CHAPTER 28

# COASTAL DUNES: A STUDY OF THE DUNES AT VERA CRUZ

**A Study of the Dunes at Vera Cruz**

**Manuel Diaz Marta**
**Consulting Engineer, Universidad Veracruzana**

Coastal dunes are formed when winds gather the dry sands from beaches and carry it inland. The repeated scouring of surface sand and its deposit in other areas does more to shape the diverse hillocks and depressions characteristic of certain coastal areas than any other physical factor.

For fifty years we have been battling the sand dunes at Vera Cruz. Some observations made from the experience gained over these years may be of interest.

## NATURAL DUNE FORMATIONS

In the coastal areas near Vera Cruz the sandy dune strip (or "Faja") reaches a length that varies from 8 to 10 kilometres considering only the distance in which the wind is the predominant factor. Further inland old eolitic formations are still found, but being far from the beaches they are no longer active and the rains and vegetation govern their configuration.

Most dune strips lie on beaches exposed to the strongest winds. In the area of Vera Cruz the prevailing winds are from north to north-north-west and the gusts of these "nortes" at times exceed 40 mts. per second velocity. An aerial view of the faja which stretches from Punta Gorda (north-west of Vera Cruz) shows clearly how the process of sand bank formation follows the direction of the strongest winds (fig.1 ). From the beach, banks of sand penetrate the vegetal platforms; in the photograph these sandy inlets appear like purls oriented lengthwise in the same direction as the north and north-west mean.

Each new beach penetration becomes a "fountain of sand", helping to form successive dunes. The wind carries these sands from the beach and deposits them in small hillocks nearby. However farther on at a distance of about 2 kilometres there occurs a series of large dunes totally arid and in continuous movement reaching heights of up to 35 mts. This cordon is followed by one or two more with separations of intermediate level stretches about 200 mts. wide. This is the most active dune area; the sands are activated by the minutest wind movement. When the winds are moderate the inside surface of the dunes undulate giving a scaly appearance; strong winds make them larger and form high inclined planes and furrows.

The front face of the dunes has the most gradual slope. The sands are impelled by the wind up the slope to the crests where strong eddies and vortices of air whirl about and the particles in suspension are in part thrown on the slope, and in part carried further afield in the general direction of the wind. The crests give the appearance of interlaced half-moons.

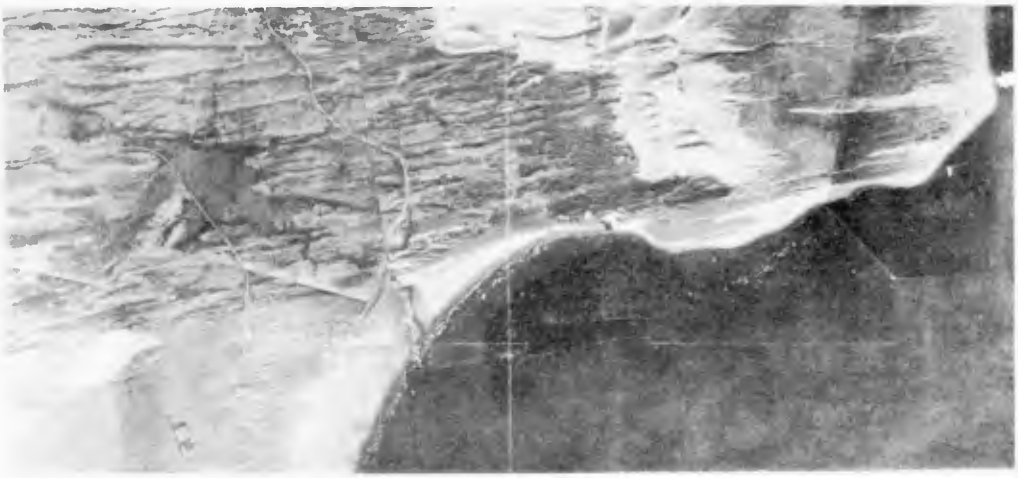

Fig. 1 - Aerial view of the strip of dunes which extends from Punta Gorda showing the process of sand bank formation.

