Chapter 1

Introduction

1.1 INTRODUCTION

Earthquake disasters have consequences and characteristics much different from other disasters. The main characteristic of this disaster is its uncertainty. An earthquake event is uncertain with respect to its location, magnitude, intensity, time of occurrence, duration, etc. An earthquake occurs without any warning and the whole damaging effects occur within seconds. The earthquake problem is further complicated by the effects of earthquakes on different structure with different properties and varying degree of quality of design and construction. It is said "Earthquake do not kill people, but structures do". (Murthy 2005)

Designing structures to withstand design earthquakes is a challenging task, for satisfying the conflicting parameters of safety and economy. The task is further intrigued by the uncertainty of the design event. However, it is necessary to adopt a best possible approach for earthquake resistant design based on the design requirements and economical considerations.

1.2 EARTHQUAKE RESISTANT DESIGN APPROACHES

The earthquake design approaches can be grouped broadly into following two categories:

a) Conventional approach
b) Modern approach

1.2.1 Conventional Approach

Conventional approach adopted to resist earthquake generated forces and hence to minimize or to prolong the damage of structure is to provide proper strength, stiffness and inelastic deformation capacity i.e. ductility (IS 13920:1993). In conventional earthquake resistant design philosophy the structure is expected to perform without major damage under minor and moderate earthquakes and under major earthquakes the damage can be significant without complete collapse. The objective considered in this design philosophy is that collapse of structure is delayed so that humans can safely escape from the building. The earthquake energy is absorbed by structure itself resulting in damage. (Dowrick 1987)

Under gravity load (static load) condition the tensile stresses develop at a particular location in the elements of structure, such as bottom of beam, slab, etc. Under such loading no tensile stresses develop in the columns as they are subjected to axial loading only. Hence when the structure is designed as an ordinary moment resisting frame for static load, tensile reinforcement is provided at these locations only. But under earthquake excitation force (dynamic forces) the tensile forces may develop at any location of the elements of structure such as either top or bottom of beam and also in the columns. Since concrete cannot carry this tension, reinforcement is required at both faces of beams to resist reversal of bending moment. Otherwise failure will occur at the locations where tensile reinforcement is not provided (Murthy 2005).

To avoid this failure it becomes necessary to improve the ductility of the structure so that it can deform without collapse during earthquake shaking. Under this condition structures should be designed with failure-mode-control approach. Specially selected ductile components are designed to withstand several cycles well beyond yield under reversed loading. The yield levels being chosen so that the forces transmitted to other components of the structure are limited to their elastic or low ductility range. The yielding lengthens the fundamental period of the structure, detuning the response away from the energetic period of most of the earthquake ground motion. The hysteretic behavior of the ductile components provides energy dissipation to damp the response motions. The ductile behavior of the selected components ensures sufficient deformation capacity, over a number of cycles of motion, for the structure as whole to ride out the earthquake attack. In well-designed conventional structures the yielding action is designed to occur within the structural members at specially selected locations (plastic hinge zones). Yielding of structural members is an inherently damaging mechanism, even though appropriate selection of the hinge locations and careful detailing can ensure structural integrity. Large deformations within the structure itself are required to withstand strong earthquake motions. These deformations cause problems for the design of components not intended to provide seismic resistance, because it is difficult to ensure that unintended loads are not transmitted to them when the structure is deformed considerably from its rest position. Further problem occurs in the detailing of items such as windows and partitions, and for the seismic design of building services. (Kelly, et. al., 2010)

1.2.2 Modern Approach

Modern approach of design consists of either dissipating the energy or deflecting the energy using special devices so that the structure remains undamaged. The basic approach underlying more advanced technique to resist the earthquake effect is not to strengthen the structure, but to reduce the earthquake generated forces acting upon it. Modern approaches can be grouped as under.

a) Passive Control System. (Base isolation, Passive seismic dampers)
b) Active Control System. (Active seismic dampers)

c) Hybrid Control System (Base isolation + Active seismic dampers)

1.2.2.1 *Passive Control Systems*

Passive control systems do not require an external power source for their functioning. Passive control devices import the forces that are developed in response to the motion of the structure. The energy in passive controlled structural system, including the passive devices, cannot be increased by the passive control devices. Passive control devices generally require very little maintenance. The main two types of passive control systems are, Base isolation and Passive seismic dampers.

