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CONSTRUCTION CHALLENGE OF SUBMERGED FLOATING TUNNEL IN INDONESIA

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ABSTRACT

Indonesia is an archipelagic country which consisting of many islands that require competitive crossing technology. Submerged floating tunnel (SFT) responds to this challenge and comes as a competitive crossing technology. SFT structure has superior advantages to conventional crossing technologies but it also has some disadvantages especially in keeping structural stability.

Structural stability of SFT is mainly effected by site characterization and environmental disturbances. Geographical combination of water depth, crossing distance and overall dimension is one of the most important factors to decide the structu of Engimeeral design as well as environmental disturbances such as wave, current and earthquake.

This paper presents descriptions of SFT structures, some of the SFT structure challenges and the opportunities of using SFT structures for various purposes in Indonesia.

Keywords : Submerged Floating Tunnel, Site Characterization, Environmental Disturbances, Structural Design

1. INTRODUCTION

Submerged Floating Tunnel (SFT) is an innovative transportation concept for crossing sea, straits, large lakes, deep rivers or waterways in general (Mazzolani, 2007). By definition, SFT is a tubular structure that floats at a certain depth below the surface of the water that exploits the carrying capacity derived from the Archimedes force which has a fixed position through a pontoon system or anchor system made of tether connected to the seabed (Wahyuni, 2012). An SFT basically consists of four parts : (i) the tunnel structure which is made up of tunnel segments, (ii) the shore connection structures which connect SFT to shores, (iii) the cable systems which are anchored to the waterbed to balance the net buoyancy, and (iv) the foundation structures which are constructed at the waterbed to install cable systems In addition to being used as a mode of human transportation, SFT can also be used as a transportation mode for other stuffs such as oil, gas, electrical cable and communication cable (budiman, 2016). SFT structure has many advantages compared with conventional tunnel or bridge mainly in construction cost and construction time. Total length of SFT and longitudinal slope especially on land excavation side are much shorter than that of immersed tunnel and underground tunnel as shown in Figure 1. Obviously, this will reduce the use of energy consumption significantly. Futhermore, SFT structure is considered more competitive than conventional bridges because SFT does not require high cost pylons.

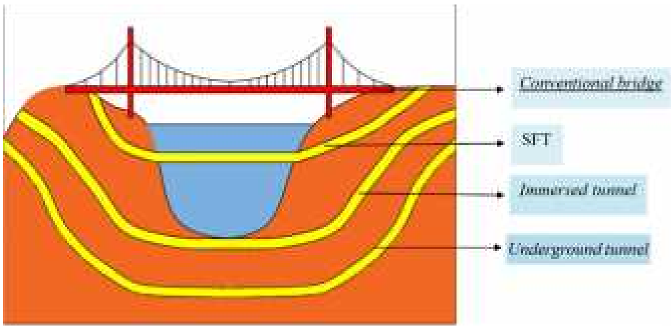

Figure 1. Illustration of water crossing comparison (Source: ITA/AITES,2006)

Martire et al. (2010) has conducted a cost comparison evaluation between the suspension bridge and SFT where the Akashi Strait, crossed by the suspension bridge featuring the largest main span in the world (1991 m), and the Strait of Messina, where a suspension bridge having a main span of 3300 m is planned to be built, are selected as case studies, in order to perform a cost comparison between the most advanced Suspension Bridge (SB) designs up to now and SFT preliminary proposals, assumed to be built in the same locations. The results show that the SFTs total cost is largely lower, it being 25.6% (Messina) and 36.3% (Akashi) of the cost of the relative SB, basically due to the huge reduction of the cost of the supporting system. In fact, SFT cable system cost is the 2.7% (Akashi) and 8.6% (Messina) of the cost of the SB supporting system (cable plus pylons). Furthermore, the cost of the tunnel structure is pretty much the same one of the SB deck for the Strait of Messina crossing, whereas it is the 62.9% of the cost of the SB deck for the Akashi Strait case. An approximate quantitative estimate of the differences in tunnel length between SFT and traditional tunnel is shown in Table 1, for a 1000-metre-wide crossing with 100 water depth (Forum of European National Highway Research Laboratories, 1996).

Table 1. Approximate total tunnel length

Type of structure	Approximate Total (km) Road	Tunnel Length (km) Railway
Underground tunnel	5.6	14
Immersed tunnel	4.5	10
SFT	2.2	4

However, a comparative evaluation can be made with respect to suspension bridges as shown in Figure 2. It should be noted that the SFT cost per unit length is approximately constant while for bridge, it significantly increases with the span length. SFT will also allow better control of air pollution, since vehicle emissions, can be collected to SFT entrances, by the ventilation system, and can be easily treated before discharge into the atmosphere.

