CHAPTER 324

COUNTERMEASURES AGAINST WIND-BLOWN SAND ON BEACHES

--- A short summary of the present state-of-the-arts and introduction of new methods ---

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and
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Abstract

Characteristics and functionings of prevention works for wind-blown sand are briefly reviewed and discussed. Then, guidelines for their use are given. In addition, new prevention works, including trench, movable porous sand fence, and large-scale sand ripples, are proposed according to the result of recent research.

I. Introduction

One of the important problems in beach stabilization is how to control wind-blown sand. Typical problems concerning blown sand are preservation and promotion of the growth of dunes, prevention of channels, inlet and river mouth closure, protection of residential and cultivated land from contamination by sand, and so on. Many kinds of works for preventing blown sand have been employed all over the world. However, no general criteria or technical standards for the use of prevention works exist at present. Therefore, the main objectives of this study are to summarize the operational characteristics of prevention works for wind-blown sand and to provide specific guidelines for their use.

Attempts are made (1) to systematize and classify prevention works for wind-blown sand according to their functioning, and (2) to evaluate conventional prevention works. In addition, (3) new prevention works are proposed according to studies recently carried out.

II. Functioning and Classification of Prevention Works for Wind-Blown Sand

Prevention works for wind-blown sand might have the following two functions: one is to restrain and stop the generation of blown sand, and the other is to trap the blown sand at the upwind side and to store the blown sand at a given location so that it is not transported further downwind. Hereafter, in short for later convenience, the former function will be known as a restrain function and the latter

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function as a trap and fixation function. If a prevention work has a perfect restrain function and can fully stop the generation of blown sand, the work does not need the trap and fixation function. However, it is usually difficult to perfectly stop the generation of blown sand by using a certain prevention work which has the restrain function. It may be expensive or it may prevent an effective use of the beach if we intend to completely stop the generation of blown sand. In such cases, it may be recommendable from an engineering point of view to employ a prevention work which has the trap and fixation function at the downwind site while it may permit the generation of blown sand by decreasing the restrain function, which could be done through changing the kind of prevention work used or downsizing the scale of the prevention work.

The restrain function can be provided by the following methods. One method is to increase the resistance force to the wind which acts on the sand surface and sets sand grains on the surface into motion as blown sand. Another method is to decrease the wind speed that acts near the sand surface to a level so that the sand grains can not begin to move. Examples of methods for increasing the resistance force of the sand surface are spraying water (fresh or salt) or coagulant on the surface and replacement of surface sand. To decrease the wind speed (or the shear stress) that acts on the sand surface, methods to be considered are placing fences, planting shrubs or trees, and covering by grass, nets or mats in order to shut off the wind from direct action on the sand surface.

Two cases are considered for the trap and fixation function. The first case is the forced trap and fixation function that traps coercively blown sand in the air without changing of the basic motion of the sand grains and brings them to rest. The second case involves trapping or bringing to rest the blown sand grains by means of decreasing the wind speed. Cases that catch blown sand grains with streamer-type traps or adhere blown sand grains to a plate coated by an adhesive are considered as cases where the forced trap and fixation function acts. However, it is not possible to trap and store a large amounts of sand by these methods. Thus, these methods can not be employed for engineering use. Another case is where blown sand grains strike a fence stretched by a net with a small mesh and with a high porosity, where the porosity is defined as the ratio of open space area to total projected area, drop and come to rest at the foot of the fence. In this case, we may think of the fence as having the forced trap and fixation function because the fence does not disturb the wind flow and the motion of the sand grains in the air significantly. Such a fence can be applicable for engineering use since the fence can be constructed easily. A trench (which will be described in Section IV) several meters wide and deeper than 1 m can trap almost all blown sand (nearly 100 % of the total amount) without disturbing the wind field (Horikawa *et al.*, 1984). The trench stops coercively the motion of sand grains in the surface creep and saltation at the upwind tip of the trench. Therefore, we may regard the trench as having the forced trap and fixation function. However, inside the trench the wind speed becomes low and sand grains dropped into the trench come to rest. Thus, the trench also has the function of trapping sand by reducing the wind speed.

