Application of Structural Fire Engineering, 19-20 April 2013, Prague, Czech Republic

DAMAGE CONTROL OF INTUMESCENT PAINTING
Influence of imperfections in intumescent painting

Tom Molkens [a]

[a] StuBeCo bvba, Engineering office, Overpelt, Belgium

Abstract
From daily experience we know that, after erection of a steel structure, damage often occurs on steel columns and beams due to transport and assembly work. In combination with intumescent painting it is normal practice that after some time all paintwork will be touched up and repaired if needed. The problem today is that at that most of the time, steel cladding is already placed and the external parts of columns and beams cannot be reached anymore and stay therefore (partially) damaged.
With the aid of thermoplastic calculation for some case studies, where the outer flange is partially loaded with an external fire instead of an ISO834 fire, we could define how big the damaged area may be and where it could be positioned without influence on the structural integrity of the protection. Until today the SAFIR calculations are done for a R30 protection.

Keywords: intumescent painting, damage, imperfections

INTRODUCTION

Different types of damage or even poor execution of intumescent painting can occur, so this becomes a safety risk if the location of the damage is no longer visible for inspection. Also, to avoid time delays, it is interesting for the constructor to neglect those parts. We did some research at different steel manufacturers to know what the common execution errors could be. From this research it became clear that with application of a painting system on site, completely non-visible or inaccessible areas even remained unprotected.
It is our purpose to simulate these kinds of defects in intumescent coating by means of a thermoplastic model. The scope of our study is limited to industrial buildings with R30 protection. This without counting on the intumescent effect of this kind of protection. To be quite clear; avoiding damage is still the best way forward, however sometimes you just have to deal with it.

Fig. 1. Local damage

1 REFERENCE CASE

As reference case we used an industrial building with an 18 m span, 4.5 m height and dead load set relatively low (0.30 kN/m²), with snow and wind loads according to Belgian standards. The bracing system is schemed with the aid of hollow square sections. Following first order unity check, the system is well used until 97 % (columns) of the capacity with S235 grade steel.

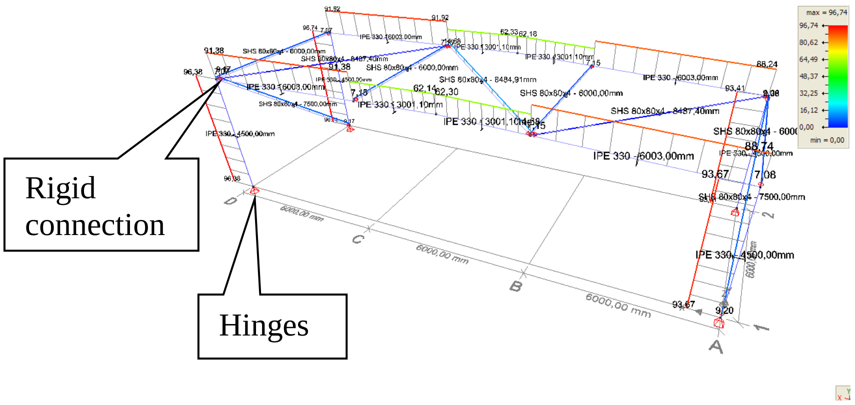


Fig. 2. Reference case, unity check at ambient temperature

2 INVESTIGATED SITUATIONS OF MISSING INTUMESCENT PAINTING

2.1 Damage pattern of local damage

Most of the damage occurs at the location of temporary support timber for storage and transport or where lifting straps are attached to beams, columns or other members. To obtain uniformly distributed stresses in the elements typically those areas are situated at $1/5^{th}$ of the total length, we have estimated them over the whole width of the IPE 330 and with a length of 200 mm.

On each beam/column we introduced a damaged part at $1/5^{th}$ of the end, in this way the initial hyper-static systems will be reduced to a kinetic one with weaker rotational springs at the referred locations

2.2 Inaccessible areas

Differently from what went before in this situation, a complete side of the steel profile will be unprotected in our simulations. This is always the outer (columns) or upper (beam) side. All other sided areas remain always protected as in the previous point.

