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Efficient Mass Participation Ratio of Building with Basement

Nagy.F. Hanna[1], Ali.M. Elrafei[2], Magdy.M.M Genidi[3],Tamer M. S. Elsaied[4]
[1]*Professor - Department Of Structural Engineering. Faculty Of Engineering - Helwan University*
[2]*Associate Professor - Department Of Structural Engineering. Faculty Of Engineering - Cairo University*
[3]*Associate Professor - Department Of Structural Engineering. Faculty Of Engineering - Helwan University*
[4]*Design Engineer - Mamdouh Hamza Office For Engineering Consultancy – Cairo - Egypt*

Abstract: *This study investigates the effect of basement floor(s) on seismic analysis of buildings. Considering the basement floor(s) in the seismic analysis using response spectrum method creates a problem regarding the mass participation ratio (MPR) which should not be less than 90% of total mass of building as a requirement by the code. While the MPR depending on the number of mode shapes used in the modal analysis, some codes allow to neglect this ratio with condition that use a reduced number of mode shapes with some restrictions to calculate it. A parametric study was performed to investigate this reduced number of mode shapes and a new restriction was performed to calculate it. The natural period, the top lateral displacement and the internal straining actions using the reduced numbers of mode shapes were compared with those of building where using the number of mode shape which can reach 90% MPR.*

Finite element simulations are conducted using ANSYS program to investigate the effect of basement floor(s). Results are presented for different buildings by considering different numbers of floors for the super structure (2, 5, 10, 15 and 20), the number of basements (1 and 3) and spring support stiffness, which simulate the effect of soil.

The numerical results of the considered cases show that the requirement of 90% MPR can be neglect by using a reduced number of mode shapes and some restrictions stated in this study. In such case the accuracy will be not less than 95%.

I. Introduction

Many buildings have basements which are used as parking lots or shopping malls etc. The current state of practice for seismic analysis of buildings with basement floor(s) involves approximate approaches that primarily differ according to the designer's judgment and experience. This is a consequence of lack of relevant recommendations in building codes. In the seismic analysis of buildings if the response spectrum analysis method is used, the accuracy of this method is depending on the participated part of the total mass of building in the modal analysis, which is called mass participation ratio (MPR). Most codes require a minimum MPR of 90%. The modal analysis is depending on the number of mode shapes (NOMS) used. In case of buildings with no basements, this requirement of the 90%MPR can be easily reached with a few NOMS. On the other hand, in buildings with one or more basements, to reach such minimum value of MPR, it requires very large NOMS. This can be explained by the fact that the superstructure mass (due to its flexibility) participates in the modes with large period whereas the basement (due to its rigidity) mass does not. In order for the basement mass to participate, the mode shapes with very small period should be recalled which sometimes is difficult to achieve.

The main objective of this study is to better understand the seismic performance of building with basement floor(s). Therefore in this study the natural period, the top lateral displacement and the internal straining actions are carefully investigated to investigate the validity of the MPR requirement by the codes of practices to be a minimum of 90%, this will be achieved by comparing the buildings using a reduced NOMS with those buildings in which NOMS can reach the requirement of 90% MPR is used. To achieve this objective, response spectrum analysis for 3D intermediate moment frame building with superstructure ranging from two to twenty stories, basement stories ranging from zero (i.e. no basement) to three basement stories and foundation type simulated as fixed base at foundation level or raft with Winkler type foundation support.

1- Problem description

3-1 Example structure

A typical flat slab with 3x3 bay spans supported by moment resisting frame system having a constant bay span width of 7.00 m and story height of 3.00 m is used as an example building to investigate the effect of basement floor(s). Fig.1 shows the plan of repetitive story slab. The thickness of the slab is taken as 0.30 m to fulfill the safety requirements against slab design (deflection, punch, etc.). The thickness of basement walls is taken as 0.30 m to fulfill the safety requirements against earth pressure. Columns cross sections are taken according to the design requirements of gravity loads with margin factor of safety for the addition straining actions from seismic analysis. The columns cross-section was curtailed every five stories as shown in Table 1.

To accomplish the investigation of the effect of basement floor(s), five 3D buildings were conducted as follows:

A- Building type ***A*** which is fixed at the ground level as shown in Fig.2
B- Building type ***B*** which has one basement with fixed base as shown in Fig.3
C- Building type ***C*** which has one basement supported on raft as shown in Fig.3
D- Building type ***D*** which has three basements with fixed base as shown in Fig.4
E- Building type ***E*** which has three basements supported on raft as shown in Fig.4

For each building different number of the superstructure floors was studied namely: 2, 5, 10, 15 and 20 floors.

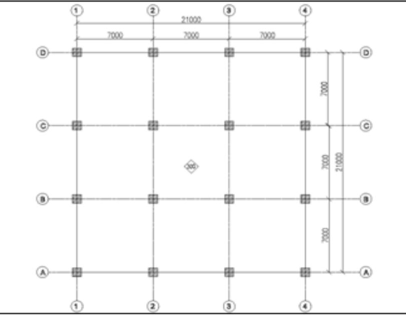

Figure 1 Typical plan

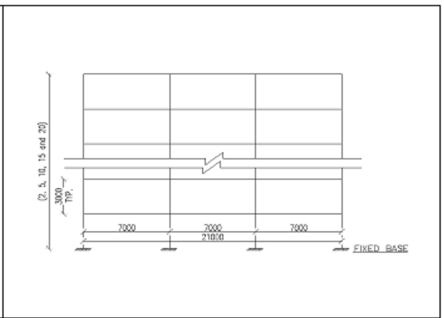

Figure 2 Building type ***A***

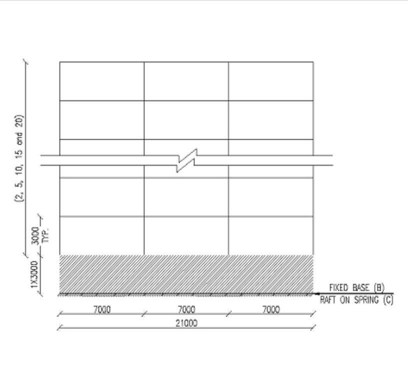

Figure 3 Building types ***B & C***

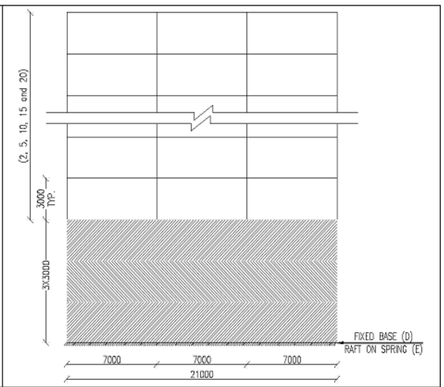

Figure 4 Building types ***D&E***

Table 1 Columns-Raft schedule

COLUMNS SCHEDULE (Mm)						RAFT (Mm)
# OF STORIES	LOCATION	FROM FOUND. UP TO 5 STORIES	FROM 5 TO 10 STORIES	FROM 10 TO 15 STORIES	FROM 15 TO 20 STORIES	
20	CORNER	800X800	700X700	600X600	500X500	2500
	EDGE	1000X1000	900X900	800X800	700X700	
	INTERIOR	1500X1500	1300X1300	1100X1100	900X900	
15	CORNER	700X700	600X600	500X500	----------	2000
	EDGE	900X900	800X800	700X700	----------	
	INTERIOR	1300X1300	1100X1100	900X900	----------	
10	CORNER	600X600	500X500	----------	----------	1500
	EDGE	800X800	700X700	----------	----------	
	INTERIOR	1100X1100	900X900	----------	----------	
5	CORNER	500X500	----------	----------	----------	1000
	EDGE	700X700	----------	----------	----------	
	INTERIOR	900X900	----------	----------	----------	
2	CORNER	400X400	----------	----------	----------	600
	EDGE	600X600	----------	----------	----------	
	INTERIOR	700X700	----------	----------	----------	

II. Modeling And Analysis

In all numerical analysis performed in this study the finite-element based program "ANSYS version 11+ Civil FEM" was used for the analysis of the 3-D buildings. The Euro code design spectrum for elastic analysis type 2, seismic zone A, design ground acceleration 1.00 m/sec, behavior factor 3.45 and ground type A were used to assign horizontal direction response spectrum.

The different structural elements were modeled using BEAM4 element for the concrete columns, SHELL63 element for the slabs, walls and raft, Spring-Damper COMBIN14 element for the Winkler type foundation. The Winkler spring Stiffness was chosen as 0.4N/mm^3 to fulfill the story drift limitation.

Three different total NOMS will be considered in the analysis and will be compared to each other. Those total numbers are:

1- Total NOMS (I) which is the NOMS which can reach 90% MPR.

