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Hazards Of Seismic Impact On Reinforced Structures Separated By a Seismic Gap

Mhd Ghaith Mahmoud Maksoud[1], Amin Saleh Aly[2], Khaled Muhammad Ali Muhammad[3]

ABSTRACT— This thesis is concerned with studying the collision of structures during earthquake shocks. Make an assessment of structures hazards due to earthquake loads and calculate collusion forces of adjacent buildings due to earthquake shocks that leads to the collapse of buildings that leads to serious human and material losses and comparison with the requirements of global and local codes. Make FORTRAN Program to calculate the seismic gap of the buildings under study and use the Excel program to find the mass and stiffness and use the ETABS program and compare the results in the two models to reach the most accurate solution. In comparison with the displacement results from the ETABS program, the results of the FORTRAN program were acceptable. Then calculating the seismic forces generated as a result of the collision during the earthquake through the ETABS program to reach the correct evaluation of these forces. Several adjacent buildings were modeled to serve each case to calculate the collision forces between them through the ETABS program, and the effect of the seismic gap distance on the collision forces and the effect of the mass of buildings on these forces were studied.

Index Terms— Earthquake, Adjacent Buildings, Gap Distance, Pounding Force, Floor Displacements.

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1 INTRODUCTION

The collision of structures, also known as pounding, occurs when two adjacent buildings impact each other during an earthquake. The phenomenon can result in significant damage to the structures and pose a risk to human life. To mitigate these risks, building codes around the world have introduced requirements for minimum separation distances between structures. These requirements are based on the potential relative displacement between the buildings during an earthquake event.

1.1 Thesis significance

The collision of adjacent buildings during earthquakes was the cause of many building collapses and the loss of real estate wealth, which led to the death of the occupants under the rubble of these colliding buildings. Therefore, all earthquake codes were concerned with defining a safe distance between these adjacent buildings to avoid collision. This thesis was concerned with calculating the seismic gap to avoid the collision of adjacent buildings during earthquakes. It was also concerned with calculating the forces of collision between them during earthquakes, and showing that in many cases they are more than they can bear, which leads to their collapse.

1.2 Thesis objectives

The main objective of the research is to reach the correct assessment of the risks of collision between adjacent buildings that may lead to the collapse of the building, and consequently huge material and human losses and calculate the pounding forces during earthquakes between adjacent budlings for various cases. modeling the pounding forces during the previous research and a simple FORTRAN program and technique to solve this problem and determine the displacement of building by FORTRAN program according to UBC 97 and Excel program to calculate the mass and stiffens of building. In comparison with the displacement results from the ETABS program, then calculating the forces of collision between adjacent buildings.
paper.

1.3 Thesis plan

The first stage: Collect the references related to the research point and study them well.
The second stage: The work of a program in the language of Fortran "calculating the displacement of adjacent buildings during earthquakes" and the construction is solved by ETABS.
The third stage: a parametric study to find pounding forces in the following cases:
Case 1: same height of building

- A. Collision of slab to column
- B. Collision of slab to slab

Case 2: different heights of building:

- A. Collision of slab to column
- B. Collision of slab to slab

The fourth stage: Compare the results

2. LITERATURES REVIEW

Many researchers have studied the phenomenon of pounding between adjacent buildings, as well as the impact and danger of its existence on the structure's behaviors.
Dr. Rabee Alsafadi, Eng. Lama branbo, [1] the effect of changing the floor mass of adjacent buildings on the forces of collision between them, displacement and shear forces during

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1 Eng. *Mhd Ghaith Mahmoud Maksoud, M.Sc. student, Structural Engineering Department, faculty of Engineering, Ain Shams University.*
E-mail: ghaithmaksoud1@gmail.com
2 prof.Dr. Amin Saleh Aly Professor of Structural Analysis and Mechanics, Faculty of Engineering, Ain Shams University, Egypt.
E-mail: aminsaly2000@gmail.com
3 Dr. Khaled Muhammad Ali Muhammad, lecture at Civil Engineering Dep.,Pyramids Higher Institute ,Cairo, Egypt.
Born in Cairo, Egypt on 1/10/1986.
ID(EGY) No.28610010129531. E-mail: Khaledelhateeb@yahoo.com
E-mail: dr.khaledmuhammadali@phi.edu.eg

