Table II.2.1 Stratigraphy of the Study Area

Age			Formation and Stratigraphic Relation	Rock Facies - Distribution
Period		Epoch		
Quaternary		Holocene	Alluvium	Riverbed deposit; Cravel and Sand - through a water course, 1 or 2 meters in thickness Flood water deposit; Mainly gravel with sand - in channel, make a flat plain about 1 meter height from riverbed Alluvial terrace deposit; Silt in upper half, cobble in lover half, make a flat plain about 3 meters height from riverbed
			Unconformity	
		Pleistocene	Diluvium	Diluvial terrace deposit; Dark gray silt with small pebble of limestone in upper most, bluish gray clay and light brown sandy clay in lower part - make a diluvial flat plain about 8 meters height from riverbed
			Unconformity	
Tertiary	Neogene	Pliocene	Mollase	Rhyolitic tuff breccia and tuffaceous sandstone, medially or weakly consolidated - East margin of irrigation area Sandy siltstone bearing Molluscs and pumiceous sandy tuff and tuffaceous siltstone, poorly consolidated - occupy central part of irrigation area Basal conglomerate, pebble, weakly or medially consolidated - west margin of irrigation area
			Unconformity	
		Miocene	Intermediate and basic volcanic rocks	Upper; Andesitic volcanic breccia and tuff breccia - westward of irrigation area, partly occupy Parota secondary canal Middle; Alternation of siltstone and tuffaceous sandstone, medially consolidated, partly intercalate andesitic tuff breccia - westward of irrigation area, crop out in the Sanrego intake weir site Lower; Andesitic or basaltic auto brecciated lava, strongly consolidated - southward and westward of irrigation area
			Conformity	
	Paleogene	Eocene	Limestone	Reef limestone, lower most is composed of carcalious sandstone and siltstone, yield large Foraminifero and fragment of Molluscs, dissolved and changed into porous mass - south-westward and eastward of irrigation area
		Oligocene	Conformity	
		Palaeocene	Intermediate and basic volcanic rocks	Andesitic and basaltic volcanic pyroclastics, partly intercalate welded tuff - occupy the watershed area of the Sanrego River and the Biru River
			Unconformity	
Cretaceous			bathyal deposits	Hard shale and pure sandstone abundant in quartz grain, silicificated nearly granite - restricted to the upper reach of the Biru River

Intrusive rocks —
- — Dyke rocks; Quartz Porphyre, Porphyrite, Dolerite - abundantly intrude into the Cretaceous and Granite and rarely intrude into Limestone
- — Plutonic rock; Granite - intrude into the Cretaceous and Silicificate

Table II.3.1 Proposed Criteria to be Used at Rock Grade Classification for Engineering Purpose (Massive Rocks)

Rock grade	Hard rocks	Medium hard rocks	Soft rocks
	As an approximate criterion, rocks of more than "600 to 1,000 kg/cm2" in the unconfined compression strength of test pieces of fresh rocks are hard rocks. When hit by a rock hammer, they produce a metallic sound.	As an approximate criterion, rocks of "200 to 300 kg/cm2" to "600 to 1,000 kg/cm2" in the dry unconfined compression test of test pieces of rocks are medium hard rocks. When hit by a rock hammer, they produce a very light sound, but generally do not produce a metallic sound. Of the rocks in this range, those rather soft maybe depressed slightly on the surface, when hit by spike of rock hammer.	As an approximate criterion, rocks of less than "200 to 300 kg/cm2" in the dry unconfined compression test of test pieces of fresh rocks are soft rocks. When hit by a rock hammer, they produce a thick and loose sound, and may collapse. They are easily depressed on the surface, when hit by the spike of rock hammer.
A	Very fresh in lithologic character. The rock-forming minerals of igneous rocks and the constituent grains of sedimentary rocks are not weathered and altered at all. Few joints are distributed. The rocks as a whole are very solid and densely hard.		
B	Fresh in lithologic character. The rock-forming minerals of igneous rocks and the constituent grains of sedimentary rocks are little weathered and altered. Joints are sparsely distributed, assuring close adhesion. The rocks as a whole are solid and densely hard.	Fresh in lithologic character. The constituent grains are quite free from secondary weathering and alteration. Fissures of joints, etc. are little distributed. The rocks as a whole are solid and hard. In this case, those close to soft rocks which have the above properties may not belong to this class, but to C(a).	
C	Almost fresh, solid and hard in lithologic character. Among the rock-forming minerals of igneous rocks, feldspars and colored minerals such as mica and amphibole maybe slightly weathered and altered, and in sedimentary rocks feldspars and colored minerals existing secondarily as constituent grains maybe slightly weathered and altered. Joints are distributed considerably and joint walls are mostly weathered and altered, being discolored. Sometimes, weathered materials adhere thinly to joint walls. However, in general, the joints assure close adhesion. The rocks as a whole are solid and hard.	Fresh in lithologic character. The constituent grains are free from secondary weathering and alteration. Joints are sparsely distributed, assuring close adhesion. The rocks as a whole are almost solid and hard. In this case, those close to hard rocks may belong to class B.	Rocks of this class are close to medium hard rocks (about 150 kg/cm2 in the dry unconfined compression strength of fresh rocks). Fresh in lithologic character. Constituent grains are quite free from weathering and alteration, and joints are little distributed.
D	Generally a little weathered and altered in lithologic character. In igneous rocks, feldspars and colored minerals excluding quartz are weathered, often being brown. In sedimentary rocks, feldspars and colored minerals existing secondarily as constituent grains are weathered and altered, often being brown or reddish brown as in case of igneous rocks. Joints are open and often hold clay or weathered materials. Rocks of this class often have many fine hair-like fissures. Therefore, when hit strongly by a rock hammer, they often collapse, being separated at the hair-like fissures. In addition, rocks which are fresh in lithologic character but have open joints distributed considerably to indicate crecky state are also included in this class.	Feldspars and colored minerals existing secondarily as constituent grains are mostly a little weathered and altered. The weathering is not so intensive, but since the rocks are medium hard, they give a little soft impression in absolute hardness. Joints are distributed considerably, and most of them are a little open. The joints are weathered and altered, being discolored and often hold thin layers and weathered materials. Rocks of class have hair-like fissures to some extent. Therefore, when hit by a rock hammer, they often collapse, being separated at the hair-like fissures.	Fresh in lithologic character. Constituent grains are free from secondary weathering and alteration. Joints are little or sparsely distributed, assuring close adhesion. The rocks as a whole are little weathered, but since they are soft, they give soft impression in absolute hardness. In the case, those less than about "60 to 70 kg/cm2" in the dry unconfined compression strength do not belong to this class, but to [illegible].
E	Since the rock-forming minerals of igneous rocks or the constituent grains of sedimentary rocks are considerably weathered, the rocks as a whole are generally brown or reddish brown. Joints are open, and hold clay and weathered materials considerably. In rocks of this class, fine hair-like fissures are distributed remarkably and weathering occurs along the fissures. Therefore, even if hit lightly by a rock hammer, they easily collapse are depressed. In addition, rocks which are fresh in lithologic character but have open joints considerably distributed to indicate masonry state are also included in this class.	Constituent grains are weathered and altered, and the degree of consolidation is very low. Since the rocks are medium hard, they give considerably soft impression in absolute hardness. Joints are considerably distributed. They are open, and hold weathered materials and clay layer considerably. Rocks of this class are considerably weathered along hair-like fissures, and when hit lightly by a rock hammer, they collapse easily.	Constituent grains are a little weathered and altered, and the degree of consolidation is very low. The rocks as a whole give very soft impression in absolute hardness. When the rocks are hit by the spike of rock hammer, the spike often sticks in them.
F	The rock-forming minerals of igneous rocks or the constituent grains of sedimentary rocks are considerably weathered, and sandy and clayey portions are often seen. With rocks of this class, the distribution of joints is rather unclear.	Constituent grains are considerably weathered and altered, and the degree of consolidation is considerably low. They are often sandy and clayey. With rocks of this class, the distribution of fissures is rather unclear.	The degree of consolidation of constituent grains is very low, and most are sandy or clayey.

