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Review Paper on Submerged Floating Tunnels

Ravi Chopra
Assistant Professor, Gateway Institute of Engineering & Technology, Sonipat(Haryana)
Pulkit Sharma, Hemant
Gateway Institute of Engineering & Technology, Sonipat(Haryana)

Abstract

This paper presents analysis on submerged floating tunnel (SFT) with working loads considered on the tunnel are current and wave loads. The tunnel structure is assumed of steel tube with 150 m length and 5 m of diameter. Several crossings with a variety of different conditions under which a Submerged Floating Tunnel, SFT or Archimedes Bridge, may be used. However, swell, vortex shedding and slowly varying internal waves due to layers of different salinity presented a hazard of significant dynamic oscillations. In addition to the challenge of these various conditions some common accidental situations have to be solved for all applications including fire, sinking ships, falling anchors as well as sudden massive water ingress into the tube. Combining with the characteristics of submerged floating tunnel (SFT) and surrounding environment, it is of great theoretical and practical significance to develop research in the areas of potential risk and impact factors, risk index system, risk level of SFT. Risk management workflow of SFT was given. Then we focused on discussing the potential risks of SFT in investment, design, and environmental condition during planning and feasibility study stage.

Keywords: Submerged Floating tunnel (SFT), design, construction

1.Introduction

1.1 General

Tunnels in water are by no means new in civil engineering. Since about 1900, more than 100 immersed tunnels have been constructed. Bridges are the most common structures used for crossing water bodies. In some cases immersed tunnels also used which run beneath the sea or river bed. But when the bed is too rocky , too deep or too undulating submerged floating tunnels are used .

The Submerged Floating Tunnel concept was first conceived at the beginning of the century, but no actual project was undertaken until recently. As the needs of society for regional growth and the protection of the environment have assumed increased importance, in this wider context the submerged floating tunnel offers new opportunities. The submerged floating tunnel is an innovative concept for crossing waterways, utilizing the law of buoyancy to support the structure at a moderate and convenient depth .The Submerged floating Tunnel is a tube like structure made of Steel and Concrete utilizing the law of buoyancy .It supported on columns or held in place by tethers attached to the sea floor or by pontoons floating on the surface. The Submerged floating tunnel utilizes lakes and waterways to carry traffic under water and on to the other side, where it can be conveniently linked to the rural network or to the underground infrastructure of modern cities.

1.2 Basic Principle Of SFT

SFT is a buoyant structure which moves in water. The relation between buoyancy and self weight is very important, since it controls the static behaviourf the tunnel and to some extend, also the response to dynamic forces. Minimum internal dimension often result in a near optimum design. There are two ways in which SFT can be floated.

- **Positive buoyancy:** In this the SFT is fixed in position by anchoring either by means of tension legs to the bottom or by means of pontoons on the surface. Here SFT is mainly 30 metres below the water surface.

- **Negative buoyancy:** Here the foundations would be piers or columns to the sea or lake. This method is limited to 100 meters water depth

SFT is subjected to all environmental actions typical in the water environment: wave ,current , vibration of water level, earthquake, corrosion, ice and marine growth. It should be designed to with stand all actions, operational and accidental loads, with enough strength and stiffness. Transverse stiffness is provided by bottom anchoring.

2.Review Of Literature

A submerged floating tunnel (SFT), also called a suspended tunnel or Archimedes bridge, is a tunnel that floats in the water, supported by its buoyancy (specifically, using hydrostatic thrust or the Archimedes principle).

The tube is placed under the water, deep enough to avoid water traffic and weather, but not so deep that high water pressure should be treated, it is usually sufficient 60-50 feet (20-50 m). Cables anchored to the Earth or pontoons on the surface prevent them from floating to the surface or submerging, respectively.

The concept of submerged floating tunnels is based on known technology applied to floating bridges and offshore structures, but the construction is mostly similar to that of submerged tunnels: one way is to build the pipe into sections in a dry dock; then float these to the construction site and sink them in place, as long as it is sealed; and, when the sections are secured together, the seams are broken. Another possibility is to build the unsealed sections, and after welding them together, pump the water.

