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A RATIONAL FORMULATION FOR THE q-FACTOR IN STEEL STRUCTURES

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SUMMARY

A rational simplified procedure for the definition of the structural coefficient in steel framed structures is presented herein. The different parameters affecting this coefficient are analyzed together with the implications deriving by a collapse mechanism which is not of the global type.

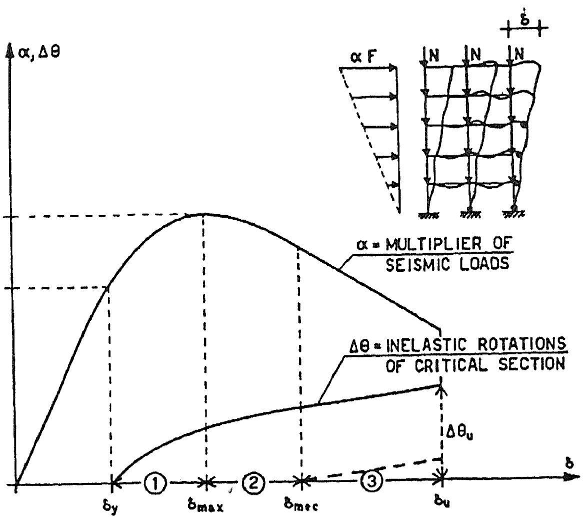


Fig. 1 Inelastic behaviour of multistoriy frames

INTRODUCTION

The structural coefficient represents a drastic simplification commonly used in most codes for the analysis of framed structures subjected to seismic forces. This coefficient is defined as the ratio between the maximum acceleration which the structure can sustain (compatibly with its assigned ductility) and the acceleration which corresponds to the attainment of first yielding. It should be reminded though, that it doesn't seem that sufficient studies have been carried out for a rational derivation of this coefficient.

In this paper, on the basis of previous studies (Refs. 1,2,3), an approximate procedure for the definition of this coefficient, is presented. This procedure is based on the hypothesis that the first mode is significative and therefore the complete framed structure can be analyzed by means of single parameter of force and a single parameter of displacement, i.e. a SDOF. In this case, with reference to fig.1, the static behaviour is defined by the parameter α_u/α_y, which describes the redistribution capacities of the structure; by the parameter $\mu=\delta_u/\delta_y$ which represents global ductility of the structure and which is strictly related to the rotational capacity of the elements; by the slope of the mechanism γ which is related to the vertical loads and to the type of mechanism. A measure of the level of vertical loads is provided by the elastic critical multiplier α_c. When the dynamic behaviour of the structure is taken into account, the other parameters which come into picture are the natural period T and the structural damping which is usually assumed about 5%. The structural coefficient therefore depends on the natural period T and on the constitutive relation of fig.1, hence:

$$q = q\left(\mu, T, \gamma, \alpha_u/\alpha_y\right) \qquad (1)$$

Hereafter the effects of the different parameters are analyzed separately.

STRUCTURAL DUCTILITY

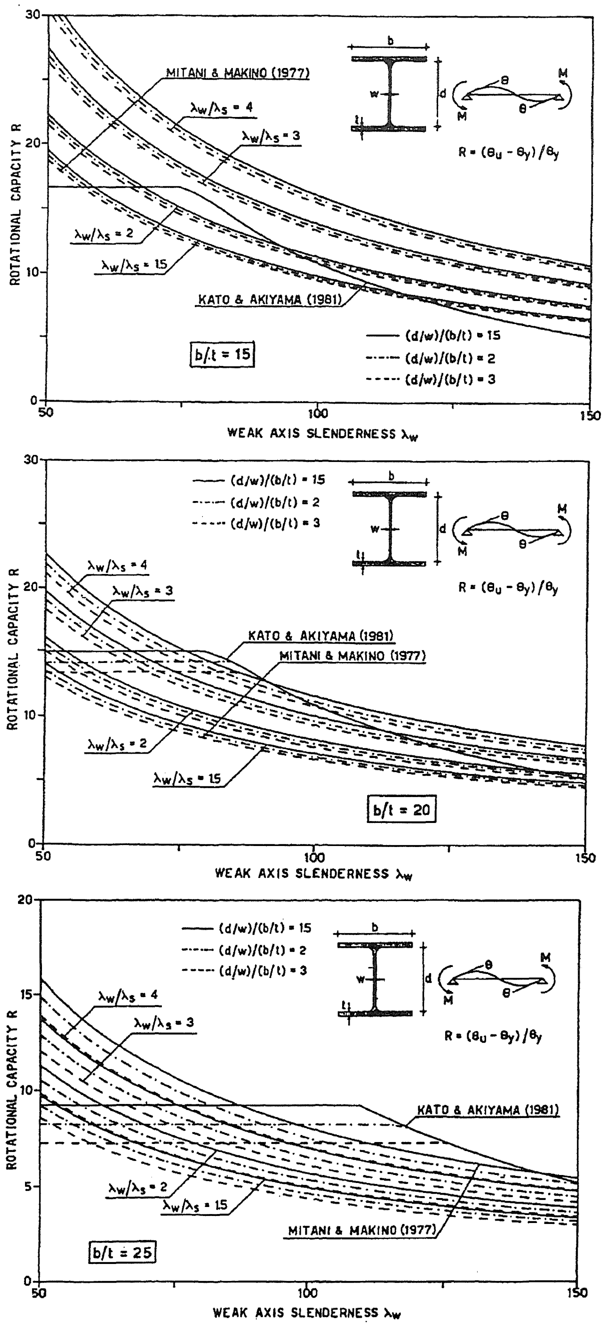
The available ductility of steel members, in which it can be assumed that the energy dissipation occurs outside the joint is limited by the problem of local instability of the compressed flange which can interact with the lateral instability of the entire member.

