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ERRORS IN CONCRETE SHEAR WALL ELASTIC STRUCTURAL MODELING

BY

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Abstract. A requirement for the linear elastic structural concrete wall analysis is represented by the error control during the modeling. The analyst must be aware of the consequences coming from choosing from the diverse design models and take decisions accordingly, in order to maintain the error level as low as possible. The paper is dedicated to the study of some of these errors and investigate their magnitude in few representative cases.

Key words: shear walls; concrete walls; coupled walls; structural design; finite element model; shell model; frame model; design method; design errors.

1. Introduction

Linear elastic practical modeling of reinforced concrete shear walls is made by idealizing the walls and coupling beams using frame or shell finite elements. Analysing these structures calls for choosing the type of idealizations that would approximate with satisfactory precision the real structure behaviour. The challenge for the analyst is then to maintain the modelling errors at as low level as possible considering the will to fast attain to actual results.

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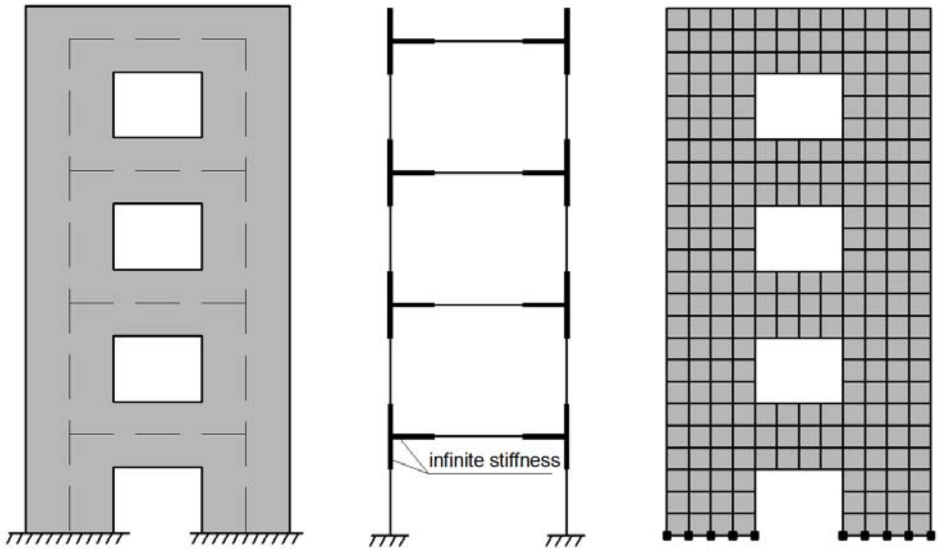
2. Objectives and Scope of Work

The paper wants to show out some errors that could appear through modeling of reinforced concrete shear wall structures in the linear elastic domain and to investigate their magnitude in few representative cases.

In Fig. 1 are shown two plane design models witch are frequently used for shear walls with overlapped openings.



a *b* *c*

Fig. 1 – *a* – Real structure; *b* – equivalent frame idealization; *c* – shell elements idealization.

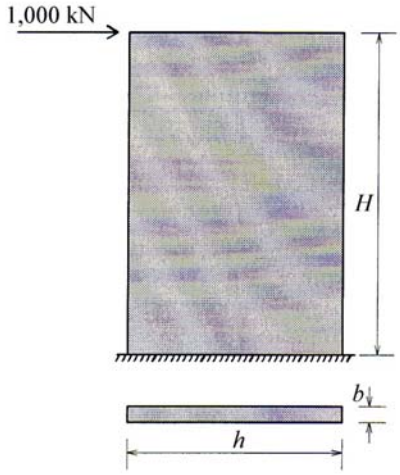
3. Designing Hypotesis

In order to analyse the errors, there are compared some models of structural walls with a precise model for each situation, so called “exact” model. The comparison is made on the main results for the structural analysis, such as maximum displacements and forces. Since the purpose of the documentation is to analyse errors in elastic domain, the differences between results will be important, rather than their actual values.

