Abstract

Seismic Retrofitting is in general referred to technique which either may alter the existing configuration or enhance by modification of a structure in order to resist higher level of to earthquake ground motion. Now improve understanding of seismic demand of the structure by the research investigators made it possible to have a required technique which can be applied appropriately for the seismic resistance of a structure. Further, the scientific study about the earthquake ground motion about Indian conditions made it possible to improve / revise the relevant Indian standard code considering recent experience of earthquakes in India. Also these understandings have made it possible to acknowledge the need of seismic retrofitting. As it has been stated in literature that 50% of the Indian land has become seismically active this was not taken into considerations in earlier version the code(s). According in new seismic map of India 60% of the Indian land and 78% of the population come under zone 3, 4 and 5 refer illustrated in the new seismic map of India. In chapter two of this report (in the revised code IS: 1893:2002 part 1 has four seismic zone instead of 5. Erstwhile zone 1 is merged into zone 2 which was considered inactive seismic area. Hence, zone 1 does not appear in the new seismic zone map; the only zone 2, 3, 4, and 5 applicable, this explain the value of seismic zone factor have been changed this now reflect more realistic value of effective peak ground acceleration considering maximum considered earthquake and service life of the structure in each seismic zone. Several building and other structures constructed before revision of the code need to be rehabilitated and retrofitted which is fall under red zone of the Indian seismic code. For large number of existing infrastructures not design as per new codal provisions to safe-guard such structure which include seismic retrofitting of the old building structures.

It has been practice of the practicing engineer The fiber reinforced polymer composites (i.e. FRP) are increasingly being consider as an enhancing and /or substitute for infrastructure component or structure that are constructed by traditional civil Engineering material namely concrete and steel. The typical characteristics of FRP composite are (i) light weight, (ii) high strength to weight ratio, (iii) corrosion resistance, (iv) exhibit high specific strength and (v) specific strength and easy to construct, and can be tailored to satisfy performance requirement. This special practice being consider as advantageous which FRP composite has in many construction and rehabilitation of structure trough its used as a

reinforcement in concrete for strengthening and seismic up gradation. In India Kandla is the special example of post rehabilitation post Bhuj Earthquake in year 2001.

For external application of the FRP involve of continuous carbon fiber (C), Glass fiber (G), Aramid fiber (A), fiber bonded together in a matrix made of epoxy, vinyl ester or polyester are being employed extensively throughout the world in retrofitting of concrete and steel structure. Earlier the application of FRP were limited to aircraft and automobile sector, but due to several properties such as the 1)High strength to weight ratio, 2) Immunity to corrosion, 3) Easy handling and application make FRP user friendly in civil Engineering areas.

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CHAPTER-1

Introduction and Literature Survey

INTRODUCTION:

Traditional method of retrofitting of the steel bridge and structure typically utilizes steel plate that is either bolded or welded to the structure. However, constructability and durability are associated with this method. Steel plate requires heavy lifting equipment can add considerably more dead load to the structure, which reduce their strengthening effectiveness. To add steel plate which also susceptible to corrosion which leads to a future increase in the maintenance cost. In many cases welding is not a desirable solution due to the fatigue problem associate with weld defect. On the other hand, mechanical detail such as bolted connection, which are better fatigue life but time consuming and costly.

The need for adopting durable material and cost effective retrofit technique is evident. One of the possible solutions is to use high performance and non metallic material such as fiber reinforced polymer (FRP). The superior mechanical and physical property makes them quite promising to use in repair and strengthening of steel structure.

The use of FRP material in concrete structure has been successful which is evident from the relevant literature(s). The effectiveness has been demonstrated in variety of retrofitting mechanism. In present time the use of carbon and glass fibers to retrofitting of the concrete bridges is becoming more widely accepted in practice.FRP is use in the form of sheet or plate attached to the concrete surface for flexure and shear retrofitting and FRP sheet for wrapping column to increase ductility of their ductility and axial strength.

Bonding of the FRP material to the metallic structure was first use in mechanical Engineering application. Carbon fiber reinforced polymer (CFRP) has been successfully used to repair aluminum and steel aircraft. The bonding of composite laminate shown to many advantages in marine structure. In the civil engineering structure, the previous work conducted on strengthening of metallic structure using CFRP laminate or sheet focused on three main areas; strengthening of iron and unwedded steel girder, rehabilitation of corroded steel girder, and repair and fatigue damage of riveted steel connection.

While considering retrofit of the steel structure with FRP versus retrofit using steel late there are two considerations that favor FRP material, the cost associated with FRP retrofitting is much associated with the time limitation for completion of the project, as well as labor cost and cost to divert traffic and to lesser extent with material cost. Due to the light weight of FR material it is expected that they could installed in less time by strengthening with equivalent number of steel plate.

1.1. FRP as Technology

A fiber reinforced polymer is deign as a polymer matrix, either thermo set or thermoplastic is reinforced with fiber or other reinforcing material with sufficient aspect ratio to provide a discernable reinforcing function in one or more direction. FRP composite are different from other traditional material such as steel, Aluminum etc. FRP composite are anisotropic (Property apparent in the direction of applied load) where as steel and aluminum is isotropic (uniform property in all direction, independent of applied load)

Therefore FRP composite properties are directional dependent means the best mechanical property are in the direction fiber placement.

1.1.1. Matrix of Composites of FRP

The entire FRP technology encompasses following:

Epoxy:-The primary function of the resin to transfer the stress between reinforcing bar act as a glue to hold the fiber together, protect the fiber from mechanical and environmental damage. The most common resins used in the production of FRP is polyesters, vinyl esters and phenolic.

Fiber/Reinforcement:- The primary function of the fiber and reinforcement to carry load along the length of the fiber to provide strength and stiffness in one direction. The reinforcement can be oriented to provide tailor property in the direction of the applied load imparted on the end product.

Resin:-Resin impregnation is necessary to obtain good mechanical property of the glass fiber. For standard FRP wrapping, resin is impregnated on site under ordinary temperature and pressure. One of the important property of the resin regarding workability is optimum viscosity that simultaneously enable good impregnation into the fiber and keep the fiber in place.

Plate: -This is pre curd FRPC laminate are used mainly to increase banding and shear capacity of the section. This laminate are manufactures by pultrusion in factory with high reliability of performance. However, the shape of the laminate must be known at the time of production. It is unsuitable when FRP laminate need to be bent at site.

Table 1.1:Typical Properties of the CFRP laminate(Refer Mukherjee, Bagadi [1]).

No	Items	Test result
1	Width(mm)	50.8
2	Thickness(mm)	1.4
3	Ultimate Tensile Strength (GPa)	2.51
4	% Elongation at break	1.8
5	Tensile Modulus(GPa)	155

Figure 1.1:-Typical FRP Laminate

Sheet:-These are uncured fiber tapes with unidirectional fiber or bidirectional woven roving. The main advantage of this form is that it can be laid in any form at site. Therefore they are more suitable in wrapping around decorated concrete member. The main application of this sheet is to wrap around the concrete section to increase confinement and shear strength. However, their strength is not reliable as FRP laminate and bar.

Table.1.2:-Typical Properties of the FRP wrap

No	Items	Test result
1	Mass per meter square(g/m²)	644
3	Ultimate Tensile Strength (MPa)	876
4	% Elongation at break	1.2
5	Tensile Modulus(GPa)	72.46

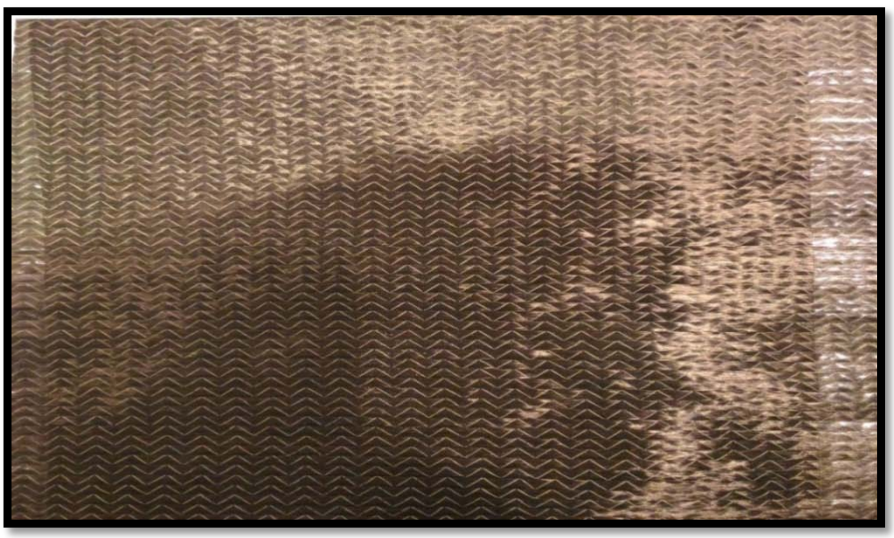

Figure.1.2:-Typical FRP Wrap

Table 1.3:-Typical Property of the Epoxy

No	Items	Test result
1	Tensile Strength (MPa)	21.4
2	Tensile Strain failure (%)	5
3	Flexure Modulus(MPa)	1690
4	Flexure Strength (MPa)	40.7

1.2. Theory of failure.

1.2.1. Shear Stress Failure Theory

According to Tresca and Guest Theory, Plastic deformation occur when maximum shear stress on the element reach the same level exhibited on the element in a Uni-Axial tensile test loading at yield stress. Means any state of stress (Complex stress condition having all stress component) resolved into a Max. Shear stress (σu)and compare with shear stress at the Uni-Axial tensile test loading at yield stress(σy). If ($\sigma u \geq \sigma y$)Then plastic deformation in the element in occurs. If not, according to Tresca and Guest Theory there will not be any plastic deformation in the element. So that Tresca and Guest gives threshold value between elastic and plastic region.

1.2.2. Bending Failure Theory

In applied mechanics bending is also known as Flexure characterized the behavior of the slender structure element subjected to external applied load perpendicular to the longitudinal axis of the beam. The beam deforms and stress developed inside it when a transverse load is applied on it. In quasi-static case, the amount of bending deflection and stress that developed in the element is assumed not to chine over time. In a horizontal beam supported at the end and loaded downward at the middle, the material over side of the beam is compress and while the material at the underside is stretched.

In Euler Bernoulli theory of slender beams ,major assumption is that , Plane section remain plane, in other words deformation due to shear across the section is not accounted for no shear deformation. also this linear distribution is only applicable if maximum stress is less than yield stress of the material. Plastic deformation in the material is occurring when maximum stress in the material is more than yield stress. Maximum stress experienced in the section is at the farthest point from the Neutral axis

Basic Assumption in Bernoulli, 1) Plane section perpendicular to neutral axis remain plane before and after bending. 2) Deformation are small, 3) the beam is linear elastic, isotropic, poissons ratio effect are ignored. For beam is homogenous along the as well constant cross section and the deflection under the transverse load (qx) can be calculated as,$EI\,\frac{d^4wx}{dx^4} = qx$ This is Euler Bernoulli equation of beam.

Dynamic bending of the beam is also called as a flexural vibration of the beam, was first investigated by Daniel Bernoulli in the 18 century. Bernoulli equation of motion of a vibration beam tended to overestimated the natural frequency of the beam and was marginally improved by Rayleigh in 1877by the addition of the mid plane rotation.

In 1921 Stephen Timoshenko improves the theory by incorporating effect of shear deformation in the dynamic response of the beam. This allow the theory to be used for problem involving higher natural frequency of vibration, where dynamic Euler Bernoulli theory inadequate.

The Euler Bernoulli Equation of the dynamic bending for slender, isotropic, homogenous beam of a constant cross section under an applied transverse load$q(x,t)$.

$EI\frac{\partial^4 w}{\partial x^4}+m\frac{\partial^2 w}{\partial t^2}=q(x,t)$,$E$ young's modulus of elasticity, I moment of inertia of the cross section, $W(x,t)$is deflection of neutral axis the beam,m mass per unit length of the beam.

1.2.3. Torsion Failure Theory

Theory:-torsion is twisting of the object due to torque. Resultant shear stress in section is perpendicular to the radius. Shear stress in the shaft is resolved in to principal stresses via Mohr circle. If the shaft is loaded only for torsion then one of the principal stresses will be in tension and other in compression. This stress is oriented at 45° in helical angle around the shaft, if the shaft is made u of brittle material, then the haft will be failed by a crack initiating the surface and propagation towards the core of the shaft, fracturing in 45° angle helical shape.

Torsion vibration is angular vibration of the object. Torsion vibration is often concern in Power Transmission system using rotation shaft or coupling where it can cause failure if not controlled.

1.3. Requirement Retrofitting Technique

In general retrofitting of any existing structure may be needed in any one or more of the following cases:

1. The structure was not originally designed for seismic loads. In most of the cases of old structures, the structure was not originally built against seismic demands. In such cases, it is important to check the existing structure against current seismic demands and is needed, to retrofit the same.

2. The design Basic Ground Motion for the site gets revised. As the knowledge of seismic activity of a particular region grows, the authorities may allot a higher seismic demand associated with a particular region. Change of seismic zones according to new 1893:2002 is a typical example to explain this. In such cases, the structures whose seismic zone gets upgraded might need retrofitting.

3. Structure of building to be extended (e.g. extra floor to be constructed). In such cases, the dynamic characteristics of the structure changes and it may attract higher forces. In such cases also, retrofitting may be needed.

4. Functionality (Importance) of the building changes. Consider a case, where a building designed as a residential building is required to be used for the purpose of running school. In such case, the importance of the building becomes higher and it might need retrofitting.

5. Changes in design methodology. As the knowledge of seismic behavior of systems grow, the prevalent design methodologies may be replaced by a better more suitable methodology. For example, in structures: Soft storey design which was accepted earlier is stopped in present design; in piping and components: Method of design for high stiffness is becoming obsolete and new designs are aiming for high flexibility and energy absorbing capacity; Performance based design in the place of conventional design. In such cases, the new design philosophy may render the existing structure unsuitable against seismic loads and may recommend retrofit.

1.4. Steps by Step Seismic Retrofitting Technique

The following steps are generally followed for seismic retrofitting of structures:

1. Formation of a team.

2. Deriving as earthquake level for seismic re-assessment as per the current practice.Gathering information about different type of lifeline structures and construction.

3. Assessing the information on in-situ condition of the structure (Non-Destructive examination).

4. Identification of systems for which the seismic re-assessment is to be carried out.

5. Assessment of seismic capacity of the systems with respect of the derived higher earthquake load as per the current design practice.