Table II.3.2 Ranges of Physical Values of Rocks Estimated from the Classification Method

Rock Grade	Static modulus of elasticity of rocks (kg/cm2)	Modulus of deformation of rocks (kg/cm2)	Cohesion of rocks (kg/cm2)	Internal frictional angle of rocks (°)	Velocity of elastic wave of rocks (km/sec)	Rebound of the rock test hammer
B	60,000 or more	50,000 or more	40 or more	55~65	3.7 or more	36 or more
C	80,000~40,000	50,000~20,000	40~20	45~55	3.7~3	36~27
D	40,000~15,000	20,000~5,000	20~10	30~45	3~1.5	27~15
E	15,000 or less	5,000 or less	10 or less	15 38	1.5 or less	15 or less

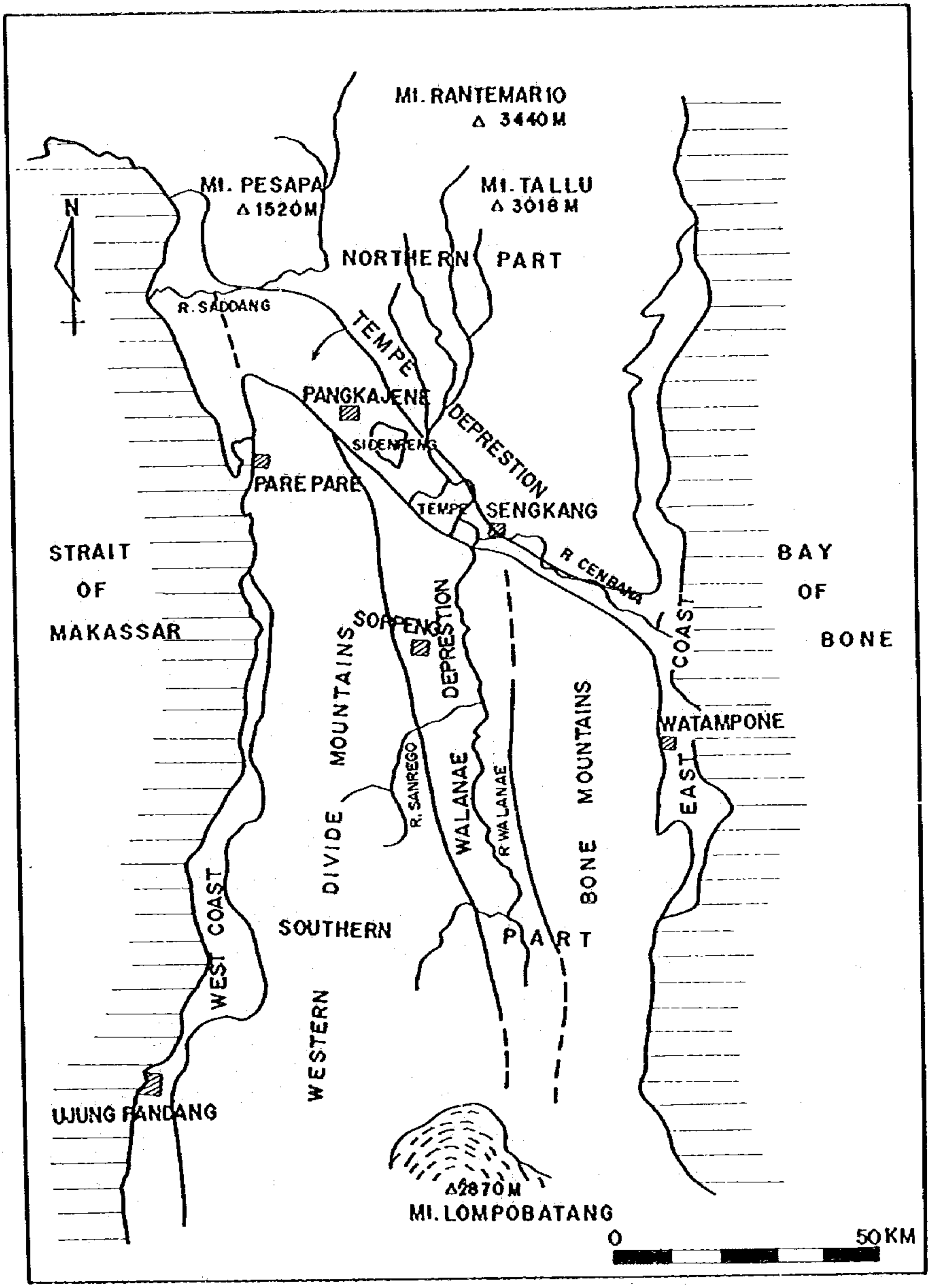


Fig. II.2.1 GEOMORPHOLOGICAL CLASSIFICATION OF SOUTHWEST ARM OF SULAWESI

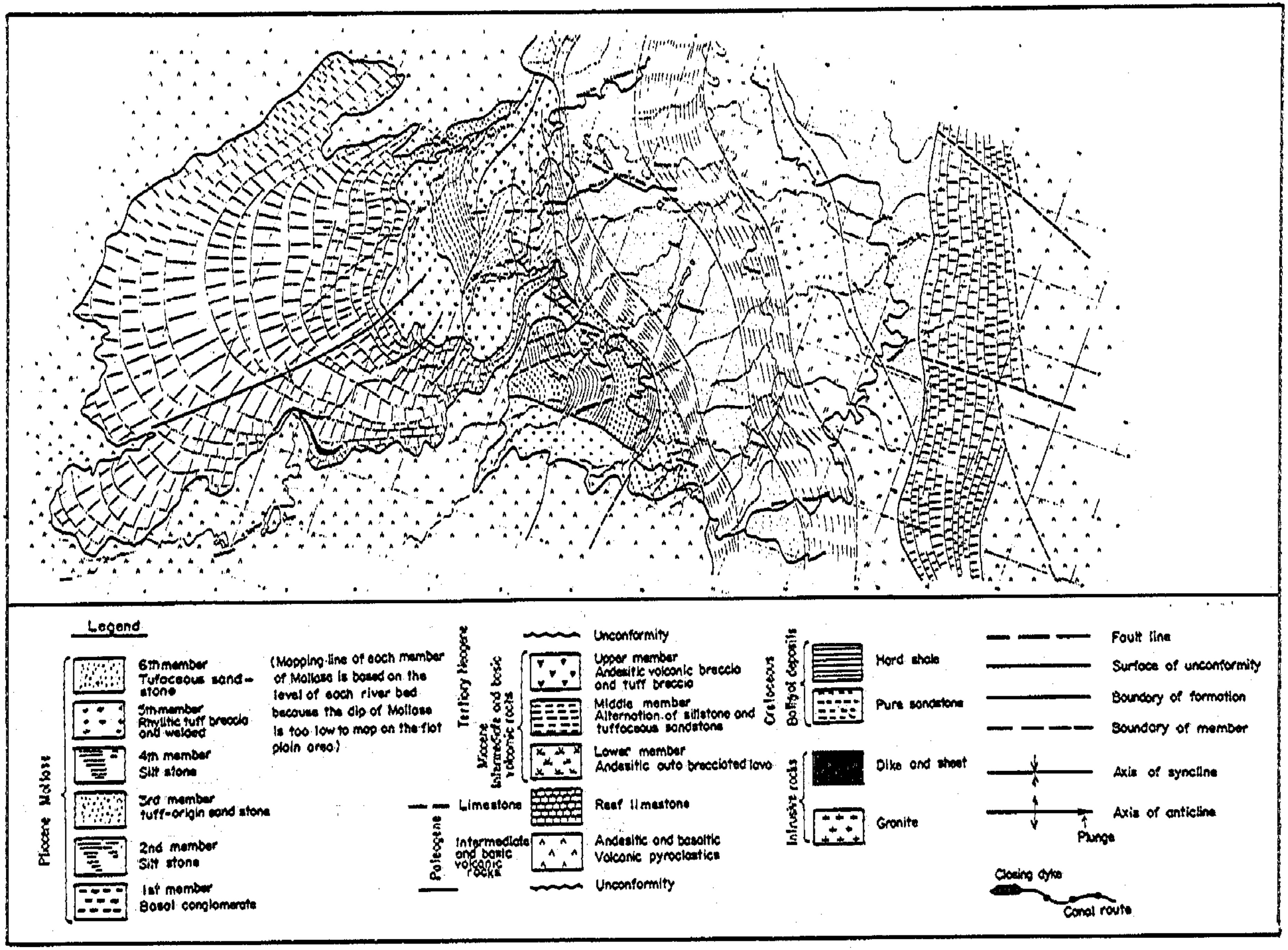


Fig. II.2.2 GEOLOGICAL MAP OF STUDY AREA

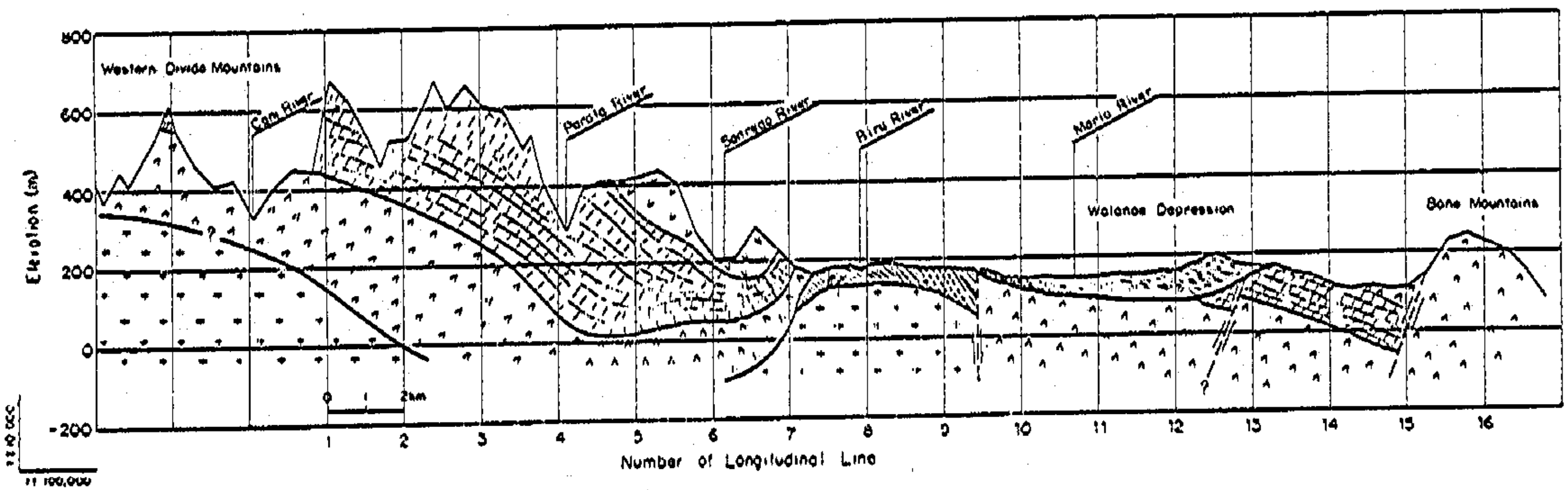


