SEISMIC PERFORMANCE OF SULTAN AZLAN SHAH BRIDGE IN PERAK UNDER LOW EARTHQUAKE GROUND MOTION

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ABSTRACT :

In recent years, Malaysia is more aware of the seismic effect on their structures because the tremors were repeatedly felt over the centuries from the earthquake events around Malaysia. Most bridges in Malaysia do not take earthquake loadings into structural design consideration. Therefore the seismic structural vulnerability is very important in order to recognize the performance of the bridges. The seismic analysis for bridges will be conducted as linear and nonlinear problems. In this analysis, Sultan Azlan Shah Bridge in Perak which consists of 5 spans (360 meters) was modeled using two dimensional and three dimensional concepts. The site specific analysis will be performed to determine the earthquake loading (e.g. surface time history and design response spectrum) using borehole data. Design response spectrum will be constructed using IBC2000 modification. The seismic analyses conducted were vibration analysis, time history analysis, response spectrum analysis and damage inelastic analysis. Free vibration analysis presented the periods and mode shapes of the structure while time history and response spectrum analyses considered the applied forces on the deck and piers. Damage inelastic analysis showed the critical part of the bridge structural failure under several peak ground accelerations (PGA). It can be concluded that Sultan Azlan Shah Bridge is safe under earthquake loading when subjected to local site effect of surface acceleration at 0.161g. The bridge started to show initial cracking at 0.25g and collapsed at 0.32g.

KEYWORDS: Site specific, free vibration, Time history, response spectrum and inelastic damage analysis

1. INTRODUCTION

Most bridges in Malaysia do not take into account earthquake loadings in the structural design consideration, even though the effects of earthquake are often felt in peninsular Malaysia. Thus, the effects cannot be completely ignored, especially for critical structures such as bridges. In this paper, the seismic performance of Sultan Azlan Shah Bridge in Perak was investigated

2. RESEARCH OBJECTIVES

The overall objective of this phase of the study was to evaluate the seismic response of Sultan Azlan Shah Bridge with the emphasis on the two and three-dimensional effects of ground excitation. Among the objectives are;

(i) To perform 2D and 3D modelling analysis to investigate the seismic response of Sultan Azlan Shah Bridge in the longitudinal direction;

(ii) To determine the time history at surface and construct design response spectrum for Sultan Azlan Shah Bridge; and

(iii) To determine the seismic response of the bridge under earthquake ground motion at different intensity levels, from the initial failure stage up to the collapse level. At this stage, the results would be able to show the critical portions of the bridge under different earthquake ground motions (PGA).

3. BACKGROUND OF SULTAN AZLAN SHAH BRIDGE

Sultan Azlan Shah Bridge is the main bridge in Perak which crosses the Perak river. The bridge is a segmental prestressed box girder concrete bridge which has 5 spans bridge and is approximately 360 meters long and 41.5 feet (12.5 meters) wide and will be analyzed to withstand earthquake and all other anticipated loads. It consist of five spans supported by 4 intermediate piers and two abutments (Figure 1)

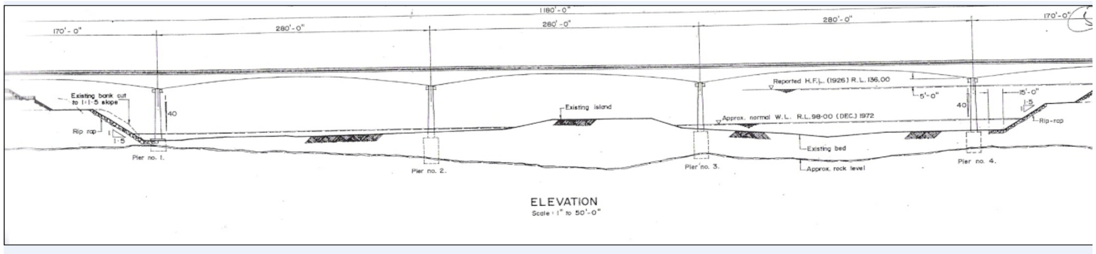

Figure 1 Elevation of Sultan Azlan Shah Bridge

Sultan Azlan Shah Bridge is a concrete segmental box girder which has different depth for every segments. Figure 2 shows the cross section of Sultan Azlan Shah Bridge.

