PARAMETRIC STUDY OF NONLINEAR INERTIAL COUPLING EFFECTS IN ASYMMETRIC BASE-ISOLATED STRUCTURES

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It is well proved that seismic base isolation systems as passive control tools of structure reduce the earthquake forces. On the other hand, structures are often built in irregular plan where lead to much more damages by earthquake forces. So the present research covers study of dynamic interaction of asymmetric base-isolated structures in new point of view. In this paper, the motion equations are presented in two coordinates, one fixed on the building base (inertial or global coordinate) and the other on the torsional isolation level (local coordinate).

In the conventional approach, the motion equations are calculated on linear form in the inertial coordinate system, whereas in the new approach proposed in this research, motion mechanics analysis in the secondary coordinate system will lead to non-linear equations. Eqs. (1)-(6) describe the motion of the structure and base floors masses in local coordinate by three degrees of freedom for each of them: displacement in the X-direction, displacement in the Y-direction, and torsional rotation of the floor about the vertical axis Z through the center of mass.

$$m_b\ddot{u}^b_{xb}+\left(c_{xb}+c_{xs}\right)\dot{u}^b_{xb}+\left(k_{xb}+k_{xs}\right)u^b_{xb}-c_{xs}\dot{u}^b_{xs}-k_{xs}u^b_{xs}=$$
$$-m_b\left(-2\dot{u}^b_{yb}\dot{u}_{\theta b}-u^b_{yb}\ddot{u}_{\theta b}-u^b_{xb}\dot{u}^2_{\theta b}+\ddot{u}_{gX}\cos\theta_b+\ddot{u}_{gY}\sin\theta_b\right) \tag{1}$$

$$m_b r_b^2\ddot{u}_{\theta b}+\left(c_{\theta b}+c_{\theta s}\right)\dot{u}_{\theta b}+\left(k_{\theta Rb}+e^2{}_{xb}k_{yb}+k_{\theta Rs}+e^2{}_{xs}k_{ys}\right)u_{\theta b}+$$
$$\left(e_{xb}c_{yb}+e_{xs}c_{ys}\right)\dot{u}^b_{yb}-e_{xs}c_{ys}\dot{u}^b_{ys}-c_{\theta s}\dot{u}_{\theta s}+\left(e_{xb}k_{yb}+e_{xs}k_{ys}\right)u^b_{yb}-e_{xs}k_{ys}u^b_{ys}-\left(k_{\theta Rs}+e^2{}_{xs}k_{ys}\right)u_{\theta s}=0 \tag{2}$$

$$m_b\ddot{u}^b_{yb}+\left(c_{yb}+c_{ys}\right)\dot{u}^b_{yb}+\left(k_{yb}+k_{ys}\right)u^b_{yb}+\left(e_{xb}c_{yb}+e_{xs}c_{ys}\right)\dot{u}_{\theta b}-c_{ys}\dot{u}^b_{ys}-e_{xs}c_{ys}\dot{u}_{\theta s}+$$
$$\left(e_{xb}k_{yb}+e_{xs}k_{ys}\right)u_{\theta b}-k_{ys}u^b_{ys}-e_{xs}k_{ys}u_{\theta s}=-m_b\left(2\dot{u}^b_{xb}\dot{u}_{\theta b}+u^b_{xb}\ddot{u}_{\theta b}-u^b_{yb}\dot{u}^2_{\theta b}-\ddot{u}_{gX}\sin\theta_b+\ddot{u}_{gY}\cos\theta_b\right) \tag{3}$$

$$m_s\ddot{u}^b_{xs}+c_{xs}\dot{u}^b_{xs}+k_{xs}u^b_{xs}-c_{xs}\dot{u}^b_{xb}-k_{xs}u^b_{xb}=-m_s\left(-2\dot{u}^b_{ys}\dot{u}_{\theta b}-u^b_{ys}\ddot{u}_{\theta b}-u^b_{xs}\dot{u}^2_{\theta b}+\ddot{u}_{gX}\cos\theta_b+\ddot{u}_{gY}\sin\theta_b\right) \tag{4}$$

$$m_s r_s^2\ddot{u}_{\theta s}+c_{\theta s}\dot{u}_{\theta s}+\left(k_{\theta Rs}+e^2{}_{xs}k_{ys}\right)u_{\theta s}-e_{xs}c_{ys}\dot{u}^b_{yb}-c_{\theta s}\dot{u}_{\theta b}+e_{xs}c_{ys}\dot{u}^b_{ys}-$$
$$e_{xs}k_{ys}u^b_{yb}-\left(k_{\theta Rs}+e^2{}_{xs}k_{ys}\right)u_{\theta b}+e_{xs}k_{ys}u^b_{ys}=0 \tag{5}$$

