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In Situ Formation of Stable Foam in Sea Water to Cause Salty Wind Damage (II)

—Wind Transport of Stable Foam Masses—

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Abstract

In the winter monsoon season enormous masses of stable foam are produced along the shore of the Japan Sea in the Tohoku District. Wind action may then disperse the accumulated foam in fragments and carry them inland, and much damage has been caused to the electrical facilities, and to trees and farm products.

In this paper wind transport phenomena and related characteristics of stable foam of sea water were treated using data obtained in situ and in the laboratory. Thus, we have found that the change in the density of stable foam is primarily due to drainage of sea water from the bubble membranes, and that this is given by the formula.

$d=C_1e^{-kt}+C_2$ where d, t, C_1, C_2, and k are respectively density, time and characteristics of the foam.

1. Introduction

In the winter monsoon season enormous masses of stable foam are produced along the shore of the Japan Sea in the Tohoku District. Wave action resulting from the prevailing winds may cause foam accumulations to a depth of one meter or more, which persist for several hours. Wind action may then disperse the foam in fragments and carry them inland. Masses of the foam can attach themselves to electric and telephone lines and cause current leakage. In the past, such interference with the electrical facilities has disrupted the service over a very large area. Considerable damage to trees, farm products and bare metallic surfaces has also been noted. A result of the accumulation of stable foam masses on railroads has been the slippage of train wheels on the tracks. This has been the source of many rail accidents. This type of damage resulting from wind transport of stable foam has been confused with that due to dispersed sea water particles caused by splashing.

One of the authors (T. Abe 1962, 1963) has already reported on the principal cause of the appearance of stable foam in the affected region. The water is rich in surface active substances coming primarily from proteins derived from damaged coastal phytoplankton (mainly a certain type of diatom) and minute fragments of sea weed. It is these protein substances which seem to account for the unusual stability of the foam masses. In this article the physical properties of the stable foam are considered with reference to its transport by the wind.

2. Effect of organic substances on the foaming of sea water

In the following discussion, organic substances refer to the products derived from the plankton and sea weed. What is designated foam powder is the residue obtained from drying of stable foam.

Microscopic examination of the foam liquid shows that it contains large amounts of phytoplankton (a diatom), protein debris from damaged phytoplankton and small pieces of sea weed. Substances diffused from these materials are apparently the surface active agents which stabilize the foam. This is demonstrated by the addition of the foam powder to ordinary sea water with a resulting decrease to between one-half and one-third of the normal value for the surface tension.

The effect of the foam powder upon foaming of sea water has been investigated by use of a shaker apparatus. A constant amount of foam powder was placed in an acrylite ampule containing filtered natural sea water collected at the Fukura Beach. The mixture is then shaken under constant conditions. Upon stopping, the features of the foam layer created by the vibrations are photographed at continuous equal intervals under the illumination of an ultra-high pressure mercury lamp. The results are shown in Table 1.

Table 1. (a) Effect of organic substances on the foaming

Sample	Initial Height of Foam Layer at 20°C (mm)	Decay Const. (k)	Half Life τ (sec)	Foaming Factor ($h_0\tau$)
Sea Water+No-powder	8.53	0.155	2.75	23.5
〃 〃 +0.005 g/101.2 cc	7.08	0.115	4.48	31.7
〃 〃 +0.05 / 〃	8.73	0.000254	273.0	2390.0
〃 〃 +0.08 / 〃	9.10	0.000115	4620.0	41600.0

Obtained by the author et al

As seen in Table 1 (a), the addition of the foam powder definitely alters the foaming characteristics of the sea water. The value of h_0 (initial height of the foam layer) increases significantly. All results are expressed at 20°C. The value of τ (the half life of the foam layer) increases enormously. An addition of 0.05 g of foam powder per 100 c.c. of sea water increases the half life value by about 100 times and 0.08 g of the powder increases the value of τ by 1680 times. *The organic substances contained in the powder have a much greater effect upon the stability of the foam upon the quantity.* It is interesting to note that the value of h_0 is less when a small amount of foam powder (0.005 g) is added than when none is. No adequate explanation can be offered for this curious situation.

