International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 04 | Apr 2021 www.irjet.net p-ISSN: 2395-0072

Pounding Analysis of Non-structure Element in Adjacent Building

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Abstract - Pounding is very destructive phenomena. Due to which, during earthquake, strong ground motion, the acceleration at pounding level considerably increases and creates additional pounding force which causes major structural collapse or failure of structure.

This paper deals with the study of effects on non-structural element of building due to pounding during an earthquake. Response spectra method and time history analysis has been done for evaluating the pounding effects on different model of building when subjected to different ground acceleration. The result of study has shown the effect of earthquake on adjacent building in pounding and no pounding case for different floor level of non-structural element.

Keywords: SAP 2000, earthquake, pounding, non-structural element and Peak ground acceleration.

1. INTRODUCTION

Experiences of past and current earthquake-collapse have well established pounding as one of the main causes of structural damages in buildings, constructed very close to each other or without any gap at all. Pounding, which is a collision between adjacent buildings during an earthquake, commonly occurs due to their different dynamic characteristics, adjacent buildings vibrate out of phase and there is insufficient seismic gap between them. This situation can easily be seen in metropolitan cities where buildings have been constructed very near to each other due to very high population density and lack of knowledge about pounding and its consequences.

In case of pounding, during strong ground vibration, the acceleration at pounding level considerably increases and generates impact force which causes structural damages or sometime results into building collapse. And to avoid this situation of pounding, regulations of minimum seismic gap between buildings have been formulated but it is often seen that these regulations are neither followed by landowners nor strictly implemented by respective governments body. This leads to a situation like century City(USA) earthquake (1992) where, 45% of 340 damages or severely damaged buildings are cause of pounding only. That is why proper seismic gap is provided between newly constructed building and I.S code guidelines should must be followed. But for old adjacent buildings reliable techniques are used to control damages during earthquake like friction damper, concrete shear wall or rigid steel bracing must be used for structural, non-structural safety and life safety. To avoid pounding different countries in all over the world have adopted their own codal specification to avoid pounding.

1.1 Objective of study

One of the main objectives of this study is to evaluate the global response of non-structural element in adjacent buildings when pounding occurs during an earthquake due to insufficient separation between them. For accomplishment of the study different cases such as:

1. Adjacent building with same floor height while NSE is incorporated in building A at third floor level and there is no pounding.

2. NSE is incorporated in building A at third floor level and pounding occurs between building A and building B.

3. NSE is incorporated in building A at fourth floor level and pounding happens between building A and building B.

To accomplish this study, different cases are analyzed analytically using SAP 2000. Time history analysis using below ground motion are used to perform non-linear dynamic analysis.

