Proceedings of the Tenth Pacific Conference on Earthquake Engineering
Building an Earthquake-Resilient Pacific
6-8 November 2015, Sydney, Australia

Application of a Proposed Methodology on Performance-Based Assessment to a Reinforced Concrete Heritage Buildings in the Philippines

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ABSTRACT:

Methods developed for structural assessment and strengthening focuses on life safety and structural stability of existing buildings. Apparently, these methods have minimal consideration to the historical value that makes these heritage buildings unique and important. This study is an application of a developed methodology to a heritage building in the Philippines. The methodology considered the artistic assets of the heritage building, which is a significant part of its historical value. The artistic assets were considered by quantifying the artistic loss that the primary components, beams and columns, of the heritage building will incur after a predetermined seismic demand. The quantified performance of the building was based on the yielding of hinges of the beams and columns defined using FEMA 356 standards using pushover analysis in SAP2000. The performance was amplified by using importance factors to consider the artistic value of the components, by classifying each based on how it supports or carries the artistic details of the heritage building. The total damage incurred by the heritage building was represented by a damage index, which depends on yielding of hinges of all primary components after the predetermined seismic demand. The performance state of the heritage building was determined using a code-based performance criterion that depends on the yielding of the hinges of the beams and columns. The application of the methodology allowed the heritage building to be strengthened to a level that will enable it to endure earthquake with acceptable degree of artistic losses.

1 INTRODUCTION

1.1 Background of the study

The Philippines is home to hundreds of heritage structures including churches, houses and monuments. Taking into account the high risk of the Philippines to Earthquake, these structures are prone to structural damage or collapse considering that these were structurally designed using old codes, which has low consideration to seismic ground motions and some, are continuously deteriorating. Although guidelines were developed in the Philippines for conservations of heritage buildings, these focus only on the repair of architectural damage. These guidelines lack the ability to evaluate the effects of earthquake to the primary structural components that holds the artistic assets of the heritage building. Therefore, a methodology that can quantify the damage of artistic details held and supported by primary structural components of the existing and retrofitted heritage building upon the occurrence of different seismic demand can be an essential tool for heritage conservation. This can provide a support on the selection of a heritage-conservation-compliant retrofit system for strengthening the heritage buildings.

1.2 Related Literature

In order to protect heritage buildings Lagomarsino (2014) recommends that the focus should be in the improvement in methods of analysis and assessment procedures rather than improvement of intervention techniques. In his study, he suggested the use of pushover analysis to evaluate the heritage building due to the complexity of heritage buildings. Moreover, he suggests that due to the rarity of destructive earthquakes, heritage buildings should be strengthened to bare allowable damage instead of no damage at all but should be ductile enough that it would not collapse.

Heritage Buildings should be considered different from other buildings as suggested by Wenk and Bayer (2014), since it should consider not just the protection of occupant and the building conservation, but also the conservation of artistic assets. Moreover, they proposed that the performance state of the heritage building at different ground motions should be classified according to their importance. In their case, they proposed that the classifications in importance are as follows: international importance, national importance, regional importance, and local importance.

The study of Lakshmanan (2006) defined the vulnerability index as a measure of the damage in a building obtained from the pushover analysis. "*It is defined as a scaled linear combination of performance measures of hinges in the component, and is calculated from performance levels of the components at the performance point or the point of termination of the pushover analysis"* (Lakshmanan, 2006). He used Equation 1 to compute for the vulnerability of the building. Where N_i^c and N_i^h were the number of hinges in columns and beams, respectively for the *i*th performance range. These performance range refered to the, O-IO, IO-LS, LS-CP, CP-C, which were the status of the hinges in non-linear pushover analysis in SAP2000. He assigned 1.5 and 1.0 impact factor for columns and beams, respectively. He provided higher consideration to columns because these are the components supporting the structure during seismic ground motion. Weighted factor or component damage, α_i, are assigned per performance point in Table 1.

$$VI_{bldg} = \frac{1.5\sum N_i^c \alpha_i + \sum N_i^h \alpha_i}{N_i^c + N_i^h} \quad (1)$$

Table 1. Component Damage (Lakshmanan, 2006)

Performance range	α (component damage)
O-IO	0.125
IO-LS	0.375
LS-CP	0.625
CP-C	0.825
C	1.0

2 CASE STUDY: GALA RODRIGUEZ ANCESTRAL MANSION

The Gala Rodriguez Ancestral mansion (Fig. 1) was home to some of the prominent and well-respected citizens of Sariaya, Quezon. This house represents the history that Sariaya, Quezon has been through during the world war II and famine. Today this house is declared as a national treasure since it was declared by the National Historical Institute on 2008.