Fig. II.2.3 GEOLOGICAL PROFILE OF STUDY AREA

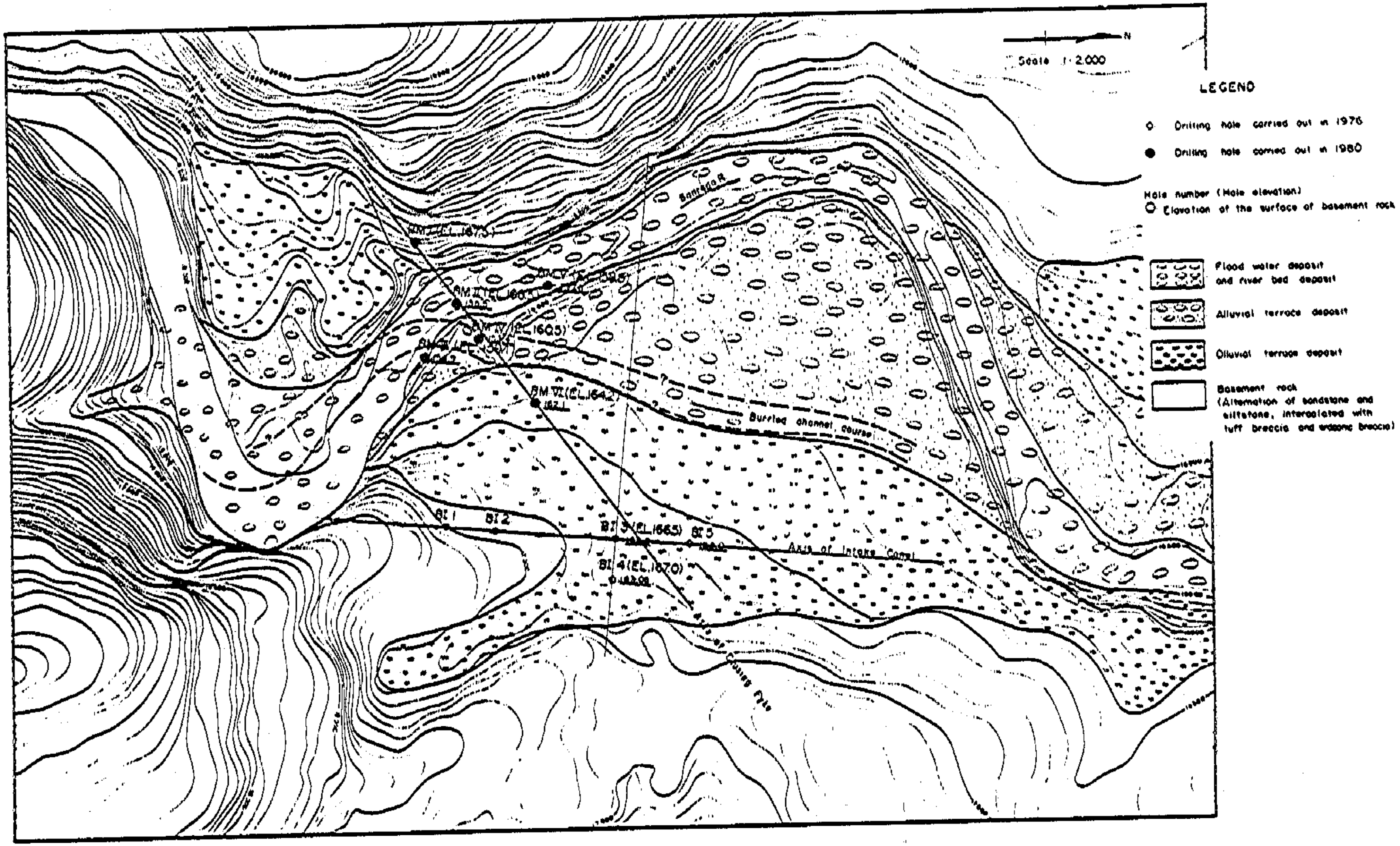


Fig. II.3.1 LOCATION OF DRILLING HOLES CARRIED OUT AT INTAKE WEIR SITE

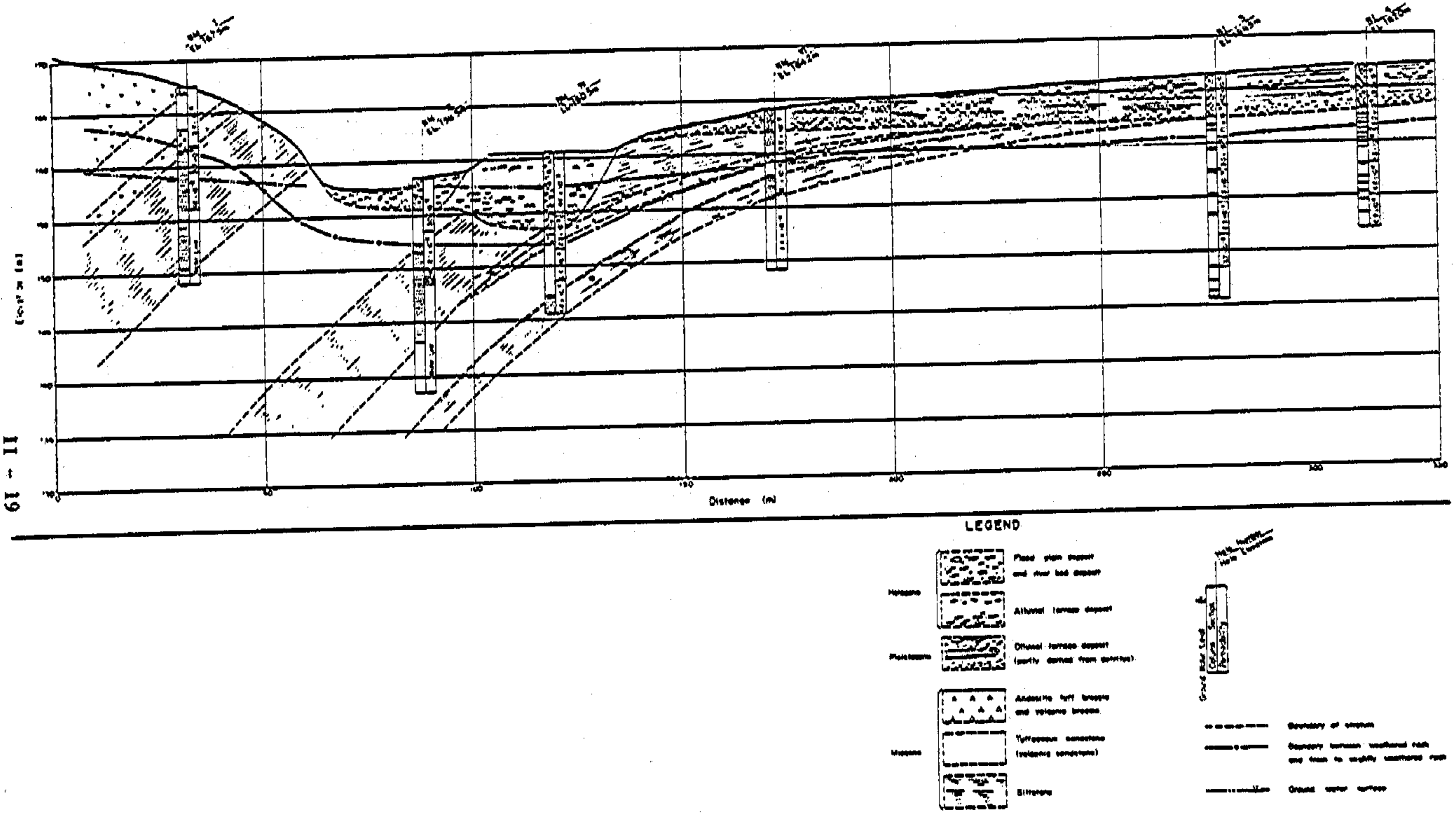


Fig. II.3.2 GEOLOGICAL PROFILE OF CLOSING DIKE AXIS

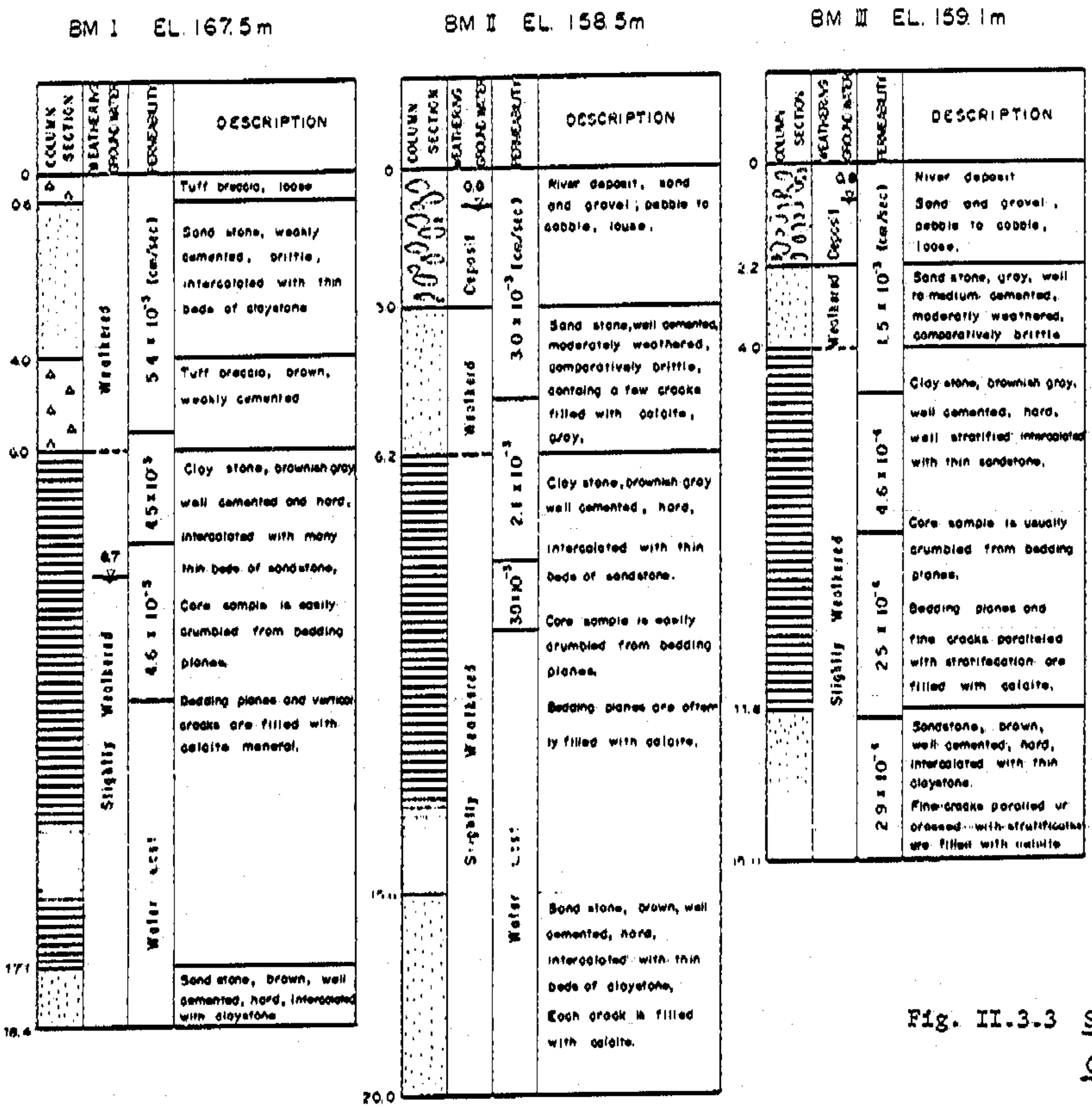


Fig. II.3.3 SUMMARIZED COLUMN SECTION OF INTAKE WEIR SITE (1/3)

(BM Series was carried out in 1976, along the intake canal axis.)

