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Scalable Response Prediction of Underwater Explosion Effects on Critical Infrastructure

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NPS NRP Executive Summary

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Report Date: [31/01/2017 Project Number (IREF ID): [NPS-N16-N156-A]
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Scalable Response Prediction of Underwater Explosion Effects on Critical Infrastructure

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Project Summary

Critical port infrastructure is especially vulnerable to *waterborne improvised explosive devices* (IED) and other *underwater explosions* (UNDEX). These massive engineering structures such as bridges, tunnels and piers serve the public day in and day out providing transportation, commerce and connectivity throughout waterfront areas. In addition, they are fully integrated into society and serve as the visible backdrop for all sorts of recreational, social and ceremonial events in the port area. However this need for accessibility also makes them stand particularly vulnerable to the powerful effects of *fluid structure interaction* resulting from UNDEX.

In response to these growing concerns, various security measures such as structural protection against ship collisions, heightened surveillance and physical barriers in close proximity to bridge abutments has been implemented. In some instances it is unclear that these changes have improved or actually degraded the overall survivability of the structure. The goal of this investigation is to analyze the resulting potential damage to *critical port infrastructure* subjected to near field UNDEX. Representative of the profound importance of our nation's massive civil engineering structures, a suspension bridge is used as the object of theses analyses. Findings from physics-based modeling and simulation of the shock event reveal the damage potential of UNDEX as a function of charge weight and standoff distance, and serve as a template for future efforts for other bridge structures in direct contact with significant bodies of water.

Keywords: Critical Port Infrastructure, Mine Warfare, Waterborne IED, Fluid Structure Interaction (FSI), Underwater Explosion (UNDEX), Suspension Bridge

Background

In the event that an underwater improvised explosive device, commonly referred to as a waterborne IED, is found within the waters near critical port infrastructure, typically Explosive Ordinance Disposal (EOD) units will mitigate the threat by conducting a controlled detonation of the bomb. The controlled detonation must be executed a safe distance from the structure to ensure its survivability. This study is designed to assist in providing on scene commanders with information that could help aid them in their decision making process during such an incident.

Many types of critical port infrastructure have been studied in order to correlate charge weights, types and standoff distances with potential damage [1-3]. The current study focuses on bridges, specifically suspension type bridges and their abutments. Sample structures of this type were examined and a particular bridge chosen as an example for this analysis in order to present the proposed modeling and simulation approach.

To characterize the most critical scenario, the underwater detonation of TNT was simulated at varying horizontal standoff distances from the bridge structure at several water depths. The fluid structure interaction of the UNDEX with a bridge foundation was observed. Explosive charge weights ranging from 20 to 2000 lbs TNT equivalent were considered in this study. These charge weights cover the practical range of explosives that could be readily delivered within the surrounding waters of the bridge foundation.

Findings and Conclusions (to include Process)

In order to determine the extent of the potential damage that would be experienced by the bridge structure, it is first necessary to clearly outline how this prediction is made based on the given inputs of charge weight, charge type, geometry of the charge placement and characteristics of the structure and surrounding fluid environment.

The physics of UNDEX sees multiple competing loading phenomena that are present and at work simultaneously in the area of the blast. Direct shockwaves, bottom reflections, surface or rarefaction waves, all occur nearly instantaneously while the effects of the gas bubble oscillation can affect the late time response which occurs on the order of seconds post detonation. The surrounding depth of the water, depth of the charge, environmental materials, structural materials and geometry of the blast area all come into play and influence the structural response of the critical element under analysis.

Conducting full scale testing of bridges using UNDEX is neither practical nor desired. Additionally, live fire testing of a scaled structural model is not always feasible due to similitude requirements in materials and more importantly overall cost. However the continued development of physics-based modeling and simulation approaches such as the finite element method have allowed highly detailed simulations to be generated via high power computing resources which accurately capture the response of structures due to UNDEX loading. A detailed finite element model of the suspension bridge piers including appropriate material and dynamic load representations was generated based on construction drawings, visual inspection and other available engineering data.

