Different Techniques for the Modeling of Concrete I-Girder Bridges

Jimmy Chandra
Graduate Student, SET
Asian Institute of Technology
Bangkok, Thailand
chandra.jimmy@yahoo.com

Naveed Anwar
Associate Director, ACECOMS
Asian Institute of Technology
Bangkok, Thailand
nanwar@ait.ac.th

Deepak Rayamajhi
Graduate Student, SET
Asian Institute of Technology
Bangkok, Thailand
rayamajhi_deepak@yahoo.com

ABSTRACT:

This paper presents a comparison between response of post-tensioned concrete I-girder bridges analyzed by using different modeling techniques. Each type of modeling technique requires a certain set of assumptions to simplify the problem and thus results obtained from these techniques vary according to the assumptions made. In this study, a typical concrete I-girder bridge is analyzed using commercially available finite element software for two analysis cases, static and modal. Static analysis is used to study the responses of the bridge for dead load, moving load and post-tensioning load cases whereas modal analysis is used to study the modal dynamic response of the bridge. Finally, response of the bridges is compared in terms of natural time periods or frequencies, mode shapes, support reactions, deformations, internal forces, etc. The results obtained show that similar results can be achieved from different modeling techniques if proper assumptions are used.

KEYWORDS: Post-Tensioned, I-Girder Bridge, Finite Element Modeling, Bridge Response.

Nowadays, the use of computer models to perform structural analysis in the field of bridge engineering has become a common practice. Engineers are supposed to use proper model in order to accurately predict the response of the bridge model for design purposes. In recent years, researchers have been developing many modeling techniques that can be used to model a bridge. Each type of modeling technique requires some set of assumptions to simplify the problem and thus results obtained from these techniques vary according to the assumptions made. Moreover, each type of modeling technique has its own advantages and disadvantages. Therefore, sometimes engineers use several modeling techniques to model complex bridge structures in order to compare the results and to use them for various purposes.

The modeling techniques used by engineers to model a bridge range from the simplest one to the highly complex one. The simplest model (spine model) usually comprises only one single girder to model the bridge deck and hinge or roller supports to model the bearing and abutment. Even though this model is very simple, it is able to give reasonable prediction of the bridge response under dead load such as maximum displacement and moment at the mid span and support reactions. However, there are many limitations of this model such as transverse analysis of moving load in bridge deck cannot be performed, inaccurate prediction of modal analysis, etc. Therefore, nowadays most of engineers use this model only to do preliminary analysis or sizing of a bridge's components. To overcome some limitations in spine model, a frame/grid model was developed. In this model, the bridge deck is modeled using many frames and these frames are connected each other using cross members representing the diaphragms. In this model, transverse analysis of moving load in bridge deck can be performed. Furthermore, this model gives more accurate prediction of modal responses as compared to the spine model. Nevertheless, slab behavior cannot be modeled properly in this model, especially the two-way response including twisting. Frame shell model can be used to improve the accuracy of frame/grid model. In this model, the slab is modeled using shell elements, which means the effects of the slab (both for out-of-plane loads and in-plane stresses) are included explicitly in the model for analyzing purposes. Thus, it can improve the accuracy of analysis results under several load cases. Full shell model is considered as one of the most complex models nowadays to model bridges. In this model, all elements, including girders and slabs, are modeled using shell elements. Due to its complexity, sometimes it is difficult to extract information from analysis results for design purposes. However, with the help of powerful analysis software and computers that are available nowadays, this problem can be overcome. Therefore, many engineers have started to use this model in order to get accurate prediction of bridge responses under many load cases.

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In this study, a typical concrete I-girder bridge is modeled and analyzed. The bridge has total length of 80 m. The bridge has two spans of 40 m each and 10 m wide concrete deck which is supported by four concrete I-girders. The concrete compressive strength (fc') for the I-girders is 41 MPa whereas for the deck is 28 MPa. The modulus of elasticity of the concrete used in this study is 30,442 MPa and 24,856 MPa for I-girder and deck, respectively. In this study, the selected bridge has only two lanes for the vehicles. The connection between the deck and pier I restricts the displacement of the deck in X, Y, and Z direction and permits the rotation about X, Y, and Z direction (i.e. hinge support). The connections between the deck and pier II and III permit the displacement along X direction and rotation about X, Y, and Z direction but restrict the displacement along Y and Z direction (i.e. roller support).

In this study, finite element models of bridge are developed in SAP2000. The bridge is modeled with five different modeling techniques in which the complexity of the model is gradually increased. They are spine model, frame model, grid model, frame shell model and full shell model. Some certain assumptions are applied in each model as described before. In this study, the bridge is analyzed and reviewed for static and modal analysis cases. Static analysis is used to study the responses of the bridge for dead load, moving load and post-tensioning load cases whereas modal analysis is used to study the mode shapes of the bridge. Dead load is considered from the self weight of the bridge. The standard truck HSn-44 in accordance with American Association of State Highway and Transportation Officials (AASHTO) [1] is used for moving load case. The moving truck loads are applied in two lanes in opposite direction with particular vehicle speed. For post-tensioning load case, tendon elements are used as a load pattern on the bridge. The post-tensioning is estimated in such a way that moments produced by the post-tensioning effect should be able to balance most of the moment from dead load.

From modal analysis, it can be seen that for first mode and second mode, almost all models give longitudinal mode shape and the natural period is about 0.38 s for first mode and 0.37 s for second mode. Only frame model gives transverse mode shape and different natural period. In the case of frame model, longitudinal mode shape comes as third mode with natural period is about 0.39 s. Furthermore, it should be noted that in all three modes, frame shell model without any modifications always gives higher natural period which means the structure is more flexible. This happens due to incorrect girder location which in this model, the girder centroid is located at the same elevation as the slab centroid. Thus, it reduces the moment of inertia of the whole section of the bridge and definitely reduces the bridge stiffness. For maximum displacements and moments at middle span, almost all models give approximately same values. The major difference can be found in frame shell model without any modifications. As explained before, incorrect modeling of the girder location causes reduction in the bridge stiffness. Therefore, in this model, the displacement values are higher as compared to other models in all load cases (dead, live, and post-tensioned). For support reactions, for dead and post-tensioned load cases, almost all models give approximately same values for external support reactions as well as internal supports reactions. However, a major difference can be found for live load case in spine model which the values are much less as compared to other models.

This paper compares the response of post-tensioned concrete I-girder bridge which is modeled with different modeling techniques. The models used are spine model, frame model, grid model, frame shell model, and full shell model. From the two analysis cases (static and modal) which can be classified as longitudinal analysis, the responses are quite similar between different modeling techniques, except for some cases. It should be noted that proper assumptions are needed to achieve these similar results. Indeed, this is an advantage for engineers who want to do a preliminary design or analysis with a simple model and they can achieve reasonable results. This can save computational effort, cost, and time. However, it may not be the case for transverse analysis which is quite complicated and is not considered in this study. Therefore, it is recommended for future research to investigate the effect of different modeling techniques in the response of post-tensioned concrete I-girder bridge for the transverse analysis case.