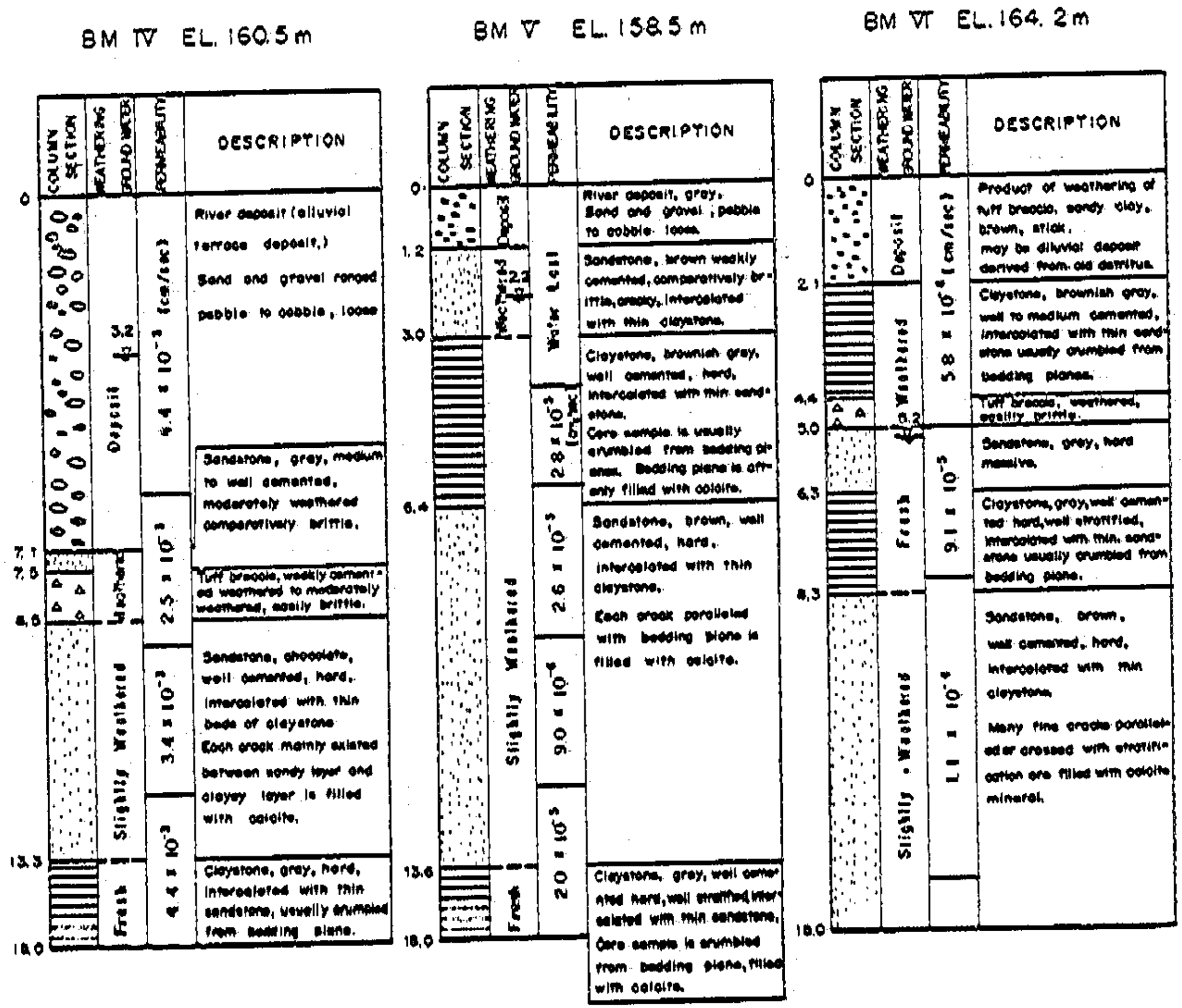
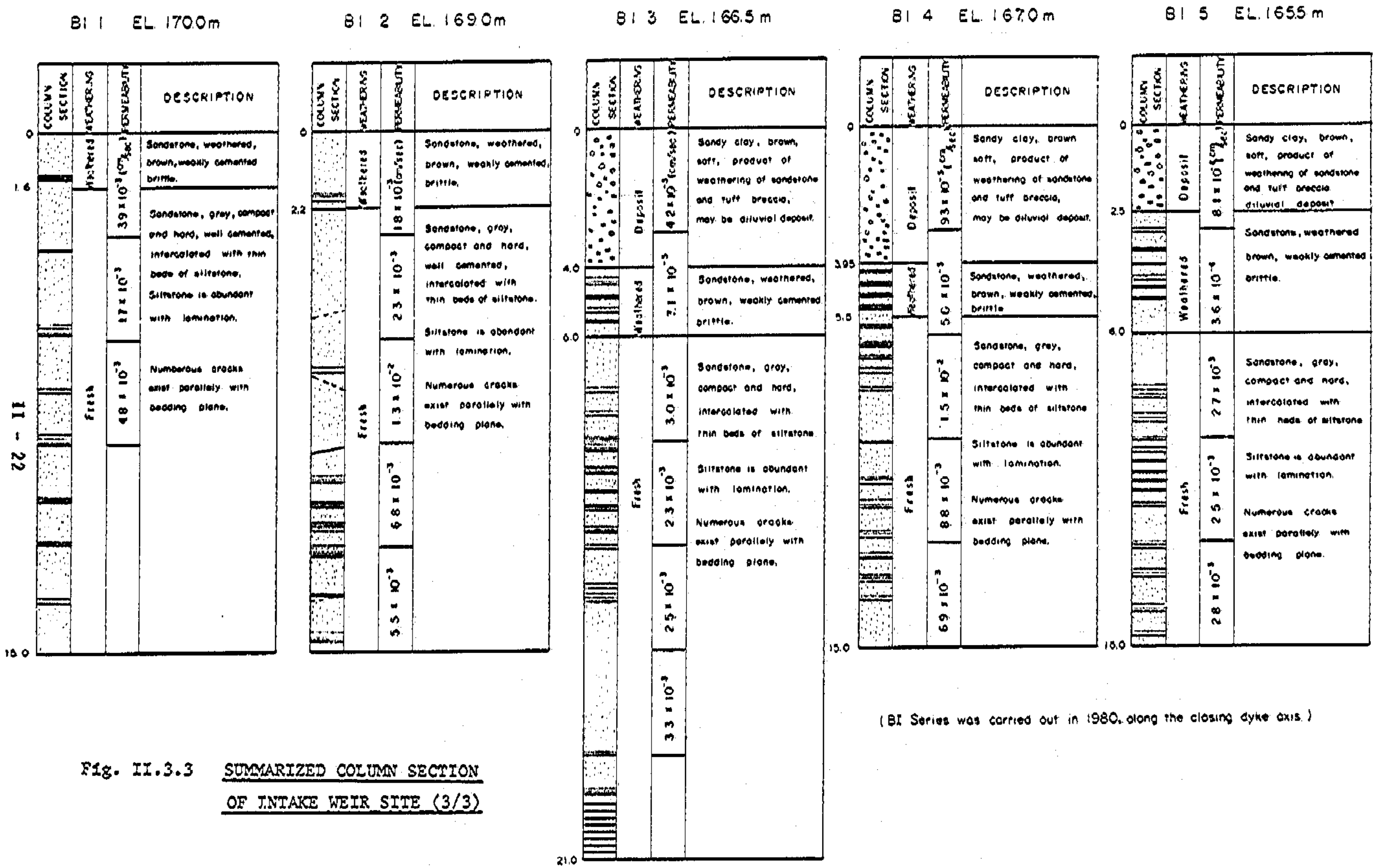


Fig. II.3.3 SUMMARIZED COLUMN SECTION OF INTAKE WEIR SITE (2/3)



(BI Series was carried out in 1980, along the closing dyke axis.)

Fig. II.3.3 SUMMARIZED COLUMN SECTION OF INTAKE WEIR SITE (3/3)

