Chapter 2
Related Reviews

Abstract The modification of existing structures to enhance the resistant to seismic activity, ground motion or soil failure due to earthquakes is called Seismic Retrofitting. The force that causes the damage of the structure due to earthquake is termed as F-Inertial which is the internal force generated by the weight of the structure. Several factors are associated for the design of a structures to be seismic resistant such as torsion, ductility and so on. In this chapter a brief overview of many new technologies that are rapidly becoming more prevalent in the seismic design of building structures are presented. Retrofitting seismically deficient structures to reach an acceptable level of performance is highly regarded issues in the current context. To achieve this, methodology such as reducing the load effect input to the existing structures, or by improving the strength, stiffness, and/or ductility of the existing structures can be taken into considerations.

2.1 Definition of Retrofitting

Seismic Retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion or soil failure due to earthquakes. Retrofitting techniques are applied when there is a danger of damage to the structure by some catastrophe. For example; if a bridge is being damaged by any disaster and maintenance is required to make up the structure for its existing capacity then this is re-strengthening as the design remains the same and it is only repaired. If the structure is designed in the year 2005 and in year 2010 it is required to increase the load carrying capacity of that structure in order to meet the demands, then this is retrofitting. Retrofitting techniques are applied where we have to increase the capacity of the reinforced concrete structure.

© Springer Science+Business Media Dordrecht 2016

R.R. Hussain et al., *Computer Aided Seismic and Fire Retrofitting Analysis of Existing High Rise Reinforced Concrete Buildings*,
Solid Mechanics and Its Applications 222, DOI 10.1007/978-94-017-7297-6_2

2.1.1 Background

The seismic measures are used to calculate forces that earthquakes impose on buildings. Ground shaking (pushing back and forth, sideways, up and down) generates internal forces within buildings called the Inertial Force (F-Inertial), which in turn causes most seismic damage.

$$\text{F-Inertial} = \text{Mass (M)} \times \text{Acceleration (A)}$$

The greater the mass (weight of the building), the greater the internal inertial forces generated. Lightweight construction with less mass is typically an advantage in seismic design. Greater mass generates greater lateral forces, thereby increasing the possibility of columns being displaced, out of plumb, and/or buckling under vertical load (P delta Effect).

2.1.2 Seismic Design Factors

The following factors affect the design of the building. It is important that the design team understands these factors and deal with them prudently in the design phase.

Torsion
When the centre of rigidity and centre of mass do not coincide with each other the torsion is produced in the structure. Torsion is produced when the earthquake resistive vertical members are non-uniformly distributed in plan.

Ductility
The earthquake forces develop greatly depend upon the type of lateral load resisting system provided in a building which is also the measure of ductility present in the structure. Good ductility can be achieved with carefully detailed beam column joints in R.C.C.

Building Configuration
This term defines a building's size and shape, and structural and nonstructural elements. Building configuration determines the way seismic forces are distributed within the structure, their relative magnitude, and problematic design concerns (Fig. 1.1).

Redundancy
The ability of a structure to redistribute seismic loads to other elements, if a particular element fails or is damaged. If a particular element of a building's lateral load resisting system should fail or be damaged during an earthquake, it is very desirable that the seismic load be redistributed to other elements and thereby avoids collapse. This is called redundancy.

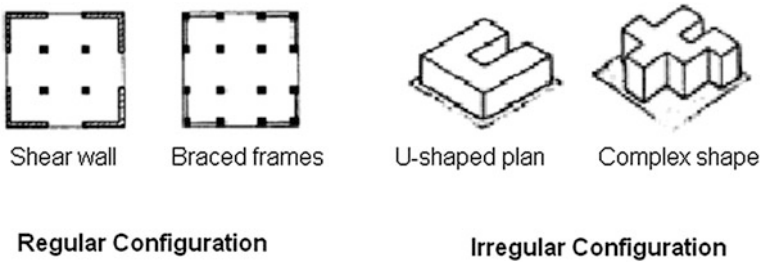

Fig. 1 Regular and irregular configuration of a building

Knowledge of the building's period, torsion, damping, ductility, strength, stiffness, and configuration can help one determine the most appropriate seismic design devices and mitigation strategies to employ.

