Journal of Engineering Research and Reports

17(2): 23-33, 2020; Article no.JERR.60910
ISSN: 2582-2926

The Effect of Soil Poissons Ratio on the Response of Buildings with Sufficient Embedment Depth

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JERR/2020/v17i217185
Editor(s):
(1) Dr. Felipe Silva Semaan, Fluminense Federal University, Brazil.
Reviewers:
(1) Adeyanju, Bayode Benson, Engineering Materials Development Institute, Nigeria.
(2) David Mendoza Cachú, Engineering and Industrial Development Center (CIDESI), México.
Complete Peer review History: http://www.sdiarticle4.com/review-history/60910

Original Research Article

Received 17 July 2020
Accepted 23 September 2020
Published 06 October 2020

ABSTRACT

The present study highlights the effect of soil poissons ratio on the response of buildings with sufficient embedment depth. The interaction effect between the structure and its foundation control the dynamic behavior of the structure during seismic analysis. Not only the foundation of structure control the results of seismic analysis but also the embedment depth of the structure increase this effect. The ground motions produced by the seismic excitation at the base of the building are the result of shear deformation in the soil. The effect of the inertial resistance of soil surrounding the basement floors is taken into consideration by adding virtual masses to the basement floors to obtain more accurate shear forces acting on the flexible basement columns. The study calculates the response values at any required time and the maximum response values in addition to its time of occurrence.

Keywords: Soil poisons; inertial resistance; ground motions; embedment depth.

1. INTRODUCTION

The dynamic relation between the response of structure and the foundation became more interested after Cairo earthquake on 12, October 1992. The interaction effect between the structure and its foundation control the dynamic behavior of the structure during seismic analysis. Not only the foundation of the structure control the results of seismic analysis but also the

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embedment depth of the structure increase this effect. Due to the results of the studies of many cases under the dynamic analysis, it is noticed that some variables affect the values of these results [1]. One of these variables is the value of Poissons ratio of the soil surrounding the foundation of the building. A computer program contains a main program and 14 subprogram were used to implement the results of the effect of Poissons ratio of soil confined the structure under the seismic excitation. A mode of 15- story building including three basements under the effect of varying the Poissons ratio of soil. All the results are implemented under the effect of the north –south component of El-Centro earthquake which occurred in California in 1940. The maximum peak acceleration is equal to 0.35 g (g is the ground acceleration) and its time of occurrence was 2.12 sec. Fig. (1) shows a plot for the time history of the ground acceleration, velocity and displacement of El-Centro records.

1.1 Behavior of Soil and Proposed Model under Seismic Excitation

The ground motions produced by the seismic excitation at the base of the building are the result of shear deformation in the soil .Soil often does not behave as linear elastic material. The response of soil can be evaluated using the lumped mass solution. The analysis using lumped mass divides the soil into several layers each of them with varied properties and idealized by series of lumped masses connected by springs which resist lateral deformations. These springs represent the stiffness properties of the material between any two lumped masses and the damping is assumed to be linear viscous. In case of high ground motion, the relationship of stress-strain of soil behave as nonlinear. The analysis in these cases can take the stress-strain curve into consideration by idealizing the curve of any soil layer by equivalent bilinear one. Model is suggested for the layer and connecting pairs of masses attached in series to dashpot and also springs. The spring of the model considered to represent the force-displacement and the dashpot represents the viscous damping in soil. Other dashpots may attached in the model to represent the creep of soil. The objective of many studies in this area was to investigate the effect of the foundation medium on the response of structure during the earthquakes. The studies investigate the influence of the building – foundation interaction on the frequency and motion of the structure.it was found that the response of a structure on soft soil may be different from that obtained for the same structure supported on a rigid base . The reasons behind these differences are that the flexibly supported structure has more degrees of freedom than the fixed – base and also different resonant frequencies (frequency at maximum amplitude) and modes of vibrations. In many solutions, the material properties are assumed linearly viscoelastic with solving the dynamic equations in the frequency domain. The nonlinear characteristics of soil are one of the most important factors which influence the magnitude of the dynamic soil effects, so the dynamic analysis for soil amplification and the phenomenon of soil structure interaction should be taken into consideration.

