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# A Model for Predicting Thermal Response Across Steel C-Joist Floor Assemblies Exposed to Fire

Mohamed A. Sultan, Farid Alfawakhiri[1], Venkatesh Kodur and Noureddine Benichou
Fire Risk Management Program
Institute for Research in Construction
National Research Council Canada,
Ottawa, Ontario, K1A 0R6

**Abstract**

This paper discusses the development of a model and compares the temperature predictions from the model with results from 5 full-scale experimental test data. The model developed predicts reasonably well the temperature distribution across steel C-joists protected with gypsum board floor assemblies, with and without insulation in the floor cavity. Model limitations and further developments are identified.

## Introduction

With the advent of performance-based codes and fire safety design options, the need for validated fire resistance models becomes important. The fire resistance behaviour of lightweight steel C-joists floor assemblies, protected with gypsum board and subjected to axial compression load as well as to sever heating conditions, is determined by defining the thermal and structural responses of the assemblies when exposed to fire. To adequately model fire resistance structural behaviour of an assembly, a thermal model for predicting the temperature across it must be developed first. Thus, development of a thermal model precedes the development of a structural model. This is because the output temperature distributions across the assembly from the thermal model constitutes the input needed for the structural model to calculate the thermally-induced stresses and deformations as the structural model requires the physical and mechanical properties of the assembly's component at elevated temperatures.

## Thermal Model

A number of assumptions were made to reduce the complexity of the model. To predict the temperature history across a floor assembly with the cross section shown in Figure1, a finite-difference method was used to solve the heat transfer governing equations. The numerical equations for all boundaries and inside the gypsum board, insulation and plywood sub-floor boards will be given. Model simulations for insulated and non-insulated floor assemblies were carried out using the CAN/ULC-S101/ ASTM E119 time-temperature relationship. The model also can be used to predict the temperature distribution across the assembly using ISO or any other defined design fire time-temperature relationship.

## Experimental Work

To validate the model, five full-scale fire resistance tests were carried out in accordance to the CAN/ULC S-101 standard method which is similar to ASTM E119, using full design load on (4m by 5m) insulated (glass and rock fibre insulation) and non-insulated floor assemblies. Details on tested assemblies, gypsum board fell-off time and fire resistance are given in Table 1. Description of test apparatus, test procedure and construction details will be presented. The temperature measurements on the gypsum board surface facing the cavity, mid steel C-joists, joist flanges on both exposed and unexposed sides sub-floor surface facing cavity, unexposed sub-floor surface as well as gypsum board fell-off time of these tests are shown in Figures 2 to 6.

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[1]Canadian Steel Construction Council, Toronto, Ontario, Canada

## Summary

A good comparison between temperature predictions and measured temperatures at different surfaces across the assemblies tested was achieved and is presented in Figures 2 to 6. The model predicts the temperature for the joist flanges on the exposed and unexposed sides that are necessary for predicting the fire resistance of floor assemblies using the structural model that is being developed in a collaborative study between the National Research Council of Canada and Canadian Steel Construction Council. Predicted temperatures are slightly higher for steel C-joist flanges compared to the experimental measurements and are appropriately conservative for most fire safety structural model designs. Limitations of the model and future improvements will be presented.

Table 1 Construction Details and Results of Tested Assemblies

| Assembly Number | Floor Framing | Joist Spacing (mm) | Gypsum Board & Thicknes s (mm) | Insulatio n Type (fibre) | Sub-Floor Thickness (mm) | Applied Load (kN/m$^2$) | Gypsu m Board (face) Fall-off (min) | Gypsum Board (base) Fall-off (min) | Structural Failure Time (min) |
|---|---|---|---|---|---|---|---|---|---|
| 22 | LSF | 406 | 2x12.7 | Non | Ply (15.9) | 2.9 | 66 | 73 | 73 |
| 23 | LSF | 406 | 2x12.7 | Glass | Ply (15.9) | 2.9 | 59 | 63 | 67 |
| 24 | LSF | 610 | 2x12.7 | Glass | Ply (19.0) | 1.8 | 59 | 65 | 68 |
| 25 | LSF | 406 | 1x12.7 | Rock | Ply (15.9) | 2.9 | 35 | - | 46 |
| 27 | LSF | 406 | 2x12.7 | Glass | Ply (15.9)+ Concrete (51) | 1.9 | 49 | 53 | 61 |