Prevention works which have the trapping function by reducing the wind speed are fences, foredunes (artificial embankments), planting shrubs, conservation forests for wind-blown sand, artificial large-scale sand ripples, and movable porous fences.

An attempt to systematize and classify the prevention works according to their functioning is given in Fig. 1. In Fig. 1, the prevention works involving trenches, artificial large-scale sand ripples, and movable porous fences are those proposed by the present authors for future use, and they are described in more detail in Section IV.

The prevention works normally employed have both the functions of restrain and of trap and fixation, although some prevention works only have either the function of restrain or trap and fixation. Therefore, the fundamental rule for employment of prevention works is to use more than one type of works, considering the conditions for the generation of blown sand and the general purpose of the works, aiming for the works to perform both functions as effectively as possible.

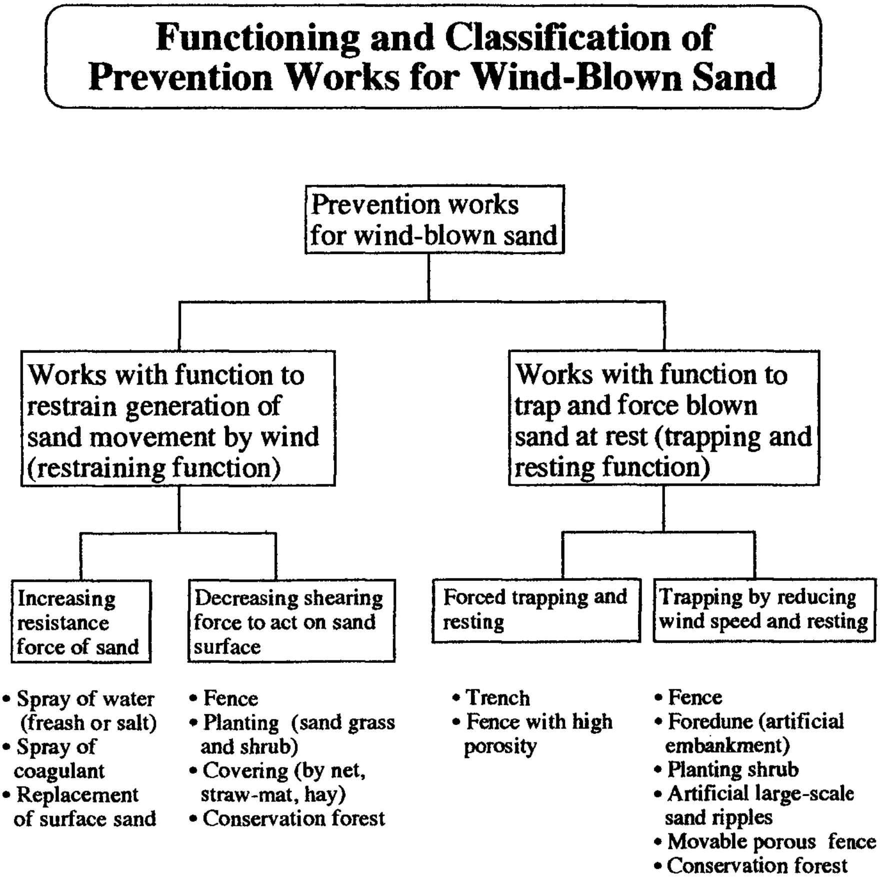

Fig. 1 Functioning and classification of prevention works for wind-blown sand.

III. A Brief Summary of Operational Characteristics and Guidelines for Use of Prevention Works

The prevention works commonly employed worldwide are sand fences, foredunes (including artificial embankment quickly constructed by earthmoving machines), vegetation (planting sand grass or shrubs), and coastal conservation forests. The characteristics and guidelines for practical use of these prevention works are briefly summarized in the following sections.

