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Numerical analysis-based study for fire resistance capacity of RC bridge with standard time-temperature curves

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ABSTRACT

This study is to numerically analyze the fire resistant capacity of a reinforced concrete bridge which was undergone in fire damage. For the numerical analysis using MIDAS FEA, 5 standard time-temperature curves were applied and the temperature gradient was identified at concrete cover depth of 30mm. From the fire parameter analysis, it is possible that some fundamental factors to the fire resistant design for a bridge structure can be discussed then practically determined.

1. INTRODUCTION

The highway bridge fire is recognized as risk that cannot be ignored according to traffic increase and transport quantity increase such as flame sources due to the recent city expansion. In case of building structures, they have systematic fire-resistant design method established to prevent life and property damage in case of closed structure fire. However, it is possible to get massive social losses in case of fire on the civil structure, especially bridge, because special fire-proof design is not established. In Korea, the interest in fire safety on the bridge structure constantly is increasing due to the traffic increase through massive expansion of the cities, and the increase of flame or toxic sources transport.

According to the New York state, USA, bridge collapses from fire occurred three times more than the ones by earthquakes between 1990 and 2005 (NYDoT, 2008). According to the national emergency management agency (2011), in case of national

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vehicle fire damages in past 5 years, large or small fires occurred about 6,000 times a year, and vehicle fire covered 13% of total fire incidents for constant occurrences. In case of the recent fire at Seoul perimeter highway, the repair cost was 150 billion won and 1,958 billion won of tangible and intangible social cost losses occurred, because superstructure of steel girder bridge was nearly collapsed due to the illegally parked oil-tanker (Korea Highway Corporation, 2011). Therefore, it is time to research the method of fire-resistant design for minimization of fire damage on bridge structures, which are social overhead capital in Korea. This research is the basic approach for the suggestion of a fire-resistant design method for newly constructed concrete bridge among various bridge types. The goal of this research is to analyze major factors of concrete bridge's fire-resistant design with temperature distribution fire-variable analysis in concrete structured through international standard time-temperature curves by the general-purpose program MIDAS FEA.

2. FIRE RESISTING CAPACITY MANAGEMENT STANDARD

Generally, steel structure, fire-resistant abilities of reinforced concrete, or pre-stressed concrete structures are determined by the fire-resistant standard temperature of steels in case of fire. In case of Korea, the fire-resistant management standard for high-strength concrete columns and beams is regulated as less than average 538℃ and less than highest 649℃ under the Ministry of land, transport, and maritime affairs notice No. 2008-334. Table 1 is a chart that shows domestic and foreign steel temperature limit ranges. Also, it uses standard time-temperature curves to evaluate fire-resistant efficiencies, and correspondence to the fire-resistant management standard is evaluated through examination and numerical analysis. The applied standard time-temperature curves for the fire-resistant analysis of concrete bridge members in this research are ISO 834, ASTM E 119, RABT, hydrocarbon curve (HC), and modified hydrocarbon curve (HCM).

Table 1 Temperature limit of Steel

<table>
<tr><th>Division</th><th>KS, ISO</th><th>JIS</th><th>ASTM</th><th>BS</th></tr>
<tr><td>Wall</td><td>-</td><td rowspan="2">Reinforced Concrete :Maximum 550℃ less Prestressed Concrete : Maximum 450℃ less</td><td>-</td><td>-</td></tr>
<tr><td>Floor</td><td>-</td><td>Reference temperature limit in principle the heating load is loading, different applications in different structure</td><td>-</td></tr>
<tr><td>Column</td><td rowspan="2">Maximum 649℃ Average 538℃</td><td rowspan="2">Reinforced Concrete :Maximum 500℃ less Concrete : Maximum 400℃ less</td><td>Maximum 649℃
Average 538℃</td><td>-</td></tr>
<tr><td>Beam</td><td>Reference temperature limit in principle the heating load is loading, different applications in different structure</td><td>-</td></tr>
</table>

3. THE MODELING AND ANALYSIS METHODS

Fig.1 is the status of fire damage on the analysis target bridge, and Fig.2 shows entire models of assumed fire analysis target concrete bridge in this research. To analyze fire parameters from various standard time-temperature curves, this research analyzed fire-resistant efficiency numerically from various parameters of the materials, when standard time-temperature curves are applied by extracting the 2D model by MIDAS FEA assuming the bottom surface of concrete bridge members where fire is concentrated. To analyze concrete bridge temperature according to the fire-resistant standard, we selected 30mm of reinforced concrete covering depth and detected steel temperature distribution every 5 minutes. Concrete bridge model is 2000mm*800mm beam material, and is composed with 16,000 2D face elements with 10mm grid element size. We applied thermal conductivity 2W/m℃, which effects on temperature distribution and is similar to the real fire characteristics, and specific heat was 1000J/kg℃ (Korea Highway Corporation, 2009). The analytical application of standard time-temperature curve fire is directly applied to the bottom of the finite element model considering the fire at the lower part of the bridge, and applied standard time-temperature curve of fire directly at the contacted part on the bottom with considering experiment environment. This kind of applications can be considered as the worst fire damage status for materials. Fig. 3 is the 2D model element for numerical analysis, and Fig. 4 is an example of fire analysis result and temperature detection.

