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ICE RIDGES INTERACTION with CONFEDERATION BRIDGE PIERS, RESULTS of DETAILED VIDEO and SONAR DATA ANALYSIS

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1.0. ABSTRACT

After eight winters of the extensive monitoring program of the interaction between ice features and the piers of the PEI Confederation Bridge, a detailed video and sonar data analysis of all the events including interactions between first year ice ridges and the bridge piers has been done. This paper introduces the results of this video and sonar data analysis related to the interaction of the underwater part with piers. A statistical study concentrates on the effect of the keel and the consolidated layer geometric properties, such as the keel depth, the keel width and consolidated layer thickness, on the load resulting from the above mentioned interaction. Moreover, the relation between the load on one side with the geometric properties of the keel underwater part and the ice ridge velocity is introduced. The real full-scale observations and results presented in this paper can be taken as a key to the development of an accurate load model.

KEY WORDS: Ice ridge; Keel; Geometric Properties; Velocity; Influence

2.0. INTRODUCTION

Sea ice is composed of a wide variety of different forms of ice features. Further from shore, strong wind conditions and ocean currents often force ice floes to collide creating rafted ice, ice pressure ridges, hummocked ice and ice shear ridges. Nowadays offshore structures are extensively used, especially for oil and gas purposes and bridges. Due to their massiveness, first year ice ridges represent one of the most hazardous threats to shipping, navigation, pipelines and offshore structures. Therefore, offshore structures must be designed to withstand the loads resulting from the interaction with first year ice ridges. There are problems and confusion when determining the loads associated with interactions with first year ice ridges, attributed to the lack of efficient and accurate theories that define these loads. There are many models proposed to calculate the load resulting from the above mentioned interaction. With these models, the geometric properties of first year ridges are among the most important parameters affecting the resulting load. Knowing the geometric properties of first year ridges is important, since deriving theories that can be used to estimate failure modes and load values for first year ridges is highly dependent on the geometric properties of ridges. First year ridges are generally formed of three parts: sail, keel and consolidated layer. The most important geometric properties of first year ice ridges are: the keel depth, keel width and the consolidated layer thickness. One of the important parameters that has been neglected by most of the first year ice ridge load models is the ridge velocity. This parameter has been studied extensively in this paper. The failure against the Confederation Bridge Piers is a complicated process where there are large number of different parameters that will affect the ice ridge load. Four parameters were selected to study their direct influence on the ice ridge load value. These four parameters are: ice ridge velocity, keel depth, keel consolidated layer thickness, and keel width. This study is a detailed probabilistic study based on the data given by the Confederation Bridge Monitoring System. A total of 800 events were originally selected, but after detailed analysis, only 519 of them were considered to be ice ridges and the rest considered to be rubble fields. This paper presents only the results for the ice ridges. The aim of this paper is to present the results of the statistical study that has been done based on the results of the Confederation Bridge Monitoring Program. It concentrated on the part related to the influence of the geometric properties of the keel and the consolidated layer on the load resulting from the interaction of first year ice ridges with offshore structures. Moreover this paper took care of one of the important parameters affecting the load magnitude and was not enough studied while proposing the current load models. This paper introduces the influence of the ridge velocity on the load magnitude plus its relation with the ridge geometric properties.

3.0. METHODOLOGY

In order to estimate the relation between first year ice ridge loads on one side with the ridge velocity and geometric properties on the other side, certain analysis procedure has been followed. The analysis process can be summarized as follows:

1. Detailed analysis of video and sonar data was carried out using the video tapes and the sonar data recorded during the Confederation Bridge monitoring program. This detailed analysis focused on ridge interactions with the Confederation Bridge pier No. 31. In all, a total of 519 events were analyzed. This analysis resulted in considerable understanding of the geometric properties of the ridges that encountered the pier during the above mentioned 519 events.
2. For each of the events, the corresponding peak load was identified from the tiltmeter record, corrected for the effects of wind.
3. For each of the events, the geometric properties of the keel have been identified analyzing the sonar data. The consolidated layer thickness has been measured using the video tapes.
4. For each of the events, the ridge velocity has been recorded using the data from the Acoustic Doppler Current Profiler (ADCP).
5. Detailed statistical analysis has been done to find the relation between the load on one side with the ridge velocity and the ridge geometric properties on the other side.

