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Applications of continuous wavelet transforms on ice load signals

Morten Bjerkås[a,b,*], Asle Skiple[b], Ola Iver Røe[c]

[a] *Engineering Division, Reinertsen AS, Leiv Erikson Senter, 7492 Trondheim, Norway*
[b] *Department of Civil and Transport Engineering, Norwegian University of Science and Technology, Høgskoleringen 7a, 7491 Trondheim, Norway*
[c] *Department of Mathematical Sciences, Norwegian University of Science and Technology, Alfred Getz vei 1, 7034 Trondheim, Norway*

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Abstract

This paper gives an introduction to how Continuous Wavelet Transform (CWT) can be applied in analyzing ice load time series to gain more information about the distribution of power on different frequencies in the time domain. The aim of the study was to localize short intervals of intermittent crushing in initially long time series. Intermittent crushing was supposed to occur with dominant frequencies in the range of the fundamental frequencies of the structure and to give resonance-like response histories of the structure. To ensure that the localization of periods of intermittent crushing was realistic, corresponding time signals of normalized acceleration were plotted together with selected CWT coefficients. Five different time records were selected for analyses. The length of intervals was calculated from the up and down crossing of chosen threshold values for both normalized CWT coefficients and normalized acceleration signals. The presented method seems to be suitable for analyzing signals in time and frequency domains simultaneously, however the threshold values have to be tuned in the case of new structures and/or new loading situations. Together with already existing tools for analyses, CWT will give more information from ice load time series than traditional methods. More work is needed on significance testing of wavelet coefficients and development of a proper background spectrum for such testing.

Keywords: Ice load; Frequency; Full-scale measurements; Fourier; Wavelets; CWT

1. Introduction

Dynamic ice loads due to crushing failure of infinite floating ice sheets have been thoroughly analyzed by numerous authors since Peyton [11] published his results from measurements on platforms in the Cook Inlet, Alaska. The ice pressure and the corresponding structural response have usually been analyzed separately in the time and frequency domains. Analyses in the time domain have been proposed by e.g. Engelbrektson [3] and Jefferies and Wright [6] who reported severe steady-state vibrations on a lighthouse structure and a caisson structure, respectively. Laboratory investigations by e.g. Sodhi [15] detected three different types of ice crushing in dynamic ice structure interaction; namely, brittle crushing, intermittent crushing and ductile crushing which included creep failure. Intermittent crushing failure was reported to be the reason for severe steady-state vibrations during ice actions.

Reddy et al. [13] studied how the response spectrum method could be applied in the analysis of ice forces, which can be defined both for a stationary and non-stationary excitation process. The response spectrum method is nowadays widely used in, for instance, seismic analysis of structures. Sundararajan and Reddy [16] initiated the application of stochastic processes and random vibrations in the analyses of dynamic ice actions. Määttänen et al. [10] applied both the response spectrum method and the stochastic approach to study the behaviour of the Kemi I lighthouse under ice actions. Recently, Kärnä et al. [8] followed up the idea of ice loads as stationary random processes and proposed a new spectral method based on measurements from the Norströmsgrund lighthouse in Sweden (Fig. 1). The popularity of the methods initiated by Sundararajan and Reddy [16] are limited because they do not cover situations with steady state vibrations and ice loads of lock-in type.

Spectral methods have been used extensively for analyses of environmental loads on structures for decades. Due to time

* Corresponding author at: Engineering Division, Reinertsen AS, Leiv Erikson Senter, 7492 Trondheim, Norway. Tel.: +47 56 24 98; fax: +47 73 56 24 11.
E-mail address: morten.bjerkaas@gmail.com (M. Bjerkås).

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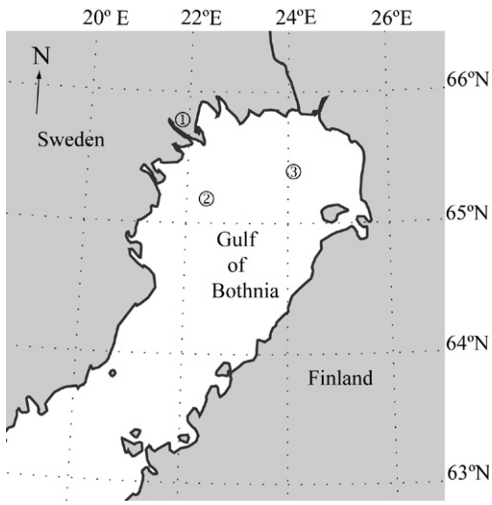

Fig. 1. Map of the Gulf of Bothnia with locations of ① Luleå city, ② Norströmsgrund and ③ Kemi.

