INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

A PATH FOR HORIZING YOUR INNOVATIVE WORK

SPECIAL ISSUE FOR
NATIONAL LEVEL CONFERENCE
"SUSTAINABLE TECHNOLOGIES IN CIVIL ENGINEERING"

SEISMIC POUNDING RESISTANT DESIGN OF RC BUILDINGS

MISS MONALI G. INGLE

Asst Proff, Navasahyadri Group Of Institutes, Pune.

Abstract — Pounding between closely spaced buildings structures can be a serious hazard in seismically active areas. Pounding of adjacent buildings could have worse damage as adjacent buildings with different dynamic characteristics which vibrate out of phase and there is insufficient separation distance or energy dissipation system to accommodate the relative motions of adjacent buildings. Past seismic codes did not give definite guidelines to preclude pounding, because of this and due to economic considerations including maximum land usage requirements, especially in the high density populated areas of cities, there are many buildings worldwide which are already built in contact or extremely close to another that could suffer pounding damage in future earthquakes. A large separation is controversial from both technical (difficulty in using expansion joint) and economical loss of land usage) views. The highly congested building system in many metropolitan cities constitutes a major concern for seismic pounding damage. For these reasons, it has been widely accepted that pounding is an undesirable phenomenon that should be prevented or mitigated zones in connection with the corresponding design ground acceleration values will lead in many cases to earthquake actions which are remarkably higher than defined by the design codes used up to now.

Keywords- Seismic pounding; Adjacent building; Energy dissipation; Seismic design

Corresponding Author: MISS. MONALI G. INGLE

Co Author:

Access Online On:

www.ijpret.com

How to Cite This Article:

PAPER-QR CODE

Monali G. Ingle, IJPRET, 2015; Volume 3 (8): 134-148

134

INTRODUCTION

The highly congested building system in many metropolitan cities constitutes a major concern for seismic pounding damage. For these reasons, it has been widely accepted that pounding is an undesirable phenomenon that should be prevented or mitigated zones in connection with the corresponding design ground acceleration values will lead in many cases to earthquake actions which are remarkably higher than defined by the design codes used up to now. The most simplest and effective way for pounding mitigation and reducing damage due to pounding is to provide enough separation but it is sometimes difficult to be implemented due to detailing problem and high cost of land. An alternative to the seismic separation gap provision in the structure design is to minimize the effect of pounding through decreasing lateral motion. Which can be achieved by joining adjacent structures at critical locations so that their motion could be in-phase with one another or by increasing the pounding buildings damping capacity by means of passive structural control of energy

I.1 Seismic Pounding Effect between Buildings

Pounding is one of the main causes of severe building damages in earthquake. The non-structural damage involves pounding or movement across separation joints between adjacent structures. Seismic pounding between two adjacent buildings occur:

· During an earthquake

· Different dynamic characteristics

· Adjacent buildings vibrate out of phase

· At-rest separation is insufficient
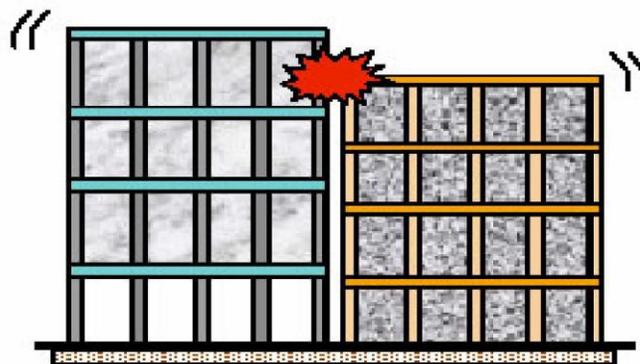
A seismic gap is a separation joint provided to accommodate relative lateral movement during an earthquake. In order to provide functional continuity between separate wings, building

utilities must often extend across these building separations, and architectural finishes must be detailed to terminate on either side. The separation joint may be only an inch or two in older constructions or as much as a foot in some newer buildings, depending on the expected horizontal movement, or seismic drift.This experiment involved testing of a steel building scheduled for demolition in Northbrook, Illinois. The demolition team tore out four selected columns from the building to simulate the sudden column removal that leads to progressive collapse. The structure was instrumented with strain gauges that recorded the change in strain in various structural members while the columns were removed. The author instrumented the beams and columns in the building, managed the testing, and analyzed the recorded data.

