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Developing a Preliminary Hazard List (PHL) Analysis of Submerged Floating Railway

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Abstract The construction of Submerged Floating Railway is in conceptual design phase. It is important to identify and list relevant potential hazards and mishaps that may exist in the system. PHL (Preliminary Hazard List) Analysis can be used as a tool for the management to focus on hazardous areas in the system which requires more resources for hazard elimination or risk controlling to an accepted level. The aim of this paper is to set up a ground work for creating a complete Preliminary Hazard List for the total system and to facilitate Preliminary Hazard Analysis in evaluating design at the preliminary level. The scope of this study will be limited to 2 major components; tubes and foundation on seabed and the joining between them. This study initiates the listing of preliminary hazards related to the basic structure of Submerged Floating Railway, which can be further extended to sub-system levels for a complete set of PHL for the total system. Preliminary Hazard Analysis will be benefited by this resource to eliminate and control design faults during the preliminary design phase to ensure a more reliable and safer design.

Keywords: Preliminary Hazard List, Preliminary Hazard Analysis, Submerged Floating Railway

1. Introduction

Submerged Floating Railway (SFR) is a tube-like structure floating below the surface of the water at a pre-fixed depth as a means of railway transportation for shallow-depth waterway crossing in deeper waters. Unlike immersed tunnel and conventional tunnel, Submerged Floating Railway system running within floating tunnel supported by buoyancy, which can be built independently of water depth. It's cost effective due to modular construction before assembling the tunnel under water and the construction period can be reduced drastically as well. SFR can be especially considered for the environmentally sensitive areas where the preservation of landscape is a high priority.
With the growing interest in Submerged Floating Tunnel (SFT), especially in Japan, Italy and Norway; number of advanced research projects has been developed. In parallel, Republic of Korea has also been engaged in an independent mega research project collaborating together with various research institutes in Korea. As safety should be the first priority for SFT research, a systematic risk analysis should be done from the initial stage of conceptual or preliminary design phase.
In order to identify and list all the potential hazards and mishaps existing in the system that may lead to an accident; Preliminary Hazard List analysis technique can be performed during the conceptual or preliminary design phase. Identified hazards in PHL analysis will be later subjected to more in-depth hazard analysis and evaluation, as more detailed information become available about system design. PHL analysis can further facilitate Preliminary Hazard Analysis to identify Safety Critical factor relevant to design safety. In this study, SFR system has been broken down into several main components to identify and list potential hazards that may exist in the system. In case of analysis, only the structural components have been considered. Significant numbers of hazards have been identified which addresses important design attention that must be in consideration during the development of the further design process. [1][2][3]

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2. Main Contents

2.1 Design Summary

In this study, the conceptual design of submerged floating railway is based on Honam-Jeju area which is a pipeline-shaped composite structure (Figure 2) with sufficient buoyancy and strength required in running under the water. The structural buoyancy of SFR exceeds the gravity and is balanced by the tension of mooring. Among variety of materials, chains have been used for mooring line to convey the tension by buoyancy to sea-bed and is fixed to sea-bed to provide combined horizontal and vertical support. In terms of anchoring, due to the cost and construction efficiency, gravity anchoring method using concrete block has been considered. There are 4 mooring cables per 100m module for the consideration of the buoyancy-gravity ratio of the body and for the passenger evacuation and ventilation; there is one stationary structure at every 10Km. [2]

2.2 System Items and System Boundary

The design of the SFR covers many aspects. A SFR basically consists of four parts including tunnel structure, shore connection structure, cable system and seabed foundation. In this study, shore connection structure has been excluded from the consideration. The remaining system has been divided into 6 items (Figure 2) for facilitating the process of hazard identification as follows:

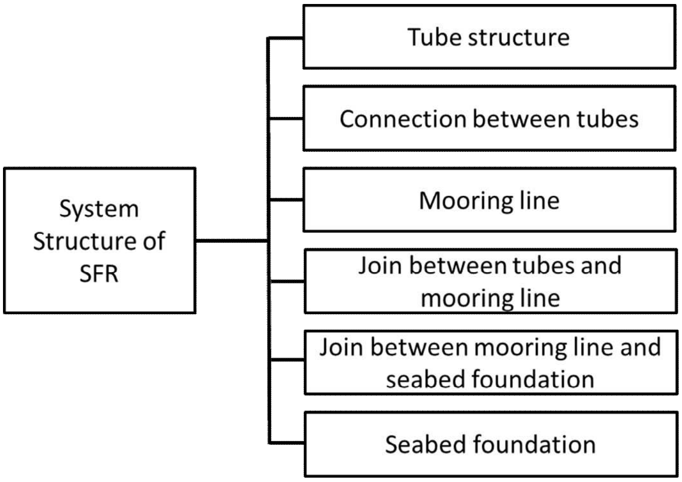

Fig. 1 System items categorization

Number of tube segments connected together; build up the tunnel structure which allows accommodating road and/or rail traffic. Connections between tubes hold the tunnel structure in a single piece and it’s an important factor of consideration in terms of waterproofing. The mooring line is connected to both the tube and seabed foundation to balance the net buoyancy. Seabed foundation is constructed at the waterbed to install cable systems. The domain of this study will be limited to outer structure of tube, cable connection and seabed foundation. Moreover, for this study, only the related structural hazard will be identified and listed. [1][4]

