PhD Dissertation Defense

RESPONSE OF STEEL AND COMPOSITE BEAMS SUBJECT TO COMBINED SHEAR AND FIRE LOADING

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Abstract

Civil infrastructure are built to last for several decades and hence, they are exposed to various risks throughout their service life, such as fire. Thus, structural fire safety of civil infrastructure (which are often designed with steel and/or composite beams/girders) is one of the primary considerations in their design. Since steel structural members exhibit lower fire resistance due to high thermal conductivity of steel and rapid degradation of strength and stiffness properties, they are vulnerable to fire-induced damage or collapse. Therefore, behavior of steel and composite beams, under fire conditions, is of critical concern from fire safety point of view.

In contrast to current design philosophy at room temperature, where steel and composite beams are to be designed for flexural limit state and then checked for shear resistance, fire design of these beams is carried out based on flexural limit state only, without any consideration to shear limit state. Moreover, the effect of concrete slab is only considered in flexure and neglected in shear design of composite beams. This makes design philosophy inconsistent, and may not be representative under certain scenarios where shear forces are dominant or shear capacity degrades at a rapid pace under fire. Further, there is limited data and understanding in literature on the mechanism of shear failure in steel and composite beams under shear loading and fire conditions.

To overcome some of the limitations in current design philosophy with respect to shear limit state considered in beams, a research program involving experimental, numerical and analytical investigation on the fire response of steel and composite beams/girders is undertaken. Four composite beams were tested under simultaneous loading and fire exposure to study their flexural and shear behavior. Each of these composite beams is made of uninsulated standard hot-rolled steel section compositely attached to a concrete slab through shear studs. The main test variables are; level of composite action, type, and magnitude of loading. Results from fire tests indicate that composite beams can experience failure under standard fire conditions in about 30-55 minutes and their response is highly influenced by type of loading and development of sectional instability.

As part of numerical studies, a finite element model was developed in ANSYS for tracing thermal and structural response of composite beams under fire conditions. The developed model specifically accounts for geometric and material nonlinearities, temperature-dependent material properties, shear effect, sectional and global instability, composite action, and various failure limit states. This model was calibrated utilizing test data generated from fire experiments. The validated model was applied to carry out detailed parametric studies to quantify critical factors influencing
response of composite beams under dominant shear and fire loading. the variables included are; sectional instability, web slenderness, load level, fire scenario, loading configuration (type), level of composite action, shear stud stiffness and thickness of concrete slab.

Results from experimental and parametric studies are utilized to derive an approach for evaluating shear capacity of steel and composite beams. This methodology accounts for property degradation of constituent materials, temperature-induced sectional instability and level of composite action offered by concrete slab in evaluating shear capacity in beams. This approach is combined with flexural capacity calculations available in literature to developed a unified approach for design (and analysis) of fire-exposed beams. The unified approach can be used to optimally design and analyze steel and composite beams/girders. Also, the proposed unified approach can be utilized in current design provisions to enhance design philosophy of steel and composite beams subjected to dominant shear and fire loading.