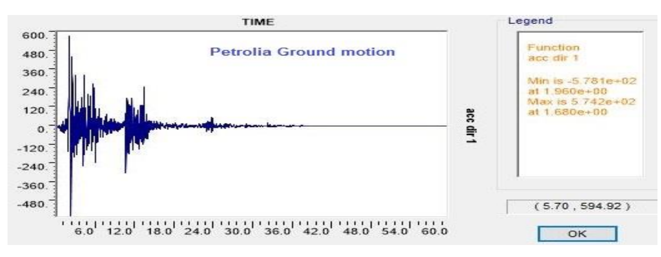

Fig 1.1: Petrolia ground motion acceleration graph

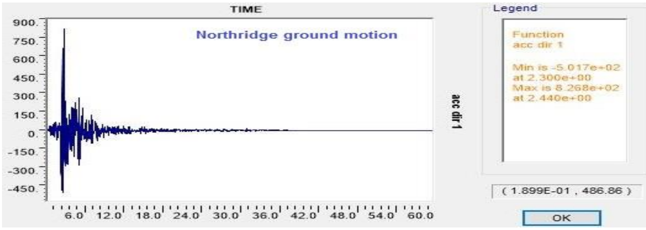

Fig 1.2: Northridge ground motion acceleration graph

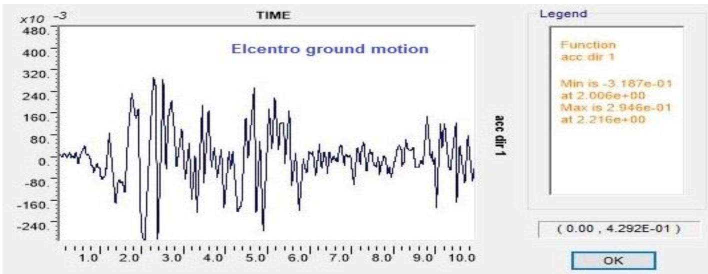

Fig 1.3: El Centro ground motion acceleration graph

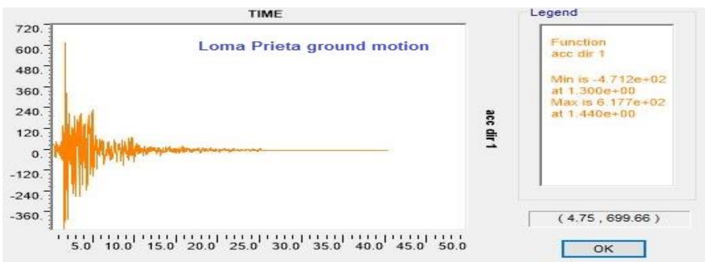

Fig 1.4: Loma Prieta ground motion acceleration graph

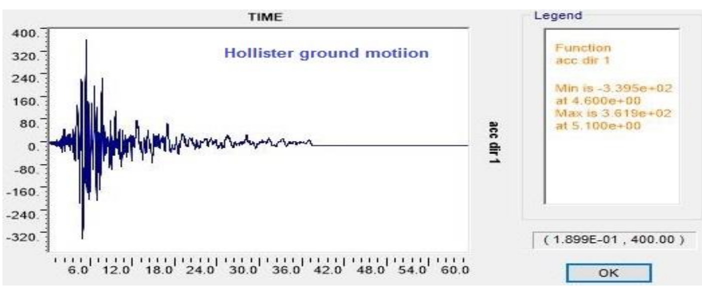

Fig 1.5: Hollister ground motion acceleration graph

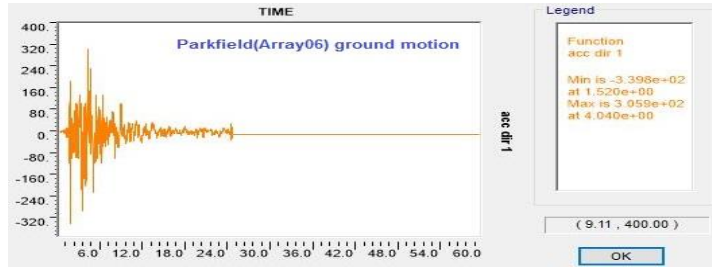

Fig 1.6: Parkfield ground motion acceleration graph

2. LITERATURE REVIEW

A. Shehata E. Abdel Raheem (2008), have studied the effect of impact using linear and non-linear contact force model for different separation distances and compared with nominal model without pounding consideration. The results were illustrated that acceleration and shear at various story levels, produced during pounding, were greater than those obtained from the no pounding case. He also illustrated that pounding was especially harmful for equipment or secondary systems having short periods due to amplified acceleration response at pounding level.

B. K. Kasai, V. Jeng(1994) were studied the pounding effects in Loma Prieta earthquake and found that a rigid adjacent building case provided the results similar to those from a relatively heavy flexible adjacent building case. It was established in their study that peak floor acceleration could be more than 10 times those from the no-pounding case.

C. R.C. Barros and S.M. Khatami (2010), have studied the effect of different link elements such as GAP element of SAP2000, Lessloss element and Kelvin-Voight element for simulating the pounding effect when models were subjected to three different ground motions of Kobe earthquake, Loma Prieta earthquake and Chi-Chi earthquake. They concluded that high lateral displacement can cause a strong impact force between two neighbouring buildings. They also showed that the impact force evaluated using Kelvin-voight is higher than Lessloss element and gap element of SAP2000.

D. Chetan J. Chitte, Hemraj R. kumavat (2012) have studied the variation in the responses of adjacent structures due to pounding, when they subjected to near-source ground motion and far-source ground motion. They concluded that the displacement in structure when it subjected to near-source ground motion was much higher than that of far-source ground motion. Therefore, the pounding effect for same seismic gap would be larger in case of near-source ground motion than the case of buildings subjected to far-source ground motion.

