SPECTRAL ANALYSIS OF WAVE FORCES FOR THE DESIGN OF ROLLING GATES OF THE LOCK OF AMSTERDAM

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INTRODUCTION

In the Dutch city of IJmuiden, a new ship lock is currently under construction. With a lock chamber of 500 m long and 70 m wide, it will be the largest lock in the world. Using this lock, the latest generation of seagoing vessels will be able to access the harbour of Amsterdam. The lock closes with rolling gates constructed in steel. Waves generate forces on the gate and push the gate onto its supports. During gate mission (opening or closing), the attenuator mechanism (equipment to close or open the gate) should overcome the wave generated friction forces in the supports. A set maximum installed force of the attenuators is chosen. A wave force that exceeds the maximum installed capacity of the attenuators results in delay.

The lock is built under a DBFM (Design, Build, Finance and Maintain) contract. The construction companies have to maintain the lock for 28 years and are paid by the government based on the availability of the lock. The attenuators must have sufficient power obtain the set availability requirement and to reduce the probability and duration of a delay. On the other hand, the attenuators must be feasible, which means that the attenuator capacity is limited.

This paper presents the methodology which is developed to calculate the probability and duration of delay of a gate mission. An overview is given covering the spectral design approach using linear wave theory for evaluating the required attenuator capacity and the expected gate mission delay.

PRESENT LIMITATIONS IN WAVE FORCE FORMULAE

Normally the wave force is calculated using either the formula of Goda, or the linear wave theory for a single wave height and wave period. However, the wave spectrum loading the gate consists of two peaks:

- Long period waves (swell; <0,14 Hz)
- Wind waves (>0,14 Hz)

Due to the large depth of the lock of 20 meters, long waves penetrate down to the toe of the gate, generating a large force at the gate. This force cannot accurately be calculated using the general wave theories:

- Linear wave theory using the significant wave height and a single wave period gives an underestimation of the force. The penetration of the pressure to the toe of the gate cannot calculated correctly using a single wave height and period.
- When using a formula based on only one wave height and one wave period, the force during gate mission is constant. To calculate the gate duration of delay for a gate mission a wave force time series must be made.
- The method of Goda appears to overestimate the total wave force due to the linear schematization of the wave pressure between still water level and the toe of the gate. The calculated force will result in a very large required attenuator capacity, resulting in high costs
- The wave spectrum is required for deriving the force spectrum and elaborating the probability density function of the wave force and to express the probability of delay.

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APPLIED DESIGN METHODOLOGY

To include the effect of long waves, and to be able to calculate the wave force time series and gate mission delay, a spectral design approach based on linear wave theory is applied. A response function is derived for the full gate mission (opening or closing of the gate) and for the full range of wave frequencies (0Hz up to 1Hz) to calculate the wave force in each gate support. The supports are presented in the right figure of Figure 1. During gate mission the gate acts as a cantilever beam, this results in a combined absolute reaction force in the supports larger than the total incoming wave force. The absolute reaction force generates a friction force in the supports during gate mission. To calculate the total friction force during gate mission, the reaction force is multiplied with a friction coefficient. The cantilever effect is included in the final response function as the total friction force. The total friction force, delay and probability of exceedance of the delay duration is derived by the following steps which will be addressed in the paper:

- The conversion of the wave spectrum to a wave force spectrum describing the transverse wave loads in each gate support (Figure 1 – force number 1)
- The derivation of the longitudinal wave forces generated by passing waves at the head of the gate (Figure 1 - force number 2)
- The conversion of the wave spectrum to a wave force spectrum describing the longitudinal wave loads (friction forces in the support; Figure 1 – force number 3)
- The transformation of the longitudinal frictional wave force spectrum to a random wave force field
- The interpretation of the longitudinal frictional wave force spectrum for the final design using:
  - o The probability of exceedance of wave forces
  - o The expected delay using a random longitudinal wave force field

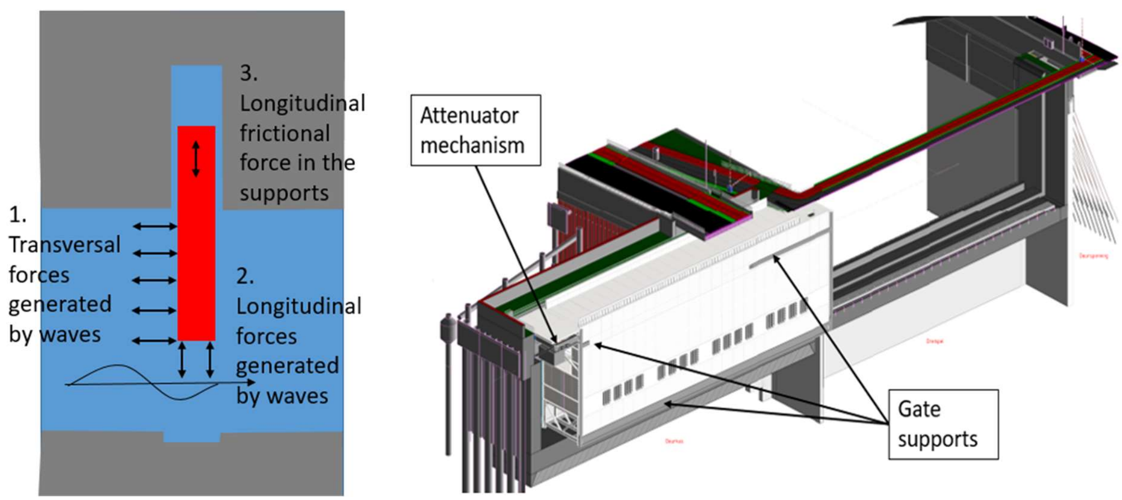

Figure 1: Overview of wave forces on the gate

CONCLUSION

The spectral approach gives more insight into the forces in the attenuator mechanism, compared to other theories. The main advantages of the spectral design approach are listed below.

1. The wave force is accurately calculated for low frequency waves. 1,5% of wave energy below 0,14Hz results in 17% of the total wave force. A small amount of wave energy gives a major contribution to the total wave force which would not be calculated when using only one wave height and wave period using either Goda's method or linear wave theory.
2. The required attenuator capacity and the probability and duration of delay can be calculated by transferring the wave spectrum into a longitudinal wave force spectrum. This analysis cannot be done when using a theory based on only one wave height and wave period, like is practice for the theory of Goda and linear wave theory (based on a single wave height and period).