2. RESULT OF BORING AND SOIL TEST

2.1 General

The following field works and laboratory tests were carried out by the Contractor in Jamaica during the field investigation period.

Work item	Unit	Quantity
Field Works		
Drilling works	Site	13
Sampling	Nos.	9
Vane share test	"	9
Standard penetration test	"	37
Permeability test	"	10
Laboratory test		
Natural water content	L.S.	1
Wet density	Nos.	11
Permeability test	"	10
Consolidation test	"	5
Compaction test	"	5

The locations of boring test are shown in the Fig. E-1, and all test results are shown in Tables E-1 to E-5 and Figures E-2 to E-16.

1) Boring test

Thirteen boring tests were carried out in average depth of 11 m. It is found that the typical strata of the predominant area consists of peat, silty clay and decomposed limestone. The thickness of peat varies from 0 m to 13 m depending on the location. Under the peat layer there is clayey peat or silty clay. Decomposed bed rock (limestone) is found at 9 m below the ground surface on an average.

2) Standard penetration test (S.P.T.)

S.P.T. is made using bore holes at each one meter in principle. The results are shown in Figures E-2 to E-14. The average N-value at each layer is as follows;

Peat layer	0 to 2
Silty clay	12
Decomposed bed rock	40

3) Permeability test

The result of field permeability test shows that coefficient of permeability (k) of peat and clay is about 4×10^{-5} cm/sec. There is no large difference between the permeability of peat and the clay. The largest (k) of the decomposed limestone is 2.2×10^{-4} cm/sec as shown in Table E-1.

On the other hand, (k) of silty clay and peat is 1×10^{-5} to 1×10^{-7} cm/sec and that of limestone is 1×10^{-4} cm/sec based on the laboratory test result as shown in Table E-1.

4) Vane shear test

The result of the vane shear test shows that the shearing strength of peat is from 0.4×10^{-1} to 0.75×10^{-1} kg/cm^2 and that of silty clay is 2.5×10^{-1} to 8.3×10^{-1} kg/cm^2 as shown in Table E-2.

5) Wet density test

Nine samples were tested and the result shows that there is a remarkable difference between the wet density of clay and that of peat as shown below.

Type of soil	Wet unit weight
Silty clay	1.352 (1.800) kg/cm^3
Organic clay	1.069 "
Peat	0.982 (0.950) "

The value of the wet unit weight is necessary for the analysis of the movement of soil. The above listed value for silty clay seems to be too low compared with the results of experiments. Accordingly the modified value shown in parenthesis is to be used for succeeding analysis. This value for peat is also modified for the reason mentioned in the Section 3.3.

6) Compaction test

Five materials were tested and the result is shown in Fig. E-15 and E-16.

7) Consolidation test

Five consolidation tests were carried out and the result is shown in Table E-5. The result is not employed for further analysis but is used as reference because of the complicated nature of peat. This is also explained in detail in Section 3.3.

8) Water content test

Eleven tests were carrried out to examine the water content ratio of peat soil. According to the test result the average water content ratio is 355.5%. This result is remarkably different from the ones carried out by the survey team at the site. The result of the survey team is shown in Annex H. The reason why there is a big difference between the laboratory of the contractor test and the ones of the survey team is supposed that the peat sampled is dehydrated during transportation from the site to the laboratory of the contractor. Water content ratio of 1,200% is to be used in the study.

2.2 Foundation of Structures

1) Drainage pump station of the Black River left bank

The estimated depth of foundation of the pump station is 3 meters below the ground surface. According to the test result of Bore Hole No. 6, N value at that depth is N = 6.

The ultimate bearing capacity is assumed to be 8.28 t/m^2 by Terzaghi equation as shown below

$$qa = 1.2N\ (1 + 0.3B/L)\ (t/m^2) \ \ldots\ldots\ (2\text{-}1)$$

where qa = ultimate bearing capacity (t/m^2)

N = value of S.P.T.

B = length of the short side of the rectangular foundation (m)

L = length of the long side (m)

(assume L = 2B and safety factor, Fs = 3.)

On the other hand, the weight of the pumping station is assumed to be less than 5 t/m^2. This value is lower than the ultimate bearing capacity. Accordingly the shallow foundation is proposed for this pump station.

2) Drainage pump station of the Black River right bank

No boring test was carried out at the exact place of the station, however there is an island covered by stiff silty clay near the proposed station site. Since the bearing capacity of this upland soil is assumed to be strong enough to support the weight of the pump station, the shallow foundation type can be adopted for this pump station.

3) Drainage pump station of the Broad River left and right banks

As a result of site investigation, exposed bed rock can be seen at the site of these two pump stations. The shallow foundation type is also proposed for these stations.

4) Irrigation pump station at Lacovia

According to the boring test result (Bore Hole No. 1), N value of this site is about 12. The ultimate bearing capacity is assumed to be 16 t/m^2 based on the said equation (2-1). This is strong enough to support the weight of the pump station. Accordingly the shallow foundation type can be adopted.

5) Weir in the Y.S. River

The exposed bed rock of limestone can be seen at the present river bed. The weir structure is proposed to be constructed directly on this bed rock after excavating the projecting part of the rock and overburden.

2.3 Borrow Material for the Construction of Irrigation Canal

1) Mountainside canal

The proposed borrow pit is located at the upland area in Hatfield. The area of this site is estimated about 0.5×10^6 m^2. The Boring test (Bore Hole No. 12) and laboratory test were carried out.

The thickness of the clayey overburden is about six meters according to the test result. Therefore 0.5×10^6 m^3 of soil can be borrowed from this site, even if the area is excavated 1.0 m in depth. On the other hand, the necessary soil volume for the canal construction is estimated to be 6×10^4 m^3. Accordingly this pit can supply sufficient material for the construction.

The permeability test result shows that the silty clay is almost impervious (i.e., coefficient of permeability is less than 1×10^{-7} cm/sec. Refer Table E-1 PERMEABILITY TEST RESULT)

As a result of compaction test, the maximum dry density is 2,090 g/cm^3. (Refer No. 5 compaction test result.) Consequently the material of this borrow pit is suitable for the construction of irrigation canal.

2) Slipe canal

The same borrow pit for the Mountainside canal is also proposed for the construction of this canal. The necessary volume of materials for the construction is about 100,000 m^3. Proper materials can be also borrowed from the pit in Hatfield.

3) Y.S. River canal

This canal is constructed mostly by means of cutting of the soil. As the excavated clayey soil is to be used as embankment material, it is not necessary to look for borrow pit for this canal.

2.4 Aggregate of Concrete Work

1) Fine aggregate

The borrow pit of sand available is very limited around the project area. The nearest pit is located at Thachfield, about 9 km from the Salt Spring Bridge to the south. The quantity is estimated to be more than 0.5×10^6 m^3. On the other hand proposed concrete volume and soil cement is to be 50×10^3 m^3. Therefore the sand volume at the borrow pit is sufficient for this project.

Although the grading size of this sand is rather small, it will be possible to be used as fine aggregate for concrete works. The gradation analysis test is necessary during the period of the detailed design.

2) Course aggregate

The exposed limestone can be seen everywhere in and around the project area. They are, however, highly weathered and not suitable as material for concrete works. Relatively stiff limestone was found at Burnt Savanna and in Holland Estate. Since there is no appropriate crushing plant in the vicinity, a portable plant is to be installed at the said places.

3. CONSTRUCTION OF POLDER DIKE

3.1 Construction Method

In general the water content ratio and void ratio of peat are very high compared to those of clay and sand, resulting in a large amount of settlement. Physical settlement of the peat consists of consolidation and plastic flow. Its initial strength is so small that plastic flow will occur when a load is applied.

There exist very deep areas with 10 m thickness of the peat in the project area and its shearing strength is very low. Cone index (qc) is less than 0.5 kg/cm^2. In the planning of the construction of polder dike on such peat layers, comparison of several method of construction, displacement method and other appropriate methods, were made.

In this project, the displacement method was not considered suitable for economic and technical reasons. Because of the relatively high thickness of the soft peat layer which has to be displaced, a large amount of clayey soil would be necessary to replace the soft layer. The excavation of the submerged peat would be difficult. It would also be difficult to get adequate amounts of clayey soil in the vicinity of the project area because the clay overburden on the limestone is very thin. Therefore, appropriate other counter measures would have to be considered.

Generally, the stability of an embankment constructed on a soft soil assumes failure along a curved sliding surface in the soil. This stability is shown by the ratio between total shearing resistance ($\Sigma\tau f\cdot\ell$) and total shearing strength ($\Sigma\tau.\ell$) along the sliding surface. This ratio is called the safety factor.

- Safety factor $Fs = \dfrac{\Sigma\tau f\cdot\ell}{\Sigma\tau\cdot\ell}$

However, the actual phenomenon of failure in peat soils is different from the above because of the importance of plastic flow.

On the other hand, settlement of the embankment is analysed with respect to consolidation independent of the question of stability. For peat soils, settlement by plastic flow is inevitable. Theoretical estimations of settlement in peat differ largely from those determined by actual field observations. For determinations of settlement and stability in peat, it will be reliable to use empirical formulas which were formulated from the results of actual construction works. These estimates will finally have to be corrected by observations of the movement of the embankment, during some period before and after completion of the embankment. In the actual construction, it is necessary to anticipate a sufficient safety factor and to observe constantly the movement of embankment during the construction. The consolidation of embankment requires a rather long period of time. In this context a staged construction is considered to be the most economical and effective, as special equipments and materials would not be required.

The initial shearing strength of peat is known to be very low, but it shows rates of increase in strength with increasing degrees of consolidation, much higher than characteristic of other soils. Therefore, by adopting a staged construction method and taking enough time for adequate consolidation at each stage, the shearing strength of the peat can be expected to increase to accommodate successive stages without failure.

3.2 Embankment Materials

The materials excavated from the drainage channel are to be utilized in the construction of the embankments of the polder dikes as well as roads. In this case, the following advantages and disadvantages are expected:-

(a) Suitable borrow pit sites for appropriate clayey materials is limited in the vicinity of the project area requiring long hauling distance of materials resulting in costly embankment. Use of the excavated peat material in the nearby embankments is therefore the most economical solution.

On the other hand, a first stage allowable embankment height is calculated by the following equation;

$$hc = \frac{No \cdot C}{\gamma_E \cdot F} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}1)$$

where hc = allowable embankment height

γ_E = the average unit weight of peat after air dried ($0.8\ t/m^3$). Refer Section 2.3.1

No = coefficient of stability (5.5)

C = shearing strength of peat, calculated from the cone index qc

$$C = \frac{1}{20}\ qc\ (t/m^3) = \frac{1}{20} \times 0.5 = 0.25\ t/m^2 \quad \ldots\ldots \quad (3\text{-}2)$$

(Refer Annex G)

F = safety factor (assume 1.13).

As a result of calculation, the height of the first stage embankment should not exceed 1.5 m. The addition of the next stage should await about 80% consolidation of the embankment. The embankment height is determined with reference to ground surface elevation. The groundwater level is assumed to be the same as ground surface elevation.

Settlement of the embankment will occur during consolidation and it will therefore be necessary to carry out additional embankment to compensate for the loss in height and load. Embanked peat which settles below the ground water surface, does not work as a consolitation load, hence the need for additional banking to maintain a constant load.

3.3 Settlement of Embankment on Peat Land

3.3.1 Extent of settlement

Actual settlement of the peat land is known to be different from the result of theoretical calculations based on the conventional consolidation test, due to the existence of plastic flow. Therefore constants of settlement used were based on the results of other simple tests. A statistically treated correlation between natural water content (W) and e - log P curves was utilized.

