SİSMİK KUVVETLERE MARUZ SİMETRİK OLMAYAN ÇOK KATLI YAPILAR
-BURULMA KUVVETLERİNİN BELİRLENMESİNE BİR KATKI-

ASYMMETRIC MULTISTORY STRUCTURES SUBJECT TO SEISMIC LOADS
CONTRIBUTION TO THE EVALUATION OF TORSIONAL FORCES

Dr.A.S.Scarlat[1]

ABSTRACT

The problem of strengthening existing buildings in areas prone to strong earthquakes needs,as a first step,a rapid evaluation of these buildings based on their aseismic resistance.The author proposed a technique to provide a "first screening" of these buildings,based on the main ideas set forth in Japan by a number of researchers between 1970 and 1980.

The paper provides a short description of the criteria for the classification of existing buildings from the point of view of their degree of regularity in the horizontal plane and puts forward a proposal for evaluating the order of magnitude of the torsional forces.

1. One of the most urgent problems facing the civil engineers in Israel is the need to strengthen existing buildings in areas prone to strong earthquakes and which were not designed according to modern aseismic codes;most of these buildings were constructed between 1950 and 1970.

I have to point out that,according to the present seismic map of Israel,maximum ground accelerations of 0.20g-0.30g should to be taken into account in large areas in the north of the country and along the Jordan Valley.

2. The first step in deciding on the need to strengthen existing buildings is to classify them from the aseismic resistance point of view.Scarlat (1992) proposed a technique to carry out a "first screening" of existing buildings in Israel,based on the answers provided to a number of questions and the corresponding computation of a "seismic index";the answers are based on a visual inspection of the building and on the assumption that no technical documentation is available.

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1 Director Research & Technology , Givataym
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The basic ideas and criteria were put forward by Japanese researchers between 1970 and 1980;they were derived from statistical analyses of the behavior of existing buildings during strong earthquakes (see Shiga 1977,Aoyama 1981).The method was used in USA (Bressler et al. 1977,Hawkins 1986) China (Ref.[14]) and New Zeeland (Glogau 1980).

3. Two main aspects have to be dealt with in the frame of the first screening: the irregularities in the vertical direction (i.e. the problem of the weak stories) and in the horizontal plane (i.e.the problem of the asymmetrical structures).The present paper is concerned with the second aspect;it gives a short description of the criteria for classifying the structures from the point of view of their irregularity in plane accompanied by a critical review of the Lin`s method for determining the torsional forces.We note that most of the computations performed in design offices for determining torsional forces are based on Lin`s theory (1951).

A first assumption accepted by Lin implies vertical rigidity of the slabs,together with the classical (and justified) assumption of their horizontal rigidity.Subsequently,the torsional forces increase in proportion with the distance from the given resistant element to the center of rigidity of the slab (CR);the maximum forces will develop in the perimeter columns (Fig.1).An accurate analysis displays a significant decrease of the torsional forces in the perimeter columns so that the maximum torsional forces occur in the columns of the next row.

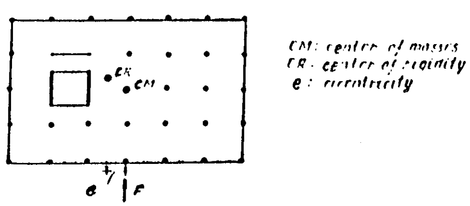
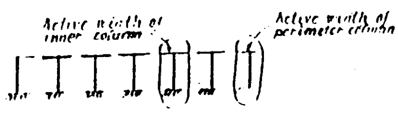


Fig.1. Definition of eccentricity.

It is a previsible phenomenon: the effective width of the slab strip acting together with the facade columns is much smaller than the effective width acting together with the inner columns and consequently the rigidity of the façade columns is significantly smaller (Fig.2).



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In order to quantify this effect,we shall refer to the structure shown in Fig.3a (12 stories,slabs 60/32/0.20 m , columns 0.40/0.40 m on a mesh of 5.00/4.00 m).For sake of simplicity we have assumed columns of uniform height) and a central core 10.00/8.00 m ; shallow beams were assumed in order to emphasize the effect of the vertical deformability of the slabs.The distribution of the torsional shear forces along the columns of the frame "c" is shown in Fig.3b. We note that the maximum shear forces occur in the columns close to the façades.

