CHAPTER II

LITERATURE REVIEW

2.1 Seismic Assessment

Still nowadays the design of buildings under seismic loading is performed mainly assuming linear elastic analysis. In linear analysis, it is sufficient to assume that the material remains linear and elastic. This is particularly true in the seismic response case, since most structures are not designed to respond elastically when subjected to the design earthquake, instead experience significant inelastic deformations under large events.

Majority of existing buildings falls short of meeting prescriptive detailing requirements and provisions of the relevant standards for new buildings, which presents a challenge for the evaluation and the retrofit with the use of elastic analysis methods. As a result, seismic evaluation and retrofitting of existing buildings has been one of the primary drivers for the use of nonlinear analysis in engineering practice.

Many clients do not want to pay for understanding, they only want to pay for code compliance. It is our task to convince clients that the value of engineering services does not lie in code compliance but in providing the best product within the constraints set by society for life safety and collapse protection (in addition to a cost/benefit assessment of potential monetary losses)

2.2 Retrofitting

Retrofitting is technical interventions in structural system of a building that improve the resistance to earthquake by optimizing the strength, ductility and earthquake loads. Strength of the building is generated from the structural dimensions, materials, shape, and number of structural elements, etc. Ductility of the building is generated from good detailing, materials used, degree of seismic resistant, etc. Earthquake load is generated from the site seismicity, mass of the structures, important of buildings, degree of seismic resistant, etc.In the design of retrofitting approach, the engineer must comply with the building codes. The results generated by the adopted retrofitting techniques must fulfill the minimum requirements on the buildings codes, such as deformation, detailing, strength, etc.

Retrofitting is needed when the assessment of structural capacity results in insufficient capacity to resist the forces of expected intensity and acceptable limit of damages. It is not merely poor quality of materials and damage of structural elements serves as the reasons to retrofit a building. Change of the building's function, change of environmental conditions, and change of valid building codes could also be the reasons for retrofitting.

Retrofitting must be conducted by experts from each field. In most retrofitting process, an engineer plays the main role. An engineer must assess and analyze the structural capacity. An engineer must also design the best retrofitting techniques to strengthen the structural deficiencies. The role of the novice is restricted to identify the possibility of insufficiency of building capacity.

Some factors should be considered to decide whether to retrofit or not, i.e:

a) Technical aspect

b) Cost intervention

c) Importance of building

d) Availability of adequate technology

e) Skilled workmanship to implement the proposed measures

f) Duration of works.

The advantages of adopting retrofitting approach, despite of reconstructing the building, are as follows:

- When retrofitting approach is adopted, retrofitted building can still be operated.
- Retrofitting will take relatively less construction cost with similar structural performance achievement.
- Retrofitting will involve relatively less resources, either human resources or natural resources.
- Retrofitting will not significantly change the building configuration and shape. It is preferable when the retrofitted building has historical values.
- Retrofitting the building will produce less debris than reconstructing the building. Besides the advantages, retrofitting also has several disadvantages, such as:

a. The skill of the worker must comply with the adopted retrofitting approaches

b. Limited access of the construction site, since the building could be still in function.