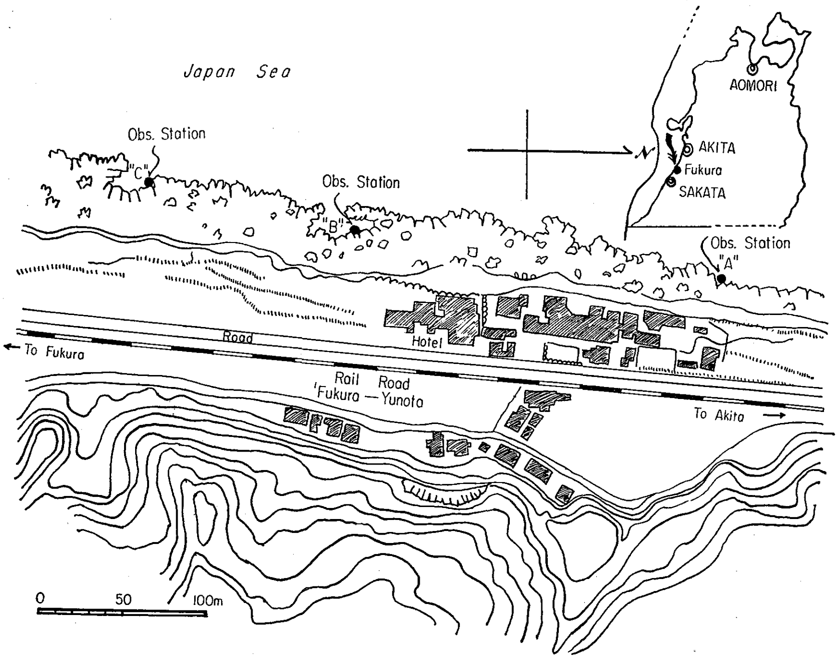

Fig. 1. Map of Location.

Table 1 (b) shows that surface sea water *in situ* contains 0.099 eq.mg/L (equivalent milligrams/L). Foam liquid contains from 100 to 1000 times as much. This indicates that the organic materials have a strong influence on foam stability and are easily absorbed in foam bubble membranes.

Table 1. (b) Organic substance contents of foam liquid (Fukura Beach)

Sample	Time	Date	Appearance	Organic S. Contents
1	1400	25 Jan. 1965	Pale Brown Color	8.55 eq mg/L
2	1400	26 Jan. 1965	Pale Brown Color	8.35 〃 〃
3	1030	28 Jan. 1965	Dark Brown Color	24.0 〃 〃
Surface Sea Water	1030	28 Jan. 1965	Colorless	0.099 〃 〃

Titrated by Dr. Y. Sugiura

3. The in situ production of stable foam and its transport by wind

The processes involved in the *in situ* production and wind transport of stable foam are shown schematically in Fig. 2. First, patches of foam stabilized by organic substances are produced on the water surface by wind stress and resulting wave action. This is referred to as the "production stage". The masses of stabilized foam are gathered together in suitable locations on shore (accumulation stage). Then gusty winds scatter the piled foam masses. Increasing time assists in this

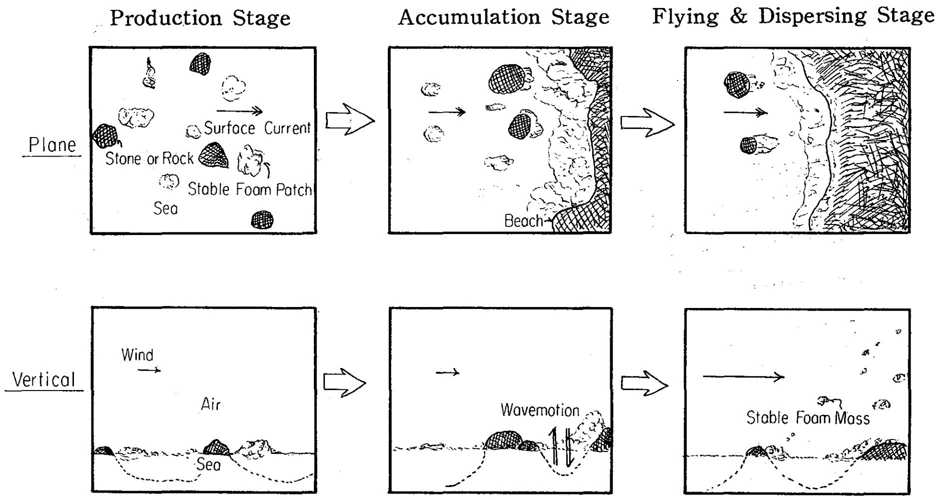

Fig. 2. Schematic Diagram of Stable Foam Production and Flying.

stage since the foam density decreases due to interior liquid flow through the bubble membranes. (See appendix).

