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Dynamic response of submerged floating tunnel in the flow field

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Abstract

With the rapid growth of economy and the continuous improvement of the society, the problem of the crossing channel becomes more and more difficult to be solved. As a new type of transportation facilities, submerged floating tunnel (SFT) has many advantages in environmental damage, strong adaptability and so on. The structures of SFT mainly include the main body and the supporting system balancing weight and buoyancy. Due to the complexity of water load, the safety and stability of SFT is very important. Therefore, in the preliminary design stage, the response of SFT to the environmental load is the key point of the study. In this paper, vortex induced vibration response of cable under the action of current and parametric vibration response of pipe section are mainly studied. First of all, the partial differential equations of the cable vibration is derived, and the influence of main pipe section is simplified as parameter excitation. Then the tunnel-cable coupling model is considered to obtain a more realistic response. The cable of SFT is considered as a simply supported beam. By using the vortex induced vibration equation of the cable, the response of the cable is analyzed. The influence of parameter excitation is discussed, and the difference between the coupling and non- coupling of the tunnel and the cable is discussed.

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Keywords: submerged floating tunnel; anchor cable; differential oscillatory equation; maximum response

1. Introduction

SFT (Submerged Floating Tunnel) is a new type of traffic structure, which is used to cross a variety of water channels. It is the balance between the self-weight, the buoyancy and the support system. When the tunnel buoyancy is greater than the gravity, the tension leg or mooring system is generally used to fix the tunnel in a certain position of the depth. Because SFT is directly in the natural environment of the wave and current, the response analysis of the SFT under the action of wave and current should be the focus of attention. In Norway, Italy, Japan and other

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countries, the academic research, conceptual design and feasibility study of SFT have carried out nearly 30 years, which also include analysis of response under environmental loads. However, the main emphasis of the study is the dynamic response analysis under the action of wave, and the response under the action of the water flow is very little. For underwater structures such as SFT, the effect of water flow on the structure is likely to be greater than that of the wave. In addition, because of the long length of SFT, though the deformation of the structure is very small under the action of the water flow, the structure form will have great changes, which may be a nonlinear large displacement and large rotation, so as to have a greater impact on the safety and stability of the structure of SFT. Therefore, it is of practical significance to calculate and analyze the response of the suspended tunnel under the action of water flow [1].

The SFT is generally composed of tubes suspended in water, which is kept in an appropriate position by the buoyancy force, and is anchored on the seabed by a reasonable anchoring system, such as an anchor cable or a tension leg. Thus it can be seen, compared with the traditional tunnel, the SFT is more likely to produce vibration under the dynamic action [2, 3, 4]. The parameter vibration phenomenon [5] of cable refers to that the vibration of the SFT makes the axial tension of the anchor cable change periodically. When the frequency of the tube reaches a certain value, the small amplitude of the tube vibration can also cause local vibration of the large amplitude of the anchor cable. At present, the parametric vibration analysis of SFT’s cables mainly draws on the experience of the results obtained from the study of the vibration of cables about cable-stayed bridge with certain parameters, which are very similar to that of the cable in the suspension. Kovacs [6] is the first to use parametric resonance to explain substantial transverse vibration of cable in the case of no wind or rain. The first order parametric vibration of the cable is studied by Tagata [7] and dimensionless Mathieu equation is derived disregarding the effect of sag and considering cable as a no-weight string. The dynamic stability region of parametrical resonance of cable is discussed by Takahashi [8]. The nonlinear response of the suspension cable is analyzed by the multi-scale and test method, and the possibility and the dynamic stability of the nonlinear vibration of the cable are discussed by Perkins [9]. The simplified Mathieu equation is used to study parametric resonance by Uhrig [10].The parametric resonance of stay cable was tested by Fujino [11] and other people. Lilien [12] uses Tagata’s method to derive the standard string equation, and the harmonic balance method is used to study vibration amplitude of cable in steady state and the expression equation of the tension of the cable during the transient state (before reaching the steady state).Pinto Da Costa A [13] studied the vibration of the cable caused by the vertical vibration of the bridge deck. The cable-bridge coupling vibration is decomposed to parametric vibration along the axial direction and forced vibration perpendicular to the axial direction, and the mass model with the interaction of cable and bridge is established by Michel Virlogeux [14].He thinks that when the cable is close to the natural frequency of the main structure, the small transverse vibration of the cable can cause a very large amplitude. Vincenzo Gattulli [15, 16] built a simplified analysis model of coupling vibration of cable and bridge. The main beam is simplified to a beam whose one point is fixed, and the other is connected to the stay cable.

At the same time, many experts and scholars at home and abroad have also carried out relevant research on all aspects of SFT. On the dynamic response of SFT under the action of wave and flow, the work [17, 18] of Remseth and Brancaleoni, etc. is representative. The former analyzes the global dynamic response of SFT under the action of wind and waves, and uses the finite element method based on the Navier-Stokes equation to calculate the hydrodynamic force of the two dimensional model under the action of regular waves. The latter puts forward the complete engineering analysis program under the environment load, thus avoiding a lot of tedious calculation. The Mechanics Research Institute of Chinese Academy of Sciences also carries out numerical analysis on the dynamic behavior of SFT in the position of the tension leg in the wave environment. The vortex induced vibration of tension leg of offshore platform was studied by Dong Yanqiu [19] earlier. The tension leg is simplified as a simply supported beam. Considering the micro amplitude wave and non-uniform flow in a linear distribution and calculated by using the Galerkin method and four-order Runge Kutta method, some important conclusions are obtained. On the basis of Dong Yanqiu's work, the vortex induced vibration of the tension leg of the SFT in water was studied by Mai jiting, et al [20]. Kiyokawa et al [21] investigated the influence of fluid compressibility on seismic force, and the wave potential theory of the compressed fluid is given. It shows that there is a great influence on the fluid force caused by compressibility of water in the deep water and high frequency. Morita et al [22] based on two-dimensional potential wave theory, namely, Green's function method, considering water compressibility, use numerical simulation to analyze dynamic response of SFT under vertical seismic excitation. The results show that