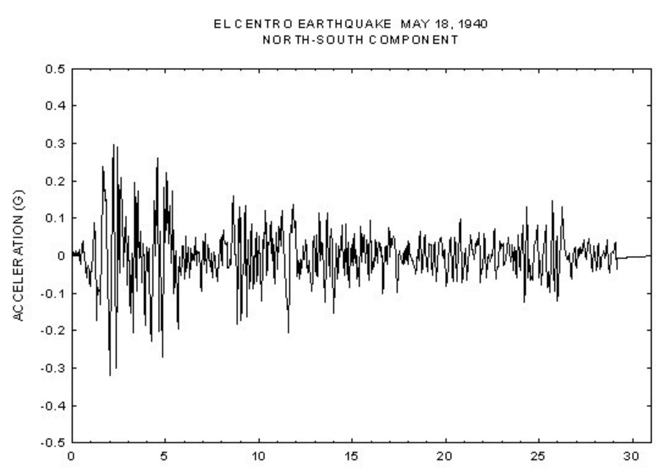

Fig. 1. A plot for the time history of the ground acceleration, velocity and displacement of El-Centro records

2. DYNAMIC EQUATIONS OF MOTION

A nonlinear analysis of reinforced concrete structure with the equations of motions and the suggested model is studied. The plastic behavior of concrete elements of structure are studied. The characteristics of soil medium involving the structure foundations with sufficient embedment depth are also included. The interaction forces arising due to soil structure-interaction are investigated. The frequency independent stiffness and damping coefficients are obtained using a set of springs and dashpots in parallel using simplified model similar to that obtained by Balendra, Tan and Lee [2].

The motion of the building with embedment depth can be described by differential equations. These dynamic equations are derived for both external forces and ground motion. In dealing with these type of equations, it is suitable to derive the equations for a limited number of stories and then the results are generalized to obtain the general equation of motion.

2.1 Equations of Motions Due to External Forces

The various forces acting on the floor mass are the external forces, inertia forces and the elastic resisting forces. The inertia forces act to the left opposite to the direction of positive acceleration but the elastic resisting forces act to the left opposite to direction positive deformation. Due to the external dynamic forces, the building is displaced laterally. The equilibrium equations of motion of multi-degrees of freedom building due to external forces as shown in Fig. (2) (a) and Fig. (2) (b). It is assumed that the damping forces are proportional to the velocity and can be written in the form [2]:

$$m\ddot{U} + C\dot{U} + KU = P(t)$$

Where :

m = Mass matrix of structure .
$\ddot{U}$ = Acceleration vector .
C = Damping matrix of structure .
$\dot{U}$ = Velocity vector .
K = Stiffness matrix of structure .
U = Displacement vector .
$P(t)$ = Vector of external dynamic forces.

2.2 Equations of Motion Due to Ground Motion

The excitation in case of an earthquake is the earthquake motion which affects the base of the structure and assumed to be a horizontal component of ground motion with displacement, velocity and acceleration effects.

The equilibrium equations of multi-degree of freedom structure due to ground motion. Fig. (3) (a) and Fig. (3) (b) can be expressed in the form:

$$m\ddot{U} + C\dot{U} + KU = -m\,1\,\ddot{U}_g(t)$$

Where :

$\ddot{U}g(t)$ = The ground acceleration.
1 = A vector contains elements equal to unity.

