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A case study of fires in structural elements

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Abstract. Several severe fires in structural elements, or so-called "structural fires", have occurred in Sweden in recent years. In order to study this phenomenon, a dozen fires in structural elements have been studied in a recent project. This paper provides a description of the characteristics of "structural fires" and examples of how such events can be managed and limited. Constructional fire protection, rescue service response and fire development are the three main factors that control the outcome of structural fires. However, there are several underlying and more specific factors affecting the outcome of each fire.

1. INTRODUCTION

Fires in buildings can be divided into three different categories depending on the characteristics of the building and the area in which the fire starts and develops (see Fig. 1) [1]. The first category: "Fires in structural elements" involves fires that start in, or spread to, a structural element e.g. inside walls, attic space, facade or roof. The second category: "Compartment fire" involves fires that start in, or spread to, enclosures where a hot-gas-layer can form as the fire develops. The temperature throughout the hot-gas-layer will be rather homogenous due to the stirring of the hot gas by the fire. The enclosure can, however, be so large that it is not reasonable to assume that a homogenous hot-gas-layer will form, and this is the last category is referred to as "Fires in large enclosures". The terminology might create a bit of confusion because "Fires in large enclosures" are also fires in compartments but the "Compartment fire" is considered to be an established concept that refers to a model of fires in small- or medium-sized enclosures (e.g. residential rooms, cellular offices, or small industrial units) and therefore, that terminology is used in this paper.

The three categories constitute an idealization and the categories will of course overlap and it is possible that several categories may be included in the same fire, e.g. a compartment fire can spread to a structural element, like the façade, or vice versa.

Several devastating fires in recent years have created an attention to fires in structural elements, so-called "structural fires", in Sweden. Fires in structural elements can lead to an extensive damage and in many cases a totally destroyed building. In a Canadian study [2] the severity of 120 fires in apartment buildings were studied and categorized based on where they started as: compartment fires, concealed fires and exterior fires (which included façade fires). Ten per cent of the compartment fires in the study spread to another fire compartment or to the exterior of the building through window openings. The concealed fires did spread in 56% of the cases to other concealed spaces or to a compartment.

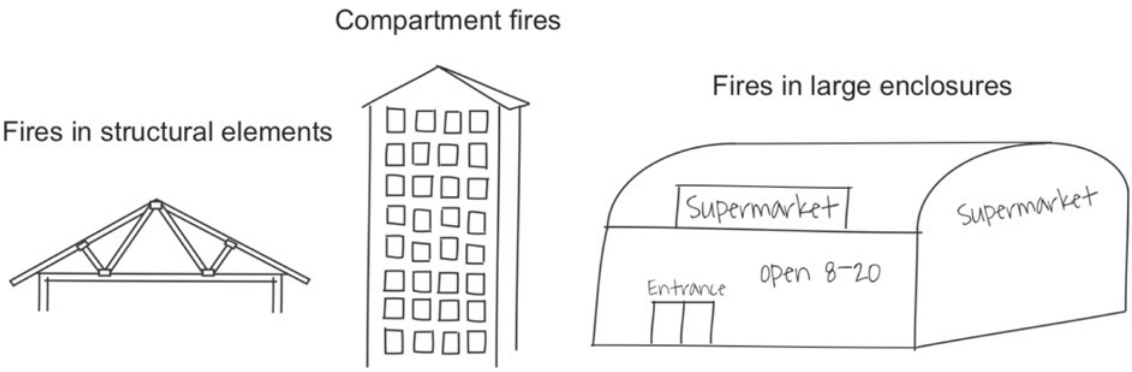

Figure 1. Different categories of fires in buildings. Based on an illustration in Johansson [1].

