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EVALUATION OF THE CONSTRUCTION SEQUENCE LOADING EFFECTS ACCOMPANIED WITH TIME DEPENDENCY OF CONCRETE ON SEISMIC PERFORMANCE OF HIGH-RISE BUILDINGS WITH DIFFERENT STRUCTURAL SYSTEMS

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ABSTRACT

To have a reasonable and economic design, information about the initial condition of the structure is very important because different initial states can change the seismic analysis results and may cause some problems when trying to satisfy the prescribed limits of deformations and strengths. Therefore, seismic design should be accompanied by considerations of the time-dependent behavior and its coupling effects with construction sequence loading on structural and nonstructural members as an initial condition.

This paper has two main parts. The first part contains the results of the sensitivity analyses, which are performed on buildings with different structural systems (in elevation or plan) to find the particular characteristics that made the structures more sensitive to additional considerations. The second part of the paper contains the weak points of each structural system due to the analyses.

Introduction

In the simulation of structural behavior through the use of classical methods, a structure is assumed to act together to resist any foreseeable loading. In fact, when looking closely at the construction sequence of a structure, one finds that the structural members are added in stages and hence their dead load is carried by that part of the structure completed at the stage of their installation. Hence it is clear, that the distribution of stresses in any part of the completed structure at some stages, due to the dead load of members installed by that stage, does not depend on size, property or indeed the presence of members composing the rest of the structure (Saffarini and Wilson 1983).

Considering the above behavior in numerical modeling of structures may cause some secondary effects, with generally different severities in each structural element depending on its corresponding location in plan and elevation. Also, the respected reliability of gravity and lateral systems may be hardly affected by this consideration, proportionally to their corresponding structural system. These effects have been generally observed on old concrete structures. However, in the case of new structures, where the strengths of concrete and steel are exploited to a high degree and where the dimensions of the structural

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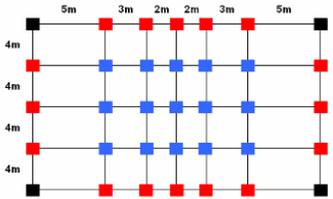
members are very slender, the mentioned behavior should be considered with particular care and attention.

The work presented here discusses the changes that may occur in the behavior of structural elements which are used in residential and office buildings, due to construction sequence analysis. In the following discussion, two groups of structures with different heights are distinguished: frame structures, consisting of three dimensional members, and panel structures assembled from plate-shaped panels and some interconnection beams. The analyzed structures have different number of stories: 5, 10, 15, 20, 25 and 30 and are assumed to have a simple symmetric plan to omit any other structural problems like torsion. Also a 10-cm concrete slab was selected as a floor system. Moreover, the time dependency of concrete like creep was considered in the analyses as a material. The MIDAS/Gen software version 6.3.2 (released No.1) was used in numerical modeling process by means we were able to consider construction sequence structural effects with time dependency of concrete, simultaneously.

Frame Structures

Concrete frame structures consist of columns and beams corresponding to Table 1. The compatibility of deformations must be maintained in the rigid supposed connections of concrete frame members. The structure has four different span lengths, and the corresponding structural behaviors such as shear (for 2m span length), bending (for 5m span length) and shear-bending (for 3&4m span lengths) are investigated separately.

Table 1. Distribution of frame cross sections in plan and elevation locations.



	Identity	5-Story	Identity	10-Story	Identity	15-Story	Identity	20-Story	Identity	25-Story	Identity	30-Story
Corner Column Sections	1	25x25	2	25x25	3	25x25	4	25x25	9	25x25	10	25x25
			4	30x30	4	30x30	4	30x30	4	30x30	4	30x30
			4	35x35	4	35x35	4	35x35	4	35x35	4	35x35
					4	40x40	4	40x40	4	40x40	4	40x40
							4	45x45	4	45x45	4	45x45
											4	50x50
Side Column Sections	2	25x25	2	30x30	3	30x30	4	30x30	5	25x25	6	25x25
	3	30x30	4	35x35	4	35x35	4	35x35	4	30x30	4	30x30
			4	40x40	4	40x40	4	40x40	4	35x35	4	35x35
					4	45x45	4	45x45	4	40x40	4	40x40
							4	50x50	4	45x45	4	45x45
									4	50x50	4	50x50
Central Column Sections	2	30x30	2	35x35	4	35x35	3	35x35	5	35x35	6	25x25
	3	35x35	4	40x40	4	40x40	4	40x40	4	40x40	4	30x30
			4	45x45	4	45x45	4	45x45	4	45x45	4	35x35
					4	50x50	4	50x50	4	50x50	4	40x40
							4	55x55	4	55x55	4	45x45
									4	60x60	4	50x50
Beam Sections	Direction	10-Story	15-Story	20-Story	25-Story	30-Story						
	x	20x40	20x45	20x45	20x45	20x45						
	y	20x45	20x50	20x50	20x50	20x50						

Panel Structures

Concrete panel structures consist of panels and beams corresponding to Table 2. The structures are a combination of different panel systems together, which are connected by perimeter beams. Each of panel system is assumed to represent different special gravity or seismic behavior. The compatibility of deformations must be maintained in the rigid continuous form of each structural system and generally forms the whole structural continuity.

