Case Studies on different software tools for Numerical Modeling of Passive Fire Protection

Migyeong Kim*, Beomgyu Kim, Munsoo Kim, Heoksoon Lim
Korea Hydro & Nuclear Power, Central Research Institute
**Corresponding author: migyoeng@khnp.co.kr*

1. Introduction

According to the statistics for the reliability of fire protection systems, it is normally regarded that PFP (Passive Fire Protection) system shows good reliability compared to active systems [1,2]. Additionally, it has high efficiency and durability as well as minimum inspection and maintenance work are required. Therefore, in many industries, PFP system is widely used as one of the most practical way to increase the fire resistance of structure. Generally, performance of PFP system is verified by the properly performed experiments so engineers usually apply PFP based on its performance test results. However, in some cases, PFP cannot be applied as its initial design due to the constraints of space, workability, cost and other complicated reasons. In cases of low utilization against in-place load and very limited fire exposure, partially or thinly applied PFP could be acceptable if response under fire is fully assessed to ensure the integrity of the structure. To perform the fire redundancy analysis, temperature field of structural members should be determined at first and finite element tools are utilized for this purpose. In this paper, FAHTS (Heat transfer analysis module of USFOS) and LS-dyna are adopted for simulations. Considering the characteristics and functional limitations of each tool, heat transfer analysis with and without PFP are carried out. By comparing the results with analytical solution, proper modeling techniques to simulate the heat transfer analysis for each software are confirmed.

2. Numerical heat transfer analysis

2.1 Preliminary heat transfer analysis

Preliminary analysis is carried out for the purpose of input keyword test to improve the accuracy of numerical heat transfer analysis. In order to simplify the process and result evaluation of the analysis, a simple plate shown in Fig. 1 is selected as a target structure. Material of the plate is high tensile steel, and uniform heat flux from engulfing fire of 100kW/m^2 is applied for 7200s.

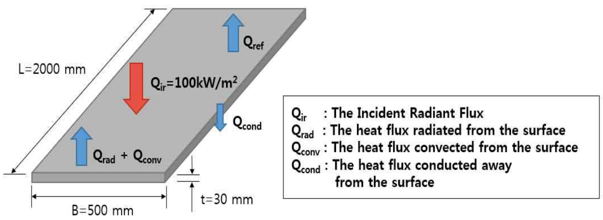

Fig. 1. Target structure of preliminary heat transfer analysis

To model the plate, beam element and quad elements are generated for FAHTS and LS-dyna, respectively. However, actually the same grid model is used for both tools because 1D element of FAHTS are automatically converted to 2D elements during calculations. Since both USFOS and LS-dyna models are composed of shell elements with one node in the thickness direction, only one surface of the plate receives heat and it flows negative direction of shell normal vector if additional option is not handled. Therefore, to implement the condition that flame engulfs whole plate, 6 analysis cases listed in below table are individually analyzed to decide the suitable keywords for engulfing fire.

Table I: Selected cases and results for preliminary analysis

Software	Case No.	Load direction	Keywords to implement	Heat flux [kW]	Suitability
FATHS	F1	One way	default	100	X
	F2			200	O
	F3	Two way	Exposure	100	O
LS-dyna	D1	One way	Thin shell	100	X
	D2			200	X
	D3	Two way	Thick shell LOC	100	O

Load direction of FAHTS module is controlled using Exposure keyword. In case of 'thin shell' of LS-dyna, heat input to both surfaces cannot be modeled so thick shell option of control card is applied. The number of integration points in the thickness direction is fully increased, and LOC keyword is additionally used to decide the direction of thermal input. Heat transfer analysis results of 6 different cases are shown below Fig. 2 to compare with the formula of Eurocode 3[3].

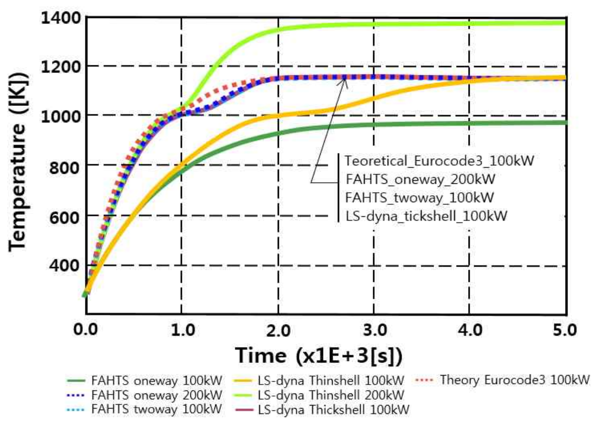

Fig. 2. Comparison of heat transfer analysis results

In case of FAHTS, the final temperature of steel plate is lower than applied flame temperature when the plate receives heat from one side, such as F1 and F2. Based on these results, it is assumed that FHATS calculates temperature rise based on the accumulated amount of heat energy. Therefore, like case F2, even if the thermal load is acting on one surface of the plate, the same analysis results can be obtained if the total energy input to the structure is equal to engulfing fire. Moreover, the results shows a good agreement with the theoretical formulas in case of F3, where thermal load applied to both surfaces of the plate.