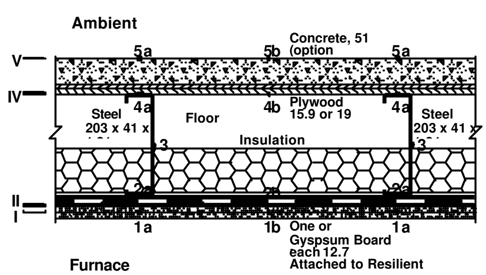



Figure 1 Cross Section

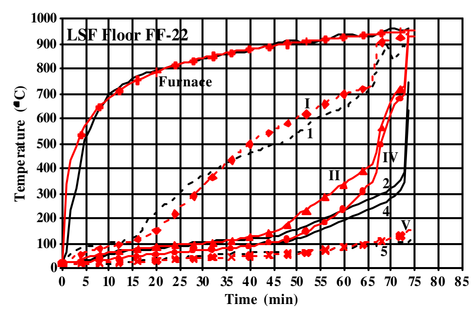



Figure 2 Temperature Distribution, model vs test

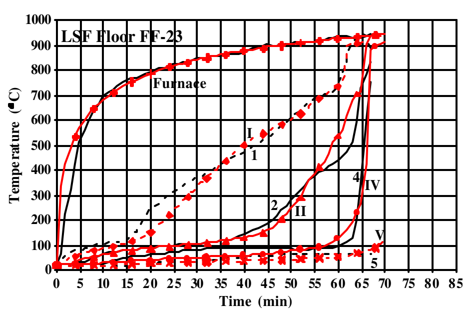



Figure 3 Temperature Distribution, model vs test

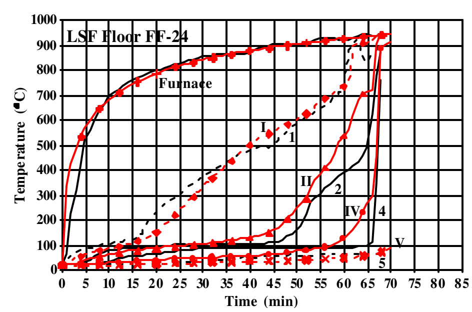
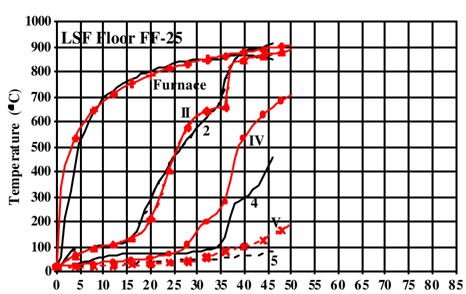



Figure 4 Temperature Distribution, model vs Test



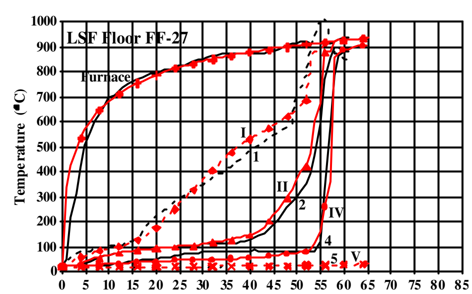



Figure 5 Temperature Distribution, model vs test

Figure 6 Temperature Distribution, model vs test

In Figures 2 to 6 above, the temperature distributions marked with number are measured and marked with Roman figures are model simulations at the boundaries shown in Figure 1.