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An Analysis on Strain Gauge Signal Measured from Repetitive Ramming in Heavy Ice Condition

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ABSTRACT

To navigate ice-covered waters, ice-breaking process is required. Ice-breaking mode depends on material properties of sea ice and ice conditions. Ice-breaking mode is classified into ramming and continuous ice-breaking. Ramming has a great effect on large ice features, such as thick ice ridge and icebergs, and continuous ice-breaking does on level ice. In general, the impact time duration in crushing or bending on ice sheets ranges from 0.2 to 1.0 second. However, impact duration in ramming will be increased.

The Korean ice-breaking research vessel ARAON conducted her research voyage in the Antarctic sea ice during the winter of 2012. The IBRV ARAON measured strain in ramming and continuous ice-breaking. Strain gauge signals were recorded during the planned ice-breaking performance and the unplanned ice transits in heavy ice conditions.

The aim of this study is to investigate the strain gauge signals measured in ramming processes under the heavy ice condition. Based on the time history of the signals, a raising and a half-decaying time were investigated and compared with the previous study which was suggested the five profiles on the strain gauge signals.

KEY WORDS: Ice-breaking process, Ramming, Strain gauge signal, Time-history, Raising time, Half-decaying time

INTRODUCTION

As the Arctic ice was reduced to less than 4 million km^2 in the recent 30 years due to global warming, it was reduced to the level allowing free voyage of vessels. Due to climate change, the Northern Sea Route (NSR) came to be provided with conditions allowing voyage during summer period. The NSR means the sea route connecting Europe, Asia and America through the Arctic sea. It also collectively refers to the northwest sea route and the northeast sea route. According to the demonstration voyage of NSR by Stena Bulk Company, about 48 days of voyage is required when the existing sea route is used from Busan to Ust-Luga of Russia through Suez Canal. However, when NSR along the north coast of Siberia through Bering Strait is used, about 35 days of voyage is required (Stena Bulk, 2013). When compared with the case of using south sea route, The NSR shortens the sea route by about 7,200km, which is the greatest advantage of its route.

Such construction of sea route leads to the advantages of allowing commercial use of various natural resources such as enormous crude oil and natural gas, etc. of the Arctic, drawing worldwide attention due to interests in the Arctic circle. Also, it is being expanded to an increase in the demand for icebreaking cargo ships in the market for ice-going ships which include oil tankers containing icebreaking capability in the features of the existing ships, icebreaking LNG carriers, icebreaking container carriers, etc. in addition to icebreakers.

Icebreaking capability is essential requirement for voyage of ships in the ice field. In general, icebreaking is divided into ramming and continuous icebreaking. The ramming has a great effect for thick ice or ice ridge, while continuous icebreaking is greatly effective for level ice. When icebreaking operation is performed, the ship is subjected to forces as a global or locally due to collision or contact with sea ice. Such force is called ice load or ice pressure. Ice pressure is the expression in a general form of local ice load acting only on a local area of a particular part. Since ice loads acting on the icebreaking ship are larger than the wave loads produced in general shore regions or the forces due to slamming, the magnitude of ice load is given a high importance upon design (Kim, 2014).

The ARAON as the Korean first icebreaking research vessel sailed Amundsen Sea of the Antarctic between January 31 and March 20, 2012 (Choi et al., 2012). The ARAON conducted full scale measurement tests of the bow side part by division into icebreaking voyage and general voyage in the ice field. For ice load measurements, 21 rosette gauges were attached to inside of the side shell in the bow side part. The data measured through this was recorded during two official icebreaking performance tests and general ice transit with breaking of ice in the ice fields with various ice concentrations.

Since the amount of impact was proportional to time duration in ramming and impact load, in this study focused on the fact that damages to the hull produced by ramming could be increased, the longer the time duration in ramming. Prior to data analysis, strain data measured upon ramming was converted to stress. The measurement data when peak stress of higher than 20MPa was recorded was analyzed. After dimensionless conversion of the time-history by using the maximum stress, raising time and half-decaying time were checked by using this graph, and impact time duration calculated. Also, classification was made with application of the criteria of the previous study (Lee et al., 2016) where the measured signals were represented by 5 types, and the characteristics were examined and analyzed.

