Sand Control Measures and Sand Drift Fences

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Abstract: Sand drift and sand dune movements are typical logistic problems facing civilian and industrial cities in arid and semiarid countries like Saudi Arabia. Some of these countries are considered active when it comes to sand drift and sand dune movement, due to the high annual sand drift rate. Urban cities have extensive facilities in the middle of these active areas that require good protection and innovative solutions to this problem. This paper briefly reviews sand movement control measures and highlights sand drift fence design guidelines for the first time.

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Introduction

Approximately one-third of the Arabian Peninsula is covered by sand dune areas. The Empty Quarter (Rub Al-Khali) probably contains the largest continuous sand dune area in the world, covering an area of nearly $600{,}000\ \mathrm{km}^2$. Another $180{,}000\ \mathrm{km}^2$ is covered by the Great Nafud and Ad Dahna deserts in the interior part of the peninsula (Fig. 1). The Jafura sand sea covers the Arabian Gulf coastal region in the Eastern Province of Saudi Arabia. The Jafura sand sea extends from an area of high wind energy in the north to an area of low wind energy in the south, resulting in a general sand drift direction southwards to southeastwards. Fryberger et al. (1983) zoned the eolian landscape of the Jafura sand sea into an area of deflation (erosion) on the north, an area of deposition in the south, and an area of transport in between. Most of the relevant literature is focused on sand dune modeling and advancement and little is revealed regarding sand drift fencing [see, e.g., Qong (2000); Amarouchene et al. (2001); Lima et al. (2002); and Kroy et al. (2002)].

The Jafura sand sea of the Eastern Province is an elongated 32–250 km wide sand body extending along the western side of Arabian Gulf from Kuwait in the north to the Empty Quarter in the south, a distance of about 800 km (Research Institute 1985). This body forms narrow band in the north then widens in the south where it merges with Empty Quarter. The annual sand drift rate varies from 10 to 120 tons/m in the Jafura sand sea and can reach higher values in very active areas (Bagnold 1971; Dhir 1995).

As a result of this, sand control is a pressing necessity to minimize hazardous impacts on existing facilities. National governments spend tens of millions of U.S. dollars for contractors removing accumulated sand near civilian and industrial facilities. For example, Saudi Aramco (the Saudi Arabian oil producing company) uses 300,000 barrels of heavy crude oil (tar-oil) per year for sand dune stabilization along pipelines, roads, runways, and foundations. Some of the Saudi Aramco facilities that experience these problems are gas-oil separation plants, pump stations of the East-West Pipeline, and skid roads. Saudi Aramco has recognized the importance of sand control measures since the start of its operation (Kerr and Nigra 1952). The latest study of such controls was completed in 1998 by the Research Institute at King Fahd University of Petroleum and Minerals (KFUPM) (Research Institute 1998).

Generally speaking, worldwide sand control measures have been applied based on various studies and on personal judgment that lacks scientific and engineering consideration. Thus, in some places, ill-designed measures actually create sand hazards rather than controlling them. This paper outlines sand movement control measures and discusses proper sand fence design as an effective means of sand movement control.

