Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Comparison of Time Period of Bridge under Rigid and Flexible Foundation

Suman Raj Regmi [a], Rajan Suwal [b]

[a] *Department of Earthquake Engineering, Thapathali Campus, IOE, Tribhuvan University, Nepal*
[v] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] sumanrgm@gmail.com [b] rajan_suwal@ioe.edu.np

Abstract
Bridges are, if not, the most important structural components of any highway system and they are expected to operate post-earthquake. The failure of bridges leads to the disturbance to the whole highway system and in the situations after earthquake in which relief materials and manpower needs to be catered to the most affected areas, which are often faraway from the places with abundant resources. The substructures of the bridges are designed for the most adverse combination of loadings as per the relevant codes. These codes incorporate the traditional force-based approach for the evaluation of seismic loadings and adopt capacity based design principles for the purpose of detailing catering to the deformation demands that can be expected during the design seismic events. In doing so, the designers often overlook the contribution of soil-structure interaction(SSI) which can affect the way the whole bridge structure i.e. structure, sub-structure, foundation and the soil mass combined, responds during the earthquakes. One of the governing parameters of a system for the dynamic response is the natural time period of the structure. This paper looks into how incorporation of SSI can affect the natural time period for a RC-bridge located in Kathmandu.

Keywords
RC-bridge, time-period, flexibility, foundation

1. Introduction

The seismic designing of bridges involves determination of forces as per the provisions in the design codes which employ the traditional force-based design approach. But, the irony to the approach being called force-based design approach is that the forces are not critical to the design process, obviously, because the design base shear obtained from the linear analysis is reduced by a factor owing to the ductility capacity and overstrength that can be given to the strucure. And, hence the substructures are detailed as per the capacity-based design principles and they need to undergo the required deformation as per the ductility factors taken for evaluating the response reduction factor recommended in the codes. These reduction factors are based upon the equal displacement principle [1].

When along with the response of the superstructure, the response substructure is also included into our model soil-structure interaction(SSI) is said to be modeled. For the model, we need a convincing model of dynamic properties of the substructure as well along with the soil mass surrounding the foundation. It is of high importance for alluvial deposits because the soil is often found to be of inferior strength and stiffness. The response of the superstructure excites the sub-structure and vice-versa. In light of the understanding developed over the years of incorporating the soil-structure interaction (SSI), which was previously considered to be advantageous for structures, owing to the fact that the incorporation of soil-structure interaction in the design process actually increases the degree-of-freedoms (dofs) of the whole structural system and, hence higher dispersion and dissipation of seismic energy in more mechanisms, has been qualified by the recent studies that the pier-top displacement demand actually increases during major seismic events [2, 3]. This leads to a conclusion that the soil underlying the structure can have a massive impact on the damage of the bridge components and hence, the components require extra attention for those situations. The instances of Hanshin highway destruction has been fluently covered in [4]. Also, the role of mutual response of soil and footing has been discussed in [5].

The performance of any structure can be qualified using its dynamic characteristics. Dynamic characteristics of a system can be established using modal analysis, of which eigen modes are the most used. The performance of a system during expected earthquakes can be, to an extent, visualized using the modal properties, and obviously for the linear case. The eigen-value analysis takes into account the distribution of mass and the stiffness throughout the structure. The consideration of the SSI makes changes to these quantities in these distributions and hence, influence the eigen decomposition of the structural system, in the way, intuition might suggest, resulting in a higher fundamental time period which implies that the structure will be a much flexible one. On the account of the flexibility introduced to the system, it may be apparent that the seismic loading decreases but, as previously mentioned, it has more to do with the displacement demand at top of the pier section, on account of which the effects due to second-order moments may also be pronounced.

In this paper, time periods of a sample bridge in Kathmandu is subjected to eigen value analysis considering and without considering the flexibility of its foundation, and OpenSees [6] is used for the purpose.