In the following steps the wall thickness, their total height and the elastic characteristics of the material are considered constant. Loads are applied concentrated at the slab level. The computation was made in structural design program – Etabs, using finite elements having each node six degree of freedom (although there have been used only degrees of freedom in the plan).

3.1. Solid Shear Wall Modeling

For start there is considered an example of a solid shear wall having a structure with one level, subjected to superior part by a horizontal concentrated load equal with 1,000 kN (Fig. 2).



F = 1,000 kN
H = 12 m
h = 36 m/24 m/12 m/8 m/6 m/4 m/3 m/2 m
b = 0.60 m
$E = 3 \times 10^7$ kN/m^2
ν = 0.2

Fig. 2 – Solid shear wall.

Model "1A" presents a fixed bar (vertical cantilever), "1B" presents a finite element, "shell" type, without mesh, "1C" is obtained meshing the previous model in a sufficient number of finite elements, to be considered the "exact" model (Fig.3).

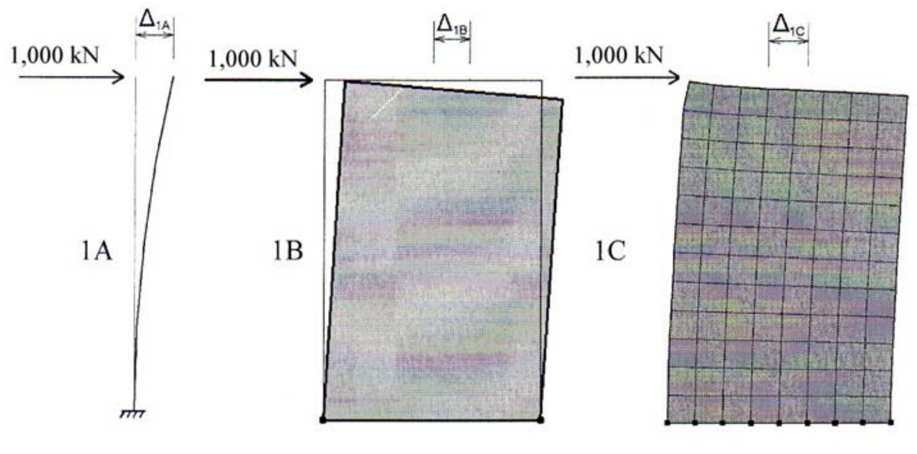


Fig. 3 – Computation models for solid shear wall.

The number and shape of the considered finite elements were chosen for model "1C" according to the following principle: the elements have almost square shape and lead to a difference of displacement (maximum) of 1% less than the maximum displacement obtained by dividing the model into four elements, each finite element of the considered model.

Maximum displacement of the models with finite elements was given as arithmetic average for horizontal displacements of the nodes situated on the upper side of the wall (Eurocode 8, 2003).

Because the maximum displacement in case of model "1A" can be directly computed with the relationship presented below, it is observed that the total displacement is obtained by summing the displacement from bending and shear, displacement whose variation is directly influenced by solid wall size, H/h. In accordance with the chosen model, the ratio H/h takes the values 1/3; 1/2; 1/1; 1,5/1; 2/1; 3/1; 4/1; 6/1. Consequently

$$\Delta_{1\mathrm{A}} = \Delta^M + \Delta^V = \frac{FH^3}{3EI} + 1.2\frac{FH}{GA} = 0.222\left(\frac{H}{h}\right)^3 + 0.160\left(\frac{H}{h}\right), [\mathrm{mm}]$$

3.2. Results for Solid Shear Wall

Table 1 presents the maximum displacements and errors obtained for the three types of models depending on different values of the ratio H/h, emphasizing the value of displacements from bending and shear for the model"1A".

