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TITLE: Vulnerability Assessment of a submerged river bridge via a simplified approach			
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ABSTRACT

This study aims to provide a simplified approach to investigate the influence of the immersed water depth on a bridge's seismic performance. Due to the service life of an infrastructure is often long, it is important to realize the seismic performance in its life. However, there are tens of thousands of bridges in Taiwan and therefore, an easy but accurate analysis approach is needed. A case study is conducted to illustrate the proposed methodology and the structural performances with added mass are investigated to show the submerged water effect. The structural performance is measured by the displacement ductility during seismic excitation. According to the results obtained, highly variability of seismic performances is observed and it is important to include the immersed water depth to capture the seismic capacity of a bridge.

Keywords: seismic; river-crossing bridge; damage index; added mass; fragility curve

Introduction

Taiwan is a long, narrow island shaped country with climate of having more rainfall, more typhoons, more earthquakes. When heavy rain occurs, a river often flows rapidly into the sea and seldom stays in land. Because of this, the depth of a river bed is often decreased due to scouring. However, the rapid river flow also increases the sediment deposition and the river bed will regain its level. Due to the raining condition, the water level of the bridges may be high or low possessing an inevitable uncertainty and should be addressed. The natural frequency of a bridge, which is often used as a bridge safety index, is affected by immersed water depth resulting to a different outcome from that of a bridge completely exposed to the air. It is important to take such effect into consideration in a bridge safety evaluation. Therefore, in this study, a probabilistic approach such as a fragility curve is adopted to evaluate the selected bridge and the added mass method is used to consider the effect of immersed stream depth.

Research motivation and objective

It is recognized that an immersed pier in a flood could damage a bridge. However, only few of earlier researches focus on the effect of the surrounding water around a pier. Thus, such impact is considered in this study. In addition, because the river bed will be scoured away by flows, the scouring depth must also be considered. The inevitable and highly uncertain nature possessed in the assessment process such as flow velocity and scouring depth, a probabilistic approach (e.g., fragility analysis) must be used. To consider the effect of the immersed water depth, this study will compare different types of additional mass approach. For example, the extra mass may be arranged on the top of the piers or distributed along the pier. Two different but common analyses: the nonlinear static analysis and the nonlinear dynamic analysis are adopted and their efficiency, accuracy and suitability are addressed. In the end, the fragility curve will be adopted to show the bridge is in which damage index level. Figure 1 displays the overall analysis process.

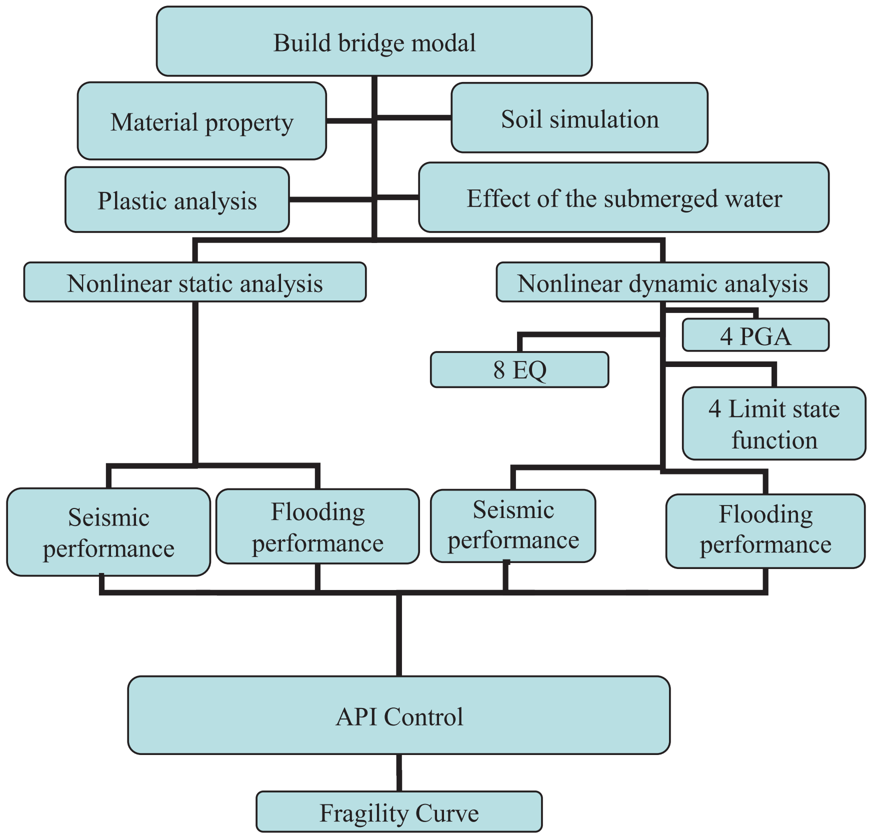

Figure 1 The Flow Chart of the Overall Analysis

Finite element simulation of a bridge

In this study, SAP2000 was first used to simulate the bridge on the Xizhao Bridge in Yunlin County, Taiwan. The bridge was a single-column, pile foundation and reinforced bridge across the river. When establishing the stress-strain（σ-ε curve）relationship of the material, concrete was used the theoretical formula of Mander, et al. (1988), as shown in Figure 2. Reinforced steel is used the theoretical formula of Priestley et al. (1996), as shown in Figure 3. When the stress-strain curves of the respective materials have been established, they are placed in the section of the SAP2000 model and given well mesh to the sections appropriately. It is also necessary to pay attention to the connection conditions while establishing the 3D model. Finally, after the soil spring and additional mass are added to different conditions, do the dynamic diachronic analysis and get the fragility curves in each case.

