Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

A new proposal for a structural reduction factor formulation

B. Palazzo & F. Siano
Institute of Civil Engineering, Salerno University, Italy

ABSTRACT: A rationale methodology to evaluate the Structural Reduction Factor based on an appropriate definition is presented. The method requires the explicit use of the ductility ratio in seismic codes and also takes into account the P-Δ effect for structures which are sensitive to geometrical deterioration.
Having defined theoretical collapse conditions for the non linear SDOF system subject to simulated excitations corresponding to linear elastic design response spectra used in the code, the minimum strength spectra needed for the structural survival, has been evaluated. Dividing the elastic design spectra by the analized collapse spectra, derived by non linear analysis, the q-factor functions have been evaluated for EC8 and GNDT Italian Code proposal. The overstrength factor is also considered by simplified criteria.
According to the results, analytical expressions for this coefficient are proposed.

INTRODUCTION

The structural response modification factor is a building seismic design coefficient used by several codes to scale down the Linear Elastic Design Response Spectrum (LEDRS), corresponding to the Maximum Credible Earthquake (MCEQ) expected at a site, to the Inelastic Design Response Spectrum (IDRS).

The aim of the scaling procedure consists in accepting that significant but controllable inelastic deformations of code designed buildings occour under MCEQ without collapse.

The reduction factor philosophy was included in Seismic Regulations to take into account, in a very simple way, the principal characteristics of the non linear behaviour of structures. The scaling procedure needs also to take into account P-Δ effects because structures subject to significant geometric effects, due to vertical loads, collapse under lower seismic excitations. At present, it is very difficult to judge the rationale and validity of the q-values recommended by codes because the theoretical procedures by which current factors were determined have not been generally defined or documented. However, the relationships between inelastic and elastic response are influenced by a lot of factors and therefore is quite complicated to directly obtain reduction factors. The investigations reported in references (Palazzo & Fraternali 1987) clearly show that the structural coefficient must be dependent on the ductility of the structure, on the fundamental vibration period and on the geometric degrading phenomena.

However, it is not well recognized by codes that, for any given structural system, the acceptable decrease in strength cannot be constant for the entire range of the fundamental period in order to provide uniform seismic risk for all types of structures.

Fortunately, as shown in (Bertero 1988), the total overstrength to lateral forces that generally occurs in code-designed structures is about 2-3 times greater than the minimum code specified yield strength.

The strength in excess of seismic code requirements helps the majority of buildings to survive strong earthquakes. On the other hand, if the building possessing a low degree of redundancy has a real ultimate strength equal to the code minimum specified yield strength, its response to MCEQ may not be acceptable.

In this paper, on the basis of previous studies (Palazzo & Fraternali 1987), a rational procedure for the evaluation of the structural coefficient, taking into account structural ductility and global instable effects, is presented.

However, to correctly apply the procedure taking into account the overstrength, the global resistance against lateral forces of the building should be estimated by inelastic design procedures for the whole three-dimensional system. If elastic procedures are still used in seismic codes an overstrength factor for each typical structural system should be estimated and introduced in the evaluation of the reduction factor as shown in this paper.

THE REDUCTION FACTOR: DEFINITION AND METHODOLOGY

In the present proposal, the reduction factor q is defined as the ratio:

$$q(T) = \frac{R(T)\ A_{max}}{A_y(T, \mu, \gamma)}$$

where:

- A_{max} represents the peak ground acceleration of the Maximum Credible Earthquake (MCEQ) expected at a site
- R(T) is the amplification response factor of **LEDRS**
- $A_y(T,\mu,\gamma)$ is the minimum elastic limit (expressed as an acceleration) required for a structure having inelastic main characteristics μ,γ to avoid collapse during **MCEQ.**

To reduce seismic actions to the "working stress design force level", the appropriate reduction factor q_w should be used:

$$q_w = \gamma_s q$$

where γ_s is the local margin of safety used in working stress design method. Assuming a set of independent accelerograms which correspond to the (LEDRS) defined by codes, in terms of frequency content, it is possible to evaluate the main effects on simple degree of freedom model by means of non linear analysis. By using system with a minimum number of parameters, Collapse Spectra, representing the strength required to avoid specifically defined collapse conditions, are established. Dividing **Linear Elastic Design Response Spectra (LEDRS)** by such Collapse Spectra, a reduction factor q as function of a period and model parameters are determined. To take into account typical overstrengths for common structural systems, the reduction factor should be amplified. Assuming α_u as overstrength and α_d as code design strength, the overstrenght factor is:

$$q^\circ = \alpha_u/\alpha_d$$

The amplified reduction factor q clearly results as:

$$q = q^\circ q(\bar{\mu}, \gamma, T)$$

where $\bar{\mu}$ represents the ductility factor reduced proportionally to q° to take into account the different actual yield displacement.