2.2 Retrofitting Techniques

The purpose of this chapter is to provide a brief overview of many new technologies that are rapidly becoming more prevalent in the seismic design of building structures, and to provide guidance for the consideration and evaluation of the use of these systems in selected buildings. Recent earthquakes in all parts of the world have highlighted the urgency and importance of retrofitting seismically deficient structures to achieve an acceptable level of performance. This can be achieved, in part, by reducing the load effect input to the existing structures. Or by improving the strength, stiffness, and/or ductility of the existing structures. Over the past 20 years, significant advancements have been made in the research and development of innovative materials and technologies for improving the seismic performance of existing structures through rehabilitation processes.

2.2.1 Structure System-Level Rehabilitation

Structure system-level rehabilitations are commonly used to reduce lateral drift and decrease ductility requirement and to enhance the lateral resistance of existing structures. Such rehabilitations for RC buildings include adding infill walls, steel braces, post-tensioned cables, steel plate shear walls, and base isolators. The methods described below are commonly used when implementing a structure system-level rehabilitation technique. The studies show that there is no unique solution and that several difference retrofit schemes can be designed to provide effective seismic resistance. Satisfactory response was obtained only for schemes that adequately controlled inter-story lateral drifts.

Structure System-Level Rehabilitation Include the following Techniques

- Supplementary Energy Dissipation
- Addition of RC Structural Walls
- Addition of Steel Plate Shear Wall
- Use of Steel Bracing
- Ferrocement

2.2.1.1 Seismic Isolation and Energy Dissipation Systems

Seismic isolation and energy dissipation systems involve the use of special details or specific device to alter or control the dynamic behaviour of buildings. The structural systems that utilize these technologies can be broadly categorized as passive, active, or hybrid control systems. Definitions of these terms are provided below, although the primary focus is on passive control systems. Additional guidelines and design provisions for base isolation systems are provided in FEMA 302. Similar guidance for energy dissipation systems is provided in FEMA 273. The definitions of the passive, active and hybrid control system are mentioned below.

Passive Control Systems

These systems are designed to dissipate a large portion of the earthquake input energy in specialized devices or special connection details that deform and yield during an earthquake. Since the deformation and yielding are concentrated in the device, damage to other elements of the building may be reduced. These systems are passive in that they do not require any additional energy source to operate, and are activated by the earthquake input motion. Seismic isolation and passive energy dissipation are both examples of passive control systems. It is interesting to note that many of these devices can be used at the base of a structure as part of an isolation system or in combination with braced frames or walls as energy dissipation devices.

(a) Seismic isolation systems: The objective of these systems is to decouple the building structure from the damaging components of the earthquake input motion, i.e., to prevent the superstructure of the building from absorbing the earthquake energy. The entire superstructure must be supported on discrete isolators whose dynamic characteristics are chosen to uncouple the ground motion. Some isolators are also designed to add substantial damping. Displacement and yielding are concentrated at the level of the isolation devices, and the superstructure behaves very much like a rigid body.

(b) Passive energy dissipation systems: The objective of these systems is to provide supplemental damping in order to significantly reduce structural response to earthquake motions. This may involve the addition of viscous damping through

the use of viscoelastic dampers, hydraulic devices or lead extrusion systems; or the addition of hysteretic damping through the use of friction-slip devices, metallic yielding devices, or shape-memory alloy devices. Using these systems, a building will dissipate a large portion of the earthquake energy through inelastic deformations or friction concentrated in the energy dissipation devices, thereby protecting other structural elements from damage.

Active Control Systems

These systems provide seismic protection by imposing forces on a structure that counter-balance the earthquake-induced forces. These systems are active in that they require an energy source and computer-controlled actuators to operate special braces or tuned-mass dampers located throughout the building. Active systems are more complex than passive systems, since they rely on computer control, motion sensors, feedback mechanisms, and moving parts that may require service or maintenance. In addition, these systems need an emergency power source to ensure that they will operate during a major earthquake and any immediate aftershocks.

