

Structural Health Monitoring of a Five-Story Reinforced Concrete School Building in Preparation for the Upcoming West Valley Fault Movement using USHER Technology

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Abstract:

Public school buildings are very essential in times of calamities because it serves as one of the evacuation facilities in the Philippines. In preparation for the upcoming movement of west valley fault line that will cause a major destruction of lives and properties in metro manila, this study aims to conduct a structural health monitoring on a five-story school building by the aid of wireless smart sensor and conducting capacity spectrum method. The sensor was installed on the ground floor of the building as stated on the national structural code of the Philippines. In addition to this, the second sensor was installed on the top most floor of the building to record the data experience by the structure itself. After the installation, the actual reading on the ground are 0.00196159g on longitudinal, 0.002137g on transverse, and 0.00206172g on vertical direction. The actual reading on the structure are 0.00221014g on longitudinal, 0.00192106g on transverse, and 0.00214517g on vertical direction. Compare to the 0.3g peak ground acceleration from the Philippine Institute of Volcanology and Seismology atlas and comparing also the threshold on the structure, it indicates that the building is safe at its current state. 0.3g serves as the threshold on ground while 0.3071g on longitudinal, 0.3725g on transverse, and 0.35g on vertical direction are the threshold on the structure, this serves as an initial guide in helping the building owners and structural engineers to decide if it is needed to conduct further structural assessment on the building.

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I. INTRODUCTION

According to the Metropolitan Manila Earthquake Impact Reduction Study, the movement of west valley fault-line will cause a major destruction that can result to 170,000 collapse of residential houses, partly damage of 340000 residential houses, 34000 deaths, and 114000 injured people. There will be bridges collapse and major roads closure that will result to difficult access of disaster response and relief. Aside from this, secondary hazards like fire will cause 18000 additional deaths and loss of

properties.

When the west valley fault produce a 7.2 magnitude earthquake, it is said on the *Oplan Metro Yakal Plus* study that Metro Manila will be divided into four quadrants due to collapse of infrastructures illustrated in figure 1. The emergency response and relief distribution will greatly affected due to difficulty of passageway. In line with this, evacuation areas and medical assistance must be strongly functional in times of this disaster.



Figure 1. Oplan Metro Yakal

Public school buildings in the Philippines are built and monitored by the government to serve not just for educational purposes but also for evacuation areas in times of calamities. These buildings are monitored and maintained by the government for its dual purpose. This study aims to conduct structural health monitoring on a five-story school building located in Metro Manila by deployment of wireless sensor technology and assessment of its structural integrity through non-linear analysis. This study will help to establish an alarm system in which recommend if the building must undergo further structural assessment in case of seismic events. This study limits on the super structure and cost analysis is not included. Deterioration of the materials was not considered.

II. METHODOLOGY

A. Structural Model

The first step is creating a realistic structural model of the five-story reinforced concrete school building using SAP2000 software. The supports in the foundation was assumed to be fixed. The distance of the building to the west valley fault is 93km and the area on which the building was located has a high percentage of liquefaction based from the data provided by the Philippine Institute of Volcanology and Seismology. The final structural model was shown in figure 2.

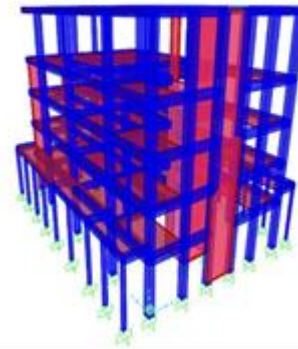


Figure 2. Structural Model

B. Location of the Earthquake Recording Instrument

After creating the model using the original structural and architectural plan of the building, the analysis will show if there are failed structural members. The earthquake recording instrument location was placed in accordance to the National Structural Code of the Philippines as shown in table 1. This building categorized as government buildings in letter b: schools with twenty (20) classrooms or more and more than three stories.

