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Seismic Design of Resilient Sliding Isolation System for Protection of Equipment

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Abstract

Seismic isolation is one of the high-quality options to defend equipments. It allows manipulating reaction acceleration transmitted to gadget under its allowable stage. Amongst several sort of isolation machine, the combination of restoring spring and slider (resilient sliding gadget) is a very powerful device for protection of equipment. In design of this sort of isolation system to make certain functions of equipments, there are many appropriate mixtures of stiffness and friction coefficient. But on the same time it is also essential to govern relative displacement of isolation system so as to offer safety to the connections of gadget with other structures like energy deliver, major servers and so on. This have a look at offers with most excellent design of equipments with those resilient sliders which could manage acceleration underneath allowable stage and at equal time decrease the relative displacement. Ideal parameters of resilient sliding isolators are determined analytically for different degrees of allowable acceleration. The validity of analytical technique used, is also proven by shaking table checks. Effects of this examine display that 1) most desirable values of period are decreased with increase of allowable acceleration 2) The most excellent friction coefficient is elevated with higher allowable acceleration.

1. Introduction

Traditional mitigation strategies like; bolting, cross bracing and structural stiffening may work to keep equipment upright but actually they provide a direct path way on which damage shock and vibration can travel. The more rigid the connection, the more likely there will be damage to fragile components like drive heads, optical lasers, and other sensitive components.

Recently desired performance objective of "operation" or "immediate occupancy" of sensitive equipments has made the engineers to adopt non-conventional method for protection of these systems. Seismic isolation as a reliable and economical method can be recommended to achieve these performance objectives. So far almost all seismic isolation systems that were developed for equipment consist of coil springs to provide flexibility and energy absorbing device in the form of friction slider or oil dampers [1]. There are many seismic isolators like Friction Pendulum Bearing (FPS) [1, 2], Resilient Friction Base Isolation (R_FBI) [3] and Hybrid Base Isolation [2] (Slider and Laminated Rubber bearing) which are using same mechanism to protect equipments. This paper focuses on dynamic behaviour and design of isolation systems that comprise of friction slider and restoring spring. First, a numerical model of a raised floor, seismically isolated with friction slider and spring is proposed. Then the model was validated by performing shaking table test. This model was used to predict dynamic behaviour of seismic isolated equipments and to reach at the optimum design of isolation system. For the purpose of this study, design of isolation system is defined as optimum if it results in minimum displacement while maintaining the maximum acceleration below allowable level. Two groups of earthquakes recommended by Transportation Ministry of Japan were considered in this paper.

2. RESILIENT SLIDING ISOLATION (RSI) SYSTEM

Sliding bearing limits the transmission of seismic force to stage this is feature of friction coefficient of sliding interface. This behaviour is thrilling for protection of non-ductile and non-structural additives in opposition to earthquake when anticipated acceleration is greater than their strength degree. But there are a few negative factors in seismic behavior of sliding bearings like loss of restoring force and transmission of high frequencies [5,6]. Transmission of excessive frequency excitation causes harm in sensitive equipments. To keep away from these unwanted capabilities, sliding bearings are generally utilized in mixture with a restoring spring. While spring and slider are used in collection (Fig1), sliding does no longer arise for seismic excitation underneath a certain threshold, and the remoted structure responds handiest in elastic part [7]. This conduct can filter direct and indirect excitation of excessive frequency due to stick-slip. But in sturdy excitation, this machine may result in residual displacement. When spring and slider are in parallel mixture i.e. Resilient Sliding Isolation device (Fig 2) transmission force to gadget is same to restoring force of spring plus friction force at sliding interface. This aggregate can lessen both transmission of oblique high frequency excitation and residual displacement.

Seismic Behavior of Resilient Sliding Isolation System

Since the shear force activate the slider bearing, its horizontal stiffness drops from large value to zero and causing an unrestrained displacement. In this regards combination of slider and restoring spring provide an additional stiffness to control displacement. Thus force-deflection relationship of the combined system.