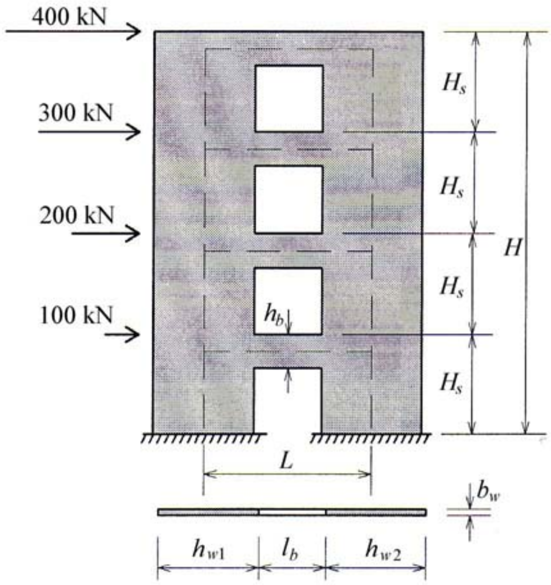
Table 1

Displacements and Errors for the Models of Solid Shear Wall

H/h	ΔM mm	ΔV mm	Δ_{1A} mm	Δ_{1B} mm	Δ_{1C} mm	Error Δ_{1A} %	Error Δ_{1B} %
0.33	0.008	0.053	0.061	0.049	0.079	–27.93	–61.23
0.5	0.028	0.080	0.108	0.194	0.300	–178.7	–55.07
1.0	0.222	0.160	0.382	0.288	0.394	–3.01	–36.63
1.5	0.749	0.240	0.989	0.742	0.989	0.03	–33.29
2.0	1.776	0.320	2.096	1.572	2.079	0.81	–32.25
3.0	5.994	0.480	6.474	4.856	6.405	1.07	–31.90
4.0	14.208	0.640	14.848	11.141	14.713	0.91	–32,06
6.0	47.952	0.960	48.912	36.711	48.434	0.98	–31.93

3.3. Shear Wall with Overlapped Openings Model

There is considered a wall with overlapped openings (Fig.4), subjected to horizontal loads similar to those produced by an earthquake. Equivalent static loads act at floor level (the upper edge of the coupling beam) and are simple distributed according to the first mode of vibration.



$H = 4H_S = 12$ m; $H_S = 3$ m
$b_w = b_b = 0.2$m
$h_{w1} = h_{w2} = h_w$
$l_b = 2$ m
$E = 3 \times 10^7$ kN/m^2; $\nu = 0.2$

Wall	h_w, [m]	h_b, [m]
1	6	0.25
2	5	0.5
3	4	0.75
4	3	1
5	2	1.5
6	1	2

Fig. 4 – Structural wall with overlapped openings.

Model “2A” is obtained by the equivalent frame method; the two walls and coupling beams are idealized by bars having infinite rigid parts at the end, in discontinuity regions (Fig. 5).

Model ”2B” is obtained using shell finite elements, with minimum mesh (Fig. 6).

Model ”2C” (“exact”) is obtained by meshing walls and coupling beams based on the same principles used for model ”1C” (Fig. 7).

At coupled walls the displacements and the stresses depend not only on the bending and shear rigidity of the walls and coupling beams, but also on their rigidity at tension–compression. As result, in case of shear wall with openings, the variable chosen for comparison should be a parameter that indicates the “coupling degree” of the solid walls through the coupling beams.

The degree of coupling and its influence has been studied up to now in different ways corresponding computation methods. For example, there was considered size/layout/openings percentage of the shear wall or the ratio between rigidity of the solid shear walls and of the coupling beams.

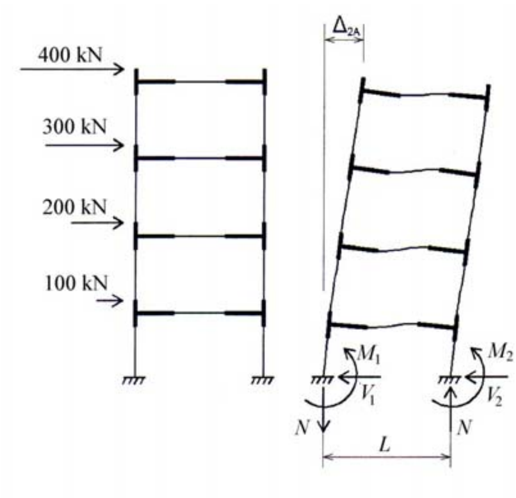


Fig. 5 – Model “2A”.