Table 2. Layout of panel element thicknesses in plan and elevation locations.

Side Walls				Main Wall			
20 - cm				20 - cm			
From	20th story	to	30th story	From	1st story	to	5th story
25 - cm				30 - cm			
From	10th story	to	20th story	From	5th story	to	10th story
30 - cm				40 - cm			
From	1st story	to	10th story	From	10th story	to	15th story
30 - cm				50 - cm			
From	15th story	to	20th story	From	15th story	to	20th story
30 - cm				60 - cm			
From	20th story	to	25th story	From	20th story	to	25th story
30 - cm				70 - cm			
From	25th story	to	30th story	From	25th story	to	30th story

Each panel structure consists of some sub structure as follows, and which are illustrated in Fig. 1.

- A:** Panel system with near 1-m span interconnecting beams (lintels) between sidewalls and a mainwall
- B:** Panel system with irregular openings
- C:** Panel system with far 1-m span interconnecting beams within sidewalls
- D:** Panel system with near 3-m span interconnecting beams (lintels) between sidewalls and a mainwall
- E:** Panel system with regular openings

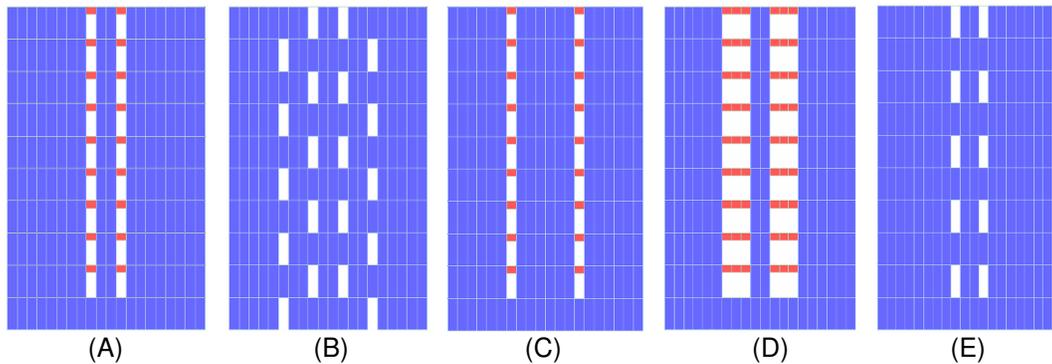


Figure1. Corresponding sub structure of each panel system.

Analysis of Results

At first, each structure is assumed to act as a whole to resist all of the applied forces. Then, the corresponding ratio of each force components, bending moment and shear, is calculated as a classical static ratio $R(st)$. After that, a more accurate simulation of actual behavior would then performed on each numerical model, while considering that each story of the building would be built completely in 30 days and concrete would be loaded for about 7 days after casting (Smerda and Kristek 1988). It should be noted

that the structure is simultaneously loaded by live loads after the structure is built completely. The structure would be under sustained loads up to 5 years after the first period of construction. This will allow us to neglect the rest deformations due to time dependency of concrete after that period. Subsequently, the corresponding ratio of each force components, bending moment and shear, is calculated as a construction sequence ratio $R(cs)$. To have a general comparison between each element sensitivity, the $R(cs) - R(st)$ ratio, R' , is calculated for each element and controlled if it is greater than 1. The element with higher R' is assumed to be more sensitive than the other in terms of the component which its ratio was calculated.

Frame Structures

In frame elements, a variation deformation is followed by a variation of the internal forces. Hence, any shortenings of the columns produced by time dependency of concrete plus construction sequence loadings may be very significant. As it is observed from Table 1, the differences between column cross-sections and their location in the plan, would result different column axial loads and consequently, lead to non uniform shortenings in columns. This non uniformity in vertical displacements at both ends of beam elements may produce some significant demands on interconnecting beams, and occupy the more percentage of element capacity which would reduce the respected capacity for seismic resistance (Khan and Fintel 1968).

