COMPARING DESIGN TECHNIQUES FOR EARTHQUAKE LOADING ON BRIDGES USING JAPANESE METHOD AND PAPUA NEW GUINEA METHOD

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ABSTRACT

A comparison of some aspect of Japanese and the Papua New Guinea (PNG) method for determining seismic loading on Bridges was done. The areas looked at include a review of the history of the development of the Japanese Seismic Code based on lessons learned from the past large earthquakes including the 1923, Great Kanto Earthquake, the 1964 Niigata Earthquake, the 1978 Miyagi-ken Oki, the 1995 Hyogo-ken Nanbu Earthquake and the 2011 Great East Japan Earthquake. The study also involved comparing the standard acceleration response spectra for both countries based on the 1985 PNG Code and the 1996, 2002 and 2012 version of the Japanese code and the evaluation of an existing Bridge Pier in PNG using the Japanese Method. A very brief comparison was also done on seismic restrainers used in Bridges in PNG and the reinforcement detailing near the plastic hinge zone of the circular column used in the bridge pier and the section details was also compared with the detailing arrangement as specified in the English version of the 2002 Japanese Design Specification of Highway Bridges Part V. Seismic Design. The findings which include (1) basic standard acceleration spectrum for seismic design in PNG was only suitable for normal earthquakes whilst the Japan Code allows for both normal earthquakes as well as larger scale earthquakes (2) difference in steel reinforcement arrangements for circular sections (3) termination of starter reinforcement bars for the pier columns in the bridge evaluated being located in the plastic hinge zone (4) sufficient strength, displacement and ductility capacity in the bridge pier designed according to PNG code were then presented in the report.

Keywords: Bridge, Seismic Loading, Reinforcement Details, Pier Columns.

1.INTRODUCTION

PNG is seismically active with the Pacific plate and the Indo Australian Plate colliding with each other and three smaller tectonic plates in the middle also colliding with each other and also colliding with the major tectonic plates. The top 10 major earthquakes range from Mw 7.6 to Mw 8.1. Therefore the study of earthquake engineering and consideration for earthquake loading on building and bridge structures is important in PNG. In this study, comparison was made on some aspect of the both design codes with

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more focus on the standard acceleration response spectrum and the evaluation of an existing pier in a bridge in PNG using the Japanese method for strength, displacement capacity and ductility capacity. The study also briefly looked at the PNG code, 'Earthquake Engineering for Bridges in PNG', which have 3 short chapters and 8 appendix and when compared to the Japanese code, the PNG code only caters for smaller earthquakes. A brief discussion on the seismic restrainers specified in the PNG code and the seismic detailing of reinforcement the circular column section and the termination of the starter bars and the location of the plastic hinge was also discussed and comparison was done against the Japanese code.

2.DATA

The data used in this study was from the seismic code from both Japan and PNG and the Design Drawings for Warangoi River Bridge. The properties of concrete and steel used in the calculations are briefly presented below in Table 1 and Figure 1;

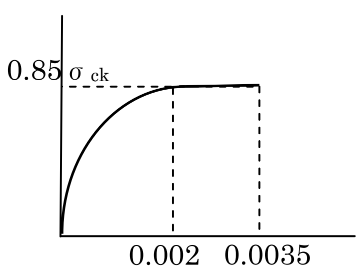
Table 1 –Properties of Concrete and Steel Reinforcing Bars used in the Evaluation

(1) Concrete			**(2) Steel Reinforcing Bars**		
Design Compressive Strength	f'_c	25MPa	Yield Strength	f_y	500MPa
Young's Modulus	E_c	$2.53x10^4$MPa	Yield Point of Confining Reinforcement	σ_{sy}	345MPa
			Young's Modulus	E_s	2.0 x 10^5MPa

Stress-strain relations

Shown below in Figure 1 are the stress strain curves adapted for the concrete and steel reinforcement bar used for the pier column considering the circular concrete column is not confined. The maximum strain of concrete is 0.0035. A bilinear model was adapted for steel reinforcing bars as shown in Figure 1(2) below and other strength properties of concrete and steel reinforcing bars are shown in Table 1 above.

(1) Concrete



(2) Reinforcing bar

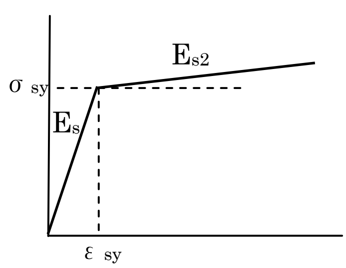


Figure 1(1) and 1(2) Stress Strain Curves used for Calculation Strength Displacement and Ductility Capacity of the Pier.

