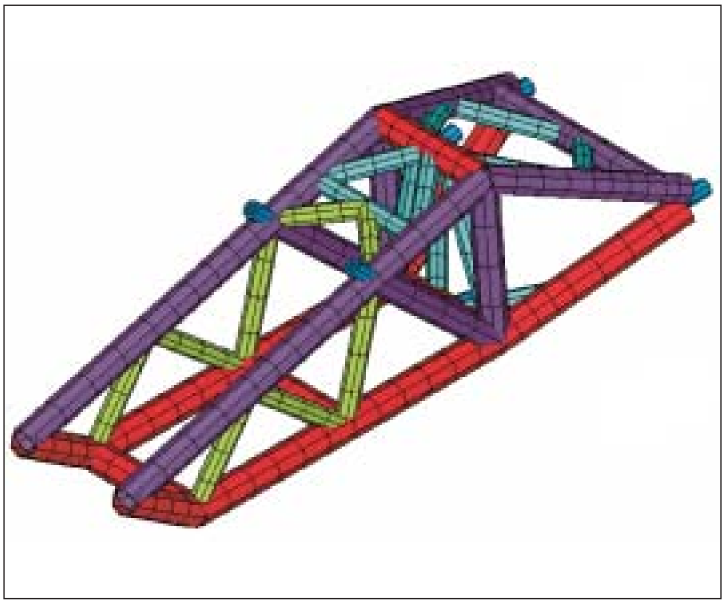
The motion of the machine influenced by the ship's heave and pitch during heavy sea conditions is depicted in Figure 6. Four snapshots covering 8 seconds out of the 9- second cycle time are presented here.

The *dynamic* rotation is mainly the result of:

– inertia effects of the discharge hose: the mass of the discharge hose resists acceleration; and
– a "wind vane" effect: in contrast to the main frame, the boom has a relatively large area with respect to the mass.

The position of the hoisting point on the machine has been modified in order to reduce the machine's static and dynamic pitch angle.

Figure 4. The boom with additional elements in green.



Conclusions

Computer Aided Engineering or virtual prototyping has given insight in the behaviour of the submerged machine lifted by a cable. This has enabled several improvements to the design and the detection of flaws before construction of the machine. The virtual prototype has been used to determine the systems-operating window.

The availability of a virtual prototype facilitates research into best improvement in case of undesired system behaviour in a very short time span. Because of the possibility to keep repeating an undesirable situation, a virtual prototype is a useful tool in failure analyses.

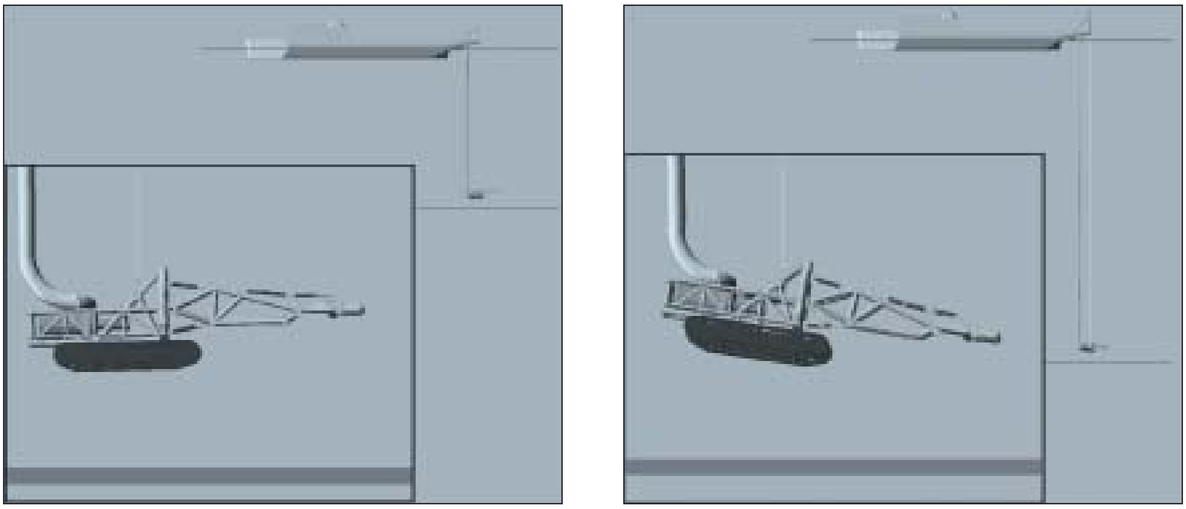


Figure 5. Static angle as a result of the buoyancy of the discharge hose (left 100 m, right 200 m) prior to modification of the hoisting point.

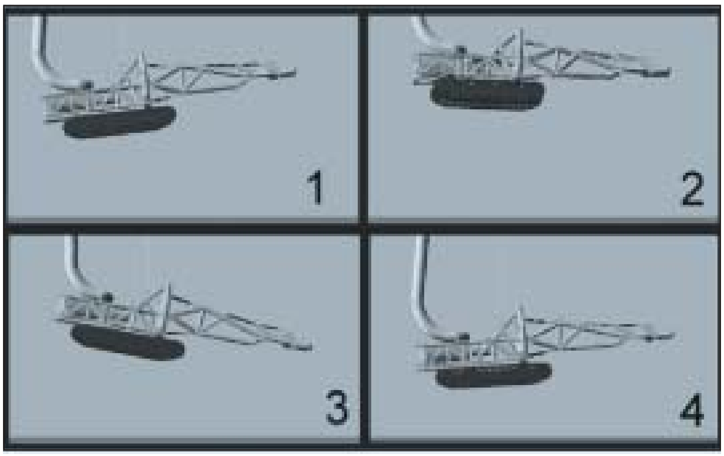


Figure 6. Machine pitch owing to heavy ship motion and water-related forces prior to modification of the hoisting point.

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