earthquakes was studied through 2D models for two buildings of 3 and 5 floors with the same floor height and different in the total height and without sufficient separation between these buildings.Dr. Mays Ghosoun, Dr. Ali Al-Jarash, [2] many 3D models with different dimensions of adjacent buildings were studied through the ANSYS program, and all these cases were analyzed non-linearly to find out the factors that affect the collision forces by comparing the results of all cases and discussed changing the transitions and stresses and strains. Dr. George Bogdan NICA,Dr Andrei Gheorghe PRICOPIE, [3] the collision forces between neighboring buildings during earthquakes were studied through the development of the MATLAB program based on the stereo mechanics approach, and to ensure the validity of this approach, whose results were not accurate. The study contains the nonlinear response of the structures .Dr. Domenico ALTIERI, Dr. Enrico TUBALDI, Dr. Edoardo PATELLI, [4] a parametric study was conducted using a single degree of freedom system, and a dimensional analysis was conducted to find out the behavior of these structures and the factors that affect the collision forces between these structures during an earthquake. Dr. Lihua Zou, Liangfeng Li, Jianqiang Huang, Kai Huang, [5] adjacent buildings with different story heights were modeled, and a parametric study was conducted for them through the period ratio of structures, initial gap, and pounding location to find out the effect of these factors on the collision forces between these adjacent buildings during earthquakes. Mohamed Adel, Ashraf Elsabbagh, and Mohamed Elghandour, [6] two adjacent buildings of different heights and a variable separation distance were modeled, and the results were compared in the event of a collision between these buildings and in the normal case without a collision between them to know the effect of the collision and the separation distance on displacements, stories drift, and shear forces of the floors. (Nupur Saxena, Rahul Ghosh, Rama Debbarma ,[7] the change of the sufficient seismic separation distance between two adjacent reinforced concrete (RC) structures was determined by the equivalent static force method (ESFM) by conducting a parametric study of the effect of grade of concrete, zone factor and store height on the sufficient seismic separation distance. Dr. Kamel Tamer, [8] 2D frames were used to idealize the adjacent buildings, and a parametric study was conducted by using equal or different total height and a variable separation distance, and exposing them to three different real earthquake records with different characteristics to study the effect of this separation distance on the max collision forces, and then verifying. Chenna Rajaram, Ramancharla Pradeep Kumar, [9] many of international building codes were compared with regard to the sufficient seismic separation distance through two linear single degrees of freedom oscillators for five different ground motions to know the impact forces between them, and the seismic separation distance between them was calculated as recommended by these codes. Muhammad Noman, Bashir Alma, Muhammad Fahad, Khan Shahzada & Muhammad Kamal,[10] several adjacent building models of different heights and different geometry were used, using the ground motion of Kashmir earthquake. And by analyzing these models to find out the displacements, stories drift, and floor shear forces, and to compare the cases between them, and to ensure that the seismic separation distance recommended by UBC 97 is sufficient.

3. CODE REQUIREMENTS TO AVOID POUNDING

The greatest displacement of the adjacent structure is used by most of the code to determine the gap distance. The distance between two points is then determined using a variety of methods, such as the Square Root of the Sum of the Squares (SRSS) and the Complete Quadratic Combination (CQC). This table (1) compiles, in one place, the various gap-calculating equations required by several international standards

TABLE 1
CODE REQUIREMENTS TO AVOID POUNDING

Code	gap distance (δ m)
Egyptian Code (ECP: 203-2007)	Square root sum of the square (SRSS) can be used to calculate the overall displacement for two structures, when the slabs have the same elevation, multiply by 0.7 to obtain the minimal separation distance. $\delta \text{ m} = \sqrt{\delta m_1 + \delta m_2}$
Uniform Building Code (UBC-1997)	Take the square root sum of the squares of displacements for adjacent structural to get the maximum distance between them. $\delta \text{ m} = \sqrt{\delta m_1 + \delta m_2}$
Federal Emergency (FEMA:273-1997)	Prevent pounding by increasing the separating distance to 4% of the whole height.
Indian standard (IS:1893-2002)	Multiply the sum of structure displacement by R (Response Reduction Factor). $\delta \text{ m} = \delta m_1 + \delta m_2$
National Building Code (NBC: E030-2003)	Take a sufficient gap between structures as the sum of the maximum distance between two structures multiplied by 2/3

Canada (Clause 4.1.9.2, NBCC 2015)	The sum of structure displacements calculated using the code loads and adding torsion effects must be multiplied by R $\delta m = \delta m_1 + \delta m_2$
USA (Clause 12.12.3, ASCE 7-10)	$S = \sqrt{\delta \mathbf{m}_1^2 + \delta \mathbf{m}_2^2}$, $\delta m = \frac{c_d * \delta_{mac}}{I_e}$ δmax= Maximum elastic displacement at critical location Cd = Deflection Amplification factor location Ie= Importance factor

4. MODELING OF POUNDING FORCES

We can summaries models that contributed to the study of earthquake impact forces based on previous research. FEM and analytical derivation are two methodologies typically employed in pounding research. This section describes the various models utilized to simulate the collision between adjacent structures. The distance between buildings (gap) is a crucial component of the pounding model, as it impacts the pounding force and level of damage. Modelling adjacent structures with masses and simulating the impact between these masses with a contact or gap element. When masses collide, this gap element is activated, and when masses separate, it is deactivated. The linearity or nonlinearity of the contact element is determined by the spring element's rigidity and the damping properties of the dashpot. As suggested by Athanassiadou (1994), the stereo mechanical model, which is based on the principles of momentum conservation and coefficient of restitution, is not recommended when a precise structural response to pounding is required, particularly in the case of multiple impacts of longer duration. The stereo mechanical approach utilizes an instantaneous impact with a very short duration of impact, which is not the case for building pounding. Furthermore, as stated by Papadrakakis (1991), this approach cannot be implemented in extensively used commercially available software.

4.1 Stereo mechanical model

The ultimate velocity of impacting bodies is calculated using a stereo mechanical model based on their initial velocity. Through the coefficient of restitution, as approximated by Goldsmith (1961), the effect of the masses' material properties was also considered. The coefficient of restitution value can be obtained from any material by performing a drop test in which a sphere made of the material is dropped from a height (h) and the rebound height is measured to obtain (h*). Coefficient of restitution (e) values range between 0 and 1. As shown in Equations (1), (2), and (3), when (e) converges to 0 it indicates plastic collision and when it converges to 1 it indicates elastic collision. Moreover, the implementation of the Stereo-mechanics-based model is deemed infeasible for multiple-degree-of-freedom systems in which multiple collisions are anticipated at various times (Jankowski, 2005).

$$\upsilon'1 = \upsilon 1 - (1 + e)\frac{(m2v1 - m2v2)}{(m1 + m2)} \quad (1)$$

$$\upsilon'2 = \upsilon 2 - (1 + e)\frac{(m1v1 - m1v2)}{(m1 + m2)} \quad (2)$$

$$e^2 = \frac{h^*}{h} \quad (3)$$

Where ʋ'1, ʋ'2 are the velocities of the colliding bodies (m1, m2) after impact and (ʋ1, ʋ2) are the velocities before impact and (e) is the coefficient of restitution.