The Dynamic System Mechanics Advanced Simulation (DYSMAS) [4] suite was chosen as the primary computational solver for this work. DYSMAS is a three dimensional finite element hydrocode designed to study the effects of an explosive charge on a user-defined structure. DYSMAS uses Eulerian fluid equations to conduct a finite element analysis of the water volume during an UNDEX event while Lagrangian finite element equations of motion capture the response of the structure. The program combines the data from the Eulerian and Lagrangian solutions at each time step to develop a fully coupled system solution, which is of great importance as the structure intersects a multiple fluid media.

Finite element method codes offer various options to consider while ascertaining the potential to which a particular scenario will damage the structure. Direct and derived quantiles such as pressure, stress, strain, displacement, and others relating the resulting response of the nodes and elements representing the structure offer insight into its ultimate disposition as failed or not.

Herein, the damage criteria were determined by using the following variables: a) Damage Parameter and b) Plastic Strain found in the rebar embedded into the concrete. The values were selected and outcomes assigned as presented in Table 1.

Table 1. Description of Damage Parameter

Damage Parameter	Plastic Strain in Rebar	Result
$\leq$ 0.0001 and	no	Safe
0.0001 - 0.001 and	no	Slightly Damaged
$\geq$ 0.001 or	yes	Damaged

Damage Parameter values were chosen to be conservative to account for uncertainties in the model as modeled condition of the bridge structure. Examples of this are considerations for aging of construction materials, corrosion of metals etc. Such items are more difficult to characterize yet affect the strength and therefore response of the structure.

Next damage curves, similar to the one presented in Figure 1, were generated for the specific cases which were investigated as part of this study. Various combinations of charge weight and standoff distance were directly verified by simulation using the

DYSMAS suite of computer codes. Figure 1 summarizes the simulation results in a damage curve profile for a typical scenario.

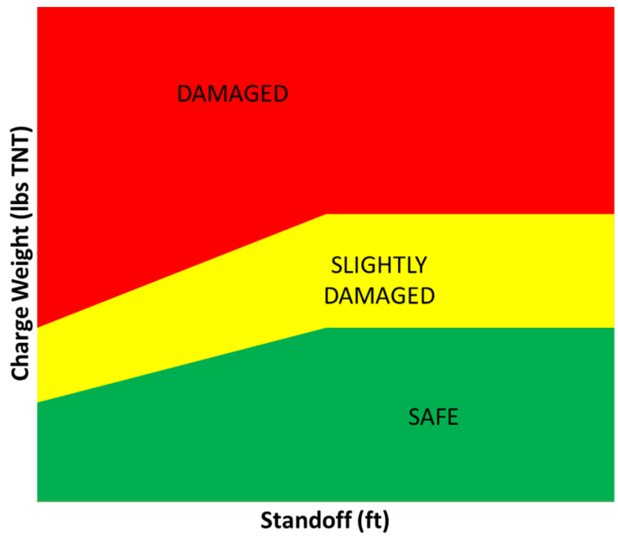

Figure 1. Damage potential as a function of charge weight and standoff

As stated, this study employs modeling and simulation to characterize safe detonation distances for a given charge weight of TNT. The results of this research will allow operational commanders to anticipate the effects of UNDEX on nearby infrastructure. Full details of the completed work are provided in a MAE Department Technical report.

Recommendations for Further Research

The work presented here was based on a specific type of critical port infrastructure - suspension bridges. However, even within this single category of bridges, there are many other types of structures that could potentially exhibit different failure modes when subjected to UNDEX. Cable-stayed, beam, truss, arch, cantilever and pontoon bridges are just a few of the others. Of particular interest are bridges that incorporate multiple characteristics of these simpler structures in a complex system such as the Hood Canal floating bridge. This bridge represents a unique challenge as it is comprised of floating pontoon and fixed girder sections as well as a portion that retracts to create the passage opening. An investigation of this critical port infrastructure using the method presented here is recommended as follow on work.

References

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