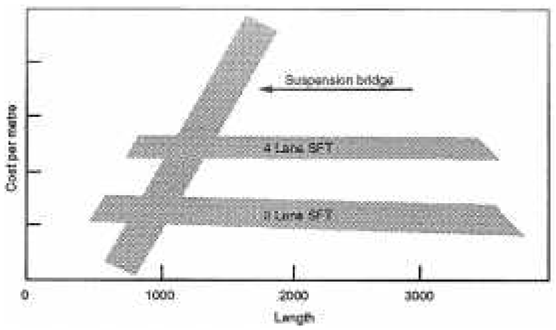

Figure 2. Cost comparison between SFT and suspension bridge.

All structures will have to be removed or replaced sooner or later and as the amount of structures increase it is important to prepare for these operations already at the planning and design stage. Removal, recycling or reuse of materials or parts of the structures will become increasingly necessary in the future, for both economic and environmental reasons. SFT is in most cases a floating structure as a whole and may therefore be towed away to some place where parts of the SFT may be reused. One may imagine such an operation by for instance placing bulkheads in the original elements and then separating the SFT in suitable lengths to be perhaps towed to different locations for reuse or destruction.

2. FOUR PRINCIPLE TYPES of SFT

As well as other floating structures, the SFT structure must be anchored or fixed against the excessive movement. There are four different types of anchoring as the following explanation.

2.1 Free Anchoring

SFT type in Figure 3 has no anchoring at all (tethers, pontoons, colomns) except at landfalls and is then independent of depth. There is obviously a limit to the length because it could be imposed large environmental load which cause excessive movement.

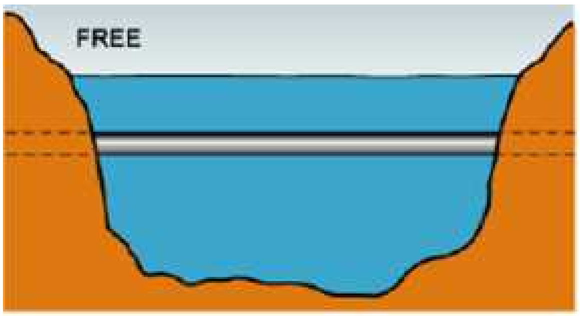

Figure 3. Free anchoring SFT

This type is commonly used in calm waves and currents. Beside that, the loads acting on this type of structure should be relatively small so they are commonly used only on pedestrian road or light vehicle traffic. Based on at least some insight, the length of this type is considered to range from 150 m to 300 m.

2.2 SFT supported on columns

SFT type in Figure 4 is similar with the conventional bridge with foundations on the bottom, in principle the columns are in compression but they may also be a tension type which change alternatively. Water depth will play an important role in this case and a few hundred meters depth is considered a limit at the present time.

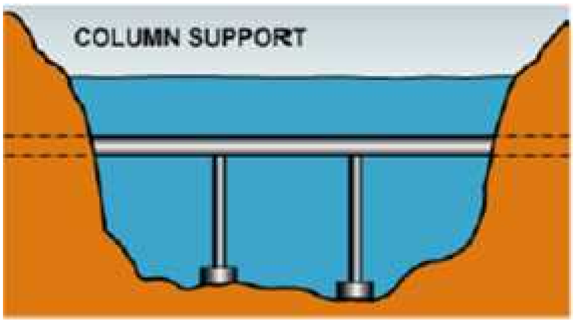

Figure 4. SFT supported on colomns

This type of SFT certainly does not take advantage of its superior superiority which is a special feature of this structure. Because of that reason, this type of SFT is not recommended to realized because tts construction costs will be high close to conventional bridge construction costs.

2.3 SFT with pontoons

SFT type in Figure 5 is independent of water depth, the system is sensitive to wind, waves, currents and possible ships collision. Design should allow for one pontoon to be lost and the structure should still survive.

