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Proceedings of the 7th International Conference on Asian and Pacific Coasts
(APAC 2013) Bali, Indonesia, September 24-26, 2013

IMPACT ANALYSIS OF SUBMERGED FLOATING TUNNEL FOR EXTERNAL COLLISION

Y. Lee[1], D.-M. Kim[1], S.-H. Han[2] and W.-S. Park[2]

ABSTRACT: Submerged floating tunnel is an innovative tunnel infrastructure passing through the deep sea independent of wave and wind so that high speed vehicle or train can run. It doesn't depend on water depth and is cost effective due to modular construction on land. The construction period can be reduced drastically. In this paper, a concept design of submerged floating tunnel is introduced and a method to analyze structural behavior of the body in case of collision with ships or submarines is proposed for securing safety. In this study, the local damage and global behavior of submerged tunnel in collision with submerged moving body are simulated via commercial hydrocode ANSYS LS-DYNA. In simulations, a conceptual tunnel section prepared in Korea is considered and various penetration and deformation responses with respect to impact velocity, applied materials and collision scenarios are obtained. Finally, for a conceptual design of submerged floating tunnel, maximum deformation, bending moment and impact forces are analyzed based on force and energy equilibrium.

Keywords: Collision, submerged floating tunnel, penetration, impact analysis, hydrocode
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INTRODUCTION

Recently, many submerged floating tunnel projects connecting inter-continents have seen the increase, especially those between Korea & China and Korea & Japan. The submerged floating tunnel technology can be used when developed to accommodate drive ways for vehicle and rails for train for 3 nations.

Submerged floating tunnel can maximize the use of undersea space and if a part of tunnel can be built transparent, it can be environment-friendly world class tourist attractions. Bridge is very difficult to build over the deep waters and is not easy to secure the safety over the sea lanes where there are heavy vessel traffics, floating debris or ices. However, submerged floating tunnel will be free from all those obstacles. There have been significant progresses made and technologies accumulated on the development of submerged floating tunnel technology from 1960s through 1970s, however, no such commercially operating tunnels are yet built. The technical gaps between domestic and foreign technology can be quickly reduced considering the level of construction technology sophistication of domestic firms. It is noted that time is rife for the domestic development of the technology over the technical licensing from overseas. Furthermore, it is desirable to develop those technologies employed in submerged floating tunnel within country which are also applicable to the building of offshore construction as gigantic sea platform construction.

This research to analyze the impact load and its characteristics was undertaken given consideration to those domestic industrial considerations. The existing structures for impact loads, except few cases, are not designed for with such details, and thus this study is done with consideration given to excess pressure loads. Ideally, tests are warranted for the performance and for movement of structures for impact loads, but due to its restrictions in both testing sites and measurements and for the lack of accuracy, movement analysis and its design are mostly conducted utilizing analytical tools.

This analysis was conducted using LS-DYNA, a commercial structure analysis program to analyze the impact loads for submerged floating tunnel.

Impact load is different from existing static analysis and dynamic analysis in that it takes place in a very short instance with big pressure loads, its response time is within the range of shock.

It thereby needs a new approach for other than existing analytical approaches. The study performed to design and for movement of structures when submarine collides with submerged floating tunnel and when the submarine sunk due to collision. This analysis was conducted under those realistic impact scenarios of submerged floating tunnel applying non-linear concrete material models.

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[1] Department of Civil Engineering, Daejeon University, 96-3,Yongun-dong, Dong-gu, E-mail :yunis@dju.ac.kr, Daejeon 300-716, SOUTH KOREA,

[2] Coastal Engineering and Ocean Energy Research Department, Korea Institute of Ocean Science and Technology, Sa-2-dong, Ansan, Gyeonggi, SOUTH KOREA