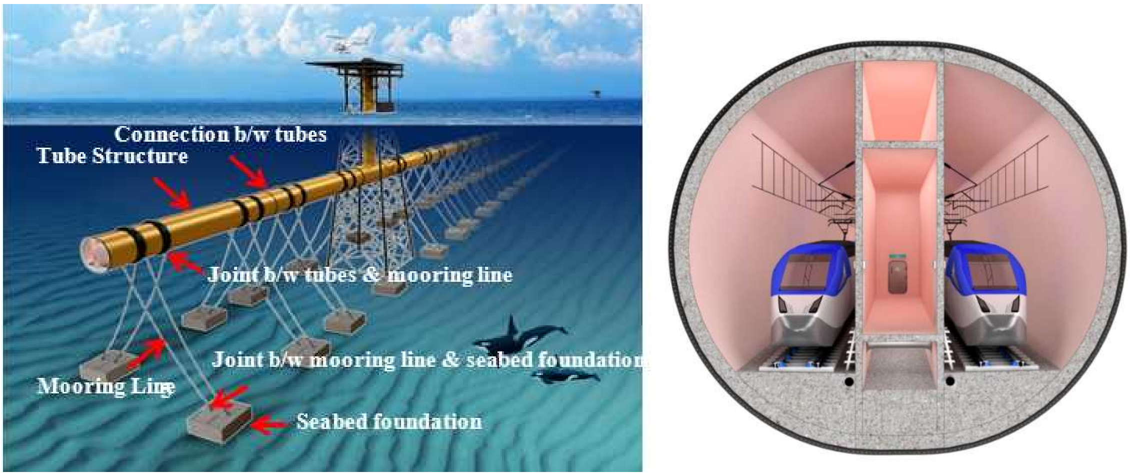

Fig. 2 Pipe-line shaped SFR indicating system items and the cross-section of SFR

2.3 PHL Analysis Process

PHL analysis process combines the design information with known hazard information in order to identify hazards and is performed by comparing the design knowledge to hazard checklist. Overview of the basic PHL analysis process is shown in the Figure 2. The process begins by gathering various design information in the form of design concept, operational concept, major components planned for use in the system from various sources such as design specification, sketches, drawings, etc.

To provide structure and documentation to the PHL analysis process, a worksheet has been prepared and used. PHL no. column identifies hazard number for reference purposes. System Item column identifies major system item of interest as previously categorized in previous section (Figure 1). Specific hazards associated with the each indicated system are identified in the column labeled as Hazards. The effects of the identified hazards are described in the column labeled as Effects. Finally, the Comments column is to record comments referring to any significant information, assumptions, recommendations etc. [1]

Fig. 2 Overview of PHL analysis process

3. Result

After careful observation, a total number of 28 hazards had been identified and listed on the worksheet. Among all hazards, 5 hazards were related to the structural damage resulted from causes such as surface cracks, excessive deformation and collisions but limited to only tube structure and tube connection. Among the Hazard Effects, leakage is the most identified, which is followed by the flooding as because leakage and flooding are quite related to each other. Disturbance of train operation and derailment of train have also been identified in several occasions as hazard effects. Disturbance in train operation can contribute in service failure but derailment can be associated with severe accidents resulting in damaging of the inner structure of tube. However, inner structure of tube is not in the scope of this study; therefore not discussed. In terms of mooring line which functions to keep balance of the tube structure against the buoyancy, the hazard events are mostly related to the upward motion of the tube structure which might lead to other severe mishaps such as leakage, structural damage and even breaking down of the tube structure. Mooring line joining Tubes and seabed foundation in the opposite ends is mainly concerned with connection failure.

Among the identified hazards under Tube Structure and Tube Connection category, hazards resulting in disturbing the waterproofing characteristics of tube structure such as leakage must be in special consideration due to its severity of the impact. Mooring line is more vulnerable element of the system due to its constant exposure in the water. Therefore, corrosion and factors of damaging the mooring line must be well considered in the design phase. Both of the joints between the tube structure and mooring line and mooring line and seabed foundation are vulnerable to corrosion and fatigue. Finally, greatest threat for seabed foundation is earthquake. The complete list of hazards is presented in Table 1.