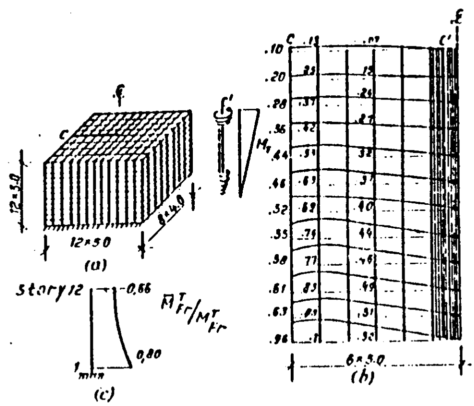


Fig.3. Decrease of torsional forces along perimeter columns.

In a lecture given at the Faculty of Civil Engineering of the Technion,Haifa in November 1989,Prof.P.Mazilu noted that during the strong 1977 and 1986 earthquakes in Romania relatively small torsional forces acted on the corner columns of structures subject to general torsion and this may be a result of the above mentioned phenomenon.

The vertical deformations of the slabs lead to a decrease in the rigidity of the columns with respect to the rigidity assumed by Lin;this means that the ratio of the moment of torsion taken by the core is greater than the ratio assumed in Lin`s theory.By referring to the model shown in Fig.3a,we obtain according to this theory :

$M^T = M^T_{SW}$ (taken by the cores) + M^T_{FR} (taken by the columns)

An accurate analysis yields :

$$M^T = \bar{M}^T_{SW} + \bar{M}^T_{FR}$$

where :

$$\bar{M}^T_{FR} = (0.66...0.80)\ M^T_{FR}$$

This effect increases along the height of the structure (Fig.3c).

4. A second assumption accepted by Lin implies perfect fixed ends of columns and shear walls/cores,i.e. soil deformability is neglected.The effect of this second assumption is very important. The soil deformability leads to :

a) An increase of the fundamental period T of the structure and as such ,to a decrease of the seismic forces.Computations based on the SEAOC-88 code (where the seismic forces are assumed as proportional to $T^{-2/3}$),show that decreases of 10 - 30 % may be expected.

(b) A significant decrease of the rigidities of shear walls and especially of cores relative to the rigidities of the columns. Consequently,the center of rigidity moves toward the center of masses and the eccentricity of the resultant seismic forces significantly decreases.

In order to assess the order of magnitude of this effect,a 10 story structure was considered,30.00/20.00 m in the horizontal plane with 0.50/0.50 columns,a core 5.00/5.00 and 0.20 m thick slabs (Fig.4).

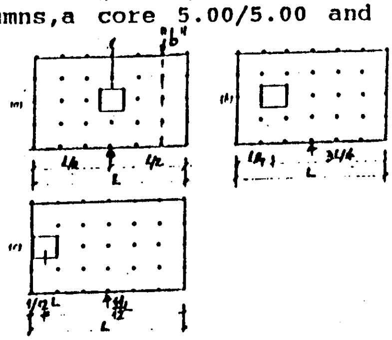


Fig.4. Symmetric and asymmetric cores.

Three structural models were considered : (1) central core (symmetric),(2) core at L/4,(3) core at one of the extremities. The resultant seismic force acts along the symmetry axis.
Three assumptions relating to the soil deformability were considered:
(1) Rigid soil (fixed ends) , (2) Elastic - strong soil (k_s = 100,000 kN/m^3) , (3) Elastic - weak soil (k_s = 20,000 kN/m^3).

The magnitude of the torsional forces was checked by computing the sum of the shear forces parallel to the seismic force, developed in the column of the row "b", where, according to the conclusions of paragraph 3, the maximum torsional forces are expected to occur.

The ratio $\Sigma Q_{max} / \Sigma Q^{o}_{max}$ was computed for each case, where: ΣQ^{o}_{max} denotes the sum of shear forces computed assuming fixed ends and ΣQ_{max} denotes the same sum computed assuming deformable soil.

Curves of the ratio $\Sigma Q_{max} / \Sigma Q^{o}_{max}$ for several types of structures, by referring to three subgrade moduli of the soil are displayed in Fig.5. We note that the increase of the ratio may reach 2.5 for rigid soil (fixed ends), while maximum ratios of only 1.3 are reached when deformable soil is taken into account.