Fig. 1 Fire damage of bridge

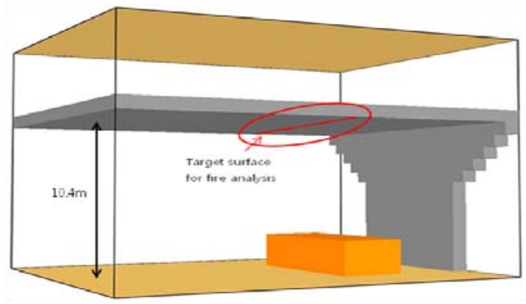

Fig. 2 Bridge fire modelling

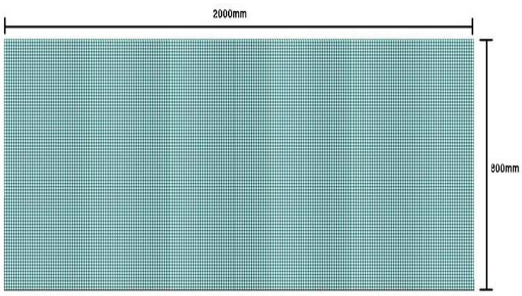

Fig. 3 Finite element model

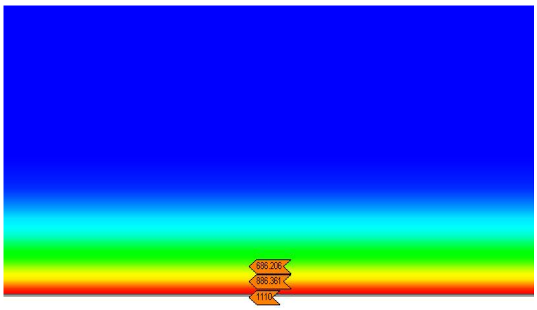

Fig. 4 An example of Temperature detection

4. FIRE RESISTING CAPACITY ANALYSIS

For the fire-resistant capacity in 30mm of concrete covering depth based on the standard time-temperature curve, the time to reach the highest temperature 649℃ were measured and compared according to the Ministry of land, transport and maritime affairs notice No. 2008-334. The temperature on the detection region was confirmed as increased or decreased due to the temperature gradient of applied standard time-temperature curves. The approaching time of fire-resistant management temperature in bottom surface of concrete bridge's covering depth can be considered as the most critical factor of bridge fire-resistant design, because this part is the dominant position of the bridge superstructure tensile stress. In addition, the temperature reduction measures before the temperature reach fire-resistant management level are significant problems to possible fire safety redundancy. This research analyzed the detected fire-resistant management temperature reaching point of covering depth in each standard time-temperature curve. Fig. 5~Fig. 9 is the results of temperature chart in bridge material covering depth with standard time-temperature curves. In case of ISO 834 standard time-temperature curves, the temperature reached 649℃ in 67 minutes, in case of ASTM E 119, about 62 minutes, RABT, about 27 minutes, hydrocarbon curve, about 37 minutes, and modified hydrocarbon curve, about 22 minutes after fire. ISO 834 standard time-temperature curve took the longest time to reach fire-resistant management temperature, and the modified hydrocarbon took the shortest time to reach. This reaching time is related to fire curve characteristics such as reaching and duration time of the highest temperature, as well as temperature increasing and decreasing. Therefore, the dominant fire environment evaluation is necessary for each bridge to determine characteristic values of bridges, and the establishment of a standard time-temperature curve application method is expected.

