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ABSTRACT

Reinforced concrete shear walls have an important contribution to building stiffness. So, it is necessary to know their behavior under seismic loads. The ultimate behavior study of shear walls subjected to dynamic loadings includes:

- a description of the nonlinear global model based on cyclic static tests,
- nonlinear time history calculations for various forcing functions.

The comparison of linear and nonlinear results shows important margins related to the ductility when the bandwidth of the forcing function is narrow and centred on the wall natural frequency.

1. INTRODUCTION

Nuclear reactor buildings contain many reinforced concrete walls. These walls are subjected by a seism to shear forces which induce, in some cases, nonlinearities.

So the first stage for the seismic analysis of these buildings is related to the ultimate dynamic behavior of shear walls. This paper shows the results of nonlinear dynamic calculations performed on shear walls and their comparison with linear calculations.

2. CALCULATION MODEL

The local models with representation of concrete and reinforcement (Nahas, 1986; Clément, 1987) are expensive and not suitable to nonlinear dynamic analyses of buildings. So global models describing the cyclic behavior of the various building members are the base of seismic structure analysis. The global model of each member, defined for example from static cyclic tests, are then assembled for the building calculation.

In the following paragraphs, we limit our study to shear wall global model.

Hysteresis Curves

The shear wall hysteretic behavior is different from the flexural beam behavior: the shear curves are strongly pinched (fig. 1) (Fouré, 1985 ; Ohmori, 1987 ; Oesterle, 1980). This pinching is due to sliding along the horizontal cracks when the loading is reversed ; the wall stiffness is small when it is subjected to shear load. This explains also why natural frequencies of such structures as reinforced shear walls are strongly affected by microcracking, even if the cracks are not visible.

The shape of shear wall hysteresis curves leads to a smaller dissipation capacity than for flexion.

The shear stiffness depends strongly on axial loading as it can limit the expension and the opening of microcracks. In addition, when important cracks appear the axial compression increases the friction of crack lips.

Analytical Models

Many studies have been performed in order to establish analytical models for reinforced concrete ; models have been constructed for structures subjected to bending: as an example we can mention the Takeda model (Saiidi, 1982 ; Takeda, 1970).

A way to determine shear model is to modify the bending model in order to represent the pinched shape; it is done in a modified Takeda model (Roufaiel, 1987).

Description of the Studied Wall

Dynamic analysis was performed on a squat wall (height = 0.375 m, width = 0.75 m, thickness = 0.05 m).

Static monotonic and static cyclic tests have been carried out at the CEBTP Laboratory on shear wall at scale 2 from the previous one (Fouré, 1986). The shear curve has been determined from the static tests by taking into account the scale factor and the following hypothesis:

- the monotonic curve and the envelop of the cyclic curve are identical,
- the monotonic curve after steel yielding is horizontal, which gives a perfect elastoplastic curve,
- the stiffness during the closure of diagonal cracks can be neglected.

The associated modified Takeda model represented on figure 2 can be simplified by neglecting the stiffness while the opening of the cracks (figure 3).

It is this last model which was used for the dynamic analyses. The displacement corresponding to the elastic limit is 1.35 mm and that to collapse 4.5 mm. So the ductility of the studied structure is equal to 3.3 (= 4.5/1.35).

3. DYNAMIC CALCULATION

A mass (M = 1500 kg) was added at the top of the wall and a dynamic force, F(t), was applied on it.

The dynamic study of the wall is similar to that of a one degree of freedom system whose nonlinear stiffness, K(X), is known . The mass motion equation is given by:

$$M X''(t) + C X'(t) + K(X)X = F(t)$$

where X is the displacement of the wall top,
C is the viscous damping.

The dynamic study was related to the calculation of the force level which induces the collapse and to the comparison of this level with the one calculated by linear analyses.

The wall natural frequency calculated from the initial stiffness is equal to 41 Hz. The damping β is taken equal to 4% ($C = 2\beta\sqrt{KM}$).