E. Robert Jankowski (2004) has studied the fundamental problem concerning the application of non-linear analysis, its viability and limitations in calculating the seismic gap between the buildings. To simulate the seismic behaviour of structure for his research, he used elastoplastic multi-degree of freedom lumped mass models and to model collision, he used non-linear viscoelastic impact elements. The study established the fact that the pounding has considerable effect on the behaviour of adjacent structures.

F. Arash Rezavani and A. S. Moghadam (2006) have illustrated various methods for mitigation of pounding effect on adjacent buildings during earthquakes. Increasing seismic gap between neighbouring buildings, linking the two adjacent buildings together at different floor levels such that they could move together and incorporation of impact absorbing materials like dampers, were main recommendation they proposed for mitigating the pounding effects on buildings during earthquake.

G. Chenna Rajaram, Pradeep kumar Ramancharla (2014) have studied the feasibility of codal provisions of various countries regarding minimum seismic gap required between adjacent buildings when buildings subjected to different ground motions such as Parkfield, Northridge, Petrolia, El Centro etc. They illustrated that the duration of strong ground motion intensified with an increment in magnitude of ground motion. Similarly they also concluded about the seismic gap between adjacent buildings that it increased with increment in PGA value of ground motion.

H. S. A. Anagnostopoulos (1998) has illustrated the pounding effects in his study based upon the evidences from the past earthquakes and of the results from numerical and theoretical studies presented. He also concluded that theoretically when two buildings of similar masses if subjected to pounding during an earthquake, the response of the stiffer building would be amplified and of the softer building would be deamplified but practically the amplification would be inconsiderate for the buildings of same height.

I. Bipin Shresta (2015) has studied the minimum seismic gap required between two neighbouring buildings to avoid the pounding phenomenon during earthquake using analytical method. He postulated that seismic gap calculated by using double difference combination (DDC) method was much more accurate than that of square root of sum of squares (SRSS) method.

3. METHODOLOGY

The study has been carried out by models of 08 storey building (i.e building A) and 05 storey building (i.e building B) have been considered. The floor level of both buildings have been kept at same level and 05mm space has been kept between adjacent buildings. That element has been introduce between buildings to simulate the effect of pounding. NSE is mounted over spring and friction dampers. Non-linear dynamic analysis has been done by using response spectra method and time history analysis. Response envelops of adjacent buildings are provided in terms of acceleration of floor. The impact forces are achieve by incorporation of gap elements and are also in terms of in form of response envelop for different ground motion.

There are 03 Cases considered under this which are:

1. Adjacent building with same floor height while NSE is incorporated in building A at third floor level and there is no pounding.

2. NSE is incorporated in building A at third floor level and pounding occurs between building A and building B.

3. NSE is incorporated in building A at fourth floor level and pounding happens between building A and building B.

3.1 SEISMIC GAP REQUIRED AVOIDNG POUNDING

It is well established fact that providing a proper seismic gap between adjacent building is one of the best methods to reduce the effect of pounding (Masion and Kasai et al, 1992). Seismic codes and regulations for the minimum separation gap between the adjacent buildings have been specified in worldwide to exclude seismic pounding effect.

3.1.1 ABS and SRSS rules for minimum seismic gap required.

There are mainly two approaches to calculate minimum separation gap which are famous all around the globe are detailed below:

Square root of sum of squares (SRSS) rule:

$$S = \sqrt{U_A{}^2 + U_B{}^2}$$

Where,

S = Seismic gap required
U_A = Peak displacement response of building A
U_B = Peak displacement response of building B

Absolute Sum (ABS) rule:

$$S = U_A + U_B$$

Where,

S = Seismic gap required
U_A = Peak displacement response of building A
U_B = Peak displacement response of building B

3.1.2 PROVISION OF SEISMIC GAP AS PER IS 4326:

Bureau of Indian Standards (BIS) clearly illustrated in IS 4326 that a separation section should be provided between the neighboring buildings. The term separation section has been defined in the code as "A gap of specified width between adjacent buildings or parts of the same building, either left covered or uncovered suitably to permit movement in order to avoid hammering due to earthquake".
Further it also states, "For buildings of height greater than 40 m, 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 structures shall not be less than the sum of their dynamic deflections at any level."