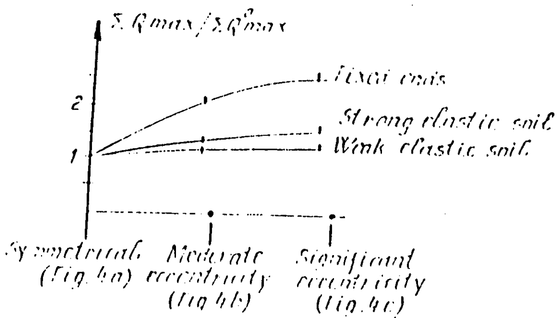


Fig.5. Effect of soil deformability on torsional forces.

By considering both effects due to soil deformability (decrease of seismic forces and decrease of eccentricity), very significant decreases of torsional forces may be expected. Hence, analyses based on Lin`s assumptions lead to grossly exaggerated torsional forces and consequently to unjustified overdesign.

Remarks

(1) Contrary to the prevailing view, foundations on piles do not ensure a high degree of vertical fixity and consequently can not prevent rotation of the shear walls/cores. We performed computations based on the assumption that vertical settlements of the piles at service loads are in the range of 0.3 % - 0.5 % of the pile diameter (see Meyerhof 1976, Poulos 1980). The results show that in the case of piles with small diameters (0.40 m) we obtain subgrade moduli of "equivalent spread foundations" of $k_s = 50000 - 320000\ kN/m^3$, while for large piles diameter (1.50 m), subgrade moduli of $13000 - 85000\ kN/m^3$ are obtained (Scarlat, 1990). It follows that the order of magnitude of the rigidities of the piles is rather close to the values accepted for spread foundations.

(2) Lin neglects the effect of shear forces on the rigidity of the vertical resistant elements. For columns or shear walls with ratios $L_{sw}/H < 5$ (Fig.6) the assumption is practically valid, but for more rigid elements we have to consider this effect.

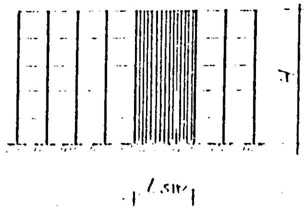


Fig.6. Notations of shear walls sizes.

5. Most modern codes require a minimum unavoidable eccentricity e = 0.05 L ...0.10 L to be taken into account in case of symmetrical structures (L is the building's length, normal to the seismic forces). CEB - 85 proposes as an alternative to multiply the translational forces by the factor (Fig.7a):

$$1 + 0.6\, x / L$$

in order to include the effect of general torsion. It leads to a maximum increase of 30 % of the translational forces.

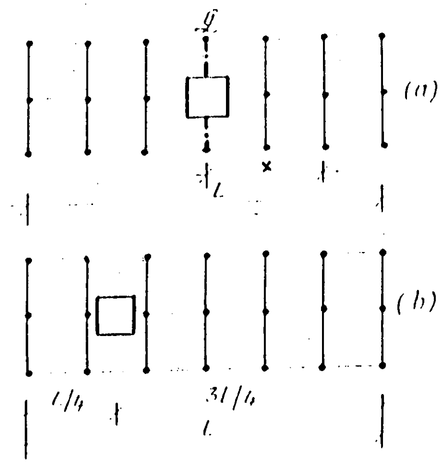


Fig.7. Position of cores corresponding to centric and "unavoidable eccentric" structures.

Accurate analyses (taking into account the soil deformability) have shown that such an increase corresponds approximately to the situation displayed in Fig.7b where the core is positioned at L / 4 ; this is obviously an exaggeration.

6. In order to classify the structures from the point of view of their degree of irregularity in the horizontal plane,we have to check structures with two parallel shear walls/cores;depending on the rigidity of the shear walls and the distance between them we can classify the structures as regular or irregular.

We have checked the 10 story structures shown in Fig.8, subject to a central force.The structures have an eccentric core and two supplementary shear walls with lengths of 2.50 - 5.00 m,positioned at various distances from the core.Rigid soil,strong soil (k_s = 100,000 kN/m^3)and weak soil (k_s = 20,000 kN/m^3) were considered.The ratio$\Sigma Q_{max}/\Sigma Q^{o}_{max}$ was checked, whereΣQ_{max} denotes the sum of shear forces parallel to the given force developed in the columns of row "b"for the asymmetric structure shown in Fig.8b,c; ΣQ^{o}_{max} denotes the same sum computed for the asymmetric structure shown in Fig.8a.