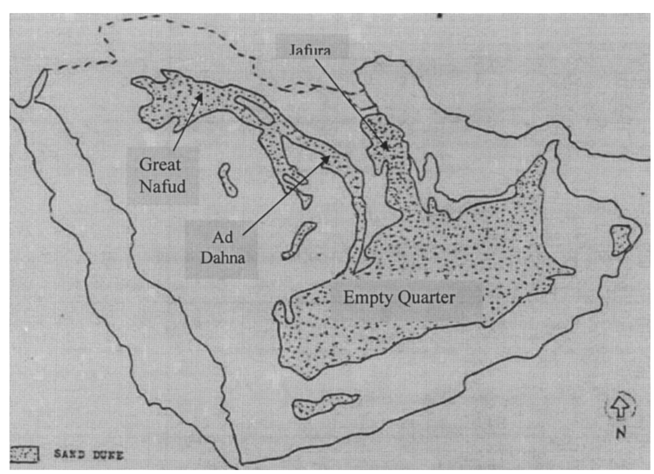

Fig. 1. One-third of Arabian Peninsula is covered by sand dunes

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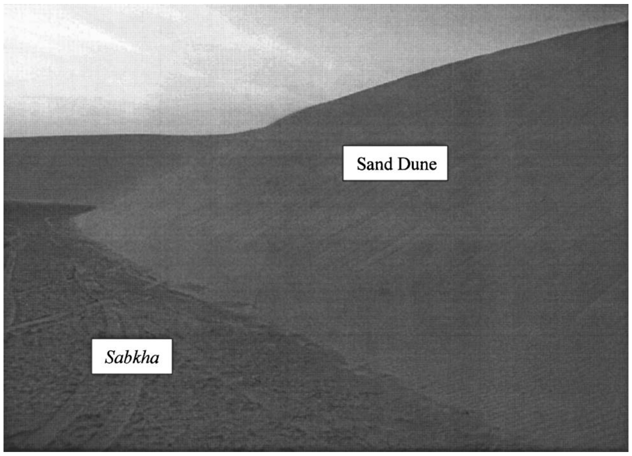

Fig. 2. Sand dune advancement is limited on *sabkha* surfaces

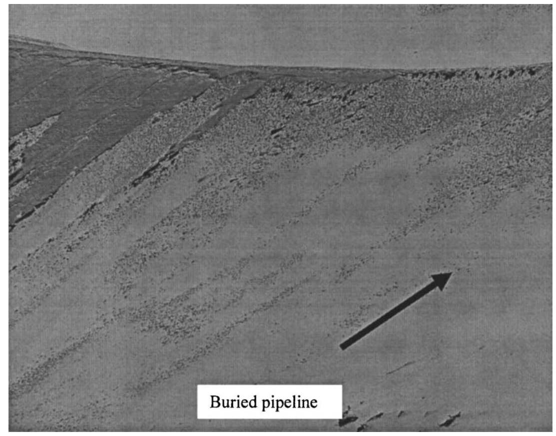

Fig. 4. Wind erosion of pipeline berms

Sand Movement and Its Impact on Existing Facilities

Sand Transport

Sand is transported by three different mechanisms. Suspension accounts for 5% of the transport, involving very small particle sizes ($<100\ \mu m$). Almost 75% of the sand travels by saltation, a trajectory movement for medium sized particles. Large particles move by surface creep and represent 20% of the transported sands. The details of sand transport, sand deposition mechanisms, and sand dune formation can be found in Bagnold (1971).

Sand movement is highly affected by geomorphology (vegetation, shapes and height of terrains, and grain sizes of the sand) and wind energy. The most important factors that affect sand movement are summarized as follows:

1. Wind speed: A minimum of 6–8 m/s wind speed is needed for sand transport.
2. Sand particle size: Heavy particles creep on the surface, while small ones fly in suspension.
3. Terrain type: Sand transport is rare on *sabkha* (*sabkha* is a sand sheet with near-surface seawater) surface (see Fig. 2). The reason for this is not very clear, but one possible scenario attributes this to the wet surface of the *sabkha*.
4. Vegetation cover: This increases surface roughness, thus decreasing surface wind speed (Fig. 3).
5. Groundwater: Areas with shallow groundwater resist sand dune advancement.
6. Precipitation: This directly affects surface hardness and vegetation.
7. Temperature: High temperatures increase the mobility of sand particles.

Impact on Existing Facilities

Many government and private sector facilities are located in sand sea areas. Sand drifts and sand erosion dictate budgets to combat these problems, mainly mechanical removal, crude oil splashing, and construction of sand barriers. In general, infrastructures—whether roads, pipelines, industrial facilities, airports, or industrial areas—are subjected to sand drift accumulation and wind erosion that undermine the facility and require continuous maintenance and budgeting costs to perform temporary remedial solution. The following is a list of some of the typical problems that face onshore facilities:

1. Erosion of pipeline berms and anchors (Fig. 4);
2. Road blockage by sand drift (Fig. 5);
3. Wind erosion of utilities foundations (Fig. 6);
4. Sand dunes forming and surrounding facilities (Fig. 7); and

