## CHAPTER 80

# Landward Transport of Spray Generated from a Wave Absorbing Sea Wall

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## Abstract

A landward transport process of spray generated from a wave absorbing sea wall under a strong wind has been investigated experimentally. Near the wall, the concentration of spray decays exponentially both in the leeward direction and in the upward direction. The profiles are determined by the equilibrium between the advection of spray and the sedimentation. The characteristic quantities on the profiles have been related to the experimental parameters.

## 1. Introduction

Extending from August to October every year, Japan often suffers severe damages due to typhoons. In winter, a strong seasonal wind from the northwest blows against coastal areas fronting the Japan Sea. Moreover, Japanese coastal line is exposed to the danger of tsunami disasters because Japanese Archipelago is one of the world's most seismologically active areas. Therefore, most of Japanese coastal engineers and researchers have devoted their energies to the prevention against the coastal disasters due to big waves, storm surges, tsunamis and so on. Various types of wave aborbing works have been developed to protect the coastal areas and have made remarkable achievements.

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Wave absorbing sea wall construction is one of them. In a storm, however, a wave absorbing sea wall generates a large amount of spray in compensation for the effective dissipation of wave energy. If it is transported landward, salt damages are given to the agricultural products or the infrastructural system in the coastal zone. Recently, the human life zone is expanding rapidly in the seaward direction. It also requires that the generation of sea water spray should be reduced from the standpoint of the preservation of atmospheric environments. Several studies have been already made on the generation of water spray and the transport of sea-salt particles. Hayami & Toba (1958) and Toba (1959) observed the generation of spray in the bursting process of air bubbles floating on the water surface, and concluded that the process is essential as a source of sea-salt particles in the atmosphere. Toba & Tanaka (1963) and Toba (1965 a, b) measured sea-salt particles in the atmosphere and demonstrated a good agreement to be seen between the observed results and the theoretical ones. Matsunaga et. al (1994) investigated a transport process of spray generated from breaking waves by using a wave tank equipped with a wind tunnel. They showed that a large amount of spray is separated from the crests of breaking waves and the concentration of spray decreases exponentially in the vertical direction.

However, no studies have been made on the generation of spray from coastal structures in a storm and its landward transport process. In this study, how spray occurring from a wave absorbing sea wall is transported landward has been investigated experimentally.

## 2. Experimental methods

Experiments were carried out by using a wave tank, which is equipped with an inhalation-type wind tunnel (see figure 1). The tank

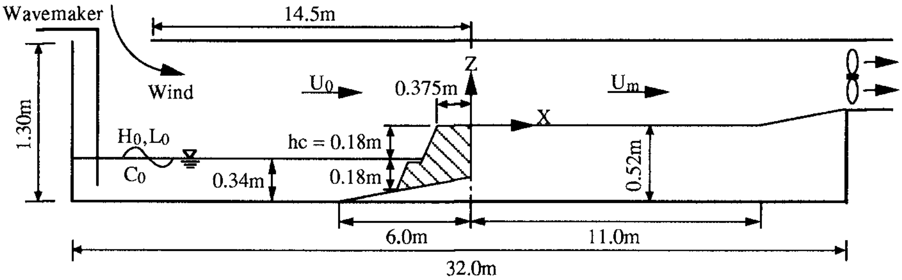


Fig. 1 Schematic diagram of experimental set-up.

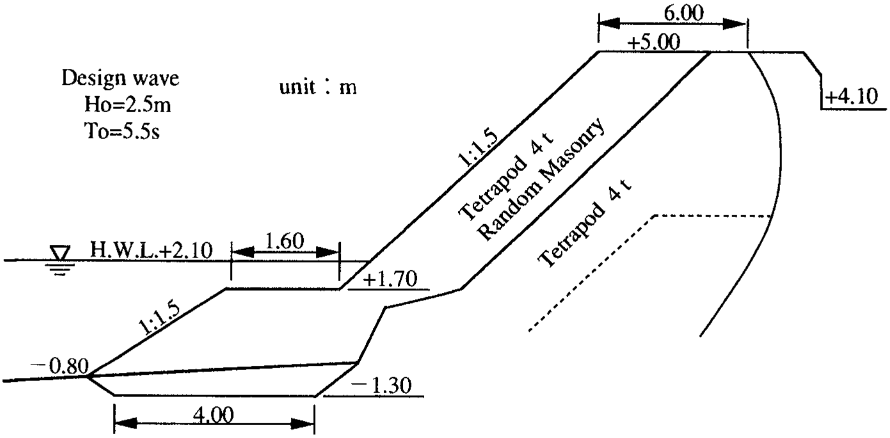


Fig. 2 Cross section of wave absorbing sea wall.

