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Applicability of Seismic Base Isolation in Structure

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ABSTRACT

This paper briefly reviews the concepts, applicability and benefits of using base-isolation in structures in severe seismic zones. It is a passive means to obtain seismic response control in structure through utilizing three basic functions – horizontal flexibility, energy dissipation and rigidity against normal lateral loads. The rubber-lead bearing appears to be the best isolator performing all three functions efficiently while the base-isolation of masonry building through a planned sliding joint gets considerable attention. Conditions favor the choice of base-isolation alternative to conventional elastic or elasto-plastic designs are indicated.

Keywords : Seismic response, Base- isolation, Response Spectra, Hysteretic energy dissipation.

I. INTRODUCTION

It is customary to represent ground acceleration through a series of positive and negative peaks of varying amplitude and time interval between them in any three mutual perpendicular directions with total duration of recording runs from few seconds to few minutes depending on earthquake magnitude and type of source. However motion is particularly intense over short time duration (Fig. 1), which is the main cause of damage of structure and their contents both structural and non-structural.

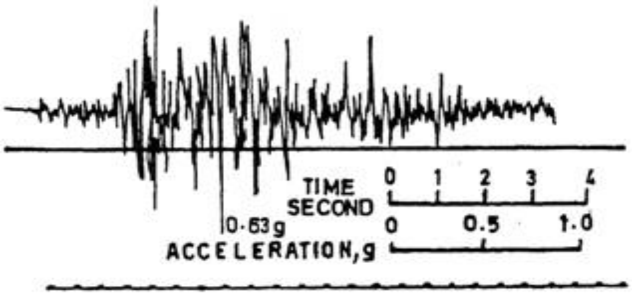

Fig. 1 Accelerogram of Koyna Earthquake (December 11, 1967) along axis of dam.

Conventionally structures are built firmly attached to ground receiving all the ground movement at their base. Since response of structures against such dynamic force depends on mass, stiffness and damping characteristics, a careful observation of acceleration response spectra, indicating response of linear elastic system to given earthquake-time history reveals (Fig. 2):

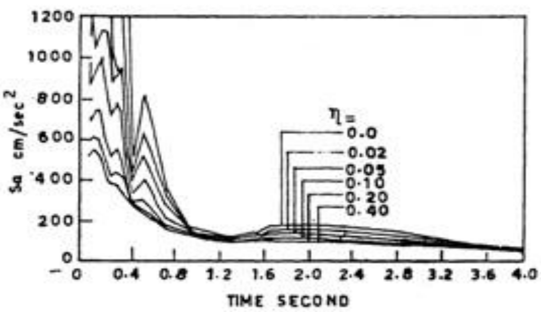

Fig. 2 Response Spectra for elastic system of Koyna Earthquake (December 11, 1967) along axis of dam.

(i) For zero period of absolute acceleration response is equal to peak ground acceleration.
(ii) For low period (e.g. Stiff system) response get amplified, it is highly peaky and become several times the peak ground acceleration. Amplification is significantly affected by damping – being lower for higher damping.
(iii) For long period (e.g. flexible system) acceleration response curve is smooth and lower than peak ground acceleration, tending towards zero. Here significance of damping is very much reduced. Unfortunately, most of the engineering

structures and systems lie in the low to medium period range hence subjected to very large inertia forces.

Now, for "fail-safe" approach it is required to design a structure that can resist resultant inertial forces through incremental sizes of structural members and connections, bracing system and shear wall, etc. - full catering of these elastic response forces require large additional financial input over those for normal condition without earthquake consideration. Therefore, for economical reasons, "non-collapse" design is preferred, that is design the structure for "lower-than-expected" seismic forces so as structure to remain in the elastic range and for expected maximum seismic motion it is allowed to go into plastic stage with sufficiently large deformations, or damage to non-structural and structural elements but ensuring that collapse is avoided [1].

However, energy absorption through plastic deformations or minor damages capable to reduce dynamic response effectively, but put a great responsibility on designer who should ensure that structure must possess enough ductility and energy absorption capacity without strength deterioration throughout the seismic time-history of future probable earthquake motions since building designed for code based seismic forces without the requisite detailing for ductility, are likely to collapse in severe ground motions as happened in case of nine storied pre-fabricated framed R.C. Buildings in Spitak (Armenia) earthquake of Dec. 7, 1988.

