# STSM Scientific Report

*Eki Lehtimäki, Tampere University of Technology*

## Basic information of the Short Term Scientific Mission (STSM)

| | |
|---|---|
| COST Action: | TU0904 |
| Beneficiary: | Lehtimäki Eki, Tampere University of Technology |
| Host: | Burgess Ian, University of Sheffield |
| Period: | from 05/12/2011 to 18/12/2011 |
| Place: | Sheffield (United Kingdom) |
| Reference code: | COST-STSM-ECOST-STSM-TU0904-051211-013552 |

## Purpose of the STSM

This STSM was related to a current research project of integrating fire simulation and structural analysis at elevated temperatures together with building information modelling (BIM). Previously in the project, the commercial version of the structural analysis program Vulcan had been successfully linked with the building information modelling program Tekla Structures and fire simulation program FDS. Purpose of this STSM was to:

1. familiarise with the research version of Vulcan developed in University of Sheffield,
2. link research version of Vulcan with Tekla Structures and FDS the same way commercial version of Vulcan had been linked, and
3. carry out a case study to demonstrate the advantage of the more advanced research version of Vulcan over the commercial version.

Vulcan is a structural analysis program for analysing the behaviour of steel and composite structures at elevated temperatures, developed in University of Sheffield. Commercial version available for the industry has a user friendly graphic interface. The research version aimed for academic use only lacks the graphic interface, but has some highly advanced features that have not been implemented for the commercial version so far. Most important of these features are the static-dynamic analysis and the component method based connections. Case studies of this report concentrate on the static-dynamic analysis.

## The work carried out

On the first working day of the STSM it was found out, that the file format of the research Vulcan is rather different from the file format of the commercial Vulcan, and therefore the goal 2, linking research Vulcan with Tekla and FDS, was found to be too time consuming to perform during a two week period. Instead, all the effort was put on getting to know the program and it's features, and analysing different case studies. This way, maximum advantage of the visit was gained for the usage and possible future integration of the research Vulcan in the form of usage guidance from the program developers.

Three of the case studies examined are presented here.

## Case 1: a continuous beam and a column

An extremely simple case of a structural failure leading to a dynamic collapse phase and then to re-stabilising of the structure is a continuous beam supported by a very slender column, which will buckle at an early stage of the fire when the beam still has plenty of bending capacity left. As the static analysis of commercial Vulcan would stop at the buckling of the column, dynamic solver of the research Vulcan can go past the sudden drop of the no longer supported part of the beam and then continue the static analysis of what now is a simply supported beam.

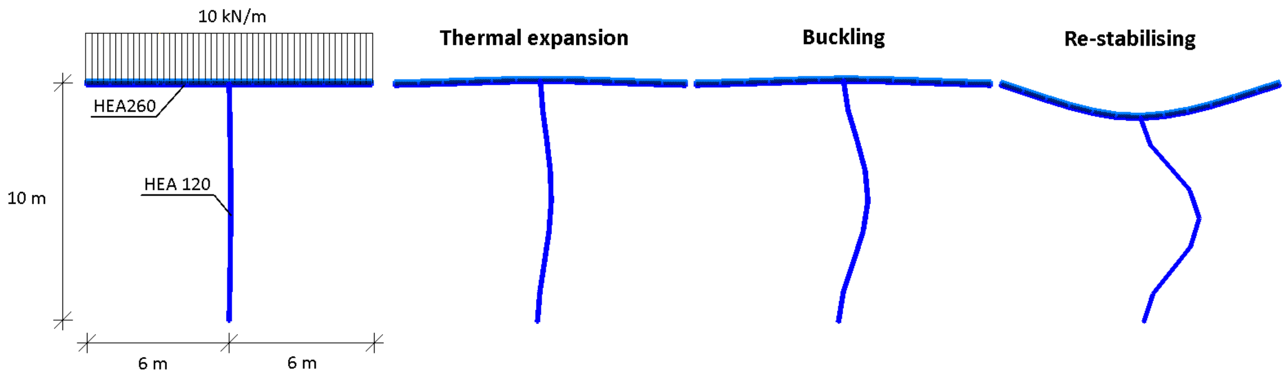


Figure 1 – The structure of case 1 and the deformed shapes at different stages of fire loading.