4.0. RESULTS

4.1. Ridge Velocity Vs Load

The ice ridge velocity is one of the parameters that may affect the load resulting from the interaction of first year ice ridges with offshore structures. Ridge velocity has been neglected in the proposed load models. The reason for this can be attributed to the poor knowledge about the effect of the interaction velocity. The hydrodynamic effects around the pier are complicated and remain unresolved (Lemée, 2003). One of the aims of this paper is to decide whether the ridge velocity is an effective parameter on the load or not. Also, to make it clear to researchers who will develop new ridge load models whether to take ridge velocity as one of the model parameters or not. The four figures 1a, 1b, 2a and 2b present the concept that when the ridge velocity increases, the load increases as higher velocities will result in higher inertial load on the cone. Trying to find a relation between the ridge velocity and size, a detailed study has been done to study the effect of the ridge velocity on the load controlling the ridge size (keel depth or keel width). This has been done by estimating the relation between the ridge velocity and the load for different ridge sizes. In our case the size of the ridge has been determined by the keel depth and width. In this study the load has been related to the ridge velocity for different sizes of the ridge controlling the keel depth (H_k) as follows: H_k<4m, H_k<6m, H_k<8m, H_k<10m, H_k<12m and H_k<14m.

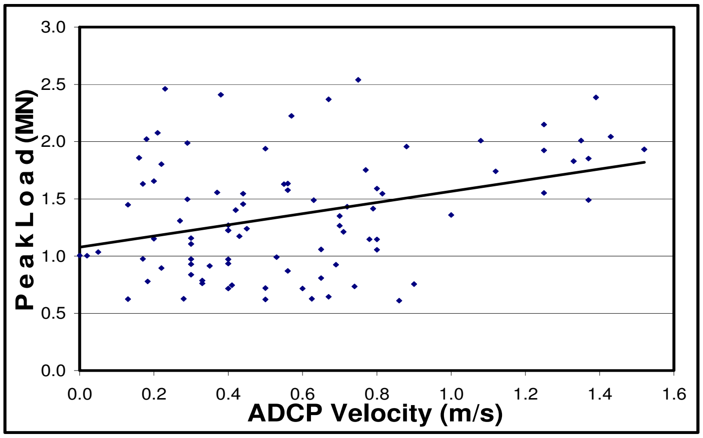

Figure 1a. ADCP Velocity Vs Peak Load for Keel Depth Range of H_k<4m

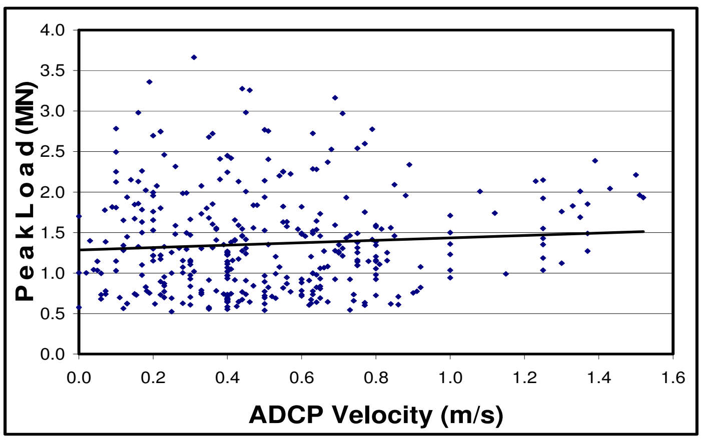

Figure 1b. ADCP Velocity Vs Peak Load for Keel Depth Range of H_k<10

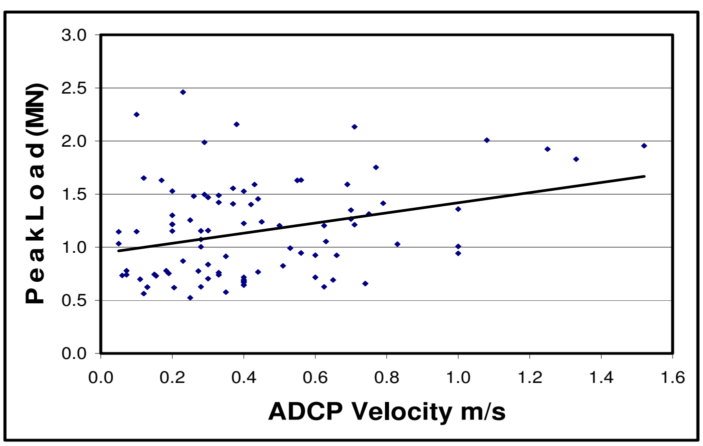

Figure 2a. ADCP Velocity Vs Peak Load for Keel Width Range of W_k<20m

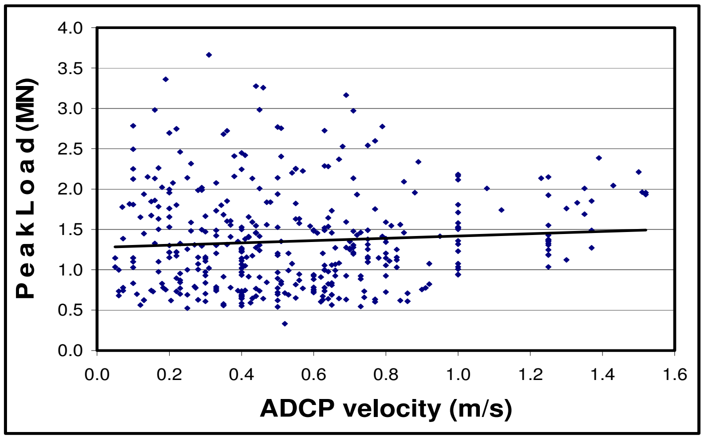

Figure 2b. ADCP Velocity Vs Peak Load for Keel Width Range of W_k<150m

Similarly, the relation between the velocity and the load has been studied for the following keel width (W_k) ranges: W_k<20m, W_k<40m, W_k<70m, W_k<100m and W_k<150m. The results of this study addresses to a point that the size of the ridge plays an important role on determining the level of the influence of the ridge velocity on the load. Decreasing the size of the ridge increased the influence of the ridge velocity on the load magnitude. This may be attributed to the fact that in order to have a large load, high kinetic energy must be exerted. In order to exert high amount of kinetic energy, either the mass or the velocity of the ridge has to be high. So, for the events where large loads are recorded decreasing the size of the ridge must be accompanied by an increase of the ridge velocity.