II. METHODS AND MATERIAL

A. Response Control Approach

The above stated approach does ensure safety of lives and properties that would have suffered due to collapse of structures but leaves a number of uncertain questions:

(i) How much will be the cost of damaged non-structural element,

(ii) How functional will be the remain damaged structure,

(iii) How much will be the economic loss due to disruption of transportation, communication, water supply line, etc.

The scenario in this regard will be different between developed and developing countries; between urban and rural areas; and zone of frequent and infrequent earthquake occurrences. In developed and urban areas the concern are increasing for continuity of life-lines besides basic issues of saving of lives and keeping the economic losses to the minimum.

The above goal is effectively achieved by shifting design strategy from "confrontation" to "accommodation" of ground motion through "base isolation". In this approach, the structure is not attached firmly with ground, instead through a device that partially transfer ground movement to the structure, cutting down the intense peaks of the ground motion. The objective is to reduce the structural response such a levels that it should remain safe without damage – hence to achieve a "no-damage" or "safe" structure. As the intensity of shaking of structure could be make less than that of ground, the content and non-structural elements will also be relieved of intense shaking, hence should remains undamaged. Thus economic losses will either be prevented altogether or reduced to a minimum. Other means of "seismic response control "are developed such as incorporation of energy dissipating devices and resonant mass damper in the structure.

B. Seismic Response Control

The concept of seismic response control can be described in terms of number of possibilities arises with respect to acceleration response spectra (given in Fig. 2):

First, if flexibility could be introduced in the system for given mass and damping to elongate its period considerably, the response could be brought down substantially and to the desired level of "no damage" situation.

Second, if damping could be increased without changing the mass or stiffness, the peaks in the response will be eliminated, and the response reduced considerably, particularly in the low period range.

Third, the effective vibrating mass could be altered at appropriate instants of time-history so as to significantly reduce the amplification of the main structural system.

Fourth, attempt could be made to alter the base motion, hence the response, by an active dynamic actuator system which is actuated by the structural response, continually analyzed and monitored through a dedicated computer system.

Fifth, combination of some of the above approaches may be attempted with a view to evolve an effective, reliable and economical control mechanism to achieve "no damage" design for structure.

Therefore, on basis of general understanding of various systems following classification can be proposed [11]:

(a) Classification based on basic principal of dynamics – (i) A method to control and adjust restoring forces characteristics (ii) A method to control and adjust damping, (iii)A method to control and adjust mass, and (iv) A method to adjust input motion (a combination of above methods)
(b) Classification based on Realization Procedure – (i) Passive ay and (ii) Active way
(c) Classification based on Installed Location – (i) External types (like base isolation), and (ii) Internal types (internal element)

According to the above classification, the seismic base isolation is an external type, works in passive way and provides a method of seismic response control by adjusting stiffness and damping.

C. Base Isolation fundamentals and Devices

The fundamental principle behind base isolation [2] is to introduce flexibility at the supports of a structure in the horizontal plane so as to ensure that the time period of the structure is well above the predominant periods of the probable earthquake. Now in this process, the relative displacement amplitude increases, hence often damping or restraining elements have to be introduced simultaneously to restrict the extent of relative movement caused by the earthquake.

There are three basic elements in practical base isolation system, and these are –

(i) Decoupling between the super-structure and the base with or without flexible mounting so that effective period of vibration of the total system is lengthened sufficiently to reduce the force response.
(ii) A damper or energy dissipater so that the relative displacements between the structure and its supports can be controlled; and
(iii) A means of providing rigidity under low in-service load levels such as wind and minor earthquakes so that the structure behaves as if fixed at base during normal service loads.

1] Flexibility

The vibration isolation principle is frequently used for reducing the transmission of machine vibrations to the buildings by mounting machine on flexible pads or springs, act as effective means of reduction of vertical vibration. For seismic protection, introduction of horizontal flexibility is actually required and the vertical flexibility is rather undesirable. Therefore, the isolators must maintain vertical rigidity while allowing horizontal flexibility. Steel roller or rubber bearings as used in bridges for providing longitudinal movements fulfill these objectives. These rubber bearings [3] are constructed in layers by sandwiching steel shims between each layer and bonding together by gluing. The steel shims constrain the lateral deformation of the rubber under vertical load resulting in vertical stiffness several hundred times the lateral stiffness. These bearings are found very practical for use in buildings also. Other possible devices for introducing flexibility include spherical balls, cylinders with spherical ends, cable suspensions, pinned or soft storey columns, sleeved piles and sliding or rocking arrangement as shown schematically in Fig. 3.

