Lateral-Torsional Instability of Box Girder Bridges at Erection

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Summary

Open top trapezoidal box sections of steel are widely used as a part of composite bridges. Before the rigidifying effect of the slab has developed, they usually have extremely low torsional rigidity. The collapse of Bridge Y1504 in Sweden 2002 during its construction raised a number of questions concerning the design and erection of box girder bridges. Based on this case, various aspects on the stability and behaviour of box girder bridges during construction will be addressed. Particularly prone to lateral-torsional instability at erection are single span bridges with no warping restraint at the ends. A method for a second order analysis of the lateral-torsional behaviour is presented together with some results.

Keywords: box girder bridges, lateral-torsional instability, thin walled beams, bridge collapse, formwork of profiled steel sheeting, imperfections, wind load, monitoring, second order analysis

1. Introduction

On June the 12th in the afternoon, workers started to pour concrete for the deck of the new road bridge Y1504 located 90 km west of town Umea in the northern part of Sweden. The concreting of the deck had deliberately been planned to start in the afternoon in order to avoid strong sunshine which could increase the risk of cracks due to shrinkage. However the sky was overcast most of the day and the sun didn't appear until the evening, when the concreting started. The concreting was planned to be done in two steps, the first one about 66 m^3 covering approximately half of the span symmetrically located around mid span. About 17 m^3 concrete had been poured when the bridge suddenly rotated nearly 90 degrees at mid span and five out of six workers fell into the river. The bridge then took a new state of equilibrium. Fig.1. Fortunately, nobody was severely hurt, and those who fell into the river could reach the riverbank.

The collapse of bridge Y1504 shows several similarities with the Marcy footbridge, which failed during construction about four months later.

Fig. 1: Lateral-Torsional Instability occurred during casting of the deck slab. The old bridge can also be seen from the photo. (Courtesy of NCC)

The new bridge Y1504 is a simply supported bridge spanning 65 m with a clear width of 7m. The cross section is a welded trapezoidal box with nine intermediate diaphragms @ approximately 7m.The box girder was fabricated in three separate parts and transported to the site, where they were assembled by welding. Prior to launching the girder into its final position, formwork for the concrete deck was set up.

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2. Some technical remarks to the collapse

Due to the increasing rotation, the twisting moment caused by external loads will also increase in turn increase the shear flow in the permanent shuttering. This part of the structure is the weakest link with respect to torsional moments. Loss of shear stiffness of this part due to e. g. sheet tearing along seem fasteners or sheet to flange fasteners implies that the box girder acts as an open box girder section characterised by strong warping. It was the capacity of the shuttering to carry the shear flow that was almost entirely decisive for the stability during construction of bridge Y1504.

3. On the stability of transversally loaded beams with an open cross section

The sensitivity with respect to lateral torsional instability depends primarily on the St Venant torsional stiffness together with lateral bending stiffness. For box girders like those in bridge Y1504, and the footbridge in Marcy, the lateral bending stiffness is relatively large. The torsional stiffness is extremely low even if the girders are provided with a profiled metal sheet shuttering, thus creating a closed cross section.

Also the span length plays an important role, and single span bridges are relatively more sensitive to lateral torsional buckling than are multi span bridges. The negative influence of the Wagner effect is less significant for continuous beams. One should remember that the critical value for a uniform load is approximately inversely proportional to the span length to the third power.

4. Sheet steel shuttering used as a stabilising component.

By connecting the top flanges with profiled sheeting, e. g., trapezoidal profiled sheeting with a thickness of 0.8 – 1.0 mm gives a closed cross section with an increased St Venant torsional stiffness. The sheeting is a part of the form work for the concrete deck. This is an economically efficient solution. The ability of the profiled sheeting to carry the shear forces is mainly limited by the following criteria:

- Sheet tearing of the fasteners connecting adjacent panels
- Sheet tearing of the fasteners connecting the panels to the top flanges
- End collapse of the sheeting (distortion, web crippling, local buckling)
- Global buckling
- Effects of the combination of transversal and in plane loading.

5. Conclusions

Outgoing from the collapse during the construction of the Swedish bridge Y1504 a number of aspects concerning the behaviour of open box girders have been addressed. Profiled sheeting used as permanent shuttering is an economically effective solution. This will also improve the torsional rigidity by a factor 10 - 30 provided it is adequately fastened to the top flanges of the box girder. All four sides of the panel should be fastened in order to get a continuous shear flow.

An effective way to estimate the internal forces, e.g. in fasteners, is to apply the theory of thin-walled beams, where also certain measures of imperfections are to be accounted for. The governing system of differential equations can be solved by approximating the derivatives with finite difference approximations, which leads to a system of simultaneous linear equations. However it is important that any kind of imperfections and all relevant loads are taken into account in the design procedure. This is particularly important in the design of fastenings for the sheeting.

For long single span bridges profiled sheeting of ordinary thicknesses may not give sufficient torsional rigidity. By connecting the top flanges with plan bracing (truss) the torsional stiffness could easily be increased by a factor 100 -1000. With plan bracing present, then the girder will respond as in simple bending with negligible rotation.