4.2. Keel Depth Vs Load

In all failure models the keel depth is the most important geometric parameter aside from the physical strength of the rubble. All models assume a full contact with the structure over the entire depth of the keel with pressure either constant or varying with depth. Global failure models are also dependent on the keel as the failure plane must exit the far side of the keel.
The results shown in figure 3 are compatible to the results that Lemée (2003) presented. The keel has no visible trend on load. This finding is enough to provoke the researchers to put in mind that developing a new keel load model became an essential.

4.3. Consolidated Layer Thickness Vs Load

As stated above, all the current ice ridge load models consider the keel depth to be the most important geometric parameter affecting the load magnitude. The consolidated layer thickness (H_c) effects are not included in the keel failure models but added separately as a flexural failure or a crushing failure against the pier. Brown and Maattanen (2002) stated that the keel and the consolidated layer must be treated as a system functioning together and failing together.
The results show that consolidated layer has a reasonable correlation with the load and this finding is also compatible to Lemée's (2003) results. Figures 4a and 4b show that increasing the consolidated layer thickness cause a direct increase in the load.
Also it can be noticed from figures 4a and 4b that increasing the consolidated layer thickness range increases the influence on the load value. In other words, the consolidated layer thickness range H_c>1.4m gives higher influence than the range H_c>0.8m. This can be noticed from the slope of the trend line which is steeper in figure 4b than in figure 4a. This maybe attributed to the idea that the thicker the consolidated layer means the thicker the level ice that formed the ridge. This has an indication that this consolidated layer is much more solid because the longer the level ice lives, the more consolidated is the consolidated layer formed

from this level ice. Once the consolidated layer is much more consolidated, this increases the load caused by it.

