IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

EFFECT OF INCREASING NUMBER OF STORIES ON SEISMIC BEHAVIOR FOR RC STRUCTURES

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Abstract: During the last few decades, it has been revealed that since earthquakes are one of the most common natural disasters, which affect both human life and property, hence design codes shall study all of its parameters that affect it from all sides. To avoid negative effects of earthquake, the nonlinear response of structures under dynamic loading should be accurately modeled in order to ensure safe and sound design. To yield proper results, accurate representative structural models should be developed for the elements resisting lateral loading and representative ground motions pertaining to the site should be employed. Then relating such response to that of elastic behavior should be conducted to correlate response modification factors in design codes with actual response. The main goal of the research is to investigate the effect of number of stories on the seismic response modification factor for reinforced concrete multi-story structures, based on ABAQUS software analysis using two methods of analysis, pushover analysis and time history analysis. For this purpose, experimental results of individually tested RC structures are used in order to verify modeling technique to be adopted.

***Index Terms* -** Reinforced concrete structures, ABAQUS software, Pushover analysis, Reduction Modification Factor, Time history analysis

I. INTRODUCTION

Reinforced concrete structures designed to withstand earthquakes must have enough strength and stiffness to control deflection and prevent any possible collapse. Recent seismic design codes include R factors in definition of lateral forces used for seismic design to reduce the design elastic spectral acceleration to account for its components yielding.

R factor reflects the structure capacity to behave in-elastically without collapsing. In fact, the response reduction / modification factor is a combined effect of over strength, redundancy and ductility. Response modification factors play an important role in the seismic design. No other parameter in the design base shear equation affects the design actions in a seismic framing system as does the value assigned to R-factor.

II. LITERATURE REVIEW

A summary of previous available analytical work was conducted for this study is presented as follows.

- In 2016, Bholebhavi [1] modeled RC SMRF with medium rise that have irregularity in elevation, vertical irregularity and in Plan irregularities to evaluate the (R) factor for irregular RC structures using the non-linear static analysis. The results explained that as percentage of horizontal irregularities increases R-value decreases, as a percentage of sudden vertical irregularities increases, R-value was decreasing and a structure with gradual irregularities in elevation didn't show considerable deviation in R-value.

- In 2015, El Azizi [2] tested six RC walls under displacement controlled quasi-static cyclic lateral loading. The walls had three different configurations, rectangular, flanged and end confined. The study aimed at calculating and comparing the ductility capacities of the three configurations. The results of the study show that the flanged and end confined walls had a significantly higher ductility capacity than their rectangular counterparts. El-Azizi suggested assigning different seismic force reduction factors for walls with different cross sectional configurations.

- In 2014, Hakim [3] aimed to investigate building performance on resisting expected seismic loadings. Two 3D reinforced concrete(RC) frames were analyzed using the push-over analysis following (ATC-40). One was designed based on a design practice which takes in account only gravity load and other frame was designed based on Saudi Building Code (SBC-301) [4]. The results explained that the RC structure designed considering only gravity load was found not sufficient. While, the RC frame designed based on (SBC 301) satisfies Immediate Occupancy (IO) acceptance criteria following (ATC-40).

- In 2014, Apurba Mondal [4] focused on estimating the value of the response reduction/modification factor (R) for realistic reinforced concrete(RC) structures detailed and designed based on Indian standard (IS) for that they made models consist of 3, 5, 9 & 13 stories reinforced concrete (RC) frames and analysis was carried out with non-linear static method using static push-over analysis The results explained that the Indian standard (IS) recommendation for a higher value response reduction/modification factor (R) than actual value of response reduction/modification factor (R) is potentially dangerous.

- In 2004, Sungjin [5] studied the different factors that have effect on ductility. Evaluation of distortion capacity of the RC columns was important in performance-based seismic design. The capacity of RC columns in deformation was being expressed in various ways, which are drift, curvature ductility or displacement ductility. The effect of axial load, reinforcement ratio, volumetric ratio, concrete strength and shear span to depth ratio of the confining reinforcement, on various ductility factors were discussed and evaluated.

III. FINITE ELEMENT COMPUTER PROGRAM USED

The ABAQUS program [6] is a powerful, intuitive, finite element program developed and maintained by Hibbitt, Karlsson and Sorensen, Inc. (HKS) through their company established in 1978. The ABAQUS system consists of a pre-processor ABAQUS/Standard, ABAQUS/Explicit and a postprocessor ABAQUS/Viewer or ABAQUS/CAE. The program is completely modular allowing the user to acquire and load only the modules that are needed. The input data for the program include nodal points, type of element, loading condition, material properties, dimensioning of the geometry of the structure, the restraints of nodes, the required type of analysis and the termination criteria.

3.1. Solid Elements

ABAQUS has an extensive element library to provide a powerful set of tools for solving many different problems. Generally there are five main important aspects for choosing an element and characterizing its behavior. These aspects are the element family, degrees of freedom, number of nodes, formulation and integration. Figure 1 shows the element families that are used most commonly in a stress analysis. One of the major distinctions between different element families is the geometry type that each family assumes.

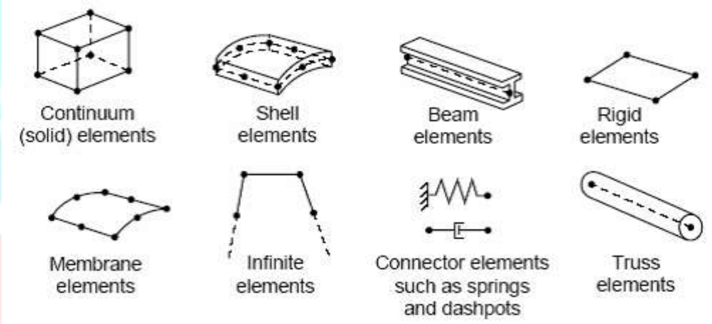


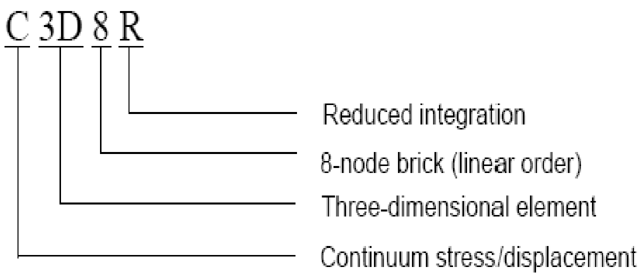
Fig. 1. ABAQUS commonly used element families (HKS 2010)

The degrees of freedom are the fundamental variables calculated during the analysis. For a stress/displacement simulation the degrees of freedom are the translations and, for shell and beam elements, the rotations at each node.

3.2. Solid Elements

Solid (continuum) elements are the standard volume elements of ABAQUS; they can be composed of a single homogeneous material or can include several layers of different materials for the analysis of laminated composite solids. Solid elements are more accurate if not distorted, particularly for quadrilaterals and hexahedra. The triangular and tetrahedral elements are less sensitive to distortion.

Regarding the finite element models introduced in this work, three dimensional 8-node first order reduced integration continuum elements (C3D8R - Bricks) are used to model the concrete core of the concrete deep beam specimens. These elements are versatile and can be used in models for simple linear analysis or for complex nonlinear analyses involving contact, plasticity and large deformations. The mentioned abbreviation stands for:



C3D8R is an element with reduced integration which has 1 Gauss point. This type of element solves the shear locking problem. Due to insufficient stiffness, spurious singularity (hourglass) may occur. In order to control this, an artificial stiffness method and artificial damping method in the ABAQUS code is proposed. As less integration points need to be computed, the computational time is largely shortened [7].

3.3. Material Models

In order to obtain accurate analysis, proper material models are needed. To be able to understand the mechanical behavior to final failure, it is important that this non-linear behavior can be simulated in the finite element analyses. The nonlinearities of the concrete in compression and the steel were accounted for with plasticity models. Three major effects cause the non -linear response of reinforced concrete namely:

- Crushing of concrete in compression.
- Cracking of concrete in tension.
- Yielding of reinforcement.

Nonlinearities also arise from the interaction of the constituents of reinforced concrete such as, bond - slip between reinforcing steel and surrounding concrete, aggregate interlock at a crack and dowel action of the reinforcing steel crossing a crack. The steel elements were provided with isotropic multi linear elasto-plastic material model.