Table 1. Seismic Instrumentation Requirements (NSCP 2015)

TABLE 1. SEISMIC INSTRUMENTATION REQUIREMENTS		
TYPE/HEIGHT OF BUILDING	LOCATION	REQUIREMENTS
GOVERNMENT BUILDINGS		
A. Hospitals, schools and other buildings above fifty (50) meters in height	At least 3 accelerographs located at: 1. Ground Floor/ Lowest Basement; 2. Middle Floor, and 3. Floor below Roof	ERI in compliance with this IRR
B. Hospitals with fifty (50)-bed capacity or more and schools with twenty (20) classrooms or more but not less than three (3) storeys	One Accelerograph installed at Ground Floor/Lowest Basement	ERI in compliance with this IRR
C. Provincial/City/Municipal Halls and Buildings	One Accelerograph installed at the Ground Floor / Lowest Basement	ERI in compliance with this IRR

C. Earthquake Recording Instrument Development

The development of sensors is made by the USHER team in the Philippines. The sensor as shown in the figure, reads the natural frequency of the building in three direction; transverse, longitudinal, and vertical direction. The sensor is located at the ground floor/lowest basement of the building as illustrated in the national structural code of the Philippines.



Figure 3. USHER Sensor

D. Determination of Threshold on Ground

The sensor reading on the ground floor was compared to the peak ground acceleration map of metro manila from Philippine Institute of Volcanology and Seismology (PhiVOLCS) atlas, this shows the different contour lines of the range of values of areas. The 500-year period on Vs30 site model was chosen to be the reference because it suites the 400-500 years return period of the projected west valley fault movement.

The data from the sensor will be sent real time on the portal and the peak ground acceleration from the map of PhiVOLCS will be set as the threshold. This threshold serves as the limit states wherein if the frequency exceeds at that level, the building is recommended to have a further structural assessment.

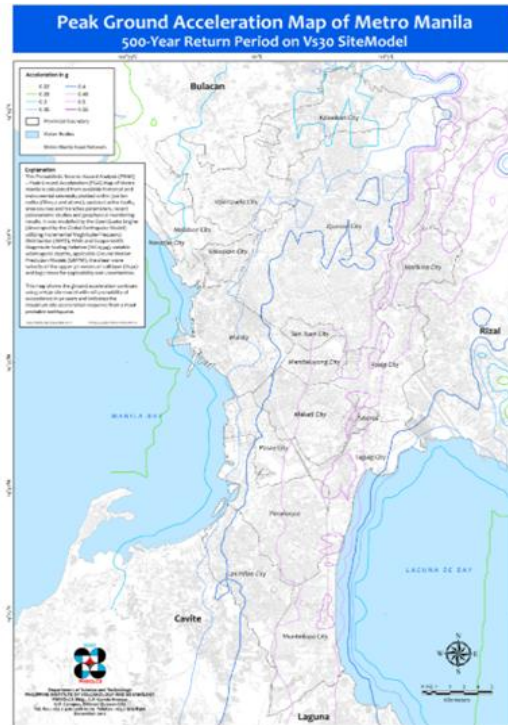


Figure 4. PGA Map from PhilVOLCS

E. Determination of Threshold on Structure

Capacity Spectrum Method

This method will estimate the displacement and forces experienced by the structure on its non-linear state. Through simulating the non-linear push over analysis, maximum displacement and base shear was illustrated in the push over curve. Performance points on intersecting to the push over curve was gathered after incorporating the ground motions.

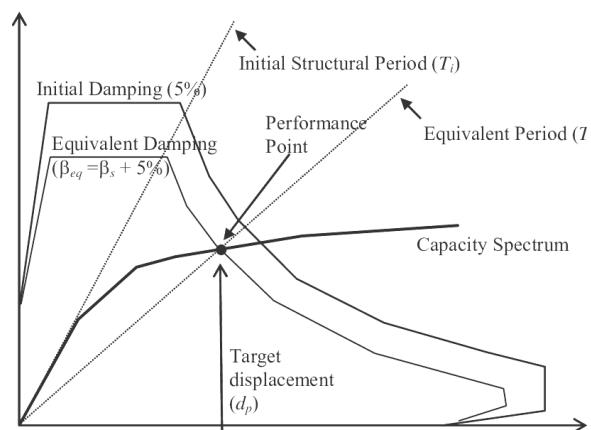


Figure 5. Capacity Spectrum Method

According to Moschonas (2008), the formula in determining the different level of damage states from

the displacement on the push over curve are shown in the table.