Table 1 Experimental parameters and characteristic quantities of spray concentration profiles.

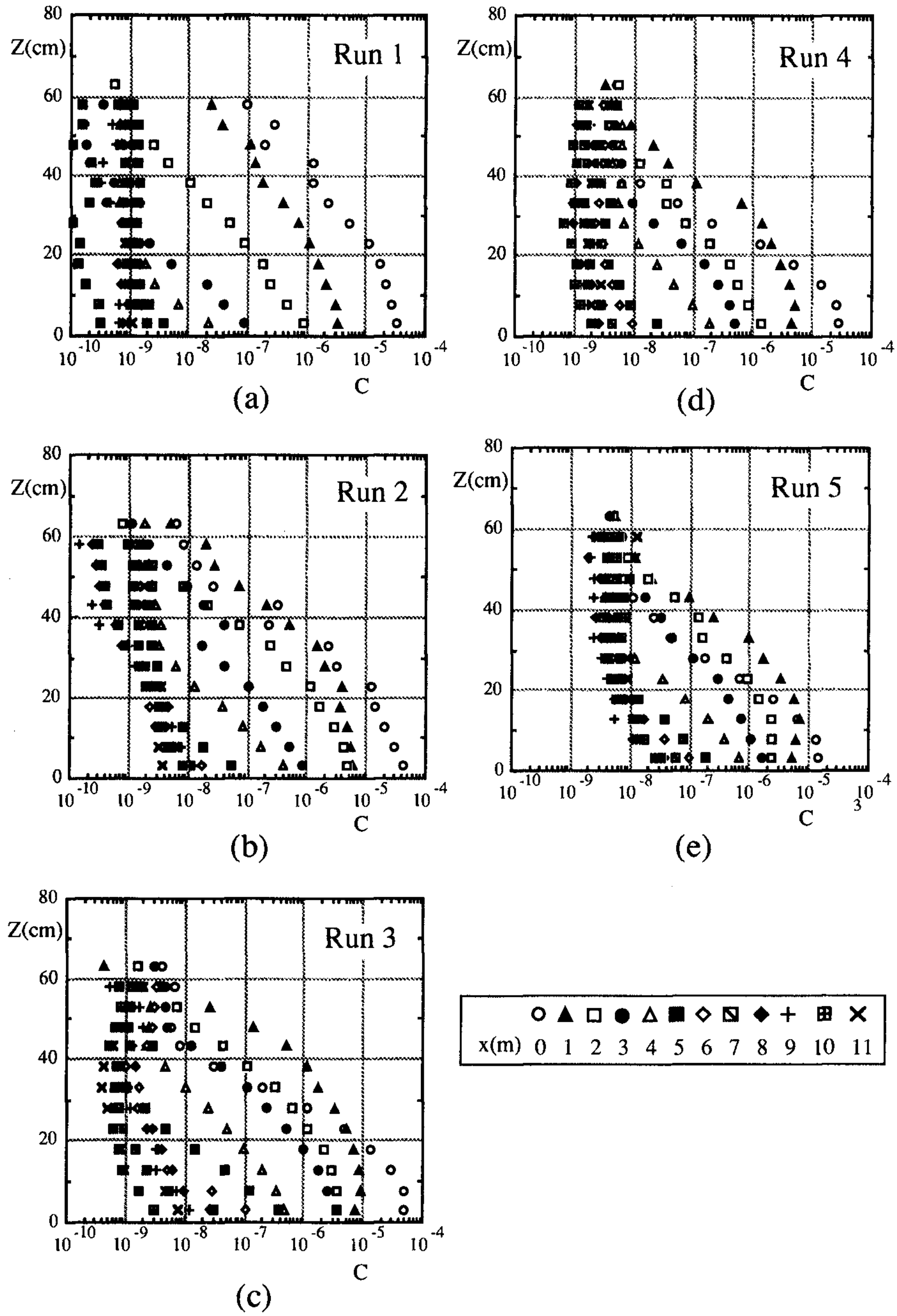
| | Experimental Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Run | T(s) | $H_0$(cm) | $L_0$(cm) | $C_0$(m/s) | $U_0$(m/s) | $U_m$(m/s) | $H_0/L_0$ | $U_0/C_0$ | $h_c/H_0$ |
| 1 | 1.38 | 14.3 | 295 | 2.14 | 9.43 | 11.9 | 0.048 | 4.41 | 1.27 |
| 2 | 1.38 | 14.3 | 295 | 2.14 | 13.1 | 16.6 | 0.048 | 6.12 | 1.27 |
| 3 | 1.38 | 14.3 | 295 | 2.14 | 15.1 | 19.1 | 0.048 | 7.06 | 1.27 |
| 4 | 1.20 | 11.7 | 225 | 1.88 | 13.1 | 16.6 | 0.052 | 6.97 | 1.55 |
| 5 | 1.20 | 11.7 | 225 | 1.88 | 15.1 | 19.1 | 0.052 | 8.03 | 1.55 |

