CHAPTER 209

FUNCTION OF SAND FENCE PLACED IN FRONT OF EMBANKMENT

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ABSTRACT

In order to find the optimum sand fence porosity and the best position for placing a sand fence in front of an embankment, a series of experiments were conducted in a large wind tunnel. The results obtained were that a fence with 40 % or 50 % porosity should be placed at a distance between 15 H and 20 H in front of the embankment, where H is the fence height.

I INTRODUCTION

Sand fence are often employed to control wind-blown sand. However, the characteristics of sand fences are not well understood. The reasons why the characteristics of sand fences have not yet been entirely clarified are that (1) the air flow around the fences is governed by the Navier-Stokes equations and the equations are difficult to solve in practical problems, and (2) the mechanisms that govern the air flow near the sand surface and the interaction with the surface itself, which is constantly changing due to accumulation or erosion, are not clear. Therefore, the function of sand fences has mainly been studied through experiments performed in the field or the wind tunnels. Recently Hotta et al. (1987) made a comprehensive literature survey on the function of sand fences. The review summarized the operational characteristics of sand fences and provided specific guidelines for their use.

Recently in Japan, expressways have been constructed along the coastline. Also, to protect conservation

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forests or residential and cultivated land from coastal disasters such as tsunami, storm surge or contamination by wind blown sand, embankments are often constructed along sandy beaches. Wind-blown sand often intrudes beyond these embankments and contaminates conservation forests and residential and cultivated land. Sometimes wind-blown sand accumulating on the expressways will prevent vehicles from passing. Sand fences are often placed in front of the embankments to interrupt the wind-blown sand. In order to find the optimum fence porosity and the best position for the fence in front of the embankment, a series of experiments were conducted in a large wind tunnel. The purpose of this paper is to describe the results of the experiments. Because of the space limitation, results obtained from a mobile sand bed experiment will be described. A description of results concerned the wind flow field will defer to a future paper.

II EXPERIMENTAL FACILITY AND PROCEDURES

2.1 Experimental Facility

Experiments were carried out using a blow-off type wind tunnel with a cross-section that was 1.1 m high and 1.0 m wide, and with a length of 20 m belonging to the Central Research Institute of Electric Power Industry. The experimental section was located at a segment of the tunnel from 14 m to 18 m from the upstream end. On the top of the tunnel in the segment, a 4-cm wide groove wide was cut along the center line in the direction of the wind. Small rails were laid along to the groove with a spacing of 20 cm for carrying an anemometer array and a profile indicator for measuring changes in the sand surface elevation.

Wind speed was measured with an array of hot-film anemometers consisting of fifteen anemometers. An amplifier unit of anemometer equips A-D converter itself and changes data into RS232C signal. Data were transferred to a personal computer and recorded on a floppy disk. The sampling frequency was 10 Hz.

For visualizing flow patterns around the fence, a smoke tube with a 5-mm diameter having a funnelled-shaped mouth with 1-mm diameter was employed.

In order to measure changes in the sand surface elevation, a profile indicator developed especially for this study and modified from the indicator commonly employed in sounding the sea bottom topography in wave tank experiments was used. The output from the indicator was recorded with an open-reel type digital data recorder, simultaneously monitoring the signal with a chart recorder.

The sand used in the mobile-bed experiment was taken from a natural beach having a median diameter of 0.3 mm and a uniformity coefficient of approximately 1.7. The uniformity coefficient is defined as d_{60}/d_{10} where d is the grain size and the subscript denotes the cumulative percentage. More information on the sand characteristics are given in Horikawa et al. (1983).

