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DESIGN OF SEISMIC ISOLATION OF G+4 MULTI STORIED BUILDING

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ABSTRACT
This paper presents the use of high damping rubber bearing system and lead plug bearing system as seismic isolation devices for the considered G + 4 multi storied building. The paper presents the provisions of ASCE-07 used in the analysis of the system. The study deals with the building located in zone V and zone IV as per IS 1893 (Part 1): 2002. The study showed that the high damping rubber bearing is efficient than the lead plug bearing system when compared with the dimensions of the bearing systems obtained in the design process.

KEYWORDS: Seismic Isolation, Seismic analysis, High rubber bearing damper, Lead plug rubber bearing damper.

INTRODUCTION
The concept of isolation has become practical since it was used in the elementary school in Skopje, Yugoslavia, by rubber isolation system to protect the school from earthquake. At present multilayer isolation bearings are used which are made by vulcanization of sheets of rubber to thin steel reinforced plates. These bearing systems are very stiff in vertical direction and carry the vertical load of the structure, very flexible in horizontal direction to move in lateral direction under strong ground motion.

A variety of isolation devices including elastomeric bearings frictional, sliding bearings and roller bearings have been developed and used practically for seismic design of buildings during the last 20 years. There have been several existing building that have been seismically retrofitted using base isolation over the last two decades or so. To protect the historically appearance of the structure the base isolation is the only way for seismic retrofitting of the structure.

The laminated rubber bearings (LRB) are most commonly used base isolation system. The basic components of LRB system are steel and rubber plates built in the alternative layers. The dominant features of LRB system are parallel action of linear spring and damping. Generally the LRB system exhibits high damping capacity horizontal flexibility and high vertical stiffness. The damping constant of the system varies considerably with the strain level of the bearing. The system operates by decoupling the structure from the horizontal components of earthquake ground motion by interposing a layer of low horizontal stiffness between structure and foundation. The isolation effects in this type of system are produced not by absorbing the earthquake energy but by deflecting through the dynamics of the system. These devices can be manufactured easily and are quite resistant to environmental effects. Usually there is a large difference in damping of a system and the structure and the isolation system, which makes the system non classically damped. This will lead to coupling of the equations of the motion and to analyse the system correctly.

In bridges the base isolation devices can rather easily incorporated by replacing the traditional bridge bearings by isolation bearings. Base isolation bearings serve the dual purpose of providing for thermal movement as well as protecting the bridge from dynamic loads by increasing the fundamental period and dissipating the seismic energy by hysteretic damping. In order to demonstrate the effectiveness of seismic isolation a three span continuous deck bridge made of reinforced concrete can be considered. The properties of the bridge deck and piers are to be established as per site requirements. The bridge is seismically retrofitted by using the elastomeric bearings at pier and abutment locations. The bridge is mathematically idealized as lumped mass system divided into number of small discrete segments. Each adjacent segment is connected by a node and at each node two degrees of freedom is considered. The masses of each segment are assumed to be distributed between the two adjacent nodes in the form of point masses. In addition the bridge superstructure and piers are assumed to remain isolation attempts to reduce the earthquake response in such a way that the structure remains within the elastic range.

LITERATURE REVIEW

Jianyun chen et al [2014] studied seismic analysis and evaluation of base isolation system in AP 1000 NI under SSE loading. The feasibility of base isolation using NI was evaluated. A comparison of structural response with effective system of isolation was studied. DAR was proposed to validate the effectiveness of base isolation under SSE. Connection of pipes, seismic gap and fail safety system are also considered.

M.K.Shrimali et al [2002] studied seismic response of liquid storage tanks isolated by sliding bearings. The earthquake responses considered for analysis were imperial valley, 1940, Loma prieta earthquake, Kobe earthquake, Broad tank imperial valley, Loma priesta 1999, Kobe 1995 earthquake. The numerical analysis found that sliding systems are found to be quite effective in reducing earthquake effect in base shear and impulsive displacement of the liquid storage tanks. Dependence of the friction coefficients on the relative velocity of the system has no noticeable effects on the peak response. The bi-directional interaction of frictional forces has significant effects on the response of isolated tanks. There exits an optimum values of friction coefficient and damping for which the base shear in the liquid storage tanks attains the minimum value under earthquake ground motion.

