EVALUATION OF THE USUAL PROCEDURES OF ANALYSIS FOR TALL BUILDINGS IN MASONRY STRUCTURE

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ABSTRACT

The present work consists on the comparative study of structural analysis obtained by a three-dimensional analysis program for tall building in a masonry structure with those results obtained by usual procedures. The present program performs the analysis on first and second order effects and incorporates the use of thin-walled elements with open-section to represent structural walls, beams with or without torsion strength to represent lintels, and slabs as rigid diaphragms. In this program structural walls are analyzed by Vlassov's bending-torsion theory, whereby the warping and the bimoment force are taken into account. The usual procedures considered in this work are: isolated walls, group of isolated walls, and groups of isolated walls with interaction. These procedures are simplified and generally become unpracticed for large structures. Besides, they require from the designer a good experience at structural projects. The intention of this work is to check the efficiency of these procedures on structural analysis of tall building in structural masonry with the results obtained by this program.

Key words: structural masonry, tall buildings, structural analyses

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INTRODUTION

The distribution of actions on walls is one of the most important problems to be faced by the designer during analysis and design of buildings in masonry structures. According to [1], to proceed the analysis is necessary to establish at least two points: a) how to treat the loads of floors on the walls; b) how to simulate the interaction among walls.

There are many methods to evaluate the support reactions of slabs on the walls, as for example, line of rupture, Marcus' table, Czemy's table, theory of elasticity, etc. The Brazilian code, [2], specifies for rectangular slabs with uniform loading distributed, the method of lines of rupture. This was the method used in the computational program that was developed to perform the analysis in masonry structures.

The interaction of walls is a demonstrated fact as much theoretically as experimentally. According to [3], studies performed has shown that shear walls working together with floors, have the capacity of distributing the actions, which leads to favorable effects on the reduction of the strength needs and on the structural behavior of them, because the walls that are less loaded serve to receive those that are more loaded.
The usual procedures, being represented here by isolated walls, group of isolated walls, and groups of isolated walls with interaction, used to perform the distribution of loads among the supporting walls and therefore the determination of stress, are simplified. In most cases, these procedures become complicated in proportion to the increases of complexness of structure, as for example, the non-existence of symmetry of the structure. In addition, the use of these procedures normally require a designer of good experience with structural projects.

From the exposed above, one intends in this work to evaluate the efficiency of these procedures, using the results of program of tridimensional analysis for tall buildings in masonry structures. This work is being developed as part from the dissertation " Three-dimensional Analysis of Tall Buildings in Masonry Structures.

USUAL PROCEDURES

To proceed the distribution of vertical and horizontal loads on the bearing walls of a masonry structure, using the procedures mentioned before, it is done separately. Thus, the effects of vertical and horizontal loads are considered acting alone, where the resultant stresses of each action is calculated separately and then they are superposed to obtain the final stresses.

Distribution of Vertical Loads

The usual procedures used to perform the distribution of vertical loads are described below.

Isolated Walls

It is a very simple procedure where walls are considered separate from the others. The loads that they receive from floors are uniform. According to [4], these actions are usually analyzed by subdividing the area of each floor into triangles and trapezoids as it is done in the usual design of beams and grids of reinforced concrete.

As the interaction of walls is a demonstrated fact, this procedure, despite being quick and simple, is anti-economic because it results in specifications of blocks with strengths relatively high.

Group of Isolated Walls

It is also a simple procedure despite being a little harder than the previous one. In this procedure, according to [5], floor is divided into areas of influence around the walls that are interlinked and separated from the others by openings.

This procedure is very interesting because it considers the fact of interlinked walls interact with the tendency of uniforming stress throughout the height of the building.

It is admitted that the loads are totally uniform at each group of walls considered, but they don't interact with the others. Thus, it may become little economic or unsafe depending on the considered groups.

The designer is responsible for the definition of the groups of isolated walls where there are not well-defined rules that can guide one on this work. There are same indications that consist in separating them from the others by theirs openings, but it is not a safe rule. It is important that the designer has a good experience with structural projects when he proceeds it because incorrect choices may result in improper specifications for strengths of blocks.

Groups of Isolated Walls with Interaction

The difference between this procedure and the previous one is that the groups of bearing walls defined previously now interact according to a interaction rate forming macro groups.