6. Evaluation the requirements to be met by retrofit (e.g. codal requirements).

7. Developing and designing of retrofit.

The strengthening methods can be classified as 1.Global strengthening methods 2. Local strengthening methods

1.4.1. Global strengthening methods

Global strengthening methods modify the dynamic characteristics of the whole structure by stiffening rather than strengthening. These methods include bracing, addition of shear walls, addition of masonry shear walls etc. Bracing is popular in removing the deficiencies in a structure due to soft-storey mechanism, where the bottom most storey stands bare framed to act as parking space whereas upper stories are stiffer due to masonry infill panels. Similarly shear walls may be added in a framed shear walled structure to enhance the stiffness of the structure

1.4.2. Local strengthening methods

Local strengthening methods involve in enhancing the strength of the members of the members of the structural system so that they can withstand higher forces. Some of the methods used for local strengthening include concrete jacketing steel jacketing, external prestressing, strengthening with Fiber composites etc. These are discussed in details below:

Concrete Jacketing

Concrete jacketing is a popular and conventional method for strengthening of RC members. I.S 13935:1993 gives guidelines for retrofitting using this method and refers to it as casing that is providing additional cage of longitudinal and lateral tie reinforcement around the member and casting a concrete ring. Some of the advantages of this method are as follows 1) Both the strength and ductility of the section can be improved using method 2) Additional concrete and reinforcement contribute to strength increase, and disadvantage re as follows 1) The sizes of the sections are increased and the free available usable space becomes less2) Huge dead mass is added 3) The stiffness of the system is highly increased, 4) Requires drilling of holes in existing column, slab, beams and footings, Placement of ties in beam column joints is not practically feasible5) The speed of implementation is slow

New longitudinal reinforcement is set around the existing column, and precast concrete segments are set around the new reinforcement, all segments are tied together by strands, After injecting no-shrinkage mortar between the existing concrete and precast concrete segment, prestressing force is introduced in the strands to assure the contact of the segments.

Steel jacketing

Steel jacketing is also one of the popular methods of strengthening. The lap splices of column longitudinal reinforcement and the shear resistance of the sections can be improved by using steel jackets (through confinement). The steel jackets provide passive confinement to the member and can be considered as continuous hoop reinforcement, Encasing the column with steel plates and filling the gap with a non-shrink grout, Provides passive confinement to core concrete, Its resistance in axial and hoop direction can neither be uncoupled nor optimized, Its high young's modulus causes the steel to take a large portion of the axial load resulting sometimes in premature backlight of the steel, Rectangular steel jackets on rectangular columns are not generally recommended and a use of an elliptical jacket is solicited, Vulnerable to corrosion and impact with floating materials, Not used for columns in river, lake and seas, Not used for columns in river, lake and seas

1.5. Maladies and Remedies

Several rehabilitation works successfully completed in last decade. Over the year, much measure has been evolved and adopted in practice. Some of the important one with the proven efficiency is highlighted here.

Treatment of crack by Epoxy

It is known that every crack is not significantly important. The crack in the structure is signifies distress. However, size, frequency and cause of the crack, this are some important parameter which are need to be consider carefully.

The integrity of the structure is restored by epoxy treatment. Solvent free epoxy resin compound which is cured by chemical reaction between hardener are used for treatment of the cracks. Fast development of the strength and bond with the concrete this are some main important characteristic of the epoxy which is important in restore the structure in original condition. Some time porosity of the concrete is required to be improved. In such case treatment with epoxy injection can help in improving impermeability property.

Treatment of Honeycomb and damage concrete

Fast setting repair mortar is found to be suitable for patchwork of the concrete. Cement based mortar containing, admixture are used when high early strength required. Polymer based special mortar is also used. The reinforcement encountered here is treated with passivating paint.

Jacketing

Jacketing involve fastening of the external material such as concrete and steel etc. over the existing member to provide required performance characteristic. The interface between old concrete and new concrete has to be treated by suitable bond coat. Beside, positive connection between two elements is achieved by providing dowel in the old concrete. On several Indian bridges, this method has been used for pier, arched and column with success.

Replacement of the damage concrete

Situation like delaminating of the concrete, contamination of concrete by chloride ions or sever cracking of the concrete can be tackled by removing of the defective concrete. Equipment used, should be such that it should not damage the good concrete. Fresh concrete is added by casting or spraying on the existing concrete. It is necessary that replaced concrete property should match with existing concrete as closed as possible.

Bonding of Steel plates or Carbon Fiber Sheets

A beam, columns of steel plates enhances the resistance of existing elements in blending, tension and shear. The aim of this technique is to modify or improve load bearing capacity of the structure. Before gluing the plates, the surface should be well prepared duly de-greased in a bath and covered with primer. The plates are applied under pressure to squeeze the film of glue and allow the plate to follow the profile of the member. The plates are protected against corrosion. Fiber reinforced plastic and carbon fiber sheets are now available in India and their use is already begun on rehabilitation projects. These sheets have an advantage over the steel as they can assume any shape being thin can be wrapped/bonded with the structure more easily. Besides, they are not prone to corrosion.

1.6. Need for Seismic Assessment

Many existing buildings may be designed without adequate consideration for earthquake loading, ductility detailing, a seismic configuration and an understanding of stiffness, strength and dampening. Over the last four decades there have been a number of changes and modifications in the relevant codes of practice and in some cases even in the philosophy of design itself. The seismic deficiency in existing buildings may be due to several reasons. In these situations a cost-benefit analysis is required to be done in order to decide between either strengthening the already existing structure or go in for reconstruction elsewhere.

1.7. Concepts and Principles for Strengthening of Buildings

The concepts and principles of strengthening of buildings are enumerated as, (a) before adopting any retrofitting scheme the structural inadequacies of existing building should be seismically evaluated. (b) All the members and components of retrofitted structures must be suitably tied together so that integral action may be achieved during motion. (c) Adequate structural members, strong and ductile connections between diaphragm walls and foundations should be ensured. (d) High quality of construction and use of special binding material is key to retrofitting. (e) Addition of new elements like shear walls, infill walls etc. should ensure adequate connection between old and new construction using shear keys and suitably designed dowels. (f) Besides strengthening and increasing ductility, reduction in dead load may have to be recommended in some cases to improve seismic performance e.g. reduction in number of stories.

1.8. Retrofitting Techniques

Lateral strength and ductility are the most essential factors governing the seismic performance of the structure and an effective seismic strengthening schemes aims to improve (a) the ultimate strength of overall structure, (b) inelastic deformability of the system, i.e. ductility and (c) a proper combination of these two features. An increase in the combination of strength and ductility is generally required to meet life safety performance level, which requires collapse prevention, maintenance of exit paths and prevention of buildings. Even when sufficient ductility is added, adequate strength is required to reduce inelastic deformation, hence, damage to structural/non-structural components. Many techniques have been developed for each strategy. For example, RC in filled walls or steel braced frame enhances lateral strength of existing frames, whereas jacketing of structural elements such as beams and columns with steel strap and ductile steel braces strength as well as ductility. Determination of a suitable strengthening approach requires careful consideration of the expected performance of the structure in a future earthquake. Selection of a particular seismic strengthening scheme depends on several factors:

1. The scheme must correct known seismic deficiencies of the system and new strengthening elements should be compatible with existing system. 2. It should be functionally and sometimes aesthetically compatible and complimentary to the existing building. 3. It should meet the expected performance goal whether they are life safety for residential units or limited damage for quick return for full operation for an essential facility. 4. It should minimize the disruption to occupants, if it has to be occupied during the strengthening work. In occupied buildings, strengthening work done from the exterior of the building perimeter are the most satisfactory. Some of the state of art methods employed for seismic retrofitting are described below:

Addition of New Shear Walls

The introduction of new shear walls from base to roof in the existing RC framed buildings is one of the most commonly used approaches to seismic retrofitting. Shear walls add strength and stiffness to the buildings. These walls should be so chosen as to minimize the eccentricity. New shear walls can be added to strengthen, RC frames, especially open storey. These new shear walls will be complete with boundary elements and foundation. This intervention greatly adds to strength and stiffness to framed structures. The primary disadvantages include considerable increase in mass of the existing structure and expensive and cumbersome for new footings. They can be a major problem on soft soils and in pile supported structures. Location of new shear walls should be chosen such that they. (a) Align full height of the building. (b) Minimize torsion and (c) can be easily tied with existing frame.

Addition of Infill Walls

The infill walls of RC, masonry or precast concrete elements can be added to framed buildings. This method can increase the strength of the inadequate buildings appreciably. The Precast infill panels have been used to strengthen the non-ductile RC framed buildings. The previous investigations have shown that the infill affects significantly the stiffness, strength and deformation capacity (i.e. ductility and energy dissipation and absorption capacities) of the bare frames. All these effects result in changes in dynamic characteristics of the building in which the infill is used. The changes depends upon how the infill is constructed and integrated (i.e. anchored or connected) to the bare framed building. The addition of infill brings an increase in building mass, which results, into increase in reactive mass and time period. By virtue of infill wall addition, increase in stiffness takes place, which decreases the time period ‘T’. Addition of Wing (Side) Walls Columns of non-ductile RC frames can be strengthened with addition of side or wing walls. The design characteristics of these wing walls are similar to addition of new shear wall.

Addition of Buttresses

Non-ductile RC and Un-Reinforced Masonry (URM) structures, which are significantly weak in shear strength, can immensely benefit from installation of buttress walls. All exterior work results in minimal disruption to functional use of the facility and occupants. However, a large vacant space is required adjacent to the building for the construction of buttress wall. Further, it significantly affects the aesthetics of the strengthened structure. Also, large resistance from the piles or foundation of the building will be required because the buttress will not be able to mobilize the dead weight of the building which means horizontal members (shear collectors) have to be installed on the interior of the building.

Addition of Bracings to Frames

The steel bracing can be added to existing inadequate building frames to increase the strength and stiffness of building without much addition of mass. Typically braced frames provide lower level of stiffness and strength than the shear walls. Bracing pattern can be adopted as per the aesthetic and strength point of views. Various kind of bracing patterns are used such as single diagonal, latticed, knee, etc. The use of cross bracing is more common in steel structures of industrial and commercial nature.

Pre-stressed Wire Wrapping

An enhanced form of confinement may be achieved by wrapping an enhanced form of confinement may be achieved by wrapping pre-stressing wire under tension onto a column. The lateral confining stresses needed to increase flexural ductility are thus primarily provided by active pressure, rather than passive pressure. This is generally used for large silos etc.

Jacketing of Reinforced Concrete Members

The deformation capacity of non-ductile concrete columns can be enhanced through provisions of exterior confinement jacketing, done from one or more sides of the members. Numerous buildings have been retrofitted by this procedure. Steel jackets for seismic strengthening of columns have also been employed. This method is useful when columns have inadequate lap splices in longitudinal reinforcement and inadequate transverse reinforcement in columns. Glass Fiber and Carbon fiber binding method is a new seismic retrofit method for the existing RC columns. The method is considered superior to steel plate jacketing or RC jacketing. Jacketing with SIMCON (Slurry Infiltrated Mat concrete) is a variety of High Performance Fiber Reinforced Concrete (HPFRC). The readymade fiber mats are wrapped around the existing concrete elements. Thus cracking in plastic hinge regions is delayed giving gradual failure of members and also increases the strength.

Supplemental Damping Devices

Nowadays, the supplemental damping devices have been used extensively in the retrofitting works. One of the ways of providing supplemental damping to inadequate building is by incorporating simple and inexpensive friction damping devices at strategic locations in buildings. Their earthquake resistance and damage control potential is dramatically increased. The friction dampers are simple and foolproof in construction, possess very high-energy dissipation capacity and provides reliable and maintenance free performance over the life of building.

Seismic Base Isolation Technique

This approach requires the insertion of complaint bearings within a single level of building’s vertical load carrying system, typically near its base. The bearings are designed to have low stiffness, extensive lateral deformation capacity and may have superior energy dissipation characteristics. Installation of an isolation system results in a substantial increase in the building’s functional response period and potentially its effective damping. The significant reduction in displacement response and acceleration that occur within the superstructure of an isolated building results in much better performance of equipment, systems and other non-structural elements than is attainable with most other retrofit systems.

1.9. Other Techniques of Retrofitting of RC Members

The following are the methods for retrofitting of individual members.

For Column Strengthening following are the methods for retrofitting of existing RC Columns depending upon the availability of equipment and ease of construction:

Propping Up:-One of the simplest and most effective methods for retrofitting column of an existing building , partially unload the column by jacketing between floors and then insert two or more props to carry portion of axial load. The props are usually rolled steel sections, which may subsequently be encased in concrete to improve fire protection and appearance. The disadvantage of this procedure is that considerable floor space is lost and that props may not be effective in transferring moments unless positive connections are introduced at both ends e.g. in the form of end plates bolted through holes drilled in the floors.

Sleeving:-The sleeves consists of additional longitudinal and horizontal steel ties on ram stetted to the existing column and with a cast in place concrete and gunite cover.

Collar Type:-A simpler, cheaper but aesthetically less pleasing means of providing moment transfer is to introduce a steel collar, which fits snugly to the column end to under side of the upper floor and the steel collar may be either bolted or glued.

Casing:-In casing additional reinforcement and concrete is added on four sides of the concerned member. This method is suitable for interior columns.

Jacketing:-A reinforced concrete layer on three sides of the concerned member. This method is quite suitable when one face of column is flushed to wall and the other three sides are open.

Building up:-The building up may be used on one or two faces of the column. During the retrofitting process the column should be partially unloaded so that the total axial load is finally shared between the new and old construction material. The effectiveness of strengthening with the help of casing or jacket or build-up depends upon the degree of adhesion of the old and new concrete, which in turn depends on the condition of application of concrete mix, method of its compaction and finish of the surface to be connected.

Strengthening of Slabs

Though the floor system in as RC building is not a part of the structural systems resisting lateral forces (but acts as a diaphragm for transmitting lateral forces), sometime the need may arise to strengthen the weak slabs depending upon the type of weakness. The following methods can be used to strengthen the existing slabs.

Underlay:-This method is used to increase the sagging moment resisting capacity of slabs. Additional tensile reinforcement is fixed to the underside of the existing concrete slabs and a concrete coating of proper thickness is applied to cover the new reinforcement.

Overlay:-This method is used to Increasing the hogging moment carrying capacity. A new concrete layer with additional tensile reinforcement is placed over existing slab. Strengthening of Foundation g is typically required if bearing capacity is not adequate for excessive soil pressure due to seismic overturning forces. Some of the techniques generally used are as follows: a) increasing the footing depth. This will increase the shear capacity of the concrete shear- resisting mechanisms. b) Drilling vertically through the footing and anchoring vertical rebar, preferably pre-stressed. This will act as additional shear reinforcement. c) Drilling longitudinally through the footing and pre-stressing, as recommended for flexural strength enhancement. The shear strength will increase, as with the pre-stressed beams. Strengthening of Foundation is not only expensive but a very disruptive process. It is usually cost effective to change strengthening scheme so that foundation strengthening is not required.

Bonding Steel Plates to the Sides of RC Member

This is a unique, inexpensive, versatile and effective technique for the rehabilitation/retrofitting of reinforced concrete beams by bolting and gluing steel plates to their surfaces. Plating can substantially increase the strength, stiffness, ductility and stability of the reinforced concrete element but it is also observed that the plated structure is prone to premature de-bonding of the plate. The system of plating that is being developed is unique as the bolt shear connectors act as permanent and integral restraints. The bolts are first used to hold the plate in position during construction of the glued joint. However the bolts are also designed to resist interface forces in order to take care of the forces even if the glued bond were destroyed by fire, chemical breakdown of the adhesive, rusting or simply bad workmanship. Hence, this technique is much more reliable than existing techniques as it uses two independent systems to transfer the interface forces. The development of this dual system approach has required research into new or relatively untouched areas such as peeling of side plated beams and buckling of plates restrained at discrete points, and has also required the creation of a new branch of composite research, namely lateral – partial interaction.

1.10. LITERATURE REVIEW

Literature review emphasis on recent and traditional method of rehabilitation and retrofitting along with retrofitting of heritage building is also discussed in this chapter, which gives clear idea about where we standing now in the field of rehabilitation and retrofitting and what needs to be done to make retrofitting less expensive and convenient.

