CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the present day scenario, the necessity of more flexible civil engineering structures such as tall buildings and long span bridges is increased and they are subjected to undesirable vibration, deformation and accelerations due to strong earthquakes, blasts, wind, moving loads, machines and large ocean waves. Excessive vibration in structures is an unwanted phenomenon which causes human discomfort, waste of energy, partial collapse of structural parts, transmits unnecessary forces and also poses a threat to structural safety and, sometimes leads to collapse.

In order to eliminate the undesirable effects of vibrations in structures, it is necessary to understand the behaviour and response of structural systems subjected to dynamic loads such as earthquake and wind loads. One of the main challenges the structural engineers of the present decade are facing, is towards the development of innovative design concepts to protect the civil engineering structures from damages, including the material contents and human occupants from the hazards of strong winds and earthquakes. Traditionally, the structural systems relied on their inherent strength and ability to dissipate energy to survive under severe dynamic loading and blast loads. The energy dissipation in such systems may occur by the inelastic cyclic deformations at the specially detailed plastic hinge regions of structural members. This causes localized damages in the structure as the structure itself must absorb much of the input energy from dynamic forces and this involves high cost of repair. But essential structures such as hospitals, police and fire stations must remain functional even after an earthquake. For a structure to
remain functional after the earthquake, the conventional design approach is inappropriate as it allows a structure to undergo considerable damages.

Tall buildings are a special class of structures with their own peculiar characteristics and requirements. Tall buildings are often occupied by a large number of people. Therefore, their damage, loss of functionality, or collapse will have very severe and adverse consequences on the life and limb and on the economy of the affected regions. Each tall building represents a significant investment and as such tall building analysis and design is generally performed using more sophisticated techniques and methodologies. Furthermore, typical building code provisions are usually developed without particular attention to tall buildings, which represent a very small portion of the construction activity in most regions. Therefore, understanding modern approaches to seismic analysis and design of tall buildings is very much essential for the structural engineers and researchers who would like to have a better grasp on design and performance of these icons of a modern megacity.

In recent years, innovative means of enhancing structural functionality and safety against dynamic loadings have gained momentum. This includes the use of supplemental energy absorption and dissipation devices in structures to mitigate the effects of these dynamic loadings. These systems work by absorbing and reflecting a portion of input energy that would be otherwise transmitted to the structure itself. These systems can be classified as passive, active, semi-active and hybrid vibration control systems based on the manner in which they act to control the vibrations.

For the past few decades, the use of energy dissipation devices in structural system has gained momentum. To keep the vibration of these structural systems within the functional and serviceability limits and to control and reduce the structural and architectural damage caused by the extreme loads, different passive, semi-active, active and hybrid devices and design
methodologies are being developed. Addition of supplemental passive devices and semi active energy devices such as Viscosity Fluid dampers (VFDs) and MR dampers are considered to be viable strategies for enhancing the seismic performance of building structures. Several researchers have carried out theoretical and experimental studies on passive and semi-active vibration control systems.

1.2 GOALS OF EARTHQUAKE RESISTANT STRUCTURES

It is economically not feasible for ordinary buildings to be designed as absolute earthquake proof. However, the goals for Earthquake Resistant Design (EQRD) are shown below.

Serviceability level Earthquake

- Frequent and minor earthquakes
- Building should not be damaged and continue to remain in service
- Expected ten times during the life of building

Damageability level Earthquake

- Occasional moderate earthquakes
- No structural damage is expected.
- Non structural damage should not lead to any loss of life.
- Expected once or twice during the life of building.

Safety level Earthquake

- Rare major earthquakes
- Building should not collapse
- Non-structural & structural damage should not lead to any loss of life.
1.3 CHARACTERISTICS OF EARTHQUAKE-RESISTANT BUILDINGS

Basic Principles of Conceptual Design

- The aspect of seismic hazard shall be taken into consideration in the early stages of the conceptual design of the building.
- The guiding principles governing this conceptual design against seismic hazard are:
  - Structural simplicity,
  - Uniformity and symmetry,
  - Redundancy,
  - Bidirectional resistance and stiffness,
  - Torsional resistance and stiffness,
  - Diaphragmatic action at storey level,
  - Adequate foundation.

1.4 NEED FOR DAMPING DEVICES IN STRUCTURES

Current trends in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value. Out of the several techniques available for vibration control, concept of using energy dissipation devices is an effective one. As structure tends to be more sensitive to seismic and wind excited vibrations, this has led the engineers to turn up the implementation of damping devices in structures in order to increase the damping and thus decrease the uncontrolled vibrations and accelerations which cause human discomfort. The selection of a particular type of vibration control device is governed by a number of factors which include efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety.
Energy dissipation by means of damping is one of many different methods that have been proposed for allowing a structure to achieve optimal performance when it is subjected to seismic, wind storm or other types of vibration disturbances. The level of damping in convectional structures is very low, and hence the amount of energy dissipated during transient disturbances is also very low as the energy dissipation occurs by means of inelastic deformation of the structural elements. Therefore, most of the energy dissipated is absorbed by the structure itself through localized damage. The concept of add-on dampers within a structure assumes that sum of the energy input to the structure from a transient disturbances will be absorbed, not by the structure itself, but rather by supplemental damping elements. An idealized supplemental damper would be of a form such that the force being produced by the damper is of such a magnitude occurs at such a time that the damper forces do not increase overall stress in the structures. Properly implemented and installed ideal dampers should be able to simultaneously reduce both stress and deflection in the structure.

