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Continuous Retaining Dikes by Means of Geotextiles

Digues continues de rétention au moyen de géotextiles

In the city of Cubatão, in São Paulo, Brazil, the City Hall, in conjunction with the D.A.E.E. Department of Water and Electric Energy, has been carrying out a large hydraulic fill project since 1980, a fill upon which will be built the city of "New Cubatão", with roughly 32.500 inhabitants. It was expected that this fill be contained along its entire length by dikes built with the soil derived from on-site excavation of the projected drainage channels. However, during construction on the very soft organic clay existing particularly in some spots, the drag lines would sink, despite the fact that the work was done on wooden grating. Field tests were conducted using geotextiles sewn together lengthwise and filled with the dredged material. Theses envelopes of fabric varying in length and with an average height of 1.4 meters successfully replaced the conventional dikes without burdening the work and allowed for a threefold increase (or more) in work performance time, even with rain. This paper deals with work site conditions, field tests performed, improvement of the filling process, and the building of more than 4.000 meters of continuous geotextile dikes.

La préfecture de Cubatão, São Paulo - Brésil, et le DAEE Département d'Eaux et Energie Électrique, exécutent depuis 1980, un grand terrassement hydraulique où sera construite la "Nouvelle Cubatão", ville qui aura une population d'à peu près 32.500 habitants. Ce terrassement aurait dû être retenu par des digues construites avec le sol local, provenant des creusements de canaux de drainage. Toutefois, pendant la construction, les "drag-lines" s'enfonçaint, particulièrement sur l'argile très molle existente en certains endroits, même travaillant sur des treillis de bois. Des essais de champ ont été alors exécutés, en employant des géotextiles cousus et remplis avec le matériel dragué. Ces éléments, de longueur variables et hauteur moyenne de 1,4 m, ont substitué avec succès les digues conventionnelles, sans être onéreux au chantier et permettant une vitesse d'exécution au moins trois fois plus grande, même sous la pluie. Ce travail rapporte les conditions locales du chantier, les essais effectués en champ et la construction de plus de 4.000 m de digues continues avec géotextile.

I . INTRODUCTION

In various Brazilians cities, a low-cost housing program is being developed to house the low income classes that usually inhabit the shanties in substandard living conditions offering poor health and hygiene conditions. Because it is a far-reaching and far-extending program, the solution making it economically viable lies on reclaiming useless land by building polders, mechanical fills, or hydraulic fills.

One of the areas to be benefitted by this programa is in Cubatão, São Paulo where a "New Cubatão" is to be erected with the infra-structure needed to house roughly 32.500 inhabitants in 6.500 homes. This area, however, was subject to flooding because of the tidal range, a problem requiring the study of two basic solutions: converting the entire area into a polder or making a hydraulic fill secured by dikes. The hydraulic fill proved a more economical solution provided that all dikes would be built with the material retrieved from projected channel drainage excavations.

When the work began in July, 1980, dragline performance was seen to be low, primarily when working on very soft silty organic clay. The machines would sink in the soft soil even when treading on wooden grating, and recovery of the machines was slow and difficult. Erection of the dikes with imported soil was out of the question in that the average distance of transport from source was 15 kilometers a factor that would make the project economically unfeasible.

The idea of using geotextiles as a containing medium arose in late 1980 with the news of a similar project being conducted on the Seine in France. Unfortunately, enough information on the project was not available, prompting the conducting of field tests to ascertain the problems associated with using the medium, observe what shape the medium would acquire, and determine fabric quantities and labor requirements for the job.

II. LOCAL CONDITIONS

The areas to be reclaimed are on the São Paulo State coast line in the boggy marshland between the Anchieta and Imigrantes highways. Filling the 130 hectares that make up the four large-sized blocks of the residential project call for 4×10^6 m^3 of material being dredged from a 40 hectare plot of land that, once the work is concluded, will be turned into a lake for the new city.