1.10.1. Retrofitting Using FRP.

[Mukherjee and Rai [2]]This paper represent the result of the experimental study to investigate the flexure behavior of the RC beam that have reached their ultimate bearing capacity and then retrofitted with Externally pre-stressed carbon fiber composite laminate (CFRP).The effect of variation of the pre-stressed force on the CFRP laminate bonded to the RC beam is investigate in terms of the Flexure strength, Deflection, Cracking behavior, and failure modes. The result indicates that rehabilitation of the significantly cracked beam by bonding CFRP laminate is structurally efficient. Recovery from the deformation is increased with the increase in the pre-stressed force. As a result the load deformation curve was much higher for higher pre-stressed beam. However the ultimate load and maximum deflection did not grow up significantly increased with higher pre-stressed force. To design the rehabilitation one must decide the amount of CFRP laminate based on the requirement of the ultimate capacity

MUKHERJEE and JOSHI [3], This paper discuss novel technique of rehabilitation of earthquake affected structure and retrofitting of the structure against possible earthquake using fiber composite. It conclude, this technique require understanding the behavior and property of new set of material such as carbon, glass and kelvar and thermosets such as epoxy, polyester resin. It this connection, it must be mentioned that this technique demand different set of skill.

MUKHERJEE, KALYANI [4], This paper, design methods for up gradation of reinforced concrete frame with fiber reinforced composite material has been demonstrated. It shows comparison and bending model moment rotation relation for FRC up graded beam column member.

Roy, Sharma [5], To investigate effectiveness of different strengthening technique in restring heat damaged concrete column and beam an experimental investigation is carried out. The strengthening scheme is namely Glass fiber reinforced Polymer GFRP, High strength fiber reinforced concrete HSFRC, Ferro-cement and steel plate jacketing were employed in the study. A total 4 reinforced concrete column and 24 T beam were first subjected to elevated temperature. The heat and cooled specimen were strengthening using chosen technique. After the entire specimen were tested under monotonic loading to determine ultimate strength, Stiffness, ductility and energy absorption capacity. The strengthen column and beam shows significant increase in ultimate strength as compare to Un-strengthen column and beam and in some cases strengthen enhancement is more than unheated control beam and column. GFRP jacketing was found to be most effective technique for strengthen fire and heat damaged concrete column and beam.

1.10.2. Retrofitting using Fiber Reinforced Concrete

Ramaswamy [6], The study presents developments and applications of alternate material systems for repair that have evolved in recent years for application to structural concrete elements as a means of rehabilitation or retrofit. Firstly the widely used fiber reinforced polymer (FRP) of glass, or carbon in the form of a laminate or wrap with epoxy binding as a material in structural concrete applications is discussed. While its main attraction is high strength to weight ratio, the system has some limitations such as de-bonding due to progressive de-lamination at flaws or sudden brittle rupture. Moreover, its limitation in certain applications, particularly exposure to adverse environmental conditions such as moisture (if the binding epoxy is hygroscopic), high temperature (if the binding epoxy melts) such as due to fire is brought to light. The possibility of shielding the FRP repaired concrete in a ceramic or geo-polymer shell so as to offer a complete thermal shield together with a mechanical strengthening system is discussed. Merits of an alternate cement based systems such as fiber reinforced concrete with chopped short wire fibers made from steel, polyester, carbon and glass that are mixed into a concrete matrix, even with a self-compacting concrete consistency at the time of casting as an alternate form of a repair system is then discussed. Experimental results and analytical procedures that have been developed to predict the capacity of the variously reinforced structural elements is presented to illustrate the merit of different approaches. The study has explained the use of different repair material in reinforced concrete application. The option of SSC particularly with fiber offer considerable strength and ductility enhancement in comparison to GFRP or CFER and has a lot of promise. Self-consolidation characteristic of the concrete material offer easy repair possibility in location where structural damage difficult.

Zhao and Zhang [7], The use of the FRP to strengthen the steel structure has become attractive option which may produce confident retrofitting of the existing structure. The paper review the following area that have received very small coverage in previous review article, but have developed rapidly, the bond between steel and FRP, Strengthening of the steel hollow section member and fatigue crack propagation in the FRP steel system. Future research topic have also been identified, such as the as bond sleep relationship, the stability of the CFRP strengthen steel member, crack propagation modeling.

Sheikh and Bayrak [8], In this paper they specifically focus on the column, Result from a select group of eight circular columns and four square columns are presented in this paper. All columns subjected to simulated seismic load. Base d on the comparison of the moment-curvature response the critical section of FRP retrofitted specimen with those of similar companion specimen with FRP, it can be concluded that FRP wrap significantly improve the seismic resistance of the column.

Badoux and Jirsa [9], The use of steel bracing for seismically inadequate Reinforce concrete frame is examined. Diagonal bracing is excellent approach for strengthening and stiffening the existing building for lateral force. A variety of retrofit objective ranging from drift control to collapse prevention can be achieved. The designer can determine the force path in retrofitted structure and adjust the strength and stiffness as required. A analytical study is done to get understanding into behavior of the braced frame under the cyclic loading particularly frame with weak short column. Inelastic buckling of the braces influences detrimentally cyclic behavior of the braced frame. The instability can be prevented by using the braces that yield in compression and buckle in compression under low axial load. The advantage of the altering the beam of the braced frame are described. The strength of the beam can be reduced to behave ductile for future failure mechanism.

1.10.3. Retrofitting by Seismic Isolation

Matsagar and Jangid [10], Analytical Seismic response of the structure using base isolation device is investigated. The retrofitting of the various important structures using base isolated action technique is studied. Three important structures such as Historical building, bridge, and liquid water tank are selected to study the effectiveness of the base isolation technique. Different type of isolator device such as elastomeric bearing and siding system are evaluated for their performance in the retrofitted work. The response of the retrofitted structure is evaluated by solving governing equation of the motion under different earthquake and compared with conventional without retrofitted structure; in order to investigate effectiveness of the base isolated structure. It is observed that the effective response of the base isolated structure is reduced significantly in comparison to the conventional structure.

Das, Deb [11], This paper is representing the detailed study on feasibility of Un-bounded fiber Reinforced Elastomeric Isolator as comparison to steel Reinforced Elastomeric Isolator for seismic isolation of the un-reinforced building. Un-reinforced masonry buildings are inherently vulnerable to seismic excitation, and U FREI is used as a seismic isolation in this study. The shake table testing of the base isolated 2 storied unreinforced masonry building subjected to four prescribed input excitation is carried out to ascertain the effectiveness in the seismic response. To compare the performance of U FREI, same building is placed directly on the shake table without base isolator and fixed base condition is simulated by restraining the base of the building with shake table. The response characteristic of the base isolated building subjected to different intensity of earthquake is compared with response of same building without base isolation system. The acceleration response amplification and peak response for with and without base isolation system is compared for different intensity of table acceleration. Distribution of bending moment and shear force along the height of building and response time hysteresis indicate significant reduction in dynamic response of structure with U-FREI system. The study clearly demonstrated that the seismic performance of the response building supported on U-FREI under the action of ground motion.

1.10.3. Retrofitting of Heritage Structure

Bauer and Menches [12], This paper discuss about the example of the engineering problem solved during the execution of the Golden Gate seismic retrofitting. Golden gate is situated between 2 major fault, san Andreas and Hayward fault. The experts have predicted that there is 65% chance of occurring of earthquake of 6.7magnitudes up to 2030. Nine structure of the golden gate is design to withstand the lateral force approximately equal to 7.5% of the total self-weight of the structure. The objective of the retrofitting of the structure is to withstand non creditable earthquake which produce lateral forces in the structure up to 68% to 220% of the self-weight if the structure and experience only limited damage in to the structure without compromising structural integrity.

Ismail and Ingham [13], The lateral load carrying member of the building comprised of URM wall. This wall has In-plane and out of plane stiffness depending upon their material and size if the structural member. This structure also does not have well defined load transfer path for the seismic loading. A proposed mitigation strategy comprised of isolation of the structure and intervention of the super structure for that global and local FEA is used to access the efficiency of the retrofitted structure. The proposed methods Isolation with retrofitting significantly reduced seismic demand such as storey drift, top floor displacement and base shear. The wall has been retrofitted with inserting the steel rod throughout height of the wall which is ultimately increasing the out of wall stiffness of the wall.

Cheung, Foo [14], PWGSC is come up with recent innovative technology for seismic retrofitting by using composite material and passive damper device. The use of this innovative technology for retrofitting is found to be satisfactory which reduce seismic demand of the structure, less intrusive to the occupants of the building and reduce the cost of the retrofitting project.

The challenge to the structural engineer is to select the appropriate retrofitting technology which is technically, economically and socially acceptable. In this paper used different retrofitting technology such as friction damper, fluid viscous damper, CFRP, fiber reinforced cement and progressing.

CHAPTER - 2

Methodology of Experimental Study and Technique of Retrofitting

2.1. Introduction

Experimental Model is tested using Electro-mechanical shake table which is available in NIT Jaipur Disaster management mitigation laboratory. Computational model is made using SAP 2000 software package. Result of computational model is compare with experimental result. Details of the experimental model and working of shake table along with software used to generate input is discussed in this chapter.

2.2. Instrument used for Experiment

Power Amplifier: - Vibration testing of specimens or testing at high 'g' levels require a high power drive to the shaker. Hence, the amplifier being a Class D Amplifier serves to amplify the input signal to a level so as to drive the shaker up to the desired level. 3 Phase power is divided in to 2 part one is DC, which is used to supply power module. It is used to generate variable frequency which is transferred to the Armature and AC supply directly transferred to the field coil of the shaker.

Vibration controller: -Digital vibration controller is designed using DSP hardware module with build in signal controller. The controlled signal generated by DSP hardware which is sent to amplifier. The amplifier used this signal to drive the shaker. The acceleration induced in the specimen/table is measuring through the accelerometer mounted on the specimen/table. The controlled signal is continuously updated to minimize the deviation between programmed and achieved vibration level through the software in order to perform closed loop operation.

DLC: The major section is the Amplifier Digital Logic unit which acts as system governor. It is a microcontroller based intelligent unit placed at the top of the power modules and keeps vigilance on the amplifier operation while acting as an interface between user and the system. It is a solid state, *sinusoidal* signal generator with modular construction. This logic unit routes the path of a signal towards the power amplifier and thereafter to the shaker after amplification. It can send its own signal to the digital power amplifier or can accept a signal from an External source/ vibration controller and route it to the power amplifier so as to drive the shaker, working in controlled loop

Horizontal Slip table: - The slip table works on the principle of an oil film maintained between granite surface and slip plate supported by low-pressure oil bearings to eliminate overturning moments.
These are designed for testing of heavy loads & voluminous objects in x & y direction. The bearings are designed to restrain pitch, roll & yaw moment.
Slip tables can be used standalone with optional seismic base or integrated ona common base with a vibration shaker.

Specification of slip Table

1	Platform size and material	600mmX600mm and magnesium alloy
2	Dynamic weight	45Kgs
3	Hole pattern	M10 with 50 mm grid
4	Reservoir capacity	10 liter
5	Motor Power	1 HP
6	Useful frequency	5-2000 Hz
7	Payload capacity	200 Kg
8	Oil grade	Hydrosol 68 Engine oil
9	Pressure gauge	Indicate the pressure oil inside bearing
10	Input supply	3 Phase 415 v (±10%)

Cooling Blower:-To maintain the temperature in the shaker cooling blower is installed outside the lab because it makes noise**.**

Accelerometer:-Determine phase and amplitude relationship of a vibration at various points on a structure permit modal modeling. The resulting modal mode provides valuable information regarding system integrity and valuable modal shape. It can be easily fitted to different test object with selection of mounting clip. In present experiment shear accelerometer is used which is having sensitivity 10.12 and 10.16 pC/which was fixed on the pate by bee wax. The accelerometer used in present experiment study is shown in the Fig.2.1.

Figure 2.1:-Accelerometer

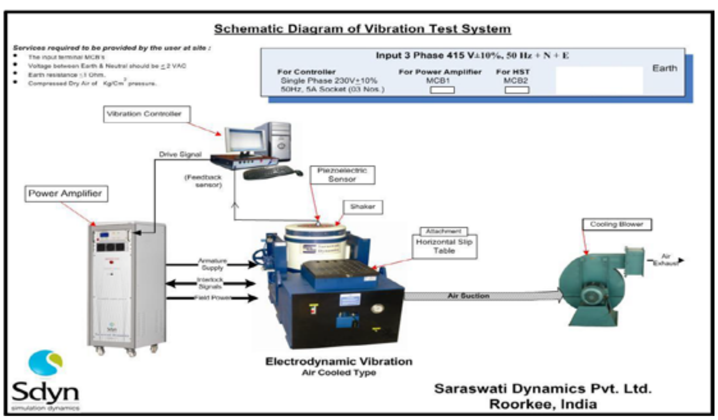

Figure 2.2:-Schematic Diagram of Vibration Test system.

2.3. Input given for excitation

Sin Vibration software is used to operate vibration shake table.

Control parameter

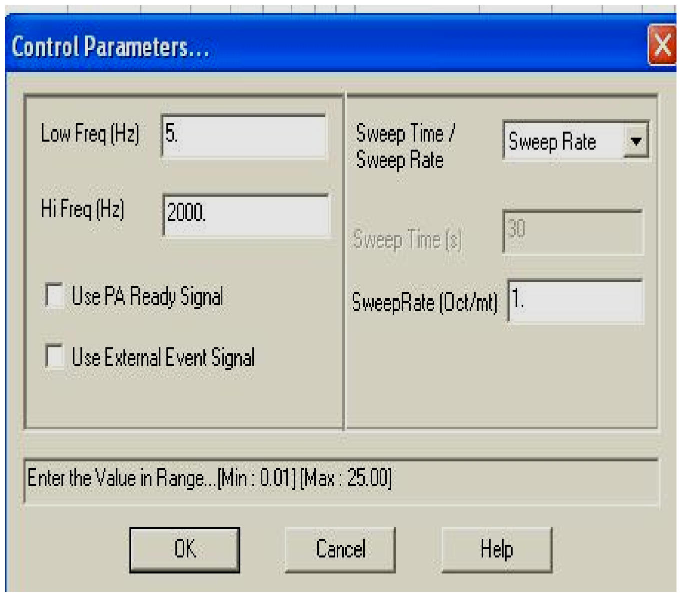

Figure 2.3:-Control parameter.

No	Parameter	Description
1	LOW FREQUENCY	This will be the starting test frequency or the lower limit of the test Frequency range:- Range: 0.01 to 5000 Hz
2	HIGH FREQUENCY	This will be the upper limit of the frequency range. Range: Lo Frequency to 5000.00 Hz
3	SWEEP TIME	This is the time to be taken to complete one sweep. The frequency Sweep rate is automatically adjusted by the controller. Limit: 30 to 14,400 seconds.

