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Base-isolation system using short columns and dampers

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ABSTRACT: The base-isolation system using short columns and dampers, having nonlinear characteristic is presented. Details and the dynamical response of such a type of isolator are exposed. The dynamical analysis performed on a structure, having as input data the Bucharest March 1977 earthquake accelerogram showed the satisfactory seismic response of the proposed system.

1 INTRODUCTION

There are two ways of protecting structures from earthquakes. In practice, the structure designed for the seismic loads normally recommended by codes can survive strong ground shakings only if they have sufficient strengthening and ability to dissipate seismic energy. This energy dissipation is provided mainly by inelastic deformations in critical regions in the structural system.

The second way of protecting structures is represented by the seismic isolation concept. The idea that a building can be uncoupled from the damaging effects of the ground movement produced by an earthquake has existed for a century, but it is only within the last fifteen years that serious study of the problem has been carried out.

The system presented by the authors (PRB-Pendulum Rubber Bearing) consists of a series of short pendular reinforced confined concrete columns hinged at the top on the superstructure and at the bottom on the basis, laterally embedded in a mass of neopren (Olariu, Pocanschi, Olariu 1982) (Fig.1). The transverse and horizontal section of the short column are presented in Fig.2.

The kinetic energy absorbed by the system from the ground motion is partly dissipated by inner friction and partly transformed in elastic reversible energy, that produces controlled distortion of the superstructure. Different from other systems, this type of isolator has the possibility to ensure the general stability of the structure against the overturning moments. As the rubber is not subjected to compression, except during earthquakes, its "aging" danger is diminished.

2 STIFFNESS CHARACTERISTICS OF A PENDULAR UNIT

The force-displacement diagram of an elastic nonlinear rigid isolator is detailed in Fig.3. On account of the nonlinearity in stiffness represented by a tangential function of the relative displacement, the response has an inherent stabilizing effect. Increasing the restoring force at the supposed maximum ground displacement d the isolator becomes practically rigid and hence the possibility of controlling the supestructure displacement. The stiffness K_0 of a pendular unit for elastic linear range of deformation results from the energetical equilibrium under a unit lateral base displacement. According to the notations from Fig.4, the strain energy of a damping unit may be written as:

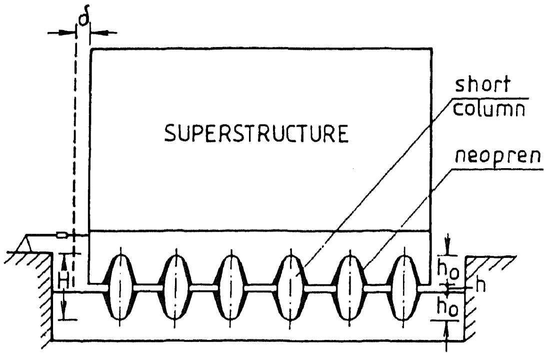

Figure 1. Pendular isolating system.

$$L_i = \int_V \frac{E_0 \varepsilon_z^2}{2} dV, \text{ with } \varepsilon_z = \frac{z\, \Delta l_0}{h_0\, l_0}$$

$$L_i = \int_0^{l_0}\int_0^{b}\int_0^{h_0} \frac{1}{2}\, \frac{z^2\, \Delta l_0^2\, E_0}{h_0^2\, l_0^2}\, dx\, dy\, dz$$

The external work done by the force F_1 is:

$$L_e = \frac{F_1 \Delta}{2}$$

For the unit displacement $\Delta = 1$:

$$K_0 = \frac{E_0 b\, h_0^3}{6\, l_0 H^2} = \frac{E_0 b\, h_0^3}{12 H^3 \tau}$$

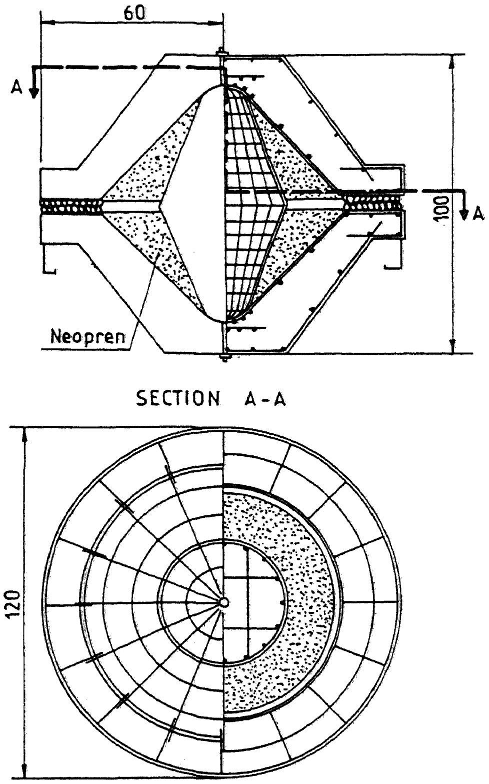

Figure 2. Transverse and horizontal section.