2.2 Model Fences

The model fences employed in the experiments were slat-type fences made of small pieces of wood. Each slat had a thickness of 2 mm . The porosity of the fence, which is defined as the ratio of space area to total projected area, was changing by varying the width of the slats while keeping a constant gap of 2 mm between the slats, i.e., widths of 2 mm, 3 mm, 5 mm, 8 mm and 18 mm gave 50 %, 40 %, 28.5 % (hereafter this porosity is referred to as 30 % for convenience), 20 %, and 10 % fence porosity. The slats were glued to horizontal slide bars that were 5 mm in width. Therefore, porosity of 10, 20, 30, 40 and 50 % correspond to 9, 18, 25, 36 and 44 %, respectively if definition is strictly followed. The height of the fence was 9 cm on the fixed-bed experiments for measuring the wind speed field. The height of the fence on the mobile sand experiments was 12 cm, but the

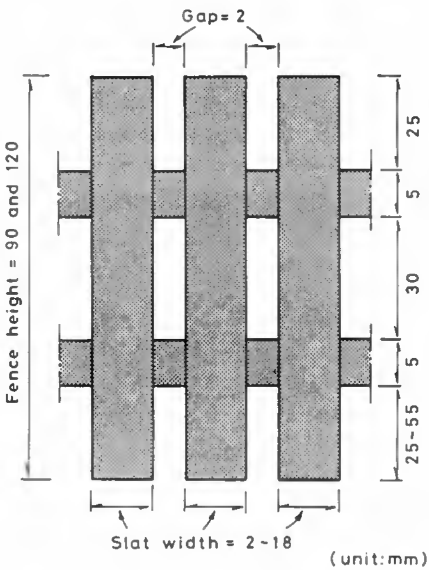

Fig. 1 Dimensions of the model fence.

lower 3-cm part of the fence was buried in sand implying a 9-cm effective height as in the fixed-bed experiments. Figure 1 shows the dimensions of the model fence.

2.3 Experimental Procedures

At first, the flow patterns were observed by using smoke tubes and the wind speed field was measured by an anemometer array on the fixed surface glued sand grains, which were used in a mobile bed experiment. After completing the experiments with the fixed sand surface, the bed was replaced by a mobile bed. Then, experiments on a mobile sand bed were carried out in the order as follows:

(1) Experiments for fences with 0, 10, 20, 30, 40 and 50 % porosity on a flat bed without an embankment.
(2) Experiment for an embankment without fences.
(3) Experiment for fences with 20, 30, 40 and 50 % porosity with an embankment, varying a fence position at 5 H, 10 H, 15 H and 20 H in front of embankment.

The sand surface change was measured by the profile indicator. The measurements of sand surface elevation were made a time interval of 10 min and the experiment duration was 60 to 90 min, depending on the specific run.

In the mobile bed experiments, the vertical distribution of the wind speed was measured at the elevation 10, 20, 35 and 50 cm at a location of 14 m from the upstream end on the tunnel.

Figure 2 shows the model beach and locations of fence placed.

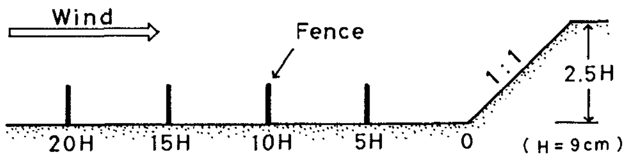

Fig. 2 Model beach and employed location of the fence.

III RESULTS AND DISCUSSION

3.1 Vertical Distribution of Wind Speed on the Fixed Sand Surface

Figure 3 shows an example of the vertical distribution of the wind speed on the fixed sand surface measured without a fence and an embankment. A logarithmic velocity distribution provided a satisfactory description. Attempts were mode to keep a constant wind speed of 9.8 m/sec at the reference point throughout the experiments. However, some experimental errors occurred. The shear velocities calculated from the measured vertical distribution in the runs ranged from 41 to 45 cm/sec with an average value of 43 cm/sec, which gave a wind speed of 9.8 m/sec at the reference point.