Final settlement was calculated using the following equation which describes the correlation between w and e - log P curve (Refer to Fig. E-16).

$$S = \Sigma \Delta S = \left(\frac{e_o - e}{1 + e} \cdot H\right) \quad \ldots\ldots\ldots\ldots\ldots (3\text{-}3)$$

S	-	Final settlement (m)
ΔS	-	Settlement at each layer (m)
e	-	Void Ratio at $P_o + P_z$ ($P_z = I_z \cdot \gamma_E \cdot h$)
e_o	-	Void ratio at pressure of over-burden (Po)
H	-	Thickness of consolidated layer (m)
γ_E	-	Unit weight of embankment ($^t/m^3$)
h	-	Height of embankment (m)
I_z	-	Coefficient of pressure influence
Po	-	Pressure of overburden (t/m^2)
P_z	-	Additional pressure (t/m^2)

Coefficient of influence I_z in the formula was found in the Fig. E-17.

(a) Unit Weight of Wet Peat

From the result of natural water content tests, average natural water content was found to be 1,216%. This value varied from place to place and layer to layer, but no significant tendency was found in the test results. Therefore, a water content of 1,200% was used in the settlement analysis of the total area.

The unit weight of wet peat (γt) was indicated by Fig. E-18 to be 0.95 t/m^3.

(b) Unit weight of air dried peat

Measurement of water content for 35 air dried samples were made. An average result of W = 700% was obtained.

Saturated peat is excavated and then utilized for the construction of polder dike. Though surface of the embanked materials will dry gradually, the bottom of the embankment will remain saturated due to the high groundwater table.

In the analysis of settlement, the increase of pressure is brought by means of loading. The assumption is made that the water content ranges from the initial water content, 1,200% to the air dried water content, 700%. An average 1,000% seems to be reasonable. The corresponding average unit weight of embanked peat is calculated at 0.8 t/m^3 ignoring shrinkage due to disiccation. Consequently the amount of settlement is calculated by adopting the above mentioned equation and figures. The result is shown below.

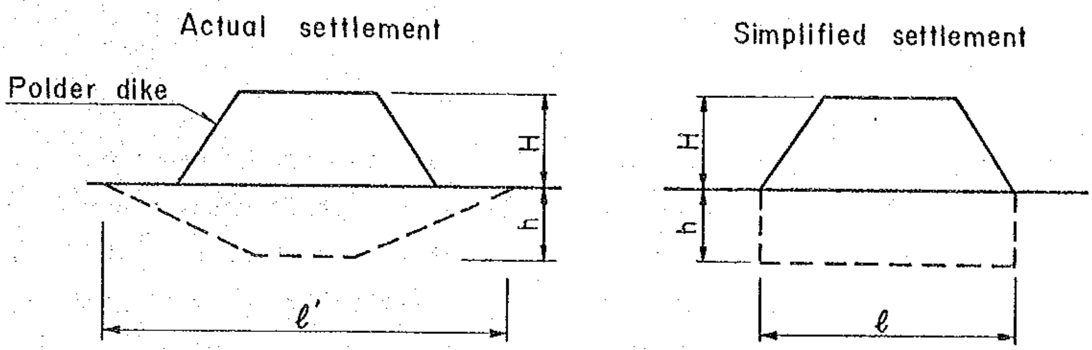
Amount of settlement at main dike embankment

(m)

Thickness of peat (m)	Height of embankment (m)		
	1.0	1.5	2.0
10	1.38	2.09	2.61
8	1.22	1.78	2.25
6	1.03	1.44	1.85
4	0.78	1.08	1.38
2	0.50	0.72	0.90

(Refer Tables E-6, E-7 and E-8).

The actual volume for construction of polder dike is to be computed taking the above mentioned settlement into consideration. Generally the influence of settlement will reach to the nearby ground surface as illustrated below (left). However the extend of influence is indefinite based on the any theories of soil mechanics particularly in case of peat ground. Consequently it is determined as illustrated below(right) for practical purposes.



Where H: height of embankment

h: amount of settlement calculated by the consolidation theory

ℓ': actual range of settlement (This is known by means of the observation in the actual construction site.)

ℓ: provisional range of settlement used in the calculation of construction volume

The embanked peat will shrink according to time due to desiccation. The degree of shrinkage was examined during the field investigation period. The test result is shown in ANNEX H. According to the result three-dimensional shrinkage was observed, namely the original volume will decrease as shown in the next equation.

$$Vd = Vo \times (1-a) \times (1-b) \times (1-c)$$

where Vd: volume after desiccation,

Vo: necessary volume embanked,

a: vertical shrinking ratio = 0.194,

b: long side shrinking ratio = 0.114,

c: short side shrinking ratio = 0.117

Therefore the actual construction volume (V) is calculated as follows.

$$V = Vo \sum_{n=1}^{n} (1-0.63)^{n-1} + h \times$$

$$= Vo \times \frac{1}{1-0.37} + h \times \ell = 1.59 \times Vo + h \times \ell$$

where, n: time of embankment work

The figures used for the cost estimation shown in Annex is to be derived from the above mentioned equation.

3.3.2 Settlement time

The determination of settlement time is usually made by means of coefficient of consolidation (Cv). The consolidation test results and consolidation theory by Terzaghi, are used in the calculation of this coefficient. However, the actual settlement of the polder dike on peat lands, is known to be different from that obtained from theoretical calculations. In this project empirically derived factors concerning settlement time were used. The elapsed settlement time (t) was calculated using an empirically derived coefficient of consolidation in the following equation.

$$t = \frac{H^2 \cdot T}{Cv} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}4)$$

where, t: Time elapsed

H: Thickness of peat layer

T: Time factor

Cv: Coefficient of consolidation (3.0 to 8.0 x 10^{-2} m^2/day)

The Time Factor (T) is dependent on the degree of consolidation as listed below.

Degree of consolidation U %	T	Remarks	
10	0.008	U =	$\frac{Sn}{Soc}$ x 100
20	0.031		
30	0.071	Sn ;	amount of settlement at arbitrary time
40	0.126		
50	0.197	Soc ;	final amount of settlement
60	0.287		
70	0.403		
80	0.567		
90	0.848		

As the clay which exists under the peat layer is almost impermeable, the elapsed settlement time (t) be calculated under the condition of one side drain. It is desirable to install a 0.6 - 1.0 metre thick sand mat on the ground before construction of the embankment, but no proper borrow pit for sand exists in the vicinity of project area. For this unavoidable reason, the excavated peat has to be placed on the peat ground directly.

The results of the calculation of elapsed settlement time are summarised below and the time - settlement curve shown as Fig. E-20.

Thickness of peat Layer (m)	Period reaching at U - 80 (days)
10	1,150
8	720
6	400
4	180
2	45

A consolidation coefficient of 5 x 10^{-2} m^2/d was assumed in the above results.

3.4 Seepage through the Foundation of Polder Dike

The polder dike is constructed on the peat or clay which overlies decomposed limestone. Fig. E-16 shows a typical cross-section of the dike.

The coefficient of permeability of peat and clay is about 4×10^{-5} cm/sec based on the test result. This figure shows that the volume of seepage from the outside of the polder dike through the dike itself and through the clayey ground which supports the dike is expected to be so small.

On the other hand, the coefficient of permeability of underlying decomposed limestone is 2.2×10^{-4} cm/sec as shown in Table E-1. The amount of seepage water through this layer seems to be larger, than that of peat and clay.

The volume of seepage through the decomposed limestone is calculated at 5.9×10^{-7} m^3/sec by Darcy's Law as shown below.

$$Q = k.A.i = k.A.\frac{\Delta h}{\ell} \quad (m^3/sec) \; .... \; (3-5)$$

where k = coefficient of permeability

A = area of flow: assume 2 m^2/m

i = hydraulic gradient $= \frac{2}{15}$

Δh = difference of head: assume 2 m

ℓ = distance at Δh : assume 15 m

(See Fig. E-20)

The estimated seepage from the limestone is small enough to ignored when comparing with the proposed capacity of the drainage pump.

4. CONSTRUCTION OF DRAINAGE CHANNEL

Excavation work on peat ground is mainly concerned with the construction of drainage channels. In the excavation on the peat ground, problems generally involved are (a) bulging, (b) failure of cut slope, (c) heaving at the base and (d) settlement of adjoining ground surface. These problems result from the extremely low shearing strength of the saturated peat. Accordingly excavation of peat ground in the project area will be made in stage wise construction. The excavation of the main drainage channels are to be executed along with the embankment of polder dikes, allowing enough time for adequate consolidation at each stage of construction.

Drain pump stations are to be constructed as a first priority of this project and after completion of the first stage polder dike, drainage work will be commenced to permit additional excavation and completion of the drainage channels.

5. CONSTRUCTION OF IRRIGATION CANAL

The construction of the irrigation canal is to be made after the ground surface has been drained (i.e., after the construction of drainage pump station, first phase polder dike, and drainage channel). In this case, initial void ratio will be changed as shown in Table E-12 due to consolidation of the underlying peat, by the load applied by the layer of the air-dried peat.

To construct irrigation canal on the peat layer, it is necessary to take specific measures during its construction, which take account of the small shearing strength and significant settlement of the peat.

The embankment material is to be clayey soil to minimise leakage from the canal. The unit weight of clay is expected to be 1.80 t/m^3 which is much heavier than peat. Use of Equation (3-1) (section 3.2) to compute a first stage height for the clay embankment provides for a value of 0.7 m. Such a thin layer of clay would not have enough strength to support the heavy equipment used in the construction of the canal. Also, such a small incremental height would extremely necessitate long construction period for high embankment, as required in the Styx River area. The first stage height is proposed to be 1.0 meter based on field observations of the existing small scale dike constructed in the project area. The same staged method as proposed for the construction of the polder dike is also to be used to construct the irrigation canal embankment. The 1.0 meter first stage clay embankment is to achieve 80% consolidation prior to the second phase increment. This consolidation period will vary depending on the thickness of the underlying peat layer, as follows.

Thickness of peat Layer (m)	Period (days)
10	1,150
8	720
6	400
4	180
2	45

During the period of consolidation, additional embankment will be required to maintain the initial consolidation load. The additional height (h) needed to compensate a loss in load is given by the Equation (5-1) below.

$$h = \frac{h_1 + d \times \gamma e - d}{\gamma t} \qquad \text{assume } h_1 \gg d \text{ .... (5-1)}$$

where h = additional height of embankment (m)

γe = unit weight of semi-aired dried peat (0.8 t/m^3)

d = drained depth (0.6 m)

γt = unit weight of clay material (1.8 t/m^3)

h_1 = total settlement (m)

Consolidation of 80% must be achieved at each stage of embankment construction. At the final embankment height, after 80% consolidation achieved, the canal shall be excavated in the crest of the embankment.

The extent of settlement, total embankment height and number of construction stages for various depth of peat and a drained depth of 0.6 m are summarised below.

	Original thickness of Peat Layer (m)				
Item	10	8	6	4	2
Period when peat layer will be consolidated at 80% (Years)	9.5	5.9	3.3	1.5	0.4
Final height from the ground level (m)	2.01	2.36	2.29	2.67	3.08
Total embankment in height (m)	6.33	5.90	4.88	4.38	3.92
Numbers of stages of embankment (times)	3	3	3	3	3

(Refer to Tables D-7, D-8 and D-9).

The actual construction volume including settlement is calculated as explained in Section 3.3.1. Furthermore the final extent of settlement for various thickness of peat and height of embankment is illustrated in Fig. E-21.

