Seismic Forces Distribution between Walls with Different Capacity

Urrego, H.
AREA Ingenieros Consultores S.A.S, Medellín - Colombia
e-mail: hurrego@une.net.co

SUMMARY:
This article presents a proposal for inelastic analysis and design of a building supported by walls with different capacity especially by their different length (Lw), taking into account the influence of higher modes in the distribution of shear forces and bending moment. For each wall is necessary to consider its displacement and force capacity starting from the moment-curvature relationships.

It emphasizes the importance of study of individual behavior of the walls and their participation in the building, rather than complex analysis with some dubious assumptions.

Keywords: Higher modes, Seismic Shear demand, Shear distribution, Inelastic analysis

1. INTRODUCTION

In the 14 WCEE the author presented a method based on displacement in which he proposed a way to take into account higher modes.

This paper presents a proposal for the seismic forces distribution in a given spatial structure taking to account its inelastic behavior and the higher modes.

An iterative procedure is based on reinforced sections considering the axial stress, from which it calculates the maximum bending moment and with the curvatures required for equilibrium, the maximum displacements are determined for each of the walls.

For the effect of the diaphragm formed by the floor slabs, the displacement of all walls shall be equal in each level, if there is coincidence between the center of mass and center of rigidity, or it will be related in function of the eccentricity between the two centers.

Given the existence of walls with different lengths in the same building, the maximum displacement must be controlled by the wall of greater length. That is, when the wall of greater length reaches its displacement capacity.

Then it determines the stress level in each wall and therefore how the real distribution of seismic forces is performed between all the elements.

In this paper are reproduced some examples of the literature which show the effectiveness of this methodology.

Since the results are some suggestions for future research and for inclusion in earthquake-resistant standards.

2. BACKGROUND

Displacement-based methods are justified primarily on the importance of the first mode of vibration, which is perfectly reasonable to explain the demand for the peak displacement and for the bending moment at the base.

However, it has demonstrated the importance of the higher modes, especially in flexural demand through the building height, which can lead to further plastic zones, Panagiotou (2008) and Rad and Adebar (2008), and also a significant increase of shear demand.

The proposal to concentrate the mass of the building in four points, Urrego and Bonett (2008), to analyze and design small and medium rise buildings in a practical way, takes into account these aspects.

Distribution of seismic demand for bending moments between all seismic-resistant walls can be done from the compatibility of displacements for the first mode of vibration, Urrego (2005). Other way to take into account higher modes effects have been proposed in (New Zeland Standards) and Priestley (2002) by amplification factors and also through some formulas, Rutenberg (2004).

This paper presents a practical way to perform the analysis and design of a building taking into account the influence of higher modes in seismic demand, as well as the distribution of this demand between walls of different sizes, especially with different lengths.

3. CRITERIA FOR THE ANALYSIS OF A PROJECT

The methodology proposed here is based on that floor slabs are rigid diaphragms in its plane but has no ability to restraint the displacement in the bending plane of the walls, shear deformations are not considering.

It is also necessary to know the vertical loads acting on earthquake-resistant system walls.
There must be at least one wall in each direction with a ratio H/Lw, equal to or less 4.0. It must also ensure that Pu/φf'c/b/Lw is less than 0.4. This could ensure a displacement ductility $\mu\Delta \geq 3$. Dimensioning of elements including the allocation of a reinforcement ratio is developed bearing in mind the influences described above. Initially assumes a mechanical ratio w =As.fy/b/lw/fc´=0.2.

From these data can be determine the yield and ultimate curvatures and with them, for the analysis, the maximum displacement, maximum moment and shear at the base of the wall.

Taking into account the capacity of each wall, the capacity curve of the whole building, is constructed in the two orthogonal directions. For each increment of curvature is calculated the displacement and bending capacity of each wall, the sum of the capacities for each displacement is the capacity of the building. Figure 1