ANTARCTIC VOYAGE OF THE IBRV ARAON IN 2012

The ARAON has conducted various full scale measurement tests such as ice load and ice resistance, etc. in Antarctic Ocean and Arctic Ocean from January, 2010 through recent times since its construction. Between January 31 and March 20, 2012, the ARAON conducted full scale measurement and icebreaking performance tests in the ice field of Amundsen Sea, Antarctic. The place where ramming was conducted is displayed by (X) in Figure 1.

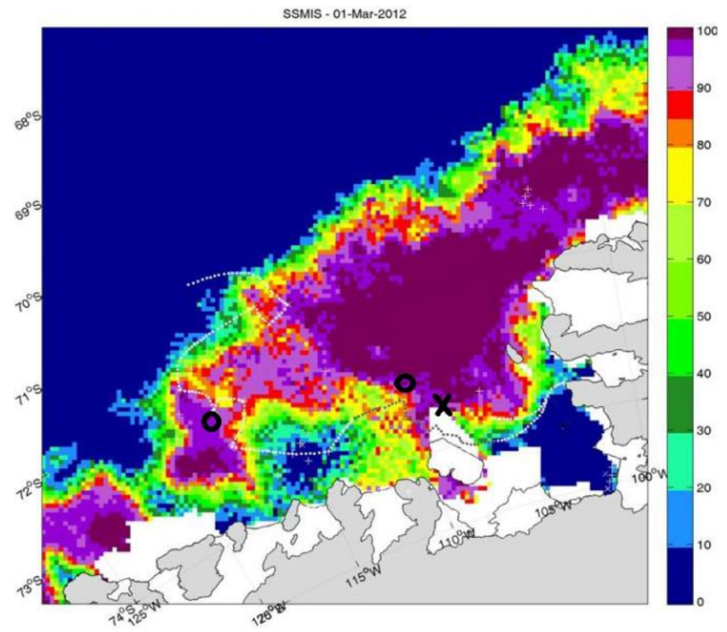

Figure 1. Ice concentration in the Amundsen Sea, Antarctic
(O) Official ice performance test sites; (X) Location where ARAON was stuck on heavy ice
(Choi et al., 2015)

A total of 21 rosette gauge including 10 ea. on the port and 11 ea. on the starboard were attached around the draft part inside the side shell between FR.106 and FR.111 of the lower part of second deck inside the bow thrust room. It was configured so as to allow simultaneous measurement for a total of 63 channels in rosette form. The parts instrumented by rosette gauges are shown in Figure 2. Shell material is EH36 steel with 355MPa for yield strength, 200GPa for elastic modulus, and 0.3 for Poisson's ratio (Kim, 2014).