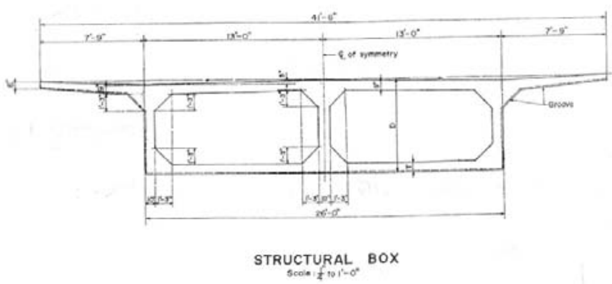

Figure 2 Deck cross section of Sultan Azlan Shah Bridge

4. LOCAL SITE EFFECT ANALYSES

Soil data were collected from existing soil investigation (SI) of the bridge. The shear wave velocity (VS) were obtained by converting the N-SPT value from Standard Penetration Test to shear wave velocity using empirical formula proposed by Ohsaki and Iwasaki (1973), Imai and Tonouchi (1982) and by averaging those two formulas. Based on analysis, the VS-30 of BH-7 is 262 m/s, respectively. Based on these results, generally the site can be classified as stiff soil or site class D (SD) in accordance with 1997 UBC. Based on macrozonation study (Figure 3), the peak ground acceleration (PGA) at the bedrock for 500-year return period of earthquake is 0.073g (73 gal). The results of analysis can be seen in Figures 4. Generally, the accelerations at the bedrock were amplified on the surface in the range of 2.2-2.4. The predominant periods of the spectra generally occur in the range of 0.3 – 0.8 second. Time history at the surface can be seen at the Figure 5.

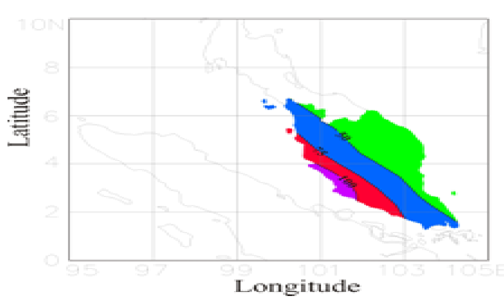

Figure 3 Macrozonation map for 500 years return period (Azlan et al, 2006)

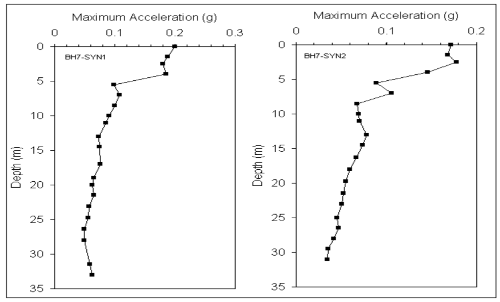

Figure 4 Result of ground response analysis

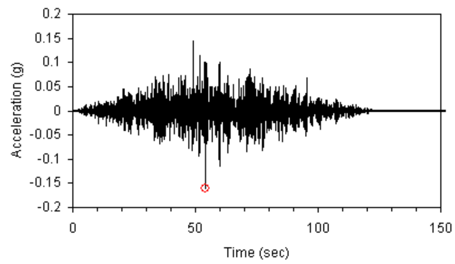

Figure 5 Time history at surface (0.161g) for RapidKL elevated span Bridge

Response spectrum analysis used IBC2000 to construct the design response spectrum. The design response spectrum can be seen in Figure 6.

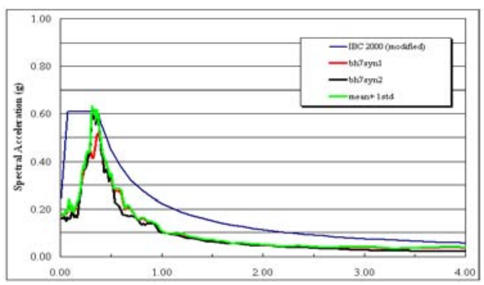

Figure 6 Design response spectrum using IBC2000 (modified)

5. SEISMIC ANALYSES

5.1. Two Dimensional Analyses of Sultan Azlan Shah Bridge

The seismic analysis of Sultan Azlan Shah Bridge was carried out using SAP2000 for two-dimensional modelling. Figure 7 shows the computer model simulation for Sultan Azlan Shah Bridge. Three types of seismic analyses were implemented in this study; the Free vibration, Time History and Response Spectrum analyses respectively.