Energy dissipation devices can absorb a portion of earthquake induced energy in the structure and minimize the energy dissipation demand on the primary structural elements such as beams, columns or walls. These devices can subsequently reduce the inter-storey drift and consequently non-structural damage.

A number of passive energy dissipation devices are commercially available or under development. Device that have most commonly been used for seismic protection of structures include viscous fluid dampers, viscoelastic solid dampers, friction dampers, and metallic dampers. Other devices that could be classified as passive energy dissipation devices or, more generally, passive control devices include tuned mass and tuned liquid dampers, both of which are primarily applicable to wind vibration control, re-centering dampers,
and phase transformation dampers. With the introduction of energy dissipation devices, supplemental damping of 20% - 30% of critical damping can be easily achieved while the inherent or natural damping is merely 1% - 5%.

1.5 LATERAL LOADS ON BUILDINGS

The loads acting on a structure are mainly the vertical and lateral loads. The vertical loads mainly consist of dead load and the imposed loads and the behaviour of the structure when subjected to various vertical loads are the same. The lateral loads mainly consist of seismic forces, blast load, wind load, mooring load, tsunami etc., amongst which the seismic force and the wind force are the common ones. The application of these forces and the behaviour of the structure vary (Aravind Ashok 2011).

In order to design a structure to resist wind and earthquake loads, the forces on the structure must be specified. The exact forces that will occur during the life of the structure cannot be predicted. Most national building codes identify some factors according to the boundary conditions of each building considered in the analysis which needs to be provided for life safety (Khaled & Magdy 2012).

1.6 IMPORTANCE OF THE PROJECT

Under severe earthquakes, structures designed using the conventional strength based approach have failed and caused severe damages, which led to the evolution of motion based structural design. This approach lays emphasis to magnify the damper force and minimize the lateral displacement by placing the dampers in the different bracing mechanisms in the structural system which acts as a passive control system. This method employs the supplemental energy dissipation devices in the structural systems in order to dissipate the input energy efficiently without causing damage to the structural and non-structural elements. This study is carried out to find out the
optimal utilization of damper fitted in different types of bracing configurations in the structural system. The effectiveness of VFDs usage with scissor-jack, lower toggle and chevron configuration in structures is investigated, so that these systems can be employed in the future civil engineering structures confidently.

When subjected to a strong lateral forces such as wind and earthquake forces, the infill walls tend to interact with bounding frame and may induce a load resistance mechanism that is not accounted for the design. The present study aims to evaluate the response of reinforced concrete buildings with various types of masonry infills.

Understanding on the performance of multistory frames with different types of lateral force resisting systems will help the design engineers to design the building to have better performance under earthquake forces. Experimental and analytical investigations are carried out to study the performance of RC frame and steel frames with brick infills and steel bracings.

1.7 OBJECTIVES

The major objectives of the present work are:

- To carry out linear time history analysis (LTHA) for 20-storey, 3D RC framed building using SAP2000 version 14 software.
- To carry out response spectrum analysis (RSA) for 20-storey, 3D RC framed building using SAP2000 version 14 software.
- To study the effective placement of infill-brick walls and shear walls for the structural performance enhancement of RC framed buildings to resist the lateral loads and to reduce the response of the buildings.
To carry out linear time history analysis for 20-storey, 2D steel framed structure using SAP2000 version 14 software.

To study the effective placement and distribution of viscous fluid dampers under scissor-jack, lower toggle and chevron mechanism for performance enhancement of steel frame to resist the lateral loads and to reduce the response of the building.

To evaluate the damping coefficient \((C_0)\) of the viscous fluid dampers.

To investigate the behaviour of 2D quarter scale RC square frame with various masonry infills under diagonal static loading.

To analyse the following five types special moment resisting frame using equivalent static analysis and response spectrum analysis using ETABS software and investigate their performance under seismic forces:

- Model 1: Bare frame
- Model 2: Full Infill masonry (masonry is considered as single strut)
- Model 3: Soft Ground Storey (masonry is considered as single strut)
- Model 4: Full Infill masonry (masonry is considered as cross bracing)
- Model 5: Soft Ground Storey (masonry is considered as cross bracing)

To carry out analytical study on seismic performance of three types of frames such as Bare steel frame, Masonry in-filled steel frame and Braced steel frame by pushover analysis using ANSYS software and to validate it experimentally.
1.8 SCOPE OF THE PROJECT