6. SETTLEMENT OF FARM LAND AFTER DRAINAGE

The settlement is caused by different processes, being :

- desiccation of de-watered layer,
- consolidation of the subsoil,
- oxidation of organic matter.

6.1 Effect of Dessication

In its natural state the peat is extremely wet and soft. Its natural water content and shearing strength were determined at 1,200% and 0.25 t/m^2 respectively. (Refer Sections 3.2 and 3.3.1.)

This extremely high water content lead to a considerable shrinking upon drying, which is one of the causes of the settlement of the land surface after drainage.

Effect of desiccation has been estimated at 20% of drained and dried depth based on the field experiment made by our survey team. The result is referred to in ANNEX H.

6.2 Effect of Consolidation

An evaluation of this effect was based on the following assumption :-

(a) The consolidation of the lower peat strata will occur as a result of the increased weight of the overburden. At present there is no overburden on the peat. The effective weight of the fully submerged peat itself is almost zero. Therefore no spontaneous consolidation occurs. However, if drained the weight of the peat becomes about 0.8 t/m^3. This will exert a pressure on the lower peat strata which has a large compressibility (Refer section 3.3.1 b).

(b) The calculation of the amount of settlement resulting from consolidation is made using the theory mentioned in Section 3.3.1.

6.3 Effect of Oxidation

The peat is formed in a submerged and oxygen depleted (i.e., reducing) environment. When the peat is drained it comes into a sub-aerial oxygen-rich environment and it is consumed by aerobic microfauna.

In order to make the organic peat soils suitable for agriculture it is necessary to drain it. However, to minimise settlement due to oxidation, drainage should be restricted to permit as high a water table in the peat as possible.

A study in Indiana showed annual settlement of 1.1, 1.8 and 3.0 cm when the water table in peat was lowered by drainage to depths of 42, 68 and 98 cm below the surface of the peat. (Jongedyk et al, 1950). In Minnesota, settlement of 15 and 60 cm over a 5 year period were observed to result from a lowering of the water table by depth of 30 and 135 cm respectively (Roe, H.B. 1983). Under climatic conditions of the Florida Everglades, reductions in the height of the water table 30, 60 and 90 cm resulted in settlement in peat of 1.6, 3.6 and 5.7 cm per year, respectively (Jones, 1948). These data indicate that if the depth of the peat soil above the water table is doubled then the rate of settlement is also doubled. Another Florida Study has shown that the rate of settlement in peat soils for both vegetable fields and pastureland were similar, but was about 30% less for sugar cane lands (Shih et al, 1977). However this amount by settlement reported in above mentioned studies is caused by not only oxidation but also consolidation and desiccation. Effect of oxidation would be smaller than these figures.

In this project it is proposed to use the peat soils to support paddy cultivation. Therefore, the soils will remain flooded for relatively long periods of a year resulting in a lower rate of settlement due to oxidation than is reported for other crops. Oxidation induced settlement may also be reduced by keeping the peat soils flooded when not being utilised and by adding the residual rice straw to the surface of the paddy field.

It is estimated that the use of the above mentioned practises will limit the rate of settlement due to oxidation to about 0.5 cm per year. Therefore, settlement to be expected after 25 years of drainage of the Black River Lower Morass, assuming a drainage depth of 0.6 m and use a paddy field, are as shown below.

Initial thickness of peat (m)	Settlement by consolidation (m)	Shrinkage (m)	Oxidation (m)	Total (m)
2	0.14	0.12	0.13	0.39
4	0.33	0.12	0.13	0.58
6	0.50	0.12	0.13	0.76
8	0.64	0.12	0.13	0.89
10	0.72	0.12	0.13	0.97

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Table E-1 PERMEABILITY TEST RESULT

1. FIELD TEST

Borehole No.	Diameter of borehold (CM)	Depth of the test (CM)	Coefficient of permeability (CM/SEC)
1	10.16	305	7.45×10^{-5}
1	10.16	700	2.2×10^{-4}
2	10.16	305	7.57×10^{-5}
2	10.16	892	3.90×10^{-5}
4	10.16	305	1.64×10^{-5}
4	10.16	792	2.73×10^{-5}
5	10.16	305	1.09×10^{-5}
11	10.16	305	6.40×10^{-5}
11	10.16	1006	7.79×10^{-5}
12	10.16	914	1.08×10^{-5}

2. LABORATORY TEST

Sample identification	Sample depth taken (m)	Soil type	Coeff. of permeability cm/sec
Borehole No. 1 (T.W.S.) Lacovia	2.5 ∿ 3.0	Silty clay undisturbed	9.8×10^{-6}
Borehore No. 7 (T.W.S.) Lacovia	2.5 ∿ 3.0	Silty clay undisturbed	1×10^{-5}
Borehole No. 8 (T.W.S.) Broad River	2.5 ∿ 3.0	Silty clay undistrubed	1×10^{-5}
Borehole No. 9 (T.W.S.) Baptist Sample No. 1	2.5 ∿ 3.0	Peat undisturbed	2.0×10^{-5}
" Sample No. 2	8.5 ∿ 9.0	"	6.4×10^{-6}
Decomposed limestone compacted at opt. moisture content	0	Decomposed limestone	1.1×10^{-4}
Sample compacted at opt. moisture content	0.1 ∿ 0.3	Peat	1×10^{-7}
Taken in Holland Estate and compacted	0.5 ∿ 0.8	Clay	1×10^{-7}
Taken in Hatfield and compacted	0.2 ∿ 0.5	"	1×10^{-7}
"	0.2 ∿ 0.5	"	1×10^{-7}

Table E-2 VANE SHEAR TEST

B.H. NO.	SOIL TYPE	READINGS (KG/CM^2) x 10^{-1}	DEPTH (M)
1.	Silty clay	5.5	3.5
4.	"	7.5	3.5
5.	"	7.5	4.5
6.	"	2.5	4.5
7.	" with organics	0.5	3.5
8.	Peat	0.4	3.5
8.	"	0.75	5.5
9.	"	0.5	2.5
10.	"	0.5	4.5
10.	"	0.5	8.5
12.	Silty clay	8.25	4.5

Table E-3 MOISTURE CONTENT TEST

Location	Description of soil	Water content ratio (%)
Baptist	Peat	462.2
Baptist	Peat	238.6
Baptist	Peat	129.7
Baptist	Peat	516.4
Baptist	Peat	760.4
Baptist	Peat	421.3
Baptist	Peat	360.4
Baptist	Peat	150.6
Styx River	Peat	160.1
Styx River	Peat clay	70.6
Styx River	Peat clay	57.4

Table E-4 WET UNIT WEIGHT (γt)

Sample identification	Sample depth (m)	Soil type	t(Kg/cm^3)
Borehole No. 1 (T.W.S.) Lacovia	2.5 ∿ 3.0	Brown silty clay with some organics	1.537
Borehole No. 7 (T.W.S.) Lacovia	2.5 ∿ 3.0	Medium brown silty clay	1.130
Borehole No. 5 (T.W.S.) Cataboo	2.5 ∿ 3.0	Light brown silty clay	1.614
Borehole No. 6 (T.W.S.) toward Cataboo	3.5 ∿ 4.0	Brown firm silty clay	1.078
Borehole No. 7 (T.W.S.) Black River	2.5 ∿ 3.0	Soft silty clay with some organics	1.363
Borehole No. 8 (T.W.S) Broad River	2.5 ∿ 3.0	Very soft black peat	0.988
Borehole No. 10 (T.W.S.)	3.5 ∿ 4.0	Soft organic clay	1.003
Bore hole No. 9 (T.W.S)	3.5 ∿ 4.0	Very soft black peat	0.976
"	8.5 ∿ 9.0	Dark grey clayey peat	1.134

Table E-5 CONSOLIDATION TEST RESULT

Sample number / Item		1	2	3	4	5
Bore hole No.		1	7	8	9	9
Depth of sample (M)		2.5 ∿ 3.0	2.5 ∿ 3.0	2.5 ∿ 3.0	3.5 ∿ 4.0	8.5 ∿ 9.0
Description of soil		Silty caly	Organic clayey soil	Peat	Peat and clay	Clayey peat
Initial void ratio e		1.5	2.7	3.7	2.72	0.93
Preconsolidation pressure (kg/cm^2)		0.48	0.36	0.33	0.25	0.28
Compression index Cc		0.368	0.795	2.000	1.225	0.46
Coeff. of consolidation cm^2/sec	Load (kg/cm^2) $\bar{P}$ = 0.069	$14.38x10^{-4}$	$30.6x10^{-4}$	$20.15x10^{-4}$	$23.47x10^{-4}$	$12.05x10^{-4}$
	$\bar{P}$ = 0.206	$1.820x10^{-4}$	$4.6x10^{-4}$	$7.26x10^{-4}$	$3.97x10^{-4}$	$25.11x10^{-4}$
	$\bar{P}$ = 0.411	$2.088x10^{-4}$	$2.9x10^{-4}$	$21.19x10^{-4}$	$2.43x10^{-4}$	$7.10x10^{-4}$
	$\bar{P}$ = 0.822	$1.678x10^{-4}$	$4.4x10^{-4}$	$10.49x10^{-4}$	$1.52x10^{-4}$	$3.82x10^{-4}$
	$\bar{P}$ = 1.644	$1.655x10^{-4}$	$2.8x10^{-4}$	-	-	-

Table E-6 CALCULATION TABLE OF SETTLEMENT

Main dike Banking height 1.0^m $\gamma_E = 0.80 t/m^3$

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m)	10	8	6	4	2
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of over-burden Po(t/m^2)	0	0	0	0	0
Void ratio at Po eo	18.5	18.5	18.5	18.5	18.5
Iz	0.83	0.89	0.94	0.97	1
Additional pressure PZ (t/m^2)	0.664	0.712	0.752	0.776	0.80
Po + Pz (t/m^2)	0.664	0.712	0.752	0.776	0.80
Void ratio at Po + Pz e	16.2	16.0	15.8	15.7	15.6
eo - e	2.3	2.5	2.7	2.8	2.9
1 + eo	19.5	19.5	19.5	19.5	19.5
$\frac{eo - e}{1 + eo}$	0.118	0.128	0.138	0.144	0.149
$\Delta S' = \frac{eo - e}{1 + eo} H$	1.18	1.02	0.83	0.58	0.30
$\Delta S = \Delta S' + Ss$	1.38	1.22	1.03	0.78	0.50

Dessication of the peat material used in the construction of embankment will cause a 20% reduction in the height of the embankment.

$\Delta S'$: Settlement due to consolidation.
ΔS: Total settlement including shrinkage at embankment.

γ_E: Semi - air dried density of peat

Table E-7 CALCULATION TABLE OF SETTLEMENT

Main dike Banking height 1.5^m $\gamma_E = 0.81 t/m^3$

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m)	10	8	6	4	2
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden $Po(t/m^2)$	0	0	0	0	0
Void ratio at Po eo	18.5	18.5	18.5	18.5	18.5
Iz	0.83	0.89	0.94	0.97	1
Additional pressure $PZ (t/m^2)$	0.996	1.068	1.128	1.164	1.200
Po + Pz (t/m^2)	0.996	0.068	1.128	1.164	1.200
Void ratio at Po + Pz e	15	14.9	14.8	14.7	14.4
eo - e	3.5	3.6	3.7	3.8	4.1
1 + eo	19.5	19.5	19.5	19.5	19.5
$\frac{eo - e}{1 + eo}$	0.179	0.185	0.190	0.195	0.210
$\Delta S' = \frac{eo - e}{1 + eo} H$	1.79	1.48	1.14	0.78	0.42
$\Delta S = \Delta S' + Ss$	2.09	1.78	1.44	1.08	0.72

Dessication of the peat material used in the construction of embankment will cause a 20% reduction in the height of the embankment.