A macrogroup is defined by the following attributes: number of groups, interaction rate, and the groups of isolated walls that compose the macrogroups. The rate interaction can be defined as a value between 0.0 and 1.0 and represents the term of differential load among the groups that compose the macro group, on the considered level, which have to be uniformed. The implementation of this rate can be expressed by the expressions:

$$q_m = (q_1 + q_2 + \ldots + q_n)/n$$
$$d_i = (q_i - q_m) * (1 - t) \quad (1)$$
$$q_i = q_m + d_i$$

where: n = number of groups of walls that composes a macro group
d_i = load of group i on the considered level
q_m = average load of macro group on the considered level
d_i = differential load of group i on the considered level
t = interaction rate

From expressions (1), one concludes that the interaction rate represents the percentage of the differential load that has to be uniform. If the rate is equal to zero, the macro group will not be active and the results obtained would be the same as if it were not defined. In case of rate being equal to 1, the interaction will be complete and thus, representing the definition of only one group. Thus, it is important to make a good estimate of the value of this rate. In the lack of it, one can estimates it by a theoretical model or by some experimental procedure.

It is important to define which groups of walls will be interacting because groups where the difference of loads are great, they will not have to be uniformed. Thus, like the previous procedure, it is important the experience of the designer as much to choose the macro groups as to determine the value of rate, because they are factors that lead to considerable differences in the loads and can effect considerably on safeness and economy.

Distribution of Horizontal Load

In tall buildings is essential the analysis of strength to lateral loads that are caused mainly by actions of wind and seismics. In this work, for example, only wind loads will be considered. The horizontal actions due to wind are distributed to the bracing walls of the structure by floors proportionally to the stiffness of each wall. The determination of loads and therefore the stress on walls can be done through many procedures. Here it will be presented the procedure of isolated walls, which is more usual.

Isolated Walls

This procedure is very simple and efficient especially in cases of actions acting in direction of the axis of symmetric of the structure. This procedure is presented by [6], where panels of walls are modeled like isolated walls, receiving loads of wind actions proportionally to their relative rigidities. The stiffness is inversely proportional to the displacements (Δ) and it is computed by equation (3) whose formulation comes from equation (2).

$$\Delta = \frac{F \cdot h^3}{3 \cdot E \cdot I} + \lambda \frac{F \cdot h}{A \cdot E_v} = \Delta_f + \Delta_c \tag{2}$$

$$R = \frac{1}{\Delta} \tag{3}$$

Where A = area of cross section;

Ev = shearing modulus of elasticity = 0.4E;

λ = form factor of section (for rectangular section, λ=1.20);

h = vertical distance from a floor to the other;

R = stiffness of wall;

Δf = displacement due to bending;

Δc = displacement due to shearing forces;

Tall walls prevail the displacements due to bending whereas low walls the displacements due to shearing forces is prevalent. Tall walls are those whose total height is superior to five times the largest dimension in plant, as it defined by mechanics of materials. Thus, in case of having tall walls with constant stiffness throughout its height, the stiffness will correspond to its own moment of inertia I, that is, the displacement due to shearing forces are despised. Thus, it can be defined as the sum of all rigidities:

$$\Sigma I = I_1 + I_2 + I_3 + \ldots + I_n \tag{4}$$

Therefore the relative stiffness of each wall will be:

$$R_i = \frac{I_i}{\Sigma I} \tag{5}$$

Then the action on each wall will be:

$$F_i = F_{tot} \cdot R_i \tag{6}$$

where F_{tot} is the total force acting on a floor considered.

From actions one can compute the bending moment and then obtain the stress due to theses internal forces.

In the cases where wind actions don't act in direction of the axis of symmetric of the structure, the procedure of isolated walls becomes complicated to be performed without a computational program. It happens due to the fact of occurring rotations of floors that cause also the mobilization of the perpendicular panels to wind actions, which have also to be considered in the analysis. Besides, the results obtained by this procedure are relatively high. In this method the interaction of walls are no considered.

TRIDIMENSIONAL ANALYSIS PROGRAM – MASAN 01

The techniques of computational analysis, as matrix analysis and finite method, are the most versatile and accurate processes. Despite being an ideal procedure, the tridimensional analysis in finite-element is not yet viable for usual projects, due to great computational effort and time necessary to model the structure.