Advance Parameter Option

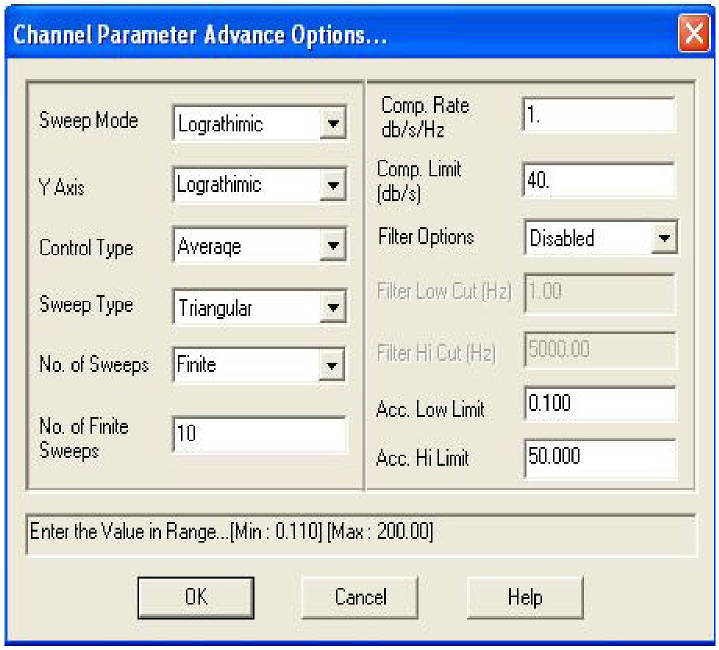

Figure 2.4:-Channel Parameter Advanced option

No	Parameter	Description
1	SWEEP MODE	Either of the option *Linear* or L*ogarithmic* can be selected thru the combo box. The frequency will increase either logarithmically or linearly depending upon the choice.
2	Y AXIS	The y-axis can be set to *Linear* or L*ogarithmic* scale. This option can also be Change during the test.
3	CONTROL TYPE	This sets the control strategy as *Average or Maximal*. In case of Average, the control value will be average of all channels configured as control. In case of Maximal, the channel with highest value will be taken as control value.

4	SWEEP TYPE	This will be set as *forward*, *triangular* or *backward*. In case of *forward* sweep, the control will start from Lo Limit of frequency, Sweeps up to Hi Limit and then jump back to Lo Limit to resume next sweep. In case of *backward* sweep, the control will start from Hi Limit, sweeps down to Lo Limit and then jump back to Hi Limit to resume next sweep. In case of *triangular* sweep, the control will start from Lo Limit, sweeps to Hi Limit and sweeps back to Lo Limit to resume next sweep. Generally, triangular Sweep is used.
5	NO. OF SWEEPS	This will set the no. of total sweeps to be performed. This can be set to Infinite or Finite
6	NO. OF FINITE SWEEPS	For finite no. of sweeps, this can be set Between 1 to 9999.
7	COMPRESSION RATE	This is the rate at which the drive signal will be released to run the test. Range: 0.1 to 3.0 dB/Sec/Hz Optimum Value: 0.2
8	COMPRESSION LIMIT	This is the max. Limit for the *COMPRESSION RATE* at a particular frequency. Range: 2.0 to 200 db/second Optimum Value: 40
9	FILTER LO CUT	A value below the Lo Limit of the frequency range must be entered. Limit: 1.0 Hz to Lo Limit of frequency.
10	FILTER HI CUT	A value above the Hi Limit of frequency range must be entered. Limit: High limit of frequency to 5200.00 Hz.
11	REFERENCE TABLE	Control by:-Displacement/Acceleration/Velocity In Present Experiment displacement is set as a Reference Table

Data logging Option

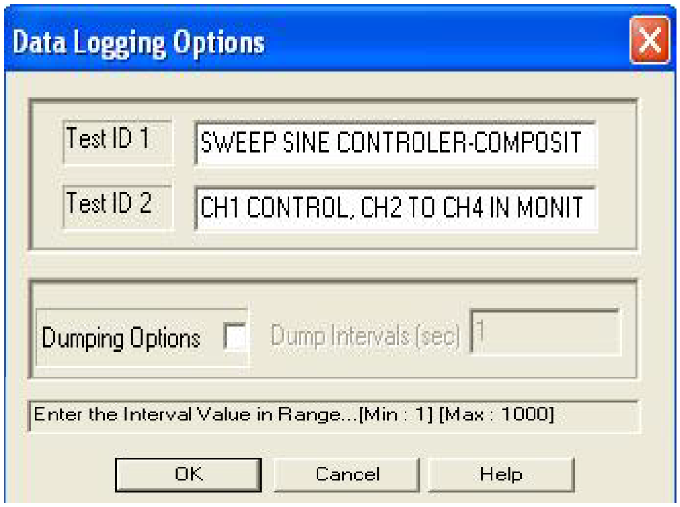

Figure 2.5:- Data Logging Option

No	Parameter	Description
1	Test 01/02	These are 2 lines of 40 characters to type test identification notes before starting the test. These appear on the main graph window during the test.
2	Dump Option	If checked this will store the parameter and values in to a user specified file on the hard disk at programmed dump interval. The programmable dump interval is 1 to 1000 second.

Configuration Parameter

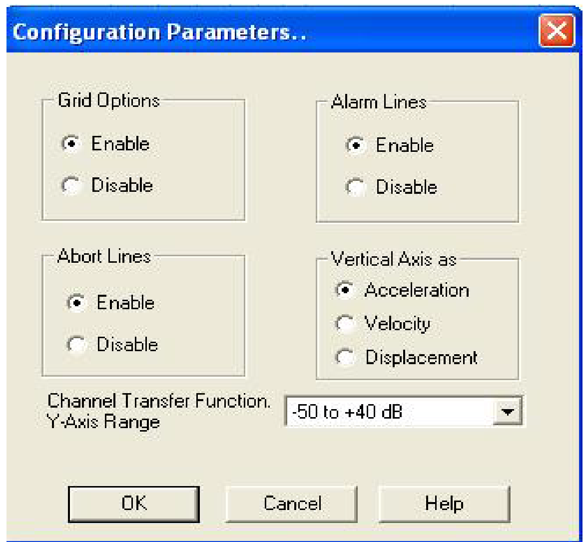

Figure 2.6:-Configuration Parameter.

No	Parameter	Description
1	GRIDOPTION	Draw the grid line on X & Y axis.
2	ALARMLINES	Draw alarm limit along the reference profile programmed by the user..
3	ABORTLINES	Draw abort limit along the reference profile programmed by the user
4	VERTICALAXIS	Set vertical axis as a displacement /velocity/Acceleration

Safety Parameter

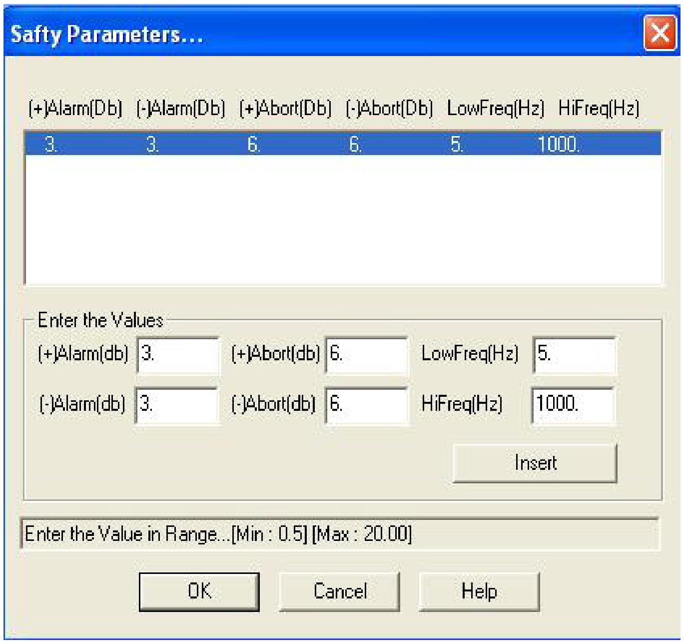

Figure2.7:-Safety Parameter.

The SAFETY PARAMETERS are the tolerance limits (Alarm & Abort) during execution of the tests .Maximum 10differentalarmregionscanbe programmed over the entire test frequency range. Thus ,if you have programmed 10setsthenyou can have unique alarm values for each region.

Channel Table

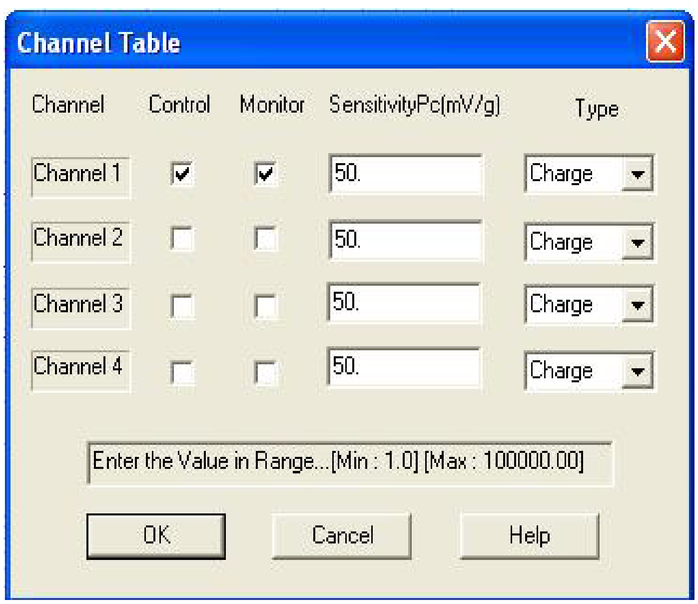

Figure.2.8:-Channel Table 01.

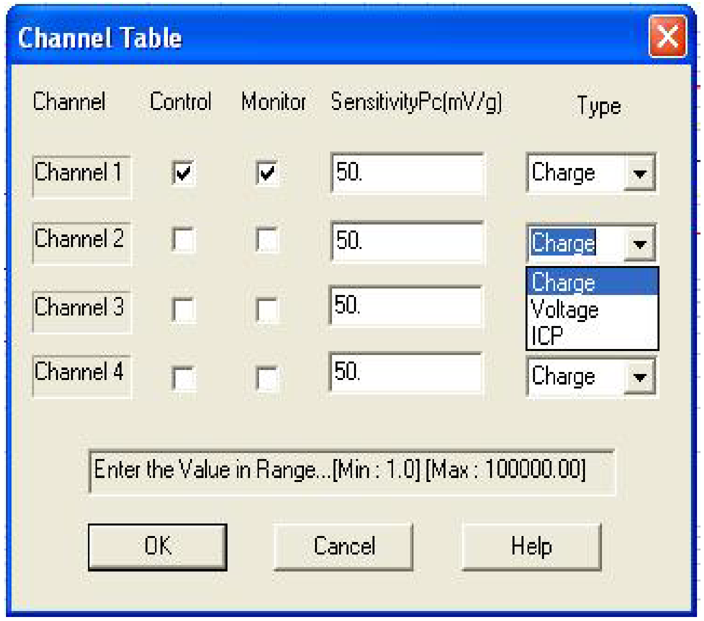

Figure.2.9:-Channel Table 02.

Reference Table

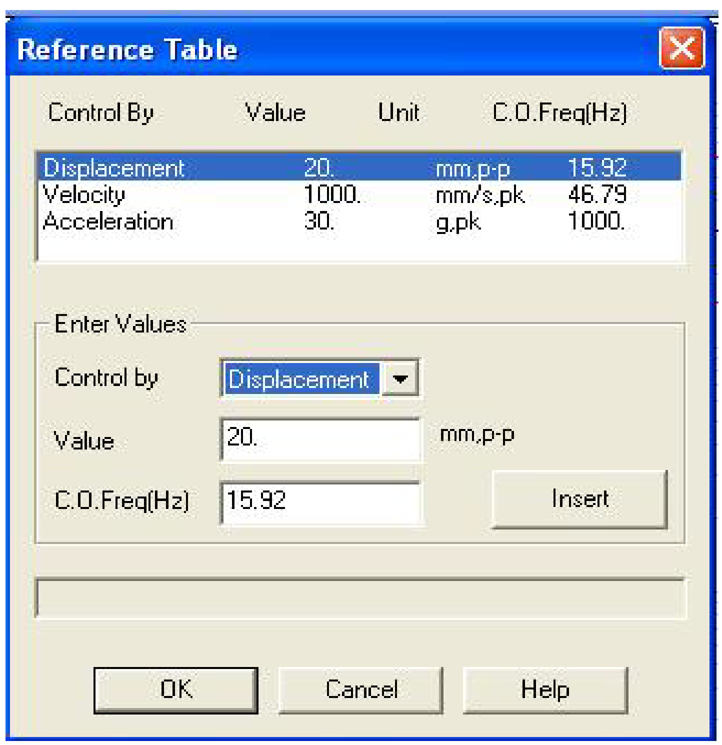

Figure2.10:-Reference Table.

2.4. Procedure of Retrofitting

STEP 1: Before application of FRP laminate/FRP wrap the substrate has to be prepared. In case of damaged structure/ member the first step is to rebuilt to damage member. Remove all the loose material and expose the steel surface.

Figure.2.11:-Removing Oil Film Steel Plate.

Make the mixture of (GOLDBOND 1893 SA) in proportion of 3:1. After preparation of surface, low viscous primer is applied on the steel surface to improve bond between steel and FRP laminate.

STEP 2:-Apply the mixture of (GOLDBOND 1893 SA)on FRP laminate and stick the laminate to steel plate. For making proper bonding use clips. Keep as it is for at least 8Hr

Figure.2.12:-Structural Adhesive part A/B

.

Figure.2.13:-Application of Adhesive.

STEP 3:-After proper bonding of laminate to the steel plate apply the (GOLDBOND 1893 primer) on the surface of the laminate. (GOLDBOND 1893Primer) also mixed in1:1 proportion after some time (GOLDBOND 1893 Saturant) is applied on the laminate over primer in 1:1 proportion.

Figure.2.14:-Primer part A/B

STEP: 4–Fiber sheet are cut to required size. An allowance for length of lap joint must be given while cutting the sheet. A lap length is decided based on the experiment in laboratory and precision that can be maintained in construction. Cut fiber sheet rolled in circular spindle to make them easy for wrapping.

Figure.2.15:-Cutting of FRP Wrap

STEP: 5:-After that FRP 400G is wrapped around the periphery of laminate, minimum lapping should be give for proper bonding**.** It's very important to choose proper epoxy for rapping application. The resin must viscous enough to hold the fiber in place. The wrapping must be completed within pot life of the epoxy resin that is usually 20-30 min.. Therefore, it is advisable to mix the epoxy in required quantity. A thin coat of resin is applied after wrapping over. After resin is completely cured (usually 24 hour) the wrap is inspect t rule out any defect**.**

Figure 2.16:-Warping damage steel column

STEP 6:-After wrapping of FRP single coat of (GOLDBOND 1893) Saturant is applied on the FRP wrap for proper bonding of internal fiber.

