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SIMPLIFIED NON-LINEAR ANALYSIS OF BASE ISOLATED BUILDING

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ABSTRACT

A simple yet accurate non-linear analysis of base isolated building with laminated rubber bearing (LRB), subjected to earthquake excitation is presented in this paper. Simulation of experimental horizontal shear force-displacement hysteresis loops of LRBs are carried out and parameters governing the behaviour of LRBs are identified. An efficient solution algorithm, which takes into account the non-linear behaviour of LRBs, is developed for computation of response of base isolated building. It is observed that simulated hysteresis loops are in close agreement with experimental hysteresis loops and also, the response of base isolated building obtained from simple analysis presented in this paper are accurate and useful for practical design use.

KEYWORDS

Base Isolation, LRB, Hysteresis Loop, Simulation, Non-linear Analysis

INTRODUCTION

Seismic base isolation of building has attracted considerable attention in recent years and number of base isolation system have been patented or proposed. Among the isolation systems that gained acceptance for practical implementation, the most common one is the LRB.

In this study, hysteretic force in the LRB was computed from modified hysteretic model based on expression proposed by **Wen(1980)**. An efficient solution algorithm has been developed for computation of the response of base isolated building subjected to earthquake excitation. This solution algorithm is based on Newmark's method. The force mobilized in the non-linear elements of the isolation system is computed from close form solution of differential equation of hysteretic model and this made the solution algorithm simple and computationally efficient.

NON-LINEAR HYSTERETIC MODEL OF LRB

Hysteretic component of restoring force developed in LRB is expressed as:

$$f = (1-\alpha)\, Y\, k_e\, z \tag{1}$$

Where, k_e is the pre yielding stiffness of LRB, Y is yield displacement of the bearing, α is the ratio of post yielding to pre yielding stiffnesses and z is hysteretic dimensionless constant. In addition to this, non-hysteretic component of stiffness provided by rubber/elastomer has also been taken into account.

The hysteretic constant z can be calculated from the following equation **[Wen(1976)]**:

$$Yz + \gamma\, |\dot{u}_b\, z|\, z + \beta\, \dot{u}_b\, z^2 - A\, \dot{u}_b = 0 \tag{2}$$

Where, γ, β and A are the dimensionless constant which govern the general shape of the hysteresis loop and Y represents a displacement quantity. u_b is the bearing displacement. It has been shown that when A = 1 and $\gamma+\beta = 1$, the model of Eqn.(2) reduces to a model of visco-plasticity and in this case Y represents the yield displacement.

Considering the signs of $\dot{u}_b$ and z in Eqn.(2) are the same, the equation simplifies to the following form:

$$\frac{dz}{dt} + z^2 \left[\frac{\dot{u}_b}{Y} \right] - \frac{\dot{u}_b}{Y} = 0 \tag{3}$$

The explicit solution of the Eqn.(3) is given in close form as:

$$z = \tanh \left[\frac{\dot{u}_b}{Y} \right] \tag{4}$$

EQUATIONS OF MOTION

The floor and basement slab of the building are assumed to be infinitely rigid in plane. The superstructure is idealized as an elastic lumped mass model with one lateral degree of freedom at each floor level. The responses of three storeyed framed building isolated by LRB and subjected to Koyna earthquake (1967) - longitudinal component are computed.

The governing equations of motion of elastic superstructure for lumped mass model are expressed as:

$$\mathbf{M}\,\ddot{\mathbf{u}} + \mathbf{C}\,\dot{\mathbf{u}} + \mathbf{K}\,\mathbf{u} = -\,\mathbf{M}\,\mathbf{r}\,(\ddot{u}_g + \ddot{u}_b) \tag{5}$$

Where, **M**, **C** and **K** are mass matrix, damping matrix and stiffness matrix respectively of size nxn of the superstructure, n is the number of floors, **r** is the vector of size nx1 of earthquake influence coefficient. Here, $\ddot{\mathbf{u}}$, $\dot{\mathbf{u}}$ and $\mathbf{u}$ represent respectively the floor acceleration, velocity and displacement vectors (nx1) relative to the base.