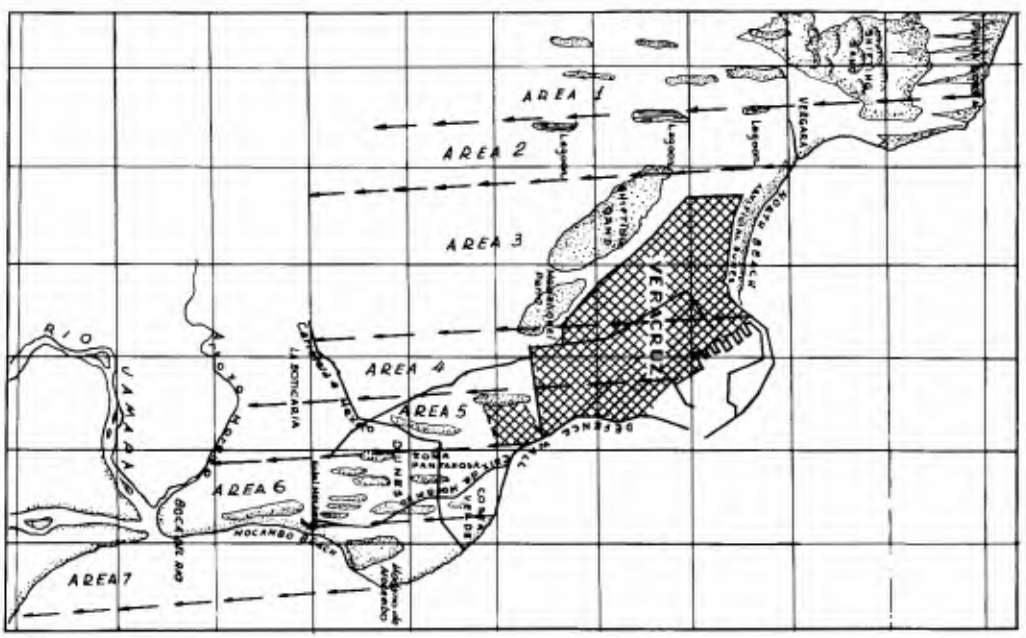


Fig. 2 - Influence of the orientation of beaches in the leeward zones.

The sands driven over the crest slide down the back slope forming an angle o approximately 33 degrees (the angle of repose) and they determine the landwa displacement of the dunes. Before the first stabilization projects were init iated Engineer Quevedo calculated the advance of the dunes at 10 to 14 mts. per annum, depending on the intensity of the winds and the relative humidity or aridness of the beach. These moving dunes have their high crests almost normal to the wind thus establishing calm leeward zones immediately to the rear. Sandfall on these zones is scarce and vegetation may flourish.

The terrain behind the active zone is composed of wooded area lying in the direction of the strongest wind in parallel lanes with low,level strips dividing it where sand deposit has been negligible. Strong winds do blow in a direction normal to them, but their force is channeled into ravine and the topography is not noticeably altered. Land behind active dunes is always a combination of woods and ravines combed in the direction of the strongest wind.

Climate and the Value of Stabilization Works - The coast of Vera Cruz is the scene of a struggle of opposing forces - the wind on one hand and the rain and heat on the other. The wind hinders the growth of vegetation by smothering plants with damaging grains of sand or tearing off the topsoil ar reducing seed supply. The abundant rainfall (1300 mm. annually) and intense heat (26º C. mean temperature) act in a contrary manner to encourage plants to take root. These opposing forces are pretty well equilibrated and with a little effort man can alter things in favor of vegetal growth and halt the advance of arid dunes. This has been done in Vera Cruz and could be equally well accomplished in any other area with similar characteristics. Good resul can be obtained by a close study of the behaviour of dunes in each area and the most practical methods to halt their movement and stabilize them.