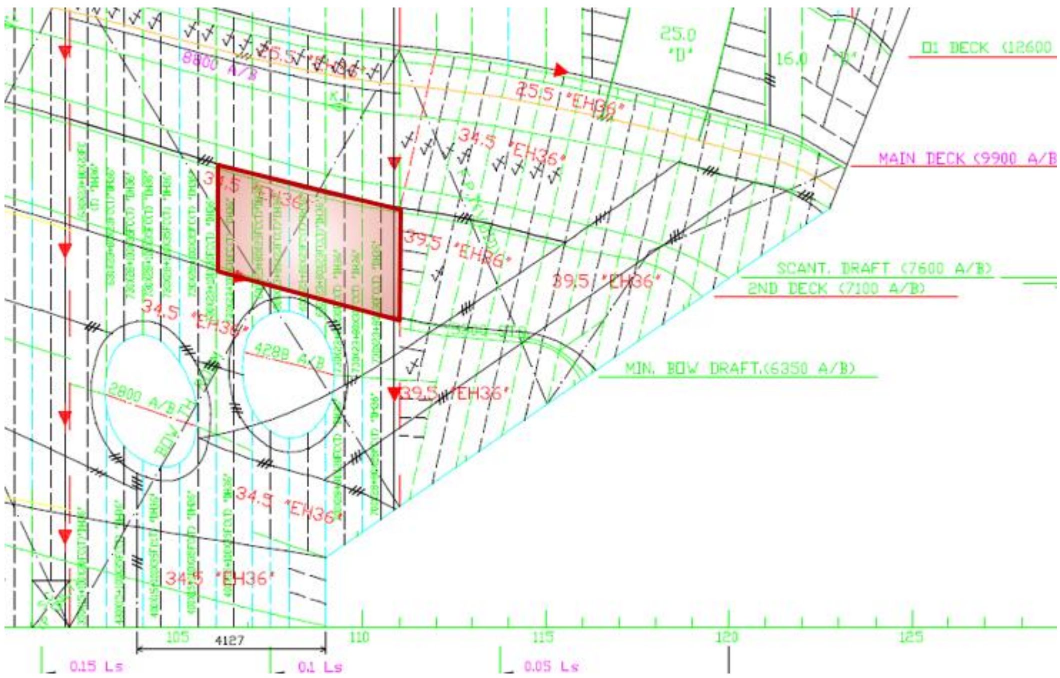

Figure 2. Area instrumented by strain gauges in the IBRV ARAON (Kim, 2014)

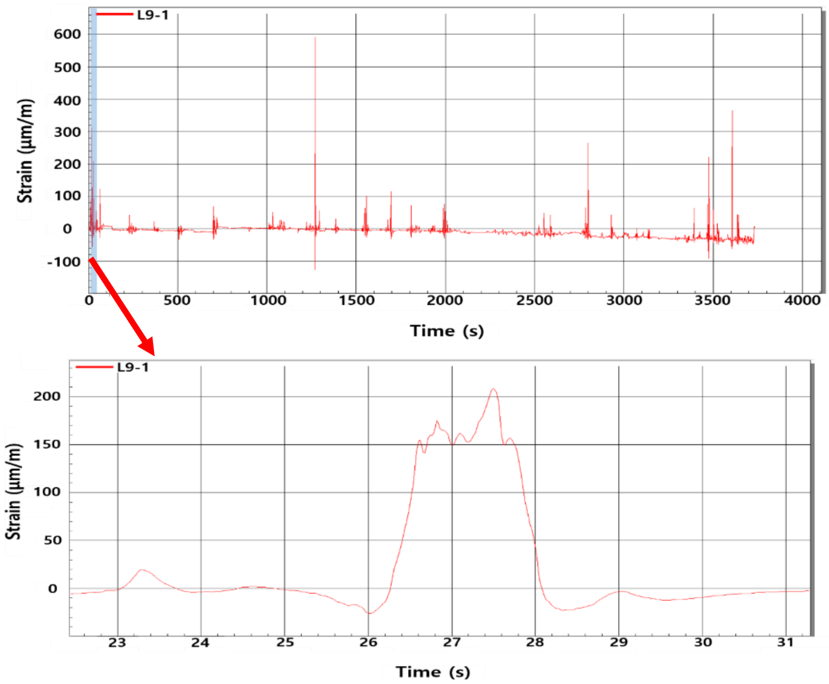

Figure 3. Example of measured strain gauge data

LOCATION AND SITUATION IN REPEATED RAMMING

Table 1 shows a summary of information related to data involving ramming among the data measured during general ice transit of the ARAON. Here, the test number represents the number continuously granted for each measurement by the measurement team during general voyage. In this study, it is focused on two times of measurement for nos. 9 and 10 where ramming occurred. Also, measurement times are arranged based on UTC (universal time coordinated). Ramming occurred when moving from the position of 73°37’33015”S, 109°29’64878”W to that of 73°34’44119”S, 109°38’61929”W and while moving from 73°33’20699”S, 109°40’98492”W to 73°31’95289”S, 109°45’51126”W. No measurements with R5 gauge were made since the gauge was defective at the time of measurement.