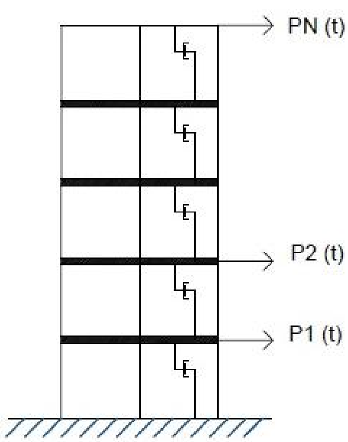

Fig. 2(a). A multi-story shear building

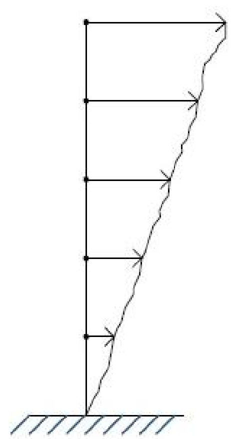

Fig. 2(b). A lumped mass system and displacements

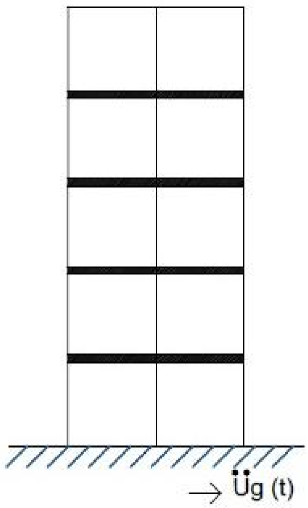

Fig. 3(a). A multi-degree of freedom system subjected to ground motion

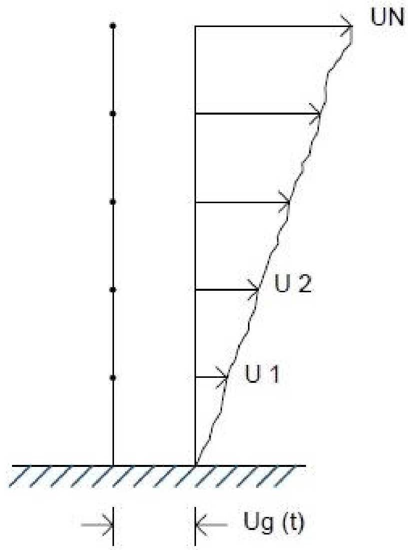

Fig. 3(b). Lumped mass system and displacement

The mass and stiffness matrices can be calculated from the dimensions and sizes of the elements of structure. The damping matrix of structure is computed in terms of modal damping ratios in which their values are obtained from experiments on similar structures.

3. COMPUTER IMPLEMENTATION

The used computer program called "MBASE" [3] is developed to obtain the results of the elastic, elastic-plastic and bilinear analysis of a reinforced concrete shear type building with multi-basements under seismic excitation. The data file contains the number of both stories and basements. The properties of the sections of the structure, dimensions of sections of the columns in each floor and the values of both tension and compression steel, the width of foundation and floors, height of the floors, shear wave velocity of soil, Poissons ratio, damping ratio of the superstructure. The data file contains also the dimensionless stiffness and damping coefficients at the base of building and at each basement story for both translational and rotational stiffness and damping coefficients. The values of the frequency independent translational and rotational stiffness and damping coefficient are calculated through the program because they are functions of Poissons ratio, shear wave velocity and number of basements. The effect of the inertial resistance of soil surrounding the basement floors is taken into consideration by adding virtual masses to the basement floors to obtain more accurate shear forces acting on the flexible basement columns [4]. The program is executed on two data files, the first is for the properties of structure as mentioned before and the other for records of earthquakes which are the accelerations at every 0.02 second. The output file contains results about the story shear forces, base shear, ductility demands, mode shapes, the displacements at each story and the base, and also the story drift. The units of output results are in Kg, cm and sec. The program calculates the response values at any required time and the maximum response values in addition to its time of occurrence.

4. CASES STUDY

Three buildings 7- story with 3- basements, 12-story with 3-basements and 17-story with 3-basements, all of them are 3 bays are studied under the effect of the N-S component of the EL-Centro earthquake. For the purpose of comparison, the geometry and properties of the superstructure are considered as constant data.

Figs. (4), (5), (6) and (7) show plan and elevations of the cases which are studied.