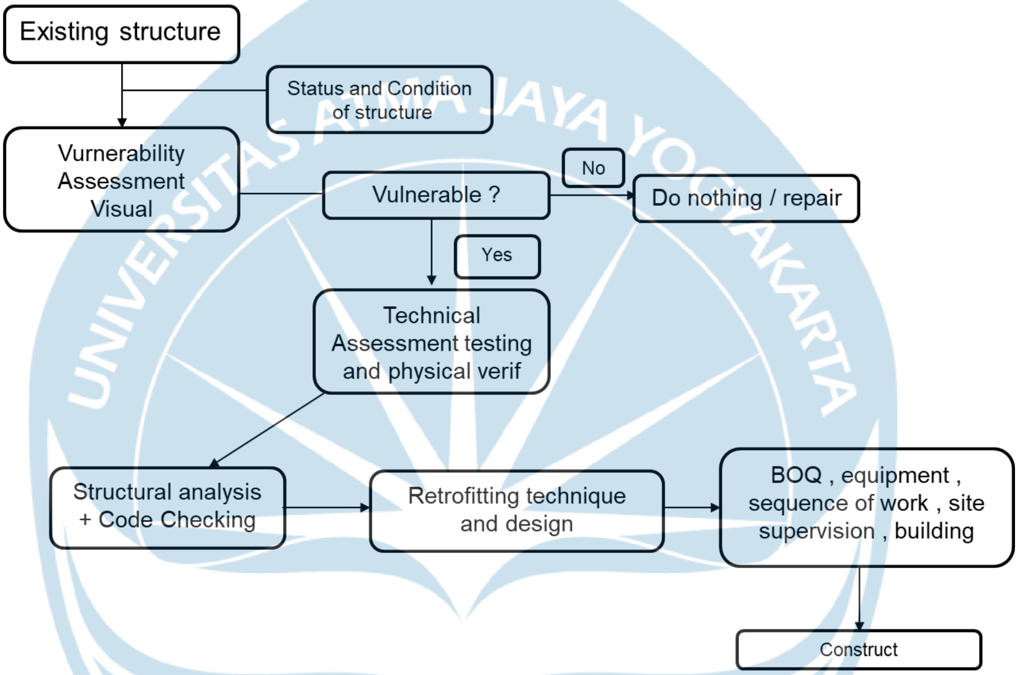

Figure 2.1 Retrofitting Stages

Common Problems of Reinforced Concrete Structure are :

1.) Insufficient lateral load resistance.

2.) Inadequate ductility due to insufficient confinement of longitudinal reinforcement, especially at the joint of the elements.

3) A tendency of overstressing due to complex and irregular geometry in plan and elevation.

4.) Interaction between structural system and non-structural walls resulting in unintended torsional forces and stress concentration.

5.) High flexibility combined with insufficient spacing between buildings resulting in risk of neighboring structures pounding each other during shaking

6.) Poor quality materials or work method in the construction.

2.3 Non-Linear Analysis

Nonlinear analysis is becoming a popular tool for performance evaluation of structural systems at the life safety and collapse prevention levels. let us assume that all non-structural life safety hazards, such as release of hazardous materials, fire-related hazards, falling hazards, etc., are taken care of by other means, including story drift and floor acceleration limitations. The objective is to push the structure to the displacement expected under the design earthquake

The use of nonlinear analysis to assess the seismic response of both existing as well as newly designed buildings (or other types of framed structures) is becoming more and more recurrent. Within this simplified framework, the engineering task is to prevent, through good structural design, an unacceptable loss of vertical load-carrying capacity. Structures would not collapse in earthquakes were it not for a few, often predictable, phenomena. In general, collapse may be ‘vertical’ or ‘lateral’ (sidesway mode). Vertical (partial or progressive) collapse could be triggered by the inability of columns to maintain their axial load-carrying capacity in the presence of high bending moments and shear forces. There are other general phenomena on which the response of structures close to collapse may strongly depend, such as vertical and plan irregularities and higher mode effects.

2.4 Pushover Analysis

Pushover analysis is a useful but not infallible tool for assessing inelastic strength and deformation demands and for exposing design weaknesses. Its foremost advantage is that it encourages the design engineer to recognize important seismic response quantities and to use sound judgment concerning the force and deformation demands and capacities that control the seismic response close to failure. Pushover can provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. The following are examples of such response characteristics:

• Realistic force demands on potentially brittle elements, such as axial force demands on columns, force demands on brace connections, moment demands on beam to- column connections, shear force demands in deep reinforced concrete spandrel beams, etc.

• *Estimates* of deformation demands for elements that have to deform inelastically in order to dissipate the energy imparted to the structure by ground motions. Unfortunately, these estimates are not always realistic.

• Identification of critical regions in which the deformation demands are expected to be high and that must become the focus of thorough detailing.

• Identification of strength discontinuities in plan or elevation that will lead to changes in dynamic characteristics in the inelastic range.

• Verification of completeness and adequacy of load path, considering all elements of the structural system, all connections, stiff non-structural elements of significant strength, and the foundation system.

Pushover analysis provided the analytical model incorporates all elements, whether structural or non-structural, that contribute significantly to lateral load resistance.