2.3 Situations investigated

Previously, two patterns must be combined with different materials and situations. A steel roof decking profile with a height of 100 mm is always used. It is composed of a 0.75 mm thick (trapezoidal) steel profile and a 100 mm insulation layer = sandwich construction. For the wall cladding the same sandwich construction is used at a distance of 20 or 200 mm away from the column, also concrete at 20 mm distance was investigated.

Tab. 1 Investigated situations

Name	Roof material	Slit (mm)	Wall material	Slit (mm)	Supporting system
R10S-W20S	Sandwich	100	Sandwich	200	Purlins
R10S-W2S	Sandwich	100	Sandwich	20	Liner trays
R10S-W2C	Sandwich	100	Concrete	20	Panels

3 TEMPERATURE OF PROTECTED PART OF THE STEEL MEMBER

We start from the idea that the intumescent painting is a well-engineered system with no extra safety built in. Practice (Sanghoon et al. & Schaumann et al.) had already showed that in laboratory tests it seems there is always a certain safety margin in this kind of protection. However it is not our intention to take this into account.

As already applied by ourselves we simulated the behaviour of a steel IPE330 member with the aid of a tri-linear diagram. In the beginning the protection is rather low due to foam growth in an initial phase and in a second phase the rise of temperature slows down.
From measurements of the results we could define a slope ratio of 2.69 between the initial and second phase at a temperature of 250°C. Finally at the required protection time of 30 minutes the critical steel temperature of 520°C is reached by the aid of a fictive end gas temperature at the required protection time. The temperature of the steel member is calculated by the aid of the NBN EN 1993-1-2 formula.

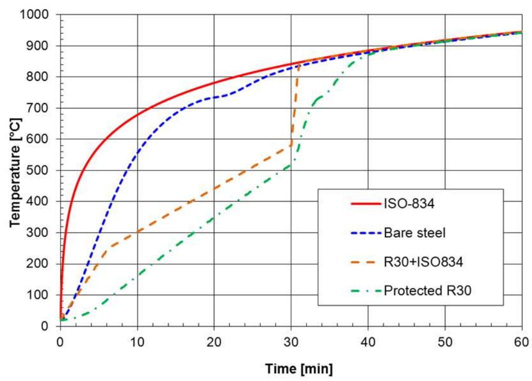


Fig. 2. Assumed tri-linear time-temperature relationship for protected steel (IPE330)

As boundary conditions for defining the curve we used 20°C at 0s, a slope ratio of 2.69 at 250°C end the fictive gas temperature which leads to a steel temperature of 520°C we can describe a bilinear curve. At the end in a time step of 60s the protection is assumed to degenerate completely so the curve fits the ISO834 one = the third part of the curve.

4 HEAT FLUX ON NON PROTECTED PART

It can be imagined that boundary conditions in the neighbourhood of roof or wall cladding are different compared to an open space. It is not at all easy to simulate a temperature profile like that of ISO834 in a numerical way. Results in the narrow space between column and inner side of the elevations (= a slit) seem to be extremely difficult. In addition this would not give any physical insight into the problem. Therefore we apply a modified heat flux on the non-protected part based on the classic time-temperature relationship according to ISO834.

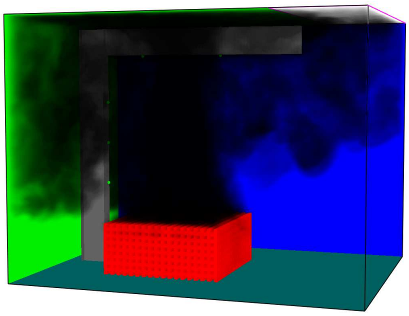
4.1 Numerical model

We built a model for a small room with two insulated borders at the sides (symmetrical boundary conditions), an open space on one end, concrete or sandwich (steel + insulation) at the other end with different spacing to a column, concrete floor and sandwich roof structure. This study was done with a fire load of wood (wooden pellets? of 1400x40x40 mm³) equal to 30 kg/m² uniformly distributed. In the following table and figures the data is shown.

