Towards the development of a digital twin for subsoil monitoring and stability against overturning of a mobile drilling rig

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Abstract -

Mobile drilling rigs are particularly susceptible to overturning due to the high location of their centre of mass. In some cases, overturning occurs due to a failure in the subsoil. Until now, machine operators are solely responsible for monitoring the machines' stability, and assessment of dangerous conditions is based mainly on experience. This investigation aims to set the grounds for elaborating a digital twin to online monitor the machine's stability to prevent overturning. Stress transmitted to the ground, tracks' settlement, and bearing capacity are calculated from a multibody simulation (MBS) and following existing standards. Furthermore, soil-dependent stability diagrams are generated to describe the stable location of the machine's centre of mass and predict soil failure. Results offer the possibility to function as an online alarm system running parallel to the machine's operation and alerting the operator about dangerous conditions.

Keywords -

Digital Twin (DT); Multibody simulations (MBS); Stability of mobile drilling rigs; Settlement prediction; Monitoring of bearing capacity

1 Introduction

Every year, the overturning of construction machinery causes several accidents worldwide. From 2007 to 2008, there were 38 fatalities and 679 injuries in the UK caused by the overturning of construction machinery, including drilling rigs [1]. Similarly, in the USA, there were 323 fatalities from 1980 to 1992 [2]. In Germany, there were 9 fatalities and 21 serious injuries from 1993 to 2003 [3]. Among the causes of these accidents is ground failure due to poorly prepared working platforms. Satoshi and Tomohito [4] summarize the operations before the accident, equilibrium conditions, and ground properties for a real case study of the overturning of a drilling rig. In this case, a ground penetration of the tracks was observed.

This publication investigates the idea of developing a digital twin to monitor the stability of the subsoil underneath the construction machine's tracks. A multibody simulation (MBS) of the mobile drilling rig is implemented in the Simscape environment of the software Matlab/Simulink. Signals simulating the reading of the internal machine's sensors are used to recreate working conditions. Following standards DIN EN 16228-1, DIN 4019 and DIN4017, the stress distribution, settlement and bearing capacity underneath the machine's tracks are estimated online for the MBS. For these estimations, local information about the soil properties is required. This work presents a mockup dashboard for an online monitoring system of the stability of the subsoil for limiting scenarios.

Additionally, stability diagrams are generated by analyzing the limiting conditions for the failure of the subsoil. Thus, stable areas are determined for the subsoil for all possible locations of the centre of mass. These could be helpful for on-site rapid stability checks or enhance current standards.

The company Liebherr has developed a system following similar industry standards [5]. However, this publication conceptually differs since the calculations of the location of the centre of mass follow an MBS. Furthermore, to the authors' best knowledge, the Liebherr system is based on the assumption of a rigid subsoil.

2 Theoretical framework

This section presents the theoretical tools used in this work. First, the idea of digital twins is briefly addressed. Secondly, the concept of MBS is mentioned, and then a review of the used standards is included.

2.1 Digital twins

In recent years, the fast development of simulation, data acquisition, data communication, and other technologies facilitated the interactions between physical and virtual spaces [6]. The digital twin's framework has emerged from this recent development as the natural consequence to merge simulations and physical space. A digital twin is defined as a comprehensive physical and functional de-

4 Conclusions and outlook

This work introduced the first steps for developing a digital twin to monitor the stability of drilling rigs. The stability monitoring combines existing industry standards and focuses on redefining the concept of stability for drilling rigs to include soil conditions. This work presents an insight into the results of this new stability concept and the perspective of developing a digital twin to online stability monitoring, providing examples of how this system could look for limiting cases. The results of this work seek to include basic information about the soil in the stability assessment of drilling rigs since current standards are based solely on the assumption of a rigid subsoil for their calculations.

Extensive work elaborating on the presented results must still be done to achieve full online stability monitoring and a complete digital twin. Experiments should be conducted to establish communication with the internal sensors on existing drilling rigs since this is crucial for the real-time use of the developed system. Suitable hardware should be selected for this purpose, considering the possible training required for the machine operators to use it and the involved costs.

It should be clear that the stand-alone application works in real-time with current simplifications and assumptions; afterwards, the simplifications should be gradually eliminated to include a more realistic digital twin. Furthermore, numerical calculations using the finite element method (FEM) with state of the art constitutive soil models and field measurements should be carried out to improve the stress estimation underneath the tracks. Preliminary results show that the assumption of the trapezoidal distribution results in an oversimplification. Then, a correction function for the stress should be defined, and a new soil stability criteria should be created.

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