$\Delta S'$: Settlement due to consolidation.

ΔS : Total settlement including shrinkage at embankment.

γ_E : Semi-air dried density of peat

Table E-8 CALCULATION TABLE OF SETTLEMENT

Main dike Banking height 2.0m $\gamma_E = 0.80 t/m^3$

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m)	10	8	6	4	2
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden Po(t/m^2)	0		0	0	0
Void ratio at Po eo	18.5	18.5	18.5	18.5	18.5
Iz	0.83	0.89	0.94	0.97	1
Additional pressure PZ (t/m^2)	1.328	1.424	1.504	1.552	1.60
Po + Pz (t/m^2)	1.328	1.424	1.504	1.552	1.60
Void ratio at Po + Pz e	14.2	14.0	13.8	13.7	13.6
eo - e	4.3	4.5	4.7	4.8	4.9
1 + eo	19.5	19.5	19.5	19.5	19.5
$\frac{eo - e}{1 + eo}$	0.221	0.231	0.241	0.246	0.251
$\Delta S' = \frac{eo - e}{1 + eo} H$	2.21	1.85	1.45	0.98	0.50
$\Delta S = \Delta S' + Ss$	2.61	2.25	1.85	1.38	0.90

Dessication of the peat material used in the construction of embankment will cause a 20% reduction in the height of the embankment.

$\Delta S'$: Settlement due to consolidation.
ΔS : Total settlement including shrinkage at embankment.
γ_E : Semi-air dried density of peat

Table E-9 CALCULATION TABLE OF SETTLEMENT

Influence of drainage (Drain depth : 0.6m)

	1	2	3	4	5
Soil Classification	"	"	"	"	"
Thickness of consolidated layer H(m)	10	8	6	4	2
Water Content W(%)	1200	"	"	"	"
Pressure of overburden Po(t/m^2)	0	"	"	"	"
Void ratio at Po eo	18.51	"	"	"	"
Iz	0.85	0.92	0.95	0.97	1
Additional pressure PZ (t/m^2)	0.408	0.442	0.456	0.446	0.480
Po + Pz (t/m^2)	0.408	0.442	0.456	0.446	0.480
Void ratio at Po + Pz e	17	16.8	16.7	16.6	16.5
eo - e	1.5	1.7	1.8	1.9	2.0
1 + eo	19.5	19.5	19.5	19.5	19.5
$\frac{eo - e}{1 + eo}$	0.007	0.087	0.092	0.097	0.103
$\Delta S'=\frac{eo - e}{1 + eo}\cdot H$	0.72	0.64	0.50	0.33	0.14
$\Delta S = \Delta S' + Ss$	0.84	0.76	0.62	0.45	0.26

Dessication of the peat material used in the construction of embankment will cause a 20% reduction in the height of the embankment.

$\Delta S'$: Settlement due to consolidation

ΔS : Total settlement including shrinkage at embankment.

Table E-10 CALCULATION TABLE OF SETTLEMENT

Influence of drainage (Drain depth : 0.8 m)

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m)	10	8	6	4	2
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden Po(t/m^2)	0	0	0	0	0
Void ratio at Po eo	18.5	18.5	18.5	18.5	18.5
Iz	0.85	0.92	0.95	0.97	1
Additional pressure PZ (t/m^2)	0.544	0.589	0.608	0.621	0.64
Po + Pz (t/m^2)	0.544	0.589	0.608	0.621	0.64
Void ratio at Po + Pz e	16.6	16.5	16.4	16.3	16.2
eo - e	1.9	2	2.1	2.2	2.3
1 + eo	19.5	19.5	19.5	19.5	19.5
$\frac{eo - e}{1 + eo}$	0.097	0.103	0.108	0.113	0.118
$\Delta S' = \frac{eo - e}{1 + eo} H$	0.89	0.74	0.56	0.36	0.14
$\Delta S = \Delta S' + Ss$	1.05	0.90	0.72	0.52	0.30

Dessication of the peat material used in the construction of embank- will cause a 20% reduction in the height of the embankment.

$\Delta S'$: Settlement due to consolidation

ΔS : Total settlement including shrinkage at embankment

Table E-11 CALCULATION TABLE OF SETTLEMENT

Influence of drainage (Drain depth : 1.0m)

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m)	10	8	6	4	2
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden Po(t/m^2)	0	0	0	0	0
Void ratio at Po eo	18.5	18.5	18.5	18.5	18.5
Iz	0.85	0.92	0.95	0.97	1
Additional pressure PZ (t/m^2)	0.68	0.736	0.76	0.776	0.8
Po + Pz (t/m^2)	0.68	0.736	0.76	0.776	0.8
Void ratio at Po + Pz e	16.2	15.9	15.8	15.7	15.6
eo - e	2.3	2.6	2.7	2.8	2.9
1 + eo	19.5	19.5	19.5	19.5	19.5
$\frac{eo - e}{1 + eo}$	0.118	0.133	0.138	0.144	0.149
$\Delta S' = \frac{eo - e}{1 + eo} H$	1.06	0.93	0.69	0.43	0.15
$\Delta S = \Delta S' + Ss$	1.26	1.13	0.89	0.63	0.35

Dessication of the peat material used in the construction of embankment will cause a 20% reduction in the height of the embankment.

$\Delta S'$: Settlement due to consolidation

ΔS : Total settlement including shrinkage at embankment.

Table E-12 CALCULATION TABLE OF SETTLEMENT

1st stage embankment of canal
(Embankment of clayey soil)

$\gamma_t = 1.80 t/m^3$

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m) *	9.16	7.24	5.38	3.55	1.74
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden Po(t/m^2)	0.408	0.442	0.456	0.466	0.480
Void ratio at Po eo	17.0	16.8	16.7	16.6	16.5
Iz	0.85	0.92	0.95	0.97	1
Additional pressure PZ (t/m^2)	1.53 h=1.00	1.656 h=1.00	1.71 h=1.0	1.746 h=1.00	1.8 h=1.00
Po + Pz (t/m^2)	1.938	2.098	2.166	2.212	2.280
Void ratio at Po + Pz e	13.0	12.8	12.7	12.4	12.2
eo - e	4.0	4.0	4.0	4.2	4.3
1 + eo	18.0	17.8	17.7	17.6	17.5
$\frac{eo - e}{1 + eo}$	0.222	0.225	0.226	0.239	0.246
$\Delta S' = \frac{eo - e}{1 + eo} H$	2.03	1.63	1.22	0.85	0.43
$\Delta S = \Delta S' + Ss$	-	-	-	-	-

SUMMARY (Initial height of embankment: 1 m)

Thickness of peat layer (m) *	9.16	7.24	5.38	3.55	1.74
Height of embankment above ground level after Consolidation	0.03	0.21	0.39	0.56	0.76
Additional Embankment (m)	1.06	0.84	0.61	0.41	0.19
Total Embankment	2.06	1.84	1.61	1.41	1.19

* Refer to Table E-9.

Table E-13 CALCULATION TABLE OF SETTLEMENT

2nd Stage embankment of canal $\gamma_E = 1.80^t/m^3$

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H(m)	7.13	5.61	4.16	2.70	1.31
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden Po(t/m^2)	1.938	2.098	2.166	2.212	2.280
Void ratio at Po eo	13.0	12.8	12.7	12.4	12.2
Iz	0.85	0.92	0.95	0.97	1
Additional pressure PZ (t/m^2)	h=1.50 2.295	h=1.50 2.484	h=1.00 1.71	h=1.00 1.746	h=1.00 1.8
Po + Pz (t/m^2)	4.233	4.582	3.876	3.958	4.08
Void ratio at Po + Pz e	10.0	9.6	10.3	10.2	10.1
eo - e	3.0	3.2	2.4	2.2	2.1
1 + eo	14.0	13.8	13.7	13.4	13.2
$\frac{eo - e}{1 + eo}$	0.214	0.232	0.175	0.164	0.159
$\Delta S' = \frac{eo - e}{1 + eo} H$	1.53	1.30	0.73	0.44	0.21
$\Delta S = \Delta S' + Ss$	-	-	-	-	-

SUMMARY

Thickness of peat layer (m)	7.13	5.16	4.16	2.70	1.31
Height of embankment above ground level after Consolidation (m)	0.85	1.13	1.07	1.36	1.67
Additional embankment (m)	0.85	0.72	0.41	0.24	0.12
Total embankment	4.41	4.06	3.02	2.65	2.31

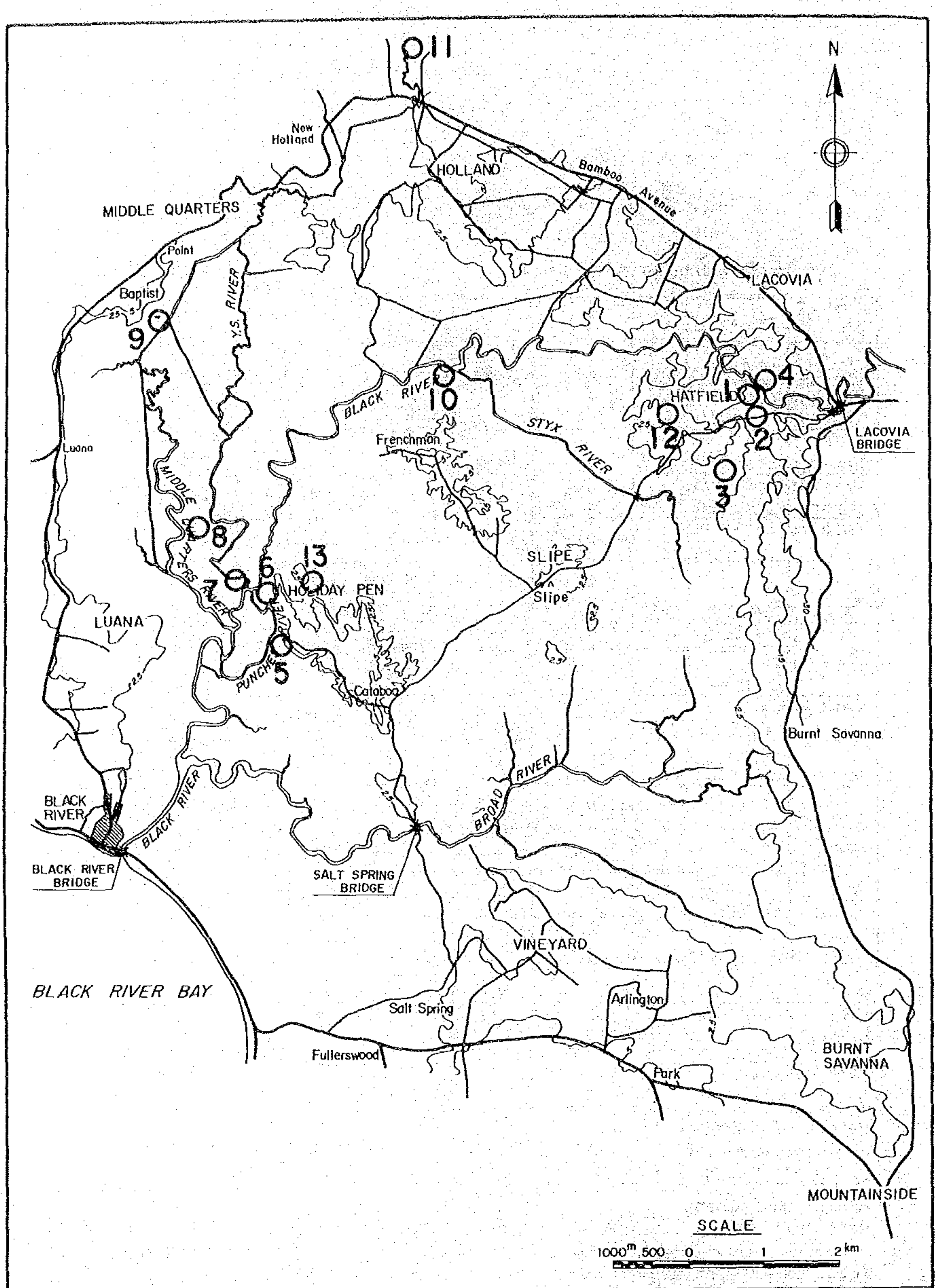
Table E-14 CALCULATION TABLE OF SETTLEMENT