The following parametric study and variables are:

- Number of stories = 10 , 15 and 20 story
- Number of basements = 3 basements

- Width of foundation = 1300 cm
- Soil shear wave velocity = 240 m/sec
- Soil Poissons ratio (μ) = 0 , 0.25 and 0.45
- Superstructure damping ratio [5] = 0.06
- Base mass (m_b) = 2 m_F = 94.7 Kg . sec ^{2}/cm

5. NUMERICAL RESULTS

The results of the three cases 10, 15 and 20 story with three bays and three basements are as follows: -

5.1 Erical Results

The results of the three cases 10 , 15 and 20 story with three bays and three basements are as follows : -

5.1.1 Case of 10 – story building with 3- bays and 3 – basements

Table (1) shows the results of the effect of Poissons ratio on the response of 10 – story building under EL – Centro earthquake.

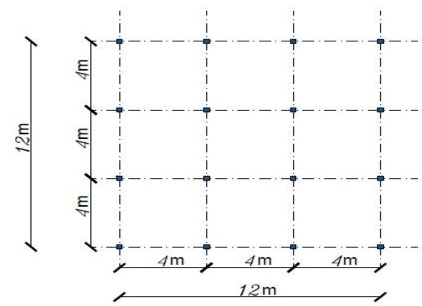

Fig. 4. Plan of considered buildings

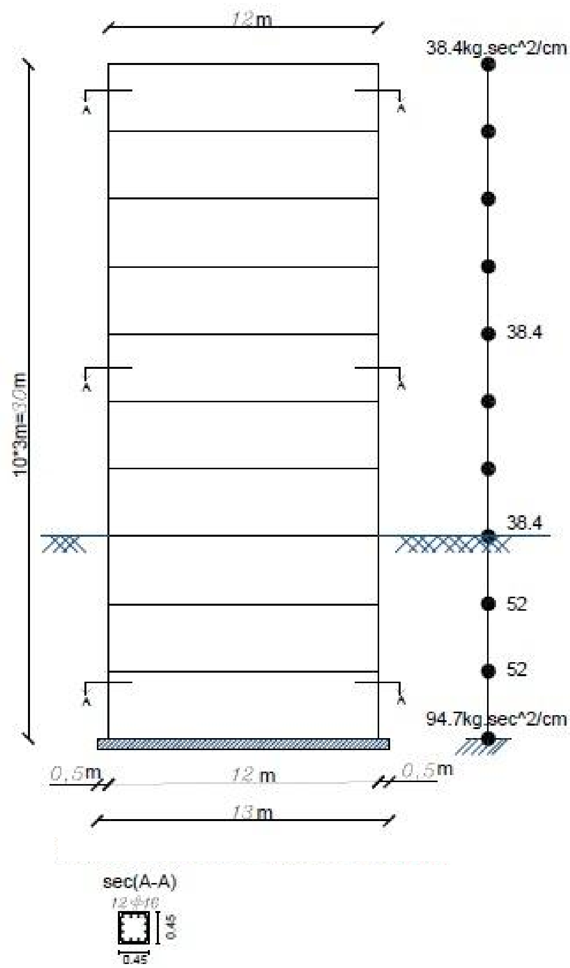

Fig. 5. Elevation of case (1), 10-story building

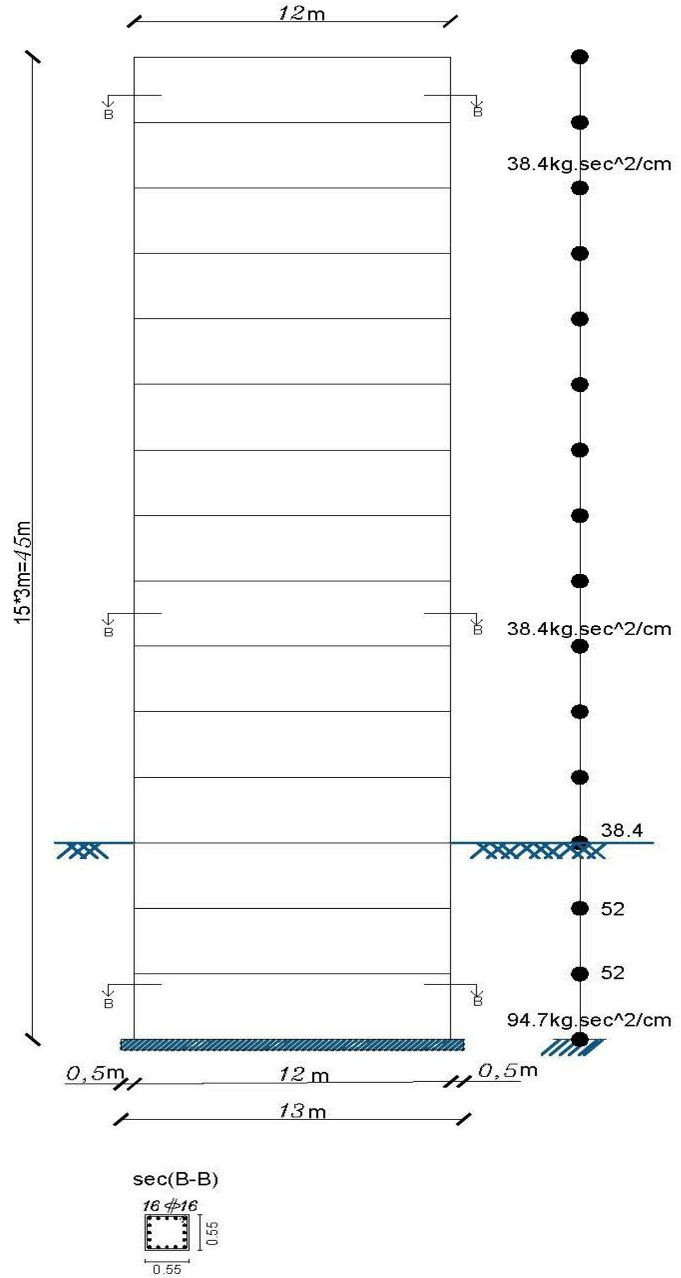

Fig. 6. Elevation of case (2), 15-story building

Table 1. Effect of poissons ratio (μ) on the response

Poissons ratio / Results	0	0.25	0.45
Max. base displacement (cm)	23.58	26.71	30.51
Max. base shear (t)	2.32	2.23	1.57
Max. story displacement (cm)	0.33	0.315	0.2
Max. story shear (t)	2.32	2.23	1.57

(10-story, 3 basements building)

