



Seismic response of low-rise steel moment-resisting frame (SMRF) buildings incorporating nonlinear soil–structure interaction (SSI)

Prishati Raychowdhury*

Department of Civil Engineering, Indian Institute of Technology Kanpur, UP 208016, India

ARTICLE INFO

Article history:

Received 6 September 2009
Received in revised form
22 April 2010
Accepted 9 December 2010
Available online 19 January 2011

Keywords:

Soil–structure interaction
Nonlinear modeling
Seismic response
Shallow foundations

ABSTRACT

Nonlinear behavior at the soil–foundation interface due to mobilization of the ultimate capacity and the associated energy dissipation, particularly in an intense earthquake event, may be utilized to reduce the force and ductility demands of a structure, provided that the potential consequences such as excessive settlement are tackled carefully. This study focuses on modeling this nonlinear soil–structure interaction behavior through a beam-on-nonlinear-Winkler-foundation (BNWF) approach. The results are compared with those from fixed-base and elastic-base models. It is observed that the force and displacement demands are reduced significantly when the foundation nonlinearity is accounted for. Moreover, the foundation compliance is also found to have a significant effect on the structural response.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

It is well recognized that the nonlinear behavior of a soil–foundation interface due to mobilization of the ultimate capacity and the consequent energy dissipation during a seismic event may be utilized to reduce the force and ductility demands of a structure. However, current design practice does not account for the nonlinear behavior of soil–foundation interface primarily due to the absence of reliable nonlinear soil–structure interaction (SSI) modeling techniques that can predict the permanent and cyclic deformations of the foundation as well as the effect of foundation nonlinearity on the response of structural members.

SSI may affect the response of a structure in several ways. Namely, foundation movement can alter the period of a system with introducing flexibility; nonlinear behavior and hysteretic energy dissipation may reduce the force demand to the structure; and the foundation flexibility may alter the input ground motion. However, it is not uncommon to date to completely ignore the effect of SSI while designing a structure, assuming that incorporation of SSI generally leads to a conservative design. For buildings with high periods, the effect of foundation movements may not be very significant. But for relatively stiffer structural systems, such as medium-height shear walls and braced frames, the foundation movements can cause significant flexibility in the system, and may result in an inaccurate estimation of the seismic demands [1]. Also, the strength and stiffness characteristics of the

underlying soil controls the foundation movements and the SSI effects on the structure significantly. It is also recognized that the effects of SSI on the structural response is dependent on the dead and live loads on the foundation. If the existing loads are over 50–67%, the foundations have potential for large displacements, causing a greater effect on the superstructure response [2].

Performance-based earthquake engineering encourages the incorporation of foundation nonlinearity and energy dissipation capabilities to reduce the structural force demand. According to ATC 40 [2], “stiff and strong” foundations are not always better than “flexible and weak” foundations (Fig. 1). Design and rehabilitation provisions (e.g., [2–5]) have traditionally focused on simplified pseudo-static force-based or pushover-type procedures, in which the soil–foundation interface is characterized in terms of modified stiffness and damping characteristics. However, the above-mentioned approaches are not able to capture the complex behavior of nonlinear soil–foundation–structure systems, such as hysteretic and radiation damping, gap formation in the soil–foundation interface and estimation of transient and permanent settlement.

Numerous studies have been conducted in the past to understand the behavior of structures supported on shallow foundations. Some of the studies have modeled the soil–foundation interface as a system of closely spaced springs [6–15]. For example, Chopra and Yim [6] and Yim and Chopra [7] used nonlinear elastic–plastic Winkler springs to model the behavior of shallow foundations and observed the reduction in moment demand of the structure when SSI is incorporated. Nakaki and Hart [8] used elastic, no-tension Winkler springs with viscous dampers to model the response of an inelastic shearwall, and found that the ductility demands were

* Tel.: +91 512 259 6692; fax: +91 512 259 7395.

E-mail addresses: prishati@iitk.ac.in, prishati@gmail.com.