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Damage State Assessment of a Pre-Stress Concrete Girder (PSCG) Bridge using Non Linear Analysis for Real-time Structural Health Monitoring

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Abstract. Philippines is located in the pacific ring of fire, which indicates that seismic movement is frequently happening. West valley fault line located in the central Luzon might move due to its 400 to 500-year recurrence, and the last recorded movement was on 1958. According to MMIERS, the movement of west valley fault with 7.2 magnitude earthquake can cause one of the biggest devastation in Metro Manila. In preparation for that, this study aims to assess the vulnerability of a pre-stress bridge against seismic movement by the aid of USHER technology. The USHER system includes structural assessment, remote sensing, and real time monitoring through the portal. This study will focus on the structural assessment of the bridge, which identify the acceleration limits that the bridge can endure to interpret different level of damage. As a result, by 10% of probability of exceedance from SEAOC using the moderate damage fragility curve, the results in three directions are 0.37641g in longitudinal axis, 0.366025g in transverse axis, and 0.394498g in the vertical direction. The most critical is in the transverse direction, which can produce a maximum of 67mm displacement of the bridge in the inelastic stage. In validation through the sensor, which has a reading from the smart bridge project, the maximum acceleration recorded was 0.138g. This concludes that the bridge is safe and no retrofitting works is need.

1. Introduction

On the 22nd day of April 2019, Castillejos, Zambales was hit by a 6.1 magnitude tectonic quake that reported intensities as high as Intensity VII, described by the PHIVOLCS Earthquake Intensity Scale as destructive earthquake causing liquefaction, landslides and slight damage on well-built structure.

This kind of seismic activity has been evident within the Philippine archipelago ever since, being located within the Pacific Ring of Fire wherein collisions of tectonic plates occur. Historical records show that the Philippine archipelago experiences an average of 20 earthquakes per day at around 100 to 150 earthquakes annually, contributing to the fact that the country is the third most exposed to natural hazards among 172 countries. Earthquake hazard is a major threat to the economic development of the Philippines. The 7.2M quake in Bohol last October 2013 resulted into 2.2 billion pesos' total cost of damages, almost 67, 000 houses, 41 bridges and 18 roads damaged, and 3.2 million of people affected. [5,6]

This example of an earthquake event shows that a short period disaster can cause a huge loss in the country's economic assets and can be detrimental to thousands of lives. Earthquake hazards cannot cause as much damages only if a system or community is not exposed and vulnerable as much to these hazards. So one way to mitigate this hazard is ensuring the integrity of infrastructure in an area exposed to earthquake hazard. Among the standard practices in evaluating, the integrity of existing infrastructure is through rapid visual survey. An emerging platform is the development of structural health monitoring technologies that help in managing disaster risk. Introduction of accelerometer for structural health monitoring is now emerging, hand in hand with rapid visual inspection. [1,4,7]

For an advance monitoring process, this paper uses a sensor and a web-based portal that records and presents structural health data of selected infrastructure. The sensor utilized by the system developed through the smart bridge project and improved now by the USHER project, which enables the sensor to record three directional movements (x, y, and z). This helps to determine the different damage state of the bridge and to give an idea on the action needed to perform. This study will not cover cost analysis and foundation investigation.

2. Methodology

The bridge was a type IV AASHTO pre-stress girder. All of the piers has one column except from the middle pier, which consist of two columns. The model was illustrated using CSI Bridge software. The earthquake data came from the Kobe 1995 earthquake magnitude 6.5, Tohoku 2011 earthquake magnitude 9, and local earthquakes in the Philippines.

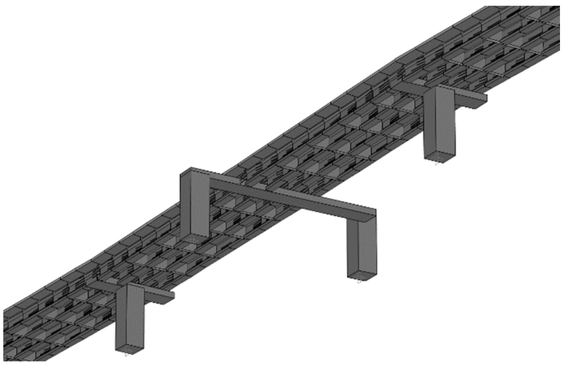

Figure 1. Bridge Model.