4.2 Linear spring model

A linear impact of stiffness (kl) can be used to simulate impact. The impact force is provided by

$$Fc(t) = k1\delta(t)$$

A linear elastic spring was used to model the contact element between two structures. This contact element is called a gap element when its stiffness depends on the axial stiffness of the colliding elements of the structures, as Masion and Kasai (1990) did, as shown in Fig.1. When buildings vibrate out of phase, the relative distance between them changes, and the spring starts to feel the force when the distance between the buildings at the start is less than the distance between them now. Eqs. (4) and (5) can be used to figure out the force on a contact or gap element.

$$Fc = k1\,(u1 - u2 - gp);\; u1 - u2 - gp \geq 0 \quad (4)$$

$$Fc = 0;\; u1 - u2 - gp < 0 \quad (5)$$

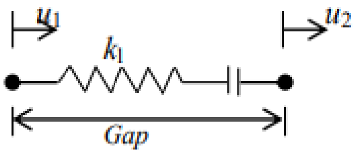


Fig.1 Linear spring model

Where u1 and u2 are the displacements of the impacting masses during oscillator (pounding), k1 is the spring stiffness constant and gap is the initial separation distance between the structures.

4.3 Hertz damp contact element model

The pounding force formula is:

$$Fc = \left[k_{\mathrm{h}}\left(u_{\mathrm{i}} - u_{\mathrm{j}} - g_P\right)^{\mathrm{n}} + \mathrm{c}_{\mathrm{h}}\left(\dot{u}_{\mathrm{i}} - \dot{u}_{\mathrm{j}}\right)\right]\mathrm{H}\left(u_{\mathrm{i}} - u_{\mathrm{j}} - g_P\right) \quad (6)$$

$$H\left(u_{\mathrm{i}} - u_{\mathrm{j}} - g_p\right) = \begin{cases} 1, & u_{\mathrm{i}} - u_{\mathrm{j}} - g_p \geq 0 \\ 0, & u_{\mathrm{i}} - u_{\mathrm{j}} - gp < 0 \end{cases} \quad (7)$$

Where, H is the unit step functionk_h is the stiffness of impact spring,g_P is the initial gap between pounding individuals,u_i is the displacement of i ,$u_j$is the displacement of j Fig 2. The nonlinear damping coefficient c_h $Eq(8)$,and ξ E.q (9) is a damping constant. According to the conservation law of energy, where, e is the recovery coefficient, for concrete it is 0.65, it is expressed as:

$$c_h = \xi \left(u_i - u_j - g_p\right)^n \quad (8)$$

$$\xi = \frac{3k_h(1 - e^2)}{4\left(\dot{u}_i - \dot{u}_j\right)} \quad (9)$$

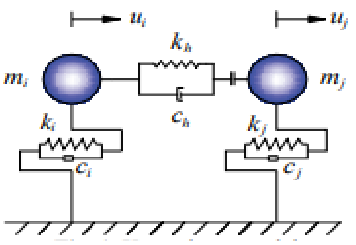


Fig.2 Hertz damp contact element model

5. METHODOLOGY

First of all, the maximum displacement will be studied through the FORTRAN program, and these results will be compared with the results of the ETABS program, and then the collision forces between adjacent buildings will be calculated during the earthquake using the ETABS program for the cases studied during this research.

5.1 Brief description of the study buildings

The buildings consist of multi-story reinforced concrete. During our study, we will rely on two models of adjacent buildings as shown in the figure (3), (4) and the elements section for first model and for the left bunding in the second model table (2), and the elements section of the right bunding in the second model table (3). The total height of the buildings is 21m, 15m, and the floor height will vary according to the cases studied to achieve cases of collision between adjacent buildings as follows

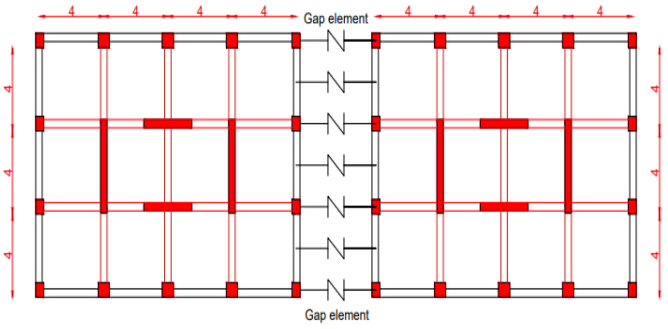


Fig.3 The first plans models

TABLE 2
THE ELEMENTS SECTION FOR FIRST MODEL AND FOR THE LEFT BUNDING IN THE SECOND MODEL

Element	Section dimensions cm
C1	50*70
C2	70*70
B	40*60
W1	40*450
W2	30*300
Solid Slab	20

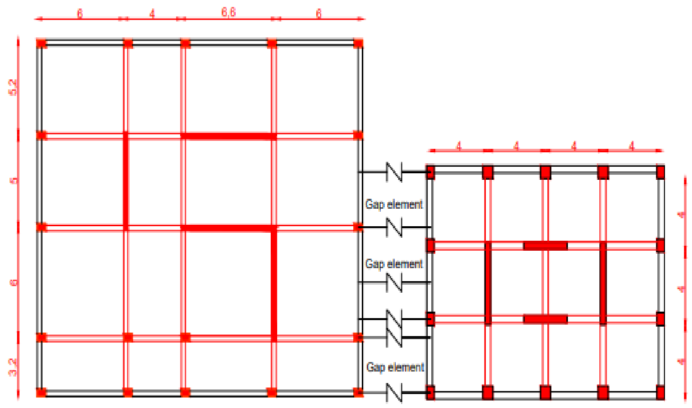


Fig.4 The seconds plans models

TABLE 3
THE ELEMENTS SECTION OF THE RIGHT BUNDING IN THE SECOND MODEL TABLE

Element	Section dimensions (cm)
C	60*40
B	70*30
W1	30*500
W2	30*600
W3	30*660
Solid Slab	20