Description of the sailing situation with the ARAON on the relevant day is as follows. On February 28, 2012, the open channel was closed due to gale. The ARAON became trapped in the middle of heavy ice. On that day, thick ice floe moved by more than 20km. Subsequently, the front side of open channel completely vanished. For 20 hours, the ARAON made efforts to find a way out of the thick ice flow by enforcing repeated ramming at the full engine power. As a result, the ARAON successfully escaped, and a considerably large amount was recorded for the strain gauge signals (Choi et al., 2015).

Table 1. Summary of information related to data involving ramming

Test no.	Date	Time(UTC)	Measuring site	Measuring time(sec)
9	2012.02.28	14:35 ~ 15:40	73° 37’ 33015”S-109° 29’ 64878”W~ 73° 34’ 44119”S-109° 38’ 61929W	3,900
10	2012.02.28	15:45 ~ 18:00	73° 33’ 20699”S-109° 40’ 98492”W~ 73° 31’ 95289”S-109° 45’ 51126”W	8,100

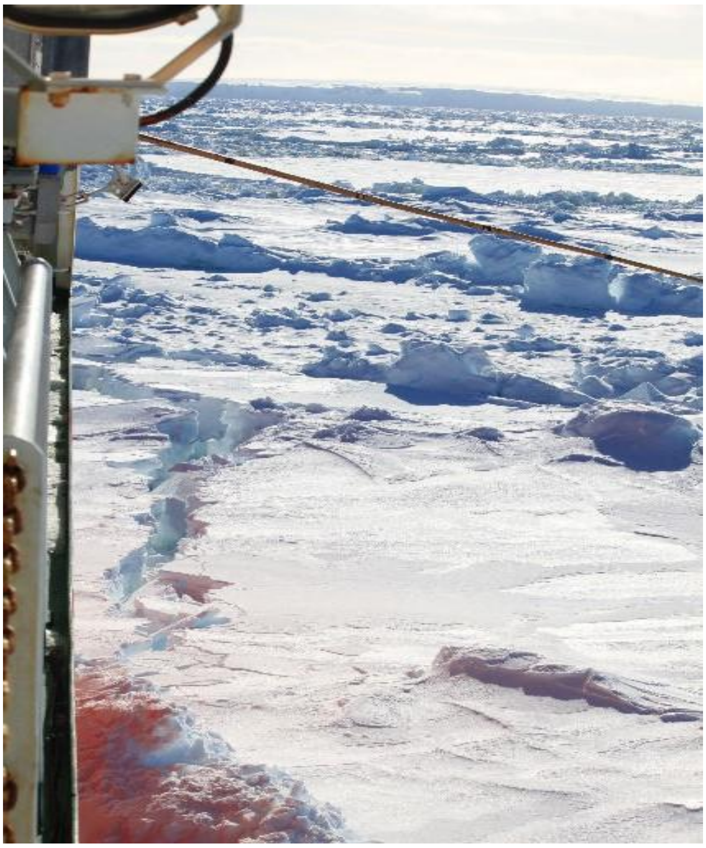

Figure 4. Heavy ice condition in repeated ramming (Choi et al., 2015)

ANALYSIS OF ICE LOAD SIGNALS MEASURED IN RAMMING

Data measured from rosette gauge was converted to stress by application of Hooke's law. Among the signals measured from rosette gauge, the value in the direction of bow & stern was taken as the representative value, which considered that the ice broken by bow icebreaking flowed along the side shell according to advancement of the ship (Jeon et al., 2013). In Tables 2, S_{max} shows the maximum value of peak stress, T_r the raising time, T_{hd} the half-decaying time, and T_d the time duration. Here, the raising time means the time taken from the time where signal passed through zero point to the time of arriving at peak point, while the half-decaying time is the time taken by dimensionless stress level moving from the peak point to the 0.5 point (Lee et al., 2016). And, time durations of Type Ⅰ and Ⅱ were taken as the value of doubling the half-decaying time with the raising time added. However, time duration values of Type Ⅲ, Ⅳ and Ⅴ were taken as the time difference from the raising time point to the calculated point by calculation of the time when the stress became after decaying time had ended.