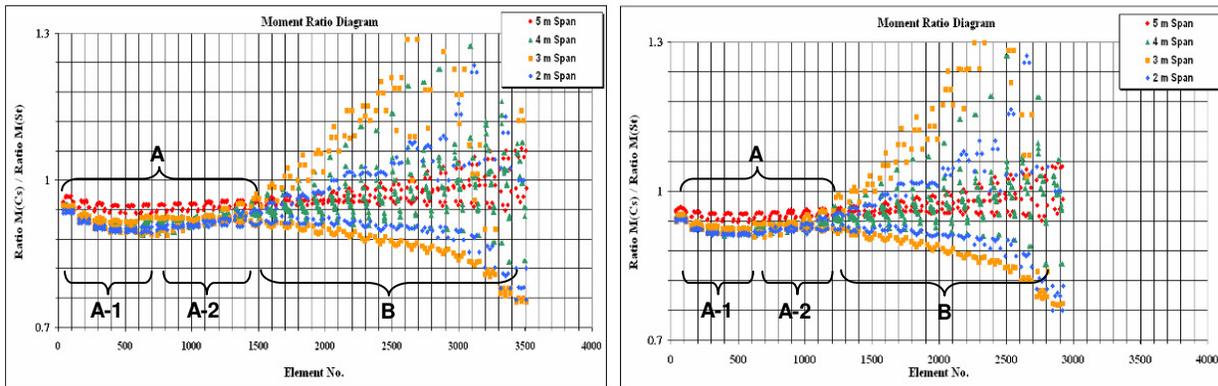


Figure 2. Moment ratio diagram for 30 story building with frame system (left), and for 25 story building with frame system (right).

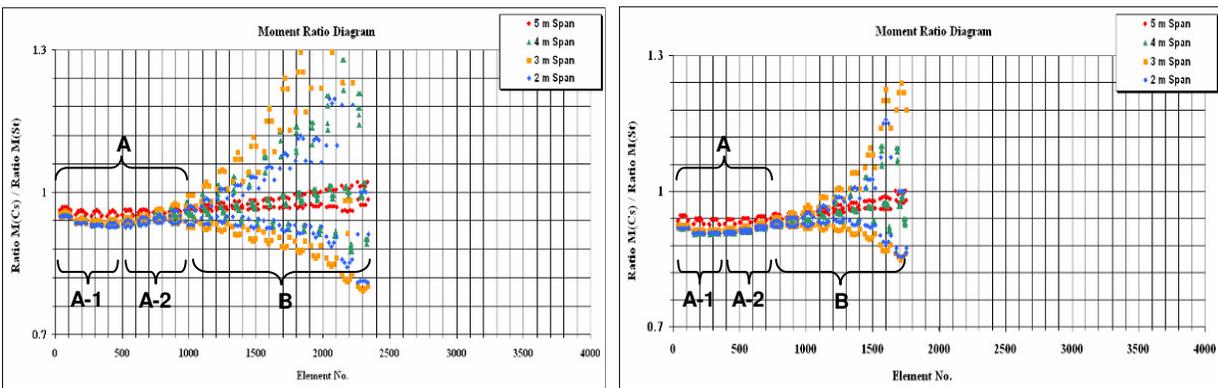


Figure 3. Moment ratio diagram for 20 story building with frame system (left), and for 15 story building with frame system (right).

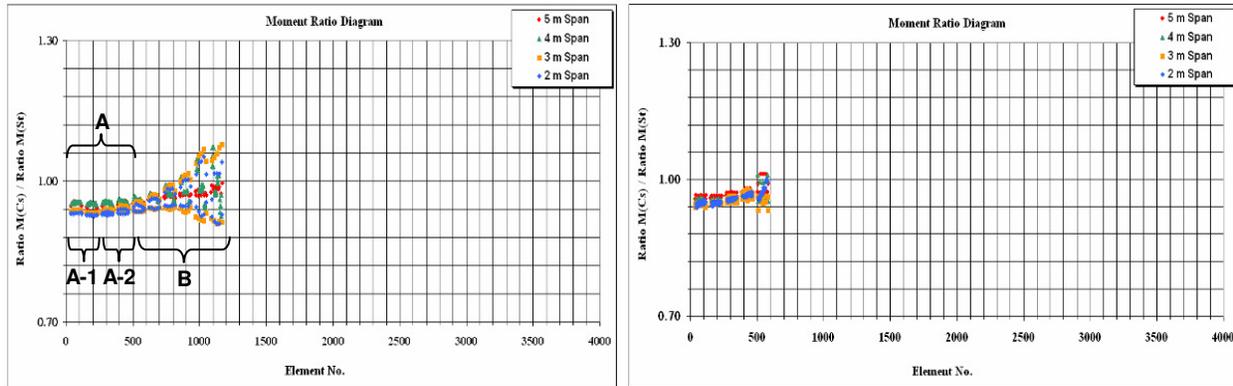


Figure 4. Moment ratio diagram for 10 story building with frame system (left), and for 5 story building with frame system (right).