Table 3.1 Seismic gap for adjacent buildings

SL. No.	Type of Constructions	Gap width/ storey, in mm for Design Seismic Coefficient αh=0.12
1	Box system or frames with shear walls	15.0
2	Moment resistant reinforced concrete frame	20.0
3	Moment resistant steel frame	30.0

Hence overall it is advised to provide sufficient seismic gap between neighboring buildings, greater than the sum of the bending of both of the buildings at their top, so that they vibrate freely without any collision.

3.2 NON-LINEAR DYNAMIC ANALYSIS

Buildings in different cases are modeled in SAP 2000. Non-linear dynamic analysis has been carried out considering various earthquake ground motion of different PGA. The equation of motion for the structure when it subjected to ground motion is given as:

$$[M]\{\ddot{X}_b\} + [C]\{\dot{X}\} + [K]\{X\} = -[M][I]\{\ddot{X}_g\}$$

Where,
$[M]$ is mass matrix, $[C]$ is damping matrix and $[K]$ is stiffness matrix of the building. $\{X\}$ and $\{X_b\}$ are displacements of superstructure and base of the building. $\{\ddot{X}_b\}$ and $\{\ddot{X}_g\}$ are base acceleration and acceleration relative to ground. $[I]$ is the earthquake influence coefficient matrix.
Further, all non-linear properties are restricted to the non-linear link element i.e. , gap element, only. The above non-linear dynamic equation considering the superstructure as elastic and link as non-linear can be written as:

$$[M]\{\ddot{X}(t)\} + [C]\{\dot{X}(t)\} + [K_L]\{X(t)\} + r_N(t) = r(t) - [r_N(t) - K_N X(t)]$$

Where,
$[K] = [K_L] + [K_N]$
$[M]$ is diagonal mass matrix; $[C]$ is the proportional damping matrix; $[K_L]$ is stiffness matrix of all linear elements; $[K_N]$ is stiffness matrix for all of the non-linear degrees of freedom; r_N stands for the vector of forces from non-linear degrees of freedom in the gap elements; r(t) in the equation is vector of applied load; $\{\ddot{X}(t)\}$, $\{\dot{X}(t)\}$ and $\{X(t)\}$ are the relative acceleration, velocity and displacement with respect to ground, respectively.
The effective stiffness at non-linear degrees of freedom is arbitrary, but the value of it varies between zero and the maximum stiffness of that degree of freedom.

3.3 GAP ELEMENT

Gap element is a link element defined in SAP 2000.It is compression only member and is used to model the collision between buildings and simulating the effect of pounding. When buildings come close, gap element gets activated and when buildings go away from each other, it gets deactivated. Transmitting the force through the link only when contact occurs and the gap is closed is the main purpose of providing gap element between adjacent buildings.

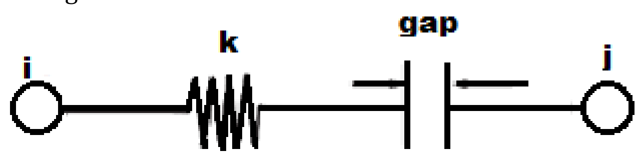

Fig. 3.7 Gap element model from SAP 2000

Gap element model shown in fig.3.1 specifies that the element has two joint nodes i.e. , i and j where the mass contributed by the link/ support element is considered to be lumped and half of the mass is assigned to the 3 translation degree of freedom at joint.
The force deformation relationship of gap element is given below.

$$f = \begin{cases} k(d + gap), & if(d + gap) < 0 \\ 0, & otherwise \end{cases}$$

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
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Where, k is spring constant, 'gap' is the initial opening which must be positive or zero and d is the relative displacement across the spring.

Generally stiffness of gap element (k) is recommended as one or two orders of magnitude greater than equivalent adjacent springs. Here stiffness of gap element has been taken 4.776×10^5 kN/m.

3.4 RESPONSE SPECTRA METHOD

Response spectrum analysis is the most common method used in design to assess the maximum structural response as a result of seismic excitation. It is a linear imprecise method based on modal analysis and on a response spectrum definition. Design response spectra which is detailed in clause 6.4.5 of IS code 1893:2002 and represented in Fig. 2 of the same code, has been used for the study. It is expressed in terms of maximum pseudo acceleration at constant 5% damping.