Probes made on site revealed the existence of three basic types of soil :

- fine sand ("good" soil)
- silty or clayey sand or sandy clay ("fair" soil)
- silty dark grey and very soft organic clay ("poor"soil)

Capacity of the "good"soil is likewise good, and therefore can be easily dredged, without presenting any problems The "fair" and "poor" soils, besides being problematic make up most of the area in question. After performing various tests, the following average values were adopted for calculating load resistance and capacity:

"Poor"soil: $\Phi_u = 0^o$; $C_u = 8.0$ kPa ; $\gamma_{sat} = 14.0$ kN/m^3

"Fair"soil: $\Phi_u = 15^o$; $C_u = 8.0$ kPa ; $\gamma_{sat} = 16.0$ kN/m^3

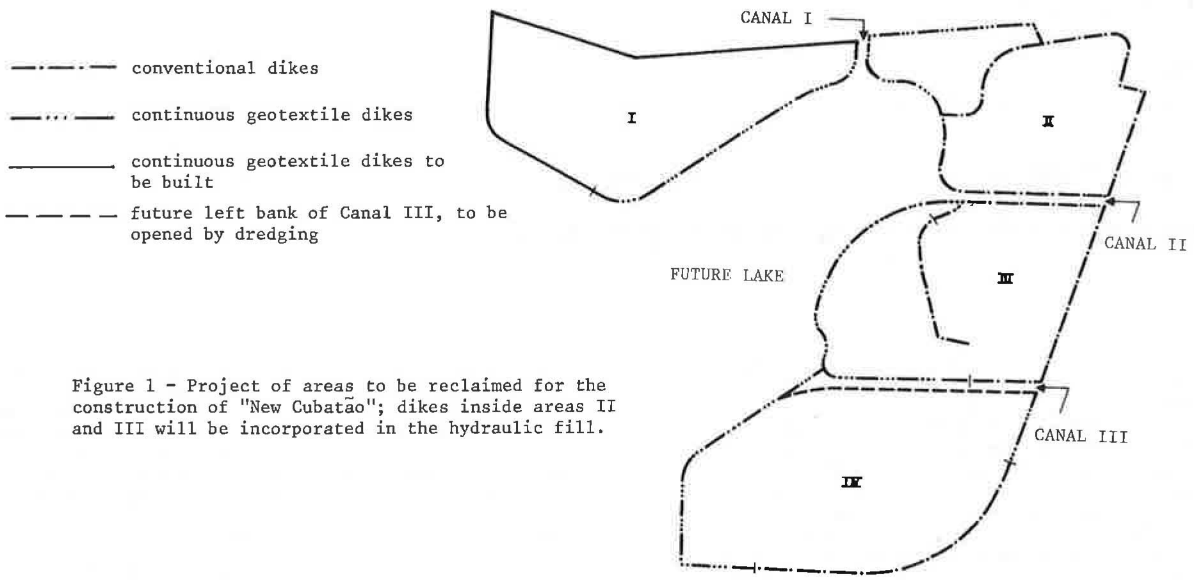

Figure 1 - Project of areas to be reclaimed for the construction of "New Cubatão"; dikes inside areas II and III will be incorporated in the hydraulic fill.

III. THE PROJECT AND THE WORK

The project calls for the building of 4 fill zones separated by drainage channels and adjacent to the future lake from where the soil will be taken. Datum points of fills, along their extremities and in contact with the dikes braces, range from 1.40 to 1.45 (height of the dikes is between 0.95 and 1.00, respectively). Toward their center, fills should have a datum point reaching 1.70 m, but average surface declivity should be 1 $^{o}/oo$ (figure 1).

After the site was cleared work began with dikes built by draglines, and fills built by dredging machines. In building the dikes two problems upset the work schedule :

- Regardless of the type of soil excavated, the deposited soil shape did not conform to project demands; the solution was to wait until the saturated soil dried and to form the dike manually in accordance with the project.
- In "poor" soils the draglines would sink even though treading over wooden grating; this hindered average machine performance considerably. Operating both over "good" or "fair" soil, each dragline was able to perform an average of 4 meters per hours of dike work; however, over the "poor" soil, its performance would drop to half of that amount. Therefore, in a daily 10 hour work period, each machine could render an average production rate of 20 to 40 meters of dike building.

The final shape of the dikes exhibited the following geometric features :

- height: 0.95 - slope inclination: 1V : 4H
- largest base: 15.10 m - cross section area: S = 10.73 m^2

IV. TESTS WITH CONTINUOUS DIKES

a) In France

In late 1980 we learned of an experiment performed using a nonwoven geotextile in a similar project. The goal of this experiment (1) conducted in August 1977 was to determine if, by filling a geotextile with dredged material, a sausage could be made to serve a provisional dike for a large hydraulic fill to be made at the estuary of the Seine in France. For this purpose, 300 meters of dike were built using two rolls of 5.30 m wide Bidim U-64 folded and sewn lengthwise. This enourmous "sausage" was filled by way of metal tubing joined to one of the ends of the "sausage".

During the filling process a rupture developedin the tube/geotextile connection, though it was fixed without any problem.