3rd stage embankment of canal $\gamma_E = 1.80\,^t/m^3$

	1	2	3	4	5
Soil Classification	Peat	Peat	Peat	Peat	Peat
Thickness of consolidated layer H (m)	5.6	4.31	3.34	2.26	1.10
Water Content W(%)	1200	1200	1200	1200	1200
Pressure of overburden Po (t/m^2)	4.233	4.582	3.876	3.958	4.08
Void ratio at Po eo	10.0	9.6	10.3	10.2	10.1
Iz	0.92	0.95	0.97	1.0	1.0
Additional pressure PZ (t/m^2)	2.484 h=1.50	2.565 h=1.50	2.619 h=1.50	2.70 h=1.50	2.70 h=1.50
Po + Pz (t/m^2)	6.717	7.147	6.495	6.658	6.78
Void ratio at Po + Pz e	8.1	7.7	8.2	8.1	8.1
eo - e	1.5	1.5	2.1	2.1	2.0
1 + eo	11.0	10.6	11.3	11.2	11.1
$\frac{eo - e}{1 + eo}$	0.136	0.142	0.186	0.188	0.180
$\Delta S' = \frac{eo - e}{1 + eo} H$	0.76	0.61	0.64	0.42	0.20
$\Delta S = \Delta S' + Ss$					

SUMMARY

Thickness of peat layer (m)	5.6	4.31	3.43	2.26	1.10
Time elapsed (year)	9.5	5.9	3.3	1.5	0.4
Height of embankment above ground level	2.01	2.36	2.29	2.67	3.08
Additional embankment (m)	0.42	0.34	0.36	0.23	0.11
Total embankment (m)	6.33	5.90	4.88	4.38	3.92



BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT

Fig. E-1
LOCATION OF BORING TEST

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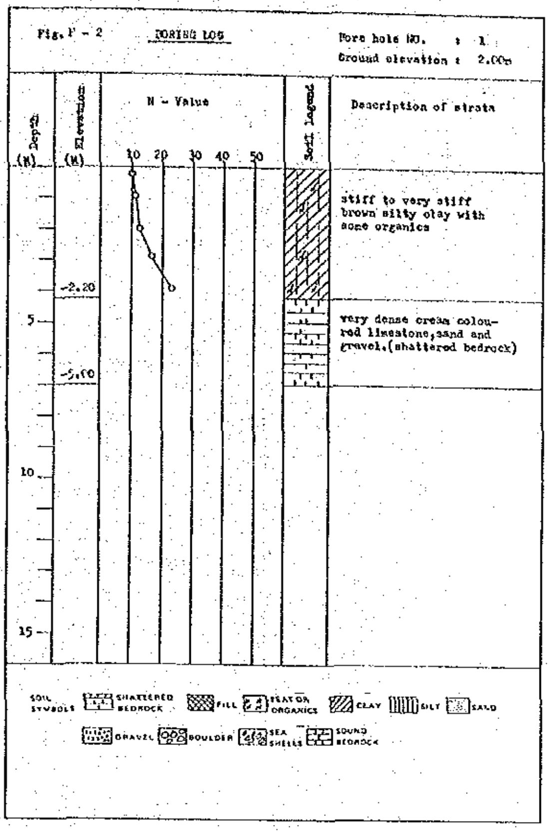

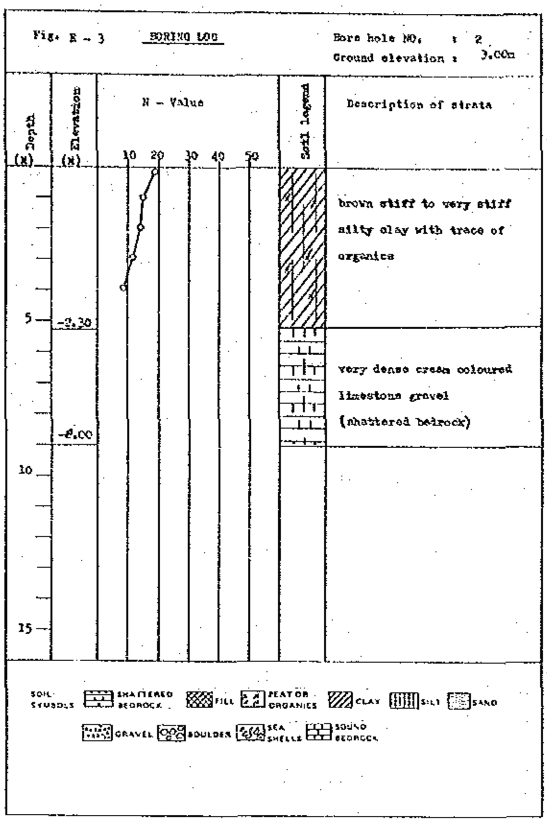

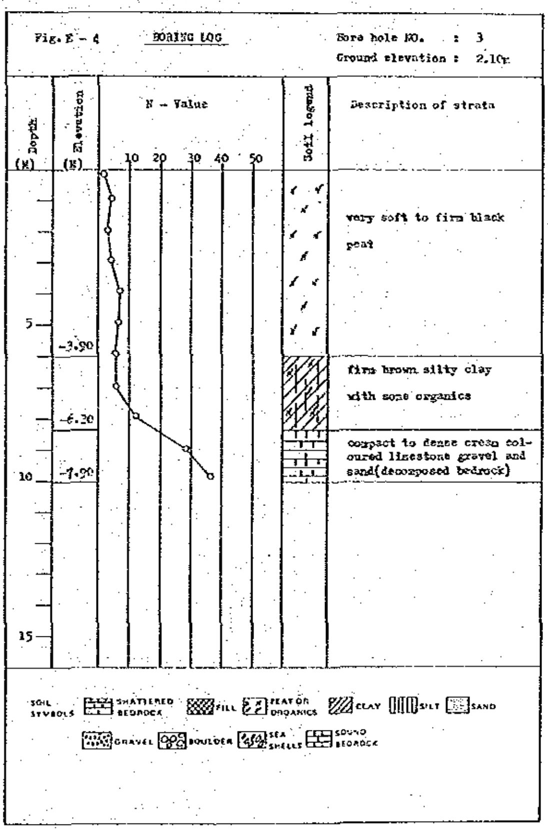

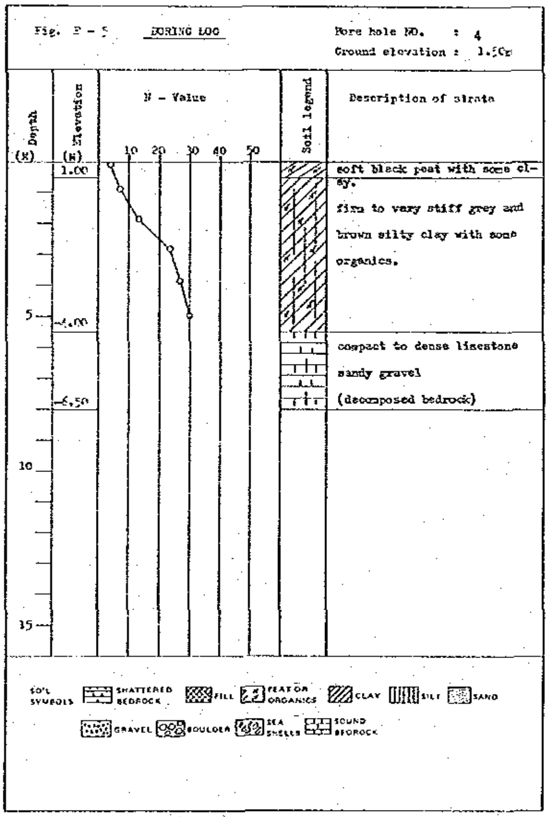

BLACK RIVER LOWER MORASS
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Fig. E-2 - E-5
BORING LOG BOREHOLE NO. 1 - 4

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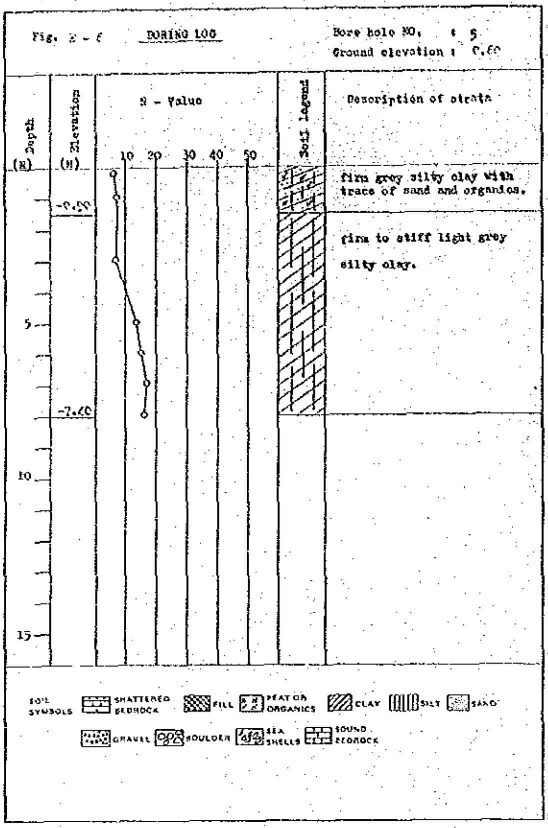
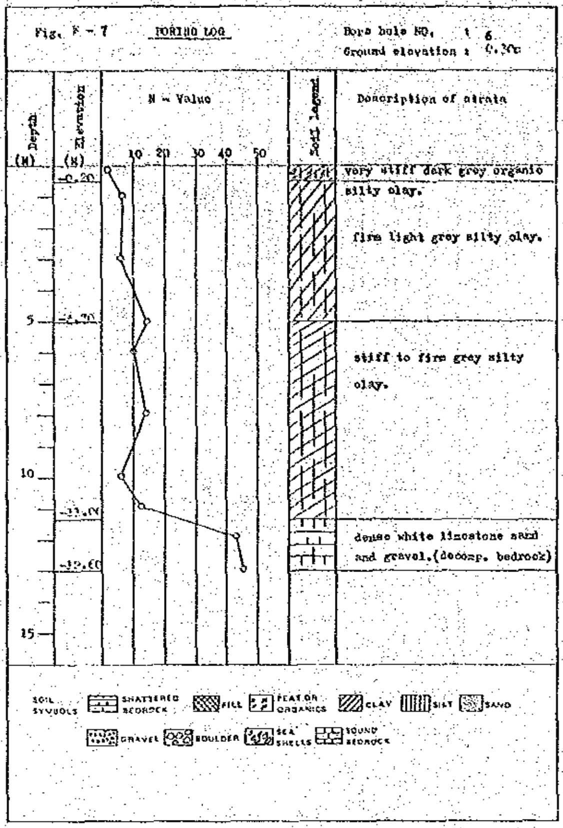
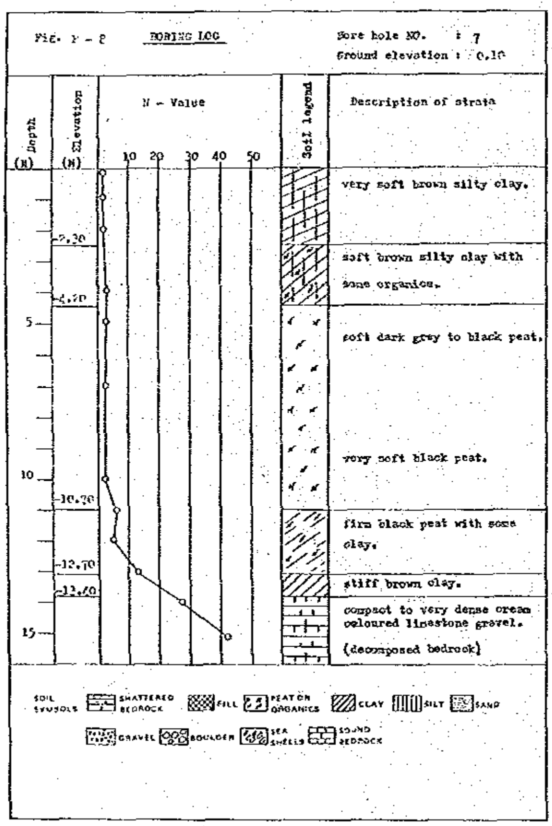
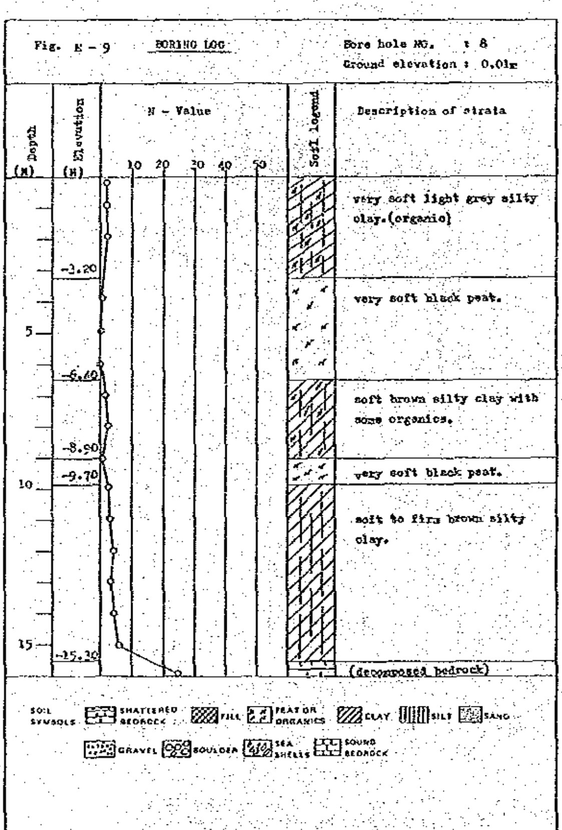