Figure 1. Gala Rodriguez Ancestral Mansion

3 APPLICATION OF PROPOSED METHODOLOGY

Presented in Figure 2 is the proposed methodology for the performance-based assessment of reinforced concrete heritage building and retrofit systems. This methodology was divided into five phases. The first phase was gathering the structural parameters for the development of the analytical model for phase 4. Original information regarding the heritage building would have been the best source, however, were not available. Destructive and non-destructive tests were conducted to collect the properties of concrete and configuration of the steel reinforcements. Traditional rebound hammer was performed on some of the columns and beams to get an average of the compressive strength. Core extraction was conducted to calibrate the collected values from rebound hammer. The configuration of the steel reinforcements were determined using rebar detector and cover meter. It was not possible to retrieve data regarding the steel reinforcement and so the default properties recommended by FEMA 356 (2000) were used. The applicability of US standards was assumed since structural codes were instigated only starting on the year 1976 in the Philippines. The first National Structural Code of the Philippines directly incorporates the American codes since there was no official code to be followed.

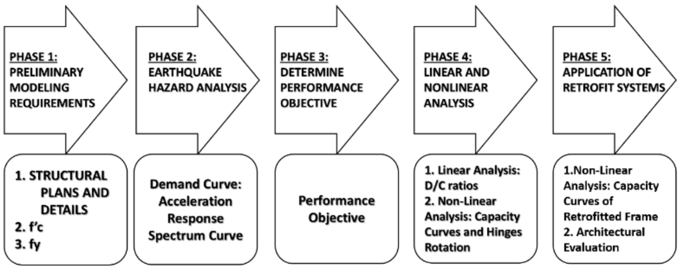

Figure 2. Proposed Methodology

The second phase defined the earthquake ground motion depending on the specified level of shaking with the given probability of occurrence that follows the ATC-40 levels of earthquake ground motions. The procedures developed by Uniform Building Code (1997) were used for the development of the demand curve where the result was in the form of Acceleration Response Spectrum Curve. This was characterized by the soil characteristics and nearness of the site to active faults. Three Earthquake Hazards was used, Service with 73 years return period (50%/50 Years), Design Earthquake with 475 return period (10%/50 Years) and Maximum Earthquake with 2,475 year return period (2%/50 years).

The third phase focused on determining the corresponding performance objective depending the historical importance of the building. The developed performance objectives by Wenk and Beyer (2014) for the PERPETUATE project was the basis in this proposed methodology (Tab. 2). Traditionally, performance objectives are assigned using only the serviceability and structural performance levels, however to give more emphasis to corresponding effect to the historical value the historical preservation performance level was added. The heritage buildings were classified into three: International, national and local importance. The performance objectives assigned to each are the combination of performance levels similar to those formed by FEMA 356 (2000) designated as Limited Objectives, Basic Objectives, and Enhance Objectives. The proposed performance objective suggests those with international and national importance shall follow an enhanced objective, while those with local importance should follow the basic objectives.

Table 2.Proposed Performance Objective

Proposed Performance Objectives					
		Performance Level			
	Structural Stability	No Damage	Slight Damage	Moderate Damage	Extensive Damage
Earthquake Hazard	Historical Preservation	Conserved	Restorable	Major Loss	Lost
Service Earthquake		Yellow	Red		
Design Earthquake		Dark blue	Yellow	Red	
Maximum Earthquake			Dark blue	Yellow	Red

Red	Local Importance
Yellow	National Importance
Dark blue	International Importance

The fourth phase involves the structural analysis of the heritage building. Linear dynamic analysis was initially conducted to capture the elastic behaviour of the structure using the FEMA 356 (2000) provisions using SAP2000, but will not be explained in this document. Nonlinear pushover analysis was performed using SAP2000 utilising those collected data from Phase 1 to develop an analytical model. The identified seismic hazards from Phase 2 were used to define the earthquake demands. The performance objective was decided based on the importance of the building in Phase 3. The beams and columns were assumed to experience ductile failure or flexural failure and were defined using the average of the modelling parameters and acceptance criteria from FEMA 356.