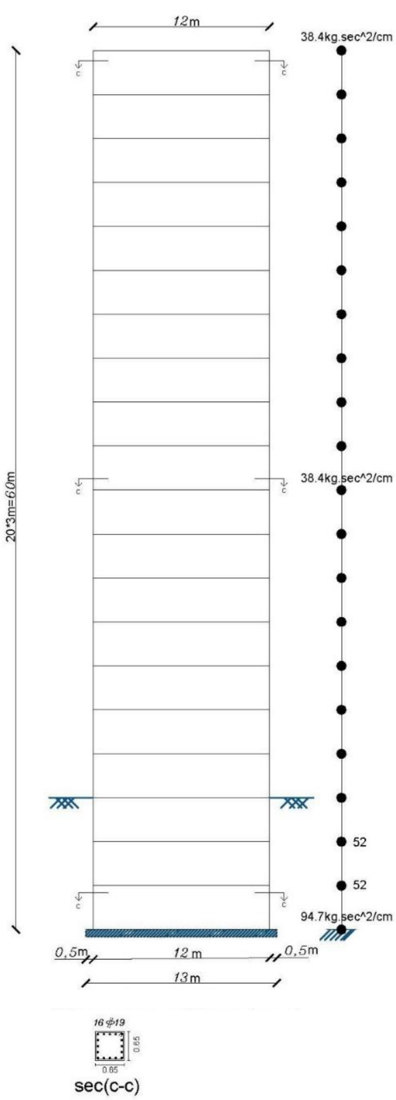

Fig. 7. Elevation of case (3), 20 – story building

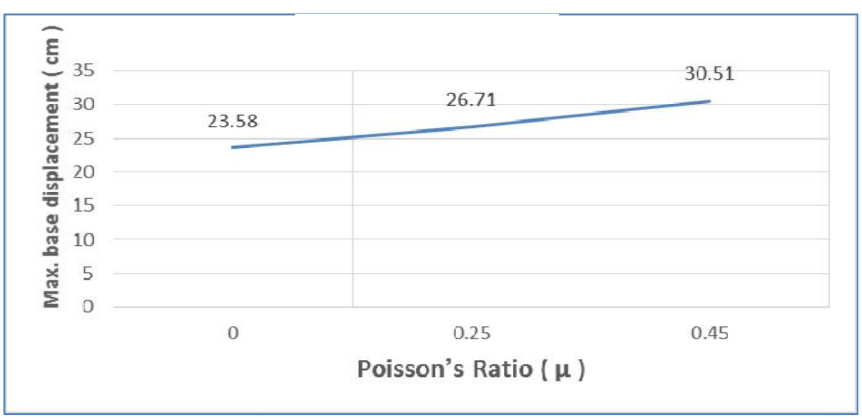

Fig. 8. Relation between poissons ratio value and the max. base displacement
(10 – story building)

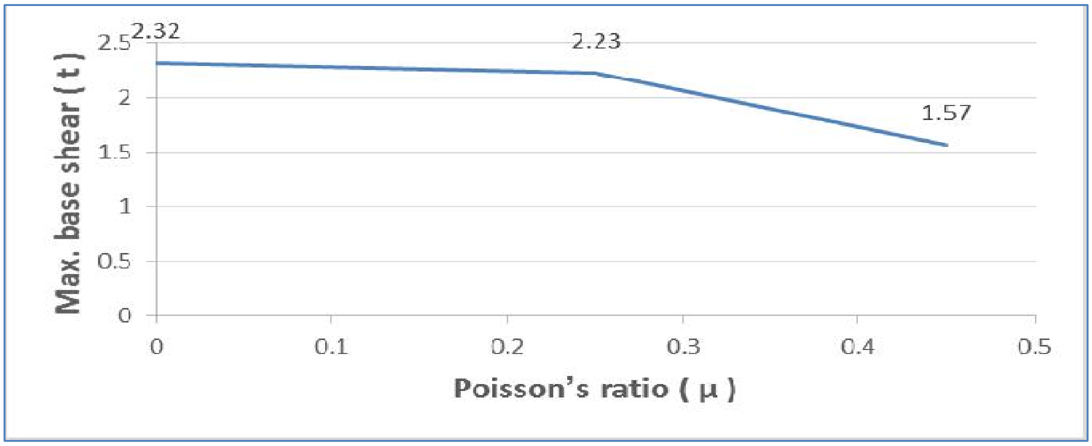

Fig. 9. Relation between poissons ratio value and the max. base shear
(10 – story building)

From the results of Table (1), it is shown that as the Poissons ratio of soil increased the max. base displacement increases and the max .base shear decreases. The max. story displacement and story shear decreased with increasing the Poissons ratio [6] .

5.1.2 Case of 15-Story building with 3bays and 3-basements

Table (2) shows the results of the effect of Poissons ratio on the response of 15 – story building under EL – Centro earthquake.

Table 2. Effect of poissons ratio (µ) on the response

Poissons ratio / Results	0	0.25	0.45
Max. base displacement (cm)	25.19	19.77	26.33
Max. base shear (t)	53.8	40.41	5.97
Max. story displacement (cm)	10.03	4.49	0.22
Max. story shear (t)	53.80	42.99	6.44

(15-story, 3 basements building)

