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SEISMIC DUCTILITY DEMAND IN BUILDINGS IRREGULAR IN PLANE A NEW SINGLE STORY NONLINEAR MODEL

Bruno PALAZZO and Fernando FRATERNALI

Institute of Civil Engineering, University of Salerno,
Penta di Fisciano, Salerno, Italy

SUMMARY

This paper presents a parametric study of the seismic response of a new single-storey nonlinear building model. A limit elastic domain of the generalised forces acting on the model is introduced. The influence of the most significative parameters on the peak ductility demand of the border frames in systems projected according to the provisions of the Actual Italian Seismic Code is analysed.

INTRODUCTION

It is common knowledge that the heavy damage or collapse frequency verified after the past earthquakes has been as much higher as more eccentricity had been between gravitation and stiffness axes owing to inertial and torsional actions unexpected or underestimated during the project. This experience has stimulated recently many authors to a critical re-examination of the various regulations tending to give the buildings the torsional resistance (Refs. 1,2). Recently (Ref. 3) the authors of this work have proposed a new model, illustrated forthwith, conceived to point out the essential aspects of the complex seismic three-dimensional behaviour of buildings even beyond the elastic phase, taking care of a limited number of parameters. This model is used in this work to test the influence of the different parameters involved on the torsional non-linear response of dyssimetrical buildings and to develop an analysis of the seismic responses of systems projected according to the provisions of the Actual Italian Seismic Code.

SINGLE STOREY MODEL WITH ELASTO-PLASTIC BEHAVIOUR

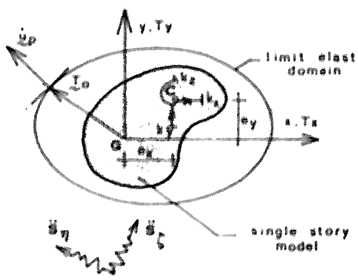


Fig. 1 Single story model

We consider a single-storey sistem,shown in Fig. 1, whose floor slab, of general shape, is assumed to be rigid in its own plane.The mass, assumed to be uniformly distribuited with radius of gyration ϱ , has its center in G while the distribution of lateral stiffness centres in C of eccentricity e_x and e_y compared to G.

The system configuration during the motion induced by the base seismic excitation characterized by translational conponents in the directions ξ and η, is described by the global displacement vector {U} of components u, v, φ and the equations of the system motion can be written in the matricial form:

$$[M]\{\ddot{U}\} + [K]\{Ue\} - [G]\{U\} + [C]\{\dot{U}\} = -[M]\{\ddot{s}\} \tag{1}$$

where [M], [K], [G], represent respectively the mass, the stiffness and the geometric matrix which considers the unstabilizing effects.

$$[M]=\begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & m\varrho^2 \end{bmatrix} ; \; [K]=\begin{bmatrix} K_x & 0 & -K_x e_y \\ 0 & K_y & K_y e_x \\ -K_x e_y & K_y e_x & K_\varphi + K_x e_y^2 + K_y e_x^2 \end{bmatrix} ; \; [G]=\begin{bmatrix} mg/H & 0 & 0 \\ 0 & mg/H & 0 \\ 0 & 0 & (mg/H)\varrho^2 \end{bmatrix} \tag{2}$$

In the space of the generalized forces on the foor, Tx, Ty, T , we define a limit elastic domain of a "global" type whose frontier is represented by the equation convex surface:

$$S(Tx,\ Ty,\ T\varphi) = 0 \tag{3}$$

These bases given and domain assigned, the relation between the load increment and the displacement increment is completely defined either inside the domain, (S<0), or on the frontier, (S=0), according to the law of plastic sliding.

$$\begin{aligned} \{\dot{U}\} &= [K]^{-1}\{\dot{T}\} && ; S < 0 \text{ or } S = 0,\ dS < 0 \\ \{\dot{U}\} &= [K]^{-1}\{\dot{T}\} + \dot{\lambda}\nabla\underset{\sim}{S} && ; S = 0,\ dS = 0,\ \dot{\lambda} > 0 \end{aligned} \tag{4}$$

CRITERIA OF CONSTRUCTION OF THE LIMIT ELASTIC DOMAIN

The limit domain of the generalized forces on the floor can be bulit by means of the classical theorems of plastic theory.

