POAC'15
Trondheim, Norway

Proceedings of the 23rd International Conference on
**Port and Ocean Engineering under Arctic Conditions**
**June 14-18, 2015**
**Trondheim, Norway**

# COMPARISON OF PEAK ICE PRESSURES ON THE IBRV ARAON DURING THE PLANNED AND THE UNUSUAL ICE TRANSITS

Kyungsik Choi[1], Eun-Jee Cheon[1], Ho-Yeon Kim[1], Jong-Ho Nam[1] and Tak-Kee Lee[2]
[1] Korea Maritime and Ocean University, Busan, Korea
[2] Gyeongsang National University, Tongyeong, Korea

## ABSTRACT

In various ice conditions, icebreakers generally suffer significant ice load on ship's hull. Normal operating conditions are expected from the planned field ice trials and also from general ice transits. Sometimes an icebreaker encounters extraordinary ice conditions during unplanned and/or unusual ice transits. In this paper peak ice pressures recorded from the Korean icebreaking research vessel ARAON, during her normal operation and also during unplanned ice transits are discussed. The IBRV ARAON had sea ice trials in the Antarctic sea ice during 2012 summer season. Strain gauge signals were recorded during her planned icebreaking performance tests and also during the unplanned ice transits in heavy ice conditions. In this paper the effect of ARAON's speed on ice load is investigated by comparing the peak ice pressures on the ARAON's hull during the planned and the unusual ice transits. Unlike the normal operating conditions, the peak pressures on the ship hull are higher in general and do not show any relationship with ship's speed.

## ANTARCTIC VOYAGE OF THE IBRV ARAON

One of the concerns that arise while navigating ice-covered waters is the magnitude of the ice load encountered by ships. Normal operating conditions are expected from the planned field ice trials and also from general ice transits. Sometimes an icebreaker meets extraordinary ice conditions during unplanned and/or unusual ice transits. Extreme ice loads are expected from large ice features and these loads occur most likely when the ice is unbroken. When a ship encounters large ice features such as thick ice ridge or icebergs, continuous icebreaking process is impossible and the ship should continue by using repeated ramming or it fails to proceed.

The icebreaker ARAON had official ice trials twice in the Antarctic Sea in Feb/March 2012. Ice field tests were carried out in the Amundsen Sea as shown in Figure 1. The ARAON's 2012 Antarctic voyage and the analysis of icebreaking performance of ARAON were described in Choi et al.(2012), which provides information in the evaluation of ice loads and ship's performance in an ice-covered sea. The official icebreaking performance test sites were selected according to the availability of large and flat ice floes for the ice trial of ARAON.

The first official ice trial (Feb. 21, 2012; W73° 30' 43", S109° 02' 11") was performed on an first-year ice floe of size 900m × 600m and the mean ice thickness was approximately 1.5m. The second official ice trial (March 3, 2012; W72° 15' 11", S117° 49' 32") was performed on an ice floe of size 1,100m × 600m. This ice floe was believed to be a multiple-layered first-year ice with hummocks and ridges in the middle of ice floe. Ice thickness was not uniform.


Figure 1. ARAON's voyage to the Amundsen Sea, Antarctica (Feb./March 2012)

