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SEISMIC RESPONSE ANALYSIS OF 3D FINITE ELEMENT BRIDGE MODEL USING TIME HISTORY LOADING

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ABSTRACT

The seismic response between 3D solid elements model and simplified beam elements model have been investigated. Due to numerical software constraint, the studies of the numerical modeling using 3D solid element for time history loading are minimal. The Finite Element Analysis using 3D solid element was chosen to study displacement response of laminated rubber bearing (LRB) bridge using real time history loading. In this research a simply supported bridge (single span), fixed at support was analyzed by using time history loading of Kobe earthquake. Numerical modelling was validated by comparing the natural frequency and damping ratio from simplified equation and 3D Finite Element bridge modeling.

Keyword: laminated rubber bearing; solid element; simplified beam element; time history loading

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1. INTRODUCTION

Many of studies have been done about rubber bearing subjected to seismic loading. However, the analysis has been done in simplified method. The whole structure is simplified by using a structural element such as truss or beam element and the rubber bearing is simplified by using spring element and damping. Y.Pan [1] has used multilinear plastic link elements to model the bearing. Mohd Zamri Ramli [2] used a simple connection element to employ modeling of bearing. Azlan Adnan [3] had introduced circular elostomeric hollow rubber bearing. A 3D modeling has been done in the study, but the bearing just gone through the local analysis. The main advantage of using simplified element is fast evaluation for the global displacement at major sampling point [4].

However, it is very difficult to estimate the optimum location, numbers and material properties of the bearing due to simplification in the numerical model. While a 3D modeling with local analysis is not very significant because some seismic response of the whole bridge cannot be identified. Local analysis also fails to capture the interaction between different components or subsystems of the bridge and could therefore result in significant errors in the estimation of the demand on the analyzed component. Therefore, three-dimensional finite element method by using solid element has been used in this study to increase the accuracy of the analysis result. In this paper, the seismic response of laminated rubber bearing between 3D solid elements model and simplified beam elements model has been investigated. A simply supported bridge (single span), fixed at support was analysed by using real time history loading of Kobe earthquake.

2. SEISMIC ANALYSIS OF LAMINATED RUBBER BEARING (LRB) USING TIME HISTORY LOADING

2.1. Equation of motion for seismic analysis

The motion of the structure is the response due to the ground motion and it depends on its mass, stiffness, damping and applied load or displacement.

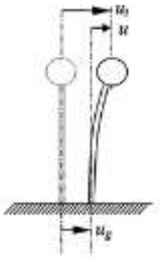


Figure 1 Earthquake induced motion of an SDOF system[5][9]

As in Figure 1, the earthquake induced a motion on the system. The displacement of the ground motion ug, the total displacement of the single mass ut and the relative displacement between mass and ground u are related by

$$u_t = u + u_g \qquad 1$$

By applying Newton’s law and D’Alembert’s principle of dynamic equilibrium, it can be shown that

$$f_I + f_D + f_S = 0 \qquad 2$$

where fI is the inertial force of the single mass and is related to the acceleration of the mass by fI = müt ; fD is the damping force on the mass and related to the velocity across the viscous damper by fD = cú ; fS is the elastic force exerted on the mass and related to the relative displacement between the mass and the ground by fS = ku , where k is the spring constant; c is the damping ratio and m is the mass of dynamic system.

Substituting these expressions for fI, fD and fS into equation (2) gives

$$m\ddot{u}_t + c\acute{u} + ku = 0 \qquad 3$$

Equation (3) is also known as equation of motion for an SDOF. For a system subjected to the ground motion can be obtained by substituting equation (1) into equation (3) and given by

$$m\ddot{u}_t + c\acute{u} + ku = -mu_g \qquad 4$$

The equation of motion for MDOF system is similar to SDOF system. The difference is only the stiffness k, mass m and damping c are in matrices form. Therefore, the equation of motion gives

$$[\mathbf{M}]\{\ddot{u}\}t + [\mathbf{C}]\{\acute{u}\} +[\mathbf{K}]\{u\} = -[\mathbf{M}]\,[\mathbf{B}]\{u_g\} \qquad 5$$

Where [K] stiffness matrix is obtained from standard static displacement-based analysis models and may have off-diagonal terms. The mass matrix [M] is expressed in the form of lumped masses.