Table 2. Different Damage States Formula

Damage State	Required Interventions	Formula
D0 No Damage	None	<0.7dy
D1 Slight Damage	Inspect	>0.7dy
D2 Moderate Damage	Repair Components	>min(1.5dy, dy + (1/3)*(du-dy))
D3 Extensive Damage	Rebuild Components	>min(3dy, dy + (2/3)*(du-dy))
D4 Collapse	Rebuild Bridge	>du

Fragility Curve Analysis

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 was used in identifying the probability of exceedance and its corresponding peak ground acceleration through fragility curve analysis in this equation: M. Shinozuka (2001)

$$F(a) = \Phi \left[\frac{\ln\left(\frac{a}{c}\right)}{\zeta} \right] \quad (1)$$

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

III. RESULTS AND DISCUSSION

The figure shows the actual installation of the sensor on the ground level of the school building. It is enclosed by the cage with a monitor in the front that shows the real time frequency reading of the ground. The cage serves as a protection on the sensor so that unappropriated reading will be avoided. The screen on the front of the cage displays the three dimensional frequency reading. The threshold is directly programmed on the portal.



Fig. 6. Installed Sensor

The figure shows the usher portal interface which displays the longitudinal, transverse, and vertical frequency reading on the ground, the values are 0.00196159g, 0.002137g, and 0.00206172g respectively. The intensity was also displayed; this was in accordance to the Philippine earthquake intensity scale.

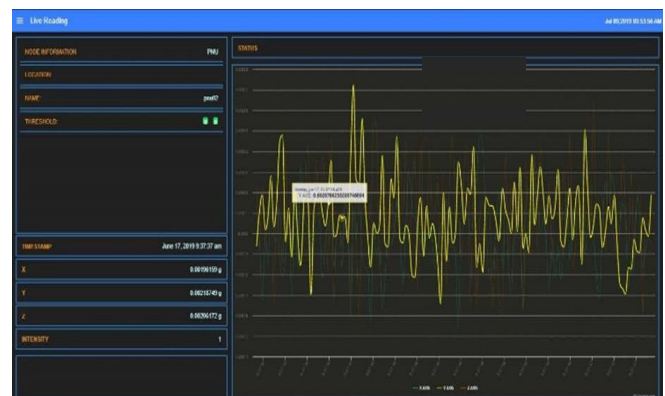


Fig. 7. Usher Portal Reading on the Ground

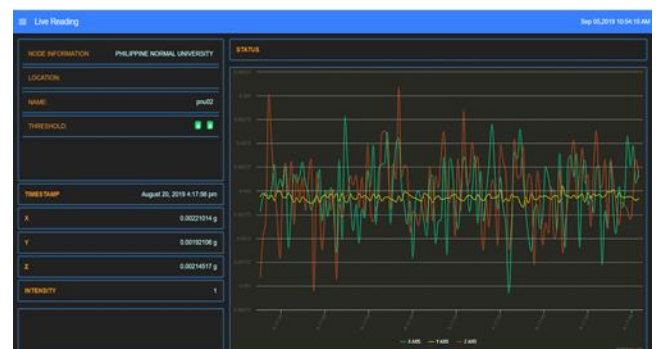


Fig. 8. Usher Portal Reading on the Top Most Floor

Based from the peak ground acceleration map of metro manila from Philippine Institute of

Volcanology and Seismology (PhiVOLCS) atlas, the location of the building falls on the boundary with 0.3g peak ground acceleration. This value will be compared on the actual reading, and also this serves as the threshold pre, during, and after earthquake.



Fig. 9. PGA on the Building Location

Push Over Curve

The maximum displacement on the linear state was 0.061191mm (dy) while 3.001595mm (du) for the non-linear state.