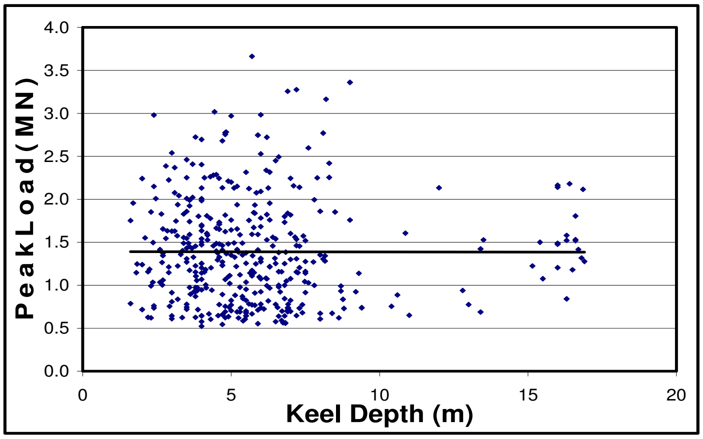

Figure 3. Keel Depth Vs Load

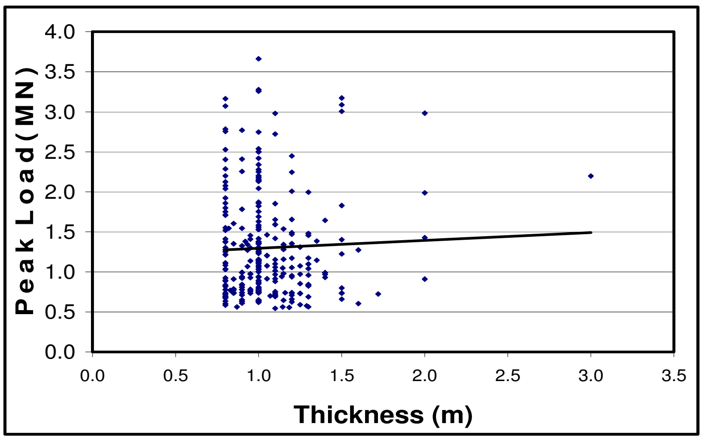

Figure 4a. Consolidated Layer Thickness Vs Load for a Range of H_c>0.8m

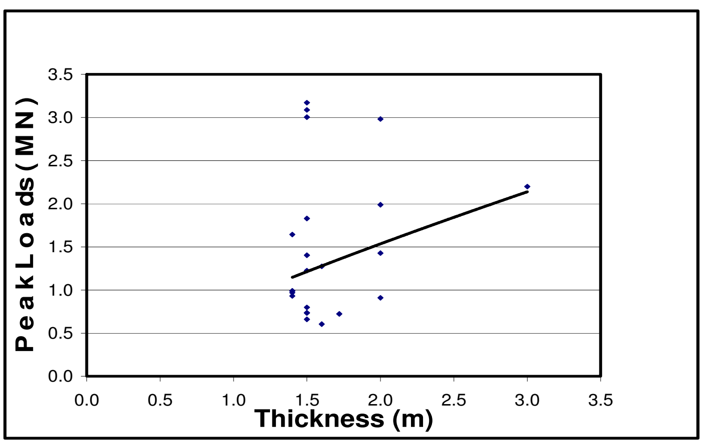

Figure 4b. Consolidated Layer Thickness Vs Load for a Range of H_c>1.4m

4.4. Keel Width Vs Load

The keel width is one of the parameters that may affect the load resulting from the interaction of first year ice ridges with offshore structures. Keel width has been neglected in most of the