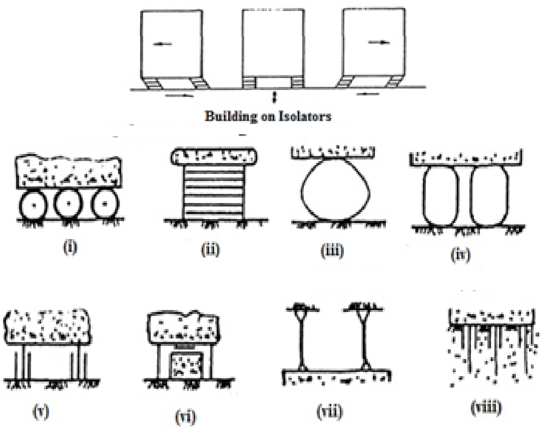

Fig. 3 Base Isolation Devices (i) Rollers (ii) Rubber (iii) Rocker (iv) Rocker (v) Soft Column in Cylinder (vi) Soft First Story (vii) Suspension (viii) Piles in Sleeves.

The acceleration response spectra of the maximum probable earthquake for major project in India are shown in Fig. 4. Substantial reductions in the acceleration are clearly seen when the periods of vibration of the structure is lengthened from 0.4 sec. to 2.0 sec. Such a reduction in force response is primarily dependant on the characteristics of the earthquake ground motion and the original period of the fixed base structure.

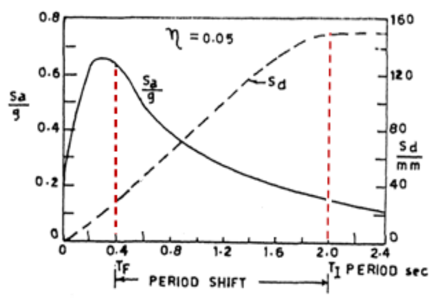

Fig. 4 Acceleration and Displacement Response Spectra for design MCE

The force reduction effects are most significant where the intense part of earthquake record has pre dominantly short to medium range of periods say less than about 0.5 sec and also the fixed base structure is stiff type, so that the isolation system takes the structure to well beyond the peak response.

Simultaneously the additional flexibility of structure gives rise to large relative displacements across the flexible mount, cleared from fig. 4. Such displacement problem can be overcome by introducing higher damping along with flexible mount or restrainers/ stoppers to restrain displacement reaching undesirable values.

2] Energy Dissipation

For fixed base structures dissipation of kinetic energy due to seismic motions takes place through internal damping, frictional damping at supports and radiation damping through the base and side soils. The damping available in the undamaged small deformation state is rather small, less than 4% of critical in most cases. This value does increase with large plastic deformations and damage, but this is undesirable for "no damage" design approach. Therefore in base isolated system additional damping is introduced externally, may be through hysteretic energy dissipation [4, 5]. The term hysteretic refers to the cyclic nature of building vibrations in which energy is dissipated as building moves from side to side. Fig. 5 indicates an idealized force-displacement loop where the enclosed area is a measure of the energy dissipated during one cycle of motion. Several mechanical devices that use plastic deformation of either mild steel or lead to achieve energy dissipation behavior were developed [6], and these includes – round steel bar cantilevers (Fig. 6 (a),(b),(f),(g)) [7], flexural beam (Fig. 6 (c), (d)),spiral bar (Fig. 6 (e)) , plate cantilevers (Fig. 6 (g)) and through sliding friction (Fig. 6 (h)).