The program of analysis for masonry structures proposed in this work, named MASAN 01, and which will be used to perform the evaluation of the usual procedures, uses another program called CEASO 01. This one was developed by [7] and analyzes the interaction of resistant cores and space frames of structure of tall buildings in reinforced concrete, taking into account shear deformation.

Due to the CEASO 01 program incorporating elements that allows it to model masonry structures and other features, it was developed the program MASAN 01, which plays two roles at the same time: pre- and postprocessor. MASAN 01 includes graphical interface with CAD resources to model masonry structures as well as to view the analysis results that has been processed by CEASO 01.

CEASO 01 Features

The thin-walled member of open cross section, which is used in CEASO 01 to model resistant cores in buildings of concrete, is analyzed using Vlassov's bending and torsion theory where is taken into account the warping and the force termed the bimoment B. On the program, the cross section of this member is divided into finite elements which allows it to compute stress and displacements on this elements.

In this work used this same model to model the bearing walls. Thus, the normal stress, parameter of great importance on the analysis of masonry structures, passes to be evaluated by the expression below:

$$\sigma = \pm \frac{N}{S} \pm \frac{M_z}{I_z} \cdot y \pm \frac{M_y}{I_y} \cdot z \pm \frac{B}{J_w} \cdot \omega \qquad (7)$$

being N, B, Mz e My, respectively, normal stress, bimoment, and bending moments, respectively, in direction of z, and y, and S, Jw, ω, Iz, and Iy, respectively, cross-sectional area, moments of sectorial inertia, sectorial area, and moments of inertia in direction of y and z axes, respectively.

CEASO 01 performs linear analysis and includes P-delta for second order effect as well as spring supports; concrete slabs working as rigid diaphragms; bending of walls and lintels being governed by Timoshenko's theory, where the distortion of the cross section of member is considered.

COMPARATIVE EXAMPLE

To exemplify the comparative analysis it was used the example that was analyzed by [8]. This example consists of a four-story apartment building constructed with blocks of compression strength of 4.5MPa, whose plant is shown in Figure 1. The floor to floor height is 2.80 meters.

On the analysis performed by MASAN 01 it was considered first order effect taking into account shear deformation in walls as well as lintels. The longitudinal and shearing moduli of elasticity used for walls and lintels were the same utilized by [8], that is, respectively, 142 and 72 KN/cm^2.

To proceed the comparative analysis it was selected three walls, identified on Figure 1 by W1, W5, and W8. As one can observe in Figure 1, the wall W8 is isolated, and thus its behavior is not affected by interaction.

With intention to check the behavior of normal stress in the referred walls are presented in Table 1 the results obtained by the usual procedures and by MASAN 01, considering the acting of vertical loading. The identifiers M1, M2, and M3, represents, respectively,

isolated walls, group of isolated walls and group of isolated walls with interaction. The results correspond to the first to the last floor.
To analyze the effect of horizontal loading, it has been used the same building shown in Figure 1, changing just the number of floors to 8 and considering the acting of a wind load in direction Y. With intention to evaluate these loads, which determines the stress, it is presented in Table 2 the values of bending moments for walls PY7 and PY10, obtained by MASAN 01 and by the procedure of isolated walls.

Observing the results of table 1, one can conclude that the consideration of the influence of interaction is essential for the analysis of walls separated by openings, as one can see through the groups of walls W1 and W5. For example, on the fourth floor, wall PY5, the differences between stresses evaluated by MASAN 01 and M1, M2, and M3 procedures, reach respectively the following values: -45%, -168%, and –150%. On the other hand, on the third floor, the values are better, having respectively the following differences: 0%, -45%, and –38%.

These differences between MASAN 01 and the usual procedures exist because the evaluation of normal stress is performed by program in an overall way, considering further normal force the stress caused by bending and bending-torsion as shown in equation (7). In the usual procedures the result of normal stress is obtained normally only by the term of normal force, as it was done by [8], which resulted in high values of stress for walls where the interaction is considered high. For the case of isolated walls, like W8 wall, the results determined by MASAN 01 and the usual procedures are the same. It has occurred because the resultant stress, in this case, just depends on the term of normal force.