3.4. Element Size

Element size has significant effect on accuracy of finite element results. It effects the convergence of the problem, computational time and penetration between the master and slave surfaces. Fine mesh could improve the accuracy of results; but, it increases the computational time required to do the simulation. Coarse mesh leads to inconsistent results, penetration and convergence problems during simulation process. However, time required to complete the simulation is less due to less number of elements. One alternative to get the advantages of fine mesh with less computational time is the adaptive meshing. Adaptive meshing maintains a high-quality mesh throughout the solution by adjusting the mesh to restore aspect ratio of highly distorted elements. Two types of mesh elements were used; linear and quadratic, Using quadratic meshing made the error smaller due to some reasons as follows:

1. The high order approximation for the finite element (keeping the same size) leads to the small error for the solution if all parameters (boundary conditions, geometry, materials) are sufficiently smooth. Thus the quadratic approximation is better than linear one.
2. Triangular shapes for FE of low order (linear) leads to the larger error (locking for bending).
3. Small size of FE leads to the smaller error (but it leads to many FE's).
4. If the parameters are not smooth (singularities in geometry such as edges, or in boundary conditions) than combinations of the low order FE around these singularities together with high order FE somewhat far from singularities leads to the both optimal small error and number of DOF.

3.5. Concrete Damaged Plasticity

Under low confining pressures, concrete acts in a brittle manner and the main failure mechanisms are cracking in tension and crushing in compression. If the confining pressure is adequately large to prevent the crack, the brittle behavior of concrete disappears. The damage in quasi-brittle materials can be defined by evaluating the dissipated fracture energy required to generate micro cracks.

Advantages of using concrete damaged plasticity model in ABAQUS:

1. Provides a general capability for modeling concrete and other quasi-brittle materials in all types of structures (beams, trusses, shells, and solids).
2. Uses concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behavior of concrete.
3. Can be used for plain concrete, even though it is intended primarily for the analysis of reinforced concrete structures.
4. Can be used with rebar to model concrete reinforcement.
5. Consists of the combination of non-associated multi-hardening plasticity and scalar (isotropic) damaged elasticity to describe the irreversible damage that occurs during the fracturing process.
6. Can be defined to be sensitive to the rate of straining.

IV. RESPONSE REDUCTION FACTOR

The response reduction/modification factor (R) simply represents the ratio of the maximum lateral force if the structure remains elastic (Ve) to the lateral force (Vd), it is designed to withstand [8]. R factor is an essential seismic design parameter that is typically used to describe the inelasticity level expected in lateral load resisting systems during earthquakes. And depends on the over-strength factor (Ω), the ductility factor (R_μ), the damping factor (R_ξ), and the redundancy factor (R_R) as indicated in equation (1) as suggested by ATC-19 [9].

$$R= R_s R_\mu R_R R_\xi \qquad (1)$$

4.1. Over Strength Factor

The over-strength factor (Ω) considers the structure yielding at load higher than the design load because of various partial safety factors such as the difference between actual and design material strength, conservatism of design procedure and ductility requirements, load factors and multiple load cases, serviceability limit state provisions, participation of non-structural elements, minimum reinforcement and member sizes that exceed the requirements of design, redundancy of the RC structure and stresses redistribution between structural members, strain hardening, actual confinement effect.

The over-strength factor is a measure of the built-in over strength in a lateral load resisting system and is obtained by dividing the yield base shear (Vy) by the design base shear (Vd) as indicated in equation (2).

$$\Omega = V_y / V_d \qquad (2)$$

4.2. Ductility Factor

The ductility factor (□□) is a measure of the global non-linear response of a lateral load resisting system in terms of its plastic deformation capacity. It depends on the fundamental period of the structure as indicated in equations (3), (4) & (5).

Short period ($T < 0.2$ seconds): $R\mu = 1$ (3)

Intermediate ($0.2 < T < 0.5$ seconds): $R\mu = (2\mu-1)0.5$ (4)

Long period ($T > 0.5$ seconds): $R\mu = \mu$ (5)

Where: $\mu = \Delta u / \Delta y$

Figure 2 shows the three above mentioned ranges for time periods. The first region is referred to as equal acceleration, the second as equal energy and the third as equal displacement. The limits of these regions are not fixed for all earthquakes and the above period ranges are only indicative.

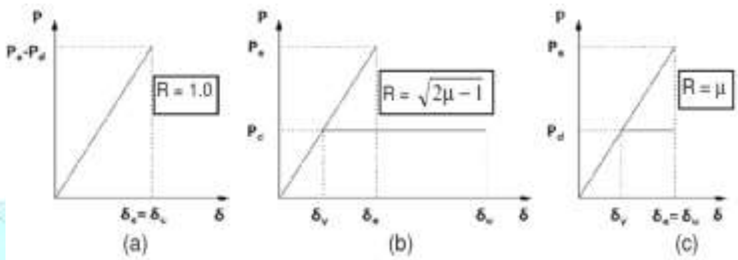


Fig. 2. Relationship between elastic and in-elastic forces for (a) short period (b) intermediate period (c) long period structures. (Newmark and Hall, 1982) [10]

4.3. Damping Factor

The damping factor (R_ξ) considers the effect of added viscous damping and its primarily applicable for structures provided with supplemental energy dissipation devices. Without such devices, the damping factor is usually taken as 1.00.

4.3. Redundancy Factor

The redundancy factor (R_R) is a measure of redundancy in a lateral load resisting system. The redundancy factor is taken as 1.00 for redundant structures.

V. ANALYSIS METHODS

Two methods of analysis were used in modeling in this study. These methods are non-linear static pushover analysis and non-linear time history analysis.

5.1. Pushover Analysis

Non-linear static pushover analysis is defined as an analysis where in a mathematical model directly incorporating the non-linear load deformation characteristics of individual elements and components of the structure shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a target displacement is exceeded. Target displacement is the maximum displacement (elastic &in-elastic) of the structure at roof expected under selected earthquake ground motion.

The pushover analysis assesses performance by estimating the force/deformation capacity and seismic demand using a non-linear static analysis. The seismic demand parameters are story drifts, global displacement, story forces and component deformations / forces. The analysis considers material in-elasticity, geometrical non-linearity and internal forces redistribution.

Pushover analysis can be performed by either force-controlled or displacement-controlled depending on the physical nature of the load and the behaviour expected from the structure. Force-controlled option is useful when the load is known and the structure is expected to be capable of resisting the load. Displacement-controlled procedure should be used when specified drifts are sought, where the magnitude of the applied load is not known in advance, or where the structure can be expected to lose strength or become unstable.

The lateral loadis increased in increments with a specific pre-defined pattern (such as uniform or inverted triangular pattern). The gravity load is held constant at its full value.

5.2. Time History Analysis

Non-linear dynamic analysis can be conducted using non-linear time-history analysis. The building codes require that accelerograms (time-acceleration histories) be compatible with a given design spectrum if the 5% damped response spectrum of the accelerogram is close to the design spectrum within a specified period range, which is usually referred to as the period range of interest.

A review of advanced codes for seismic design of buildings shows that there are certain differences between building codes regarding the period range of interest and the degree of compatibility of the accelerograms. According to the ASCE standard, at least three accelerograms are required for analysis of buildings.

ASCE requires that the selected accelerograms be properly scaled such that the 5% damped mean spectrum of the set is above the design spectrum for all periods between 0.2T and 1.5T, where T is the fundamental period of the building for the analysed direction. The ASCE standard also requires that if less than seven accelerograms are used then the three maximum values of the responses should be considered for the design. If seven or more expectations are used, then the average values of the response parameters should be used in the design. Fig. 3. Shows a typical relationship between time and acceleration.