M.Dicleli et al [2003] Studied economical and structural efficiencies of frictional pendulum bearings for retrofitting typical seismically vulnerable bridges in Illinois State. A conventional retrofitting strategy was developed for the bridge analysis and estimation of cost effectiveness of the retrofit of bridges. It was observed that the use of friction pendulum seismic isolation mitigates seismic forces and found the cost effectiveness of conventional retrofitting systems and the FPB system can be used for seismic retrofitting of typical bridges and also in moderate risk seismic activity conditions.

It was concluded that in plane torsion rotation of the bridge, uniform distribution of seismic forces among substructures can be identified. The results showed that the energy dissipation and lower equivalent linear stiffness of FPB compared to that of the seismic isolation bearings other than rubber bearings are effective in application.

Shi Liu et al [2012] made a numerical study on seismic performance and sensivity of floor isolation systems in steel plate shear wall structures. Results of the study showed that can effectively limit, average, absolute acceleration demands on equipment in the upper levels of multi story buildings through isolator displacement demands can be large. Two models were considered for analysis which are of schematic of steel plate shear wall frame, nomenclature and strip model and also with base isolated building and fixed base building with floor isolation.

Lyan-ywan Lu et al [2013] made an experimental study on the variable frequency rocking bearing effect for near fault seismic isolation. For experimental study a full scale steel frame isolated by several prototype bearings are tested using shaking table. Experimental results showed that with stimulated ones, demonstrated the prototype bearings exhibited the desired variable hysteretic property.. Test results also showed the VFRB system with proposed mechanical property will able to effectively suppress the excessive isolator displacement induced by a near fault earthquake.

A.Rahman Bhuiyan et al [2013] examined seismic performance of highway bridges equipped with super elastic shape memory alloy based laminated rubber isolation. The study found that seismic responses of the bridges can be effected by use of different types of isolation bearings moreover residual displacement of deck are noticeably reduced after earthquakes .

SEISMIC ISOLATION ANALYSIS DATA

Thickness of slab = 0.15m
Load due to roof finish = 2kN/m^2
Load due to floor finish = 2kN/m^2

Thickness of outer walls = 0.3m
Thickness of inner walls = 0.15m
Imposed load = 4kN/m^2
Size of column at ground level = (0.4 x 0.4) m
Type of foundation used is isolated footing.
Soil condition considered are medium soil and soft soil available at depth of 1.5m below ground level.
Seismic zones considered are Zone V and Zone IV
Length in x-direction and length in y - direction are (20 x 20)m
Total floor area considered is = 400m2
Floor to floor height of building is = 3.5m
Ground level is = 4m
Total height of the building is = 19.5m
Unit weight of masonry considered is = 20 kN/m^3
Unit weight of reinforced concrete masonry considered is = 25 kN/m^3
Self weight of slab is = 3.75kN/m
Number of floors without silt and roof floor is = 3

Steps involved in analysis:

Step 1: Specifying of the soil condition for isolated structure.
Step 2: Selection of design shear strain and effective damping ratio for the bearing and the target time period for isolated structure is to be assumed.
Step 3: Determination of total weight of the building.
Step 4: Layout of the bearing locations and determination of number of bearings.
Step 5: Determination of maximum vertical load using IS 1893 PART I: 2002.
Step 6: Determination of fundamental time period of isolated structure using IS: 1893 (PART I): 2002.
Step 7: Determination of base shear and lateral inertia force distribution over the entire height of the multistory structure as per clause 7.7.1 of IS: 1893 (PART I): 2002.
Step 8: Determination of effective horizontal stiffness and maximum horizontal displacement of the bearing is made by using static/dynamic analysis.
Step 9: Material properties, young's modulus E and shear modulus G, are assumed as per the requirement.
Step 10: height of the rubber in the bearing system is to be calculated according to the design displacement and design shear strain.
Step 11: effective area and thickness of individual rubber, lead layers is to be calculated.
Step 12: Calculation of effective cross section area of the rubber bearing was calculated as per rubber hardness, young's modulus, shear modulus, load free area. Obtaining of minimum cross section area of the bearing system is calculated for shear failure of the bearing, identification of the requirement of the rectangular/circular bearing system.
Step 13: shape factor and thickness of the rubber, lead bearing system is to be calculated.
Step 14: steel plate's thickness which will be on the top and bottom of the rubber, lead bearing system is to be calculated.
Step 15: All the parameters made for design of rubber bearing system are to be checked against shear strain and stability conditions and then the shear force and roll out displacement of the bearing system is to be calculated.