Structural Model Used.

The structural model adapted for analysis in line with the guidelines from the Japanese code is show in Figure 2 below. In this model the structure is fixed at the pier in the middle and

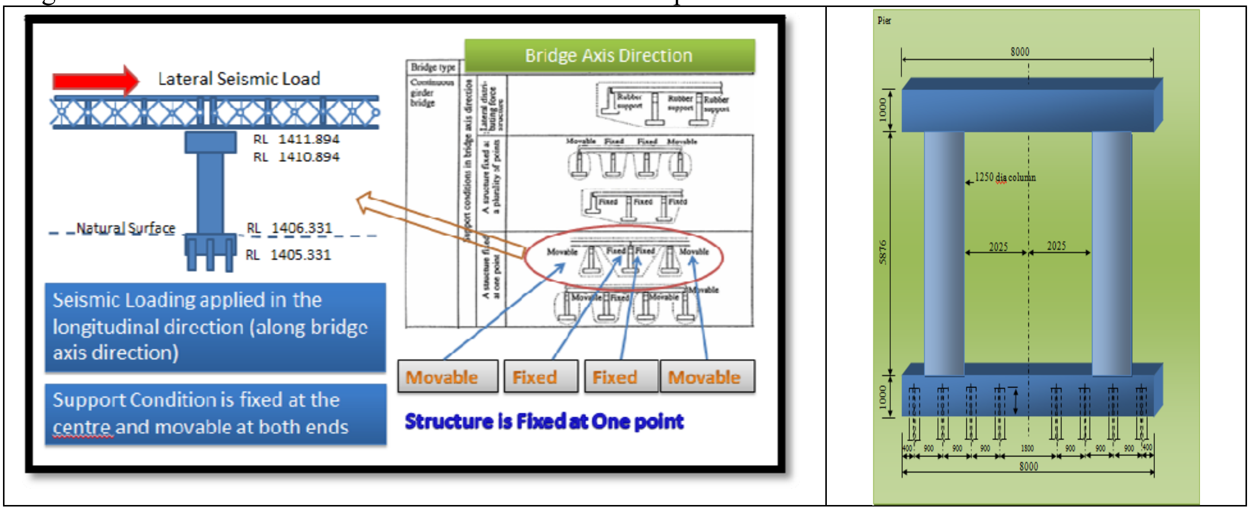


Figure 2 – Analysis Model Adapted Assuming Loading in the Bridge Axis Direction and Support Condition adapted.

The standard acceleration design spectrum for determining seismic coefficient in PNG Code is not shown here due to space limitation but presented in Figure 3 below are standard acceleration spectrum from the Japanese code used to check the pier for its adequacy for large scale earthquakes.

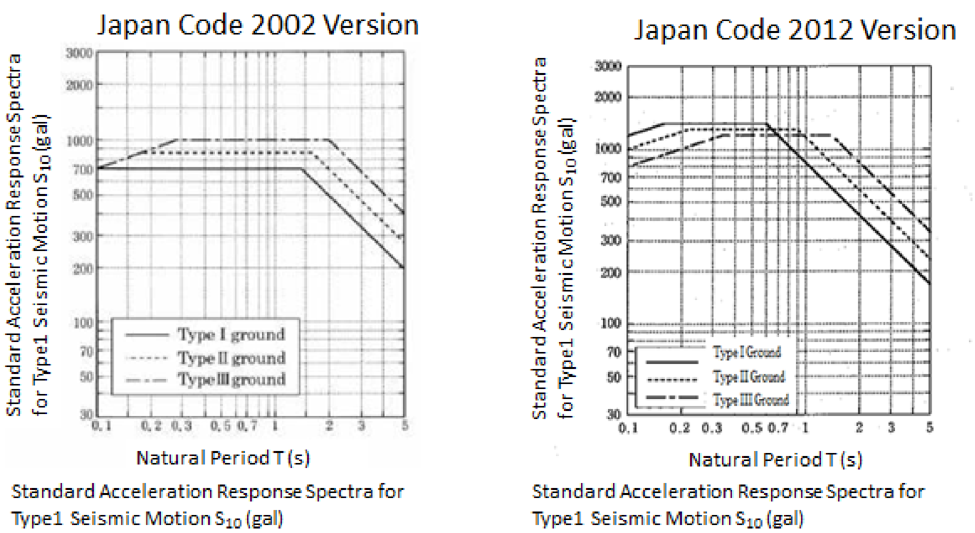


Figure 3 –Standard Acceleration Response Spectrum for 2002 and 2012 used in Evaluation of the Bridge Pier in this Study