Some of the flying foam masses become attached to tail objects near the shore. That power poles offer nice points for accumulation was pointed out above.

The minimum wind velocity necessary to cause inland movement of the foam was investigated. Serial observations for several days during the monsoon season at the Fukura shore showed that the vertical components were, at most, only about one-tenth the strength of the horizontal components. Thus only the horizontal wind movements were monitored. Table 2 shows the probability of movement of foam masses ranging from several centimeter in diameter up to tens of centimeters. The data were too scanty to be conclusive but they indicate that wind transport of the foam masses will invariably occur at velocities greater than 8.25 m/sec. At velocities smaller than 1.4 m/sec such movement rarely takes place.

Table 2. Wind speed at the flying instant and its probability

Wind Speed Range	(median value)	Probability
4.0—4.5 m/sec.	4.25	0.27
4.5—5.0	4.75	0.44
5.5—6.00	5.75	0.67
8.0—8.50	8.25	1.00

4. Changes in horizontal wind velocity (dv/dt) during transport

The record of serial wind observations *in situ* is shown in Fig. 3. Many pieces (>20) of the stable foam masses were transported when the wind velocity (V_t) at time "t" increased to $V_t + \Delta V$. The length of AB is an arbitrary constant. BC

equals ΔV and the arrow AC shows the degree of velocity changes by its slope. From an analysis of the data, the following conclusions were reached:

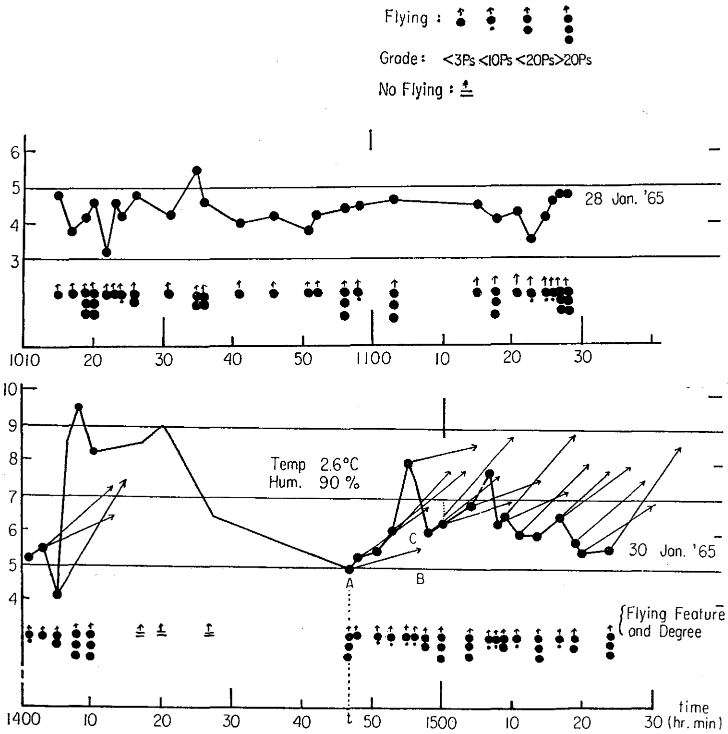

Fig. 3. Flying of Stable Foam Masses of Sea Water (Fukura).

(1) In the case of high velocity winds, a comparatively small increase of wind velocity is required to cause the movement of the stable foam masses. Increments of only 0.5 m/sec in an 8 m/sec wind results in the breaking up and transport of the foam.

(2) In the case of low velocity winds, large increases are necessary to move the foam. A wind speed of 4.0 m/sec must increase by 3.0 m/sec to transport the foam.

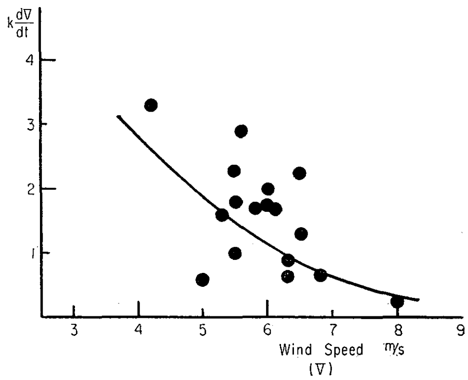

Fig. 4. Flying of Stable Foam Masses of Sea Water (Fukura).

