EARTHQUAKE PERFORMANCE EVALUATION OF TYPICAL BRIDGE STRUCTURES DESIGNED BY A FORCE-BASED DESIGN METHOD IN THE PHILIPPINES

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ABSTRACT

The Philippines is an archipelagic country consisting of large and small islands. It is essential to have link structures like bridges. After a disaster like earthquakes, bridges must be maintained to give way for an effective rescue operation and transporting of relief goods to the affected area. Most of the bridges in the Philippines were built on designs using the old code, which is based on the traditional approach, the Force-Based Design Method. In this method, demand and capacity are compared in terms of forces, and the displacement is verified at the end of the design process. Currently, the Displacement-Based Design method is the new approach in evaluating the seismic performance of a bridge, which is more precise in terms of assessing damages, in which the seismic displacement is the primary criterion in this approach.

In this study, the author tries to apply the Displacement-Based Design methods to an existing typical bridge in the Philippines to evaluate the damaged deformation capacity by Nonlinear Dynamic Analysis (Time History Analysis).

In conclusion, the author extracts some earthquake displacement response characteristics of typical bridges in the Philippines, which have not been evaluated so far and clarifies the merits of the displacement-based design method.

Keywords: Force-Based Design, Displacement-Based Design, Displacement.

1. INTRODUCTION

The Philippines is one of the countries located in the Pacific Ring of Fire, and it is vulnerable to disasters like earthquakes. Regarding transportation and assistance, bridges play an essential role after disasters happen. When large earthquakes happened in the Philippines in the past, most of the existing bridges were damaged due to large deformation or displacement of the columns, resulting in collapse and unseating of the superstructure. For many of the existing bridges in the Philippines, the seismic design was evaluated with old specification and done by the traditional approach called the Force-Based Design Method (FBD) where the force is the main criterion in evaluating the demand and capacity of the component of structure; therefore, displacement was not checked and also the seismic performance of

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bridges could not be evaluated. The linearly elastic procedure is effective as along as the structure performs within elastic limits. Recently there is a new approach in evaluating the seismic performance; this method is called the Displacement-Based Method Design (DBD). Under this method, the primary criterion is based on displacement, where damage can be checked better (Priestley 2000). The Displacement-Based Design Method is more reliable to identify the limit states that cause damage, leading to collapse, and in other cases, the results are more efficient in designs against collapse.

2. TARGET STRUCTURE AND APPLIED DESIGN METHOD

The target structure is shown in Figure 1. was designed using, DPWH Design Guidelines, Criteria and Standards, 2004 edition and DPWH Department Order No.75, Series of 1992 for seismic design. The DPWH Design Guidelines, Criteria, and Standards, 2004 edition adopt the concept of AASHTO Standard Specification for Highway Bridges, 19th Edition, 2002.

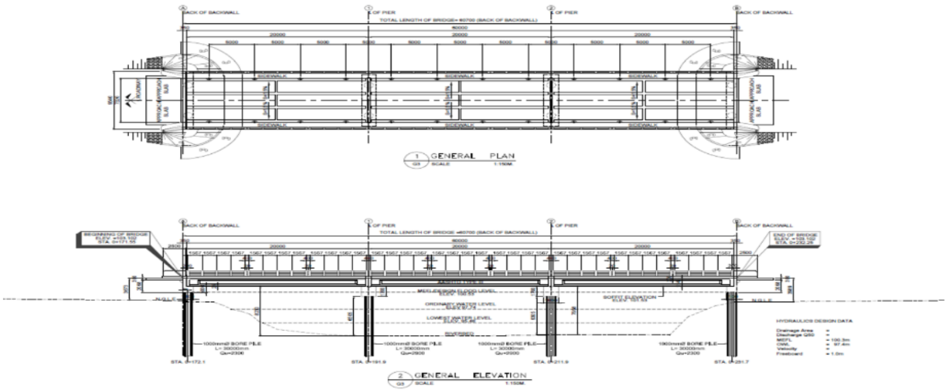

Figure 1. General Plan and Elevation of the target bridge.