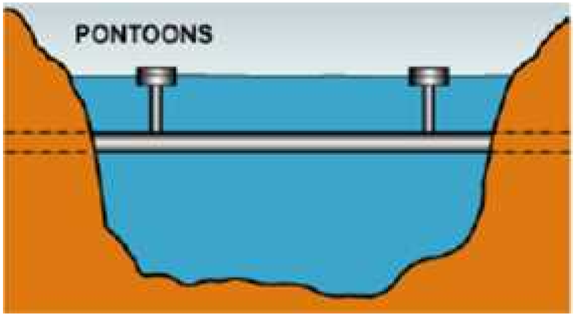

Figure 5. SFT with pontoons

This type of SFT has weak link between pontoon and /or connections to SFT. It should arrange proper distance, size and shape of pontoons. This type of SFT is proper to deep water with the extreme sea depth contour. For very deep waters, additional anchoring methods may be necessary. Based on at least some insight, the length of this type is considered to range from 1000 m to 3000 m.

2.4 SFT with tethers to the bottom

SFT type in Figure 6 is based on tethers being in tension in all future situations, no slack in these ethers may be accepted in any future load cases. The present practical depths for this type of crossing may be several hundred meters, whether the tethers are vertical or a combination of vertical and inclined.

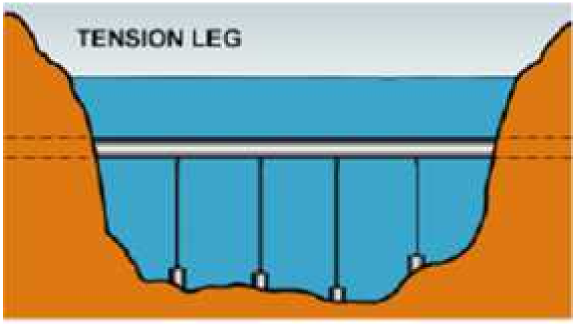

Figure 6. SFT with pontoons

This type of SFT is the best choice to resist the environmental load (wave, current and earthquake). However, a serious problem will be encountered by this type of structure that is the emergence of slack phenomena and snap force (Lu W et al., 2010)

3. STRUCTURAL COMPONENTS

An SFT basically consists of four parts: (i) the tube structure which is made up of tunnel segments and allows traffics and pedestrians to get through, (ii) the shore connection structures which connect SFT to shores, (iii) the anchoring system consist of pontoons system and the cable systems which are anchored to the waterbed to balance the net buoyancy (the present paper concentrates on the SFT type of tunnel buoyancy larger than tunnel weight), and (iv) the foundation structures which are constructed at the waterbed to install cable systems (Long et al., 2008).

3.1 The Structure of Tube

The tube should accommodate traffic lanes (road and/or railway) and equipment. External shape could be circular, elliptical or polygonal. The tube could be steel or concrete. If the steel structure of SFT is chosen, the buoyancy weight ratio (BWR) value will be high and structure stability of SFT will be increased. SFTs that use steel structures require a tunnel frame as shown in Figure 7. However, the corrosion will threat for any structure located in water included SFT structure so that the corrosion protection should be given. If the steel structure of SFT is chosen, the buoyancy weight ratio (BWR) value will be high and structure stability of SFT will be decreased. A combination of both materials may be a very interesting development as a composite structure may combine the best of the two material. The tube is composed of elements having, in general, lengths of the order of magnitude from one hundred metres to a alf kilometres. They are joined together and joints should be designed and constructed in order to simplify installation procedures; joints must also provide sealing, strength and stiffness, at levels not less than those of the tube itself.

3.2 The anchoring System

In principle, there are three types of anchoring for SFT where they are tension leg to the seabed, pontoons, and colomn support. The tension leg method will make it possible to build a completely invisible crossing. However, using pontoons on the surface may, in some instances, be desirable; perhaps to pontoon themselves may be used for specific purpose such as recreational activity or perhaps fish framing. In some cases, anchoring should also provide transverse stiffness; in these cases, they should be inclined. This is a typical case for highly seismic areas and for crossing where extreme wave and strong current exists. In less severe conditions, transvere stiffness can be provided by the shape of the tube itself, forming an arch in the horizontal plane.

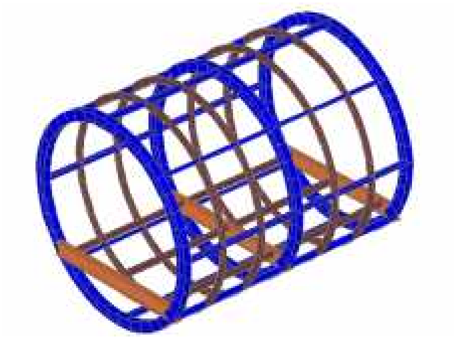

Figure 7. The frame of SFT's tube

Pontoons are only able to provide vertical support and lead more to more flexible systems; the can be applied in less severe environmental load condition.