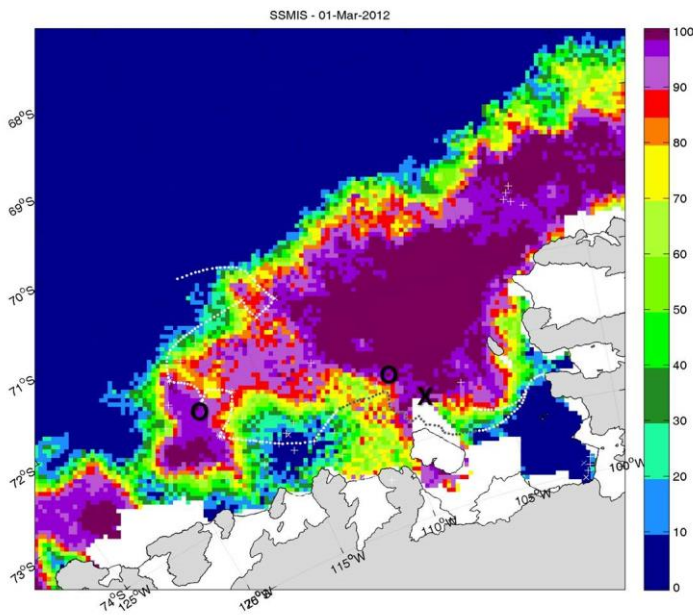


Figure 2. Ice concentration in the Amundsen Sea, Antarctica
(O) Official ice performance test sites; (X) Location where ARAON was stuck on heavy ice

In order to estimate the ice pressure on ARAON's hull, strain gauges were attached inside the shell plating of port and starboard sides between FR.106 and FR.111 of the lower part of second deck inside the bow thrust room. During the Antarctic voyage of the ARAON in 2012, strain gauge signals were recorded during her planned official icebreaking performance tests and also during the general ice transits in various ice conditions.

The Antarctic voyage of the ARAON in 2012 comprises of two official ice performance tests and general ice transit between ice field research stations. The sea ice in the Amundsen Sea consists of pack ice with varying concentration, some hummocks, ice floes and huge icebergs. Most of sea ice was old ice but there were some first-year ice floes. On Feb. 28, 2012, the strong wind closed the open channels and the ARAON was stuck in the middle of heavy ice. Thick ice floes moved more than 20km on that day and the open channel ahead has disappeared completely. For the next 20 hours, the ARAON had to try to find a way out of thick ice field with full engine power and by repeated ramming. Finally ARAON made a success to find the planned track and strain gauge signals were again fully recorded.

This paper focuses on peak ice pressures recorded on ARAON's hull during her normal ice transit operation and also during unplanned transit situation. The effect of ARAON's speed on ice load is investigated by comparing the peak ice pressures on the ARAON's hull during the planned and the unusual ice transits.

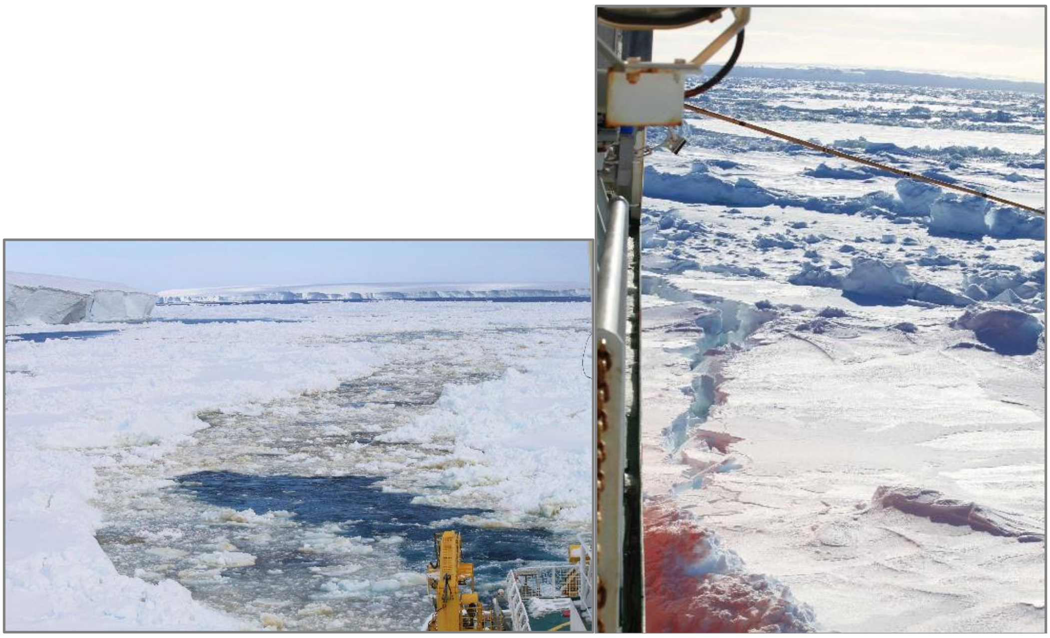

Figure 3. General ice transit and repeated ramming mode under heavy ice condition