As it is observed from Figs. 2, 3, and 4, the general shape of the moment ratio diagram is divided in two main parts; parts A and B, which approximately have the same height in elevation. Part A is actually divided in two subdivisions; A-1 and A-2, which are approximately corresponding to a quarter of the height.

The results have shown that, the calculated R' for bending moment at both ends of each beam located in the lower midpoint of the structure height, part A, is actually about 0.9 with a little descending trend, up to the quarter of the structure height, part A-1, and then with a small ascending trend, up to the midpoint of the structure height, first of part B, the point in which the diagram is going to be bifurcated due to symmetrical form of the structure. As the structure is erected, the amplitude of the fluctuation zone is going to be larger and the beam sensitivity would be more significant. Consequently, the taller the building, the more susceptible the beams.

In part B, the beams are located in the upper midpoint of structure height and beside the ones in 4-m span which have different cross-section area, the larger the span, the lesser R' would be calculated and the farther location of the beam, the higher R' would be resulted. That's why; the beams in 2-m span length are less sensitive in bending moments in comparison with the ones in 3-m span length. If the location of the beam is farther and the length of its span is larger too, like 5-m span length beams, the sensitivity of the element due to differential displacements at both ends would be lesser than the same beams with shorter ones.

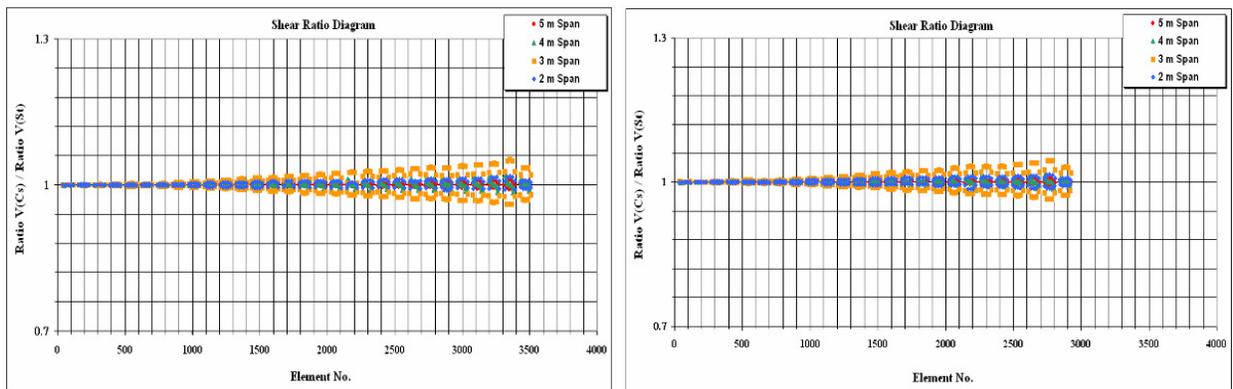


Figure 5. Shear ratio diagram for 30 story building with frame system (left), and for 25 story building with frame system (right).

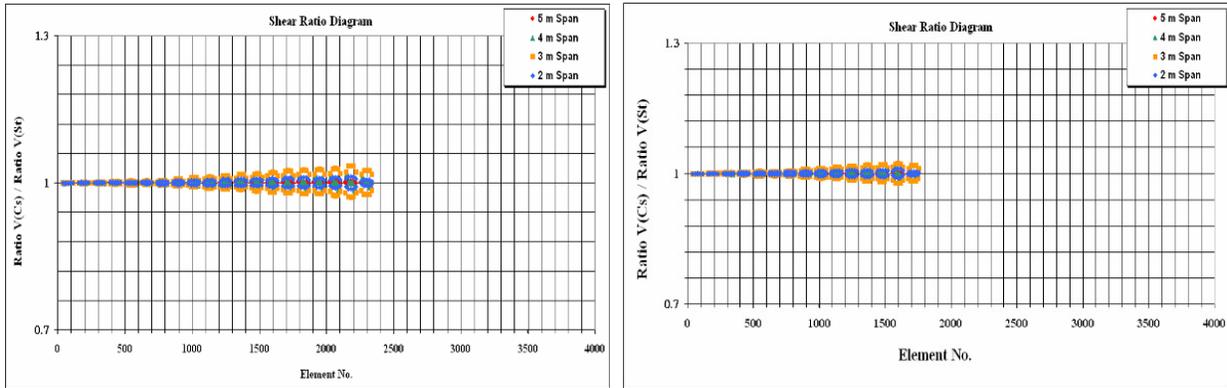


Figure 6. Shear ratio diagram for 20 story building with frame system (left), and for 15 story building with frame system (right).