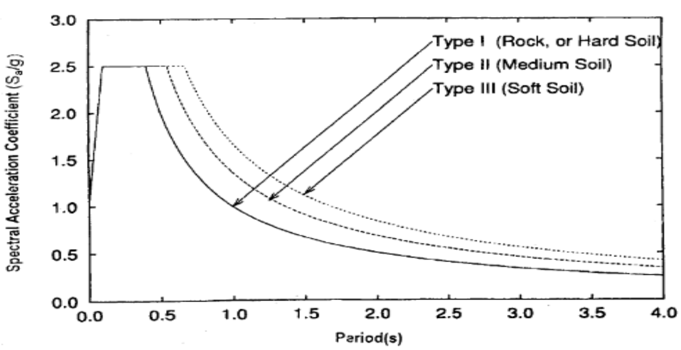

Fig 3.8 Response spectra for 5 percent damping (After IS code 1893:2002)

3.5 TIME HISTORY ANALYSIS

Time history analysis consists of the dynamic response of the structure at each increment of time, when its base is subjected to a specific ground motion time history.

3.6 FUNDAMENTAL NATURAL PERIOD (T_a)

The approximate fundamental natural period of vibration (T_a), in seconds, for moment-resisting frame buildings with brick infil panels is calculated as per clause 7.6.2 of IS code 1893(Part I):2002. It is estimated by following empirical expression:

$$T_a = \frac{0.09\,h}{\sqrt{d}}$$

Where,
h = Height of building, in m.
d = Base dimension (in m) of the building at the plinth level along the considered direction of the considered lateral force.

3.7 ASSIGNING LOAD

3.7.1 LOAD CASES

Adjacent buildings in different cases have been modeled in SAP2000 and after that the possible load case like gravity loads (dead load, super dead load, live load) and the lateral loads (earthquake loads) are assigned to the model as per the calculation.

3.7.2 DEFINING LOAD COMBINATIONS

Load combinations have been defined as per IS code 1893:2002. In the limit state design of reinforced concrete structures, following load combinations have been defined as per clause 6.3.1.2 of IS code 1893:2002.

Table 3.2 : Load combinations as per clause 6.3.1.2 of IS code 1893:2002

SI No.	LOAD COMBINATIONS
1	1.5 (DL + IL)
2	1.2 (DL + IL ± EQ_X)
3	1.2 (DL + IL ± EQ_Y)
4	1.5 (DL ± EQ_X)
5	1.5 (DL ± EQ_Y)
6	0.9 DL ± 1.5 EQ_X
7	0.9 DL ± 1.5 EQ_X

3.8 FORCE APPEARING ON NON-STRUCTURAL ELEMENT (NSE)

Elastic force, $F_{NSE} = \boldsymbol{A_{NSE} W_{NSE}}$

Where,

A_{NSE} = Horizontal acceleration coefficient

W_{NSE} = Weight of NSE

Again,

$$\boldsymbol{F_{NSE} = a_{NSE} A_{floor,H} W_{NSE}}$$

Where,

a_{NSE} = Component amplification factor

$A_{floor,H}$ = Horizontal acceleration experience by the floor

Again,

$$\boldsymbol{F_{NSE} = a_{NSE} \eta_{floor} A_{ground,H} W_{NSE}}$$

Where,

$A_{ground,H}$ = acceleration experienced by ground

η_{floor} = floor response acceleration modification factor

Now Inelastic force appearing on NSE,

$$F_{NSE,inelastic} = \frac{a_{NSE}\eta_{floor}A_{ground,H}W_{NSE}}{R_{NSE}} W_{NSE}$$

Where,

R_{NSE} =Response reduction factor that reflects the ductility potential of NSE

4. STRUCTURAL MODEL

4.1 Geometrical details of building A and B

Table No. 4.3: Geometrical details of adjacent buildings while NSE is incorporated into one building.