2. Materials and Models

Firstly, the the piles are subjected to lateral loadings and the force-displacement relation is obtained for a reasonable range of displacement is obtained which is assigned to a zerolength element at the base of the pier, which corresponds to the elevation of centreline of the pile cap. The dofs are fixed in the vertical and along all the rotational degrees of freedom. The soil-pile interaction is simulated by the PySimple1, QzSimple1 and TzSimple1 uniaxial material models available in OpenSees with the required parameters determined using the soil SPT data available in the design documents. The materials are assigned to zerolength elements connecting nodes just beside the pile nodes. One end of the elements are fixed and other is constrained with the pile nodes in all translational degrees of freedom and the rotational degrees of freedom of the nodes of the soils these springs connect are restrained in lieu of the fact that the soil only exerts force on the pile nodes and no moment. As the piles were circular and symmetrical, the translational dofs in the horizontal plane could be simulated by a single constitutive law. Piers were modeled using dispBeamColumn elements available in Opensees which was formulated using traditional stiffness based approach with fiber sections. The displacement based elements have a number of integration points in between and at the ends of the element. At each of these integration points, we have to define a proper fiber section with material constitutive relations at each point of the section. The number of these integration points can be defined using the beamIntegration command available in Opensees. The corresponding integration scheme also has to be chosen at the same time. There are various schemes available such as the Gauss-Lobatto, Gauss-Legendre, etc. These schemes define the location and weight of each of the integration points. The end curvatures of the elements obtained by solving the finite element assemblage equation is interpolated at these integration points using the Hermite interpolation functions after which the sections at those integration points are rotated by the same curvature obtained from the interpolation. Thereafter, fibers making the section are given compatible axial deformations, and the stress distribution corresponding to those deformations are used to calculate the resisting axial force and bending moment at the section. The axial force and bending moment at the section are divided by respectively the axial deformation and curvatures to get the stiffness of the section. The stiffness thus obtained is multiplied by the weight of the integration scheme and added with stiffness from the other sections of the element similary weighted to form the element stiffness matrix for the next iteration. These iterations are continued until the deformations converge for the given loads. These elements, however, have a problem. As the forces at the intermediate sections are calculated based on the interpolated axial and bending deformation obtained at the element ends, the forces don't generally satisfy internal equilibrium with the member end forces. However, the equilibrium state improves as the number of elements between the earlier member ends are increased or discretized. Further, these elements can develop plastic hinge localization at the mostly stressed sections for elastoplastic or strain-hardening material constitutive models which can be remedied by defining plastic hinge lengths as given by various researchers among which the one proposed for concrete sections by Priestley [7] is popular. The materials used for construction were M30 for concrete and Fe500 for steel.

The core concrete properties was evaluated using the theoretical relations proposed by Mander [8]. Concrete02 and Steel02 were used for representing the material models. The deck was modeled using elasticBeamColumn element utilizing the properties of uncracked plain concrete section. It may be often of concern that can one-dimensional elements like beams be able to capture the dynamic characteristics of at least a two-dimensional deck section. But, for the dynamic characteristics to be effectively captured, the distribution and quantification of mass and stiffness should be proper which can still be captured with elasticBeamColumn elements. Further, deck offers little to no contribution to stiffness to the lateral load resisting systems which primarily consists of piers and abutments because decks are supported by a bearing over the piercap. Hence, if equivalent area with comparable elasticity can be imposed to the beam-column element to restrain the axial deformations, it should be good. Also, the analysis would be less expensive computationally with lower loss in accuracy. The connections between the pier sections and the pier caps were ensured using rigid links which constrains the translational dofs and evaluates the displacement of the constrained node using the displacement of the retained node, relative distance between the nodes and the rotation at the retained node.

Figure 1 shows a fiber-section for pier modeled in OpenSees. Figure 2 shows the bridge modeled with rigid footing. Figure 3 shows the fiber response under gravity loading.