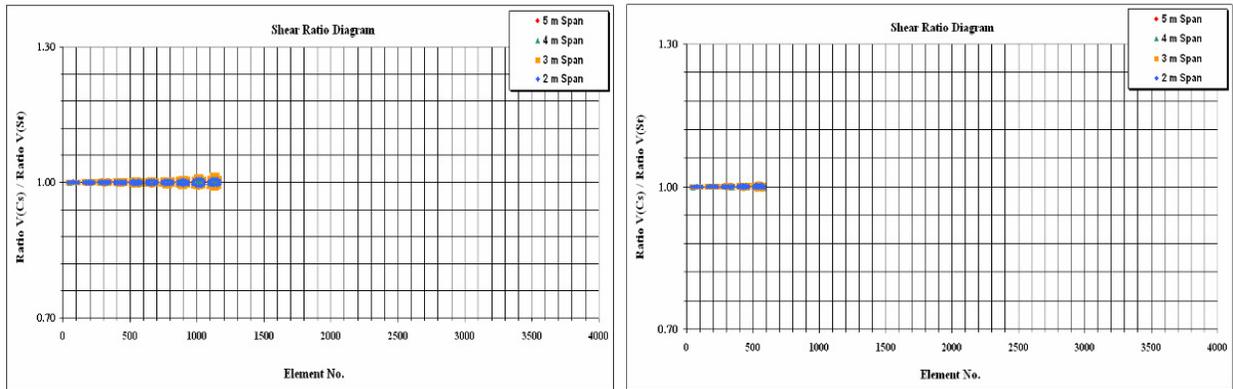


Figure 7. Shear ratio diagram for 10 story building with frame system (left), and for 5 story building with frame system (right).

As it is observed from Figs. 5, 6, and 7, generally the shear analysis of moment resisting frames is not sensitive to the construction sequence analysis with time dependency of concrete considerations. Only by erecting the structure, some insignificant fluctuations would be seen in the upper stories.

Panel Structures

In panel structures, usually having significant differences between load bearing panel walls are making a tendency to be sensitive to the construction sequence analysis with time dependency of concrete considerations. For example, the panel structure like the ones which are studied in this paper have five sub structures with different axial stiffness as follows: $D < C < A < E < B$, see Fig. 8. These differences may cause the significant sensitivity in perimeter beams which interconnect the sub structures and may produce large shear demands if the spaces between sub structures are shorter.

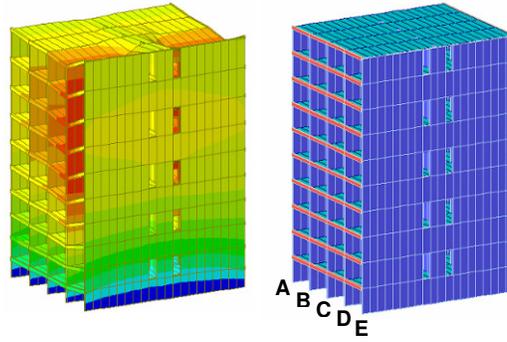


Figure 8. Differential axial stiffness of sub structures.

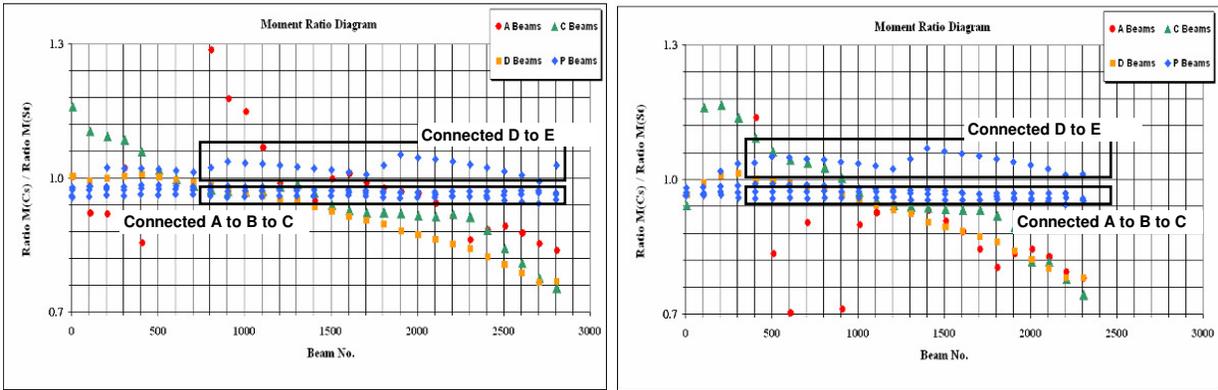


Figure 9. Moment ratio diagram for 30 story building with frame system (left), and for 25 story building with frame system (right).