## ICE PRESSURE DATA DURING ICE TRANSITS

On the hull plate, a total of 63 channels of strain gauge signal were recorded during her official icebreaking performance tests and also during her general icebreaking activities while in motion. The measured strain data were converted to the equivalent stress values and the effect of ship speed on the hull stress was investigated in previous study (Choi et al., 2014). Figure 4 and Figure 5 show the calculated peak ice pressures converted from von-Mises equivalent hull stresses by using a finite element analysis and an influence matrix.

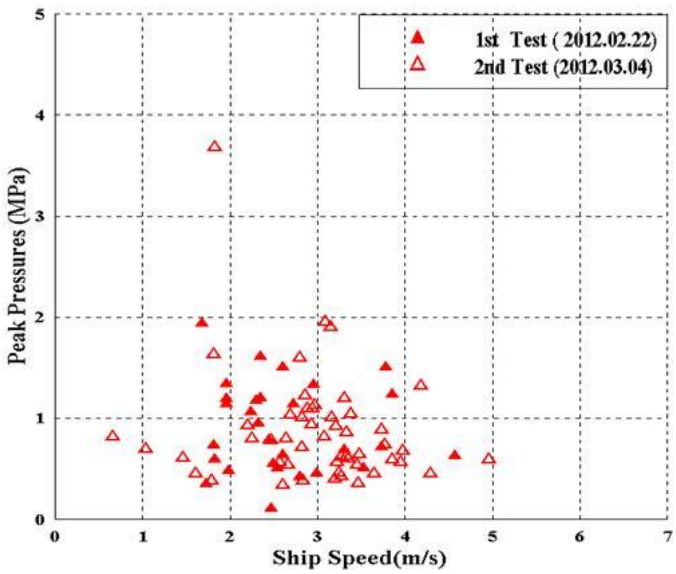


Figure 4. Peak ice pressures vs. ship speed during the official ice performance tests

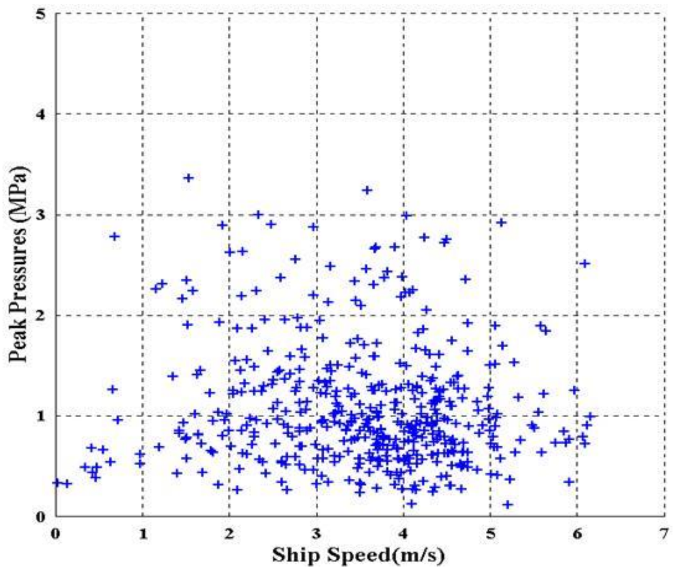


Figure 5. Peak ice pressures vs. ship speed during the general ice transits

As seen in Figure 4 and Figure 5, the peak pressures do not increase rapidly as the ship speed increases. Here the ship speed was determined from the onboard GPS information as the speed at the time of entering an ice collision event. Table 1 shows the data on the ice collision events during general ice transits of the ARAON. Except some data, peak pressures rather increase very slowly or become flat as the ship speed increases. Two graphs may be combined into Figure 6 to explain the general trend in peak pressure vs. ship speed. Even though the magnitude of global ice load is not equal to the sum of the peak ice pressures, the trend of peak pressure (also ice load) vs. ship speed is very similar to an explanation by Tsoy et al.(1998) for SA-15 class ships.