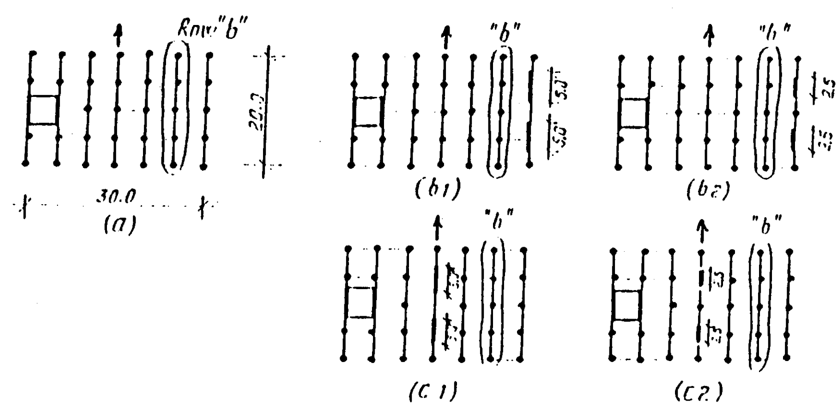


Fig.8. Assymetric structures with a core and a shear wall.

The results are displayed in Fig.9.We note that in the range of deformable soils the supplementary shear walls lead to a decrease of the maximum shear forces by 10-15%;most of this decrease is due to the decrease of the eccentricity.

We also checked the moments acting on the "supplementary shear walls" shown in Fig.8 and the corresponding stresses.The examination showed that these walls are able to bear the stresses due to horizontal forces yielded by a seismic coefficient of 10 %; this includes most of the buildings in seismic zones with a maximum ground acceleration Z = a/g = 0.20.

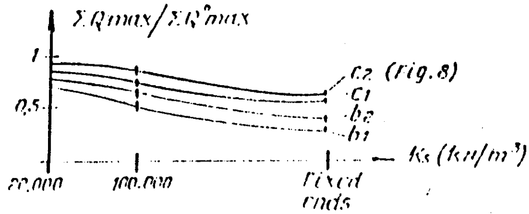


Fig.9. Effect of soil deformability on
asymmetric structures with a core
and a shear wall.

We reached the conclusion that ,when faced with the need to determine torsional forces we have two choices : either to perform an accurate analysis in which soil deformability is taken into account, or to accept increases of the translational forces (shear forces yielded by planar models where the effect of torsion is neglected) by multiplying them by prescribed factors.Analyses based on Lin`s assumptions do not represent an acceptable solution.

Taking into account the afore-mentioned results,we propose the following classification of structures from the point of view of their irregularity in the horizontal plane :

I. Regular structures : symmetrical or nearly symmetrical in both main directions - Fig.10.An increase of 15% of the translational forces is required in order to cover the unavoidable eccentricities.

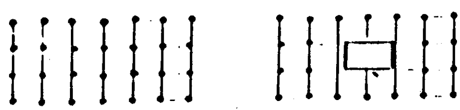


Fig.10. Regular structures.

II. Structures with moderate irregularity : structures with at least two parallel shear walls or a core and a shear wall with lengths of at least 3 m and positioned at more than 10 m distance between their centers of gravity - Fig.11.An increase of 25 % of the translational forces is required in order to allow for the effect of torsional forces.

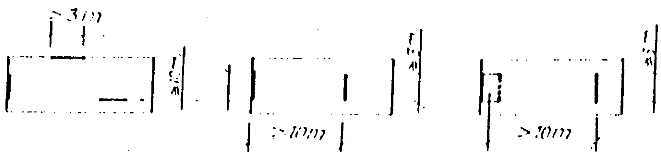
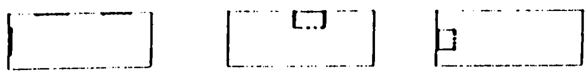


Fig.11. Structures with moderate irregularity.

III. Structures with significant eccentricity: structures not included in the two previous categories - Fig.12.An increase of 40% of the translational forces is required in order to allow for the effect of the torsional forces.



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Deprem tehlikesi ile karşı karşıya bulunan bölgelerdeki binaların güçlendirilmesi, bu yapıların depreme dayanıklılıkları açısından hızla değerlendirilmelerini gerektirir. Böyle bir değerlendirme için yazar, 1970 - 1980 arasında pek çok Japon araştırıcının üzerinde durduğu noktalardan hareketle ilk eleme için yeni bir yol önermektedir.