In the ramming on February 28, 2012, the maximum peak stresses higher than 20MPa for a total of 12,000 seconds were recorded for a total of 347 times. Data was classified into 5 types of signals based on the presence status of intermediate peak (Lee et al., 2016). Maximum value, minimum value, and average were arranged for peak stress, raising time, half-decaying time, time duration in Table 2, respectively. The maximum value for measured peak stress was 159.6MPa. Also, the average of raising time was 0.540 second, the average of half-decaying time 0.326 second, and the average of time duration 1.173 seconds.

Table 2. Summary on peak data in ramming

Type	No. of peak over 20MPa		S_{max} (MPa)	T_r (sec)	T_{hd} (sec)	T_d (sec)
I	185	Max.	159.6	7.231	1.854	9.750
		Min.	20.1	0.050	0.013	0.128
		Avg.	37.8	0.286	0.138	0.562
II	43	Max.	111.3	4.863	1.781	8.425
		Min.	20.3	0.124	0.042	0.225
		Avg.	32.1	0.516	0.181	0.879
III	43	Max.	119.4	3.237	3.733	9.952
		Min.	20.1	0.077	0.066	0.242
		Avg.	39.6	0.305	0.333	0.986
IV	16	Max.	83.2	1.308	0.812	3.326
		Min.	20.9	0.188	0.048	0.467
		Avg.	39.4	0.557	0.337	1.223
V	60	Max.	90.9	6.470	5.698	14.077
		Min.	20.3	0.174	0.108	0.497
		Avg.	35.4	1.507	0.999	3.387
Total	347	Max.	159.6	7.231	5.698	14.077
		Min.	20.1	0.050	0.013	0.128
		Avg.	37.0	0.540	0.326	1.173

Figure 5 is the graph showing relationship between the raising time and the peak stress among data measured in ramming. Peak stresses measured in general ice transit were shown to be high in the section with a short raising time as analyzed by Lee et al. (2016). However, some data was recorded to have relatively high peak stresses in the sections with a long raising time, which is attributed to the situation at the time of icebreaking of relatively thick ice at a low speed (Kim, 2014). When peak stress was high, signals of Type Ⅰ were recorded most frequently. And, when the raising time is more than 2 seconds, the majority was classified as Type Ⅴ. Such data with a long raising time was not observed at all in the data for analysis of ice load signals of Arctic Ocean in 2010 (Lee et al., 2016). Also, much of the data for Type Ⅰ, Ⅲ and Ⅳ is distributed before about 0.4 second, while much of the data for Type Ⅱ and Ⅴ was distributed after about 0.4 second.

Figure 6 shows the relationship between half-decaying time and peak stress. When the half-decaying time is more than 2 seconds unlike the raising time, only signals of Type Ⅴ were recorded. However an exception of Type Ⅲ was recorded. Because bending strength of ice is higher than other, the bow has a long time on ice in ramming. Also, with 0.4 second as the reference, much of the data for Types Ⅰ, Ⅱ, Ⅲ and Ⅳ can be seen to be distributed before, while much of the data for Types Ⅴ are distributed after.

Figure 7 shows the relationship between time duration and peak stress. Hysing et al. (1979, in Choi, 2015) presented that time duration was in the range of 0.3~0.5 second when ramming by an icebreaking cargo ship. On the other hand, the average of time duration in ramming measured while ramming was actually executed in the Antarctic was 1.173 seconds as seen from ramming. Also, the range of distribution was varied with types. In the case of dominant Type Ⅰ among the entire data, it was distributed in a wide range from 0.1~10 second. Type's Ⅱ and Ⅲ were distributed in 0.2~10 seconds, while Type Ⅳ was distributed in 0.4~4 seconds. In the case of Type Ⅴ having the longest time duration, it lasted up to the maximum of about

14 seconds. However, it can be seen to be distributed between 0.8~10 seconds through the graphs in most cases.