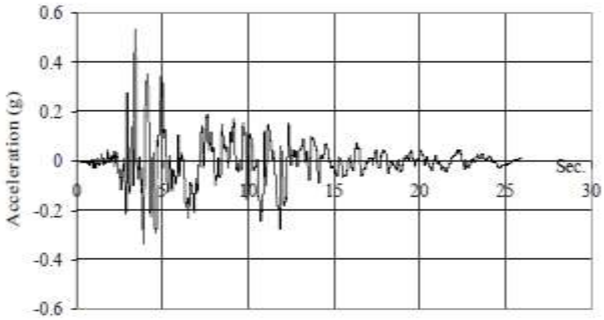


Fig. 3. Typical relationship between time (second) and acceleration (g)

Table 1 Properties of ground motions (adopted from PEER 2006)

Record	Earthquake	Site	Date	PGA (g)	PGA (MAX) (g)
1	San Fernando	La Hollywood Stor Lot	Feb- 09, 1994	0.174	1.55
2	San Francisco	Golden Gate	March-22, 1944	0.112	2.90
3	Northridge	Playa Del Rey	Jan- 17, 1994	0.136	1.03
4	Imperial Valley	Bonds Corner	Oct- 15, 1979	0.775	1.13
5	Imperial Valley	El-Centro	May- 19, 1940	0.143	1.29
6	Imperial Valley	El-Centro	May- 19, 1940	0.313	1.19
7	Loma Prieta	Apeel Crystal-Spr Res	Oct- 18, 1989	0.104	1.33

A series of three earthquakes with low, medium, and high frequencies were selected for the nonlinear dynamic analyses to be assigned for the 1st case study and the 3rd case study. By reference the PEER database (PEER 2006) [11], time history of selected earthquakes along with peak ground acceleration (PGA) and year of occurrence of the earthquake are illustrated in Fig. 4. The maximum value for base shear is considered as per ECP code recommendations; in case of studying three earthquakes.

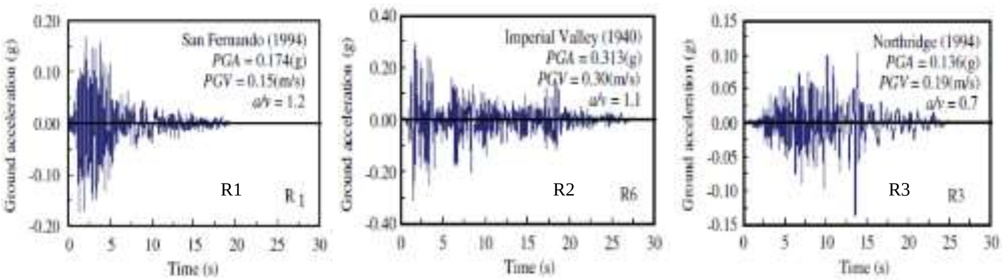


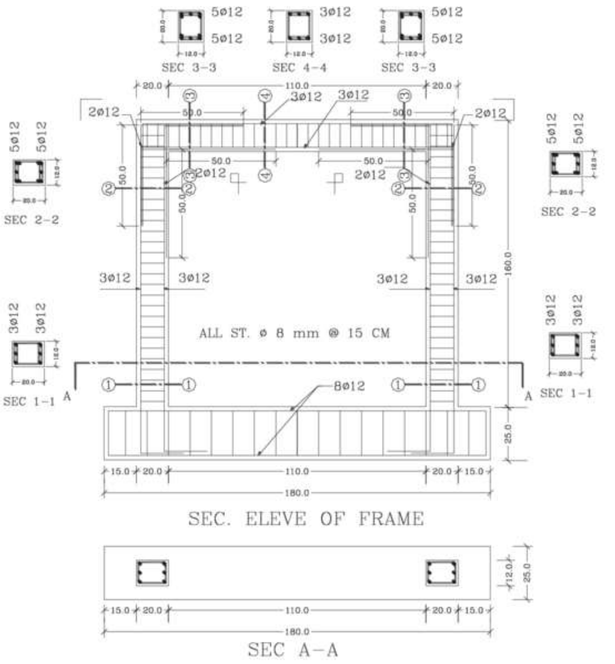
Fig. 4. Time history of selected ground motions

VI. VERIFICATION MODELS

In this respect, two experimental output data for reinforced concrete(RC) frames using pushover analysis and an additional experimental output data based on nonlinear time history analysis (three records for each) were compared with the output results from ABAQUS 6.14 software analytical models in order to check the reliability and validity of a nonlinear finite element model.

6.1. Experimental Data

6.1.1. Lila M.Abdel-Hafez et.al. (2015)



6.1.2. Ali Mansouri et al. (2013)

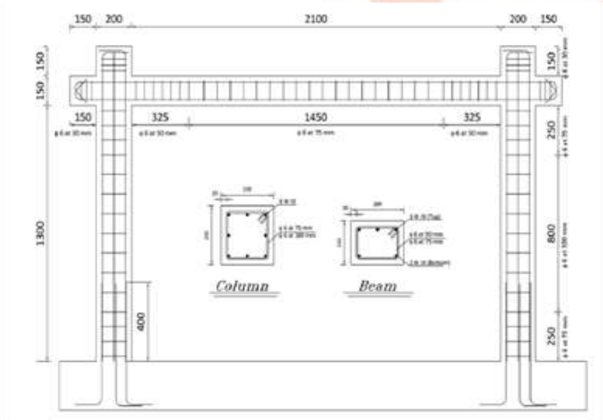


Fig. 4. Cross-Sections of the tested RC frames and their dimensions

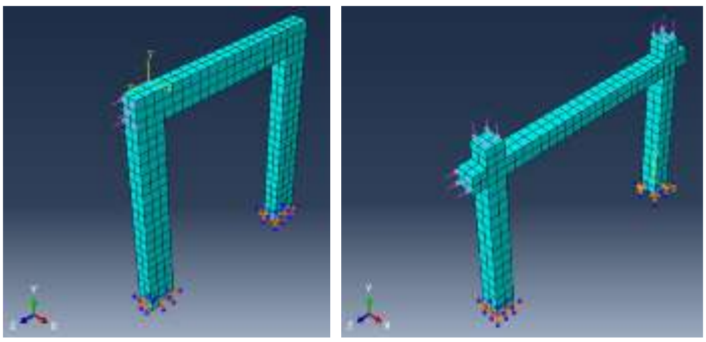


Fig. 5. ABAQUS analysis models developed for the tested RC frames

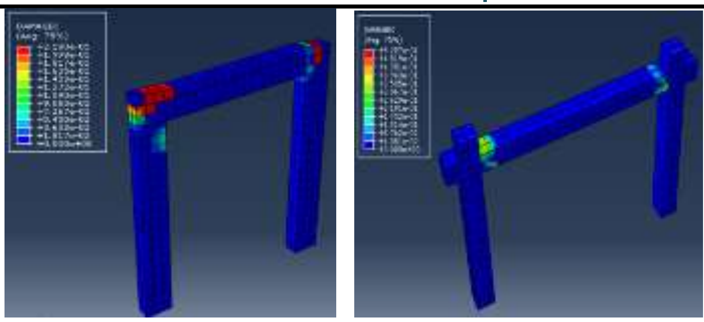


Fig. 6. Plastic hinges formation & crushing in concrete

6.1.3. Aslan Sadeghi Hokmabadi et, al. (2014)

Aslan et, al. (2014) tested ten story height moment resisting building frame under shaking table using time history analysis with three records of earthquake to study dynamic response of structures. Benchmark earthquakes including the 1995 Kobe, the 1994 Northridge and the 1940 El Centro earthquakes are adopted. Fig. 7. illustrate the shaking table tests on the fixed-base ten story model structures. Fig. 8. shows the ABAQUS analysis model conducted for this model.