Using the "equilibrium" approach, the limit load T, for each assigned line of action,is equal to the maximum load that satisfies the equilibrium equations :

$$\begin{aligned} T_x + \Sigma Q_{x_i} &= 0 \\ T_y + \Sigma Q_{y_i} &= 0 \\ T_\varphi L + \Sigma Q_{y_i} x_i - \Sigma Q_{x_i} y_i &= 0 \end{aligned} \tag{5}$$

and yield condition :

$$\begin{aligned} -F_{y,x_i} \leqslant Q_{x_i} \leqslant F_{y,x_i} \\ -F_{y,y_i} \leqslant Q_{y_i} \leqslant F_{y,y_i} \end{aligned} \tag{6}$$

where F_y are the yield forces of the frames.

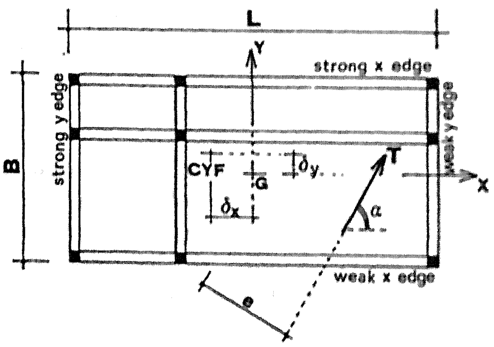


Fig. 2 Floor plan of model

In a dual way, using the "cinematical" approach, the limit load is equal to the minimum value of the loads corresponding to mechanisms of plastic deformation defined by an arbitrary position of the plastic limit swing center.

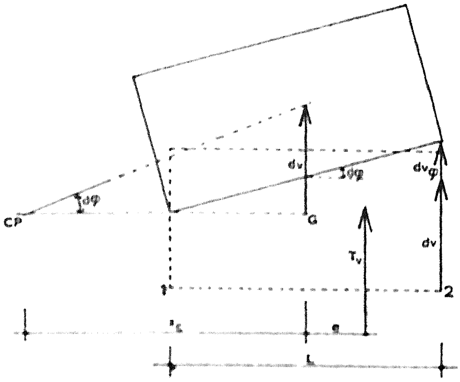


Fig. 3 a) Floor mechanism of sliding

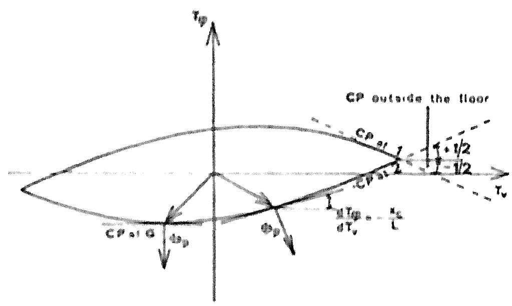


Fig. 3 b) Correspondence between CP and limit domain frontier

In the case of a monosymmetric single story structure the correspondence between the position of the plastic limit swing center and the domain frontier can be determined by means of the law of plastic sliding that implies :

$$dT_v\, dv + 1/2\, dT_\varphi\, dv_\varphi = 0 \qquad (7)$$

where dT_v , dT_φ are the components of the stress increment and dv , dv_φ are the component of the displacement increment in the mechanism condition. The position of the plastic limit swing center, as shown in Fig. 3(a), is defined by the relationship :

$$x_c/L = 1/2\ dv/dv_\varphi \qquad (8)$$

Therefore it follows that :

$$x_c/L = -dT\ /dT_\varphi \qquad (9)$$

that is, the distance between the plastic limit swing center and the mass center is equal to the slope of limit domain frontier, see Fig. 3(b).

Exemples of two- and three-dimensional limit domains are shown in Figs.4,5.