Using high damping rubber bearing:

Design time period is T_D = 1.0 sec
Mean horizontal time period is T_M = 2.5 sec
Consideration of response reduction factor for the building is :
R = 5 (seismic load reduction factor)
shear modulus of rubber at large strains is
G = 500 KN/m^2 (for large shear strains)
shear modulus of rubber at small strains is
G = 700 KN/m^2 (for small shear strains)
Bulk modulus of rubber is K = 2000000 KN/m^2 (Bulk modulus)
Maximum shear strain as per IBC code is
γ_{max} = 150% ;
Weight of the structure calculated as per
IS : 1893 : 2002 is W_T = 27442.31 KN
The obtained lateral force for each floor obtained using IS 1893 (Part 1) : 2002 are :
For Silt level : 114.8kN, For 1st floor : 398.8kN, For 2nd floor : 769.43kN, For 3rd floor : 1260.6kN, For 4th floor : 1160.94kN.
From table 11.4-1 and clause 11.4.3 of ASCE/SEI 07-05
for building in zone V using HRD for medium soils T_D =1sec considered as explained in

step 2:-
As per clause 17.5.3.2 effective time period

$$T_D = 2\pi\sqrt{\frac{w}{K_{Dmin}\, X g}}$$

As per clause 17.5.3 of ASCE/SEI 07-05

$$D_D = \frac{g}{4\pi^2}\ X\ \frac{S_{D1} T_D}{B_D}$$

g= Accerlation due to gravity
S_{D1} = Minimum design damped spectral accerlation
B_M =numerical coefficient related to the effective damping of the isolation system at maximum displacement

$D_D = \frac{g}{4\pi^2} X \frac{S_{D1} T_D}{B_D}$

From code IBC 2000 clause 1615.1.2

Where, $S_{D1} = \frac{2}{3}$ x S_{M1}

$S_{M1} = F_v$ x S_1

The damping reduction factor B_D is calculated from the equation

$$\frac{1}{B_D} = 0.25(1 - \ln \beta)$$

$$\frac{1}{B_D} = 0.25(1 - \ln(0.15)) \Rightarrow B_D = 1.38$$

Taking γ_{max} =150% shear strain as per ASCE/SEI 07-05

$$\gamma = \frac{D}{tr}$$

Thickness of the disc can be calculated from $t_r = \frac{D_D}{\gamma_{max}}$

for building in Zone V using HRDB γ_{max} =150%
Shear modulus of rubber G=500kN/m^2
Area can be calculated from the formula

$K_H = \frac{G*A}{tr}$

$A = \frac{KH*tr}{G}$

We know that shape factor for circular bearing is $S = \frac{\varphi}{4t}$

φ= diameter of the bearing

According to IBC-2000 S=shape factor =8
The compression modulus, E_c, from Equation

$E_c = (\frac{1}{6GS^2} + \frac{1}{K})^{-1}$

Total vertical stiffness K_v is calculated from the formula
$K_v = (E_c$ x $A)/t_r$
Vertical displacement is calculated from the equation $\Delta t_v = W/K_v$

3.3Using Lead Plug rubber bearing system:

Taking γ_{max} =150% shear strain as per ASCE/SEI 07-05

$$\gamma = \frac{D}{tr}$$

Energy dissipated per cycle is
$W_D = 2\pi(K_{eff})D^2$ x β_{eff}
Area of the hypothesis loop, however is given by
$W_D = 4Q_d(D - D_y)$
D_y is very small so neglecting it.
$W_D = 4Q_d(D)$
for building in Zone V using HRDB γ_{max} =150%
Shear modulus of rubber G=500kN/m^2
The total cross sectional area of the lead plug area needed for the entire isolation system is

$A_{pd}^{total} = \frac{Q_d}{F_y^{pb}}$

Vertical fundamental period of vibration:
$T_v = T_H/(\sqrt{6}$ x S)

Shape factor $S = \frac{\varphi}{4*to}$

RESULTS AND DISCUSSIONS

1. Compared to case I and case II for zone V and T = 1.0 sec the single rubber layer thickness To has increased a percentage of 33%.
2. Compared to case III and case IV for zone IV and T = 1.5 sec, the single rubber layer thickness To has increased a percentage of 25%.
3. The increase in height of Lead plug rubber bearing system is due to the consideration of compressive strength consideration of lead plug and also due to the consideration of yield strength of the lead plug.
4. The above considerations of lead plug are essential due to the load resistance properties of the lead plug, lead plug is an alloy of carbon and at its highest bearing capacity of the axial load stress applications the plug losses its load bearing capacity resulting in brittle failure, hence an increase in area of the lead plug with respect to height is indirectly effecting the height of the rubber cover surrounded by the lead plug. The change in height comes due to the effect of lead plug material property.
5. Increase in height will not affect the lead plug in buckling condition, due to its property of toughness and protected by the rubber cover throughout its surface.
6. In conclusion the change in increase in area of the lead plug bearing system is due to the increase in area of plug system resulted in