Also observed was a shift in the position of the dike toward the sea as the dike was being built, due to the launching of the fill and filling of the dike at the same time. The dike took on the shape of an arc, though this factor did not upset its purpose.

This first experiment done with nonwoven material was a complete success and encouraged us to conduct supplementary tests in Brazil for immediate on-site application.

b) In Brazil

first test :

At the same time as work was being initiated in Cubatão, São Paulo, a similar project had started in the city of São Luiz, Maranhão. In line with the program of building low-cost houses, the São Luiz project intended to build hydraulic fills secured by rock fill, since the tide range in that region was 7 meters. But the building of these rock fill embankments proved very expensive due to the great transport distance and great volumes involved. As a result, two solutions using geotextiles were proposed:

- containment using "sausages"
- containment using palisades covered with a geotextile and protected by small rock fills

In late 1980 expriments using the palisades were conducted following through with the entire building sequence. This solution proved to be technically and economically viable.

In January 1981 we began the first experiment with "sausages" in Brazil. The work conditions at this site differed greatly from those in Cubatão in that the dikes were built on beach sand and filled with sand. To broaden our knowledge of continuous dikes we decided to use Bidim OP-30, whose resistance to monodirectional traction is 16 kN/m, about half the resistance of the U-64 type.

Acoordingly, 50 meters of 4.30 m wide OP-30 were foldedin half and sewn lenthwise. One of the extremities was sewn together and the other joined to the metallic tube. The geotextile was extended and positioned so that the closed extremety lay at a lower datum point than the dredge-fed extremity. Filling of the sausage started at low tide while the hydraulic fill was being from one of the dredge tube sources. The sausage feeding pipe had a gate to regulate the outflow which could be controlled within a range from 0 to 1,000 m^3/h, and a 15% solid material concentration. Two problems arose: bursting of the nonwoven fabric 2 m beyond the tube/sausage junction, and bursting at the upper generatrix one meter from the closed end of the sausage.Also observed was a near 2 meter shifting of the dike (translation and rotation),that did not,however,hamper the experiment.The rupture at junction was due to the erosive cutting action of the jet of dredged material containing, besides sand, small sharp shells.The rupture at the opposite end was probably due to greater hydraulic pressure and seepage force,considering the spot was at a lower datum point.

We sewed a new sausage with the same measurements, but with a triple layer of nonwoven fabric in the first and last 8 meters. We proceeded to fill it in the same manner but this time no problems ensued. We observed that the dike takes on the shape into which it has been filled, further determined by its length, and that its cross section resembles an ellipse.

To derive the numerical correlations of the experiment, we presumed that the cross section was an ellipse. Thus the following formulas become valid:

$$S = \frac{\pi}{4} \cdot B \cdot H \quad \ldots\ldots (1)$$

$$p = \frac{\pi}{2} \cdot (B + H) \cdot \frac{64 - 3\left(\frac{B - H}{B + H}\right)^4}{64 - 16\left(\frac{B - H}{B + H}\right)^2} \quad \ldots\ldots (2)$$

In that : S = cross section area of ellipse

p = perimeter of ellipse

B = width of ellipse

H = height of ellipse

In the center cross section we measured the width "B", half-height " $\frac{H}{2}$ " and apparent height " H_a " -- defined in figure 2. Owing to the inclination of the beach surface, it was not possible to measure the useful height " H_u ". The following measurements were taken:

p_o = 4.20 m (undeformed perimeter)

B = 2.00 m (width of the dike)

H = 0.80 m (effective height of the dike)

H_a = 0.70 m (apparent height of the dike)

The following ratios were then determined :

$F = \frac{H}{B}$ = shape factor (adimentional) .... (3)

$\frac{p_o}{H}$ = perimeter/height ratio (adimentional)... (4)

$H - H_u$ =real sinkage (m) .... (5)

$H - H_a$ =apparent sinkage (m) .... (6)

$\varepsilon = \frac{(p - p_o)}{p_o} \times 100$ = average specific deformation along the length of the perimeter (%) .... (7)

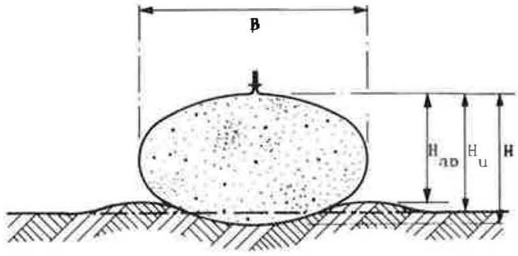

Figure 2 - Continuous geotextile dike cross section; symbols used: width (B), apparent height (H_{ap}), useful height (H_u) and effective height (**H**).

