MODELING OF TWO-CELL CONCRETE CORES FOR INVESTIGATION OF RELIABALITY OF EQUIVALENT COLUMN METHOD

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Abstract. The behavior of coupled and non coupled shear walls have been the subject of many researches in the recent past. In contrast, only little mention has been made of the shear core walls structures. Shear core walls behaviors are different of the planner shear walls. In order to model shear walls three different methods exist: one-dimensional equal elements, equal panel elements and precise finite elements. Equivalent column method is main approach in modeling by using one-dimensional equal elements. Shear core walls are modeled by the same methods. One of the key points in this study is to determine whether equivalent column method is precise in solution or not.
This research focuses on the modeling of shear core wall with equivalent column method and two dimensional panel elements method. The models examined are: (a) models composed of panel elements, (b) models composed of equivalent column in different hand arrangement. These models are compared with one another and with the solution considered accurate, which is the one obtained by using a finite element method consisting of an adequately dense mesh of finite shell. It can be concluded that application of equivalent column method in cores, leads to inaccurate or even unacceptable results .This deficiency can be improved by using flexible rigid links.

Key words: Shear core wall, coupling beam, equivalent panel element, equivalent column element, core rotation, Warping.

Introduction

The penetration of the finite element method into almost all fields of structural computation has not yet been able completely to replace the use of simplified modeling and analysis methods. Widely accepted models for the analysis of multi-story buildings with planar shear walls and cores are: equivalent frame models, also referred to as wide column analogy, and panel element models. Also—in some cases—core models consisting of a sparse mesh of finite elements are used.
Mainly the use of the equivalent frame model has been a major success. This model was devised for the analysis of planar shear walls approximately four decades ago [1,2,3,4]. The simplicity and effectiveness of this model has almost self-evidently led to the extension of its application to composite shear walls (cores) in three dimensional analysis of multi-story buildings [1,2,3,4,5]. However, soon, serious deficiencies in the performance of this model were detected. Several investigations on this matter have shown that application of this model to open, semi-open and closed building cores subjected to strong torsion leads to inaccurate or even unacceptable results [6,3,4]. Also, significant deviations from the correct solution are observed for planar shear walls with varying width along their height or with irregularly distributed openings [6].
Furthermore, it should be noted that the equivalent frame model for a given core is not unique. Quite the contrary, it depends on certain necessary assumptions that can lead to different spatial frame models [6]. The differences between the possible models concern: (a) the number of equivalent columns; (b) their location in the core cross section; and (c) the cross sectional properties of equivalent columns and interconnecting auxiliary beams (links) used at the story levels. The reliability and efficiency of a series of various equivalent frame models for open, mainly U-shaped cores have been investigated in depth in the recent past [6]. On the contrary, the reliability of

equivalent frame models for multi-cell cores, and especially for open two-cell cores is very poor, although such cores are very often encountered in practice. In Fig 1 different arrangements of equivalent frame model are presented:

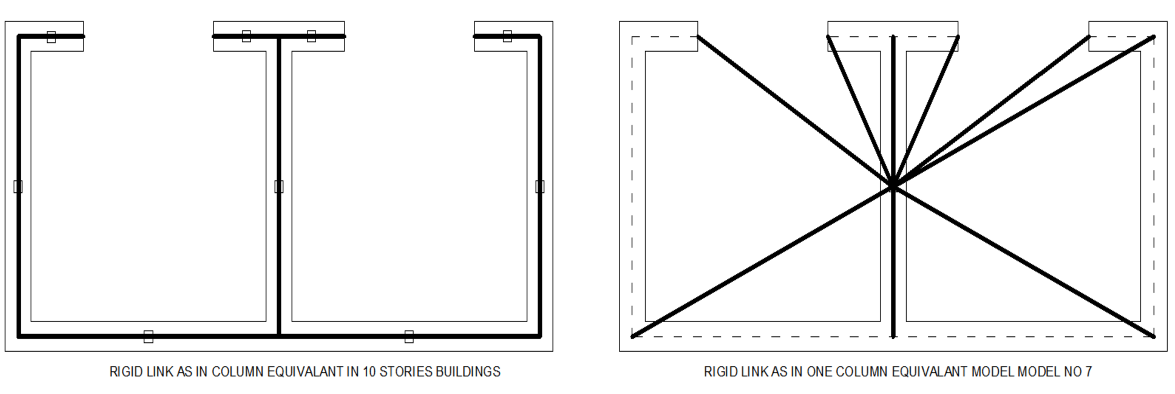


Fig 1: Normal Arrangment and one column in the center of mass models

STRUCTURAL SYSTEMS AND MODELS

Basic modeling assumptions In the present paper, all analyses are carried out using the two-cell semi open core shown in Fig 1 and the 10- story building shown in Fig 2:

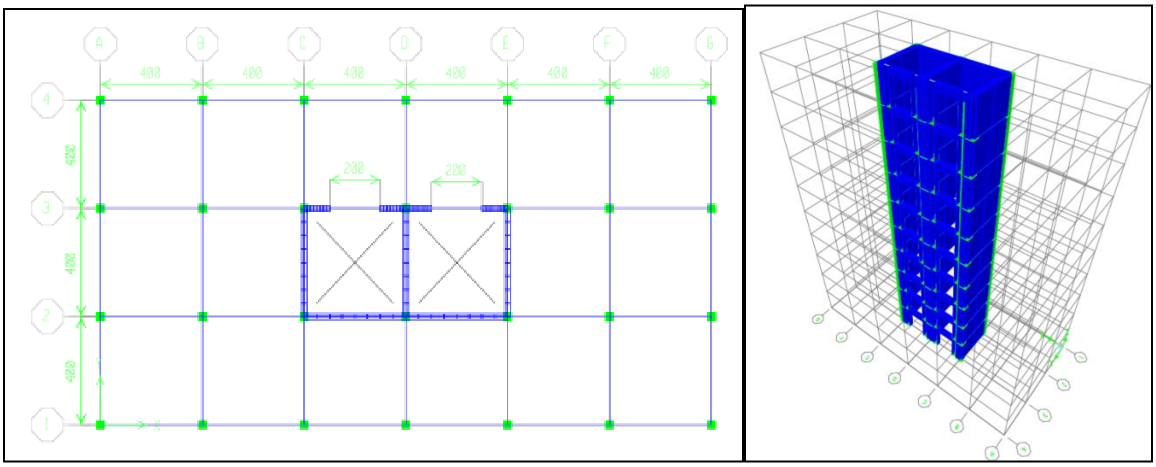


Fig 2: 10-story building

The investigated building (Fig 1) is 10-story high, and absolutely fixed at its base. The height of the stories is 3.0m. The magnitude and vertical distribution of horizontal load is according to the design spectrum of the Iranian seismic design code (2800-05 code, third edition) and is used with the following data: soil II, seismic zone I (A = 0.35g), importance factor = 1, damping coefficient = 5%. Each building has a opening in cross section of core, The width is 2.0 m. A coupling beam in each stories closes the core. The sections used in models are as follow:

Table I, (centimeter)

Beam section	Column section	Wall section
35×50	60×60	thickness 40

The magnitudes and the vertical distribution of the horizontal seismic loads for the equivalent static analysis of the building are determined according to the design spectrum of the Iran seismic design code (2800-05 code, third edition) by using the period of the building. These equivalent static loads are not exactly the same for all models. They are slightly different because of slight differences in the geometry of the various models. All calculations are performed using ETABS. The Concrete is used according to Euro Code C25/35 and rebars are according to ASTM GRADE60 (A615G60).

Dead and live load is uniform on all floors and assumed equal to 200 kg per square meter for live load and 300 kg for dead load. Self weight of structural elements like beam, column and slab are considered.

Core modeling with finite shell elements (Model No. 1 and No 2) The bases for comparison and reference solution are served by a core model consisting of an adequately dense mesh of finite shell elements (Model No. 1). Model no 2 is an alternative modeling, similar to that with Model No. 1 with one shell element per flange and story.