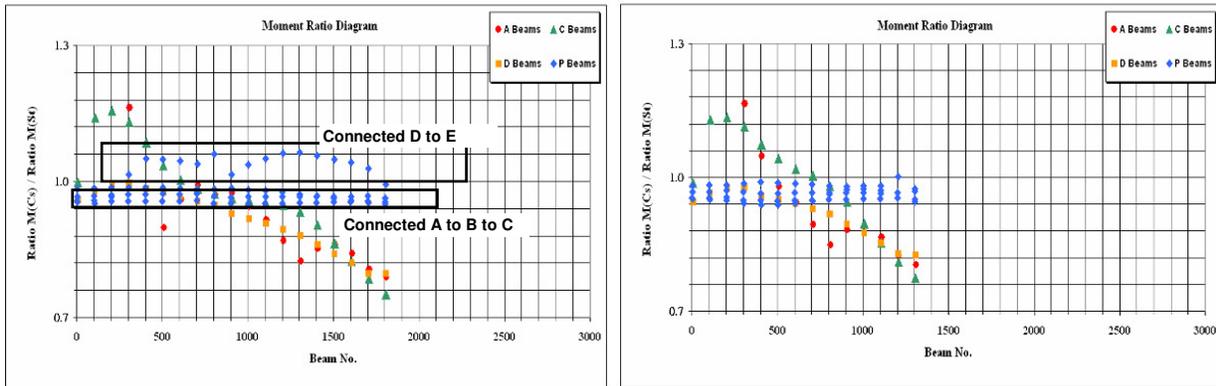


Figure 10. Moment ratio diagram for 20 story building with frame system (left), and for 15 story building with frame system (right).

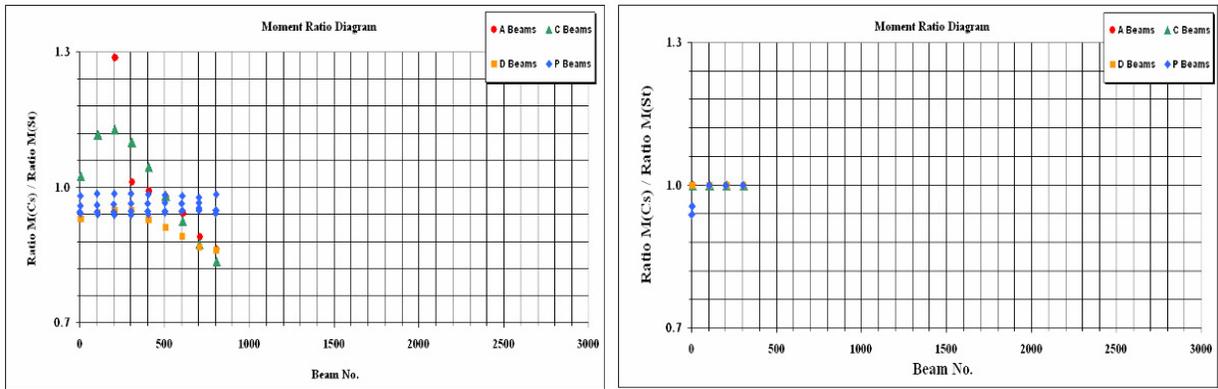


Figure 11. Moment ratio diagram for 10 story building with frame system (left), and for 5 story building with frame system (right).

As it is observed from the Figs. 9, 19, and 11, the beams which are located in the sub structure A are not sensitive to the bending moments at all due to construction sequence analysis with time dependency of concrete considerations and the ones in sub structure D are not either. The lower level beams of sub structure C are more sensitive to bending moments with ascending trend than the upper ones and this is happening in all of the panel structure models. The perimeter beams, which interconnect the sub structures, are going to be more susceptible to bending moments when the structure is erected.

