Structural Response Analysis and Fatigue Damage Estimation of a Floating Bridge Subjected to Inhomogeneous Wave Loads

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ABSTRACT

In this paper, a computational study of the structural responses of a floating bridge for crossing of the Bjørnafjord in Norway is presented. The study employs an idealized floating bridge model developed based on the phase 3 design concept which comprises a very long, straight and side-anchored floating bridge. Due to the very long span and complex topology, the local wind waves exhibit some inhomogeneities. This study investigates the effects of inhomogeneous wave loads on the global responses of the floating bridge. The structural responses of both the bridge girders and the mooring lines are presented and discussed. In addition, the short-term fatigue damage induced by inhomogeneous wave loads in the mooring lines is also evaluated.

KEY WORDS: Floating bridge; inhomogeneous waves; structural response; short-crested waves; fatigue damage.

INTRODUCTION

The Norwegian Public Road Authority (NPRA) initiated the E39 coastal highway project with the aim to significantly reduce the time for travel by road along the Norwegian coastline. The reduction in travel time will be mainly achieved by replacing time-consuming ferry trips across the fjords with road connections by means of bridges and/or tunnels. Owing to the fact that many fjords along the E39 highway route are very wide and deep, this brings challenges for constructing road connections across the fjord. For example, the combination of a span of up to 5 km and waters as deep as 500 m makes it very difficult for conventional bridges to cross the Bjørnafjord. Constructing floating bridges for this fjord crossing was soon identified as an appealing option because of their advantages of using natural buoyancy for load-carrying purposes and being less sensitive to seabed conditions as compared with other kinds of bottom-founded structures. Since then, many research activities related to the feasibility of floating bridge concepts across the Bjørnafjord have been carried out (Cheng et al., 2018a; Cheng et al., 2018b; Viuf et al., 2019; Xiang et al., 2018).

Although floating bridges have distinct advantages over other types of structures for crossing of the Bjørnafjord, the design of such structures is still technically challenging. For example, available field measurement data show that the wave field along the bridge crossing exhibits some inhomogeneities (Cheng et al., 2019a). This brings complications when it comes to the detailed modeling and analysis of the floating bridge. Although a common practice in engineering design is to apply the worst wave condition to the entire bridge structure, the literature shows that such an assumption could lead to underestimated responses in certain cases (Fylling, 2012). It is therefore important to include the inhomogeneity of wave conditions when examining the bridge responses.

In this paper, we present a numerical study of the dynamic responses of a floating bridge subjected to inhomogeneous wave loads. An idealized floating bridge model is employed based on the phase 3 design concept for the crossing of the Bjørnafjord. The bridge model comprises a 4.6 km long straight bridge girder resting on 35 evenly spaced pontoons. To limit the bridge response to the wave loads in the horizontal plane, four clusters of deep water mooring lines spaced 1 km apart are engaged to increase the transverse stiffness of the bridge. This study examines the various effects of inhomogeneous wave loads on the dynamic responses of the floating bridge. These inhomogeneities include the spatial variation of the wave direction, significant wave height as well as the coherence and correlation of waves along the entire length of the floating bridge. For the purpose of comparison, the case describing a homogeneous wave condition is also considered. In addition, the fatigue damage induced by inhomogeneous wave loads in the mooring lines is also evaluated and discussed.

NUMERICAL MODEL

The phase 3 design concept of the floating bridge across the Bjørnafjord is illustrated in Fig. 1. The design concept comprises a straight, side-anchored floating bridge section followed by a cable-stayed bridge section located at the south end. For the sake of simplification, in this study, we employ an idealized bridge model comprising a 4.6 km long straight bridge girder vertically supported by 35 evenly spaced pontoons. The bridge girder is elevated 18 m above the water surface. The water depth is taken as 300 m and is assumed to be constant throughout the entire length of the bridge. Four standardized clusters of deep water mooring lines are attached to four pontoons in order to limit the transverse response of the bridge. Figure 2 shows a schematic view of the floating bridge model. Note that the global x-axis refers to the longitudinal direction of the bridge.