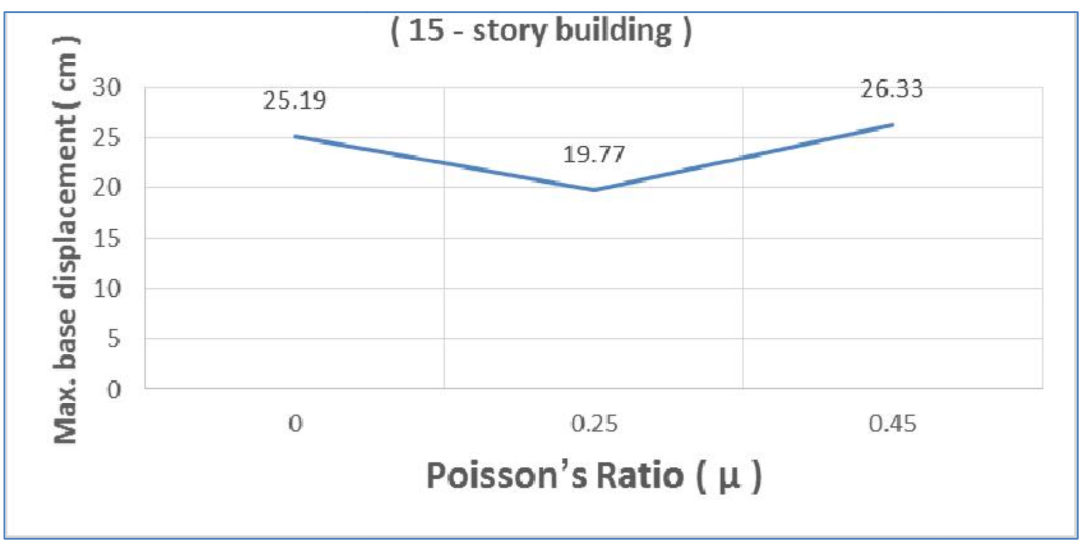

Fig. 10. Relation between poissons ratio value and the max. base displacement
(15 – Story building)

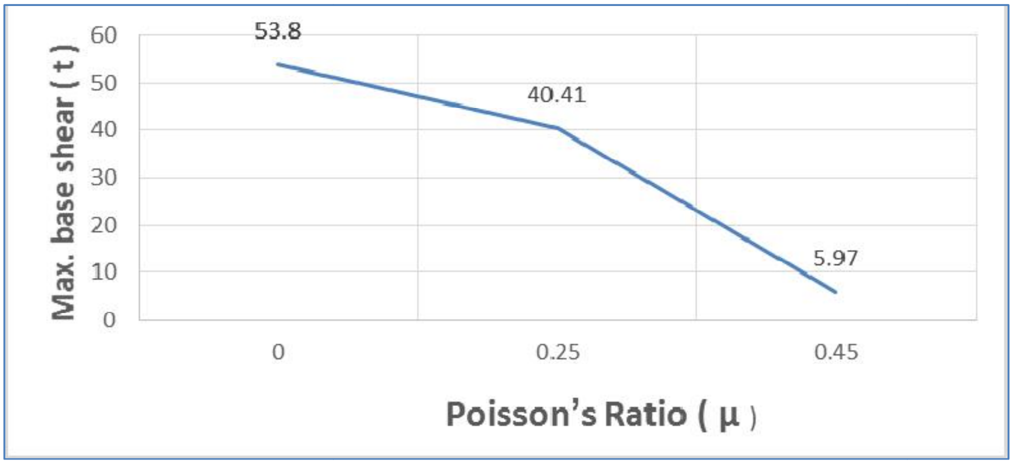

Fig. 11. Relation between poissons ratio value and the max. base shear
(15 – story building)

From the results of Table (2), it is found that the max. base displacement decreases at Poissons ratio equal to 0.25 then increases with increasing Poissons ratio, while all of max. base shear, story shear and story displacement decrease with increasing the Poissons ratio value.

5.1.3 Case of 20-story building with 3 bays and 3-basements

Table (3) shows the results of the effect of Poissons ratio on the response of 20-story building under EL – Centro earthquake.