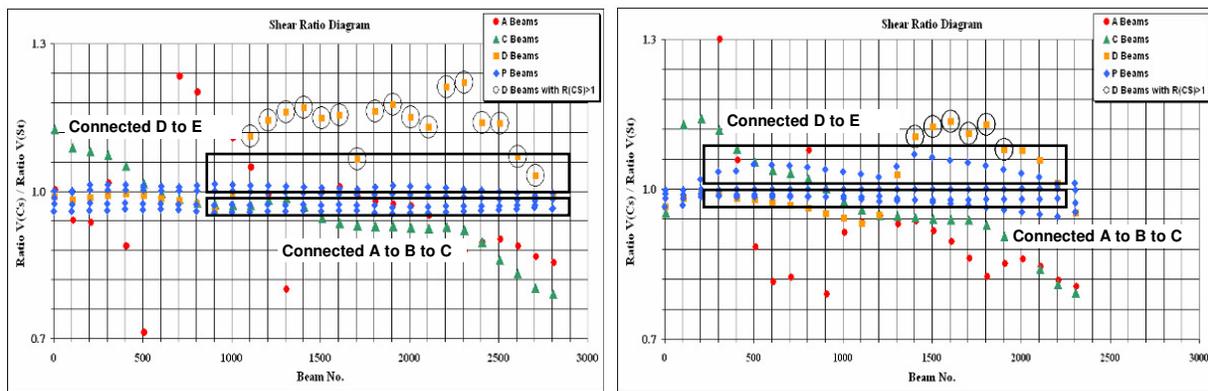


Figure 12. Shear ratio diagram for 30 story building with frame system (left), and for 25 story building with frame system (right).

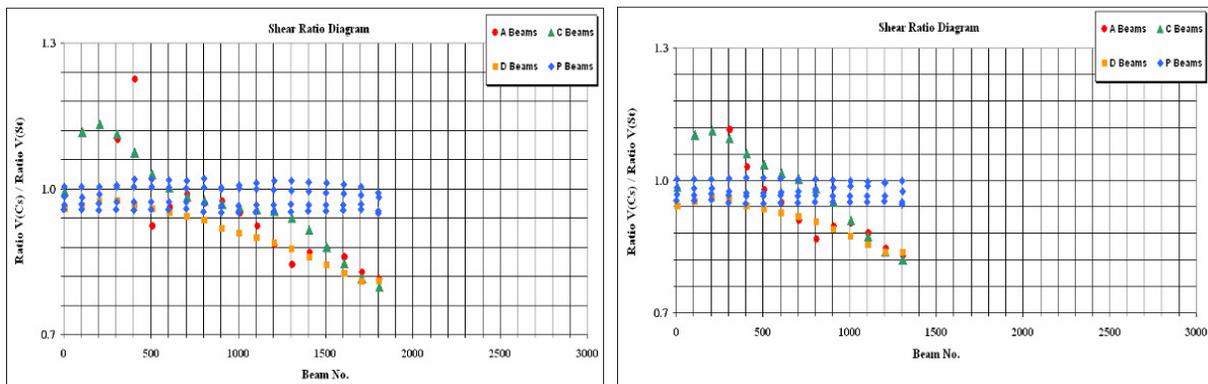


Figure 13. Shear ratio diagram for 20 story building with frame system (left), and for 15 story building with frame system (right).

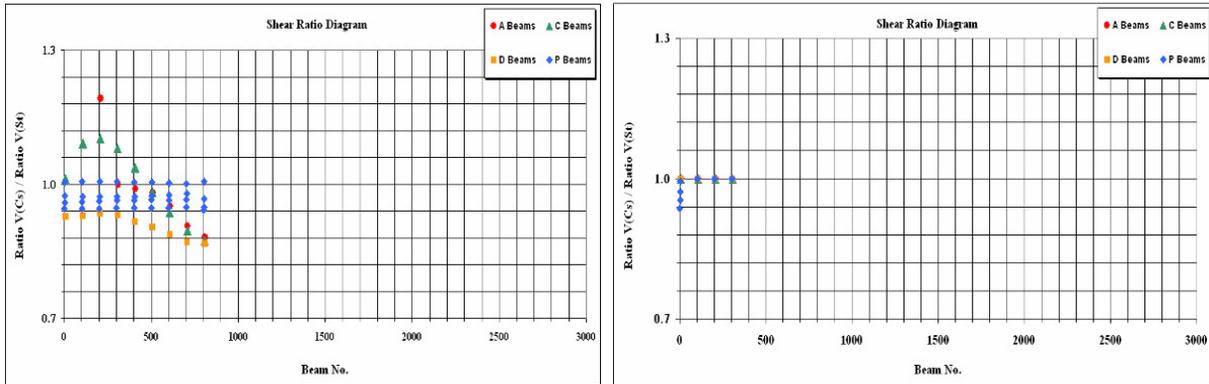


Figure 14. Shear ratio diagram for 10 story building with frame system (left), and for 5 story building with frame system (right).