2.5 Non-Linear Static Procedure

Nonlinear Static Procedure a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components of the building is subjected to monotonically increasing lateral loads representing inertia forces in an earthquake, until a target displacement is exceeded. The main objective of the method is to assess the capacity of the structure, considering both the deformability and strength of all structural members.

The lateral loads are gradually applied until the displacement of a selected 'Control Node', typically located at the center of mass of the top story of the building, reaches the so-called 'Target Displacement', which represents an approximation of the displacement demand under earthquake ground motion.

Blind prediction exercises can be used to spot and evaluate the sources of variation between analytical predictions and actual data, and to identify analytical procedures that appear to be consistently better (or worse) than others

2.6 Performance Objectives and Seismic Hazards

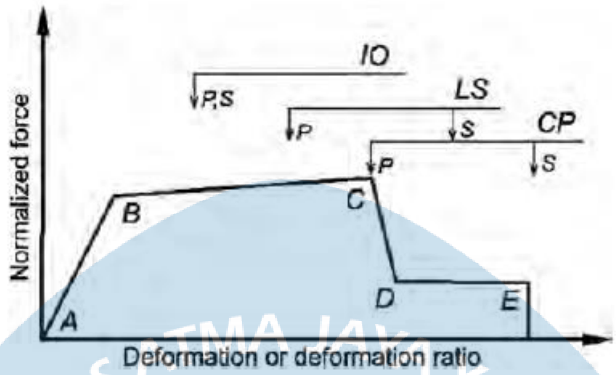

Figure 2.2 Acceptance Criteria Illustration

Immediate Occupancy: The deformation at which permanent, visible damage occurred in the experiments but not greater than 0.67 times the deformation limit for Life Safety . Life Safety: 0.75 times the deformation at point E . Collapse Prevention: 1.0 times the deformation at point E on the curve

Based on ASCE 41-17 Chapter 2, target building performance levels are mentioned in the chapter:

- **2.3.1.1** Immediate Occupancy Structural Performance Level (S-1). Structural Performance Level S-1, Immediate Occupancy, is defined as the postearthquake damage state in which a structure remains safe to occupy and essentially retains its preearthquake strength and stiffness. A structure in compliance with the acceptance criteria of this standard for Immediate Occupancy is expected to achieve this postearthquake state
- **2.3.1.3** Life Safety Structural Performance Level (S-3). Structural Performance Level S-3, Life Safety, is defined as the postearthquake damage state in which a structure has damaged components but retains a margin of safety against the onset of partial or total collapse. A structure in compliance with the acceptance

criteria specified in this standard for this Structural Performance Level is expected to achieve this state.

- **2.3.1.5** Collapse Prevention Structural Performance Level (S-5). Structural Performance Level S-5, Collapse Prevention, is defined as the postearthquake damage state in which a structure has damaged components and continues to support gravity loads but retains no margin against collapse. A structure in compliance with the acceptance criteria specified in this standard for this Structural Performance Level is expected to achieve this state

The seismic hazard caused by ground shaking shall be based on the location of the building with respect to causative faults, the regional and site-specific geologic and geotechnical characteristics, and the specified Seismic Hazard Levels. Assessment of the site-failure hazards caused by earthquake-induced geologic and geotechnical conditions shall be performed in accordance with Chapter 8 of ASCE 41-17. The site class shall be determined consistent with the requirements of Chapter 20 of ASCE 7.

2.7 Local Retrofitting

Section enlargement consists in placing additional concrete around an existing structural element to increase its seismic resistance. This is the oldest method of seismic retrofitting. Typical applications include bridge deck, column wrapping, and join strengthening. This method is easy and economically effective, but labor intensive.

2.8 Reinforced Concrete Jacketing

Concrete jacketing is needed to increase bearing load capacity following a modification of the structural design or to restore structural design integrity due to a failure in the structural member. This technique is used on vertical surfaces such as walls, columns, and other combinations such as beam sides and bottoms. RC Jacketing aims at increasing capacity of the structure by increasing its stiffness, ductility and combination of them.