The rotational capacity is usually defined in the following manner:

$$R = \left(\theta_u - \theta_y\right)/\theta_y \qquad (2)$$

and depends upon the slenderness of the cross-section (web and flange b/t ratios), the yield stress σ_y, the global slenderness of the element, the bending moment diagram and the level of axial load.

In figs. 2, 3 & 4 are provided the rotational capacities of steel shapes for different slendernesses defined on the weak axis, λ_w, for different weak to strong slenderness ratios and different web and flange slenderness ratios. The three figures refer respectively to the b/t values of 15, 20 and 25. The family of curves provided in the figures are those following the formulation of Mitani & Makino (Ref. 4) and Kato & Akiyama (Ref. 5). The rotational capacity has been conservatively referred, to the rotation θ_u which corresponds to the maximum value of the bending moment.



Figs. 2, 3, 4 Rotational Capacity; b/t=15, 20, 25

The relation between global ductility μ and rotational capacity R, depends upon the mechanism, upon the rate of plastic hinges formation which can be expressed by the ratio α_u/α_y and upon the effectiveness of geometric nonlinearitites which can be expressed by means of the multiplier α_c.

If the hypothesis of global mechanism is made, and it is assumed that there is a contemporary plastic hinge formation and the geometric nonlinearities are negligible, the following relation holds:

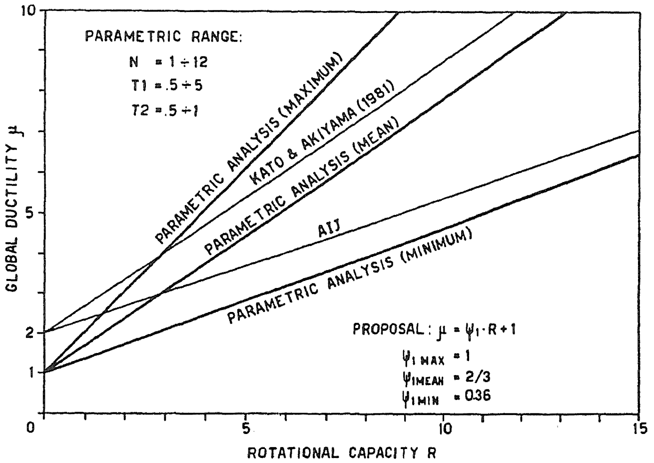


Fig. 5 Relation between global ductility and rotational Capacity.

$$\mu = \delta_u/\delta_y = 1 + \psi_1 R \quad (3)$$

where δ_y and δ_u are displacements of the top story of the frame (fig.1).

The parameter ψ_1 can be derived by elastic analyes. For this purpose, the parametric analysis carried out in Ref. 3 provides the relation between μ and R which is given in figure 5. The relation is provided as a function of the following paramaters: n (number of stories), T1(column to girder stiffness ratio), T2 (coefficient of variation of column stiffness along the height). The values of ψ_1 oscillate among the values of 0.36 and 1.0 with an average value of 2/3. In fig.5 are also provided the μ-R relations provided by AIJ and by Kato & Akiyama (Ref. 5). The different formulations, even though are based upon different hypotheses and experimental observations, provide results which are in good agreement with each other.

A more accurate definition of these values can be derived by expressing the relation between ψ_1 and the typological parameters n, T1, T2. In this manner the numerical analyses carried out yield:

$$\psi_1 = 1 - \left[0.24 - 0.06\left(T1 - 0.5\right)^{0.4}\right]\left(n - 1\right)^{0.4} \quad (4)$$

which is valid within the parametric range analyzed: n=1÷12, T1= 0.5÷5, T2=0.5÷1. In this range equation (4), which eliminates the dependency upon T2 (proved to be nonsignificant), provides a maximum error of ±15%.

