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Vibration Control of the Submerged Floating Tunnel Under Combined Effect of Internal Wave and Ocean Current

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Abstract

For investigating vibration control of the Submerged Floating Tunnel (abbreviated to ' SFT ') under combined effect of internal wave and ocean current on the basis of inherent characteristics of structure itself and combined loads, the tunnel tube is modeled on a beam with a superposition of simple and rigid beams, that is, the vibration shape is approximated by the combination of a flexural sine mode and a rigid body mode. By establishing combined fluid field in stable stratified ocean, the free vibrations other than the forced vibrations of the SFT induced by combined loads are controlled to achieve the goal of vibration control. Finally, the verification of vibration control measure is conducted by the dynamic response of a proposed project of SFT. The results show that the measure presented in this paper is effective, and the optimal stiffness coefficient of tension leg for vibration control is determined by load period of combined effect of internal wave and ocean current, only several preceding odd multiples of environmental load period to half of vibration period of the SFT should be considered in analyzing the dynamic response because of smaller vibration amplitudes. The conclusions in this paper provide useful discussions for vibration control analysis of the SFT and meaningful references for the study of the complicated periodical ocean environment loads around the SFTs and even other ocean strait-crossing engineering structures.

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Keywords: Submerged Floating Tunnel; internal wave; ocean current; vibration control; dynamic response

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1. Introduction

After undersea tunnel, immersed tube tunnel and long span bridge, an increasing attention is focused on submerged floating tunnel (abbreviated to ‘ SFT ’)(e.g., Ahrens [1]; Ingersle [2]; Tveit [3]) , as it can effectively solve the environmental problems, lower the project costs and be born with superior anti-vibration characteristics as an innovative proposed structural solution for waterway crossings. The SFT is a new direction of tunnel engineering technology research and development. In view of conceptual design, structure analysis and design and dynamic characteristics of SFT under complex and volatile ocean environment, several researches have been conducted since last century especially in Norway, Japan, Italy(e.g., Loken [4]; Kunisu [5]; Svein [6]). Entering the 21st century, numerous explorations are performed in many aspects, such as dynamic response behavior of SFT under seismic loads (Fogazzi [7]; Martinelli [8]), and vortex-induced vibrations in a SFT system (Chen [9]; Xiang [10]). Using the added mass and damping coefficients from a two dimensional model, Paik [11] investigated the response of SFT in three dimensional model under wave loading. Considering complicated ocean environment, Tariverdilo [12] investigated the effect of submergence on the dynamic response of SFTs due to moving load by performing an evaluation on the effect of moving load velocity on the dynamic amplification factor.

Based on the foregoing, a single load or surface wave and current are main considered on the study of SFT, few research works about combined load especially induced by internal wave and ocean current have been conducted. As is well-known, internal wave can cause the whole migration and torsion of ocean structures with enormous failure from shear force. And ocean current formed by tidal movements and the large-scale flow of sea water also leads to vertical vibration of SFT suffered by vortex-excited dynamic, where the vibration direction is perpendicular to the direction of incoming flow. Both above fluid loads are regarded as well representative factors which could cause great destruction to structural stability and security of SFT.

In this paper, all research work is aimed at putting forward effective vibration control measure of the dynamic response of SFT under combined effect of internal wave and ocean current, and verifying it by the calculation and analysis on a proposed project of SFT. Relative to existing published work, the combined fluid field of internal wave and ocean current in stable stratified ocean is first established for the dynamic response control of SFT in this paper, and inherent characteristics of structure itself and combined load, instead of addition damping devices are taken into consideration to achieve the purpose of vibration control. At present, most studies about internal waves and ocean currents are based on the experimental observation, few pure theoretical methods were used to analyze this kind of problems. In order to facilitate the research work, a structural mechanic method is adopted under the premise that the analysis results wouldn’t be influenced.Through the qualitative and quantitative analysis of the dynamic response of SFT under combined effect of internal wave and ocean current, this paper could provide an effective way for studying the dynamic behavior of SFT under fluid reaction during the primary research stage.

2. Theory formulation

In order to analyze the dynamic behavior of SFT under the combined effect of internal wave and ocean current in theory, simplified mode, governing equation and its theoretical solution will be present in this part. The mechanical environment of tunnel-fluid interaction is shown in Fig.1.

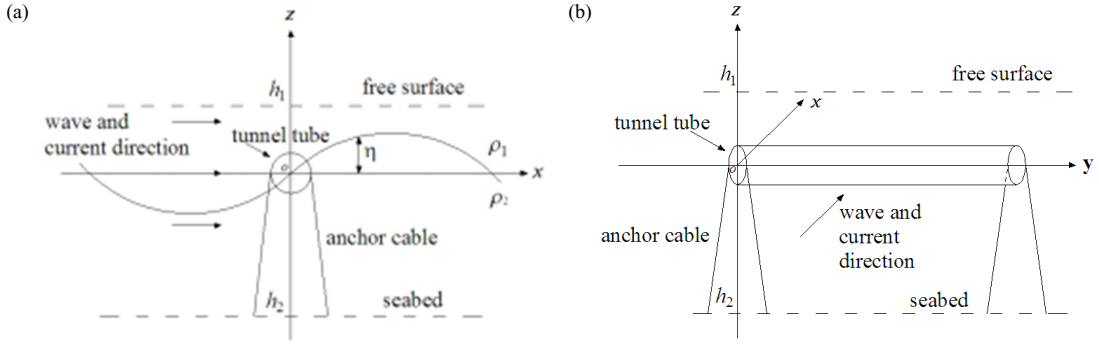

Fig.1. SFT subjected to the combined loads of internal wave and ocean current.(a) Cross-section view; (b) Side view.