INELASTIC SPECTRA FOR GEOMETRICAL AND MECHANICAL DETERIORATING OSCILLATOR

B. Palazzo (I)
A. De Luca (I)

SUMMARY

A simple model is adopted for simulating hysteretic behaviour of actual structures. P-Δ effects together with degrading of stiffness and strength are introduced in the model by using appropriate deterioration laws which can be derived by the measure of the amplification of the period of damaged structures. Inelastic response spectra are then developed in terms of ductility and strength requirements for the earthquake recorded at Sturno on november 23rd 1980.

INTRODUCTION

The seismic behaviour of a building undergoing a strong earthquake can be considered as a process during which mechanical properties of the structure modify. In fact, since the structure is designed to resist a medium-intensity earthquake, it will undergo some cycles in the inelastic range thus experiencing different types of deteriorations (cracking, loss of bond and anchorage, crushing and/or splitting of the concrete cover, local buckling, slippage of connections, etc.) which yield to degradation of general mechanical properties. As a consequence of these phenomena, story drifts become larger and larger thus leading to P-Δ effects which cause a further geometrical deterioration. It would be cumbersome to take into account all these effects in the dynamic analysis of a structure. Instead, these aspects can be more concisely introduced in the S.D.O.F. model which can give significant informations in the inelastic response spectrum representation, provided it is representative of a wide range of actual behaviour of structures. Several models (Refs. 1,2,3,4) have been proposed by different authors to represent the hysteretic behaviour of actual structures, while the problem of the damage laws of mechanical properties has been investigated in Refs. 5,6, 7 and 8. In this paper, a simple continuous model is adopted for simulating the non-linear hysteretic behaviour. Deterioration of mechanical properties is assumed to depend upon deformation amplitude and energy dissipation. Mechanical and geometrical deterioration are analyzed separetely. These effects are then combined together in a parametric study devoted to investigate the influence of different deterioration parameters on the inelastic response of structures subjected to seismic loading.

(I) Department of Structures, University of Naples, ITALY

DYNAMIC BEHAVIOUR OF NON LINEAR S.D.O.F. MODEL WITH P-Δ EFFECTS

If we consider a S.D.O.F. shear type model characterized by a constitutive law $F(u)$, for a given lateral strength F_y, initial stiffness k, elastic limit u_y, damping c and mass expressed by:

$$m = \Sigma\, P/g \qquad (1)$$

the P-Δ effect can be taken into account in a linearized form by introducing the fictitious shear:

$$Q(t) = \Sigma\, Pu(t)\,/H \qquad (2)$$

Having defined with $|\ddot{S}|_{max}$ the peak acceleration, and with:

$$\mu(t) = u(t)/u_y \quad ; \quad \lambda = F_y/m\,|\ddot{S}|_{max} \qquad (3)$$

respectively the updated ductility factor and the lateral strength factor, the equation of motion becomes:

$$\mu(t) + 2\nu\omega\mu(t) + \omega^2\{q(\mu,\dot{\mu}) - \gamma\mu(t)\} = -\omega^2\alpha(t)/\lambda \qquad (4)$$

in which $q(\mu, \dot{\mu})$ gives the adimensional response, $\alpha(t)$ represents the base excitation and γ a geometrical deterioration factor defined by:

$$\gamma = g/H\omega^2 \qquad (5)$$

Geometrical deterioration

The introduction of the P-Δ effect (Refs. 9,10,11) in the model allows to define a condition of geometrical collapse which is represented by reaching of the maximum displacement u_c at which the fictitious shear equals the lateral strength of the system. By taking into account this condition, we will have:

$$\Sigma\, P/HK \quad u_c/u_y = 1 \qquad (6)$$

which, upon substitution, leads to:

$$\mu_c = u_c/u_y = 1/\gamma \qquad (7)$$

We can therefore infer that the inverse of the abovedefined geometrical factor γ, represents the value of ductility which yields to geometrical collapse of the structure. In the particular case of elasto-plastic constitutive law, the assumed geometrical deterioration, leads to the model of fig. 1 where γ represents the slope of decreasing strength.