5.2 Materials Properties

Characteristic compressive strength of reinforced concrete and Yield stress of reinforced steel are
Fc= 25 MPa, Fy = 400 MPa, Fys = 240 MPa

5.3 Load

5.3.1. Vertical Loads

Vertical loads included own weight of the different elements which is calculated by program. It included also live load was taken 3 KN/m2 and flooring cover was taken 2 KN/m2.

5.3.2 Seismic Loads

In this study, the modal response spectrum according to UBC 97 was used to calculate the displacement using the ETABS program and compare it with the FORTRAN program, fig (5) and table (4)

TABLE 4
THE PARAMETERS OF UBC 97

parameter	value
damping	0.05
soil type	SD
Ca	0.36
Cv	0.54

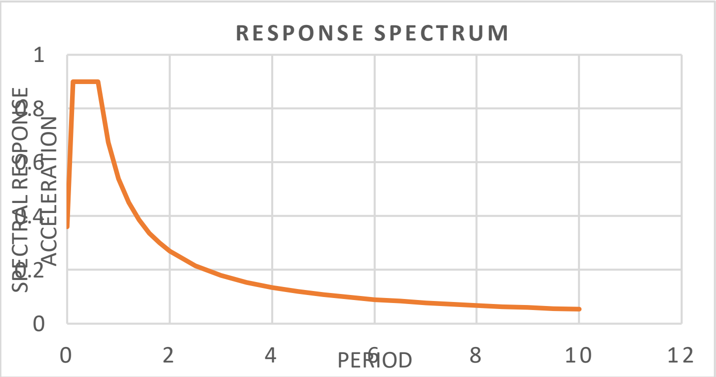


Fig.5 The seconds plans models

seismic action the Non-linear direct integration time history analysis was used as a method of analysis taking into account the effect pounding through matching the used response spectrum according to UBC 97, fig (6).

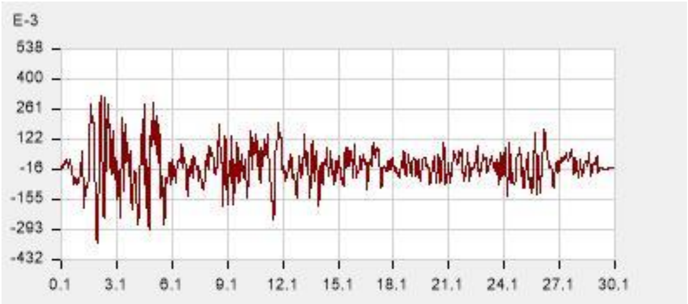


Fig.6 The time history

5.4 Reduction factor

The inertia of the structural elements is reduced according to Table (5)

TABLE 5
REDUCTION FACTOR

Element	Reduction Factor
Slab	Membrane & Binding = 0.25
Beam	M2-2 = M3-3 =0.35 Torsion = 0.2
Column	M2-2 = M3-3 =0.7
Wall	Membrane = 0.7 Binding = 0.1

5.5 Gap Element

The gap distance between adjacent buildings was modeled in ETABS program by gap element, fig (7)

$$f = k(d - \text{open}),\ \text{if}(d - \text{open}) < 0 \quad (10)$$

$$f = 0 \qquad , \text{otherwise} \quad (11)$$

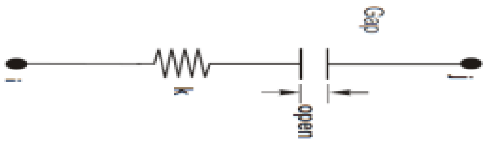


Fig.7 Gap element tool

Where, k is spring constant, 'd' is the initial gap which must be positive or zero and d distance between adjacent buildings. Stiffness: take gap stiffness as axial stiffness of pounding adjacent budlings , $K = 2 * 10^6$ kN/m (Maison and Kasai, 1992). Opening: is a separation distance between two adjacent structures.

5.6 FORTRAN program

Multi degree of freedom system treated as generalized single degree system using assumed linear shape function, The first step is to calculate the mass and stiffness for each story and then calculate the generalized mass, generalized stiffness, and generalized excitation to obtain the period time for each building for the possibility of calculating the displacement of each building. The generalized mass $\overline{m}$, generalized stiffness $\overline{k}$, and generalized excitation $\overline{L}$ are given by

$$\tilde{m} = \sum_{j=1}^{N} m_j \psi_j^2 \qquad \tilde{k} = \sum_{j=1}^{N} k_j (\psi_j - \psi_{j-1})^2 \qquad \tilde{L} = \sum_{j=1}^{N} m_j \psi_j \quad (12)$$

The assumed shape function is linear, where ψ is an assumed shape vector

The story stiffness is the sum of the lateral stiffnesses of all columns in the story:

$$k = \sum_{\text{columns}} \frac{12EI_c}{h^3} \qquad (13)$$

To calculate spectral response acceleration, we will use the response spectrum according to UBC 97 fig (3.7)

