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Capacity of Open Rectangular Shear Walls

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Abstract*— A study was developed to assess the relative influences of various torsional resisting on the capacity of open rectangular shear walls. The stability is considered a four system of loads which produce zero distortion on cross section of shear wall. Finite element software ANSYS is used to perform the buckling analysis of open rectangular shear walls, also theoretical analysis will be presented for obtaining the critical buckling loads of open rectangular shear walls. An extensive set of parameters is investigated including dimensional parameters (walls thickness, shape factor, monosymmtry, and proportion factor) and a discussion of the results are illustrated.. Finally, Conclusions which may be useful for designers, have been drawn, and represented.

Index Terms— **Thin wall, Ansys, Torsion, Buckling, and Critical loads.**

I. INTRODUCTION

As the height of building increases, the lateral loads as well as the vertical loads tends to control the design. The rigidity and stability requirements become more important than the strength requirement. The first way to satisfy these requirements is to increase the size of the members which may lead to either impractical or uneconomical members. The second is to change the form of the structure into something more rigid and stable to confine the displacements and increase stability. The core supported structure serves the main structural element for supporting loads. The core invariably has opening for access into building services, therefore, its cross section can be considered open. The core behaves as thin walled open section connected by lintel beams or floor slabs, which leads to large warping deformation throughout the height of building, which are depended on geometrical characteristics of core walls. Therefore, when the core undergoes warping deformation, the floor slab and lintel beam are forced to bend out of plane in resisting the warping deformation of the core, where the system are interconnected. It is necessary in most cases to define the geometry and loading conditions by analytical closed formulas to obtain the optimal practical solution and to define the choice of the best cross section characteristics shear wall, which offer a high degree of decreases out of plane bending and twisting forces on floor slabs and lintel beam. Torsion usually assumed to be secondary importance and shear wall wear often designed to resist axial, bending and shear forces only. If the shear wall is restraint at the ends against warping, axial stresses will result as well as a redistribution of the stresses.

Naderi & Saidi [1] presented an analytical solution for the buckling of moderately thick functionally graded sectorial plates. The stability equations were derived according to Mindlin plate theory and the eignvalue problem for finding the critical buckling load was obtained. Camotim et al.[2] provide an overview of the generalized beam theory fundamentals and report the buckling and post buckling behaviours of the elastic isotropic/orthotropic members . The lateral buckling of beams of arbitrary cross section taking into account moderate large displacements is discussed by Evangels & John [3], the stability criterion is based on the positive definiteness of the second variation of the total potential energy and was established using the analogy equation method. . By adopting the joint equilibrium for the angled frame (with thin-walled I-beams) and the force-displacement relations for the members defined at the bucked position (rather than the initial position), the analytical solutions for buckling moments was presented by Jong [4]. 3-D second-order plastic-hinge analysis accounting for lateral torsional buckling was developed by Seung et al. [5]. A model consisting of unbraced length and cross section shape was used for accounting the lateral torsional buckling. Also, efficient ways of assessing steel frame behavior including gradual yielding associated with residual stresses and flexure, second-order effect, and geometric imperfections were presented by Seung [6]. Finite element software, LUSAS 13.6, was used to study the warping behavior of cantilever steel beam with openings subjected to couple torsional force at the free end by Tan [7]. The analysis of the results showed that opening has a close relationship with warping since opening can reduce web stiffness.

The critical buckling loads are extremely sensitive to the boundary conditions, shape and dimensions of its cross section of shear wall. Also the elastic and inelastic buckling behavior for shear wall of uniform symmetric cross

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section is different than shear walls of monosymmetric cross section.

A. *Statement of the Problem*

Torsion usually assumed to be secondary importance and shear walls were often designed to resist axial, bending and shear forces only. If the shear wall is restraint at the ends against warping, axial stresses will result as well as a redistribution of the stresses. Hence, the statement of the problem in this study is to find out the relationship between warping affect and the shape of shear walls. Also, find out the capacity of the open shear walls to the critical loads

B. *Objectives*

The objective of this study was to carry out theoretical parametric studies obtained by closed formulas and compare them with the results of a numerical simulation. The study also attempted to determine the optimum shear wall cross section, which has a major impact on the structural behaviour and design of high rise building. It is realized that the fulfilment of the following sub-objectives would in turn fulfil the main objective:

1. To analyze the effect of wall height on capacity of reinforced concrete open shear walls.
2. To analyze the effect of wall thickness on capacity of reinforced concrete open shear walls.
3. To analyze the effect of monosymmetrical of cross section on capacity of reinforced concrete open shear walls.
4. To analyze the effect of cross section shape on capacity of reinforced concrete open shear walls.
5. To analyze the effect of proportion of cross section on capacity of reinforced concrete open shear walls.