The yielding of hinges in SAP2000 was indicated by colored dots. Each of these colors represented a certain performance level either IO (Immediate Occupancy), LS (Life Safety) or CP (Collapse Prevention) from the hinge acceptance criteria and the 5-point modeling parameters (A,B,C,D, and E) of hinges shown in Figure 3. Observe that the performance level in SAP2000 corresponded with an increasing degree of damage from left to right. This was the reason why the component damage (α) in Table 1 was assigned with values increasing from O-IO at 12.5 % damage of the component to C (Collapse) at 100% which indicated the loss of strength of each component when subjected to seismic demands. The component damage (α) was used in the computation of damage index by representing the damage incurred by each component based from the yielding of hinges in non-linear pushover analysis in SAP2000.

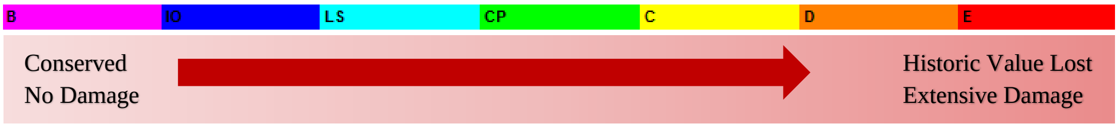

Figure 3.Performance Levels in SAP2000

To calculate the Damage index (DI), the number beam and column hinges (N_i) that yielded was multiplied with the corresponding Importance Factor (IF) and α. The product was divided by the total number of hinges, T, to obtain the damage index of the building for the designated seismic demand. This computation of DI was based on the study of Lakshmanan (2006) but used importance factors to represent the artistic value of the components on Tab. 3 instead of structural value. The general formula for computing the damage index (Eq. 4.7) is:

$$DI = \frac{\sum N_i IF_i \alpha_i}{T} \quad (2)$$

Where N_i is the sum of beams and columns hinges that yielded at the *i*th performance range and α is the corresponding component damage in Table 1 taken from the study of Lakshmanan (2006).

Table 3.Importance Factors

Component	Importance Factor (If)
Non-artistic Interior Beams –plain beams with or without paint and plaster	1.0
Artistic Interior Beams – beams with attached or grooved artistic details	1.25
Artistic/ Non Artistic Exterior Beams	1.25
Non-Artistic Interior Columns – plain columns with or without paint and plaster	1.5
Artistic Interior Columns – columns with attached or grooved artistic details	1.75
Artistic/ Non Artistic Exterior Columns	1.75

Moreover, this methodology assessed the performance state of the heritage building based on the fraction of components that reached these performance ranges per storey. To take into account the historical asset of each component, an importance factor, IF, depending on the attached artistic details defined in Table 3, was designated which in effect amplified the percent damage computed.

The performance state criteria in Tab. 4 from TEC-2007 (2007) served as the basis if ever the building has achieved the performance objective designated. This criteria was based on the hinges that yielded at the beams and columns. If the performance state failed to meet the designated performance objective based on this criteria, this indicates that a seismic retrofit shall be decided following the basic principles of heritage conservation, which is the fifth phase of the methodology.

Table 4.Performance State Criteria (TEC-2007)

	Performance States			
Structural Stability	**No Damage**	**Slight Damage**	**Moderate Damage**	**Extensive Damage**
Historical Assets	**Conserved**	**Restorable Losses**	**Major Losses**	**Lost**
Beams	All hinges at Operational status	10% of beams have hinges exceeding IO	30% of the beams have hinges exceeding LS	At most 20% of beams have hinges exceeding CP
Columns	All hinges at operational status	Limited to IO	Limited to LS	Limited to LS

4 PRESENTATION AND ANALYSIS OF RESULTS

4.1 Phase 1: Preliminary Modelling Requirements

Actual measurements were done to develop detailed structural plans of the heritage building. The front elevation of the heritage building is shown in Fig. 4. The yield strength of steel reinforcement that was used is the default value provided by ASCE 41(2013) for those building constructed during 1911-1959, which is 228 MPa. The summary of the modelling parameters are presented in Tab. 5. The over strength factor (R) was set to 3.5 to account for the Low Code Design taken from the study of Hernandez & Pascua (2012). The Low Code Design refers to the design method that assumes the elastic response of materials which is common for older buildings. The loads were taken from the National Structural Code of the Philippines of ASEP (2010).