PROCEDURE FOR RETROFITTING

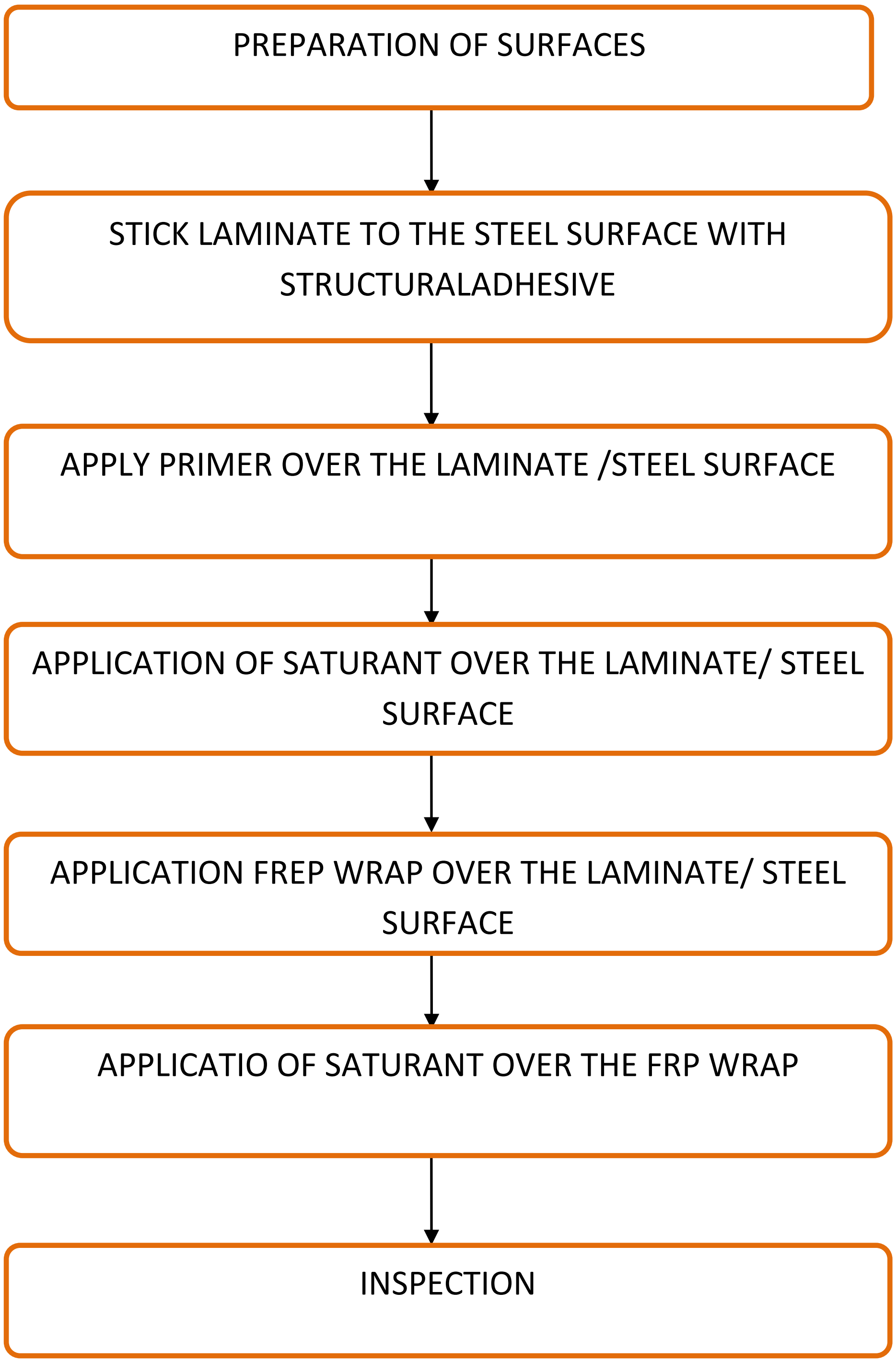

Figure.2.17:-Procedure for application of Retrofitting material

NOTE: - One must remember that FRPC layer is very thin. Therefore, it is very important to make smooth concave surface of concrete before the wrapping is begun. FRPC is ineffective if it leave the surface of concrete. Care must be taken to avoid wrinkle, voids and sheet deformation. Moreover sharp edge and corner is the potential zone of the fiber breaking due to the stress concentration. Therefore, it is necessary to remove all the projection and round of all corners. The corner of radius 25 mm is found sufficient to avoid stress concentration.(Only applicable to the concrete structure.

Figure.2.18:-Equipment used for chamfering column edge.

Special technique is used for lapping the fiber wrapping over the concrete surface because in conventional lapping procedure special care need to take for proper bonding in lap area. In this technique lap area more or less will be same but bonding between FRP wrap will be more as compare to conventional.

Figure.2.19:-Fiber used for Lapping of FRP wrapping.

Figure.2.20:-Fiber used for Lapping of FRP wrap.

There are two method laying dry layup and wet layup. In dry layup dry fiber sheet is directly applied over the concrete /steel surface freshly coated with epoxy resin. In wet layup fiber sheet is wetted with epoxy resin before wrapping. It is not always convenient to go for wet layup in hot climate. Therefore dry layup has been used in the resent work. The sheet should not be slack at the time of wrapping and care must be taken to maintain intended fiber direction. The sheet rolled by serrated Teflon roller so that resin oozes out through the sheet properly. Rolling must be in the direction of the fiber. The lap end must be thoroughly passed to avoid any defect in the bond. Spreading some extra resin on the lap area is good idea.

CHAPTER – 3

Experimental Investigation of Building Model

3.1. Introduction

Experimental model is tested using electro-mechanical shake table. Input to model is given using Sin software package. This software gives flexibility to vary frequency up to 5000 Hz and set vertical axis as Displacement, Velocity and Acceleration. Input and response of test models were recorded in tabular form. Analytical study was also carried out using Eigen value solution to check first three fundamental frequencies of test model(s). Further, detail study on the experimental and computational model is discussed in this chapter for original as well damage model.

3.2. Details of Experimental model

The model consists of single bay Ground plus 2 story frame. In order to ensure rigid foundation to the prototype structure so that column can be assumed to be fixed in the ground in the ground. The cross section of the column is 2.5mm x 5mm throughout. Thickness of the slab is 12.5mm. Structure is consisting of only column and slab. Column is act as a lateral force resisting member and mainly inertial force is developed due to the slab. Material property is assumed to be 250 MPa for the yield strength of steel. The dimension of the building is 300mm x 150mm. The strain gauge is mounted on top floor for measuring the response. Steel is used for experimental study having density 7850 Kg/m^3 and Modulus of Elasticity is 200Gpa.

3.3. Experimental Investigation

The 1^{st} and 2^{nd} fundamental frequencies of the Experimental model is 3Hz and 9Hz.The structure is excited with Sine wave, having amplitude 3mm and frequency varying from 1Hz to 10 Hz. During experimentation it was found that few models threads steel plate failed, therefore, the amplitude of the excitation was kept low during Experimentation. This was taken consideration while deciding the amplitude of excitation so that the model does not rupture in steel plate threads.

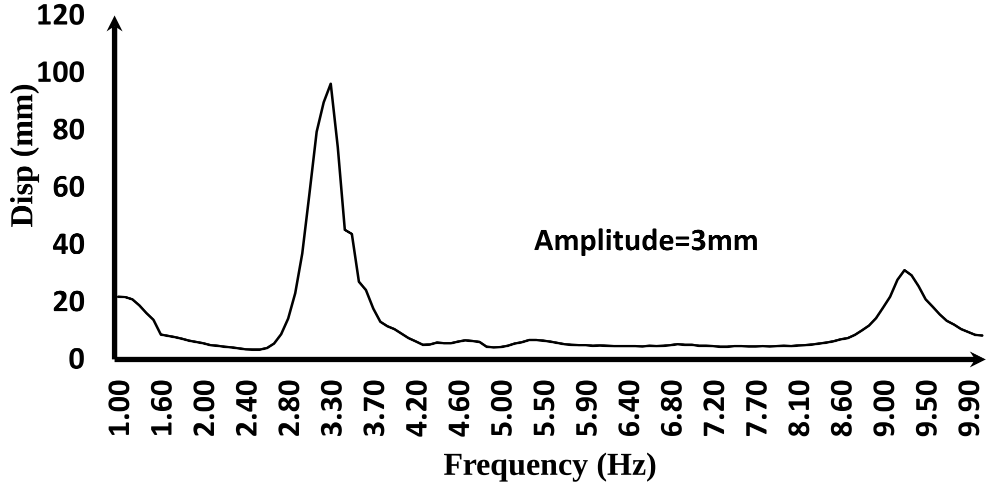

Figure 3.1:- Response of the Structure.

For specific study of seismic performance of damaged, predefined cuts were made in the models and amplitude of the Input increased from 3mm to 8 mm. After giving continuous excitation to the structure (Fig.3.1-3.11), frequency of the structure is reduced monotonically from 9Hz to 7.5 Hz which is indicative of stiffness of the structure being reduced. From this could be concluded that frequency of damaged structure frequency reduces which could help in system identification.

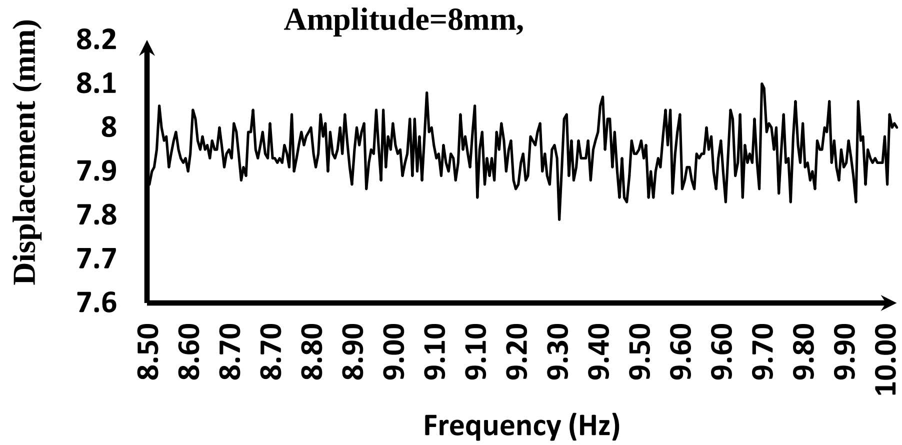

Figure3.2:-Input for the proposed Structure 01.

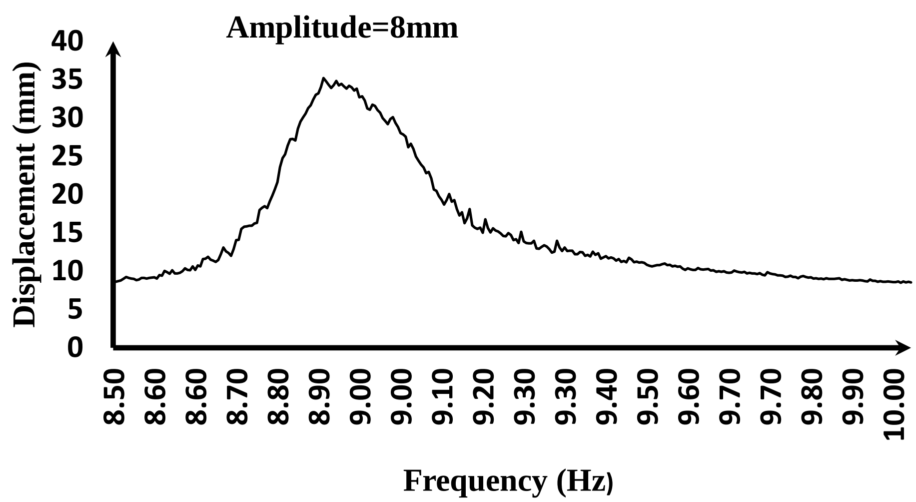

Figure.3.03:-Frequency-Response of the Structure 01.

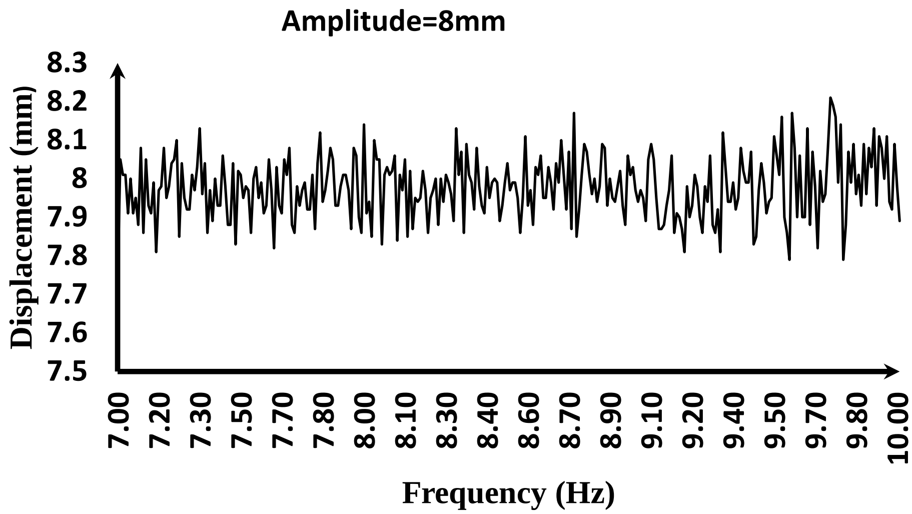

Figure.3.4:- Input for the proposed Structure 02.

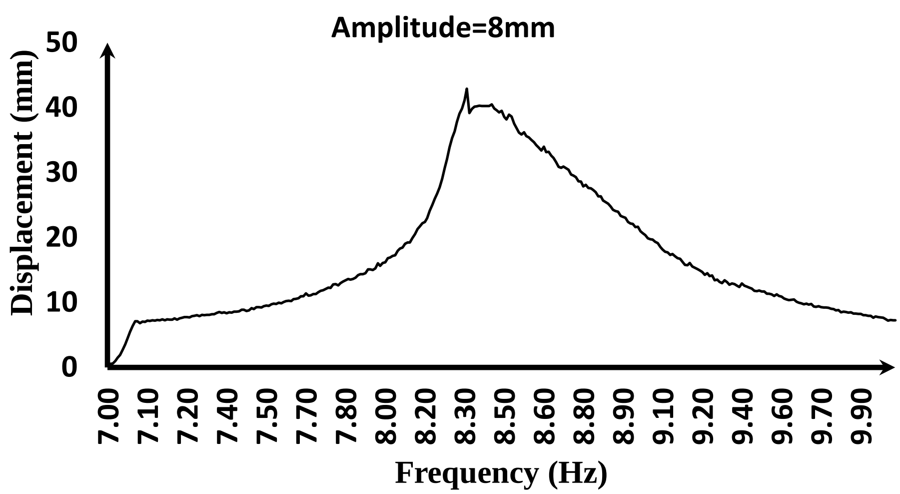

Figure.3.5:-Frequency-Response of the Structure 02.

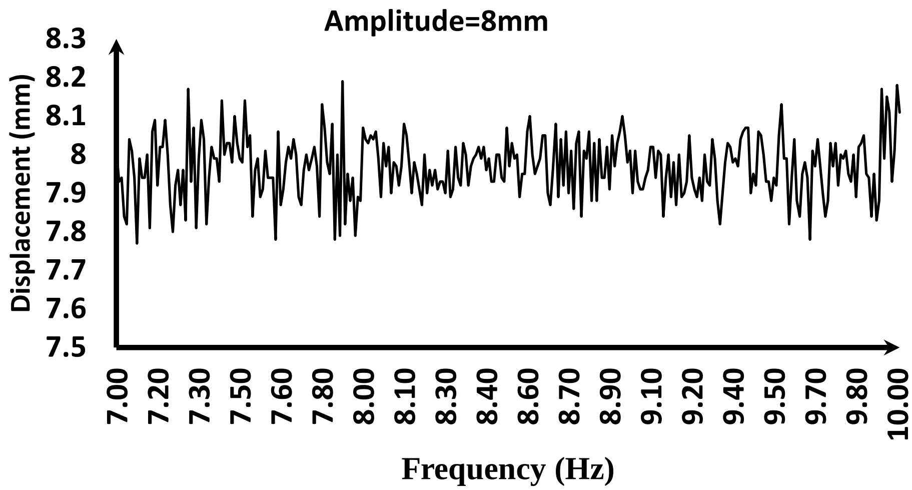

Figure.3.6:-Input for the proposed Structure 03.