Table 1 Complete list of identified preliminary hazards

PHL No.	System Item	Hazard	Effects	Comments
1	Tube structure	Surface cracks resulting in structural damage	Leakage in tube structure and flooding	Crack initiated by fatigue or initial defection
2	Tube structure	Excessive deformation resulting in structural damage	Distortion of track and disturbance of train operation	External severe loading due to wave or current
3	Tube structure	Excessive motion of tube structure due to earthquake	Structural failure and derailment	Acceleration of tube structure in the designated seismic scale
4	Tube structure	Excessive oscillation due to external flow	Leakage in tube connection and speed down of train	Flow induced vibration by vortex shedding
5	Tube structure	Collision with submarine and structural damage	Perforation of tube structure and flooding	Accidental loading
6	Tube structure	Collision with dropping objects and structural damage	Perforation of tube structure and flooding	Accidental loading
7	Tube structure	Excessive corrosion	Structural failure and leakage	Painting deficiency and insufficient anti-corrosion protection
8	Tube structure	Impulse motion due to underwater explosion	Structural cut-down and flooding	Most severe condition and ALARP applicable
9	Tube structure	Local deformation or failure	Leakage and distortion of track disturbing train operation	Small objects colliding with tube structure or contact with train and inside tube structure
10	Tube structure	Heavy weight and sinking	Disturbance to train operation and derailment	Temporary heavy loading exceeding buoyancy
11	Tube structure	Expansion or shrinkage	Failure in connection and leakage	Temperature change in tube structure
12	Tube structure	Excessive vibration due to running train	Derailment and leakage in connection	Related with frequency of moving train
13	Tube structure	Accidental explosion inside	Local opening or permanent deformation to disturb train operation	
14	Tube connection	Erosion or failure of water-tightness	Leakage and flooding	Erosion of shim or flexible joint
15	Tube connection	Structural damage and failure	Leakage and flooding	

16	Tube connection	Excessive movement of connection	Leakage and flooding	Caused by oscillation of tube structure
17	Mooring line	Position displacement of tubes	Unbalanced tension in lines and failure of line	Mismatch of mooring line with tube structure
18	Mooring line	Corrosion or wearing out of connecting line	Crack initiation to cut line and concentration of tension on neighboring lines causing heavy upward motion of tube structure	Neighboring lines bearing the tension of cut line
19	Mooring line	Sudden cutting of line due to collision with moving objects	Concentration of tension on neighboring lines causing heavy upward motion of tube structure and derailment	Neighboring lines bearing the tension of cut line
20	Mooring line	Gradual crack propagation and cutting	Concentration of tension on neighboring lines causing heavy upward motion of tube structure and derailment	Repeating varying tension causing crack initiation/Neighboring lines bearing the tension of cut line
21	Mooring line	Excessive oscillation due to flow	Motion of tube structure and cutting of line	Flow induced vibration of mooring line transferred to tube structure
22	Mooring line	Slack due to excessive motion of tube structure	Heavy motion of tube structure and derailment	Large lateral movement of tube structure
23	Mooring line	Impulsive tension due to heavy motion of tube structure	Cutting of line and concentration of tension on neighboring lines causing heavy upward motion of tube and derailment	Collision of mooring line with moving objects
24	Mooring line	Insufficient buoyancy and negative tension	Downward motion of tube structure and disturbance to train operation and derailment	Temporary heavy loading exceeding buoyancy
25	Joint between tube structure and mooring line	Failure of connection	Concentration of tension on neighboring lines causing heavy upward motion of tube structure and derailment	Erosion or fatigue or collision
26	Joint between mooring line and foundation	Failure of connection	Concentration of tension on neighboring lines causing heavy upward motion of tube structure and derailment	Erosion or fatigue
27	Foundation	Movement of foundation	Unbalanced tension in lines and failure of line causing heavy motion of tube structure and derailment	Caused by earthquake or slide
28	Foundation	Broken-down into pieces	Negligible tension and heavy upward motion of tube structure and derailment	Caused by earthquake or gradual erosion

4. Conclusion

The main focus of this study was to identify and list related hazard and mishaps that may exists in some particular items of submerged floating railway. Recommended preventive measures against the hazards had not been established. However, due to the nature of PHL analysis, the generated PHL is capable of providing useful design guidance to the system which presents mishap risk. Additionally it can address the areas which require further design attention for safety.

This study was limited to tube structure, mooring line and seabed foundation of SFR due to the lack of available resources as because the system is still in conceptual design phase. However, it is possible to bring all other remaining components under consideration to create a complete PHL for submerged floating railway with the availability of more information. Moreover, as a future work, all the 28 identified hazards will be carried into the Preliminary Hazard Analysis for more detailed analysis and establishing the initial System Safety Requirements (SSR).

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