| | Characteristic Quantities | | | |
|---|---|---|---|---|
| Run | $\bar{l}$(cm) | $\bar{l}/h_c$ | C(0,0) | $w_0/U_m$ |
| 1 | 7.52 | 0.42 | 9.03E-5 | 1.37E-1 |
| 2 | 5.48 | 0.30 | 8.58E-4 | 9.37E-2 |
| 3 | 5.28 | 0.29 | 1.08E-3 | 8.03E-2 |
| 4 | 6.69 | 0.37 | 6.01E-4 | 1.26E-1 |
| 5 | 5.96 | 0.33 | 1.00E-3 | 9.83E-2 |

was 32 m long, 0.6 m wide and 1.30 m high. A wave absorbing sea wall, which is constructed at Beppu Port in Oita Prefecture, Japan, was used as a model. Figure 2 shows its cross-section and dimensions. The sea wall is covered with randomly piled 4 t-Tetrapod blocks. The gradient of the wall surface was 1 : 1.5. In the experiments, the scale of the wall was reduced to 1/16. The mean water depth was set at 0.34 m. The crown height $h_c$ was 0.18 m. As a model of land, a 11 m solid bed was attached horizontally to the back of the wall model. Five tests were made by varying wave parameters and wind velocity (see table 1). Two types of regular waves were made by a wavemaker. Their periods T were 1.38 s and 1.20 s. The wave heights in deep water $H_0$ were 14.3 cm and 11.7 cm. The wave parameters $L_0$ and $C_0$ are the wavelength and the wave velocity in deep water, respectively. $U_0$ is the cross-sectionally averaged wind velocity above the water surface and $U_m$ is the one above the horizontal bed. The values of $U_0$ were varied from 9.43 to 15.1 m/s. The coordinate axes x and z were taken leeward and vertically upward from the back of the wall model, respectively. Water spray was captured by using cylindrical containers filled with cotton. They were 3.0 cm in diameter and 5.0 cm in depth. The vertical profiles of spray quantity were obtained by setting the containers at 5.0 cm vertical intervals. The measurements were made at 1.0 m horizontal intervals in the range of x=0 m to 11 m. The descriptions about the characteristic quantities $l$, C(0, 0) and $w_0/U_m$ shown in table 1 will be given in the next section.

## 3. Results and discussion

Figures 3 (a) to (e) show how the vertical profiles of spray concentration C vary in the leeward direction. The values of C are calculated from $C = q / \rho U_m$, where q is the mass of spray transported per unit area and time, and $\rho$ the density of water. The concentration decreases exponentially with the increase of z and approaches to a constant value. As spray is transported in the leeward direction, the concentration decreases rapidly near the bed surface and the vertical profiles become uniform. It means that relatively large spray distributing at the back of the sea wall precipitates rapidly during the advection. On the other hand, very small spray remains to be suspended in a region far away from the wall. Therefore, the equilibrium between the advection of spray and the sedimentation may be essential near the wall and the advection-diffusion equilibrium may determine the concentration profiles far away from the wall. A typical profile of spray concentration is drawn schematically in figure 4, and the characteristic quantities are defined. The spray concentration at z=0, i.e., C(x, 0), is estimated by extrapolating from the data in the exponentially decaying region. The characteristic length scale $l$ is defined as a height at which the spray concentration takes the value of C(x, 0)/e. $C_*$ is defined as a spray concentration at a large value of z and $z_*$ is the height where C becomes nearly equal to $C_*$. It is unsuitable to examine experimentally the spray concentration in the



