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FIRE RESISTANCE PERFORMANCE OF SUBMERGED FLOATING TUNNEL UNDER VARIOUS FIRE CONDITIONS

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ABSTRACT: Submerged Floating Tunnels (SFT) were researched by countries had many island as Norway, Italy, China, and Japan. Several sites were examined in China and Norway. Most of them investigated about seismic, dynamic, and collision performance. However, present researches lack to apply the construction fields, therefore, additional researches need. Fire resistance performance of the SFT is important one of the various researches. If fire break out in SFT, it is damaged by thermal loads. The damage of the SFT varies by type of fire. Structure of the SFT is able to collapse partially by fire scale and fire exposure time. For this reason, fire resistance design of the SFT must be suggested. Fire resistance performance of SFT could be investigating for fire resistance design of SFT. Fire condition could be expressed fire curves which are suggested by fire scale and fire exposure time. In this paper, temperature distributions of the SFT were investigated through FE analysis under various fire conditions. Heat transfer analysis was applied to investigate conduction of heat by fire. And there was to draw the biggest influence fire condition to the SFT from FE analysis results. Also, preliminary study was performed for fire resistance design.

Keywords: SFT, Fire Resistance, Heat Transfer, FE Analysis

INTRODUCTION

The method of crossing the channel or river can be classified four types as shown in Fig. 1. They are bridge, submerged floating tunnel, immersed tunnel, and submarine tunnel. The submerged floating tunnels (SFT) of those were researched by countries had many island as Norway, Italy, China, and Japan. Several sites were examined in China and Norway. Most of them investigated about seismic, dynamic, and collision performance. However, present researches lack to apply the construction fields, therefore, additional researches need.

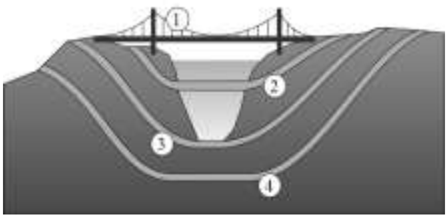

Fig. 1 crossing method on the river or channel ((1) bridge, (2) submerged floating tunnel, (3) immersed tunnel, and (4) submarine tunnel)

Fig. 2 shows the conceptive figure of the SFT for the Funka Bay in Japan. It was designed that vehicles were operated in upper components and trains were run in lower components respectively. Traffic accident of vehicles and trains can be caused. At this moment, possibility of fire outbreak by accident is very high. And fire can be not only loss of life but damaged of tunnel by fire heat.

Fig. 2 Conceptive figure of submerged floating tunnel for the Funka Bay (Kanie S., (2010))

Fire resistance performance of the SFT is important one of the various researches. If fire break out in the SFT, it can be damaged by thermal loads. The damages of the SFT are different by type of fire. Structure of the SFT is able to collapse partially by fire scale and fire exposure time. For this reason, fire resistance design of the SFT must suggest considering the fire condition. Fire condition could be expressed fire curves which are suggested by fire scale and fire exposure time. In this paper, temperature distributions in the SFT were investigated through FE analysis under various fire conditions. Heat transfer analysis was applied to analyze

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conduction of heat by fire. Fire resistance performance of the SFT was investigated. These preliminary studies could be basis for definition of the fire resistance design.

VERIFICATION OF ANALYSIS METHOD

Material properties by temperature for heat transfer analysis are shown in Tables 1 and 2 that show properties of steel and concrete by temperature respectively.