The ballast used is calculated so that the structure has an approximate hydrostatic equilibrium (ie, the tunnel has approximately the same overall density as water), while submerged tube tunnels are further weighed to load them to the seabed. This, of course, means that a submerged floating tunnel must be anchored to the ground or water surface to keep it in place (which of these depends on which side of the equilibrium point the tunnel is).

Floating tunnel is the totally new concept and never used before even for very small length. It can be observed that the depth of bed varies from place to place on a great extent. The maximum depth is up to 8 km. also at certain sections. The average depth is 3.3 km. The two alternatives are available for constructions are bridge above water level or tunnel below ground level. Since the depth is up to 8 km it is impossible to construct concrete columns of such height for a bridge. And also the pressure below 8km from sea surface is nearly about 500 times than atmospheric pressure so one cannot survive in such a high pressure zone. So the immersed tunnels also cannot be used. Therefore, floating tunnel is finalised which is at a depth 30m from the sea level, where there is no problem of high pressure. This is sufficient for any big ship to pass over it without any obstruction.

3. Key Technology of SFT tube design

The key technology of SFT tube design mainly includes section design, structural analysis, waterproof and corrosion protection, joint design, ventilation design and so on. Ripe experience of immersed tunnel and highway tunnel can be used to guide SFT tube design.

3.1. Selection of tube type

Both concrete tube and steel-concrete tube can be adopted in SFT. The prefabricating technique, construction technique, waterproofing work of two material tubes is different, and each has advantages and disadvantages. The concrete tubes are usually prefabricated on quayside dry-dock or moving dry-dock. Then, the tube segment is floatingly transported to the design position for installation. For the steel-concrete tubes, firstly, steel tube junctions are welded and assembled on quayside shipyard near the design site. Secondly, the steel junctions are transported to design position and subsections are balance cast to form steel-concrete junctions. Finally, the junctions are floated to design position and installed. The section shape of steel-concrete tube mainly adopts round section or double round section, which are beneficial to resist hydrostatic pressure and arrange ventilation channel and other service line. The section shape of concrete tube mainly adopts rectangular section for template pouring. The section should be broadened to accommodate ventilation channel and other service line. Comparison of concrete tube and steel-concrete tube is listed in table 1

Table 1. Comparison of concrete tube and steel-concrete tube

Items	**Concrete tube**	**Steel-concrete tube**
Cost	Low Cost	High Cost
Section Type	Rectangular Section is majority	Round Section or Double Round Section
Construction	Cast is dry-rock, long construction cycle	Steel shell acting as template, pouring concrete in floating state, quick construction
Water Proofing	Control Structural Cracks and Shrinkage Cracks. Difficulty of waterproofing is relatively great.	The outer steel shell is used to waterproof. Difficulty of waterproofing is relatively small.

The buoyancy to weight ratio and hydrodynamic resistance performance need to be considered in the process of the outer contour design of SFT tube. The inner contour design of SFT tube should correspond with structural approach limit of tunnel, meanwhile, allowable spaces are all taken into account for ventilation, lighting, fire protection, escape system, operation and maintenance system etc. guaranteeing conformity with the principle of safety, economy and application

3.2. Structural design of SFT tube

SFT tube keeps balance under the action of buoyancy and cable tension bears vehicle load, wave-current load, temperature load and so on. In the system transformation during prefabrication, floating, installation and operation,the stress of tube is complex, so the tube design should carry on longitudinal and transverse analysis under these working conditions.

- SFT tube load is divides into permanent load, variable load and accidental load.
- The permanent includes structure weight, buoyancy, hydrostatic pressure, concrete shrinkage etc.
- The variable load includes vehicle load, water head load, wave-current load, temperate load, construction load etc.
- The accidental load includes seismic, sunken ship load, blast load, leakage etc.
- SFT tube is designed under ultimate limit state and serviceability limit state just as traditional hydraulic structuredesign, moreover, the stress and displacement should be analyzed and checked under progressive damagelimit state and fatigue limit state based on structural reliability theory.