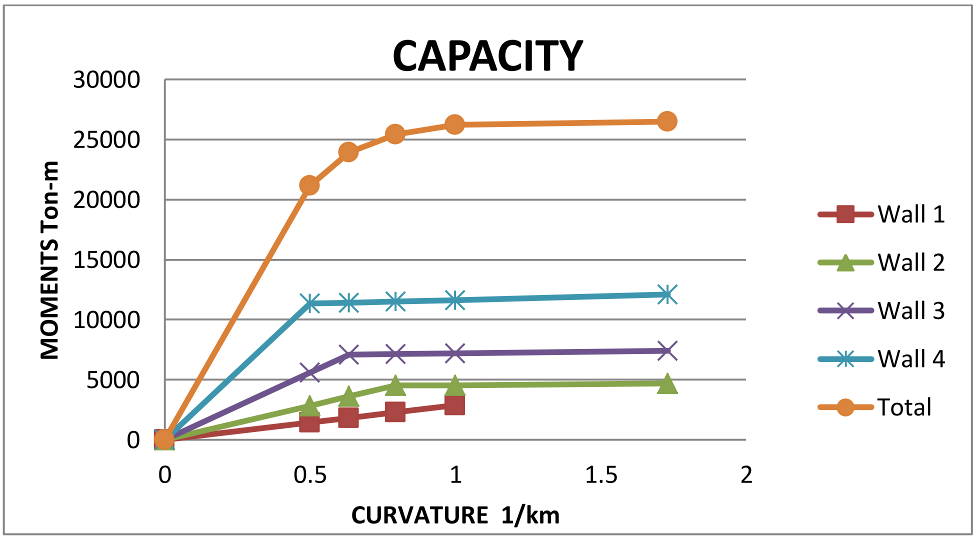

Figure 1. Moment-curvature diagram of different walls

It proceeds iteratively, as Urrego and Bonett (2008) to ensure that the capacity is greater than the demand.

4. DISTRIBUTION OF SHEAR

It has been shown that a distribution of shear demand from the elastic stiffness or bending capacity of each of the walls, underestimates the demand of the walls of shorter length and overestimates the walls of greater length.

The cause of error when made from elastic stiffness is that this does not take into account the stiffness degradation because of cracking that occurs until the reinforcement of the wall reaches the yield and with it its maximum capacity.

In the case of a distribution from the bending capacity, although it corrects the deficiency of the previous case, still does not consider the influence of the higher modes as shown by Rutenberg (2004).

Rutenberg analyzed the system of walls that Paulay and Restrepo (1998), have already done, using the Time History of ten earthquakes, finding that the demand due to the influence of higher modes is very significant both in value and participation of each wall.

The author believes that under the proposed analysis model, with four concentrated masses, it can keep the physical concept and will only be necessary to consider the alteration of sections properties of the elements when are undergoing lateral loads and hence to a displacements.

A good approximation to distribute shear demand into the walls of earthquake-resistant system is made from the yield displacement of the last wall that reach it, namely the shorter length wall. For each wall is calculated its effective stiffness:

$$K_i = EIeff_i \approx \frac{M_i}{\varphi i} \qquad (4.1)$$

It is therefore necessary, from the latter Δy, calculate for each wall the curvature and the corresponding bending moment:

$$\varphi i = \frac{6\left(\Delta y / _{Lpi^*}\right) - \varphi_y i(3H - 2Lpi^*)}{Lpi^*} \tag{4.2}$$

H = height of the building
φyi : yield curvature of the wall i
Lpi* = length of wall that reaches the yield

An iterative process is required to determine φi, initially φi is assumed, with this curvature, the bending moment, the length L*pi and the displacement are calculated; this process is repeated until Δ is equal to Δy.

$$\Delta = \frac{\Delta y(H - Lpi^*)^2}{3} + \frac{\left(\varphi y(3H - 2Lpi^*) + \varphi i(3H - Lpi^*)\right)Lpi^*}{6} \tag{4.3}$$

Eqn. 4.2 y Eqn. 4.3 are equivalent.

Shear demand in each wall will be proportional to their effective stiffness:

$$V_i = \frac{VKi}{\sum_1^n Ki} \tag{4.4}$$

V: Total shear
Vi: shear at wall i

5. EXAMPLE 1

The first example reproduced from Rutemberg (2004), Figure 2

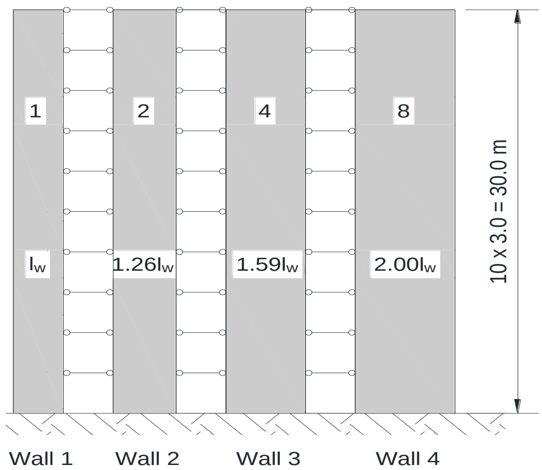

Figure 2 Four walls lateral load-resisting system of 10-storey building (after Paulay and Restrepo)

The weight of each floor is considered as 306 tons. Peak acceleration is taken as the peak accelerations average of ten earthquakes analyzed by Rutenberg, the properties of the walls are shown in Table 5.1. Figure 3 Figure 4 shows the results from Urrego and Bonett (2008) model, maximum bending moment: 13820 Ton-m maximum Shear: 1541 Ton.