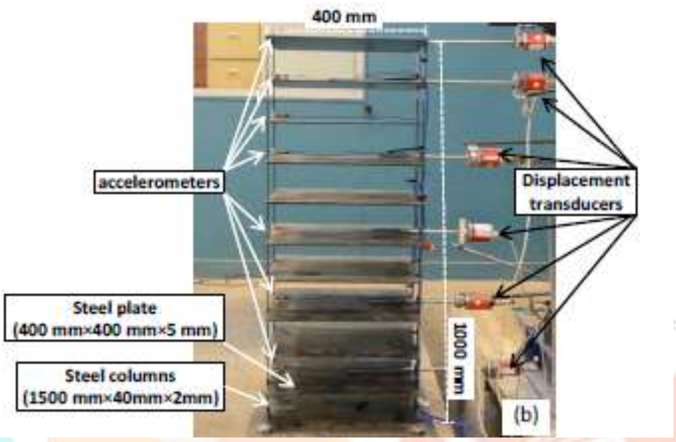


Fig. 7. Ten storey fixed-base model structure for shaking table tests

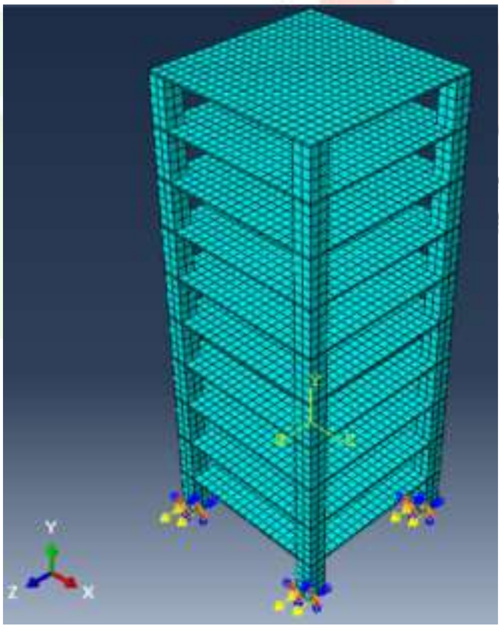


Fig. 8. ABAQUS analysis model for Five storey fixed-base structure

6.2. Evaluation of the Numerical Results

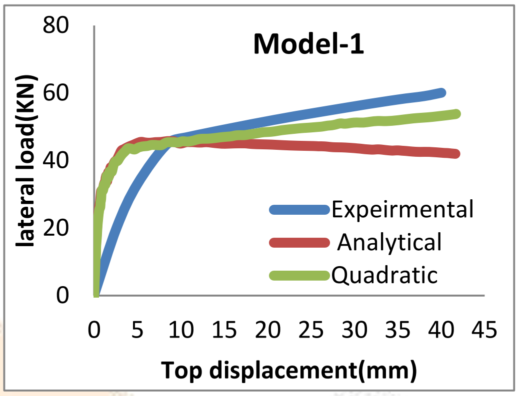
Fig. 9 & 10 show that there is a good agreement between the experimental results and the corresponding results from the pushover analysis for tested RC frames. A comparison between analytical & experimental results is presented regarding to pushover curve in Table 2, 3 and the error in results as shown is taken as the ratio between the difference of analytical and experimental result to the experimental value.

(Analytical mean value - Experimental mean value) / Experimental mean value] * 100%

Table 2 Results for the two reinforced concrete (RC) frames specimens

Model	Experimental (shear)	Analytical (shear)	% Error
	Qult(KN)	Qult(KN)	
1	65	55	15.3
2	60	57	5.00

Model	Experimental (displacemen)	Analytical (displacement)	% Error
	Δult (mm)	Δult (mm)	
1	40.07	41.70	4.07
2	16.8	19.53	16.2



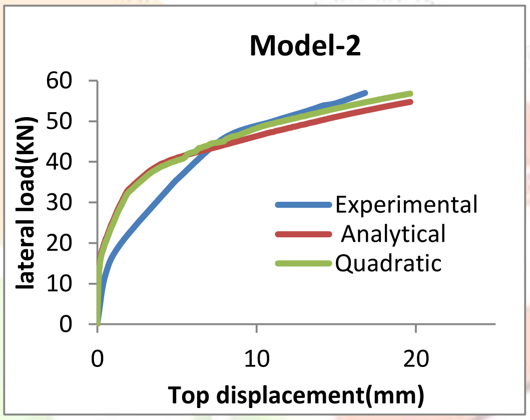


Fig. 9. Modeling Results for the two reinforced concrete (RC) frames specimens

Table 3 Results for nonlinear time history analysis

Story No.	(NORTHRIDGE 1994)		(KOBE 1995)		(ELCENTRO 1940)	
	Experimental displacement	Analytical displacement	Experimental displacement	Analytical displacement	Experimental displacement	Analytical displacement
0	0	0	0	0	0	0
1	1	0.98	1	1.04	1	0.966
3	5	5.79	2.5	2.66	2.5	1.95
5	11	11.65	6	5.3	5	5.82
7	16	16.2	9	8.25	7.5	7.65
9	17.8	18	12.5	11.1	8.5	9.3
10	18	18.8	13	12.01	9	10.9

% Error (NORTHRIDGE 1994)	
Story No.	Displacement
0	0
1	2.00
3	15.80
5	5.91
7	1.25
9	2.86
10	4.44

% Error (KOBE 1995)	
Story No.	Displacement
0	0
1	4.00
3	6.40
5	11.67
7	8.33
9	11.20
10	7.62

% Error (ELCENTRO 1940)	
Story No.	Displacement
0	0
1	3.40
3	22.00
5	16.40
7	2.00
9	9.41
10	21.11

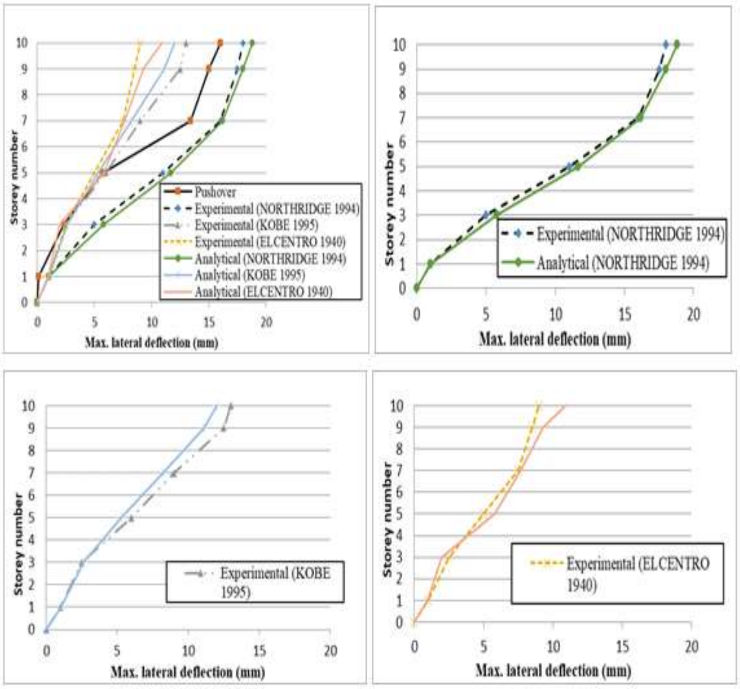


Fig. 10. Comparison between pushover and time history records for Max. Lateral deflection (mm) for model-3

VII. PARAMETRIC STUDY

7.1. Yield Deformations

Three case studies were analyzed to investigate the effect of number of stories on (R) factor. Fig. 11, 12 & 13 show the case studies geometry (plans & reinforcement details) used for modeling. The case studies configurations were selected to simulate a huge number of buildings that contain the same elements with a proper distribution in plan. In all cases, retaining walls were used to support two stories in basement, as the RC building contains two stories in basement and typical stories above ground with an upper roof. In the first case study, five typical stories were used, and in the second case study, ten typical stories were used, while for the third case study, fifteen typical stories were used. Their structural system is combined between RC frames and cores. Fig. 15 shows reinforcement details for columns, beams & cores.

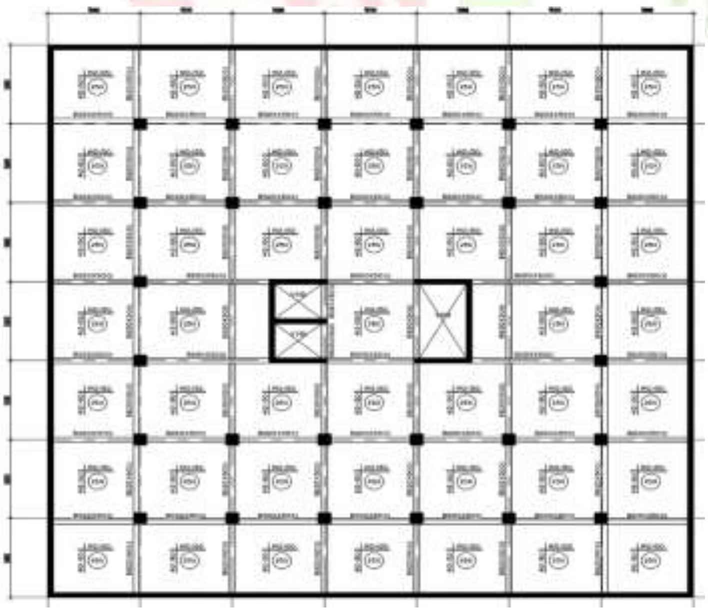


Fig.11. All case studies geometry (Two stories in basements)