Tab. 2 Materials and properties

Material	location	Conductivity (W/mK)	Specific heat (J/(kg.K))	Density (kg/m³)	Thickness (m)
Concrete	Floor, walls and columns	1,60	900	2300	0,200
Steel (profile)	Beams	50	500	7800	0,010
Steel (sandwich)	Beams	50	500	7800	0,00075
Insulation	Side + sandwich	0,05	1030	40	0,100

In this way we can check the difference between the net heat flux on the directly heated, visible part and the part which stays invisible and therefore unreachable for touch-up work. The same ratios can be applied to the ISO834 heat flux which will lead to a modified one. Measurement devices for temperature, net heat flux, convective and radiation part are located at 1/4 of the profile width (proposed to be the mean value over the width). For the column at 1, 1.5 and 2 m height, for the beam at 1, 1.5 and 2 m from the inner part of the elevation.



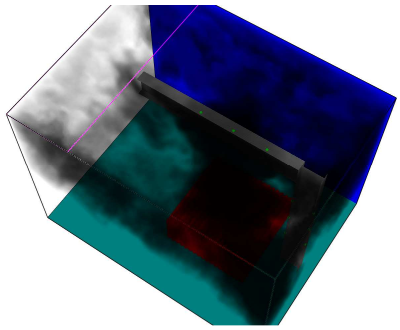


Fig. 3. Isometric view @11.3 s, R10S-W20S Fig. 4 Top view @11.3 s, R10S-W20S

Smoke particles in the figures above show already that smoke can/will penetrate the slits of 200 mm and 100 mm, this is also the case with more narrow spaces of 20 mm. From the measured results it seems that the slit at the column must be treated differently to the one above the beam:

- Most elevated temperature + heat flux and best corresponding to ISO834 is reached at 1m height for the columns and at 1.5m for the beam.
- The convective part for the columns seems to be almost negligible. This is perhaps not the most important because convection is only important in the beginning.
- For the beam the convective part is also more rapidly decreasing as in ISO834.

4.2 Determining reduced heat flux

Based on the formulas 3.1, 3.2 and 3.3 we propose to modify the net heat flux which we are going to apply to the non-protected surface as follows:

$$\dot{h}_{net,column} = \Phi_{s,c}\dot{h}_{net} = \Phi_{s,c}\left[\alpha_c(\theta_g - \theta_m) + \Phi\varepsilon_m\varepsilon_f\sigma(\theta_g^4 - \theta_m^4)\right] \qquad (1)$$

where $\Phi_{s,c}$, $\Phi_{s,b}$ general reduction factor for a slit to be applied on column or beam
For other symbols see EN 1991-1-2

Up to now we did not make a separation for the slit factor to be applied on the convective and radiation term, so we only used one general reduction term. From the numerical simulations it emerged that for our purposes, the accuracy was already satisfactory. The factor depends on time (t in s), slit (s in m) and profile width (p in m):

$$\Phi_{s,c} = \frac{1}{1+0.6\frac{p}{s}}0.2101t^{-0,3840} \qquad (2)$$

$$\Phi_{s,b} = \frac{1}{1+0.6\frac{p}{s}}2.3406t^{-0,24} \qquad (3)$$

For the beam this approach seems to be very accurate, for the column it is rather conservative due to the "over-estimated" influence of the convective term.

5 RESULTS

5.1 Temperature profile

For thermal and structural analysis we used the well-known SAFIR software (Franssen). By using this software tool for thermoplastic analysis a temperature profile is independently calculated and applied to a whole structural member. This is of course not the case for the damaged section parts. The following figures shows the differences for the three main sections used in our model, maximum temperature at 1800s respectively 535, 534 and 534°C.