IMPACT ANALYSIS OF SUBMARINE COLLISION IN OPERATION

Overview

This analysis has performed mesh modeling with specification of submerged floating tunnel described in Fig. 1. Partition wall has little effect in this analysis when it comes to resisting against actual impact loads. It is expected that when partition wall are built, it will have many configurations and therefore did not consider partition wall in this analysis as in Fig.2 and instead gave considerations to outer walls. In order to take into consideration of elliptical impact objects as submarines, the elliptical objects as in Fig.2 was modeled. And to take into consideration of elliptical objects as vessels and submarines for collision, the elliptical objects as 1,860 tons SON WON-IL class submarine (in Korea) with 50m length and 10m width has been selected shown in Fig.2 and was modeled with rigid solid elements. The impact velocity in operation was assumed to 5 m/s. The submarine was considered as a rigid body which did not permit any deformation. Considering the hydrodynamic behavior of submerged body, the added mass of both submarine and tunnel with approximate spherical shape was increased by 50%, respectively. Outer walls of tunnel are reinforced by rebar with 100mm cover depth on top and bottom and a reinforcement ratio of 0.2% was applied. 8 Node solid elements was used in modeling for impact structure and for tunnel and 2 Node Truss element was used for rebar modeling. Analysis used LS-DYNA v.971 and 72(*MAT_CONCRETE_DAMAGE) was used for concretes. The diameter of tunnel is 20m and thickness of wall is 1m and 100m for the length of tunnel. This analysis has performed mesh modeling with specification of submerged floating tunnel described in Fig. 1. Since partition wall is factored in the conceptual design phases for submerged floating tunnel, this modeling is attempted to model its typical cross section of tunnel’s outer wall and partition wall in order to simulate as close as actual movements.

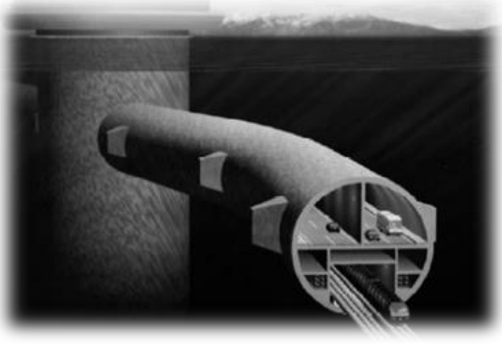

Fig. 1 Trader submerged floating tunnel specification and planned tunnel modeling

Fig. 2 Submerged floating tunnel impact structure, tunnel (concrete) and rebar modeling

Analysis Results

Collision scenarios are categorized into 4 cases labeled to scenario A, B, C and D. Each scenario A, B, C and D is assigned to head-on impact, impact on middle of hemisphere, impact on top of hemisphere and sinking impact, respectively.

Fig. 4 and 5 show distribution of cracks and strains on tunnel when collided head-on with impact structures. It is indicated that the penetration failure of the submerged tunnel will take place in the event the tunnel is impacted with head-on collisions.

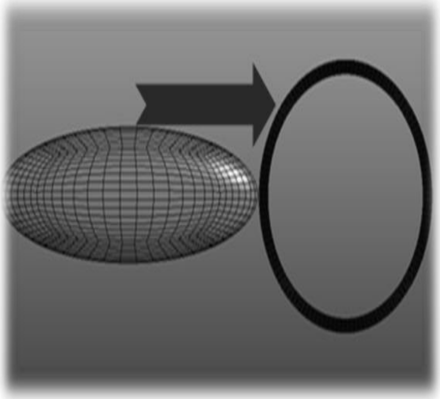

Fig. 3 Submerged floating tunnel impact scenario A (head-on collision)

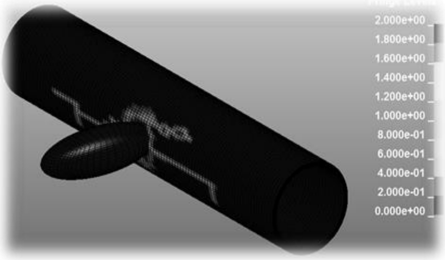

Fig. 4 Crack strain distribution after 1 sec impact

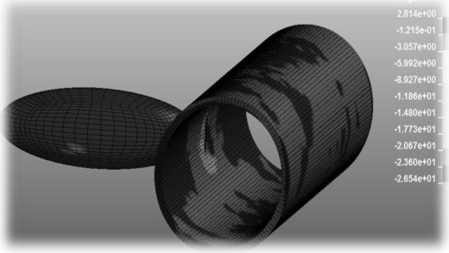

Fig. 5 Principal stress distribution after 1 sec impact

Fig.6 shows the reduction of movement energy from its impact structure as it is progressing to the energy history of each impact scenario A~D.