Core modeling with equivalent frames (Models No. 3, No 4, No. 5 and No. 6) The basic rules for the creation of models using equivalent frames for shear walls and cores are described in detail in the literature (see, for example, MacLeod, 1977 and Avramidis, 1991). Fig 1 represents a plan-view of the two equivalent frames models, No. 3, No. 4 No. 5 and No. 6, whose performance is investigated in the present paper. In these models the core has been break down to rectangular part and a column is modeled in the center of rectangle. These columns are connected to the entire structure by link beams. These link beams get from flexible in Model No.3 to rigid beams in Model No.6.

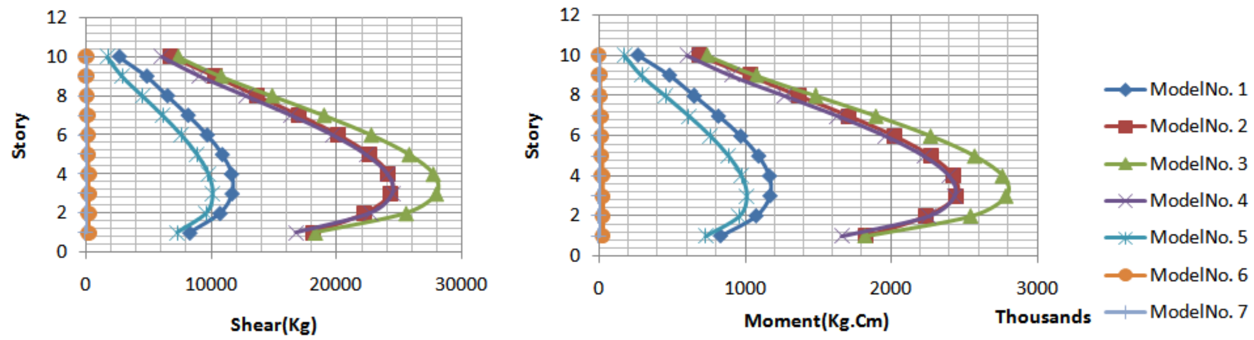
Core modeling with one equivalent column (Model No.7) Fig 3 represents a plan-view of the equivalent frames models No. 7. At this point the reader should be reminded of the important role played by the absolutely stiff beams (rigid offsets, rigid links interconnecting the equivalent columns at the story levels) in correctly rendering the torsional behavior of the core: these beams must not hinder the warping of the core's cross-section. This can be achieved only in the case of classical Models No. 3, No 4, No. 5 and No. 6, while in models using only one equivalent column (No. 7) warping of the cross-section cannot be simulated at all [7].

Core modeling with close core (Models No 8) In order to reach more accurate conclusions, a building with close core has been modeled. This model has no opening.

MODEL COMPARISON AND SELECTIVE PRESENTATION OF RESULTS

Introduction The results obtained from the analysis of the building structure are selectively presented below. The results include static displacements and drifts along x- and y-direction and core rotation along vertical axes of building, and also natural vibration periods for all models presented (No. 1–No. 8).An important Factor in the core modeling is warping which is presented below. The comparison and evaluation of models are based on the results from the static analysis of the equivalent static analysis of the 10-story building for seismic loading along the x- and y-directions. In addition, the comparisons include line elements of the coupling beams which are expected to develop relatively large shear and moment. As mentioned before, the basis for all comparisons is served by the results obtained from the analysis of the investigated structural systems using a highly accurate finite shell element model (model No. 1)

Moments and shear stresses in coupling beams(Fig 3). The highly simplified Models No. 7 and model No. 6 with rigid link beams are not capable of modeling of coupling beams; the shear and moment in coupling beam are reported too small. On the other hand, Model No. 3 and model No.4 behaves rather well with acceptable values for forces. The conclusion can be reached that the flexible link beam can simulate coupling beam more accurate.



Figur 3. Moment and shear in Coupling Beams

Displacements and rotations of the stories' mass centers 10-story building. (Fig 4 and 5). The flexible link beams model No3 , No 4 and No.5 exhibit a quite acceptable behavior, with rotation and displacement values that are practically identical with the corresponding values of the reference Model No. 1. The rigid link beam Model No.6 and the model with one shell element per flange and story (No. 6 and No. 76, respectively) exhibit behavior like close core model No.8.