The target structure considered in this study is a typical bridge structure commonly used in the Philippines. The bridge structure adopted in this study is located in the southern part of Luzon. This bridge crosses a river to connect two significant barangays of the municipalities. The bridge is a three-span prestressed girder bridge with a total length of 60.80 linear meters with seat type abutments. It is a two-way bridge with a total width of 9.34 meters with shoulders. The bridge is supported by two circular columns, which are confined columns on bored pile foundation. The diameter of the column is 1.0 meter, the unsupported length is 7.35 meters, and 9.95 meters is the height from the bottom of the column to the center of the superstructure. The total weight W, supported by the columns, is 6690 kN. The column is reinforced longitudinally with deformed bars whose diameter is 18 pcs – 25 mm and with reinforcement spirals whose diameter is 16 mm. They are used to confine the concrete core, with a space of 70 mm at the plastic region and 100 mm at the center portion of the pier.

In computation of superstructure and substructure weight, we consider 24 kN/m^3 for concrete weight ratio and 28 Mpa for the Compressive strength of concrete for cast in place concrete, 276 Mpa for Reinforcing Steel Yield Stress for Grade 40 and 414 Mpa for Grade 60.

The bridge properties are used as a reference in the creating of analyses model for this study using the Japan Road Association Specifications for Highway Bridges, Part V, Seismic Design, 2002 (JRA, 2002). The target structure considered in this study is only one of the typical type of bridge structure in the Philippines. In this study will focus only on the effect for RC piers of the bridge, and it will conduct analyses with a condition of fix support at the bottom of the pier.

3. SEISMIC RESPONSE ANALYSES ON TARGET BRIDGE FOR THIS STUDY

The objective of this chapter is to evaluate the seismic performance of an existing bridge that is typical in the Philippines using the Displacement-Based Method to evaluate the effect on the nonlinear displacement in the bridge structure. The bridge is a three-span bridge supported with two columns pile bent pier and abutment. For this evaluation, nonlinear dynamic analysis (time history analysis) will be used to evaluate the bridge model**.**

3.1. Outline of the Analysis by Displacement-Based Design Method

In the Displacement-Based Design Method, the main philosophy used in this approach is that the structure in the seismic region can be designed on specific displacement. This specific displacement may be characterized by either serviceability or an ultimate criterion. This criterion is likely to be defined by strain limits, which can be related to displacements or drifts of the structure geometry in both cases. (Kowalsky et al. 1995). For the Displacement-Based Method, we need to evaluate deformation limit, and deformation response since it predicts the response displacement.

When inelastic behavior is expected, linear static and linear dynamic analyses cannot be reliable to quantify structural performance precisely; therefore, nonlinear methods must be used. In this study, the nonlinear dynamic analysis, often called the "time-history analysis" is used to evaluate the nonlinear deformation capacity of the system and the numerical model is according to Japan Road Association Specification for Highway Bridges, Part V, March 2002 (JRA, 2002).

3.2. Methodology and Analyses Model

The objective of this analysis is to evaluate the nonlinear earthquake response displacement of the target structures. The following steps were carried out:

1. Evaluation of the Force-deformation relationship
2. Determination of the Limit State for Seismic Performance evaluation.
3. Execution of Nonlinear response time history analysis.
4. Consideration of Seismic Performance based on Capacity Spectrum Method

The bridge structure was modeled as a three-dimensional finite element model with six degrees of freedom at nodes, as shown in Figure 2.

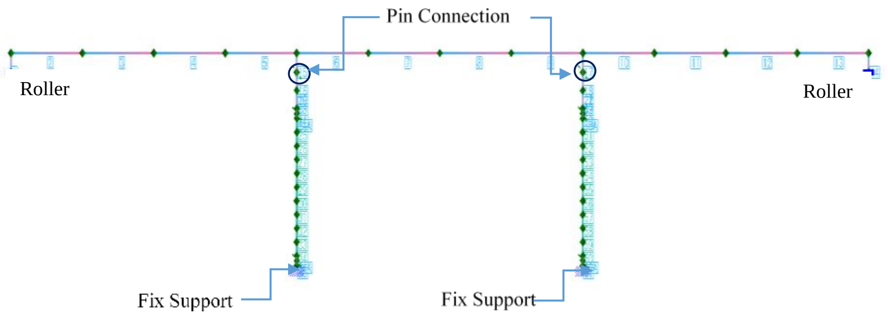

Figure 2. Analyses Model.