(a) (b) (c) (d) (e)

Fig. 3 Leeward variation of vertical profiles of spray concentration.

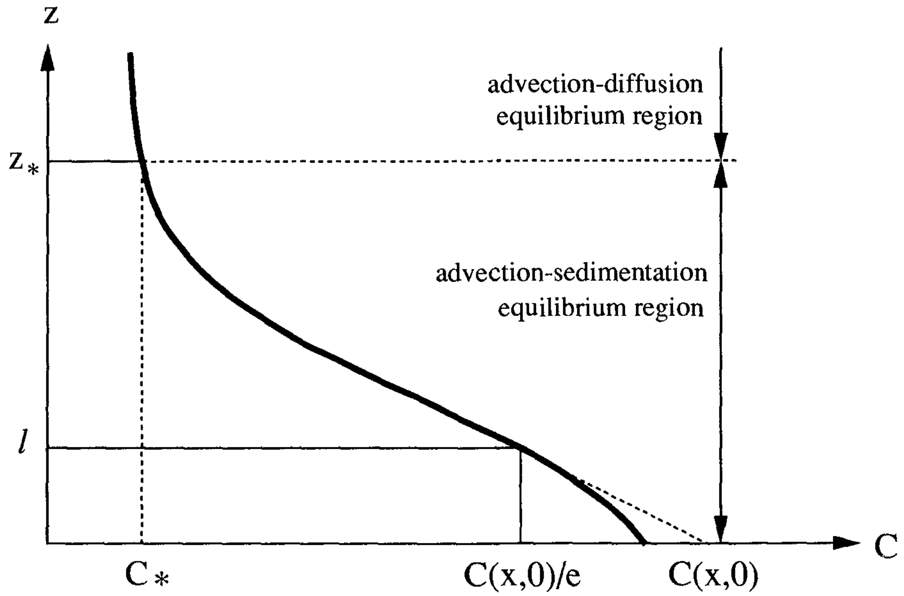


Fig. 4 Typical vertical profile of spray concentration and definition of characteristic quantities.

advection-diffusion equilibrium region because the concentration depends strongly on the height of the wind tunnel. Therefore, the characteristic quantities of C* and z* are not discussed here. In the advection-sedimentation equilibrium region, the equation of the spray concentration is given by