C. *Scope*

Theoretical analyzes were developed to simulate the capacity of open shear walls, and then finite element models were developed to check the stability using the ANSYS program. The analysis carried out is conducted on 28 reinforced concrete open shear walls; the study is limited to the following scopes:

1. The shear wall is prismatic.
2. The shear wall is long [(a\L), (b\L)] < 0.1
3. Five cases for shear wall height effect are considered (Ho, 1.25Ho, 1.50Ho, 1.75Ho, and 2.00Ho).
4. Shear wall thickness is assumed 20, 30, 40, and 50 cm.
5. Symmetric and monosymmetric shear wall cross section shape are considered.
6. Two cases for cross section shape are considered.
7. Two cases for proportional limits is assumed 1.50, and 3.00.

Conclusions from the current research and recommendations for future studies are included.

II. THEORITICAL ANALYSIS

A. *Possible Buckling*

The first type is the torsional buckling, where the middle part of shear wall rotates bodily relative to the ends. It is linked to low torsional rigidity. The instability is possible through a combination of flexural and torsional type according to the boundary conditions, dimensions and type of cross section for long or intermediate shear wall height. Then, buckling can be torsional or flexural buckling in the elastic range. The second type is the local buckling which appears as series of waves along the height of shear wall, which is limited only by the characteristic strength of material due to local buckling in the plastic or nonlinear range.

B. *Analytical Analysis*

The second order theory is valid for shear walls with arbitrary cross section and boundary conditions. It can be applied to shear wall of large dimensions. The more important formulas repeated by the same applied notations as in N. S. Trahair [8]. A critical forces can be calculated at which the shear wall buckle out its plane of initial configuration. It is also the higher load at which equilibrium positions with zero displacement are possible. Simultaneously it is an imagined load and a convenient reference load regarded as instable one. Therefore, critical force can be expressed by closed mathematical formulas depend on geometric properties of cross section and Euler's loads. In this way, critical force can be calculated separately or from combined loads. The equilibrium equations for the stability are proved from general forms of second order theory.

1. Critical longitudinal force P_{cr} :-

The critical longitudinal force is the smallest root obtained from the following general equation:-

$$P^3(A_1r^2 - A_3\eta_{2A}^2) + P^2\left[A_2\eta_{3A}^2 p_2 + A_3 p_3 \eta_{2A}^2 - A_1 r^2(p_2 + p_3 + p_\varpi)\right] + p\left[A_1 r^2(p_2 p_3 + p_3 p_\varpi + p_2 p_\varpi)\right] - A_1 r^2 p_2 p_3 p_\varpi = 0 \quad (1)$$

Where

$$P_2 = EI_2 A_3 \alpha^2 \quad (2)$$

$$P_3 = EI_3 A_2 \alpha^2 \quad (3)$$

$$P_\varpi = r^{-2}(E\bar{I}_\omega A_1 \alpha^2 + K_s), \quad (4)$$

$$r^2 = \frac{I_2 + I_3}{A} + (\eta_{2A})^2 + (\eta_{3A})^2 \quad (5)$$

$$A_1 = 1/\mu_1^2 \quad (6)$$

$$A_2 = 1/\mu_2^2 \quad (7)$$

$$A_3 = 1/\mu_3^2 \quad (8)$$

$$\alpha = \frac{n\pi}{H} \quad (9)$$

$\mu_i =$ describe boundary condition of each i displacement

2. Critical Moment Mcr :-

Stability condition is based on critical moment ,M**icr** where critical moment is the smaller value from $M_{2cr1}$and M_{2cr2} for uniform moment about η2 axis,

$$M_{2cri} = \left[2A_1\beta_3 p_3 \mp (4p_3^2 A_1^2 \beta_3^2 + 4A_1 A_2 r^2 P_3 P_\omega)^{\frac{1}{2}}\right](2A_2)^{-1} \quad (10)$$