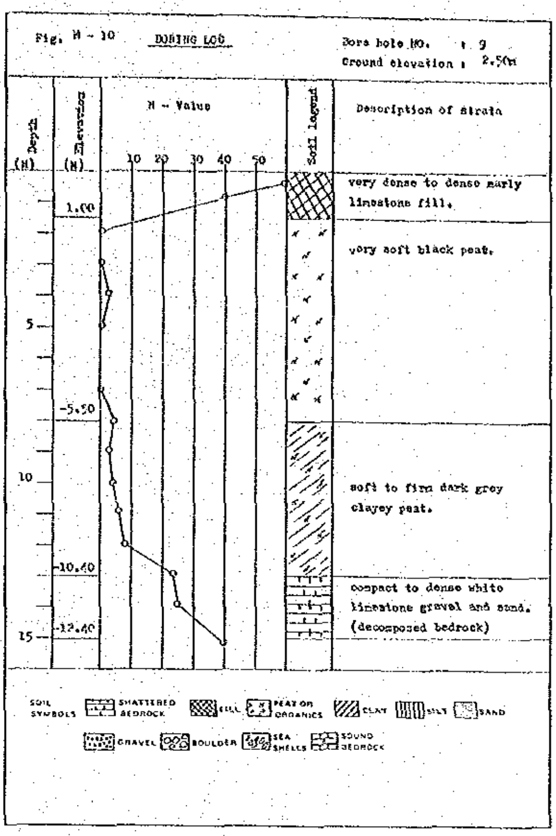


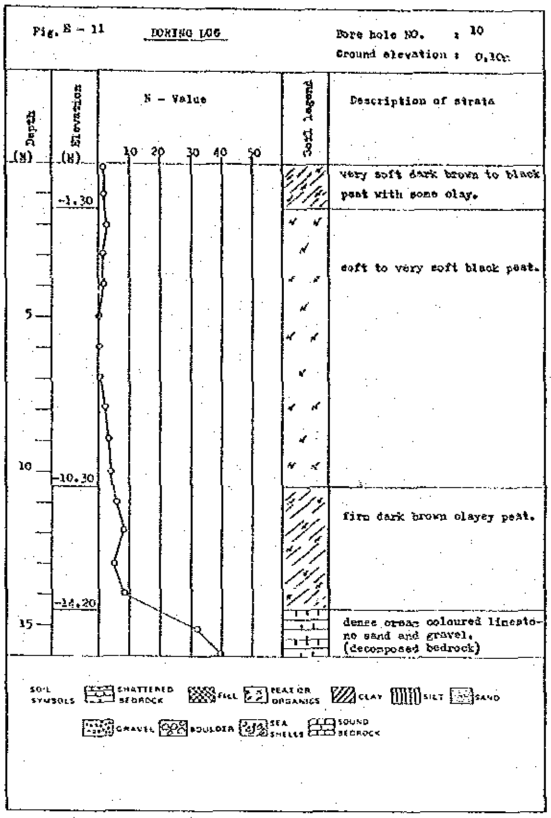


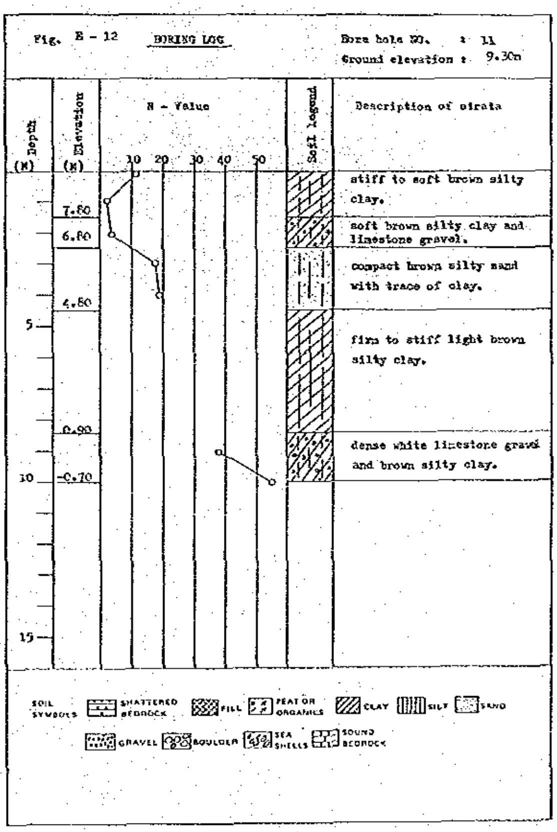
BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT

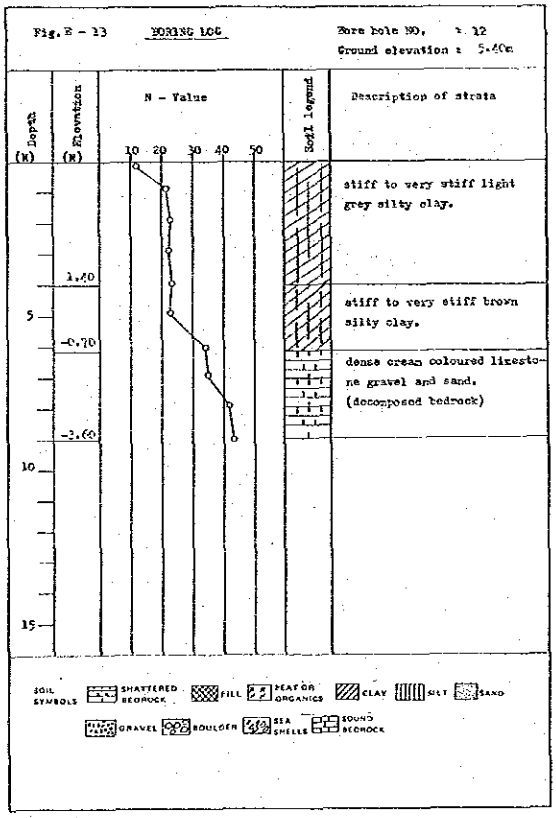
Fig. E-6 - E-9
BORING LOG BOREHOLE NO. 5 - 8

JAPAN INTERNATIONAL COOPERATION AGENCY









BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT

Fig. E-10 - E-13
BORING LOG BOREHOLE NO. 9 - 12

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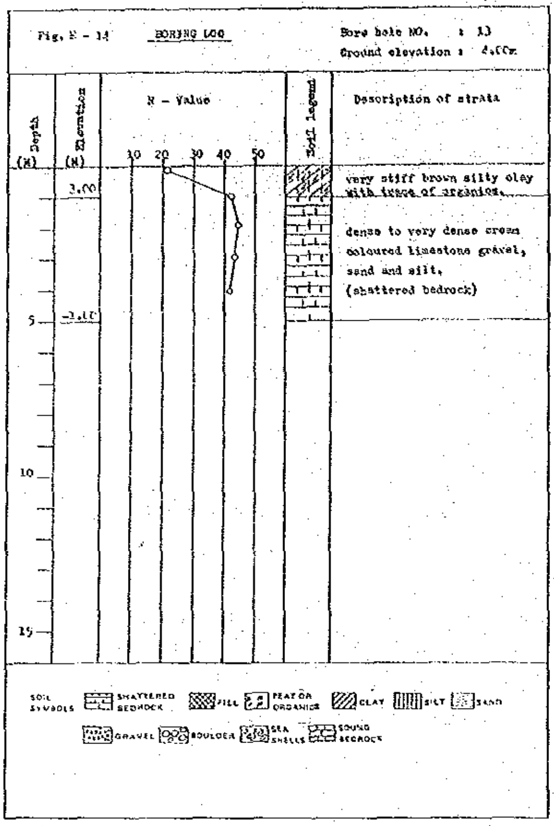

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Fig. E-14
BORING LOG BOREHOLE NO. 13

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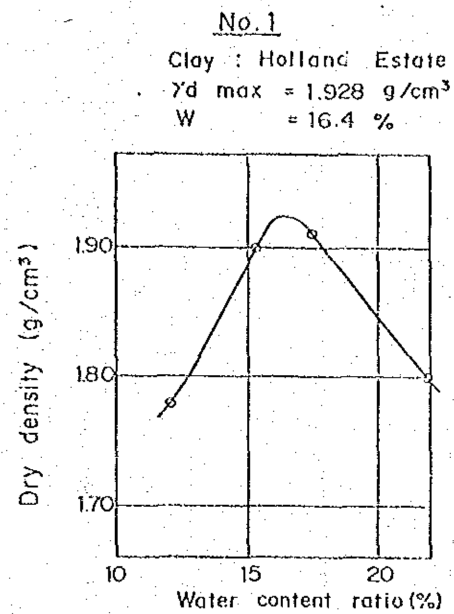

