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IMPACT RESPONSE OF
COLLISION TOLERANT PILE STRUCTURES

BY

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B.S., University of New Hampshire, 1987

Thesis

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Master of Science

in

Mechanical Engineering

September, 1989

ABSTRACT

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In previous work, computer models were created to predict contact and foundation force impulses during the impact process. These programs lacked the ability to calculate detailed force - time histories at the contact point and foundation.

In this thesis, computer models are developed to predict pile contact and foundation force time history during an impact. The dynamic analysis design software package called (DADS) and a modal synthesis program are used to add pile flexibility to the impact model. The models are found to reproduce the contact force time history for upper and lower impact to experimental data obtained in a 1/15 physical scale model.

The most general model is applied to predict impact behavior of a fullscale pile. The model indicates the insignificance of fluid drag.

hinge moment, buoyancy, gravity and bell attachment on impact behavior for the fullscale scale model. Local compliance between the barge and the pile is shown to be critical to the impact response. Pile flexibility is shown to decrease the contact force and increase the horizontal component of the foundation force.

This thesis presents a detailed mathematical development of computer models to predict impact behavior. Programs include a simplified analysis for use in CTPS design applications. The program models most of the critical processes, but is written to be easy to use by practicing design engineers. A listing and a "how to use" section is included for each program.

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The most general model is applied to predict impact behavior of a fullscale pile. The model indicates the insignificance of fluid drag,

hinge moment, buoyancy, gravity and bell attachment on impact behavior for the fullscale scale model. Local compliance between the barge and the pile is shown to be critical to the impact response. Pile flexibility is shown to decrease the contact force and increase the horizontal component of the foundation force.

This thesis presents a detailed mathematical development of computer models to predict impact behavior. Programs include a simplified analysis for use in CTPS design applications. The program models most of the critical processes, but is written to be easy to use by practicing design engineers. A listing and a "how to use" section is included for each program.

CHAPTER I

INTRODUCTION

1.1 Fixed Pile Destruction Problem

Rigid pile structures are currently being used by the Coast Guard to support aids to navigation along the edges of shallow channels. These structures are susceptible to collisions with marine traffic. Towed barges often collide with these piles causing complete destruction of the structure. Considerable expense is required to replace these piles which requires locating and removing the damaged stub and driving a new pile. A Collision Tolerant Pile Structure (CTPS) was proposed by Swift and Baldwin (1985) to be able to withstand such an impact.

1.2 CTPS Approach

The CTPS consists of a flexible pile, hinged above the mudline on which a navigational aid can be mounted. This pile has an omnidirectional hinge at the base and is free to fold down during a collision. A hinge spring is attached to the base of the pile providing a restoring moment to return the pile to an upright position. The cladding is in the form of a thick layer of closed cell foam to help resist local damage upon impact. Sections of the pile can also be closed to provide buoyancy chambers which aid in pile recovery.

1.3 Previous Work

During the initial Coast Guard supported 1984 project, computer simulations were developed; hinge concepts were evaluated, and a 1/15 scale physical model was built and lab tested. Engineering results reported by Swift and Baldwin (1985, 1986) showed that the concept was both technically and economically feasible. The following academic year (1984-85), a student design team, participating in the Ocean Projects Course, designed and constructed a 1/4 scale peripheral stay CTPS which was collision-tested in Little Bay, NH. Subsequently, modifications were made to improve the 1/4 scale model's recovery after collision and to monitor pile motion under extreme wind, wave, and current activity. The 1/4 scale tests showed that the pile can sustain direct impact barge collisions and recover. Recovery was further enhanced by using a central stay configuration as described by Swift et al. (1986).

The central stay concept was then used in a fullscale prototype design presented by Ward (1989). Other features of this design include the use of a compression spring, a buoyancy chamber and foam cladding. Three prototypes were built to this design and are scheduled for installation in the near future.

To support the initial development efforts, computer models were developed to predict CTPS dynamics during storm conditions, collision knockdown and pile recovery. The original computer simulations, described in the above references, were vertically 2-dimensional in which the CTPS was modeled as a rigid beam - flexible hinge system. As a consequence, collision modeling yielded impact force impulses and not detailed force as a function of time. Model predictions were compared

with experimental observations with reasonably good correspondence as reported by Swift and Baldwin (1985, 1986), Meilke (1987) and Baldwin et al. (1987). More recently, Medzorian et al. (1988) upgraded these models and adapted them for application to central stay with buoyancy type CTPSs.

During the prototype design development, it became evident that knowledge of impact force details is critical. The contact impact force can cause local damage at the point of impact. Impact reaction forces must be sustained by the foundation. For adequate design, these forces need to be understood as a function of time.

1.4 Problem

In this thesis, computer models are developed to predict pile contact and foundation force time history during an impact. Attention is focused on contact force time history because of its role in causing local pile damage. Foundation force time history is needed for the foundation design. The deformation phase and maximum force values at the end of this phase are of particular interest.