Table 1. Properties of steel by temperature (Zicherman (1996))

Temperature (^{o}C)	Specific heat ($J/kg \cdot {}^{o}C$)	Thermal conductivity ($J/kg \cdot mm \cdot {}^{o}C$)	Density (mg/mm^3)
0.00	449.91	197.97	7.85
93.58	484.64	185.89	7.82
105.04	488.88	184.41	7.81
114.59	492.42	183.18	7.81
197.35	523.11	172.51	7.78
398.55	597.74	146.55	7.7
700.57	872.51	107.59	7.59
750.39	1046.05	101.16	7.57
827.59	687.49	91.25	7.54
850.03	583.28	92.23	7.53
1200.00	674.87	108.18	7.40

Table 2. Properties of concrete by temperature (Zicherman (1996))

Temperature (^{o}C)	Specific heat ($J/kg \cdot {}^{o}C$)	Thermal conductivity ($J/kg \cdot mm \cdot {}^{o}C$)	Density (mg/mm^3)
0.00	1260.12	8.46	2.35
93.58	1314.12	6.44	2.33
105.04	5256.5	6.19	2.33
114.59	3036.52	5.98	2.32
197.35	954.09	5.84	2.3
398.55	983.25	5.51	2.26
700.57	1207.07	5.00	2.18
750.39	1232.11	4.92	2.17
827.59	1270.92	4.79	2.15
850.03	1282.22	4.75	2.15
1200.00	1458.14	4.17	2.07

Solid element is applied DC2D4 and transient analysis for heat transfer analysis. Thermal loads that are applied to the surface of tubes are the standard temperature time curve ISO-834 (1999), as in Eq. (1) and Fig. 3.

$$T = 345 \cdot Log_{10}(8t+1) \quad (1)$$

where, T is heating temperature (°C), t is time (minutes)

Table 3. Section properties (Yang et al. (2008))

Articles	Properties
Diameter (mm)	400
Hollow ratio	0.5
Thickness of External tube (mm)	4
Thickness of Internal tube (mm)	2.87
Diameter of hollow	200

We use the section properties in Table 3 for verification of the analytic method. Fig. 3 shows the distribution of temperature by time, where thermal load is conducted up to the internal tube. Fig. 4 shows that the FEM analysis has similar changes of the temperature by time, compared with the value of Yang et al. (2008). This analytic method has established the reliability. It can be applied in the SFT.

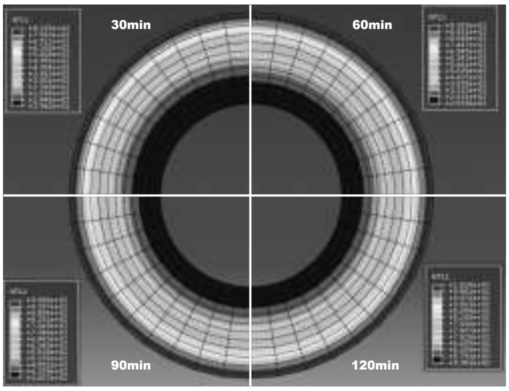


Fig. 3. Distribution of temperature by time

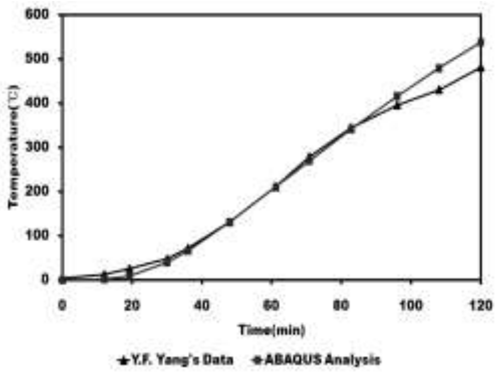


Fig. 4. Distribution of temperature by time on internal tube

FIRE RESISTANCE OF THE SFT UNDER VARIOUS FIRE CONDITIONS

Heat transfer analysis is performed using suggested analysis that is verified in previous chapter. And, fire scenario was proposed by some researchers and institutions as shown in Fig. 5.