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increase in area of LPRD of nearly 6% than the area of HRD. An increase in area of 6% is minimum when not considering the economical standard.

7. On the other hand, consideration of energy cycle in lead plug rubber bearing design, the bearing system also resists the energy comes from fatigue loads or cyclic load conditions which increase the safety of the bearing system.
8. Total height of the bearing system of case I high rubber damping system is nearly equal to case IV lead plug bearing system.
9. Lowest diameter and area of bearing are obtained for case III i.e., zone IV high rubber damping system of 95cm and 0.701m^2 respectively.
10. Effective horizontal stiffness of the bearing system is 3944.149 KN/m and for LRB is 631.06 KN/m which has a reduction of 16% of horizontal stiffness for each bearing system.
11. Obtained time period of the building is 0.392(Ta), and obtained design time period for the bearing systems is 0.7(T_D) which satisfies the condition of Ta < T_D as per ASCE 07-10 coda provisions.
12. Obtained base shear for zone V is 3704.712kN, and for zone IV is 2469.13kN, the change of base shear considering in calculation of horizontal stiffness considering base shear value as "W" for determining time period is also a parameter which governs the change of bearing dimensions of the bearing systems.
13. Area of HRD bearing in zone V is 1.23m^2 and in zone IV is 0.701m^2 by change of zone intensity value from 0.36 to 0.24 the change of base shear considered in calculation of design time period finally resulted in reduction of 56.9% of area of bearing system which shows the effect of base shear in determining the dimensions of bearing systems.
14. Similarly there is a reduction in thickness of rubber bearings from zone V to zone IV of nearly 20% for HRDB to LRB systems.
15. Similarly for zone V the diameter of HRDB system reduced by 20% to zone IV diameter HRDB system. For LRB system nearly 40% reduction was observed from change of zone intensity from zone V to zone IV.
16. Roll out condition of HRD bearing system for zone V is 0.06151 and for LRB system is 0.06814 which is similar, for Zone IV condition HRD bearing system, roll out condition is 0.1254 and for LRB is 0.110 which also a nearer value show that the roll out condition depends on the intensity of the base shear obtained from static condition in recurrent of horizontal stiffness of the bearing system calculations.

CONCLUSIONS

1. Design displacement for zone V condition is 0.1m and maximum allowable displacement is 0.2340m, Design displacement for zone IV is 0.15m and maximum allowable displacement is 0.2340m.
2. In both cases of zones maximum allowable displacement is 0.2340m but the design of base isolation displacement is restricted to 0.1m to 0.15m for the considered zones so as to increase the safety of the building from much displacement due to horizontal forces of ground acceleration.
3. End steel plate thickness considered for calculations for all the cases are kept constant.
4. Most effective choice appears in case of HDRB than LRB but choice of bearing system is to be made for low isolation frequency and then in low peak accelerations which will result in reduction of floor level accelerations and reduces the amplification of building displacements.
5. Design of isolation system requires lateral stiffness and viscous damping, equivalent damping of HDRB is designed in such a way that isolation time period and the damping ratio are considered.
6. While LRB is characterized by the isolation period and the normalized yield strength of the lead plug denoted by "F" considered, total weight of the structure and acceleration due to gravity, bearing parameters and restoring force, dimensions of the bearing system are determined.
7. The investigation was based on consideration of free excitations in accordance with considering the Indian method i.e, equivalent static method data of time, soil conditions and zone parameter.

8. ASCE 07-10 code provides a care of providing isolation systems in soft soils also but for applying in soft soil conditions or where more significant long period excitation are considered, base isolation needs care to avoid resonance effects.
9. Choice of displacement of building for soft and medium soils are considered, where a peak acceleration response at the support conditions can be reduced far from a non isolated structure, the project results in extensive sensitivity soil condition building study.
10. From all the above discussion, base isolation was found to be effective in reducing the seismic risk reduction

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