SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

INTEGRATED SEISMIC DESIGN AND ASSESSEMENT OF FOUNDATION AND SUPERSTRUCTURE

Roberto PAOLUCCI[1] and Alain PECKER [2]

Recognition that the increase of strength of a structural system does not necessarily increase its safety and performance during earthquakes has led to the development of the capacity design philosophy. However, while this philosophy is widely implemented in structural seismic design, it is given less attention in geotechnical engineering.

As a matter of fact, the capability of the foundation to dissipate energy during seismic loading is generally neglected in seismic design and in most cases is explicitly avoided by the requirement that the foundation should resist the action effects resulting from the response of the superstructure, without substantial permanent deformations. This means that foundations are generally designed to behave in the linear range, with very limited non-linear response, if any. This is generally accomplished by verifying that under the design shear force and overturning moment, in addition to the vertical load, the bearing capacity of the foundation be not exceeded.

The main practical reason behind this requirement is that the foundation cannot be easily inspected and repaired after an earthquake. However, this conservative approach may have several important drawbacks, mainly related to the following considerations:

a. spectral ordinates of recorded accelerograms during moderate-to-strong earthquakes are often in excess of design spectra and a temporary mobilization of the bearing capacity of the foundation is unavoidable, with the corresponding development of permanent settlements and rotations;
b. the elastic requirement for seismic design may lead to uneconomic oversized foundations;
c. foundation retrofitting of existing or damaged structures is practically impossible to be accomplished under the requirement of elastic behaviour.

The last item, i.e., the seismic assessment of foundations of existing buildings, poses specific problems in those cases, which are becoming more and more frequent in the engineering practice, where the foundation system is assessed under seismic actions larger, or much larger, than those considered for design. The decision to retrofit the foundation system for the sole reason that it has attained its bearing capacity under the increased seismic load may be too simplistic and over-precautionary. As a matter of fact, many recent research works, both analytical and experimental [Anastasoupoulos et al., 2013; Deng et al., 2012; Paolucci et al., 2013; Pecker et al., 2014], have clearly highlighted that the foundation system may undergo significant excursions in the ductile range with several additional positive features for the overall behaviour of the structure: 1) under rocking response, which is the prevailing one for shallow foundations, the system tends to naturally be re-centred, since at its maximum rocking in one direction the foundation is typically subjected to an overturning moment in the opposite direction; this means that the permanent rocking of the foundation is generally of limited amount; 2) such non-linear behaviour at the base induces a substantial

[1] Professor, Dept. of Civil and Environmental Engineering, Politecnico di Milano, P.za L. da Vinci 32, Milano, Italy
[2] Géodynamique et Structure, 157 rue des Blains, 92220 Bagneux, France; Professor, Dept. of Civil Enginering, Ecole des Ponts ParisTech

dispersion of input energy, not only by radiation, as for the linear case, but for hysteresis as well; 3) the overall seismic demand on the superstructure is substantially reduced, and accounting for foundation non-linearity may provide less pessimistic, albeit realistic and more physically based, answers in terms of the seismic assessment.

Similar benefits may also be considered within an integrated seismic design of foundations and superstructures, provided that the non-linear dynamic interaction of those systems is adequately accounted for, with additional damping on the superstructure response and reduced ductility demand, partly absorbed by the foundation movement.

The vision of such an integrated seismic design and assessment of foundations and superstructures, based on the controlled share of ductility demand between the superstructure and the foundation, is supported by a long lasting theoretical research on the role of non-linear dynamic interaction on the seismic response of structures, and, more recently, by substantial experimental works, in Europe, Japan, and United States.

In this presentation, a summary of such research progress will be reviewed, together with some recent application examples of the role of non-linear foundation response on the assessment of existing structures. Finally, some recent examples where such concepts were introduced in performance-based seismic regulations, such as in the draft of ASCE 41-13, will be reviewed and discussed in view of a possible similar introduction within the new versions of Eurocode 8.

REFERENCES

Anastasopoulos, I., M., Loli, Georgarakos, T., Drosos, V. [2013]. Shaking table testing of rocking-isolated bridge pier on sand. *Journal of Earthquake Engineering*. 17: 1-32.

Deng, L., Kutter, B. L., Kunnath S. [2012]. Centrifuge modeling of bridge systems designed for rocking foundations. Journal of Geotechnical and Geoenvironmental Engineering, ASCE. 138: 335-344.

Paolucci, R., Figini, R., Petrini, L. [2013]. Introducing dynamic non-linear soil-foundation-structure interaction effects in displacement-based seismic design. *Earthquake Spectra*, 29: 475-496.

Pecker A., Paolucci R., Chatzigogos C., Correia A., Figini R. [2014] The role of non-linear dynamic soil-foundation interaction on the seismic response of structures. *Bulletin of Earthquake Engineering*, 12:1157-1176.