The force induced by the damper in the superstructure is:

- for the linear response: $F_L = K_0 d$

-for the nonlinear response: $F_{NL} = \frac{2K_0 d_c}{\pi} tg \frac{\pi d}{2 d_c}$

The dimensions and number of the pendular units and neopren mass are chosen so as to get the optimum response to a severe earthquake.

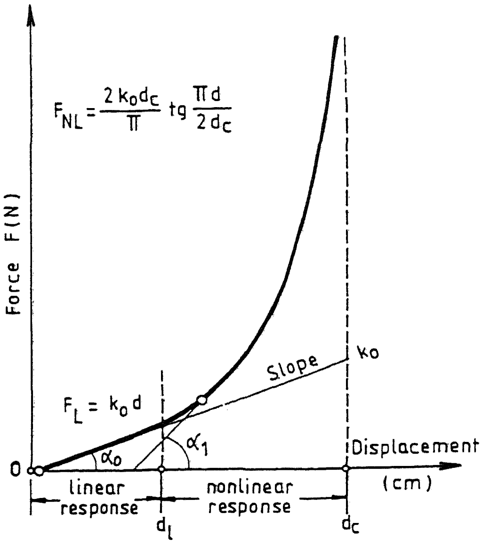

Figure 3. Force - displacement diagram.

3 THE SYSTEM WITH DAMPERS

To improve induced energy - dissipating capacity, damping devices of different types may be added. The initial friction force value R_0 is obtained by:

$$R_0 = \mu F_0$$

The damper stiffness under stress for the linear range is (Fig.5):

$$K_0 = \frac{E_0 A}{n t}$$

where:

n = the number of neopren layers of thickness
A = the transversal surface of the damper
E_0 = the initial modulus of elasticity of the neopren.

If the dissipating support in vertically compressed by d_0, an initial stress value is obtained:

$$F_0 = K_0 d_0$$

The nonlinear stress value F(x) due to this translation may be given by:

$$F(x) = \frac{2K_0}{\pi} \Delta_{VC}\, tg \frac{\pi x^2}{4\pi \Delta_{VC}}$$

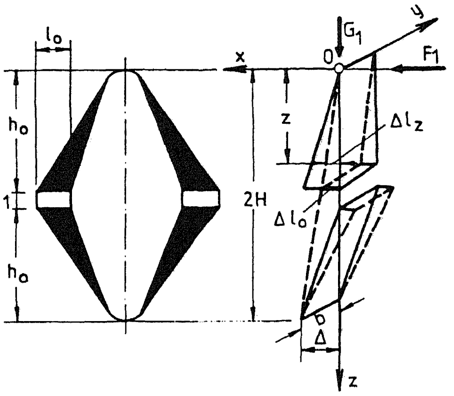

Figure 4. Deformation pattern of a unit.

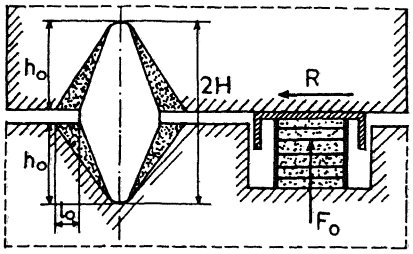

Figure 5. The system with damper.

where the characteristic thickness Δvc is about 80% of the support height. The expression of the friction force during motions is (Fig.6):

$$R(x) = \mu \left[F_o + F(x)\right]$$

The dynamic equilibrium differential equation for the single - degree - of - freedom structure is written as:

$$F_i + F_e + F_a \frac{\dot{x}}{|\dot{x}|} = -m\ddot{u}$$

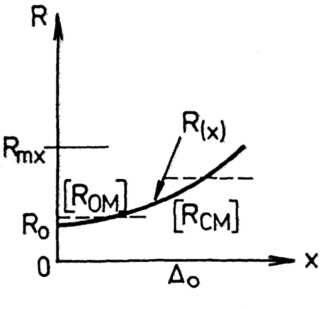

Figure 6. The friction force.

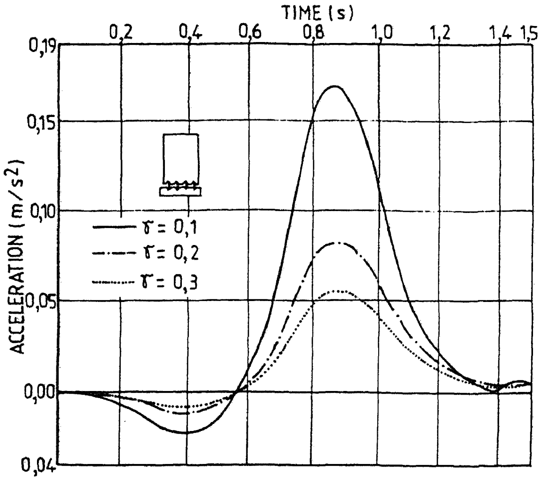

Figure 7. Acceleration response.

