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Structural monitoring of an end-supported pontoon bridge

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ABSTRACT

A comprehensive monitoring system is designed and installed on the Bergsøysund Bridge. The system is thoroughly described, including descriptions of all exact sensor positions and the fundamental workings of the system. Acceleration, displacement and excitation sources, such as wind and waves, are monitored. The effects on the response of the characterizing environmental parameters, namely, mean wind speed, mean wind direction, significant wave height, and wave peak period, are investigated, with long-term extreme response analyses in mind.

1. Introduction

The first concept of a floating bridge is believed to have appeared around 2000 BCE [1], but it was first applied as part of critical infrastructure during the last half of the 20th century. There is a constant strive to achieve longer spans, and thus, a good understanding of the current floating bridges is crucial.

The developments in the field of floating bridges and other very large floating structures (VLFSs) were reviewed by Wang et al. [2] and Wang and Wang [3]. In an international context, the continuous pontoon girder is by far the most common type of floating bridge. These bridges are generally side supported by anchoring to the seabed, which drastically reduces their flexibility. For some crossings, these two widespread characteristics are not feasible or beneficial. The crossings planned for the ferry-free Coastal Highway E39, on the northwestern coast of Norway, are examples of this case. The deep fjords make side anchoring to the seabed practically impossible. Furthermore, the requirement that ships should be able to pass through makes a discretely distributed pontoon solution more obvious. Only two long-span end-supported pontoon bridges exist worldwide: the Bergsøysund Bridge and the Nordhordland Bridge.

A structural monitoring system enables capturing of highly valuable recordings, describing both the environment and the bridge response. First, statistical data representing the relationships between environmental factors and the response can be established. Furthermore, the measurements will serve as a starting point for establishing the modal parameters, which characterize the bridge behaviour in an easily interpretable manner. By also monitoring the environment, the effect of changing environment on the modal parameters can be quantified. It is also possible, although challenging, to use the continuous recordings for structural health monitoring [4,5]. Numerous land-based civil structures have previously been instrumented for measuring response and environmental excitation (see, e.g., [6–8]). Similar surveys have been conducted for offshore structures (see, e.g., [9]). However, structural monitoring surveys of floating bridges are not widespread.

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Ultimate limit state (ULS) design checks are vital for all engineering structures, but these checks are far less straightforward for structures exposed to environmental excitations, such as floating bridges. Several approaches are commonly used for establishing the extreme load effects, and their appropriateness depends on how dynamic the structure is in both behaviour and excitation. The most accurate approach is the full long-term approach [10,11], but due to practical limitations, the traditional approach for offshore installations is to apply a simplified procedure, for example, as described in the NORSOK Standard (N-003) [12]. To perform a full long-term design evaluation, a joint probability density function (PDF) between all the characterizable environmental parameters is, in theory, required. Successfully establishing a close-to-exact PDF is cumbersome and unlikely. To assess the validity of the simplified approaches, a qualitative description of how the different environmental parameters are related to each other and the response is needed. This task is one of the main objectives of this paper. In other words, the answer to the following question is sought: what environmental parameters are the most crucial for the response of floating bridges?

The relationship between environmental factors and the response of the Bergsøysund Bridge is studied using a comprehensive measurement system. The correlations between several of the most common environmental parameters and the response of the bridge are studied in an attempt to describe the causalities between them. All important aspects of the measurement system are presented in detail, including accurate positions of all sensors. The performance of the real-time kinematic global navigation satellite system (RTK-GNSS) displacement sensor is also assessed by comparison, in the frequency domain, with accelerometer readings. Due to the vast amount of information gathered in the database with recordings from the monitoring system, some selected quantities have been chosen for analysis at the sacrifice of others. For instance, an investigation of the spreading of the wave field is not performed. According to previous studies, the spreading of the wave field does not considerably influence the response of this bridge when exposed to realistic sea states due to the small wave heights combined with the curved geometry of the structure [13]. Furthermore, response predictions or response checks are not conducted in the current paper because these topics deserve more attention for them to be beneficial to include.

2. Monitoring system

The Bergsøysund Bridge, a 931 m long, arch-shaped floating bridge, bridges the gap between Aspøya and Bergsøya on the northwestern coast of Norway. The steel superstructure rests on 7 separate light-weight concrete pontoons, as shown in the photograph in Fig. 1. The geography surrounding the bridge is shown in Fig. 2. The abutments consist of rubber bearings that support the bridge vertically and horizontally, and a steel rod on each of the ends absorbs all the axial forces. The bridge has no mooring, thus making it a particularly interesting case study: the Bergsøysund Bridge is the second-longest end-supported floating bridge in the world.

The monitoring system installed on the bridge is extensive. Sensors for environmental monitoring, consisting of 5 anemometers distributed in lampposts on top of the bridge deck and 6 wave radars distributed close to the centre of the bridge, and sensors for measuring the global response, consisting of two triaxial accelerometers on each pontoon supplemented with a global navigation satellite system (GNSS) sensor at the centre of the bridge, have been recording on site since March 2015 (sub-sets of the monitoring system have been in operation prior to this). Photographs of all the types of sensors are presented in Fig. 3. The sensor positions are shown in Fig. 4, and their accurate coordinates are listed in Table 1. Furthermore, specific details regarding the sensors are presented in Table 2. Traditionally, wind measurements are captured at 10 m above sea level. To reduce disturbances from the bridge, the anemometers are mounted approximately 8 m above the bridge deck, even though this implies a probe height of approximately 16 m.

All of the sensors on site are connected to a nearby logger unit, of which there is one on each pontoon. The logger units acquire a common time stamp for the measurements using GPS to ensure synchronous sampling. The data from the sensors

Fig. 1. The Bergsøysund Bridge. Photograph by NTNU/K.A. Kvåle.