1.5 Modeling Approach

The pile is first considered as a rigid beam pinned at the base by the use of rigid body modeling. Flexibility is introduced into the system by a contact spring located between the barge and the pile. This spring represents both pile local contact compliance and pile bending flexibility. The model only includes effects due to inertial, contact

an foundation force. An analytical solution is developed to obtain a mathematical relation for the contact force and horizontal foundation force versus time during upper impact.

The Dynamic Analysis Design Software package (DADS) is considered for its ease to include additional effects due to buoyancy, gravity, fluid drag and an off center pivot point. The DADS model can also easily assemble a lower impact scenario. Experimental data obtained by Swift and Baldwin (1985) for the 1/15 scale prototype contain contact force time histories during both upper and lower impact. Analytical and DADS models are created to simulate the 1/15 scale prototype and results are compared with the experimental data. The models are also run for the most general case with and without certain parameters to investigate important effects.

Pile bending flexibility is introduced explicitly into the system to determine how much compliance is due to pile bending and how much due to local deformation. The first model uses a semi analytical modal summation approach and is called the modal synthesis model. This model simulates the upper impact scenario with a uniform pile mass assumption and only includes effects due to inertial, contact and foundation force.

Pile bending flexibility is introduced explicitly into the DADS model by supplying a flexible body input file. The DADS model can include extra effects due to a non uniform mass distribution, fluid drag, buoyancy, gravity, hinge spring, an off center pivot point and can easily assemble a lower impact scenario. Modal synthesis and DADS 1/15 scale upper impact simulations are created for a uniform mass, impulsive forces only case, to investigate consistency between models.

A non uniform mass distribution is added to the DADS 1/15 scale

upper and lower impact models. These models also include effects due to the hinge spring, fluid drag and gravity. The models are run with and without pile flexibility to investigate pile bending effects. Also, parameter studies are performed on pile bending flexibility to investigate impact reponse effects due to pile bending.

DADS rigid and flexible models are created to simulate fullscale pile upper and lower impact. Input parameters are obtained from Ward (1989). These models include effects due to fluid drag, buoyancy, sliding friction, gravity, and an off center pivot point. The models are run with and without pile flexibility to investigate pile bending flexibility effects. Also models are run for the most general case with and without certain parameters to consider other important effects.

A computer program is created for design purposes to simulate rigid body upper and lower impact. This program models most of the critical processes, but is written to be easy to use by practicing design engineers. Fullscale design simulations are obtained for both upper and lower impact and results are compared with the DADS rigid body output. The design models are also run for the most general case with and without certain parameters to check the program accuracy. A listing and a "how to use" section is included for each program.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Analytical rigid body and DADS rigid body for the impulsive force only case were found to give identical predictions. Furthermore, direct comparisons of the contact force predictions with 1/15 scale physical model experimental results show that both models (when calibrated with respect to length of impact) provide good correspondence with measurements. The consistency of these intercomparisons provides strong evidence of the reliability of the analytical approach.

When compliance was separated into local deformation and pile bending explicitly using flexible modeling, it was found that the modal summation technique and DADS flexible modeling for the impulsive forces only case were also consistent. Comparison of flexible and rigid DADS models showed that pile bending was not important at the 1/15 scale. Further intercomparisons indicated that upper impact model response changed little when effects of hinge spring, and fluid damping were altered. The lower impact model had a 22 percent change in contact force impulse when the hinge spring was removed. Also there was a 15 percent change in contact force impulse when fluid damping was removed from the system. These effects were only important for lower impact.

When DADS was applied to the fullscale prototype to predict contact and foundation forces, calibration of the contact spring was not possible. Both barge and foam stiffness had to be considered directly.

Foam stiffness was obtained through experimentation and a companion program which accounted for the interaction geometry. The barge stiffness coefficient, however, was assumed as $1.0(10^7)$ N/m. Collision predictions were made using both rigid and flexible DADS.

Comparisons provided insight into the relative importance of processes at fullscale. Upper impact was found to be the worst case, and the contact force was by far the largest. The rigid model over predicted the maximum contact force by 10 percent and under predicted the x ground force by 30 percent. Flexibility was of major importance to the x foundation forces when impact forces were large. Flexibility effects were also more important for lower impact than in upper impact. The rigid model over predicted the maximum contact force by 30 percent and under predicted the x ground force by 64 percent. Rigid body modeling would therefore be conservative for contact force analysis only. Effects due to buoyancy, hinge spring, gravity, and the bell were insignificant for both upper and lower impact with respect to the contact spring coefficient. When the contact spring coefficient was increased to over $1.0(10^7)$ N/m, a spike occurred in the contact force response. However when the barge compliance coefficient was lowered to $0.5(10^7)$ N/m, both contact force and foundation force were lowered considerably. Further research needs to be performed to investigate barge compliance effects due to its importance in impact.

This result suggests that design improvements should focus on modifying the local deformation. For example, two layers of foam surrounding the pile with a layer of super tough foam on the exterior could be used. This should significantly reduce the contact force.

Design program predictions were consistent to the DADS rigid body

models. The design program is a very easy program to use and is considered as a design tool for future use. The user should use care when analyzing reaction force output created by this program for it may under estimate the x ground force.