NUMERICAL DESIGN AND ANALYSIS
ISOLATED SINGLE SPAN PEDESTRIAN BRIDGE
UNDER SEISMIC LOAD

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Abstract—In recent time earthquake has been the most
dangerous threat to structures. As Bangladesh has a high
risk of facing earthquake it is necessary to ensure safety of
the structures. Bridges are very vulnerable to earthquake
ground motion. In this study a single span composite bridge
is modelled with SAP 2000 and is analysed. The bridge is
analysed without using isolators subjected to modified El
Centro data for 15, 20 seconds. Nonlinear time history
analysis was performed. Then this same bridge is analysed
using a lead rubber bearing at one end of the bridge. The
behaviour of the bridge is observed using isolators. From
this analysis displacement vs time and acceleration vs time
curves are found for different El Centro data. For base
isolated and not isolated condition this results are
compared. The comparison shows how seismically isolated
condition can improve the response of bridge during
earthquake.

Keywords—isolators, El Centro data, lead rubber bearing
etc.

I. INTRODUCTION

Technologies for seismic protection have been developed, in
order to design structures in highly seismic hazardous area. One
of the most interesting solutions applied in bridges are passive
energy dissipation systems [1]. Isolation systems can be steel
hysteretic dampers or viscous dampers. Bridges built in
seismically sensitive regions require special consideration in
their structural design. Performing an accurate and realistic
numerical simulation of the seismic response of the pedestrian
bridges presents a significant challenge to the field of
earthquake engineering. Base isolation results in increasing the
natural period and damping characteristics of the bridges.
Isolation devices have the ability to increase period of vibration
of the structure towards a lower amplification range of the
response spectrum for design ground motion, thus reducing the
input energy or force demand into the structure. to control these
increased deflections within desirable limits. Reducing the
effect of the lateral displacement and horizontal forces
generated from earthquake motion is of great concern to
designers. The structural bearing technique is one of the tools
to reduce the lateral displacement of the bridges.

II. LITERATURE REVIEW

Base isolation was firstly registered as a patent in 1800’s, with
Lead Rubber Bearing (LRB) providing high flexibility and
damping. The natural rubber has been used for base isolation
since 1840’s, through the process of material development
synthetic rubber or poly-tetra-fluoro-ethylene (PTFE) which is
developed by DuPont was used, and designed for 50 years or
more [9].

Unjoh and Ohsumi (1998) have conducted numerical study on
the earthquake response characteristics and the design method
of the multi-span continuous girder bridge with seismic
isolation design concept [3].

Ghobarah and Ali (1988); Turkington et al. (1989a); Turkington
et al. (1989b) and Jangid (2004) Have evaluated the suitability
of using LRBs in reducing the seismic responses of bridges [7].

Su et al. (2002) and Pagnini et al. (1998), Tongaokar and Jangid
(2000) have evaluated the effect of modeling of the isolation
bearings on seismic Responses of bridges. Paragraph content
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B. Conceptual design of lead rubber bearing

There are two of the most commonly used procedures for designing bridges with lead-rubber bearings are: (1) In New Zealand, the Ministry of Works and Development (MWD) design guide (1983); and (2) in California, the Dynamic Isolation Systems (DIS) procedure (1984). Both procedures in figure 2.4 represent the seismic response of the bridge by a single-degree-of-freedom (SDOF) structure with inelastic spectra.

Where, M is the Mass, K is the stiffness, C is the damping and F (t) is the vibration with respect to time of the system. Figure 2.5 shows free body diagram of single degree of freedom system (SDOF). Where, f_i= Inertia force = Mass times Acceleration = M \left[x',f_v\right] f_v= Viscous force = Viscous damping times with velocity = C \left[x'\right] f_s= spring force = Stiffness times Displacement = KX. The damping ratio is a parameter, usually denoted by \( \zeta \) (zeta) that characterizes the frequency response of a second order ordinary differential equation. \( \zeta \) = actual damping (C) / critical damping (Cc). The critical damping coefficient is \( \text{Cc} = 2\sqrt{km} \) or \( 2m\omega n \). The lengthening of the first mode period results into the reduction of the earthquake-induced forces in the structure, but only for short period structures. For long period structures, this effect might be negligible.

C. Design Procedure for isolated Bridge

In the model, the effective stiffness \( K_{\text{eff}} \), and the equivalent damping ratio, \( \zeta \), are considered constant during the time of earthquake. These parameters are determined from the hysteresis loop of a bearing obtained for the design displacement, \( D \); [15]

\[
K_{\text{eff}} = \frac{F(D) - F(-D)}{2D} \quad (1)
\]

\[
\zeta = \frac{\Delta W}{2\pi W} \quad (2)
\]

Where; \( F(D) \) is a lateral force at displacement \( D \), \( \Delta W \) is an energy dissipated in each cycle (area enclosed by the hysteresis loop) and \( W \) is a strain energy induced in a bearing:

\[
W = F(D)^2 \Delta D \quad (3)
\]

\[
K_{\text{eff}} = k_r \Delta d/D \quad (4)
\]

Where, the effective stiffness is computed using the maximum displacement of the deck; the characteristic yield strength of lead, \( Q_d \) and the post-elastic stiffness of the bearing; \( k_r \).

