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BENDING STRENGTH ANALYSIS OF STEEL-COMPOSITE SUBMERGED FLOATING TUNNELS

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ABSTRACT: A submerged floating tunnel (SFT) must have enough strength to resist to various external loadings such as bending, torsion, tension, and compression. The expected main deformation of SFT is caused by bending moment. And this bending moment makes tensile stress and compression stress on the wall of SFT. Thus, bending moment is a main affecting factor on the safety of SFT. Until now, a reinforced concrete tunnel was suggested for SFT by other researchers. In this study, an internally confined hollow reinforced concrete tunnel and a double skinned composite tubular tunnel were proposed. And their bending strengths were studied and compared with that of a reinforced concrete tunnel. The analysis results showed the proposed SFT structures had enough strength to guarantee safety.

Keywords: SFT, tunnel, composite, bending strength, submerged.

INTRODUCTION

A submerged floating tunnel (SFT) has been considered as an interesting structure to connect the banks separated by a narrow and deep sea. Reinforced concrete (RC) tunnels have been suggested as SFT structures. Because the governing load of a SFT is bending moment, a structure with enhanced stiffness and ductility will be useful for a SFT. Therefore, two new-type structures which have superior stiffness and ductility were proposed for the SFT.

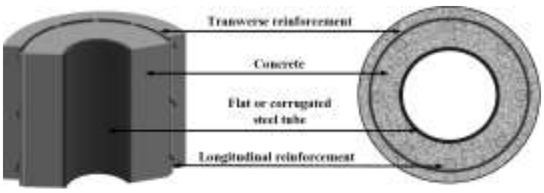

Fig. 1 ICH RC structure (Han et al., 2008)

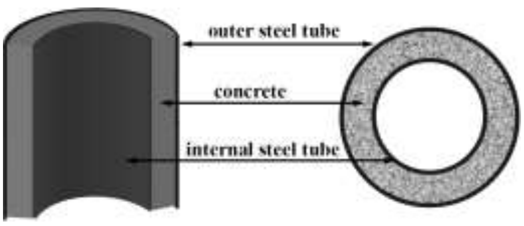

Fig. 2 DSCT structure (Han et al., 2010)

One is internally confined hollow RC structure which is hollow (ICH) RC structure with a steel or fiber reinforced polymer (FRP) tube as shown in Fig. 1. The other is double–skinned composite tubular (DSCT) structure which is composed of two concentric steel or FRP tubes and concrete between them as shown in Fig. 2. In this study, the application of the ICH RC and DSCT structures to SFTs was investigated by the analyzing their bending strengths. The dimensions of ICH RC SFT and DSCT SFT were determined referring the RC SFT proposed in the guidebook published by SFT Research Group of Japan (Kanie, 2010). The bending analyses were carried out by using an exclusive program with the considerations of material nonlinearity and confining effect of concrete (Han et al., 2010; Han et al., 2013). And also the analysis results were compared with those of the RC SFT with the reference design.

BENDING STRENGTH ANALYSIS

Bending Strength of RC SFT

SFT Research Group of Japan proposed a RC SFT section of the middle part of the SFT (not the connection part) as Fig. 3. The RC SFT has the 23,000mm of the outer diameter and 21,000mm of the inner diameter. The applied material properties are summarized in Table. 1.

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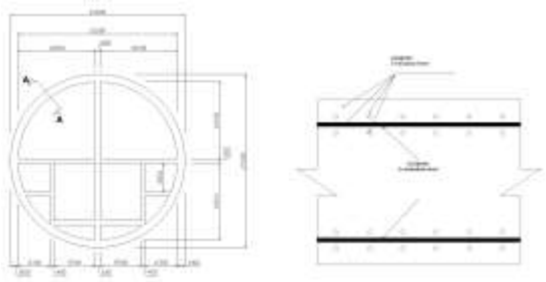

Fig. 3 Dimensions of RC SFT for Funka Bay (Kanie, 2010)

Table 1 Material properties

Material	Compressive or Yield Strength	Modulus of Elasticity
Concrete	39.2Mpa	30.4GPa
Mild Steel (SS400)	400MPa	206GPa
Re-bar (SD345)	345MPa	206GPa

The behavior of this RC SFT depends on the arrangement of re-bars. In the reference RC SFT, 25mm-diameter re-bars were arranged with the spacing of 200mm in the longitudinal and transverse directions. For the analysis of a DSCT and ICH RC SFTs, the mild steel in Table 1 was applied to the tubes. Fig. 4 shows the axial load-bending moment (P-M) interaction curve of the RC SFT. The peak axial strength and bending moment of the RC SFT were 2,660MN and 9,062MN-m, respectively.