By the same way critical moment about axis η_3 can be obtained as follows:-

$$M_{3cri} = \left[2A_1\beta_2 p_2 \mp (4A_1^2 \beta_2^2 p_2^2 + 4A_1 A_3 r^2 P_2 P_\omega)^{\frac{1}{2}}\right](2A_3)^{-1} \quad (11)$$

3. Critical bimoment

According to instability condition, critical bimoment β_{cr} may be determined from loaded bimoment only as follows:-

$$B_{cr} = \frac{-1}{2\beta_\omega}(EI_\varpi A_1 \frac{\eta^2}{H^2} + K_s) \cdot \quad (12)$$

III. NUMERICAL ANALYSIS

In order to validate the present formulations, numerical analysis for the critical buckling loads on open shear wall core fixed at the base are carried out using the commercial finite element program ANSYS (version 11 with civil FEM software) which has been used for many analyses of structures in recent years. By using ANSYS, there are two primary means to perform a buckling analysis:

Eigenvalue: Eigenvalue buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural eigenvalues for the given system loading and constraints. This is known as classical Euler buckling analysis. Buckling loads for several configurations are readily available from tabulated solutions. However, in real-life, structural imperfections and nonlinearities prevent most real- world structures from reaching their eigenvalue predicted buckling strength; i.e. it over-predicts the expected buckling loads. This method is not recommended for accurate, real-world buckling prediction analysis.

Nonlinear: Nonlinear buckling analysis is more accurate than eigenvalue analysis because it employs non-linear, large-deflection; static analysis to predict buckling loads. Its mode of operation is very simple: it gradually increases the applied load until a load level is found whereby the structure becomes unstable (i.e. suddenly a very small increase in the load will cause very large deflections). The true non-linear nature of this analysis thus permits the modelling of geometric imperfections, load perturbations, material nonlinearities and gaps. For this type of analysis, note that small off-axis loads are necessary to initiate the desired buckling mode.

The nonlinear buckling analysis procedure is used; the civil FEM is adopted for the pre-processor while the ANSYS is adopted for both the solution and post-processor stage.

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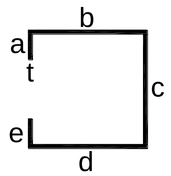
For purposes of comparison, shear wall cores with five different heights are considered, and for each height of the cores, different cross section properties are used to calculate the critical loads. The heights adopted in the analysis are 60m, 75m, 90m, 105m, and 120m, and the section properties in all the analyses are showed in Table 1. All the shear wall cores have the same cross sectional area for all the studied cases.

Table 1 Details of the investigated shear wall cores.

H (m)	**t**	**a**	**b**	**c**	**d**	**e**	**H**	**t**	**a**	**b**	**c**	**d**	**e**
60-120	0.2	1.5	6.0	6.0	6.0	1.5	60	0.2	1.5	5.2	7.8	5.2	1.5
	0.3	1.5	6.0	6.0	6.0	1.5	75	0.2	1.5	5.2	7.8	5.2	1.5
	0.4	1.5	6.0	6.0	6.0	1.5	90	0.2	1.5	5.2	7.8	5.2	1.5
	0.5	1.5	6.0	6.0	6.0	1.5	105	0.2	1.5	5.2	7.8	5.2	1.5
60	0.2	3.0	6.0	6.0	6.0	0.0	120	0.2	1.5	5.2	7.8	5.2	1.5
75	0.2	3.0	6.0	6.0	6.0	0.0	60	0.2	1.5	3.6	10.8	3.6	1.5
90	0.2	3.0	6.0	6.0	6.0	0.0	75	0.2	1.5	3.6	10.8	3.6	1.5
105	0.2	3.0	6.0	6.0	6.0	0.0	90	0.2	1.5	3.6	10.8	3.6	1.5
120	0.2	3.0	6.0	6.0	6.0	0.0	105	0.2	1.5	3.6	10.8	3.6	1.5
60	0.2	0.0	7.5	6.0	7.5	0.0	120	0.2	1.5	3.6	10.8	3.6	1.5
75	0.2	0.0	7.5	6.0	7.5	0.0							
90	0.2	0.0	7.5	6.0	7.5	0.0							
105	0.2	0.0	7.5	6.0	7.5	0.0							
120	0.2	0.0	7.5	6.0	7.5	0.0							