Influence of the Orientation of the Beaches in the Eolitic Formation to the Leeward - It is curious to observe how the fringes of the fajas whicl commence at the beaches similarly oriented hold almost identical characteri (fig. 2). In the zig-zag which forms the outline of the Vera Cruz coast, ea beach oriented in the direction east to west, almost normal to the winds of maximum velocity creates a sandhill zone very similar to that described abo The moving arid dunes appear at distances which vary between 2 and 3.5 kilo metres from the coast and this phenomenon is repeated in sudh a manner that arid dunes reproduce the form of the zig-zag coast line.

In the stretches of the coast oriented more or less north to south, appearance of the strips of ground bordering them are very distinct, the or inal arid zones being covered with vegetation even up to the beaches. From air one can observe the lots developed to pasture nearly up to the sea in t east direction, whereas to the north, the limit is 2 or 3 kilometres from t beaches.

The Mocambo beach, the favorite in Vera Cruz, has approximately the direction north-south and is, moreover, protected from the northerly winds nearby heights. With such orientation, plantation of trees, etc., for the embellishment of the resort is possible close up to the dry upper beach. Th behaviour of the north-south beach is very different from that of the east-west front across the winds of maximum velocity, these winds supply hardly sand. In effect the northerly winds are already weakened by the immediate hillocks at the beach, and instead of picking up the sands of the sea they

drift them in a parallel direction to the limiting zone of the water, and after a while increase the water-level and the wave height and thus the send of the breakers up the beach. The action wets the dry sand and impedes its removal. The "whip" of the sands is therefore weak and does not prevent the growth of vegetation.

It will be appreciated that these beaches do not release sand for the zones to the leeward; further proof is provided by the abundance of low marshy areas and lagoons all elongated to the leeward of these stretches of beach. Thus behind the beach of Vergara (fig.2 ) the depressions and lakes are oriented very like those behind the beach of Mocambo, although the latter is not protected by nearby high ground. The largest dunes are formed along fajas 1, 3 and 6 which originate on coasts normal to the winds; however faja 3 shows areas which have been stabilized by artifical dunes and faja 6 has a defence sea-wall. Faja 1, behind Punta Gorda, has begun stabilization thanks to the recent construotion of an artificial dune.

Faja 2 is preserved more or less in its natural state with a series of small lagoons. In faja 4 the northern end is now fully ocoupied by modern city buildings, and the quays and harbour wall of the Port of Vera Cruz; until recently this area was swampy and at a low level, whilst the original coast line ran approximately north-south.

The Beach to the North of Vera Cruz - To the north of the city the beach holds an orientation north-north-west, without any large variation for some thirty miles north of Tuxpam. As this orientation is that of the winds of maximum valocity, the formation of the sand hills have less importance than those in the fajas of the coast about Vera Cruz and in those which follow towards the south of this port.

Observed from an aeroplane one can see large stretohes in which the vegetation reaches almost to the coast. On occasions, one notes a single cordon of sand of appreciable height immediately alongside the beach which, not having received the full force of the wind charged with sand, has been able to support vegetation. On the coastal stretches forming angles of from 20º - 30º to the wind - such as that between Nautla and Tecolutla - two or three cordons of sandhills are formed without much danger from windborne sand invasion. A highway may be safely constructed right behind these cordons.

On this same coast north of Vera Cruz, when the orientation of the coast tends more towards the west, as in the case north of Punta Delgada, the same features occur as on the coast of Vera Cruz. The salient in the sea terminates in a mountainous cordon and limits beaches which face relatively to the north. The currents of air drift and lift the sands that form several sandhills and in flight, once transported over the edge of the cape, they fall into the sea. To the south of these irregularities one does not oome across the same aridity, the land remains protected from the strong winds and with the vegetation produces an agreeable countryside. However it is also subjeot to the same topographical movements as those already described at Mocambo.

## PROCEEDINGS TO ESTABLISH AND ORGANIZE THE VERA CRUZ DUNE AREA

### ARTIFICIAL DUNES

Antecedents.- Engineer Quevedo, builder of the first artificial dune at Vera Cruz, attributed the calamity of moving dunes to the destruction of the "woods contigent to the founding site of the city" by the early residents.