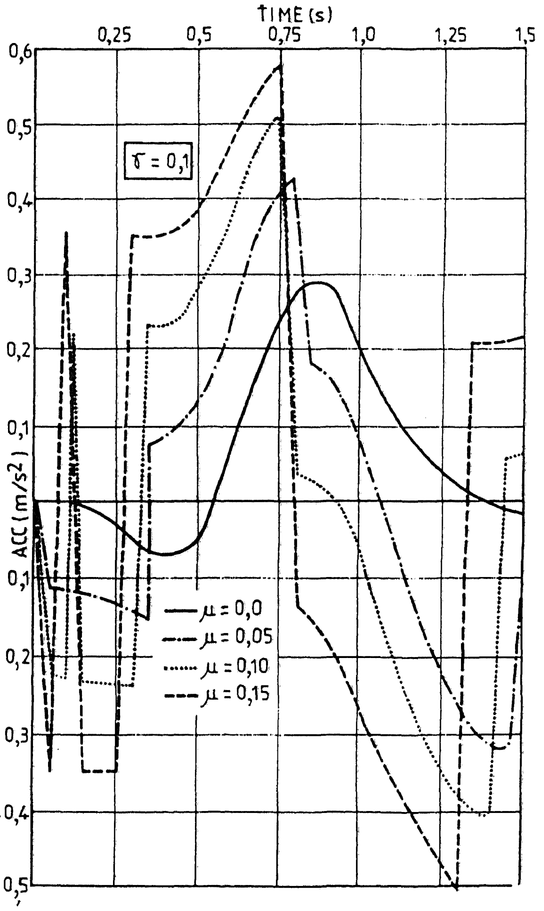

Figure 8. Acceleration response (with dampers).

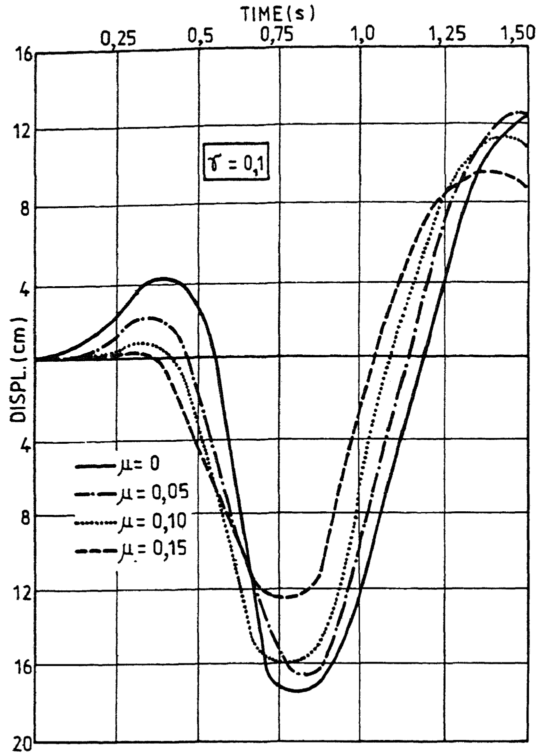

Figure 9. Displacements response (with dampers).

where:

F_i = force of inertia
F_e = elastic force
F_a = damping force
m = structure mass
$\ddot{u}$ = ground acceleration

$\frac{\dot{x}}{|\dot{x}|} = \mathrm{sgn}(x)$ = the sign for velocity, which is 1 for $\dot{x} \geq 0$, 0 for $\dot{x} = 0$ and -1 for $\dot{x} < 0$.

The damping force produced by the dry nonlinear friction is obtained through the relation:

$$F_a = \mu \left[F_0 + F(x) \right]$$

where:

μ = friction coefficient
F_0 = constant
$F(x) = a\, x^2\, \mathrm{tg}\alpha$

4 DYNAMIC RESPONSE

To investigate the earthquake response of the proposed isolating system, a dynamical analysis was performed. A R/C shear wall 20 m high, 5.10 m wide and 20 cm thick supporting a gravity load of 200 tf was supposed to be provided with four pendular units with the following characteristics: b = 20 cm, E_0 = 5 daN/cm, Υ = 0.1; 0.2 and 0.3. The response was performed (step by step, Newmark, Runge-Kutta methods) on an idealised single degree of freedom system (Fig.7).

For the analysis of the system with dampers the following characteristics were used:

E_0 = 200 N/m
Δ_{VC} = 4 cm
d_0 = 1 cm
n = 3
t = 2 cm
A = 706cm

The values of the friction coefficient were:
μ = 0.05; 0.1 and 0.15.
Fig.8 and 9 show the response in accelerations and in displacements, respectively.

5 CONCLUSIONS

The theoretical study of the presented system leads to the following general conclusions:

- the PRB system combines the advantages of kinematic system with that of the laminated rubber bearing (LRB) system;
- the mass acceleration is strongly reduced: for an isolator factor Υ = 0.3, the reducing acceleration factor is about 25 for Bucharest earthquake;
- it was made clear that the presented system has good isolation effect and considerable mitigates the seismic forces compared with the case without PRB system.

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