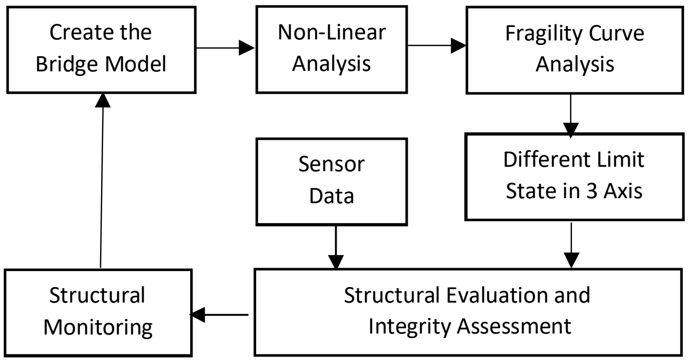

Figure 2. Conceptual Framework.

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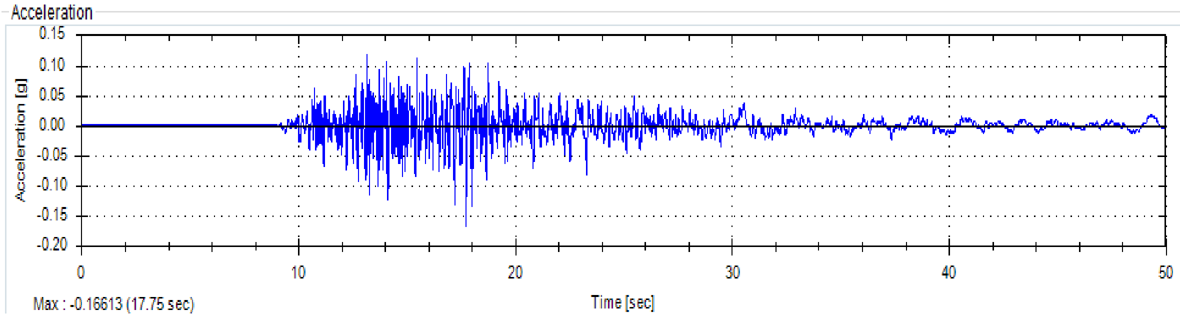

Figure 3. KOBE 1995 Earthquake Raw Values.

Push over analysis and capacity spectrum method was analyzed to get the upper and lower limit of ground acceleration to consider in levelling the damage state. These damage states were used in identifying the probability of exceedance and its corresponding peak ground acceleration through fragility curve analysis in this equation [3] :

$$\mathbf{F(a)} = \boldsymbol{\phi}\left[\frac{\ln\left(\frac{a}{c}\right)}{\zeta}\right] \qquad (1)$$

Wherein “a” is the peak ground acceleration and ϕ [...] is the standardized normal logarithmic distribution function. Shinozuka (2001).

3. Results and Discussion

The maximum displacement in the inelastic stage of the bridge is 67.67mm which occurs at 11315.273 KN shear force, while 140.38 mm dispacement at 13415.018 KN shear force is recorded maximum in the elastic stage. This values was used in the classification of the different damage states. The maximum displacement.

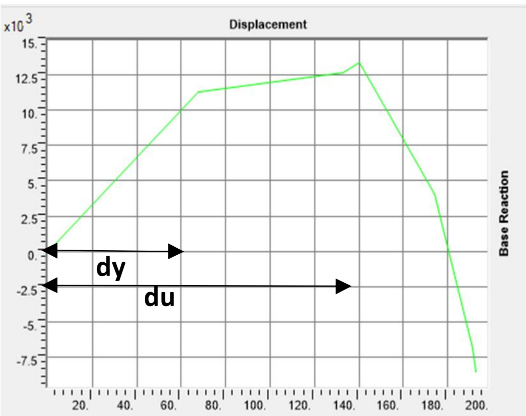

Figure 4. Push Over Curve at Longitudinal Direction.

Table 1. Push Over Curve Data.

Displacement (mm)	Base Force (KN)
67.673895	11315.273
133.033962	12708.512
140.385777	13415.018
174.155716	4057.423
191.066784	-6846.757
192.456781	-8550.317
192.462662	-8557.053
192.692406	-8569.286
192.698288	-8575.76
192.732671	-8577.613

A set of mathematical model can be use to categorized the data from the results of capacity spectrum method and push over analysis to produce the limits of different damage states.[2]

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Table 2. Limits for Different Damage States.

Damage State		Lower Limit	Upper Limit
DS0	None	< 0.0473717265	0.047371727
DS1	Minor	0.047371727	0.091911189
DS2	Moderate	0.091911189	0.116148483
DS3	Major	0.116148483	0.140385777
DS4	Collapse	0.140385777	> 0.140385777

The graphs shown below are the fragility curves of different damage states at three directions produced using the data from the non linear static and dynamic analysis.