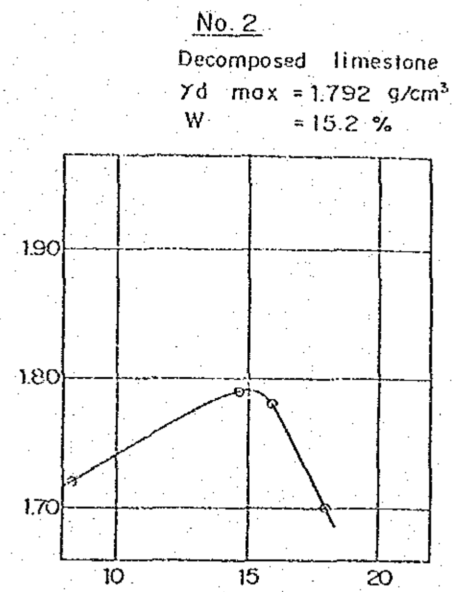

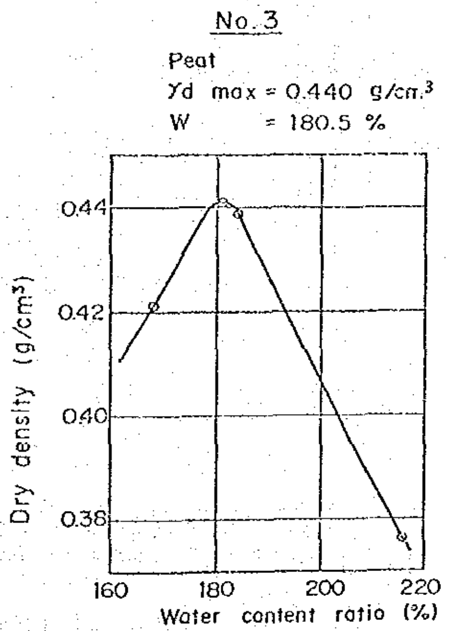

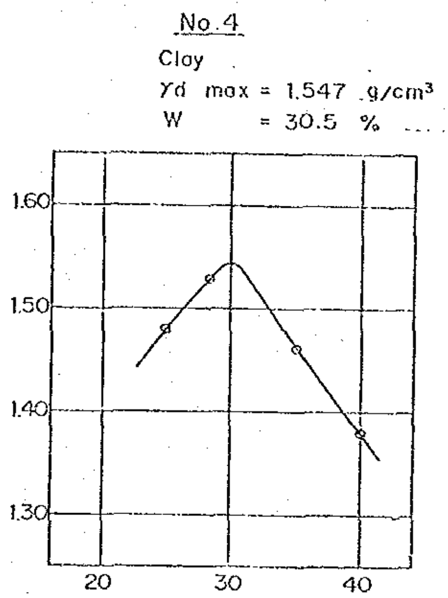

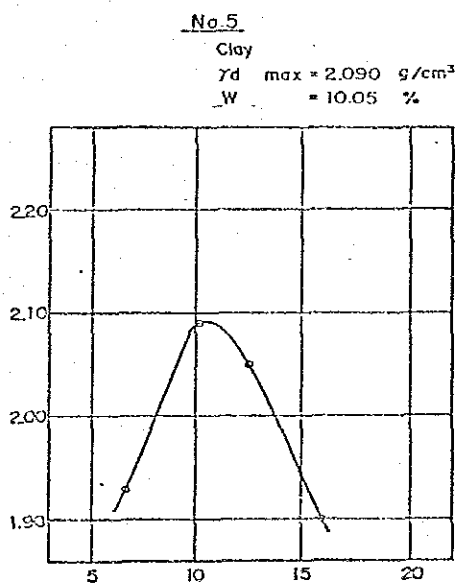

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Fig. E-15 COMPACTION TEST RESULT

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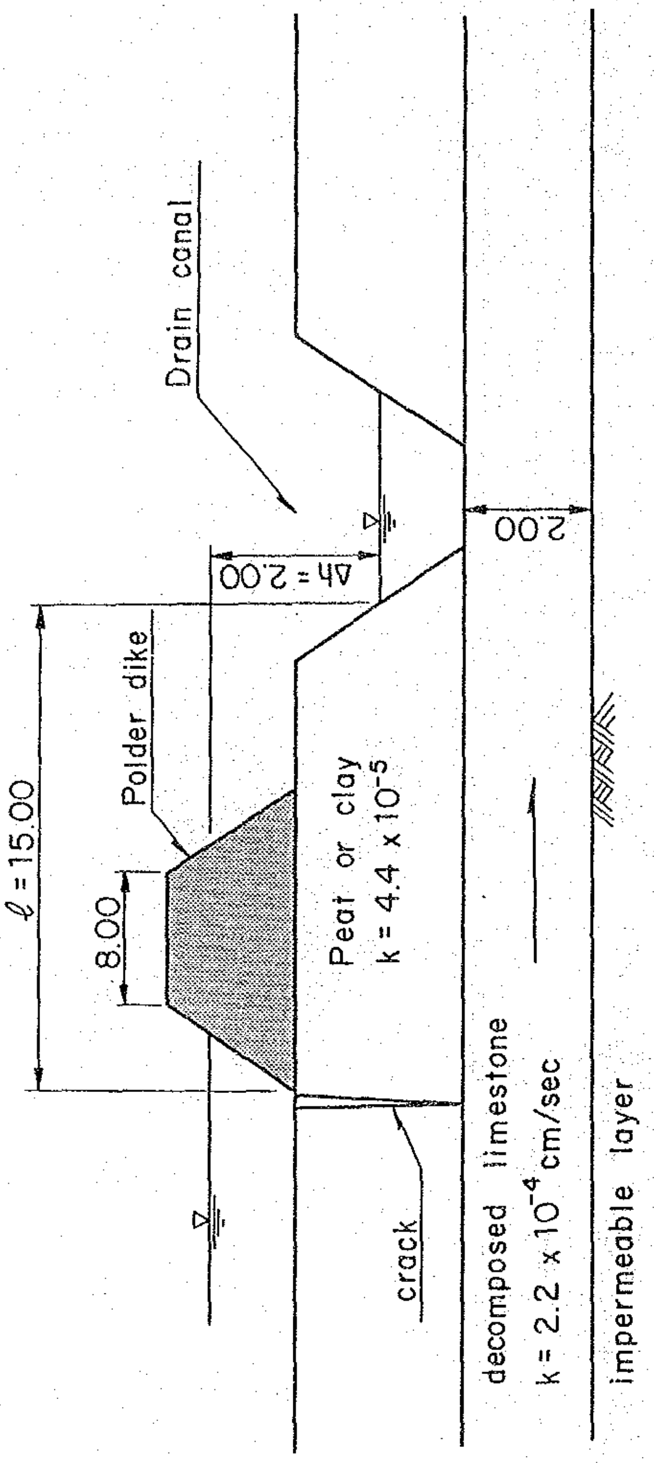

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Fig. E-16
SEEPAGE THROUGH THE FOUNDATION OF POLDER DIKE

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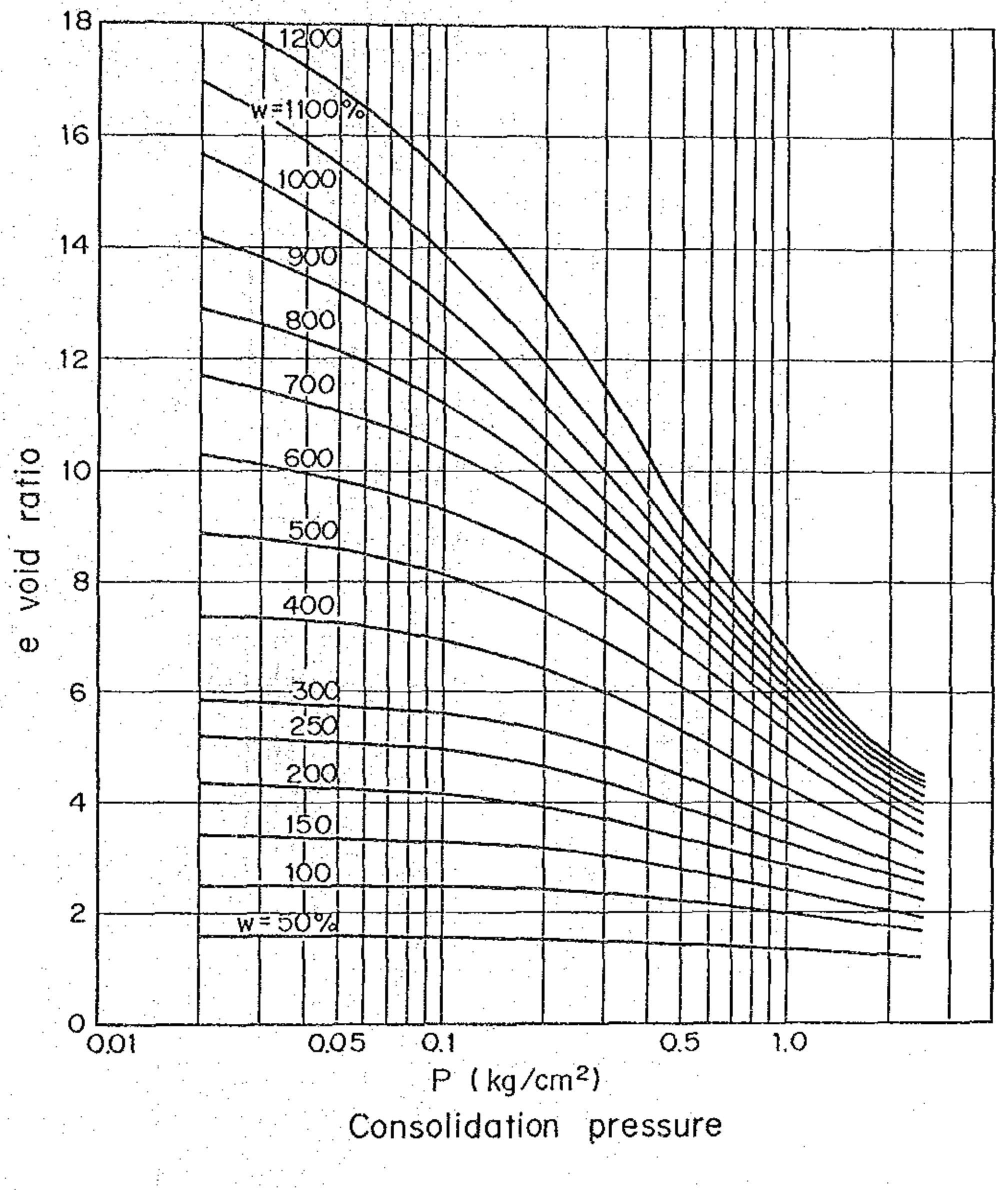

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Fig. E-17
RELATIONSHIP BETWEEN WATER CONTENT AND e-LOG P CURVE