proposed load models. One of the aims of this paper is to find out the influence of the keel width on the load. Also, to make it clear to researchers developing new ridge load models whether to take keel width as one of the model parameters or not.
The four figures 5a, 5b, 6a and 6b make it clear that when the keel width increases, the load increases as larger keel widths will result in higher inertial load on the cone. This may be attributed to the fact that in order to have a large load, high kinetic energy must be exerted. In order to exert high amount of kinetic energy, either the mass or the velocity of the ridge has to be high. So, for the events where large loads are recorded increasing the keel width increases the mass of the ridge and consequently increases the impact load of the ridge.
Analyzing figures 5a and 5b, it can be concluded that decreasing the keel depth the keel width influence on the load magnitude increases. It is noticed that in figure 5a where the keel depth range is smaller than 4m the slope of the trend line is remarkably larger than the slope of the trendline in figure 5b where the keel depth range is smaller than 11m.

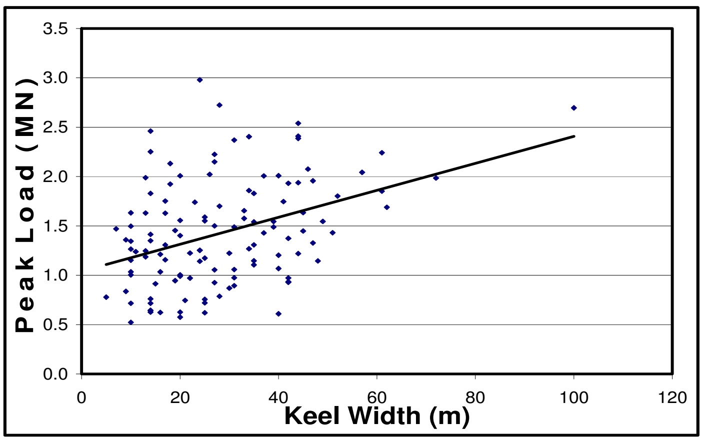

Figure 5a. Keel Width Vs Load for Keel Depth Range H_k<4m

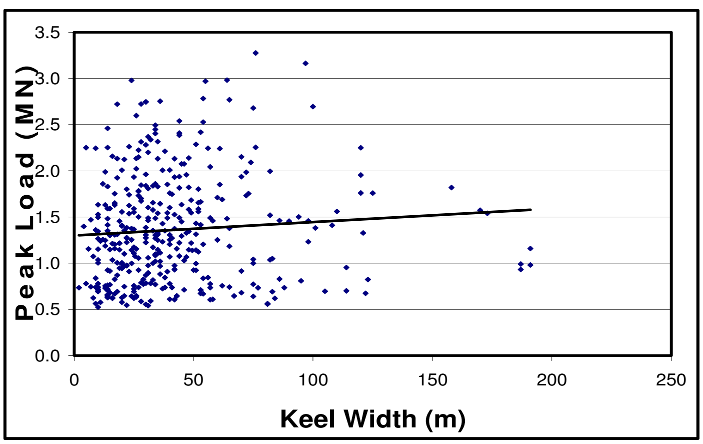

Figure 5b. Keel Width Vs Load for Keel Depth Range H_k<11m

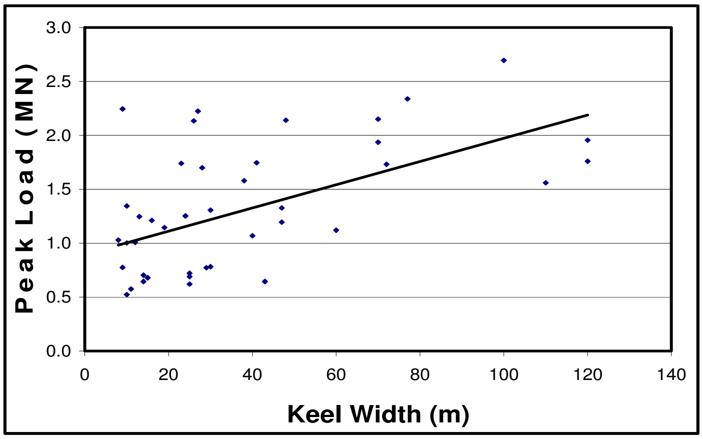

Figure 6a. Keel Width Vs Load for Consolidated Layer Thickness Range $H_c<0.6$

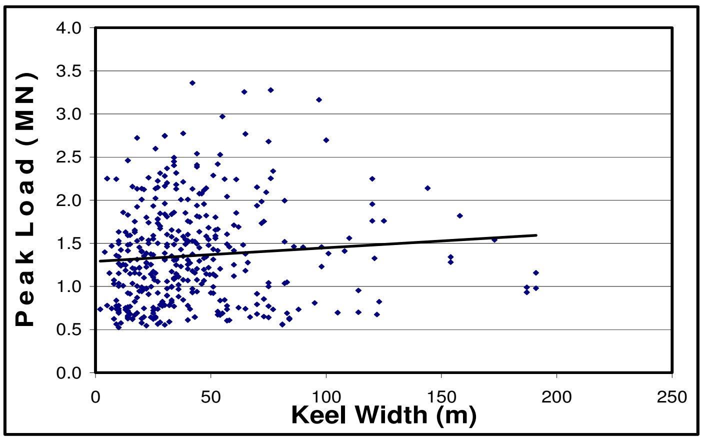

Figure 6b. Keel Width Vs Load for Consolidated Layer Thickness Range $H_c<1.5$

Analyzing figures 6a and 6b, it can be concluded that decreasing the consolidated layer thickness, the keel width influence on the load magnitude increases. It is noticed that in figure 6a where the consolidated layer thickness range is smaller than 0.6m the slope of the trend line is remarkably larger than the slope of the trend in figure 6b where the consolidated layer thickness range is smaller than 1.5m.

5.0 DISCUSSION

The analyses have been carried out on the basis of setting best-fit lines to the relations between load and the geometric and kinematic parameters. It may be argued that one should only consider the upper bounds to the relations as these points are representative of the most conservative field conditions. Whether one uses best-fit relationships, or upper bounds, depends on the approach taken in a design process. Both involve uncertainties, and the approach used must consider the uncertainties in the appropriate manner. At the present