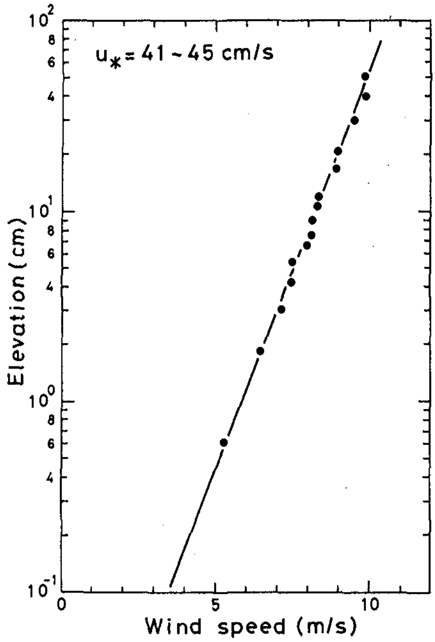

Fig. 3 Vertical distribution of wind speed on a fixed bed.

3.2 Sand Trapping Efficiency of Porous Fences

Figure 4 shows the time evolution of the sand accumulation around porous fence. For the 60 % fence, no experiment was conducted become it was inferred from the wind reduction conditions around the fence that the sand trapping ability would be low. In Fig. 4, the undulation of initial sand surface is vertically exaggerated since the horizontal distance is reduced by 1/14.5 compared to the vertical distance (figures are drawn at a scale of 1/1.1 in the vertical direction and 1/16 in the horizontal direction).

The time evolution of the sand accumulation is quite different depending on the fence porosity. Sand is mainly accumulated in front of the fence for the 0, 10, 20 and 30 % porosity fence. In contrast, sand is accumulating at a high rate behind the 40 and 50 % porosity fence. Sand was rapidly accumulating during the early stage of the experiments but with time elapsed the rate

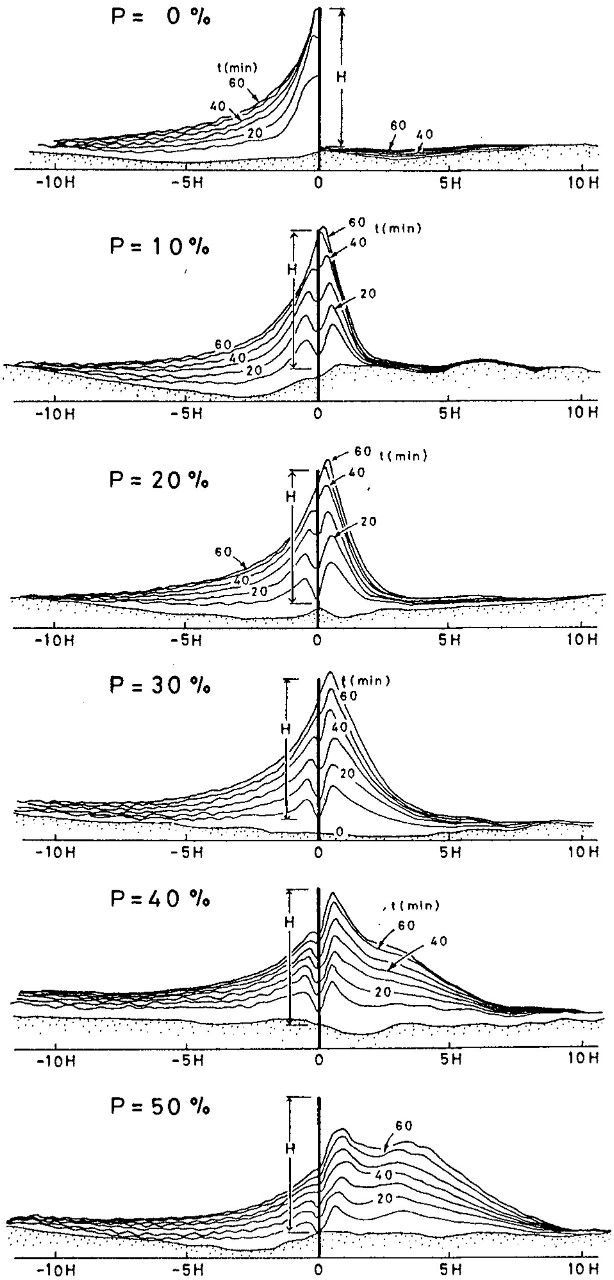

Fig. 4 Time evolution of the sand accumulation.

of accumulation was reduced. The small depression in the sand surface at the fence position caused by local scour due to the accelerating wind passing through the fence gaps, and the scour disappeared when the fence was buried to about 80 % of its height as seen for the 10, 20 and 30 % porosity fences. Also, the rate of sand accumulation rate became considerably smaller when a fence was buried at this stage of the experiment. That is, the sand fence practically looses its sand trapping function when the fence is buried to about 80 % of its height.

