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A MATHEMATICAL MODEL FOR THE
THREE-DIMENSIONAL DYNAMICS OF A
COLLISION TOLERANT PILE STRUCTURE

BY

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Abstract:

This thesis deals with the development of a mathematical model to predict the behavior of a collision tolerant pile structure, a navigational warning device capable of surviving hits by marine traffic. The model covers the large angle dynamics involved and accounts for the offset axis hinge mechanism employed in the device. It allows the user to choose various environmental inputs including water depth and wave and current action as well as the initial angle of the pile and the sheave. The computer generated information allows the user to track the pile's angle and velocity as a function of time. The computer simulation was applied to a 1/4 scale physical model and experiments were conducted to confirm that the computer model reproduced the oblique stability characteristics and the weakness of the restoring moment in the oblique recovery.

This is an M.S. thesis.

INTRODUCTION

Background

Pile structures are utilized by the Coast Guard to support navigational aids marking coastal channels and intercoastal waterways. Barges, being towed by tug boats, will occasionally impact a channel marker breaking it at or above the mudline. In this event, serious problems arise. Aside from the fact that the channel is no longer marked, the remaining pile section is embedded in the mud, and may be protruding at a depth that represents a hazard to maritime traffic. Furthermore, the Coast Guard is responsible for performing the costly task of locating the remaining section, removing it, and finally, replacing it.

The Coast Guard, in an effort to resolve this problem, supported studies to develop a pile structure that would bend on impact and restore itself to an upright position following a collision. The concept, whose major components are shown in Figure 1, will be referred to here as a Collision Tolerant Pile Structure (CTPS). In 1982, Miller explored the possibility of using a rubber tube as the hinge for the pile, but was unable to show that it was stiff enough at full scale. Later, Swift and Baldwin (1985, 1986) devised more capable hinge