2- Total NOMS (II) which is required for the superstructure only (without considering the basement in the analysis) to reach the minimum requirement MPR of 90%. This number will be applied in the case of the whole building including basement(s) and will be considered as a reduced NOMS recommended by the authors.

3- Total NOMS (II) which is a reduced NOMS required by EUROCODE 8 (2004) clause 4.3.3.3.1(5) witch state that :

The minimum number of k modes to be taken into account in a spatial analysis should satisfy both the two following conditions:

$K \geq 3.\sqrt{n}$ And $T_K < 0.20$ Sec

Where

K is the number of modes taken into account;

n is the number of stories above the foundation or the top of a rigid basement;

T_k is the period of vibration of mode T_k

III. Results

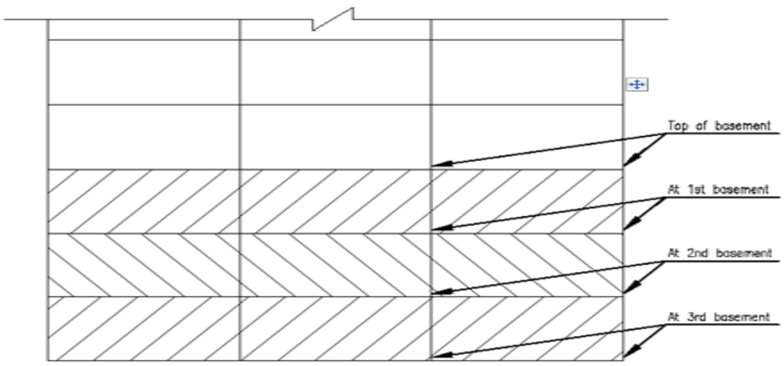

Figure 5 Studied sections

The comparison of the results between building type ***A*** (considered as the reference building) and the other buildings types ***B*** to ***E*** will be based on the following parameters: the natural period of vibration, the story shear, the lateral displacement and the straining actions of columns A-3, A-4, B-3 and B-4. These columns cover the following cases:

A- Case of column connected to concrete retaining wall along its longitudinal direction (Column A-3).

B- Case of column connected to concrete retaining wall at its corner (Column A-4).

C- Case of column not connected to concrete retaining wall but the column cross section is extended to the base of building (Column B-3).

D- Case of column connected to concrete wall along its transverse direction (Column B-4).

For these columns, only the sections which are shown in figure 5 were considered. The comparison of the different variables is presented in form of ratios. By ratios we mean the value of a given variable for buildings types ***B*** to ***E*** using the reduced number of NOMS (II) and (III) divided by the value of the same variable for same buildings using NOMS method (I), then the envelope of these ratios is developed. Also comparison is developed between the internal straining actions in basement floor(s) (1st, 2nd and 3rd basement) with the internal straining actions at the top of basement slab.

5-1 Number of mode shapes

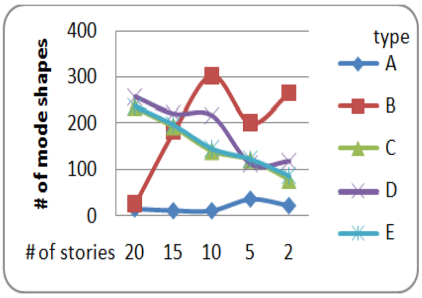

Figure 6 Number of mode shapes (I)

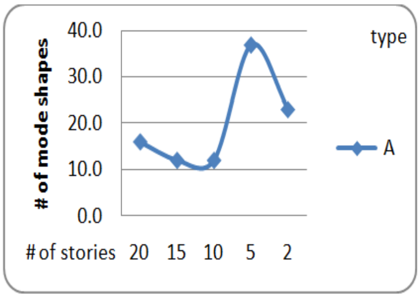

Figure 7 Number of mode shapes (II)

Figures 6, 7 and 8. Shows that the number of mode shapes (I) reach up to 300 mode shape to achieve 90% MPR. With max 40 mode shapes, NOMS (III) is higher than that required for (II) for the high building (20, 15 and some of 10 stories). while for medium and low buildings (some of 10, 5 and 2 stories) Number of mode shapes (II) is higher than that required for (III),

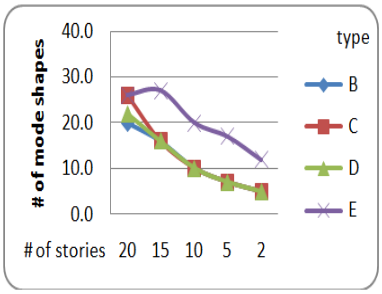

Figure 8 Number of mode shapes (III)

5-2 Effect of the reduced number of mode shapes on the MPR

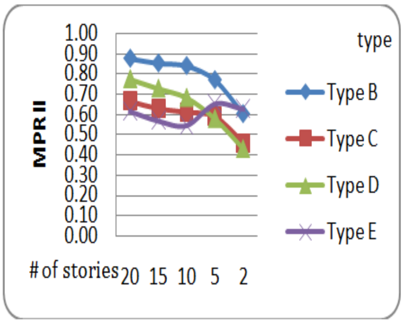

Figure 9 MPR II

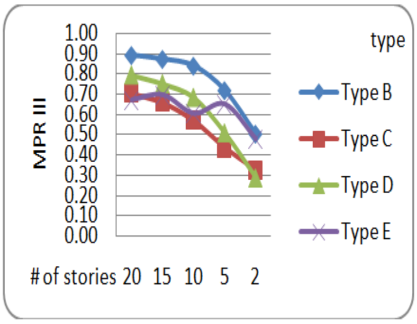

Figure 10 MPR III

5-3 Lateral displacement ratios

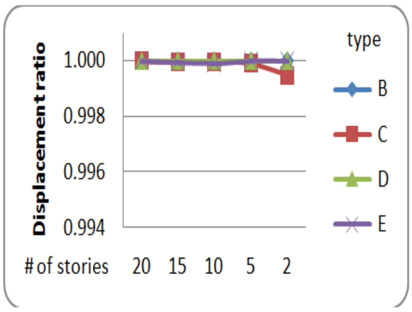

Figure 11 Comparison between lateral displacement ratios for (II/I)

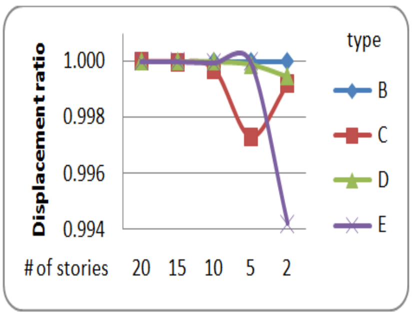

Figure 12 Comparison between lateral displacement ratios for (III/I)

Figures 9 and 10 shows the decreases of the MPR for the reduced NOMS (II) and (III) which is reach up to 25% MPR

Figures 11 and 12 shows the effect of the reduced NOMS on the lateral displacement of buildings, for buildings (20, 15 and 10 stories) it is clear that there are no different between mode shapes (II) and (III), however for buildings (5 and 2 stories) mode shapes (II) is more accurate than mode shapes (III).

5-2 Bending moment and shear force ratios of columns

5-4-1 Column at axes A/3

5-4-1-1 At top of basement slab

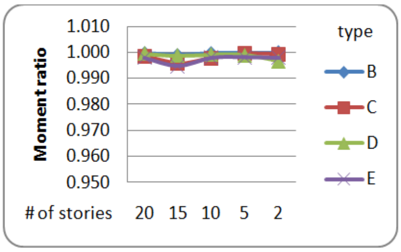

Figure 13 Ratio of (II)/(I) for Moment (At top of basement)

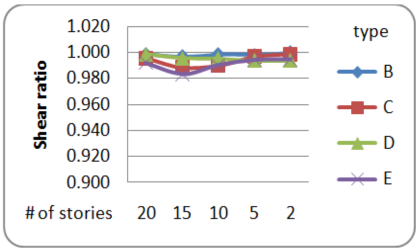

Figure 14 Ratio of (II)/(I) for shear (At top of basement)

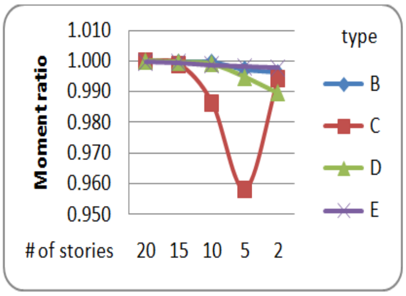

Figure 15 Ratio of (III)/(I) for Moment (At top of basement)

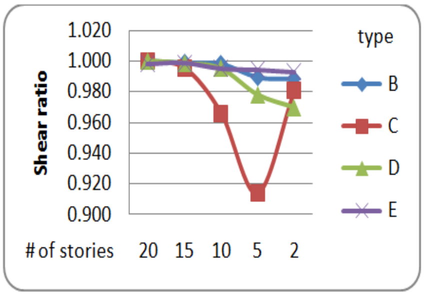

Figure 16 Ratio of (III)/(I) for shear (At top of basement)