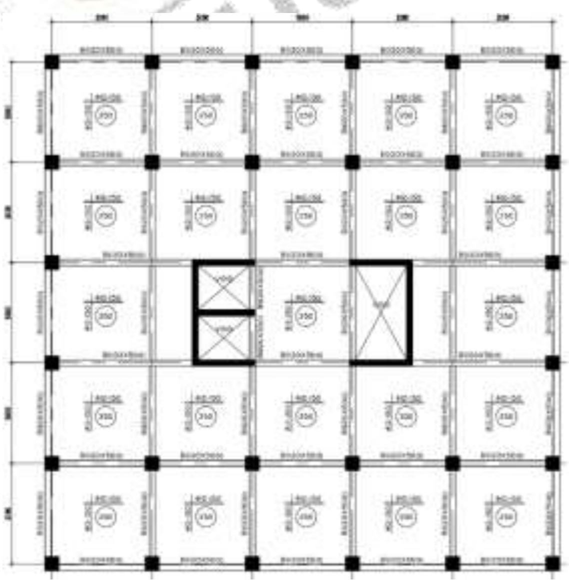
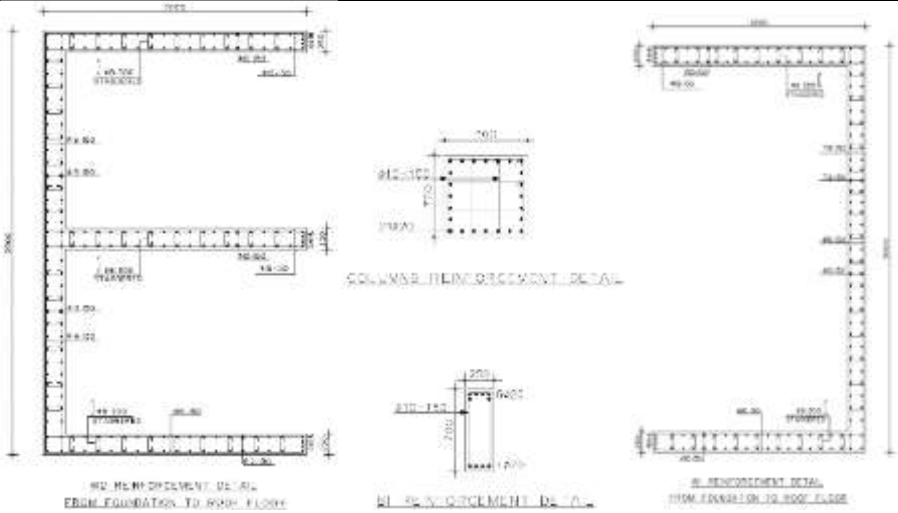


Fig.12. All case studies geometry (Stories in super structure)



. Fig. 13. Case studies geometry (reinforcement details)

The following material properties were used in the parametric study:

- Concrete compressive strength (cube) (fcu) =40 MPa
- Concrete young's modulus (Ec) = 26587.215 MPa
- Specific weight for concrete =25 kN\m3
- Steel yield strength (fy) = 400 MPa for vertical reinforcement and stirrups
- Steel young's modulus (Es) =200 GPa
- Specific weight for steel =78.5 kN\m3

  Vertical load was assigned to all levels, as follows:

- For basement stories & typical floors:

  Floor Cover = 2 kN/m2, Walls load = 2 kN/m2 and Live Load = 2 kN/m2.

- For roof floor & upper roof floor:

  Floor Cover = 2.5 kN/m2 and Live Load = 2 kN/m2.

Fig. 14, 15 & 16 show the ABAQUS modeling for concrete solid meshed elements and steel wire elements, while Fig. 17 shows the boundary conditions. Also Fig. 18 show the constraints assigned in analysis models. Fig. 19, 20 & 21 show loading for a sample from case studies (Vertical, Soil pressure & Lateral loading).

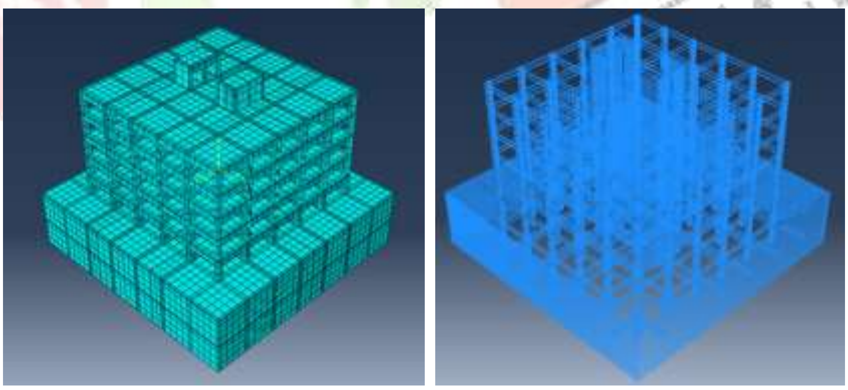


Fig. 14. 1st Case study ABAQUS model (concrete meshed elements & steel wire elements)

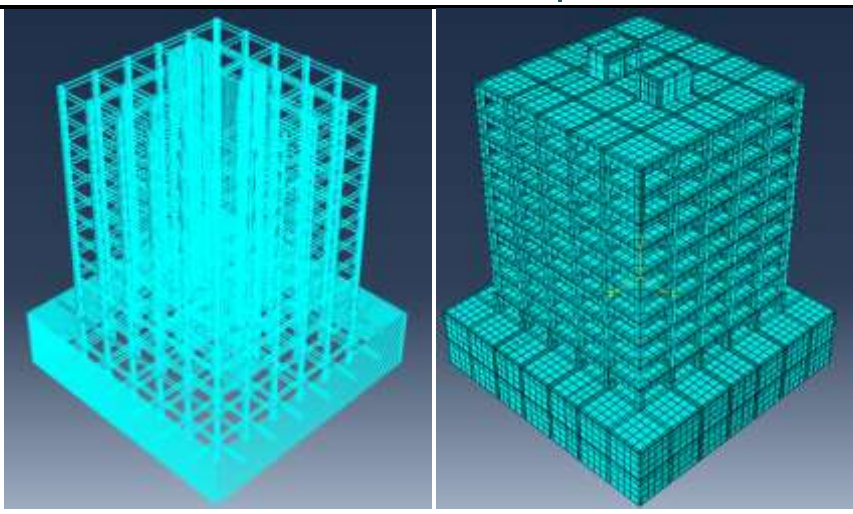


Fig. 15. 2nd Case study ABAQUS model (concrete meshed elements model & steel wire elements)

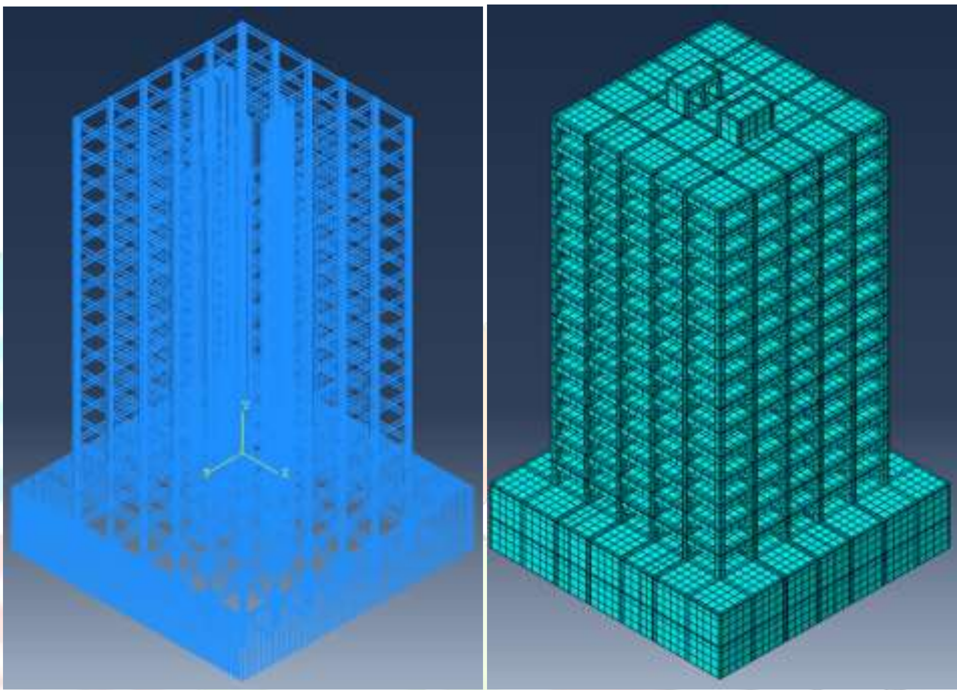


Fig.16. 3rd Case study ABAQUS model (concrete meshed elements & steel wire elements)