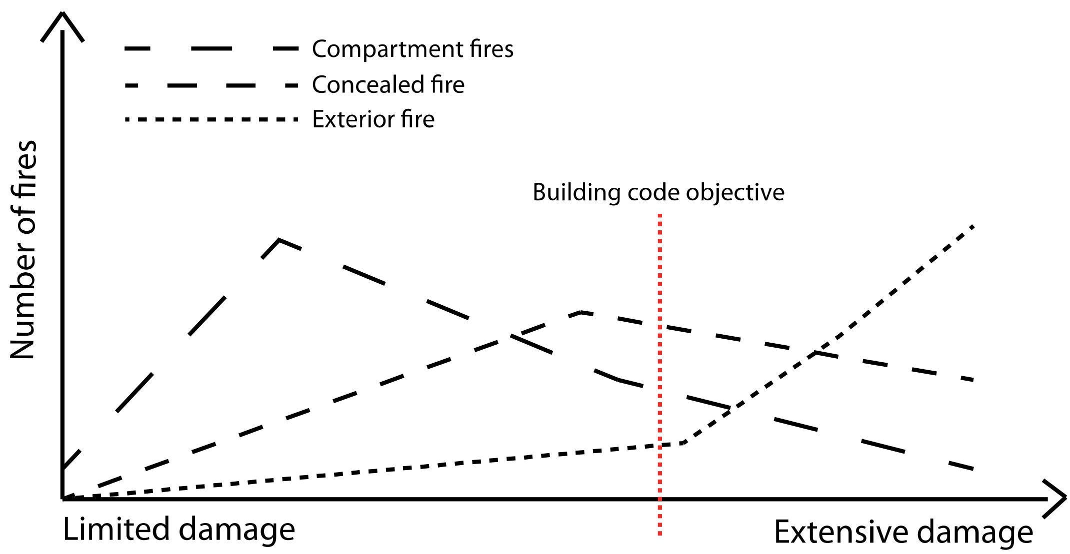

Figure 2. Schematic representation of the results from the study by Senez, Calder & Li [2].

The exterior fires did spread in 92% of cases to more than one floor, and in several cases all the way up to the roof of the building. The Canadian study is limited to 120 fires, but it indicates that the concealed and exterior fires (both are included in the fires in structural elements category in Fig. 1) more often will result in larger fire damage and property losses compared to fires in compartments.

The concept of "fires in structural elements" is not clearly defined but it has been used to describe fires inside walls, floors, crawl attics, roof structures etc., i.e. in concealed spaces areas where it is difficult easily detect and observe the fire. This type of fire is radically different from the well-ventilated compartment fires. A lot of effort has been put into research on how various objects burn, e.g. the size of the heat release rate and the combustion products [3, 4] much of this research has also been focused on fires with good supply of oxygen [5]. Fires in concealed spaces are different, since the fire is restricted, the volume is smaller and oxygen supply is limited. A fire in a normal room usually burns with flames while a concealed fire generally smoulders. If fresh air for some reason, flows to the concealed fire (e.g. if parts of a roof collapse) it can flare up. Well-ventilated compartment fires are different from ventilation limited concealed fires; consequently, the models that are used to describe compartment fires cannot be used for concealed fires.

Exterior fires can also be included in the term "structural fires". Although it is not as common in Sweden as concealed fires but there are several international examples of fires in tall buildings where vertical flame spread occurred rapidly along the façade [6]. In a comprehensive case study [6] funded by the Fire Protection Research Foundation has some twenty facade fires in high-rise buildings been included. Some of the conclusions from the case study were:

- Extensive facade fires often result in extensive property damage, but rarely in any fatalities.
- The events occur more frequently in countries with insufficient or no rules on combustible materials in facades at times when the buildings were erected.
- An internal fire (compartment fire) that spread to the outside of the building is the most common initiating scenario for exterior fires.
- Falling burning materials can pose a great danger and contribute to the spread of fire downwards.
- U-shaped facades (such as glass-enclosed balconies that creates a corridor vertically along the facade) presents a risk of fire spread faster than on flat facades.
- Extensive facade fires occur more frequently during construction and before the building is taken fully into operation.