IV. ANALYSIS RESULTS AND DISCUSSION

In total, five parameters are investigated in the current study. These are:

- Four values for shear wall cross section thickness are considered (20, 30, 40, and 50 cm.).
- Five values for shear wall height effect are considered (60, 75, 90, 105, and 120 m.).
- Symmetric and monosymmetric shear wall cross section are considered.
- Two cases for cross section shape factor are considered.
- Two cases for proportional limits is assumed 1.5, and 3.0

Comparisons of the obtained results from theoretical and ANSYS were made and the convergence of the five response parameters is shown in Table 2. Both procedures gave very similar results.

Table 2 Critical buckling load Pcr (/ 1000 t)

H m	t cm	F.B. ansys	F.B. Theor.	T.B. Theor.
60	20	36.6	30.6	7.1
75		23.4	19.6	4.9
90		16.2	13.6	3.6
105		11.9	10.0	2.9
120		9.14	7.8	2.4
60	30	51.8	46.0	12.3
75		33.2	29.4	8.8
90		23.0	20.5	7.0
105		16.9	15.0	5.7
120		13.0	11.5	4.9
60	40	65.3	61.4	19.1
75		41.8	39.3	14.4
90		29.0	27.2	11.6
105		21.3	20.0	9.7

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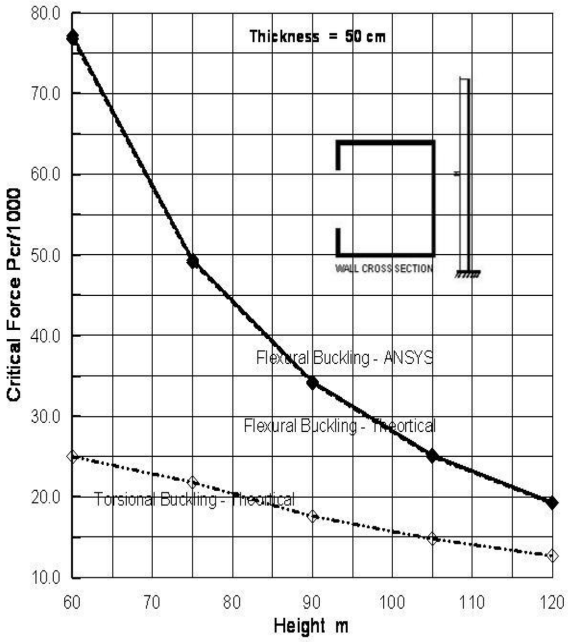
120		16.3	15.3	8.4
60	50	77.2	76.7	28.0
75		49.4	49.1	21.6
90		34.3	34.1	17.6
105		25.2	25.0	14.8
120		19.3	19.2	12.7

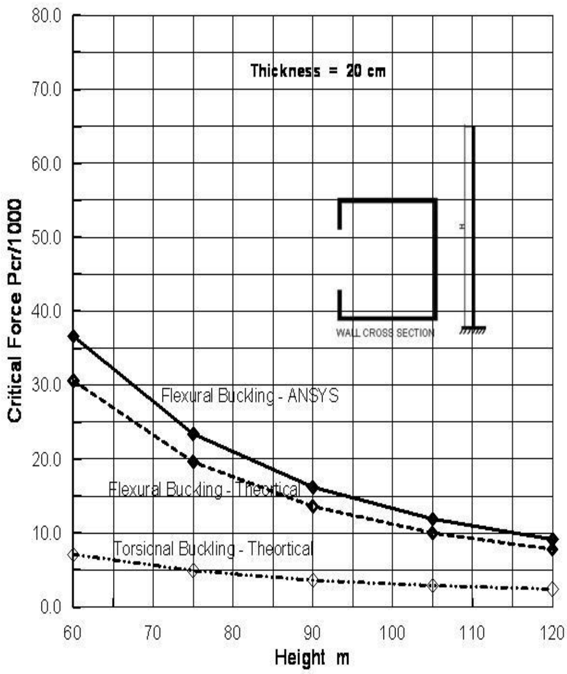
F.B. Flexural Buckling T.B. Torsion Buckling

The results obtained from the analysis are presented and discussed in such a way, that the effect of different parameters can be separately investigated. The effect of each above mentioned parameters on critical buckling forces was examined.