A lowering of the sand surface was observed at the downwind area from a distance around 15 H behind fence, although no figure are shown here. This is probably due to the fact that sand is not conserved for this region. The fence trapped sand coming from the updrift side and the amount of sand flowing into the area was smaller than the amount flowing out from the area. As a result, the sand surface in the area was lowered.

A dune was formed immediately behind the fence and Figure 5 shows the growth of the dune crest taking the initial sand surface as the zero elevation. Figure 5 shows that among the five porous fences tested the fence porosity for which the dune crest grew most rapidly was 20 %.

As seen from Fig. 4, almost all of the sand accumulated in a region defined by a distance of 10 H in front and behind the fence. Figure 6 shows the accumulated sand volume with elapsed time. The sand volume was determined as the cross-sectional area measured on the

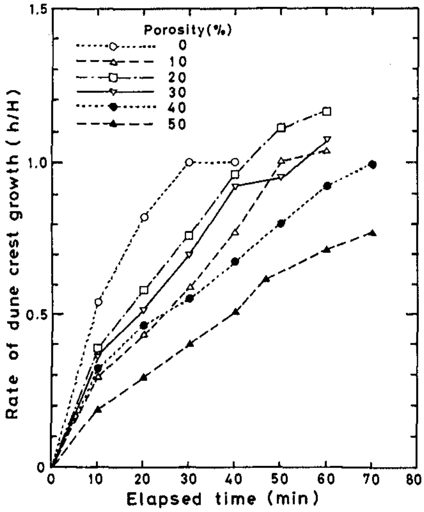

Fig. 5 Dune crest growth rate with elapsed time for different fence porosity

distorted figures as described before. The ordinate gives the distorted area. Figure 6 shows that for a fence porosity of 40 % a large amount of sand accumulates rapidly. Thus, with respect to the fence porosity. The porosity of 40 % may be considered to be the optimum fence porosity. Fences with 20 % and 30 % porosity trapped nearly equivalent volumes of sand, although the shape of the sand accumulation was different.

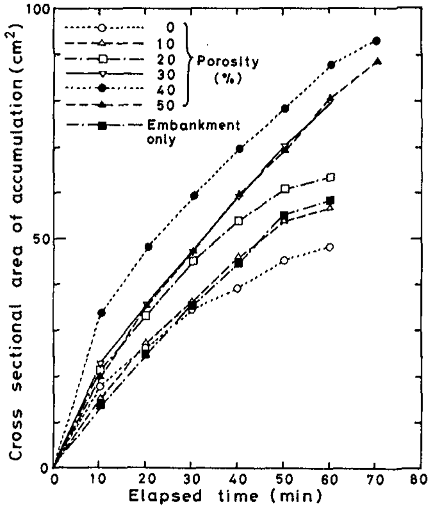

Fig. 6 The time evolution of the sand accumulation for different fence porosity.

3. 3 Sand Accumulation in front of an Embankment

Figure 7 shows the time evolution of the sand accumulation in front of the embankment. Sand is mainly accumulated in a region extending from the foot of the embankment to a location 10 H in front of the embankment.

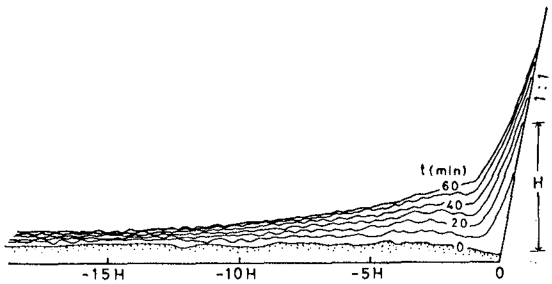

Fig. 7 Sand accumulation in front of an embankment.

