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Review

Comparison of Kemi-I and Confederation Bridge cone ice load measurement results

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ABSTRACT

A Joint Finnish Industry Project in 1983–87 measured cone ice loads by installing an instrumented cone around the Kemi-I lighthouse in the Gulf of Bothnia. A Canadian University/Joint Industry Project has been conducting cone ice load measurements since 1997 on two instrumented piers of the Confederation Bridge, in the Southern Gulf of St Lawrence. The diameters of the cones at the waterline are 10 and 14 m respectively. Ice conditions are more severe at Kemi-I but ice movement is faster and ridge encounters more frequent at Confederation Bridge. However, all types of first year ice features have been encountered at both locations. The cone ice load measurements and observations indicate that ice failure patterns and broken floe clearing mechanisms are, in general, similar. Comparisons with reference to ice thickness, temperature, and velocity, are made on: rubble formation, rubble surcharge height, rubble jamming, pressure ridge failure modes, dynamic effects, and measured and predicted ice loads. The results pave the way for a better understanding of ice failure against cones and cone ice load design.

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1. Introduction

A conical shape at the waterline promotes failure of oncoming ice in bending. Scale-model tests have verified that the resulting ice forces are significantly lower, compared to ice crushing loads. An additional

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bonus is the almost complete elimination of ice-induced vibrations, especially continuous resonant vibrations (Karna et al., 2007). In contrast to a relative abundance of scale-model data, published full-scale data on cone ice forces are scarce. The first were the Japanese tests at Hokkaido conducted in 1983 (Toyama and Yashima, 1985). However the downward breaking 65° cone was small, with a waterline diameter of only 3.3 m. The second was the Finnish Kemi-I test cone project, in the Gulf of Bothnia with a 10 m diameter cone. The latest is the Confederation Bridge ice load measurements in the Southern Gulf of Lawrence. The measurements are still continuing on two of the bridge piers, each having a 14.2 m diameter, 52°, cone at the waterline. In China in the Bohai Sea JZ9-3 field, there are three oil and gas production platforms with conical foundations. These structures have 58° cone angles and 28 and 34 m diameters at the top while the waterline diameter varies from 30 to 40 m depending on the structure and tidal cycle (Riska et al., 1994). A lot of visual and video observations have been made but the cones have not been instrumented for ice load measurements. More recently, a structure in the Bohai Sea JZ20-2 field, equipped with smaller cones has been instrumented to obtain ice forces (Yue et al., 2007). Two new cones have been deployed recently: a Single Point Mooring system at DeKastri, Russia for the Sakhalin Field, and a large faceted cone at Varandey in north Russia. No information on instrumentation on these cones is currently available. Thus, despite the potential advantages of conical structures, there has been little full-scale data acquired that could be used to validate ice load models and consequently few models that can be used with confidence.

There have been a considerable number of small scale tests conducted in ice tanks and sheltered areas close to shore around the world. The inventory includes the early tests by Edwards and Croasdale (1976) and those by Saeki et al. (1979); the larger scale tests on a faceted cone by Esso (Metge and Weiss, 1989; Metge and Tucker, 1990), which were paralleled by tests carried out on smaller model faceted cones by Irani et al. (1992); and tests carried out by Timco et al. (1995) and by McKenna et al. (1995) that were used to support the determination of the design loads for the Confederation Bridge.

The Kemi-I test cone measurements were conducted in 1984–1987 and final data analysis was conducted in 1995 as a joint industry project (Tam et al., 1995). Due to industry funding, the data was proprietary to the end of year 2000. The Confederation Bridge cone ice loads measurements started in 1997, and the data acquisition and analysis has been ongoing since inception. Data is propriety for five years after acquisition. These two ice load measurement projects have both common and differing features. Comparing and analysing the results from the two measurement programmes give a wider view and a more holistic understanding of ice failure against a conical structure.