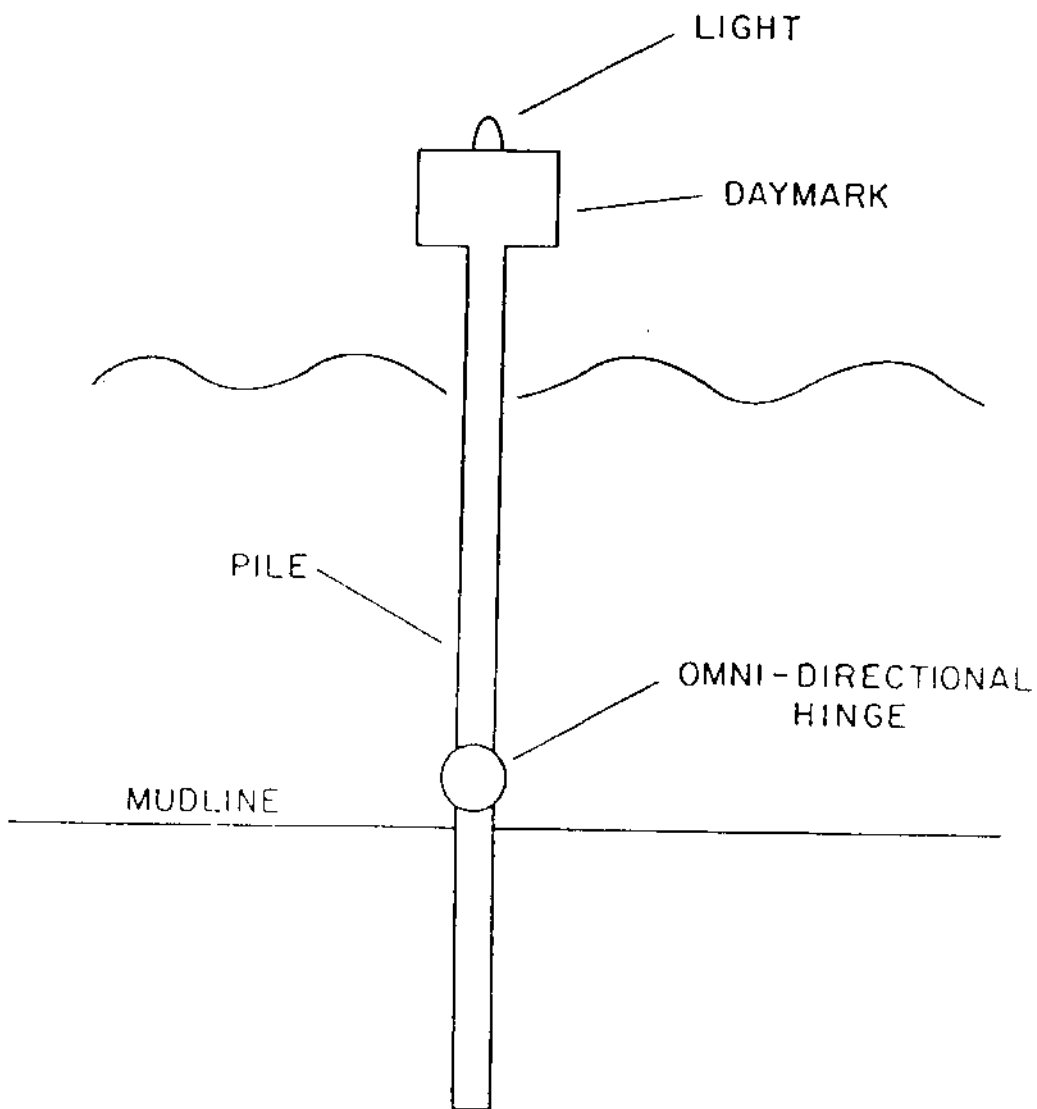


Fig. 1 The Collision Tolerant Pile Concept

concepts, developed computer models for the 2-dimensional CTPS dynamics, and successfully tested a 1/15 scale (2.5 ft. in height) physical model.

More recently, Cloutier, et al. (1985) designed, built, and field tested a 1/4 scale (10 ft.) physical model. Their design utilized the central universal joint, peripheral stay hinge concept shown in Figure 2.

Field tests by Cloutier et al. have shown that when deflected the 1/4 scale model will tend to recover along the oblique path. In other words, the oblique recovery path is the stable path while any other recovery path is unstable. This phenomena is due to the stay/sheave arrangement. The stays are the cables that transfer spring tension, and the sheaves are the semicircular elements that provide the moment arms for the spring tension. The instability will exist when rotation about one axis is greater than rotation about the other. In this event, only one stay will have tension on it; therefore, while the pile is recovering about the axis with the taut stay, it will be falling about the other axis. Metaphorically, the instability can be illustrated with a two-legged stool; the stool is unstable and falls in one of two directions. If as the stool is falling a third leg appears in the direction of the fall, the stool will immediately become stable as the third leg contacts the ground.

Cloutier, et al. provided evidence through testing that the restoring hinge moment would be less for an oblique deflection than for a single axis deflection. Because recovery along the oblique path is weakest, it became of great concern. In the previous mathematical