The sand accumulation in this region is almost equivalent to the 10 % porosity fence (see Fig. 6). From the experimental results it may be concluded that a 40 % or 50 % porosity fence should be placed at locations ranging from 15 H to 20 H in front of the embankment if rapid sand accumulation is expected in front of the embankment. Otherwise, for low rate of sand accumulation a low porosity fence (10 % or 20 %) should be placed in front of the embankment.

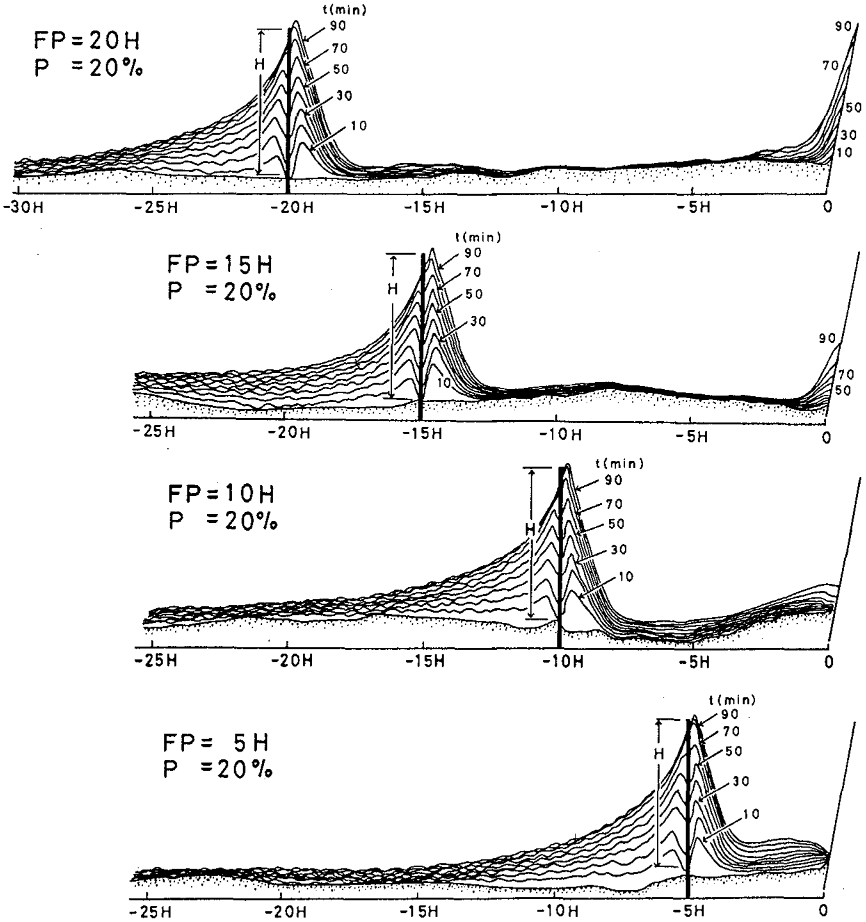

Fig. 8(a) The time evolution of the sand accumulation around fence placed in front of an embankment (P=20%).

3.4 Sand Accumulation in front of an Embankment with a Fence

Figure 8 shows the time evolution of the sand accumulation for the 20, 30, 40 and 50 % porosity fencesplaced at the locations 5 H, 10 H, 15 H and 20 H in front of the embankment. It is difficult to determine the optimum location from these figures. Figure 9 displays a comparison of the cross-sectional area of accumulated sand in the region extending from 10 H in front of the fence to the foot of the embankment. The cross-sectional area was measured with a planimeter on the distorted figures (the ordinate is given as the distorted