MECHANICAL DETERIORATION

The model (fig. 2) proposed to simulate the non-linear behaviour of structures subjected to cyclic loading, tries to give a general representation with few governing parameters. This model is characterized by the following loading curve:

$$\mu = F/F_y + (\mu_L - 1)(F/F_y)^r \qquad (8)$$

where μ_L is the limit of ductility. The exponent r, representing strain-hardening behaviour of the structure, can be determined by appropriate conditions on residual deformations. The unloading curve is assumed to be linearly elastic.

Damage laws

Different deterioration laws(Refs. 5,6,7,8) have been proposed in order to take into account degrading of stiffness and strength. These studies lead to assume that deterioration mainly depends upon:

a) amplitude of maximum deformations,
b) energy dissipated in the previous cycles.

If we indicate with u_r and $\mathcal{D}_{max}$ the limit values of deformation and energy absorption capacity, the deterioration law of the generic parameter of strength or stiffness can be expressed by:

$$K = K_0 - \Delta K \; \{ a(|u|/|u_r|)^n + b(\mathcal{D}/\mathcal{D}_{max})^m \} \qquad (9)$$

where K_0 is the value of the parameter in the initial conditions and ΔK is the maximum deterioration. This expression allows to represent deterioration both under few cycles, the governing parameter being expressed by the first term, and under low-cycle fatigue where the $(\mathcal{D}/\mathcal{D}_{max})^m$ term can be derived by the Palmgren-Miner law. It should be noted that deterioration of stiffness corresponds to the amplification of natural elastic period of the structure from T_0 to T_f (last cycle elastic period). If we assume, for simplicity, a = 0, b = 1 and $\alpha = T_f/T_0$ we have:

$$T/T_0 = \{ 1 - (1-1/\alpha^2)(\mathcal{D}/\mathcal{D}_{max})^m \}^{-1/2} \qquad (10)$$

which gives the amplification law of the natural period with increasing deterioration (fig. 3). This representation is physically more evident, the parameters being derivable by means of experimental tests on real structures.

RESULTS

The parametric study carried out herein, is relative to the Irpinia Earthquake, recorded at Sturno on november 23rd 1980, of 6.5Richter magnitude, which yielded, in a wide region, destructive effects reaching grade X of Mercalli scale with a maximum acceleration equal to 0.322 g. The accelerogram is given in fig. 4 together with the elastic response spectrum. In fig. 5 are represented the ductility spectra relative to the case in which mechanical deterioration is not present ($\alpha = 1$), for different values of the strength factor λ. These curves are bounded, in the upper part, by the geometrical collapse condition (G.C.) as previously defined. It should be noted that the required ductility increases for decreasing periods T_0 while it is significantly greater for larger values of γ. As expected, there is a decrease in ductility requirements for larger values of strength. Particularly, this requirement is within $\mu = 3$ for $\lambda = 1$ and $\gamma \leq 0.15$. However it is noteworthy that the more significative spectra are the ones relative to $\lambda = 0.6, 0.8$ which represent more common structures from the actual specification point of view. Figures 6 and 7 show the minimum value of required strength λ_{min} in order to avoid geometrical or mechanical collapse under the defined seismic excitation, for different values of the amplification period α according to Ref. 12 representation. It can be observed that the required strength is significantly higher for smaller periods, while larger values of α or γ lead to increased required strength, the parameter γ playing a major role. Significative indications on specification requirements and provisions can be derived by the parametric study reported herein, provided the analysis is extended to further earthquake excitations.

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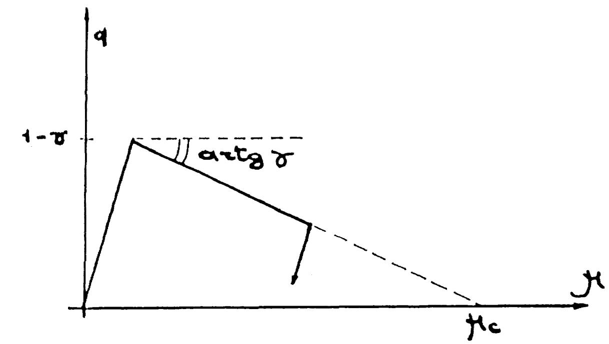