A. Critical Buckling Load Pcr

The results of the models which were investigated to study influence of core thickness on the buckling load were presented in Figures 1a, b. It has been already known a reduction in rotation or warping can be expected consequently as increasing the core walls thickness. The results show that the increasing the shear wall height (from H to 2H) leads to decrease the capacity by about 75% for wall thickness 20 cm. Increasing the wall thickness from 20 cm to 50 cm leads to increasing the flexural buckling capacity by about 200%, while the torsion buckling capacity increased by about 400%





Fig

Fig. 1-a Effect of thickness on P_{cr} – t = 0.2 m & **Fig. 1-b Effect of thickness on P_{cr} – t = 0.5 m**

Nonsymmetry of shear wall affect on buckling behaviour under axial force was shown in Figure 2. Nonsymmetry is assumed by cancelling the lipped stiffener from one edge of the core cross sectional area. Increasing the shear wall height (from H to 2H) leads to decrease the flexural buckling capacity by about 30% for wall thickness 20 cm., on the other hand, the torsional buckling capacity decreases by about 40%.

The shape of cross section is assumed by cancelling the lipped stiffener from the two edges of the core cross sectional area, keeping the total cross sectional area of the core is the same as all models. The affect of shape ratio of shear wall cross section on buckling behaviour under axial force was shown in Figure 3. For shape ratio of 1.5 of cross section, the flexural buckling capacity increased and the torsional buckling capacity decreased compared with shape ratio 1.0.

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Fig. 2 Effect of monosymmtry on P_{cr}

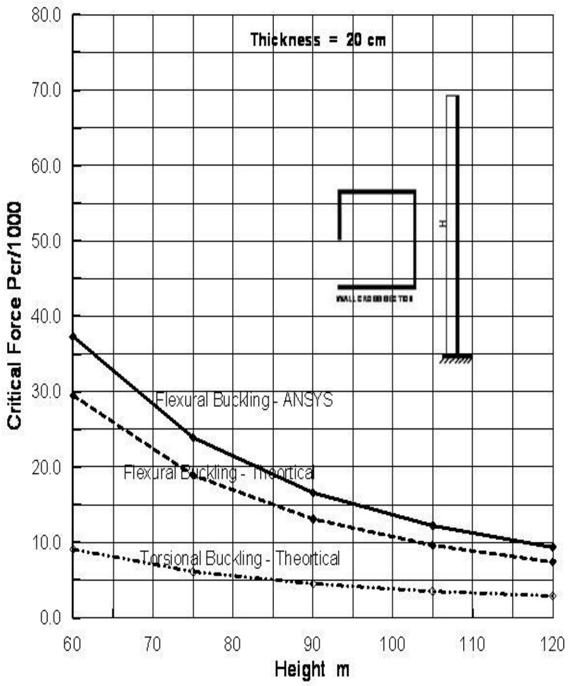
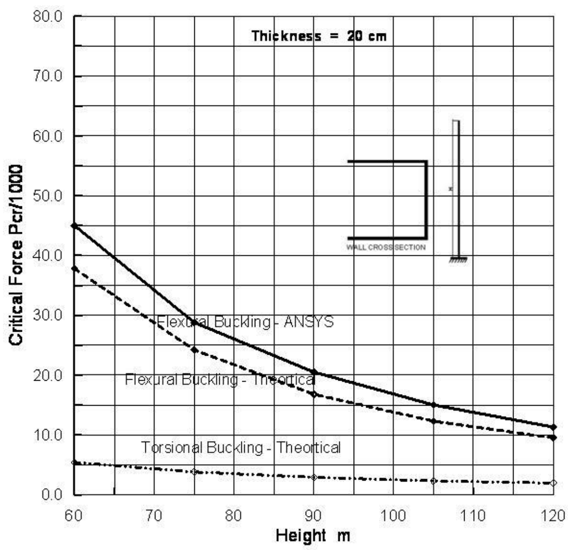


Fig. 3 Effect of shape on P_{cr}



The proportion (degree of rectangularity of cross section ratio) effect on the shear wall capacity is shown in Figures 4a, b. The results indicate that as the ratio of rectangularity increases, the flexural buckling capacity decrease by about 60%. Also, the results show that there is no effect for the proportion ratio on the torsional buckling capacity.