Response to Sinusoidal Excitation

The maximal wall deflection under sinusoidal force was calculated for various levels and frequencies of the force. The force has a constant amplitude ($F = F_o \sin 2\pi\, fe\, t$) and was applied during 40 cycles. The results show a strong modification of the resonance curve shape and a decrease of the peak frequency (see figure 4), when the force level is high.

For each frequency, the level of the force, Fe_L, leading to the elastic limit was calculated, the minimum value is obtained for the resonance frequency. In a similar way, the maximum force, Fp, leading to the wall collapse was determined by nonlinear calculations.

The evolution of the maximum forces, Fe_L and Fp, in function of the frequency is represented on figure 5. The forces have a minimum value which is obtained for the resonance frequency, f_o = 41 Hz, in the linear calculation and for a lower frequency , $\tilde{f}_o$ = 30 Hz, in the nonlinear one.

In addition, one can notice the influence of the duration of the excitation by comparison of the load giving the collapse in 40 cycles and in 5 cycles.

The margin introduced by the ductility effect on the dynamic behavior can be interpreted as the ratio Fp/Fe_L which is presented on figure 6. This margin is equal to 1 for low frequencies forces and close to the ductility factor for high frequency forces (this case is close to imposed displacement condition). But the margin is much greater near the resonance frequency.

If the amplitude of the force is not constant, but has a linear variation, the margin is modified for high frequency forces and remains important near the natural frequency.

White Noise Excitation

An explanation of the discrepancy between the margin curve and the known curve (ratio of the elastic spectra to the inelastic one) (Newmark, 1975 ; Lemasson, 1986) could be the time history variation of the input.

So it seems interesting to take a signal with better similarities to seismic signals. The study was then restarted with a signal which is a filtered white noise. The bandwidth of the filter is narrow (5 Hz) and constant for all frequencies of the filter. For each filter 10 various white noise were studied.

The margin (see figure 7) depends strongly on the time history ; near the resonance frequency, it varies from 9 to 18. But the shape of the average curve is similar to the sinusoidal excitation one.

CONCLUSION

The dynamic behavior of shear walls depends strongly on the nonlinearity and of the time history of the input force. The inelastic spectrum methods underestimate the margin given by the ductility for narrow band excitation centred on the natural frequency of the wall.

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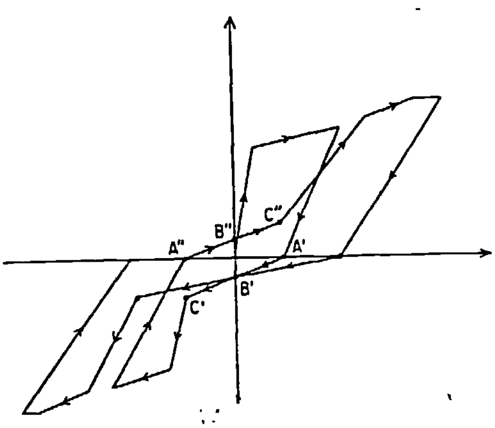