D. Response Spectrum for Isolated Bridge

According to AASHTO (1999) codes, the design spectrum for isolated bridges differs from conventional bridges. The design spectrum is specified in terms of a design displacement \( D \) rather than spectral acceleration, which is a function of the effective period \( T_{\text{eff}} \) and damping ratio of the bridge, \( \zeta_{\text{iso}} \)

\[
D = \frac{10^{A_{5}S_{\text{eff}}}}{C} \text{ (inches)} \quad (5)
\]

\[
T_{\text{eff}} = 2\pi \sqrt{\frac{W}{g\times k_{\text{eff}}}} \quad (6)
\]

C is a damping factor that depends on the damping ratio \( \zeta_{\text{iso}} \), \( A \) is the acceleration coefficient for the site, and \( S_{\text{i}} \) is the site coefficient for isolated structure. In this study, the acceleration coefficient \( A \) (which represents peak ground acceleration) is replaced by the 1.0 second period spectral acceleration coefficient \( S_{\text{i}} \) (Buckle et al., 2006a). Figure 3.2 shows Response spectra for the bridges with conventional and isolated conditions with respect to natural period.

According to the displacement \( D \) can be estimated the total lateral force in the system, \( F = K_{\text{eff}}^*D \) ......... (7)

E. Isolated Bridge with linear device

The performance of the columns will degrade once their elastic limit has been reached and larger displacement demands will be imposed on the substructure then the bridge is analysed using the design spectrum for the isolated bridge.

\[
K_{\text{total}} \text{ Or } K_{\text{iso}} = \frac{W}{g} \left( \frac{2\pi T_{\text{n}}^2}{T_{\text{eff}}^2} \right) \quad (8)
\]

Based on the total weight W and assumed natural period \( T_{\text{n}} \) of the bridge; the total stiffness, \( K_{\text{total}} \) and design base shear, \( F \). The design base shear of the whole bridge \( F_{\text{yis}} \) is calculated from the elastic base shear \( F \) and force reduction \( R \); The total displacement demand \( D \) is distributed to the isolators to their stiffness is;

\[
F_{\text{yis}} = \frac{D}{3\times K_{\text{iso}}} \quad (10)
\]
IV. NUMERICAL MODELLING AND ANALYSIS

Using SAP2000 18 the model of a single span Pedestrian Bridge that consists of steel truss members and concrete deck slab, shown figure 4

(a). Pedestrian Bridge

(b) 3D view of bridge in SAP 2000

(c) xz plane view of bridge in SAP 2000

A. Material properties

B. Section properties

C. Rubber isolator properties
Figure 5. Acceleration vs. Time (Modified El Centro for 15 sec; 20 sec)

D. Nonlinear Time History Analysis

Define > Function>Time history>Input file

Define > Load case > Add new case > Time history

Click the run for analysis. After analysis we get the displacement from.

Display > Plot function > Displacement for time history at maximum time.

V. DYNAMIC ANALYSIS RESULTS

A. Displacement vs. Time Curves

Mid-point displacement vs time curve for 15 sec, 20 sec with and without isolator in Y direction.

Table 1. Difference Maximum Displacement between with and without Isolator in Y axis

| Duration (sec) | Software (ft) Without base Isolation | Software (ft) With Base Isolation | Difference of with and without isolation (ft) |
|---------------|-------------------------------------|----------------------------------|-----------------------------------------------|
| 15            | Max(+ve) 0.0000 44 | Max(-ve) 0.0000 37 | Max(+ve) 0.0000 77 | Max(-ve) 0.0000 73 | 0.0000 73 0.0000 69 |
| 20            | Max(+ve) 0.0000 37 | Max(-ve) 0.0000 31 | Max(+ve) 0.0000 26 | Max(-ve) 0.0000 28 | 0.0000 22 0.0000 25 |

Figure 6. Mid-point displacement vs time curve in Y axis (15 sec)

Figure 7. Mid-point displacement vs time curve in Y axis (20 sec)

Figure 8. Difference in maximum negative displacement with and without isolation in Y axis

B. Acceleration vs. Time Curves

Mid-point acceleration vs time curve for 15, 20 sec with and without isolator in Y axis
VI. CONCLUSIONS
The work comprises development of working knowledge on SAP 2000 18 and its application in the dynamic analysis of simply supported bridge. For different El centro (15, 20 sec) earthquake data it is found that in every case displacement is larger when isolator is used. From this results it is found that 15 sec El centro earthquake is more risky for the bridge than 20 sec and using the base isolator at one end of the bridge was not much helpful in earthquake response. The properties of the isolator used in this study was also assumed and it was used at one end of the simply supported bridge.

VII. SUGGESTIONS
Suggested to the designers to ponder about the participation of structural elements in the seismic isolation global solution, given that characteristics such as lateral restoring capability are an intrinsic part of the entire structural system and not of each component. As an alternative to conventional rubber isolators such as high damping rubber bearing and lead rubber bearing, smart rubber bearing systems with shape memory alloys (SMAs) have been proposed in recent years. As a class of smart materials, shape memory alloys show excellent recovery and considerable damping capabilities which can be exploited to obtain an efficient seismic isolation system.

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