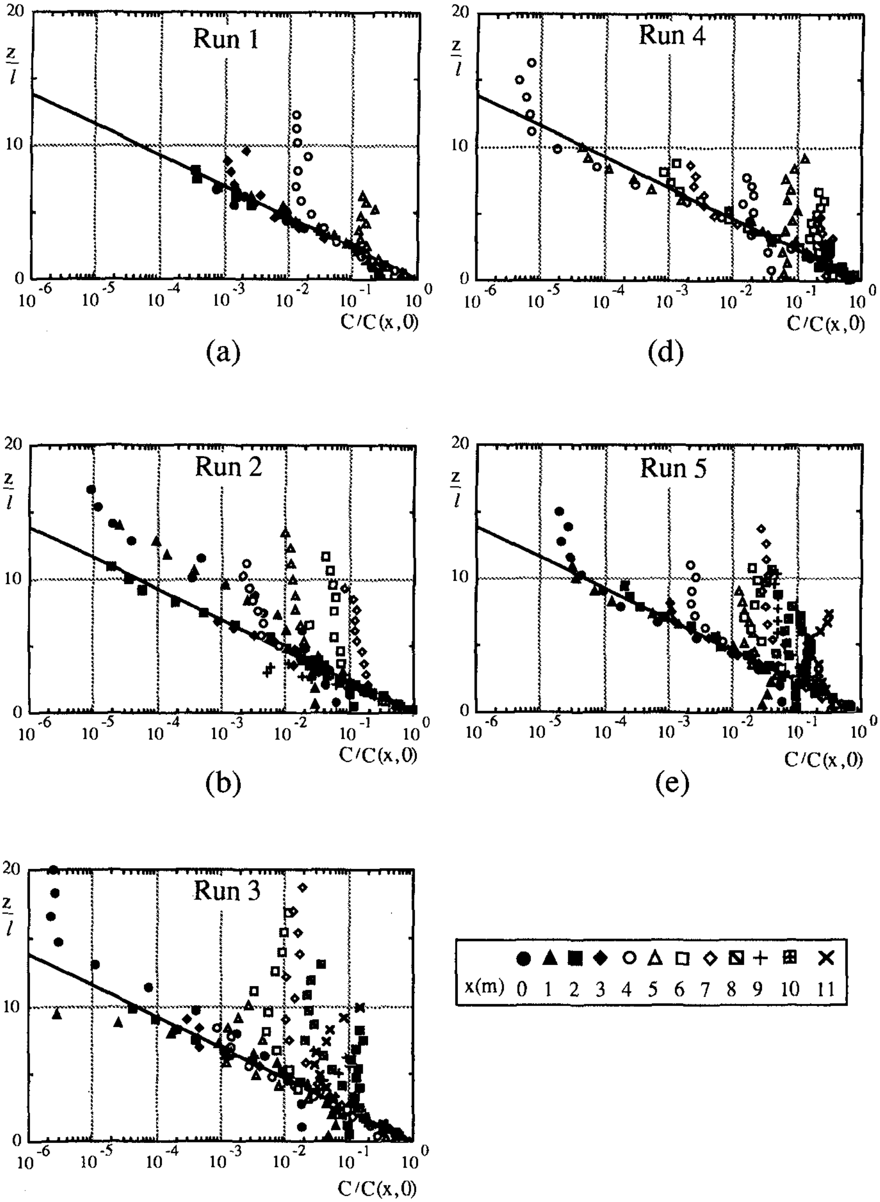
$$U_m \frac{\partial C}{\partial x} - w_o \frac{\partial C}{\partial z} = 0 . \tag{1}$$

Here, it is assumed that the distribution of the spray concentration is steady and the settling velocity of spray $w_o$ is constant. By assuming

$$C(x, z) = C(x, 0) \exp\left(-\frac{z}{l}\right), \tag{2}$$

we obtain

$$C(x, 0) = C(0, 0) \exp\left(-\frac{w_o}{U_m}\frac{x}{l}\right) \tag{3}$$



(a) (d)

(b) (e)

(c)

Fig. 5 Normalized profiles of spray concentration.

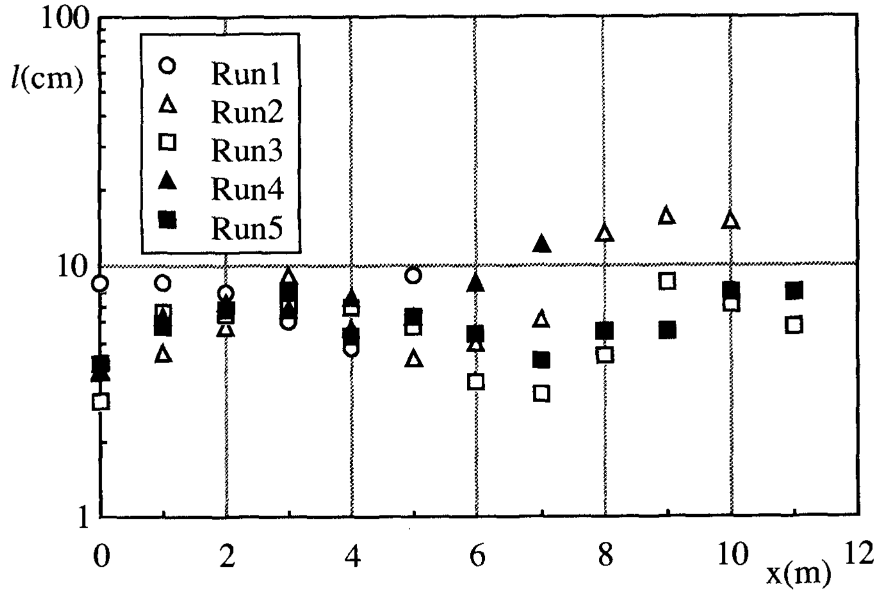


Fig. 6 Dependence of $l$ on x.