Figure 1 shows the structure and it's deformed shapes. Figure 2 shows the vertical displacement of the beam mid node. The column buckling is clearly visible at 390 ˚C. After dropping rapidly about 90 mm, the beam can re-stabilise because of the bending capacity it has left.

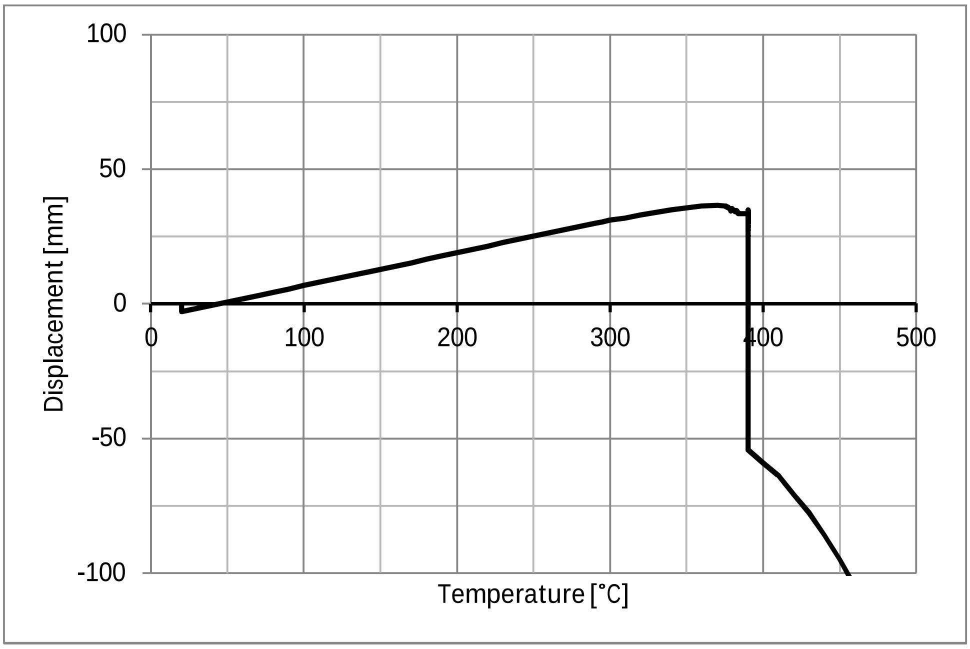


Figure 2 - The vertical displacement of the beam mid node.

## Case 2: the collapse of a steel truss in local fire

In the MSc thesis of the author, a case study of a sports hall with unprotected steel trusses exposed to a local fire was studied with commercial version of Vulcan. It was found out, that with certain fire loading the truss will fail. The static analysis of commercial Vulcan will stop at the failure of the truss, but commercial Vulcan can be used to follow the collapse of the truss with dynamic analysis.

Because the truss is statically determined, it will fall all the way to the floor, and the re-stabilising similar to Figure 2 is not likely to happen. As dynamic analysis with Vulcan is extremely time consuming, the analysis was not carried out longer than it took for some displacement to form. Results are presented in Figure 4.