Çalışma mevcut binaların sınıflandırılmasına yönelik bir ölçütün kısa tanımını, plandaki düzenlilik derecesine dayanarak yapmakta ve burulma kuvvetlerinin büyüklüğünün kestirilmesi için bir öneride bulunmaktadır.

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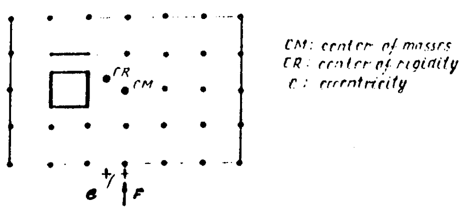

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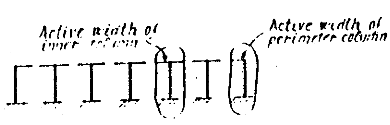

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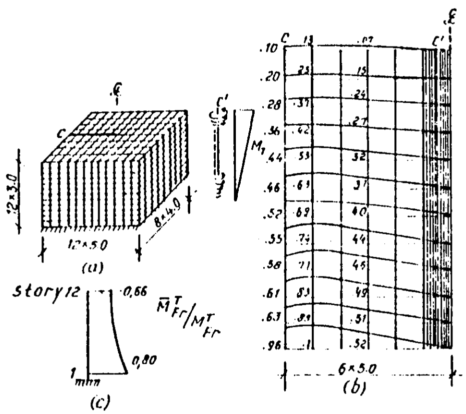

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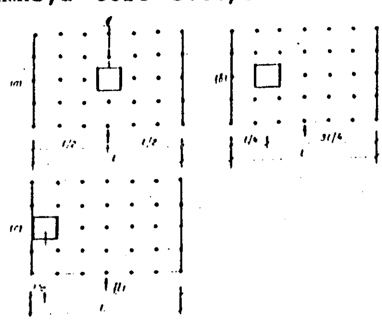

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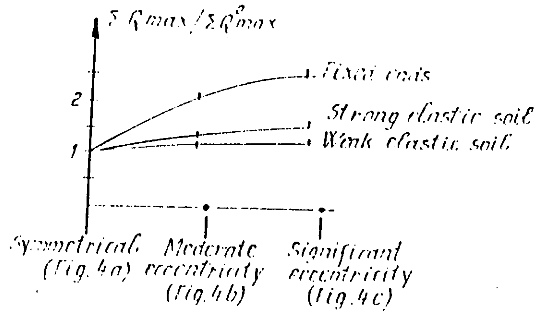

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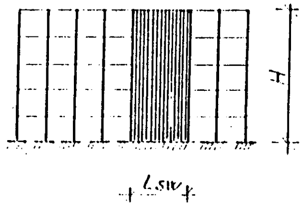

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$$1 + 0.6\ x / L$$

in order to include the effect of general torsion.It leads to a maximum increase of 30 % of the translational forces.

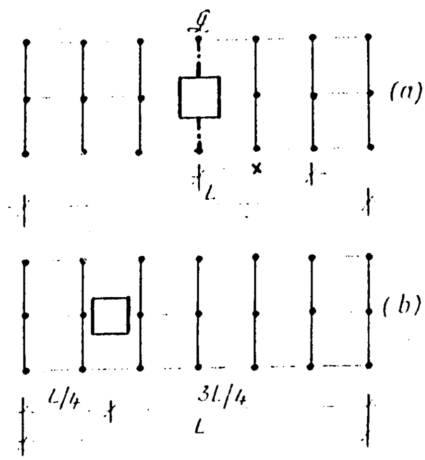

Fig.7. Position of cores corresponding to centric and "unavoidable eccentric" structures.

Accurate analyses (taking into account the soil deformability) have shown that such an increase corresponds approximately to the situation displayed in Fig.7b where the core is positioned at L / 4 ;this is obviously an exaggeration.

6. In order to classify the structures from the point of view of their degree of irregularity in the horizontal plane,we have to check structures with two parallel shear walls/cores;depending on the rigidity of the shear walls and the distance between them we can classify the structures as regular or irregular.

We have checked the 10 story structures shown in Fig.8, subject to a central force.The structures have an eccentric core and two supplementary shear walls with lengths of 2.50 - 5.00 m,positioned at various distances from the core.Rigid soil,strong soil (k_s = 100,000 kN/m^3)and weak soil (k_s = 20,000 kN/m^3) were considered.The ratio$\Sigma Q_{max}/\Sigma Q^{o}_{max}$ was checked, whereΣQ_{max} denotes the sum of shear forces parallel to the given force developed in the columns of row "b"for the asymmetric structure shown in Fig.8b,c; ΣQ^{o}_{max} denotes the same sum computed for the symmetric structure shown in Fig.8a.