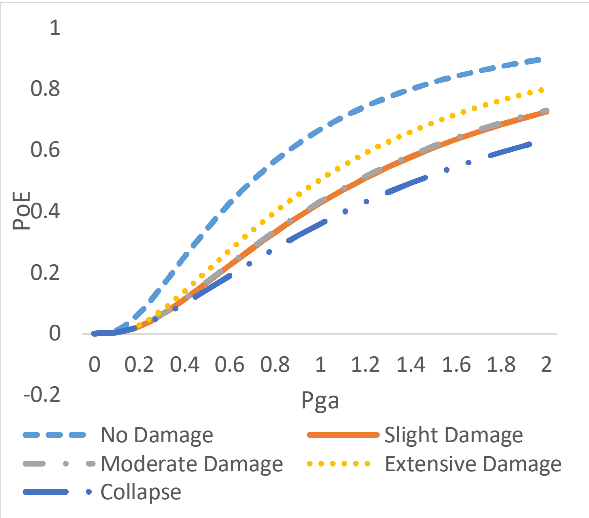

Figure 5. X- Axis Seismic Fragility Curve.

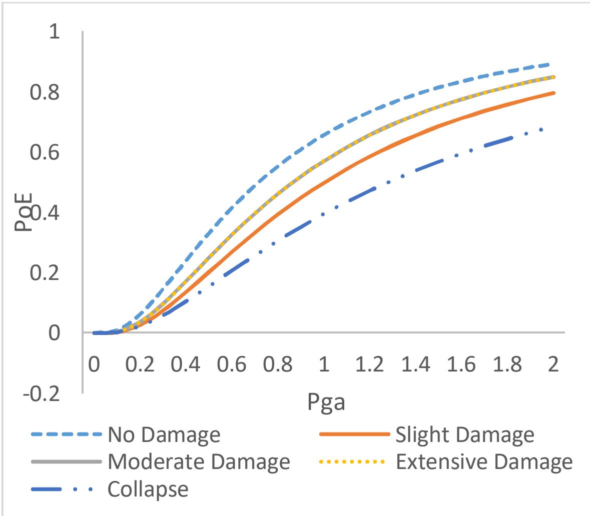

Figure 6. Y- Axis Seismic Fragility Curve.

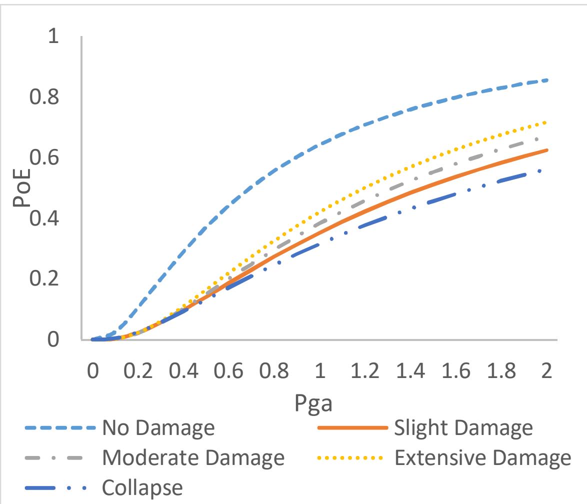

Figure 7. Z- Axis Seismic Fragility Curves.

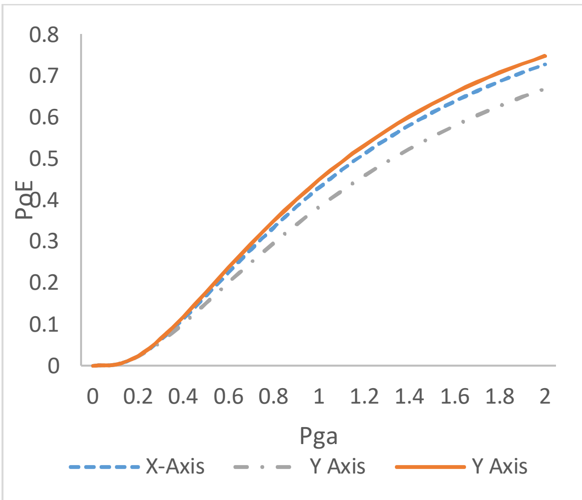

Figure 8. Moderate Damage in Three Direction.

According to the study made by SEAOC, 10% of the probability of exceedance serves as the limit state that will indicate a need for retrofitting and further structural assessment located in the moderate damage plot using the fragility curve analysis.

Table 3. Threshold in Three Direction.

	X	Y	Z
Threshold (g)	0.374641	0.366025	0.394998

4. Conclusion

The threshold obtained are 0.37641g in longitudinal axis, 0.366025g in transverse axis, and 0.394498g in the vertical direction. The weakest axis is located on the transverse direction and it indicates shear failure on the connection of bridge deck and pier. Based from the sensor reading connected on the bridge, the maximum acceleration data recorded was 0.138 g which justify that the bridge is safe and no retroffiting works to be done. The researchers recommend to investigate further the foundation and incorporate soil investigation. Analyze the foundation and how it will affect the acceleration limits.

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