	BUILDING A	BUILDING B
No. of Stories	08	05
Storey height	3.1 m	3.1 m
Total height	24.8 m	15.5 m
Size of coloumns	0.45 m x 0.45 m	0.4 m x 0.4 m
Size of beams	0.35 m x 0.45 m	0.35 m x 0.45 m
Thickness of slab	0.15 m	0.15 m
Outer wall thickness	0.23 m	0.23 m

4.2 Loading details of adjacent building A and B

Table No. 4.4: Loading details of adjacent buildings while NSE is incorporated into one building

	BUILDING A	BUILDING B
Live load	3 kN/m^2	2.5 kN/m^2
Floor finish	1 kN/m^2	1 kN/m^2
Roof treatment	1.5 kN/m^2	1.5 kN/m^2
Roof live load	1.5 kN/m^2	1.5 kN/m^2
Dead Wall (Outer)	12.19 kN/m	12.19 kN/m

4.3 Location of NSE in building A and B

The floor level of both building have been kept at same level. 5mm space have been kept between adjacent buildings. Gap element has been introduced between building to simulate the effect of pounding. NSE is mounted over spring and friction damper.

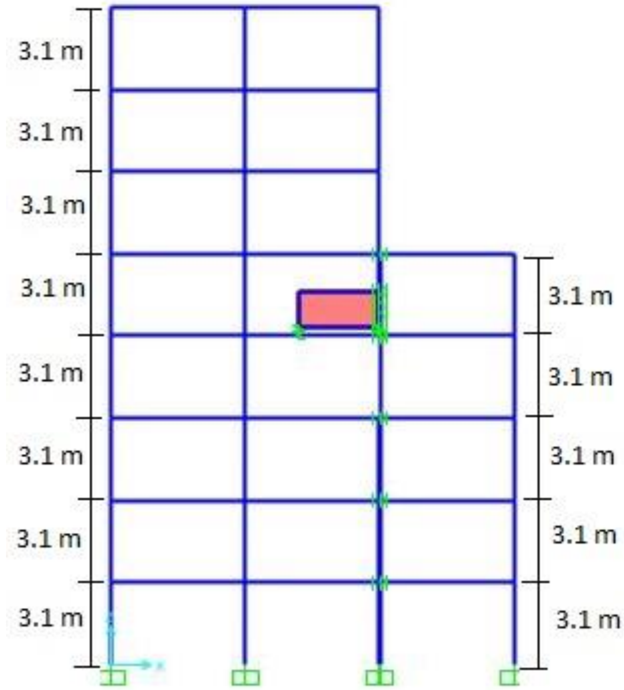

Fig 4.9: Elevation view of adjacent buildings while NSE is incorporated at 4th level of building A.

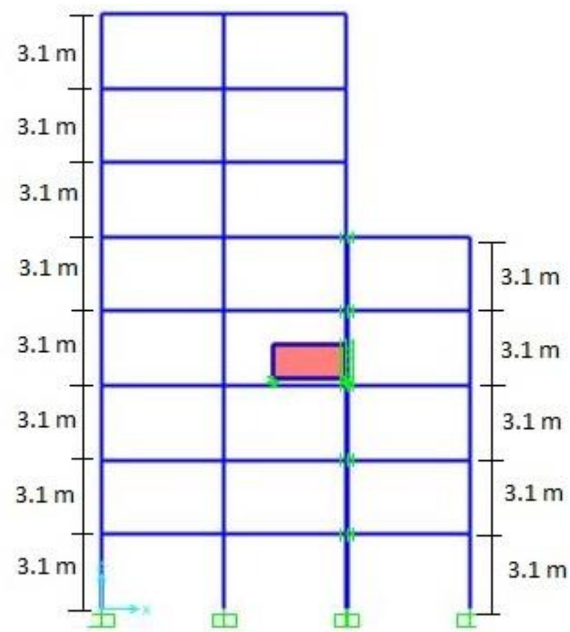

Fig 4.10: Elevation view of adjacent buildings while NSE is incorporated at 3rd level of building A.