Table 1 – Normal Stress on W1, W5, and W8 Walls due to Vertical Loads

Floor	Group of Walls	Wall	Normal Stress (10^{-2} KN/cm^2) MASAN 01 Min	Max	[8] M1	M2	M3
4	W1	PX1	0.147	-1.620	-0.653	-0.792	-0.832
		PY3	0.147	-0.600	-1.041	-0.792	-0.832
		PY5	-1.360	-2.120	-1.154	-0.792	-0.832
	W5	PX2	0.318	-1.640	-0.986	-1.004	-0.980
		PX10	0.268	-1.050	-1.974	-1.004	-0.980
		PY7	0.880	-1.050	-0.940	-1.004	-0.980
	W8	PY10	-2.390	-2.390	-2.393	-2.393	-
3	W1	PX1	-1.400	-1.850	-1.306	-1.584	-1.663
		PY3	-1.400	-1.800	-2.081	-1.584	-1.663
		PY5	-1.730	-2.300	-2.308	-1.584	-1.663
	W5	PX2	-0.944	-1.910	-1.971	-2.008	-1.960
		PX10	-1.530	-2.090	-3.948	-2.008	-1.960
		PY7	-1.530	-2.090	-1.881	-2.008	-1.960
	W8	PY10	-3.180	-3.330	-3.256	-3.256	-
2	W1	PX1	-2.260	-2.700	-1.959	-2.376	-2.376
		PY3	-2.260	-2.450	-3.123	-2.376	-2.376
		PY5	-2.580	-2.850	-3.463	-2.376	-2.376
	W5	PX2	-2.210	-2.670	-2.957	-3.001	-3.321
		PX10	-2.590	-2.850	-5.923	-3.001	-3.321
		PY7	-2.490	-2.850	-2.822	-3.001	-3.321
	W8	PY10	-4.060	-4.180	-4.119	-4.119	-
1	W1	PX1	-3.230	-3.410	-2.612	-3.167	-3.168
		PY3	-3.230	-3.250	-4.164	-3.167	-3.168
		PY5	-3.360	-3.400	-4.617	-3.167	-3.168
	W5	PX2	-3.280	-3.430	-3.943	-4.015	-4.015
		PX10	-3.720	-3.860	-7.897	-4.015	-4.015
		PY7	-3.370	-3.860	-3.763	-4.015	-4.015
	W8	PY10	-4.880	-5.090	-4.982	-4.982	-