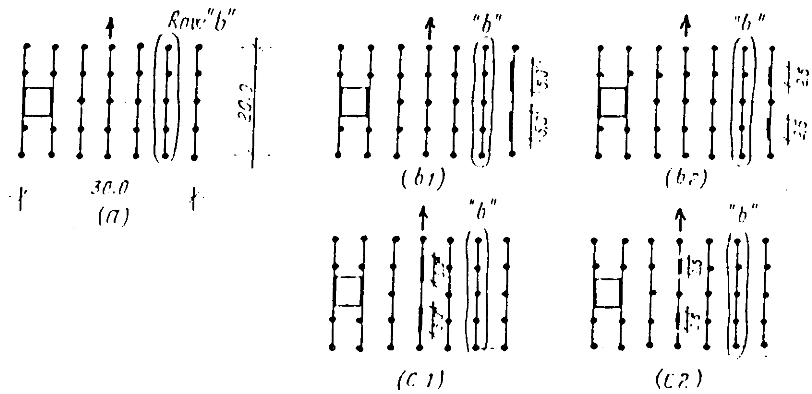

Fig.8. Assymetric structures with a core and a shear wall.

The results are displayed in Fig.9.We note that in the range of deformable soils the supplementary shear walls lead to a decrease of the maximum shear forces by 10-15%;most of this decrease is due to the decrease of the eccentricity.

We also checked the moments acting on the "supplementary shear walls" shown in Fig.8 and the corresponding stresses.The examination showed that these walls are able to bear the stresses due to horizontal forces yielded by a seismic coefficient of 10 %; this includes most of the buildings in seismic zones with a maximum ground acceleration Z = a/g = 0.20.

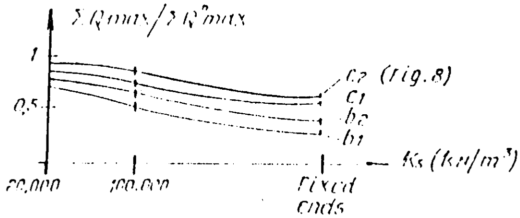

Fig.9. Effect of soil deformability on asymmetric structures with a core and a shear wall.

We reached the conclusion that ,when faced with the need to determine torsional forces we have two choices : either to perform an accurate analysis in which soil deformability is taken into account, or to accept increases of the translational forces (shear forces yielded by planar models where the effect of torsion is neglected) by multiplying them by prescribed factors.Analyses based on Lin`s assumptions do not represent an acceptable solution.

Taking into account the afore-mentioned results,we propose the following classification of structures from the point of view of their irregularity in the horizontal plane :

I. Regular structures : symmetrical or nearly symmetrical in both main directions - Fig.10.An increase of 15% of the translational forces is required in order to cover the unavoidable eccentricities.

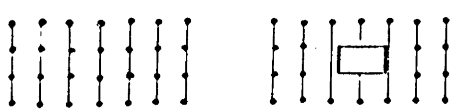

Fig.10. Regular structures.

II. Structures with moderate irregularity : structures with at least two parallel shear walls or a core and a shear wall with lengths of at least 3 m and positioned at more than 10 m distance between their centers of gravity - Fig.11.An increase of 25 % of the translational forces is required in order to allow for the effect of torsional forces.

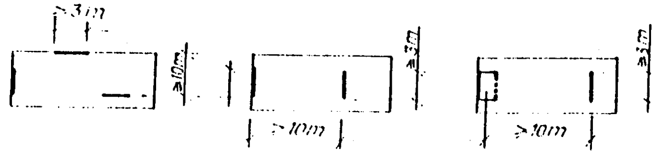

Fig.11. Structures with moderate irregularity.

III. Structures with significant eccentricity: structures not included in the two previous categories - Fig.12.An increase of 40% of the translational forces is required in order to allow for the effect of the torsional forces.

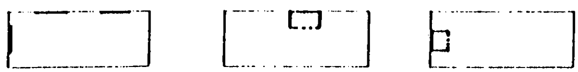

Fig.11. Structures with significant irregularity.

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