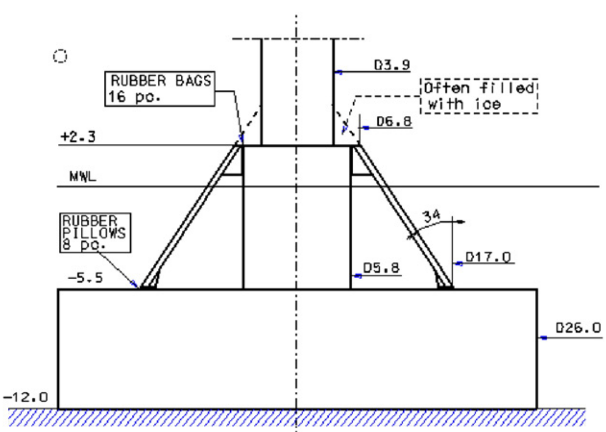

Fig. 1. Kemi-I foundation dimensions.

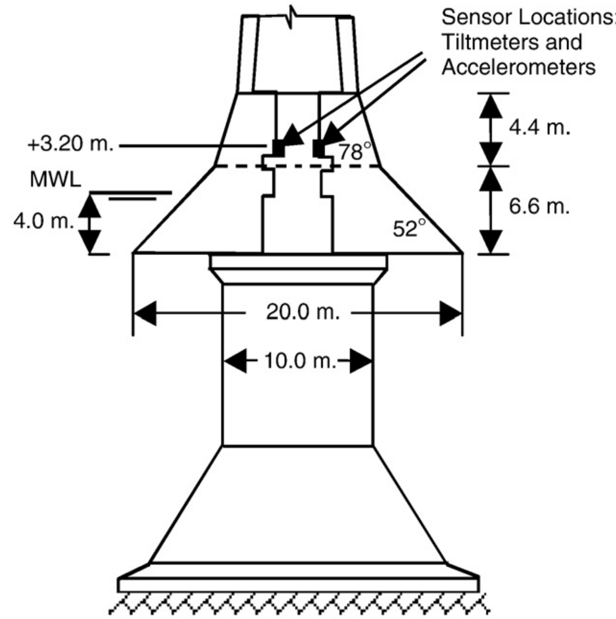

Fig. 2. Confederation Bridge pier foundation dimensions.

This paper describes the measurement principles, compares ice failure phenomena, presents measured loads in varying first year ice conditions, and verifies ice load design practices.

2. Instrumentation setup

The main dimensions of the Kemi-I and Confederation Bridge conical piers are presented in Figs. 1 and 2 respectively, and Table 1.

The Kemi-I cone was a freely floating conical annulus around the lighthouse shaft. In the vertical direction, 8 rubber pillows that had very low horizontal stiffness supported the cone. The neck of the cone transferred horizontal loads through 16 liquid filled rubber bags arranged round the perimeter. The load on each bag was measured from the internal pressure within and the total horizontal load is then the vector sum of the bag loads. The direction of this resultant is that of the true ice load. In practice the horizontal load measurements appeared to be reliable but vertical loads could not be resolved from the vertical deformation of the rubber pillows. Additional instrumentation included 96 strain gauges on the cone steel plating, accelerometers at elevations of +3 m and either +13 m or +23 m, and rods used to measure total lighthouse shaft bending moment. The strain gauges were used to verify the cone structural integrity, not for indirect calculation of ice loads. The sensitivity of the moment sensing rods was inferior to the horizontal load measurement from the rubber bags.

At Confederation Bridge, the cones are gravity based concrete structures placed at the waterline, and are integral with the pier. The

Table 1
The main dimensions

	Kemi-I	Confederation Bridge pier
Cone angle (°)	56	52/78
Neck diameter (m)	6.8/3.9[a]	9.7/7.8[d]
Waterline diameter (m)	9.9	14.2
Bottom diameter (m)	17.0	20[c]
Water depth (m)	12[b]	19/21
Surface material	Steel	Concrete

[a] After rubble filled the shelf extending apparent cone surface to +4.4 m level.
[b] The cone ends on top of a 26 m diameter caisson at −5.5 m level.
[c] The cone ends at −4 m below which it is supported by a 10 m diameter cylinder.
[d] Top of 52° cone/top of 78° cone.