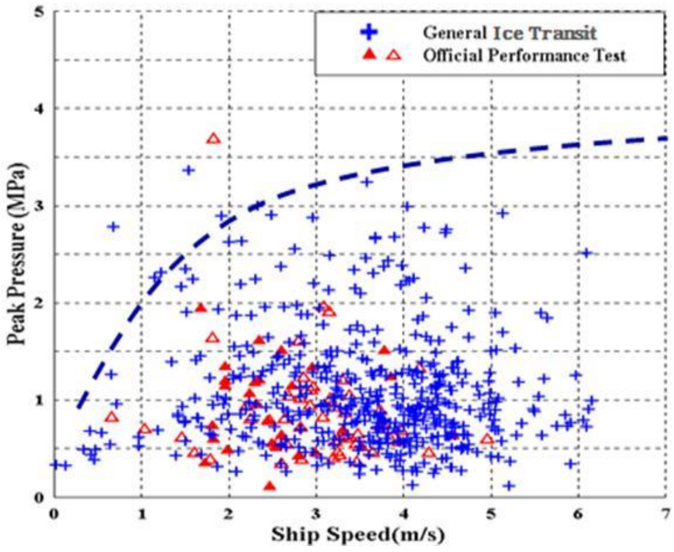


Figure 6. Peak ice pressures vs. ship speed during the general ice transits (combined data

Table 1. Number of data events during general ice transits

| Data file No. | Date | Time (UTC) | Measuring time (s) | No. of events |
|---|---|---|---|---|
| 01 | 2012. 02. 10 | 19:00 ~ 19:10 | 600 | 7 |
| 02 | 2012. 02. 10 | 19:15 ~ 19:45 | 1,800 | 11 |
| 03 | 2012. 02. 10 | 20:50 ~ 21:20 | 1,800 | 44 |
| 04 | 2012. 02. 20 | 00:45 ~ 01:15 | 2,700 | 7 |
| 06 | 2012. 02. 27 | 11:00 ~ 11:30 | 4,900 | 56 |
| 07 | 2012. 02. 27 | 02:10 ~ 03:30 | 5,100 | 45 |
| 08 | 2012. 02. 28 | 10:00 ~ 10:30 | 4,400 | 58 |
| 09 | 2012. 02. 28 | 13:15 ~ 14:30 | 3,700 | 14 |
| 10 | 2012. 02. 28 | 14:35 ~ 15:40 | 8,100 | 85 |
| 11 | 2012. 03. 01 | 15:45 ~ 18:00 | 7,000 | 39 |
| 12 | 2012. 03. 01 | 11:35 ~ 13:30 | 8,000 | 25 |
| 13 | 2012. 03. 01 | 13:40 ~ 16:00 | 1,000 | - |
| 14 | 2012. 03. 02 | 16:05 ~ 16:25 | 5,700 | 30 |
| 15 | 2012. 03. 02 | 02:15 ~ 03:45 | 8,300 | 59 |
| 16 | 2012. 03. 02 | 05:25 ~ 07:45 | 5,500 | 36 |
| 17 | 2012. 03. 02 | 07:55 ~ 09:20 | 7,700 | 58 |
| 18 | 2012. 03. 02 | 09:30 ~ 11:40 | 7,000 | 26 |
| 19 | 2012. 03. 02 | 14:40 ~ 16:35 | 6,400 | 22 |
| 21 | 2012. 03. 10 | 16:45 ~ 18:30 | 8,400 | 10 |

By the way, strain gauge signals were also recorded during the unplanned ice transits in heavy ice conditions. Figure 7 shows the peak pressures vs. the ship speed for the case of unplanned ice transits (Data no.08 ~ no.10) as shown in Table 1. For the unexpected heavy ice conditions, the ARAON could not proceed the ice field by a single pass and repeated ramming was carried out to escape from heavy ice conditions. By comparing Figure 6 and Figure 7, the peak pressure data for heavy ice conditions is somewhat different from data from general ice transits. Unlike the general ice transits, the peak pressures on the ship hull for heavy ice conditions are higher in general and do not show any relationship with ship's speed.

