

CONSTRUCTION SEQUENCE ANALYSIS OF REINFORCED CONCRETE HIGH-RISE BUILDINGS

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Abstract

This article studies the influence of the construction sequence on the response of reinforced concrete high-rise buildings. Currently, most structural systems are analyzed in only a single step with the assumption that the system can bear the entire load from the completed whole building. In reality, a structure is constructed sequentially floor by floor, which leads to differences between the theoretical analysis and the actual response of structural system, especially for the structural system of high-rise buildings. After conducting construction sequence analysis, the effecting results on the internal forces of columns and beams of the changeable high skyscraper are synthesized, compared with using the conventional technique.

Keywords: High-rise building; construction sequence; nonlinear analysis; ETABS.

1. Introduction

Engineering structural analysis using computational models that include the entire load-bearing structural system, as well as separately and independently assigned loads is based on the superposition principle [1, 2]. This technique is widely used in practice, as a basis for calculating and designing structural solutions. Here in after referred to as the conventional technique.

However, these computational models are built on the principle that the structural system is formed at a single time, regardless of the construction sequence, loading history [1-6]. This principle determines the constant initial lengths of all structural members and the fixed initial positions of nodes in the calculation scheme [6]. Load types such as self-weight, superimposed dead load, live load, etc. are assigned independently to the overall building model.

Thus, this analysis technique does not take into account the working states of the structure: changing the calculation scheme during the construction process, changing connections, adding and removing elements, changing loads, transferring from normal working state to special working state such as accident, collision, disaster... The components (columns, walls, floors, etc.) are arranged exactly in the design position regardless of the accumulated strain of the underlying structural system. In the case of low-rise buildings, such deformations are not much and can be ignored. However, for

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multi-storey buildings, especially high-rise buildings, with the presence of cores and rigid walls, transfer floors, transfer beams, etc., ignoring the deformation of the structure of the lower storey will lead to severe deviations between the actual behavior of the structural system and the results according to conventional techniques. Therefore, in order to closely simulate the working state of the building, the structural system should be analyzed in each construction phase, taking into account the change of the load. This technique is called construction sequence analysis.

2. Construction sequence analysis

The conventional analysis technique (CA) is a one-step linear analysis, shown in Fig. 1. The analytical technique that is closer to the reality is the construction sequence analysis (CSA), which is nonlinear is described, as shown in Fig. 2.

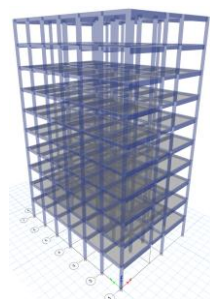


Fig. 1. Calculation model of 10-storey building according to CA.

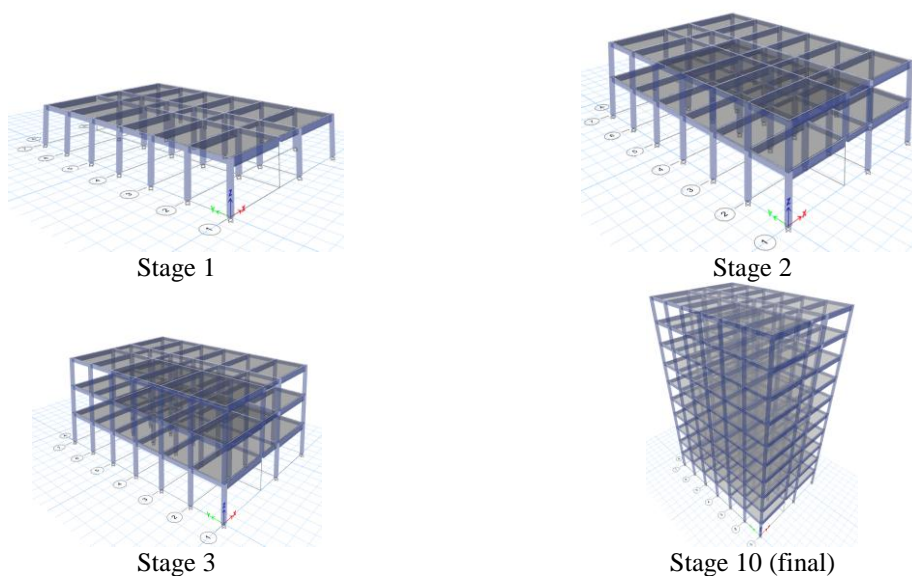


Fig. 2. Calculation model of 10-storey building according to CSA.