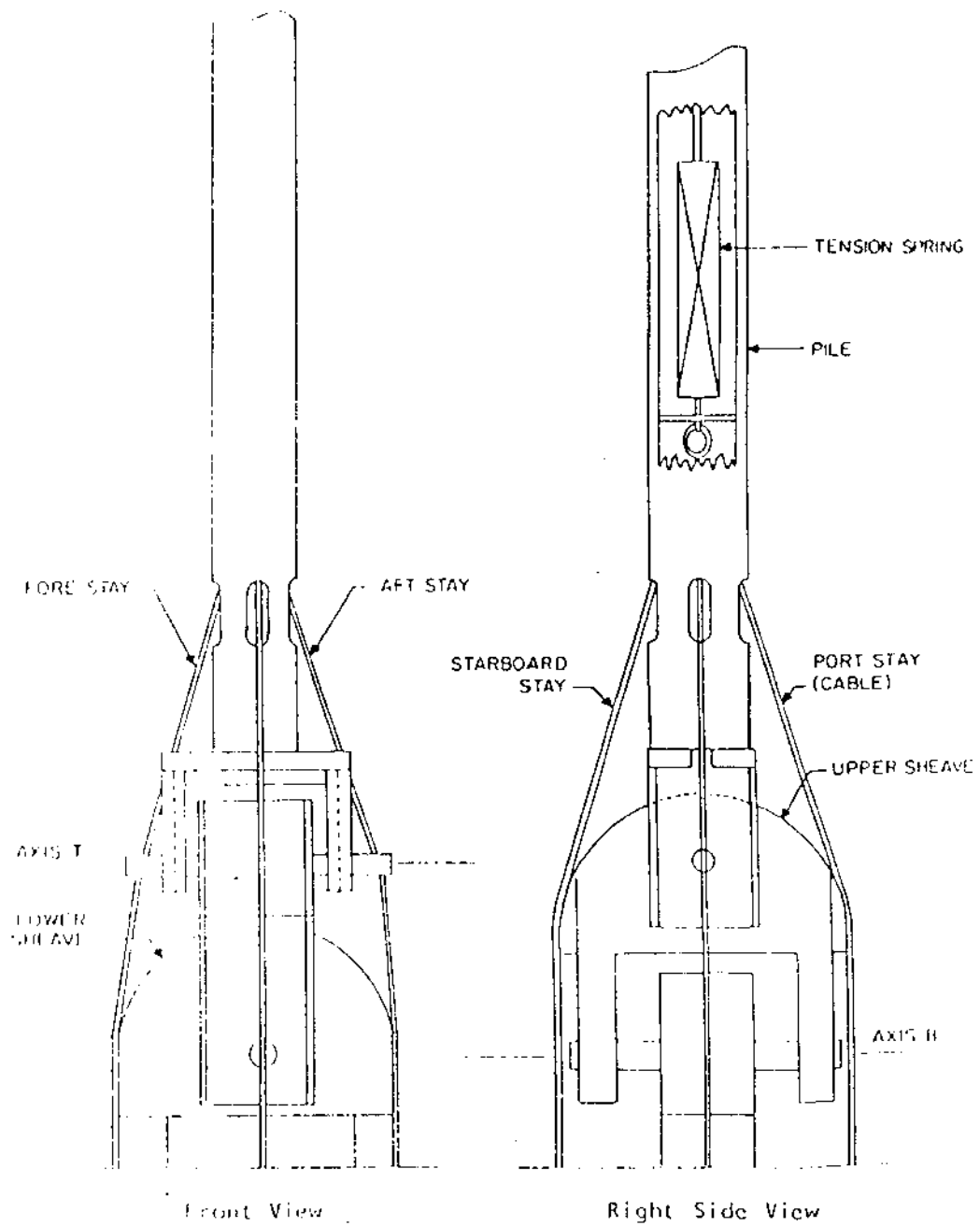


Fig. 2 The Collision Tolerant Pile Structure (CTPS)

modeling effort, the hinge was treated as a point hinge in which all recovery paths were assumed equivalent. Specifically, the 2-dimensional models did not provide sufficient insight into this inherently 3-dimensional process. Thus, in support of efforts to improve the hinge design, theoretical studies on the 3-dimensional hinge kinematics and pile dynamics were initiated.

The thesis objective is the development of a mathematical model which will accurately predict the behavior of this complex mechanical system. The model is to treat large angle dynamics and to explicitly account for the offset axis hinge mechanism. This fully 3-dimensional mathematical model will be programmed for implementation on a micro-computer.

The mathematical model is based on a two-degree-of-freedom system consisting of two masses; the pile and the upper sheave. Physical laws governing the kinetics of rigid bodies in three dimensions are used as the basis for the derivation of two, second order, differential equations which are then solved simultaneously by means of the Runge-Kutte algorithm. Forces considered are: 1) the weight loads on the pile and upper sheave; 2) the hinge moment generated by the spring acting through the taut stays(s); and 3) the hydrodynamic loads that are due to the action of steady current, waves and pile motion. The two fundamental equations were derived by summing moments about shaft axes and equating the net moment to the time rate of change of angular momentum. Because the top axis is not fixed, a rotating coordinate

system was used in addition to a global, fixed system. Moment resultants due to hydrodynamic loads distributed over the length of the pile were evaluated in terms of an integral.

For implementation of the model, a computer program was written (Appendix). It allows the user to choose various environmental inputs including water depth, wave, and current action as well as the initial angle of the pile and the sheave. The computer generated data will allow the user to track the pile's angle and velocity as a function of time. Presently, to change system parameters such as spring rate, sheave radius, etc. the user must go into the program editing mode.

Finally, the computer simulation was applied to the 1/4 scale physical model. Numerical experiments were conducted to confirm that the model reproduced the oblique stability characteristics and the weakness of the restoring moment in the oblique recovery.

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