The displacements given by flowing:

$$ujo = \psi jzo = \Gamma D\psi j \qquad j = 1, 2, \ldots, N \quad (14)$$

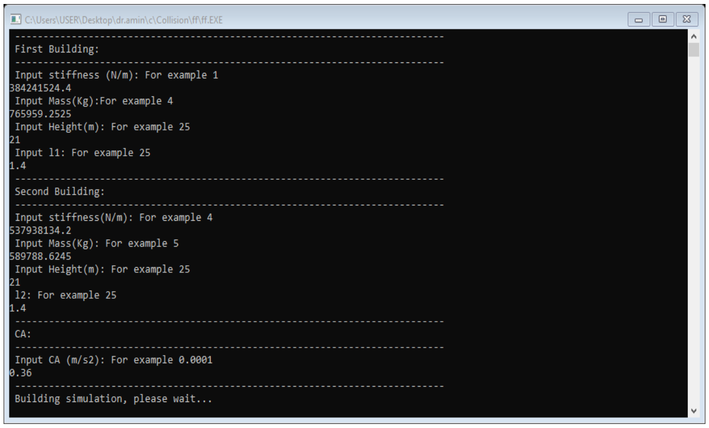
The mass m and shiftiness k and the generalized mass $\bar{m}$, generalized stiffness $\bar{k}$, and generalized excitation $\bar{L}$ was calculated by EXCEL program. And then the input and output to simple FORTRAN program are the following, fig (8), (9):

Input:

Ca,Seismic confident according to UBC 97

For first then the second buildings:

the generalized mass $\bar{m}$, generalized stiffness $\bar{k}$, magnification factor $\bar{\Gamma}$, Height H,

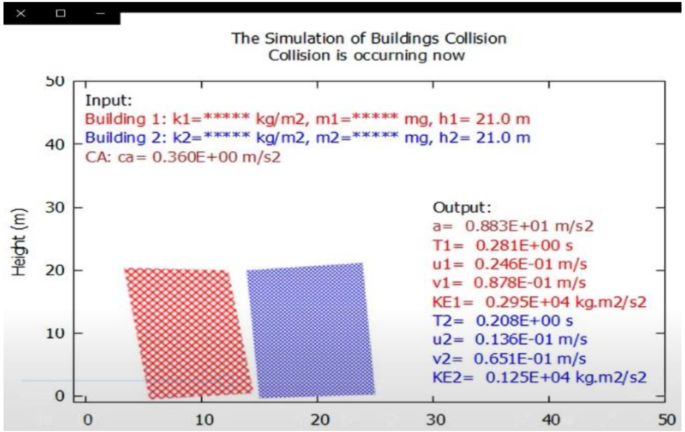


```
 ------------------------------------------------------------------------
 First Building:
 ------------------------------------------------------------------------
 Input stiffness (N/m): For example 1
384241524.4
 Input Mass(Kg):For example 4
765959.2525
 Input Height(m): For example 25
21
 Input l1: For example 25
1.4
 ------------------------------------------------------------------------
 Second Building:
 ------------------------------------------------------------------------
 Input stiffness(N/m): For example 4
537938134.2
 Input Mass(Kg): For example 5
589788.6245
 Input Height(m): For example 25
21
 l2: For example 25
1.4
 ------------------------------------------------------------------------
 CA:
 ------------------------------------------------------------------------
 Input CA (m/s2): For example 0.0001
0.36
 ------------------------------------------------------------------------
 Building simulation, please wait...
```

Fig.8 The input of FORTRAN

The output:

Acceleration and time period and displacement and velocity for first and second buildings



```
Input:
Building 1: k1=***** kg/m2, m1=***** mg, h1= 21.0 m
Building 2: k2=***** kg/m2, m2=***** mg, h2= 21.0 m
CA: ca= 0.360E+00 m/s2

Output:
a=  0.883E+01 m/s2
T1=  0.281E+00 s
u1=  0.246E-01 m/s
v1=  0.878E-01 m/s
KE1=  0.295E+04 kg.m2/s2
T2=  0.208E+00 s
u2=  0.136E-01 m/s
v2=  0.651E-01 m/s
KE2=  0.125E+04 kg.m2/s2
```

Fig.9 The output of FORTRAN

6. RESULT FROM ANALYSIS

6.1 Displacement

Through the study of two cases, they have the height shown in the figure (3) and the elevation shown in the figure(10) . The first case, the buildings have the same height 21m , the number of floors 7, and the floor height 3m , while the second case shows them a different height, the first 21m , the number of floors 7, and the second building, its total height is 15m , the number of floors 5, and the floor height For buildings 3 m, the results from the ETABS program and the FORTRAN program were as follows

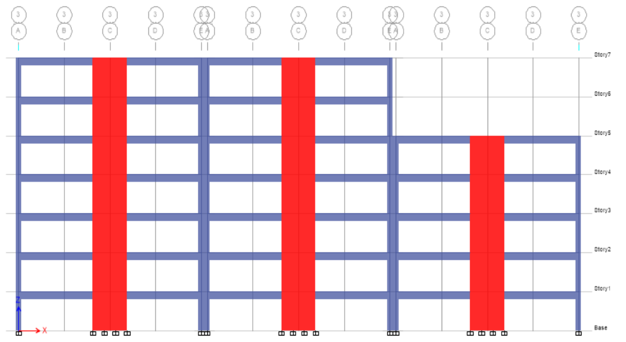
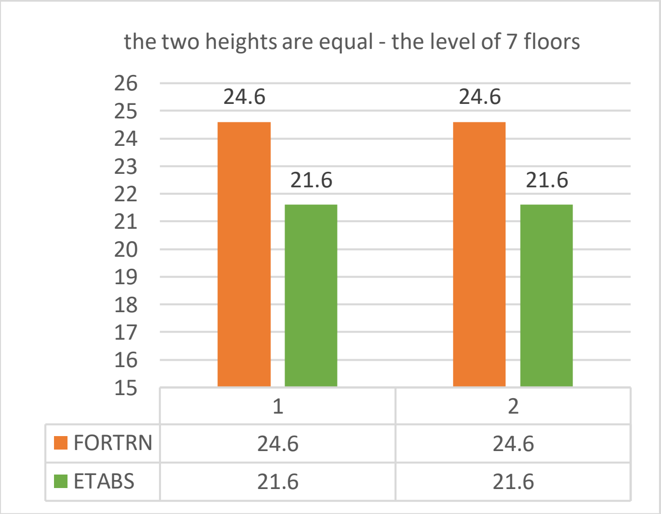