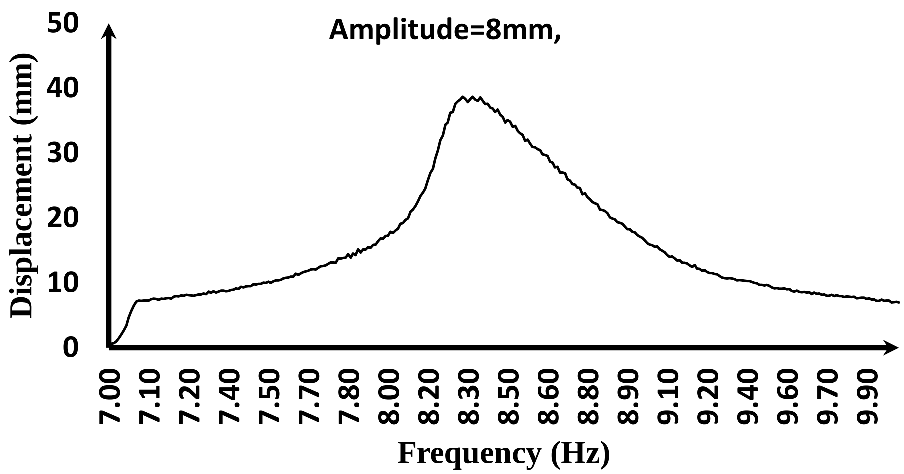

Figure.3.7:-Frequency-Response of the Structure 03.

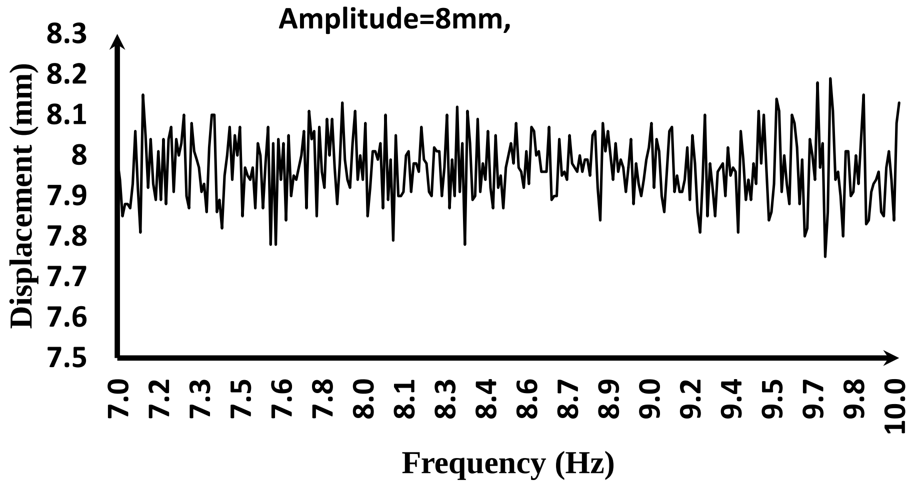

Figure.3.8:-Input for the proposed Structure 04.

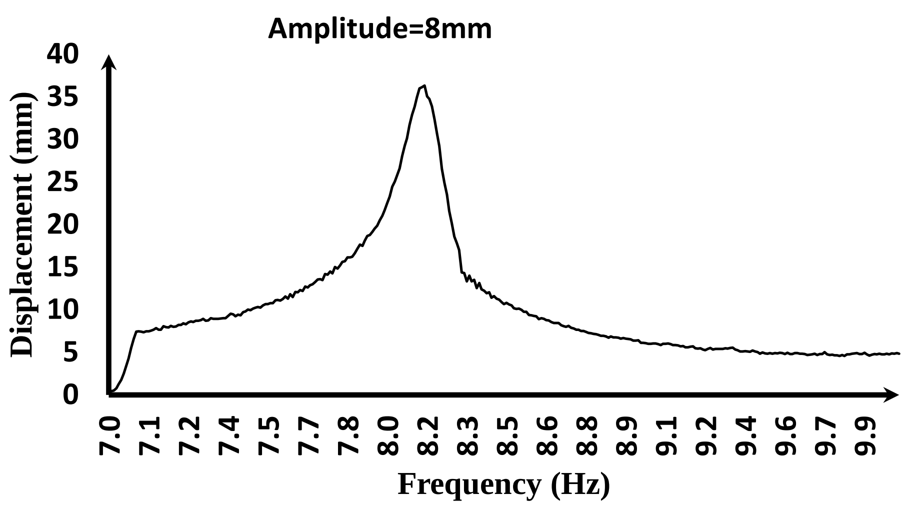

Figure.3.9:- Frequency-Response of the Structure 04.

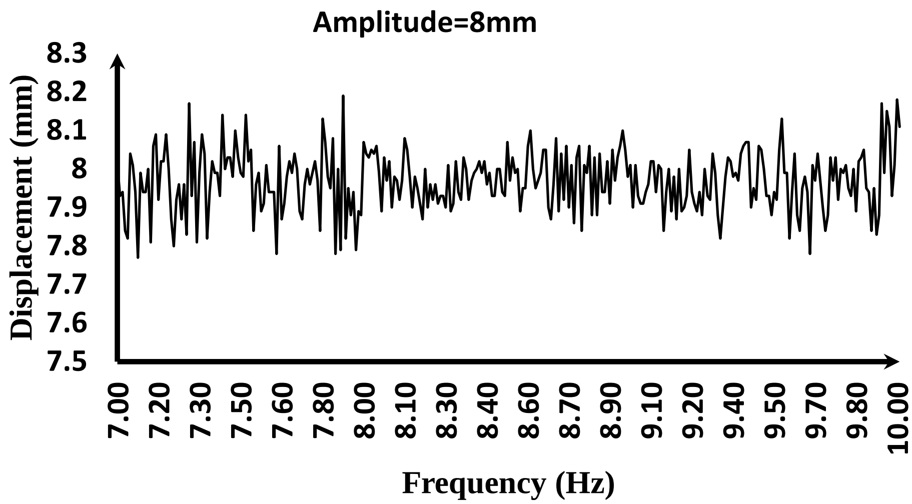

Figure.3.10:-Input for the proposed Structure 05.

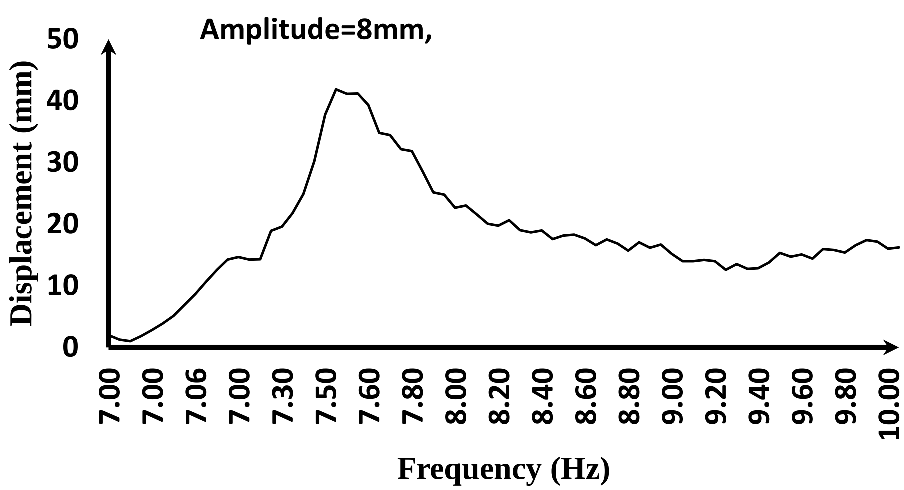

Figure.3.11:-Frequency-Response of the Structure 05.

3.4. Observation of the Damage Structure

In laboratory seismic failure of structure is conducting experiment on scaled model. This could be identified or noticed by observing gradual drop in response of the scaled model the structure. While giving unidirectional excitation to the test model (Shown in figure 3.14), it was observed that two columns failed at connection (Fig.3.12-3.14). This has happened due actual cross sectional area available is lesser in comparison other remaining two columns. This reduced area was at connection level. Further, this illustrate that Shear is major failure mode in the column (Fig.3.12-3.14). In general Shear failure occurs due to high inertia forces which are concentrated at the connection level. Since scaled model was symmetrical in plan as well elevation and due to uni-directional loading torsion induced was negligible. Since excitation of model in same direction of imparted motion bending of the test model induced bending stresses in the column concentrated at the connection level. Further, it was observed that in most of the cases, model was exited in second fundamental frequency. There could be two precise reasons for nonlinear behavior of the test model are either material behavior and damage created in the column of the test model which precisely reduces stiffness of structure up to 80% (Table.3.1).

Figure.3.12:-Damage Structure 01 Refer (3.14A)

Figure.3.13:-Damage Structure 02 Refer (3.14B).

Figure3.14A:-Damage Structure (03). **Figure 3.14B:-Damage Structure (04)**

Figure.3.14:-Damage Structure

Table.3.1:-Reduction of Stiffness of test model by observation of frequency

Sr. No.	Fig No	2^{nd} Fundamental Frequency.(Hz)	(%) Reduction in (K)
1	3.1	9.3	0
2	3.3	8.9	4
3	3.5	8.4	10
4	3.7	8.3	11
5	3.9	8.2	12
6	3.11	7.5	20

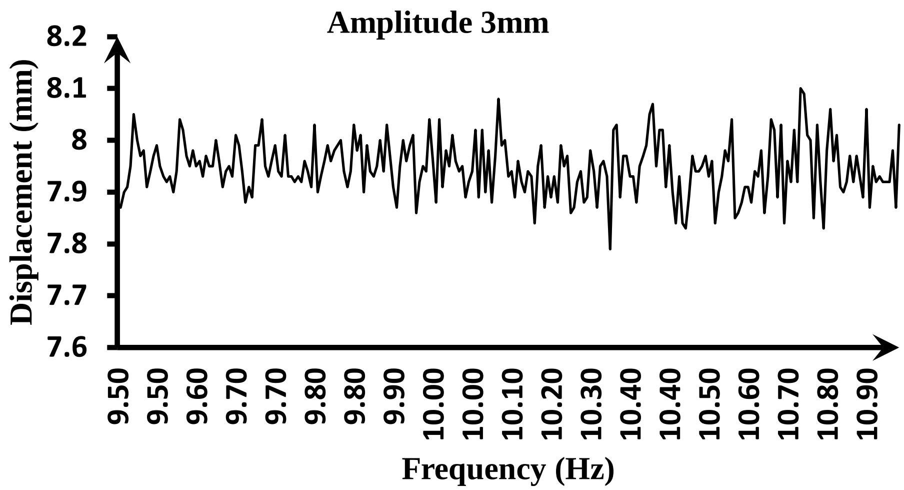

Figure 3.15:- :-Input for the proposed Structure 06.

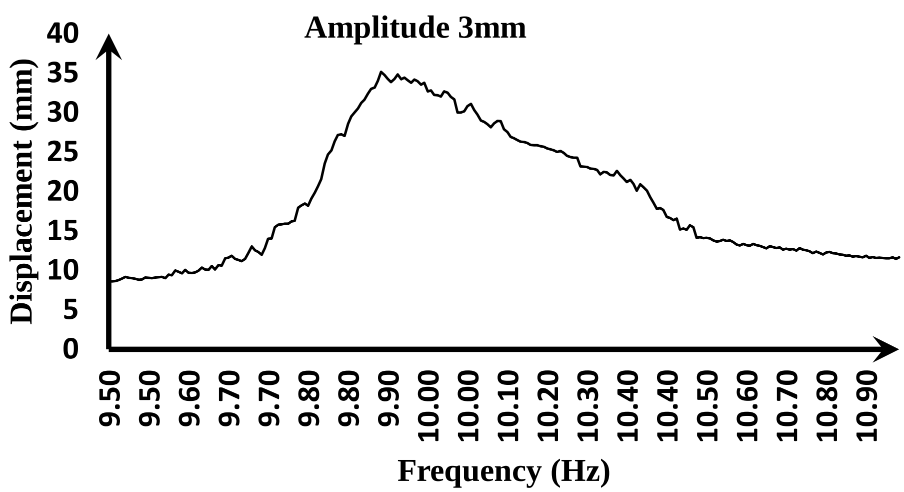

Figure.3.16:- :-Frequency-Response of the Structure 06.

3.5. Performance of Retrofitted Structure

In the selected test model defect were created at predefined locations (fig. 3.12-3.14). The defective models were retrofitted with the FRP which jacked up stiffness of the model by 33% (fig. 3.14-3.15). As a result of retrofitting the structure its 2nd fundamental frequency was shifted from 7.5 Hz to 10 Hz.

This increase in frequency observed through stake table test is indicative of increase of stiffness of the test model. This precisely is meant for system identification of the structures.

3.5. Computational Work

Further, in-order to match the experimental work an analytical work was also carried out. The computational analysis was done using SAP 2000 software platform for comparison with corresponding experiment results obtained.

The analytical model generated had same material and geometric configuration as that of experimental model. Push over analysis (methodology is mentioned in article 3.11) time history and model analysis is performed on the same computational model. Result of the computational analysis is discussed in this chapter.

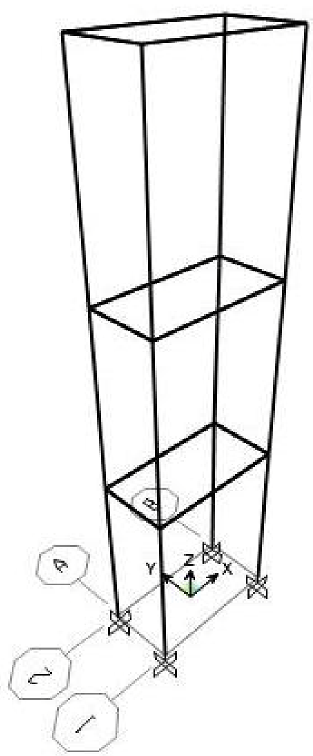

Figure.3.17:- Computational Model.

3.7. Geometric configuration of Steel frame

- 3 Storey x 1 bay x1 bay steel frame available in Dynamics laboratory, MNIT Jaipur.
- Plan dimension of the building is 0.3mx 0.15m with storey height 0.4m. Typical floor plan is

given in Fig.3.18

- Columns are of rectangular size (25mm x 3mm) directly supporting the slab.
- Slab having plan dimension 300mm x 150mmand thickness 12mm.

