The 2019 World Congress on
Advances in Structural Engineering and Mechanics (ASEM19)
Jeju Island, Korea, September 17 - 21, 2019

Calculation of tensile force on mooring line for a submerged floating tunnel

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ABSTRACT

A submerged floating tunnel (SFT) is an infrastructure that floats in water supported by an equilibrium of its buoyancy, weight and supporting force. (Ge 2010) Recently, research about the tunnel has been actively conducted with its economic efficiency of saving undersea tunnelling costs. When a buoyancy force is larger than a weight of tunnel itself, the tensile force is applied on the mooring lines in the opposite direction of the gravity. This estimation of the tensile force is critical, not only for the design of anchoring system and the connecting section of module, but also for the control of entire process of construction. (Jin 2017)
In this study, a simplified model of the SFT is numerically analysed for the calculation of tensile reaction of mooring lines, which connect the tunnel and the earth. For the analysis, a typical section of 23m outer diameter is designed refer to the Funka Bay SFT, in Japan. (Mandara 2016) A longitudinal length of a module is 50m and five modules of tunnel are connected in total and the mooring system is modelled at 50m interval. In addition to the weight of the tunnel, static pressure of seawater acting vertical direction of entire section is considered, so that the buoyancy force can be calculated. Through the analysis, the reaction and displacement of mooring line according to the relative location is performed and verified.

1. INTRODUCTION

With an increasing need for human and material resources shipping, a demand for super-long span bridges and undersea tunnels also increases. Submerged floating tunnel (SFT) has been researched as a substitutional solution with its cheaper constructional costs. An SFT is defined as an infrastructure that floats in water supported by an equilibrium of its buoyancy, weight and supporting force. If the buoyancy force of the system is bigger than its gravitational force, the system should be sustained by anchoring system. Therefore, the supporting force plays a key role for

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maintaining a safety and a stability of the SFT (DNV, 2008).

In order to decide an anchor system and a typical material properties of mooring system, the most critical factor is a force applying on the system. However, it is hard to measure a reliable value from a field test, because the research is yet on the beginning stage and a size of the tunnel is too big (Park *et al.*, 2013). Regarding the situation, a numerical simulation based on a theoretical calculation are seemed be the solution to find the tensile force. As a rough version of section was designed, exact values of buoyancy and gravity can be calculated, which will be compared with the results of numerical analyses.

On the other hand, live loads moving in the tunnel affect the stability of the SFT. Due to the design of the tunnel including vehicle roads and train rails, effects of the live loads should be considered. According to the Korean roadway codes (Ministry of land, infrastructure, and transport, Republic of Korea, 2011; Ministry of land, infrastructure, and transport, Republic of Korea, 2012), the minimum dimensions and required analytical process on the SFT should be performed with the standard loads of truck and train.

In this study, a simplified model of the SFT was established based on the design of Funka-bay SFT (Park *et al.*, 2013). Based on the model, theoretical calculation about the buoyancy and gravitational force was conducted and compared with the results of the static analyses. After that, influence lines on the second support point of the SFT was analyzed, so that the vertical effects of moving loads could be considered. Through the analytical process, the tensile force and the BWR were investigated for the possibility of the optimal section design.

2. METHOD

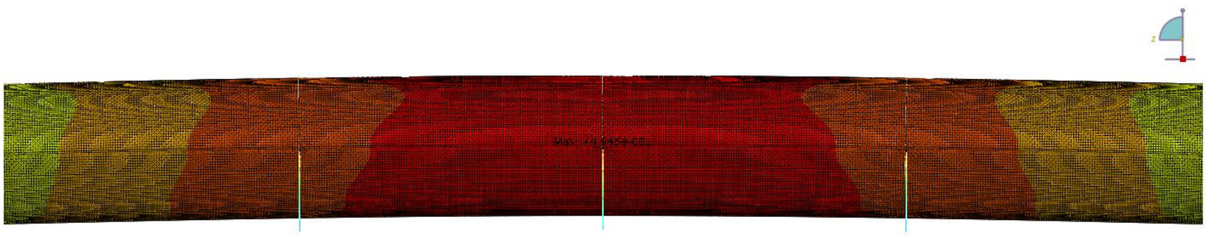

Fig. 1 Description of SFT tunnel model

For the analysis, the SFT module is modelled as described in Fig. 1. As explained above, the outer diameter of section is 23m and the inner diameter is 21m. In order to compare the vertical displacement along to the span, four modules which has 50m length each are connected. At each connection point, four mooring lines are attached to support the SFT modules. In this condition, inclined connection of mooring lines can improve the lateral motion in static and dynamic behaviors.

Also, the tunnel is composed of concrete material only, for the simplification of the first trial. Similarly, mooring lines are composed of a steel wire material. Detailed material properties of tunnel and mooring lines are as in the Table 1.

Table 1. Material properties of tunnel and mooring lines

Item	Value	Unit
Tunnel		
Young's modulus	40	GPa
Moment of inertia	6,026	m^4
density	2,600	kg/m^3
Mooring lines		
Young's modulus	108.46	GPa
density	709.6	kg/m^2

3. CONCLUSIONS

In order to investigate the effect of tunnel properties and vertical displacement on the tensile reaction of mooring lines of SFT tunnel, static numerical analysis was performed. The results and discussion can be summarized as follows:

A. With the continuously connected four-span tunnel, the reaction force continuously decreases from the center to the end of span. These analytical results can be verified through a comparison with an experimental measurement or theoretical calculation.

B. The shape of tunnel deforms convexly and the gap of vertical displacement between the center and the end is about 0.5m, which is quite larger than that expected. With the consideration of composite structure, the displacement is seemed to be decrease.

C. As the vertical displacement increases, the reaction force also increases. Therefore, dense installation of mooring lines around the center span can be considered.

With the results of this study, the basic issues for the construction of SFT have been investigated. Through the comparison with the experimental results and the detailed numerical analyses, the possibility of SFT construction can be improved.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean Government (MSIT) (No. 2017R1A5A1014883).

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