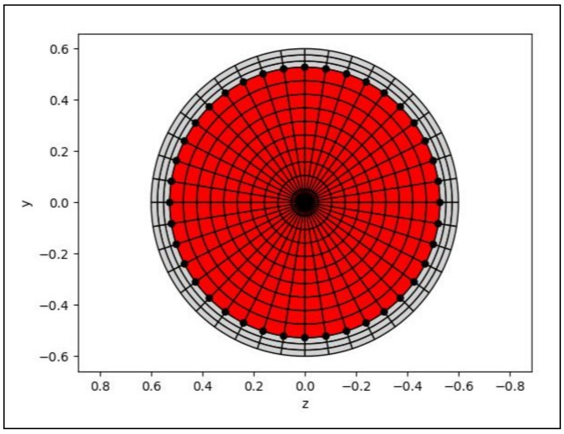

Figure 1: Pier Fiber Section

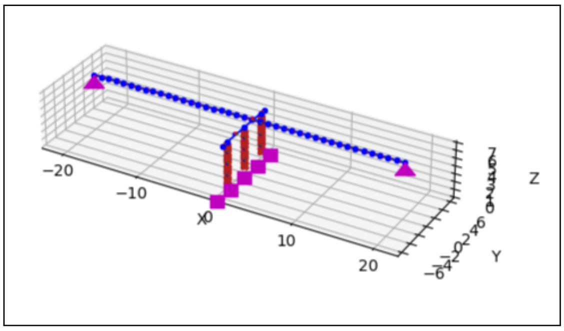

Figure 2: Openseespy Bridge Model

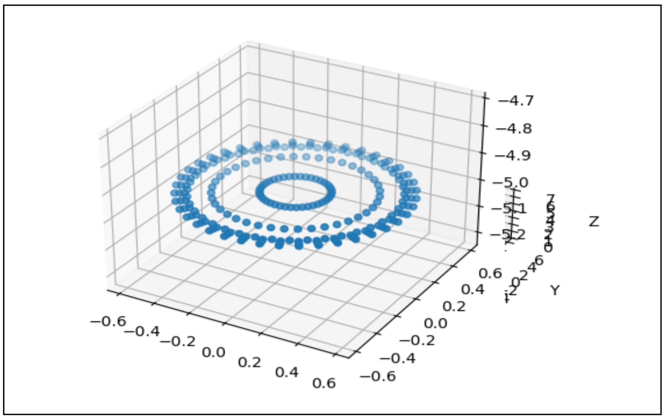

Figure 3: Fiber stress response of a pier section under dead-load

3. Result

The result of the Eigen Value analysis are as shown:

Table 1: The differences in time period

Eigen Modes	Rigid Foundation(s)	Flexible Foundation(s)
1	0.2748	0.21
2	0.2735	0.128
3	0.10	0.075
4	0.073	0.035

4. Discussion and Conclusion

In contrast to what was initially proposed about the elongation of time-period of the structure on considering soil stiffness, the time-period are actually found to be slightly lesser for bridges with flexible footing. Hence, a deeper analysis into what could be causing should be done with an exact dynamic non-linear time hisory analysis. There are separate mode shapes for flexible and rigid foundation bridges, and hence the difference in deformation patterns can be one of the reasons for the deviation. As the scope of the paper was to conduct linear eigen value analysis, it is recommended to perform a comprehensive analysis in the future.

References

[1] N. M. Newmark and W. J. Hall. *Earthquake Spectra and Design*. Earthquake Engineering Research Institute Monograph Series. 1982.

[2] James M. Kelly Farzad Naeim. *Design of Seismic Isolated Structures: From Theory to Practice*. John Wiley and Sons., 1999.

[3] A. Filiatrault C. Christopoulos. *Principles of Passive Supplemental Damping and Seismic Isolation*. EUCENTRE, 2006.

[4] George Mylonakis, Constantine Syngros, George Gazetas, and Toshiaki Tazoh. The role of soil in the collapse of 18 piers of hanshin expressway in the kobe earthquake. *Earthquake Engineering & Structural Dynamics*, 35:547–575, 2006.

[5] George Mylonakis, Sissy Nikolaou, and George Gazetas. Footings under seismic loading: Analysis and design issues with emphasis on bridge foundations. *Soil Dynamics and Earthquake Engineering*, 26(9):824–853, 2006.

[6] Frank McKenna, Gregory L Fenves, Michael H Scott, et al. Open system for earthquake engineering simulation. *University of California, Berkeley, CA*, 2000.

[7] M. J. N. Priestley, F. Seible, and G. M. Calvi. *Seismic Design and Retrofit of Bridges*. John Wiley & Sons, Inc., 1996.

[8] J. B. Mander, M. J. N. Priestley, and R. Park. Theoretical stress-strain model for confined concrete. *Journal of structural engineering*, 114(8):1804–1826, 1988.