I.2 Required Seismic Separation Distance To Avoid Pounding

The Bureau Of Indian Standards clearly gives in its code IS 4326 that a Separation Section is to be provided between buildings. Separation Section is defined as `A gap of specified width between adjacent buildings or parts of the same building, either left uncovered or covered suitably to permit movement in order to avoid hammering due to earthquake `.Further it states that ` For buildings of height greater than 40 meters, it will be desirable to carry out model or dynamic analysis of the structures in order to compute the drift at each storey, and the gap width between the adjoining structures shall not be less than the sum of their dynamic deflections at any level Structures having different total heights or storey heights and different dynamic characteristics. This is to avoid collision during an earthquake. Minimum width of separation gaps as mentioned in 5.1.1 of IS 1893 : 1984, shall be as specified in Table 1.1 The design seismic coefficient to be used shall be in accordance with IS 1893 : 1984

SL No	Type of Constructions	Gap Width/Storey, n mm for Design Seismic Coefficient αh =0.12
i)	Box system or frames with shear walls	15.0
ii)	Moment resistant reinforced concrete frame	20.0
iii)	Moment resistant steel frame	30.0

NOTE — Minimum total gap shall be 25 mm. For any other value of αh the gap width shall be determined proportionately.

According to the 2000 edition of the International building code and in many seismic design codes and regulations worldwide, minimum separation distances (Lopez Garcia 2004) are given by Absolute sum (ABS) or Square Root of Sum of Squares (SRSS) as follow:

$S = U_a + U_b$ $\qquad$ ABS (1)

$S = \sqrt{(U_a^2 + U_b^2)}$ $\qquad$ SRSS (2)

where S = separation distance and U_a, U_b = peak displacement response of adjacent structures A and B, respectively.

I.3 Methods of Seismic Analysis of a Structure

Various methods of differing complexity have been developed for the seismic analysis of structures. The three main techniques currently used for this analysis are:

.1. Dynamic analysis.

· Linear Dynamic Analysis.

· Non-Linear Dynamic Analysis.

2. Push over analysis.

1.3.1 Dynamic Analysis

All real physical structures, when subjected to loads or displacements, behave dynamically. The additional inertia force from, Newton's second law, are equal to the mass times the acceleration. If the loads or displacements are applied very

slowly then the inertia forces can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis. The force equilibrium of a multi-degree-of-freedom lumped mass system as a function of time can be expressed by the following relationship:

$$F(t)_i + F(t)_d + F(t)_s = F(t)$$

in which the force vectors at time t are

$F(t)_i$ - is a vector of inertia forces acting on the node masses

$F(t)_d$ - is a vector of viscous damping, or energy dissipation, forces

F (t)$_s$ - is a vector of internal forces carried by the structure

F (t) - is a vector of externally applied loads

For many structural systems, the approximation of linear structural behavior is made in order to convert the physical equilibrium statement, Equation (1), to the following set of second-order, linear, differential equations:

$$M \ddot{u}(t)_a + C \dot{u}(t)_a + K u(t)_a = F(t)$$

in which M is the mass matrix (lumped or consistent C), is a viscous damping matrix (which is normally selected to approximate energy dissipation in the real structure) and K is the static stiffness matrix for the system of structural elements.

The time-dependent vectors $\dot{u}(t)_a$, $\dot{u}(t)_a$ and $\ddot{u}(t)a$ are the absolute node displacements, velocities and accelerations, respectively.

1.3.1.1 Response Spectrum Analysis

The response spectrum technique is really a simplified special case of modal analysis. The modes of vibration are determined in period and shape in the usual way and the maximum response magnitudes corresponding to each mode are found by reference to a response spectrum. The response spectrum method has the great virtues of speed and cheapness. The basic mode superposition method, which is restricted to linearly elastic analysis, produces the complete time history response of joint displacements and member forces due to a specific ground motion loading. There are two major disadvantages of using this approach. First, the method produces a large amount of output information that can require an enormous amount of computational effort to conduct all possible design checks as a function of time. Second, the analysis must be repeated for several different earthquake motions in order to assure that all the significant modes are excited, since a response spectrum for one earthquake, in a specified direction, is not a smooth function.