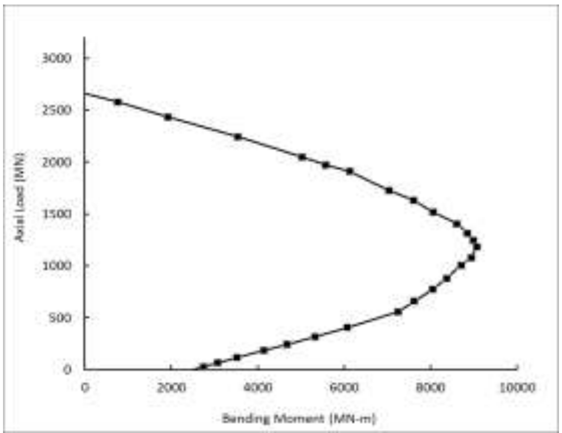

Fig. 4 P-M interaction curve of RC SFT

Bending Strength of ICH RC SFT

In the ICH RC SFT, the outer re-bars are equally arranged to the RC SFT. But an inner steel tube is settled inside of the SFT instead of the inner re-bars and inner cover concrete. Therefore the inner diameter is larger than that of the RC SFT by double thickness of the inner cover concrete (inner diameter=21,300mm). The thickness of the inner steel tube is 6.7mm which is the minimum thickness not to yield and not to be buckled by the passive pressure from the Poison effect of the concrete. The cross section of the tunnel wall is shown in Fig. 5. Considering the thickness of the inner steel tube, the ICH RC SFT has lager cross sectional space by 9.52m^2 than the RC SFT.

Fig. 6 shows the P-M interaction curve of the ICH RC SFT. Its peak axial strength and bending moment of are 2,582MN and 9,656MN-m, respectively. Its axial strength is 2.93% smaller than that of the RC SFT. But its bending strength, the dominant factor, is 6.55% larger than that of the RC SFT although it has thinner tunnel wall. Therefore the ICH RC structure is supposed to have enough safety as a SFT structure.

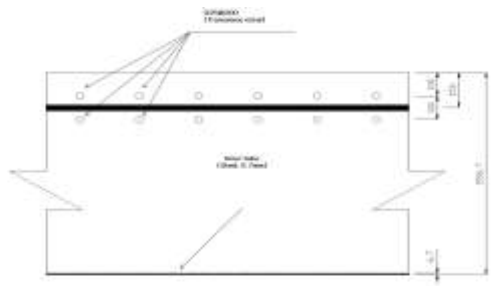

Fig. 5 Tunnel wall of ICH RC SFT

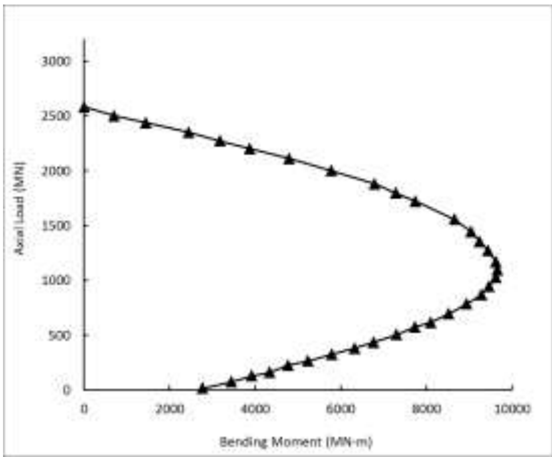

Fig. 6 P-M interaction curve of ICH RC SFT

Bending Strength of DSCT SFT

The DSCT structure is composed of inner and outer steel tubes and concrete is filled between them. Therefore, the cover concrete is not necessary for the DSCT structure and the tunnel wall thickness is thinner than the RC structure by the double times of the thickness of the concrete cover. The inner diameter of the confined concrete and the outer diameter of the DSCT SFT are 21,300mm and 22,700mm, respectively.