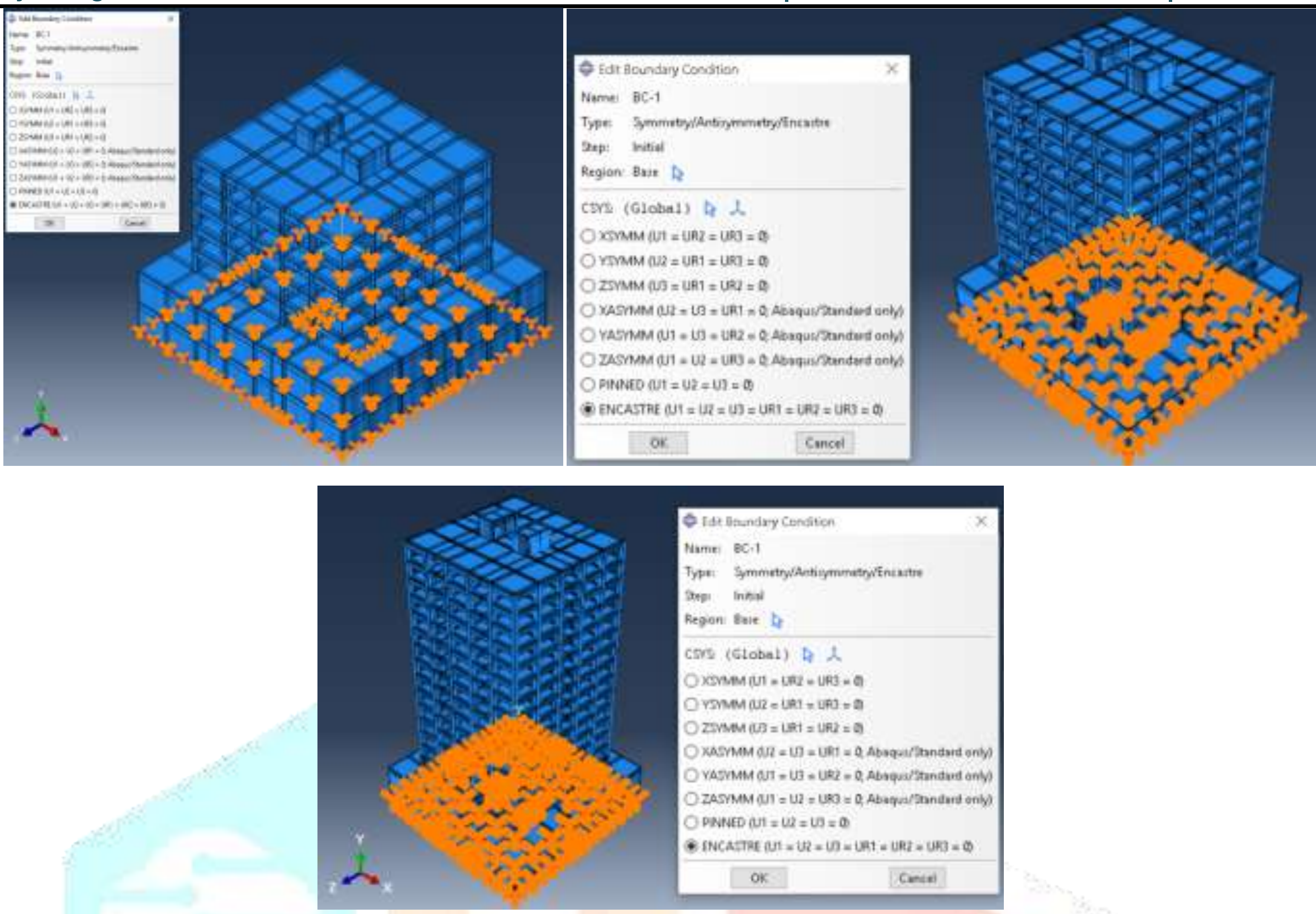


Fig. 17. All case studies ABAQUS models (Boundary conditions)