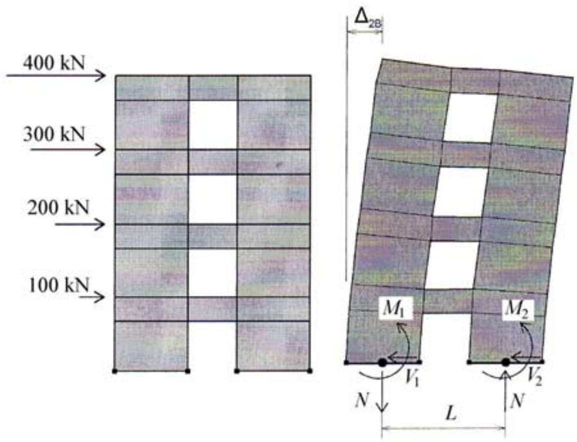


Fig. 6 – Model “2B”.

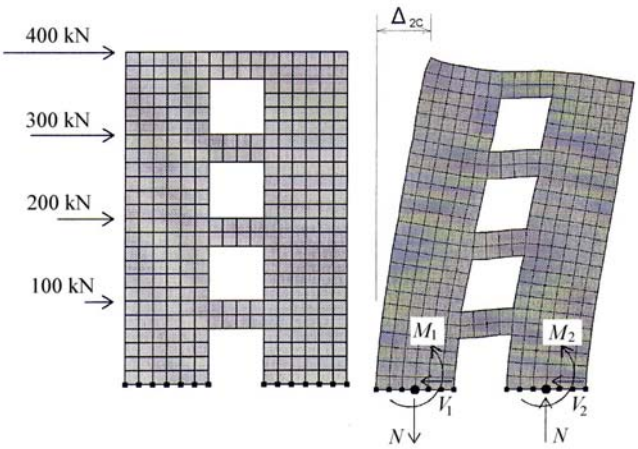


Fig. 7 – Model “2C”.

It is proposed, in this paper, as an index (Paulay *et al.*, 1990), named "degree of coupling" the ratio $C = NL/M$, where $M = M_1 + M_2 + NL$. Index values of the coupling degree are obtained considering six variants of shear walls obtained according with the table in Fig.4, considering the association between the different dimensions of the solid walls/coupling beams as follows:

a) are constant the height of the walls, the span of the coupling beams and the level heights;

b) it is considered the following options for the high of the coupling beams: $h_b = l_b/8$; $2l_b/8$; $3l_b/8$; $4l_b/8$; $6l_b/8$; $8l_b/8$ (where l_b is the span of the coupling beams). The span of the coupling beams, l_b, was chosen so that for $1.5l_b$ to have total coupling ($1.5l_b = H_s$, where H_s is the height of the level);

c) the considered options for the sectional height of the solid walls were established by taking into account the ratio h_w/H to have the values 6/12; 5/12; 4/12; 3/12; 2/12; 1/12. Increasing the section height of the columns, h_w, was made to the exterior of the wall, so that the span of the coupling beams remains constant.

The reactions (forces) at the base of the wall are computed by summing /reducing the nodal forces in the center of gravity of the section. It is preferred this option because by integrating the stresses it can be obtained values that do not provide perfect equilibrium with external forces, which could affect the comparison of errors.

3.4. Obtained Results for Shear Walls with Openings

Table 2 presents the maximum displacements and errors obtained for the three models depending on the coupling index *NL*/*M* ratio, computed for model "1C".

In Tables 3 and 4 are presented the maximum values of reaction forces, *N* and *M*, and corresponding errors obtained at the base section of the wall for considered models, depending on the coupling index values *NL*/*M*.