- In the present study, G+19 multistory RC bare framed building are considered for linear time history analysis subjected to four types of time history earthquakes such as El Centro, Kobe, Northridge and S_Monica with their PGAs normalized to 0.35 using SAP2000.
- For the G+19 multistory RC bare framed building response spectrum analysis (RSA) is carried out.
- For RC framed structures, three types of lateral force resisting systems are implemented while analyzing the building such as, RC framed building with brick infill walls (BI), shear wall_1 (SH_1) model and shear wall_2 (SH_2) model are considered for analysis.
- To study the responses of the RC structures such as displacements and inter-storey drifts for bare frame structure, brick infill wall model (BI), shear wall_1 (SH_1) model and shear wall_2 (SH_2) model.
- To study the response reduction in 20-storey RC structures with lateral force resisting system models such as brick infill walls (BI), shear wall_1 (SH_1) model and shear wall_2 (SH_2) model in comparison with bare frame RC structure.
- In the present study, G+19 storey steel frame structures are considered for linear time history analysis subjected to four types of time history earthquakes such as El Centro, Kobe, Northridge and S_Monica with their PGAs normalized to 0.35 using SAP2000.
- For steel frame structures, three types of lateral force resisting systems are implemented while analyzing the building such as, steel frame with effective placement and distribution of viscous
fluid dampers such as scissor-jack, lower toggle and chevron mechanism along the height of the steel frame.

- To study the responses such as displacements, acceleration, inter-storey drifts in 20-storey moment resistant steel frame subjected to four types of earthquake loadings for bare frame structure, scissor-jack damped structures, lower toggle damped structures and chevron damped structures.

- To study the response reduction in steel frame structure for different types of damper configuration and damper type in comparison with bare frame structure.

- To study about the damper responses such as damper displacements and damper forces for the viscous fluid dampers placed in the building during earthquake excitation.

- To find the effective damper configurations and damper type to place in steel frame structure.

- To investigate the performance of RC frames with four types of masonry infilled frames such as  
  i) RC frames without masonry infill (Bare frame),  
  ii) RC frames with brick masonry infill,  
  iii) RC frames with flyash brick masonry infill  and  
  iv) RC frames with solid hallow block masonry infill  were cast and tested under static loads.

- To analyse the following five models (shown in figure 14.1) as special moment resisting frame using equivalent static analysis and response spectrum analysis using ETABS software and investigate their performance under seismic forces.

- Model 1: Bare frame
- Model 2: Full Infill Masonry (masonry is considered as single strut)
- Model 3: Soft Ground Storey (masonry is considered as single strut)
Model 4: Full Infill Masonry (masonry is considered as cross bracing)

Model 5: Soft Ground Storey (masonry is considered as cross bracing)

To analyse and evaluate the seismic performance of 3 types of frames such as Bare steel frame, Masonry in-filled steel frame and Braced steel frame by pushover analysis using ANSYS software and to validate it experimentally.

1.9 ORGANIZATION OF THE THESIS

In the Chapter-1, a general introduction to conventional seismic design and the need for innovative methods of energy dissipation and absorption using passive, active, semi-active and hybrid methods for structural vibration control and importance of earthquake resistant structures and how to achieve it has been given. The importance of the present project and its overall objectives and scope were also highlighted.

In the Chapter-2, literatures on theoretical and analytical studies on dampers by several researchers are reviewed.

In the Chapter-3, the principles of the passive, active, semi-active and hybrid vibration control systems has been described. Some real applications of vibration systems to civil engineering structure have been discussed.

In Chapter-4, the state of the art on application of different types of energy dissipating dampers for structural control and its various types are described. Additional information on where the real damping devices are installed in the structures around the world is also discussed.
In the Chapter-5, general discussion about description of seismic resisting systems and its types have been made.

In the Chapter-6, two types of analysis of structures under earthquake forces are narrated.

In the Chapter-7, the general description of RC building model and the modeling of 20-storey framed structure have been described. Two different types of earthquake analysis are done for different models of RC buildings such as brick wall model and shear wall models and their responses for the analysis have been summarised.

In the Chapter-8, the modeling and responses of 20-storey moment resistant steel frame (bare frame) subjected to four types of time histories earthquake loads are explained. In the Chapter-9, the modeling, methodology and distribution of viscous fluid dampers are incorporated.

Modeling of 20-storey moment resistant steel frame subjected to four types of time histories earthquake loads are fitted with VFDs scissor-jack configurations and its responses under four types of time history earthquakes has been studied and presented in the Chapter-10.

In the Chapter-11, modeling of 20-storey moment resistant steel frame subjected to four types of time histories earthquake loads are with fitted VFDs lower toggle configurations and its responses has been tabulated.

In the Chapter-12, modeling of 20-storey moment resistant steel frame subjected to four types of time histories earthquake loads are with fitted VFDs chevron configurations and its responses has been analysed.
In the Chapter-13, Experimental investigations on the performance of RC frames with four types of masonry infilled frames have been presented.

In the Chapter-14, Analytical investigation on five types of special moment resisting frames with various types of infills using equivalent static analysis and response spectrum analysis using ETABS software have been depicted.

The analytical and experimental investigations on steel frame with steel bracings and brick infill have been carried out and the results are discussed in the Chapter-15.