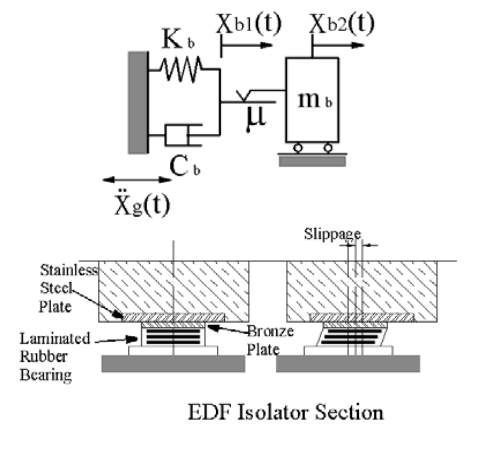


Fig.1 Slider and spring in series

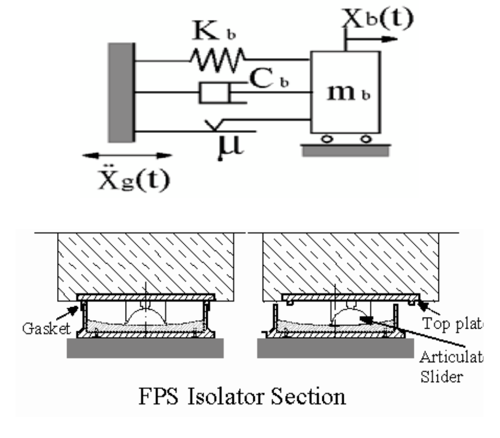


Fig.2 Slider and spring in parallel

3. ANALYTICAL MODELING OF RSI

In numerical model of resilient sliding isolation the essential feature that needs to be modeled for behavior of sliding bearing is the velocity dependence of the coefficient of friction and influence of bearing pressure in the coefficient. Although, biaxial interaction and its effect can be considered as another feature of modeling. Here, velocity dependence of friction coefficient can be modeled by the following equation,

$$\mu=\mu_{max}-\Delta\mu\ \exp(-\alpha\ U) \qquad (1)$$

In which, μmax is the maximum value of the coefficient of friction, Δμ is the difference between its maximum and minimum value. Effect of bearing pressure on friction coefficient is accounted by factor α and U& is the absolute velocity. Biaxial interaction is considered as model proposed by Park and Wen [11]. In addition to friction element, laminated rubber bearings are assumed as a linear spring and frames is considered as elastic beam element. Mass of frame elements and blocks deemed as lumped mass element that have degree of freedom in horizontal direction (X-Y) and rotation about vertical axis (θ). In the present study, in addition to this numerical model, a different analytical model, termed here as SDOF model is proposed that computes maximum values of response parameters for different sets of friction coefficient and spring stiffness. In fact this model considers the bilinear model for forcedisplacement behavior of isolation system as shown Fig.3. The design parameters for this model are μmax and spring stiffness. In this analytical model equipment and raised floor is modeled as rigid block.

4. VERIFICATION OF ANALYTICAL MODEL

Provisions and codes provided procedures to verify acceptable performance of equipment for expected ground motions. For example IEEE 693 recommends procedures, which comprise analytical studies (Static analysis, response spectrum analysis) and experimental methods (response history testing, shaking table test). The economical impact of failure of equipment in earthquake generally makes it necessary, any seismic design method or protection strategy to be verified for its accuracy with precise numerical analysis or with experimental test.

Experimental Test

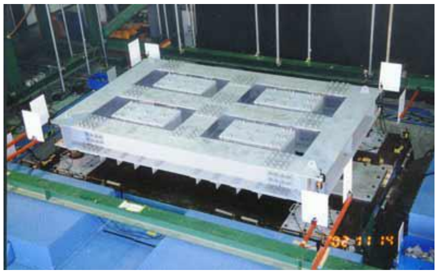


Fig.3 Experimental Setup

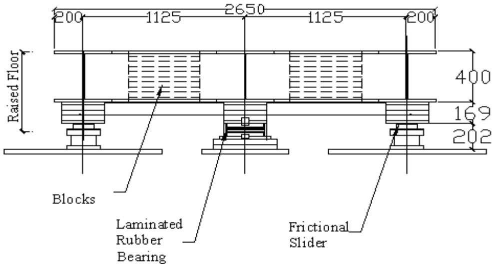
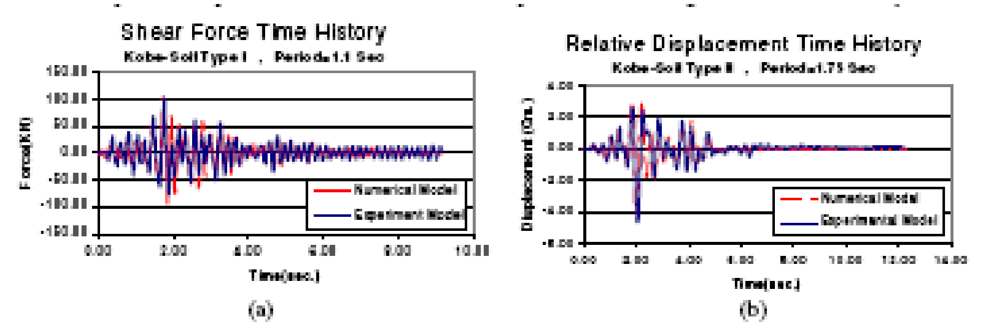