The damping matrix [C] accounts for all the energy-dissipating mechanism in the structure and may have off-diagonal terms. The vector [B] is a displacement transformation vector that has values 0 and 1 to define DOF to which the earthquake loads are applied. In this study transient dynamic analysis is implemented to determine the time history dynamic response of the bridge structure to arbitrary forces varying in time. New mark method is used to solve time integration of dynamic equation.

2.2. Modeling of Bridge Component

The issues arise in Finite Element modeling of bridge structures include geometry, stiffness, mass distribution, and boundary conditions. The geometric modeling of bridge component can be divided into several parts. There is superstructure, column, multi column bents, foundation, abutments, movement joint and bearing pad. The modeling assumptions should be suitable with the computer program used to perform the static and dynamic analysis. In the seismic response analysis of bridges, the pier or the support are the critical elements that provide gravity-load and earthquake force transfer to the ground and ground motion input to the bridge super structure[7]. For elastic response analysis, a column element connected at the superstructure soffit and the top of the footing is sufficient to model the seismic response as long as generalized mass distribution and effective properties of pier are considered.

2.3. Types of element in FE model

The bridge model is formed by assembling the individual structural member into one structure. The elements used can be classified by their geometry and their principal structural action as defined by structural mechanics. The three groups of structural members or elements used in bridge models are line element, plates and shell elements and solid elements. Line elements are represented by a beam element with six degrees of DOFs or unknown member end deformations at each joint. Typically, the plate element is integral part of in-plane element. However, the plate or shell element can be represented in 3D with 3DOFs per node. Finally, three dimensional solid elements feature three displacement DOFs per node and similar to the planar elements can have either a lower-order formulation with corner nodes only or a higher order formulation with mid side and center nodes.

However, mathematical models are often limited by the capabilities of the computer program utilized. Therefore, in this study, all the recommendations and limitations in the modeling and analysis of bridges are based on capabilities of Ansys R14 and LUSAS software.

3. MODELING OF LRB BRIDGE

The details of the bridge are as in Figure 2. The bridge is simply supported bridge using post-stress beam. The abutment type is seat abutment. It is single span with length of 44000 mm. However, the abutment is formed with column and crosshead beam. The Laminated Rubber Bearing is used with dimension 400mm x 400 mm [6][7]. The width of the deck is 15300 mm which can be considered as R5 road geometry class. All the design consideration is based on BS 5400:2006.

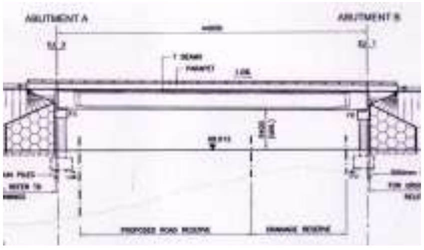


Figure 2 Details of bridge

The material properties of bridge assigned in the FE model are shown in Table 1.

Table 1 Material Properties of LRB Bridge

Types of material	**Young's Modulus [kN/mm^2]**	**Poisson's Ratio**	**Density [kg/m^3]**
Post-stress concrete	34	0.15	7,874
rubber	0.01	0.4999	910
Reinforced concrete	31	0.15	2,400

In this study, high intensity of earthquake loading was applied in transient analysis. The Kobe earthquake data was obtained from the website of Pacific Earthquake Engineering Research Centre (PEER) as shown in Figure 3.

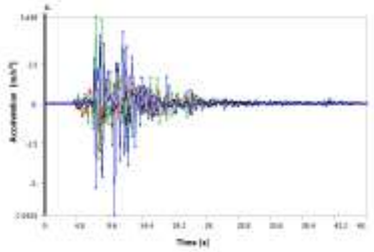


Figure 3 Kobe earthquake time history loading

The modelling of the bridge is divided into two, solid elements and simplified beam elements. Both have different method to operate. By using Ansys software, full method of transient analysis can be implemented. The reason for choosing Ansys software is because of its capability to apply 3D solid elements model. While by using LUSAS software, it is involved numerical modeling with developing simplified beam method. The transient analysis was done by using mode superposition method.

