CHAPTER 123

USING FENCES TO CREATE AND STABILISE SAND DUNES

Brian B. Willetts¹ and Christopher J. Phillips²

Introduction

Coastal sand dunes act as a barrier to wind and sea, as a reservoir of sand available to supply areas of eroding coast, and as a trap for mobile sand which would otherwise be blown inland and become a nuisance. Breaches of the dune system and areas bare of vegetation should be avoided or repaired in order to protect the stability of the dunes and so enable these useful functions to be sustained.

The agents of initial damage to the dunes are water, which undermines them, and animals (including man) which damage the protective vegetation by grazing or trampling. Of these, man has recently assumed predominant local importance because of the popularity of sea-side holidays and of the land-falls of certain marine engineering works such as oil and gas pipelines and sewage outfalls. The need is therefore increasing for active dune management programmes to ensure that under these accentuated pressures, the coast retain an equilibrium comparable with that delicately balanced equilibrium which obtains naturally at a particular location.

Such management programmes are already established in many countries. They tend, however, to be empirical and based on local experience (often of a very small number of people) because the difficulties of generalisation render transfer of information and technique meagre. Accounts of management techniques can be found in the literature (e.g. ref 1) but in most of such papers great emphasis is placed on vegetative restoration. Whilst this is the best way of re-introducing a lasting stability, it is often not a practical way of beginning the restoration of a deteriorating situation. The sand movement or the season may be such that planting alone is unlikely to be successful. It is the authors' opinion that, of the techniques at present available, the placement of porous fences provides the most effective means in relation to cost of creating and stabilising sand dunes (and should normally be supplemented by plantings).

The object of this paper is to present a simple numerical model of dune formation at a fence. The model is based on what is known of the physics of air and grain movements near the fence, and the purpose of approaching the problem at such a basic level is to seek sufficient understanding to enable information and prediction methods to be transferred from person to person and applied at different sites. This requires that the processes which take place at the fence be better understood than at present.

1. Senior lecturer in engineering, University of Aberdeen, Scotland

2. Reservoir engineer, B.P. Petroleum Development Ltd., Aberdeen

Previous work on sand movement and stabilisation has been reviewed at some length by the authors and a shortened bibliography provided (ref 2). The principal deduction of practical significance about sand fences which can be drawn from a study of the literature is that for best results a fence of approximately 40% porosity should be placed with its plane normal to the flow. Some uncorroborated recommendations can be found about multiple fence Since natural winds vary in direction at a given site placings. and since artificial deposits of greater height than a single fence are normally required, it is clear that this deduction from the literature is not an adequate background to practical dune management, but that more information is needed. We do not provide all this additional information and some remaining obscurities will be discussed at the end of the paper.

Uniform sand flow

As wind increases over a dry sand surface, a threshold is reached at which individual grains are dislodged by the wind and jerk forward or perform feeble saltations. At wind speeds only slightly greater than the threshold value, the population of saltating grains becomes dense enough to extract a substantial amount of momentum from the air layer adjacent to the sand surface, so screening the surface from wind strong enough to dislodge grains and changing the mechanism of dislodgement to one of intergranular collision. This mechanism is more effective than direct "plucking" by the wind, and if the wind speed is slightly reduced, the threshold at which grain motion stops is significantly lower than that at which it began in the rising wind.

A plot of point velocity against the logarithm of the distance of that point from the ground illustrates this point clearly. Fig 1 is an idealised form of such a diagram. The velocity profile corresponding to each mean "wind strength" can be characterised by the shear velocity, V_{\star} , defined by

$$V_{\star} = \sqrt{\frac{\tau_{o}}{\rho}}$$
(1)

where τ_{o} is the surface shear stress and ρ is the fluid density. The velocity at height z in the flow may be expressed as:

$$v_z = 5.75 v_* \log_{10} \frac{z}{k} + v_t$$
 (2)

As illustrated in fig 1, k' and V_{+} are the coordinates of the

focus of velocity profiles which converge very nearly at a point, V_{\perp} being the threshold velocity. As the wind strengthens above the

threshold, the velocity at any fixed height which is less than k' does not increase, and so the direct action of the wind remains insufficient to mobilise sand. It is also interesting to note that the effective origin of the logarithmic velocity profiles rises with wind strength, as the population of saltating grains becomes more dense.