MODELS AND COLLAPSE DEFINITIONS

To evaluate the lateral strength requirements needed to survive under an assigned strong earthquake, an inelastic single degree of freedom system could be used as a structural model and some "damage functionals" must be established to define the collapse conditions.

A SDOF model having two different relationships has been considered:

1. Elasto perfectly plastic type model (EPP)
2. Slip type model as represented in fig. 7a

The geometrical degrading (P-Δ effect) has been considered introducing the coefficient γ which represents the slope of the descending branch of the response taking into account second order effects. It has been shown (Palazzo & Fraternali 1987) that in multistory structures the slope of the descending branch depends on the collapse mechanism type and γ can be expressed as:

$$\gamma \simeq -\frac{1}{\alpha_p} \frac{dL_2^*}{dL_1}$$

where α_p is the limit multiplier of horizontal forces, θ represents the lagrangian parameter of the mechanism, L_2^* the second order work done by vertical loads and L_1 the work done by horizontal forces. In the case of a global type mechanism the approximate relation can be used to evaluate γ:

$$\gamma \simeq \frac{1}{\alpha_c}$$

where α_c represents the critical elastic multiplier of vertical loads. Based on these assumptions the equation of motion then may be expressed as:

$$\ddot{\mu}(t) + 2\nu\omega\dot{\mu}(t) + \omega^2 \{q(\mu, \dot{\mu}) - \gamma\mu(t)\} = -\omega^2 \varepsilon(t)/\lambda$$

where:

$\mu(t) = \frac{u(t)}{u_y}$ is the actual ductility

$\varepsilon(t) = \frac{\ddot{s}(t)}{|\ddot{s}|_{max}}$ represents the base acceleration

$\lambda = \frac{F_y}{m|\ddot{s}|_{max}}$ is the lateral strength factor

$\gamma = \frac{g}{h\omega^2}$ represents the geometric degrading factor

ν is the dumping factor

Several accelerograms artificially generated using (SIMQKE program 1976) assuming EC-8/84 **LEDRS** (based on a 5% dumping factor) spectra as target spectra are considered.

COLLAPSE FUNCTIONS

To define collapse states the following conditions have been applied:

A) Ductility demand surmounts the supply

$$D\mu(t) = \frac{\mu(t) - 1}{\mu_u - 1} \geqslant 1$$

B) Ductility function $\mu(t)$ equals the critical one μ_c given by $\mu_c = u_c/u_y$ where u_c represents the displacement where P-Δ effects annul residual strength:

$$D_c = \frac{\mu(t)}{\mu_c} \geqslant 1$$

C) Park & Ang plastic fatigue functional (Park et. al. 1987) which takes into account the effect of the cumulative damage resulting from numerous inelastic cycles:

$$D_{P.A.}(t) = \frac{\mu(t) + \beta(\mu_E(t) - 1)}{\mu_u}$$

Where: $\mu_E = \frac{Eh}{Fy\ uy} + 1$

represents the hysteretic ductility, β the parameter used in Park's model and E_h the irrecoverable energy.

ANALYSIS OF RESULTS

With the procedure just outlined, the Collapse Spectra in therms of absolute acceleration for different values of the ductility factor and the geometric degrading factor, have been evaluated for EPP and slip type models, (Figg. 1a-8a) In these figures we can observe that the minimum strength required to avoid the above defined collapse conditions, is strongly affected by both parameters μ and γ. In the figures the **LEDRS**, which can be considered as special Collapse Spectra for $\mu = 1$ and $\gamma = 0$, are also shown. Reduction coefficients derived by dividing LEDRS by Collapse Spectra are shown in figg. (1-7) b). These results cleary show that the reduction factor, assuming zero the overstrength, depends on the natural period T, on the global ductility factor μ and on the geometrical factor γ:

$$q = q(\mu, T, \gamma)$$

Results show that reduction factors are quite lower than ductility ones and the influence of the geometric degrading factor is very strong. Figures clearly show that structures with T < 1 sec. require to have yielding strengths significantly higher than structures having higher periods. In figg. 8, 9 the comparison between collapse spectra obtained using slip type and EPP models jointly with the assumed collapse criterium is shown. The influence of the type of model and the assumed collapse criterium results very small. Collapse Spectra according GNDT italian seismic code proposal obtained by Palazzo & Fraternali (1987) with the same procedure but using different interpolating criteria applied in this paper are shown in figures 10-13.