5. SOLUTION TECHNIQUE

The models are tested with help of SAP 2000 and graphs are plotted in different cases

5.1. In no pounding case

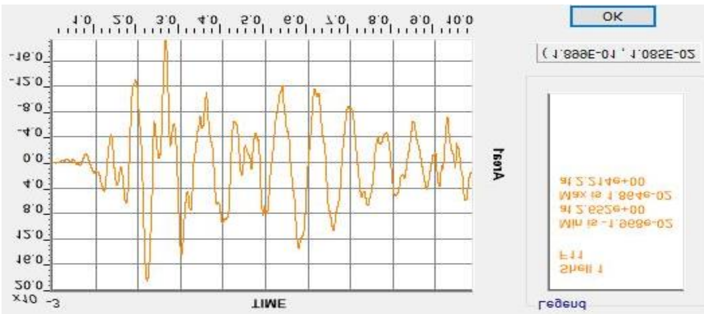

Fig 5.11: Force in NSE shell in no pounding case

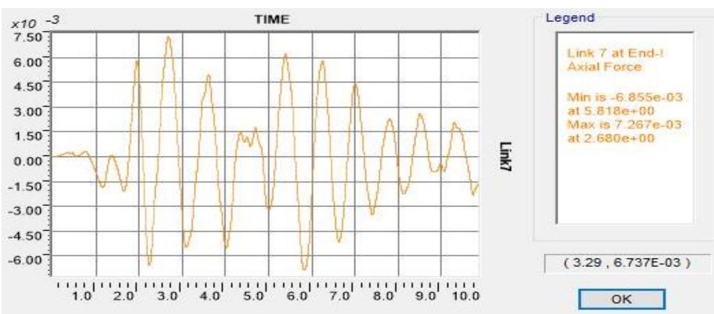

Fig 5.12: Force generated in spring system at which NSE is mounted (no pounding case)

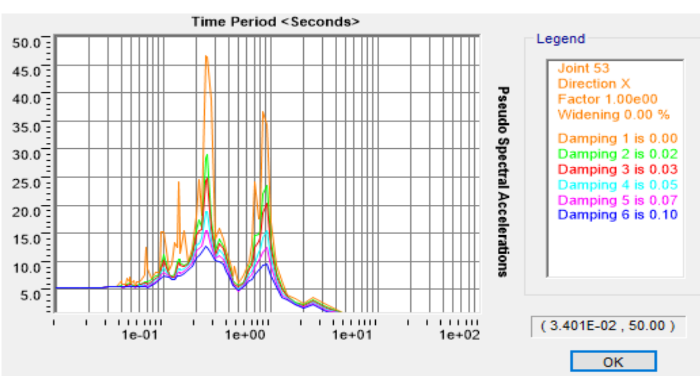

Fig 5.13: Response spectra of lower joint of NSE in no pounding case

5.2. NSE IS INCORPORATED IN BUILDING A AT 3RD LEVEL AND POUNDING OCCURS BETWEEN BUILDING A AND BUILDING B

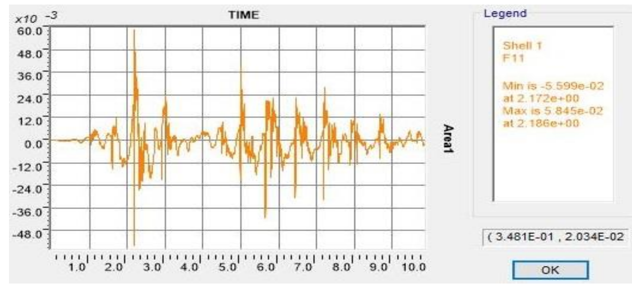

Fig 5.14: Force in NSE shell in case of pounding while NSE is placed at 3rd floor

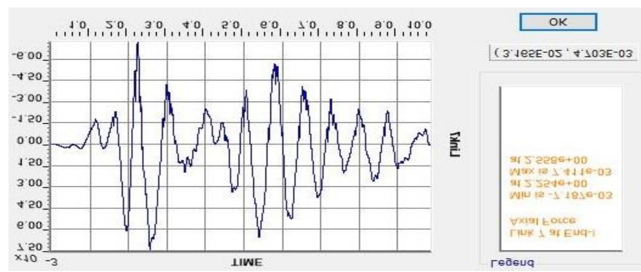

Fig 5.15: Force generated in spring system at which NSE is mounted (in case of pounding)