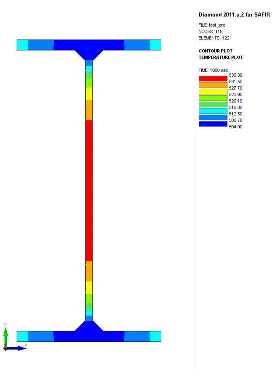


Fig. 5. Protected

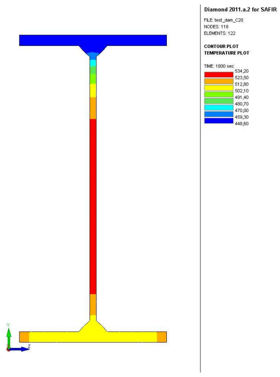


Fig. 6 Damaged, s=200mm

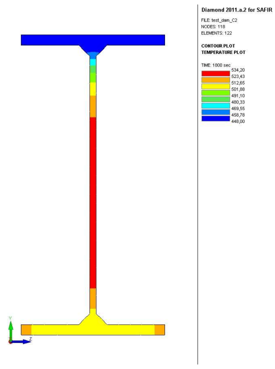


Fig. 7 Damaged, s=20mm

5.2 Structural behaviour with damage.

For a column slit of 200 mm; a maximum displacement of 44 mm is obtained after 1800s and at the failure time of 1907s, this displacement becomes 744 mm. With a narrow slit of 20 mm, those values become 77 mm @ 1800s and 2828 mm @ 1907s.

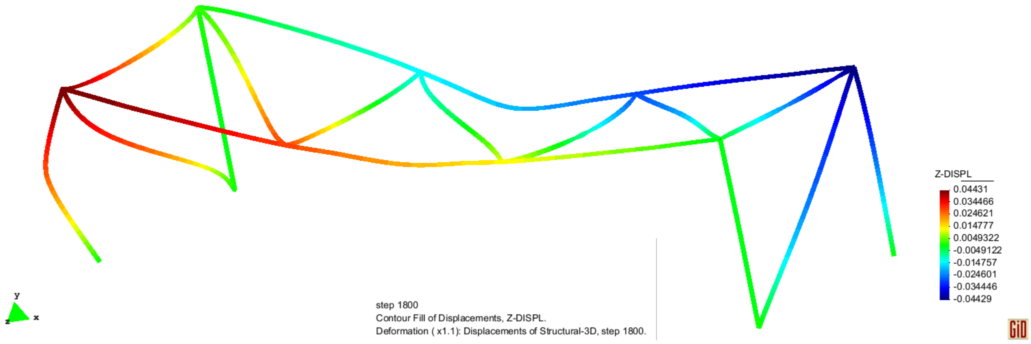


Fig. 8. Structure deformation @ 1800s, 200 mm slit for columns

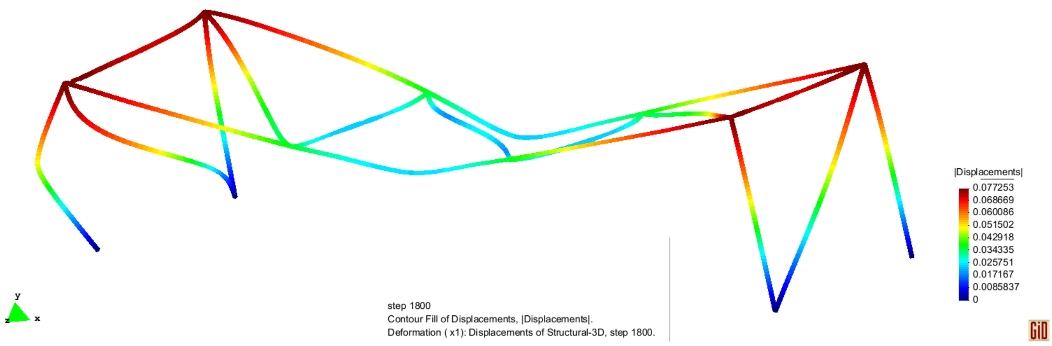


Fig. 9. Structure deformation @ 1800s, 20 mm slit for columns

5.3 Structural behaviour with unprotected areas.

For a column slit of 200 mm; a maximum displacement of 76 mm is obtained after 1800s and at the failure time of 1909s, this displacement becomes 1632 mm. With a narrow slit of 20 mm, those values become 76 mm @ 1800s and 2131 mm @ 1910s.