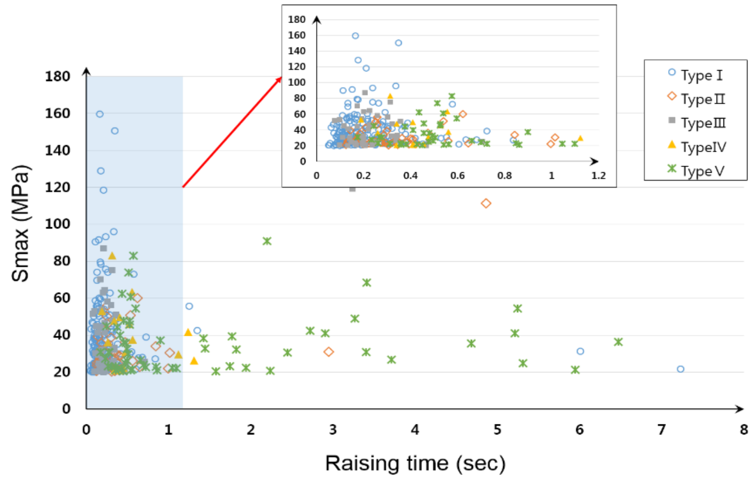

Figure 5. Relationship between raising time and peak stress

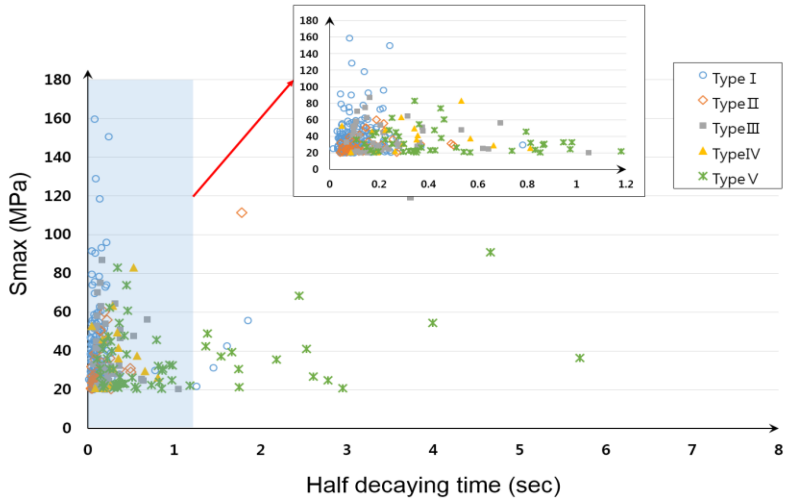

Figure 6. Relationship between half-decaying time and peak stress

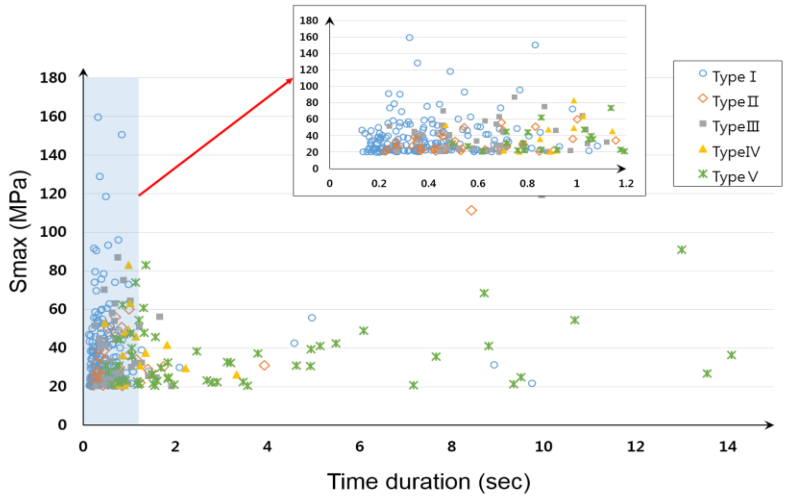

Figure 7. Relationship between time duration and peak stress

Table 3 summarizes peak stress, raising time, half-decaying time, and time duration by extraction of 3 data with the longest time duration in ramming from ramming. Average of time duration for ramming was shown to be 13.537 seconds. Also, while all case shown to be Type V for ramming. The top 3 on time duration appeared at only test no.9.

Since the ice as level ice or pack ice is mainly distributed when the icebreaker conducts continuous icebreaking, icebreaking can be executed continuously while sailing at a speed higher than a given value. However, since ice ridge or thick ice is broken when ramming is conducted, there is a feature that icebreaking occurs at a relatively higher engine power in a low-speed. The fact that time duration is observed to be long upon ramming can be considered attributable to such characteristics of icebreaking.

Table 3. Summary of the top 3 on time duration

No.	Type	S_{max} (MPa)	T_r (sec)	T_{hd} (sec)	T_d (sec)
R6 in Test no.9	V	36.3	6.470	5.698	14.077
R7 in Test no.9	V	26.8	3.709	2.612	13.543
R7 in Test no.9	V	90.9	2.197	4.664	12.992
Avg.		51.3	4.125	4.325	13.537