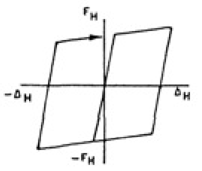

Fig. 5 Hysteretic energy dissipation

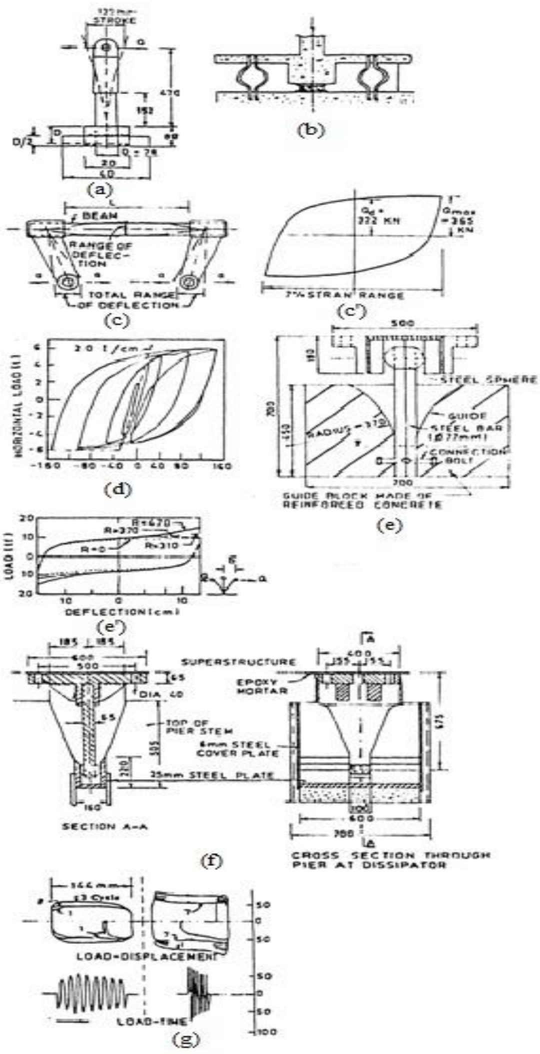

Fig. 6 Energy Dissipation Systems using steel plasticity (a) Round Cantilever Damper (b) Base Isolation method using Round Bar Damper (c)Flexural Beam Damper (c/) Force Displacement Hysteresis Loop for Flexxural Damper (d) Hysteresis Loop for Spiral Bar Damper (e) Cantilever Damper (e/) Hysteresis Loops for Cantilever Damper (f) Cantilever Plate Damper (g) Force Displacement Loop for tests on pure plate sliding layers for pressure of 33MP.

Damper that uses fluid viscosity and energy dissipation through shearing of lead cylinder are shown in Fig. 7. As lead be a crystalline material which changes its crystalline structure under deformation, but almost instantly regains its original crystal structure when the deformation ceases, indicated in Fig. 7(b) effectively be employed in such damper devices.

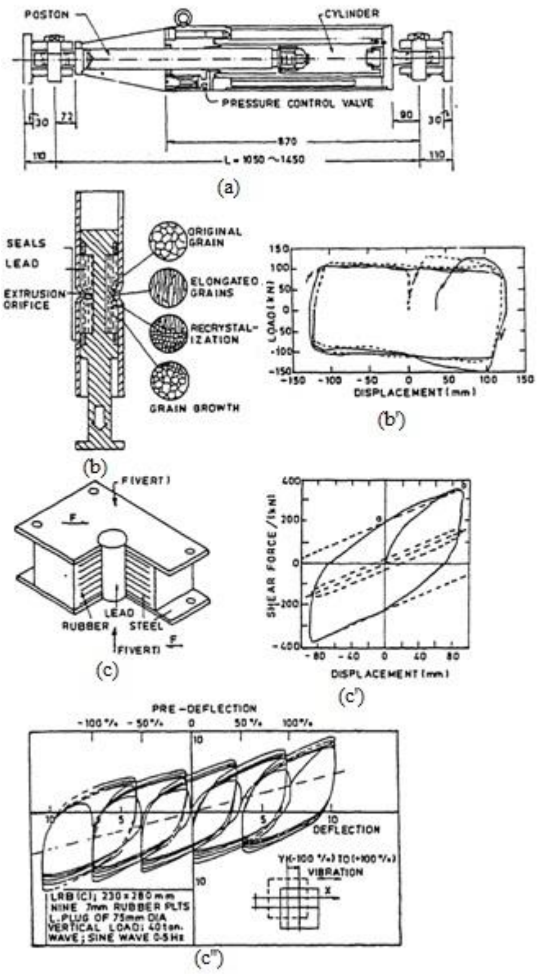

Fig. 7 Energy Dissipation Devices using Viscous Fluid or Lead (a) Oile Damper (b) Longitudinal Section of Lead-Extrusion Damper (b') Force Displacement Hysteresis loops for 140 kN Lead-Extrusion damper tested in 1976 (Solid line) and again in 1966 (Dashed line) (c) Lead Rubber Shear Damper (c') Force Displacement Curves for a Lead- Rubber bearing (Solid line) and a Rubber bearing (Dotted line) (c'') Hysteresis Loops for LRB with pre-deflection.