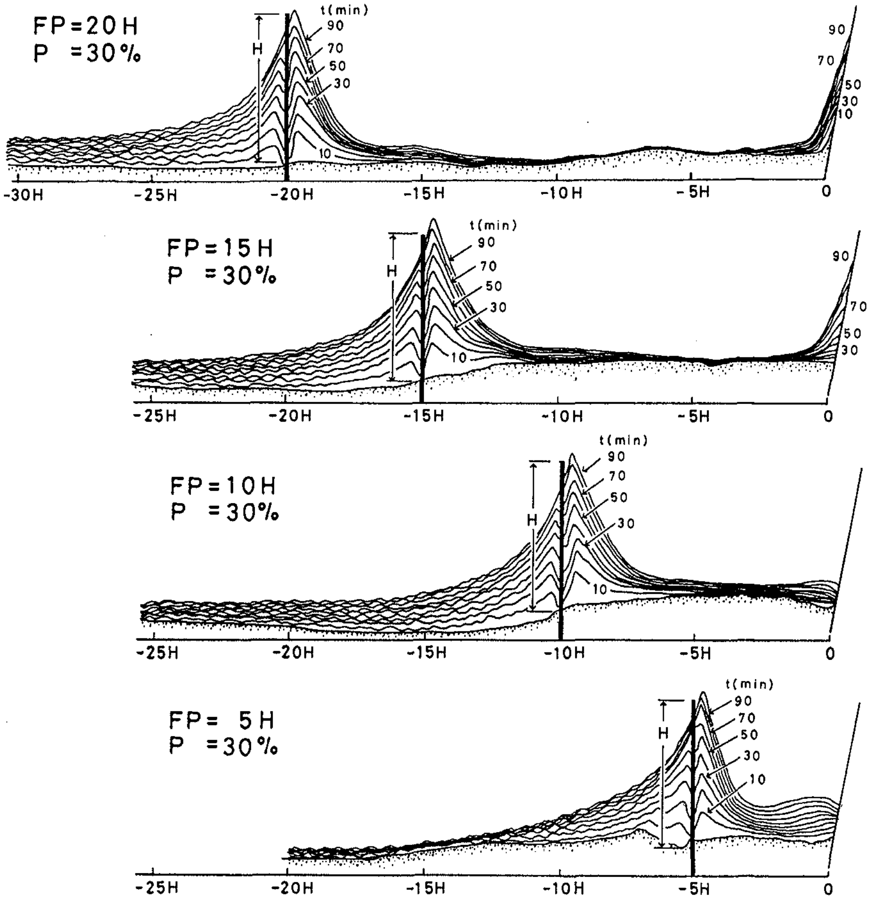

Fig. 8(b) The time evolution of the sand accumulation around fence placed in front of an embankment (P=30%).

area). In Fig. 9, there is a tendency that the sand accumulation was the largest when the fence was placed at a location of 15H, although a fair amount of scatter in the data is seen.

3.5 Sand Weight Transported beyond the Embankment

Figure 10 shows a comparison among different porosity of the sand weight transported beyond the embankment for the 90-min experiment duration. The amount of sand transported beyond the embankment was different during each stage of the experiment depending on the conditions in front of embankment. However, the fences with 20 %