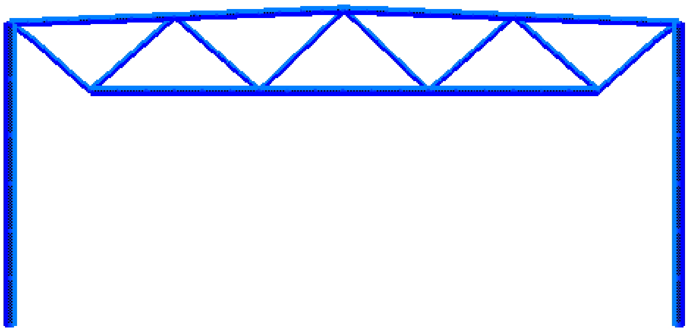

Figure 3 - Steel truss and columns of a sports hall

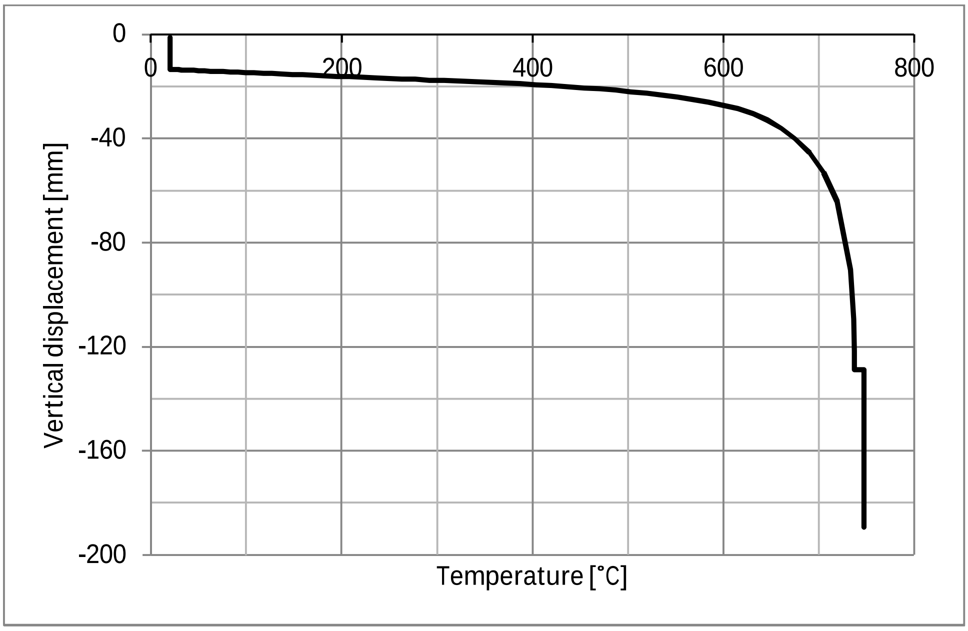


Figure 4 – Vertical displacement of the truss mid node

## Case 3: avoiding disproportional collapse in case of a roof truss failure

Steel trusses can often be left unprotected, if the fire conditions leading to the failure of case 2 can be avoided by means of fire safety engineering. Also, a failure of a single truss in local fire, the damage will remain local. If also the roof bracing is left unprotected, then bracing failure might lead to a disproportional collapse. This kind of situation was studied in the third case study.

Figure 5 presents the end of a hall case studied. A local fire directly beneath the bracing, combined with a heavy wind load, will cause the bracing to buckle. The question is, will the mid column fall, or can the surrounding columns and remaining bracing support it.