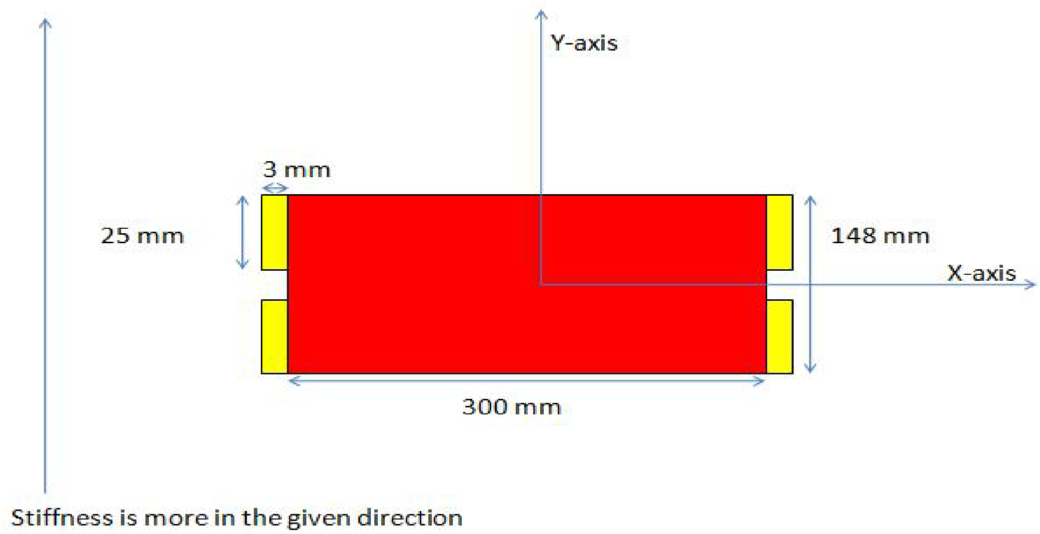

Figure.3.18:-Typical floor plan of the structural model of steel frame.

3.8. Details of the test frame

Steel frame available in Dynamics laboratory, MNIT Jaipur is taken into consideration for analysis. Natural frequency and modes shape of fixed base frame are found out by carrying model analysis using SAP 2000 software package. The result of the test is validated by experimental work with the help of Electro Mechanical shake Table Test. Fig. 3.17 represent 3D view of the steel frame modeled in SAP 2000.

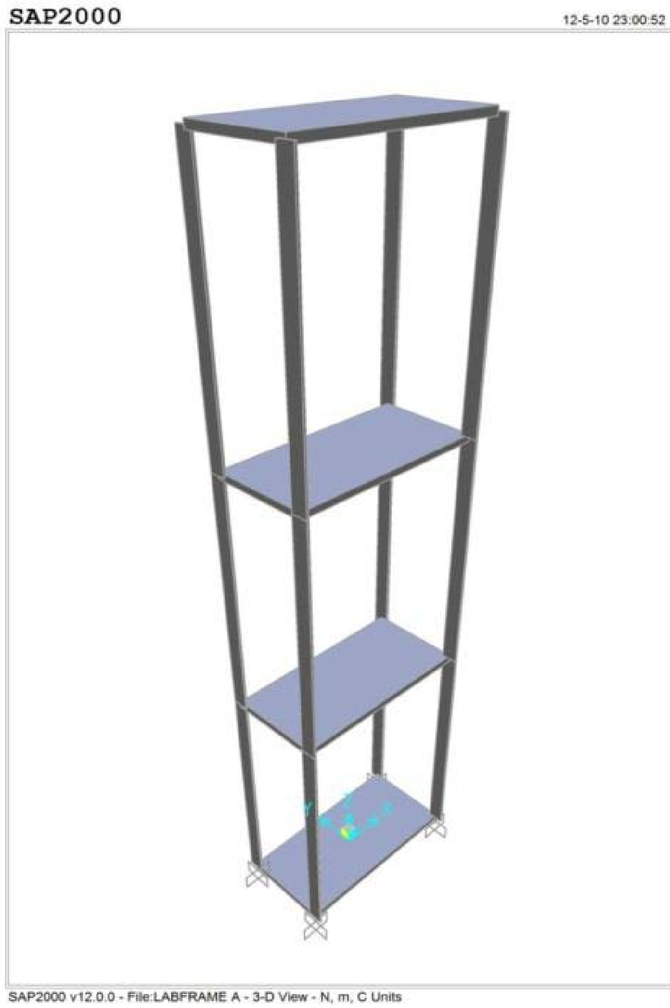

Figure.3.19:-computation model of the steel frame.

3.9. Push over Analysis

Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. Lateral load may represent the range of base shear induced by earthquake loading, and its configuration may be proportional to the distribution of mass along building height, mode shapes, or another practical means. Output generates a static-pushover curve which plots a strength-based parameter against deflection

In General Steps for Push over Analysis are:

1. The building is designed as per linear analysis, the model will initially be subjected to dead, live and response spectrum loads and after completing the design the model is unlocked.

2. The next step is assignment of hinges to the frame elements. For this first select all the beams. The hinges should be assigned at both ends at a relative distance of d/2 of both column and beam. In similar manner hinges are applied to columns as well with only a difference that P-M2-M3 hinges are assigned instead of M3 hinges for beams

NOTE-The SAP 2000 provides non-linear pre-defined non-linear hinge properties corresponding to both Caltrans hinge model and FEMA 356 hinge model. So depending upon the requirement of user the adequate auto hinge type can be used. Apart from this SAP 2000 also provides user defined hinges. The beams should be assigned M3 hinges while columns should be assigned P-M2-M3 hinges since column consists of interaction between axial load and bending moment. The transverse reinforcement confirming box should be kept active if frame is designed as SMRF (Special Moment Resisting Frame) or else it should not be active. The hinge properties are mainly dependent on member capacity; hence reinforcing ratio should be used from the current design.

3. After assigning the hinges all the members are selected and assigned for hinges overwrite command. There auto subdivide line objects at hinge box is checked; this can discredited the member and will give better results.

4. Before defining the push over load case the dead load case is set to nonlinear so that the program can use this case as the starting point for the push over.

5. Now we assign the new load case as ‘push’. The load will continue from the dead load case and it is applied as acceleration. The load is applied as displacement control and is pushed to a displacement kept equal to 2% height of the building. The analysis has also been saved in multiple states.

NOTE- It is important to note that the non-linear parameters will affect the solution control therefore the results got using different solution control parameters and hinge unloading method can deviate slightly, and hence no unique solution may be obtained for some problems.

6. Now the model is run for push over analysis. The model, live and response spectrum load cases are shut off as these were only needed for linear analysis for member sizing and only the dead and push cases are run for analysis.
7. Since the push over analysis is a nonlinear static analysis, depending upon the configuration of the system used it takes time for analysis.
8. Once the analysis is complete deformed shape for push over load case can be displayed. We can toggle through the different steps to see what hinges are forming and where they are on the force deformation curve as indicated by the color of the hinge.
9. The respective pushover curves obtained in each model and their corresponding displacements and forces are discussed in the next chapter.

A typical push over analysis was carried out on a selected virgin test model. The virgin test model is precisely non damage building model without retrofitted with FRP. For details of model refer article 3.5 and inputs given for push over analysis (Article 3.9).

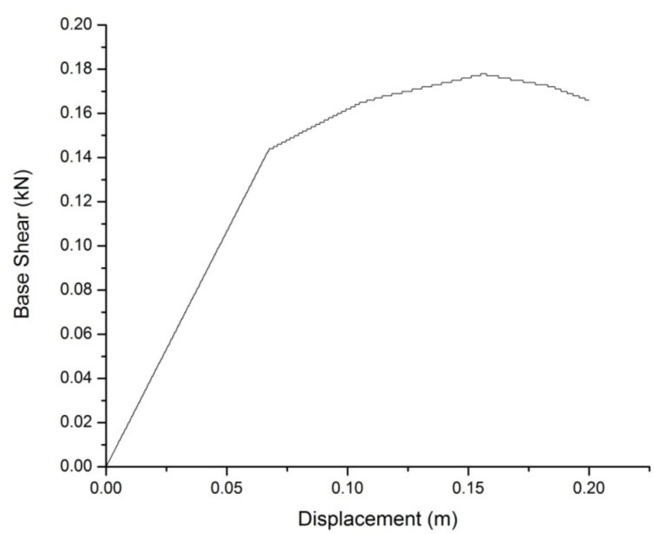

Figure.3.20:-Pushover Curve for the Selected virgin Test Model

3.10. Model Analysis

Model analysis is the study of the dynamic property of the structure under vibration excitation. Model analysis is used over all mass and stiffness of the structure to find out various frequencies at which structure resonate naturally. Different modes of the oscillating system are pattern of motion in which overall structure move sinusoid along with varying frequency and fixed base.

The model analysis is always applicable for a structure which behaves as linear one i.e precisely force deformation curve is a straight line. The modal shape is referred as deflected shape in a particular mode which has its modal frequency. Number of mode shapes depends upon number of degree of freedom associated with the structures which are paramount of interest to investigate the behavior of the structure. The modal analysis was carried in SAP 2000 software package; general formulation for modal analysis as illustrate as mentioned below:

3.11. Model Analysis

Eigen vector analysis determines undammed free vibration modes and frequency of the structure. Natural modes provide excellent insight into behavior of the structure. Free vibration of the MDOF system with damping with P (t) =0 is given as,

$$m\ddot{x} + c\dot{x} + kx = 0$$

Damping of the material is not taken into account, so resulting equation of motion is as follows,

$$m\ddot{x} + kx = 0$$

When the floor of the frame reached their extreme displacement at the same time and pass through the equilibrium position at the same time, then each characteristic deflected shape is called as natural mode of vibration of MDOF system.

During the natural mode of the vibration of the MDOF system there is a point of zero displacement that does not move at all. The point of zero displacement is called as node. as the number of modes increase, number of nodes increase accordingly.

Substituting,$q(t) = \emptyset_n(A_n cos\omega_n t + B_n sin\omega_n t)$

Where,$A_n \& B_n$ are constant

$\emptyset$: Deflected shape or mode shape

ω_n: Natural frequency of the n^{th}order

Substituting the value of $u(t)$ in above equation, we get

$$[-\omega_n^2 m\emptyset_n + k\emptyset_n]q_n(t) = 0$$

Either $q_n(t)$=0 which indicate$u(t) = 0$and there is no motion of system (called as trivial solution) solution is given as,

$$k\emptyset_n = \omega_n^2 m\emptyset_n$$

$$[k - m\omega_n^2]\emptyset_n = 0$$

This equation is called matrix Eigen value problem

It has non-trivial solution if

$$\mathrm{Det}[k - m\omega_n^2] = 0$$

The N root, of ω_n^2 determine n natural frequencies of vibration. Corresponding to the n natural frequency,$\omega_n$of the N-DOF system, there are N independent vector $\emptyset_n$ which are known as natural mode if vibration or natural mode shape of vibration.

Let the natural mode $\emptyset_n$corresponding to natural frequencyω_n has element$\emptyset_{jn}$, where (j) indicate DOF. N Eigen vector can be display in single matrix; ach column is a natural mode.

$$\emptyset = [\emptyset_{jn}] = \begin{bmatrix} \emptyset_{11} & \emptyset_{12} & \dots & \emptyset_{1n} \\ \emptyset_{21} & \emptyset_{22} & \dots & \emptyset_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \emptyset_{n1} & \emptyset_{n2} & \dots & \emptyset_{nn} \end{bmatrix}$$

Numerical Calculation of frequency by Eigen value problem:-

$$[K - \omega_n^2 M] = 0$$

Typical Experimental model

Mass of each steel plat= 4kg

Mass of column strips is not taken into consideration, Stiffness at each floor is $=\frac{48EI}{l^3}$ for each floor, where, $E = 2\times10^5$ MPa,

$I = \frac{bd^3}{12}$ mm^4,

$l = 400$ mm

Stiffness and Mass matrix for the plane frame

$$[K] = \begin{bmatrix} 10 & -5 & 0 \\ -5 & 10 & -5 \\ 0 & -5 & 10 \end{bmatrix}, [M] = \begin{bmatrix} 4 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 4 \end{bmatrix}$$

Eigen value of $[K - \omega^2 M]$,

$$[K - \omega^2 M]= \begin{bmatrix} (10-\omega^2 4) & -5 & 0 \\ -5 & (10-\omega^2 4) & -5 \\ 0 & -5 & (10-\omega^2 4) \end{bmatrix}$$

Further computation al work is done in Matlab

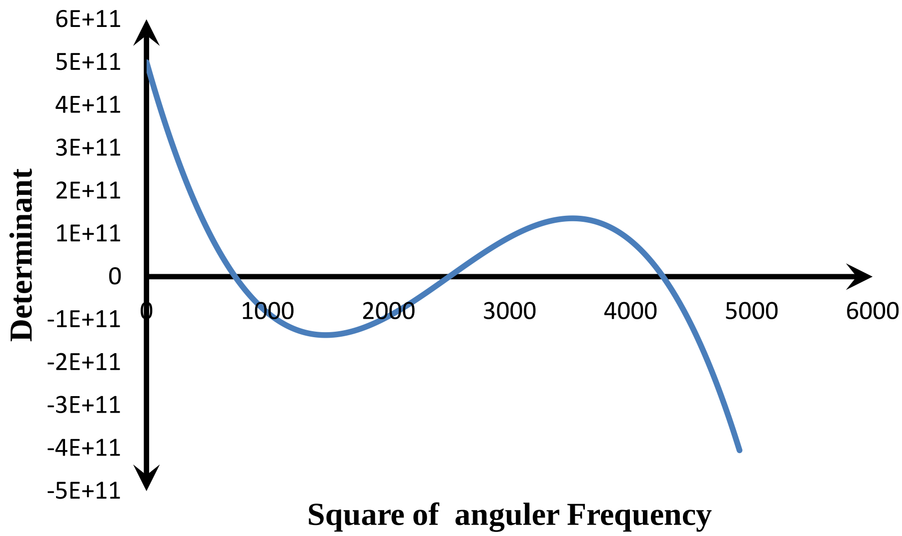

Figure.3.21:-Frequency from Eigen value Solution

3.12. Model participation factor

The dynamic analysis for an MDOF system subjected to force $\mathbf{p}(t)$ is specialized in the section for the excitation $\mathbf{p}(t)$=$\mathbf{sp}(t)$. The generalized force $\mathbf{p}(t)$= $T_n M_n \mathbf{p}(t)$ for the nth mode is substitute in the following equation to obtained model equation,

$$q_n^{\ddot{}} + 2\varepsilon_n \omega_n q_n + \dot{\omega}_n^2 q_n = \frac{p_n(t)}{M_n}$$

And final equation will be,

$$q_n^{\ddot{}} + 2\varepsilon_n \omega_n q_n + \dot{\omega}_n^2 q_n = T_n p(t)$$

The factor T_n that implies that the force $p(t)$ is sometime called model participation factor implying that it is a measure of the degree to which the nth mode participate in the response, this is not the usual terminology, however T_n is not independent of how the mode is normalized, or measure of the contribution of mode to response quantity. Both the drawback are overcome by model contribution factor.

$$\frac{\sum_{i=1}^{n} w_i \emptyset_{ik}}{\sum_{i=1}^{n} w_i (\emptyset_{ik})^2}$$

or particular special distribution of forces, the model participation factor for higher mode is larger for Base shear then roof displacement, suggesting that higher mode contribute more to base shear then to roof displacement.