Advantages of concrete jacketing **:**

1. To increase the shear & flexural capacity of Beam
2. To improve the compressive strength & Moment caring capacity of column
3. Ease in construction
4. Easily available material

Disadvantage of concrete jacketing **:**

1. The sizes of the sections are increased, and the free available usable space becomes less
2. Huge dead mass is added.
3. Requires adequate dowelling to the existing column.
4. Longitudinal bars need to be anchored to the foundation and should be continuous through the slab.
5. Requires drilling of holes in existing column, slab, beams and footings.
6. Placement of ties in beam column joints is not practically feasible.
7. The speed of implementation is slow

Jacketing is largely used as a strengthening scheme of a member. Following steps are followed to determine the increase in strength.

- Determine the strength of the column
- Compute the new Area of concrete (Ac') and new area of steel (Asc') after RC jacketing the column
- Calculate the new strength of column after increase in area of steel and concrete after RC jacketing
- Compute the percentage increase in the strength of the column after RC jacketing

The column size and self-weight were increased significantly. The stiffness of the retrofitted structural system was also significantly increased which could cause the structure to attract more seismic load.

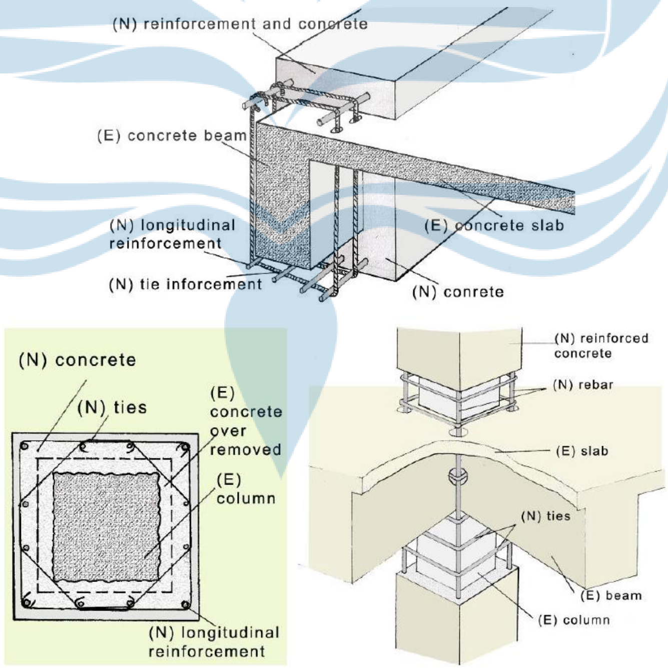

Figure 2.3 Concrete Jacketing

2.9 CFRP Wrapping

CFRP wrapping is a developed technique to increase the strength and ductility of damaged or under-designed reinforced concrete structures. CFRP provides effective confinement to concrete, achieving a significant improvement in ductility. Its effectiveness is affected by number of parameters which include concrete strength, level of axial compression, CFRP sheet thickness or number of layers, and wrap angle. CFRP strengthening is a quick, neat, effective, and aesthetically pleasing technique to rehabilitate reinforced and pre-stressed concrete structures. Unlike steel plates, CFRP systems possess high physical and chemical deterioration or mechanical actions.The increment in lateral resistance ranged from 2-4 times the unretrofitted resistance. The use of epoxy resins can be advisable when a thorough study of the structural consequences of such an increment in strength in selected portions of the building shows that there is no danger of potential damage to other portions.

Figure 2.3 CFRP Wrapping

2.10 Seismobuild

SeismoBuild is an innovative Finite Element package wholly and exclusively dedicated to seismic assessment and strengthening of reinforced concrete structures that is targeted to the design office. It is the only civil engineering software worldwide that is totally committed to structural assessment and retrofitting.

The program is capable of fully carrying out the Code defined assessment methodologies from the structural modelling through to the required analyses and the corresponding member checks. Currently six Codes are supported (the Eurocodes along with the majority of the available National annexes, the American Code for Seismic Evaluation and Retrofit of Existing Buildings ASCE 41-17, the Italian National Seismic Codes NTC-18 & NTC-08, the Greek Seismic Interventions Code KANEPE and the Turkish Seismic Evaluation Code TBDY). Both metric and imperial units, as well as European and US reinforcing bars types are supported.