The damage after a fire is related to direct fire and smoke damage, and also to water damage. The water damage may be due to the rescue effort but can also have other causes, e.g. rainwater after a roof fire or water from water pipes that for some reason burst during the fire [7].

There is no good overview of the phenomenon of "structural fires" in Sweden. One reason for this can be that the collection of fire statistics are based on the compartment fire concept that the fire starts in a object inside a room and spreads to other objects in the room of origin or other rooms in the building, "structural fires" fall outside of this description. The circumstances differ between these two categories of fires and the models that are used to describe and predict compartment fires cannot be used on fires in structural elements.

In summary, there is a lack of knowledge about "structural fires" and it is important to study such fires in order to clarify why fires in structural elements in general causes larger property losses than compartment fires. There is a lot of data, in terms of fire investigation reports, that can be studied, and a structured study of previously occurred fires in structural elements could be used to identify measures to prevent or limit the impact of future fires in structures. Therefore, a number of actual fires in structural elements are studied in this paper with the objective to clarify what factors that contribute to the extensive fire damage in some of these fires.

The research presented in this paper has been conducted within a project on fires in structural elements. The paper is a summary of a report [8] written in Swedish.

2. METHOD

A number of occurred fires in structural elements in various types of buildings are studied in the paper with a case study methodology developed previously by the authors [9]. The basis of the methodology is to conduct a systematic review of several actual events in order to identify underlying problems or faults that have led to a certain unwanted event (see Fig. 3). The method consists of the following six steps:

1. Define the problem
2. Interviews and literature review
3. Specify problem
4. Select events

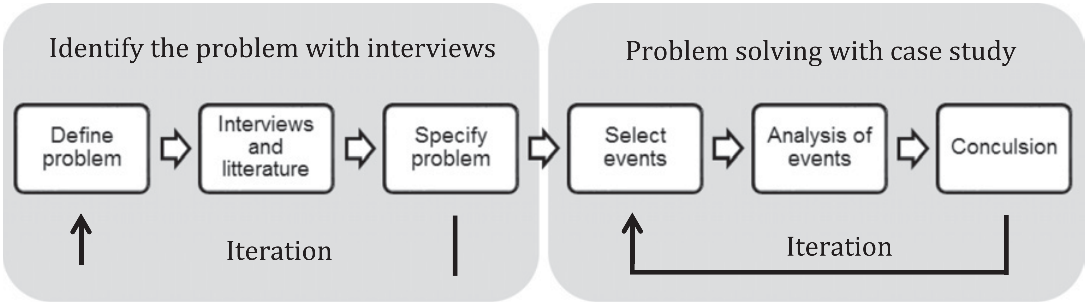

Figure 3. The six different steps in the method used in the paper. The method is based on a method presented by Johansson et al. [9].

5. Analysis of events
6. Conclusions.

The first three steps are essentially used to refine and specify the characteristics of the events that are relevant to study. In the first step the problem is defined. How the problem is formulated depends on the information that is available, and it can be rather vague when little information is available. In this paper the problem is related to “structural fires”: how they are defined, begins and develops. In step 2 more information is gathered in order to refine the problem. In this study interviews with different stakeholders was considered as the best option in order to gather more information. Semi-structured interviews were performed with people at the Rescue Service in Gothenburg, a representative for the Swedish Contingency Agency and a representative from The Swedish Fire Protection Association. The results from the interviews made it possible to specify the problem (step 3). In this study the first three steps are used to clarify and define what a fire in a structural element is and how it behaves.

In step 4 a number of events are selected in accordance with the problem description. In step 5, *Analysis of events*, the material for each event is studied. The material consists of fire investigations from the rescue service and information (newspaper articles and photos) about the event found on the Internet. Each event is analysed in regard to the fire development and the behaviour of the building in a fault tree. In a fault tree analysis a deductive systems analysis is conducted [10], based on a certain outcome of a system (successful or unsuccessful). Fault tree analysis starts with specifying the outcome and then identifying factors or events that have or may have contributed the outcome. Two types of so-called gates can be used in the fault tree, namely “and”-gates (more than one component needs to occur) and “or”-gates (only one of several components are necessary). An example of a fault tree is presented in Fig. 4.