As it is observed from the Figs. 12, 13, and 14, the beams which are located in the sub structure A, are not sensitive to the shear at all due to construction sequence analysis with time dependency of concrete considerations and the beams in sub structure D up to story 20, are not either. In the structures higher than 20 stories, the beams become more susceptible with the maximum in upper levels and in some cases failure can occur under static loads. The lower level beams of sub structure C are more sensitive to shear than the upper ones with the ascending trend and this is happening in all of the panel structure models.

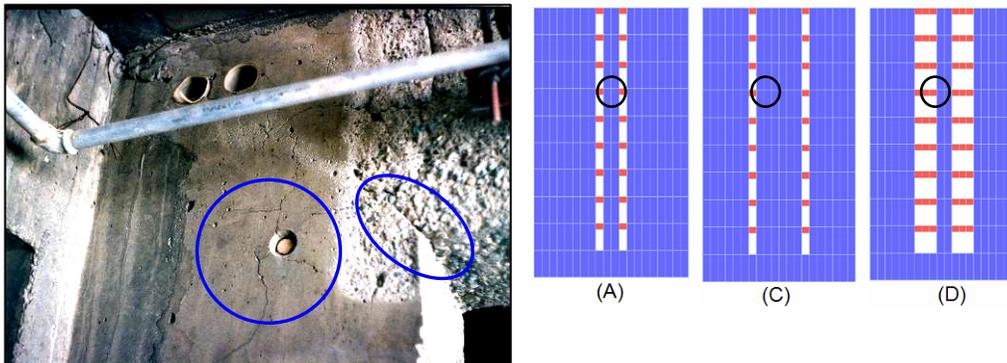


Figure 15. Real structural shear cracking of a coupling beam in middle stories of a 56 story tall building with panel system.

In the sub structures A and C and D, with a regular pattern of openings, the designer must ensure that the integrity of the structure in terms of flexural strength is not jeopardized by gross reduction of wall area near the extreme fibers of the section. Similarly, the shear strength of the wall, in both the horizontal and vertical directions, should remain feasible and adequate to ensure that its flexural strength can be fully developed. Also the theoretical and experimental studies show that in coupled wall structures like the ones illustrated above, plastic hinges are formed in the coupling elements before the walls yield and that such plastification can substantially increase the ductility of the structures. Within certain limits, the earlier the beams start to yield, the greater will be the increase in ductility. However, if the beams yield prematurely, the lateral strength of the wall structures might be severely impaired and the ductility of the beams might become exhausted when the walls start to yield. Thus for best overall performance, the beams should yield well before the walls do but not at so early a stage as to cause excessive reduction in lateral strength or breakage of the beams before the wall fails.

Despite the fact that coupling beams are assumed to be cracked prematurely in earthquake, this event might take place under permanent gravity loads as a result of concrete time dependency and construction erecting process. According to above, some coupling beams, connecting main wall to sidewall, were found to be cracked, Fig. 15. Level of axial stresses associated with floor loads on sidewalls and main walls were the same and the only probable cause, might be time-dependent effects based on self-weight of interconnected panel systems. It can be concluded that coupling beams are plastified under fixed moments due to non-uniform vertical displacement and may lead into change the overall seismic structural response through the decreasing of structural period.

Conclusions

In this work, the sensitivity of the structural components of two groups of structures with different heights is distinguished: frame structures, consisting of three dimensional members, and panel structures assembled from plate-shaped panels and some interconnection beams. It was obviously obtained from the comparison between classical static analysis and construction sequence, while considering the time dependency of the concrete analysis results, which moment frame systems are not sensitive to shear due to small differential displacements occurring at both ends of the beam elements. Also, the span length and corresponding location of the beam element have the most important role in the sensitivity of the beam element. Moreover, the sensitive beams are mainly located in the third quarter of the building height the from bottom, and the bottom half of the building height is actually not sensitive to bending moment due to construction sequence analysis. Also, panel systems with different patterns were considered and it should be noted that the differential axial stiffness is the most important factor to make the system more sensitive to construction sequence analysis. Designers should recognize the presence of time-dependency of concrete and construction sequence loading effects, and provide for them in the design. Having concrete structural elements with different longitudinal stiffness (here, $D < C < A < E < B$), makes the tower to be more sensitive to differential displacements due to concrete time dependency. Despite the fact that coupling beams are assumed to be cracked prematurely in earthquakes, this event might take place under permanent gravity loads as a result of concrete time dependency. Redistribution of loads according to creep and construction sequence loading will intensely change the primitive assumptions on gravity load tributaries and consequently the level of ductility.

Acknowledgments

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