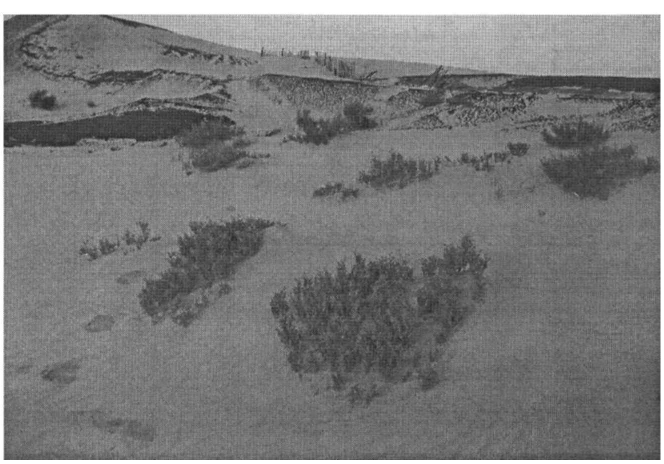

Fig. 3. Vegetation helps to stabilize sand dunes

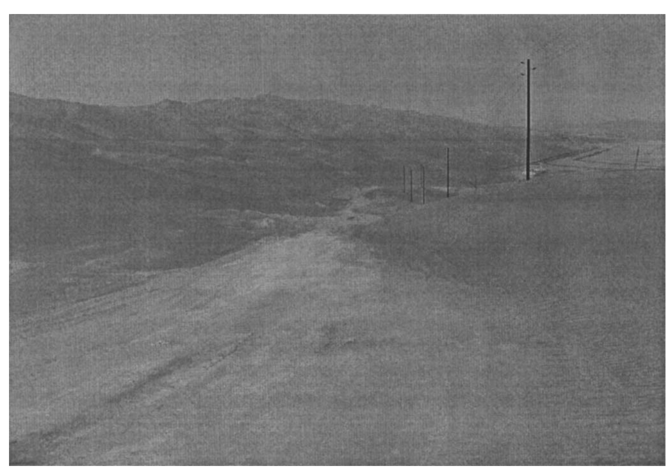

Fig. 5. Sand drift into right of way or access road

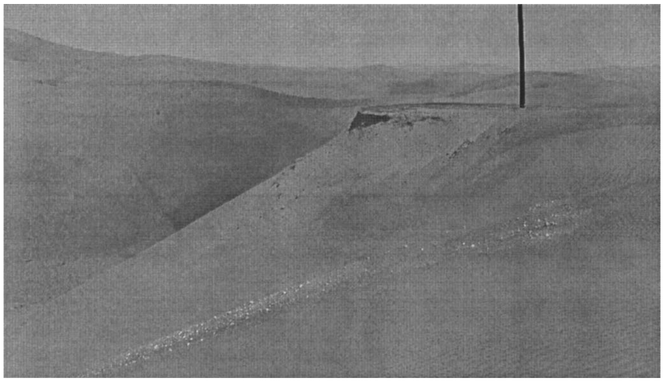

Fig. 6. Erosion of power poles located in mobile sand

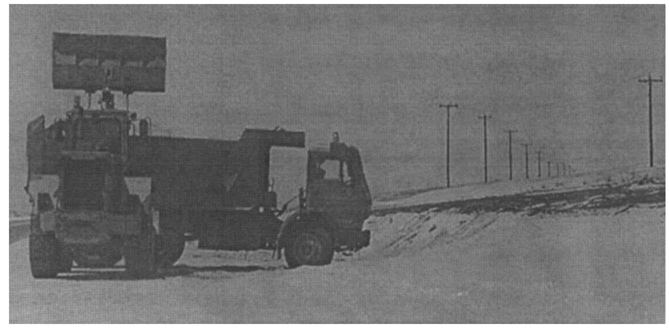

Fig. 8. Contractor removing sand using dump truck

5. Megabarchan sand dune advancement to facilities (Fig. 7). Sand dunes can take many shapes, but the most common ones are barchans and crescents.