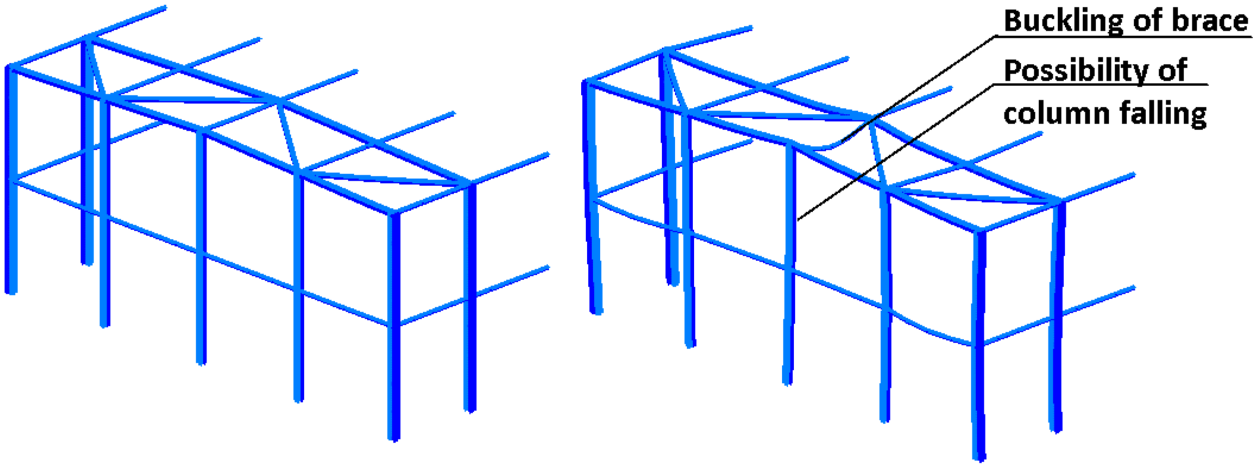


Figure 5 - Case 3, roof bracing under local fire

Static-dynamic Vulcan analysis was performed several times to this model with different simplifications. However, no reasonable results were gained, because the calculation time with an accurate model grew too long, and the simplified models were too rough for the results to be accurate.

## Main results

Main purpose was to study the possibility of integrating the research version of Vulcan with fire simulation and building information modelling programs.

On the very first working day of the STSM it was found out, that although this kind of integration has already been done for the commercial version of Vulcan, the amount of work for integrating the research version would be more than the two weeks available in this STSM. Main reason to this was the slightly different input file format the commercial and research versions of Vulcan use, so that the existing source code from links to commercial Vulcan would require more modifications than expected before the STSM.

Instead of focusing on the integration of research Vulcan, the time available was used to learning to use research Vulcan supported by experienced users and developers in Sheffield University, so that the knowledge gained would support the possible future integrating work in Tampere University of Technology research projects. Following observations were made:

- Working with the input and result files of static-dynamic Vulcan without a graphic user interface is slow, which supports the idea of constructing the input file automatically from BIM.
- Dynamic analysis is more time consuming than expected prior to STSM.
- Simplifying the model is often needed in the time-consuming static-dynamic analysis. In BIM, simplifications are not preferable. Therefore 1:1 transfer of the model may not be the best approach when integrating static-dynamic Vulcan with BIM.
- Research version of Vulcan is sensitive to a certain rules of node numbering, so the numbering of the building information modelling program may not be used as it is, but has to be modified during the file transfer. This makes the transfer slightly more challenging.
- The input of steel temperatures is different from the commercial Vulcan. Because of this, the methods of linearising and grouping temperature curves developed for integrating commercial Vulcan with FDS cannot be used in their initial form.

Based on these observations a conclusion may be drawn, that integrating the research version of Vulcan with BIM and fire simulation is possible but not trivial. Calculation time currently limits the use of static-dynamic Vulcan to relatively small models, so using BIM to easily produce complex Vulcan models is not preferable in many cases.

This STSM provided valuable understanding on the possibilities that integrating the static-dynamic Vulcan with BIM would open, and the challenges that need to be overcome in order include static-dynamic Vulcan in the integrated fire design system of Tampere University of Technology. The initial assumption, that most challenges had already been overcome when integrating the commercial Vulcan, proved false. Integrating research Vulcan is possible but requires some work.

## Future research

Based on results of this visit, next steps in developing integrated fire design system may be:

1. Implementing component method for joints, for which purpose the research Vulcan is also currently being developed for.
2. After that integrating the dynamic version, which seemed to be suitable tool especially to the study of robustness of structures in fire. Robustness of structures is very important new requirement, which still needs a lot of research to become design practise for engineers.

In both of these tasks co-operation between Sheffield University and Tampere University of Technology is necessary.