The Base Isolation is one of the passive control techniques to reduce the earthquake effect on the structure up to negligible level (Kelly 1997). In base isolation system foundation and super structure are isolated with help of isolation system. If it is possible at one and the same time to hold up the building and let the ground move underneath then the large displacements, story drift and hence damage to the super structure will be greatly reduced (Kelly 1986). Base isolators reduce the structural response by filtering the seismic excitation and by dissipating energy, thereby reducing the energy that need to be dissipated by structure. The ground accelerations induce large displacements at the isolator level and minimize the acceleration and story drift of super structure. The isolation system does not absorb the earthquake energy, but rather deflect it through the dynamics of the system. Most of the isolators work through a combination of deflecting seismic energy and dissipating energy through suitable mechanism.

The basic concept of base isolation is to prolong the time period of the structure by incorporating flexible elements between the super structure and foundation (Caspe 1970, 1984). Due to flexibility of the isolator layer, the time period of motion of the isolator is relatively long; as a result the use of isolator shifts the fundamental period of the structure away from the predominant periods of ground excitation. Extensive review of base isolation systems and its applicability is available in literature (Buckle and Mayes 1990, Kelly 1993, Naeim and Kelly 1993, Jangid and Datta 1995). Conventional structures have relatively lower time period and they match with predominant period of most of the earthquakes. As a result they experience large accelerations and hence large forces. In contrast the base isolated structure has a longer time-period resulting in lower acceleration. Consequently the conventional structures experience lower displacements and base isolated structure high displacement at isolator level. Since large displacement is at isolator level, the super structure displaces as a rigid body.

Passive seismic dampers either absorb the earthquake energy or dissipate the earthquake energy in form of heat energy or add a restoring force to counter balance deflection of super structure. Passive seismic dampers are incorporated in super structure, generally at the place of diagonal bracings. The counter balancing mechanism may be placed at top storey or intermediate storey level. The feedback control scheme of passive control system is as shown in Figure 1.1

1.2.2.2 *Active control system*

Active control system is one which typically requires a large power source for operation of electro-hydraulic or electro-mechanical actuators which supply control forces to the structures. Control forces are developed based on feedback from sensors that measure the excitation and/or the response of the structures. When the earthquake excitation force reach to a particular level computer activate the active seismic dampers, which absorb or dissipate the energy or add a counter balancing force. (Spencer and Nagarajaya 2003). The feedback control scheme of active control system is as shown in Figure 1.2 (Datta 2003).

1.2.2.3 *Hybrid control system*

Hybrid control system implies the combined use of active and passive control system. In this system base isolators used as a passive device and active seismic dampers used as an active device. The base isolator primarily performs an open loop control role by acting as a superstructure input signal filter, while active dampers (TMD) perform a closed loop control role. The hybrid system involves a reduction of overall system response even in presence of non linear behavior of isolator (Bruno and Luigi 1999).

1.3 OBJECTIVES

Extensive literature is available on performance of base isolation subjected to far field ground motions. But very little literature is available on performance of base isolated structures subjected to near fault and low frequency ground motions. Due to characteristics of near fault and low frequency ground motions most of the isolation systems are found less effective. The main objective of this research work is to analytically study the performance of sliding isolation systems subjected to near fault and low frequency ground motions. Specific objectives of this research work are as below.

1. To study the literature available on base isolation systems in general and sliding isolation system in particular.
2. To confirm the effectiveness of Variable Frequency Pendulum Isolator (VFPI) under far field ground motion in comparison with other sliding isolation systems.
3. To examine the effectiveness of VFPI under near fault ground motion.
4. To examine the effectiveness of VFPI under low frequency ground motion.
5. To explore possibility of modification in VFPI for increasing its effectiveness under all types of ground motions.

An attempt is made in this research work to achieve the above objectives through analytical investigations.

1.4 OUTLINE OF THESIS

This thesis deals with performance of sliding isolation systems subjected to near-field and low frequency ground motions. The thesis is divided in 9 chapters. The content of each chapter are as follows.

Chapter 1 deals with introduction to the topic of the thesis and objectives of the thesis.

Chapter 2 deals with extensive literature review of base isolation systems. In particular detailed discussion regarding sliding isolation systems has been presented in this chapter. Mainly four sliding isolation systems are studied in this thesis viz., Pure Friction (PF), Friction Pendulum System (FPS), Conical Friction Pendulum Isolator (CFPI) and Variable Frequency Pendulum Isolator (VFPI). Geometry of these four systems, their limitations and comparison of all four sliding isolation systems has been discussed.