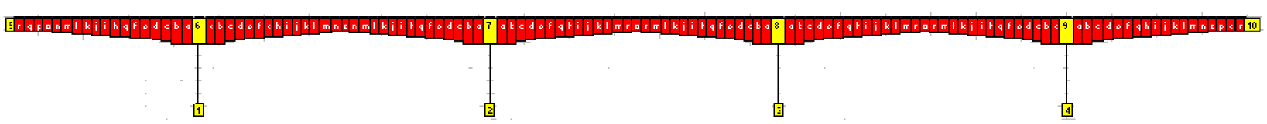

Figure 7 Computer model simulation for segmental box girder

5.1.1 Free Vibration Analyses

The free vibration analysis will consider five modes for two dimensional modeling (Figure 8). The periods of structure are shown in Table 1. Figure 8 shows the mode shape 1 of the bridge structure.

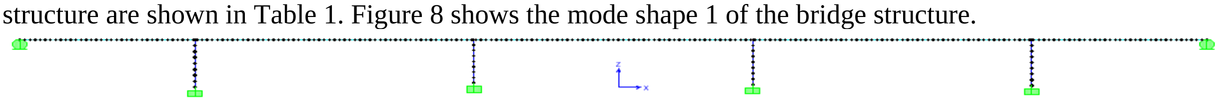

Figure 6 2D modeling by SAP2000

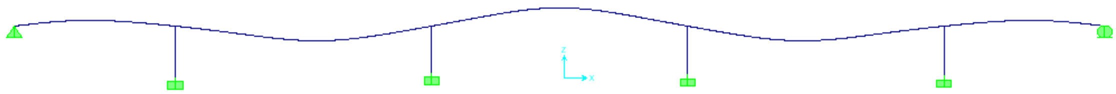

Figure 8 Mode shape 1 of bridge structure

Table 1 Natural periods of bridge

No	1	2	3	4	5
Period (s)	0.12995	0.08647	0.06065	0.04653	0.04396

5.1.2 Time History Analyses

Time history analysis of Sultan Azlan Shah Bridge model was performed using two-dimensional models. The time history analysis results with PGA of 0.161g are shown in Figure 5.The maximum forces of the structure can be seen in Table 2.

Table 2 Natural periods of bridge

Max applied forces	P(kN)	V(kN)	BM(kNM)
Deck	102	8417	136299
Pier	20818	73	914

5.1.3 Response Spectrum Analyses

IBC2000 was used to construct the design response spectrum shown in Figure 6. The maximum responses can be seen in Table 3.

Table 3 Natural periods of bridge

Max applied forces	P(kN)	V(kN)	BM(kNM)
Deck	260	8428	136535
Pier	21073	130	1540

5.2. Three Dimensional Analyses of Sultan Azlan Shah Bridge

The seismic analysis of Sultan Azlan Shah Bridge used SAP2000 for its 3 dimensional modeling. The deck and pier of the bridge were modelled using shell and beam elements. There are three types of analysis implemented in this research; the free vibration, time history and response spectrum. Figure 9 and 10 shows the elevation and side view of bridge modeling.

