Effect of Foundation Type and Compliance on Seismic Response of RC Bridges

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Abstract: Foundation compliance appears to be one of the key features of the lateral load response of bridges, but it has not been seen so far as a possible solution to the problem of regularizing the response of bridges with piers of unequal height in such a way that a reasonably uniform ductility demand is achieved. The present study focuses on the effect of pile foundation stiffness on the lateral displacements and flexibility of the bridge as a whole as well as on the ductility demand of the pier itself. Conventional lumped plasticity beam models and 2D finite-element models are used for carrying out nonlinear static (pushover) analyses of alternative bridge superstructure systems. The results clearly indicate that the foundation type, the number of piles and their arrangement, and the adopted design approach affect the distribution of ductility demand. It is confirmed that control of the foundation stiffness may be a useful tool for improving the distribution of ductility demand and hence the overall performance of a bridge during strong ground motions.

INTRODUCTION

A particularly challenging problem is the seismic design of bridges supported on piers of unequal height, a commonly adopted solution when crossing steep-sided river valleys. In a case in which the cross sections of the piers are identical, the shorter piers resist a higher level of inertia forces than the taller piers. It may be shown that, unless the variation of the pier height is consistent with the fundamental mode shape of the bridge (in the transverse direction), the shorter piers are subjected to increased ductility demand and consequently damage tends to localize in these relatively stiffer piers. Therefore, it is of particular interest to investigate the feasibility of regularizing the yield displacements of the bridge piers in such a way that a uniform ductility demand be achieved.

Some practical measures have been proposed to remedy the previously described situation. Reduction of the short-pier section size obviously reduces the inertia forces attracted, but limits are imposed by the requirement of transferring the axial forces to the ground or by the modified dynamic characteristics of the structure or both. Furthermore, aesthetic considerations dictate that all bridge piers have the same size. On the other hand, stiffening or strengthening of the high demand piers leads to the opposite result, attraction of higher forces. Decreasing their flexibility is a feasible solution only if isolation devices are used to obtain the required ductility distribution. Isolation of short piers is often used in practice and enables the engineer to regularize the bridge's expected response by selecting the proper isolation/dissipation devices and their stiffnesses, yield strengths, and elongation capacities (Calvi and Pavese 1997). A different alternative is to investigate the feasibility of adjusting the pier heights to follow a half-sine wave spanning between two abutments while keeping the in-plane rotations free and restraining the vertical displacements. Finally, placing the shorter columns into structural sleeves intervenes directly with the height of the piers and may solve the problem in certain cases.

In case the methods targeting a uniform demand are impractical or undesirable, it has been proposed that, by accounting for the mass distribution of each pier, the potential of a sequential rather than simultaneous yielding of the piers must be investigated (Priestley et al. 1980). Foundation compliance is one of the key features of the lateral load response of a bridge structure and has long been the focus of research. Nevertheless, it has not been seen so far as a possible solution to the irregularity problem. Although Priestley et al. (1980) have long suggested that adjusting the flexibility of the supporting pile systems might result in improved distribution of ductility demands, no subsequent studies are known in this specific direction.

The main aim of this study is to examine the effect of the foundation type on the lateral stiffness of the bridge supporting system, which in turn defines the distribution of forces within the superstructure. The foundation type, number of piles, and design approach used for the foundation are addressed. An attempt is made to strike a balance between theoretically acceptable solutions and practical constraints. Therefore, the sensitivity analyses carried out for the salient features to be modeled were physically limited by the possible alternative foundation types that could be selected in a feasible design to safely transmit a given axial load to the ground. With the aid of inelastic analysis, the focus then turns to the critical regions of the foundation-pier system subjected to transverse excitation while investigating the modified ductility demand in the pier itself.

OVERVIEW OF STUDIED STRUCTURE

To facilitate comparisons with previous studies, the bridge structure described in the comparative bridge example (Park 1994) has been adopted as the reference structure of the present study. It is a nine-span structure, curved in plan at a radius of 200 m, with a total length of 244 m. Single columns of height varying from 6 to 15 m support a twin box-girder superstructure. The provided bearings allow rotation and longitudinal movement of the superstructure with respect to the cap beam and restrain lateral movement transverse to the bridge axis.

The pier with a height of 9 m was the focus of this study, but some consideration has also been given to the shortest (6-m) pier. In the comparative bridge example, the pier cylinder section had a diameter of 1.5 m and was reinforced with 48 Ø 32 bars while the transverse reinforcement was Ø12/70 mm for the bottom 20% of the pier height and Ø12/140 for the remainder of the height. The diameter of the RC piles was to be decided according to the foundation type and approach adopted. The total axial load on the 9-m-high column was 8,400 kN (not including pile and pile cap self-weight).

As far as the soil conditions were concerned, the site con-

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