Figure 4 show the mesh of bridge model in 3D elements. The total Hexahedral elements have been applied in the model are 67000 elements. All the elements in the model are used linear elastic properties. The bridge superstructure including the post stress beam and concrete deck were presented using linear elastic elements. Nominal properties were used for both post stress beam and concrete deck with the post stress beam having a modulus of elasticity of 34 kN/mm^2 and concrete deck having a modulus equal to 31 kN/mm^2. Substructure elements were included in the computational models. Included in the substructure models were the abutment, column, crosshead beam and footing. Modulus of elasticity that has been assigned to the substructure elements is 31 kN/mm^2. The piles are not considered in this analysis.

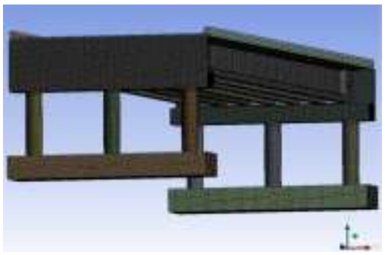


Figure 4 3D solid element of bridge model

Laminated Rubber Bearing also was modelled using solid element. The elastomer is modelled by using modulus of elasticity of 0.01 kN/mm^2. While steel shims inside the elastomer using a modulus equal to 210 kN/mm^2. For the simplified beam elements model, LUSAS software has been used. The components of bridge are modelled as follows;

a. Pier and superstructure are modelled by using 3-D beam element
b. Bearing is modelled by employing spring support

The material properties from existing bridge are used as the material properties of the bridge model. The modeling of the bridge and the LRB are shown as in Figure 5.

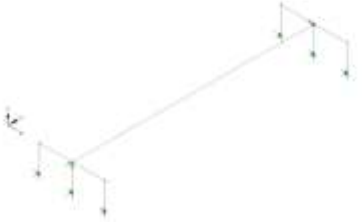


Figure 5 The modeling of the bridge using simplified beam element

The value of the vertical and horizontal stiffness of the LRB is based on the existing characteristics LRB. The LRB flexibilities have been assigned as spring stiffness. The stiffness value is depended from the existing LRB parameter including plan area of LRB, Shear modulus of LRB and total height of LRB. The equation used to obtain these stiffness values are as follows:

Vertical Stiffness, Kc = (3AG/h) [1 + 2S2]

Horizontal stiffness, Ks = AG / h

Where;

A = plan area of the LRB

G = Shear modulus of LRB

h = total height of LRB

Using the equation above, it gives the value of the Kc and Ks are as follows:

Vertical Stiffness, Kc = 0.6367 kN/m

Horizontal stiffness, Ks = 0.0029kN/m

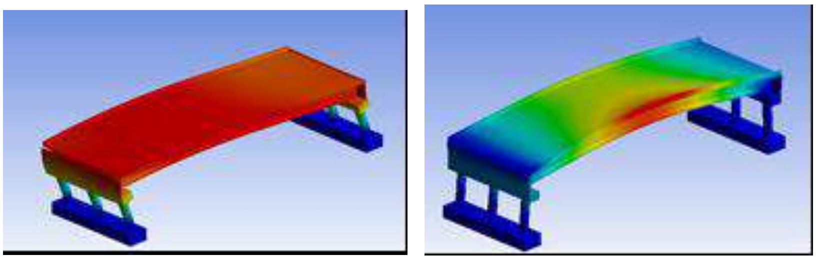
4. RESULTS AND DISCUSSION

The results of modal analysis for 3D solid element and simple element are tabulated in Table 2. The numbers of mode shape for simplified model are same with the 3D solid elements model. It gives slightly different value of natural frequency between simplified and 3D solid elements model. However, the mode shapes are shown almost same with the 3D solid elements.

Table 2 Properties comparison of The Natural Frequency Value Between 3D Solid Elements and Simplified Beam Elements

Mode Shape	Natural Frequency, Hz (3D Solid Elements Model)	Natural Frequency, Hz (Simplified Beam Model)
1	7.5756 Hz	7.6856 Hz
2	8.1896 Hz	7.7935 Hz
3	12.153 Hz	12.753 Hz
4	16.176 Hz	16.189 Hz
5	16.344 Hz	16.944 Hz

The shapes of the modes and frequency for 3D solid elements model are shown in Figure 6.