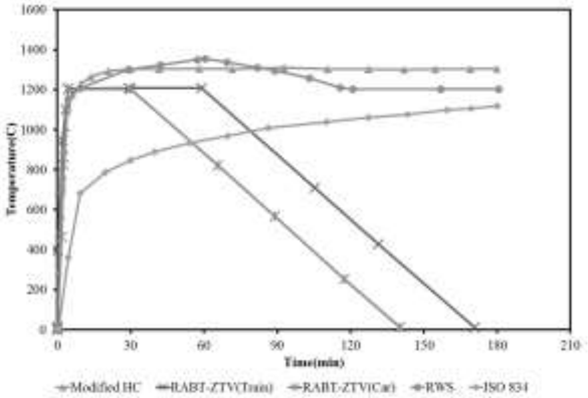


Fig. 5 Fire curve by type of fire (Gabriel A.K (2000))

Gabriel A.K (2000) summarized type of fire curve as shown Fig.5 and below paragraph. The temperature-time curves in standard fires used in testing, analysis and design were established from experience in real fires and fall into three main categories, depending upon the application. The standard furnace curve represents a typical building fire based upon a cellulosic fire in which the fuel source is wood, paper, fabric, etc. In ISO 834, the temperature increases from 20 to 842 ^{o}C after the first 30 min. The fire profile has a slow temperature rise up to 1000 ^{o}C over a period of 120min. This curve represents only one possible exposure condition at the growth and the fully developed fire stages, and does not include a final decay stage. In the 1970s, the oil company Mobil investigated hydrocarbon fuel fires and developed a temperature-time profile with a rapid temperature rise in the first 5min of the fire up to 900 ^{o}C and a peak 1100 ^{o}C. This research laid the foundation for test procedures to assess fire-protecting materials for the offshore and petrochemical industries. A spate of major tunnel fires has indicated that an even more severe fire scenario needs to be considered. In the Netherlands, the Ministry of Public Works, the Rijswaterstaat (RWS), and the TNO Centere for Fire Research have established a fire curve for the evaluation of passive protecting materials in tunnels. This RWS Dutch fire curve models a most severe hydrocarbon fire, rapidly exceeding 1200 ^{o}C and peaking at 1350 ^{o}C (melting temperature of concrete) after 60min and then falling gradually to 1200 ^{o}C at 120min, the end of the curve. RWS is intended to simulate tankers carrying petrol in tunnels with a fire load of 300MW causing a fire for 2h, and was established on the basis of Dutch experience in tunnel fires. However, the maximum temperatures attained in recent major fires did not reach RWS levels, e.g. Channel (1100 ^{o}C), Great Belt (800 ^{o}C), Mont Blanc (1000 ^{o}C), Tauern (1000 ^{o}C). The RWS fire curve, therefore, represents the severest form of tunnel fire in terms of initial heating rates and maximum temperatures, The RABT German fire curve, with a descending branch, represents a less severe fire scenario in tunnels than the RWS curve, reaching a maximum temperature of 1200 ^{o}C (melting point of some aggregates) sustained up to 1 h before decaying to ambient.

Dimension of SFT in Fig. 6 was designed by association for research on SFT in Japan. Diameter of SFT is 2300mm and thickness of main tube is 1000mm. SFT is reinforced concrete structure, transverse and longitudinal reinforcements are arranged inside and outside into section of main tube and portioned enclosures.