In this technique, each storey of the structural system is analyzed including all the stories below it. The results of the analysis reflect the behavior of the structure up to the time of completion of that storey. Today, specialized analysis software has achieved great

development, performing complex analysis techniques with ease. Sequential construction in ETABS and SAP2000 allows you to easily define a sequence of stages wherein you can add or remove portions of the structure, selectively apply load to portions of the structure [3]. The sequence of stages can be followed on how the building will be built. Time-dependent material behavior such as aging, creep, and shrinkage can also be considered.

The construction sequence analysis case can be automatically defined in ETABS as shown in Fig. 3.

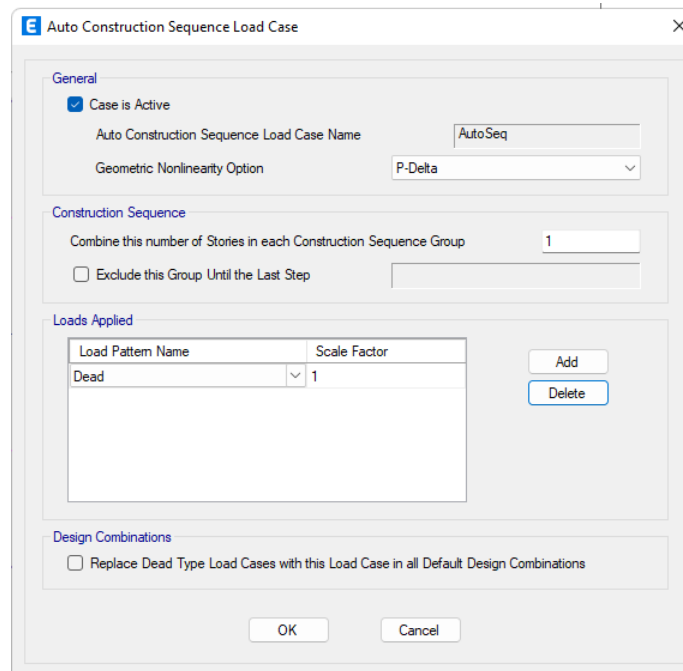


Fig. 3. Auto construction sequence load case.

When defined as an auto construction sequence case, the typical load is usually a permanent load, and a partial live load. A new auto nonlinear static staged construction load case will be generated and can not be modified. The number of stages and number of operations on each stage corresponds to the grouping of stories defined in the auto sequential construction setting. Accordingly, in each stage, the first operation of the software is to add structure, then to assign the load to the newly added structure system (Fig. 4). Other operations such as structure removal, section change, section and age change can also be performed.

Beside automatic definition, construction sequence analysis can be declared manually - nonlinear staged construction to adjust operations, object (element) type, object, time and load of each stage.