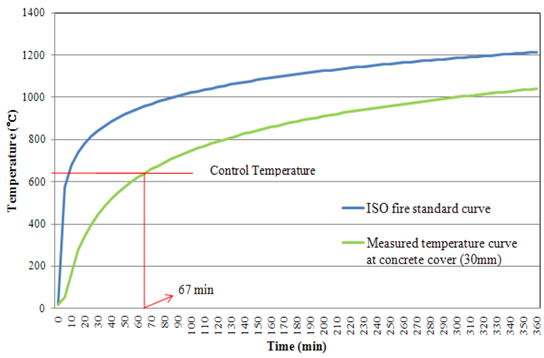

Fig. 5 Comparative result for ISO fire

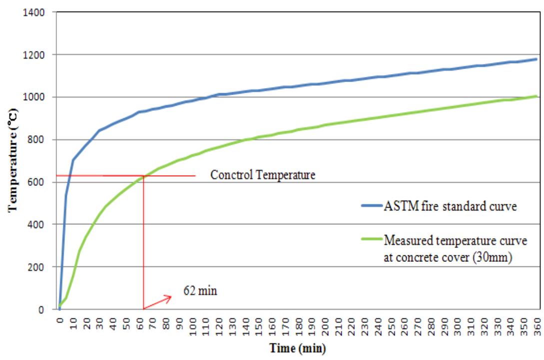

Fig. 6 Comparative result for ASTM fire

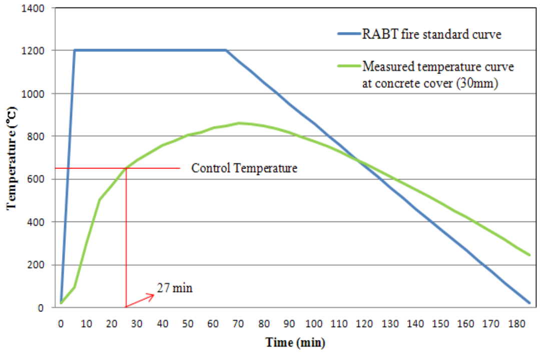

Fig. 7 Comparative result for RABT fire

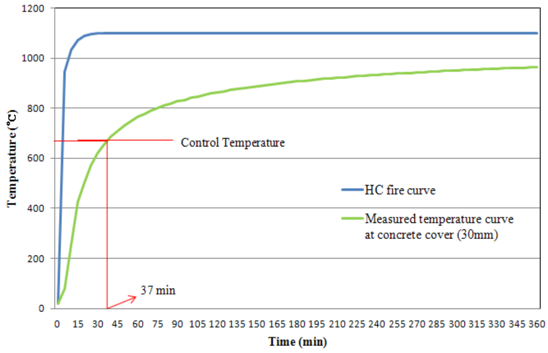

Fig. 8 Comparative result for HC fire

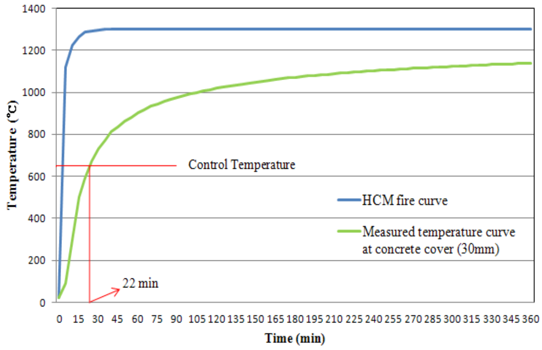

Fig. 9 Comparative result for HCM fire

5. CONCLUSION

In case of fire on the bottom surface of a reinforced concrete bridge, the approaching time to get to the highest temperature 649℃ in 30mm concrete covering depth was analyzed and compared under the Ministry of land, transport and maritime affairs notice No. 2008-334 after applying 5 standard time-temperature curves to analyze fire-resistant capacity. The conclusions are as follows.

As 5 types of standard time-temperature curves are applied on the bridge models, ISO 834 and ASTM E 119 approached 649℃, which is the highest temperature standard from the Ministry of land, transport and maritime affairs, in 60~70 minutes, 37 minute in case of hydrocarbon curve, and 20~30 minutes in case of RABT and modified hydrocarbon curve (HCM).

In case of RABT standard time-temperature curves, the temperature rises rapidly, and approached the highest standard temperature 649℃ secondly. However, the duration of fire is shorter than other fire curves and the highest temperature in 30mm of covering depth was the lowest temperature among others.

In cases of ISO 834 and ASTM E 119, the standard time-temperature curves and fire duration time were the same with others except RABT, but the temperature went up smoothly during initial fire, and it seems the reaching time is relatively slower to approach 649℃.

As the result of the fire analysis, the temperature of fire affects bridge materials, but the fire duration time also takes large part during the fire. In addition, the definition of dominant standard time-temperature curves is priority for bridge fire-resistant design. It is analyzed possible to obtain design parameters to reflect bridge fire characteristics from the parallel experimental research for bridge fire risk assessment through the CFD fire analysis and calibration of numerical constants.

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