The results of the analysis of the individual events are combined in Step 6 to find common underlying factors. The common parts for the events are included in a new fault tree where elements common to all studied the fault tree are presented (see Fig. 5). If the conclusions are not considered to be sufficiently substantiated step 4 and 5 can be repeated. Additional events may reinforce or complement the conclusions and this iteration is repeated until the findings are considered to be sufficiently robust.

3. RESULTS AND DISCUSSION

People from three different stakeholder organisations in Sweden was interviewed and a dozen events, which occurred between 2012 and 2014, was studied and analysed thoroughly with the case study approached presented in the method section.

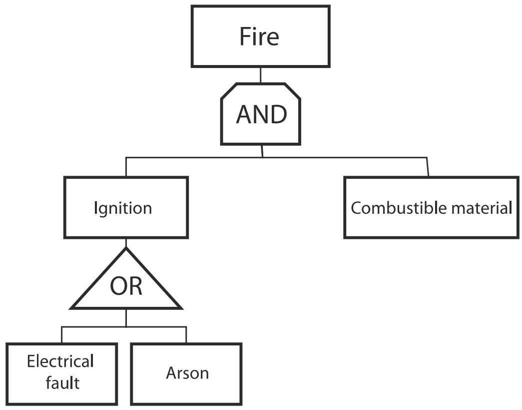

Figure 4. Example of a fault tree.

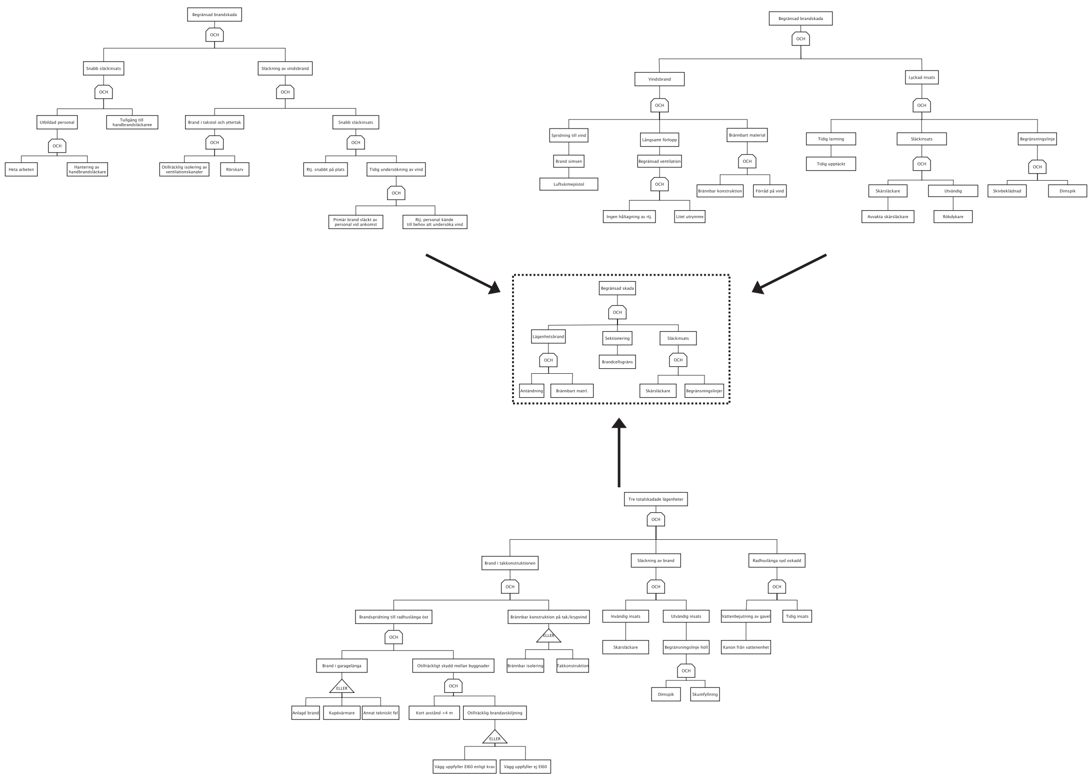

Figure 5. The end result of step 6 is a fault tree (centre) which provides a schematic representation of the features common in the studied events.