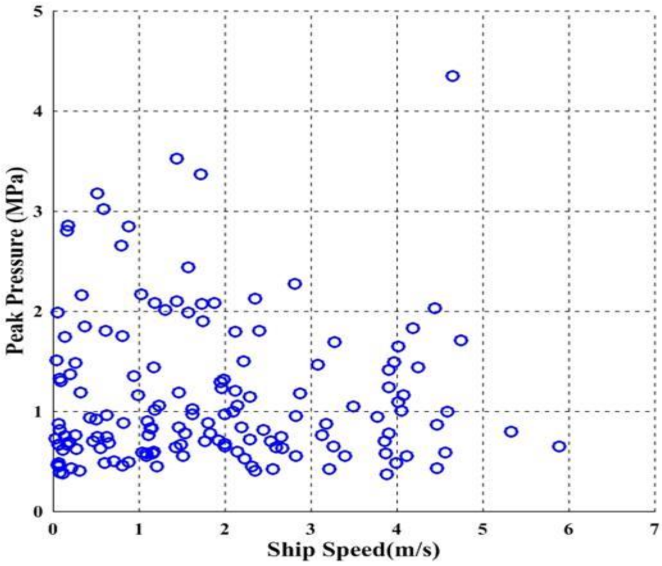


Figure 7. Peak ice pressures vs. ship speed during the heavy ice conditions

## ANALYSIS OF ICE LOAD ON THE IBRV ARAON

In a previous study (Choi et al., 2009), some published ice load data for icebreaking vessels had been collected from the model tests and also from full-scale sea trials. The authors have proposed an extreme ice load prediction formula as shown in Eq. 1 which includes two parameters, i.e., the displacement and speed of a ship,

$$F_{max} = 2.55 V \Delta^{0.4} \text{ [MN]} \qquad (1)$$

where $V$ is ship speed in (m/s) and $\Delta$ is displacement in ($10^3$ ton).

A continuous icebreaking in level ice or a minor ramming on small ice feature is the most common operational mode in the ice seas. In this case, the magnitude of ice load is not significantly high. Therefore a functional relationship between the global ice load and ship speed considering additional parameters such as ice thickness, ice flexural strength in addition to the displacement of a ship, was suggested as the relationship between ice load and ship speed as follows (Choi et al., 2009);

$$F_{max} = 0.824\Delta^{0.4}(\sigma_f \cdot h^2 \cdot V\cos\alpha)^{0.283} \quad \text{[MN]} \qquad (2)$$

where $V$ (m/s) is speed, $\alpha$ is stem angle of a ship, $\Delta$ ($10^3$ ton) is displacement of a ship, $h$ (m) is ice thickness, $\sigma_f$ (MPa) is flexural strength of ice, respectively.

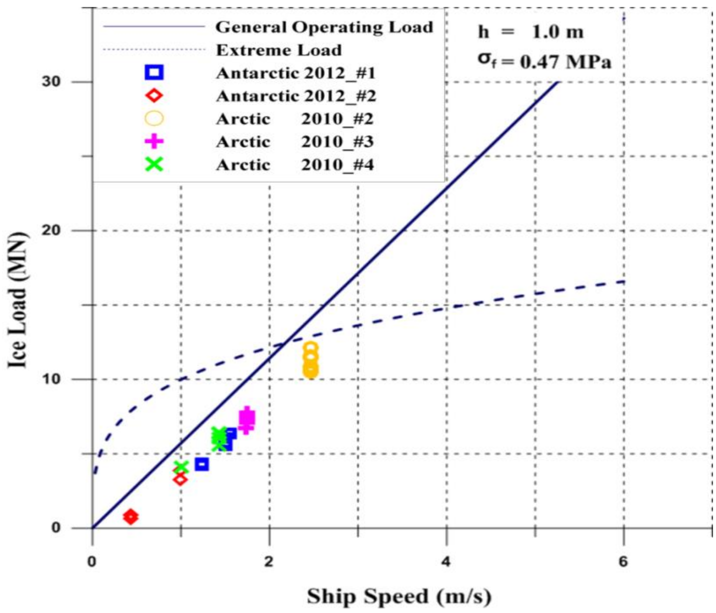


Figure 8. Global ice loads vs. ship speed for the IBRV ARAON (Choi et al., 2014).