Fig.10The elevation

6.1.1 First case:

The displacement in the 7- story for the two buildings by ETABS is 21.6 mm and by FORTRAN is 24.6 mm for the two buildings, fig (11).



	1	2
🟧 FORTRN	24.6	24.6
🟩 ETABS	21.6	21.6

Fig.11 The result for case 1

6.1.2 Second case:

The displacement of the 7- story building in the 5-story level by ETABS is 21.6 mm and by FOR TRAN is 24.6 mm and the displacement of the 5- story building in the 5-story level by ETABS is 21.6 mm and by FOR TRAN is 24.6 mm , fig (12).

Fig.12 The result for case 2

6.2 Pounding force

6.2.1 Two buildings of the same height and slab-by-slab shock:

In this case the buildings have same total high (21m) and same story high (3 m)

A. Two adjacent budlings have same plan

The plane of buildings shows in fig (3) and the elevation show in fig (13)

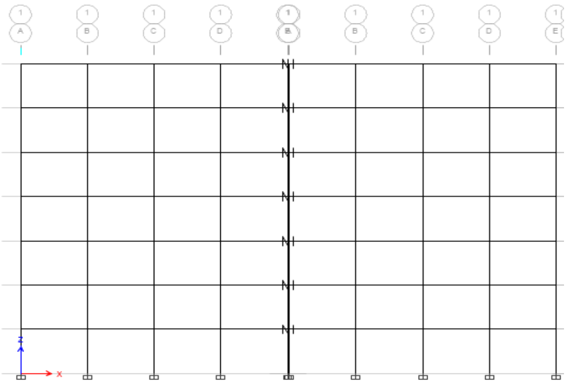


Fig.13 The elevation for case 1-a

The max displacement of the first and second buildings, δ = 20.9 mm, The gap distance $S=\sqrt{\delta m_1^2+\delta m_2^2}$ = 30.97 mm Two buildings didn't collide with each other because the two adjacent structures have same time period, two structure vibrate in phase (vibrate in the same direction) so the force of the spring is equal zero for gaps 5, 10, 20 and 40mm.

B. Two buildings have different plan

The plane of buildings show in fig (4) and the elevation show in fig (14)

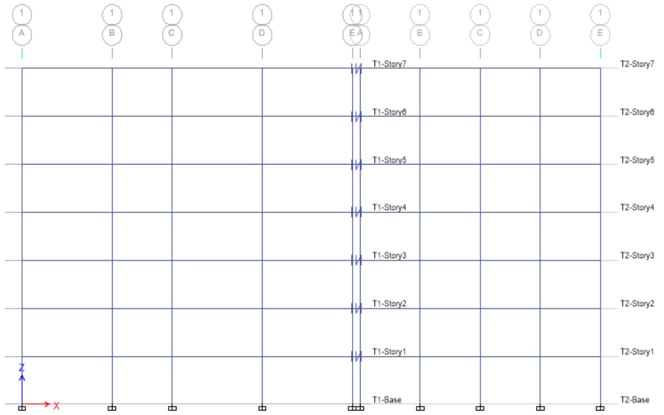


Fig.14 The elevation for case 1-b

The max displacements for right building is δ = 10 mm and for left building is δ = 21.9 mm, The gap distance $S=\sqrt{\delta m_1^2+\delta m_2^2}$ = 24.1 mm, The pounding force by used gap = 5mm ,10 mm show in fig (15) and table (6) ,for gap =10 ,15 mm the forces are zero.

TABLE 6
THE POUNDING FORCE FOR CASE1-B

Gap= 5 mm	
story	force (kN)
7	633
6	510
5	0
4	0
3	0
2	0
1	0

Gap= 10 mm	
story	force (kN)
7	571.2
6	0
5	0
4	0
3	0
2	0
1	0

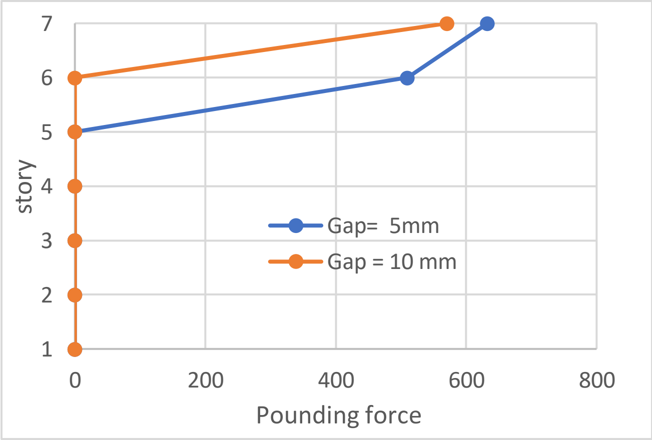


Fig.15 The pounding force for case1-b

6.2.2 Two buildings of different heights and slab-by-slab shock

In this case the buildings have different total high (21m) and same story high (3 m) and The plane of buildings show in fig(3) and the elevation show in fig(16) , Through this case, we will study the effect of increasing the mass of the low building on the collision forces with the mass of the high building remaining as it was, and the effect of increasing the mass of the high building on the collision forces while keeping the mass of the low building as it was, and in both cases during a separation distance is 5 mm.