Pontoons have the advantage of being independent of the water depth but they have to cope with ship, waves and ice. Pontoons may be made of steel or concrete, having several co mpartments to ensure buoyancy in event of ship a collision. The fixed of the pontoons to the SFT should be made through the a "weak link" joints, which would save the SFT in the event of a ship collision, i.e. the pontoon would be sheared off and the tunnel tube would remain intact.

3.3 The anchoring System

The connection of the tube to the shore (Figure 8) require appropriate interface elements to couple the flexible water tube with the much more rigid tunnel bored in the ground. This joint should be able to restrain tube movement, without any sustanainable increase in stress (therefore partially accommodating the tube displacement). On the other hand, the joint must be water tight, in order to be able to prevent ingress water. Additional care in shore connection is required, especially in seismic area due to the risk of submarine landslides).

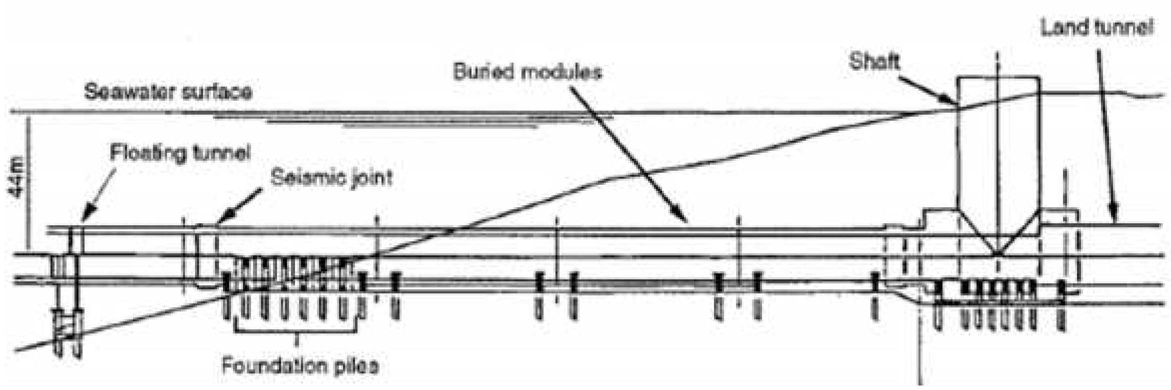

Figure 8 Shore connection scheme
(source: FEHRL, 1996)

3.4 The Foundation od SFT Structure

The foundation structures are constructed at the waterbed to install cable systems. The pile cap of these foundation will be better located in the same depth level so that the length and the inclination angle of the tension leg would still remain fixed. The pile foundation will experience a predominantly tension state but once in time will experience compression state in small quantities. Based on that fact, the foundation should be designed as a tension pile.

4. MAIN CHALLENGES of SFT CONSTRUCTION

Stability of SFT depends on the balance between dead load, moving load, buoyancy and anchoring force. Besides of those conventional loads, SFT is also subjected to environmental loads, such as the action of wave, current and earthquake (Jian et al., 2010), which plays an important role in structure design, construction and durability. To build such a bridge will encounter various scientific and technical difficulties, such as the tunnel architecture design, the cable system configuration, the connection design between tunnel tube and shores, the installation of SFT structures, etc Some main challenges in SFT construction (Xiang Q, et al., 2016) is presented as the following:

1. The action of wave and current exerting on SFT produce fluid-solid coupling vibration on structure or components. Behaviour and mechanism of SFT are very complex under such actions. They are the key points and difficulties for structure analysis.
2. Because SFT remains in the marine corrosive environment, the materials of tube and anchor cables are easy to be corroded. In addition, anchor cables are vulnerable to fatigue damage under dynamic loads, which is a threat to the whole SFT structure. Therefore, it is necessary to study the durability and resistance-fatigue failure mechanism of SFT and put forward corresponding solution strategies.
3. SFT tube is generally immersed in the depth of 20-30m under water, once collision accidents happen during its operation, the consequence is more serious. Therefore, how to improve safety degree of SFT, reduce or avoid the risk of accidents, and take reasonable escape and rescue measures as soon as possible after accidents is a critical problem for ensuring SFT’s operational safety.
4. It is still a challenge to construct foundations in 50-200m deep water with complex marine geological conditions. Putting forward effective construction methods on the basis of existing construction technology is the critical issue to the safety and economic advantages of SFT.
5. There are many risks and uncertain factors exist during construction and operation. How to recognize and control these risks and uncertainties, including investment risk, design risk, construction risk, natural disasters, extreme events, operation management risk and so on, has an important theoretical meaning and engineering guidance.