The proposed formulation for GNDT q function is represented in figg. 14-15. The analytical formulation of EC-8 q-factors proposed in this paper are shown in figg. 16-17.

CONCLUSIONS

A rationale methodology for estimating reduction factor values has been provided. The results show that structural coefficient depends on the ductility factor μ, geometrical factor γ and natural period T. It has been assumed that the overstrength factor amplify the reduction factor evaluated for a ductility factor reduced proportionally to the overstrength factor. Based on the results same analytical formulations of the q-factor for EC-8 code are obtained. The proposed formulation corresponds to the EC-8 design spectra considered in the procedure and it is also dependent on the curves related to site conditions **LEDRS.** In figg. 15-16 the q-functions for GNDT Italian Seismic Code proposal obtained by the same procedure is shown. The constant values of q-factor recommended by codes appear to be too high for short period structures without considering the overstrength.

REFERENCES

Bertero, V.V. 1988. Ductility based Structural Design. State of the Art Report. Proceedings of Ninth World Conference on Earthquake Engineering: Tokyo-Kyoto, JAPAN.

Bertero, V.V. 1986. Evaluation of response reduction factors recommended by ATC and SEAOC. Proceedings 3rd U.S. NCEE, Vol. III pp. 1663-1674. EERI: Charleston - South Carolina.

CCE, Eurocode n. 8 1988. Structures in seismic Regions Committee of the European Comunities: Bruxelles.

CNR-GNDT 1984. Italian Seismic Code Proposal. Gruppo Nazionale per la Difesa del Terremoti, Consiglio Nazionale delle Ricerche: Roma.

Cosenza, E., De Luca A., Faella, C., Piluso, V. 1988. A rational formulation for the q-factor in steel structures. Proceedings of Ninth World Conference on Earthquake Engineering: Tokyo-Kyoto, JAPAN.

Mahin, S.A., and Bertero, V.V. 1981. An evaluation of inelastic seismic design spectra. Journal Structural Division of the ASCE, 107 n. ST9 pp. 1177-1195.

Palazzo, B. & Fraternali F. 1987. The use of Collapse Spectra in the Seismic Analysis. A proposal for a new formulation of the structural factor. 3th AIDIS Congress (in italian): Roma.

Park, Y.J. Ang A.H.S., 1987. Wen Y.K. "Damage - limiting a seismic design of buildings", Earthquake Spectra Vol. 3, pp. 1-26.

Palazzo, B. and Fraternali, F. 1987. The influence of P-Δ effect on the Seismic Response of Elasto-Plastic Systems. A proposal for a different formulation of the structural coefficient. 11th CTA Congress: Trieste.

Simqke, 1976. A program for artificial motion generation. Dept. of Civil Engineering - Institute of Technology: Massachusetts.

Uang, C.M. and Bertero, V.V. 1988. Identification of Research needs in seismic resistant design of structures. UBC/EERC Report, Earthquake Engineering Research Center. University of California: Berkeley.