2.2.1.2 Hybrid Control Systems

These systems combine features of both passive and active control systems. In general, they have reduced power demands, improved reliability, and reduced cost when compared to fully active systems. In the future, these systems may include variable friction dampers, variable viscous dampers, and semi-active isolation bearings.

It is important to note that the passive energy dissipation systems described above are new technologies when applied to civil engineering structures, but have been used in mechanical engineering for many years. There are numerous situations where dampers, springs, torsion bars, or elastomeric bearings have been used to control vibration or alter the dynamic behavior of mechanical systems. Several examples include vehicular shock absorbers, spring mounts that provide vertical vibration isolation for mechanical equipment, and hydraulic damping devices that utilize fluid flow through an orifice to provide shock isolation for military hardware. Many of these devices have been in use for decades and have performed well in situations where they are subjected to millions of cycles of loading; many more than would be required for seismic resistance. The immediate challenge is therefore not to develop new technologies, but to develop guidelines that will enable us to adapt existing technologies to civil/structural engineering applications.

2.2.1.3 Addition of RC Structural Walls

Adding structural walls is one of the most conventional structure system-level rehabilitation methods to strengthen existing structures. This approach is effective in controlling global lateral drifts and in reducing damage in frame members. Generally, repair of an existing. In order to save time, cost and ensure the quality, panels can be prefabricated and assembled in-site. Many researches into structural walls have been conducted, and findings corresponding to detailed rehabilitation have been reported. Addition of new shear walls will normally result in better seismic performance, however, its side-effect on the existing structure and its relatively intrusive and disrupt construction style are disadvantages. Previous research shows that the infilling process tends to stiffen the existing structure such that the base shear can increase accordingly. Along with the addition of the weight, in turn the gravity load effect, gives more pressure to the existing foundation. Therefore, strengthening of the existing foundation is usually required when this technique is used, while commonly upgrading existing foundations under the new walls is expensive.

2.2.1.4 Use of Steel Bracing

Steel moment-resisting frames are susceptible to large lateral displacements during severe earthquake ground motions, and require special attention to limit damage to non-structural elements as well as to avoid problems associated with P-D effects and brittle or ductile fracture of beam to column connections (FEMA 2000). As a consequence, engineers in the US have increasingly turned to concentrically braced steel frames as an economical means for resisting earthquake loads. However, damage to concentrically braced frames in past earthquakes, such as the 1985 Mexico (Osteraas 1989), 1989 Loma Prieta (Kim 1992), 1994 Northridge (Tremblay 1995; Krawinkler 1996), and 1995 Hyogo-ken Nanbu (Hisatoku 1995) earthquakes, raises concerns about the ultimate deformation capacity of this class of structure. Individual braces often possess only limited ductility capacity under cyclic loading (Tang 1989). Brace hysteretic behavior is unsymmetric in tension and compression, and typically exhibits substantial strength deterioration when loaded monotonically in compression or cyclically. Because of this complex behavior, actual distributions of internal forces and deformations often differ substantially from those predicted using conventional design methods (see, for example, Jain 1979 and Khatib 1987). Design simplifications and practical considerations often result in the braces selected for some stories being far stronger than required, while braces in other stories have capacities very close to design targets. This variation in story capacity, together with potential strength losses when some braces buckle prior to others, tend to concentrate earthquake damage a few "weak" stories. Such damage concentrations place even greater burdens on the limited ductility capacities of conventional braces and their connections. It has also

been noted that lateral buckling of braces may cause substantial damage to adjacent nonstructural elements.

2.2.1.5 Ferrocement

Ferro-cement is a thin wall type composite; having a total thickness ranging between 12 to 30 mm. It is composed of hydraulic cement mortar reinforced with a minimum two layers of continuous and relatively small diameter orthogonally woven wire mesh separated by 4–6 mm dip galvanized spacer wires. The cement mortar is admixed with plasticizers and polymers of sealing pores. The wire mesh is mechanically connected to the parent surface by U-shaped nails fixed with suitable epoxy bonding system. The mesh may be made up of hot dip galvanized MS wire or some other metallic or suitable material. Special technique for compacting Ferro-cement layer is used with the help of orbital vibrators to ensure proper encapsulation of wire mash in mortar.