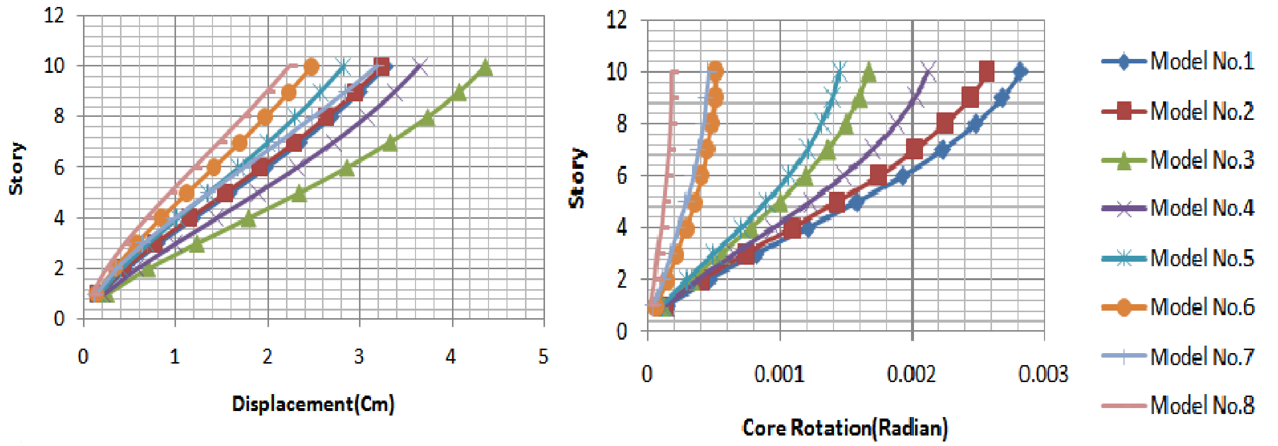


Fig 4. Displacement along x-direction and Rotation along vertical axes z-direction in center of mass

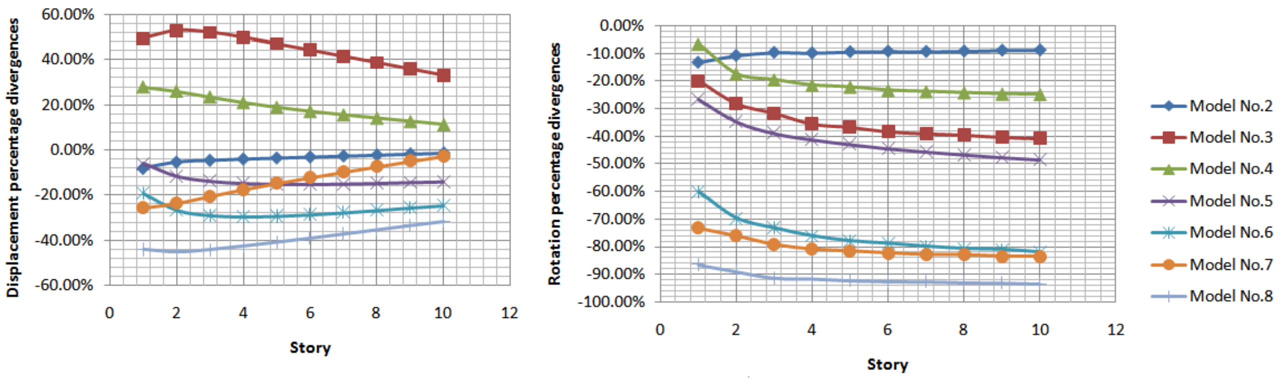


Fig 5. Percentage divergences of rotations and displacements at the stories' mass centers of Models No. 2–No.8 with reference to Model No. 1

Drifts of the stories' mass centers (Fig 6 and 7) . The flexible link beams model No3 , No 4 and No.5 exhibit a quite acceptable behavior, with drifts values that are practically identical with the corresponding values of the reference Model No. 1. Model No.5 Somehow tend to values of close core model No.8. The rigid link beam Model No.6 and the model with column (No. 6 and No. 7, respectively) exhibit behavior like close core model No.8.

