THE INELASTIC TORSIONAL RESPONSE OF STRUCTURES TO EARTHQUAKE GROUND MOTIONS

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SYNOPSIS

The torsional response of a single story framed structure with hysteretic behaviour is studied for earthquake ground motion inputs. The displacement ductility of various frames for the EL-centro record is obtained by numerical integration of the equations of motion.

INTRODUCTION

The structure studied in this paper consists of a rectangular slab, rigid in its own plane, supported on a series of parallel portal frames. The shorter side of the rectangular slab is parallel to the portal frames. The structure is assumed to have an eccentricity 'e' which is the distance between the centre of stiffness of the frames and the mass centre of the slab. Each frame is assumed to possess a bilinearly hysteretic force-deflection relation.

ANALYSIS AND RESULTS

The structure is now idealised as a two-degrees of freedom system. The lateral displacement of the centre of mass (u), and the rotation of the slab about the centre of mass (ϕ) are the two coordinates of the problem. The equations of motion of the system under a base motion ($x_s(t)$) are presented below

$$M\ddot{u} + \sum_{i=1}^{n} R_i(u,\phi) + c \sum_{i=1}^{n} (\dot{u} + r_i\dot{\phi}) = -M\ddot{x}_s \qquad \ldots(1)$$

$$I\ddot{\phi} + \sum_{i=1}^{n} r_iR_i(u,\phi) + c \sum_{i=1}^{n} r_i(\dot{u} + r_i\dot{\phi}) = 0 \qquad \ldots(2)$$

Here M is the total mass lumped at the floor level of the structure, I is the polar moment of inertia of the roof slab about the vertical axis through the mass centre. R_i represents the shear resistance offered by the i^{th} frame and r_i is its distance from the mass centre. c represents the damping coefficient. The equations of motion are

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integrated numerically on the computer after casting them into non-dimensional form. The linear acceleration method has been used for numerical integration.

As a specific example a structure with five portal frames spaced 4.0 m apart is considered. Each portal frame has a span of 8.0 m and a rise of 4.0 m. This structure is now subjected to a horizontal ground motion given by the EL-centro earthquake, May 1940, N-S Component. The direction of ground motion is assumed to be parallel to the portal frames. The position of the mass centre is varied to examine the influence of eccentricity on the dynamic response of the structure. Eccentricity is expressed as a percentage of the length of the structure.

The maximum displacement ductility experienced by each frame for the EL-centro input is presented in Table 1 below. The frames are identified by the first five letters in the alphabet.

TABLE-1. MAXIMUM DISPLACEMENT DUCTILITIES

Frame	Eccentricity e, %				
	0	1.25	5	25	30
A	1.54	2.45	0.80	0.68	0.73
B	1.54	2.38	1.04	0.45	0.53
C	1.54	2.35	1.42	1.15	1.10
D	1.54	2.34	1.80	1.86	1.77
E	1.54	2.34	2.50	2.57	2.48

The mass centre is assumed to be between frames C and E for all eccentricities. The table-1 shows that when the eccentricity is small the variation of ductility demand among the frames is not significant, although the magnitudes of the maximum ductility are larger due to the participation of the torsional mode. As the eccentricity increases there is a strong variation of maximum ductility among frames. The exterior frame closer to the mass centre experiences a ductility which is three to four times as large as the ductility of the other exterior frame. This larger value of ductility is itself about 70% more than the maximum ductility in frames if there were no eccentricity.

The results show that torsional motion can significantly affect the response of a structure subjected to ground motion even if the eccentricity is very small.