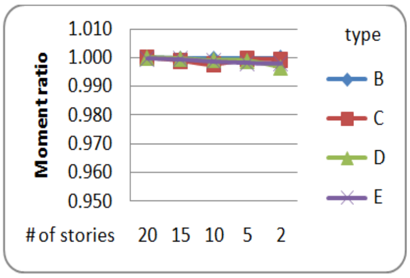

Figure 17 Envelope of the Moment ratios (At top of basement)

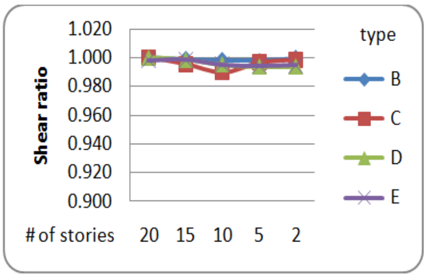

Figure 18 Envelope of the Shear force ratios (At top of basement)

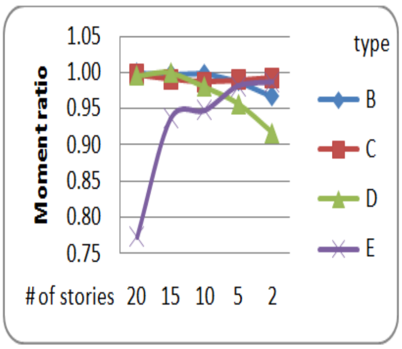

Figure 19 Ratio of (II)/(I) for Moment (At 1st basement)

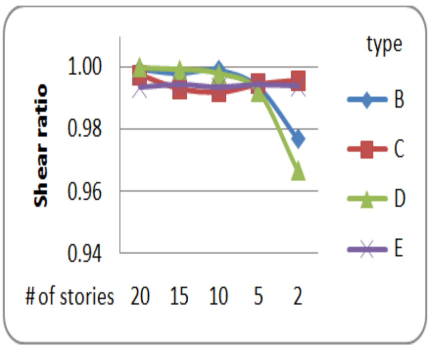

Figure 20 Ratio of (II)/(I) for shear (At 1st basement)

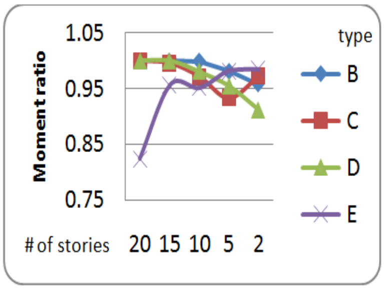

Figure 21 Ratio of (III)/(I) for Moment (At 1^{st} basement)

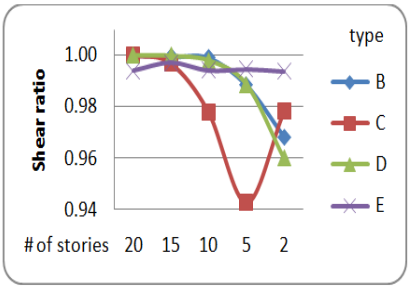

Figure 22 Ratio of (III)/(I) for shear (At 1^{st} basement)

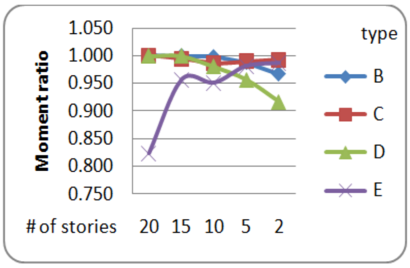

Figure 23 Envelope of the Moment **ratios** (At 1^{st} basement)

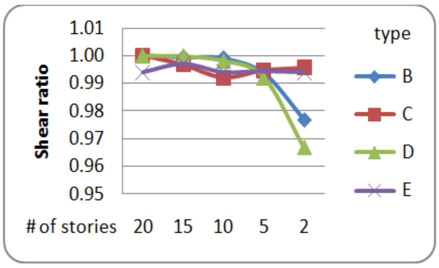

Figure 24 Envelope of the Shear force ratios (At 1^{st} basement)

At 1^{st} basement

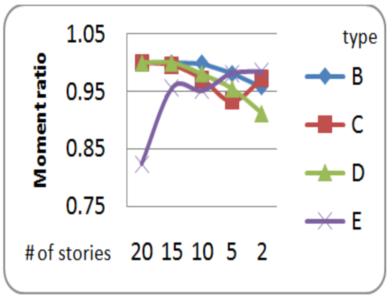

Figure 21 Ratio of (III)/(I) for Moment (At 1^{st} basement)

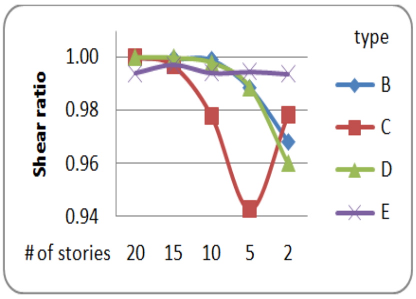

Figure 22 Ratio of (III)/(I) for shear (At 1^{st} basement)

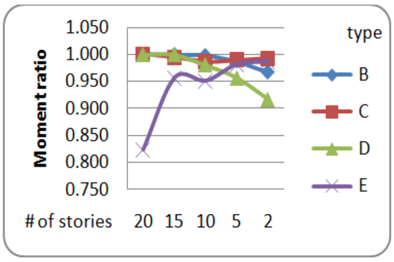

Figure 23 Envelope of the Moment **ratios** (At 1^{st} basement)

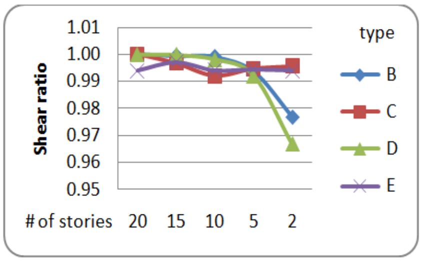

Figure 24 Envelope of the Shear force ratios (At 1^{st} basement)

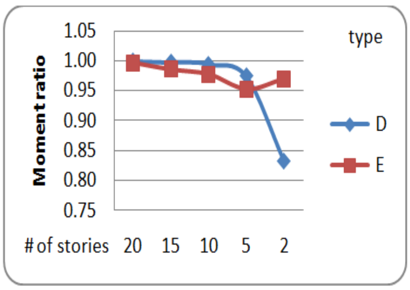

Figure 25 Ratio of (II)/(I) for Moment (At 2^{nd} basement)

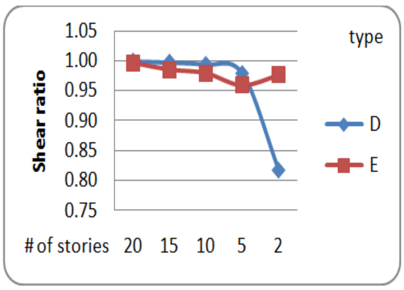

Figure 26 Ratio of (II)/(I) for shear (At 2^{nd} basement)

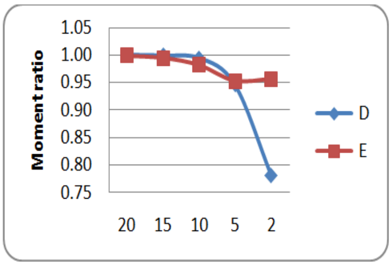

Figure 27 Ratio of (III)/(I) for Moment (At 2nd basement)

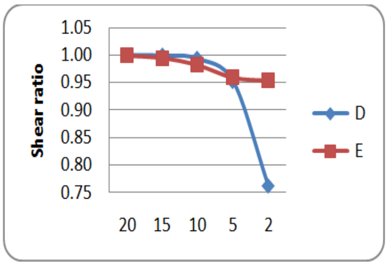

Figure 28 Ratio of (III)/(I) for shear (At 2nd basement)

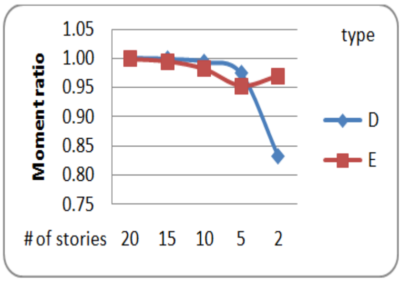

Figure 29 Envelope of the Moment ratios (At 2nd basement)