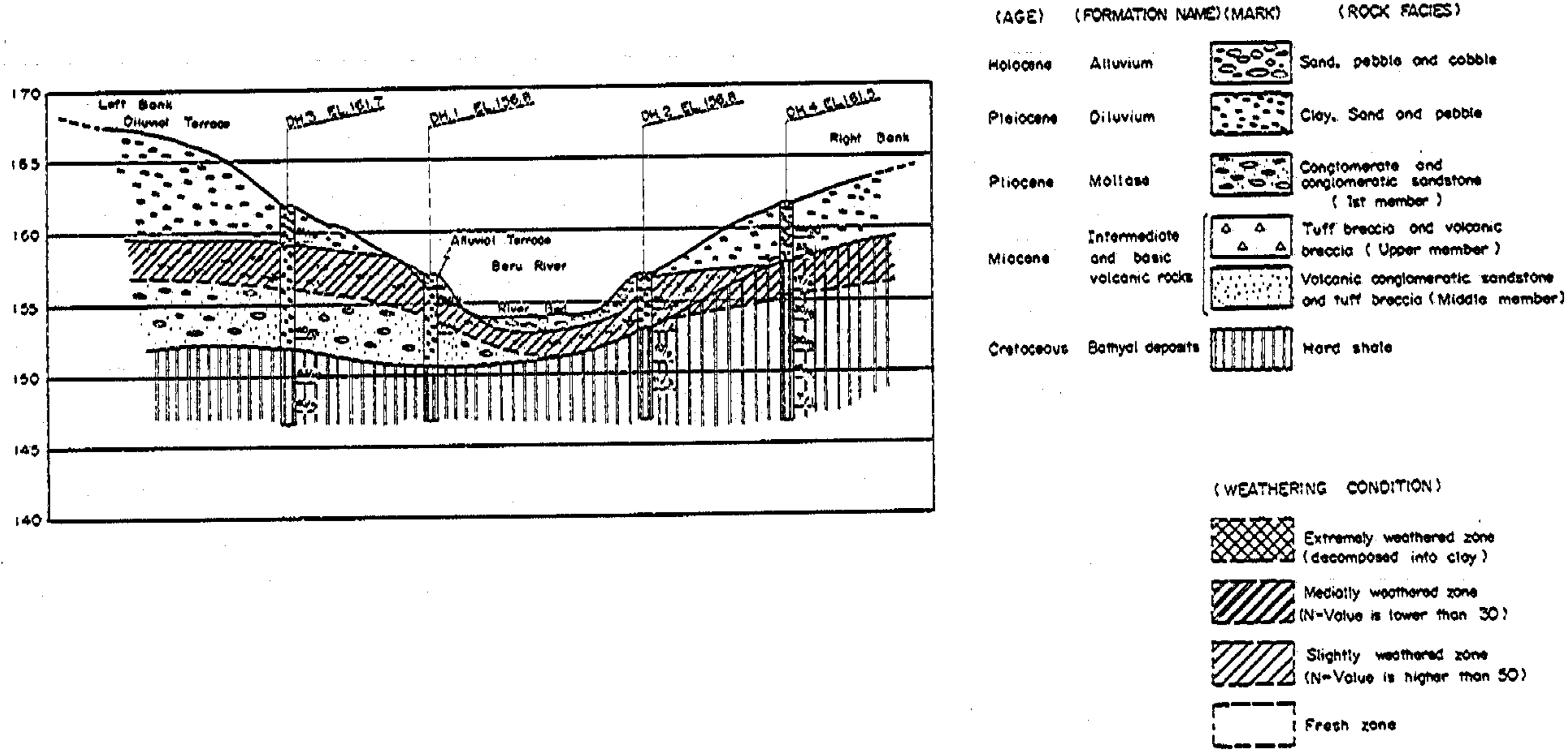


Fig. II.4.1 GEOLOGICAL PROFILE OF AQUEDUCT SITE AT BIRU RIVER

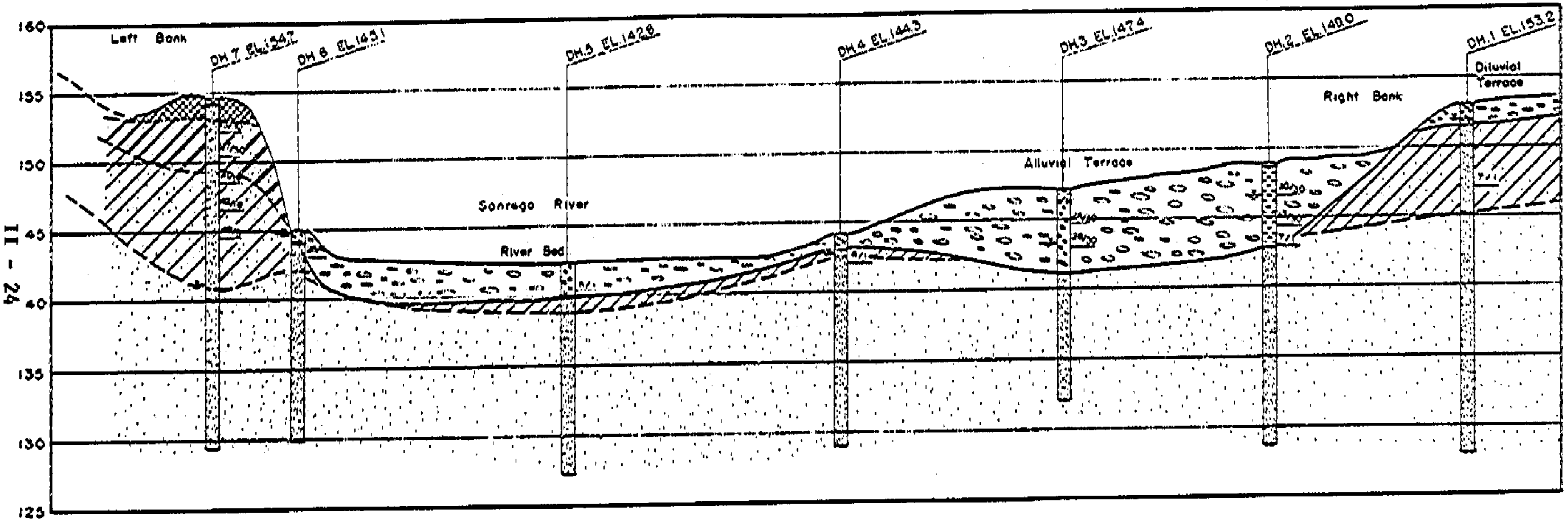


Fig. II.4.2 GEOLOGICAL PROFILE OF AQUEDUCT SITE AT SANREGO RIVER