Sand Control Measures

The importance of sand control was recognized from the beginning of Saudi Aramco operations in the field. Attempted solutions to this problem have included sand fences, sand traps, diversion walls, and barriers. However, these measures were found to be insufficient in some situations and require the use of bulldozer and dump trucks to remove sand accumulated near the facility. Common measures are reviewed briefly hereafter.

Vegetation

Vegetation increases the surface roughness of the sand sheet or sand dune surface and thus stops sand migration. Although this measure is an environmentally sound solution, it is impractical and expensive when it comes to open desert with low precipitation rates. In addition to this, loose particles of sand have low water holding capacity and low plant nutrients. Vegetation might be considered as a valuable solution in the vicinities of community areas, where treated sewage water can be used for irrigation of vegetation grass and bushes.

Sand Stabilization

Sand stabilization is achieved by covering a thin layer of sand dune with a chemical stabilizer. This treatment will result in a brittle crust surface that can be broken easily due to man, animal, or vehicle mobilization. A very important requirement in the stabilizer is that it must be a vegetation supportive and environmentally acceptable substance. As mentioned previously, Saudi Aramco used about 300,000 bbl/year of heavy crude oil (tar-oil) for general purposes including sand control and berm stabilization. Oil stabilization was found to be effective in large areas and was recognized as the most effective solution (Asi et al. 2002). However, its disadvantage is the appearance and its tendency to soil vehicles, animals, and man who must travel though it.

Other sand control measures include:
1. Ditching: digging a cut perpendicular to sand drift direction (a very expensive solution).
2. Trenching: dune destruction using bulldozers.
3. Fencing: which will be discussed in the following section.
4. Sand removal at a bulk removal rate of 0.5 US$/m^3 and a manual rate of 2 US$/m^3. However, improper sand removal to the wrong destination will result in sand recycling. Also, it is recommended to designate hazard sites as construction materials supply sites (Fig. 8).
5. Enhancing sand transport by terrain smoothing.

Fig. 7. Shaybah community surrounded by mega sand dunes; community is well protected using variety of protection systems, including system of sand drift fences

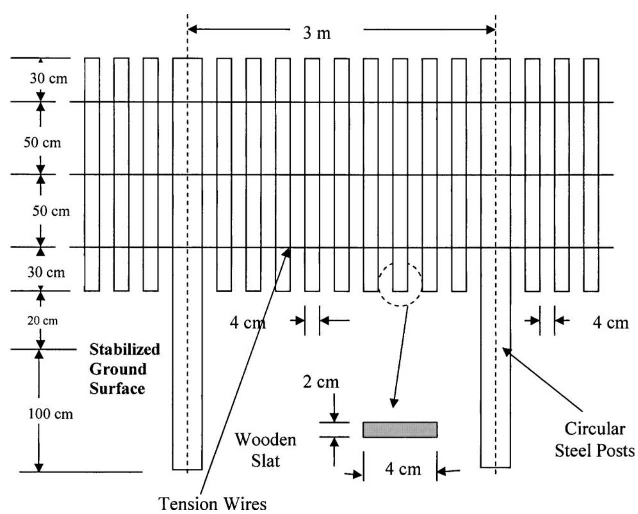

Fig. 9. Front view of suggested sand drift fence made of carbon steel posts, wooden slats, and tension wires