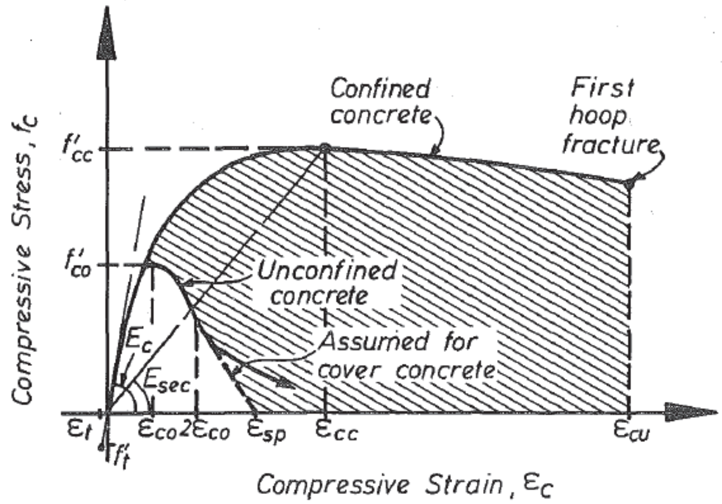

Figure 2 Stress-Strain Model Proposed for Monotonic Loading of Confined and Unconfined Concrete (Mander, Priestley, & Park, 1988)

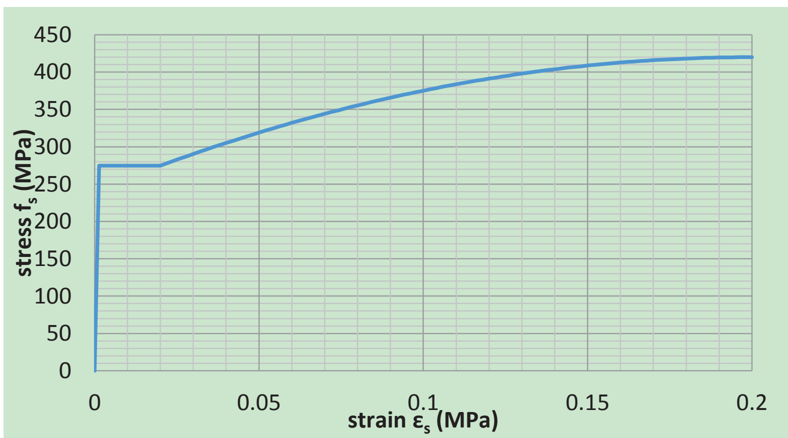

Figure 3 Schematic Diagram of Stress-Strain Curve of Reinforced Steel

Soil spring

Since the foundation piles, pile caps, and some piers are all covered by soil, soil springs are used to simulate the soil when soil is to be considered. However, when simulating a soil spring, it is divided into two parts to be discussed: The linear section simulation uses Taiwan's normative-supplementary study of seismic design codes for highway bridges (1997), whereas the non-linear section is less conservative than the passive earth pressure P_p, as shown in Figure 4.

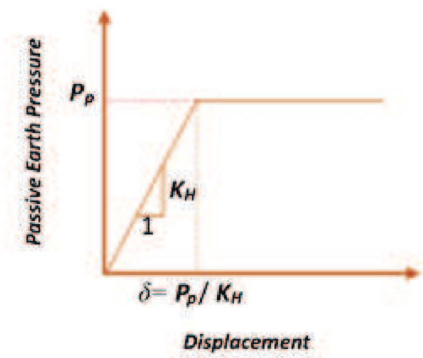

Figure 4 Bilinear Simulation of a Soil Spring

Plastic hinge

In the static structure of the non-hinged place at the external force will have a bending moment and rotation angle, in the elastic range of bending moment and the relationship between the rotation will be in proportion, but when the plastic phase, the moment and the rotation of the relationship will no longer in proportion. Its plastic behavior needs special analysis to calculate the ductility of the bridge to ensure that it can reach the ideal situation that a building in a small earthquake is safe, a moderate earthquake can be repaired, and a large earthquake does not fall down.

