Non linear soil structure interaction: a requirement for performance based design of foundations

Alain PECKER

New developments in structural earthquake engineering are definitely directed towards performance based design approaches. In geotechnical earthquake engineering performance based design has, until recently, received little attention. Obviously the main reason is that the essential prerequisite to performance based design is a reliable estimation of the induced displacements. Any geotechnical engineer is aware of the difficulties in predicting foundation settlements because of the important variability of soil properties, even in a presumably homogeneous medium, and of the highly non linear behaviour of soils. These difficulties still hold for earthquake loading but they are aggravated by the strong interaction that exists between the inertia forces developed in the superstructure and the response of the foundation; this phenomenon is known as soil structure interaction (SSI). Since the early seventies, SSI has received a great deal of attention and seismic analyses taking into account SSI have become standard practice in earthquake engineering, at least for important structures. However SSI is restricted to linear phenomena and is used only to evaluate the structural inertia forces; it cannot give an estimate of residual displacements when the foundation starts to yield.

Several possibilities are offered to the designer to calculate the foundations displacements induced by severe earthquake loading. For instance several authors have proposed to retrieve the forces acting on the foundation, calculated in a preliminary analysis accounting for SSI effects, and to carry out a Newmark type of analysis assuming the a predetermined failure mechanism in the soil; obviously, although convincing results were obtained, the method suffers from several drawbacks, the most obvious one being the lack of consideration for the changes in the forces as the foundation yields. The second alternative would be to build a global finite element model in which the structure, its foundation and the supporting soil are modelled; this approach is very demanding in terms of man hours and computer time, highly dependent on the choice of the soil constitutive model and not very amenable to parametric studies required at a design stage. The method is more suited for final verifications than preliminary design.

All these methods will be briefly reviewed and a new 3D model for non linear soil structure interaction will be introduced. This model belongs to the class of dynamic macro element models that have emerged during the last decade since the pioneering work of Paolucci (1997), Pedretti (1998), Cremer-Pecker-Davenne (2001, 2002). It is build up on the original work by Cremer et al, has been extended to 3D circular foundations, is applicable to cohesive and cohesionless soils and has been considerably simplified, which makes it much more efficient from a numerical standpoint. All the details can be found in the PhD thesis of C.T. Chatzigogos (2007).

The objective of such a tool is to model the effects on the dynamic response of the superstructure of the soil-structure interaction non-linearities that arise at the foundation level. These include the development of permanent displacements/rotations at the foundation level as well as the seismic “isolation” offered to the structure by allowing uplifting of the foundation and soil yielding. The model couples the two separate sources of non-linearity at the foundation level: the first one is due to the irreversible elastoplastic soil response accounting for the material non-linearity in the system. For purely cohesive soils, to which the presentation will be restricted, an associated plasticity model is formulated belonging to the class of bounding surface hypoplastic models. The second source of nonlinearity, of geometric nature,
is due to the uplift that may arise at the soil-foundation interface. This is a desirable feature for earthquake design, since the uplift of the footing acts as a base isolation mechanism for the superstructure. A perfectly rough interface with zero tensile strength is considered implying that uplift of the footing constitutes a perfectly reversible and non-dissipative process. This allows describing the uplift mechanism within the macroelement with a phenomenological non-linear elastic model respecting its reversible and non-dissipative character. An original feature of the model is that each mechanism is modelled independently while the surface of ultimate loads of the system is obtained from the combined result of both mechanisms. This allows departing from the conventional assumption that the yield surface of the plasticity model is identified with the surface of ultimate loads of the system. The coupling between the two mechanisms is obtained in a straightforward way by letting the parameters of the uplift model be functions of the forces acting on the system which, in turn, enter in the formulation of the plasticity model.

The model has been qualitatively validated against results from centrifuge tests conducted on a footing subjected to quasi-static monotonic and cyclic loading. The response of the system is investigated under vertical, horizontal and rotational loading and the model parameters are calibrated to provide the best fit with respect to the experimental results. The performance of the model is also compared with respect to other available macroelement formulations; this allows highlighting its advantages and detecting the points where possible improvements could be proposed.

Finally, numerical results of a parametric analysis conducted on a simple superstructure will illustrate the capabilities of the model and highlight all the benefits that can been gained in earthquake engineering design by allowing foundation uplift and yielding in a severe seismic environment.

REFERENCES


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1 Géodynamique et Structure, Chairman & Managing Director, Email: alain.pecker@geodynamique.com