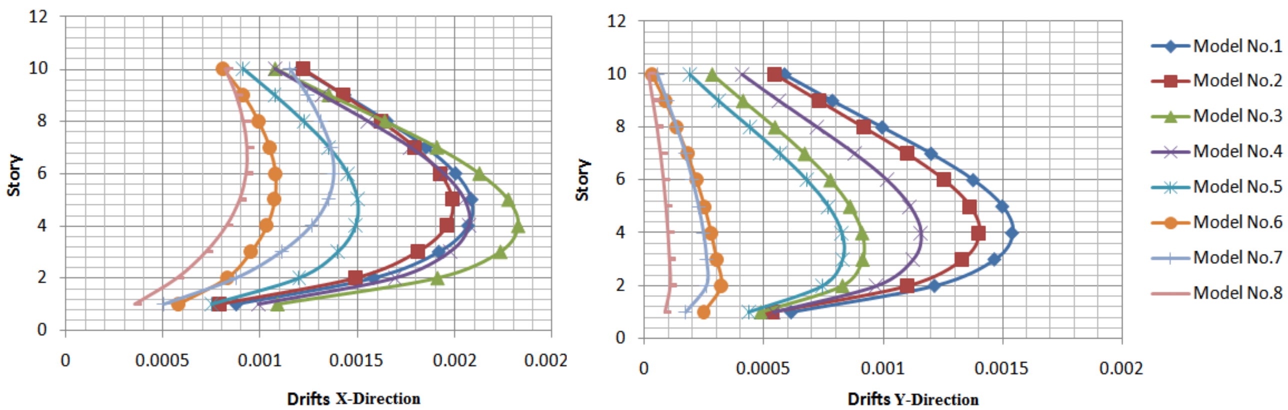


Fig 6. Drift at the stories' mass centers of Models No. 1–No.8 along X- and Y-direction

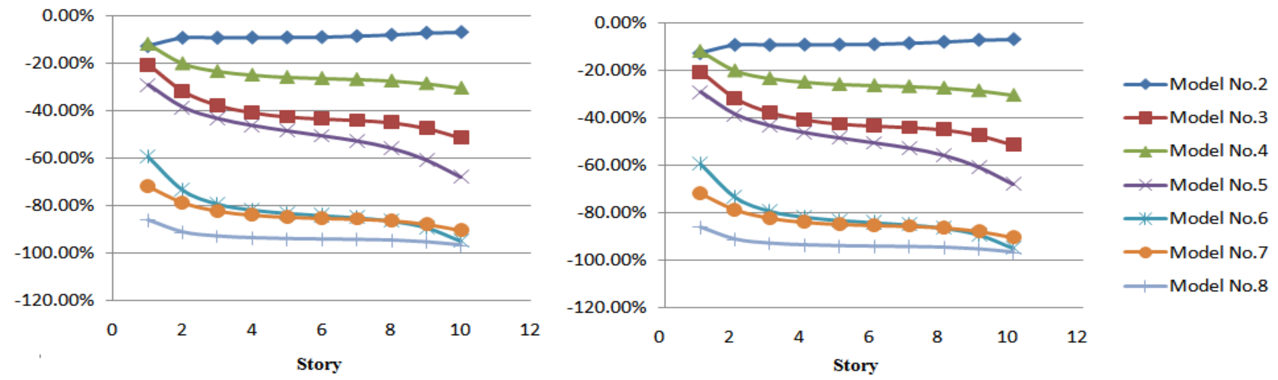


Fig 7. Percentage divergences of drift along X-direction and Y-directionat the stories' mass centers of Models No. 2–No. 8 with reference to Model No. 1

Natural periods of the 10-story building.(Table 3.) The above mentioned remarks concerning the models' performance are further consolidated by results obtained for natural vibration periods. Models No. 3 exhibit large positive deviations for the first (fundamental) vibration period, while Models No. 5 and No. 6 display exhibit large negative deviations for the first (fundamental) vibration period. In contrast to above mentioned remarks concerning the models' performance the model with one single column perform like close core. Model No.4 display acceptable responses