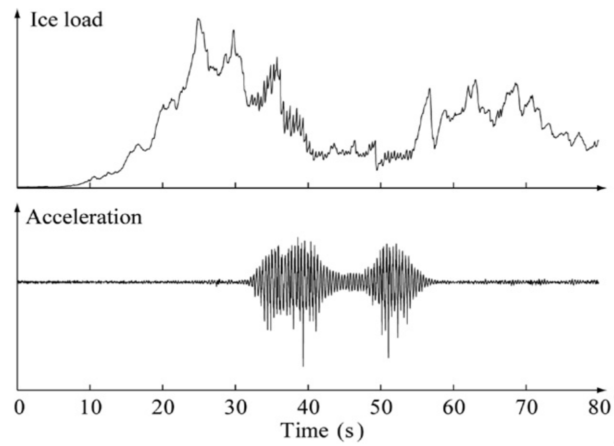

Fig. 2. Ice load with its corresponding acceleration signal from an event with ice thickness $h = 0.68$ m and drift speed $v = 0.1$ m/s, occurring 22:37:10, 9 April 2003 at the Norströmsgrund lighthouse.

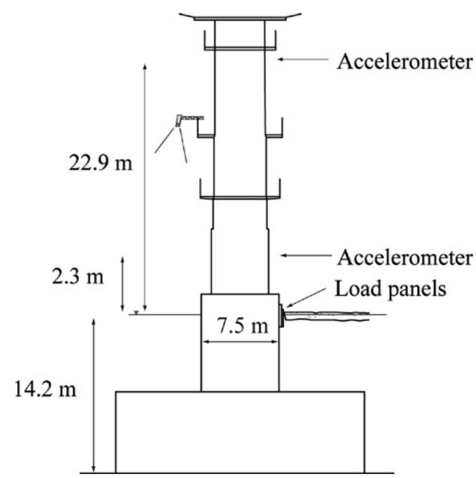

Fig. 3. Location of some of the measuring devices at the lighthouse Norströmsgrund winter 2001, 2002 and 2003.

averaging, short periods with dominant frequencies in long signals can be difficult to detect. For example, the response of a linear system to a unit amplitude stationary white noise or an impulse excitation will have identical spectral descriptions but different time histories.

At least three methods are available to meet the problems with detecting dominant frequencies in non-stationary signals. Two of those methods are the Wigner–Ville distribution and the Short Time Fourier Transform (STFT) [2]. This study contains applications of the third of these methods, the Wavelet Transform (WT).

The WT has been proven to be applicable in several engineering disciplines. Gurley and Kareem [4] show several examples of application of continuous and discrete wavelet transforms to data from wind, ocean and earthquake engineering, Jakobsen et al. [5] show the Continuous Wavelet Transform (CWT) applicability to detection of freak waves in wave records.

The detection of ice induced vibration is relatively straightforward if data describing the structural response are available (see Fig. 2); measured accelerations will most probably give high amplitudes during resonance events. As shown in Fig. 2, the occurrence of resonance vibrations is not directly connected to the magnitude of ice loads. For that reason it was decided that the frequency information from load signals have to be used in addition to the magnitude of ice loads. The main motivation behind this work was to come up with a method that could handle detection of ice induced resonance vibrations with use of measured ice loads or ice pressure.

The objective of the paper is to present a new application of CWT on ice loads and figure out if it is suitable for detection and localization of periods with intermittent ice crushing. The paper goes briefly through the experimental setup. A description of the observed ice load time records is then presented before a brief introduction of CWT is offered. Examples of applications of the CWT is then presented as a method to detect intermittent crushing in ice load signals and how these intervals correspond with measured strong accelerations.

2. Experimental setup

Extensive ice load measurements were conducted in the period 1999–2003 at Norströmsgrund lighthouse in the Gulf of Bothnia (Sweden), by the LOLEIF and STRICE teams [14]. Norströmsgrund lighthouse is located approximately 60 km offshore from Luleå in Sweden (Fig. 1). The structure is a 42 m high gravity based cylindrical structure resting on moraine masses at a water depth of 15 m + tidal changes (Fig. 3). Its water line diameter is 7.6 m. The lighthouse was instrumented in 1998 with nine load panels measuring normal forces with 167° coverage from North. Biaxial accelerometers and inclinometers were installed in 2001 to record the structural response. Measurements of the ice thickness, air temperature, wind speed and air pressure have been conducted as well. Loads and responses were recorded at a varying sampling rate between 1 and 100 Hz, depending on the category of interaction. All