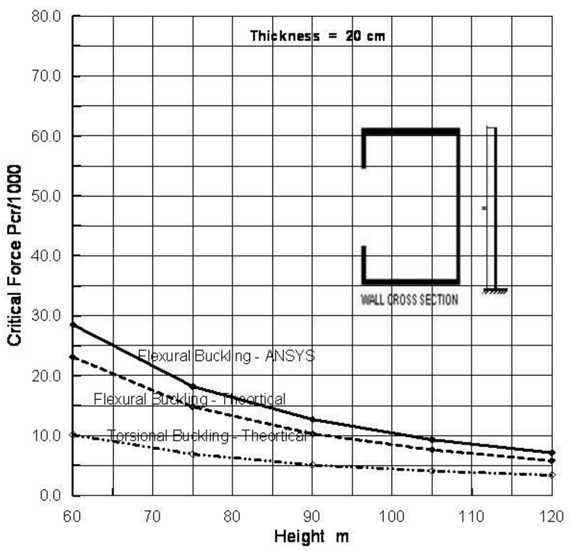


Fig. 4-a Effect of proportion (=1.5) on P_{cr}

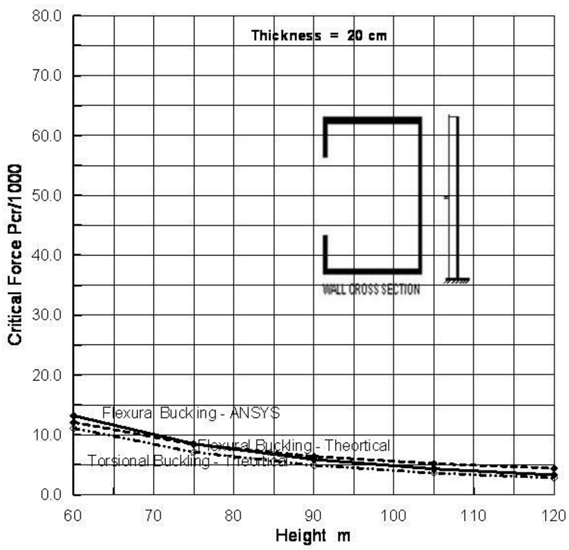


Fig. 4-b Effect of proportion (=3.0) on Pcr

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B. Critical Buckling Moment Mcr

Also, the results obtained from the analysis are presented and discussed in such a way, that the effect of different parameters can be separately investigated. The effect of each parameter on critical buckling moment was examined. The results of the models which were investigated to study influence of core thickness on the buckling moment were presented in Figures 51a, b. The results show that the increasing the shear wall height (from H to 2H) leads to decrease the buckling moment capacity by about 65% for wall thickness 20 cm. Increasing the wall thickness from 20 cm to 50 cm leads to increasing the buckling moment capacity by about 400%.