Noncontemporaneity of plastic hinge formations can be taken into account, in an approximate manner, through the following expression (Ref. 3):

$$\mu = 1 + \psi_1 R - \psi_2 \left(\alpha_u/\alpha_y - 1\right) \quad (5)$$

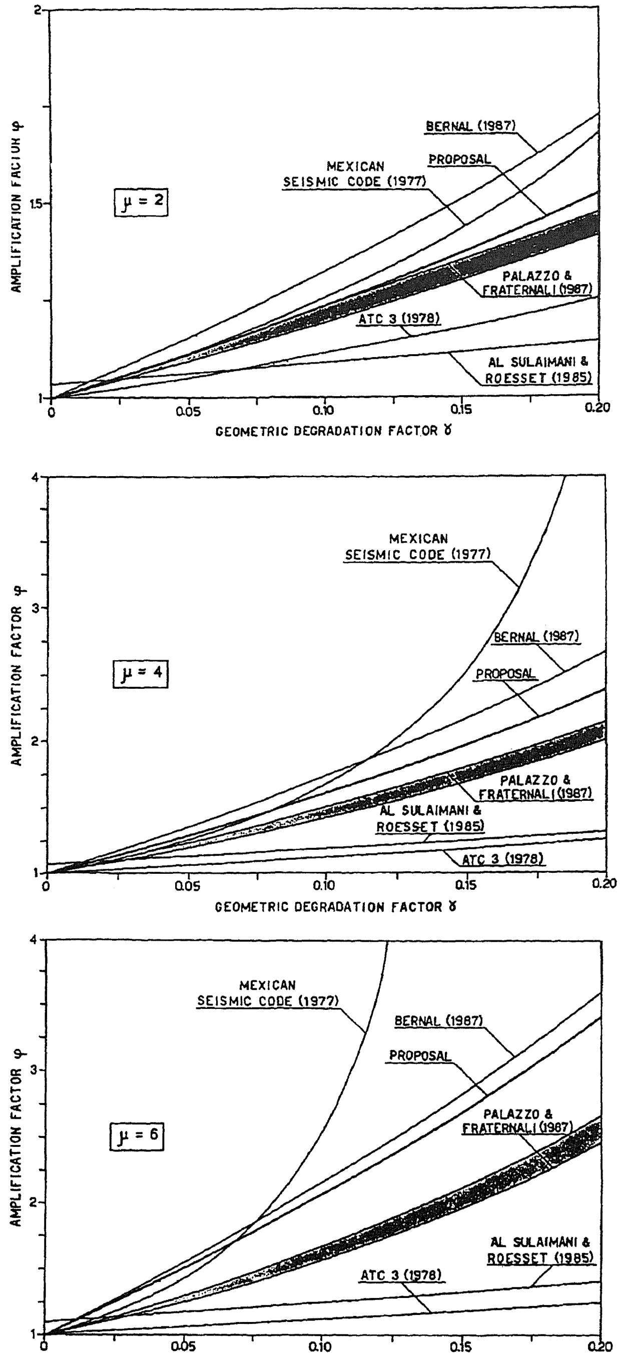
where the parameter ψ_2 can be assumed equal to 2. The effect of geometric nonlinearities leads to small variation of equation (4), while the effect of a mechanism which is not of the global type will be discussed hereafter.

STRUCTURAL COEFFICIENT AND GLOBAL DUCTILITY IN DEGRADING STRUCTURES

The constitutive relation of geometrically degrading structures is defined by the ratio γ between the slope of the softening branch and the elastic slope.

A parametric analysis carried out in the range defined in the previous section, shows that in the case of multistory structures this coefficient is equal to $1/\alpha_c$ with an error within few percents (Ref. 3). As it will be shown later, the formation of a mechanism different from the global one increases the slope of the softening branch.

An acceptable simplification for analyzing degrading structures is obtained by considering the value of q relative to γ=0 and to α_u/α_y=1, value which is amplified by the overstrength coefficient α_u/α_y and reduced through the coefficient φ>1.0 which takes into account the degrading phenomena:



Figs. 6, 7, 8 Degrading cefficient; μ=2, 4, 6.

$$q = \frac{\alpha_u}{\alpha_y}\ \frac{q(\mu, T, \gamma = 0, \alpha_u/\alpha_y = 1)}{\varphi(\gamma, \mu, T)} \quad (6)$$