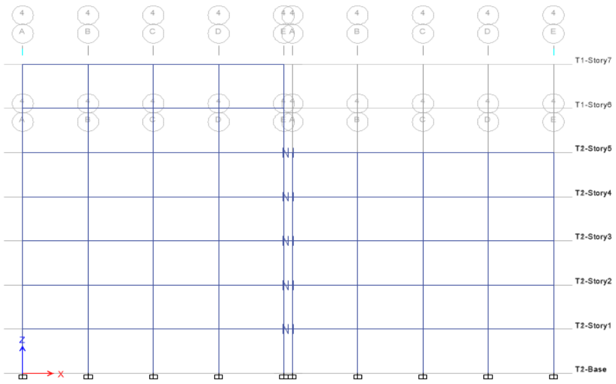


Fig.16 The elevation for case 2

A. The two adjacent buildings have the same section elements:

The max displacements for right building is δ = 21.9 mm and for left building is δ = 9.9 mm, The gap distance S=$\sqrt{\delta m_1^2 + \delta m_2^2}$ = 24.03 mm, the pounding force by used gap = 5mm show in table (7)

TABLE 7
THE POUNDING FORCE FOR CASE2-A

gab = 5 mm	
story	pounding force (kN)
5	810
4	482
3	0
2	0
1	0

B. Increase the mass of low building

Will Increase the mass of low building through use slab section 25 cm and the slab of high building is 20 cm, The max displacements for right building is δ = 21.9 mm and for left building is δ = 10.1 mm, The gap distance S=$\sqrt{\delta m_1^2 + \delta m_2^2}$ = 24.11 mm, the pounding force by used gap = 5mm show in table (8)

TABLE 8
The pounding force for case2-B

gab = 5 mm	
story	pounding force (kN)
5	1152
4	476
3	0
2	0
1	0

C. Increase the mass of high building:

Will Increase the mass of high building through use slab section 25 cm, and the slab of low building is 20 cm, The max displacements for right building is δ = 22.6 mm and for left building is δ = 9.9 mm, The gap distance S=$\sqrt{\delta m_1^2 + \delta m_2^2}$ = 24.7 mm, the pounding force by used gap = 5mm show in table (9)

TABLE 9
The pounding force for case2-c

gab = 5 mm	
story	pounding force (kN)
5	1102
4	475
3	0
2	0
1	0

We can summarize the second case that increasing the mass leads to an increase in the pounding forces, and in the case of two adjacent buildings of different heights, increasing the mass of the low building leads to a slight increase in the pounding forces compared to the case of increasing the mass of the high building Fig (17).

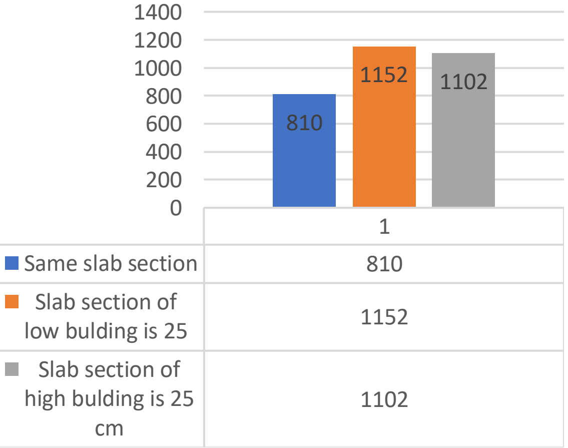


Fig.17 The result of case 2

6.2.3 Two buildings of the same height and Column-by-slab shock

In this case, we will study two buildings with different floor heights to achieve a case of collision of a slab with a column and they have the same total height, so the collision will be in the last floor slab with slab, The plane of buildings shows in fig (4) and the elevation show in fig (18), We will study the pounding forces by used gap = (5, 10, 15, 20) mm, Table. (10).

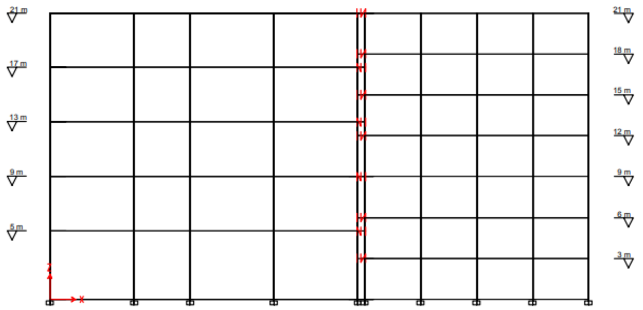


Fig.18 The elevation for case 3

The max displacements for right building is δ = 21.9 mm and for left building is δ = 9.8 mm, The gap distance

$S=\sqrt{\delta m_1^2+\delta m_2^2}$ = 24 mm

TABLE 10
The pounding force for case3

Gap= 5 mm	
Elevation (m)	force (kN)
21	1325
18	510
17	0
15	0
13	0
12	0

Gap= 10 mm	
Elevation (m)	force (kN)
21	2460
18	324
17	296
15	0
13	0
12	0

Gap= 15 mm	
Elevation (m)	force (kN)
21	928.6
18	510
17	0
15	0
13	0
12	0

Gap= 20 mm	
Elevation (m)	force (kN)
21	1437.7
18	0
17	0
15	0
13	0
12	0

We can conclude from this case that an increase in the gap distance does not mean a decrease in the amount of force, in cases where the gap distance is less than the distance recommended by international codes Fig (19).