This repair technique is used for providing protective reinforced membrane for rehabilitation of distressed RCC structures. This acts as a protective layer against the vagaries of the environment. It is also used as a water proofing technique over reinforced concrete shell structures and RCC slabs as it provides impermeable thin membrane, which prevents seepage and leakage of water.

Although there are many obstacles to the greater use of ductility is attracting researchers to exploit its potential. Ferro-cement have no apparent advantages over any other type of reinforced concrete either in direct tension or flexure, but it has a high level of control over cracking provided by the spacing and specific surface area of the wire reinforcing mesh.

2.3 Rehabilitation

2.3.1 Member-Level Rehabilitation

A critical region in an RC frame is the beam-column connection, which ACI-ASCE 352 R (2002) defines as interior, exterior or corner connection depending on its vertical and horizontal position within the structure, and where different constructive details can originate local failures, such as the shear collapse of the panel due to the lack of transverse reinforcement. The member-level rehabilitation approach can provide a more cost-effective strategy than structure system-level rehabilitation because only those components needed to effectively enhance the seismic performance of the existing structure are selected and strengthened. The member-level rehabilitation approaches include the addition of concrete, steel, composite material (FRP) jackets or pretension tendons/wires in confining RC columns, beams and

joints. This would involve jacketing the columns, beams and joint regions to improve flexural and shear strength, and concrete confinement.

Member Level Rehabilitation can be done by number of techniques. Some of them are as follows

- Column Jacketing
- External Reinforcement in the form of Steel Plate Bonding and External-Bonded (FRP Composites)
- Over slabbing
- Steel plate bonding

2.3.1.1 Column Jacketing

Columns are critical elements in any structural system and their performance during a seismic event can dominate the overall outcome of the structure. Failure of these older RC columns in shear usually takes place at low deformations and is associated with a large and sudden drop in lateral load resistance. Moreover, the shear strength of a column tends to degrade faster than its flexural strength with cycling of the lateral load. Column failures have caused the most significant failures of RC structures. So column rehabilitation is often critical to the seismic performance of a structure. To prevent the column failure mechanism during earthquakes, columns should never be the weakest components in the whole structure. The response of a column in a structure is controlled by its combined axial, flexural, and shear load. Therefore, column jacketing may be used to increase column shear and flexural strength so that columns are not damaged.

2.3.1.2 External Reinforcement in the Form of FRP or Steel

Strengthening of concrete structures by means of externally bonded reinforcements is generally done using either steel plates or CFRP laminates. Each material has its specific advantages and disadvantages. Steel plates have been used for many years due to their simplicity in handling and applying and to their effectiveness for strengthening. The properties and behavior of the steel adhesive- concrete combination are well known. Steel plates are very effective to be used as bending reinforcement. The high tensile strength and stiffness lead to an increase in bending capacity and a reduction of the deformations. Steel plates can also be used as external shear reinforcement. However, labour costs might rise quickly. Steel stirrups have to be bent or welded and very often anchored with bolts in the concrete compression zone. When several stirrups per meter are needed, these costs can make this technique economically less interesting.

CFRP sheets and laminates have very high tensile strength and stiffness. Nevertheless, they cannot be used in every strengthening situation. When used in bending, the active stresses in the CFRP laminates have to be kept small in order to

prevent the internal steel reinforcement from yielding. This means that the high strength properties of the CFRP sheets are not used effectively, except if the laminates are pre-stressed. However, pre-stressing increases the cost and decreases the ease of application, which both has negative effect on the economy of the technique. Besides pre-stressing, the required increase of bearing capacity can only be reached by adding a considerable number of sheets or a thick laminate, which increases the material and labour costs. For limiting the deflections, CFRP sheets are not very effective. Due to their very small cross sectional area per sheet, the moment of inertia will only slightly increase and so the deformation decrease will only be marginal. In these cases, steel plates offer very often a better alternative. On the other hand, CFRP sheets are more appropriate for shear strengthening than steel plates. An orthogonal net of carbon fibres bonded at both sides of a beam is very well able to take shear forces. The applying of the CFRP sheets is very easy. Even complex shapes and geometries can be done. Labour costs are considerably lower for CFRP than for externally bonded steel stirrups.

