Fire protection of steel structures using sprinkler systems

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ABSTRACT: An experimental research program has been carried out in Finland in order to study the cooling effect of two different sprinkler systems. The aim was to study how the temperatures develop in fire situation, when there's a sprinkler system present. The aim is to have the possibility to use unprotected steel trusses, beams and columns within a certain limit when a certain kind of sprinkler network is installed.

The research was based on fire tests done in a small building built from steel structures. The study consists of different sprinkler systems. One is a traditional sprinkler system and the other is a hi-fog sprinkler system using a lot less water than the previous one. In addition a research was carried out to investigate the cooling effect of Early Suppression Fire Response sprinklers (ESFR). The gas temperature was tried to follow the standard fire curve and the temperatures from the surrounding structures were studied. In the paper the results will be presented as well as a comparison to theoretical calculations done with fire simulation.

1 BACKGROUND

1.1 *Requirements*

It is very common to have a 1 hour fire resistance requirement to load-bearing structures in typical buildings in Finland and also in other European countries. To fulfill this requirement using steel structures needs normally passive fire protection, e.g. intumescent coating, gypsum or other boards to cover and protect the structure. These are naturally simple ways of achieving the fire resistance, but there are also some problems with these.

1.2 *Objectives*

The aim of this research was to study whether the cooling effect of normal and also the hi-fog sprinkler systems is enough to ensure the temperatures of steel structures to be so low that there is no need for passive fire protection. Also the so called ESFR sprinkler system was studied. It is known that automatic water suppression also keeps the fire local in most cases when functioning properly, (Hietaniemi et al. 2005).

The fire protection is always expensive whether it is done by passive or active measures. That is why there's also a financial benefit when either of these can be totally or partly left out. The sprinkler system is more important when talking about protecting the people, which of course is more essential than the building itself. Naturally in some cases the passive protection is more reasonable than using active measures.

When the automatic water suppression is required to the building for common fire safety reasons, the use of it also as structural fire protection can be very cost-effective, still not risking the life safety of the occupants or users of the building. When the fire sprinkler system is designed, installed and maintained properly, the risk that it won't work is very little, (Hietaniemi et al. 2005). As it is known the sprinkler systems are required in certain types of buildings with certain criteria. This differs from country to another, even within EU countries.

1.3 *Legislation*

In some countries the structural fire resistance can be lowered when the fire sprinklers are present. Almost in every country some other benefits in fire safety design can be gained, e.g. bigger fire-compartments, compromises in smoke extraction etc. This is also the case in Finland and especially the fire-compartment size is a normal compensation. The Authorities can then decide whether the water suppression system can also be used to lower e.g. the structural fire resistance requirements. These differences in various countries and different building types can be seen from the next Table taken from the European Sprinkler Organization's homepages, (www.eurosprinkler.org). This is just a clip of the original table, which covers more countries and building types. As can be seen e.g. in Germany the Fire rating can be lowered 60 minutes, which is actually one aim of this study also.

Table 1. Summary of Legislative Incentives for Fire Sprinklers. Part of the original Table from www.eurosprinkler.org.

Summary of Legislative Incentives for Fire Sprinklers
Construction Alternatives are in red

	Major airports sprinklered?	Places of assembly	Shopping Centres	Industry	Warehouses
Austria	No			Larger compartments.	Depends on height and st goods but generally requ sprinklers >1800m^2
Belgium	Yes		>2,000m^2		
Czech Republic	No	Exhibition halls with compartment > 5,000m^2	>1,000m^2	>20m^3 of flammable liquids	Postal stores >800m^2 >50m^3 of flammable liquids
Denmark	Yes		>1,000m^2 multi-floor >2,000m^2 one floor	>2,000m^2 high fire load >5,000m^2 other fire load Can increase compartment from 1,000m^2 to 10,000m^2	>2,000m^2 high fire loa >5,000m^2 other fire loa Can increase compartm from 1,000m^2 to 10,000
Finland	Yes	Unlimited compartment or halve fire rating and 25% smoke extraction	Unlimited compartment or halve fire rating and 25% smoke extraction	Unlimited compartment or halve fire rating and 25% smoke extraction	Unlimited compartme or halve fire rating an 25% smoke extractio
France	No		>3,000m^2 or with restaurant or >10,000kg paint Can increase storage of dangerous goods from 1,000m^3 to 2,000m^3		>3000m^2 and less than 60 >6000m^2 with risk assess and approval from Pref
Germany	Yes	>3,600m^{2}* or >22m high or below ground	>3000m^2 or underground floors >500m^2 60 minutes less fire resistance for walls and ceilings; no need for smoke extraction; can increase travel distance by 35m	fire load >15kWh/m^2 and >400m^2 fire load >45kWh/m^2 and <400m^2 Width >40m & structure not rated Halve fire service water needs Increase compartment area 3-10 times depending on fire resistance Increase first basement floor from 1,000m^2 to 3,500m^2; lower floors from 500m^2 to 1,750m^2 Can increase travel distances by 15m <5m high; 20m <10m high Need less smoke extraction	>1,200m^2 Storage > 7.5m high fire load >15kWh/m^2 & >4 fire load >45kWh/m^2 & <4
Hungary			>8,000m^2 >13.65m height		Double compartment s