3.3. Seismic ground motion

Three records of waveform were selected since it is preferable to use as the input earthquake ground motion as recommended by the Specification of Highways Bridge of Japan Roads Association (JRA, 2002) and it is recommended when time history response analysis is used as dynamic analysis method, it is specified that accelerogram made up of past strong earthquake motion records must be amplitude to be adjusted so that the characteristics of acceleration response spectra in case of 5% damping ratio of seismic waves on the base ground surface must match the standard acceleration spectra.

4. ANALYSES OF THE RESULTS

4.1. Time History Analyses results

In these results, the artificial earthquake ground motions of the Philippines design ground motion are presented.

The result of the natural period frequency of the bridge is shown in Table 1; this natural period of a bridge is one of the important parameters to check the elastic response acceleration of the bridge.

Table 1. Natural Time period and frequency of the bridge in this study.

Eigenvalues Analysis	Tn (sec)	Longitudinal	1.12
	ω (hz)		0.85
	Tn (sec)	Transverse	0.15
	ω (hz)		6.54

Table 2 shows the result of the response displacement and the limit displacement of the bridge model. It shows that maximum response displacement is less than the allowable or the limit displacement, which indicates the model bridge is safe.

Table 2. Response Displacement at top.

			Philippine Level 2 EQ.	
			Tohoku Phase	**Kobe Phase**
Displacement	Yield	δy (mm)	139	139
	Limit State 2	δls2 (mm)	493.38	493.38
	Maximum (Response)	δmax (mm)	288.00	325.34
		Remark	OK	OK

Table 3 showed that the residual displacement calculated by the JRA method (JRA, 2002) is in the allowable limit for the Tohoku phase, but it exceeds the allowable limit for the Kobe phase.

Table 3. Residual Displacement at top.

			Philippine Level 2 EQ.	
			Tohoku Phase	**Kobe Phase**
Residual Displacement	Residual	δR	90.7	112
	Allowable	δRA	99.5	99.5
		Remarks	OK	NG

Table 4 shows the result of the shear strength of the reinforced concrete pier. By assessing the shear strength of the concrete pier, the failure mode of the reinforced concrete can be evaluated. As the results show, the shear strength is greater than shear forced. Therefore, there is no shear failure in the pier of the bridge model.

Table 4. Pier Shear Strength.

			Philippine Level 2 EQ.	
			Tohoku Phase	**Kobe Phase**
Pier Shear Strength	Shear Force (kN)	S	196.73	196.71
	Shear Strength (kN)	Ps	317.66	386.23
		Remark	OK	OK

4.2. Evaluation based on Capacity Spectrum Method

The Capacity Spectrum Method (CSM), will compare the strength capacity of a structure to the demands of earthquake represented by response spectra (Freeman et al.,1978) (Otani et al., 2000). Response spectra represent the demands of the earthquake. Linear elastic response spectra, assumed at 5% damping, are adjusted to represent the effects of nonlinear response by substituting higher damped response spectra to account for the hysteretic nonlinear response of the structure.

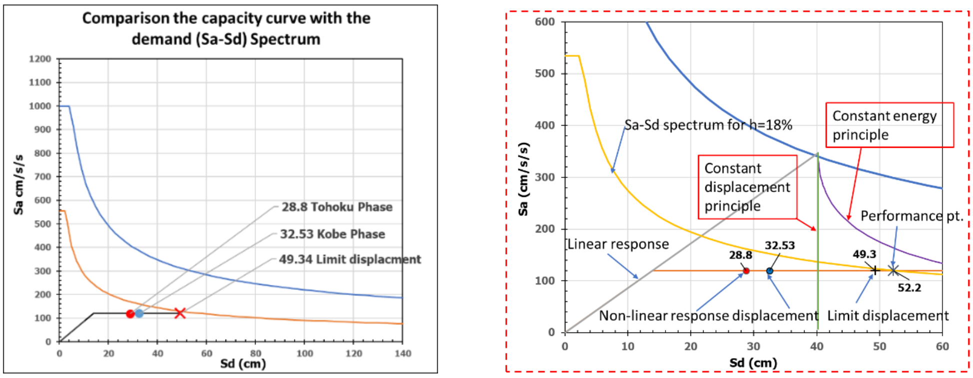

Figure 3. Results of Capacity Spectrum Method.