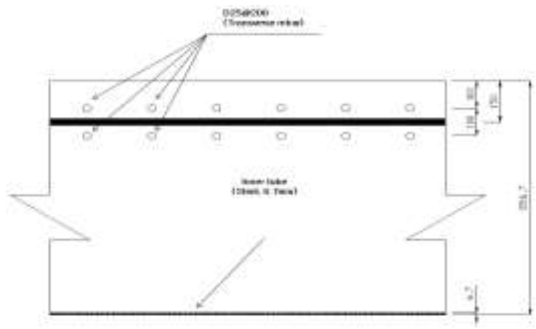

Fig. 7 Tunnel wall of DSCT SFT

The thicknesses of the outer steel tube and inner steel tubes are 20mm and 34.4mm, respectively. The thicknesses were determined considering the yield strengths and local buckling strengths of the inner and outer tubes. Fig. 7 shows the cross sectional dimension of the DSCT SFT wall. Fig. 8 shows the P-M interaction curve of the DSCT SFT. Its peak axial strength and bending moment of are 3,006MN and 9,233MN-m, respectively. Its axial strength and bending strength are is 13.01% larger and 1.89% larger than those of the RC SFT. Considering the smaller wall thickness of the DSCT SFT, the DSCT SFT has enhanced strength and enough safety.

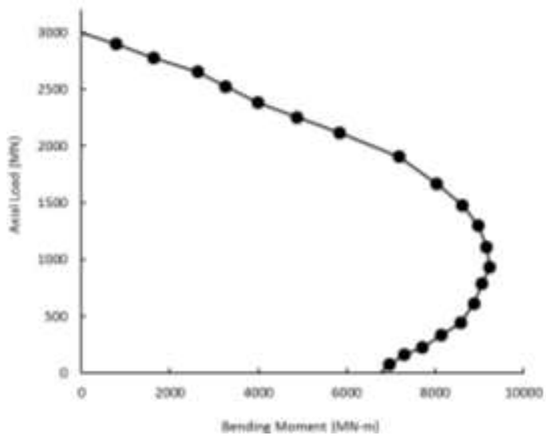

Fig. 6 P-M interaction curve of DSCT SFT

Required Quantity of Materials

The unit required quantities of the necessary materials to build the three types of the SFTs were compared. Because the quotations of steel are very sensitive by the market circumstances, only material quantities per unit length were compared. And the quantities of the re-bar and the steel tube were categorized into a same group (steel). Fig. 7 and Fig. 8 show the unit required quantities of concrete and steel to build the RC SFT, the ICH RC SFT, and the DSCT SFT, respectively. Fig. 8 shows the required concrete quantities of the ICH RC SFT and DSCT SFT reduced.

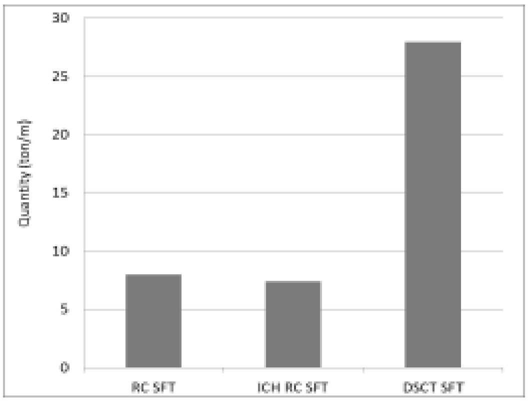

Fig. 7 Comparison of required steel (ton/m)

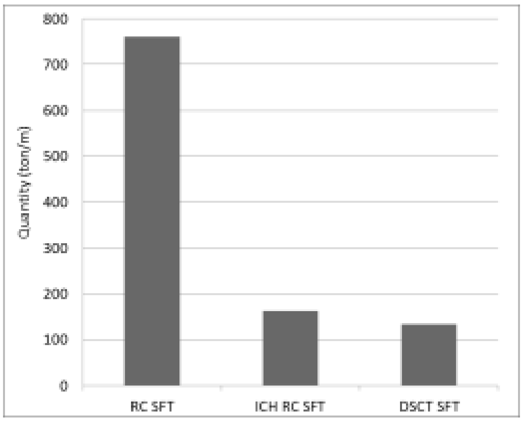

Fig. 8 Comparison of required concrete (ton/m)

DESIGN OF DSCT SFT

Referencing to the data from SFT Research Group of Japan (Kanie, 2010), a DSCT SFT section was designed for the connection part. In the original design of the RC SFT, the outer and inner diameters were 24,000mm and 21,000mm.