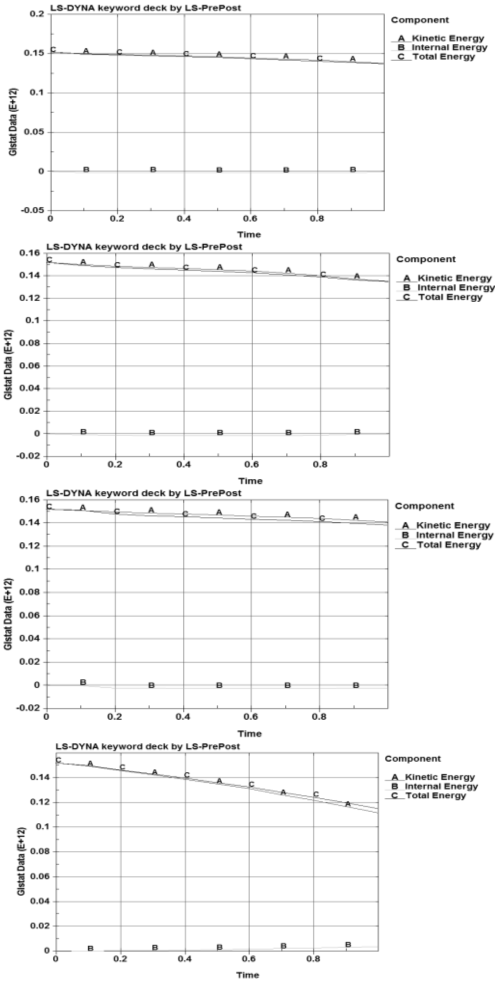

Fig. 6 Energy history of each impact scenario (A~D)

Fig 8 and 9 indicate the distribution of cracks and strains on tunnel when collided with a structure on its sides. It is indicated that the penetration failure of the submerged tunnel will take place in the event the tunnel is impacted on middle of hemisphere. Fig.9 shows distribution of principal stress when impacted on its sides. On the whole, the stress when impacted shows that it does not exceeds the concrete pressure strength of 45MPa. Fig. B shows the reduction of movement energy from its impact structure as it is progressing to the energy history of impact scenario B.

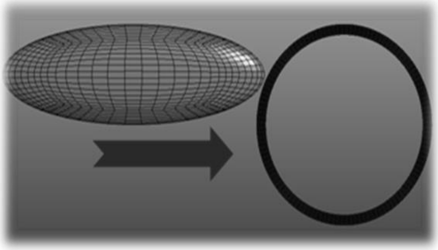

Fig. 7 Submerged floating tunnel impact scenario B (impact on middle of hemisphere)

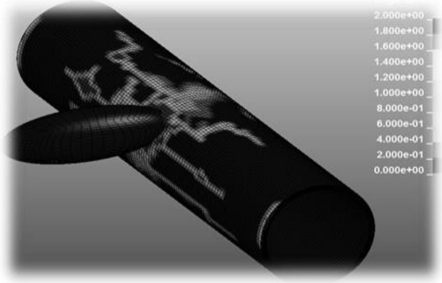

Fig. 8 Crack strain distribution after 1 sec impact

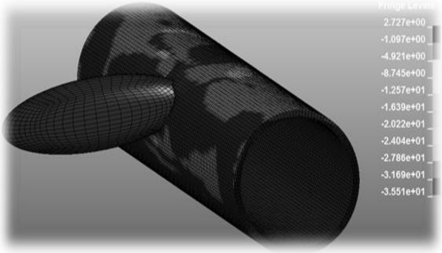

Fig. 9 Principal stress distribution after 1 sec impact

Fig 11 and 12 indicate the distribution of cracks and strains on tunnel when impacted with structure on its sides. It is indicated that the penetration failure of the submerged tunnel will take place in the event the tunnel is impacted on top of hemisphere. Fig.13 shows distribution of principal stress when impacted on its sides. On the whole, the stress when collided shows that it does not exceeds concrete pressure strength of 45MPa.