Table 3. Effect of Poissons ratio (μ) on the response

Poissons ratio / Results	0	0.25	0.45
Max. base displacement (cm)	21.63	19.29	30.22
Max. base shear (t)	87.41	85.63	84.8
Max. story displacement (cm)	7.16	8.16	15.08
Max. story shear (t)	87.4	88.14	115.7

(20-story, 3 basements building)

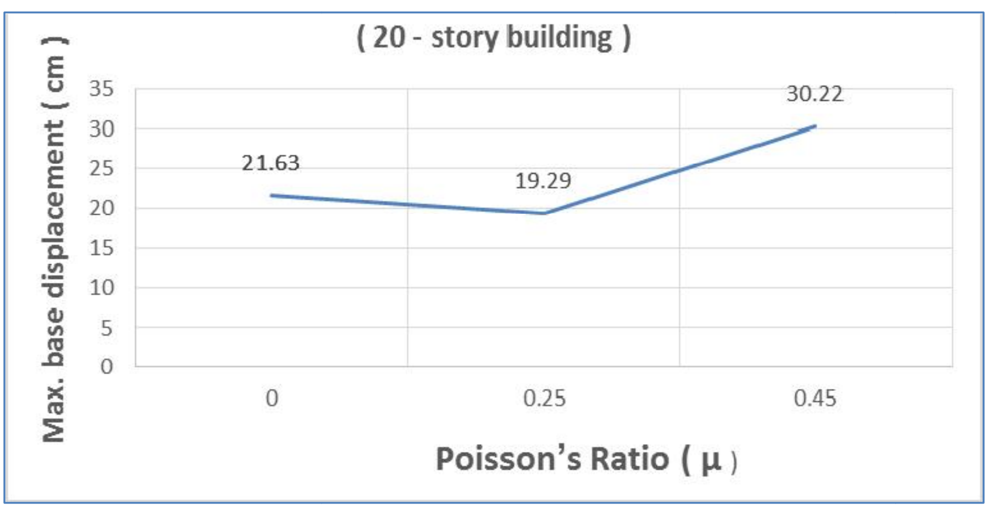

Fig. 12. Relation between poissons ratio value and the max. base displacement

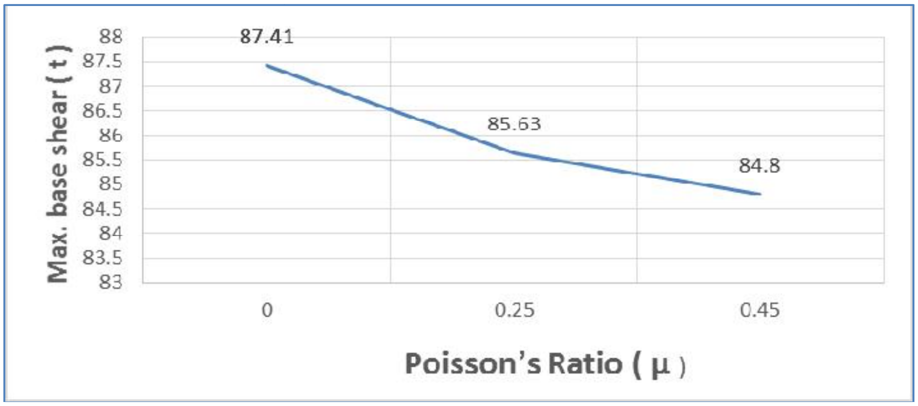

Fig. 13. Relation between poissons ratio value and the max. base shear
(20 – Story building)

From the results of Table (3), it is clear that the max. base displacement and base shear decrease at Poissons ratio equal to 0.25 then increases with increasing Poissons ratio while the max. story displacement and max. story shear increase, with increasing Poissons ratio.

6. CONCLUSIONS

The following important points and significant findings can be concluded from the previous study:

a) The max. base shear in general decreased with increasing Poissons ratio for all the building 10 , 15 , 20 – story building because of the ability of soil surrounding the building for the lateral strain.
b) For 10 – story building , it is shown that as the Poissons ratio value increasing , the max. base displacement increasing while for 15 and 20 – story building , the max. base displacement decreased up to Poissons ratio equal to 0.25 then increased suddenly with about 35 – 55 % with increasing Poissons ratio to 0.45.
c) For 10 and 15 – story building , it is found that the max. story displacement and max. story shear decreased with increasing the value of Poissons ratio of soil , while for 20 – story building, the max. story displacement and shear increased with increasing Poissons ratio [7,8] .

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Available:https://doi.org/10.1007/s10518-018-0314-z

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/60910