3.1 Characteristics of structural fires

Based on the conducted interviews conducted and the case study the following two types of fires can be included in the term structural fires:

- Hidden fires
- Fires in building materials.

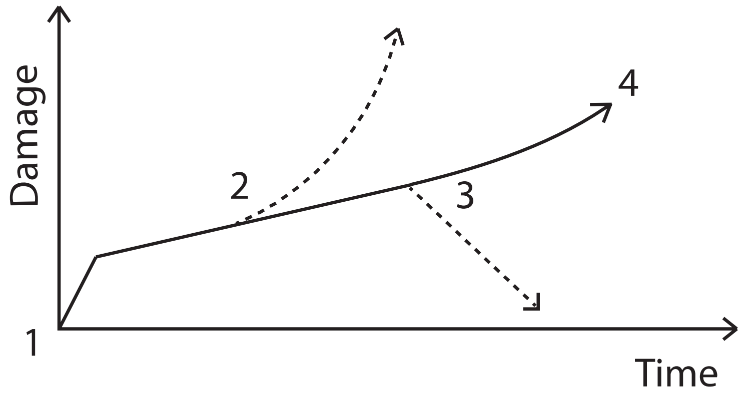

Figure 6. Illustration of fire damage over time for a fire in a concealed space.

Concealed fires include fires in composite structures such as walls, ceilings and roofs. In a composite wall with an air gap, a so-called chimney effect can occur if the ventilation is good [11]. The concealed fires are difficult for rescue services to access and extinguish. Fires in building materials are fires in linings inside the building and materials on the exterior, i.e. fires on the walls, ceilings, floors, facade and roof.

Fires in building materials in a room (e.g. a wall) differ from fires in loose furnishing but the fire development will go through similar stages as the typical compartment fire (growth, flashover and flashover), this type of fire are therefore not covered by what is commonly referred to as structural fire. When it comes to fires outside the building such as roof or facade fires there will be a good supply of air, the fire will also be influenced by external conditions (e.g. wind speed and direction). External fires are therefore very different from compartment fires and fires in concealed spaces. These different types of fires should not be lumped together because they are different due to the different conditions and fire dynamics.

Based on the results from the interviews it is considered that fires in concealed spaces is what usually is referred to when the term structural fires is used. A fire in a concealed space can be schematically described as fire damage as a function of time as presented in Fig. 6.

In Fig. 6 is a general description given of a fire in a concealed space. The fire starts in the concealed space (point 1); it can be initiated by e.g. heat transfer from a hot pipe or duct, from electrical installations or due to fire spread from a compartment to the concealed space. The concealed space is small and the amount of air is limited, which means that the fire will become ventilation controlled quickly. The extent of the damage is increasing, but not as fast as if there would be a good supply of oxygen. If the enclosure breaks (e.g. if there is no fire rating on a supporting structure) or openings to the fire are created by the rescue services, air can flow in and the fire can flare up (point 2). This can lead to a chimney effect in the construction and fire spread to more areas in the building, causing the amount of fire damage to increase rapidly. If the space is intact, the rescue services can intervene by supplying a extinguishing agent, e.g. with a cutting extinguisher or piercing nozzle, without the fire flares up (point 3). If the fire is allowed to grow, the enclosure will eventually collapse and the more air will flow to the fire, which will mean that the extent of the damage will increase faster (point 4).

The time scale of fires in concealed spaces is difficult to assess because it will be dependent on several factors such as the supply of air (oxygen) and the material burning. But, the fire development and damage progression can in general be expected to be slower than what in a compartment fire.