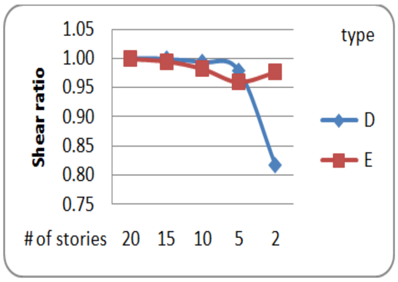

Figure 30 Envelope of the Shear force ratios (At 2nd basement)

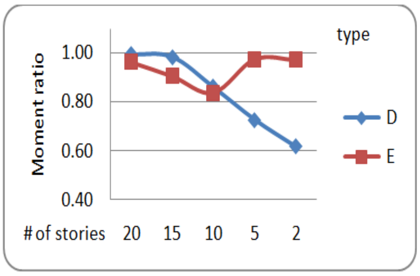

Figure 31 Ratio of (II)/(I) for Moment (At 3rd basement)

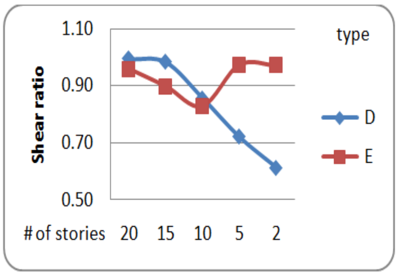

Figure 32 Ratio of (II)/(I) for shear (At 3rd basement)

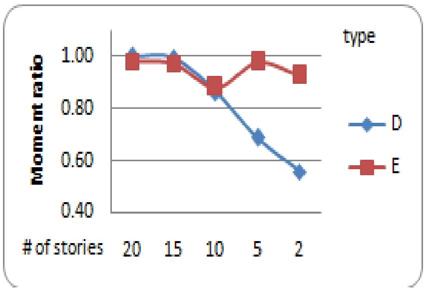

Figure 33 Ratio of (III)/(I) for Moment (At 3rd basement)

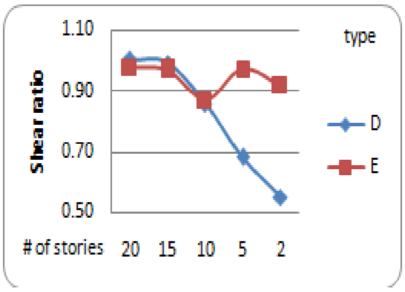

Figure 34 Ratio of (III)/(I) for shear (At 3rd basement)

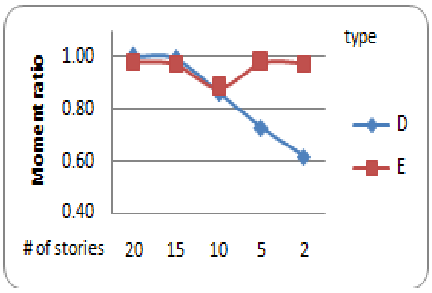

Figure 35 Envelope of the Moment ratios (At 3rd basement)

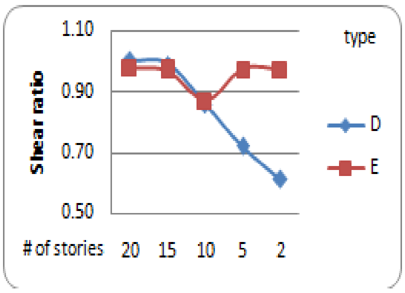

Figure 36 Envelope of the Shear force ratios At 3rd basement)

At 3rd basement

5-4-1-3 Cumulative comparison

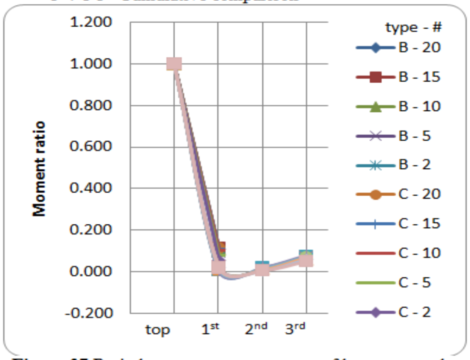

Figure 37 Ratio between moment at top of basement and moment at different basement levels for different heights of building and number of basement

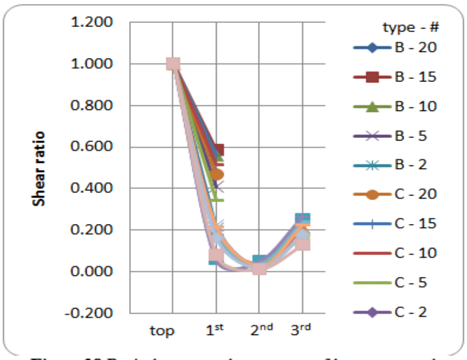

Figure38 Ratio between shear at top of basement and moment at different basement levels for different heights of building and number of basement

Figures 17 and 18 shows that the bending moment and shear force ratios at the top of basement slab have accuracy 98.9%, while figures 19 to 36 shows that the bending moment and the shear force ratios in the basement floor(s) have accuracy reach 60% which is out of acceptance. Figure 37 and 38 shows that the bending moment and the shear force ratios in the basement floor(s) are smaller than those at the top of basement slab. Consequently in the design of column A/3 the straining action value at the top of basement slab shall be adopted for all basement floor(s) in order to allow the use of a reduced number of mode shapes without jeopardizing the design safety. Hence, we can neglect the requirement of 90% MPR by using a reduced number of mode shapes on condition that they should not be less than that required by methods (II) and (III). In such case the accuracy will be not less than 98.9%.

5-4-2 Column at axes A/4

5-4-2-1 At top of basement slab

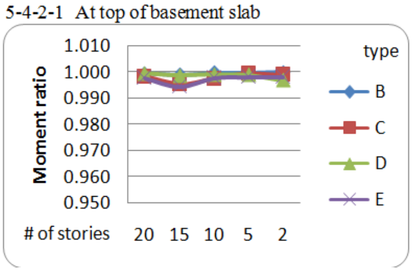

Figure 39 Ratio of (II)/(I) for Moment (At top of basement)

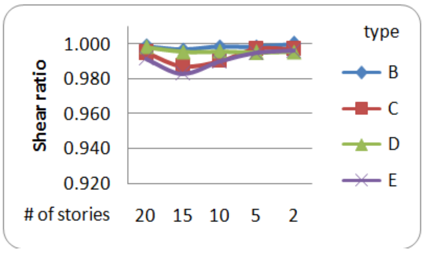

Figure 40 Ratio of (II)/(I) for shear (At top of basement)

5-4-2-1 At top of basement slab

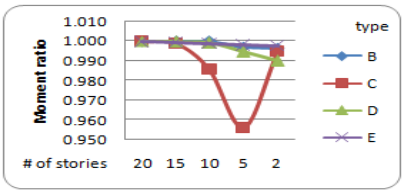

Figure 41 Ratio of (III)/(I) for Moment (At top of basement)

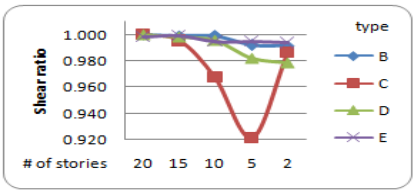

Figure 42 Ratio of (III)/(I) for shear (At top of basement)

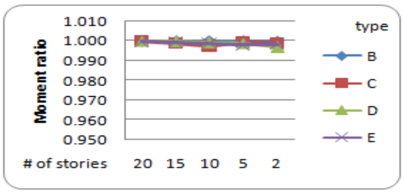

Figure 43 Envelope of the Moment ratios (At top of basement)

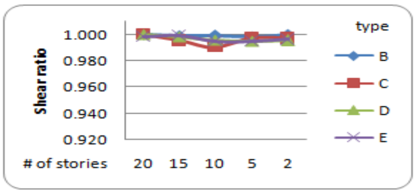

Figure 44 Envelope of the Shear force ratios (At top of basement)

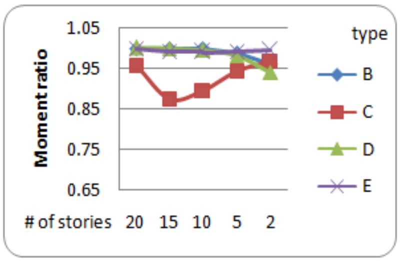

Figure 45 Ratio of (II)/(I) for Moment (At 1st basement)

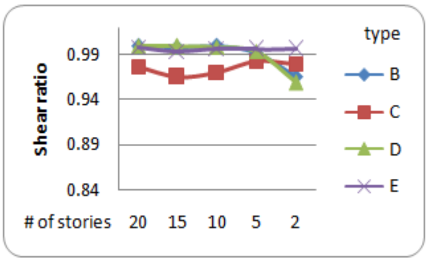

Figure 46 Ratio of (II)/(I) for shear (At 1st basement)