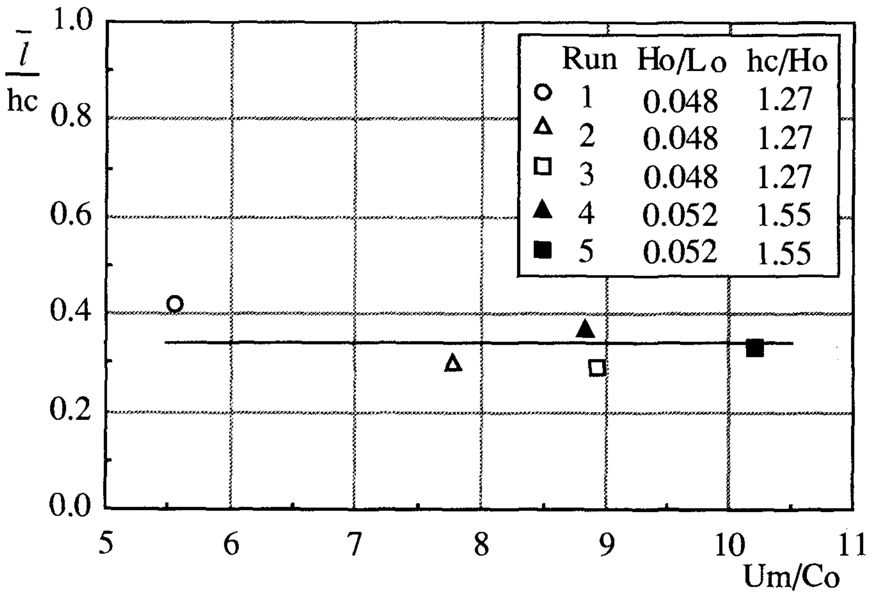


Fig. 7 Relationship between $\bar{l}$ / $h_c$ and $U_m/C_o$.

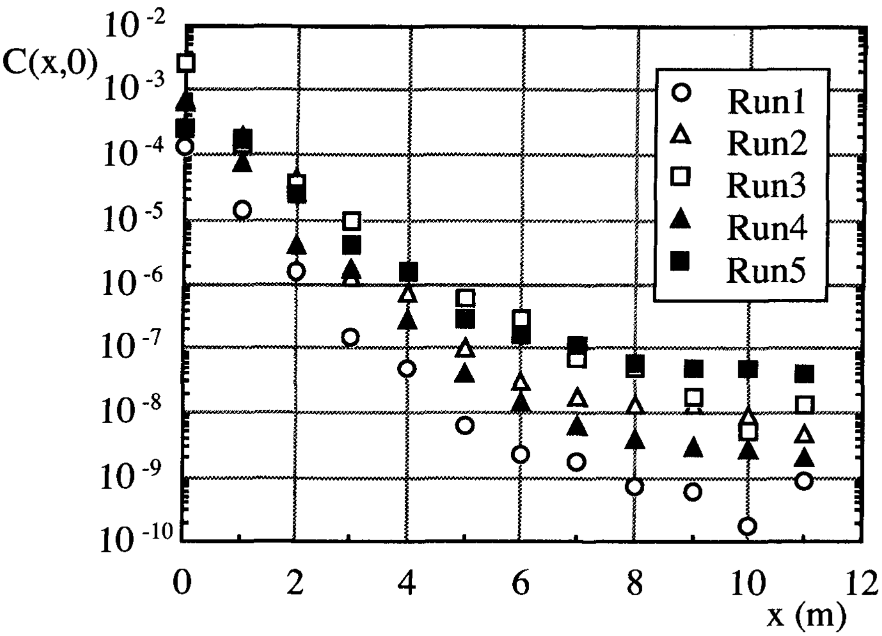


Fig. 8 Dependence of C(x, 0) on x.