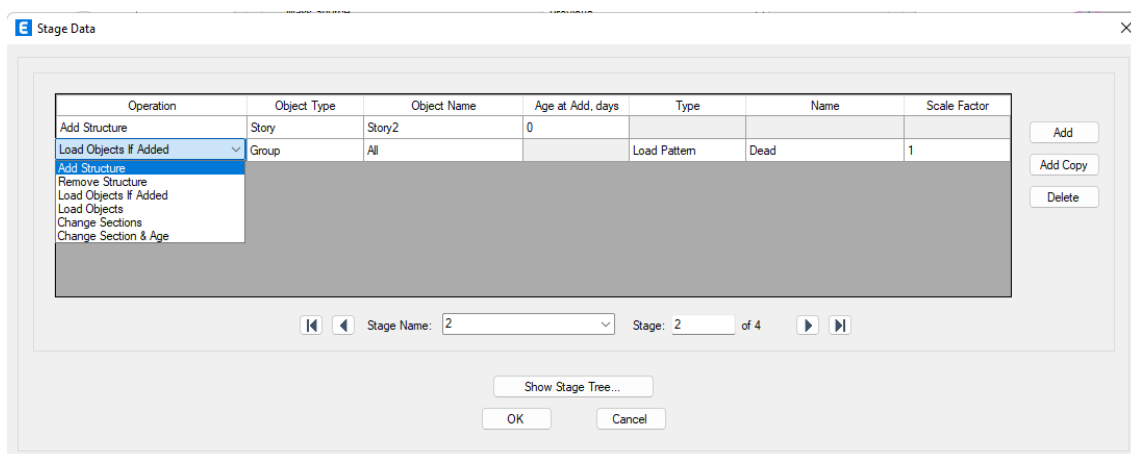


Fig. 4. Operations in each stage.

3. Result and discussion

To clarify the role of the analysis technique in the construction sequence, determine the difference in internal forces and displacements in column and beam members between the two analysis techniques in the case of constructions of the structure with 10, 20, 30, 40 floors. Thereby, evaluate the influence of the number of floors on that difference. The material used is concrete B25. The parameters of the calculated model are presented in Tab. 1. The spatial and structural plan are described as shown in Fig. 5.

The construction sequence is set that, in each stage, one story is constructed and the development of concrete strength is not considered.

Tab. 1. Parameters of calculated model

Model	M-1	M-2	M-3	M-4
Number of stories	10	20	30	40
Plan dimension (m)	15 × 21.6	15 × 21.6	15 × 21.6	15 × 21.6
Beam section for span 6 m (mm)	220 × 600	220 × 600	220 × 600	220 × 600
Beam section for span 3.6 m; 3 m (mm)	220 × 400	220 × 400	220 × 400	220 × 400
Floor depth (mm)	150	150	150	150
Exterior column section (mm)	300 × 400	400 × 500	500 × 600	500 × 700
Interior column section (mm)	300 × 500	400 × 600	500 × 700	500 × 800
Superimposed dead load (kN/m ²)	1.5	1.5	1.5	1.5
Live load (kN/m ²)	2.5	2.5	2.5	2.5

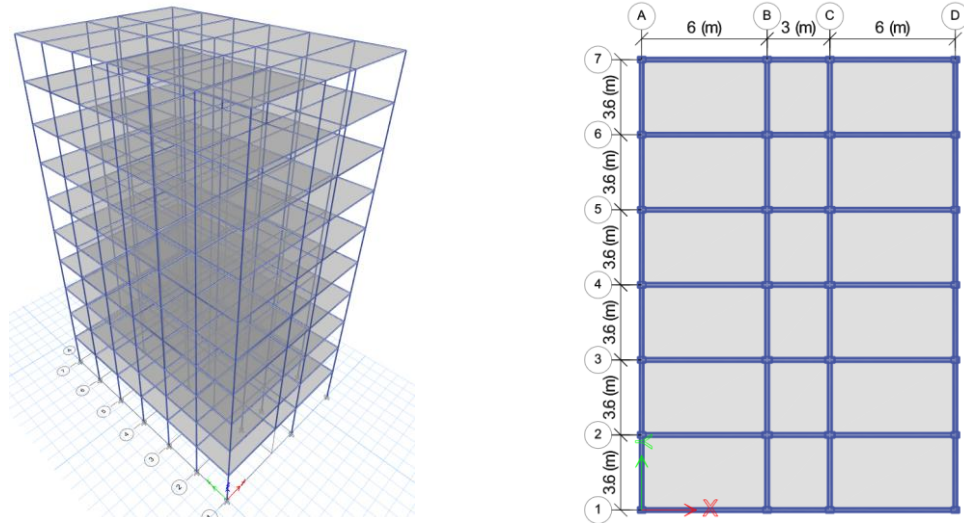


Fig. 5. Spatial model and structural plan.

3.1. Effects on the responses of structure model M-1

In Tab. 2, the differences between of vertical displacements between top-joints of exterior column (located at the intersection of axis 2 and axis A), called column C2-A and interior column C2-B, analyzed by CA and CSA are demonstrated. They are also demonstrated in Fig. 6. From the results, it can be stated that, the analysis of the structure according to the construction sequence has changed the value as well as the distribution of displacement difference of the vertical members, the most obvious is at the rooftop (0.71 mm).