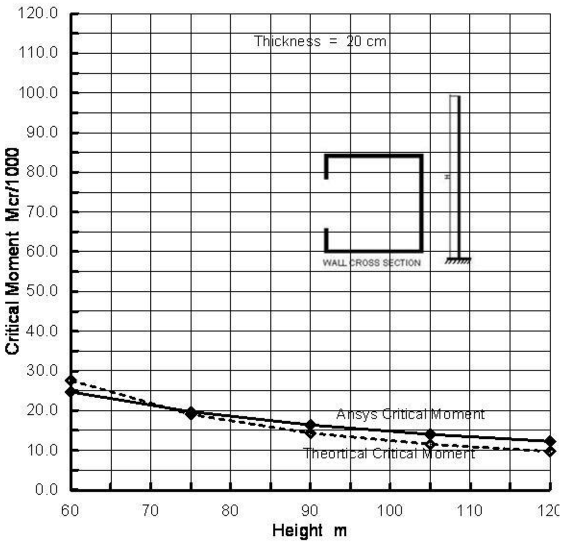

Fig. 5-a Effect of thickness on M_{cr} – t = 0.2 m

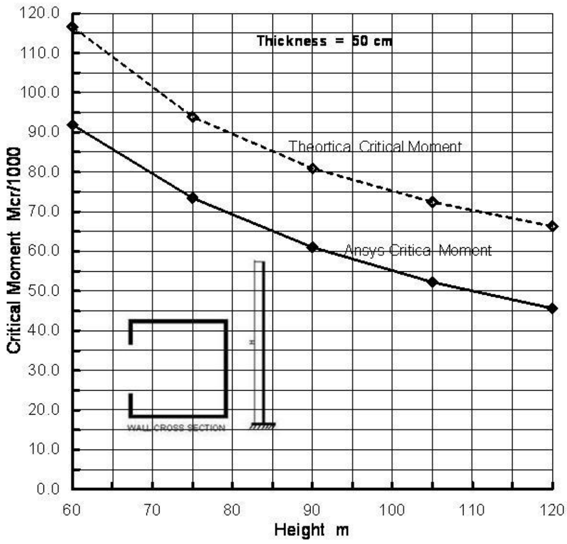

Fig. 5-b Effect of thickness on M_{cr} – t = 0.5 m

Nonsymmetry of shear wall affect on buckling behaviour under moment was shown in Figure 6.. Increasing the shear wall height (from H to 2H) leads to decrease the buckling moment capacity by about 40% for wall thickness 20 cm. The affect of shape ratio of shear wall cross section on buckling behaviour under moment was shown in Figure 7.

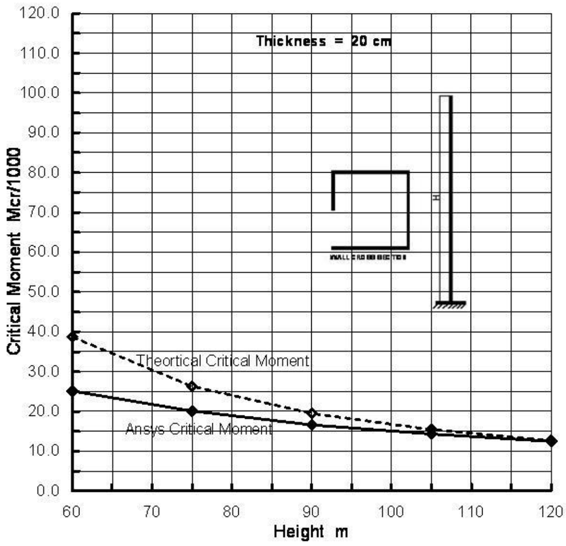

Fig. 6 Effect of monosymmtry on M_{cr}

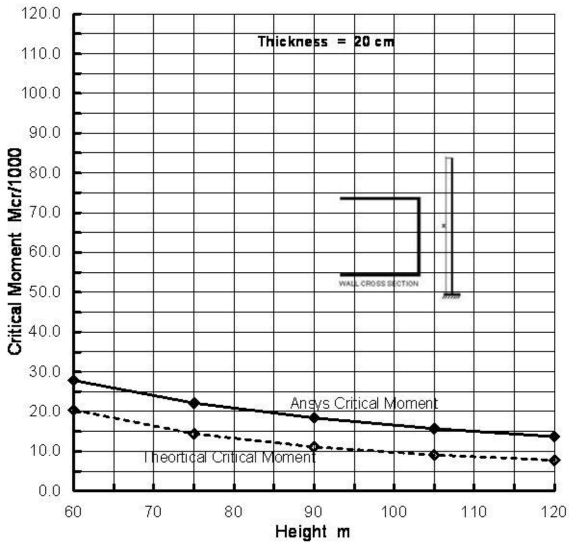

Fig. 7 Effect of shape on M_{cr}

The proportion (degree of rectangularity of cross section ratio) effect on buckling moment capacity is shown in Figures 8a, b. The results indicate that as the ratio of rectangularity increases, the buckling moment capacity decrease by about 10%.