Fig. 1 - Hysteresis curves

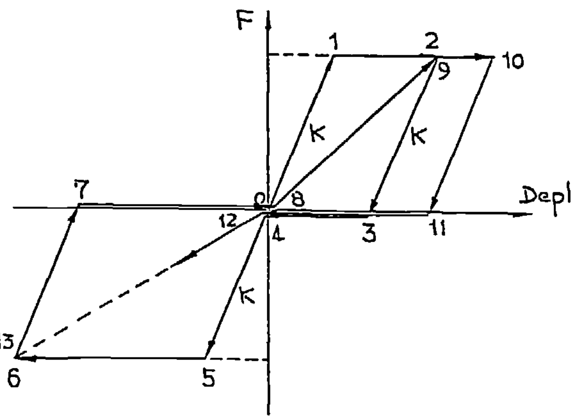


Fig. 2 - Modified Takeda model

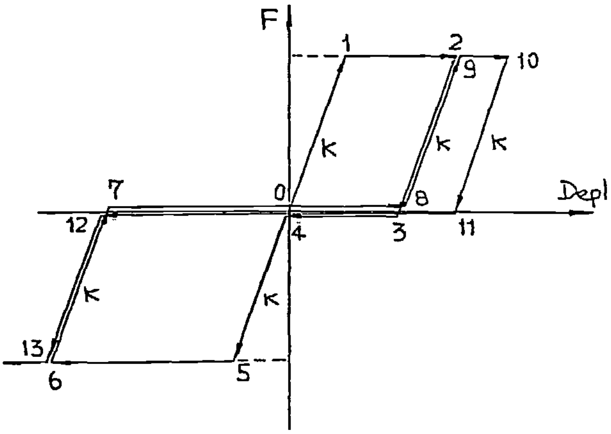
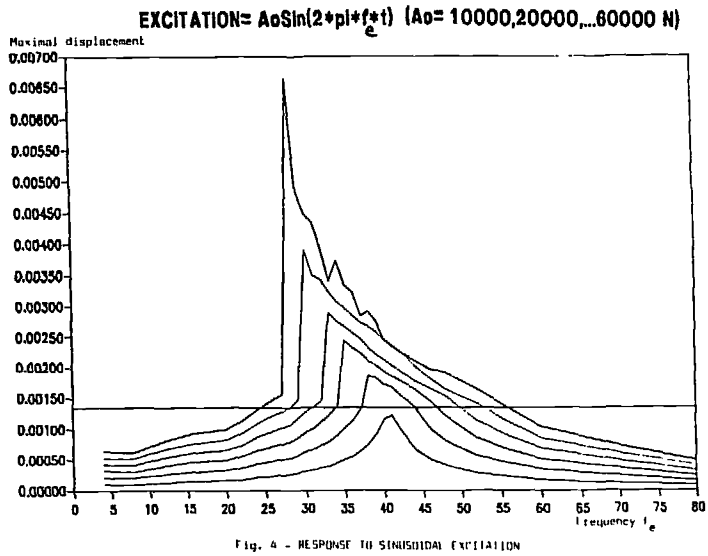