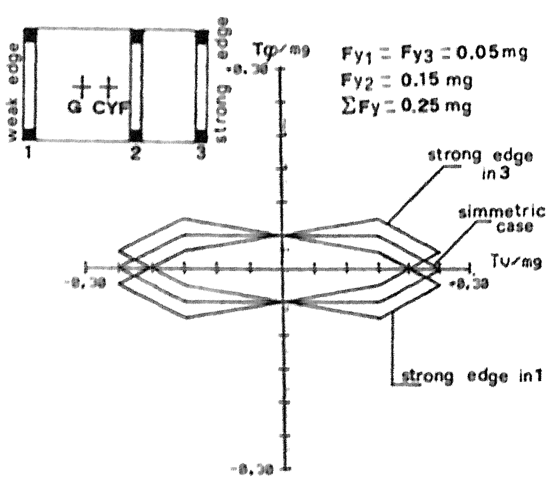


Fig. 4 Two-dimensional limit domain for a mono-symmetric structure with 3 frames.

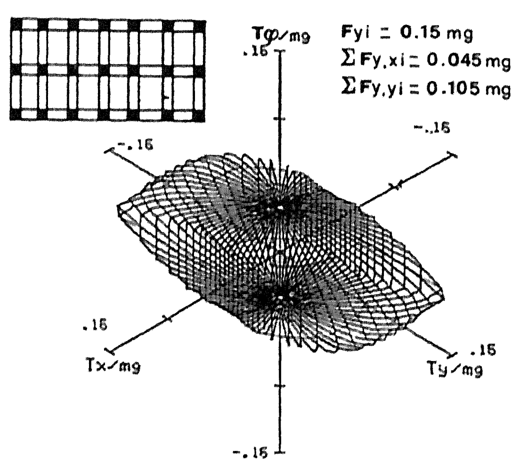
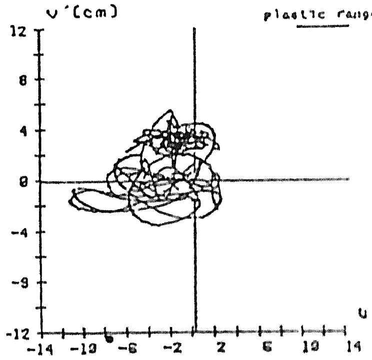
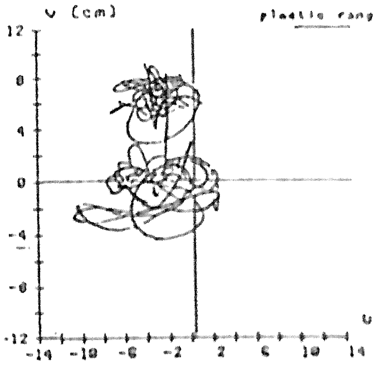


Fig. 5 Three-dimensional limit domain for a system with rectangular floor plan.