Figure 8 shows the data of Table 3. When a ship conducts icebreaking of such as ice ridge, ramming is conducted. Since the ramming is characterized by low-speed execution, the trend can be observed where the stresses are steadily increased without intermediate peaks upon raising due to continuous contact with ice. Here, the sizes of ice and ship are also considered to have an effect to a certain extent. Namely, when the ice is relatively very large with the ship, the ice will be resisted against the ship's motion. Here, a continuous increase in stresses can occur due to withstanding by ice.

The fact that small peaks occur for few times upon decaying as in the signal profile of R7 shown by a dotted line might be caused by the contact with other surfaces immediately after the surface of ice having come into contact with the hull is broken. And, when stresses higher than a given level are continued as R6 shown by the thick solid line, it is presumably due to the fact that the ice withstands without being pushed away upon ramming as the size of the ice is relatively large compared with that of the ship.

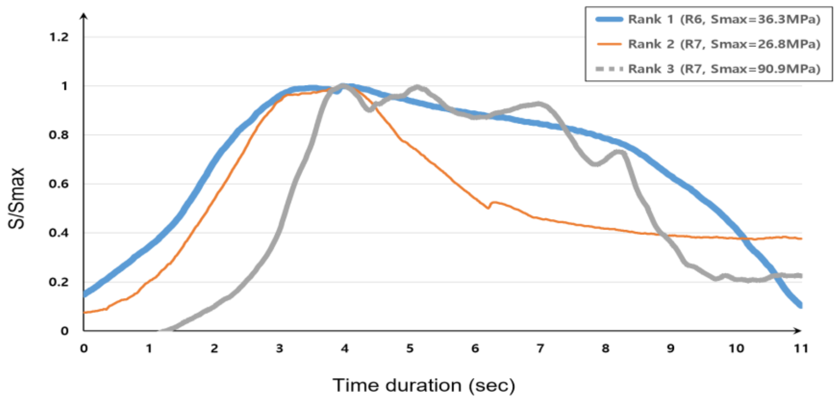

Figure 8. Comparison of the top 3 on time duration profile

COMPARISON WITH PREVIOUS STUDIES

Ritch et al. (1999) presented ice load data measured during the voyage of the Louis S. St. Laurent as a Canadian icebreaker through the Arctic in the summer of 1994. Data was examined after converting the strains inputted in the strain gauge into the stresses. Time history among the measured data was comparatively analyzed in terms of ‘sharp impact’ event and ‘sliding’ event. First, considering the ‘sharp impact’ event, time duration was shown to be about 0.4 second, and can be seen to be similar to Type Ⅰ among 5 signal types classified in the previous study (Lee et al., 2016).