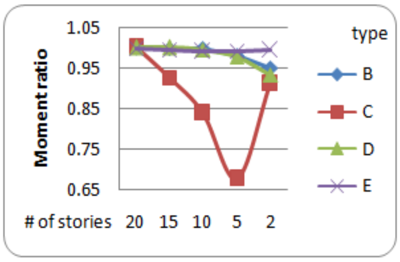

Figure 47 Ratio of (III)/(I) for Moment (At 1st basement)

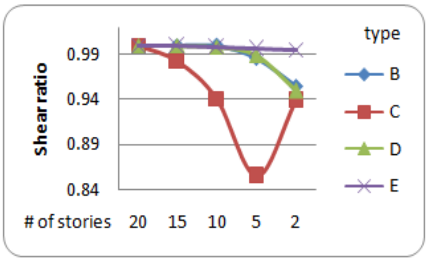

Figure 48 Ratio of (III)/(I) for shear (At 1st basement)

5-4-2-2 At 1st basement

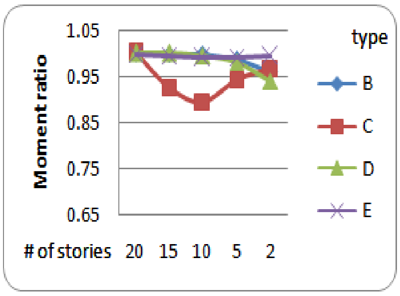

Figure 49 Envelope of the Moment ratios (At 1st basement)

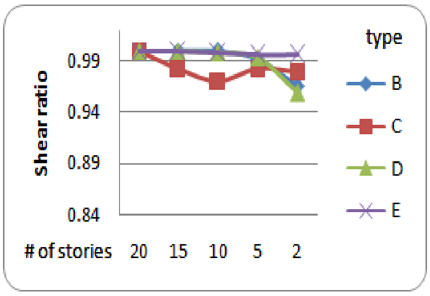

Figure 50 Envelope of the Shear force ratios (At 1st basement)

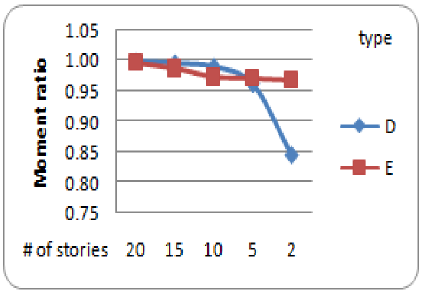

Figure 51 Ratio of (II)/(I) for Moment (At 2nd basement)

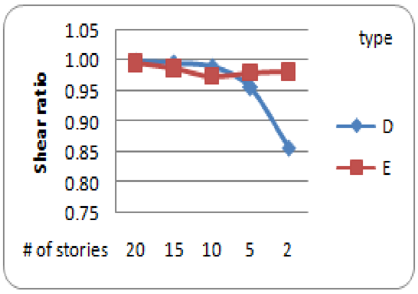

Figure 52 Ratio of (II)/(I) for shear (At 2nd basement)

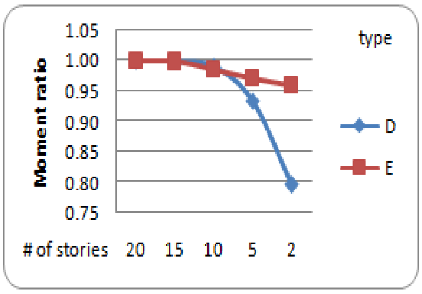

Figure 53 Ratio of (III)/(I) for Moment (At 2nd basement)

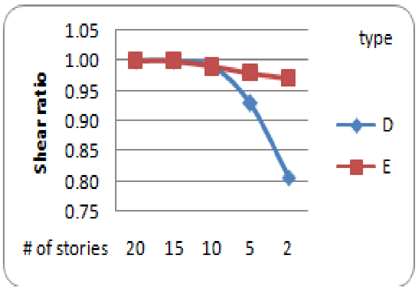

Figure 54 Ratio of (III)/(I) for shear (At 2nd 2ment)

5-4-2-3 At 2nd basement

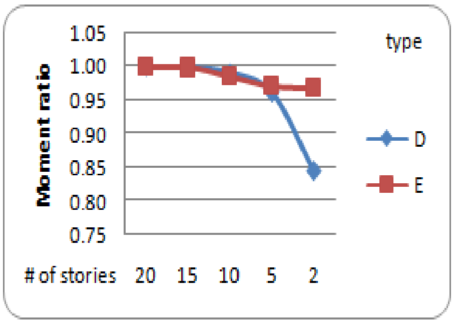

Figure 55 Envelope of the Moment ratios (At 2nd basement)

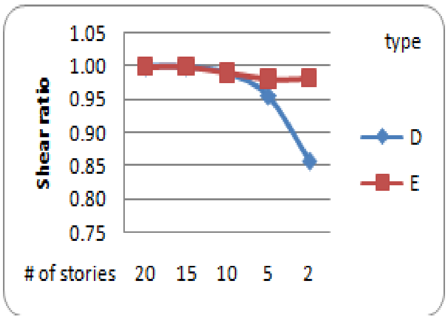

Figure 56 Envelope of the Shear force ratios (At 2nd basement)

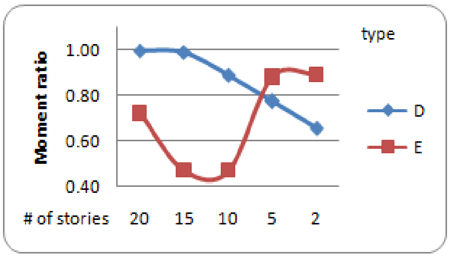

Figure 57 Ratio of (II)/(I) for Moment (At 3rd basement)

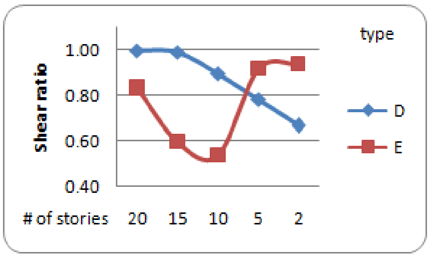

Figure 58 Ratio of (II)/(I) for shear (At 3rd basement)

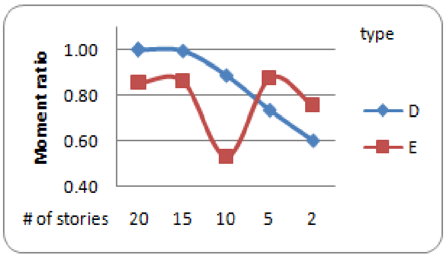

Figure 59 Ratio of (III)/(I) for Moment (At 3rd basement)

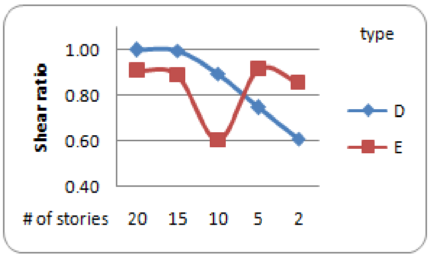

Figure 60 Ratio of (III)/(I) for shear (At 3rd basement)

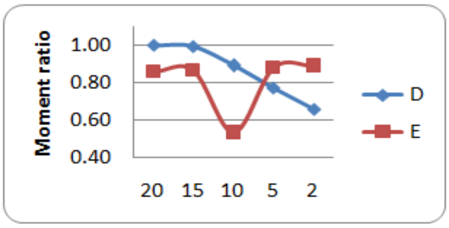

Figure 61 Envelope of the Moment ratios (At 3rd basement)

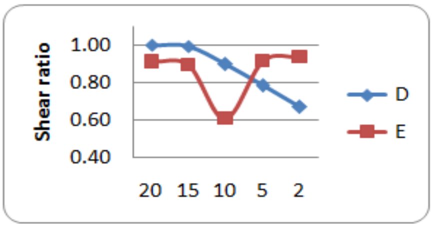

Figure 62 Envelope of the Shear force ratios (At 3rd basement)

5-4-2-5 Cumulative comparison

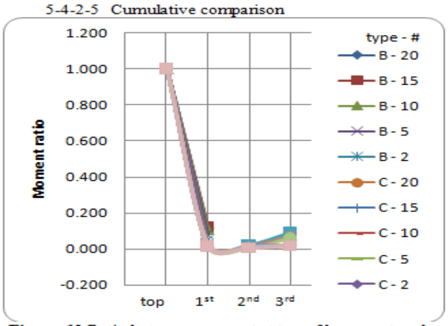

Figure 63 Ratio between moment at top of basement and moment at different basement levels for different heights of building and number of basement

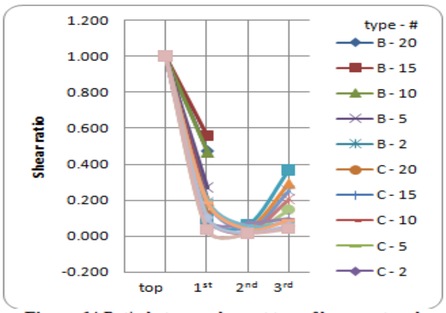

Figure 64 Ratio between shear at top of basement and moment at different basement levels for different heights of building and number of basement

Figures 43 and 44 shows that the bending moment and shear force ratios at the top of basement slab have accuracy 99%, while figures 45 to 62 shows that the bending moment and the shear force ratios in the basement floor(s) have accuracy reach 50% which is out of acceptance. Figure 63 and 64 shows that the bending moment and the shear force ratios in the basement floor(s) are smaller than those at the top of basement slab. Consequently in the design of column A/4 the straining action value at the top of basement slab shall be adopted for all basement floor(s) in order to allow the use of a reduced number of mode shapes without jeopardizing the design safety. Hence, we can neglect the requirement of 90% MPR by using a reduced number of mode shapes on condition that they should not be less than that required by methods (II) and (III). In such case the accuracy will be not less than 99%.