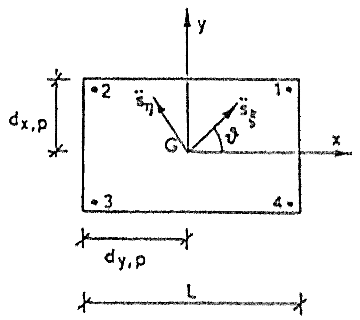
a) CENTER OF MASSES TRAJECTORY



b) CORNER 1 TRAJECTORY



SINGLE STORY ASYMMETRIC SYSTEM



Uncoupled Periods

$T_{0,x} = 1.0$ sec

$T_{0,y} = 0.6$ sec

$T_{0,\varphi} = 0.6$ sec

Strength Factors

$\lambda_x = T_{x,lim}/Mg = 0.20$

$\lambda_y = T_{y,lim}/Mg = 0.20$

$\lambda_\varphi = T_{\varphi,lim}/Mg = 0.03$

Geometrical Degrading Factors

$\gamma_x = g/H\omega_x^2 = 0$

$\gamma_y = g/H\omega_y^2 = 0$

$\gamma_\varphi = g/H\omega_\varphi^2 = 0$

Mass Radius Gyration Ratio

$\chi = \varrho/L = 0.31$

Eccentricity Ratios

$\varepsilon_x = e_x/L = 0.03$

$\varepsilon_y = e_y/L = 0.03$

Adim. Corner Coordinates

$\delta_x = d_{y,p}/L = 0.5$

$\delta_y = d_{x,p}/L = 0.2$

Damping Ratio

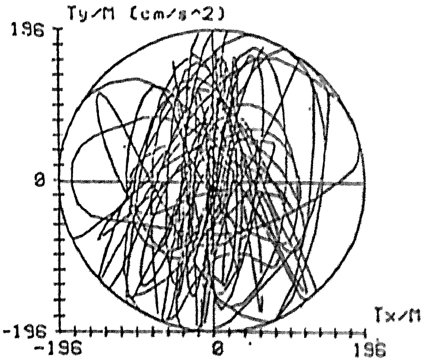
$\nu = 0.05$

Seism Direction Angle

$\vartheta = 125°$

El Centro comps. NS, WE

c) PLANE Tx - Ty STRESS PATH



d) PLANE Ty - Tφ STRESS PATH

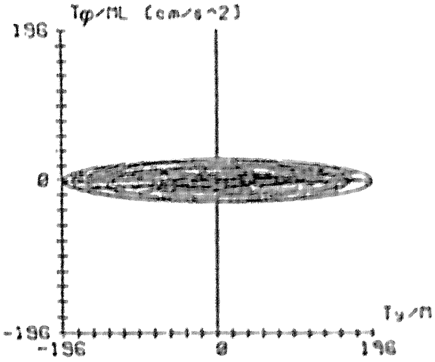
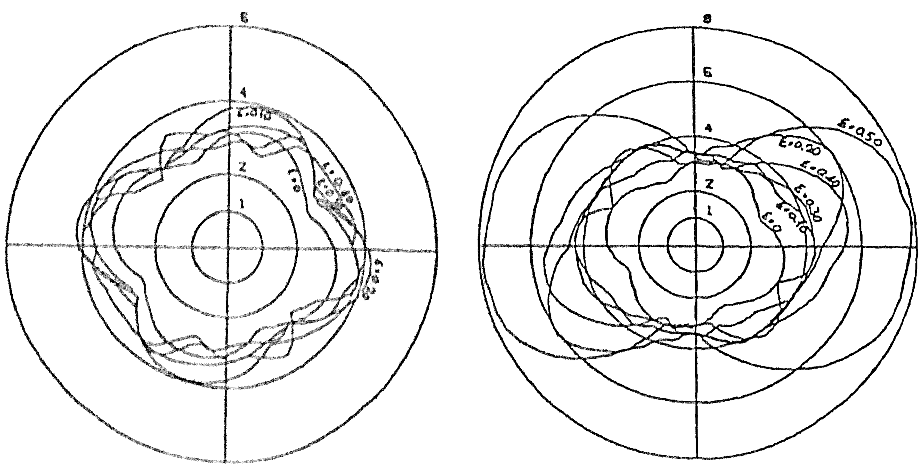


Fig. 6 Analysis of an exemple

PEAK DUCTILITY DEMAND OF BORDER FRAMES vs
SEISM DIRECTION ANGLE
polar coordinates
INFLUENCE of ECCENTRICITY RATIO

Strength factors according to Actual Italian Seismic Code
High and Low Torsional Stiffness

High Torsional Stiffness $T_{o\varphi} = 0.35$ sec   Low Torsional Stiffness $T_{o\varphi} = 0.80$ sec