Table 2
The Displacements and Errors for Shear Walls with Overlapped Openings

NL/*M*	*L*, [m]	Δ_{2A} mm	Δ_{2B} mm	Δ_{2C} mm	Error Δ_{2A} %	Error Δ_{2B} %
0.06	8	1.892	1.203	1.879	0.7	–56.3
0.28	7	2.125	1.334	2.219	–4.4	–66.4
0.45	6	2.501	1.693	2.779	–11.1	–64.1
0.62	5	2.994	2.566	3.678	–22.8	–43.3
0.80	4	4.038	4.765	5.730	–41.9	–20.3
0.90	3	8.496	14.158	15.614	–83.8	–10.3

Table 3

Values of the Maximum Reaction Forces, N (Axial Force at the Base Sections of the Walls), for Shear Walls with Overlapped Openings

NL/M	L, [m]	N_{2A} kN	N_{2B} kN	N_{2C} kN	Error N_{2A} %	Error N_{2B} %
0.06	8	53	406	68	–28.3	83.3
0.28	7	330	679	359	–8.8	47.1
0.45	6	705	950	681	3.4	28.3
0.62	5	1,127	1,292	1,119	0.7	13.4
0.80	4	1,730	1,841	1,753	–1.3	4.8
0.,90	3	2,686	2,729	2,700	–0.5	1.1

Table 4

Maximum Reaction Force Values, M (Overtuning Moment Reactions at the Wall Base), for Shear Walls with Overlapped Openings. Value of M was Obtained with the Relation $M = M_1+M_2+NL$*, where* M_1 *and* M_2 *are Overtuning Reaction Moments at the Wall Base*

NL/M	L, [m]	M_{2A} kMm	M_{2B} kNm	M_{2C} kNm	Error M_{2A} %	Error M_{2B} %
0.06	8	8,586	4,844	8,457	1.5	–74.6
0.28	7	6,688	4,245	6,483	3.1	–52.7
0.45	6	4,758	3,296	4,908	–3.2	–48.9
0.62	5	3,400	2,538	3,404	–0.1	–34.1
0.80	4	2,033	1,632	1,985	2.4	–21.6
0.90	3	992	812	899	9.4	–10.7

4. Conclusions

At solid shear wall is observed near perfect correlation between the maximum displacements corresponding to vertical cantilever model ("1A") and the reference model ("2C") for ratio values $H/h > 1$, regardless the value of the bending and shear deformations. In this domain model "1B" gives large errors of over 30% due the lack of discretization. In domain $H/h < 1$ is observed high values of the errors for both models. On this domain is recommended the exclusive use of the "exact" model for analysis in which displacements has an important role.

At shear walls with overlapped openings are observed important differences between maximum displacement of the reference model ("2C") and those corresponding to the other models. In case of the model with equivalent frame ("2A"), these differences are the consequences of the fact that the infinite rigid areas do not contribute at general displacement. Therefore, to compute displacements it should assign to these areas a proper rigidity. At the model with minimum mesh ("2B") the difference arises from insufficient discretization, the bending deformation being insufficiently emphasized.

From errors analysis of reaction forces at the section base can be noticed a very good correlation between the reference model ("2C") and equivalent frame model ("2A") for coupling index values between 0.45 and 0.80. For the rest of domain, for weak or strong couplings, it is recommended the "exact" model ("2C"). The minimum mesh model ("2B") presents large errors regardless the coupling degree, from insufficient discretization.

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ERORI LA MODELAREA ELASTICĂ A STRUCTURILOR CU PEREȚI STRUCTURALI DIN BETON ARMAT

(Rezumat)

O necesitate în analiza structurilor cu pereți structurali din beton armat este reprezentată de controlul erorilor de modelare în domeniul liniar elastic. Analistul trebuie să cunoască consecințele care decurg din alegerea diferitelor modele de calcul şi să ia decizii care să ducă la menținerea erorilor la un nivel cât mai scazut. Se urmareşte evidențierea unelor dintre aceste erori şi investigharea dimensiunilor acestora în câteva cazuri reprezentative.