5-4-5-1 At top of basement slab

Figure 65 Ratio of (II)/(I) for Moment (At top of basement)

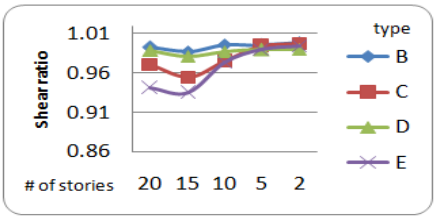

Figure 66 Ratio of (II)/(I) for shear (At top of basement)

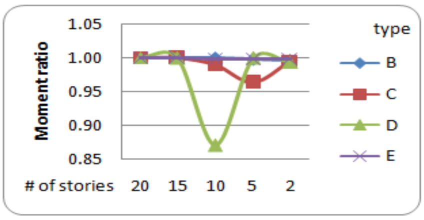

Figure 67 Ratio of (III)/(I) for Moment (At top of basement)

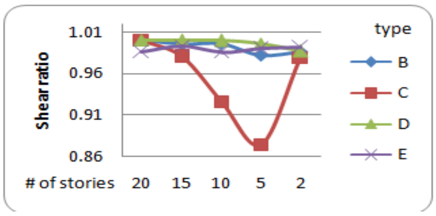

Figure 68 Ratio of (III)/(I) for shear (At top of basement)

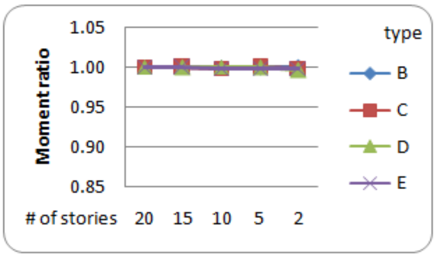

Figure 69 Envelope of the Moment ratios (At top of basement)

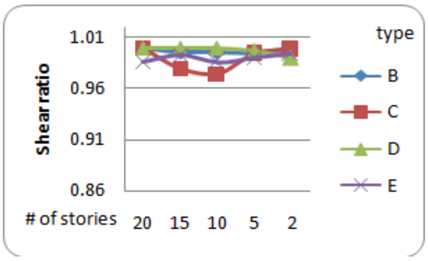

Figure 70 Envelope of the Shear force ratios (At top of basement)

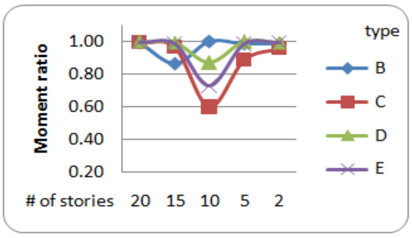

Figure 71 Ratio of (II)/(I) for Moment (At 1st basement)

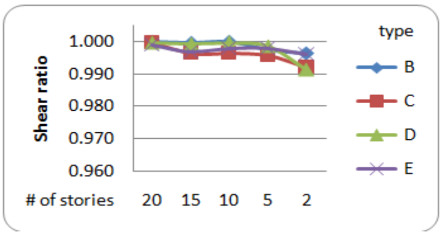

Figure 72 Ratio of (II)/(I) for shear (At 1st basement)

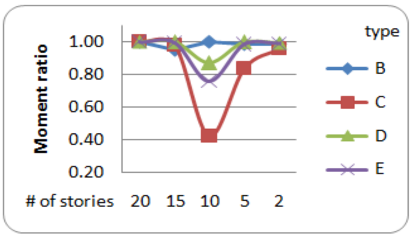

Figure 73 Ratio of (III)/(I) for Moment (At 1st basement)

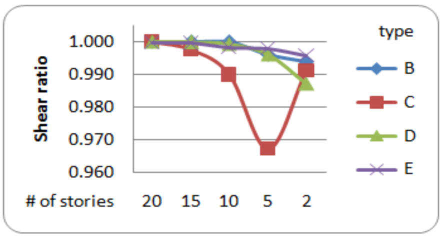

Figure74 Ratio of (III)/(I) for shear (At 1st basement)

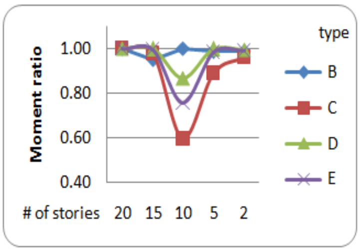

Figure 75 Envelope of the Moment ratios (At 1st basement)

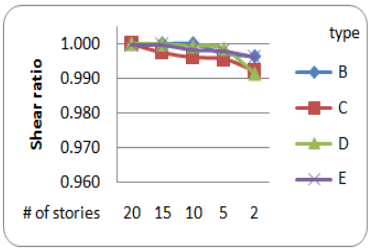

Figure 76 Envelope of the Shear force ratios (At 1st basement)

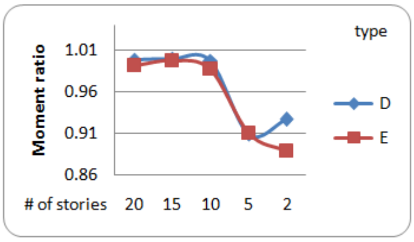

Figure 77 Ratio of (II)/(I) for Moment (At 2nd basement)

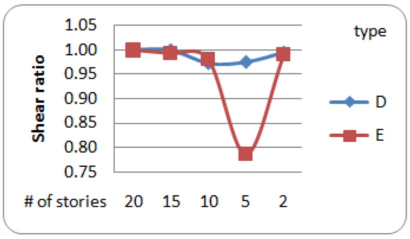

Figure 78 Ratio of (II)/(I) for shear (At 2nd basement)

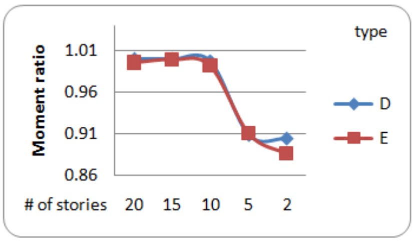

Figure 79 Ratio of (III)/(I) for Moment (At 2nd basement)

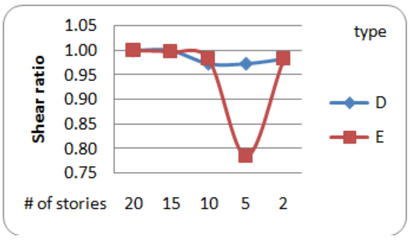

Figure 80 Ratio of (III)/(I) for shear (At 2nd 2ment)

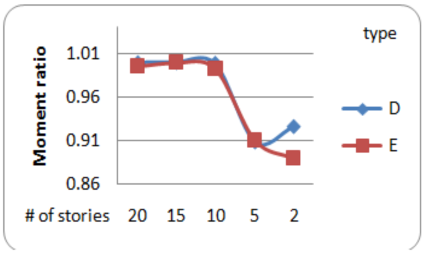

Figure 81 Envelope of the Moment ratios (At 2nd basement)

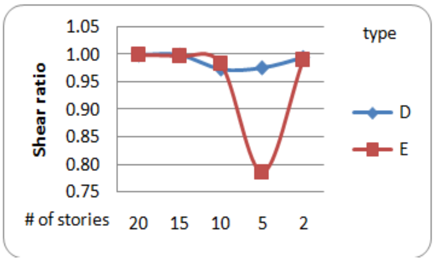

Figure 82 Envelope of the Shear force ratios (At 2nd basement)

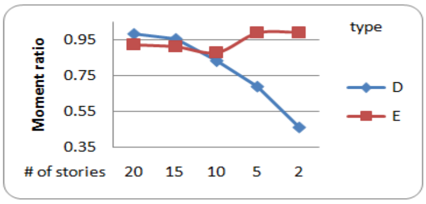

Figure 83 Ratio of (II)/(I) for Moment (At 3rd basement)