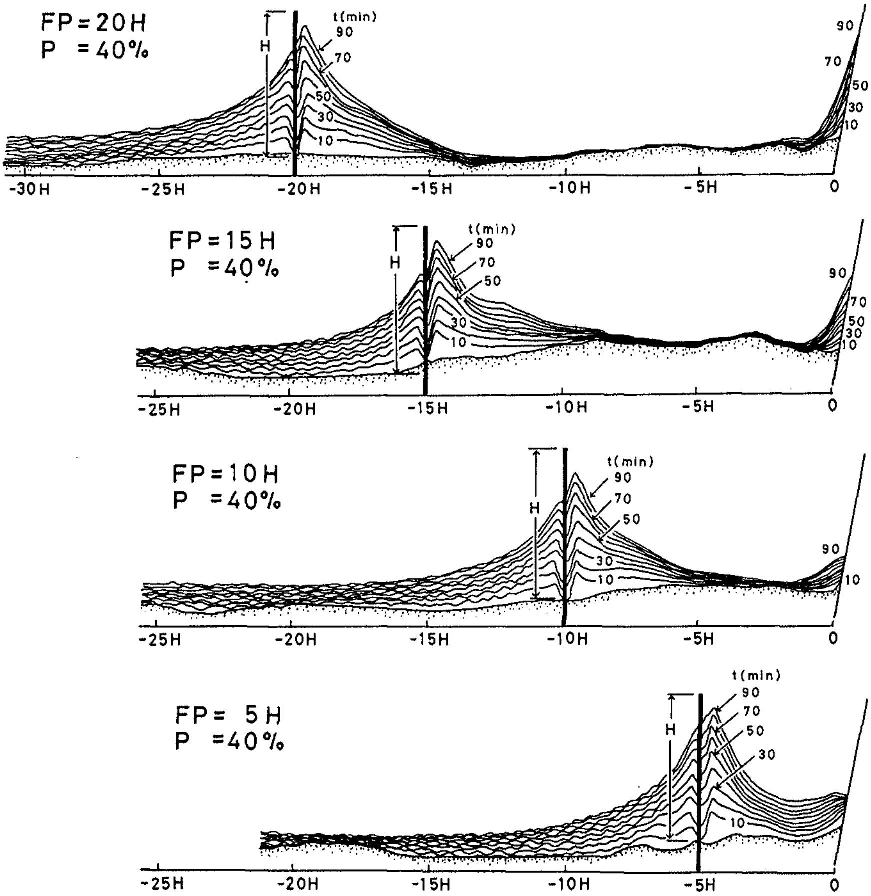

Fig. 8(c) The time evolution of the sand accumulation around fence placed in front of an embankment (P=40%).

and 30 % porosity were completely buried at every location during the entire experiment and the fence with 40 % and 50 % porosity were buried to more than 60 % of its height. If it is assumed that the fences have lost their sand trapping function at this stage, the transported sand weight shown in Fig. 10 may be used as an index todetermine a suitable location for the fence. The amount of sand transported was small when fences with 40 % and 50 % porosity were placed at locations of 15 H or 20 H in front of the embankment. This is an important conclusion for the present research work.