5. CHALLENGES AND OPPORTUNITIES of SFT IN INDONESIA

As an archipelagic country, Indonesia has the interest to connect one island to another island to cross the people and goods. This is important for economic growth, equity of the people's welfare as well as political, economic, social and cultural unity. As discussed earlier, Submerged Floating Tunnel (SFT) offers many advantages compared with conventional tunnel and bridge. The main advantages offered are low construction cost, short construction time, removable, reuse and eco friendly. There are some potential water crossings using SFT structure in Indonesia (Figure 9) to construct SFT for transportation of human being and goods such as Sunda strait which connect Sumatra Island to Java Island, Bali strait which connect Java Island to Bali Island. The aforementioned waterways crossing is in order to connect Java Island as a center of economic activity and densest population in Indonesia to Sumatra as the second largest of economic contribution to Indonesia and Bali Island as a center of tourism in Indonesia. SFT structures can also be built outside of Java island such as Bangka strait that connect Bangka Island to Sumatra Island, Baligau strait that connect Tarakan Island to Kalimantan Island and many other places in Indonesia where it depends on budget belonged to each region.

Figure 9. Potential water crossing using SFT structure in Indonesia

SFT can also be used for tourism purposes, especially in exploiting underwater scenery which can be shown in Figure 10. SFT structure could be constructed in some of beautiful underwater scenery of tourist places in Indonesia such as Derawan Island, Bunaken Island, Seribu Island, Raja Ampat Island etc.

Figure 10. Illustration of SFT used as underwater scenery tourism: by Sachiko Asai

Besides being utilized as transportation infrastructure for people and goods, SFT structure is also used as transportation of other materials such as oil and gas (Budiman et al., 2017). The acceleration of the natural gas infrastructure is in line with the Government's efforts to continue increasing the allocation of natural gas to the domestic market. In order to realize that purpose, in several cases, natural gas should be transported through the sea and the strait using submarine pipeline. There are some government's projects in order to transport natural gas which should pass through the sea or the strait. Kalija project (Figure 11) is one of natural gas pipeline which tranmits natural gas from Bontang (east kalimantan) to Semarang (central java) through Java Sea.

Figure 10. Natural gas pipeline (onshore terminal-onshore terminal)

In Kalija project, natural gas is transported by submarine pipeline from onshore terminal to other onshore terminal. On the other hand, there are submarine pipeline projects constructed from offshore terminal (natural gas producing area) to onshore terminal such as Malacca strait-Lhokseumawe as shown in Figure 11 and etc.

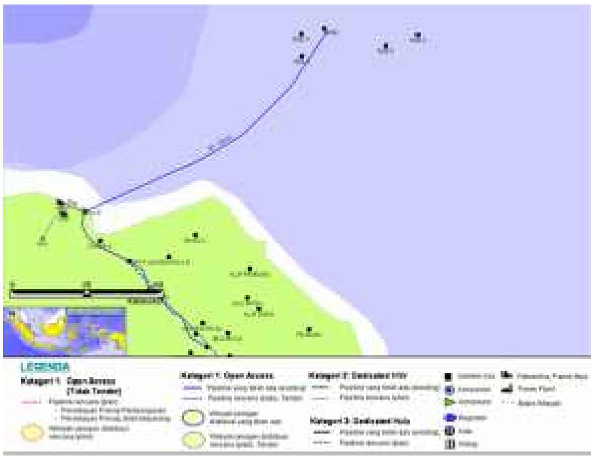

Figure 11. Natural gas pipeline (offshore terminal-onshore terminal)

The submarine pipeline is commonly constructed on the sea bed. This construction has high risk level because if leakage of submarine pipeline occurs, the owner or operator must be spent much money to overcome marine pollution and to repair submarine pipeline. Based on that fact, SFT presents to improve pipeline technology by placing pipeline into SFT structure. The SFT technology appears more economical if some stuffs are also transmitted by SFT structure like electrical cable and communication cable. However, it is a challenge for Indonesia to start developing SFT technology to take many advantages from this technology.

6. CONCLUSION

SFT structure is an innovative waterways crossing technology. It should be admitted that even though SFT structure has superior advantages compared to conventional crossing technologies but it also has some disadvantages especially in keeping structural stability. However, this is a challenge and an opportunity for Indonesia to develop and use this technology considering the amount of profits to be gained by Indonesia because of the need of this country as an archipelagic country to increase revenue from the transportation of natural resources and tourism.

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