III.1 Sand Fence

The sand fence is the most commonly employed prevention work throughout the world. Many types of sand fences of varying shape and materials have been designed and employed adapting to the local conditions. The characteristics and guidelines for practical use of sand fences are relatively well understood. Hotta, Kraus and Horikawa (1987) made a critical review of the literature about single row sand fences. They summarized its characteristics and gave guidelines for practical use.

In the guidelines they gave it is recommended to use fence with material of wooden plate, fern, reed, brush, and bamboo which rapidly decompose, expecting that the sand fence will be left in the accumulated sand after the fence is buried. However, if the sand fence is used as a collecting device to interrupt the blown sand intruding into residential area or cultivated land, and if it is planned to remove the accumulated sand for long-term use, it is recommended to use long-life fabrics or metal as the fence material.

For multi-row sand fences, Hotta, Kraus, and Horikawa (1991) also gave a review that concerned the forming of foredunes. Studies regarding multi-row sand fences are limited and many of these studies are not explaining the functioning well. Hotta *et al.* (1992) found important facts about two-row sand fences by means of a wind-tunnel study. The experiment showed that the fence placed downwind would not function to collect blown sand until the fence placed upwind was buried and lost its collecting ability when two-row fences were placed at intervals shorter than $10H$, where H is the height of the fence. This means that two-row fences have no advantage when it comes to collecting blown sand. However, experiments carried out by Manohar and Braun (1970) showed that multi-row sand fences were effective when the wind was strong. Further studies are needed to understand the characteristics of multi-row sand fences and this should be done in the near future.

III.2 Foredune (artificial embankment)

In order to control blown sand, formation of a dune by means of repeated employment of sand fences has been carried out for a long time. The dune formed is usually called a foredune. However, at present formation of a dune is often carried out quickly by using earthmoving machines, and vegetation work is used on the dune surface. A dune formed artificially by construction machines is normally called an artificial embankment.

It is often assumed that the function of a foredune or artificial embankment is almost the same as a non-permeable solid fence. But, the dune has a certain crown width and slopes on both the upwind and downwind sides. Thus, the foredune probably has a somewhat different function from the non-permeable fence. Figure 2 shows a schematic illustration of the wind flow field and sand accumulation characteristics around an artificial embankment. The wind speed profile in the vertical direction begins to distort at a location A affected by the existing embankment. A domain where the wind speed is reduced is formed at the foot of the embankment (around a location B). However, at the upper part of the front slope, the wind will accelerate and the wind speed at the front shoulder of embankment C becomes around 1.2 - 1.8 times of that if no embankment exists. A large circulation cell is formed downwind of the embankment. The wind profile will recover at a location F because of energy supplied from the upper layer. A foredune can catch and store a large amount of blown sand in the wind-reduced domain at the foot, if the foredune is sufficiently high. However, sand is transported beyond the foredune when the wind-reduced domain is filled up by the trapped sand and the storage capacity is lost.

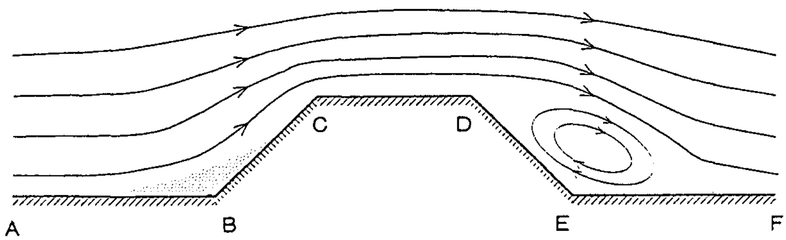

Fig. 2 Schematic illustration of the flow field around an embankment.