Figure 4. Front Elevation

Table 5. Modelling Parameters

Compressive Strength of Concrete	17.13 MPa
Yield Strength of Reinforcement	228 MPa
Ultimate Tensile Strength of Reinforcement	380 MPa
R (over strength factor)	3.5
Structural System	OMRF
Dead Load Wall Load Super Imposed Dead Load	Self Weight +1.5 KPa 1.3 KPa 0.5 KPa
Live Load Roof Live Load	1.9 KPa 1.9 KPa + 0.6 KPa
Zone	IV (PGA = 0.4 g)
Soil Type	Type D (S_D)
Distance From Fault	X >15 km
Earthquake Lateral Force Definition	UBC 97 Code

4.2 **Phase 2: Earthquake Hazard Analysis**

A soil investigation report from a nearby building was used as reference to characterize the soil condition of the heritage building that characterized the soil at the site as a very stiff soil (S_d). According to this report, the site is located in seismic zone 4 whose peak ground acceleration is 0.4g. The UBC (1997) method for constructing the demand curve using seismic coefficients was used to define the earthquake demands for the building, which is based on the soil condition and nearness to active faults of the site. The design earthquake demand was defined using seismic coefficients (C_a and C_v) that are functions of the nearness coefficients (N_a and N_v). From the design earthquake, the maximum earthquake was defined as 1.5 times the design earthquake while the service earthquake was defined half of the design earthquake, which followed the ATC-40(1996) definition of seismic hazards. The summary of the coefficients are presented in Tab. 6.

Table 6. Summary of definition of Earthquake Demands

Seismic Hazard	Seismic Source Type	N_a	N_v	C_a	Cv
Service Earthquake	A	1.0	1.0	0.22	0.32
Design Earthquake	A	1.0	1.0	0.44	0.64
Maximum Earthquake	A	1.0	1.0	0.66	0.96

4.3 **Phase 3: Determine Performance Objective**

Since the Gala Rodriguez Ancestral Mansion was a declared national treasure it should follow the performance objective for those with National Importance which was defined as an enhance objective by FEMA 356 (2000) shown in Table 2.

4.4 **Phase 4: Non-Linear Analysis**

4.4.1 *Non-Linear Analysis*

The result non-linear analysis of the Gala Rodriguez Ancestral Mansion at the X-direction in Table 7 shows that the performance state has attained the designated performance objective. It can be observed that the heritage building has reached the designated performance objective for those with national importance and may not require strengthening.

Table 7. Performance State of Existing Heritage Building (X-Direction)

		Performance Level			
	Structural Stability	**No Damage**	**Slight Damage**	**Moderate Damage**	**Extensive Damage**
Earth-quake Haz-ard	**Historical Preservation**	**Conserved**	**Restorable**	**Major Loss**	**Lost**
Service Earthquake					
Design Earthquake					
Maximum Earthquake					

4.5 **Phase 5: Application of Retrofit System**

The proposed seismic retrofit system for the Gala-Rodriguez Mansion was called the Extended Frame (EF), which was a modification of the Concrete Encased Steel (CES) from the study of Taguchi et al., (2008). This retrofit system will be attached on selected components inside the heritage building instead of the proposed external application by Taguchi (2008) that would violate the basic principles of heritage conservation. This system was applied to strengthen the weak axis of the building at three different section (Grid 2, 3 and 5) of the heritage building, which was found critical from the Linear and Non-linear diagnosis of the building. The analytical model retrofitted with EF as shown in Fig.6 was also modelled using SAP2000. The hinges of the beams and columns were assumed similar to the definition of hinges of the original analytical model.

The pushover curves of the retrofitted and original analytical model are presented in Fig. 5. The performance state derived from yielding of hinges of the beams and columns of the retrofitted analytical model shows significant improvement compared from the original as presented in Tab.8. Significant improvement was also observed based from the decrease of damage index from 21.42% to 6.42% as presented in Tab.9.

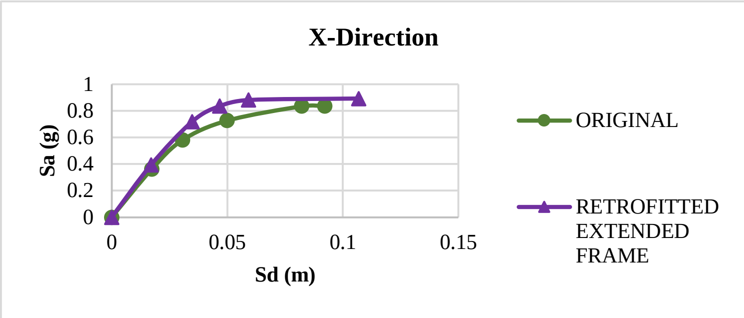

Figure 5. Comparison of Original and Retrofitted Heritage Building (X-Direction)