Tab. 2. Difference of vertical displacements between exterior and interior columns

Story	CA			CSA		
	C2-A	C2-B	Diff.	C2-A	C2-B	Diff.
10	4.21	4.93	0.71	0.77	0.92	0.15
9	4.14	4.84	0.70	1.39	1.66	0.28
8	4.00	4.67	0.67	1.85	2.23	0.37
7	3.76	4.41	0.65	2.16	2.61	0.44
6	3.48	4.06	0.58	2.33	2.81	0.48
5	3.10	3.63	0.52	2.34	2.82	0.49
4	2.65	3.10	0.45	2.19	2.66	0.46
3	2.12	2.48	0.36	1.90	2.30	0.40
2	1.52	1.78	0.26	1.45	1.76	0.31
1	0.83	0.98	0.14	0.84	1.02	0.18

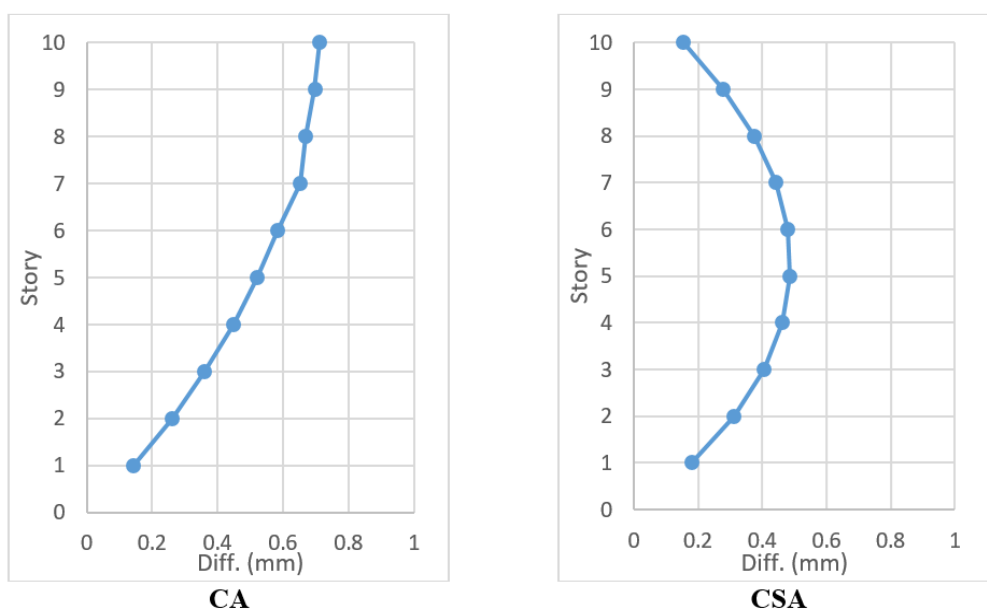


Fig. 6. Difference of vertical displacements of the exterior column and interior column using CA and CSA (in mm).

The analysis results including the axial force in bottom column (C2-B) the bending moment in perimeter beam axis 2 span A-B (2A-B) at the 1st floor are also summarized in Tab. 3 and shown in Figures 7, 8.