Fig 1 Velocity distributions of wind blowing over moving sand at three strengths, the lowest one corresponding to the threshold of motion.





Of several formulae for calculating the uniform rate of sand transport, the best known is the early one of Bagnold (ref 3), viz:

$$q = C \left(\frac{d}{D}\right)^{0.5} \frac{\rho}{q} V_{\star}^{3}$$

in which d is the grain diameter,

- D is the diameter of a "reference grain",
- ρ is air density,
- C is a coefficient which takes account of population grading and which is determined by experiment.

The range of values quoted for C is 1.5 - 2.8 so that big differences in predicted transport rate occur for different grain populations each having the same mean grain size. Consequently it is only with reluctance that one would choose a value of C by rule-of-thumb, and usually an experiment is needed to re-cast equation (3) in a form suitable for prediction. The sand used in all experiments reported here was a local dune sand having $d_{50} \approx 0.25$ mm and in measurements of uniform transport rate proved

to obey the relationship

 $q = 4.02 \times 10^{-6} V_{1}^{3}$

This formula has been used throughout the reported work.

Non-uniformity and unsteadiness

Any change of condition, either spatial or temporal, whether of the sand or of the driving wind, initiates adjustments of the saltating cloud and the near-surface wind structure. Because the momentum exchanges inherent in these adjustments cannot, by the nature of the mechanisms involved, be made instantaneously, the influence of conditions before the change persist somewhat after it has taken place.

The introduction of a porous fence into a steady air-stream produces a local distortion of the near-surface flow which leads to deposition of sand. We have measured shear stress changes in the vicinity of a fence by means of Preston-tubes (surface Pitot-tubes) and have used the shear velocity pattern derived from these stress measurements to indicate the magnitude of the flow distortion. Calculations of sand deposition have been based on the graphs of shear velocity distribution (fig 2).

Unfortunately, because the velocity profile is distorted near the fence (particularly close to the ground), shear velocity alone no longer characterises the flow field at a particular location. As fig 3 shows, the velocity gradient at ground level (and hence shear stress and shear velocity) is not consistently related to the velocity at an arbitrarily chosen distance from the surface.

(3)

(4)









Fig 5 Scheme of calculation - method 2 Removal rate of material at P calculated from local shear velocity and saltation a. Deposition rate at P calculated from shear velocity at Q and saltation b.

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Since saltating grains experience the influence of the wind at considerable distances from the ground, it would be more rigorous to describe each velocity profile fully and to use the full description in calculating the behaviour of grains in the flow field. However, as a first approximation, shear velocity has been used as independent variable in this numerical work. The complications of a full description of the time-averaged flow field are such that use of the simplistic description has great advantages and, should it provide acceptable accuracy in calculation of deposits, could well be retained despite its crudity.

Calculation methods

Two methods have been used for calculating the deposition at a fence, both are more fully reported elsewhere (ref 4). Briefly the two schemes of calculation are as follows. Both are two dimensional and it is convenient to consider unit horizontal depth of field parallel to the fence.

Method 1 (Fig 4)

For the extent of the influence of the fence, space is divided into sectors Δx in the wind direction (normal to the fence). For the sector between locations x_i and x_{i+1} it is argued that the mean rise of surface level in time Δt is equal to the difference between the weight of sand entering the sector and leaving it in that time divided by the superficial area and the bulk density of the deposit. The rate at which material enters and leaves the sector is calculated be means of equation (4) from the local values of shear velocity at x_i and x_{i+1} respectively. Shear velocity values are obtained from fig 2. The calculation proceeds in the direction of increasing x for the extent of the fence's influence for each time increment. After each pass the fence height is adjusted to the extent it has been buried by the accumulating sand.