Table 8. Performance State of Retrofitted Heritage Building (X-Direction)

		Performance Level			
	Structural Stability	**No Damage**	**Slight Damage**	**Moderate Damage**	**Extensive Damage**
Earthquake Hazard	**Historical Preservation**	**Conserved**	**Restorable**	**Major Loss**	**Lost**
Service Earthquake					
Design Earthquake					
Maximum Earthquake					

Table 9. Damage Index before and after Retrofit

Earthquake Demand	Before Retrofit	After Retrofit
	X-Direction	X-Direction
Service Earthquake	1.54%	0.06%
Design Earthquake	3.97 %	3.77 %
Maximum Earthquake	21.42 %	6.42 %

5 CONCLUSION

A proposed methodology for the assessment and retrofit with consideration to the artistic assets was developed and applied to a heritage building in the Philippines. The artistic assets were considered from the primary supporting components or beams and columns of the heritage building. Each component was classified based on how it is supporting the artistic assets. The performance state was evaluated from a code based performance criteria, whether the model has satisfied the designated performance objective. The percent damage was computed per storey from the fraction of the yielding of hinges of beams and columns using non-linear pushover analysis. The percent damage of beam and columns per storey indicated the performance state reached. The global damage was represented by a computed damage index, which took into account the designated importance factors, and components damage based on the performance range reached by the hinges.

Heritage buildings could be assessed and improved by using careful methods. This study suggests that these methods should be able consider the artistic details that are vital part of the historical value of the building.

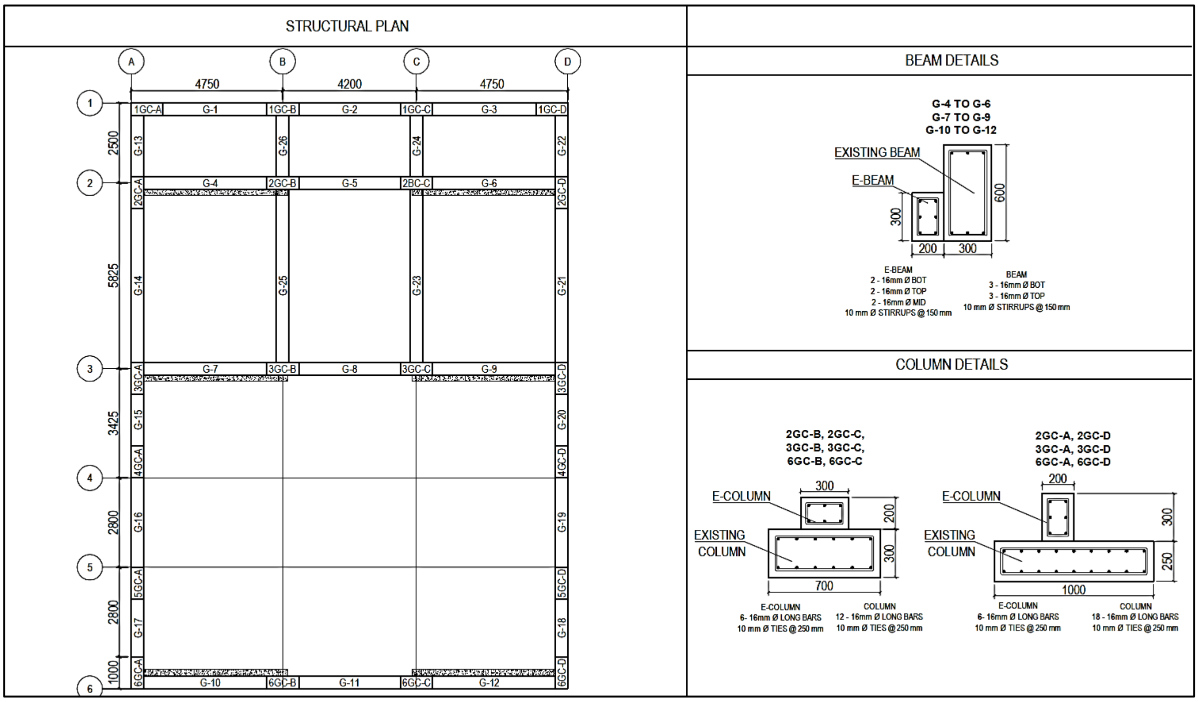

Figure 6.Details of Extended Frame at Ground Floor

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