I.3.1.2 Nonlinear Dynamic Analysis

Nonlinear Dynamic analysis can be done by direct integration of the equations of motion by step by step procedures. Direct integration provides the most powerful and informative analysis for any given earthquake motion. A time dependent forcing function (earthquake accelerogram) is applied and the corresponding response–history of the structure during the earthquake is computed. That is, the moment and force diagrams at each of a series of

138

Organized by C.O.E.T, Akola & IWWA, Amravati Center.   Available Online at www.ijpret.com

prescribed intervals throughout the applied motion can be found. Computer programs have been written for both linear elastic and non-linear inelastic material behavior using step-by-step integration procedures. One such program is SAP2000 in which three–dimensional non-linear analyses can be carried out taking as input the three orthogonal accelerogram components from a given earthquake, and applying them simultaneously to the structure.

I.3.2 Push over Analysis

The non-linear static procedure or simply push over analysis is a simple option for estimating the strength capacity in the post-elastic range. This procedure involves applying a predefined lateral load pattern which is distributed along the building height. The lateral forces are then monotonically increased in constant proportion with a displacement control node of the building until a certain level of deformation is reached. The applied base shear and the associated lateral displacement at each load increment are plotted. Based on the capacity curve, a target displacement which is an estimate of the displacement that the design earthquake will produce on the building is determined. The extent of damage experienced by the building at this target displacement is consideredre presentative of the damage experienced by the building when subjected to design level ground shaking .The most frequently used terms in pushover analysis as given in ATC-40 are:

Capacity -curve

It is the plot of the lateral force V on a structure, against the lateral deflection d, of the roof of the structure. This is often referred to as the 'push over' curve. Performance point and location of hinges in various stages can be obtained from pushover curves as shown in the fig. The range AB is elastic range, B to IO is the range of immediate occupancy IO to LS is the range of life safety and LS to CP is the range of collapse prevention.
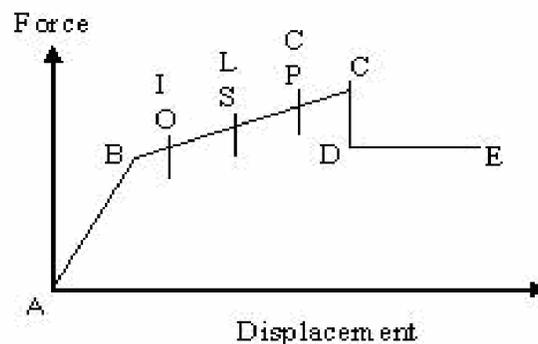

Fig 1.3 Different stages of plastic hinge

139

Organized by C.O.E.T, Akola & IWWA, Amravati Center.   Available Online at www.ijpret.com

Capacity-spectrum

It is the capacity curve transformed from shear force vs. roof displacement (V vs. d) coordinates into spectral acceleration vs. spectral displacement (S_a vs. S_d) coordinates.

Demand

It is a representation of the earthquake ground motion or shaking that the building is subjected to. In nonlinear static analysis procedures, demand is represented by an estimation of the displacements or deformations that the structure is expected to undergo. This is in contrast to conventional, linear elastic analysis procedures in which demand is represented by prescribed lateral forces applied to the structure.

Demand -spectrum

It is the reduced response spectrum used to represent the earthquake ground motion in the capacity spectrum method.

Displacement-based analysis

It refers to analysis procedures, such as the non linear static analysis procedures, whose basis lies in estimating the realistic, and generally inelastic, lateral displacements or deformations expected due to actual earthquake ground motion. Component forces are then determined based on the deformations.

Elastic response spectrum

It is the 5% damped response spectrum for the (each) seismic hazard level of interest, representing the maximum response of the structure, in terms of spectral acceleration Sa, at any time during an earthquake as a function of period of vibration T.

Performance level

A limiting damage state or condition described by the physical damage within the building, the threat to life safety of the building's occupants due to the damage, and

the post earthquake serviceability of the building. A building performance level is that combination of a structural performance level and a nonstructural performance level.