The equation of motion of basement supported over LRB isolation systems are given as:

$$m_t\,\ddot{u}_b + c_b\,\dot{u}_b + k_b\,u_b + f = -\,m_t\,\ddot{u}_g - \mathbf{r}^T\,\mathbf{M}\,\ddot{\mathbf{u}} \tag{6}$$

Where, m_t is the total mass of the isolated system, c_b is the damping coefficient of viscous isolation elements, k_b is the stiffness coefficient of non-hysteretic part of isolation bearings and f is the hysteretic part of the restoring force of isolation system. $\ddot{u}_b$, $\dot{u}_b$ and u_b represent respectively the base acceleration, velocity and displacement relative to the ground.

The implicit-implicit partitioned Newmark's method in predictor - corrector form is used for direct integration of individual coupled equations of motion in staggered fashion. The solution of differential equation governing the behaviour of non-linear isolation elements, are obtained from close form solution as per Eqn.(4).

RESULTS AND DISCUSSION

For simulation of hysteretic behaviour of LRB, the ratio of post yielding stiffness to pre yielding stiffness α of the order of 0.25 to 0.4 and the ratio of maximum bearing displacement and yield displacement (d_r) in the bearing of the order of 5 to 7 are found to be appropriate. Experimental and simulated hysteresis loops of the model LRB obtained in the present study are shown in Fig.1. The value of α and d_r are considered to be 0.33 and 6 respectively for simulation of hysteretic behaviour. Figure 2 shows hysteresis loops for LRB with lead core obtained by **Robinson** *et al.* **(1982)** and the simulated loop.

Figure 3 shows the response of a three storeyed base isolated symmetrical framed building having total weight of 2225 kN, subjected to Koyna earthquake (1967) - longitudinal component with peak ground acceleration of 0.63g. The Koyna accelerogram had most of their frequency content between 2.5 Hz to 8.5 Hz. The natural frequency of the structure (fixed base) are as ω_1 = 20.62 rad/sec, ω_2 = 57.08 rad/sec and ω_3 = 87.07 rad/sec. The properties of LRBs are: the pre yielding stiffness = 6.675 kN/mm, the post yielding stiffness = 2.225 kN/mm and the ratio of maximum displacement to yield displacement of the bearing was considered as 6. Figure 3 shows relative base displacement history, absolute roof acceleration history and Fourier amplitude spectra of roof acceleration of the isolated structure.

The simple non-linear analysis of base isolated building subjected to unidirectional ground motion can be easily extended for the cases of general plane motion caused due to asymmetry in the structure and/or due to multidirectional excitation. Figure 4 shows the comparison of base displacement response of the structure isolated by LRBs, in both X and Y directions, obtained in the present study and that obtained by **Nagarajaiah** *et al.* **(1991)**. The details of the structure considered in the analysis are: Eccentricities $e_x = e_y = 0.1L$. The uncoupled translational period and the uncoupled torsional period in both direction are considered as 0.3 sec. Damping ratio of 0.02 of critical was used for the superstructure in all modes. The properties of bearings were: the pre yielding stiffness = 3.12 kN/m, the post yielding stiffness = 0.48 kN/m and yield strength = 19.36 kN. The ground motion considered was normalized El-Centro earthquake (1940) accelerograms.

CONCLUDING REMARKS

Simulated horizontal shear force-displacement hysteresis loops of LRBs are in close agreement with experimental hysteresis loops.

Simple non-linear analysis based on simulation of hysteretic behaviour of LRB can be used to compute efficiently the response of buildings isolated by LRB.

Non-linear analysis presented in the paper can be extended for the cases of general plane motion caused due to asymmetry in the structure and/or due to multidirectional excitation. It is observed that the response obtained from the analysis presented in this paper are in good agreement with that obtained from other numerical studies reported in the literature.