There is also a possibility that sand is transported beyond the foredune when the surface of the front slope is bare or paved with some hard material. This can be explained by considering the sand grain motion. A large portion of the sand is transported in a mode of saltation. The sand grains which fall on the hard slope surface can rebound easily and continue the saltation motion. During their stay in the air, sand grains in saltation are accelerated by the wind, and the possibility for the motion to continue increases. Then, sand grains may eventually reach to the top of the foredune. When the surface of the front slope is vegetated by grass or shrubs, the vegetated surface can stop the motion of sand grains and store the grains in the space of the vegetation body. The foredune (or artificial embankment) can control the blown sand as long as the foredune does not lose its storage capacity at the foot and the vegetation on the front slope surface is not buried. Studies concerned with the function of the foredune or embankment for controlling blown sand are limited. Figure 3 shows an example of equi-ratio curves of wind speed reduction in front of an embankment from an experiment by Hotta and Horikawa (1990a). Figure 4 shows the sand accumulation process in front of an embankment under the wind condition corresponding to Fig. 3 (Hotta and Horikawa, 1990b). Note that the scales in the vertical and horizontal directions are not the same in Figs. 3 and 4 and that the figures are distorted.

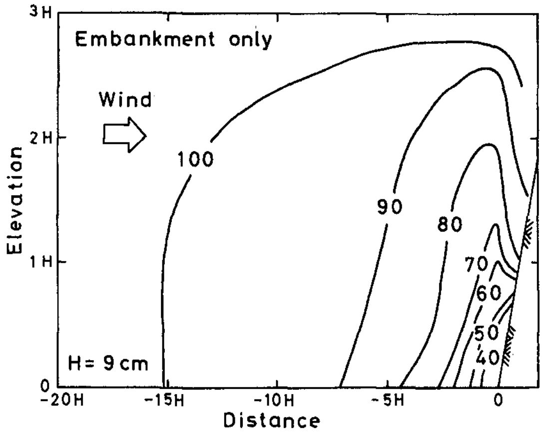

Fig. 3 Equi-ratios curves of wind speed reduction in front of an embankment.
(After Hotta and Horikawa, 1990a)

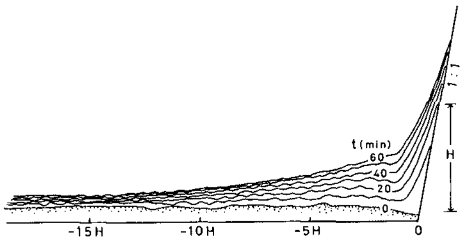

Fig. 4 The sand accumulation process in front of an embankment.
(After Hotta and Horikawa, 1990b)

III.3 Vegetation Work

Vegetation is one of the most popular prevention works for controlling blown sand and it has been employed all over the world from early times. Vegetation work has both restrain and trap and fixation functions. Plants (sand grass and shrubs) that cover the sand surface can restrain the generation of blown sand by preventing the wind from acting directly on the surface, and can also trap and fix the blown sand with decreasing wind speed. We can expect a considerable storage capacity for shrubs but not so much for sand grass. The fundamental property required for plants employed in vegetation work is that the rate of growth must be bigger than that of sand accumulation. We can no longer expect any ability for controlling blown sand when plants are buried. There are many previous examples of vegetation works used in the field. The works sometimes succeeded but they occasionally failed. The circumstances surrounding plant growth involve many factors such as weather condition, bed material, and character of plants. No guidelines for engineering use exist at present. The most suitable plants for selection may be the ones that grow at the site under consideration.

III.4 Coastal Conservation Forest

On many beaches a coastal conservation forest is often planted for several purposes. One of the most important purposes of a conservation forest is to control the wind-blown sand. We can regard the conservation forest as an aggregate of porous fences. Therefore, the function of a conservation forest is almost the same as a porous fence. However, the domain where the wind is reduced is much larger for a conservation forest than for porous fence, since the trees composing the conservation forest are considerably higher than a porous fence, and the forest has a certain width. The boundary towards the beach-end at the seaside edge of the forest is a battle field where the trees fight back against the penetration of blown sand. Therefore, to keep the primary function that a conservation forest should control blown sand, the trees planted at the seaside boundary must grew up above the thickness of the accumulating sand layer occurring during strong winds. Growth of trees is usually slow and trees at the seaside boundary are always exposed to the risk of withering due to the attack of the strong wind, blown sand, and salt transported from the sea. Therefore, it is not wise to only use conservation forests for controlling blown sand. In general, sand fences or a foredune will be placed to prevent the withering of the trees. Then, we may as well consider that a conservation forest provides protection in emergency situations.