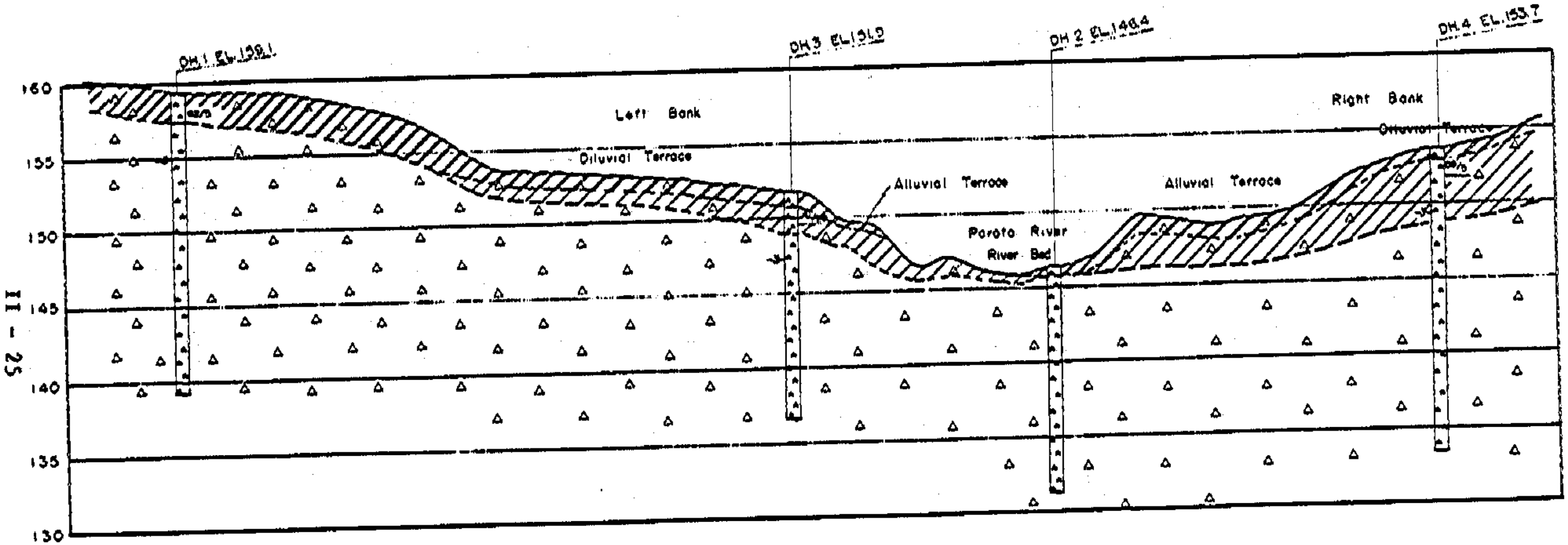
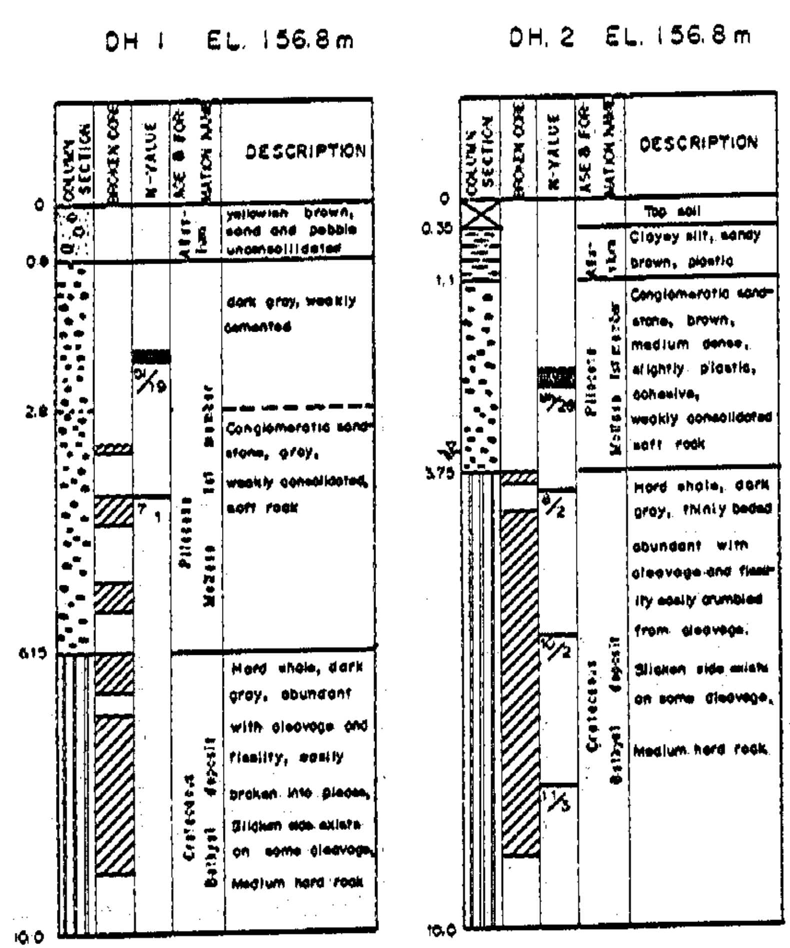
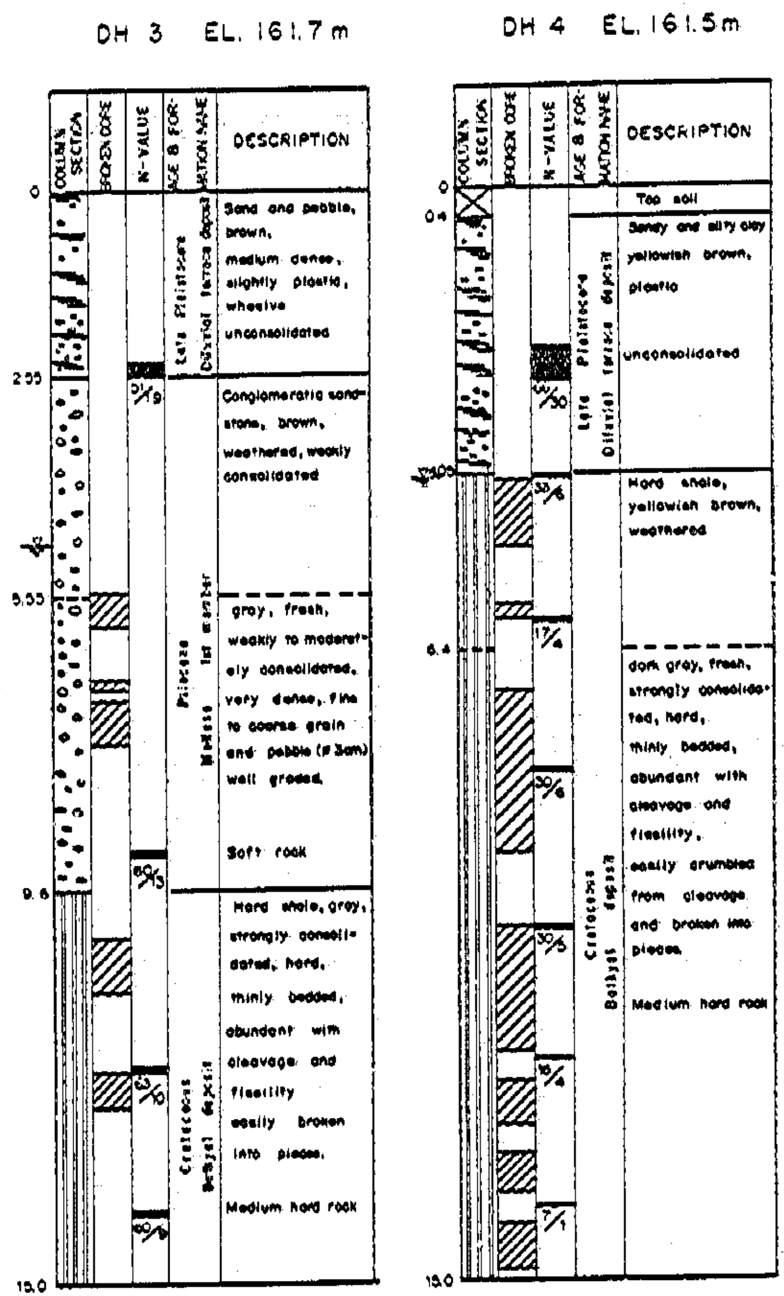


Fig. II.4.3 GEOLOGICAL PROFILE OF AQUEDUCT SITE AT PAROTA RIVER





the original report, "hard shale" was named as "siltstone".