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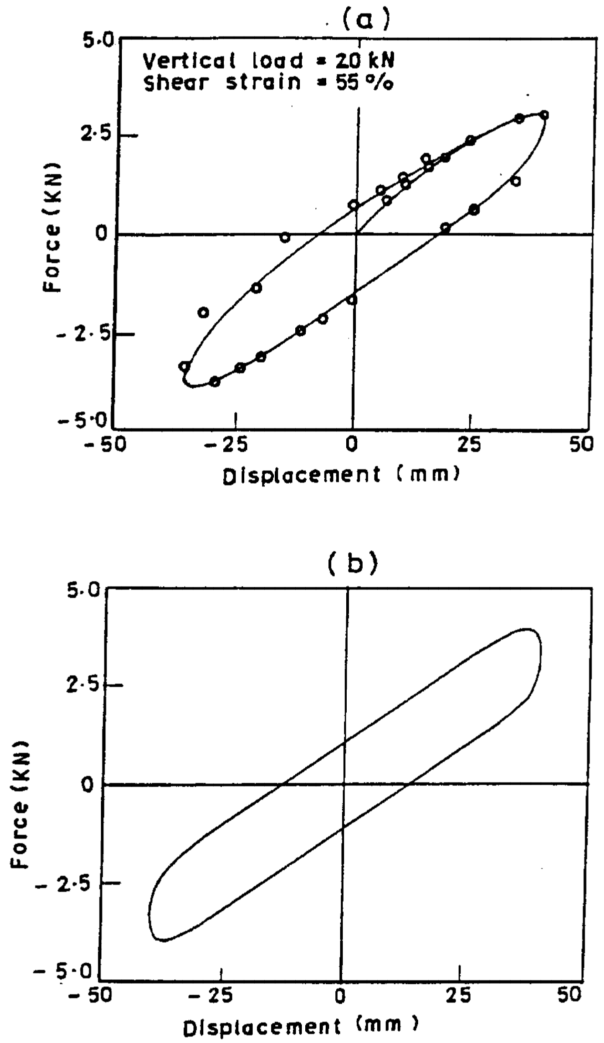


Fig. 1 Shear Force-Displacement Characteristics for Laminated Rubber Bearing Model: (a) Experimental and (b) Simulated