Table 3. Periods for Models No. 1–No. 8

	Model N0.1	Model N0.2	Model N0.3	Model N0.4	Model N0.5	Model N0.6	Model N0.7	Model N0.8
T1	1.287818	1.235436	1.317752	1.270942	1.059448	1.011059	1.243847	1.243847
T2	1.014086	1.006683	1.121072	1.054264	1.011823	0.819063	0.8458	0.8458
T3	0.712826	0.711213	0.99202	0.847635	0.727682	0.722015	0.780965	0.780965
T4	0.388073	0.373694	0.412216	0.394162	0.333599	0.267423	0.408035	0.408035
T5	0.243054	0.239829	0.302063	0.271176	0.243716	0.243072	0.237102	0.237102
T6	0.206685	0.204053	0.295885	0.253913	0.206157	0.199504	0.209939	0.209939
T7	0.197632	0.192917	0.22376	0.21277	0.18551	0.159156	0.193074	0.193074
T8	0.131228	0.127642	0.152349	0.140172	0.125485	0.113247	0.163271	0.163271

Warping of the core's cross-section (Fig 9). The preliminary remarks and conclusions concerning the reliability of the different models as resulting from the data presented so far is further consolidated by results referring to the core's cross-section warping. Model No. 7 produces unacceptably large deviations and similar to close core Model No.8. Model No. 4 simulates the cross-section warping quantitatively better than Model No. 3. Models No. 5 and No. 6 yield, like model No. 2, very good results.

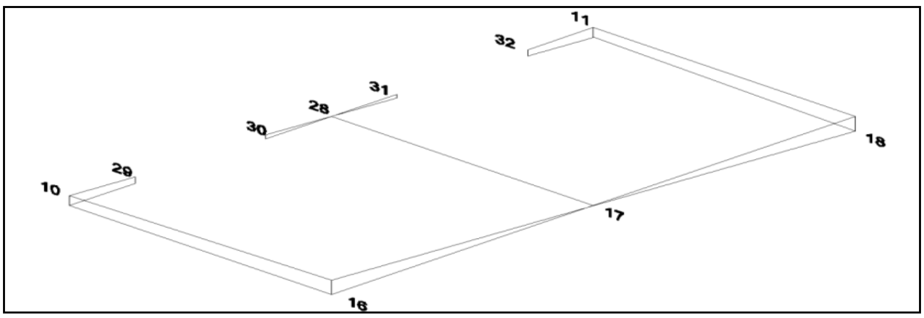


Fig 13. Node number at top of level of corefor model No.1-No.8

Table 4. Warping of the core's cross-section for Models No. 1–No. 8 along z-direction (In mm)

Node No.	Model No.1	Model No.2	Model No.3	Model No.4	Model No.5	Model No.6	Model No.7	Model No.8
10	2.254	2.474	1.937	2.228	2.859	3.134	4.508	3.234
11	-2.254	-2.474	-1.937	-2.228	-2.859	-3.134	-4.508	-3.222
16	3.251	3.392	2.823	3.08	3.137	3.134	4.508	3.248
17	0	0	0	0	0	0	0	-0.001
18	-3.251	-3.392	-2.823	-3.08	-3.137	-3.134	-4.508	-3.234
28	0	0	0	0	0	0	0	0
29	1.434	1.565	1.133	1.406	2.072	2.35	3.381	2.445
30	0.881	0.942	0.803	0.824	0.795	0.784	1.127	0.813
31	-0.881	-0.942	-0.803	-0.824	-0.795	-0.784	-1.127	-0.815
32	-1.434	-1.565	-1.133	-1.406	-2.072	-2.35	-3.381	-2.445

Summary

As mentioned in the Introduction, the present investigation concerns. Summarizing all observations and comparative remarks made above, the following conclusions can be formulated.
(a) The highly simplified Models No. 7 are not capable of simulating the structural behavior of the core. Because of the major deviations in displacements and coupling beam forces and other result, these models are considered to be of very limited reliability. (b) The highly simplified Models No. 7 and model No. 6 with rigid link beams are not capable of modeling of coupling beams; The shear and moment in coupling beam are too small. On the other hand, Model No. 3 and model No.4 behaves rather well with acceptable values for forces. The conclusion can be reached that the flexible link beam can simulate coupling beam more accurate. (c) The model No. 6 with rigid link beams behaves like model No.8 with close core and the value for both models are similar. As the rigidity of link beams decrease, the value of result get closer to accurate value. There is a optimum rigidity that as the rigidity of link beams decrease, the value of result far apart from accurate value.

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