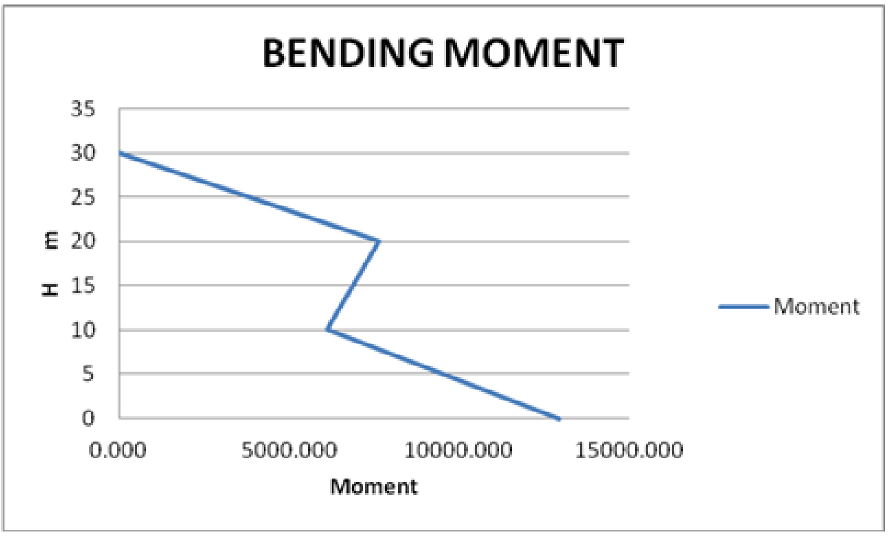

Figure 3. Bending moment diagram

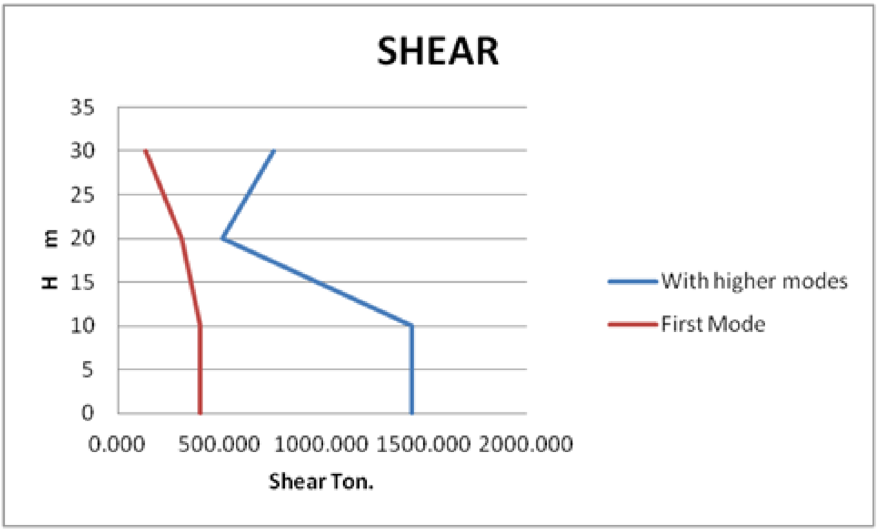

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Figure 4. Shear force diagram

Table 5.1. Walls properties

Wall	H	Lw	ϕy	My	ϕu	Mu	Δy	Lp	Δu	Δ1	Δϕ	M1
	m	M	rad/mm	Ton-m	rad/mm	Ton-m	m	m	m	m	rad/mm	Ton-m
1	30	3.50	1.000	2862	6.432	3313	0.190	4.084	0.622	0.313	1.161	2875
2	30	4.41	0.794	4515	4.929	5221	0.151	4.059	0.481	0.313	2.037	4727
3	30	5.52	0.634	7082	4.050	8175	0.121	4.009	0.388	0.313	2.743	7757
4	30	7.00	0.500	11329	3.300	13087	0.095	4.030	0.313	0.313	3.300	13087

Table 5.2. Results of model

Wall	Δϕ	Lp*	M1	K	Distribution	Shear
	rad/mm	m	Ton-m	Ton-m^2		Ton
1	1.000	0.000	2862	2859	0.186	287
2	1.731	1.064	4675	2700	0.176	271
3	1.975	1.817	7511	3803	0.247	381
4	2.046	2.570	12300	6012	0.391	602