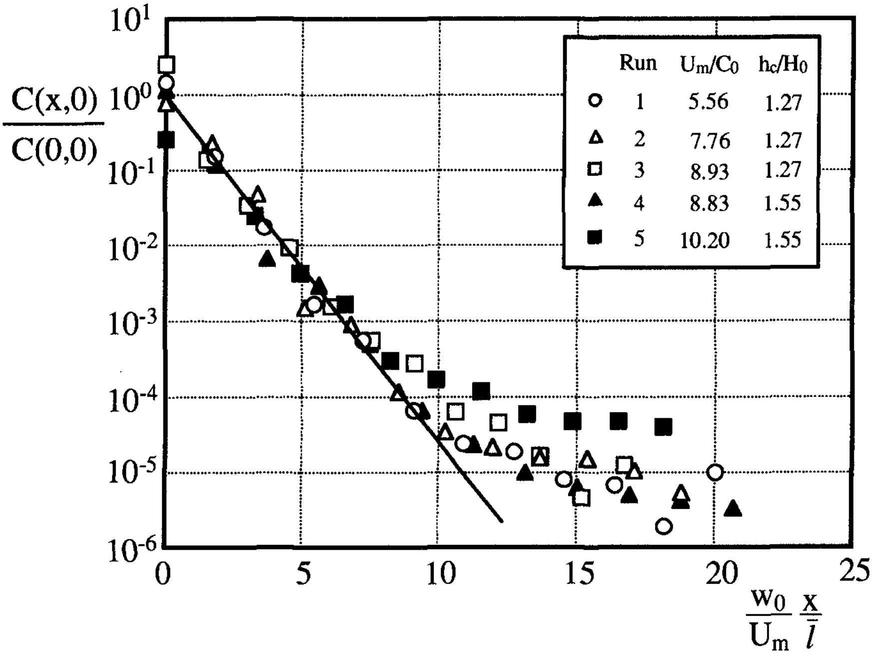


Fig. 9 Normalized profiles of C(x, 0).

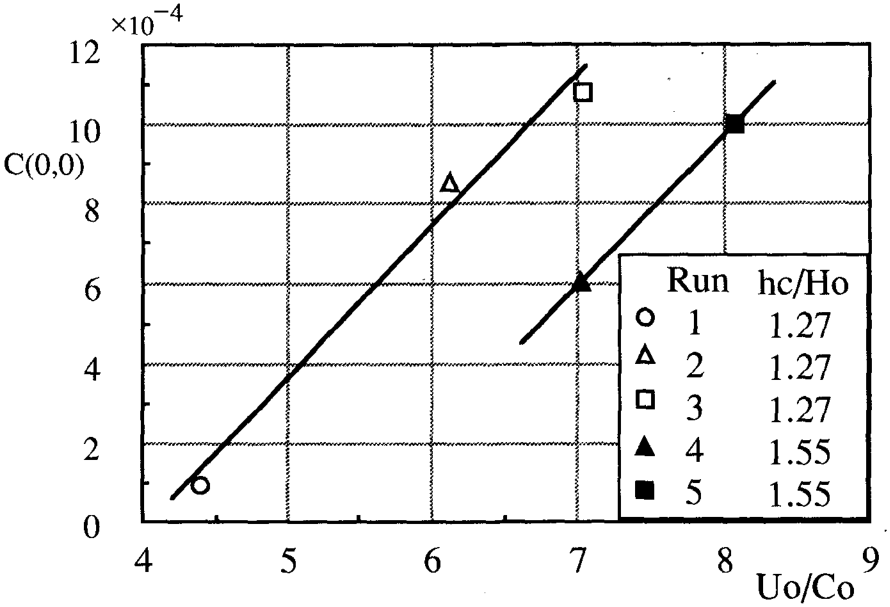


Fig. 10 Relationship between C(0, 0) and $U_o/C_o$.