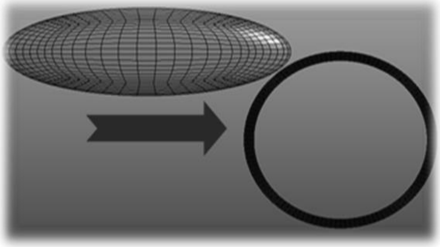

Fig. 10 Submerged floating tunnel scenario C (impact on top of hemisphere)

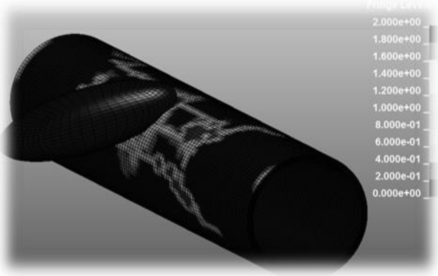

Fig. 11 Crack strain distribution after 1 sec impact

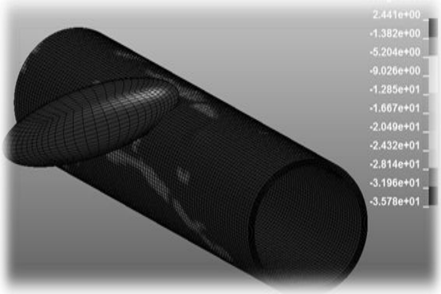

Fig. 12 Principal stress distribution after 1 sec impact

Fig 14 and 15 indicate the distribution of cracks and strains on tunnel when collided with sinking vessel structure. It is indicated that the penetration failure of the submerged tunnel will take place in the event tunnel is collided with such sinking vessel. Fig.17 shows distribution of principal stress when collided on its sides. On the whole, the stress when collided shows that it does not exceeds concrete pressure strength of 45MPa. Fig.6 shows the reduction of movement energy from its impact structure as it is progressing to the energy history of impact scenario D.

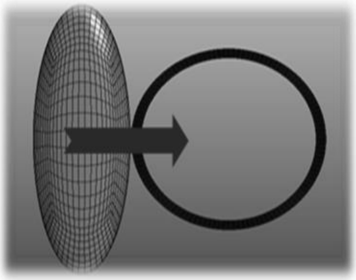

Fig. 13 Submerged floating tunnel scenario D (sinking impact)

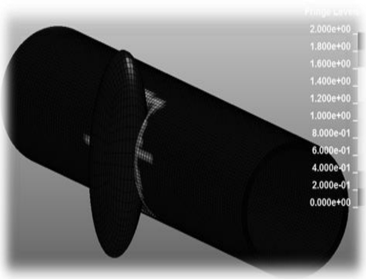

Fig. 14 Crack strain distribution after 1 sec impact

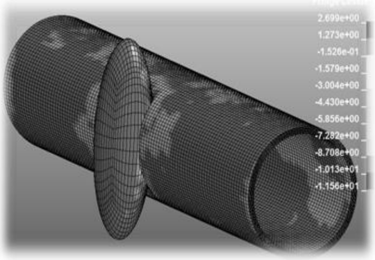

Fig. 15 Principal stress distribution after 1 sec impact

IMPACT ANALYSIS OF SUBMARINE COLLISION WHILE SINKING

Overview

This analysis has performed mesh modeling with specification of submerged floating tunnel described in Fig. 1. Since Partition wall is factored in the conceptual design phases for submerged floating tunnel, this modeling is attempted to model its typical cross section of tunnel’s outer wall and partition wall in order to simulate as close as actual movements. And to take into consideration of elliptical objects as vessels and submarines for collision, the elliptical objects as 18,750 tons Ohio class submarine with 100m length and 20m width has been selected shown in Fig.16 and was modeled with rigid solid elements. Outer walls of tunnel are reinforced by rebar with 100mm cover depth on top and bottom with collision speed of 0.463m/s and a rebar ratio of 0.2% was given consideration. 8 Node Solid elements was used in modeling for impact structure and tunnel and 2 Node truss element was used for rebar modeling. Analysis used LS-DYNA v.971(LSTC, 2007) and 72(*MAT_CONCRETE_DAMAGE, LSTC, 2007) was used for concretes. The external diameter of tunnel is 23m and thickness of wall is 1m and the length of 100m, 300m, 500m, 1000m tunnels were considered.

