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Indirect Loading and Indirect Supporting in High-Strength Concrete Beams

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Abstract

In concrete structures, most frequently, the loads and reactions are applied on the top and the bottom of the beams, respectively. These are said to be directly loaded and directly supported beams. However, situations are found in which the beams are loaded or supported by intersecting beams so that the load transfer is by shear rather than by bearing on the top or the bottom surface. These are referred to as indirectly loaded or indirectly supported beams.

The experimental investigations conducted during the past decades with normal-strength concrete beams showed that a tie shall be provided at the joint between these beams which is responsible for transferring the mutual reaction from the supported beam to the supporting beam. This transfer is accomplished by a reinforcement made up by stirrups referred to has hanger reinforcement.

This abstract is concerned with indirect loading and indirect supporting in high-strength concrete beams and reports the results of experimental investigation conducted by *Ribeiro* (1), under direction of the author, using horizontal T-shaped specimens. The specimens were B1-L and B1-R with shear span-to-depth ratio a/d = 1.89 and C1-R with shear span-to-depth ratio a/d = 3.92. The beams were designed to fail in flexure. The flexural strength was given by the supporting beam. The predicted ultimate load was $2F_u$ = 140kN and the corresponding mutual reaction was $A_u = 1.2\ F_u$ = 84kN. The specimen concrete average compressive strength at the age of the tests was about 80MPa.

The hanger reinforcement in specimen B1-L was made up by one 5.0mm diameter stirrup in the supported beam (beam B) and four 4.2mm diameter stirrups in the supporting beam (beam 1) arranged within h/2 of the center of the intersection of the beams. This reinforcement could hang up 144% of the predicted ultimate mutual reaction: 34% for the stirrup in beam B and 110% for the stirrups in beam 1. The stirrup in the supported beam was responsible to hang 24% of the effective mutual reaction and those in the supporting beam were responsible to hang 76% of the effective mutual reaction. The two stirrups in the common volume could hang 55% of the predicted ultimate mutual reaction and were responsible to hang 38% of the effective mutual reaction. The hanger reinforcements in specimens B1-R and C1-R were made up by one 8.0mm diameter and two 6.3mm diameter stirrups placed at the common volume of the beams. This reinforcement could hang 137% of the predicted ultimate mutual reaction and was responsible to hang the full load transferred.

The tests showed that, initially, the load transfer is by shear over the depth of the beams. After cracking, the cracks produced by the principal tensile stresses in the supported beam follow the principal compressive stress trajectories. The inclined cracks in the supported beam give rise to a compressive stress field which acts as struts in a truss-like system. The stirrups crossing the cracks

play the role of ties in the web The load on the supported beam is transferred to the tensile chord of the supporting beam by the last strut in the supported beam.

The tests showed that the supporting beam is initially uncracked while the load transfer is by shear. After cracking, the cracks produced by the principal tensile stresses give rise to a fan-like crack pattern similar to that known for directly loaded beams. At late load stages, horizontal cracks appear over the web of the supporting beam indicating a tie-like behaviour of the hanger reinforcement.

In specimen B1-L, at ultimate load $2F_u$ = 170kN the mutual reaction was A_u = 102kN. At this load, the four stirrups in the supporting beam were hanging up 79.3kN ($0.77A_u$) and the single stirrup in the supported beam was hanging up 23.6kN ($0.23A_u$). At the same load the two stirrups in the common volume of the beams were hanging up 47.7kN ($0.46A_u$) and the next two were hanging up 31.6kN (0.31 A_u). The two stirrups in the common volume of the beams started yielding at a load 2F = 160kN and one of the next two had started yielding at 2F = 150kN. At these late load stages horizontal cracks appeared on the web of the supporting beam at the intersection of the beams due to stretching of the hanger reinforcement. At the same time a fan-like crack surface started to outline in the web of the supporting beam at the intersection of the beams. This crack surface was bounded by wide inclined cracks due to large yield strains in the hanger reinforcement. At a load 2F = 175kN, just after the compressive chord had initiated crushing, the bottom of the supporting beam was suddenly pushed downward. This fact enhances that this hanger reinforcement did not provide effective support for the bottom of the supporting beam at the intersection of the beams, even tough this reinforcement could hang up 119% of the effective mutual reaction: 28% for the stirrup in the supported beam and 91% for the stirrups in the supporting beam. This is because the hanging stirrups placed farther from the intersection are not as efficient as those in the common volume of the beams. The stirrups in the supporting beam were able to hang up only 0. $77A_u$ ($0.46A_u$ for the stirrups in the common volume of the beams and 0.31 A_u for those in outside) and needed the help from the stirrup in the supported beam to hang up the missing $0.23A_u$.

In specimen B1-R, at ultimate load 2Fu = 170kN the mutual reaction was A_u = 102kN. At this load, the three stirrups were hanging up 106.7kN. This load is approximately equal to A_u. These stirrups started yielding at a load 2F = 160kN. At the late load stages, the same horizontal cracks and the same fan-like crack pattern appeared on the web of the supporting beam but no pushing-down failure occurred. The hanger reinforcement placed at the common volume of the beams was efficient up to failure of the specimen.

In specimen C1-R, at ultimate load $2F_u$ = 1 60kN the mutual reaction was A_u = 96kN. At this load the three stirrups were hanging up 100.4kN. This load is approximately equal to A_u. These stirrups reached yielding at failure of the specimen. The hanger reinforcement placed at the common volume of the beams once more was efficient up to failure of the specimen when the supported beam failed in shear tension.

Reference

[1] Ribeiro, F. C. V., *Apoio Carregamento Indiretos em Vigas de Concreto de Alta Resistencia,* Dissertaçao de Mestrado, Faculdade de Engenharia Civil - UNICAMP, Campinas-SP, Brasil, 1999.