Global ice loads calculated by proposed prediction formulas are shown for the IBRV ARAON in Figure 8. ARAON has an icebreaking capacity of 1m level ice with speed of 3knots. The ice load based on data measured during the Arctic and the Antarctic voyages, follows an ice load curve under normal operating conditions. In Figure 8, data points show that the calculated ice load based on head-on collision and crushing/bending failures of sea ice based on actual data from sea ice properties. The new ice load prediction formula is compared with the collected full-scale sea trials data for the ARAON and it shows a good agreement in general. As seen in Figure 6, peak ice pressures measured during the general ice transits fall under the line of normal operating load.

However the peak pressure data for the unplanned ice transits in heavy ice conditions shows different pattern from data from general ice transits. For the unexpected heavy ice conditions, the ARAON could not proceed the ice field by a single pass and repeated ramming with full engine power was the most efficient way to escape from heavy ice conditions. The ship speed was very low at the contact with ice and therefore the peak ice pressures mainly fall on low ship speed regions. As seen in Figure 7, the peak pressures on the ship hull for heavy ice conditions do not show any correlation with ship's speed. Collision with thick and large ice features can cause a huge ice load on the ship hull, independent of ice thickness or strength (Takimoto and Wako, 2007). Extreme ice loads are dependent on ship speed in general, but in this unusually heavy ice conditions, the ARAON's speed was in low ranges.

## CONCLUSIONS

In this paper peak ice pressures recorded from the Korean icebreaking research vessel ARAON, during her normal operation and also during unplanned ice transits are discussed. The IBRV ARAON had sea ice trials in the Antarctic sea ice during 2012 summer season. In order to estimate the ice pressure on ARAON's hull, a total of 21 strain gauges were attached inside the shell plating inside the bow thrust room. Strain gauge signals were recorded during her planned icebreaking performance tests and also during the unplanned ice transits in heavy ice conditions.

In this paper the effect of ARAON's speed on ice load is investigated by comparing the peak ice pressures on the ARAON's hull during the planned and the unusual ice transits. Unlike the normal operating conditions, the peak pressures on the ship hull are higher in general and do not show any relationship with ship's speed. Extreme ice loads are dependent on ship speed in general, but in this unusually heavy ice conditions, the ARAON's speed was in low ranges.

## REFERENCES


Choi, K., Jeong, S.Y. and Nam, J.H., 2009. Prediction of Design Ice Load on Icebreaking Vessels under Normal Operating Conditions. Proc. 20$^{th}$ POAC Conference, Paper No.28, Lulea, Sweden.

Choi, K., Kim, H.S., Choi, G.G., Lee, J.M and Ha, J.S., 2012. Sea Ice Field Test Report: Measuring Ice Properties during 2012 Antarctic Voyage of IBRV ARAON, KMU-ARL

Choi, K., Cheon, E.J., Lee, T.K. and Kim, H.S., 2014. Analysis of Ice Load on the IBRV ARAON during Icebreaking Performance Tests in the Arctic and Antarctic Sea Ice, Proc. 22$^{nd}$ IAHR International Symposium on Ice, Paper No.1115, Singapore.

Takimoto, T. and Wako, D., 2007. Ice Loads on Ship Hulls in Pack Ice Conditions, Proc.19th POAC Conference, Vol.1, pp.267-276, Dalian, China.

Tsoy, L.G. et al., 1998. Collection of SA-15 Operations Data. INSROP Working Paper No.107.