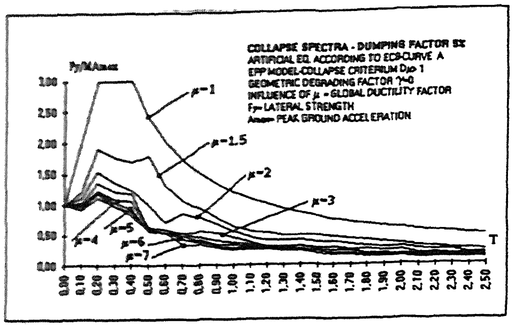

Fig. 1a

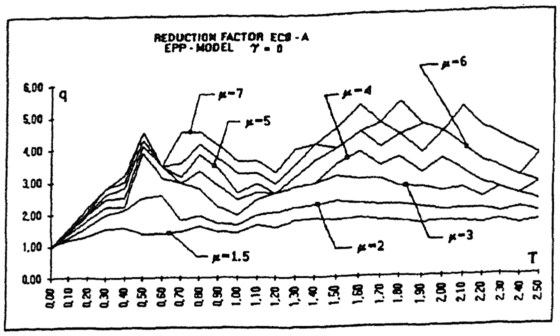

Fig. 1b

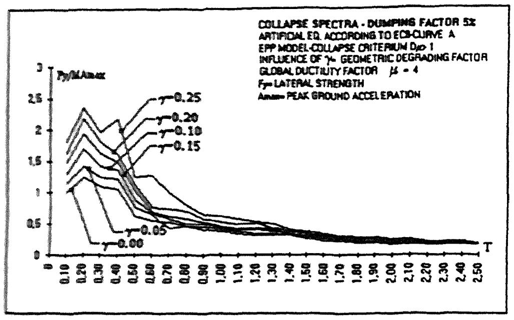

Fig. 2a

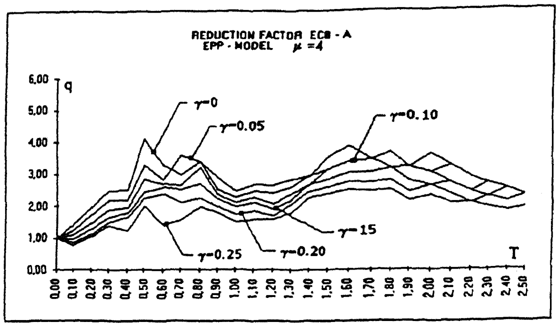

Fig. 2b

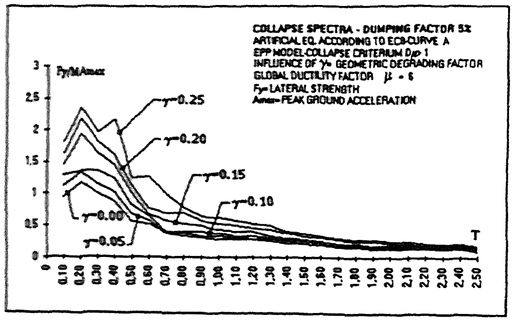

Fig. 3a

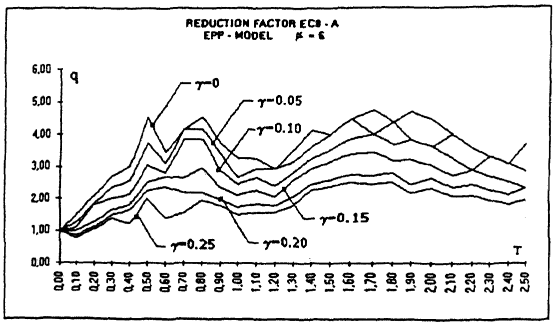

Fig. 3b

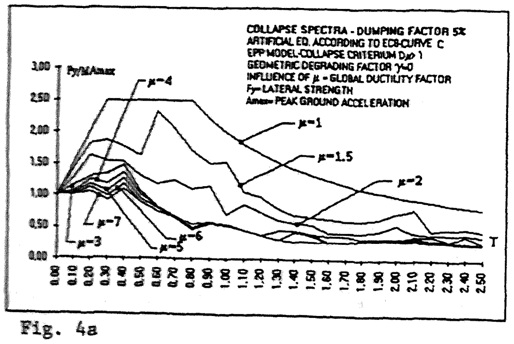

Fig. 4a

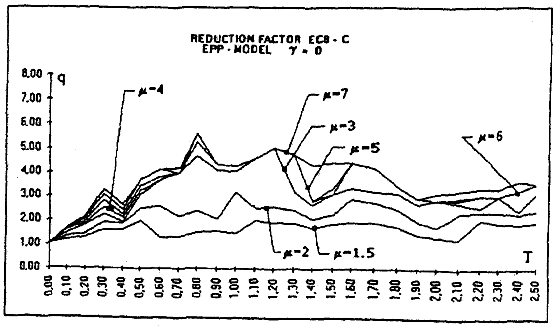

Fig. 4b