The following calculations were then made :

- using (1) .... S = 1.26 m^2 (cross section area of dike)
- using (2) .... p = 4.60 m (work perimeter of dike)

F = 0.4 (shape factor) .... (8)

$\frac{p_o}{H}$ = 5.25 (perimeter/height ratio) .... (9)

$H - H_a$ = (apparent sinkage) .... (10)

ξ = 9.5% (average specific deformation) ...... (11)

Because the project specified the height of the fill as 4.00 m, one possible solution was to terrace the fill on trree levels with an useful height of 1.33 m, each terrace. Assuming the real sinkage of the dike was 5 cm (half the apparent sinkage), according to (5) we have :

$$H = H_u + 0.05 \text{ m} = 1.38 \text{ m}$$

Thus three dikes would be needed with effective heights of 1.38 m, the undeformed perimeter of each being, according to (9):

$$p_o = H \times 5.25 = 1.38 \times 5.25 = 7.25 \text{ m}$$

Although the sausage solution was technically viable for this project, the alternative using palisades with Bidim OP-30 was adopted. This solution proved perfect: technically, economically and socially viable, absorbing a large local labor force recruited from future inhabitants of the area. (figure 3)

second test :

The second experiment with continuous dikes was conducted in February 1981 on the worksite in Cubatão. Test conditions,however,proved to be more several since the foundtion was a saturated organic silty clay with low bearing

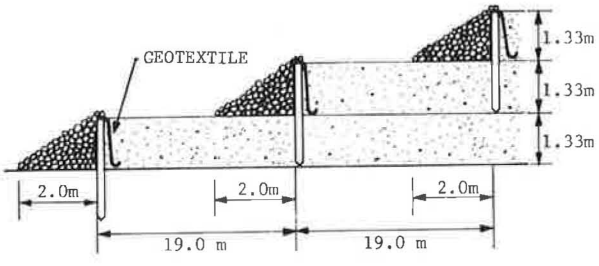

Figure 3 - Solution using palisades: wooden grates staked into the ground and covered with nonwoven geotextile

capacity, and the dredged material was the organic clay itself. Therefore, we could expect to have greater sinkage of the sausage and a greater strain on geotextile traction, since the clayey and/or silty particle would form a cake on the entire nonwoven inside surface. We opted in favor of using 4.30 m wide Bidim OP-60 with a 32 k N/m resistance to monodirectional traction. The geotextile, 90 m long, was sewn in the same manner as in the first test, with a double layer of fabric along the first 10 meters of the end connected to the tube and with a valve in the center section. The seam running lengthwise was positioned on the upper generatrix of the sausage. Were the internal pressure to rise greatly from the effect of the cake of fine particles, the seam on the valve would come apart. The tubing inlet had a 12 inch diameter and a gate allowing for outflow control within the range from 0 to 400 m^3 per hour, with a 20% concentration of solids. Once the test began, it took only 30 minutes of pumping to fill the entire sausage, which grew to an apparent height of 0.85 m.

During the filling process water managed to permeate the geotextile only in the first 15 minutes, subsiding to a very low level of permeability of the cake/geotextile during the latter 15 minute period. Once the control valve was closed the apparent height of the sausage had fallen to 0.65 m after 8 hours. New pumping cycles were effected but the height remained virtually unchanged.

From this test we could conclude that the "poor" material very conclusively could not serve as a filling for the sausage and that certain devices had to be created to allow for discharge of the clayey particles suspended in water during the filling process.

Is was not possible to measure the size of the dike's cross section in this test, in that an ellipse dit not take shape.

third test :

In March 1981 the third test was conducted. Based on results from the first two tests, the filling process was changed. As the idea was to incorporate this test into the work being done on site, it was necessary to estimate the perimeter "p_o" of the sausage to an useful height of 1 meter.

