⊙ Technical Paper

Ice Gouge Study in the Alaskan Beaufort Sea

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알라스카 뷰오포트 海岸의 氷山에 의한 海底面 損傷 硏究

제리 엘 메케멜* · 趙 哲 熙**

Key Words : Ice Keel(氷下 海底 끝), Ice Gouge(氷山흠), Ice Ridge (氷山), Seabed Scour (海底面 損傷), Ice Island(氷下섬), Sea Ice(海氷), Beaufort Sea(뷰오포트 海), Arctic Ocean(北極海)

초 록

원유의 발견과 함께 북극의 개발이 활발해져 왔고, 지역의 특수한 환경적인 요건으로 인해 시설물의 개발, 설치, 이동, 운용에 많은 어려움을 갖고 있다.

특히 빙산에 의한 극지 해안가의 해저면은 파이고, 손상되고, 변형된다. 북 알라스카의 해저면은 고르지 못하고, 불규칙하게 파이고, 손상된 형태를 보여주고, 특히 빙산의 활동이 활발한 지역과 시기에는 그 손상이 더욱 심하고, 자주 일어난다. 빙산에 의한 해저면의 흠은 빙산 해저 끝이 해저면에 접촉하여 해저 바닥을 파 나갈때 일어나는 현상이다. 빙산의 운동에너지는 해저면을 파 나가는 에너지로 변형되고, 그 힘이 평형하게 될 때까지 빙산의 운동은 계속된다.

빙산에 의한 해저면 손상은 극지 해안가의 해저시설물의 설계, 설치, 운용에 중대한 영향을 끼친다. 그러므로, 해저면 손상의 데이타 분석은 해안의 개발과 시설물의 설치에 큰 도움이 된다.

이 논문에서는 8년간에 걸친 약 십만개가 넘는 데이타를 토대로 알라스카 뷰오포트 해안가의 빙산에 의한 해저면 손상의 통계학적인 연구결과를 보여준다. 또한 각 변수의 최대치와 수심에 따른 변수의 최대 경계선을 추정하였고, 변수들의 상호관계를 연구하였다.

1. Introduction

The nearshore seabed where frequency ice features occur is disrupted and modified by ice keels (e.g., keels of ice ridges and ice islands). The ice features create a furrow and ridge microtopography on the seabed. Intense gouging is associatd with ice keels driven by forces amassed from an compassing ice pack.

Ice gouging is especially intense in the stamukhi zone and on the seaward slope of bathymetric highs[1]. Ice gouges have been noted in water depths up to 64*m* in the Alaskan Beaufort Sea. Data

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on the rate and depth of ice gouges is needed for the planning, operation, and design of offshore installations such as pipelines and subsea structures.

The number of gouges, gouge depths, densities, widths and ridge heights as related to water depths are discussed. In addition the interrelationships of ice scour variables are developed for the Alaskan Beaufort Sea.

2. Terminology

The following terminology is used for the quantitative and enumeration of the ice-gouged seabed (see Figure 1).

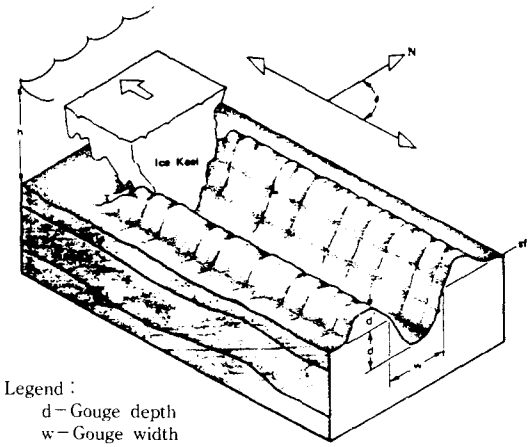

Fig. 1 Schematic diagram of an ice gouge

• Gouge depth : The gouge depth, d, is the vertical depth measured from the average level of the surrounding seabed to the deepest point in the gouge.

• Gouge density : The gouge density is the density of all ice-produced sublinear featured preserved on the seabed ; or is the number of gouges observed for each kilometer of trackline data.

• Gouge width : The gouge width, w, is the horizontal width of the gouge measured at the average level of the surrounding seabed.

• Gouge ridge height : The gouge ridge height is the height of the ridge created when sediments are plowed from the bottom. The ridge height is measured vertically from the undisturbed seabed.

3. Previous Studies

Ice gouge data have been collected in the Alaskan Beaufort Sea since 1970. To study the Arctic seabed, the side-scan sonar and a precision depth fathometer are used by Shearer, et al.[2] and Pelletier and Shearer[3].