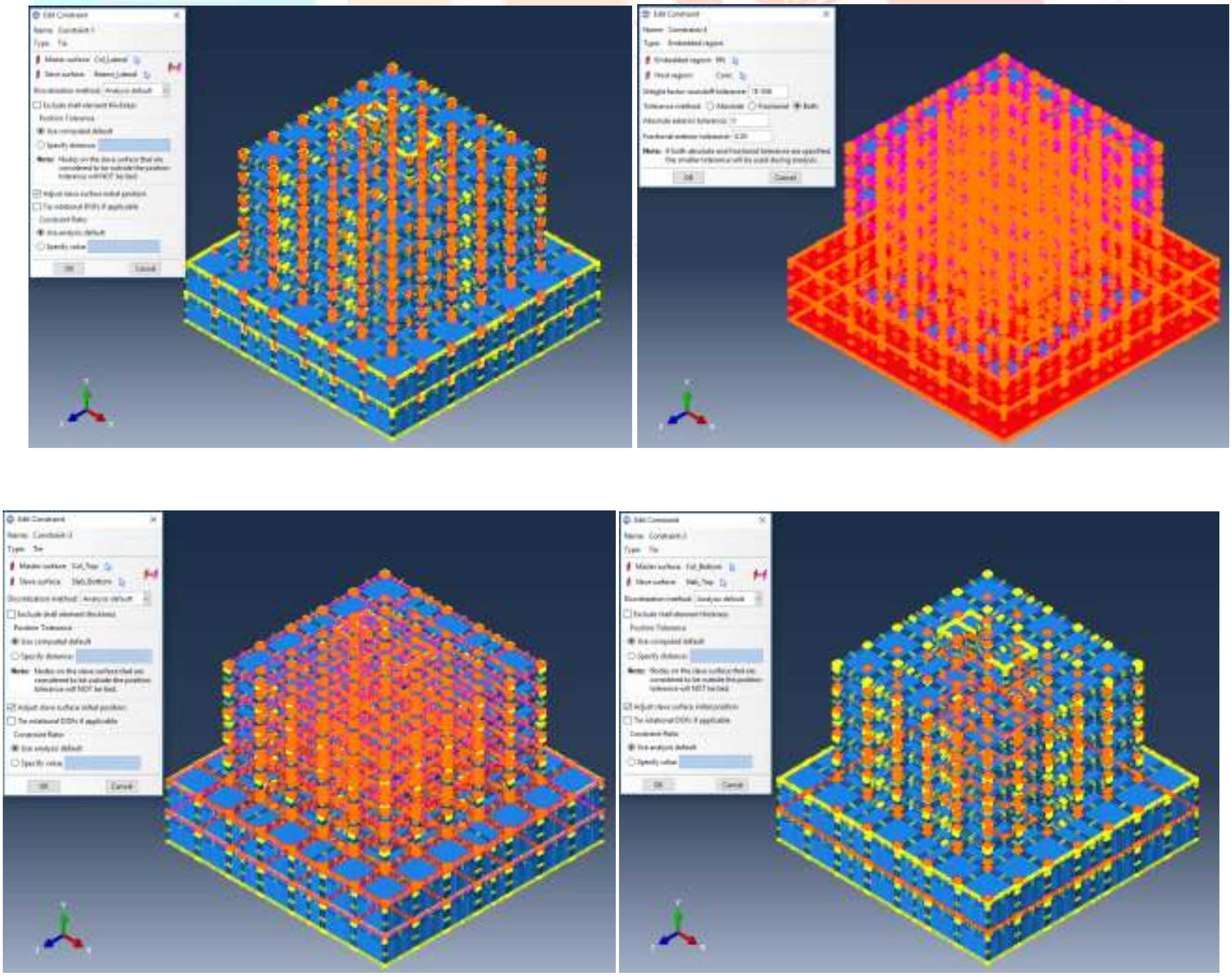


Fig. 20. Soil pressure on retaining walls

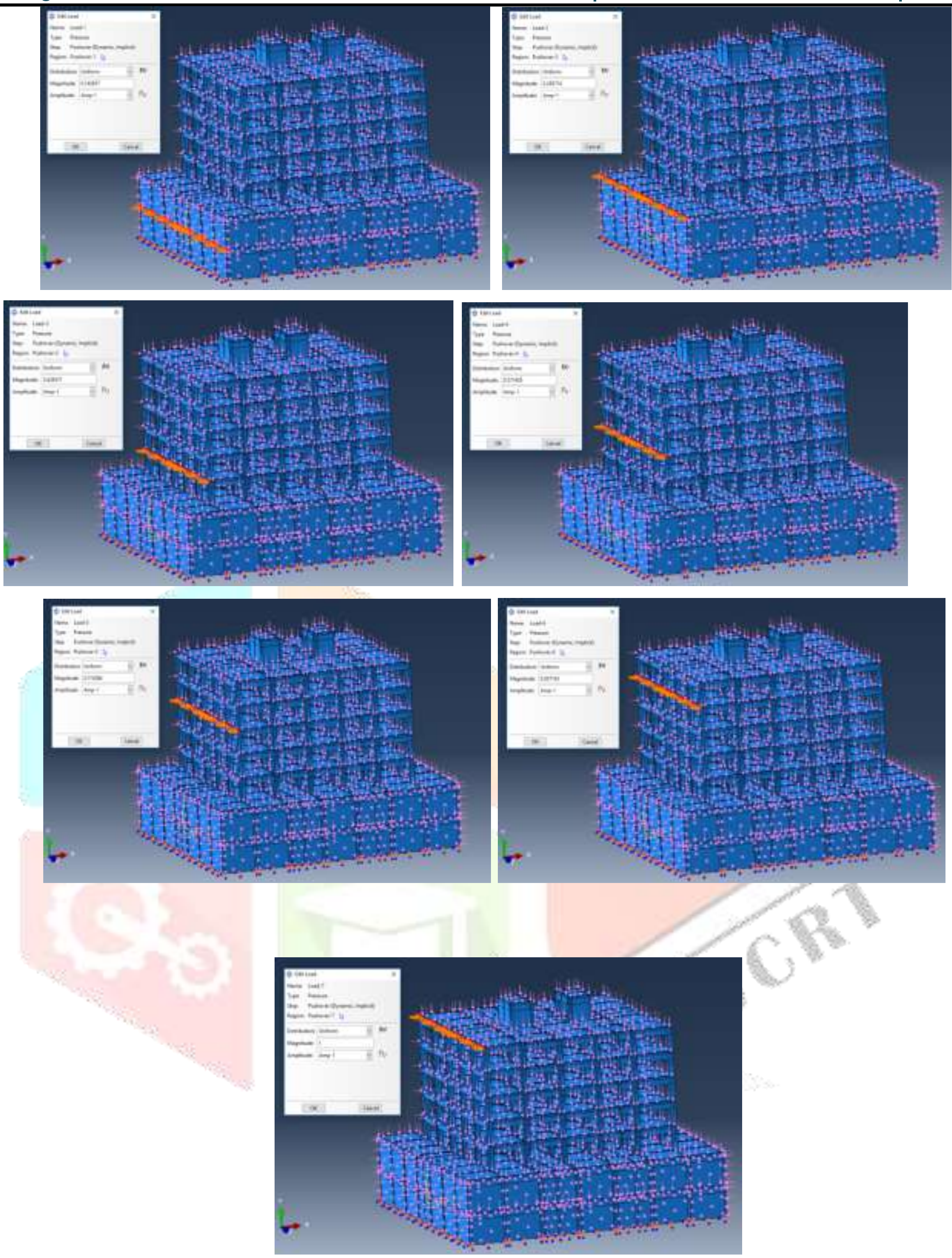


Fig. 21. Incremental loads assigned (in a triangular shape) based on pushover analysis in ABAQUS models

7.2. Failure criteria

The analyses were continued until the earlier from two options as per ECP code requirements.

- Stress in reinforcement =40 MPa
- Strain in concrete = 0.002 at maximum compressive strength according to ECP code, as shown in Fig. 22 & 23. Figure 24 shows plastic hinges formation & crushing in concrete for one model.

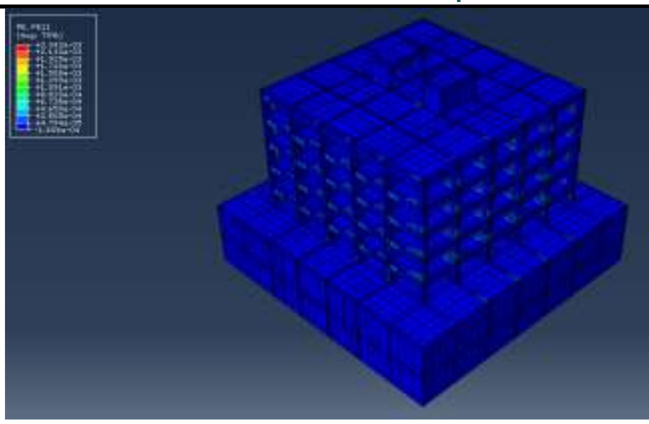


Fig. 22. Strain for concrete

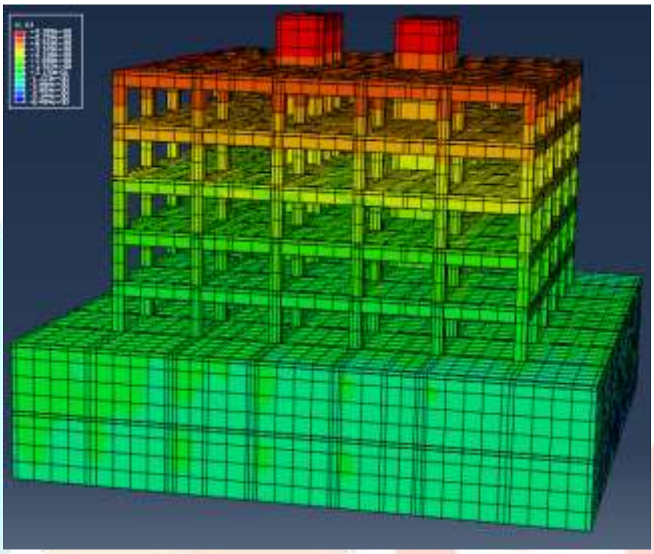


Fig. 23. Deformed shape for the 1st case study

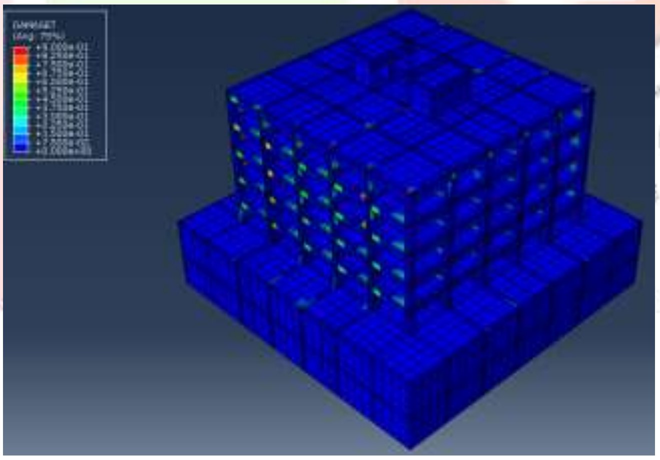


Fig. 24. Plastic hinges formation & crushing in concrete for the 1st case study

7.3. Observations From The Parametric Study

7.3.1. Pushover results

The results for base shear, displacement & calculated response modification factor considering pushover analysis are listed in Tables 3 and Fig. 25, 26 & 27.

Table 3 Results for studied RC buildings based on pushover analysis

Case study	V_u (kN)	V_d^f (kN)	T^g (second)	T^h (second)	R_s^i	Δ_u^j (mm)	Δ_y^k (mm)	μ^l	R_μ^m	R
1[a]	7191.07	4314.64	0.73	0.706	1.67	7.82	3.52	2.22	2.22	3.71
4[d]	2728.11	1636.86	1.03	1.493	1.67	34.89	9.99	3.49	3.49	5.83
5[e]	1088.11	652.87	1.30	2.357	1.67	49.90	10.91	4.76	4.76	7.95

[a]The first case study where retaining walls were used and soil pressure was assigned to them.