3. THEORY AND METHODOLOGY

Loading on Bridges consist of primary loads and secondary loads. The Primary Loads consist of Dead load (D), Prestressed Force(PS), Effects of Creep of Concrete(CR),Effect of Drying Shrinkage of concrete (SH),Earth Pressure(E),Hydraulic Pressure(HP),Buoyancy or Uplift(U)

Earthquake loading is considered as a secondary load.
In this case the only the horizontal load seismic loading is considered based on the fact that it is highly unlikely for combination of above primary loading and the seismic loading to occurred at the same time. The seismic loading is calculated is taken as the mass of the superstructure multiplied by the acceleration induced into the structure due to earthquake and the formulae specified in the PNG and the Japan Codes were used as follows;

$S_I = C_z C_D S_{10}$ ……………………………………………………………………………………..(3)
$S_{II} = C_z C_D S_{II0}$……………………………………………………………………………………..(4)

where S_I is the Type I acceleration response spectra, S_{II} is the Type II acceleration response spectra, C_z is the zone modification fact, C_D is the damping factor for damping ratio, S_{10} is the Type I-Standard Acceleration Response spectra and S_{110} is the Type II standard response acceleration response spectra

V =C*I*M*Wt ……………………………………………………………………………………..(5)

Where V is the total design base shear force in the direction being considered, C is the basic shear coefficient for the appropriate zone, period and site condition, I is the importance factor, M is the material factor, Wt is the total weight of the structure subject to the seismic acceleration, taken as the dead load plus the super imposed dead load.

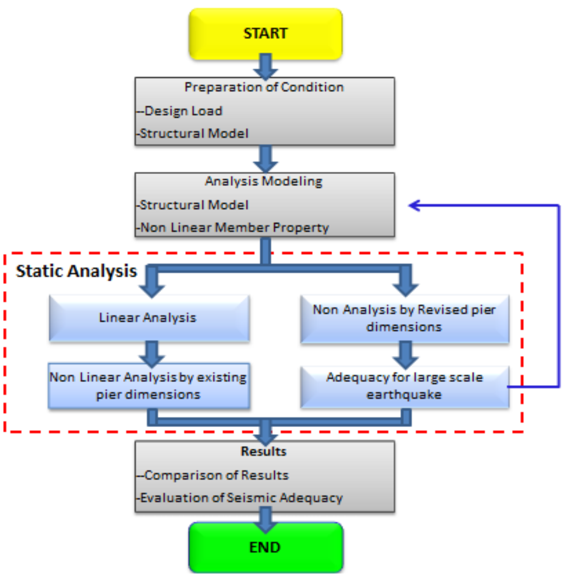


Figure 4 Flow Diagram Showing the procedure used in the evaluation of the pier

The method or procedure followed in this evaluation was to create the mode based on the structural drawing of the existing bridge structure and do a linear static analysis and a nonlinear static analysis using the existing pier dimensions and evaluate seismic adequacy.
The column sections were than revised and a nonlinear analysis was again carried out to determine the adequacy for large scale earthquakes.
The results of load deformation and moment rotation relationships were obtained and used in calculating the strength, the deformation and the ductility of the column using the Japanese method as specified in the Japan Seismic Code for Bridges 2002 English version.