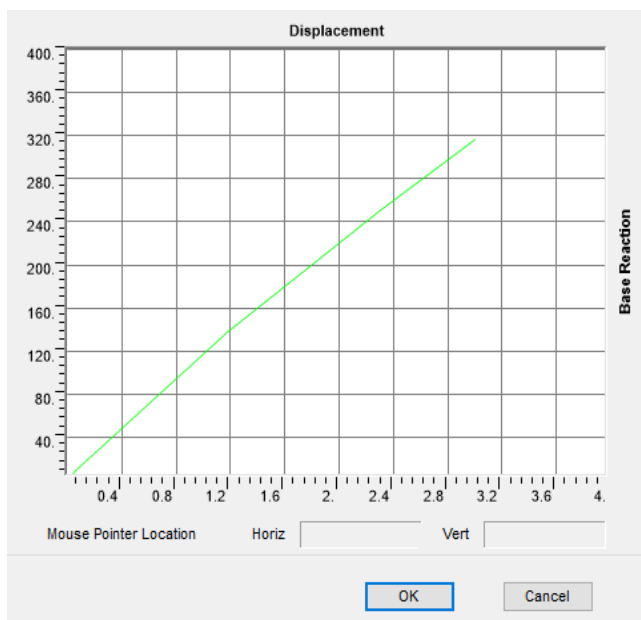


Fig. 10. Push over Curve

Table 3. Push Over Curve Values

	Displacement (mm)	Base Force (KN)
	0	0
dy	0.061191	8.48
	1.177824	137.923
du	2.306619	250.724
	3.001595	316.657

The dy and du was used in determining the limits in charactrizing the different level of damage.

Table 4. Limits of Damage States

Damage State		Lower Limit	Upper Limit
DS0	None	< 0.000428337	0.000428337
DS1	Minor	0.000428337	0.000917865
DS2	Moderate	0.000917865	0.00183573
DS3	Major	0.00183573	0.03001595
DS4	Collapse	0.03001595	> 0.03001595