$$m_s\ddot{u}^b_{ys}+c_{ys}\dot{u}^b_{ys}+k_{ys}u^b_{ys}-c_{ys}\dot{u}^b_{yb}-e_{xs}c_{ys}\dot{u}_{\theta b}+e_{xs}c_{ys}\dot{u}_{\theta s}-k_{ys}u^b_{yb}-e_{xs}k_{ys}u_{\theta b}+e_{xs}k_{ys}u_{\theta s}=$$
$$-m_s\left(2\dot{u}^b_{xs}\dot{u}^2_{\theta b}+u^b_{xs}\ddot{u}_{\theta b}-u^b_{ys}\dot{u}^2_{\theta b}-\ddot{u}_{gX}\sin\theta_b+\ddot{u}_{gY}\cos\theta_b\right) \tag{6}$$

Two types of structures are proposed with ratio of torsional-lateral correlated natural frequency on asymmetric natural frequency. Properties of these structures are shown in Table 1.

Table 1. Properties of three types of structures

Type No.	Ω_{xb}	$\Omega_{\theta b}$	Ω_{yb}	Ω_{xs}	$\Omega_{\theta s}$	Ω_{ys}	e_{xb}/r	e_{xs}/r	Ω_1	Ω_2
1	0.1	0.15	0.1	1	0.7	0.5	0.6	0.2	0.863	1.552
2	0.1	0.105	0.1	1	0.7	0.5	0.8	0.2	0.500	1.334

Responses of both linear and nonlinear models for the two types of structures under harmonic effects are compared while analyzing time history and frequency. In structure type 1, the responses of linear and nonlinear models are exactly the same. However, some differences are observed between two models in structure type 2 (Figure 1).

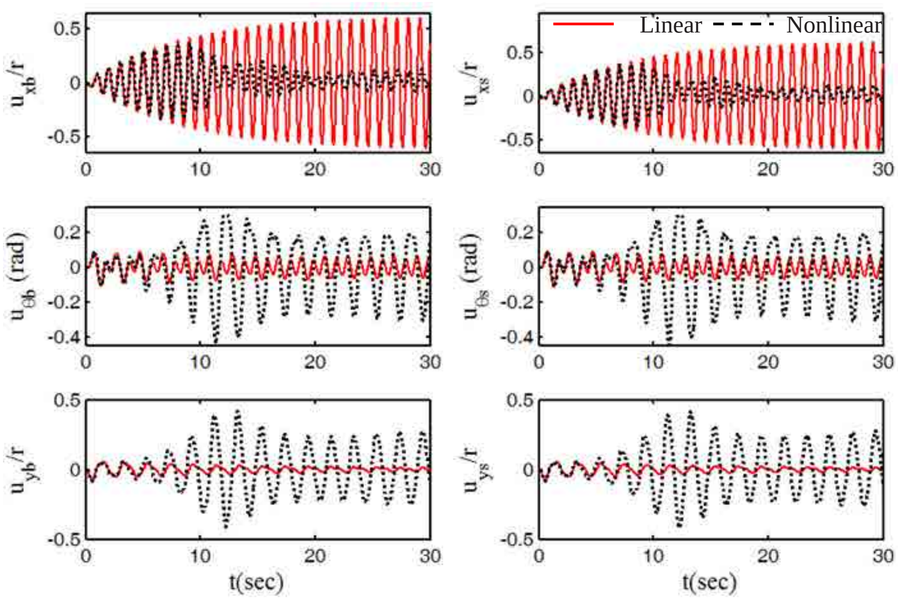

Figure 1. Time history for structure type 2 under harmonic force

Then, some non-linear phenomena such as saturation and energy transfer between modes in such structures can be observed. In figure 1, the energy of nonlinear responses in X direction saturates and then transfers to another directions (y and θ). This behavior is called saturation phenomenon and caused by existence of nonlinear inertial coupling terms in Eqs. (1)-(6).

Finally, historical and frequency response peaks of linear and nonlinear models under earthquake excitation are compared with variations of base torsional natural frequency in different directions ($\Omega_{\theta b}$). It can be inferred from the results of analysis, that nonlinear responses can be more critical than linear ones, and design prescriptions should be adapted to the nonlinear model.

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