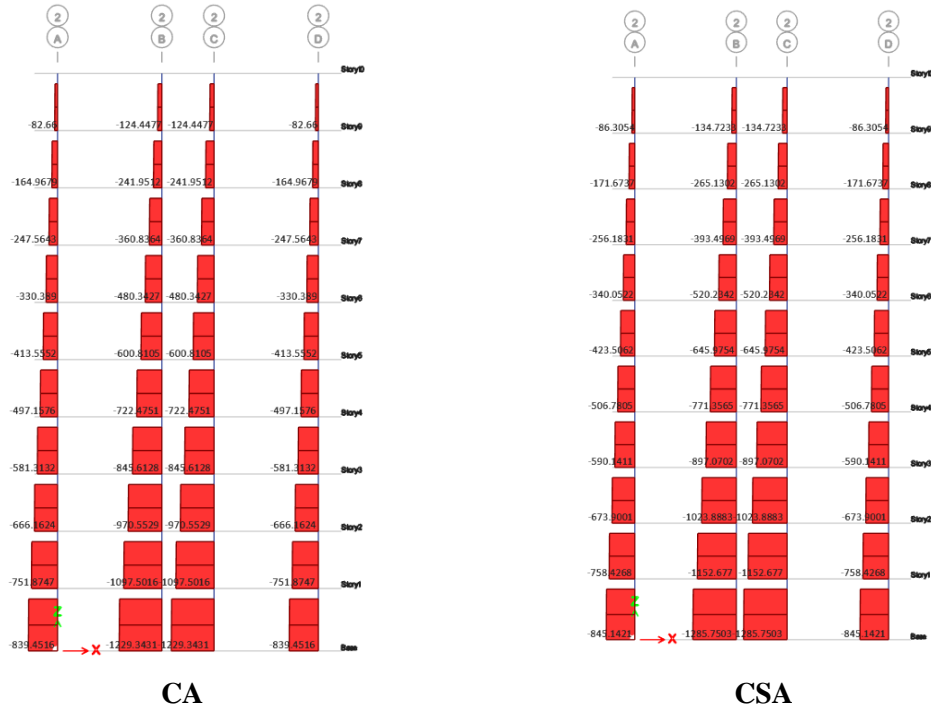
Tab. 3. Internal forces with two different analysis techniques

Structure response	CA	CSA	$\Delta\%$
Axial force at the bottom of column C2-B (kN)	1229.3	1285.8	4.60
Mid span bending moment of beam 2A-B (kNm)	38.6	43.6	12.95
Mid span displacement of beam 2A-B (mm)	1.83	2.03	10.93

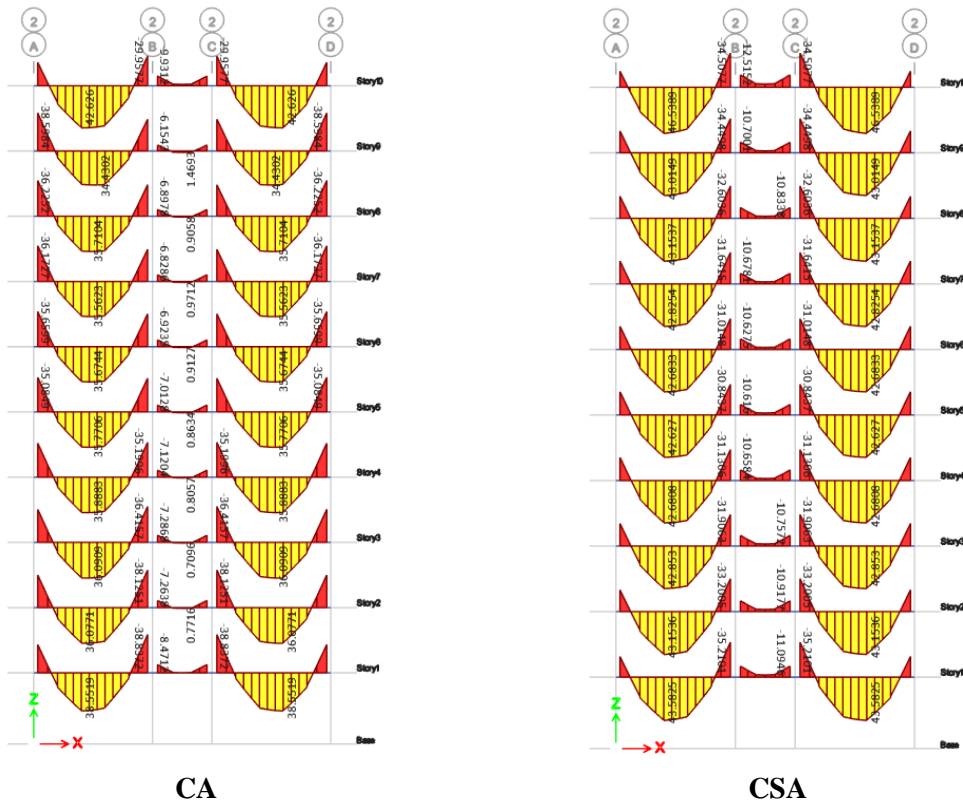
Thereby, it can be observed that:

- When using construction sequence analysis technique, the calculated internal forces such as axial of column and mid-span bending moment of beam at the bottom story are larger than those when using conventional technique. The difference of axial force and bending moment is about 4.60% and 12.95%, respectively.

