



## Vulnerability of fire protection and structural safety of tall buildings

**Markus KNOBLOCH**

Dr., Civil Engineer  
ETH Zurich,  
Zurich, Switzerland  
*knobloch@ibk.baug.ethz.ch*

**Mario FONTANA**

Prof. Dr., Civil Engineer  
ETH Zurich,  
Zurich, Switzerland  
*fontana@ibk.baug.ethz.ch*

**Elio RAVEGLIA**

dipl.-Ing., Civil Engineer  
ETH Zurich,  
Zurich, Switzerland  
*raveglia@ibk.baug.ethz.ch*

**Andrea FRANGI**

Dr., Civil Engineer  
ETH Zurich,  
Zurich, Switzerland  
*frangi@ibk.baug.ethz.ch*

### Summary

Based on experimental and numerical studies on the influence of local failure of structural fire protection on the fire resistance of structural steel members the paper analyses the vulnerability and robustness of fire protection and their consequences for tall buildings. Even small areas of missing protection distinctly decrease the fire resistance of structural members. For extreme events, like earthquake, impact or explosion followed by a subsequent fire, the vulnerability of fire protection is important for the structural safety of tall buildings and avoiding progressive collapse.

**Keywords:** tall buildings, progressive collapse, robustness, vulnerability, fire measure.

### 1. Introduction

Tall buildings often require structural fire protection to achieve adequate fire safety. Structural fire protection markedly decelerates the heating of the load-bearing structure by insulating the member. In particular, steel structures usually necessitate fire protection to avoid structural failure in case of fire. The vulnerability and robustness of fire protection are used to describe the probability of failure related to the direct consequences (damage to the fire protection) and indirect consequences (increased heating of the structural member). Accidental actions like impacts, earthquakes, and explosions may cause partial damage or even loss of fire protection. Missing protection may also be the result of improper application or removal in the area or connections and installations. Local damage of the fire protection leads to increased heating of load-bearing members in case of subsequent fire and may decrease the fire resistance of protected structural members increasing the risk of structural failure. Current fire design methods do not consider damage of fire protection caused by extreme events. Additionally, design rules often neglect causal relations of extreme events, like fire after earthquake, impact or explosion.

### 2. Consequences of local damage of fire protection on the structural behaviour

The fire behaviour of steel structures with partially missing protection was experimentally studied by a series of small-scale tests on steel plates with intumescent coatings. Intumescent coatings are directly applied to structural steel members and have an attractive architectural appearance. During heating, the coating expands and forms an insulating layer reducing the temperature rise of the structural member. The fire tests showed that only very small areas of missing protection closed up during the forming of the layer. Hence, almost the gross area of missing protection caused by improper application, removals or even accidental actions must be considered for the fire resistance. The consequences of local damage of fire protection on the fire resistance of steel columns were analysed by numerical studies. The studies showed the decisive influence of a partial damage of the fire protection on the fire resistance of structural steel members. Even if only small areas of fire protection are removed from the columns, a significant reduction in fire resistance was observed.

### 3. Vulnerability and robustness of fire protection and consequences on the design of tall buildings

The vulnerability and robustness of fire protection are important for the structural safety of buildings. The use of fire protection possessing low vulnerability helps avoiding damages that may cause increased heating and failure of structural members. For the exposures to the fire protection and its vulnerability, it is useful to distinguish the following stages: construction, use, and accidental action. Fire can occur during all stages. However, the probability of fires that immediately follow the damage of the fire protection during construction and use is low compared to subsequent fires after accidental actions. Quality control after construction and periodical inspections and repair of damaged fire protection hence positively affect the safety of the structure and reduce the risk of structural failure of protected structural members subjected to fire during use (Fig.1). Fire after earthquake and especially after impact or explosion, however, is neither independent from the preceding accidental action nor uncommon. A fire after accidental action has the potential to cause progressive collapse. Accidental actions may, first, decrease the remaining structural resistance due to partial damage of the load-bearing structure, secondly, cause partial loss of fire protection decreasing the fire resistance of the remaining structural members, and thirdly, cause subsequent fire. For tall buildings, it is of particular importance to prevent progressive collapse to fulfil the fire safety objectives (safety of occupants, fire brigade, neighbours and their property; limitation of financial loss; protection of the environment). Progressive collapse of tall buildings would lead to large indirect consequences (fatalities, property loss, business interruption...).

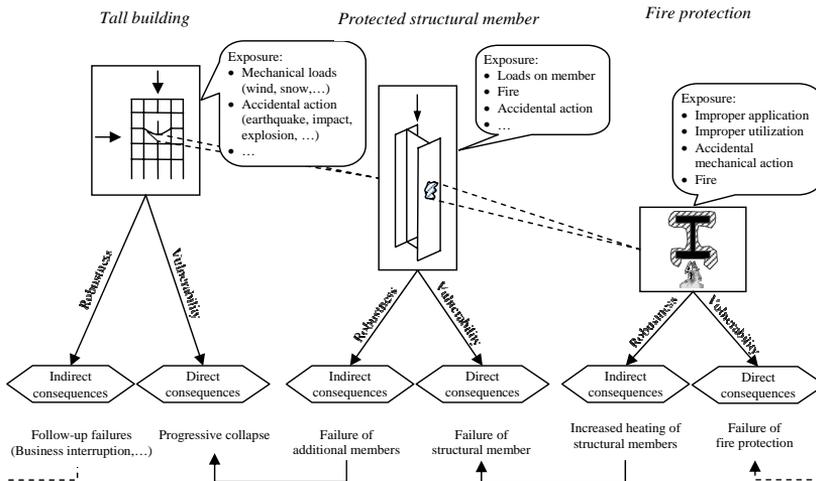


Fig.1 : Generic system characterization for buildings exposed to accidental action and fire.

### 4. Conclusions

The vulnerability of fire protection is an important indicator for the risk of increased heating of structural members subjected to fire. Locally missing fire protection distinctly decreases the fire resistance of structural members increasing the risk of structural failure. Therefore, the use of fire protection resistant to mechanical action and periodical inspections and repairs are important for the structural safety in fire. Fire after accidental action, like earthquake, impact and explosion are not uncommon and may lead to progressive collapse. Progressive collapse must be prevented to fulfil the fire safety objectives. Fire safety strategies for tall buildings shall consider the vulnerability and robustness of all kind of fire safety measures, such as protection, sprinklers and means of escape.