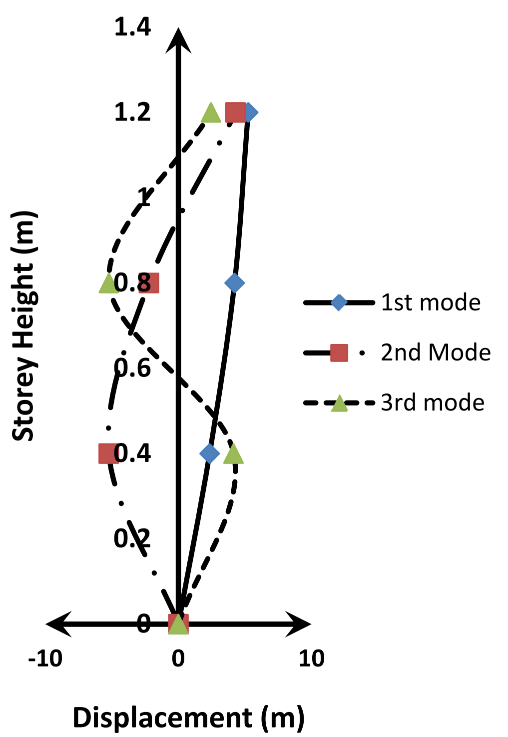

Figure.3.22:-Displacement Profile.

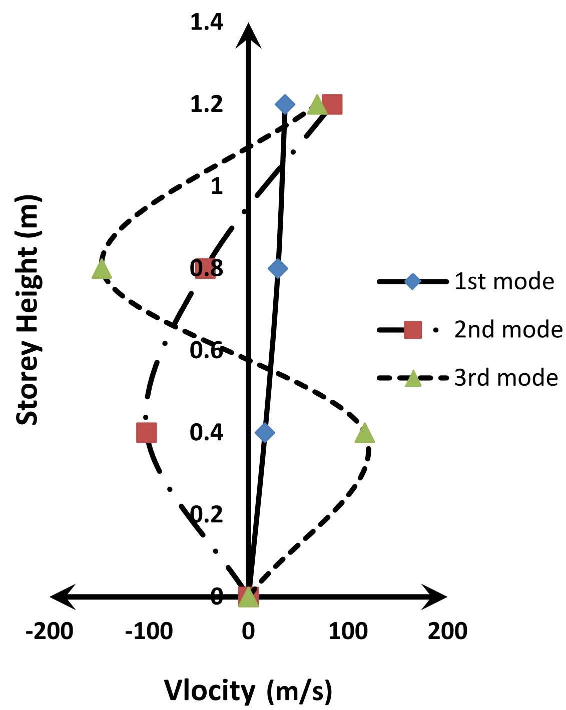

Figure.3.23:-Velocity profile.

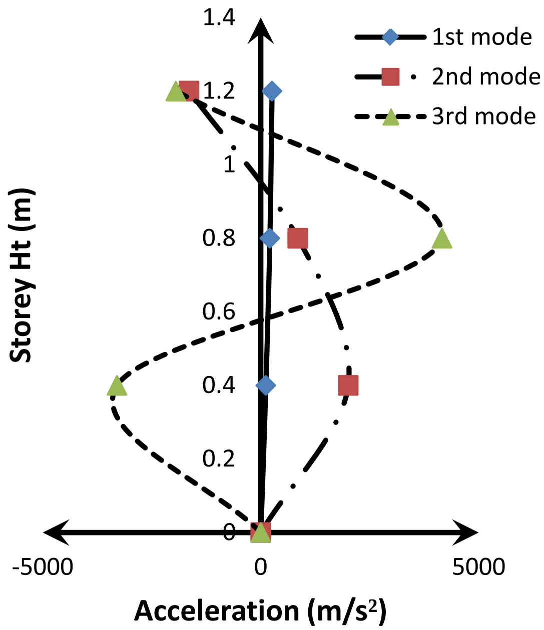

Figure.3.24:-Acceleration profile.

Following results are obtained for modal analysis of the selected structural building model:

Table 3.02:-Modal period, frequency and Modal participation Ratio.

Mode	T	F	UX (%)	UY (%)
1	0.3125	3.2	90	0
2	0.109	9.1	70	0
3	0.087	11.5	10	0

Table.3.3:-Inter storey Drift of the Steel Framed Structure.

Storey No.	Floor No.	Storey Ht	Displacement (mm)	Inter Storey Displacement (mm)	Inter Storey Drift (%)
1	0	0.4	0	17	51.51
	1		17		
2	0	0.4	17	9	27.27
	1		26		
3	0	0.4	26	8	24.24
	1		33		

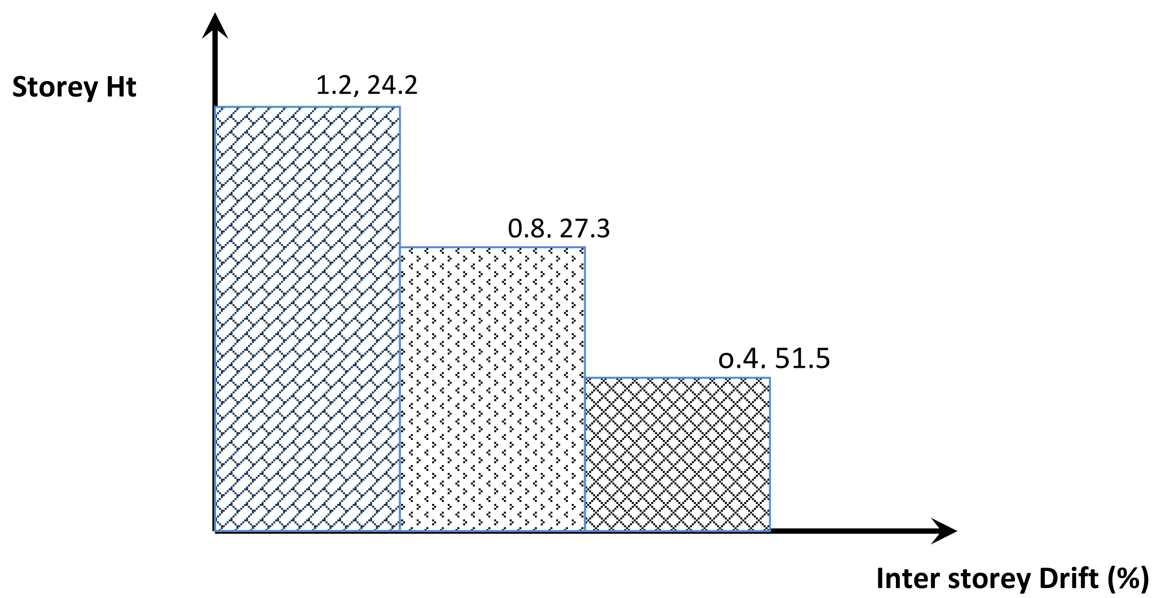

Figure.3.25:-Distribution of Inter Storey Drift.

In order to compute the contribution of number of modes participating in the response were calculated using modal participation factor. The SAP 2000 platform was used to calculate the modal participation factor analytically. The modal participation factor for first two modes for scaled model as mentioned in Table 3.2, model Modal participation mass ratio were found to be are 90 & 70 respectively for first 2 modes along x-direction, hence frequency corresponding to that modes are vital for the structure. shows mode shape corresponding to the frequency.

3.13. Time history Analysis of the frame

The response (i.e. Displacement, Velocity and Acceleration) of the steel frame subjected to selected Earthquake Ground motion was found out by nonlinear time history analysis using SAP 2000 software package. The selected ground motion is having constant amplitude and frequency 9 Hz which is shown in Fig 3.19.

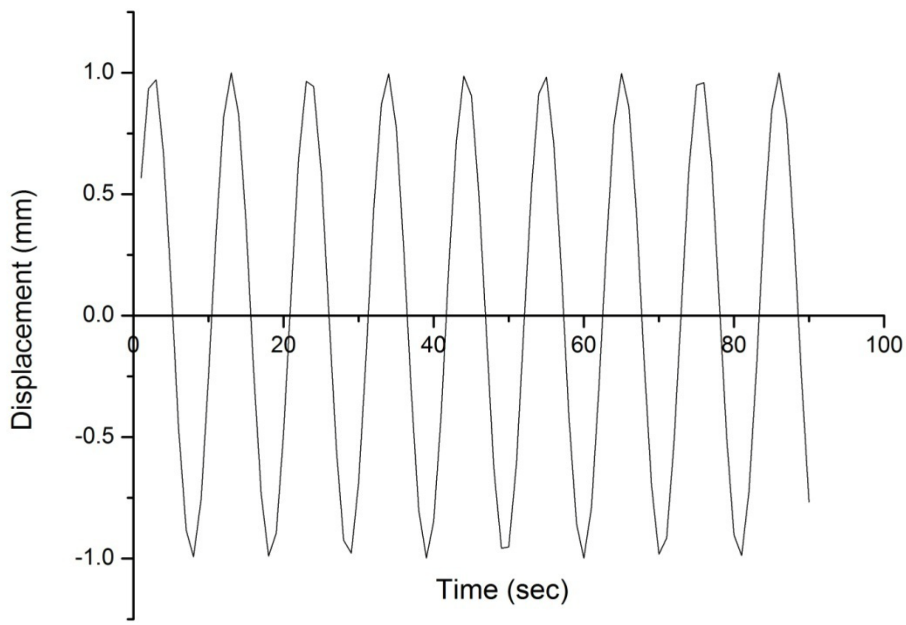

Figure.3.26:-Input to Time History SAP model.

Non-Linear Dynamic Analysis using SAP 2000

In order to perform the time history analysis the step 1 to step 3 should be repeated as discussed above.

Step-1

Define Time History

Go to Define >Functions>Time History the following form will appear. In this form choose function type to add from file.

Go to Add New Function and add the time history file from system in text format and convert it to user defined than time history file form will appear.

Step-2

Define Time History Load Case

Go to Define >Load Case>Add New Load Case >TH consisting of time history load case and the time history load case form will appear.

Select Load Case Type> Time History, Analysis Type> Nonlinear, Time History Type> Direct Integration and Geometric Non-linearity Parameters as P-Delta.

This load case should be started from a previous load case Gravity since gravity load will always be acting on the structure.

Select Loads Applied >Acceleration in the considered direction (i.e. either U1 or U2 degree of freedom) of the analysis. The scale factor for this load case should be kept equal to 1or 9.81 depending upon the input time history file whether provided in units of g or m/s2, respectively.

In Time History Load Case for time step data the Number of Output Time Steps and Output Time Step Size should be same as provided in Input time history file. The number of output time steps may be less or more than the steps in time history input file but lesser number of saved output steps may reduce the accuracy while the more number of output steps may increase the space requirements.

In Time History Load Case for other parameters, to modify the damping which needs to be considered click Modify and mass and stiffness proportional damping form will appear. It is important to note that when damping is specified it is specified by period and period corresponding to 1st and 3rd mode of vibration in the considered direction of analysis should be used. The damping used should be equal to 2%, 5% and 10% for Steel, RC and Masonry buildings, respectively.

In Time History load case for other parameters, to modify the time integration technique to be considered click Modify and time integration parameter form will appear as. The Hilber-Hughes-Taylor method of time integration should be used with alpha as zero and if convergence does not occur than alpha equal to minus 0.33 should be used.

Time Integration Parameters Form

In Time History Load Case for other parameters, the non-linear parameters should be set to default.

After defining Time History Load Case, Run the analysis.

NOTE- The non-linear time history analysis is a time consuming analysis and depending upon the size of the problem it takes large amount of time as well as space for completion of the analysis.

Step-3

Graphically Review the Time History Analysis Results

The deformed shape and hinge pattern at any instant can be viewed in similar manner as viewed in case of pushover analysis.

The peak displacement during time history analysis can be viewed through plot function. Go to > Display > Show Plot Functions and define the plot function i.e. joint whose displacement is required.

3.14. Response of model

3.14.1. Displacement

The response of the frame subjected to time history analysis record in each node in X direction. No displacement is recorded at the base since the base is in the fixed condition. Story displacement and inter story displacement are calculated and plotted graphically as shown in Fig.3.22 & 3.25.

Inter storey drift is more in the first storey which goes on decreasing in successive upper storey (Fig.3.25). The displacement of the frame is only in X direction there is no displacement in Y direction, as excitation is only given in X direction.

3.14.2Velocity

The velocity of the frame subjected to time history analysis record in each node in X direction. No velocity is recorded at the base since the base is in the fixed condition. Velocity envelope/Profile graph Fig. 3.23 is plotted for the frame along X direction.

Slope of the story velocity graph is goes on steeper for the successive upper storey as compare to lower storey, which indicate storey velocity is more in lower storey and it goes on decreasing in the successive upper storey (Fig.3.23).

3.14.3. Acceleration

The Acceleration of the frame subjected to time history analysis record in each node in X direction. No Acceleration recorded at the base since the base is in the fixed condition. Acceleration envelope/Profile graph Fig.3.24is plotted for the frame along X direction.

Slope of the story Acceleration graph is goes on steeper for the successive upper storey as compare to lower storey, which indicate storey Acceleration is more in lower storey and it goes on decreasing in the successive upper storey (Fig.3.24).

3.15. Result

Model Analysis of the fixed base steel frame is done to determine dynamic property of the structure like natural frequency, modes shape followed by its time history analysis shown in Fig.21 to determine the response of the structure.

It was concluded that the response (displacement, inter story drift, velocity, acceleration) of the structure is more in lower storey as compared to the upper storey.

CHAPTER - 4

Summary and Conclusion

4.1 Introduction

The performance and virgin and retrofitted structure is checked using electro mechanical uni directional shake table. FRP laminate and FRP wrap is used as retrofitted material and Experimental model is compare with mathematical and computational test model. It is found that FRP laminate and FRP wrap is found to be very convincing for retrofitting of damaged structure. It is found that it can regain its strength up to 100% and more.

4.2 Conclusions

The experimental model is tested for same excitation before and after retrofitting. Stiffness of the original structure is reduced up to 80% (Table 3.01). Damage in the structure is identified by failure of the column strip (Fig 3.12-3.14).in second phase of Experiment, damaged model is retrofitted with FRP laminate and FRP wrap with structural adhesive (Fig 1.1-1.2). Retrofitted model is again excited for same input which was used for original structure. Stiffness of the retrofitted structure is increased by 33% when second fundamental frequency of the retrofitted model is shift from 7.5 Hz to 10 Hz.

Experimental result is compare with computational model having same material and geometric configuration using SAP 2000 software platform. Pushover, time history and model analysis is performed on the same model. First two fundamental frequency of the model is approximately same as experimental result.

Experimental Result

The stiffness of retrofitted structure is increase by 33% (Refer Fig 3.15-3.16) as 2nd fundamental frequency of structure is shifted from 7.5 Hz to 10 Hz. It is concluded that seismic retrofitting technique is quiet efficient in increasing the Stiffness of structure up to 33%.

Model Analysis

From the modal analysis study natural frequency and the mode shape of the framed structure is obtained. The determination of mode shape is essential to analyze the behavior of the structure under applied dynamic loading. From the modal analysis of the steel frame natural frequency, mode shapes and corresponding modal participating mass ratios are obtained. The mode shapes for which, modal partiapting mass ratios are maximum taken into consideration. SAP 2000 is very effective tool to validate the results obtained experimentally. From the modal analysis first mode period of fixed base building is found to be 0.3125 sec which is approximately same as result obtained from Experiment.

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