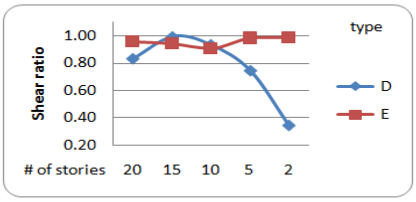

Figure 84 Ratio of (II)/(I) for shear (At 3rd basement)

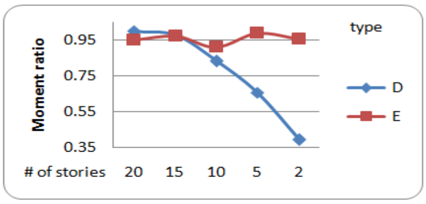

Figure 85 Ratio of (III)/(I) for Moment (At 3rd basement)

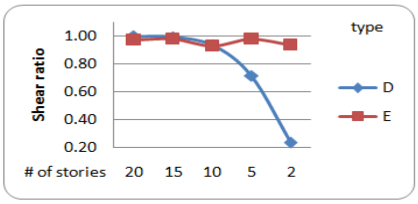

Figure 86 Ratio of (III)/(I) for shear (At 3rd basement)

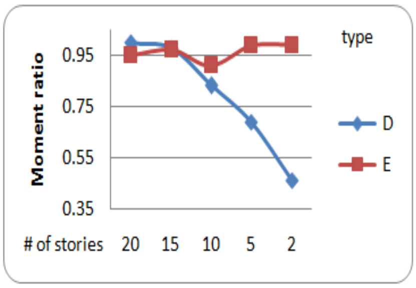

Figure 87 Envelope of the Moment ratios (At 3rd basement)

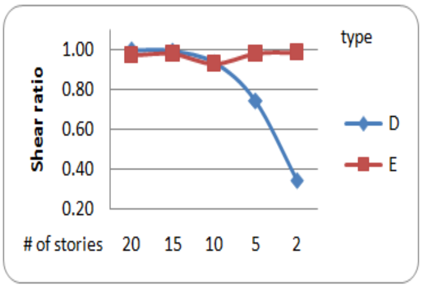

Figure88 Envelope of the Shear force ratios (At 3rd basement)

Cumulative comparison

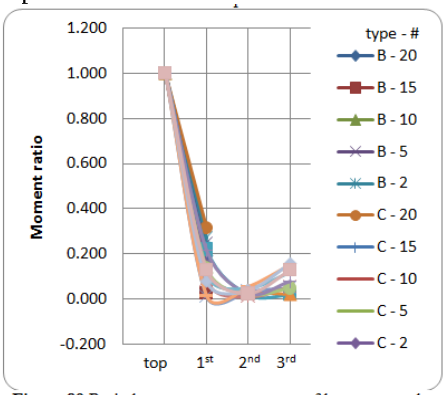

Figure 89 Ratio between moment at top of basement and moment at different basement levels for different heights of building and number of basement

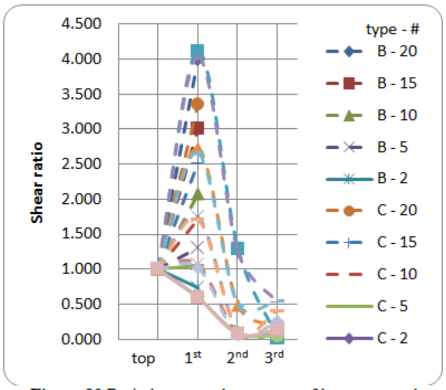

Figure 90 Ratio between shear at top of basement and moment at different basement levels for different heights of building and number of basement

Figures 69 and 70 shows that the bending moment and shear force ratios at the top of basement slab have accuracy 97.5%, while figures 71 to 88 shows that the bending moment and the shear force ratios in the basement floor(s) have accuracy reach 30% which is out of acceptance. Figure 89 and 90 shows that the bending moment and the shear force ratios in the basement floor(s) are smaller than those at the top of basement slab except of shear force ratios at 1st basement floor for buildings types B to E which have 5, 10, 15 and 20 superstructure floors are greater than those at the top of basement slab, while figure 76 show that the shear force ratios at the 1st basement floor for excepted buildings have accuracy 99.9%. Consequently in the design of column B/3 the bending moment value at the top of basement slab and the maximum of the shear force at the top of basement slab and that at the 1st basement floor shall be adopted for all basement floor(s) in order to allow the use of a reduced number of mode shapes without jeopardizing the design safety. Hence, we can neglect the requirement of 90% MPR by using a reduced number of mode shapes on condition that they should not be less than that required by methods (II) and (III). In such case the accuracy will be not less than 97.5%.

5-4-3 Column at axes B/4

5-4-4-1 At top of basement slab

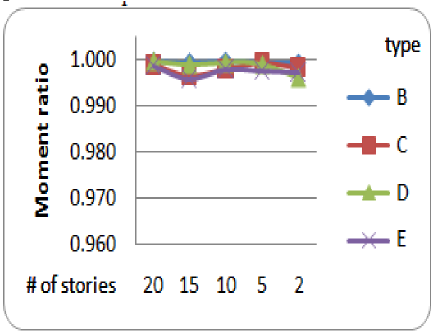

Figure 91 Ratio of (II)/(I) for Moment (At top of basement)

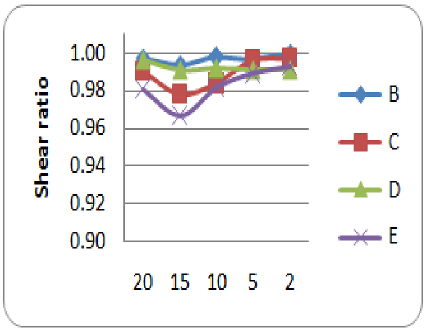

Figure 92 Ratio of (II)/(I) for shear (At top of basement)

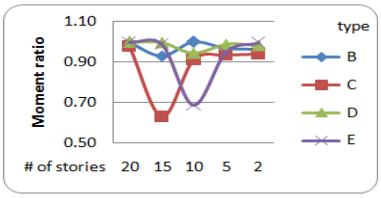

Figure 97 Ratio of (II)/(I) for Moment (At 1st basement)

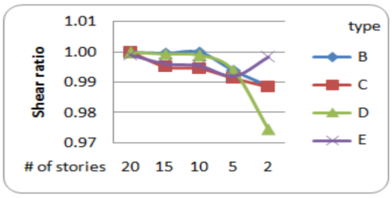

Figure 98 Ratio of (II)/(I) for shear (At 1st basement)

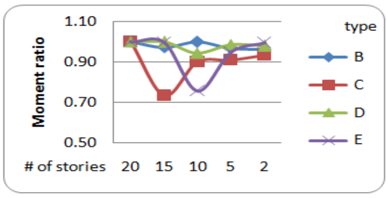

Figure 99 Ratio of (III)/(I) for Moment (At 1st basement)

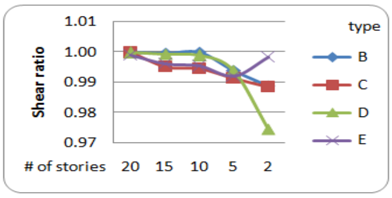

Figure 100 Ratio of (III)/(I) for shear (At 1st basement)

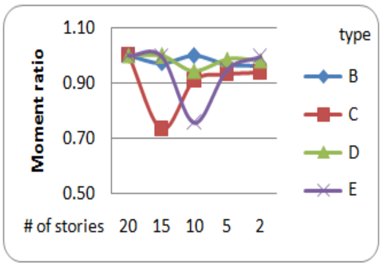

Figure 101 Envelope of the bending moment ratios (At 1st basement)

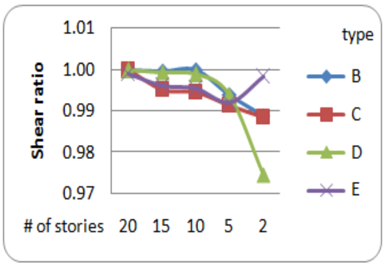

Figure 102 Envelope of the Shear force ratios (At 1st basement)

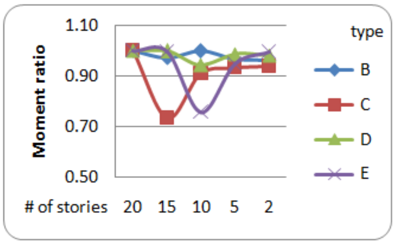

Figure 101 Envelope of the bending moment ratios (At 1st basement)

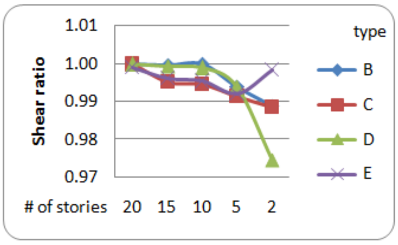

Figure 102 Envelope of the Shear force ratios (At 1st basement)