Estimating a real sinkage of 10 cm (double the amount adopted for the sandy foundation), using (5) and (9),we obtained :

$$H = 1.00 + 0.10 = 1.10 \text{ m} \; ; \; p_o = 1.10 \; . \; 5.25 = 5.78 \text{ m}$$

To attain this perimeter we had to make two longitudinal seams by joining two sheets of fabric. Since the loss of material in each seam was set at 0.10 m, two sheets of fabric would be needed, whose widths measured 5.98 m or more together. The solution was to use two bobins of OP-60 with a 100 m length, in that one's width was 4.30m and the other's was 2.15 m. Thus we achieved an undeformed perimeter of 6.25 m. The sheets of fabric were sewn with a portable Newlong NP-7 sewing machine, and a 2820 dtex nylon thread. The two ends were sewn together, and at every 20 meters (at the upper generatrix) a 0.30 m diameter opening was left unsewn. The filling process was done with a flexible plastic tube measuring 6" in diameter, inserted in the upper openings (figure 4). The dredger selected only "good" or "fair" material, and avoided picking up the organic clay. While the mixture of water and solid particles would enter one of the openings, only water with clay in suspension would be released from the other openings, thus eliminating the problem of increased hydraulic pressure inside the sausage. Only one problem arose during the experiment: at a given

Figure 4 - Sausage filling through a flexible plastic pipe.

moment it was noticed the occurance of a new material called "tabatinga", a soft pasty sedimentary clay with some grade of organic matter, wich during the pumping formed round clay pellets up to 10 cm diameter. As the pellets became deposited, advancement of the flow inside the sausage became obstructed; the solution was to switch the flexible pipe over to another opening. The test resulted in a dike measuring an useful height of 1.06 m filled hydraulically at atmospheric pressure.

V. ERECTING CONTINUOUS DIKES AT THE "NEW CUBATÃO" SITE

The total extent of dikes projected was 9,000 meters.Initially, 3,900 meters were built by excavating via draglines. However, 5,100 m still had to be built with the geotextile.

In June 1981 the continuous dikes started to be built with the adoption of one change in the spacing of the upper openings admitting and discharging the dredged material, from 20 meters to 8 meter (figure 5).

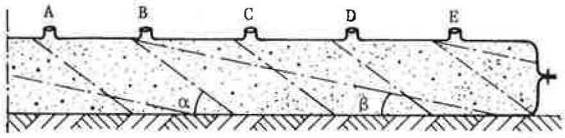

Figure 5 - Longitudinal section of the sausage;if the material is "tabatinga", feeding should be done successively through opening A, B, C, D, and E (material with a resting angle of α); if filling is done with "fair" soil, use only opening B and E (material with a resting angle of β).

In this fashion, the dikes could be filled with both the "tabatinga" and the "fair" material (figure 6), the only difference being the operational yield: the "fair" soil spread better, resulting in an approximate slope of 1 V : 20H, whereas the "tabatinga" settled with an approximate slope of 1 V : 8H, and required the successive introduction of the flexible feeding pipe in all dike opening.To avoid translation and/or rotation of the dikes during the filling process, which is done at the same time as the

Figure 6 - Cut section of sausage showing filling material already settled.

landfill process, the upper generatrix was anchored to the ground by ropes tied at 10 meter intervals. Filling was done via flexible plastic tubing fed by a I.H.C. 1500 dredger, a process wherein 250 m^3/h of dredged mixture was cast into the dikes and the balance of 550 m^3/h used to fill the area. In this way, a maximum of 16 m of sausage could be filled per hour per machine, and, on average terms (dredger maintenance), 12m/h/machine. Three dredgers operated 24-hours-a-day on the site, but only two had sausage-feeding inlets.

By employing continuous dikes at the site, changes could be made in the construction project of radial canals. In the original project, the canals were excavated by draglines and the excavated material used to build the dikes. With the new process, the areas are first filled and, after the fills have settled (an average of from 3 to 6 months), the canals are opened by the dredgers (figure 1). Hence, draglines were eliminated in site operations.

This was the process used to build 3,850 m of sausages (figures 7 and 8), using 25,000 m^2 of geotextile fabric, accomplished by the end of February 1982. By August 1982, the remainning 1,250 m should be ready, in all, a total of 33,000 m^2 of geotextile fabric.

To determine cross section features of these dikes we took measurements at 10 different spots along the length of the dikes built, and have shown the results in table 1, wherein all tests and projects described in this paper are summarized. In table 2 we have summarized features of the geotextiles employed. The economic studies made, determining the costs of such items as materials, labor, machinery and social charges, show that overall costs of the two construction processes, namely conventional dikes and continuous dikes with a nonwoven geotextile, are on a par. It can be said that there was a virtual compensation of energy costs spent in the original machinery-oriented project by the cost of the geotextile in the alternative project adopted.

Figure 7 - Final phase of hydraulic construction.

