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An Investigation on Transversely Prestressed Concrete Bridge Decks

Introduction

The conceptual idea of transverse post-tensioning bridge superstructures was first implemented during the sixties in Europe as an empirical-based practice. The technique, applicable to cell-box girder bridges exclusively, was intended to (Almustafa, 1983):

- Maximize the length of cantilever overhangs
- Minimize the number of webs
- Improve the connection between longitudinal girders
- Provide better and less congested reinforcement layout at pier locations

Analytical and experimental evidence on the behavior of transversely post-tensioned decks only became available in the mid eighties when a multi-phase project was carried out at the University of Texas at Austin (Poston et. al (1984, 1985, 1987, 1989)). The outcome of the Texas Study was a series of design specifications for the use of transverse post-tensioning in concrete bridge decks.

The design specifications developed in this study constitute a more general version of the existing recommendations (Texas recommendations). Improvements include:

(i) General support conditions for girders are possible,

(ii) The effect of the interaction between outermost diaphragms and the boundary conditions of the girder on the distribution of transverse stresses is taken into account,

(iii) The suggested specifications provide the user with more options during the design procedure.

The objective of this research project was to develop general design guidelines for the application of deck edge transverse post-tensioning required to meet desirable levels of compression stresses on the top surface of concrete bridge decks. The desired level of compression induced by the transverse post-tensioning must be enough to limit the level of tensile stresses at service on the top surface of the deck. Transverse stresses induced by live and dead load are superimposed to the stresses induced by the applied post-tensioning under the assumption of linear elastic behavior. The actual calculation of the transverse stresses induced by live and dead load is beyond the scope of this study.

The investigation is limited to the study of the effect of transverse post-tensioning on slab and deck-on-girder concrete bridges. A recent survey of the Indiana Department of Transportation (INDOT) indicates that about 80% of the concrete bridge lettings in Indiana during the last 1.5 years (February 2000 to September 2001) are slabs and deck-on-girder. Therefore, the suggested design aids should cover the largest percentage of concrete bridges in Indiana.

The work conducted in this research project is presented in two volumes. The first volume includes information such as: (i) a detailed description of the state-of-the art in the use of the methodology of transverse post-tensioning, (ii) an evaluation of alternative modeling techniques using commercial Finite Elements programs, (iii) a preliminary evaluation of the relevant variables. The second volume presents the results from parametric studies using SAP2000 and their consequent design implications. This allowed the formulation of detailed design aids and recommendations for the use of transverse post-tensioning.

Findings

In this study emphasis has been placed on developing general design guidelines for the application of deck edge transverse post-tensioning required to meet desirable levels of compression stresses on the top surface of concrete bridge decks. It is found that the required distribution of transverse post-tensioning is such that different application levels of prestressing are required in regions containing the interior and exterior (or outermost) diaphragms. It is also concluded that the magnitude of such transverse forces is mainly a function of the girder's boundary conditions, the axial stiffness of the diaphragms, the skew angle of the deck, and the position of the diaphragms/stiffener with respect to the edge of the deck.

Additional findings from this study include:

- Different modeling schemes for a particular deck-on-girder structure subjected to transverse forces only (test model of the Texas study) were found to produce results reasonably similar to the experimental values. Average ratios of calculated to experimentally inferred stresses ranged from 1.10 to 1.15.
- The influence of the diaphragm position was approximated evaluated considering a T-section having an increasing flange width as the diaphragm is placed closer to mid-span. From this model, it can be seen that the restraining effect of exterior diaphragms is more significant than the effect of interior diaphragms.
- Except for very short spans, the effect of every diaphragm in the superstructure can be taken as independent of the corresponding effect of companion diaphragms. The restraining action of a particular diaphragm is localized in a region of the deck containing such element. Subsequently, prescribing different levels of post-tensioning at different diaphragm regions is possible.
- The use of transverse post-tensioning in integral bent spans is limited in terms of efficiency. The post-tensioning is found to be ineffective in regions close to the integral support. Practically, a scheme of transverse post-tensioning to limit the size of such "ineffective region" can be proposed.
- The parametric study suggests that the methodology of transverse post-tensioning is not practical for integral-end bridges having skew angles larger than 20^{o}. For such cases the transverse post-tensioning may induce tensile stresses on top of the deck.
- For steel-girder-integral-bent spans, the transverse post-tensioning should be used only if the outermost diaphragm/stiffener is placed not less than 6 ft away from the end of the girder. Otherwise the required transverse force may be excessive.

Implementation

The data required to use the proposed design guidelines include; diaphragm size and type (concrete or steel), definition of boundary conditions for the girders, position of the outermost diaphragm with respect to the ends of the girders and, deck skew angle. The user has the choice of selecting the widths of the diaphragm regions.

The most practical (and easiest) implementation of the suggested methodology consists in considering only two categories for the boundary conditions of the girders; non-integral or integral ends. The first case corresponds to girders' ends supported on either rocker or elastomeric bearings, whereas the second case corresponds to integral-abutment ends. Two sets of design aids are available depending on the type of girders for the superstructure under consideration; concrete or steel. The user has the alternative of using more general deign guidelines but this requires a more precise definition of the boundary conditions for the girders. In all cases, the suggested distribution of transverse post-tensioning is such that different application levels of prestressing are required in regions containing the interior and exterior (or outermost) diaphragms.

In the case of skew decks, the proposed methodology requires placing the post-tensioning ducts oriented parallel to the skewed edge of the deck. The design specifications are limited to deck skew angles smaller 30^o for non-integral ends, and 20^o for integral ends.

For steel-girder-integral-bent spans, transverse post-tensioning should be used only if the outermost diaphragm/stiffener is placed not less than 6 ft away from the end of the girder.

The developed design specifications can also be applicable to slab bridges. In this case the user has to consider slab bridges as particular case of deck-on-girder bridges where the area of transverse concrete elements is zero.

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