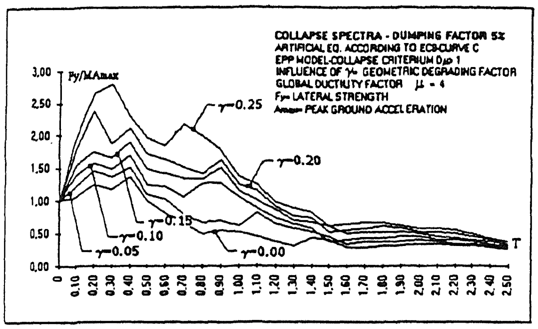

Fig. 5a

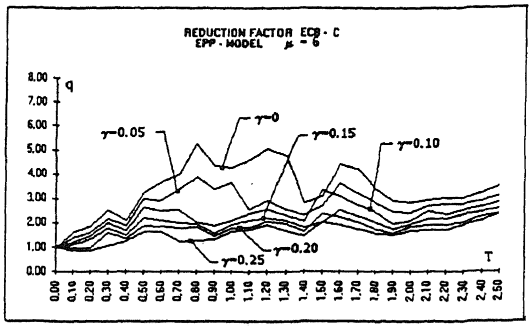

Fig. 5b

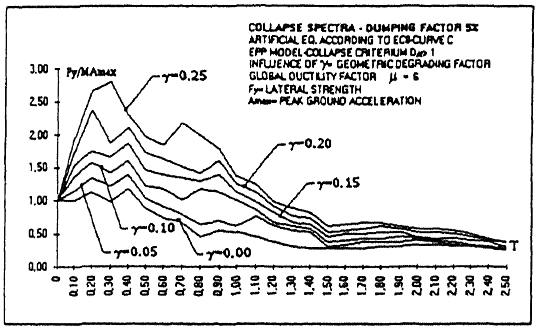

Fig. 6a

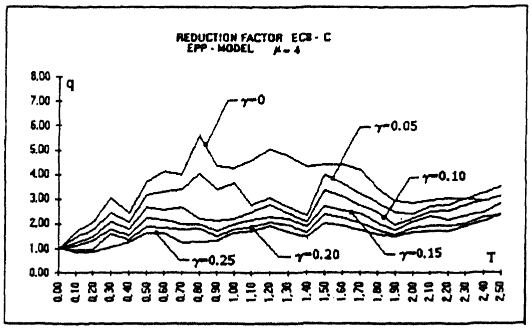

Fig. 6b

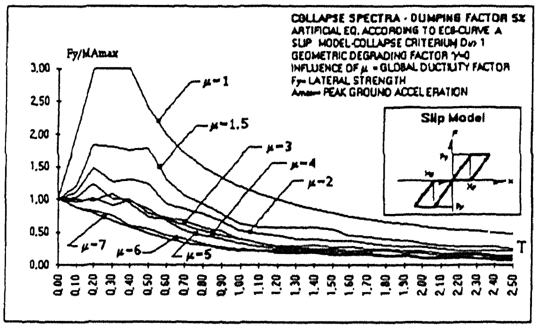

Fig. 7a

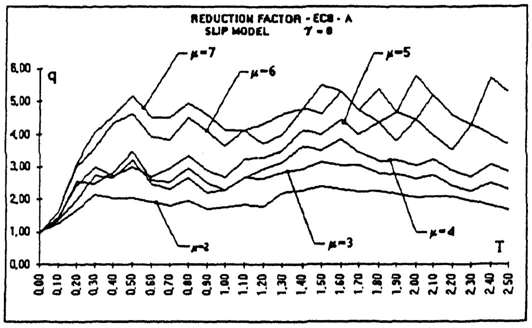

Fig. 7b

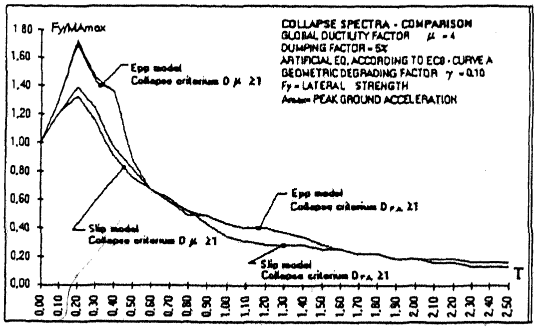

Fig. 8

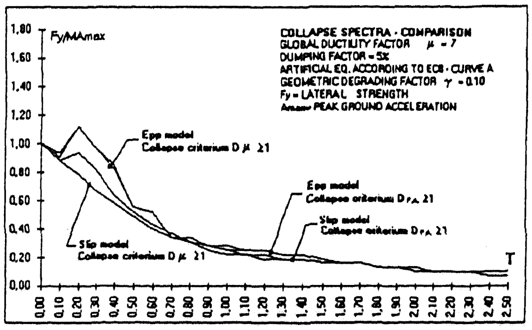

Fig. 9