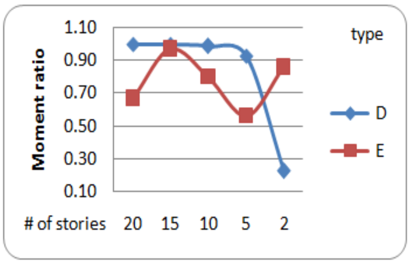

Figure 103 Ratio of (II)/(I) for Moment (At 2nd basement)

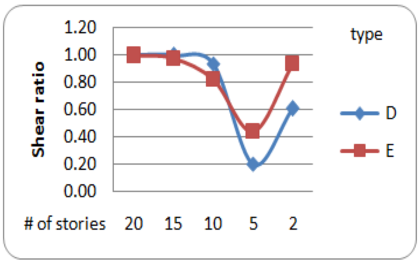

Figure 104 Ratio of (II)/(I) for shear (At 2nd basement)

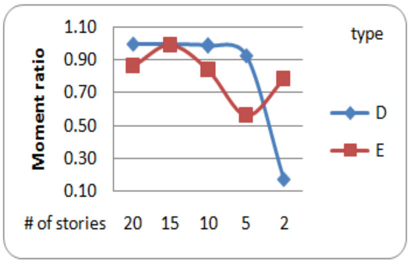

Figure 105 Ratio of (III)/(I) for Moment (At 2nd basement)

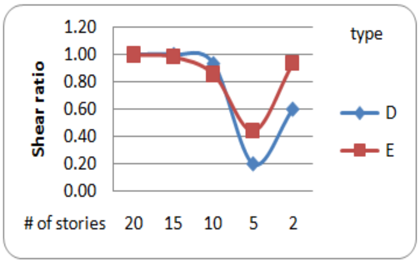

Figure 106 Ratio of (III)/(I) for shear (At 2nd 2ment)

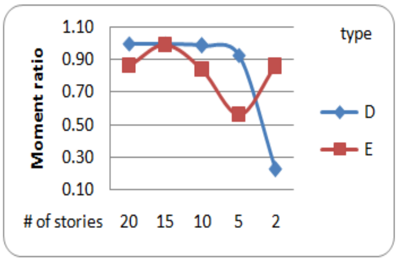

Figure 107 Envelope of the bending moment ratios (At 2nd basement)

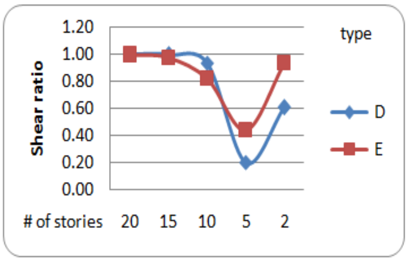

Figure 108 Envelope of the Shear force ratios (At 2nd basement)

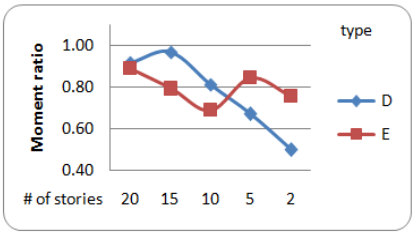

Figure 109 Ratio of (II)/(I) for Moment (At 3rd basement)

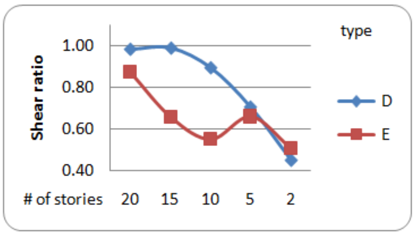

Figure 110 Ratio of (II)/(I) for shear (At 3rd basement)

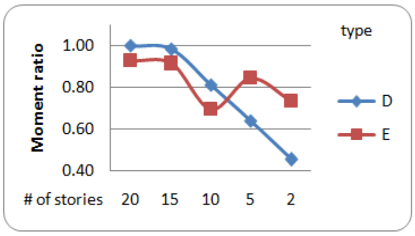

Figure 111 Ratio of (III)/(I) for Moment (At 3rd basement)

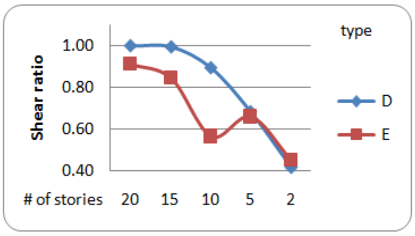

Figure 112 Ratio of (III)/(I) for shear (At 3rd basement)

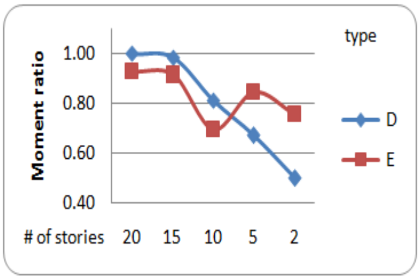

Figure 113 Envelope of the bending moment ratios (At 3rd basement)

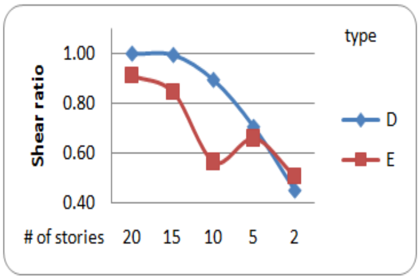

Figure 114 Envelope of the Shear force ratios (At 3rd basement)

5-4-4-2 Cumulative comparison

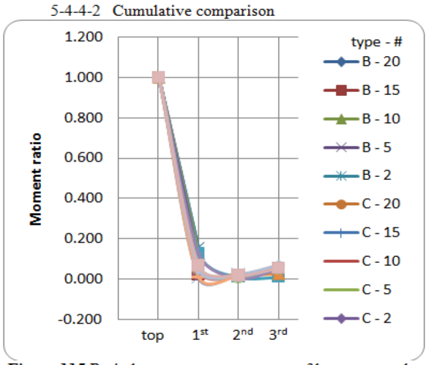

Figure 115 Ratio between moment at top of basement and moment at different basement levels for different heights of building and number of basement

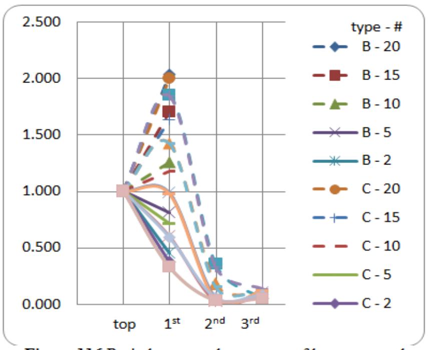

Figure 116 Ratio between shear at top of basement and moment at different basement levels for different heights of building and number of basement

Figures 95 and 96 shows that the bending moment and shear force ratios at the top of basement slab have accuracy 98.2%, while figures 97 to 114 shows that the bending moment and the shear force ratios in the basement floor(s) have accuracy reach 20% which is out of acceptance. Figure 89 and 90 shows that the bending moment and the shear force ratios in the basement floor(s) are smaller than those at the top of basement slab except for buildings types B and C which have 20, 15 and 10 superstructure floors and buildings types D and E which have 20 and 15 superstructure floors are greater than those at the top of basement slab, while figure 102 show that the shear force ratios at the 1^{st} basement floor for excepted buildings have accuracy 97.5%. Consequently in the design of column B/4 the bending moment value at the top of basement slab and the maximum of the shear force at the top of basement slab and that at the 1^{st} basement floor shall be adopted for all basement floor(s) in order to allow the use of a reduced number of mode shapes without jeopardizing the design safety. Hence, we can neglect the requirement of 90% MPR by using a reduced number of mode shapes on condition that they should not be less than that required by methods (II) and (III). In such case the accuracy will be not less than 97.5%.

II. Conclusions

Efficient mass participation ratio of building with basement were investigated in this study by varying number of mode shapes used in modal analysis and the following conclusions could be drawn. For buildings with basement(s), the requirement of at least 90% of the total mass should be participate in response spectrum analysis can be waived with accuracy not exceed 95% if:

A. Number of mode shapes should not be less than all of the three following conditions:

1- $T_K < 0.20$ Sec

2- $K \geq 3.\sqrt{n}$

3- K ≥ Superstructure (modeled as fixed base at top of basement slab) mode shapes necessary for 90% mass participation ration

Where

K is the number of modes taken into account;

n is the number of stories above the foundation or the top of a rigid basement;

T_k is the period of vibration of mode T_k

B. Designing straining actions for columns in the basement(s) floor(s) should not be less than those of the superstructure first floor or the upper basement floor which is bigger.

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