2 TESTING ARRANGEMENTS

2.1 *Tested structures*

The fire tests were conducted in Finland in the summer of 2007 and during winter 2009. In the first series a 8mx8mx8m sized steel framed hall was constructed, the sprinkler system was installed to the ceiling and the studied steel trusses, beams and columns and other parts of the building were

equipped with temperature detectors. The outer walls were left enough open from the bottom so that there would be enough oxygen for the fire. In Figures 1 and 2 the basic geometry and the sprinkler locations of the tested system are presented. The outer walls were constructed from sandwich panels and the roof was built from load-bearing corrugated steel sheets with insulations above it. Temperatures were measured also from the corrugated steel sheeting.
Same kind of series was conducted with a slightly smaller building. In this test the normal spray and also ESFR sprinkler systems were tested. This test series is still going on and only some preliminary results can be given here.

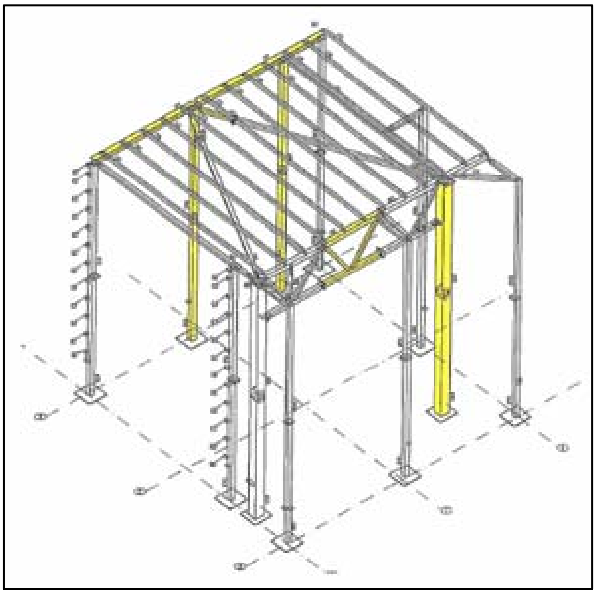

Figure 1. Skeleton of the structures

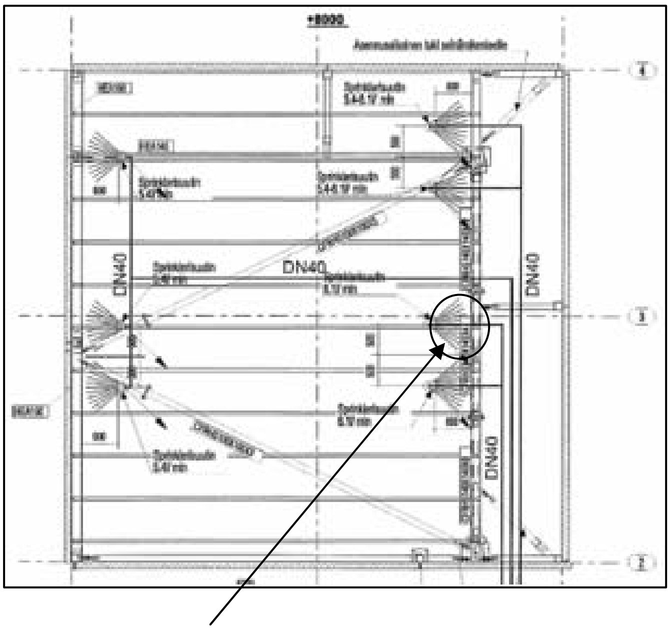

Figure 2. Sprinkler nozzles in one test

2.2 *Fire scenario*

The system was to be tested against standard ISO-fire. The fire load was produced by heptane-spray burner, which was situated centrally under the studied structures spreading the fire with three nozzles. The aim was to run the test so far, that the temperature history is enough to get the needed data for the product approval of the system. In figure 3 the temperature curve without sprinklers is presented. The test was stopped at the moment the curve was following the ISO-curve well enough.