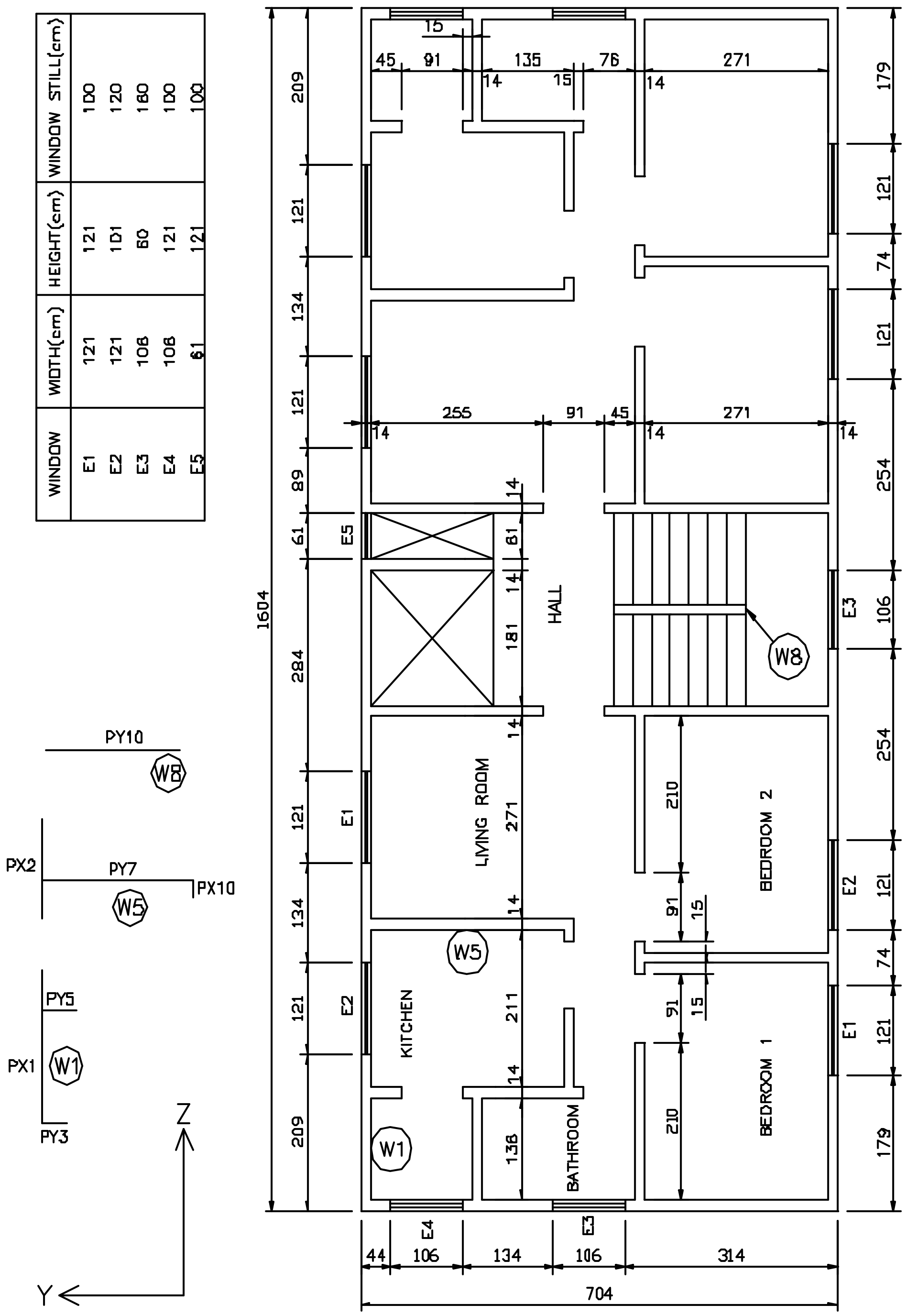

Figure 1 – Plan (dimensions in centimeters)

As one can observe in Table 2, the values of bending moments obtained by the procedure of isolated walls are high when compared to the values determined by MASAN 01. These differences have occurred mainly because of the consideration of a tridimensional analysis taking into account of shear deformation, which causes an increase in the lateral displacements of the structure. These effects affect upon the rigidities of walls. Once the procedure of isolated walls considers the determination of bending moments just depending on the stiffness of each wall, not taking into account interaction, stiffness of lab, asymmetry of the structure, which contribute to determine the bending moment, it was obtained results with great variations.

Table 2 – Bending Moments for Walls PY7 and PY10 - Horizontal Loads (Wind)

Floor	Wall	MASAN 01 (KN.m)	[8] Isolated Walls (KN.m)	Variation (%)
8	PY7	-20.46	10.557	-93.80
	PY10	-1.119	1.288	+13.10
7	PY7	-19.88	31.326	+36.54
	PY10	-0.842	3.823	+354.04
6	PY7	13.70	61.921	+351.98
	PY10	-0.275	7.557	+2648.00
5	PY7	2.665	101.903	+3723.75
	PY10	0.575	12.437	+2062.95
4	PY7	14.351	150.761	+950.52
	PY10	1.770	18.400	+939.54
3	PY7	41.939	207.881	+395.67
	PY10	3.514	25.372	+622.03
2	PY7	93.376	272.467	+191.80
	PY10	6.035	33.254	+451.02
1	PY7	199.690	343.330	+71.93
	PY10	17.288	41.903	+142.38

CONCLUSION

In the evaluation of the usual procedures for vertical loads and therefore stress, in face of the results obtained by MASAN 01, it was observed that is important to perform an analysis that involves the consideration of all the known factors that may affect in the determination of those stress so that one can have an accurate analysis of the structure.

With relation to the procedure of isolated walls for determination of horizontal loads, the consideration of a tridimensional analysis associated with shear deformation provides results with very low values of bending moments and therefore stress.

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