140

Organized by C.O.E.T, Akola & IWWA, Amravati Center.   Available Online at www.ijpret.com

Performance point

The intersection of the capacity spectrum with the appropriatedemand spectrum in the capacity spectrum method (the displacement at the performance at the performance point is equivalent to the target displacement in the coefficient method). To have desired performance, every structure has to be designed for this level of forces. Desired performance with different damping ratios have been shown below: minimize dust emissions. Burning of waste shall not be allowed.
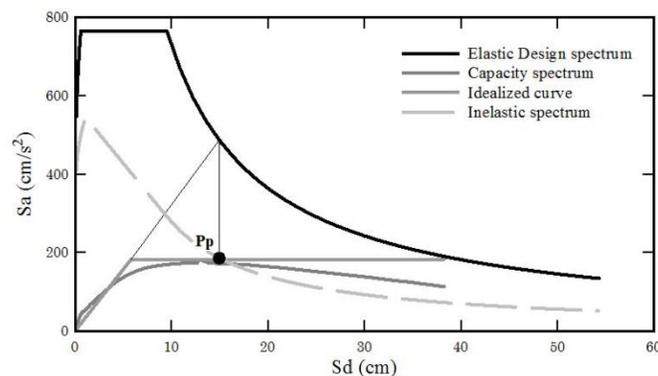
Diesel Capacity spectrum

Fig 1.4: Determination of performance point

Yield (effective yield) point

 The point along the capacity spectrum where the ultimate   capacity is reached and the initial linear elastic force deformation relationship ends and effective stiffness begins

 sto decrease.

Building Performance levels

A performance level describes a limiting damage condition which may be considered satisfactory for a given building and a given ground motion. The limiting condition is described by the physical damage within the building, the threat to life safety of the building's occupants created by the damage, and the post earthquake serviceability of the building.

141

Organized by C.O.E.T, Akola & IWWA, Amravati Center.   Available Online at www.ijpret.com

II STRUCTURAL MODELING AND ANALYSIS

In order to evaluate the Seismic gap between buildings with rigid floor diaphragms using static and dynamic a sample building was adopted. The finite element analysis software SAP2000 is utilized to create 3D model and run all analyses. The software is able to predict the geometric nonlinear behavior of space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. Three cases are considerd to determine the pounding phenomenon of the building .Case I is having different heights of building consisting of 4 storey building is adjacent to the 8 storey building. And case II having same height of buildings consisting of 8 storey building next to 8 storey building. Case III is having the same buildings as Case I but with the bracings provided in the buildings. And to study the nonlinear analysis the nonlinear gap elements are joined in between two buildings in terms of "Link".

Defining the material properties, structural components and modeling the structure:

Beam, column and slab specifications are as follows:

Column 500mm x 500mm

Beam 350mm x 250mm

Slab thickness 125mm

.Reinforcement

Columns 8-25 mm bars

Beams 4-20 mm bars at both top and bottom

The required material properties like mass, weight density, modulus of elasticity, shear modulus and design values of the material used can be modified as per requirements or default values can be accepted. Beams and column members have been defined as 'frame elements'
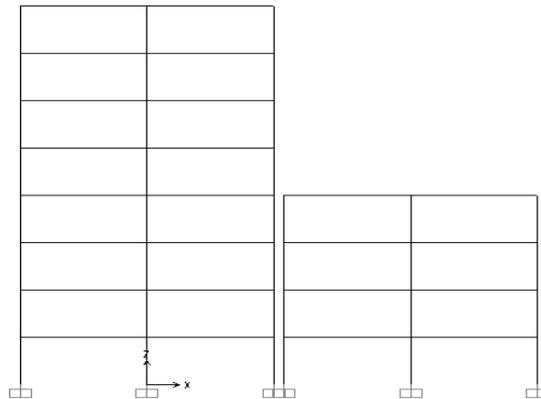
With the appropriate dimensions and reinforcement. Soil structure interaction has not been considered and the columns have been restrained in all six degrees of freedom at the base. Slabs are defined as area elements having the properties of shell elements with the required thickness. Slabs have been modeled as rigid diaphragms.

Assigning loads.

After having modeled the structural components, all possible load cases are assigned. These are as follows:

Gravity loads

Gravity loads on the structure include the self weight of beams, columns, slabs, walls and other permanent members. The self weight of beams and columns (frame members) and slabs (area sections) is automatically considered by the program itself. The wall loads have been calculated and assigned as uniformly distributed loads on the beams.

Wall load = unit weight of brickwork x thickness of wall x

          height of wall.