Based on the above reasoning, structural fires are considered characterized by the following:

- Fire inside a building structure (e.g. attic, ventilation gap)
- Difficult for the rescue services to access the fire
- Under-ventilated fire
- In many cases, slower fire development compared to compartment fires.

3.2 Case study of structural fires

A feature in the studied events is that structural fires with extensive fire damage occur if the fire development is severe and there have been shortcomings in fire barriers (fire separations) or in the rescue operations. Based on the events with extensive damage there are clear indications that problems in the structural fire protection or rescue response often are an underlying reason for the extensive damage. In several of the events the rescue service had problems getting the situation under control.

In cases where there were problems with fire separations in the building it has been due to the building did not met the building regulations in some aspects or that the building regulations were not sufficient to avoid extensive fire damage. The latter is mainly because the main objective of the Swedish building regulations primarily is and has been on life safety and secondary on property protection.

In all studied cases of structural fires with extensive fire damage, the fire started as a compartment fire (normally on the stove in the kitchen or in a living room). The fire then spread to a concealed space, e.g. through a window to the attic or to the roof structure through inadequately insulated ventilation duct. In cases with extensive fire damage there is often an uncertainty about the functionality of the fire separations, i.e. if the defect was caused by incorrect installation or if a tested and properly installed fire separation according to the regulations was insufficient.

A prerequisite for the occurrence of a structural fire is that there are flammable construction materials in the building structure. A structural fire would not occur in incombustible structure. But it is often not an alternative to construct a building of flats in totally non-combustible materials, e.g. wooden roof structures are often used in concrete buildings.

If the structural fire has spread to a second fire compartment when the fire service arrives on site, it will often take more time before the rescue service gets the situation under control. A rapid fire growth or a late call to the rescue service will result in that the there is less time take measures. The size and growth of the fire is controlled by the amount and type of combustible material and the ventilation conditions. The situation when the rescue service arrives will determine the possibilities to tackle the fire. If search and rescue of missing people is required the structural fire can spread further before full attention can be given to fire fighting measures. In about half of the studied structural fires with extensive fire damage lifesaving measures were taken initially.

In a majority of the studied events the rescue service was undersized. More personnel or other equipment (such as cutting extinguishers) in the early stage would most likely have reduced the fire damage. It is explicitly stated in some of the fire investigations reports that if cutting extinguisher had been in used, the outcome would have been different. Another aspect is that the rescue service sometimes failed to interpret the building construction, which may have affected how the resources (personnel and equipment) were allocated and used during the operation.

Knowledge and experience of the rescue service is something that emerges as an important part of a successful operation. This is not identified on the basis of the individual events but it is something that is perceived as an important success factor in the structural fires with limited damage. Good knowledge of the building construction and fire protection (e.g. fire separations) is important. Knowledge of fire dynamics is also a essential for a successful rescue service operation; such knowledge can be used to e.g. predict the fire behaviour and thereby to apply the most effective actions to extinguish the fire.

The factors and actions behind a successful management of a structural fire are in many cases not present in the studied structural fires were the outcome was an extensive damage. That the identified success factors are missing in the events with extensive damage are considered to strengthen the results.

4. CONCLUSIONS

A schematic representation of fires in concealed spaces is presented in this paper. The model is simple, but it constitutes a first step to represent structural fires. However, further work to create models, which can lead to a better understanding of structural fires, are considered necessary.

The events studied in this work can be divided into two categories: structural fires that resulted in limited damage and structural fires that resulted in extensive damage. Conclusions have been drawn in regard to each category. Constructional fire protection, rescue service response and fire development are the three main factors that determine the outcome of structural fires and these appears to be important in all the studied fires. However, there are several underlying and more specific factors affecting the outcome and these have been identified for each studied fire. The result is based a dozen events and it is not possible to generalize the result completely, but the results are considered to have a good validity because the identified failures as well as success factors reappear in the studied fires.

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