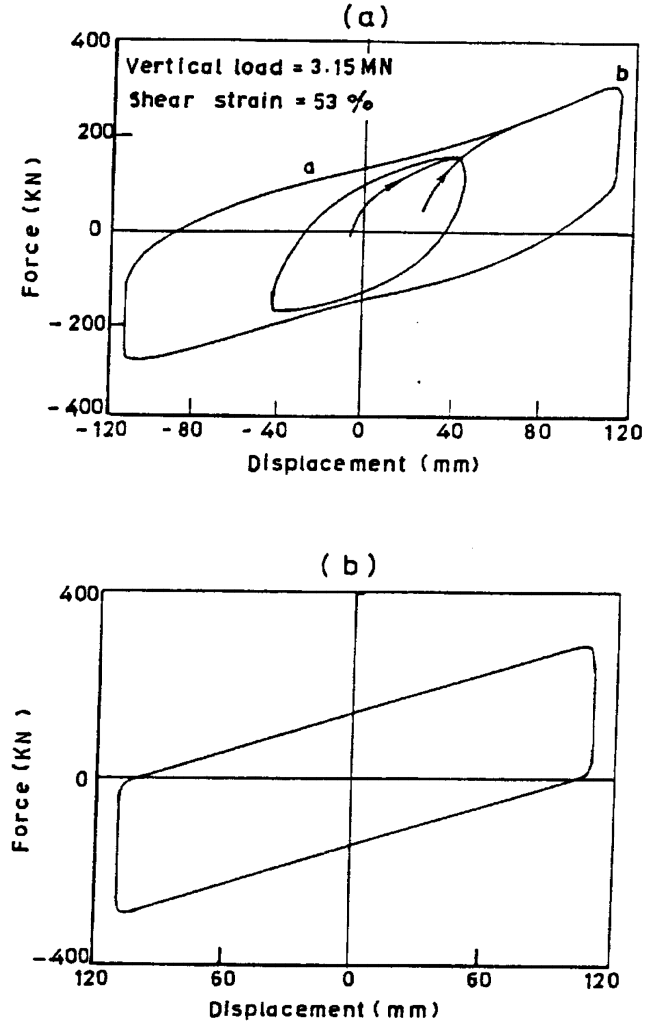
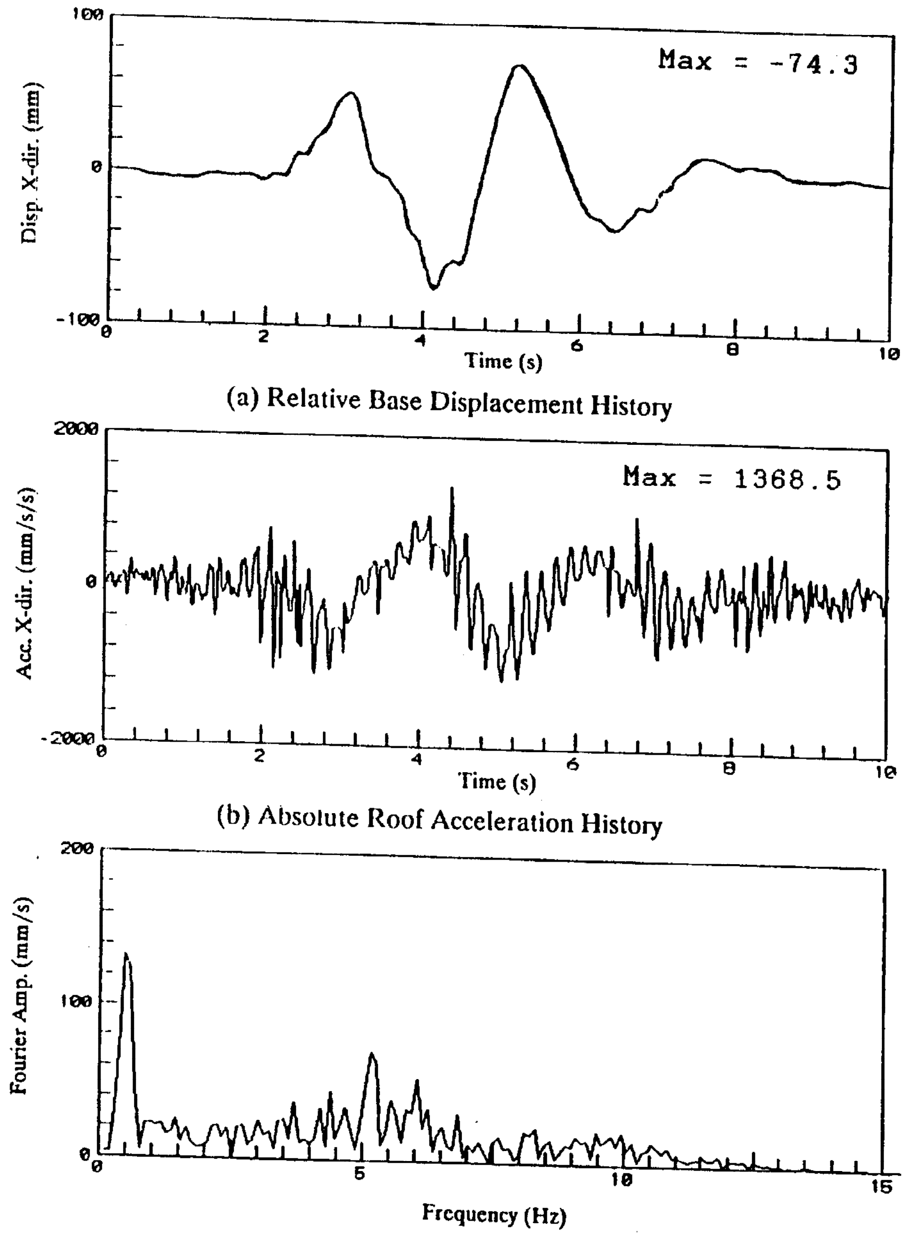


