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Vertical Shear Resistance Models for a Deltabeam

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Matti Leskelä, born 1945, received his Ph.D. in 1986 and has been carrying out research into composite structures from the early 1980's. His latest work has concerned problems of partial interaction and various shear connections in composite structures such as slim floors, composite slabs and concrete filled steel tubes.

Summary

The Deltabeam is an innovative structural form for beams for use in slim floor construction fabricated by Deltatek in Finland. The principles employed in developing vertical shear resistance in the composite state and in the initial state of steel construction are discussed. Changes in behaviour due to exposure to fire from the underside are introduced, and methods of reinforcing the system are reviewed.

1. Introduction

The Deltabeam consists of a boxed steel member in which circular web holes are spaced at constant distances along the span so as to make it possible to fill the box section with concrete and to make the structure behave compositely after solidification of the concrete. In the initial state, as a steel construction, the web holes, extending maximally to 60 % of the web depth, cause an obvious reduction in the vertical shear resistance of the beam, but the resistance is nevertheless adequate for the applications for which the beams are intended. After the solidification of the concrete the vertical shear resistance is enhanced greatly and can cope with all loads introduced in the ultimate limit state.

2. Mechanisms for shear resistance

Mechanisms for the evaluation of vertical shear resistance are defined for three states of behaviour: (1) steel construction, (2) composite construction and (3) composite construction when exposed to fire. The principal difference in the effective structure between normal conditions and fire temperatures is that the unprotected bottom flange is normally lost in fire exposure and cannot contribute to the shear resistance.

2.1 Steel construction

The resistance of the steel member to vertical shear forces should be considered with respect to stresses formed due to the combined effects of local and global actions in the sections through the web holes. It is scarcely possible to derive reasonable formulae directly for the maximum stresses around circular holes, however, and therefore an approximation with respect to a beam having square web holes of the same depth is used.

In German research into I-beams with circular and square web holes [1, 2] it has been shown that the ratio of the ultimate resistances in beams with square (resistance $V_{\square.R}$) and circular web holes (resistance $V_{\phi.R}$), $V_{\square.R}/V_{\phi.R}$, can satisfactorily be defined as a function of the relative depth of the holes, ϕ/h, ϕ being the hole depth and h the depth of the beam. Since it is possible to evaluate the stress state in the case of square holes, the known ratio of the resistances may be applied to convert $V_{\square.R}$ into $V_{\phi.R}$. The principle was verified by means of loading tests and was observed to work well when the resistance was determined based on the first yielding in the edges of the holes.` This is also justified, considering the state of construction.

2.2 Composite construction

The concrete infill inside the boxed section suggests that a system of compression struts and tension ties will develop in a truss form when the load is increased in steps to failure, i.e. compression struts will be formed between inclined cracks in the concrete contained in the boxed section and the web sections between the holes work as vertical tension ties. The system bears some resemblance to that observed in concrete beams reinforced with vertical stirrups, but it must be noted that the contributions of the concrete and steel to the shear resistance are not additive. This is explained by the considerably higher yield capacity of the web sections as compared to the normal density of stirrups in the reinforced concrete structures.

2.3 Composite construction exposed to fire

If no thermal insulation is applied in the bottom flange of the steel section, fire exposure from below will normally make it inefficient, not only for allowing excessive bending of the beam, but also for maintaining shear resistance. To ensure the bending resistance, reinforcing bars are used inside the box section, but these do not contribute to the vertical shear resistance of the structure unless it is ensured that the maximum force in the diagonal compression struts, formed in the same manner as at normal temperatures, is able to anchor to the webs of the steel section. It was observed in loading tests that the diagonal compression struts in beams with no bottom flange were finally pushed out, causing then anchorage failure in the reinforcing bars, which were not able to develop any yield. The majority of the diagonal concrete forces are anchored by the web holes, and the rest of them can be anchored to additional devices such as stirrups and shear plates welded to the inside of the top flange.

2.4 Interaction with bending

The vertical shear resistance described in section 2.2 above is such that very thick flanges in the beam are required to prevent the flanges from yielding before reaching maximum resistance. When concentrated loads are used in testing, there are normally high bending moments in the sections where the shear resistance is to be reached, and some interaction with bending is to be expected. The prediction of the vertical shear resistance by the strut and tie models has proved to be satisfactory, however, although the models developed for the shear resistance consider the bending effects only in the case of fire design.

3. References

[1] Petersen, C., Stahlbau, p. 611-612. Friedr. Vieweg & Sohn, Braunschweig/Wiesbaden 1988

[2] Clauss, H., Tragfähigkeit von Vollwandträgern mit Stegausnehmungen. Diplom-Arbeit am Lehrstuhl für Stahlbau. UniBw München 1986

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