Since then, the ice gouge study has been done by Kovacs and Mellor[4], Reimnitz and Barnes[5], Toimil[6], Pilkington and Marcellus[7], Barnes et al.[8], Weeks, et al.[9], Tickne and Toimil[10], and so on. Machemehl and Jo[11] have studied on ice gouge depths and events in the Alaskan Beaufort Sea.

The ice gouge data have been analyzed on :

• nature of gouges,

• characteristics of the ice involved in the gouging process,

• general distribution of gouging along the coast,

• force involved in the ice gouging process, and

• rates of ice gouge recurrence.

4. Mechanics of Scour

Ice pressure ridges are formed when the ice cannot withstand the forces to which it is subjected. Such ridges can form either in the grounded state in shallow water, or free-floating state. In the former type the ice immediately consolidates whereas in the latter type the ice will consolidate after some time. Only consolidated pressure ridges can cause significant scour.

When a consolidate feature (e.g., ice island or pressure ridge) comes into contact with the seabed it will either ground and cease to move, or if the environmental driving forces are sufficient

they can overcome the seabed resistance and plough into the seabed.

5. Data Collection

Over 100,000 gouges data are documented along the Beaufort Sea Coast between Smith Bay and Camden Bay (see Figure 2) from 1972 to 1980 (excluding 1974) by Rearic, Barnes and Reimnitz[12].

The ice gouge data are obtained from high-precision fathograms with resolution of 10*cm* and from side-scan sonar generated sonographs of the seabed. Details and methods involving in extraction information from these records are reported in Barnes et al.[8] and in Rearic et al.[13].

6. Analysis of Data

The ice gouge data are analyzed statistically using the SAS software and VAX/VMS 8800 computer. The overall statistical results are summarized in the Table.

• Number of gouges versus water depths : The number of gouges versus water depths and the upper bound line are shown in Figure 3. The upper bound line envelops more than 98% of the data. A peak of 196 gouges occurs in the 18 to 25*m* water depth range. A preponderance of gouges are found in less than 30*m* water depth while no gouges are recorded beyond 70*m* water depth.

• Gouge depth versus water depth : A preponderance of gouges are found in less than 30*m* water depth. In water depths less than 6*m* and more than 58*m*, maximum gouge depths are less than 1*m*. A peak of 4*m* gouge depht occurs in the 30 to 35*m* water depth range. The gouge depths versus water depths and the upper bound line are shown in Figure 4.