Trap and fixation function of a conservation forest depends on the height of the trees, planting distance, kind of tree, and width of forest. To control blown sand satisfactorily, a width of the forest of more than 100 m is required.

III.5 Other Prevention Works

It is a technique commonly employed to spray water on the ground surface to reduce the dust generation when the surface becomes dry and dusty during windy days. Spraying water increases the resistance force against the wind, and suppresses the generation of blown sand, or decreases the amount of sand transported. However, in our review, we could not find any examples where spraying water was employed for controlling wind-blown sand, although we found an example where fresh water was sprayed or showered by sprinkler or portable shower vehicles for washing down salt adhered to leaves of pine trees growing in a conservation forest. Taking care of conservation forests by showering fresh water will be reported in detail by the same authors in the near future. We could not find any examples where coagulant was sprayed for controlling wind-blown sand, although we found several examples of spraying coagulant containing fertilizer for promoting vegetation work. We suppose that usage of coagulant will not be recommended because it may contaminate beach sand and obstruct a comfortable use of the beach.

Covering work by net, hay, straw-mat, and others have often been employed to restrain wind erosion of the ground surface. However, it is difficult to cover a large area of the ground surface, such as the beach, and it is also expected to be costly. We can not ignore that there is an engineering possibility to cover a whole beach surface by a kind of plastic net for effectively controlling blown sand. But, the problem has not been studied fully yet. Employment of covering work should be limited to small areas.

IV. New Prevention Works

Based on previous studies carried out by the present authors, we would like to propose the following three new prevention works: trench, movable porous fence, and artificial large-scale sand ripples. These three type of works will be discussed in the following sections.

IV.1 Trench

The idea of a trench in prevention work for wind-blown sand is based on long-term experience and results from our previous studies. Iwagaki(1950) studied the phenomenon of blown sand by using diffusion theory. He predicted that (i) the flying distance of a sand grain in saltation motion was rather short, and that (ii) over 97 % of the sand grains in saltation fell within a range of 5 m from the end of the sand bed when the bed abruptly disappeared like at the shoreline. As a verification of his predictions he pointed out that cultivated land in a sandy beach of Tottori Prefecture where it is facing Japan Sea, was protected from the blown sand by excavating a stream upwind, letting sand grains fall into the stream, and returning the sand to the sea. Considering these results, Horikawa *et al.* (1994) tried to measure the sand transport rate by using a trench which was 1 m deep and several meters wide in the field. The measurements showed that the trench trapped almost 100 % of blown sand transported. Hotta and Horikawa (1993) measured the flying distance of sand grains in saltation using a large wind tunnel. They found that the flying distance for an amount of over 95 % of the blown sand was smaller than 1 m. Using the same technique as Hotta and Horikawa, Shiozawa *et al.* (1993) measured the flying distance of blown sand at a real beach. They found the same result as Hotta and Horikawa (1993). Therefore, the present authors concluded that the trench could be employed as a prevention work for wind-blown sand and propose to use a trench practically in the field. However, it is not clear how many meters of trench width that are suitable. Horikawa *et al.* (1996) carried out a wind tunnel experiment and a numerical experiment to determine the flow field in an open cavity. They found that a width of about 5 or 6 meters would be acceptable when the trench is dug deeper than 1 m. An example of how to use a trench for control of blown sand can be seen in Fig. 7.