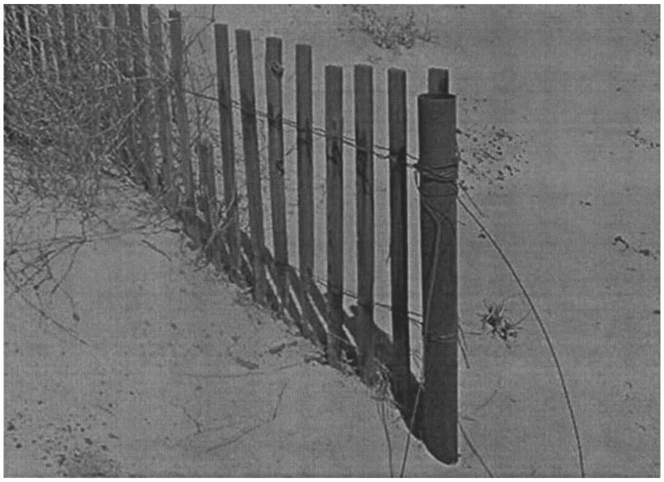

Fig. 10. Corrosion of low carbon steel post of sand drift fence

Sand Drift Fences

Sand drift fences are used to deposit sands in their vicinity. The fence is installed perpendicular to the wind direction. The direction before the fence is called the backward direction while the direction in front of the fence is called the forward direction. The majority of sand is captured in the forward wind direction. Sand deposition takes place due to the sudden drop in the airstream pressure in the neighborhood of the fence (Bofah and Owusu 1986).

Type of Sand Fences

There are several types of sand fences available in the industry. These are:

1. Vertical slat fence, shown in Figs. 9–13;
2. Horizontal slat fence (sometimes called a snow fence);
3. Palm-leaf fence (also known as a brush or Arabian fence), which is usually similar to the two preceding fences except that palm leaves are used instead of slats; and
4. Jet fence (or European fence). This fence is a vertical-slat fence but with tapered slats.

Investigations (Research Institute 1985, 1998) have revealed that the vertical slat fence is the best fence when it comes to simplicity, ease of manufacturing and erection, performance, and maintenance. Thus, only the vertical slat fence is discussed here.

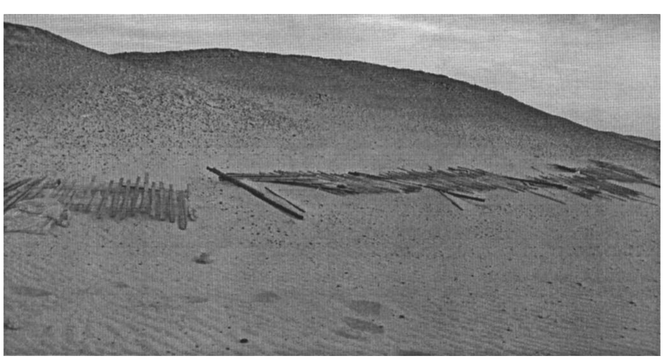

Fig. 11. Improper location caused collapse of this fence

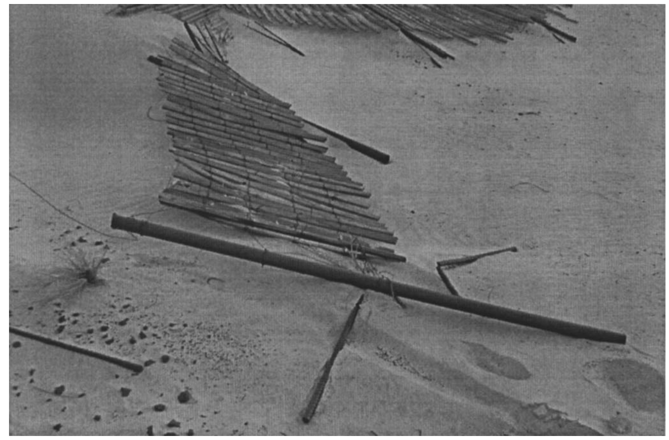

Fig. 12. Shallow depth of steel posts caused in-place toppling of fence

Sand Fences Design Guidelines

Based on previous studies on sand drift fences (Research Institute 1985, 1998; Kerr and Nigra 1952; Aramco 1984); sand fence design guidelines may be summarized as follows:

1. The sand fence must be perpendicular to the prevailing wind direction.
2. The optimum porosity is found in the range of 40–60% (porosity ratio is the ratio of the space between slates to the slat area).
3. As the porosity increases to a maximum value, frontal accumulation decreases and backward accumulation increases.
4. A V-shape fence is not recommended (V-shape in the elevation projection).
5. Avoid using plastic slats because of their brittle behavior due to sun exposure.
6. A vertical slat fence has better aerodynamic stability when compared to a horizontal one.
7. Efficiency increases with the decrease in slat width.
8. A solid diversion fence is not recommended.
9. A solid fence with zero porosity has poor performance.
10. A vertical fence tends to scour posts.
11. The recommended fence height (H) is 2 m.
12. A sand fence can accumulate $10H^2$ m^3 per meter length.
13. Erection of an extended fence is better than adding a new parallel fence.