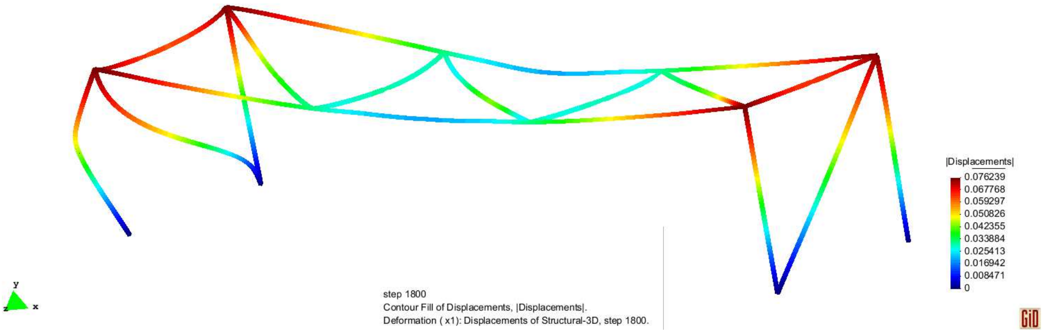


Fig. 10. Structure deformation @ 1800s, 200 mm slit for columns

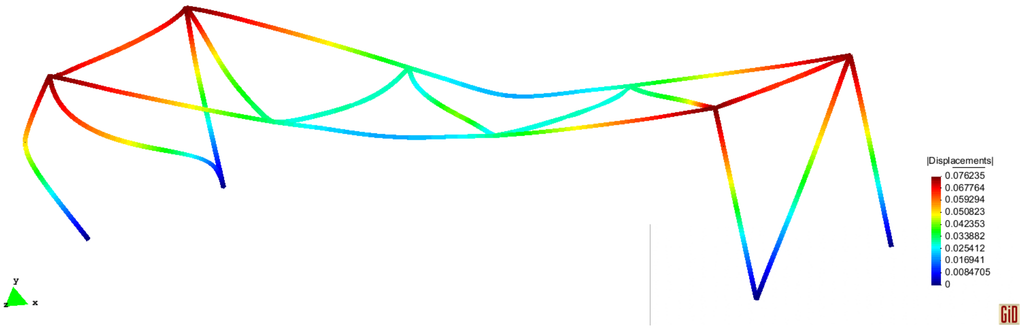


Fig. 11. Structure deformation @ 1800s, 20 mm slit for columns

6 CONCLUSIONS

With the aid of our case study it is numerically proven that the influence of a double local damage at 1/5th of the length and with a length of 200 mm has no influence on the protection time. Even with the whole surface against roof or wall cladding unprotected, we still fulfil the requirements.

The number of simulation made are still limited but the results are promising, material dependency for wider slits, differentiation from the slit factor to the convective, radiation factor must be done and also the boundary condition of this approach has to be clarified.

REFERENCES

EN 1990: 2002 + ANB; Eurocode 0: Basis for structural design, European Committee for Standardization CEN, 2002 + National application document, 2005.

NBN EN 1991-1-2 + ANB; Eurocode 1: Actions on structures - Part 1-2: General rules – Actions on structures exposed to fire, CEN 2002 + National application document, 2008

NBN EN 1993-1-2 + ANB; Eurocode 3: Design of steel structures – Part 1-2: General rules – Structural fire design, CEN 2005 + National application document, 2010

Franssen J.-M., SAFIR. A Thermal/Structural Program Modelling Structures under Fire, Engineering Journal, A.I.S.C., Vol 42, No. 3 (2005), 143-158.

Molkens T., fire resistance of partially protected steel structures, for use in industrial buildings, PLSE conference Hong-Kong 2012, 479-487.

Sanghoon H., Petrou K., Naili E.-H. & Faris A., Behaviour of protected cellular beams having different opening shapes in fire conditions, Structures in Fire 2012 – EMPA & ETH Zürich (2012), 75-83.

Schaumann P., Kirsch T. & Timmen F., Full scale fire test and numerical simulation of a steel connection, Structures in Fire 2012 – EMPA & ETH Zürich (2012), 115-124.