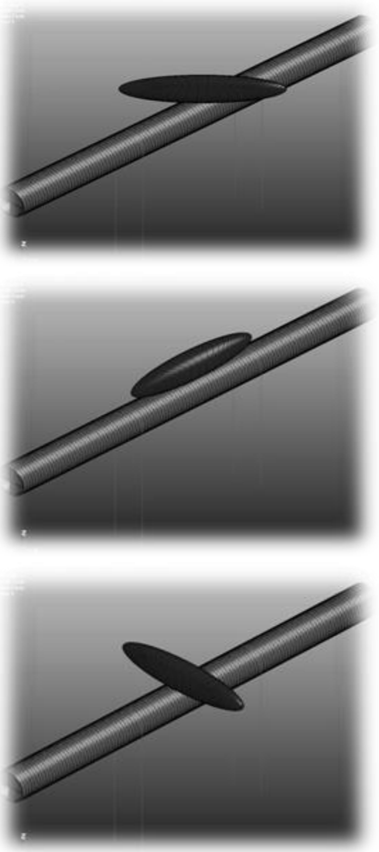

Fig. 16 Impactor and tunnel mesh modelling

Analysis Results

Fig. 17 show deformations at impact in 1000m tunnels and indicates direction and the movement from its perpendicular, skew and parallel collision when a colliding object sinks. As were the cases in the aforementioned lengths, for 1000m tunnels, pressure deformation rate occurs all over central cross section Partition wall and over the surface of top colliding plane toward tunnel due to its bending moment. No damage movements penetrating tunnel from collision from perpendicular, skew and parallel collision resulted and showed colliding structure bouncing back in reverse direction from its colliding direction. Out of 3 impact scenarios, as it were for 100m and 300m cases, the collision impacted areas varied in accordance with the shape of colliding objects, however, since the length of tunnels used for testing were longer as the colliding objects get bigger, the relative scope and difference in area of collision were not significant.

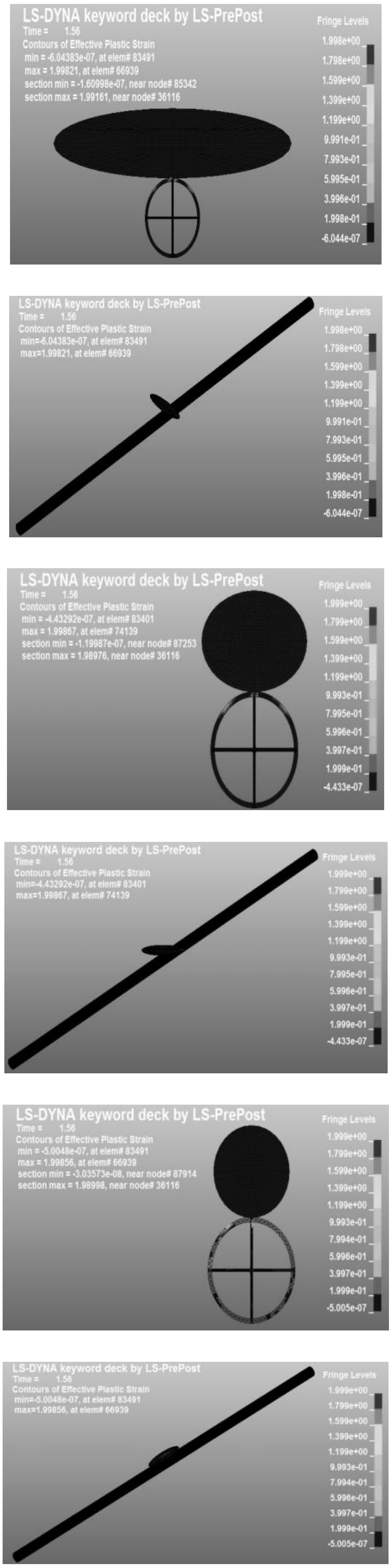

Fig. 17 Deformations at impact (Tunnel length : 1000m)