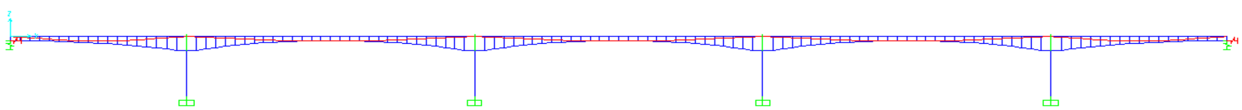

Figure 9 The elevation of three dimensional modeling

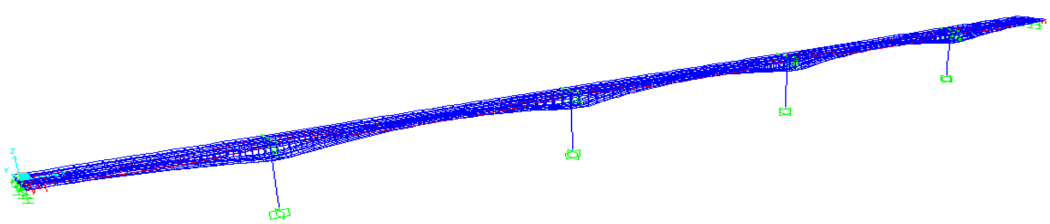

Figure 10 Side view of three dimensional modeling

5.2.1Free Vibration Analyses

The free vibration analysis considered five modes. The periods of structure are shown in Table 4. Figure 11 shows the mode shape 1.

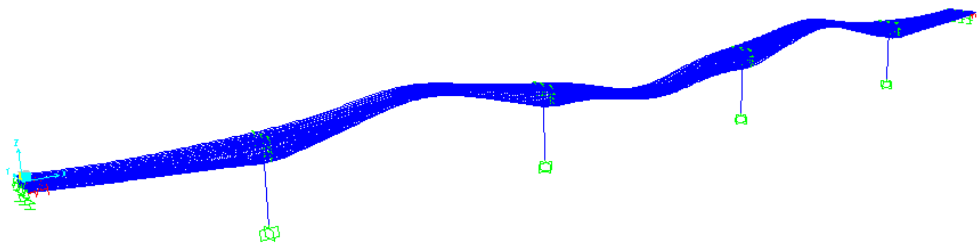

Figure 11 Mode shape 1

Table 4 Five natural periods of bridge

No	1	2	3	4	5
Period (s)	0.34151	0.31081	0.27738	0.25753	0.21533

5.2.2Time History Analyses

Time history analysis of Sultan Azlan Shah Bridge model was performed using three-dimensional models with time history of PGA = 0.161g (Figure 5). Maximum response of structures can be seen in Table 6.

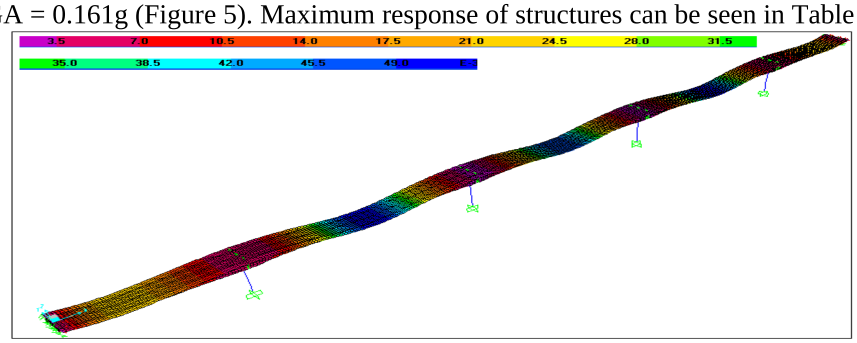

Figure 12 Maximum displacement is 0.051m

Table 6 Maximum applied force for 3 dimensional time history analysis

Max applied forces	P(kN)	V(kN)	BM(kNM)
Deck	1178	1077	18488
Pier	1350	14874	32086

5.2.3 Response Spectrum Analyses

The applied design acceleration response spectrum is shown in Figure 6.The result of analysis is presented in Table 7. Figure 13 shows the displacement value at the bridge deck.