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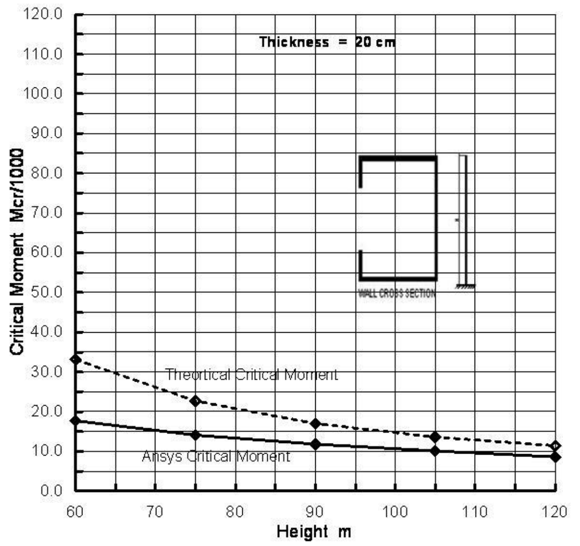

Fig. 8-a Effect of proportion (=1.5) on M_{cr}

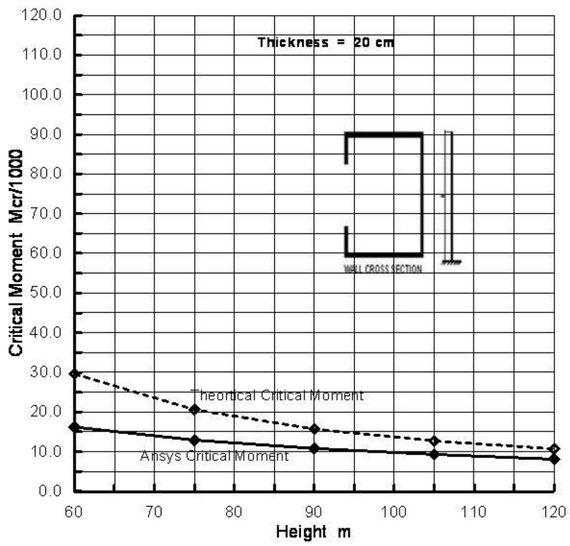

Fig. 8-b Effect of proportion (=3.0) on M_{cr}

V. CONCLUSION

On the basis of the preceding study and limitations, the following conclusions are drawn:-

- The absolute critical forces and type of buckling of the shear wall have been shown to be influenced strongly by the thicknesses of shear wall cross section.
- The capacity of shear wall has been shown to be influenced strongly by the lipped stiffener length.
- The designer should take into account the effect of these critical forces and the expected type of buckling at which they act.
- In practice, thickness, geometrical parameters of cross section must be taken into consideration for obtaining the capacity of the open shear wall core.

In spite of the fact that the finite element method is well suited for establishing the critical forces according to characteristic and boundary conditions on shear wall stability, it is better and easy to check the shear wall stability by using the obtained closed formulas for rabid estimation of critical forces. Because the relative influence of changing the dimensions of the considered parameters on core torsional behaviour have been presented to facilitate a reasonable configuration for cores subject to torsion, the rational method of replacing central core by regular shape must be depended on the closed formulas for suggestion the optimal cross section of shear wall to reduce the torsional stresses and its effect on capacity of shear wall. A dimensional investigation has been developed for a linear structural torsional analysis of shear wall using analytical and numerical analysis. The method of analysis differs from previously published techniques; it allows recognizing forces and geometrical properties of core cross section. Within the limitations of assumptions adopted and practical range of variable examined in this study.

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LIST OF SYMBOLS

$\overline{A}$	Cross section area of shear wall.
P_i	The Euler flexural buckling loads (P_2, P_3, P_ω)
r^2	Polar radius of gyration
η_{iA}	Shear canter position from the centred shear of wall cross section (η_{2A}, η_{3A}) .
E	Young's modulus.
I_i	Principal moment of inertia (I_2, I_3).
M_{icr}	Critical bending moment (M_{2cr}, M_{3cr}).
β_i	Monsymmetric parameter $(\beta_2, \beta_3, \beta_\omega)$.
K_s	Torsional rigidity for open shear wall section.
H	Total height of shear wall.
μ_i	Describe boundary condition of each i displacement.
I_ω	Warping moment of inertia (principal sectarian moment)
B_{cr}	Critical bimomert