ABSTRACT

A FRACTURE MECHANICS-BASED APPROACH FOR MODELING DELAMINATION OF SPRAY-APPLIED FIRE-RESISTIVE MATERIALS FROM STEEL STRUCTURES

By

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Steel structures exhibit lower fire-resistance due to high thermal conductivity of steel and rapid deterioration of strength and stiffness properties of steel with temperature. Therefore, steel structures are to be provided with fire insulation to achieve required fire resistance. This is often achieved through spray applied fire resistive materials (SFRM) that are externally applied on steel surface. The main function of SFRM is to delay temperature rise in steel, and thus slow down the degradation of stiffness and strength properties of steel when exposed to fire.

Delamination of fire insulation can occur during service life of the structure due to exposure to harsh environmental conditions or due to poor bond properties at the interface of steel and SFRM. Further, high deformation levels in structural members due to extreme loading conditions such as earthquake, impact or explosion can lead to delamination of fire insulation from steel structures. Fire that can develop as a secondary event following an earthquake, explosion or impact (primary events) can cause significant damage and destruction to the steel structure if SFRM applied on the steel members experience fire insulation loss during primary events. For instance, combined effects of impact or blast and ensuing fire could lead to the progressive collapse of structure as in the case of the terrorist attacks on the World Trade Center buildings (NIST, 2005) and collapse of Piper Alpha platform in North Sea (1988).

In this research, an experimental-numerical approach is adopted to investigate delamination of fire insulation from steel structures subjected to static loading and also extreme loading
conditions such as seismic, impact and blast loading. The cohesive zone behavior at the interface of SFRM and steel is determined through static fracture tests conducted for three types of SFRM namely, mineral fiber-based, gypsum-based and Portland cement-based SFRM. Subsequently, dynamic impact tests are carried out on beams insulated with above three types of SFRM to assess performance of SFRM under dynamic loading and also to assess the effect of strain rate on cohesive zone properties.

A fracture mechanics-based numerical model, that can simulate crack initiation and propagation at the interface of steel and fire insulation, is developed in ANSYS and LS-DYNA for low and high strain rate loading conditions, respectively. The numerical approach is validated against both material and structural level tests. The validated numerical model is subsequently applied to quantify the effect of critical factors governing delamination phenomenon namely, fracture energy, elastic modulus and thickness of SFRM.

Results from parametric studies under static loading were utilized to identify the critical factors governing delamination of fire insulation from steel structures. Further, these results formed the basis for defining a delamination characteristic parameter that incorporates material-related governing factors in a single parameter and maintains interdependency between them. Results obtained from parametric study under impact loading is also utilized to estimate the dynamic increase factor (DIF) on fracture energy at the interface of steel and SFRM. Eventually, the delamination characteristic parameter is modified to capture differences in the nature of seismic and blast loading conditions, i.e. the way the stresses are transferred to the interface of steel and SFRM.