Unit weight of brickwork = 20KN/m3

T h ickness of wall = 0.125m

Wall load on roof level =20 x 0.125 x 1=2.50KN/m (parapet

                    wall height = 1m)

Wall load on all other levels = 20 x 0.125 x 3 = 7.50KN/m

(wall height = 3m)

Live loads have been assigned as uniform area loads on the slab elements as per IS 1893 (Part 1) 2002

Live load on roof 2 KN/m2

Live load on all other floors 3.0 KN/m2

As per Table 8, **Percentage of Imposed load to be considered in Seismic weight calculation**, IS 1893 (Part 1) 2002, since the live load class is up to 3 KN/m2 , 25% of the imposed load has been considered. .Quake loads have been defined considering the response spectra for medium soil as per IS 1893 (Part 1) 2002.

Defining load combinations:

According to IS 1893 (Part 1) 2002 for the limit state design of reinforced and prestressed concrete structures, the following load combinations have been defined

1.5(DL+LL) DL- Dead Load

1.2(DL+LL+EL) LL- Live load

1.2(DL+LL-EL) EL- Earthquake load.

1.5(DL+EL)

1.5(DL-EL)

0.9DL+1.5EL

0.9DL-1.5EL

Earthquake lateral loads

The design lateral loads at different floor levels have been calculated corresponding to fundamental time period and are applied to the model. The method of application of this lateral load varies for rigid floor and flexible floor diaphragms. In rigid floor idealization the lateral load at different floor levels are applied at centre of rigidity of that corresponding floor in the direction of push in order to neglect the effect of torsion.
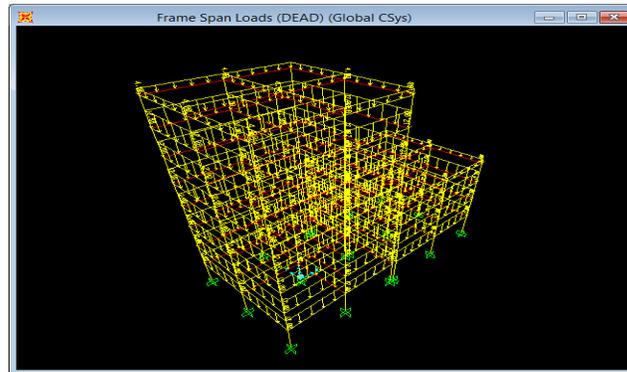
144

Organized by C.O.E.T, Akola & IWWA, Amravati Center.   Available Online at www.ijpret.com

Fig 2.1 – showing span loads for Case- I Buildings

Analysis of the structure

The analyses carried out are as follows:

- Lateral force Method

· Response Spectrum Analysis

· Time History Analysis.

III RESULTS AND DISCUSSION

Results from lateral force method and Response Spectrum analysis are observed for the natural frequencies and modal mass participation ratios and Displacements of the joints to determine the seismic pounding gap between adjacent structures of two models. The displacements for a particular joint at the top floor for two models have been tabulated as below:

Analysis of Eight storey buildings (G+7)

Storey Level	Displacements in m		
	EQ X	EQ Y	RS
GF	0.002712	0.000235	0.003839
1ST	0.007205	0.000601	0.009959
2ND	0.011954	0.000978	0.016068
3RD	0.016569	0.001339	0.021618
4TH	0.020823	0.001668	0.026396
5TH	0.024484	0.001947	0.030257
6TH	0.0273	0.002157	0.033067
7TH	0.029084	0.00228	0.034776

Table-3.1- Displacements of taller building in x & y- direction Analysis of Four storey buildings (G+3)

Storey Level	Displacements in m		
	EQ X	EQ Y	RS
GF	0.000429	7.04E-17	0.003663
1ST	0.001098	1.753E-16	0.009066
2ND	0.001701	2.623E-16	0.013506
3RD	0.002102	3.154E-16	0.01619

Table 3.2- Displacements of shorter building in x & y- direction

	EQ X		EQY		RS	
Buildings	x	y	x	y	x	y
Case – I						
Taller	0.0353	0.0031	0.0023	0.045	0.0348	0.0141
Shorter	0.0023	0.0002	0.0002	0.0032	0.0162	0.0071
Case – II						
Building 1	0.0276	0.0024	0.0018	0.0349	0.0356	0.0143
Building 2	0.0276	0.0024	0.0018	0.0349	0.0356	0.0143
Case – III						
Taller	0.0165	0.0007	0.0007	0.0186	0.0186	0.0059
Shorter	0.001	5.25*10-5	4.9*10-5	0.0011	0.0186	0.0059