Method 2 (Fig 5)

Again, the ground is divided into stream-wise sectors of length In this method, however, the book-keeping is done in terms of Δx. erosion rates per unit area rather in terms of transport rates per unit width. For each sector, the change of surface level in Δt is made equal to the difference between the deposit rate of grains landing on it and the erosion rate of grains removed from it divided by the bulk density of the deposit. It is assumed that the erosion rate at a particular position can be calculated from the local value of boundary shear stress and that the deposition rate should be calculated from the value of shear stress at one saltation length upstream. In both cases the rates by area are obtained by dividing the transport rate per unit width by a saltation length. The appropriate saltation length is that of the saltation relative to which the unit of area is central.

Experimental evidence

Most of the evidence which is useful for direct checks on the calculation method derives from wind-tunnel experiments. Field checks require that changes of wind strength and direction are monitored continuously and there is little data available from experiments in which this has been done.

Wind tunnel measurements using 5 cm and 7.5 cm high fences of various porosities between 32% and 51% corroborate calculations by either method in respect of the size and shape of the deposit. However, the position of the deposit calculated from the shear stress profile by either method is misplaced upstream by a significant amount (the crest of the deposit is predicted to be upstream of the fence, whereas it is observed to be downstream of the fence both in the wind-tunnel and in the field). This error of position is approximately proportional to fence height and is corrected by introducing a numerical routine to represent; the jetting of flow between fence members. The routine raises the shear stress on the sand by a factor equal to the reciprocal of the porosity and operates with that enhanced shear stress on the net bed width. As fig 6 shows, the resulting prediction accords reasonably well with observation at miniature fences. (The figure shows an arbitrarily chosen porosity and flow condition, but comparisons are successful to approximately the same extent for other wind strengths, porosities and experiment durations).

Near its leading edge the deposit is considerably deeper in the numerical prediction than it is observed to be when measured in the wind-tunnel. A heavier deposit is predicted as soon as the boundary shear stress begins to fall than actually occurs. There are two obvious omissions from the calculation method which might be held responsible for this error of detail. The first is neglect of the velocity profile distortion in favour of dependence on boundary shear stress alone, the second is omission of the enhancement of boundary shear stress to be expected on the convex surface formed by the developing dune. Rough and ready checks have been run on both these influences. The incorporation in the calculation of pitot-static measurements of velocity made upstream of the fence at a distance above the bed equal to approximately three-quarters the maximum saltation height effects a small improvement in the prediction of the upstream portion of the deposit as compared with Preston tube measurements of shear stress at bed-level. Also, the introduction of empirical hill-effect shear stress enhancement reduces the thickness of this early deposit without substantially



Fig.6 Comparison of measured dune profile with profile calculated for corresponding conditions and elapsed time, incorporating jetting.

changing the faithful down-wind modelling. However, the influence on transport rate of changes of surface gradient is not confined to that associated with changed shear stress; the angle and velocity at which moving grains attack the bed is also changed, and this has a significant effect on transport rate. The transport rate perturbation due to the hill effect is incapable of resolution at present, and its effect is confined to the zone upstream of the fence until the fence becomes submerged in sand. For these reasons the effect has been omitted from calculations so far, and the discrepancy at the leading edge of the deposit tolerated.

Scope for practical use of calculations

The calculation methods which have been reported have been applied only to the simplest possible circumstance, namely a fence on an initially flat sand surface with wind normal to the fence plane. Obviously practical applications would involve much more complicated geometry, and one is bound to ask whether the calculation method could be extended and modified successfully enough to become useful in real situations. The answer involves a closer look at the coastal dune system and particularly at the symptoms which show when major damage is impending (for the stable dunes require no predictive calculation).