Table 7 Maximum applied force of bridge for 3 dimensional response spectrum analyses

Max applied forces	P(kN)	V(kN)	BM(kNM)
Deck	6927	6051	97983
Pier	6991	14021	52734

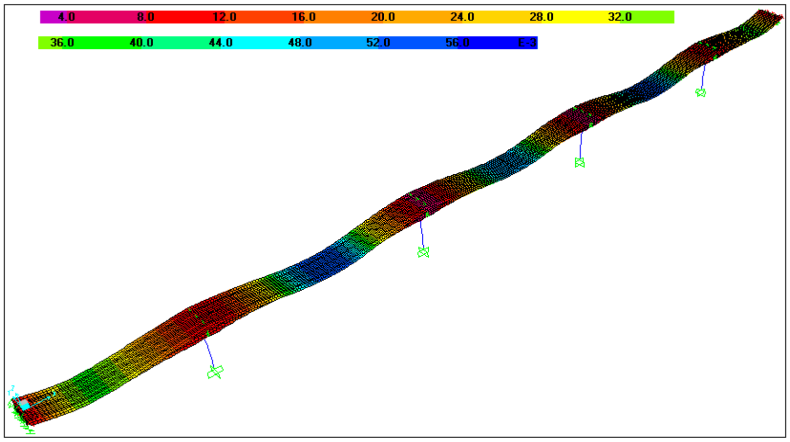

Figure 13 Maximum displacement is 0.056m

5.3. Nonlinear Seismic Damage Inelastic Analyses

The seismic analysis of Sultan Azlan Shah Bridge in Perak was carried out using IDARC for 2 dimensional modeling. From the analysis, the bridge started to crack at 0.25g and collapsed at 0.32g. The sequence of segment cracking or yielding can be seen at Figure 14 to 18. Figure 18 presents the location of the first beam yield at T = 4.505 second.

Figure 14 Flexural crack initiated at first span at PGA = 0.25g

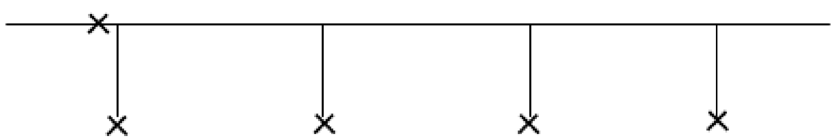

Figure 15 The flexural crack initiated at the first span and bottom of all piers at PGA = 0.27g

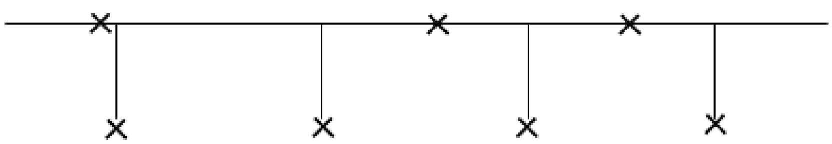

Figure 16 Flexural crack initiated at first, third and fourth span and bottom of all piers at PGA = 0.29g

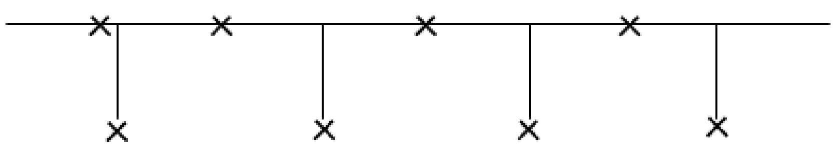

Figure 17 Flexural crack initiated at first, second, third and fourth span and bottom of all piers at PGA = 0.31g