Above table shows the displacements at the top floor of the three cases. In Case I the displacements for the taller building are larger as comparative to the shorter building. In the Case II the values of the displacements are quite similar just because the buildings are at the same height level. In Case III buildings where the same modesls as that of Case I are analyzed, we can see that the displacements for the buildings are less as comparative to the Case –I buildings just because of the diagonal members provided in the form of a strut
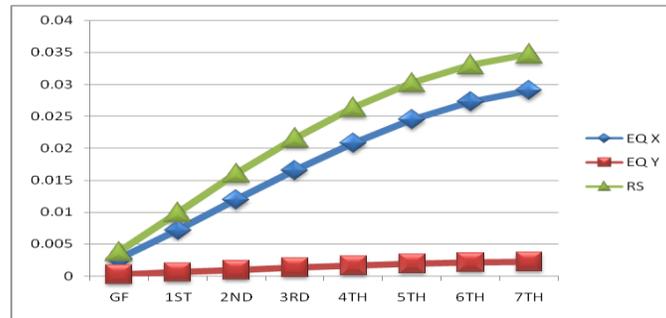
146

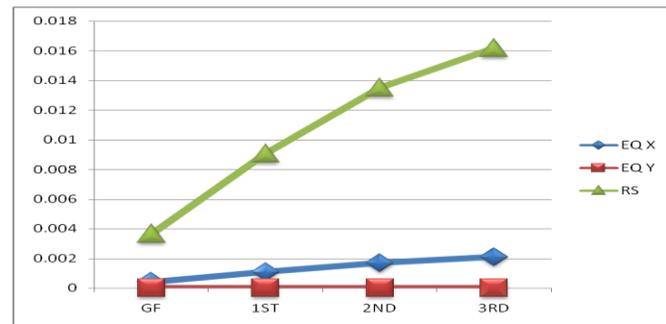**Fig 3.1– Displacements of taller building in x& y- direction**

Fig 3.2– Displacements of shorter building in x & y direction
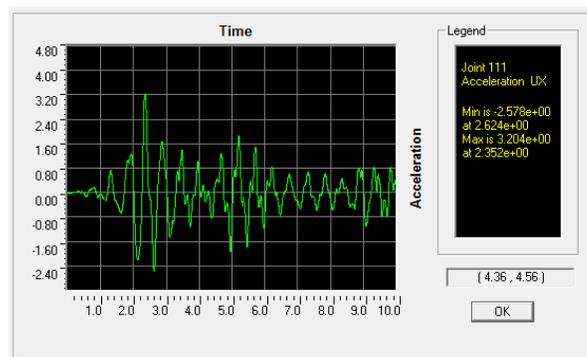

Fig3.3 - Showing the minimum & maximum acceleration at the 4th floor of the taller building

IV CONCLUSION

The purpose of this study has been to analyze seismic pounding effects between buildings and to observe the structural behavior in the post elastic range. For this, SAP2000, a linear and non-linear static and dynamic analysis and design program for three dimensional structures has

147

been used. Response Spectrum analysis gives result that the two models have displacement within the permissible limit for seismic pounding between adjacent buildings with the seismic gap provided as per IS 4326-2005. It was found that minimum seismic gap can be provided 0.012m per storey between two four storey building and two eight storey building for no seismic pounding between buildings.

V REFERENCES

1. IS 1893 (Part 1) : 2002 Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1 General Provisions and Building

2. IS 875 (Part 2): 1987 Indian Standard Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures, Part 2 Imposed Loads.

3. Anil K. Chopra [2003]"Dynamics of Structures, Theory and Applications to Earthquake Engineering" (Prentice Hall of India Private Limited.

4. Shehata E.Abdel Raheem" Seismic Pounding between Adjacent Building Structures"

5. SAP 2000 Nonlinear Version 11 Software Package.

148

Organized by C.O.E.T, Akola & IWWA, Amravati Center.   Available Online at www.ijpret.com