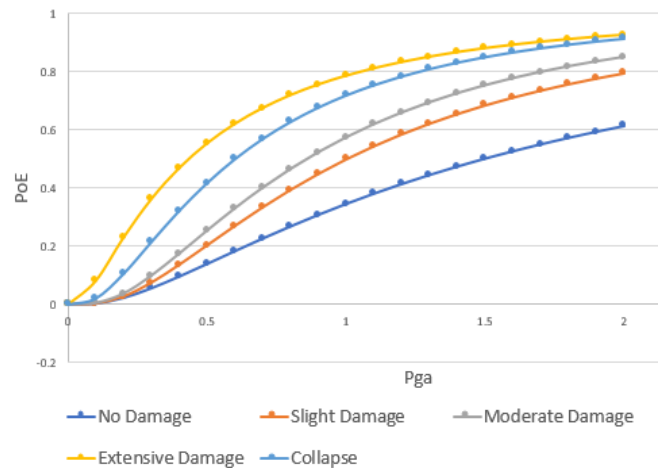


Fig. 11. Fragility Curve at X- Axis

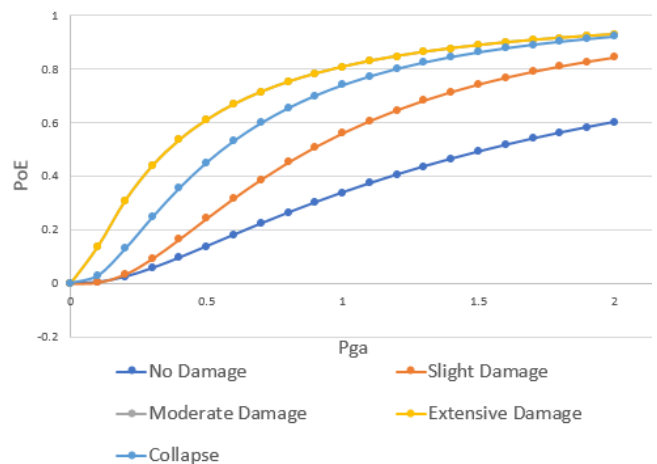


Fig. 12. Fragility Curve at Y- Axis

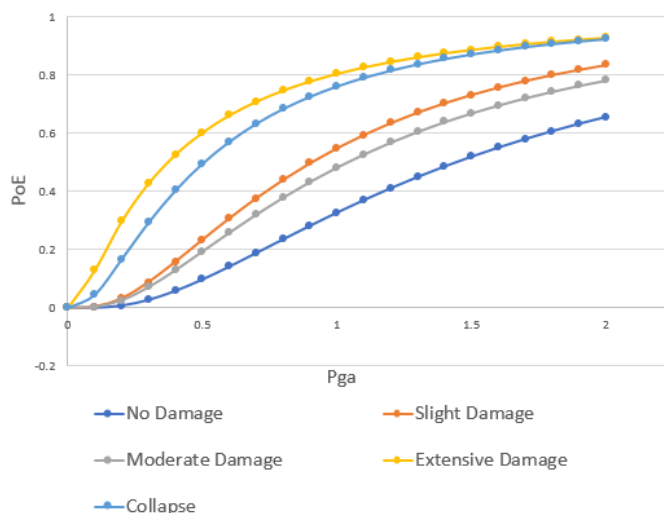


Fig. 13. Fragility Curve at Z- Axis

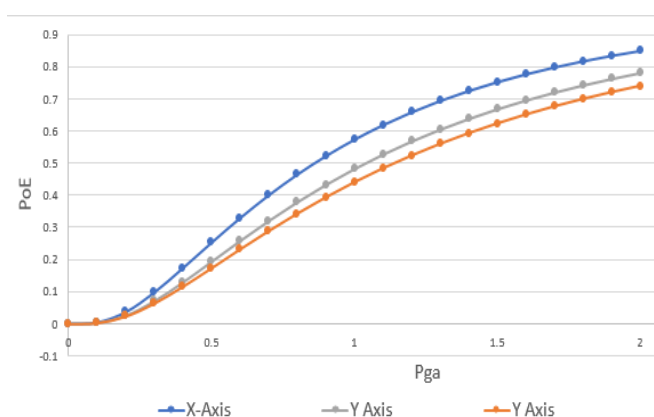


Fig. 14. Fragility Curve of Moderate Damage in Three Direction

Actual Sensor Readings

September 05, 2019 10:54am

Ground:

x	0.00196159g
y	0.002137g
z	0.00206172g

Structure:

x	0.00221014g
y	0.00192106g
z	0.00214517g

Threshold Values

Based from the PhiVOLCS Map Atlas, the threshold on the g round is:

x,y,z : 0.3g

At 10% probability of exceedance for moderate damage, the threshold on the structure are:

x : 0.3071g
y : 0.3725g
z : 0.35g

IV. Conclusion

Based from the result gathered, the actual reading are 0.00196159g on longitudinal, 0.002137g on transverse, and 0.00206172g on vertical direction, it indicates that the building is safe at its current ground motion state. This is due to the comparison of the actual reading to the peak ground acceleration from PhiVOLCS which gives a value of 0.3g.

The actual reading on the structure are 0.00221014g on longitudinal, 0.00192106g on transverse, and 0.00214517g on vertical direction. Comparing to the threshold obtained from capacity spectrum and fragility curves analysis, at 10% probability of exceedance on moderate damage, which are 0.3071g on longitudinal, 0.3725g on transverse, and 0.35g on vertical direction. The current acceleration experienced by the structure does not exceed the threshold which conclude that the structure is safe.

The threshold serves as an initial guide in helping the building owners and structural engineers to decide if it is needed to conduct further structural assessment on the building pre, during, and after an earthquake. The system starts from the structural assessment, installation of the sensor, up to the portal and evaluation of data, it will serves as a helping tool in conducting structural help monitoring of infrastructures in preparation for seismic events.

In addition to this, due to the difference of threshold values and sensor readings, deep research on the possible revision of the earthquake recording instrumentation requirements on the national structural code of the Philippines was recommended.

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