But the dunes were active long before the city was founded. So at least we are assured by Bernal de Castillo, soldier of Cortes and chronicler of the Conquest: "there before that island (Sacrificios) we all jumped to land, onto some large sand beaches where we built farmhouses and cabins with beams and sails from the ships"; and further on: "disembarked on some beaches, we made cabins on top of the sand banks which were large in that place."

Clearly then since its founding Vera Cruz has had the problem of its dunes, but an organized effort to dominate them dates from only fifty years ago with the works initiated by Miguel Angel Quevedo. This noted engineer directed the port works from 1890 to 1893 and understood the main difficulty "stemmed from the creeping sands of the beach exposed to the north winds, to the extent that the blocks for the jetties under construction have been buried by high hillocks of sand." Thence dates his proposal to do away with the scourge of the dunes, to which he attributed, among other evils "The unhealthfulness for which the port of Vera Cruz is famed". He also recognized that to drain the lagoons formed between the sandbanks, some means had to be found to prevent the sand from piling up and sealing the natural outlets.

In 1908 Quevedo began the formation of the first artificial dune between the levee and the Vergara arroyo on the north beach. He decided to use the artificial dunes of the French Landes as his model, although he introduced some modifications. One change he made was the use of saw-mill refuse in forming the wind-barriers thrust into the sand, in place of the usual fagots and arboura.

Sheet piling has various advantages. The logs of 2.5 to 3 mts. length are easy to transport and they may be recuperated with little effort when the movements of the dune exige a change in the location of the wall. In just two winters (1908-9-10) an artificial dune five mts. high was raised and in the ensuing year this height was raised to eight mts. Four years suffioed to produce such improvement in the area under the lee that the plugs of sand disappeared allowing drainage.

With the Revolution the works were ceased, ruining the artificial dune. It was reconstructed from 1917-20 - abandoned again - only to be renewed in 1929 and constantly improved up to the present day.

Behaviour of an Artificial Dune - The artificial dune in Vera Cruz has functioned very well, helping with time to improve the standards of life in the port and its suburbs. The land leeward of this artificial dune is no longer subject to a rain of sand, vegetation abounds and the lagoons have disappeared.

The system implanted by Quevedo is still being continued, with only some alterations in the placing of the first barricades.

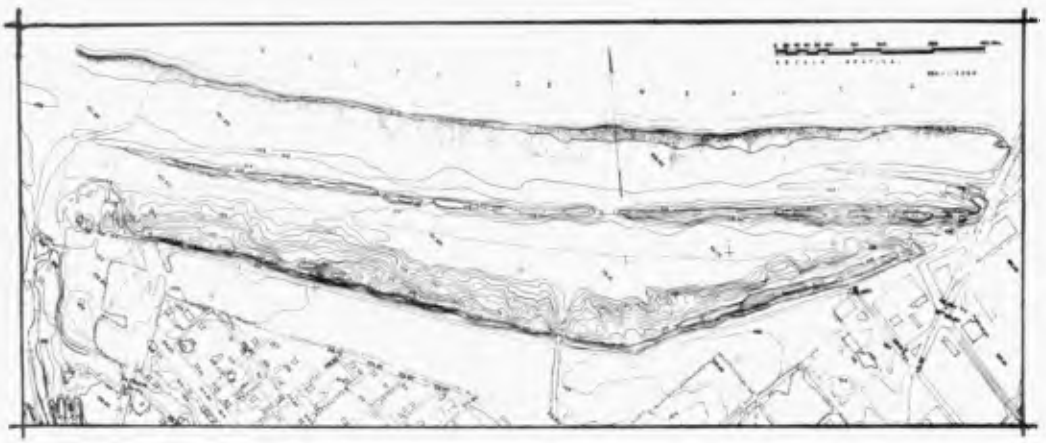

Fig. 3 - Artificial dunes in "Playa Norte" of Vera Cruz.