Fig. 3 - Sliding model

Fig. 4 - Response to sinusoïdal excitation



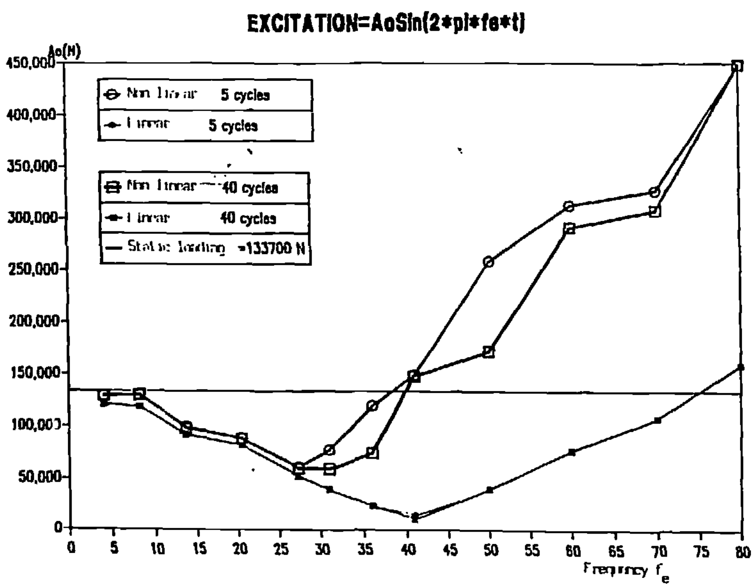


Fig. 5 - Acceleration inducing collapse

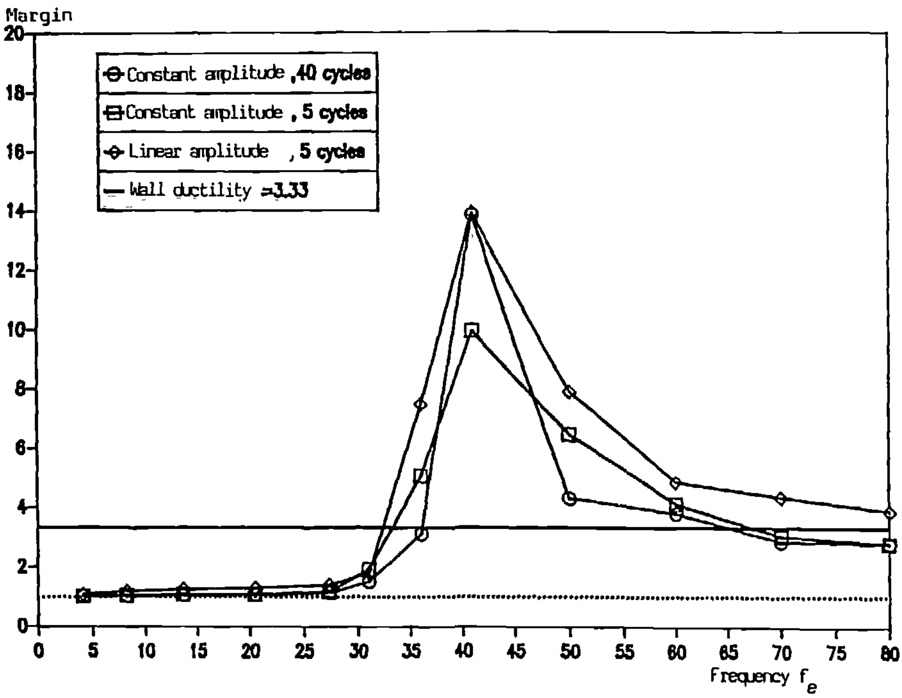


Fig. 6 - Margin

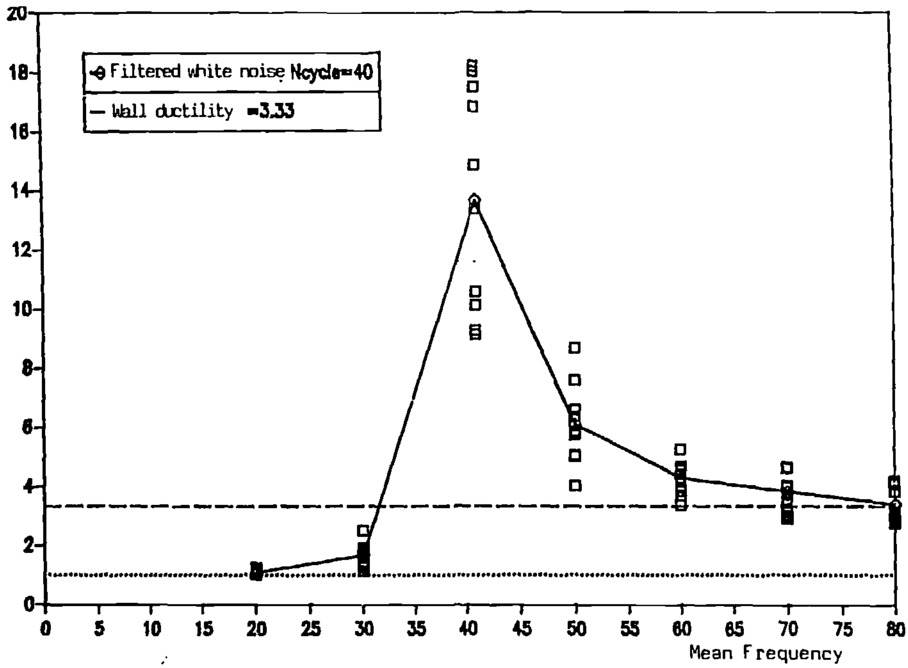


Fig. 7 - Margin (filtered white noise)