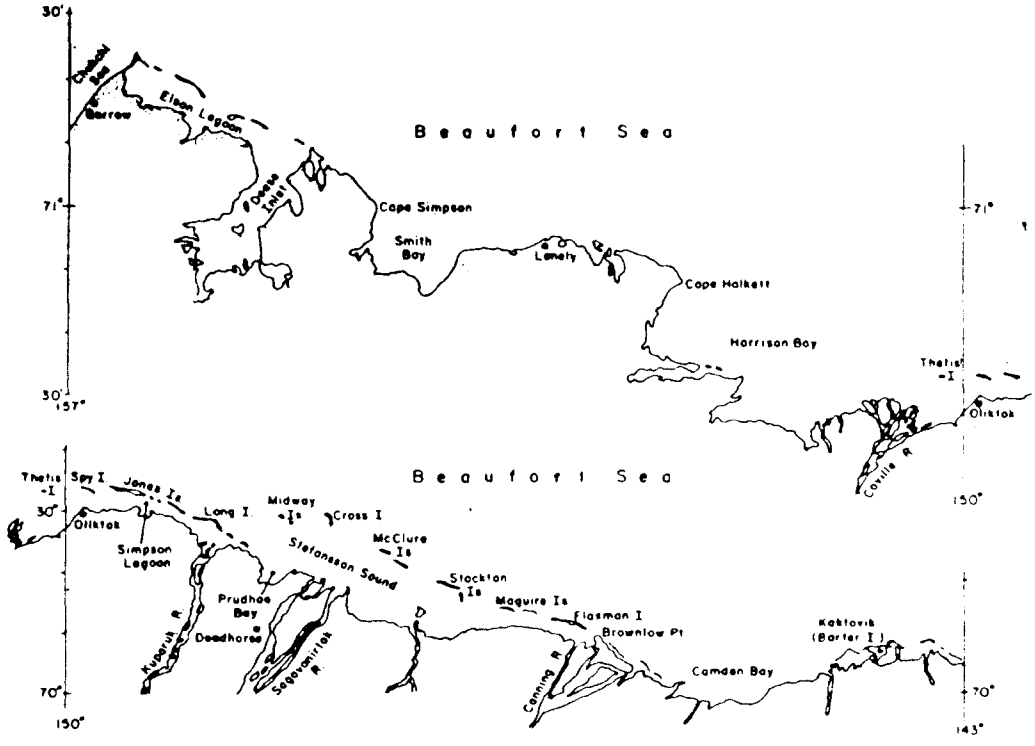

Fig. 2 Survey sites of the Alaskan coastline of Beaufort Sea

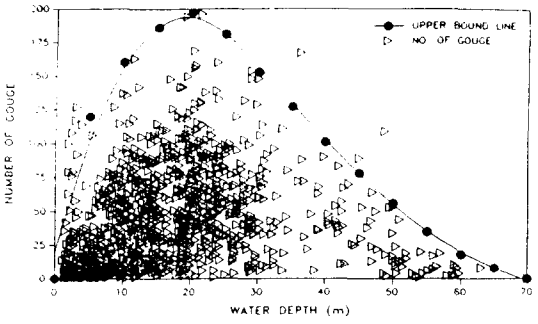

Fig. 3 Number of gouges versus water depth

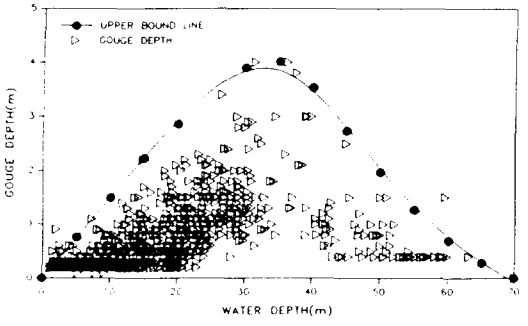

Fig. 4 Gouge depth versus water depth

• Gouge density versus water depth : A peak of 460 gouges per *km* occurs in the 15 to 25*m* water depht range. In water depths less than 1*m* and more than 50*m*, maximum gouge densities versus water depths and the upper bound line. The upper bound line can be used to determine the maximum gouge density for a specified water depth.

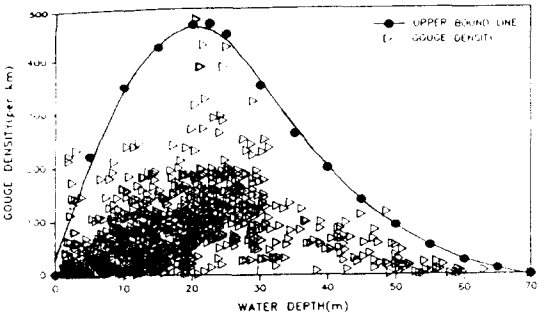

Fig. 5 Gouge density versus water depth

Table 1 Ice gouge statistics

Variable	*Mean*	*S.D.*	*Max*	*Med*
No.	36.91	35.83	196.00	28.00
d(*m*)	0.58	0.59	4.00	0.30
GD	62.83	69.19	481.20	42.00
w(*m*)	7.33	7.50	62.00	5.00
RH(*m*)	0.60	0.94	17.00	0.30

where *Mean* = mean value of variable,
S.D. = standard deviation of variable,
Max = maximum value of variable,
Med = median value of variable,
No. = number of gouges (per water depth),
GD = gouge density (number per *km*), and
RH = gouge ridge height(*m*).

• Gouge width versus water depth : Figure 6 shows the gouge widths versus water depths and the upper bound line. A peak width is 60*m* and occurs in around 30*m* water depth. A preponderance of gouges are found in less than 30*m* water depth. In water depth less than 1*m* and more than 55*m*, maximum gouge widths are less than 10*m*.

• Gouge ridge height versus water depth : A peak gouge ridge height occurs in the 25 to 35 water depth range as shown in Figure 7. The sediment ridge plowed up by an ice keel is generally less than 1*m*.