IV.2 Movable Porous Fence

This method is based on a simple idea. It is an attempt to erect or place a temporary fence, which is not large and can be movable, on the beach sand surface where the blown sand is generated during the windy season. After the windy season has passed, the fence should be removed to a storage for usage the next windy season. When a strong wind blows, blown sand will be generated even though the sand surface is wet (Hotta *et al.*, 1984). The problem with blown sand is usually most serious when the wind blows from the offshore to the inland. Therefore, the fence should be placed near the inland side of the shoreline where the blown sand is generated, although we have to consider the risk that the fence may be attacked by the runup waves during stormy sea conditions. Figure 5 shows a sketch of a test manufacture of a fence.

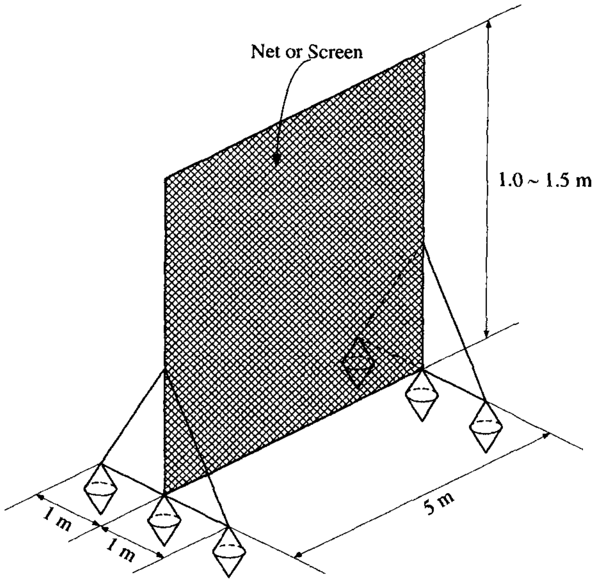

Fig. 5 A test manufacture of a movable porous fence.

IV.3 Artificial Large Scale Sand Ripples

This type of works is based on the same idea as the trench; that is , the flying distance of a sand grain in motion is not so long as described in Section IV.1. The work is simple, and the purpose is only to form giant ripples 2 or 3 m high and several meters long, as shown in Fig. 6, on the beach surface by using earthmoving machines such as power shovels or backhoes. The blown sand generated from the crest part of the giant ripple falls into the following trough part downwind. The sand is not transported beyond the next crest until the trough fills up. The blown sand will be generated on the whole beach surface and the sand will be transported into the inland when the trough is buried. We must form the ripples again as soon as the trough is buried. This type of works means that the blown sand generated from a small area is caught in a short distance downwind and brought back to the original place.

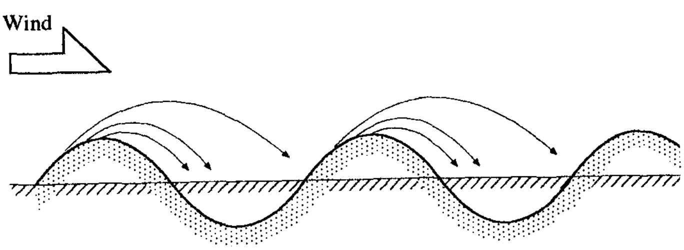

Fig. 6 A schematic illustration of artificial large scale sand ripples.

IV Systematical Use of Prevention Works

Figure 7 shows an example of the systematical use of conventional and new prevention works for wind-blown sand. Movable porous fences are placed on the part of the beach neighboring the shoreline where the blown sand is generated. When fences are buried to more than about two-third of their height, the fences must be pulled up. Then, the fences will recover their restrain and trap and fixation functions. A trench traps the blown sand which pass through the fence field. A fence erected at the downwind tip of the trench with a low fence porosity has a tendency to accumulate sand in front of the fence (Hotta and Horikawa, 1990b). Therefore, we can expect that over 90 % of the amount of the total blown sand can be trapped as far as where the fence is erected at the downwind tip of the trench.

We may remove the sand stored in the trench by using earthmoving machines as a power shovels or backhoes. But, we can also remove sand by using sea water, as described in Fig. 7. The sea water is withdrawn from outside the breaker point, flushing the water in the trench, and draining away the sand at the shoreline. Instead of using seawater, we can also use water from the landside, if enough water is available.