Fig.4 Details of test setup

In order to establish the reliability of numerical model for the isolation system used in the study a series of shaking table were performed at Disaster Prevention Research Institute of Kyoto University. This shaking table system can reproduce acceleration of 1.0g in three directions with maximum stroke of 0.3m in horizontal and 0.2m in vertical direction. In this experiment a 4.15 m x 2.65 m raised steel floor, supported on four frictional sliders at the corner and two laminated-rubber bearings was considered (Fig 6 and 7). The total weight of this raised floor was 100 KN. Rubber bearings have a square plan of 250 mm x

250 mm with three different thicknesses. Modulus of elasticity of rubber is 1.2 KN/mm2. The bearings were designed for periods of 1.1, 1.75 and 3.0 seconds respectively. Sinusoidal tests on sliding bearings before shaking table test showed that the minimum and maximum values of friction coefficient are 0.05 and 0.15 respectively. The system was tested using two groups of earthquakes, recommended by Transportation Ministry of Japan. These groups are T1 (offshore) and T2 (inland) and each one contain 9 records. Each group, based on soil condition of recording station further divided into three categories, records on stiff soil (soil typeI), medium soil (soil type II) and soft soil (soil type III). Almost 70 runs were made with different isolators and earthquakes. Displacement, acceleration, vertical pressure on bearing and lateral force of System were



(a) (b)

Fig.5 Comparison of Response of Experimental and Numerical Model

5. DESIGN METHODOLOGY

Dynamic characteristics of equipments like stiffness or damping may effect on any decision about modeling and design methodology of their isolation systems. In this regard, Almazan et al. Compared response parameters of a rigid block and flexible superstructure (period 0.5 sec.) were isolated by FPS isolator. Their result show that difference between the isolator deformation computed from both models is very small; however slightly larger discrepancies (about 10 percent) was observed in shear force. Though most of equipments have solid components, flexibility of equipment if there, do not have considerable effects on response of their isolation system. Thus in isolated equipment, response of seismic isolation system can be obtained with acceptable accuracy by assuming “equipments + raised floor” as a rigid mass. This SDOF model of sliding isolation system has been shown in Fig3. Determination of stiffness and friction coefficient of SDOF model based on seismic performance objective of equipments is purpose of design methodology in this part.

Table 1. Maximum seismic resistant acceleration on disk drives

Manufacturer's Model#	Max.g/Operating	Max.g/ Non-Operating
DEC- Alpha Server-#8200	0.5 g	0.5g–1.0g
SUN-Class III Drive	0.25 g	1.0 g
DEC-RZ28DriveUnit	0.5 g	0.5 g

HP-Model20DriveUnit	0.25g	N/A
HP-Enterprise9000	0.2g-0.5g	0.5g–1.0g

Table 1 indicates suggested peak accelerations by manufacturer for some models of disk drives in computer systems. The response acceleration if exceeds this value may cause permanent damage and loss of readable data. In this table, for operating and non-operating condition of different disk drives maximum seismic bearable acceleration varies between 0.2g-1.0g. These values in practice are reduced by safety factors to Maximum Allowable Acceleration. For protecting these systems during earthquakes, stiffness of spring and friction coefficient of slider should be selected to limit horizontal input acceleration under their allowable values.

Optimum Design Procedure

Any combination of stiffness and friction coefficient of resilient sliding isolation, which control response acceleration under allowable level of acceleration, can be accepted as eligible design parameters for protecting equipment in earthquake. But most of equipments have connections with other systems like power, water supply or main server and safety of connections to these systems is essential to ensure the functioning of equipment during earthquake. Therefore beside safety of equipments, designer should control displacement of isolated equipments in earthquake to minimum value. In this regard, determination of stiffness and friction coefficient of isolators to control input acceleration under allowable level and to minimize lateral displacement is the optimum design of resilient sliding isolation.