time, the data does not support upper bound approach, except perhaps over the lower ranges of variables as there is not sufficient data in the upper ranges to allow meaningful relations to be determined. Nevertheless, keel depths to 17 m and consolidated layers to 3.2 m have been observed. These are extremes, and yet the measured loads are still low. For this reason, best-fit linear regression lines have been used to determine the relationships between load and the independent variables. As more data is obtained and a better understanding of the relations is obtained, the nature of relations will be further investigated.

5.0. CONCLUSION

This paper presented the results of the statistical study that has been done based on the results of the Confederation Bridge Monitoring Program. It concentrated on the part related to the influence of the geometric properties of the keel and the consolidated layer on the load resulting from the interaction of first year ice ridges with offshore structures. Moreover this paper took care of one of the important parameters affecting the load magnitude and was not enough studied while proposing the current load models. This parameter is the ridge velocity. The paper showed that the ridge velocity is a parameter that can not be neglected while developing a new first year ice ridge load model. The reason for this is that the ridge velocity showed a good correlation with the recorded loads. Similarly, the keel width and the consolidated layer thickness showed good correlation with the recorded loads. On the other hand, the keel depth which was the most important parameter in the proposed models, showed no correlation with the recorded loads. The results presented in this paper is compatible with those introduced by Lemée (2003), as the consolidated layer thickness showed the highest correlation with the recorded loads while the keel depth showed no correlation. This implies that the researchers has to put in mind that the ridge velocity, keel width and the consolidated layer thickness are important parameters that must be given priority while proposing new ridge load models. Also they have to review the influence of the keel depth on the load magnitude while proposing new first year ice ridge load models interacting with conical offshore structures. Because maybe by extended research, researchers will prove that in case of conical structures interacting with first year ridges, the keel depth has minimal influence on the load magnitude.

6.0. ACKNOWLEDGEMENT

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