Applied Load

In the original design, the RC SFT is a continuous structure with 70@100m-span. The design considered self-weight of the SFT, buoyancy, wave loads and seismic loads for the periods of 145-year and 950-year. In this case, the maximum moment of the SFT occurs at the both end point because it is fixed at there. And the wave load makes the maximum bending moment. The design moments by the wave loads for the periods of 145-year and 950-year are 2,095MN-m and 3,048MN-m, respectively. The maximum axial load occurs by the seismic load. The design axial loads by the seismic loads for the periods of 145-year and 950-year are 2.91MN and 4.55MN, respectively.

DSCT SFT Design

Based on the calculated axial load and bending moment, two DSCT SFTs were designed. The cross sectional dimensions are shown in Table 2. The compressive strength of the concrete is 29.43MPa. The yield and ultimate strengths of the steel are 250MPa and 392.4Mpa, respectively.

Table 2 Dimension of DSCT SFT

Item	Type-1 (H95)	Type-2 (H90)
Outer diameter (mm)	24,000	24,000
Inner diameter (mm)	22,800	21,600
Thickness of outer steel (mm)	24.50	24.50
Thickness of outer steel (mm)	45.38	42.99

DSCT SFT Analysis

By using the analysis results of the DSCT SFTs, P-M interaction curves and moment-curvature curves were plotted as shown in Fig. 9 and Fig. 10. As shown in the figures, the bending moment strength and the axial strength of H90 are 13,227MN-m and 4,020MN, respectively. They are larger than the maximum design loads and H90 is safe under the load case. The bending moment strength and the axial strength of H95 are 8,726MN-m and 2,730MN, respectively. They are larger than the maximum design loads and H95 is safe under the load case.

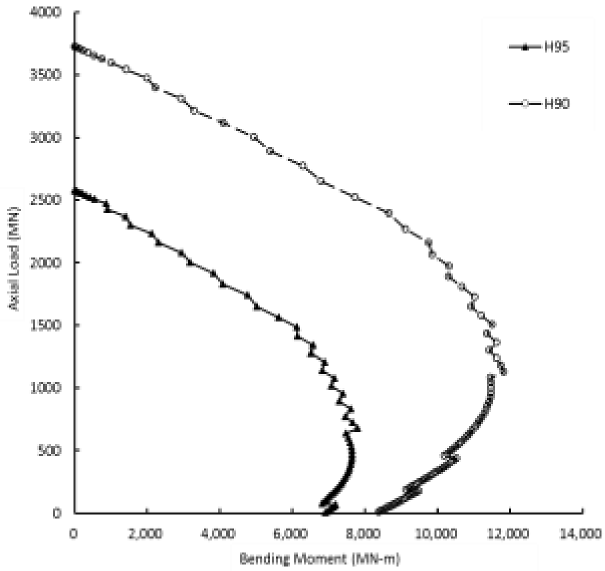

Fig. 9 P-M interaction curve of designed DSCT SFT

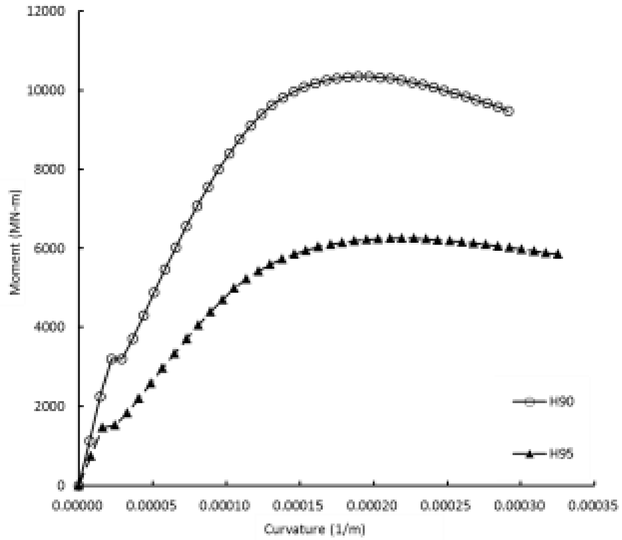

Fig. 10 Moment-curvature curve of designed DSCT SFT

CONCLUSION

In this study, to replace the RC structure which is used for SFTs with a new-typed structure, an ICH RC SFT and a DSCT SFT were designed and analyzed. The new-type SFTs were verified to have enough axial strength and bending strength to build safe SFTs. And also they had enhanced ductility.

ACKNOWLEDGEMENTS

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