Mode Shape 1 7.5756 Hz Mode Shape 2 8.1896 Hz

Figure 6 Mode 1 and 2 of 3D solid element

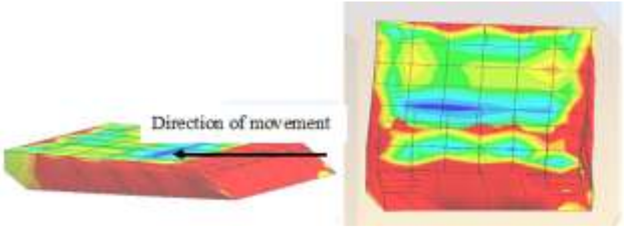
Table 3 shows the maximum displacement of LRB in x, y and z direction has been obtained. The existing of LRB was designed to sustain with limit of displacement 41.20 mm in x direction. Based on the result, the LRB could not be able to sustain under the Kobe earthquake excitation. For 3D solid elements the maximum horizontal displacement of LRB model is measured based on difference response at top and bottom of LRB. While for simplified beam method the response of LRB is based on the displacement response of node to represent the LRB.

Table 3 The Maximum Displacement Of The LRB in X,Y and Z direction Subjected To Different Earthquake Loading Intensity by using Different Element.

Displacement Axis (mm)	Simplified Beam Element Model		3D Solid Element Model	
	Malaysia earthquake	**Kobe earthquake**	**Malaysia earthquake**	**Kobe earthquake**
Laminated Rubber Bearing Displacement Response (x-axis) mm	2.041E-3	84.563	2.341E-3	90.131
Laminated Rubber Bearing Displacement Response (y-axis) mm	5.783E-6	0.521	0.102E-6	6.324
Laminated Rubber Bearing Displacement Response (z-axis) mm	1.1533E-3	31.253	1.313E-3	24.931

For the displacement response of LRB using simplified beam element model, the value is not so difference compared to the 3D solid element model. However in vertical direction, the maximum displacement response gives significant difference result between simplified beam element and 3D solid element model. This is due to the limitation of the simplified beam element model where by the LRB is represent by node. 3D solid element model would be able to simulate the differences of displacement response between top and bottom of LRB.

The overturning of the cap beam which acts as abutment causes the displacement response of LRB in vertical direction gave significant difference compared to the simplified beam element. The maximum value of displacement response is summarized in Table 3. Figure 7 shows how the LRB displaced under Kobe earthquake loading. The displacement response of LRB exceeded the limit after at time step 8.4 second. It was occurred because after 8.4 second of the earthquake event, the values of PGA increase to 0.25g.



(a) Side View (b) Plan View

Figure 7 The condition of the LRB under Kobe earthquake

From here, the displacement response of the LRB started over the limit. Figure 7(a) show the displacement response in longitudinal direction and the displacement response in vertical direction. While Figure 7(b) shows the displacement response in transverse direction. The substructure is unbalance condition. Von Mises stress can be generated by using 3D solid element. The failure pattern can be predicted by generating Von Mises strain once the strain exceeds the limit. Besides, deformation of pier and laminated rubber bearing can be observed. Figure 8 show the comparison of column deformation and von misses stress pattern can be defined through 3D solid element model.

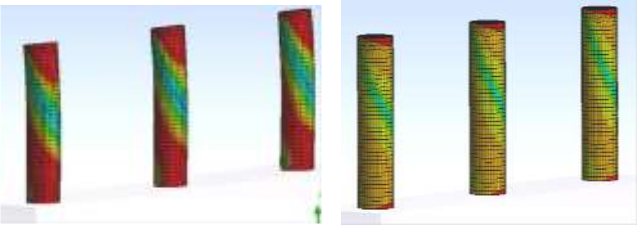


Figure 8 The deformation of column and von misses stress pattern can be defined through 3D solid element model

Transient analysis is very useful to obtain the response of laminated rubber bearing and the whole structure during high intensity earthquake excitation. The differences of displacement between top and bottom of LRB cannot be measured by using simplified beam method. Therefore, the displacement response of LRB cannot be optimized because the overturning of abutment was not considered during the measurement of displacement response in vertical direction. Furthermore, 3D solid elements can illustrate clearly the response of every bridge component through deformation and stress contour.

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