Full-Scale, Coupled Ship and Pipe Motions Measured in North Pacific Ocean: The Hughes Glomar Explorer with a 5,000-m-Long Heavy-Lift Pipe Deployed†

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A 5,000-m-long, 15-in (38-cm) outer-diameter, full-scale pipe was deployed from the large Moon Pool of the Hughes Glomar Explorer (Fig. 1) while a deep-ocean mining system operated from the ship in the North Pacific Ocean in 1976 and 1979. From the standpoint of design as well as operation, one of the most critical parameters in deep-ocean mining and deep-ocean drilling is the behavior of the pipe along its length, with its bottom free. The at-sea test includes the first-ever measurements of the full-scale pipe responses coupled with the Explorer’s motion in the deep ocean. The measurements showed that the pipe bottom undergoes dynamic stretching at axial resonance in addition to its static stretch. In addition, this occurrence of axial resonance was predicted by the calculations and it agreed with them. The axial resonance period is in the range of the commonly encountered ocean-wave periods. Further, this study in 1976-80 changed the industry’s common perception of bending stress as design stress: The axial stress can be an order of magnitude larger than the bending stress for such a long pipe, and the bending is less of an issue. This paper presents the axial stress amplitudes, including amplification at the pipe’s resonance, which are coupled with the Explorer’s motions. This design and operation issue applies to deep-ocean drilling as well.

INTRODUCTION

At the outset of development of the commercial deep-ocean mining project in the 1970s, one of the critical technical issues for the safe at-sea operation of a very long (from 4,000 to 6,000 m) pipe was the 3-D static as well as dynamic pipe motions along the pipe’s length and the positioning control of its bottom. And this issue remains one of critical concern, not only for pipe design, but also for its deployment and the positioning control operation of the pipe bottom and the equipment at its bottom.

The offshore petroleum industry in the 1970s was taking an incremental depth approach to going deeper. At the time, a water depth of 100 to 200 m was a deeper-water challenge. Our development of pipe dynamics software for operation at the 6,000-m ocean depth in a short given time required a quantum jump in technology, and consequently a fresh new approach to the development of such technology.

In order to hit the target of developing a commercial deep-ocean mining system and its technology within 5 years, starting in 1975, the incremental approach was out of the question for us. Instead, right at the start of the project, we began to develop pipe dynamics software and an integrated ship-pipe-buffer-link-miner positioning (or track-keeping) system control for the 6,000-m ocean depth.

Further, our natural perception of critical technical issues had been the anticipated enormous bending stress as design stress for such a long pipe, until our research led us to believe otherwise (Chung, Whitney and Loden, 1980; Chung and Cheng, 1999).

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Fig. 1 Hughes Glomar Explorer

This paper presents the full-scale measurements as well as the theoretical prediction of the pipe end’s dynamic behavior predicted as part of the commercial deep-ocean mining system and technology development; the comparison of the prediction with the full-scale measured axial response at its resonance is discussed. The full-scale at-sea tests of the test mining system with the Hughes Glomar Explorer were conducted in the North Pacific Ocean (Fig. 2). The results had also directly and indirectly helped the development and operation of a deep-ocean drilling system and pipe/riser.

DEEP-OCEAN MINING SYSTEM TESTED WITH HUGHES GLOMAR EXPLORER IN PACIFIC OCEAN
Commercial Deep-Ocean Mining System Developments

The Lockheed-Dutch Shell-Amoco-Bos Khalis Consortium, called the Ocean Minerals Company (OMCO), was formed in 1975: This consortium was the deep-ocean mining systems and technology developer led by the Lockheed team. As a step toward