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Developing fragility curves for a pile-supported wharf

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ABSTRACT

This study proposes a procedure for developing seismic fragility curves for a pile-supported wharf. A typical pile-supported wharf, as commonly used in the ports of Taiwan, is chosen for demonstration. For a structural model of the wharf, the deck is modeled by shell elements and the Winkler model is used for the pile–soil system, in which the piles and soils are represented by beam elements and springs, respectively. A pushover analysis with lateral loads distributed according to the fundamental modal shape of the wharf structure is conducted to deduce the capacity curve of the wharf. The procedure for developing fragility curves can be explicitly performed using the spreadsheet platform in Microsoft EXCEL. First, quantitative criteria for damage states are established from the sequence of development of plastic zones. Then a nonlinear static procedure called the Spectrum Capacity Method (CSM) is used to efficiently construct a response matrix of the wharf to 24 earthquake events with differing levels of peak ground acceleration (PGA). Based on the damage criteria and the response matrix, the fragility curves of the wharf can be thus constructed through simple statistical analysis. Shifted lognormal cumulative distribution functions are also employed to better approximate the fragility curves for practical applications.

1. Introduction

Wharf structures that accommodate import and export activities are essential components of a port transportation system. For a port in an area of high seismicity, wharf structures are susceptible to earthquake damage and may adversely affect the normal operation of the port system. For example, the 1995 Hyogoken-Nanbu earthquake damaged many wharf structures, such as caissons and pile-supported wharfs, in Kobe Port, Japan [1], and the 1999 Chi-Chi earthquake caused damage to some caisson quay walls in Taichung Port, Taiwan [2]. These ports suffered enormous economic losses due to the downtime of the wharfs.

A great deal of research using either model tests or numerical simulations or both was carried out to investigate the behavior of wharf structures during an earthquake [3–6]; however, less effort was made in determining the seismic vulnerabilities of wharf structures. The use of fragility curves has been deemed an effective means for evaluating the seismic vulnerability of a structural member or system. Fragility curves express the conditional probability of exceeding a certain damage state for a given ground motion intensity. This approach is commonly adopted in building structures [7–9] and bridge structures [10–12], as well as in some geotechnical structures such as expressway embankments [13], dams [14], and so on. It is also a useful tool in current performance-based earthquake engineering to link economic losses, like repair costs, repair durations and loss of life, to the damage of structures or systems [15–16]. With the aid of the fragility curves of wharf structures, Na and Shinozuka [17] proposed a simulation-based framework for evaluating the economic loss of a damaged seaport system.

Some well-known earthquake loss analysis systems, such as Hazards U.S. (HAZUS) [18] and the Taiwan Earthquake Loss Estimation System (TELES) [19], also use fragility curves to estimate the damage probabilities of the components in a system. In HAZUS, four classes of fragility curves are recommended for items in a port system: waterfront structures, cranes and cargo handling equipment, fuel facilities, and warehouses. In this system, wharf structures are categorized as a waterfront structure. Wharf structures actually have three main structural types: gravity quay wall, sheet pile quay wall, and pile-supported wharf. However, in HAZUS, they are assigned the same set of fragility parameters, regardless of the differences between the structural types. Since these structural types have different structural characteristics, they should have different fragility curves to express their own seismic vulnerabilities properly.

Therefore, the objective of this study is to propose a procedure for a pile-supported wharf to develop its specific fragility curves

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