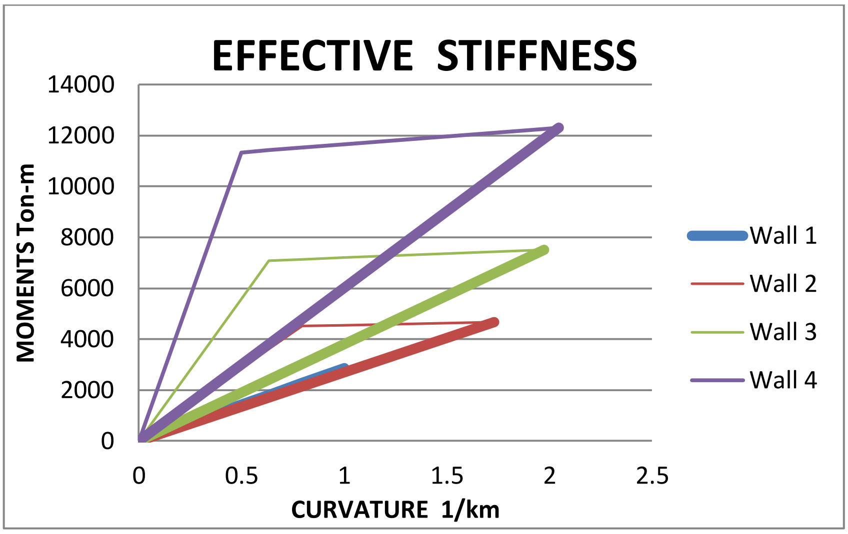

Figure 5. Effective stiffness of walls

The shear values obtained by Rutenberg (2004) were 205, 275, 360 y 691 Ton. respectively. Shear amplification factor is 3.5.

6. EXAMPLE 2

Second example reproduced from Beyer (2005), Figure 6.

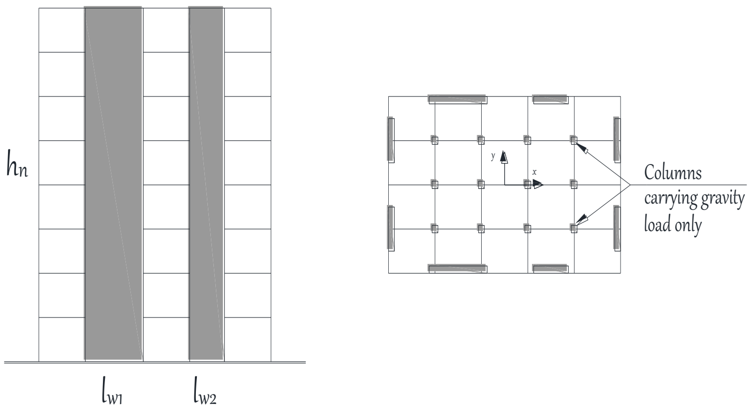

Figure 6. Storey coupled wall structure: Elevation and plan view

The weight of each floor is considered as 286 Ton, response spectrum considered is one equivalent to the recommended by the EUROCODE 8 with a ground acceleration of 0.4g. The properties of the walls are shown in Table 6.1. The results on the model of Urrego and Bonett (2008) are, maximum bending moment: 2889 Ton-m maximum Shear: 452Ton.

Table 6.1. Walls properties

Wall	H	Lw	ϕy	My	ϕu	Mu	Δy	Lp	Δu	$\Delta 1$	Δf	M1
	m	m	rad/mm	Ton-m	rad/mm	Ton-m	m	m	m	m	rad/mm	Ton-m
1	24	6	0.830	1520	2.850	1761	0.135	3.284	0.283	0.283	2.815	1757
2	24	4	1.025	719	3.890	864	0.167	4.028	0.420	0.283	2.715	805

Table 6.2. Result of model

Wall	$\Delta\phi$	Lp*	M1	K	Distribution	Shear
	rad/mm	m	Ton-m	Tonm2		Ton
1	1.452	1.173	1594	1098	0.609	274
2	1.018	0.000	719	706	0.391	177

Shear values obtained by Beyer (2005) were, 266 y 147 Ton. respectively. Shear amplification factor is 5.0.

7. CONCLUSIONS AND SUGGESTIONS

-It is observed that there is a big difference between demand for each shear wall designed from the elastic considerations and one from inelastic.
-It is necessary to verify the bending, shear and displacement capacity of each wall to reach a safe design.
-The whole ductility of the building can be determined by different walls and the ductility of each wall may be different from each other and different from the set.
-It is advisable using inelastic design spectra.
-The ductility assumed for the design of the elements must be verified in the analysis.
-Although apparently in the displacement-based analysis proposed here is not reached the maximum of all elements, is seen that a relatively small increase of displacement generates a progressive collapse. Therefore there is a relatively small capacity reserve but only for expense of very large displacements.
-The analysis proposed here is quite simple and rational methods without resorting to fairly complex spatial analyzes do not necessarily guarantee good behavior of the elements and the complete structure of reinforced concrete.

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