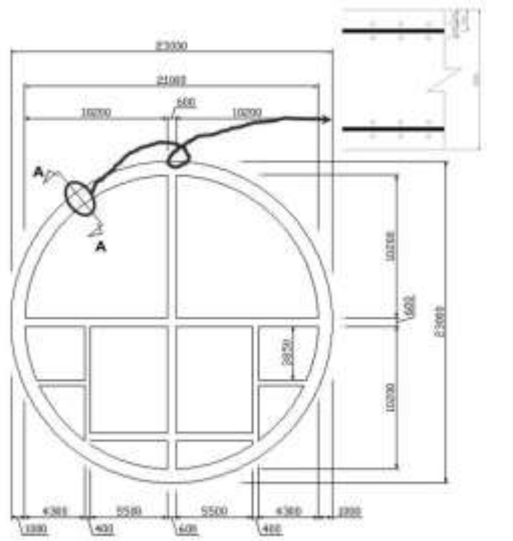


Fig. 6 Dimension of submerged floating tunnel for the Funka Bay

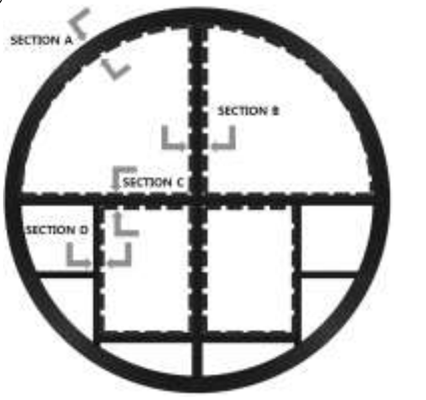


Fig. 7. Location of thermal loading

In the SFT, we assumed that the cars and trains drives as shown in Fig. 2. For the assumption, thermal loads by fire act on surface of compartments, and section of the SFT classify section A, section B, section C, and section D for detail investigation as shown in Fig. 7.

Fig. 8 shows that strength of siliceous concrete is changed by temperature. Strength of siliceous concrete reduce 50% at above 600 ^{o}C and concrete melt at above

1200 ^{o}C . The local damage in the SFT under fire is estimated using change of concrete strength by temperature as shown in Fig. 8.

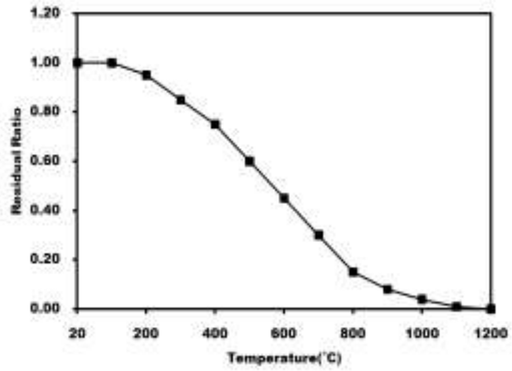
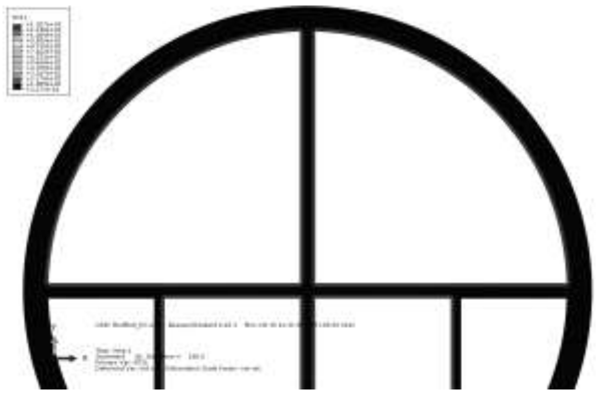


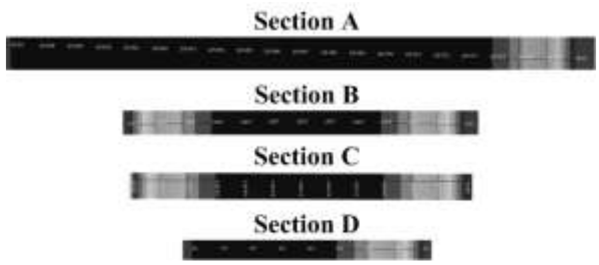
Fig. 8. Change of siliceous concrete strength by temperature(Eurocode 2)

Next, to investigate the fire resistance of the SFT, heat transfer analysis in the SFT is performed using properties in Tables 1 and 2. And, types of fire scenario are modified HC, RABT-ZTV(train), RABT-ZTV(car), RWS, and ISO-934 as shown in Fig. 5. They act on surface of compartments.

Fig. 9 shows the temperature distribution on each section. Sections A and D are temperature distribution on only right side of section, whereas sections B and C are those on both left and right side of section.