Fig. 1 *Equivalent bilinear model for geometrical deterioration*

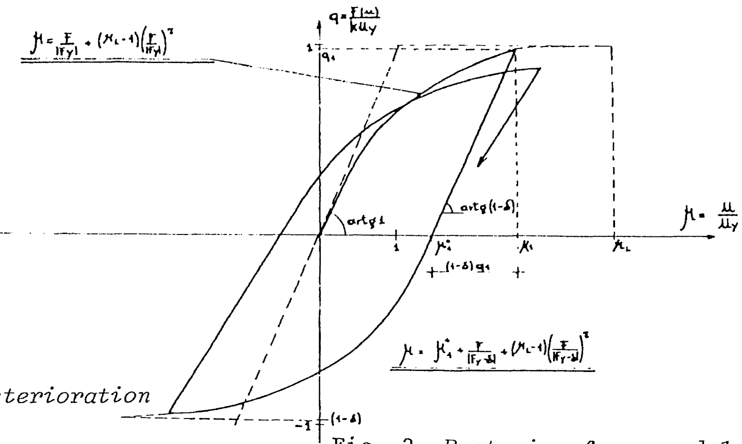


Fig. 2 *Restoring force model*

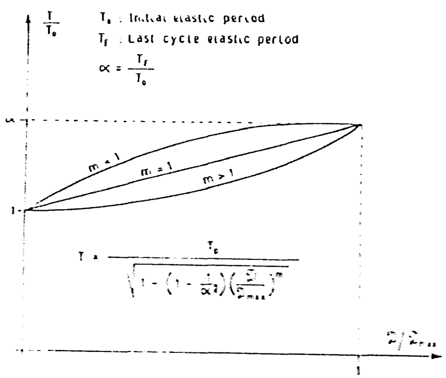


Fig. 3 *Amplification of period due to dissipated enerau*

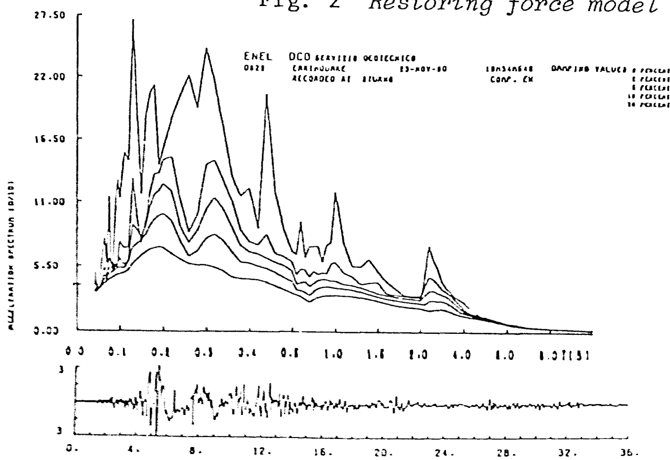