Table 1, 2, and 3 show maximum impact forces on the contact surface, when the impact forces are longitudinal, transverse, or sinking direction, respectively. The longitudinal and transverse impact forces demonstrated very little destruction, within 8% of the downward impact load, which could have resulted from the change of contact surface at the time of collision of the crashing object and the concrete part of tunnel. As seen in Table 1, the colliding force was the biggest when the crashing object was perpendicular to the longitude of the tunnel and the least when the crashing object was parallel to the longitude of the tunnel. It seemed the collision force is transferred less as the longitudinal contact surface is relatively less when collision is parallel than when it is perpendicular to the longitude of the tunnel.

Table. 1 Comparisons of longitudinal forces(X-force)

	X-force (UNIT: MN)			
	100(m)	300(m)	500(m)	1000(m)
X-force(perpendicular)	1.9	2.4	2.1	2.2
X -force(skew)	0.9	0.8	0.75	1.15
X -force(parallel)	0.31	0.39	0.22	0.23

Table. 2 Comparisons of transverse forces(Y-force)

	Y-force (UNIT: MN)			
	100(m)	300(m)	500(m)	1000(m)
Y-force(perpendicular)	0.35	0.3	0.35	0.36
Y -force(skew)	1.3	1.2	1.18	1.1
Y -force(parallel)	1.4	1.3	1.2	1.42

Table. 3 Comparisons of sinking direction forces(Z-force)

	Z-force (UNIT: MN)			
	100(m)	300(m)	500(m)	1000(m)
Z-force(perpendicular)	24	25	23.8	25.8
Z -force(skew)	20.5	24	22	25.7
Z -force(parallel)	46	19.5	20	26

As shown in Table 2, the collision force to the tunnel's vertical axis is the biggest when the impact of the crashing object is parallel and the least when the impact of the crashing object is vertical to the tunnel axis. It seemed the collision force is transferred most as the longitudinal contact surface is formed relatively larger when impact is parallel to the tunnel axis.

As shown in Table 3, except when the crashing object is longitudinally collided on 100 meters long tunnel, the maximum impact force appears to be approximately 20 to 25 MN. It is estimated that impact surface is formed momentarily wider throughout the short length of the tunnel in case of the horizontal impact of the 100 meters long tunnel, and the result would be similar of the submerged floating tunnel longer than 1 km in length.

CONCLUSION

This research performed analyses of collisions to design submerged floating tunnel against possible impact loads from anticipated colliding submerged objects and concludes as follows:

The loads vertical to the tunnel-axis were found to be less than 8% of loads along the direction of collision. This is due to the deformation occurring on the colliding surface against concrete surface of tunnel. And the maximum loads along the direction of tunnel occurred when impact object crashed vertical to the tunnel. This is due the minimum impact surface results perpendicular to the tunnel-axis direction when collision occurs along the direction of tunnel-axis. This impact in turn minimizes the loads from collision in comparison. The collision force to the tunnel's vertical axis is the biggest when the impact of the crashing object is parallel to the tunnel. It seemed the collision force is transferred most as the longitudinal contact surface is formed relatively larger when impact is parallel to the tunnel axis. When designing the structure for submerged floating tunnel against possible collision, the impact loads from crashing objects along its colliding direction is the most critical aspect in design. The study shows that maximum load lies in the range of 20 ~ 25 MN when the length of tunnel is 500m and 1000m.

This maximum loads should be carefully examined when designing the submerged floating tunnel in future, since the submarines operating in Korean waters are 10 times lighter than the one being considered for this analysis, U. S Ohio class submarine with 18,750 ton.

ACKNOWLEDGEMENTS

This research was supported by the project ‘Development of core techniques for submerged floating tunnels (PE98941)’ funded by Korea Institute of Ocean Science and Technology.

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