- The mid-span displacement of beam 2A-B when using CSA is larger than that when using CA. The difference is about 10.93%.



CA CSA
Fig. 7. Axial force of column C2-B at the bottom story.



CA CSA
Fig. 8. Bending moment on beam 2A-B.

3.2. Effects of the building height

The results of calculated axial force in the column (C2-B) (AFC2-B), mid span bending moment of span 2A-B beam (MBB2A-B), end moment of beam 2A-B (EMB2A-B), mid span displacement of beam 2A-B (MDB2A-B) in the elevation of axis 2, at first floor of buildings with different height are summarized in Tab. 4. The differences (DC2A-B) between vertical displacements of rooftop joints on exterior (C2-A) and interior columns (C2-B) are also included.

Tab. 4. Force, displacement in 4 different models

	M-1			M-2			M-3			M-4		
	CA	CSA	$\Delta\%$	CA	CSA	$\Delta\%$	CA	CSA	$\Delta\%$	CA	CSA	$\Delta\%$
AFC2-B (kN)	1229	1286	4.6	2446	2551	4.3	3844	3974	3.4	5197	5347	2.9
MBB2A-B (kNm)	38.5	43.5	13.0	33.1	36.4	10.0	30.7	32.7	6.5	29.8	31.2	4.7
EMB2A-B (kNm)	-38.83	-35.21	-9.32	-37.91	-35.39	-6.65	-36.38	-34.59	-4.92	-34.34	-32.73	-4.69
MDB2A-B (mm)	1.82	2.02	11.0	1.9	2.05	7.9	1.93	2.02	4.7	2.19	2.22	1.4
DC2A-B (mm)	0.71	0.15	78.51	1.05	0.13	87.24	1.18	0.11	90.83	1.33	0.10	92.27

Based on the data in Tab. 4, some observations can be drawn that:

- When analyzing by CSA, the axial force of columns, mid span bending moment of beam of the structure is greater than that when using CA analysis; but the end moment of beam is decreased.

- As the height of the building increases, the difference between the internal force characteristics, the displacement of the member between the two analysis techniques decreases. In the contrast, the difference between vertical displacements of rooftop joints at exterior and interior columns is increased. It can be explained by the phenomenon of column shortening. In actual construction, the self-weight of the structure has been added step by step over time. The sequential construction of the floors has partially eliminated the cumulative displacement difference due to the column-compensated concrete pouring, and the uniform elevation adjustment at each floor. Therefore, the effect of shortening is not as great as in the calculation using CA technique.

4. Conclusion

The analytical results show the influence of the construction sequence analysis technique on the responses of the structural system, which is approximately 10% than those using conventional technique. For high-rise buildings, the analysis of the construction sequence should be taken into account when conducting the design.

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PHÂN TÍCH KẾT CẤU NHÀ CAO TẦNG BÊ TÔNG CỐT THÉP CÓ KẾ ĐẾN TRÌNH TỰ XÂY DỰNG

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Tóm tắt: Bài báo nghiên cứu ảnh hưởng của trình tự xây dựng công trình đến phản ứng của kết cấu nhà cao tầng bê tông cốt thép. Hiện nay, phần lớn hệ kết cấu công trình được phân tích một bước - phân tích truyền thống, với giả thiết hệ chịu toàn bộ tải trọng, khi toàn bộ công trình được xây dựng xong. Thực tế xây dựng tuần tự tầng theo tầng dẫn tới sai khác giữa phân tích lý thuyết và phản ứng thực tế của hệ kết cấu, nhất là đối với hệ kết cấu nhà cao tầng. Các kết quả ảnh hưởng đến nội lực cột, dầm của hệ kết cấu nhà cao tầng với các chiều cao khác nhau được tổng hợp khi thực hiện phân tích theo trình tự xây dựng, và so sánh đánh giá khi sử dụng phương pháp phân tích truyền thống.

Từ khóa: Nhà cao tầng; trình tự xây dựng; phân tích phi tuyến; ETABS.

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