4. RESULTS AND DISCUSSION

4.1. Loading Deformation Chart.

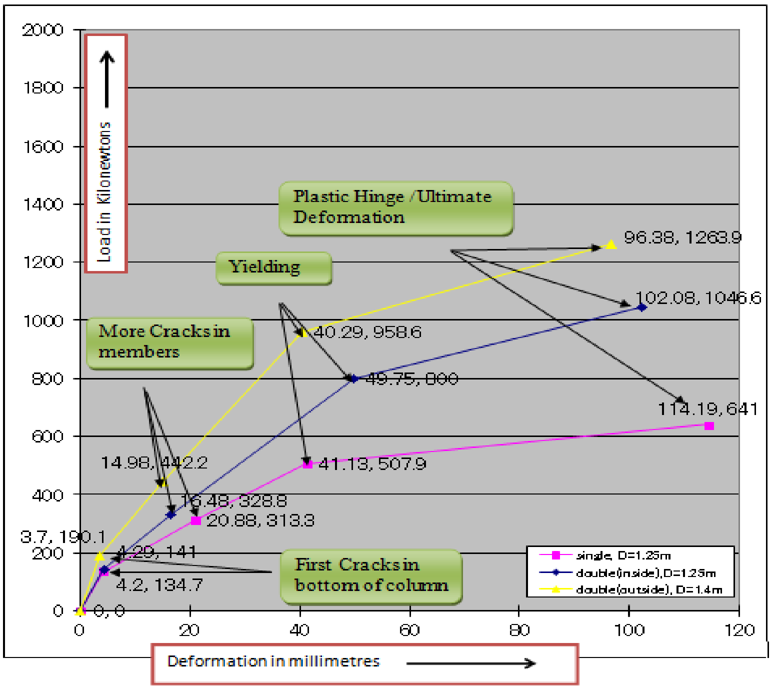


Figure 5 on the left shows the load and deformation relationship obtained using the 'non pier' which is a nonlinear analysis software developed by Chodai Company of Japan to analysis piers. The result below shows the case where the confinement effect of the hoop reinforcement was not considered. A similar analysis was also done which include confinement effect of the hoop reinforcement placed at 75mm spacing along the pier column. The results with the confinement effect consideration indicate better results and confirms that pier to have sufficient strength and deformation capacity as shown in brackets in Table 2

Figure 6 – Load Deformation Chart for both 1.25 Diametre single and double reinforcement and 1.4m diameter double reinforcement

Table 2. Results for Evaluations of Strength and Deformation of Warangoi Bridge Pier

Description	Single, D =1.25m	Double, D =1.25m	Double D =1.4m
Maximum Deformation from Non Linear Analysis	114 mm (251 mm)	102 mm (262mm)	96 mm (206mm)
Maximum Load from Non Linear Analysis, Pu	641kN (657.5kN)	1046kN (1138.3kN)	1263kN (1359kN)
Calculated Deformation, δe	94mm (148mm)	93.5mm (170mm)	84mm (135mm)
Ultimate Capacity, Pa	1162.41kN (1825.9kN)	1503.2kN (2685.4kN)	2000kN (3175kN)

Notes: Single in the table above means single layer of reinforcing bar arrangement and double means double layer of reinforcing bars arrangement and D, is the diameter of the pier column.
There original columns were designed using the PNG code and the evaluation was done using the Japanese Code 2002 English version but also used the 2012 standard acceleration spectrum for three case as shown in Table 2

5.CONCLUSIONS

In this study a comparison was done on the history and development of seismic design for bridges in Japan and PNG and the lessons learned for damages to bridge structures due to large earthquakes. A case study was also carried on an existing bridge pier which consists of two 1.25m diameter columns of 5.876m and supported at the base by a pile capping and connected at the top by a column cap which supports the superstructure as shown in Figure 2. The pier was evaluated for strength, deformation and ductility capacity in the longitudinal direction. The results obtained indicated that the revised column section with the increased diameter from 1.25m to 1.4m with double layers of main reinforcement and hoop spacing of 75mm would meet the requirements of the large and rare inter-plate earthquakes without consideration for confinement effect.

However the existing 1.25m diameter columns of the existing pier columns with single reinforcement and with consideration of confinement effect due to the shear reinforcement spaced at 75mm was found to be adequate to withstand the strong ground acceleration such as the Great East Japan Earthquake.

The only weakness found in the column was the termination of the starter reinforcing bars very close to the plastic hinge region.

6.RECOMMENDATION

In this study, it is recommended that special considerations should be given in making sure proper detailing of the reinforcement and also detailing of seismic restraining devised to prevent undesirable failures such as pulling out of reinforcement due to insufficient development length.

Inclusion of Level 2 or strong ground acceleration spectrum in the code based on recorded strong ground motion is also recommended for the PNG Code.

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8. REFERENCES

Earthquake Engineering for Bridges in Papua New Guinea, Department of Works 1985

Bridge Design Brief, Department of Works 1990.

Hollings J.P. 1971, “A Report for Earthquake Engineering for Bridges in the Territory if Papua New Guinea”.

Hoshikuma, Jun-ichi, Power Point Presentation on Japan History of Design Specification of Bridges and Bridge Damage Pattern, Chief Researcher of Centre for Advanced Engineering Structural Assessment and Research (CAESAR) –Public Works Research Institute.

Junichi Sakai, Junichi Hoshikuma and Shojiro Kataoka, Revision of Japanese Seismic Design Specifications for Highway Bridges Based on Knowledge Derived from Recent Earthquakes and Research Accomplishment, 7th National Seismic Conference on Bridges & Highways, Paper No.118, Oakland, CA, USA, 2013.5.

Specification for Highway Bridges –Part V Seismic Design, Japan Road Association March 2002