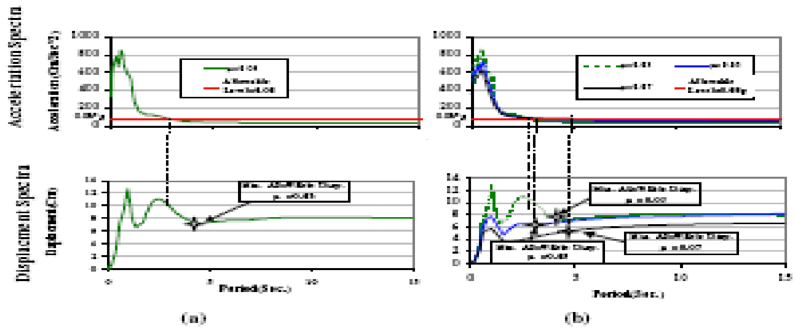


Fig.6 Procedure of Optimum Parameter Recognition for El Centro Earthquake

Safety region begins from crossing point of dashed-line with response spectra. Isolation systems with period longer than this point are eligible to ensure operation of equipment during or immediately after El Centro earthquake. Among these eligible periods just one of them has minimum displacement that is shown in displacement spectra with star symbol.

In Fig.7 optimum parameters of resilient sliding isolator for different allowable accelerations of this isolator were computed for feasible range of friction coefficient between (0.03~0.10) and periods between (0~15sec.). These parameters were computed by using cited procedure for any allowable level of

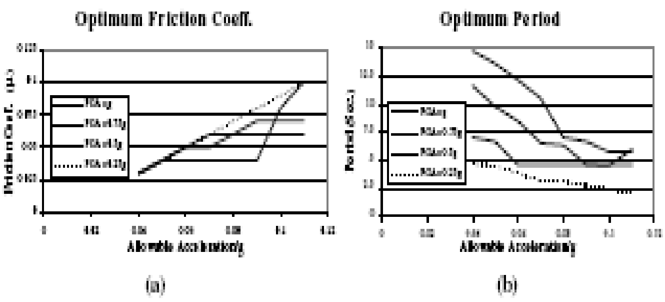


Fig.7 Optimum Parameter of Resilient Sliding Isolation for El Centro Earthquake

acceleration between (0.04g-0.11g). Input earthquake was scaled to 0.25g, 0.5g, 0.75g and 1.0g to evaluate the effect of Peak Ground Acceleration (PGA) on optimum parameters. Fig.5-a illustrates, optimum friction coefficient has ascending trend with increasing of allowable level of acceleration but different values of peak ground acceleration have not clear effect on optimum value of this parameter. Optimum period in Fig.13-b has descending variation with increase of allowable acceleration. In this figure optimum period of isolation system under higher level of peak ground acceleration of earthquake is longer.

6. EVALUATION OF OPTIMUM PARAMETERS

To determine variation of optimum parameters of resilient sliding isolators under several earthquakes gives an evaluation about optimum design of these isolators based on seismic performance objective of equipments. In this part, optimum parameters of resilient sliding isolators are obtained analytically for T1 (offshore) and T2 (in land) groups of motions. In order to have proper comparison all earthquakes are scaled to site specific Peak Ground Acceleration (PGA) equal 0.25g (Moderate seismic zone) and 0.5g (High seismic zone). Fig.6 shows optimum parameters of resilient sliding isolators under records of T1 that were scaled to 0.25g. In this figure earthquakes recorded on stiff, medium and soft soil are scripted with T1-I, T1-II and T1-III. Variation of optimum period and friction coefficient with allowable level of acceleration has same trend with variation of these parameters in El Centro earthquake. For design purposes Mean and, "Mean ± Standard deviation" of optimum values for all earthquakes show that optimum frictions are almost in the same line for all earthquakes in T1 while optimum period can be selected from a band of period for any allowable acceleration of equipments. In Fig 7 optimum parameters are computed for T2 motions that were also scaled for same peak ground acceleration of 0.25g. These earthquakes depending on soil type of recording station were divided in three

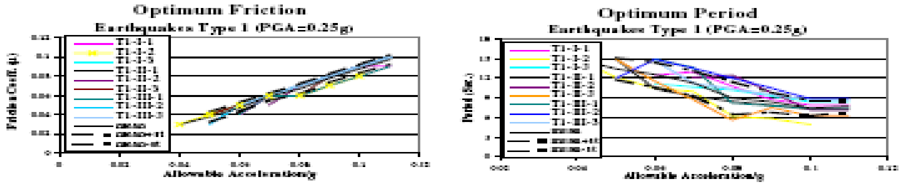


Fig.14 Optimum Friction and Period of Resilient Sliding Isolation System under records of T1