3.3. Waterproofing and corrosion protection design of SFT tube

The waterproofing of tube is critical for the reason that the destruction of waterproofing would bring ruinous disaster, so it is significant to do research on tube waterproofing which would promote the development of SFT.

As for steel-concrete tube, the steel shell is taken as waterproof layer for tube section was closed with steel shell, so the waterproofing quality lies on the welding quality and tightness of juncture. For concrete tube, self-waterproofing is pivotal issue, which means concrete should be low hydration heat and high seepage resistance grade andthe structural crack and shrinkage crack should be controlled within permissible range. Besides self-waterproofing, it is indispensable to daub waterproof materials on the surface of concrete tube. Expansion seam measureand hydrophobic coating measure usually used in immersed tunnel also can be applied in crack control of SFT tube.

3.4. Tube joint design

Joint design of SFT tube should conform to four principles:

- Not seepage in construction and operation stage, reliable water tightness and durability.
- Concise design, stressing definite and working independently.
- Transferring construction load effectively in construction stage and convenient construction.
- Transferring stress and deformation effectively in construction stage, fine seismic performance.

There are two ways of tube joint based on stiffness and deformation: rigid joint and flexible joint.

Table 2 enumerates difference of two types of joints, and figure 2 is schematic drawing of two types of joints design

Table 2. Comparison of rigid joint and flexible joint

Items	**Rigid joint**	**Flexible joint**
Structural composition	End steel shell, GINA water stop, junction steel plate	End steel shell, GINA water stop, OMEGA waterstop, shear key
Construction	Long period and great difficulty	Convenient construction
Cost	Cheap	Expensive
Applicable position	End joint	Intermediate joint

4. Methodology

4.1. Structural dynamic analysis

According to Chakrabarti (2004) there are two basic approaches that must be considered for floating structure,frequency domain and time domain. Frequency domain use for solve simple problem, in general. Attain by differential equation. But this method only work for linear equations, all non – linear equations must be converting to linear. That's the limitation from this method. As for the time domain use numerical integral for equation from all non – linear systems. Examples from this equation are drag force, mooring force and damping viscosity. In API RP 2T. 1987, structural dynamic analyses for offshore structure are: frequency domain analysis and time domain *analysis*. Frequency domain analysis a simulation of the events in each time by frequency interval. Frequency domain can also be used to predict discrete waves response including platform movement. The upper hand of this method is saving calculation time. Data and result (input/output) used more often by designer. All non – linear equations must convert to linear equation. Time domain analysis dynamic structure analysis by time domain function. This method use time integral procedure and resulting time history x(t) dynamic analysis of the structure is to have data due to responses occurred, stress and or deformation or displacement. This analysis displacement response caused by current and fluid loads. Dynamic load in this analysis is random load which is not regularly varies by time. Periodically load in this analysis is current hydrodynamic load. Hydrodynamic loads on this structure are drag, inertia, and lift forces.

Lagrange theorem used for methods. Lagrange equation for Assumed Mode Method5 with below equation:

$v(x,t) = \sum^{N} \Psi(x)_i u(t)_i$ (For i=1)

where: v(x,t) = displacement

ψ (x) = shape function

u (t) = generalized displacement

Global assumed mode method, each ψi (x) represent displacement shape for all structure model NDOF (N-degree of Freedom).Determined by system term condition ψi (x) were:

- Form one set that un free linearly
- Must non dimensional
- Each ψi (x) must have derivatives until such degree in V.
- Must have boundary condition (displacement), so called admissible function.

5. Conclusion

The submerged floating tunnel will set up new trends in transportation engineering and which shows with the advances in technology that will reduce the time required for travelling. And make the transportation more effective by hiding the traffic under water by which the beauty of landscape is maintained and valuable land is available for other purposes. Benefits can be obtained with respect to less energy consumption, air pollution and reduced noise emission. For wide and deep crossings the submerged floating tunnel may be the only feasible fix link, replacing present day ferries and providing local communities with new opportunities for improved communication and regional development.

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