To combine the features of the two materials, a hybrid steel/CFRP strengthening method can be developed. The additional longitudinal reinforcement consists of externally bonded steel plates, whereas the shear reinforcement consists of externally bonded CFRP sheets.

2.3.1.3 Over-Slabbing

In this technique, a plain or reinforced concrete slab is overlaid on the top of the existing slabs or beams to increase the section dimension in order to increase flexural strength. To ensure the composite action between the two dowels or shear studs may be installed. This method in particular may be advantageous when the member needing strengthening possesses reinforcement near or equal to balanced steel. However, as the flexural strength of a reinforced concrete member is usually limited by the capacity of the reinforcement rather than by the capacity of concrete, over-slabbing may therefore, is of no significant value. Any strength increase may be offset by the increase in dead load.

2.3.1.4 Steel Plate Bonding

Plate bonding is an inexpensive, versatile and advanced technique for rehabilitation, upgrading of concrete structures by mechanically connecting MS plated by bolting and gluing to their surfaces with epoxy. Plate bonding cans substantially increased strength, stiffness, ductility and stability of the reinforced concrete elements and can be used effectively for seismic retrofitting. The behavior of resulting composite system largely depends upon the inter-layer bond between concrete and plate. The thickness of plate needs special attention on relatively thick plates can initiate horizontal cracking and plate separation. With increase width, there is a risk of defect in adhesive, and with increasing thickness of the adhesive; the slip between

the reinforcing element and concrete becomes greater. Anchor plates are needed where the width-thickness ratio of the plate is less than 50:1 due to production of high stresses near the ends of the plates leading to premature failure. This technique cannot be used where the member shows any sign of reinforcement corrosion.

References

ASCE 352R-02 (2002) Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures

FEMA (2000) State of the art report on performance prediction and evaluation (FEMA-355F), Federal Emergency Management Agency, Washington, DC

Hisatoku T (1995) Reanalysis and repair of a high-rise steel building damaged by the 1995 Hyogoken-Nanbu 1995. In: Proceedings, 64th annual convention, structural engineers association of California, structural engineers Assn. of California, Sacramento, pp 21–40

Jain A, Goel S (1979) Seismic response of eccentric and concentric braced steel frames with different proportions, UMEE 79R1. Department. of Civil Engineering, University of Michigan, AnnArbor, July 1979, 88 p

Khatib I, Mahin S (1987) Dynamic inelastic behavior of chevron braced steel frames. In: Proceedings of fifth canadian conference on earthquake engineering, Balkema, Rotterdam, pp 211–220

Kim H, Goel S (1992) Seismic evaluation and upgrading of braced frame structures for potential local failures, UMCEE 92-24. Department of Civil Engineering and Environmental Engineering, University of Michigan, Ann Arbor, Oct 1992, 290 p

Krawinkler H et al. (1996) Northridge of January 17, 1994: Reconnaissance report, vol 2—steel buildings, Earthquake Spectra, 11, Suppl C, pp 25–47

Osteraas J, Krawinkler H (1989) The Mexico of September 19, 1985—behavior of steel buildings. Earthquake Spectra 5(1):51–88

Tang X, Goel SC (1989) A fracture criterion for tubular bracing members and its application to inelastic dynamic analysis of braced steel structures. In: Proceedings of ninth world conference on earthquake engineering, 9WCEE organizing committee, Japan Assn. for earthquake disaster prevention, Tokyo, vol 4, , Paper 6-3-14 pp 285–290

Tremblay R et al. (1995) Seismic design of steel buildings: lessons from Hyogo-ken

http://www.springer.com/978-94-017-7296-9

Computer Aided Seismic and Fire Retrofitting Analysis of Existing High Rise Reinforced Concrete Buildings

Hussain, R.R.; Wasim, M.; Hasan, S.

2016, XV, 119 p. 41 illus., 12 illus. in color., Hardcover
ISBN: 978-94-017-7296-9