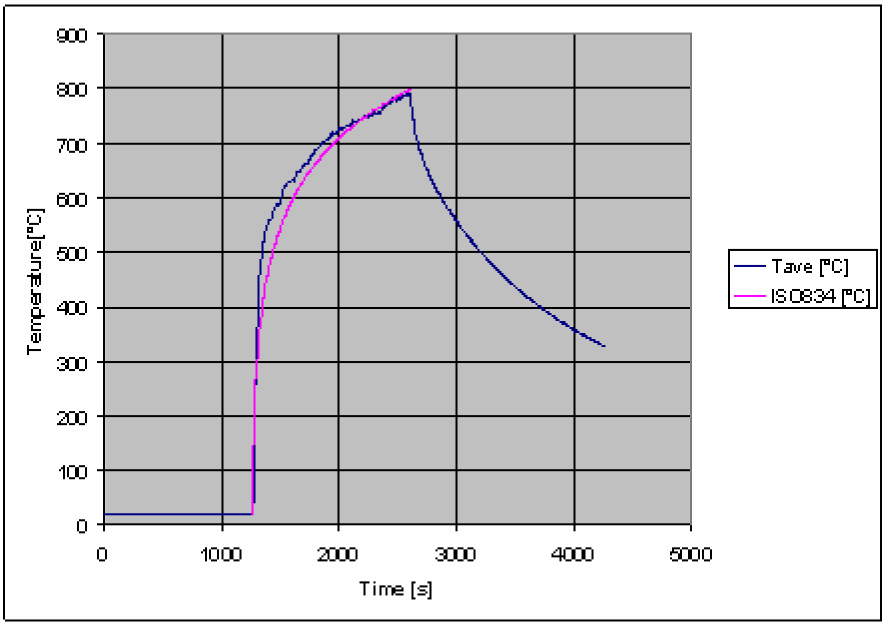

Figure 3. Temperature in the test without sprinklers.

2.3 *Tested structures*

The steel temperatures were measured from tubular steel trusses , beams and columns. Also the temperatures from the connections, bracing and steel sheeting were measured. The height of the steel truss was about 1,5m and it was built from different sized cross-sections. The temperatures were measured from different parts of the truss. The other structures were also selected so that they represented the smaller sized structures normally used, in order to widen the use of the results to bigger sections.

2.4 *Fire sprinkler systems*

Several sprinkler systems were used in the tests, a traditional water sprinkler system and hi-fog sprinkler system. Also the ESFR sprinklers were tested. The nozzles were installed with 3mx3m distances. The water flow of the normal fire sprinkler system was put to very low level in order to define the minimum water flow to the structures that would be needed for the cooling in this kind of a system.

In the hi-fog system the sprinklers produce water mist that fulfils the space and with that keeps the fire and the structures cooled during the fire. This system has previously mainly been used in cruise ships, tunnels and e.g. historic buildings, (www.marioff.com) and the aim is to begin to use this system also in wider range of buildings.

The ESFR system produces more water than the others and the system is designed to limit and put down the fire rapidly. In these tests 2 nozzles were in use.

3 RESULTS

3.1 *Temperatures*

The standard fire exposure was set by using heptane-spray burners underneath the structure system. The fire load was approximately Temperatures from the installed structures were measured during the test. For the defined set of cross-sections, the temperatures of the steel structures did not raise above critical level in standard fire exposure (TUT reports, 2007-2008).

In figure 4 the the flames in test without sprinklers is presented and in figure 5 the temperatures of the steel sheeting temperatures in test with ESFR sprinklers are presented. In Figure 4, the bottom chord of the studied steel truss can be seen engulfed in flames.

Figure 4. Freeburn test without sprinklers

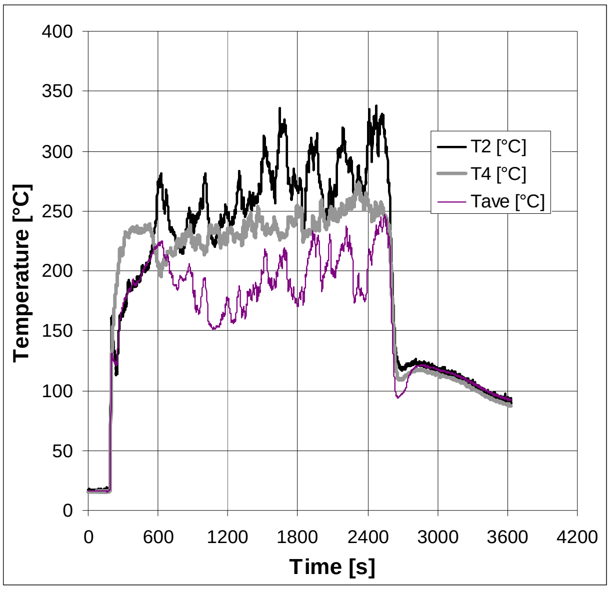

Figure 5. Sprinkler nozzles in one test

3.2 *Product approvals*

All in all the temperatures of the structures stayed at adequate level. On the basis of these tests product approvals (www.fcsa.fi) for 1 hour fire rating were got to the systems. The tests went well and the measurements were carried out successfully.

On the basis of the tests a short design guide for structural design and also for the design of the water sprinkler system was introduced. In these instructions the limitations to the structures, cross-sections, structure dimensions are set. For the water sprinklers the design principles concerning the water flow, pressure, number and location of the sprinkler nozzles are instructed. Also some advice concerning the actions that ensure reliability of the functioning of the system are given.

4 CONCLUSIONS

An experimental study concerning the fire protection of steel structures in standard fire exposure was carried out in Finland. Structural fire protection of steel structures was studied using fire sprinkler systems. Different sprinkler types were used to study the temperatures in selected steel structures.

The aim was to get fire resistance rating of 1 hour to the system and this was accomplished. The temperatures of the steel structures and corrugated steel sheeting stayed at very low level so that there is no need for additional fire protection in this kind of case.

As a result the systems got product approvals of 1 hour fire resistance. These systems will be used typically in 1-2 storey building at the moment, but the field of application will be widened in the future.

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