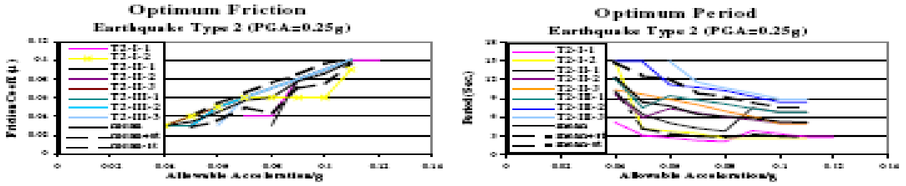


Fig.8 Optimum Friction and Period of Resilient Sliding Isolation System under records of T2

Categories T2-I, T2-II and T2-III. Even the variation of optimum parameters is the same as earthquakes in T1 but Standard deviation of optimum values is further. Comparison between mean values of optimum parameters under records of T1 and T2 and their Standard deviation is shown in Fig 8. In this figure mean values of optimum friction coefficient for two types of earthquakes are nearly same and have linear variation with increasing of allowable level of acceleration.

Also, such as variation of optimum parameters of isolation system under El Centro earthquake, mean values of optimum periods for higher level of PGA is more than lower levels. Increasing of standard deviation of optimum parameters for higher value of PGA can be explained with behaviour of resilient sliding isolators (FPS isolation) under harmonic loading. It was shown for range of relative periods (T/T0) and maximum acceleration ratios (ag/µ), maximum response acceleration is constant and independent to frequency of input motion. For an isolator with period T0 and friction coefficient µ, Fig.4 shows for lower values of ag/µ, range of constant response of isolator is longer than that for higher values. In other words when maximum acceleration ratio

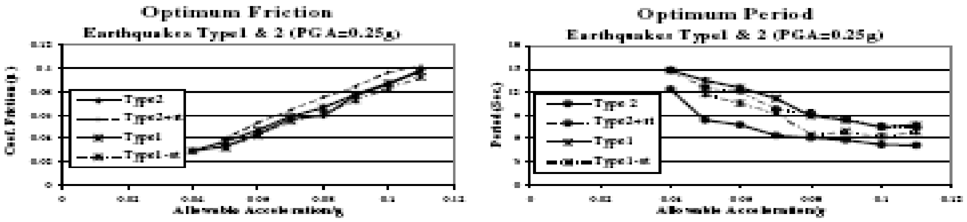
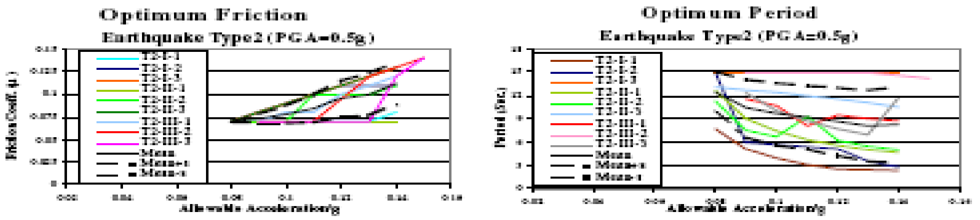


Fig.16 Optimum Friction and Period of Resilient Sliding Isolation under records of T2



of input motion (ag/μ) reduces, response of isolator below certain value of excitation period (T) will be constant. Though earthquake is comprised several harmonic excitation with different period but its maximum response acceleration is dominated by two or three harmonic excitation. Therefore for higher value of PGA, optimum design parameter also depends on frequency content of input motion and thereby increases the Standard deviation.

7. CONCLUSIONS

The paper discusses the evaluation of design parameters of the Resilient Sliding Isolation system to achieve performance objective of equipments. Analytical method based on single degree of freedom is proposed to obtain these parameters. In addition the design parameters obtained by this method also lead minimum relative displacement. The accuracy of the method is validated by shaking table test of raised floor isolated by resilient sliders. Optimum design parameters of these resilient sliding systems subjected to two type of Japan standard earthquakes are obtained for different values of allowable level of acceleration for the equipments.

Results of analysis show:

[1] For higher values of peak ground acceleration of earthquake, optimum period of resilient sliding isolation is longer.

[2] Optimum friction coefficient of isolation system under earthquakes T1 and T2 in moderate seismic zone has almost linear relation with increasing level of allowable acceleration.

[3] Optimum period of isolation system under earthquakes T1 and T2 in moderate seismic zone becomes shorter when allowable level of acceleration increases.

[4] In high seismic zone, standard deviation of optimum parameters is larger than moderate seismic zone. Mean of optimum parameters in high seismic zone has same trend of variation with moderate seismic zones.

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