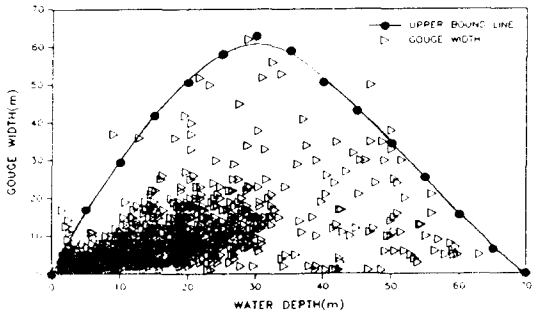

Fig. 6 Gouge width versus water depth

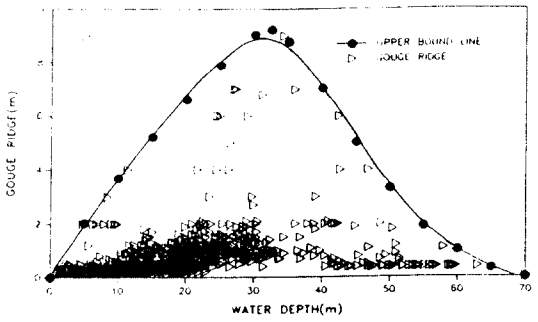

Fig. 7 Gouge ridge height versus water depth

7. Inter-Relationship of Ice Gouge Variables

Based on the upper bound lines of ice gouge variables, the inter-relationships of variables are studied. As shown in Figures 8 to 10, as gouge depth increases gouge width and gouge ridge height increase.

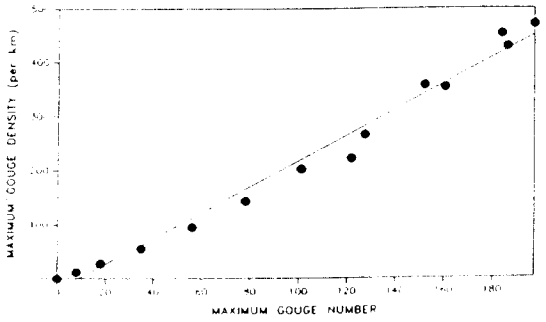

Fig. 8 Maximum gouge density versus maximum gouge number

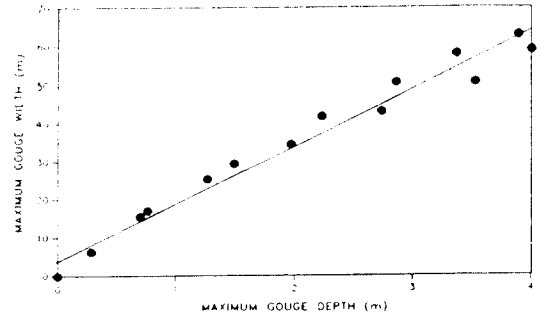

Fig. 9 Maximum gouge width versus maximum gouge depth

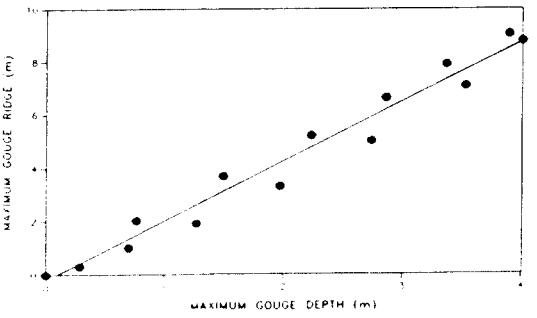

Fig. 10 Maximum gouge ridge versus maximum gouge depth

The equations for the relationships of ice gouge variables are :

$$MDN = -20.81 + 2.39MGN(\rho = 0.99), \quad \text{as } MGN > 20m$$

$$MGW = 3.80 + 15.05MGD(\rho = 0.99), \quad \text{as } MGD > 0.5m$$

$$MRH = -0.22 + 2.24MGD(\rho = 0.99), \quad \text{as } MGD > 0.5m$$

where

MDN = maximum gouge density (per km)
MGN = maximum gouge number (per water depth),
MGW = maximum gouge width (m),
MGD = maximum gouge depth (m),
MRH = maximum gouge ridge height (m), and ρ = correlation coefficient.

8. Conclusion

The relationships of ice gouge variables versus water depths are examined based on a large amount of data. Upper bound lines can be used to predict the maximum values of the variables as shown in Figures 3 through 7. The relationships of the maximum values between variables are shown in Figures 8 through 10. From the linear equations between ice gouge variables, the maximum values of variables can be approxima-

ted.

Despite the variability in geographic, sedimentologic and ice environments of the different tracklines and survey areas, ice gouging occurs ubiquitously in all areas. There are very few deep gouges and a large number of shallow gouges according to the ice gouge data sets. The most intensive gouging is associated with the major ice ridging in the stamukhi zone.

This information can be usefully used to estimate the requisite burial depths of pipelines and under-water equipments in the seabed of Alaskan Beaufort Sea.

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