(a)



(b)

Fig. 9. Temperature distribution on each section

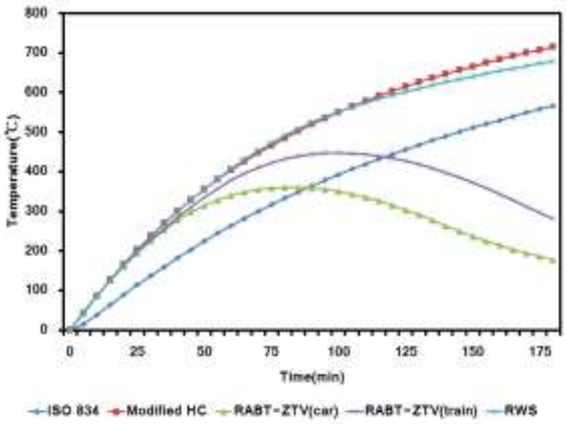


Fig. 10 Temperature distribution at 50mm from surface

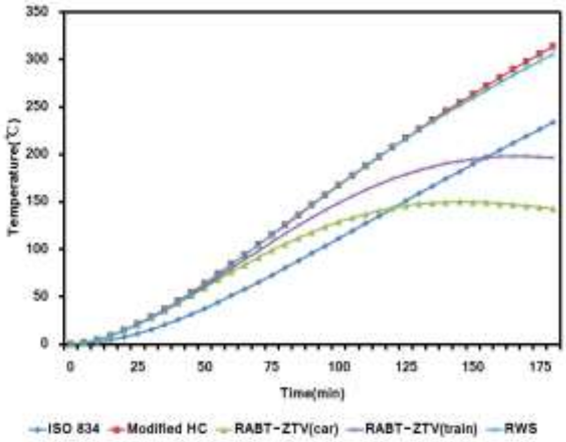


Fig. 11 Temperature distribution at 100mm from surface

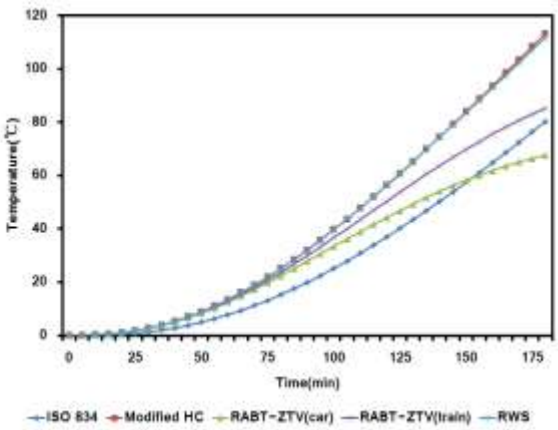


Fig. 12 Temperature distribution at 150mm from surface

Figs 10~12 show change of temperature with fire times at 0~150mm from a heat source. Temperature by Modified HC at 50mm as shown in Fig. 10 is the highest value than other fire curves, moreover, temperature exist RWS>ISO-834>RABT(train)>RABT(car). Concrete strength under Modified HC and RWS become to be 50% of original strength. Also, transverse and longitudinal reinforcements at 100mm from surface of concrete are reduced by increasing temperature.

Figs. 11 and 12 show temperature distribution at 100mm and 150mm from surface respectively. Temperature by fire is below 200 ^oC except the Modified HC and RWS. This exists that damage of concrete is below 5% of original concrete strength. Fire resistance design of the SFT is surely considered to prevent the damage of concrete and steel reinforcements by fire.

COLCLUSION AND SUMMARIES

In this paper, local damage of SFT under various fires was investigated through FE analysis.

(1) The concrete at location of 50mm from fire source had the largest damage. In the main tunnel tube, tensile strength of transverse and longitudinal reinforcements would be reduced about 30% compared with its original tensile strength.

(2) In the sections B and C, section about 30% of entire section was damaged had damaged by fire on both sides. Also, tensile strength of transverse and longitudinal reinforcements on both sides could be reduced about 70% compared with its original tensile strength.

(3) The SFT experienced continuous loads as buoyancy and ocean external force. If local damage was occurred, it could be developed global failure. For this reason, structural safety of the SFT was very important. Fire resistance design for the SFT was surely needed to block the conduction of heat by fire.

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