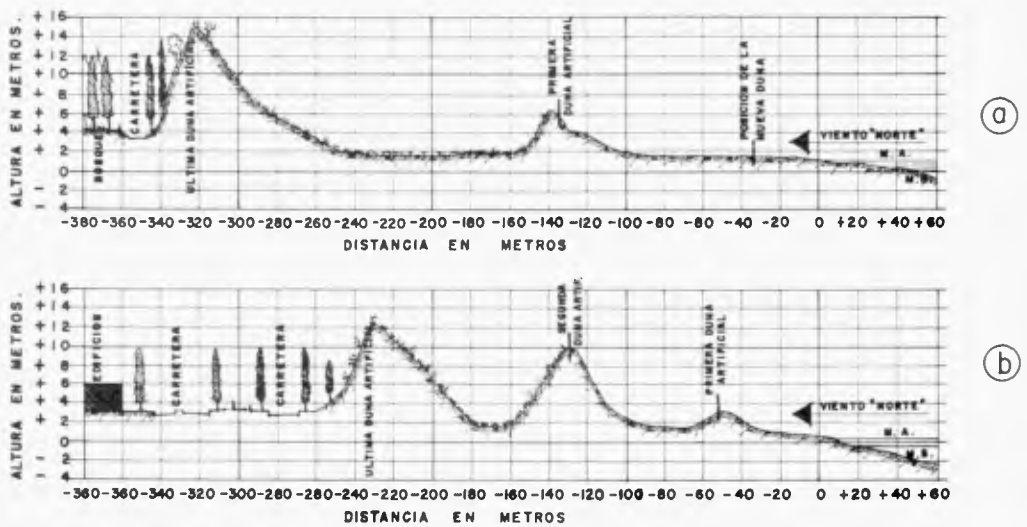


Fig. 4 - Transverse profiles of "artificial dune":

a) First dune is 135 meters from the sea, the second dune is vegetated, a new dune near the sea is necessary.

b) Two dunes with sheet piles are developing, the last dune is fixed by vegetation.

The first dune is established on the beach at about 20 mts. from the line of high tide in a direction normal to the wind. Originally Quevedo mad his first dune at 70 mts. distance from the sea (the same as that of the Gulf of Gascuña) and he recommended it to be built even farther back to avoid its destruction in seasonal gales. Since then we have learnt that it is best to place the first dune as close as posiible to the shore to prevent much windblown sand from carrying over the dune(Figs.3 & 4).

The wind on encountering the dune deposits sand against the fences. A ridge or hump grows up relatively quickly and the crest displaces itself as if pushed forward by the wind. This is because the sand is precipitated in large quantity after passing the barricade rather than falling in front of it. When the dune has advanced 100 mts. from the sea, a large dry beach remains. The wind acts over this broad surface to raise and disperse the sand. The dune is now too far from the sea to have any effect in retaining particles in movement, so a new dune is formed by erecting another palisade close to the sea. The new dune forms and increases more rapidly than the first until it overtakes and joins it. Again it becomes necessary to form another dune close to the water, and plant the other.

Behaviour of the Artificial Dune in a Northerly Gale. - A season of "Nortes" from October, 1952 to May, 1953 allowed us to observe the behaviour of the dunes under winds of hurricane force. On the 7th of October a fierce gale from the north-north-west drifted the sands of the 20 mts. wide beach and lifted them up the slope of the first dune despite its steep inclination (fig.5 ). It may be seen how the talus picked up the surface sand also. The squalls of ascending air on reaching the fence encountered other squalls and caused the dense vortices of suspended sand which was deposited about the obstruction.

The following day it was recorded that the beach from which the sand was blown had entirely disappeared and the water line had encroached to the foot of the seaward dune. On the second day the wind abated and it was found that the slopes on the land side were 29-33 degrees and on the seaward side 32-34 degrees. On the seaward slope several areas showed humps of sand well above the critical profile. The humps little by little resumed a normal inclination. The crest of the sandhill had moved considerably landward and heightened, whilst the old fence and its oresting had disappeared

After two days of the north wind the slope on the seaward side had lost on the average 60 cms. thickness. The vertical fences running transversally up both faces with the aim of reducing the force of the winds of oblique incidence were all destroyed after the third day of the "norte".