The mathematical formulation of sliding isolation systems is presented in chapter 3. The main characteristic of sliding isolation systems is non linear stick slip nature. The mathematical formulation is carried out for the two phases of sliding isolation systems (non-sliding and sliding phase), based on basic equations of motion.

Performance of sliding isolation systems subjected to far field ground motion is well established in literature. So in chapter 4 performance of sliding isolation systems subjected to far field ground motion is carried out, to conform that sliding isolation system is very effective in controlling the responses of structures subjected to far field ground motion. The analysis is carried for single storey and multi storied structures. The effective isolator for far field ground motion is also suggested.

The main objective of thesis is to prove the effectiveness of VFPI subjected to near-field and low frequency ground motion. In chapter 5 performance of sliding isolation systems subjected to near-field ground motion – single storey structure has been carried out. During near-field ground motion the effectiveness of sliding isolators is reduced with respect to sliding displacements. Hence to improve the performance of sliding isolation system concept variable coefficient of friction has been introduced. Comparison is made between constant and variable coefficient of friction and also between all isolators. Finally the effective isolator for near-field ground motion – single storey structure has been suggested.

Chapter 6 deals with performance of sliding isolation systems for multi storied structure subjected to near-field ground motion. The analysis is carried for both constant and variable coefficient of friction for all isolators. Finally the effective isolator for near-field ground motion – multi storied structure has been suggested.

Chapter 7 deals with performance of sliding isolation systems for single storey structures subjected to low frequency ground motion. The analysis is carried for both constant and variable coefficient of friction for all isolators. The effective isolator for low frequency ground motion – single storey structure has been suggested.

Chapter 8 deals with performance of sliding isolation systems for multi storied structures subjected to low frequency ground motion. The analysis is carried for both constant and variable coefficient of friction for all isolators. The effective isolator for low frequency ground motion – multi storied structure has been suggested.

Chapter 9 draws conclusion for the entire work of the thesis.

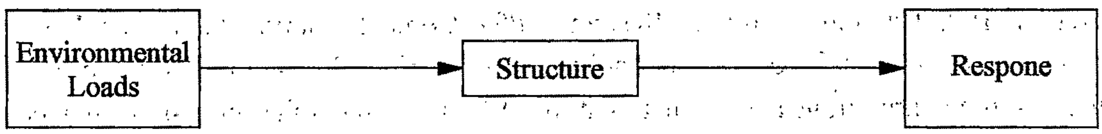

Figure 1.1: Feedback control scheme of passive control system

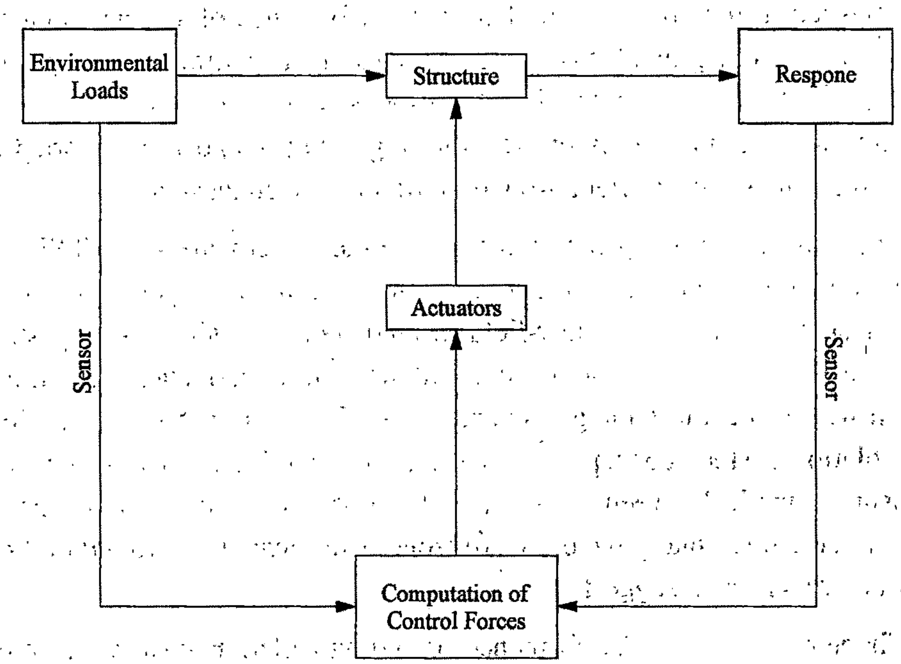

Figure 1.2: Feedback control scheme of active control system