CONCLUSIONS

The experiments and sites described in this paper allow us to draw the following conclusions :

- It is entirely possible to construct continuous dikes by using nonwoven geotextiles of varying lengths and heights, and filled hydraulically with sand or other type of soil, provided it is a sandy one.
- The perimeter of the cross section of these envelopes resembles an ellipse.
- The greater the density of the solid material dragged into the sausage and/or the smaller the deformation module of the nonwoven fabric, the flatter the ellipse.
- In regions where the soil is of low bearing capacity, this system proves to be of particular interest; at the Cubatão work-site the introduction of continuous

Table 1 - Summary of experiments and sites with continuous dikes reported in this paper.

site/place	geotextiles	foundation	dredged material	lenght (m)	P_o (m)	B (m)	H (m)	H_{ap} (m)	H_u (m)	$H-H_{ap}$ (m)	$H-H_u$ (m)	F (-)	P_o/H (-)	S (m2)	p (m)	ε (%)
test in France	Bidim U-64	sand	sand	300	-	-	-	-	-	-	-	-	-	-	-	-
test in Brazil São Luiz-MA	Bidim OP-30	sand	sand	50	4,20	2,0	0,80	0,70	0,75*	0,10	0,05*	0,40	5,25	1,26	4,60	9,5
test in Brazil Cubatão-SP	Bidim OP-60	"poor" soil	"poor" soil	90	4,20	-	-	0,65	-	-	-	-	-	-	-	-
test in Brazil Cubatão-SP	Bidim OP-60	"poor" soil	"fair"soil or "tabatinga"	100	6,25	-	-	-	1,10	-	-	-	-	-	-	-
work in Brazil Cubatão-SP	Bidim OP-60	"poor" soil	"fair"soil or "tabatinga"	3850	6,25	2,70	1,42	0,82	1,06	0,60	0,36	0,53	4,40	3,01	6,63	6,1

* assumed values

dikes increased work performance time from a minimum of three times over to a maximum of eight times over the conventional process.

The lower the bearing capacity of the foundation, the greater the sinkage of the dike, reducing useful height.

Figure 8 - Finished dike and landfill; the filled area to the right and site of the future lake to the left.

The average specific deformations of the geotextile calculated for cross sections of the dike were less than 10%; in standard bidementional tests of stress vs. strain, the deformation at rupture of the nonwoven Bidim geotextile runs in the neighborhood of 30%; this leads us to assume a near 3 safety coefficient.

Analyzing the experiments performed, it can be concluded that there is much that can still be done, primarily in terms of better design of the dikes. Questions relating to stress vs. deformation at long term, filling with other materials, strains caused by overloading, sinkage as related to bearing capacity of foundation, the shape factor in terms of geotextile deformation module, the shape factor in terms od density of filling material, specific deformation along the cross section perimeter, etc., all require that further field and laboratory tests be performed in the future.

Table 2 - Features of geotextiles mentioned in this paper

nature	type	mass (g/m2)	normal permeabi-lity (m/s)	monodi-rectional traction (kN/m)	manu-factu-rer
nonwoven fabrics produced with mechanically needled conti-nuous polyester filaments.	Bidim OP-30	300	$2,2x10^{-3}$	16	Rhodia Brazil
	Bidim OP-60	600	$2,2x10^{-3}$	32	Rhodia Brazil
	Bidim U-64	550	$3,0x10^{-3}$	33	Rhône Poulenc France

Because it is an easy and quick method, we believe this new manner of constructing dikes can replace, in some cases, the traditional procedure used in building dams and roads, and in fluvial and marine construction sites.

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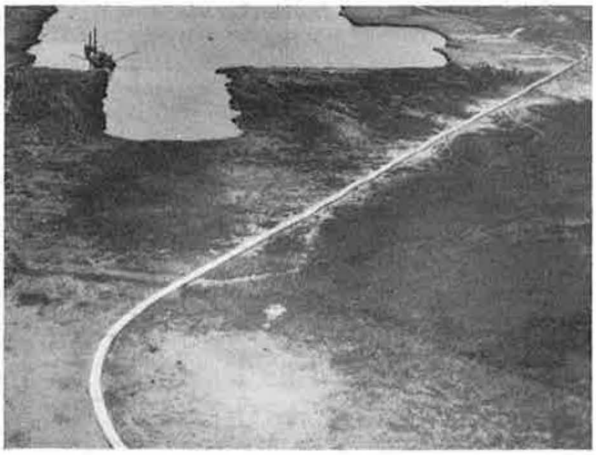

Figure 9 - Aerial view of continuous dike.