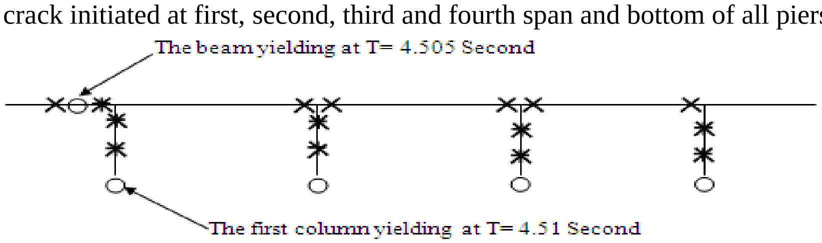

Figure 18 Location of first beam and column yielding at PGA = 0.32g

✕ = Initial Cracking

○ = Plastic Hinge Develop

✱ = Local Failure

6. CAPACITY OF STRUCTURES

To be able to know whether Sultan Azlan Shah Bridge could resist the force from external load, the response should not be not more than the structural capacity of the bridge. In this study the structure capacity was divided into 2 parts; deck and pier section. For the deck capacity, the forces considered were bending moment and shear stress capacity. While for the pier, the forces considered were bending moments and axial forces. It should be noted that due to lack of field strength testing of the concrete, increase in concrete strength due to aging was not considered and on the other hand, no strength reduction factors were applied for capacity calculations. The moment and axial force interaction diagram can be seen in Figure 19. By using strain compatibility method, we found that the bending moment resistance of prestressed concrete boxgirder of Sultan Azlan Shah Bridge was 500683 kNM and the ultimate shear force is 37867 kN.

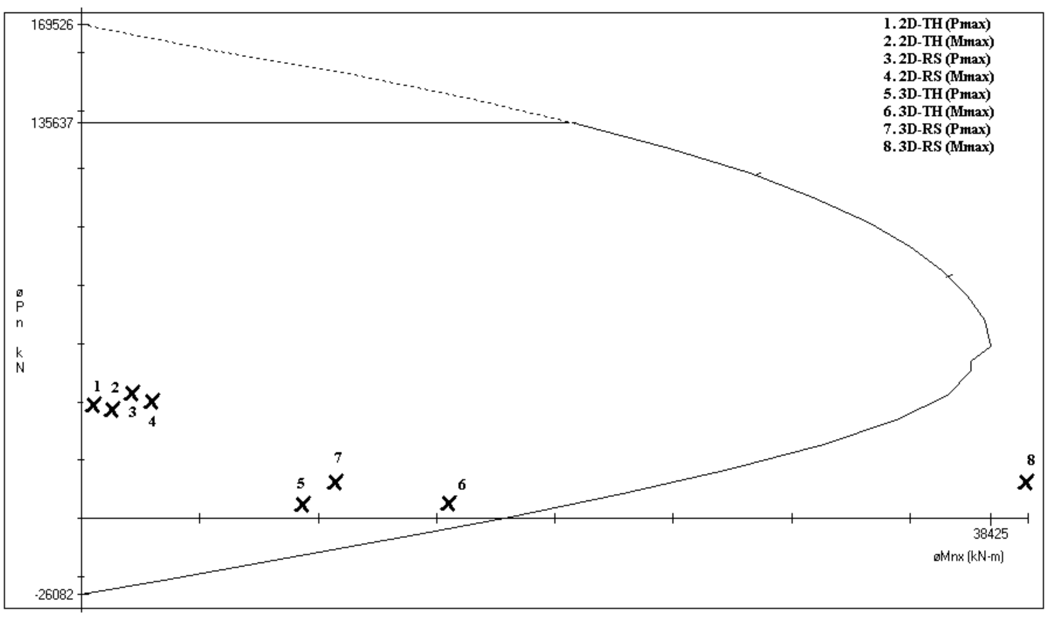

Figure 19 P-M interaction diagram

7. CONCLUSION

Based on the comparison between the maximum response and the capacity of Sultan Azlan Shah Bridge in Perak, it can be seen from Table 8 that all the responses for deck have not reached the capacity of the bridge, however, the response of the column for three dimensional response spectrum analysis more than capacity.

Table 8 The comparison of maximum applied and capacity force for bridge deck

DECK		TH-2D	RS-2D	TH-3D	RS-3D	CAPA-CITY
	Max Shear (kN)	8517	8673	1077	14021	37867
	Max BM (kNM)	139117	141867	18488	52734	500683

Table 9 The comparison of maximum applied and capacity force for the bridge pier

		TH-2D	RS-2D	TH-3D	RS-3D	CAPACITY
PIER	Max Axial (kN)	20818	21073	1350	6991	Refer to Figure 19
	Max BM (kNM)	914	1540	32086	52734	

From the analysis, it can be concluded that the column of Sultan Azlan Shah Bridge is under the assigned earthquake loadings but the column response for three dimensional response spectrum analyses is higher than the capacity when subjected to local site effect of PSA = 0.161g. The bridge started to initiate cracks at 0.25 g and collapsed at 0.32g.

8. ACKNOWLEDGEMENT

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