The graph of Figure 8 is compared with an example of the ‘sliding’ event where time duration is 5 seconds reported by Ritch et al. (1999). The ‘sliding’ event is presumed to be similar to the signal with impulsive tail in the previous study (Jeon et al., 2013). These two types of signals have longer decaying time than normal one. In this study, the half-decaying time is characterized as being continued for long like in the ‘sliding’ event. This is presumed to originate from the execution of ramming by the ARAON in a low-speed as well as the relative size difference between the ship and the ice. A ship in the low-speed will be in continuous contact after the first collision with ice to push away the ice. Here, if the ice is relatively small, it will be immediately pushed away. However, when the ice is larger than a given scale, it will withstand rather than being pushed away to extend the time duration in ramming, and the tendency toward a gradual decrease in stresses has been presumably exhibited.

Hysing et al. (1979, in Choi, 2015), has reported that the time duration is increased upon ramming and the average of time duration in ramming of icebreaking cargo ship on 40cm-thick ice is between 0.3~0.5 second. Time duration in ramming of an icebreaking cargo ship was estimated through the measurement data for an icebreaker. While the length of the crushing zone was increased to 3m when icebreaker pass through thick ice or ice ridge that it was reported that the length may be 5~6m in the case of icebreaking cargo ship (Choi, 2015). According to Kim (2014), the ship speed in ramming was reported to be less than 0.5 m/s. Upon calculation with application of 0.5 m/s for the ship speed, time duration in ramming for an icebreaking cargo ship can be shown to be longer by 4~6 seconds compared with an icebreaker due to the difference of that length. In view that the average of time duration in ramming from Table 3 was 13.537 seconds, it is presumed that about 17.537~19.537 seconds can also be measured for an icebreaking cargo ship. These values are very longer them that of Hysing et al. (1979). However, it is necessary to keep in mind that such consideration did not take into account the relative size difference between the ship and ice.

CONCLUSIONS

In this study, data with the relatively high stress level of 20MPa exceeded was extracted based on the data measured upon ramming in the ice field of Amundsen Sea in 2012 using the ARAON as the icebreaking research vessel, and waveform analysis of the signals has been attempted. A summary of conclusions obtained from the present study is as follows.

1. 347 data for test no. 9 and test no. 10 measured from the Amundsen Sea in 2012 was analyzed and classified into 5 signal types as presented in the previous study (Lee et al., 2016).
2. According to the data classification results, Type Ⅰ as the most general form was measured most frequently, accounting for 53.3%. In the case of Type Ⅱ, it accounted

for about 12.4%, about 12.4% in the case of Type Ⅲ, about 4.6% in the case of Type Ⅳ, and about 17.3% in the case of Type Ⅴ, showing much difference from the measurements of the previous study (Lee et al., 2016). Also, when time duration is long while executing ramming, Type Ⅴ is analyzed to have been frequently measured.

3. According to the analysis results of 3 data with the longest time duration in ramming, the signal type of Type Ⅴ were only observed. Since collision was executed at a low speed, impacts with continuous increase in stresses occurred and the phenomenon with extension of raising time has been discovered.
4. In ramming, the signal types of Type Ⅰ and Ⅴ were most frequently observed, where Type Ⅰ can be seen to be dominant when the time duration was short, and Type Ⅴ dominant when the time duration was long. Unlike the previous study (Hysing, 1979 in Choi, 2015) where the time duration in ramming was 0.3~0.5 second, it was diversely distributed in 0.1~14 seconds, with the average of time duration calculated to be 1.173 seconds. Also, the average duration for top 3 in ramming was calculated to be 13.537sec. Such measurement signals are considered to be precious data which are not so frequently discovered in the previous studies.

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