Fig. 4 *Irpinia earthquake*

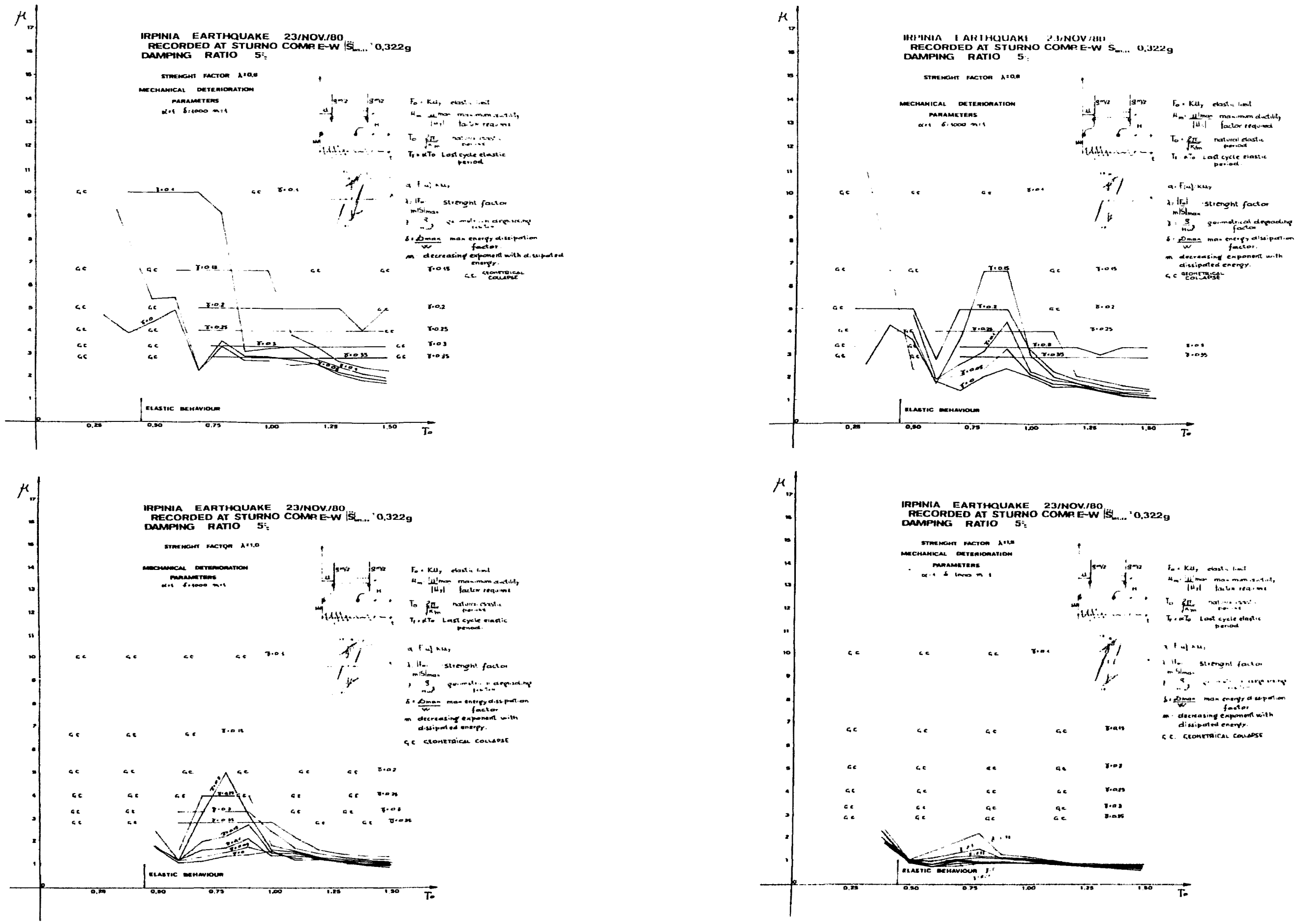
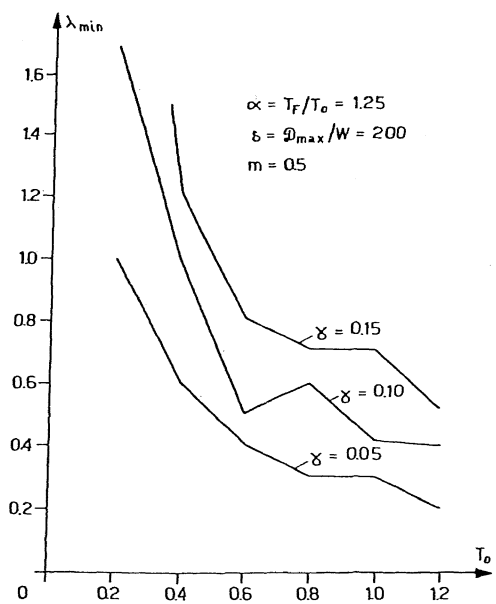
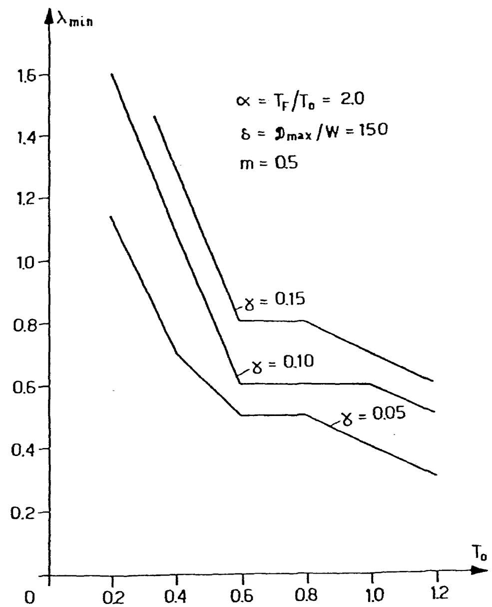


Fig. 5 *Ductility spectra*





Figs. 6 and 7 *Minimum required strength to avoid geometrical or mechanical collapse*