Geometrical influence on transverse thermal stresses in concrete bridge sections

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Summary

The temperature in a concrete bridge is affected by complex interactions of climatic factors. Varying concrete temperature will give rise to movements in the longitudinal as well as the transverse directions. Inspections of certain box girder bridges have shown cracks in only the thin vertical walls, which may be an indication of a geometrical influence. A sequence of climate input data deemed as an extreme event in a previous study was used to calculate the transverse thermal stresses in concrete box-sections with various geometries. The results show that the most influencing geometrical parameter is the member thickness ratio. If the thicknesses in the horizontal slabs and the vertical walls are different, large tensile stresses will occur in the section. The actual thickness is not as important, nor whether the slabs or walls are the thinner parts. The width and height of the cross-section is not as influential as the thickness ratio.

Keywords: *thermal actions, concrete, FE-model, solar radiation, geometry*

1. Introduction

The temperature field in a concrete bridge is affected by complex interactions of climatic factors. Solar radiation, air temperature, wind speed and long-wave heat radiation all affects the temperature field in a concrete structure. Varying temperature in a concrete structure will give rise to thermal movements. A change in average temperature will mainly give longitudinal movements while the linear as well as non-linear differentials also produce transverse movements. Temperature differences may lead to a curvature of the entire bridge. At cross-sectional level a non-uniform temperature distribution will produce various movements. Depending on the geometry, e.g. solid or box section, T-girder or slab, the movements will in turn produce stresses. For a hollow box cross-section, the walls and slabs will cause internal restraint in the cross-section.

If a temperature differential over a wall is present the wall wants to curve, the adjacent slabs will restrain the movements in the wall and stresses will be induced. Inspections of several Swedish box-girder bridges have shown cracks appearing on the inside of the vertical walls, more cracks on the south wall than on the north. This indicates that solar radiation has a large impact on the cracks in this type of structure, since this is the only factor that is significantly different between the walls.

The investigations of thermal stresses in indeterminate concrete bridges have mainly been focused on longitudinal stresses, and transverse stresses have only been analysed and discussed briefly. A study was performed by Mirambell and Aguado [1] where the actual geometry relations were considered. They found that the thickness ratio between the upper and lower flanges of a bridge section will affect the longitudinal stress distribution in the bridge. No investigation, however, was performed considering the geometrical influence on the transverse stress distribution.

https://doi.org/10.2749/222137813808627406
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2. FE-model and Simulation Method

In this research an FE-model was used with climate input data to calculate temperature profiles and resulting transverse thermal stresses in hollow box cross-sections. The model has previously been validated against temperature measurements performed in the top cross-section of the New Svinesund Bridge [2]. Extensive climate data from Stockholm in Sweden was used for the simulations presented in this paper. In most previous research concerning long-term simulations general sets of data have been used, for example daily total solar radiation instead of using hourly data. The long-wave heat radiation, which is mainly governed by the cloud cover, has also been treated in a simplified way. To get a more precise prediction of the temperature, hourly data was used for the climatic factors in the FE-model.

The simulated temperature profiles were used as input in linear-elastic simulations with the same cross-section to predict stresses induced from thermal expansion. Thermal stress fields from FE-simulations using cross-sections with differing geometry were analysed to investigate the importance of variations in different geometry factors. The geometries were chosen from the relations used in the cross-section of the New Svinesund Bridge, since this was used for the validation of the FE-model.

3. Conclusions

The largest tensile stresses appear on the inside surface of the thinnest member in a cross-section. In the top section of the New Svinesund Bridge the largest tensile stress appear in the thinner top slab. The stress distribution in the top slab when annual maximum tensile stresses occur on the inside surface is close to linear. The stress distribution in the vertical walls, south and north, is more non-linear. This is due to the larger thickness of the vertical walls compared to the horizontal ones. If the relations between the vertical and horizontal members are reversed, thinner vertical walls than horizontal slabs, the stress distributions are also reversed. This indicates the magnitude of the geometrical influence on the thermal stresses.

The most governing geometrical factor concerning thermal stress distribution is the wall thickness. With a varying thickness between the walls, large tensile stresses may appear on the inside surfaces of the thinner walls. If instead the thickness is uniform between the four walls, the stress distributions are similar for the top and south walls and the maximum tensile stress on the inside surfaces is reduced. The height and width have a much smaller impact on the thermal stress distributions.

This research has so far been focused on the relations between the various geometrical properties of box cross-sections. Most concrete bridges have, however, overhangs who will give shade to the vertical walls of the box, which will affect the temperature distribution in the cross-section and the resulting stress distribution. The other aspect of this research is the shape of the investigated cross-section. The investigation has, so far, used the cross-section used for the validation as a base for the geometrical relations. Other cross-section types will be investigated, with focus on box cross-sections commonly used, and with overhangs included.

4. References

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