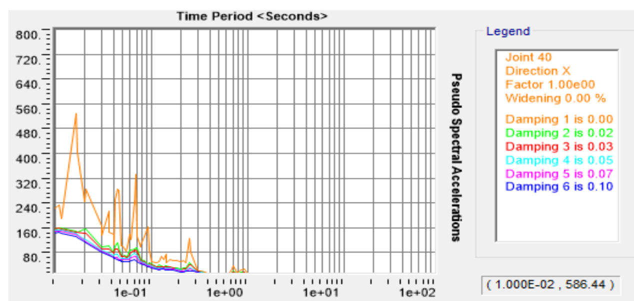

Fig 5.16: Response spectra of lower joint of NSE in case of pounding

5.3. NSE is incorporated in building A at 4th level and pounding occurs between building A and building B.

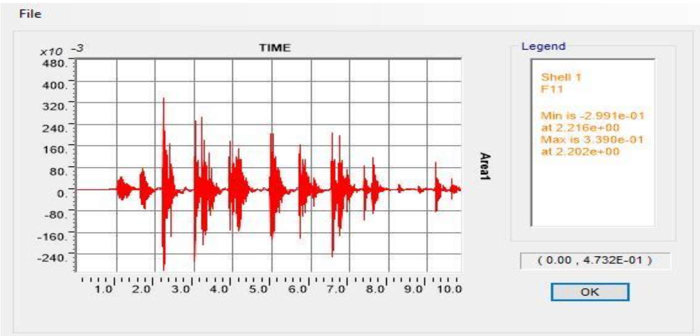

Fig 5.17: Force in NSE shell in case of pounding while NSE is placed at 4th floor

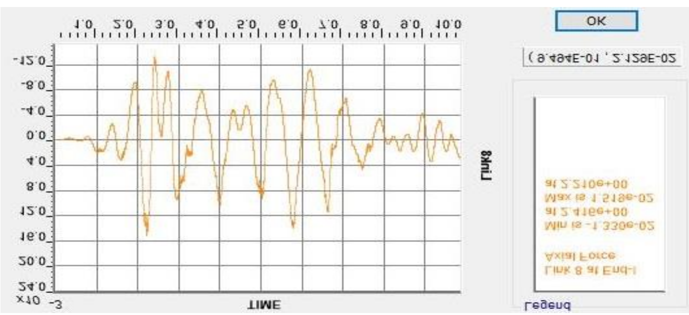

Fig 5.18: Force generated in spring system at which NSE is mounted (NSE at 4th floor)

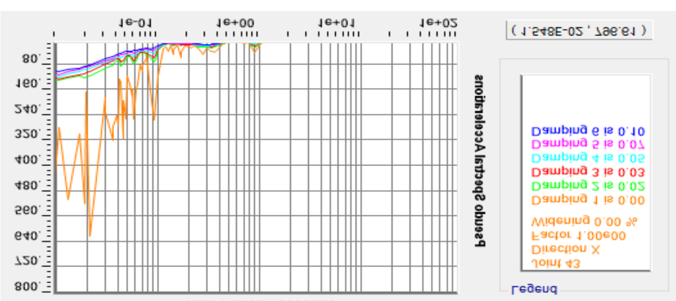

Fig 5.19: Response spectra of lower joint of NSE in case of pounding (NSE at 4thfloor)

6. RESULT AND DISCUSSION

Response of NSE in no pounding case and pounding case.

Table 6.5 Comparison of floor accelerations of floor at which NSE mounted on in pounding and no-pounding case

CASES	Position of NSE	Acceleration of floor (A_{floor}, m/s²)	
		El Centro ground motion	Hollister ground motion
No-Pounding	3rd Floor	5.41	5.10
Pounding	3rd Floor	33.012	39.89
Pounding	4th Floor	56.50	49.25

Table 6.6 Comparison of inelastic forces of NSE in pounding and no-pounding case

CASES	Position of NSE	Force of non-structural element (F_{NSE}, kN)	
		El Centro ground motion	Hollister ground motion
No-Pounding	3rd Floor	33.325	31.416
Pounding	3rd Floor	203.35	245.724
Pounding	4th Floor	348.04	303.38

By analyzing table 6.5 and 6.6, it is observed that floor acceleration of building in case of pounding is much higher than of no-pounding case. Further it is also observed that floor accelerations vary with height of building. Again it is also illustrated that inelastic forces of non-structural element for pounding case is much higher than those of in no-pounding case.

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