One curious effect worth noting was that a single sheet fence driven into the beach at a point above where it was 150 mts. wide had, in three days, created a small hillock about it no less than 1.5 mts. high. The wind dropped after 4 days and continued moderate until the 3rd of November it left the first dune entirely flattened and only a few fences standing in a half-ruined condition on the seaward slope.

In these 23 days the beach soon reestablished itself, in fact it was broader than before and the first sandhill was now 4-5 mts. farther away from the sea-line. The inland dune was replaced also, but to a lesser

Fig. 5 - The first artificial dune near the sea, a) before the hurricane, b) during the hurricane.

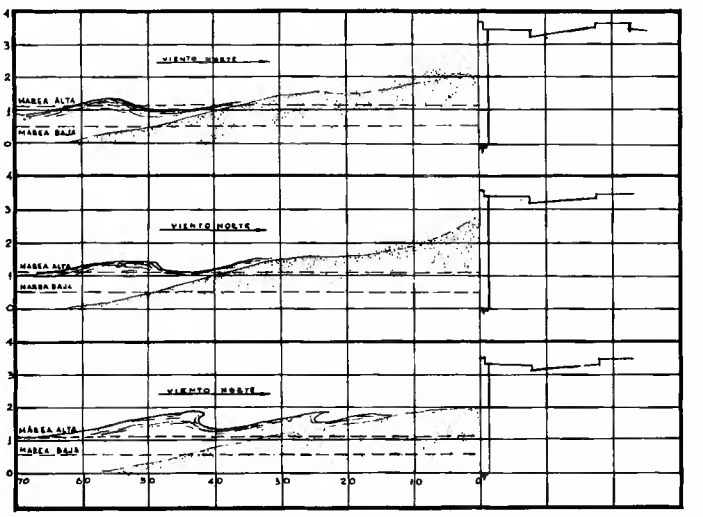


Fig. 6 - Drift and flight of sand from the beach is reduced by the sea wall. The last diagram shows the waves invading the beach and wetting the particles before being moved by the wind.

amount, although it was covered with firmly rooted vegetation. These phenomena demonstrate the wisdom of siting roads and structures well out of the range of sea action in areas which require the protection of artificial dunes.

Area Required for the Artificial Dune - In Vera Cruz the artificial dune has a normal width of 400 mts. from the beach, although it is reduced to 250 at places near the port where there is less space available. In this widht a pair of dunes are moving towards the third and last, which adjoin the highway called Circunvalación. On the other side of the highway there is a fence of loose brush ranging from 100-200 mts. width which serves to complete the functioning of the artificial dune.

In fact, then, artificial dunes act in the same way as natural dunes, only in a much more confined area. In the case of Vera Cruz artificial dunes retain sand but do not require, as do the natural dunes, a depth of borderland 8 kilometres long. When properly fenced and maintaine with adequate fencing, an efficient length of land need extend no more th 400 mts. from the beach.

## EFFECTS OF PROTECTION WORKS ON THE DUNES

Sea Walls - The dykes or sea defence walls constructed in Vera Cru have proved very effective in reducing the drift and flight of sand by wind action. This, of course, was not the reason they were built, their purpose was to protect the city from the violence of the sea and at the s time provide added amenities in the form of a marine promenade, roadway a tram route.

In effect these seawalls protect even more efficiently than artificial dunes the length of the strip in whioh they are constructed. When t sands tend to move and encounter a solid wall 2 or 3 mts. high in their path they pile up against the wall face. The partioles do not pass over because of the contained moisture and because the tide which follows the wind invades the narrow strip of beach in front of the wall, wetting it and impeding the flight of the particles. This excellent result would not have been achieved were it not for the small range of tides on this coast The maximum oscillation is 1.2 mts. On ooasts where the tide movements are much larger, low tide may uncover beaches hundreds of metres wide, a various barriers must be emplanted before the seawall to diminish the sa movements caused by wind. On the Vera Cruzian coast where the sea walls a well sited, the low water does not leave a great extent of beach: 40 to 50 mts. at the most, from which the wind removes little sand over the wall. It would be an error to place the sea wall too far from the water edge in those areas fronting the north for the purpose of obtaining a wide beach - the desire of the general holiday public - because, in such a case, the dry sand would be blown towards the wall, and spilling over, would travel inland.(fig.6).

