SEISMIC DUCTILITY DEMANDS OF ROCKING STRUCTURES UNDER PULSE-LIKE GROUND MOTIONS

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This paper provides the seismic ductility demand of rocking structures behave nonlinearity and subjected to near field pulse like ground motions. For doing this, first the interaction of nonlinear behaviour of structure and foundation uplift is evaluated using differential equations of motion, parametrically. After that, the seismic structural ductility demands are presented in forms of colourful contours as function of dimensionless parameters for a variety range of structures.

Since being introduced, many attempts have been made to detect the advantages and disadvantages of the rocking isolation idea in a wide range of structures especially bridges. Psycharis (1991) introduced the ratio of dominant frequency of the pulse to the fundamental frequency of structure as a very important factor to estimate the demands of the rocking flexible structures. Ghannad and Jafarieh (2014) evaluated the effect of footing uplift on seismic demands of the inelastic structures. Khanmohammadi and Mohsenzadeh (2018) provided a relationship to calculate displacement amplification factor as the uplift permitted structures with nonlinear behaviour imposed to near-field records.

In spite of these studies, some of the important issues are yet to be resolve, particularly, that the structure has inelastic behaviour. Here, for instance, some of them are listed as follows:

a) The effect pulse parameters on the ductility is an unknown problem in rocking inelastic structures.
b) The level that the ductility of structure is affected by footing uplift, comparing to the ductility of fixed base systems under the same base excitation.
c) Rocking motion of structures on stiff soil (or shallow footing with the factor of safety against vertical loads greater than 5 is very associated with after-impact velocity that this can be hardly modelled realistically by common finite element software. Hence, use of exact differential equations of motion for the nonlinear structures rocking on such surfaces is essential.

Vassiliou et al. (2015) has recently provided a revision to traditional differential equations of motion for flexible structures rocking on rigid surface. In these equations, it is assumed that the structural deformations is elastic. In this paper, the equations presented by Vassiliou et al. (2015) are manipulated and rewritten for structures with inelastic behaviour in which the force-deformation curve is as a bilinear.

The structural modelling related to rocking motion of bridges has been shown in Figure 1. The model consists of a deformable rocking column with a uniform mass m_c, and a mass, m, at top of the column supported by a rigid massless footing having mass m_b and mass moment of inertia I_b.

The column is as high as h and the base is also as long as $2B$. It is assumed that the thickness of the base is negligible comparing with the height. The slenderness parameter, α, therefore, can be computed by $\alpha = \tan^{-1}(B/h)$. The parameters u and θ are displacement of the mass and base rotation, respectively. The nonlinear behaviour of structure is caused by a concentrated plastic hinge located at top of the base according to figure by which a symmetric bilinear spring is modelled.

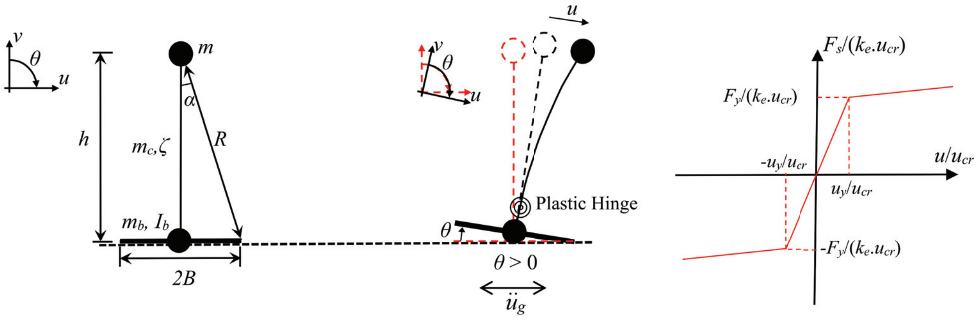

Figure 1. Structural modelling of rocking nonlinear structures.

The important parameter in rocking structures is the elastic deformation of the structure as footing uplifts statically (Vassiliou et al., 2015):

$$u_{\mathrm{cr}} = \frac{\left(m+m_{\mathrm{b}}+m_{\mathrm{c}}\right)Bg}{\left(m+\frac{11}{40}m_{\mathrm{c}}\right)H\omega_{\mathrm{n}}^{2}+\left(\frac{3}{8}m_{\mathrm{c}}+m\right)g} \tag{1}$$

Using this the nonlinear spring properties are normalized. Furthermore, another parameter, k_{e}, is initial stiffness of structure, evaluated by $F_{\mathrm{y}}/u_{\mathrm{y}}$. In above equation, the fundamental structural frequency is defined as (Vassiliou et al., 2015):

$$\omega_{\mathrm{n}} = \sqrt{\frac{k_{\mathrm{e}}}{\left(m+\frac{33}{140}m_{\mathrm{c}}\right)}} \tag{2}$$

Moreover, the normalized ductility demand are defined as the ratio of the maximum ductility demand experienced by rocking system, μ_{mu}, to that of fixed base counterpart, μ_{mf}, herein.

The results indicate that, analogous to the elastic rocking structures, most important factors in estimating ductility demand of structures allowed to uplift are ratio of predominant period of pulse, to the structural natural period (or $T_{\mathrm{p}}/T_{\mathrm{n}}$), the ratio of the yield displacement to the critical displacement (or $u_{\mathrm{y}}/u_{\mathrm{cr}}$) and the slenderness parameters, α.

In the slender models, the normalized ductility demand are decreased as the ratio of $T_{\mathrm{p}}/T_{\mathrm{n}}$ is greater than 1 so that the ratios of $\mu_{\mathrm{mu}}/\mu_{\mathrm{mf}}$ are equal around to 0.25 in some cases where the period ratio takes the values 2.5, approximately. As a consequence, these structures can usually get the benefits of the foundation uplift. By contrast to slender models, the normalized ductility of the models with large α are less affected by uplift, enhancing the ratio of $T_{\mathrm{p}}/T_{\mathrm{n}}$. Nonetheless, these types are highly sensitive to the ratio of $u_{\mathrm{y}}/u_{\mathrm{cr}}$. Increasing slightly this ratio to 1.5, amounts of μ_{mu} can exceeds the maximum ductility demand in the corresponding fixed base models.

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