Generally, in seismic analysis, plastic hinge simulation has three simulation methods: First, use Link to set the simulation. Second, using M_2, M_3 or P-M-M and other custom to simulate: input section of the moment-rotation (M-θ curve) relationship to establish plastic hinge, which should also be noted that the destruction of the behavior of shear failure, flexural - shear failure or flexural failure. Third, the use of Fiber to simulate: Careful calculation of the material stress - strain (σ-ε curve) relationship can be divided into three categories: 1. Unconfined concrete (cover). 2. Confined concrete (core). 3. Reinforced steel (rebar). After calculating the stress-strain relationship of each material, put the material properties into the model and draw the section and then give a good mesh of finite elements, as shown in Figure 5. Finally, using the fiber hinge (P-M-M) to simulate the plastic hinge analysis. This study chose to use the third type of fiber to simulate. This method will be more accurate which has also been discussed in Guidelines for Nonlinear Analysis of Bridge Structures (2008).

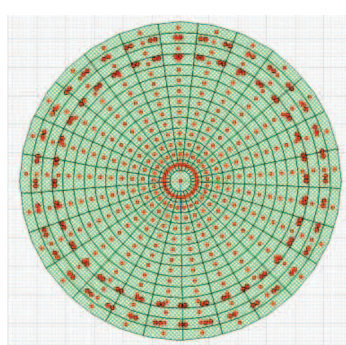

Figure 5 Schematic Diagram of a Fiber Section

Additional mass

When analyzing a river-crossing bridge, the effect of the structure being immersed in the water cannot be ignored because the natural frequency of vibration can vary accordingly. Therefore, if the structure is to be controlled to simulate the natural vibration frequency, the most realistic simulation should be done through the control mass part because the natural vibration frequency is related to the mass and elastic stiffness of the structure. However, the elastic stiffness is not easy to make some adjustments, which will affect the mechanical behavior of the force, so controlling the mass is the best choice. Therefore, this study will place extra mass on the structures to reduce the natural frequency of vibration. Moreover, there are two types of mass placement: one is to focus the mass on the top of the piers, and the other is to add different mass according to the depth of the part that will be immersed in water.

Fragility analysis

In Taiwan, earthquakes and typhoons are the major natural disasters. Therefore, when designing or evaluating many buildings and bridges, the fragility curve will be an important reference for rapidly assessing the degree of structural damage. It can be predicted that the structure goes through different degree of external force, the probability of various degrees of damage.

Fragility curve is defined as the failure probability at given loading exceeding given limit where Alipour, et al. (2012) expressed as 1 <μ<2 for slight, 2 <μ<4 for moderate, 4 <μ<7 form major and μ>7 for complete collapse damage states.

$$P_f(\mu_\Delta \geq d|PGA = x) = 1 - \Phi\left(\frac{\ln\left(\frac{d}{ax^b}\right)}{\beta_{\mu_\Delta|PGA}}\right)$$

$$\beta_{\mu_\Delta|PGA} = \sqrt{{\beta_{\mu_\Delta|PGA}}^2 + {\beta_c}^2}$$

$$\mu_\Delta = a(PGA)^b$$

$$\beta_{D|PGA} = c(PGA)^f$$

The constant “a” and “b” based on the mean of structure ductility data.
The constant “c” and “f” based on the deviation of structure ductility data.

API control and analysis automation

Soil spring, additional mass placement

Due to the high and low scouring level of the river, the soil depth, soil properties, soil spring and additional mass will change, and whenever the soil spring properties and additional mass changes, the model should be replaced with a new soil spring and additional mass will be very time-consuming and laborious. So this study will calculate and put into the soil spring and additional mass automation to speed up the analysis of the efficiency.

Fragility curves are set to automation

As the fragility curve building process is quite tedious and there are many situations to be compared, creating a fragility curve in each case will also be a huge project. So if we can automate the establishment of the fragility curve, more unnecessary time to invest in research to make this study more complete.

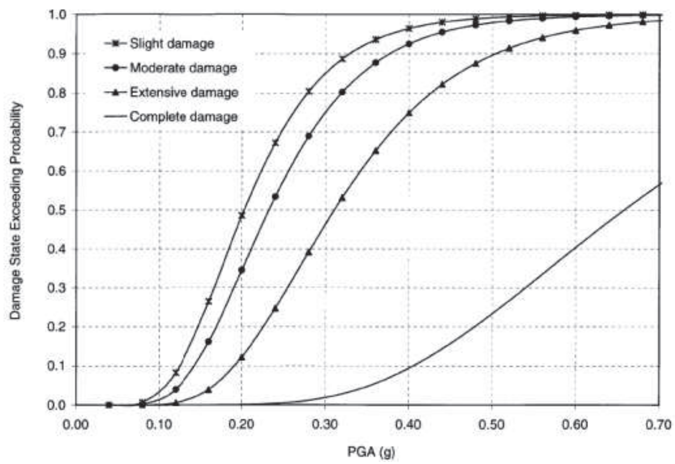

Figure 6 Schematic Diagram of Fragility curves

Comparisons and conclusions

In Deng, Guo, & XU (2017), comparing the experimental results of the cantilever beams with the added mass were immersed in the water, the results obtained by the finite element software simulation are similar to those of the experiment. Therefore, the final results of this study will be compared with finite element software's modeling analysis, the results of comparison and discussion to be verified and validated. This is an ongoing project and details of the research results will be presented in the conference.

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