It is a proven fact that the zones of Vera Cruz situated on or near the Marine Promenade are better protected from sand invasion than those in the lee of artificial dunes. The prolongation of the sea highway with its defence wall towards the south east has permitted the

construction of two new districts - "Reforma" and Costa Verde" - which would not have been possible with artificial dune areas. In the lee of the portion where the wall is constructed no sand is in movement.

Stone Barricades and Piles at Sea's Edge - Defence walls for their high cost can only be justified as a means of protecting coastal roads and urban areas. They are not the fit solution, however, to the problem of moving dunes.

But a palisade of stones, piles and horizontally placed logs can be formed which will function as well as a defence wall and at a much lesser expense. In Vera Cruz we experimented with such a palisade and got satisfactory results. The prolongation of the last stretch of the Costa Verde highway and wall was initiated in December, 1955, with the construction of the outer protective palisade shown in fig. 7 . At this point work was suspended and we have had a good opportunity to observe its behaviour with respect to the moving sands.


Fig. 7. (a) Palisade of stones, piles and logs protecting the beach in regretion S. E. of Vera Cruz. (b) Construction of the palisade.

The logs of the palisade were tied to the piles forming small compartments which were filled with stones ranging up to 500 kgs. These stones were packed as closely as possible to prevent the waves from displacing the piles and logs, while the latter in their turn helped to keep the stones fixed. The palisade is 1000 mts. long and was built rapidly and economically. The 3.5 to 4 mt. piles were sunk 2.5 mts. in the sand by means of an injection pump and a team of six men. Progress was made at the rate of 20-25 mts. daily. The rock fill was applied directly to the sand (with no excavation deemed necessary). A period of 75 days sufficed to see the work completed.

After the works of protection had been executed the waves, instead of beating against the wall, dissipated their energy over the stone rubble, and in front deposited sand. In a period of three months the stones had been almost completely covered by a depth of sand of 50 cms. The seasonal damage to the bordering vegetation ceased at once. The sand particles which had formerly penetrated this area were stopped up and plant growth allowed to flourish.

Since the completion of the palisade the beach has been renewed ar stabilized, and the dunes and sandy surfaces to the lee have diminished t the point of disappearing.

PLANTING AND OTHER METHODS OF STABILIZING THE DUNES

Without going into much detail on this subject, the type of plants which have been successfully utilised in the dunes at Vera Cruz should be mentioned.

In 1908 and 1909, when the initial phase of the construction of the artificial dunes was complete, grasses and shrubbery of the following species were successfully planted in the surrounding coast, mostly at the Island of Sacrificios: rootstock of common reed grass (arundo donax), "riñonina" or "frijolillo", cornizuelo or coastal acacia (acacia corniguera). Similarly varied species of the Opuntia class were planted. In order to complete the vegetation and coverage "privilegio", "buffet" and German hay have been added.

The "frijolillo" plant covers the sand rapidly and reproduces frequently, proportioning a large quantity of dry residue and humus to the arid upper strata of sand. In the second and third years of the formation of the dune, according to Quevedo, an intermediate seeding with "carrizo" was prescribed and after 1912 the planting of shrubs, in this case the Casuar Sunningham, which today has provided the best, most verdant results.

Various Works Contributing to Stabilization - In addition to the work previously cited, viz., artificial dunes, dykes, sea walls, barriers of vegetation, and forestation, other methods have been used to stabilize the Vera Cruz area, notably, paved roads, buildings, abundant provision o water, and the cultivation of small farms and gardens. Also mounds have been leveled, swamps filled in to distribute humidity more evenly, and this has greatly favored vegetation in areas where priorly "sand fountain from the beach had impeded it.

Such results indicate that sand dunes with similar characteristics to those in the Gulf of Mexico may be kept under definite control with reasonable economy, and that, moreover, they may be transformed into verdant pastures or become the sites of human habitats.