Mature coastal dune areas consist of non-cohesive soil in undulating features usually covered almost completely in marram grass with smaller colonies of other plants tolerant of sand and Such a system will survive quite high rates of deposition of salt. incoming sand and is retentive of deposited sand because of the protection from wind given to the surface by vegetation. It is therefore quite stable, and before sand blowing can impair the stability of the dunes, there is usually preceding mechanical damage to vegetation, the removal of which exposes the bare sand to the The agents of such damage may be waves, fresh-water streams, wind. engineering works, grazing animals, vehicle or pedestrian access, and they often result in two particular types of erosion feature. The first, resulting from water attack, consists of exposure of a near-vertical sand face of considerable length, such as can often be seen when waves have reached the fore-dune. Wind processes are often important in the subsequent development of a feature initiated in this way but the present calculation method is not useful in this case. It fails because gravity, drying processes and secondary air flows dominate the situation. The second type of feature is even more important and is often called a "blow-out". It consists of a U-shaped trough often intersecting a dune ridge and growing in size by means of two processes. Sand is blown along the trough and out of it down-wind, thus increasing the depth of the feature and the steepness of its sides. At some point the vegetation securing these sides at more than the natural angle of repose is torn away, and sand and grass tussocks fall into the base of the blow-out. Wet or calm weather at this stage may enable the grass to re-establish itself and stabilise the

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feature in the new geometry, but often the fallen debris is itself blown out of the trough so that the blow-out becomes both wider and deeper. Such blow-out development is a response to winds which blow along the axis of the feature (its base is protected from transverse winds) and it is reasonable to model the sand transport two-dimensionally as is done in the present calculation method rather than three dimensionally.

A common method of reversing the blow-out process is to place sand fences across the base of the blow-out to accumulate sand which is blown along its axis and so to reduce its depth. As this procedure improves the geometry of the feature, marram plantings are made to stabilise the new surfaces. The accumulation of sand at the fence in this case conforms closely to the assumptions of the reported numerical model; the sand is bare, the winds which propel the sand are virtually normal to the fence plane and initial longitudinal curvature of the sand surface is small. A useful indication of the growth of the sand deposit can be expected from calculation methods such as those described.

Caution is needed, however, in interpreting the results of such calculations. One difficulty, which is unavoidable, is that the rate of accumulation of sand depends on quite detailed features of the weather pattern (because the sand transport rate depends on dryness as well as wind strength and direction). It is common to base design predictions on an extreme event chosen statistically but not on the more difficult statistics of pattern occurrence. А second problem of interpretation concerns the imperfections of the present calculation methods, and is capable of reduction by improvement of those methods. There are several possible improvements, the important ones involving the effects of the dune shape on the boundary shear stress, and the influence of grain size distribution and characteristic grain shape on the uniform Both of these matters merit further research. sand transport rate.

It is also evident that the method of calculation of topographical changes from shear stress patterns can be applied to problems other than sand fence ones. Provided, in some other class of problem, it is possible to predict or measure the shear stress pattern, then consequent changes of topography will be calculable. The success of such calculations will be linked to the steepness of gradient of the shear stress change, but should be comparable with that of the fence calculations.

Conclusions

The deposition of sand at porous fences can be predicted with some success using uniform transport rate equations for the nonuniform conditions near the fence. It is necessary to incorporate the effect on sand of the locally high velocities of air between fence members. The calculation is dependent on empirical descriptions of the flow field near the fence expressed, for the purpose of substitution in sand transport formulae, in terms of boundary shear stress. The pattern of boundary shear stress for a given porosity is scaled by fence height and therefore can be evaluated for any particular fence in terms of a dimensionless plot of data for a reference fence of the same porosity.

Scope for useful application of the calculation method is limited by ignorance of the mechanisms by which dune systems deteriorate, a topic which merits further work.

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