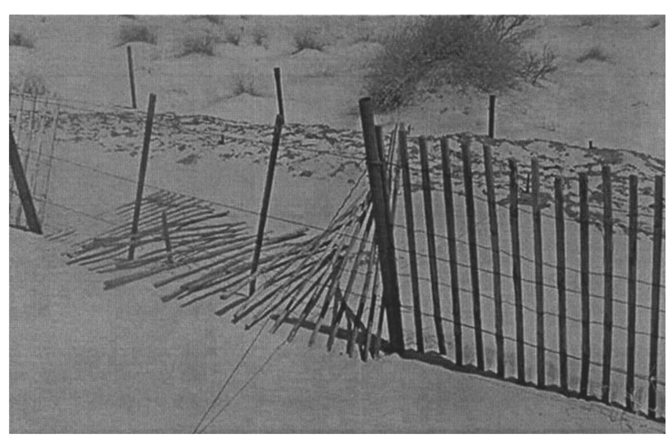

Fig. 13. Animals attack fence if it blocks their right of way

14. The recommended aspect ratio length/height is 40.
15. Allow for ten H as a boundary condition (end effect). This means for a facility of $50H$ width, a fence with $70H$ width is required.
16. Avoid fence leaning because it makes it difficult to extend a new fence on top of the leaning fence. Leaning means tilting the fence, usually in the backward direction.
17. Distance to the facility should be at least $100H$.
18. If a gap is needed between two parallel fences, the overlap length must be at least $10H$.
19. The suggested bottom gap is 10% of the height, to avoid direct drift accumulation.
20. A palm-leaf fence (Arabian fence) is efficient and easy to install.
21. Parallel fences may be used for a high rate of drift.
22. The recommended spacing between parallel fences is $40H$.
23. The slat material should be wood treated against insects, 1.8 m by 4 cm by 1 cm.
24. Posts should be made of carbon steel pipes, 50 mm in diameter, 3 m long, 3 m apart, and 4 mm in thickness, painted with primary and protective coating.
25. Galvanized or coated wires should be used, gauge 10 or higher.

The preceding design parameters are valuable for specification, contracting, and cost estimation. A detailed sketch of the recommended sand fence is shown in Fig. 9.

Fence Life

Life of the fence and price per meter length can be calculated as follows. Assume the sand drift rate is 10 $m^3/m/year$, the fence height is 2 m, and the bulk sand removal cost is 0.5 $US\$/m^3$. This fence can capture a volume of 40 m^3 during its operational life. Thus, the expected life is 4 years. The cost of removing 40 m^3 of sand is 20 US$. Thus, the breakeven point for the fence is 20 US$/m. In other words, a fence is the better choice if the erection cost is less than 20 US$/m, and bulk sand removal is best if the erection cost is more than 20 US$/m.

Fence Maintenance

Impounding fences will eventually be buried. At that point, the sand must be removed mechanically or another fence system must be installed. However, mechanical removal of sand creates not only an expense but also a problem of where to put the sand without creating additional hazards. Therefore, installing a new fence is usually preferred. Still, if an existing fence system is still in good shape, it is recommended that its life be increased by adding an extension, perhaps 1 m in height, as preferred.

Sand Fence Failure Modes

Field observation of existing sand fences showed that fences are not properly maintained. Also, it was observed that some of these fences were not located properly. Based on field observation, sand fence failure modes are as follows:

1. Post, wire, and cable corrosion (Fig. 10);
2. Improper location of the fence (Fig. 11);
3. Post scouring due to shallow depths (Fig. 12);
4. Animal attack and human vandalism (Fig. 13);
5. Gap erosion or bad design, mainly short heights (Fig. 12); and
6. Deterioration of plastic slats, mainly due to sun exposure.

Conclusions

Many of the public and private sector's facilities as well as public roads and private farms are located in the stream of sand drift in arid and semiarid countries. Sand control measures are reviewed briefly and technical experience in design of sand drift fences has been updated and summarized in this paper.

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