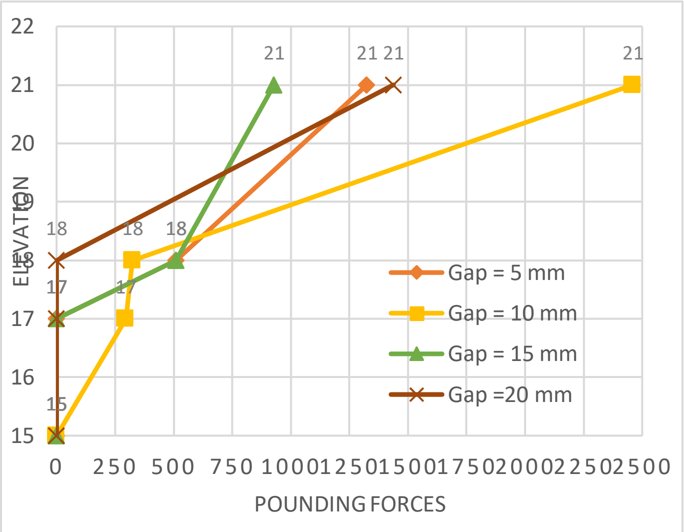


Fig.19 The result of case 3

6.2.4 Two buildings of different heights and Column-by-slab shock

In this case, we will study two buildings with different floor heights to achieve a case of collision of a slab with a column and they have the different total height, so the collision will be in the last floor column with slab. The total high of the high building is 21 and it has a floor height of 4 m except for the ground floor 5 m, and the total high of the low building is 15 m and it has a floor height of 3 in all floors We will study the ponding forces by used gap = (5, 10, 15, 20) mm show in table (11), The plane of buildings show in fig (4) and the elevation show in fig (20)

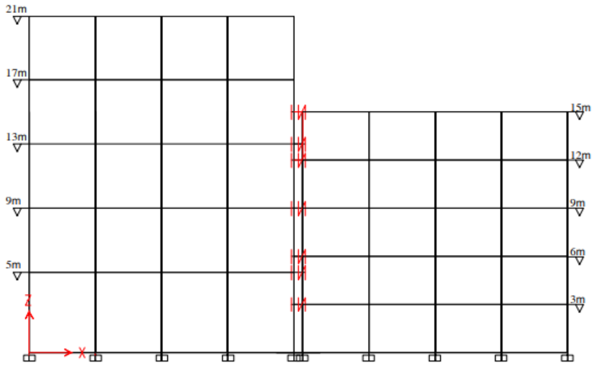


Fig.20 The elevation for case 3

The max displacements for right building is δ = 22.3 mm and for left building is δ = 9.7 mm, The gap distance

$S=\sqrt{\delta m_1^2+\delta m_2^2}$ = 24.3 mm

TABLE 11
The pounding force for case4

Gap= 5 mm	
Elevation (m)	force (kN)
21	1325
18	510
17	0
15	0
13	0
12	0

Gap= 10 mm	
Elevation (m)	force (kN)
21	2460
18	324
17	296
15	0
13	0
12	0

Gap= 15 mm	
Elevation (m)	force (kN)
21	928.6
18	510
17	0
15	0
13	0
12	0

Gap= 20 mm	
Elevation (m)	force (kN)
21	1437.7
18	0
17	0
15	0
13	0
12	0

In this case, increase the distance of gap led to decrease the pounding force Fig (21)

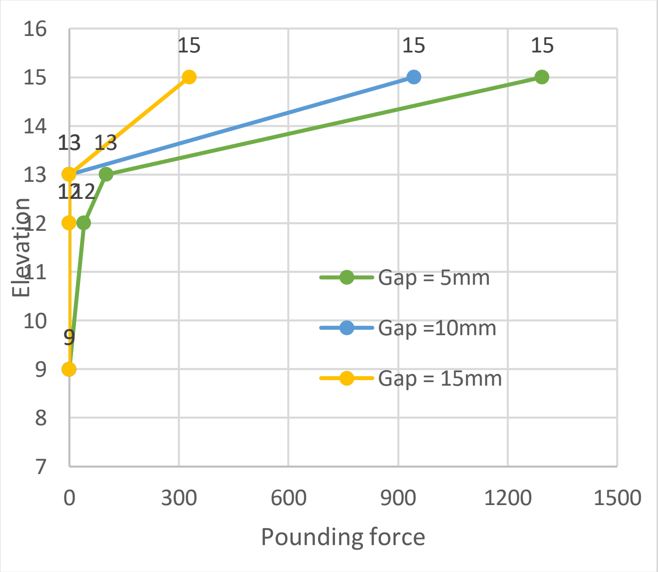


Fig.21 The result of case 4

7. CONCLUSIONS

1. Increase mass for adjacent buildings lead to increase max pounding force.
2. The seismic gap distance established by the Egyptian and European codes, multiplied by 0.7 if the slabs of adjacent structures are of the same level, is greater than enough.
3. As the distance between the two structures reduces, the quantity of impact increases; actually, this is not always the case.
4. Column--by-slab shock is more destructive and critical case more than Slab-by- shock.
5. Of the four cases that have been studied, it can be said that adjacent buildings with the same floor height are safer than adjacent buildings with different floor heights.
6. The pounding does not occur between adjacent buildings of equal height and time period.
7. The simplified FRORTRAN program and technique for determining displacement developed in this study proved to be robust and efficient.

8. RECOMMENDATIONS FOR FURTHER WORK

1. It's recommended to research and investigate more in this point
2. With different number of floors
3. With different heights of floors
4. With different area of buildings
5. With different length of bays
6. With different irregularity in plan and elevation.

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