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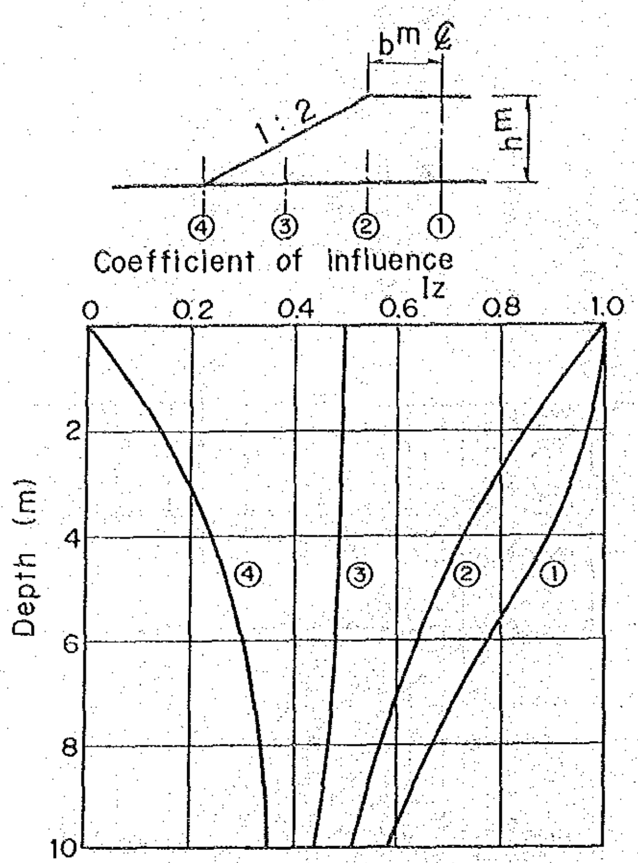

Fig. E-18 COEFF. OF INFLUENCE OF VERTICAL PRESSURE

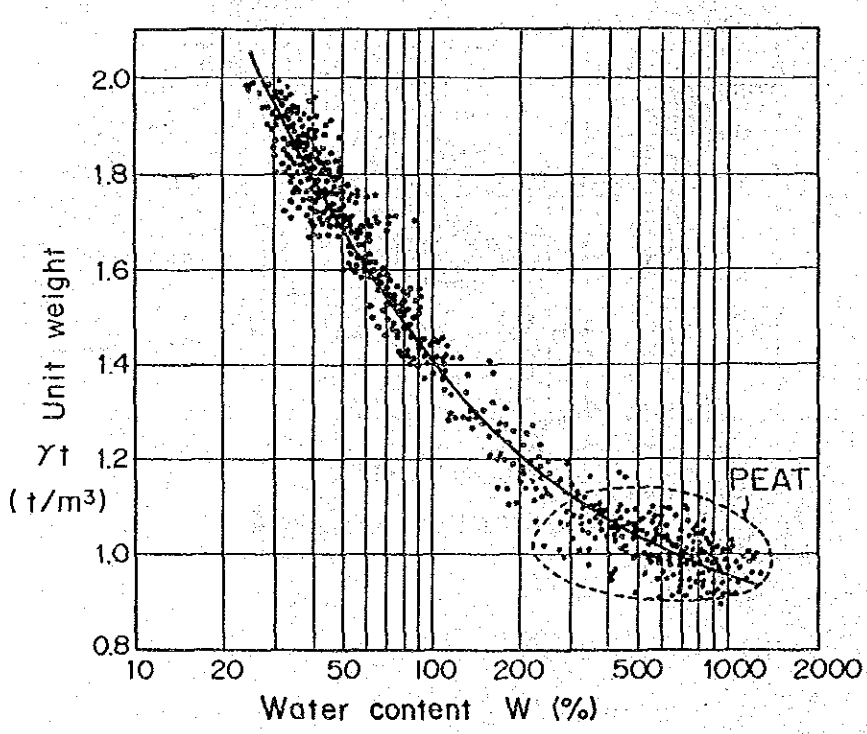

Fig. E-19 RELATIONSHIP BETWEEN WATER CONTENT & UNIT WEIGHT

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Fig. E-18 & Fig. E-19
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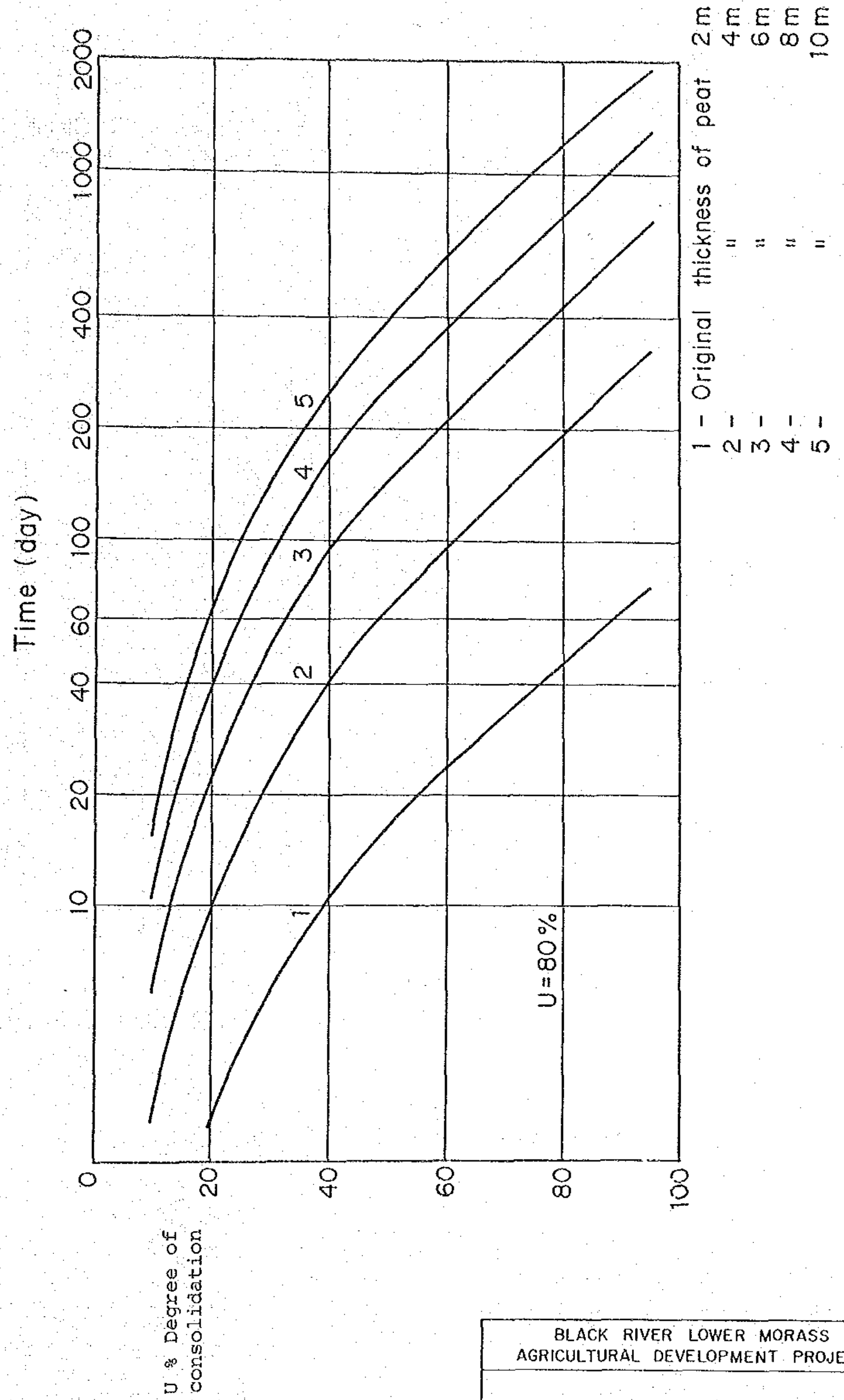

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Fig. E-20 TIME-SETTLEMENT CURVE

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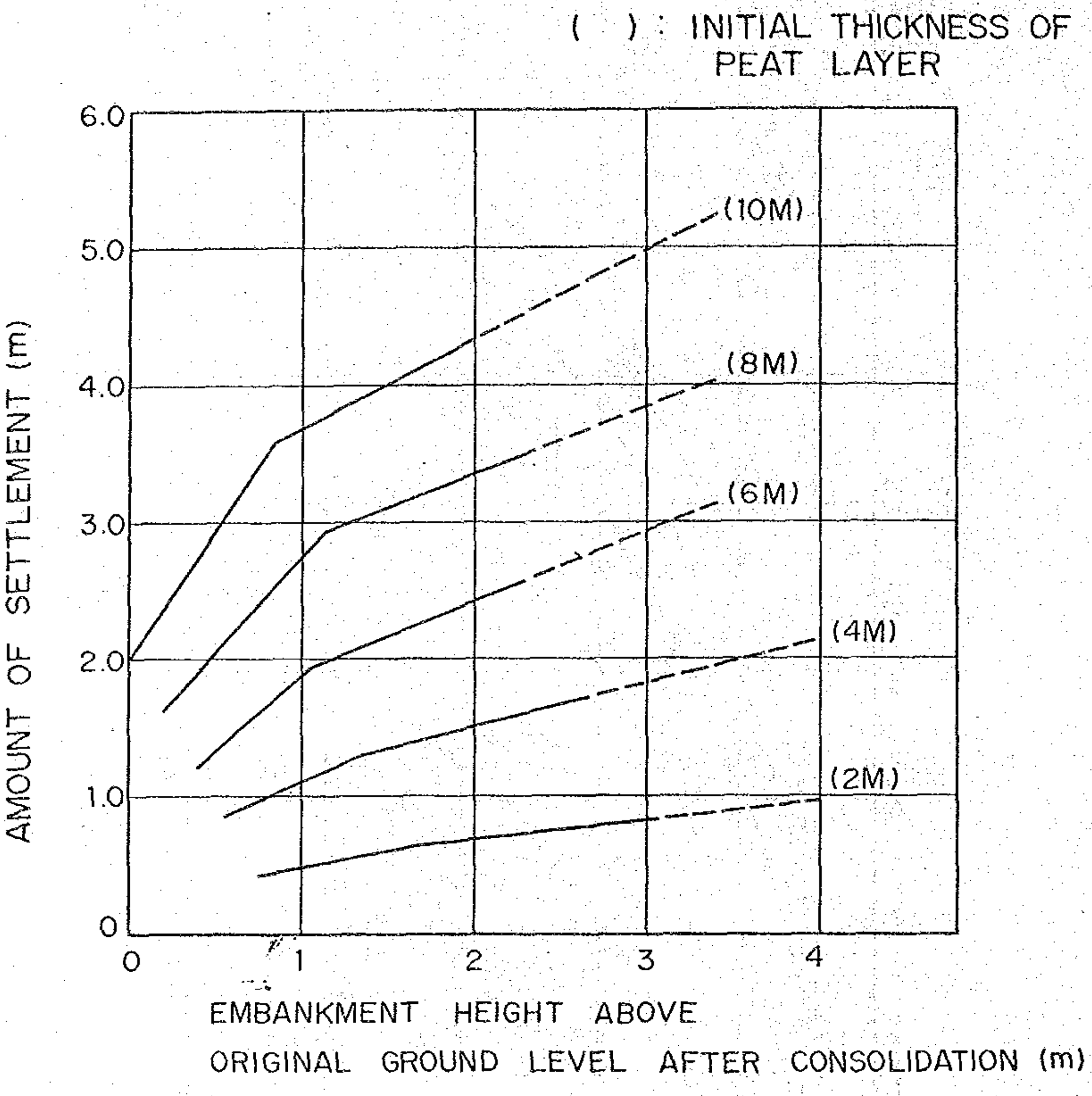

NOTE : Refer ANNEX E, Table E-12 ~ Table E-14

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Fig. E-21 AMOUNT OF SETTLEMENT DUE TO CONSOLIDATION ON VARIOUS THICKNESS OF PEAT

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ANNEX F

SOCIO ECONOMY AND AGRO ECONOMY

ANNEX F

SOCIO - ECONOMY AND AGRO - ECONOMY

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