According to the results of LS-dyna, the temperature of case D1 and D2 rise more slowly than the case of engulfing fire and final temperature of steel surface converges to applied flame temperature. Based on these results, it is concluded that one side loading analysis of LS-dyna gives more realistic result than FAHTS. For the case of D3 using thick shell option, heat transfer analysis result shows good agreement with F3 of FAHTS and theoretical formula. Therefore, in this paper, F3 and D3 cases are adopted to model engulfing fire in later heat transfer analysis for FAHTS and LS-dyna, respectively.

2.2 Heat transfer analysis without PFP

To compare the results of heat transfer analysis of FAHTS and LS-dyna in detail, a cable tray shown below Fig. 3 is generated. No PFP is coated for the structure and all bare steel members uniformly receive heat flux of 100kW/m^2. In some local area, total 450kW/m^2 thermal load is applied by adding local flux of 350 kW/m^2. Among 5 monitoring points marked in Fig. 3, temperature histories of 2 points are shown below Fig. 4 and Fig.5 to check the validity of the analysis result.

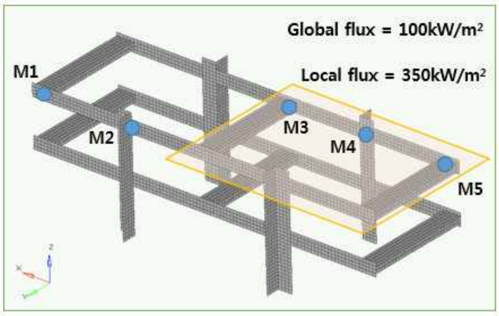

Fig. 3. Global/local heat flux and selected monitoring points

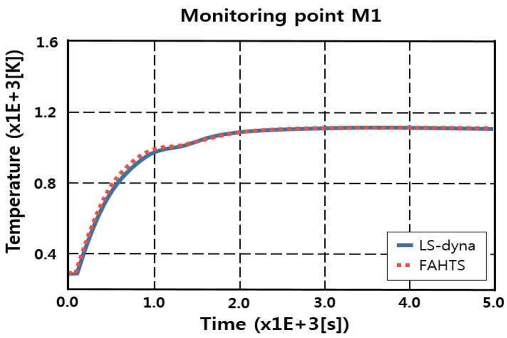

Fig. 4. Heat transfer analysis result at monitoring point M1

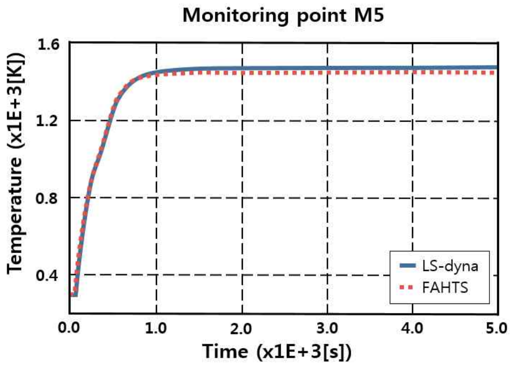

Fig. 5. Heat transfer analysis result at monitoring point M5

In above graphs, the analysis results of FAHTS and LS-dyna show similar tendency in terms of temperature rising even when the local flux as well as global flux are applied together.

2.3 Heat transfer analysis with PFP

FAHTS has internal keyword to easily model PFP for structural members by adding thermal properties of the material. Even for one section, application range of PFP can be defined in detail for local elements such as the web, flange, etc. In case of LS-dyna, solid elements are generated because implementing PFP on the surface of the structure using shell element has some limitations. Applied thickness of epoxy intumescent PFP system are determined based on section factor of each structural member and severity of fire loading to meet the temperature criteria of 400℃ at 2hr. The results of the heat transfer analysis with PFP are shown in Fig. 6.

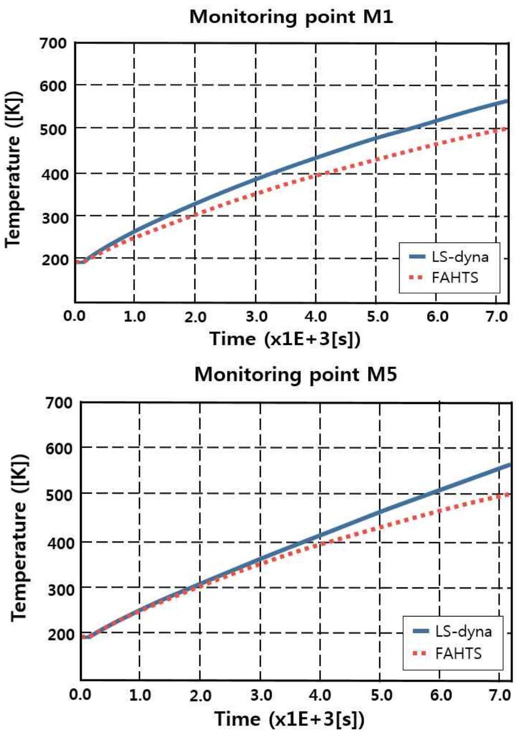

Fig. 6. Temperature history of PFP applied structure at monitoring points M1 & M5

3. Conclusions

In this paper, case studies for heat transfer analysis with and without PFP are performed using commercial FE tools and characteristics are compared. Based on analysis results, proper keywords to construct the heat transfer analysis input file for FAHAS and LS-dyna are determined, respectively. Various methods for modeling PFP such as layer or thermal contact will be performed in further studies.

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