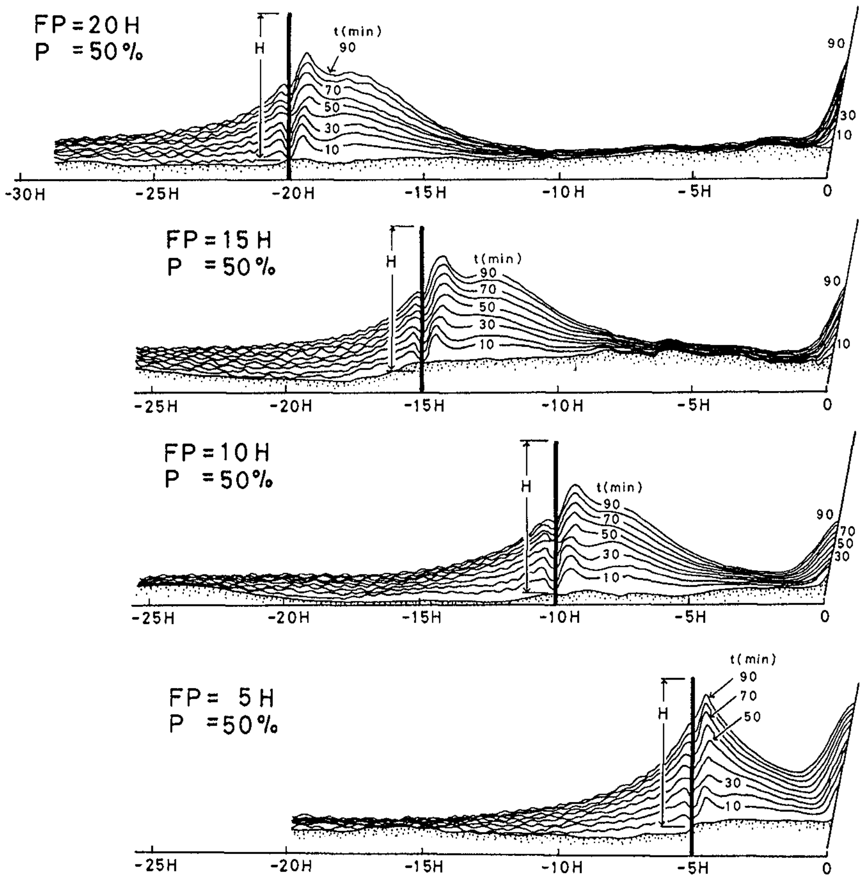

Fig. 8(d) The time evolution of the sand accumulation around fence placed in front of an embankment (P=50%).

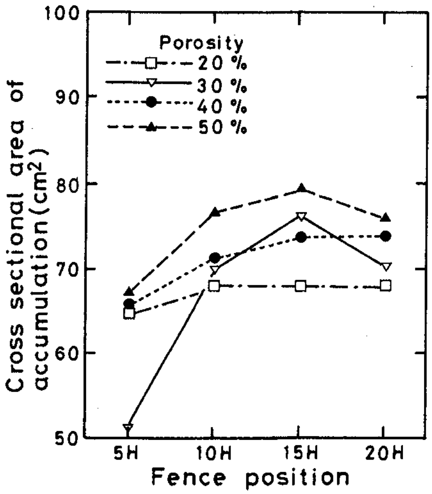

Fig. 9 Cross-sectional area of accumulated sand as a function of fence porosity and position.

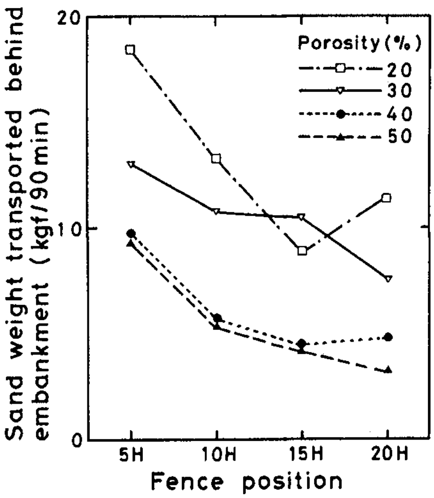

Fig. 10 Sand weight transported beyond embankment as a function of fence porosity and position.

IV CONCLUSIONS

The results obtained in this study may be summarized as follows:

1. The fence porosity for which sand accumulated most rapidly in large quantities was 40 %.
2. The fence porosity which produced the most rapid dune

crest growth was 20 %.

3. The fences lost their sand trapping function if they were buried to 80 % of their height.
4. Sand accumulated in a region extending from 10 H in front of the fence to the foot of the embankment, and the maximum accumulation occurred when the fence was placed 15 H in front of the embankment.
5. The amount of sand transported beyond the embankment was small when the 40 % and 50 % porosity fences were placed at a distance of 15 H or 20 H in front of the embankment.

Based on the above observations, the overall conclusion of this study is that, for controlling wind-blown sand in front of the embankment, a fence with 40 % or 50% porosity should be placed at a distance between 15 H to 20 H in front of the embankment.

Finally, some comments regarding the experiments should be given. This experiment was a distorted model experiment where the wind speed and sand employed were prototype-scale. The fence height was about 1/10 of a prototype-size fence which commonly has a height of 1 m (about 3 ft). Scale effects are anticipated during the experiments, although it is not possible to evaluate how the scale effects influenced the results. The wind speed employed in this experiment was of moderate strength commonly encountered on natural beaches. Sand accumulations characteristics around fences are different depending on the wind speed, especially for wind speed over 15 m/sec, requiring further studies in future. The wind blowing in the field is irregular in time and space. These facts must be kept in mind when the results obtained in this study are applied to field condition.

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