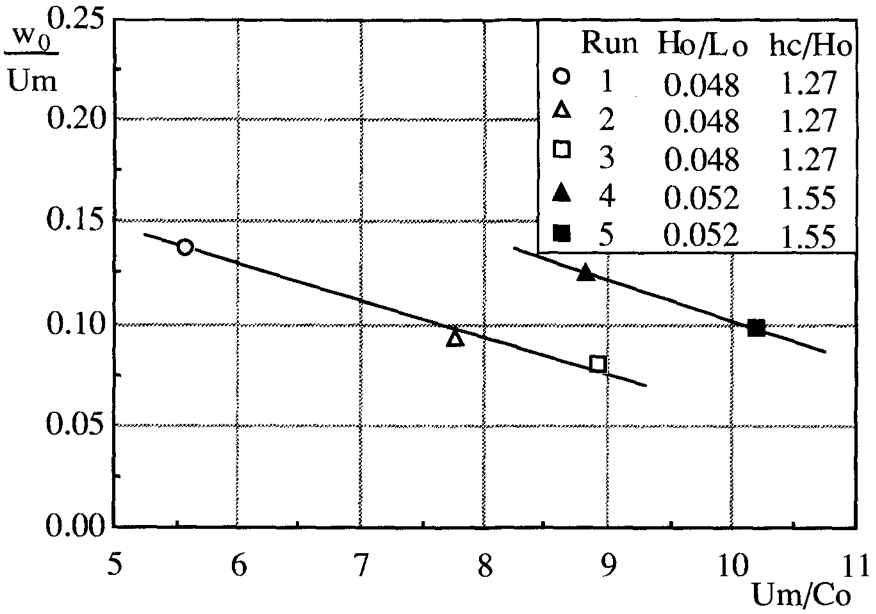


Fig. 11 Relationship between $w_o/U_m$ and $U_m/C_o$.

The values of $C(x, 0)$ and $l$ can be estimated by fitting equation (2) to the experimental data shown in figures 3 (a) to (e). In figures 5 (a) to (e), the data are normalized by using the obtained values. The data plotted above the solid lines are relatively uniform in the vertical direction and belong to the advection-diffusion equilibrium region. It is seen that the exponentially decaying region becomes narrow as the increase of x.

Figure 6 shows the dependence of $l$ on x. Though some variation is seen, it is very small in comparison with the 11 m horizontal advection. Therefore, the values averaged in the leeward direction $\bar{l}$ are given in table 1. The values of $\bar{l} / h_c$ are plotted against $U_m/C_o$ in figure 7. The values of $\bar{l}$ are approximately given by $0.35\, h_c$.

The relationship between $C(x, 0)$ and x is shown in figure 8. Near the sea wall, $C(x, 0)$ decreases exponentially in the leeward direction. It is seen, therefore, that the relationship given by equation (3) is compatible with the data. The decreasing rate becomes small with the increase of the wind velocity. On the other hand, $C(x, 0)$ takes large values with the increase of the wind velocity. The values of $C(x, 0)$ approach to constant values in the region far away from the sea wall. We can estimate the values of $C(0, 0)$ and $w_o/U_m$ by fitting equation (3) to the data and using the values of $\bar{l}$ . The obtained values are given in table 1. Figure 9 shows the profiles normalized by using $C(0, 0)$ and $w_o/U_m\ \bar{l}$ . It is seen that $C(x, 0)$ decreases exponentially in the range of $\frac{w_o}{U_m}\frac{x}{l} \leq 10$.

Figure 10 shows the relationship between $C(0, 0)$ and $U_o/C_o$. The values of $C(0, 0)$ increase with the increase of $U_o/C_o$. In the case when the relative crown height $h_c/H_o$ is large, it is seen that $C(0, 0)$ takes small values. Figure 11 shows the dependence of $w_o/U_m$ on $U_m/C_o$. The tendency is seen that $w_o/U_m$ decreases with the increase of $U_m/C_o$ and large spray is transported as the wave steepness increases.

## 4. Conclusions

In this study, the quantity of spray generated from a wave absorbing sea wall under a storm and its landward transport process were investigated experimentally. The obtained main points are as follows.

1) Near the sea wall, the spray concentration is determined by the equilibrium between the advection of spray and the sedimentation.

2) The spray concentration near the sea wall decreases exponentially both in the vertically upward direction and in the leeward direction.
3) The spray concentration on the horizontal bed decreases exponentially in the region of $\frac{w_o}{U_m}\frac{x}{l} \leq 10$.

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