The dependance of $q(\mu, T, \gamma = 0, \alpha_u/\alpha_y = 1.0)$ upon T and μ is well established (Refs. 6,7). For what concerns the factor φ a parametric analysis has been carried out. A SDOF system with softening, has been analyzed by varying the period T, the degrading parameter γ and the available ductility μ. Several earthquake inputs have been considered which have been generated from the design spectrum provided by the ECCS Reccommendations. The results show a statistic independency upon the period T, while the average value of φ, with a correlation coefficient practically equal to 1.0, is provided by the following expression:

$$\varphi = \frac{1 + 1.095(\mu - 1)^{128}\gamma}{1 - \gamma} \quad (7)$$

The values provided by this relation are given in figs.6,7,8 together with the formulations of Refs. 8,9,10. It should be noted that the prevision of AlSulaimani and Roesset (Ref. 8) are referred to the range of validity of the maximum displacement has been considered while in the prevision of Palazzo and Fraternali (Ref. 9) the case of $T_0 < T < 4T_0$ has been considered, T_0 being the value which defines the descending part of the design spectrum.

The results obtained herein are in good agreement with those of Bernal (Ref. 10) which have been derived for historical earthquakes and which refers to a higher fractile. It should be noted that the φ coefficient has a significative effect expecially for higher values of μ and γ.

THE INFLUENCE OF THE COLLAPSE MECHANISM

The formation of a mechanism which is not of the global type leads to a higher request of rotational capacity for a given value of global ductility. The slope of the softening branch is also increased. It is possible to relate the increase in request of rotational capacity and of the softening slope to the number of stories and to the index i defining the story in which the mechanism arises. The former can be done by assuming some significant types of mechanisms provided in fig. 9 and indicated as 1, 2, 3. In particular, the following relations hold (Ref. 3):

$$R_{mech} = R \cdot F'_{mech} \quad ; \quad \gamma_{mech} = \gamma \cdot F''_{mech} \qquad (8)$$

where R and γ are the parameters relative to the global mechanism. F'mech and F''mech are values greater than 1.0 (Ref. 3) provided in table 1. In fig. 9, as an example, are provided these functions for different mechanisms in the case of a 10 story frame. It should be pointed out that the story mechanism leads to results which are strongly penalizing and therefore should be avoided by means of design provisions. The other mechanisms do not lead to strong deterioration provided the number of stories which form the mechanism are not small compared to the total number of stories.

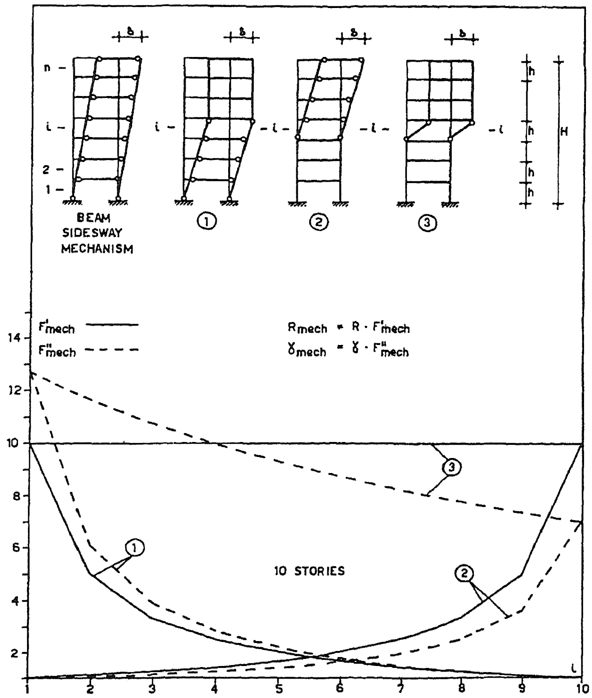


Fig. 9 Influence of mechanism

SUMMARY AND CONCLUSIONS

A rational methodology for the definition of the structural coefficient in steel framed structures has been provided. This methodology requires, having evaluated the elastic parameters T and α_c and the plastic parameter α_u/α_y, to compute the rotational capacity (figs. 3, 4,& 5). Then, by means of eqns. 4 and 5 the global ductility μ can be derived as a function of R. Finally the application of eqns. 6 and 7 allows to derive the structural coefficient q which takes into account also the overstrength factor α_u/α_y and the geometric degrading phenomena. It has been also shown how to take into account the effect of partial collapse mechanisms.

MECHANISM	F'_{mech}	F''_{mech}
1	$\frac{n}{i}$	$\frac{n(2n+1)}{i} \frac{2n+1-i}{(i+1)(2i+1)+3(n-i)(n+1+i)}$
2	$\frac{n}{n-i+1}$	$\frac{n(2n+1)}{i} \frac{i}{(n-i+1)(2n+i)}$
3	n	$\frac{n(2n+1)}{3} \frac{2}{n+i}$

Tab. 1 Influence of the mechanism

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