4.3. Evaluation result of revised model

The result of the evaluation of the revised section for Case 1 (Diameter:1.5m, Number of steel bars 36pcs-32mmϕ) and Case 2 (Diameter:1.5m, Number of steel bars 24pcs-32mmϕ), respectively shows that the revised section satisfies the demand spectrum curve.

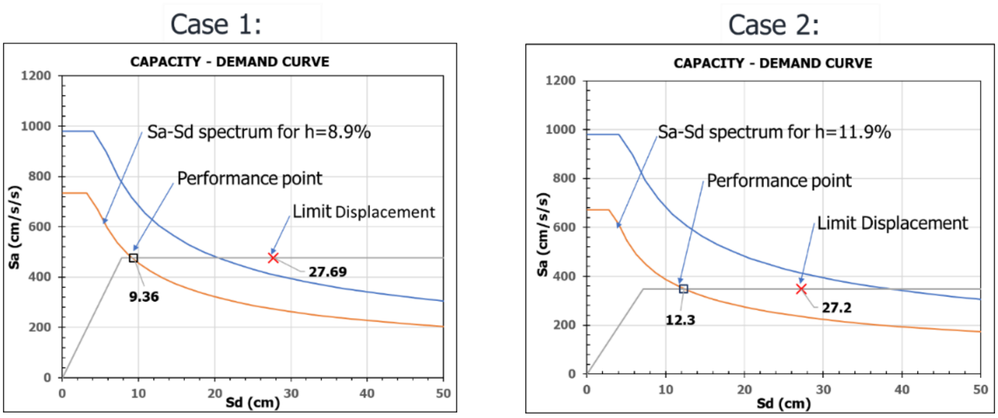

Figure 4. Results of CSM for revised section.

5. CONCLUSIONS

Using a new method like the displacement-based method in evaluating the earthquake performance of bridge structures, the displacement is the main parameter, which is more precise in terms of assessing damages. After examining the results of the nonlinear time history analysis, conclusions are as follows:

1. The results of the time history analyses showed that the response displacement did not exceed the limit displacement. It means that the target bridge will not collapse for severe earthquake expected by the seismic code of the Philippines.
2. Although the response displacements predicted by the capacity spectrum method corresponded well to those by the time history analyses, the predicted value exceeded the limit displacement.

3. From the above second results, the author considered that it would be better to make the safety of the target bridge higher and proposed the revised sections.
4. The results of the capacity spectral method showed the response displacements of the bridge whose section was revised became smaller than limit displacements.
5. The revised models also satisfy the current seismic code of the Philippines, which was recently revised in 2013. At this code revision, the R-factor was reduced to 5 to 3 with the same type of the bridge
6. We should evaluate the ability of the bridges to return to their original position as well as the deformation capacity for rapid recovery after earthquakes. The residual displacements correspond to such ability. The results of this study showed that the residual displacement is in the allowable limit for the Tohoku phase, but it exceeds the allowable limit for the Kobe phase.

We can express the limit states such as immediate occupancy, life safety, collapse, etc. by the corresponding limit displacements. By comparing such limit displacements with an earthquake response displacement, we can precisely predict damage aspects of the structure and assess its seismic performance.

The limit displacements for the structural design reflects specifications and details of each structure which structural engineers adapt flexibly under various construction conditions. Using such parameters, we can evaluate the seismic performance of the structure according to its unique characteristics. This fact may enable us to extend the design freedom.

Also, by focusing on residual displacements of a structure, we can evaluate the functionality or the reparability of the bridge after earthquakes.

And, the author considers that we need the following items to implement the DBD efficiently.

1. Technical guideline to provide how to evaluate force-deformation relationships of a structure and to determine limit displacements which correspond to some limit states.
2. Practical design computer software, which has functions to evaluate force-deformation relationships from specifications and details of a structure and so on.

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