3] Rigidity under low lateral loads

While lateral flexibility is highly desirable for high seismic loads, it also undesirable that structural system to have perceptible vibration at frequently occurring loads such as minor earthquake or wind loads. Therefore, it is necessary that flexible mount should have sufficient initial stiffness and elastic resistance to balance such loads occurred from wind and force considered to elastic design in low intensity earthquake.

The lead-rubber bearing [8, 9, 10] and other mechanical energy dissipating system provide desired lateral rigidity against low loads by virtue of initial elastic stiffness [ref. 7(c)], while base isolation system , such as rollers require separate restraining device for this purpose e.g. buffer, spring-dashpot system, or sliding friction type device.

D. Base Isolation of small Masonry Dwelling

doption of base isolation schemes makes construction of structure costlier since additional cost incurred due to installation of isolator/ damper or requirement of additional reinforced concrete beams or flat slab system for supporting super-structure above isolators besides usual foundation system, though overall design of structure is on low earthquake inertial forces. However, for small masonry dwellings, the cost of base-isolator application will be substantial, can be avoided through adoption of construction methodology that allow sliding of super-structure masonry at plinth level [12] , [ref. to Fig. 8]. Here, plinth masonry is plastered smooth and oiled to prevent bonding with upper part of structure integrated with a continuous reinforced concrete band under all walls above plinth masonry to ensure integral movement of superstructure. Development of coefficient of friction of 0.15 to 0.20 at plinth level separation result restrain against any lateral movement under wind and minor earthquakes while permits sliding under severe shocks. Such systems record reduction of response accelerations as much as two-thirds with maximum sliding displacements up to 20 mm only for Koyna 1967 and ElCentro 1940 earthquake inputs.

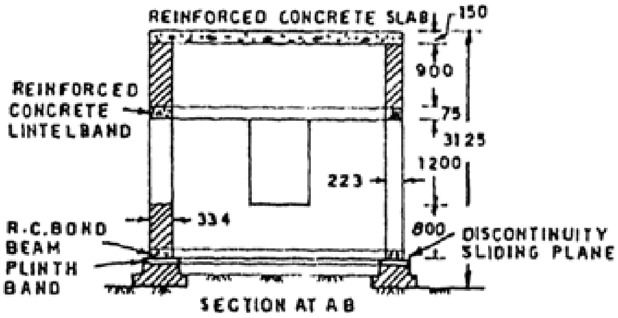

Fig. 8 Sliding System for Masonry Dwellings

E. Reduction of Damage potential by Response Control

Damage due to failure of non structural elements most of the cases under estimated, which can be controlled through seismic base isolation and energy dissipation system applicable for individual components. Computer installations, spent fuel storage tanks or battery stacks of atomic power plants, control cabinets and switch yard equipments of power stations, individual objects of art in museums, etc., can be supported individually on isolator systems. Frictional devices can be incorporated between partition walls and frames to dissipate energy during the relative movements.

III. CONCLUSION

Adaption of base isolation system over conventional fixed base design is advantageous in following cases –

(i) Moderate to hard subsoil condition with stiff structure, say two to ten storey moment resisting frames, Shear walls or braced framed buildings up to 15 storey and taller box like rigid building systems.

(ii) Permissible horizontal relative displacement of isolator up to 150 mm on either side.

(iii) Low effective earthquake force acting on building content is desirable due to presence of valuable breakable articles like museum artifacts.

Advantages of seismic isolation system with energy dissipation schemes are –

(a) The structural deformation goes into inelastic range and consequent damage likely to be completely eliminated since structure need to design for low inertial forces that proves economical.
(b) Lower relative storey displacement or drift minimizes non structural damages to cladding, partition wall, etc.

Lower response acceleration at higher floor level considerably reduced chances of damage to equipment or service lines element of buildings.

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