A small amount of blown sand in suspension can be transported beyond the fence. Prevention works arranged behind the trench must control the sand that pass. In the wind field around an embankment, a wind-reduced domain is formed at the foot of the embankment. The domain has a possibility to store the blown sand. Shrubs and grass on the slope of an embankment weaken the wind, and catch and store the blown sand.

The crown of the embankment may be used as a bicycle road or walking road. At the seaside shoulder of the embankment the wind accelerates. To moderate the wind, placement of a fence with a median porosity is recommended. The fence height should be lower than 1 m to maintain a good view.

At the landside shoulder of the crown, placement of a relatively high fence is recommended to reduce the wind and to protect the inland. A low porosity fence is recommended for the upper part of this fence.

V. Concluding Remarks

The characteristics of prevention works for wind-blown sand have mainly been studied in the field of agricultural engineering, forestry, geomorphology and coastal engineering. Studies have been carried out both in the wind tunnel and in the field. The results obtained were qualitative and quantitative evaluations of the effectiveness of the prevention works are scarce. The phenomenon is so complicated that theoretical analysis will be difficult. To evaluate the effectiveness of prevention works quantitatively, systematical and well controlled wind tunnel studies or field studies are needed, although numerical experiment based on the detailed description of the fluid dynamics in computers can assist our understanding.

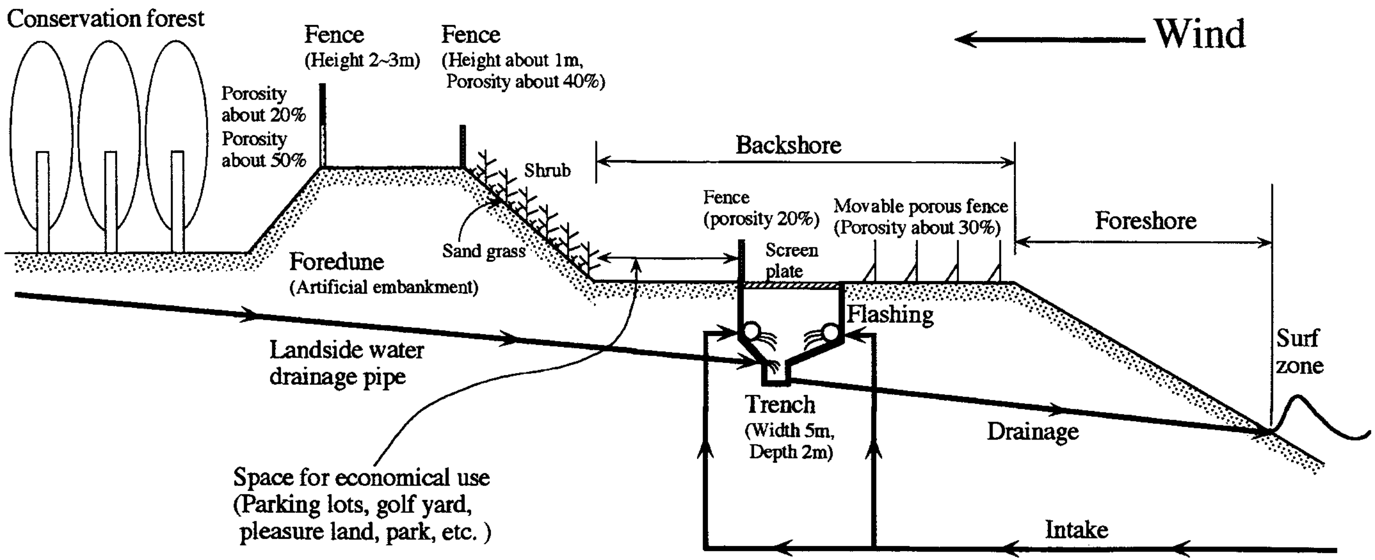

Fig. 7 An example of systematical use of conventional and new prevention works.

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