Fig. 2 Shear Force-Displacement Characteristics for Lead Rubber Bearing: (a) Experimental [Robinson (1982)] and (b) Simulated



(a) Relative Base Displacement History

(b) Absolute Roof Acceleration History

(c) Fourier Amplitude Spectra of Roof Acceleration

Fig. 3 Response of Structure Isolated by LRB System
Subjected to unidirectional Koyna (L) Motion

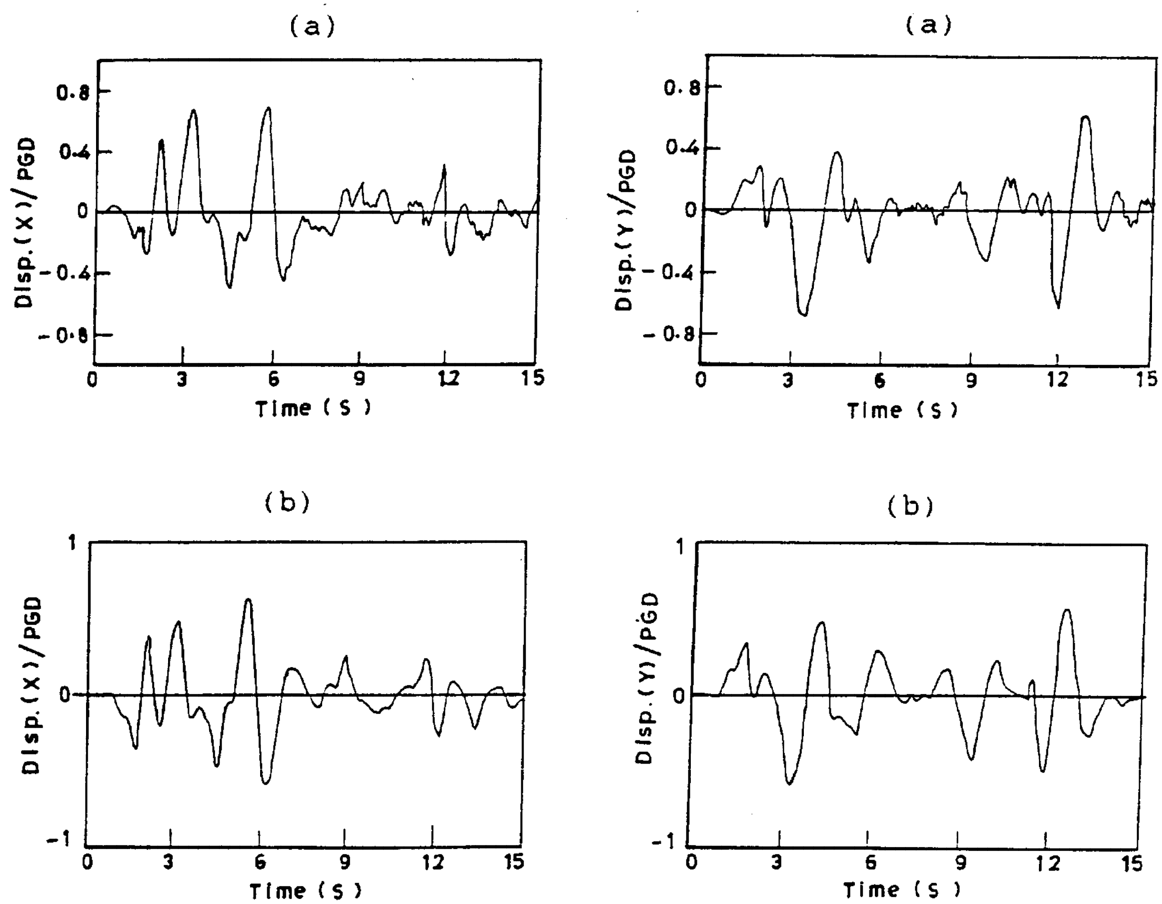


Fig. 4 Displacement Time History in X and Y-dir of a One Storey Asymmmetric Frame Isolated by Lead Rubber Bearing: (a) Nagarajaiah et al.(1991) and (b) Present Study