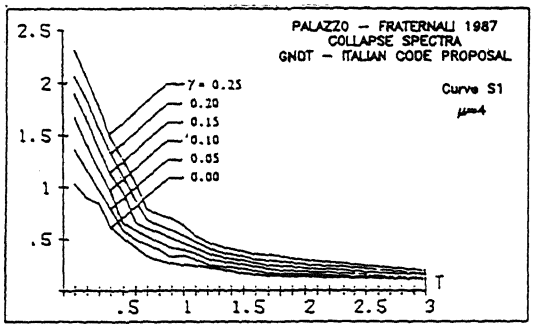

Fig. 10

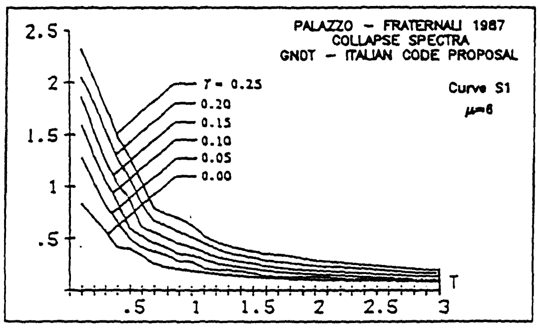

Fig. 11

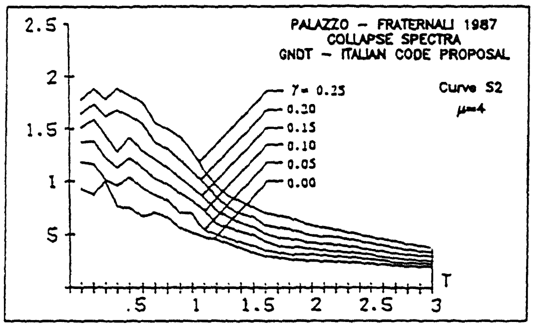

Fig. 12

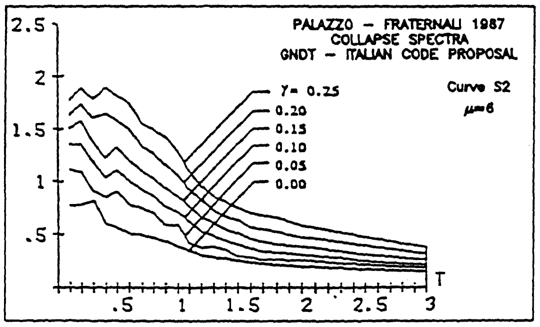

Fig. 13

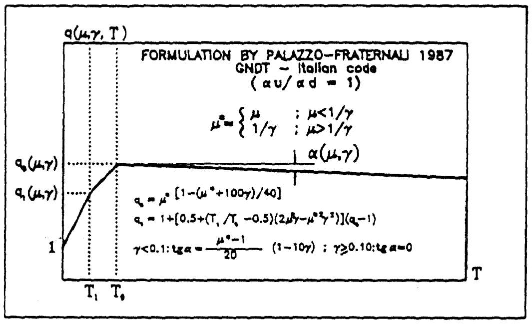

Fig. 14

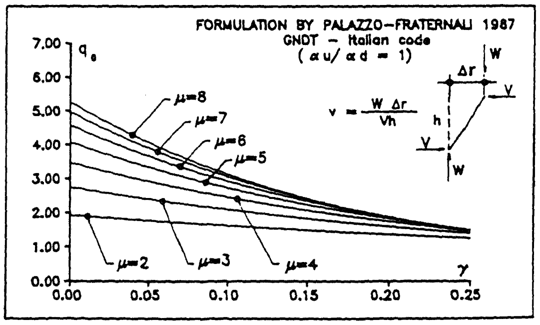

Fig. 15

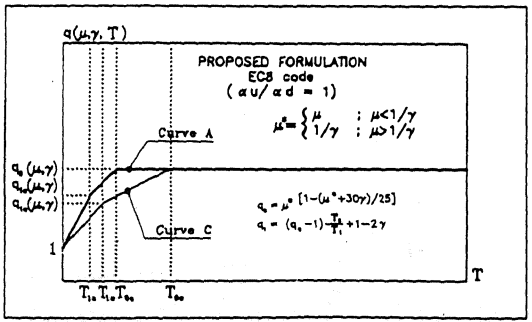

Fig. 16

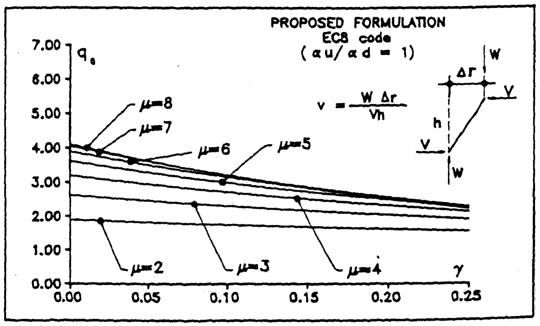

Fig. 17