Appendix

Change of density of stable foam

Measurements to determine change in foam density were done with the following apparatus. A transparent (acrylite) box 10×10×10 cm contains the foam sample.

The bottom of the box has many holes 10 mm. in diameter. The box containing the foam sample is suspended vertically from a calibrated spring balance as shown in Fig. 5. From the measured masses of the foam samples, their densities are calculated. The values obtained are plotted in Fig. 5. Density changes are primarily due to drainage of sea water from the bubble membranes. The density change is given by the formula

$d=c_1 e^{-kt}+c_2$, where d, t, c_1, c_2, and k are respectively density, time and characteristic constants of the foam. The terms c_1, c_2 refer especially to the density of the foam after water drainage from the bubble membrane has ceased.

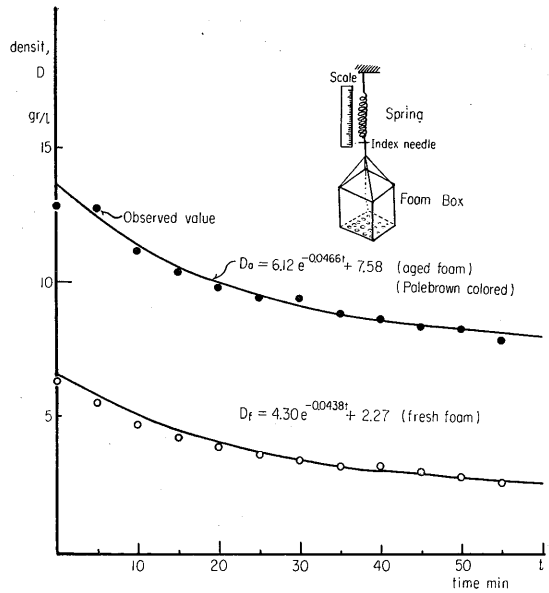

Fig. 5. Change of stable foam density of sea water (Fukura).

Solubility of foam powder in sea water

A saturated solution of foam powder was prepared with the temperature controlled within ±0.02°C. The amount of foam powder was measured by means of a chemical balance. Solubilities were determined within a temperature range of 5.2 –29.8°C. Determination was made at six temperatures with the following results:

Temperature (°C)	Solubility (g/100 cc. sea water)
5.2	0.0445
10.2	0.0335
15.6	0.0250
18.2	0.0100
25.2	0.0190
29.8	0.0145

These data show that solubility decreases with increasing temperature.

Time constant of wind meter

The wind speed meter used in this study to measure wind speed necessary for foam transport was a hot-wire type. Its time constant is a 0.2 to 0.5 sec, giving a time interval (t) indicating 90% of the value of wind speed in situ calculated as follows:

Time constant (sec)	Necessary time (sec)
0.2	0.46
0.3	0.69
0.4	0.92
0.5	1.2

In conclusion, the authors wish to express their thanks to Messrs. S. KOBAYASHI, R. MATSUMURA and A. MOMOSE, who are students of the Tokyo College of Science, and N. SAKAGUCHI for their help in field and laboratory observations. Thanks are also to Dr. Y. SUGIURA of the Met. Res. Inst. for his analysis of organic materials containing in sea water, and to Mr. W. L. RAMSEY of the Navy Electronics Laboratory, U.S.A. for his help and advice in preparing the manuscript.

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塩害の要因としての現場における海水安定泡沫の生成 (II)

海水安定泡沫の風による飛散について

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前報に続き，海水安定泡沫による災害の基礎的問題を述べる。今回は現場海岸にて安定泡沫が生成され，飛散される形態等を調べ，更にこれに関聯して泡沫密度が時間的に如何に変化するか，その機構，又安定化の要因と考えられる海産有機質と安定化状況との関係，尚これら物質の海水への溶解度等についても言及した。次に二，三をあげれば，現場における飛散時の風速と飛散の起る Probability (p) は Table 2 の如く風速 4.0 ~ 4.5 m/sec のとき $p=0.27$，風速の増加と共に p は増加し，8.0 ~ 8.5 m/sec では $p=1.00$ 即ち必ず飛散が起っている。又，飛散に関係する泡沫密度 (d) は次の如く時間 (t) の経過と共に exponential に減少する。即ち $d=C_1e^{-kt}+C_2$，ここに C_1, C_2, k は泡沫に関する常数である。この機構としては，主に泡沫内を海水が drain することによると考えられる。