[b]The second case study where retaining walls were used and soil pressure wasn't assigned to them.

[c]The third case study where retaining walls weren't used.

[d]Vd Design base shear equal 60% of the ultimate load capacity as suggested by Uang (1991) [12].

[e]T Calculated max. time period as per ECP requirements, time period shall not exceed (1.2*0.05 *h0.75)

[f]T Fundamental period obtained from ETABS model for multi degree of freedom

[g]Rs =Vu / Vd

[h]Δu Max Top displacement at Vu, calculated based on peak load, as recommended by Park, R., and Paulay, T,1988 [13].

[I]Δy yield displacement, calculated based on equivalent elasto plastic yield as recommended by Park, R. & Paulay, T,1988 [13].

[j]μ =Ratio between the ultimate displacement and the yield displacement (Δu/ Δy).

[k]Rμ Function of μ depends on time period, as per Newmark & Hall assumptions [10]:

$T < 0.2$ seconds $R\mu=1$

$0.2 < T < 0.5$ seconds $R\mu=\sqrt{2\mu - 1}$

$T > 0.5$ seconds $R\mu=\mu$

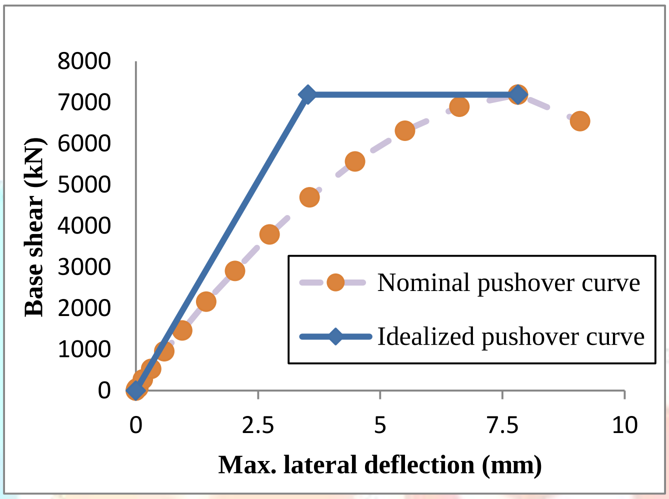


Fig. 25. Base shear versus top displacement (nominal curve & idealized curve) for 1st case study

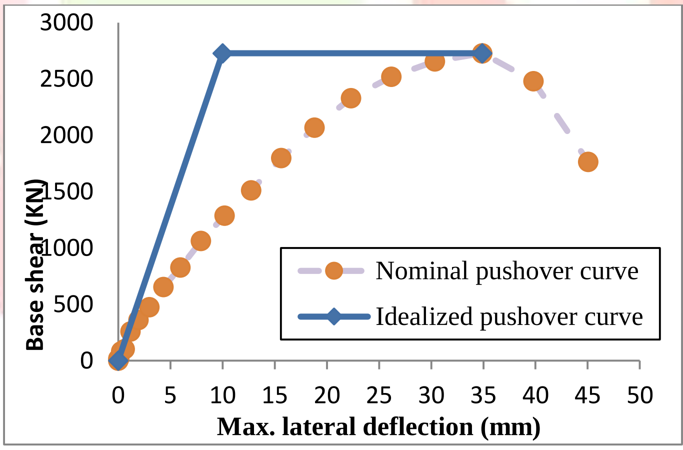


Fig. 26. Base shear versus top displacement (nominal curve & idealized curve) for 2nd case study

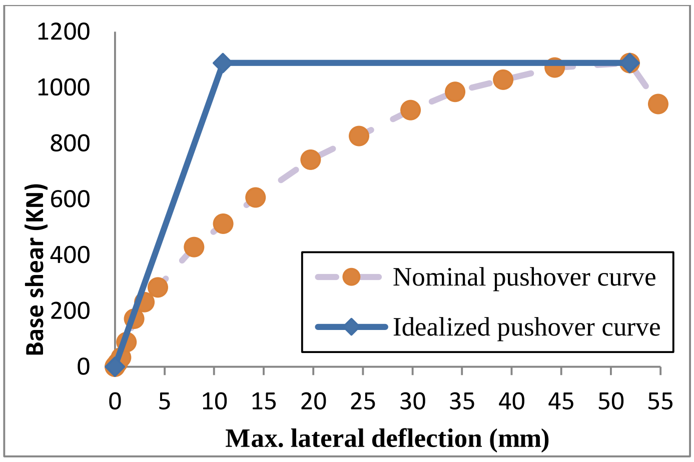


Fig. 27. Base shear versus top displacement (nominal curve & idealized curve) for 3rd case study

7.3.1. Time History results

The results for time history analysis models developed for the RC building for all case studies are listed in Tables 4 & 5.

Table 4 Results for all reinforced concrete (RC) frames models based on time history analysis

Case study	Record	(Vd = 4314.64 kN)	
		Ve (kN)	R= Ve/ Vd
1st	1- San Fernando (1994)	18578.7	4.31
	2- Northridge (1994)	17251.7	4.00
	3- Imperial Valley (1940)	16143.1	3.74
		Max.	4.31

Case study	Record	(Vd = 4314.64 kN)	
		Ve (kN)	R= Ve/ Vd
2nd	1- San Fernando (1994)	12141.5 4	7.42
	2- Northridge (1994)	11309.1 1	6.91
	3- Imperial Valley (1940)	10560.0 6	6.45
		Max.	7.42

Case study	Record	(Vd = 4314.64 kN)	
		Ve (kN)	R= Ve/ Vd
3rd	1- San Fernando (1994)	6012.90	9.21
	2- Northridge (1994)	5575.48	8.54
	3- Imperial Valley (1940)	5170.72	7.92
		Max.	9.21

Table 5 Comparison between time history results and pushover results for all case studies

Case study	Time history	Pushover
	R	R
1st	4.31	3.71
2nd	7.42	5.83
3rd	9.21	7.95

VIII. CONCLUSION

A parametric study was conducted to illustrate how the response modification factor would be affected in case of existence of multi-story basements, number of stories underground and taking in account the pressure effect from soil besides the retaining walls. The first main objective was to determine the R-value. While the second main objective was to compare the calculated response modification facto (R) values for reinforced concrete (RC) shear walls with those specified in ECP and international codes.

Some interesting conclusions could be extracted from the parametric study regarding the building behavior, taking in account that the calculated R values could be related only to similar RC structures, as follows:

- The (R) factor values, calculated for the RC structures with two basement stories and supporting retaining walls doesn't match ECP code recommended values, because the stiffness increases due to existence of retaining walls, which isn't considered in ECP code.
- The (R) factor values, calculated from analytical models for the RC structures for all case studies, match the recommended values in Euro code. As the Euro code [14] specify unique values for (R) factor for RC structures that have irregularity in elevation (a reduction of 20% shall be used), which is not considered in ECP code [15].
- Pushover analysis gives results for (R) factor that are close to time history analysis results.
- From pushover analysis, Increasing number of stories from five, ten to fifteen leads to a larger displacement, also a larger ductility factor.
- From pushover analysis, Increasing number of stories from five, ten to fifteen leads to a bigger (R) factor.
- From pushover analysis, Increasing number of stories from five, ten to fifteen leads to a smaller base shear with percentages of 62.1% & 60.11%, respectively, while time period increases with percentages of 111.5% & 57.87%.

- From pushover analysis, Increasing number of stories from five, ten to fifteen leads to a larger displacement, also a larger ductility factor.
- From pushover analysis, Increasing number of stories from five, ten to fifteen leads to a bigger (R) factor with a percentage of 157.1%.

NOTATIONS

- E_s: Steel Young's Modulus
- E_c: Concrete Young's Modulus
- F_{cu}: concrete Compressive Strength
- EQ: Earthquake
- f_y: Steel Yield Stress
- FE: Finite Element
- PGA: Peak Ground Acceleration
- PGV:Peak Ground Velocity
- R: Response Reduction/Modification Factor
- RC: Reinforced Concrete
- R_μ: Ductility Factor
- V_u: Maximum Base Shear
- Δy: Yield Displacement
- μ: Ductility Capacity
- Ω: Over-Strength Factor

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