PEAK DUCTILITY DEMAND OF BORDER FRAMES vs ECCENTRICITY RATIO

$T_{ox} = 2\pi/\sqrt{K_x/m} = 0.80$ sec

$T_{oy} = 2\pi/\sqrt{K_y/m} = 0.80$ sec

$\chi = \rho/L = 0.30$

$\lambda_x = T_{x,lim}/m\,g = 0.20$

$\lambda_y = T_{y,lim}/m\,g = 0.20$

$\lambda_\varphi = T_{\varphi,lim}/m\,g = 0.05$

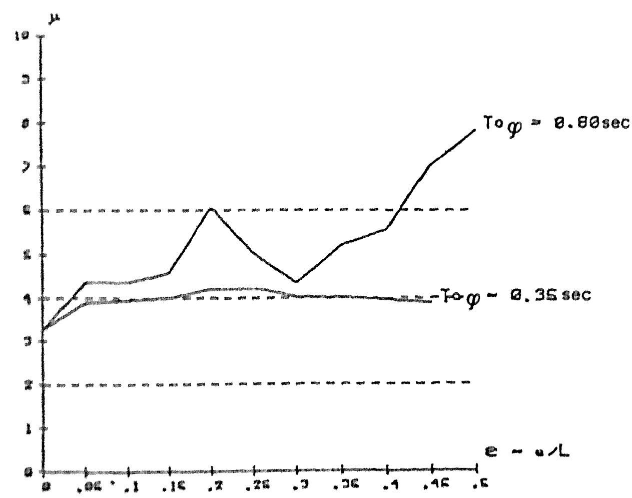
$\nu = 0.05$

$\gamma_x = g/H\omega_x^2 = 0$

$\gamma_y = g/H\omega_y^2 = 0$

$\gamma_\varphi = g/H\omega_\varphi^2 = 0$

$\theta = 0$



El Centro comps. NS,WE

Fig. 7 Peak ductility demand of the border frames in systems projected according to the provisions of the Actual Italian Seismic Code for the strength factors

ANALYSIS OF THE RESULTS AND CONCLUSIONS

We have conduced a parametric study about the coupled earthquake response of systems excited by the components N-S and W-E of the EL CENTRO accelerogram (1940). The model has been characterised by its uncoupled translational periods $Tox=2\pi\sqrt{Kx/m}$, $Toy=2\pi\sqrt{Ky/m}$, and by its uncoupled torsional natural period $To=2\pi\sqrt{K\varphi/m\varrho^2}$ for what concerns the response in the elastic phase, while it has been assumed as limit elastic domain an ellipsoid whose semi-axes coincide with the strength factors $\lambda x=Tx,lim/mg$, $\lambda y=Ty,lim/mg$, $\lambda\varphi=T\varphi,lim/mg$.

The most significative parameters involved in the analysis have been the eccentricity ratio $\varepsilon=e/L$, the seism direction angle ϑ and the peak ductilty demand of the border frames μ .

The analysis of the exemple illustrated in Fig. 6 shows how an insufficient torsional strength ($\lambda\varphi=0.03$) can involve the arising of relevant plastic rotations even in the presence of a low eccentricity (look at to the notable difference between the trajectory of the mass center G and that one of the corner 1).

In Fig. 7 is shown the influence of the seism direction angle and of the eccentricity ratio on the peak ductility demand of the border frames in systems projected according the provisions of the Actual Italian Seismic Code for the strength factors.

In the examined cases it has been observed :

- a notable variability of the peak ductility demand vs the seism direction angle;

- a marked amplification of ductility demand at the increasing of the eccentricity when the uncoupled torsional and traslational periods are coincident;

- an unaccettable ductility demand for systems projected according to the provisions of the Italian Seismic Code when the presence of a great eccentricity is joined to a torsional-traslational coupling.

REFERENCES

1. Hutchinson, G. L., Chandler, A. M., Parametric earthquake response of torsionally coupled buildings and comparision with building codes, Proc. of the 8th ECEE, Lisbon, 1896.

2. Rutenberg, A., Eisenberg, M., Shoet, G., Reducing seismic ductility demand in asymmetric shear buildings, Proc. of the 8th ECEE, Lisbon, 1986.

3. Palazzo, B., Fraternali, F., L'influenza della distribuzione planimetrica della resistenza laterale di piano sulla risposta sismica di sistemi strutturali dissimmetrici, Proc. of the AICAP seminary, Stresa, 1987.