Fig. II.4.4 **SUMMARIZED COLUMN SECTION OF AQUEDUCT SITE AT BIRU RIVER**

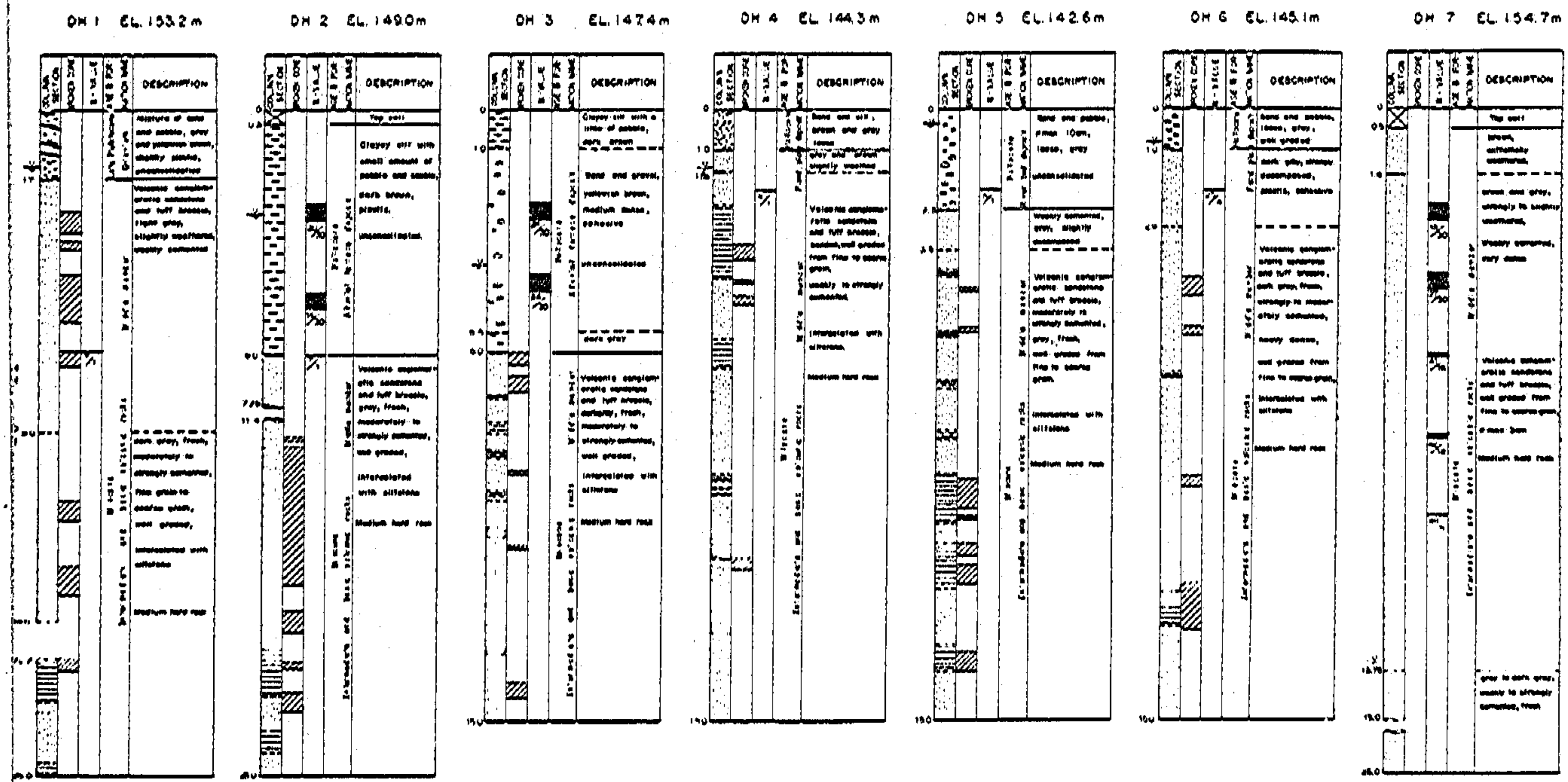


Fig. II.4.5 SUMMARIZED COLUMN SECTION OF AQUEDUCT SITE AT SANREGO RIVER

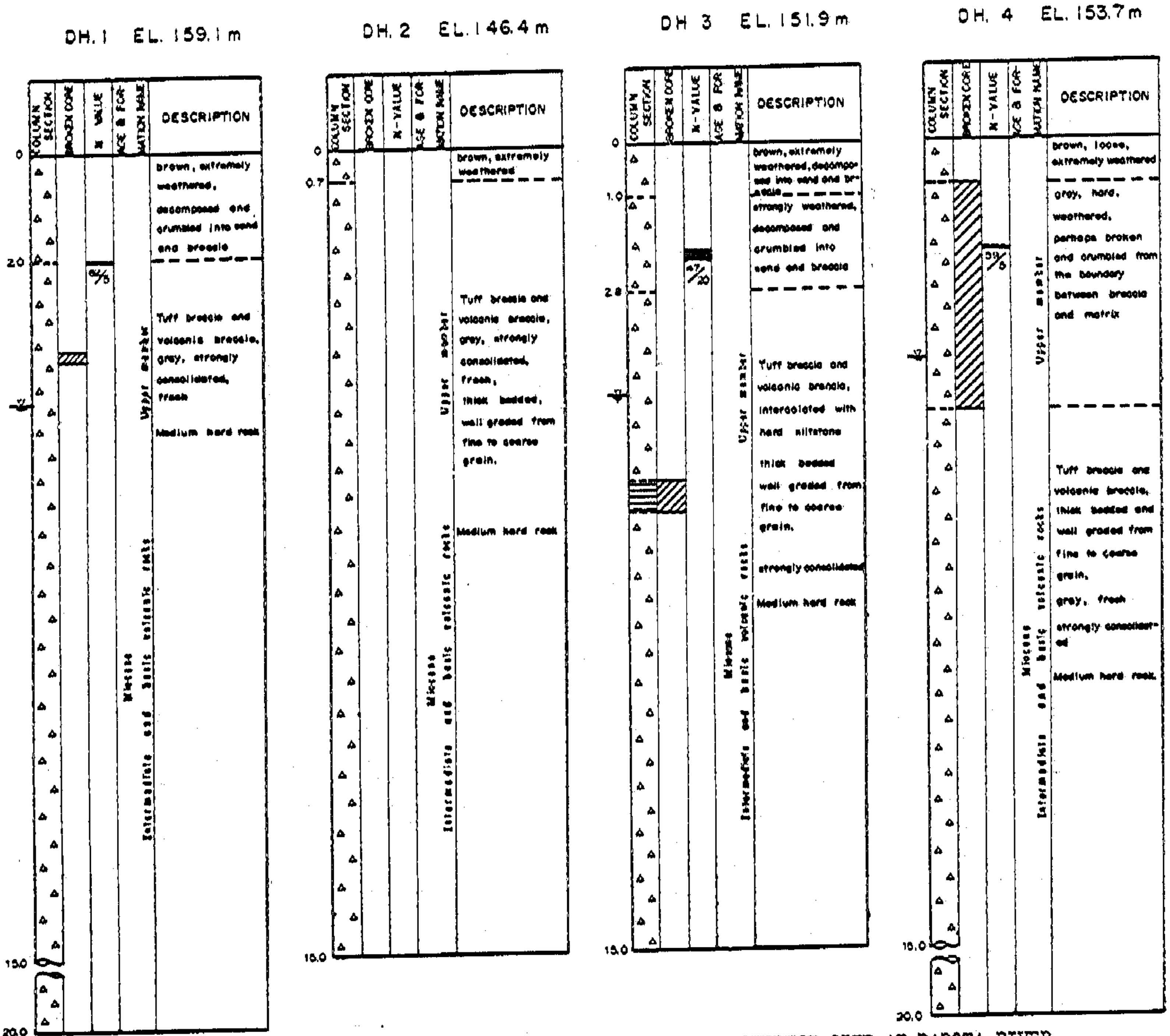


Fig. II.4.6 SUMMARIZED COLUMN SECTION OF AQUEDUCT SITE AT PAROTA RIVER

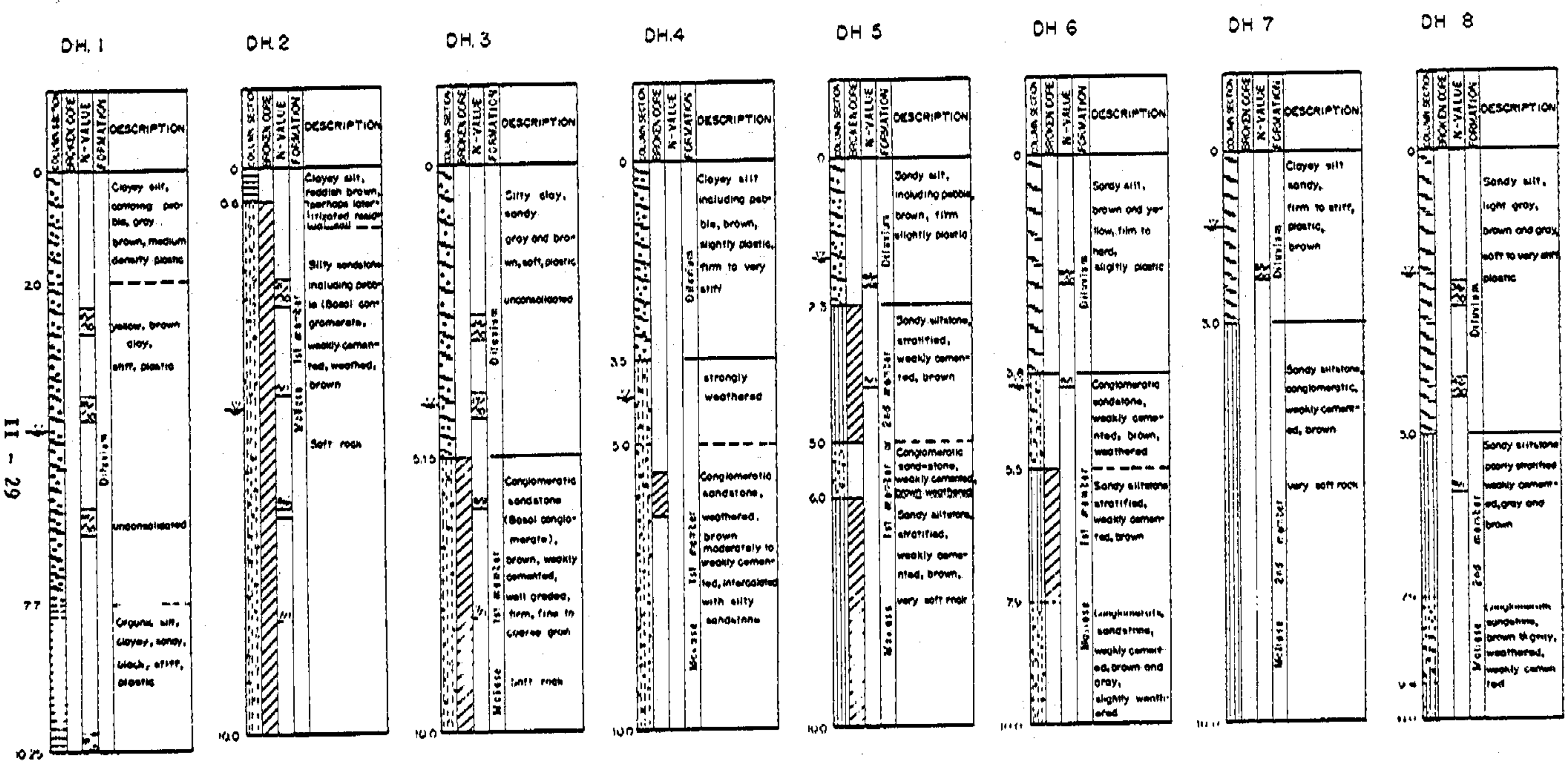


Fig. II.4.7 SUMMARIZED COLUMN SECTION OF AMING SECONDARY CANAL (1/4)

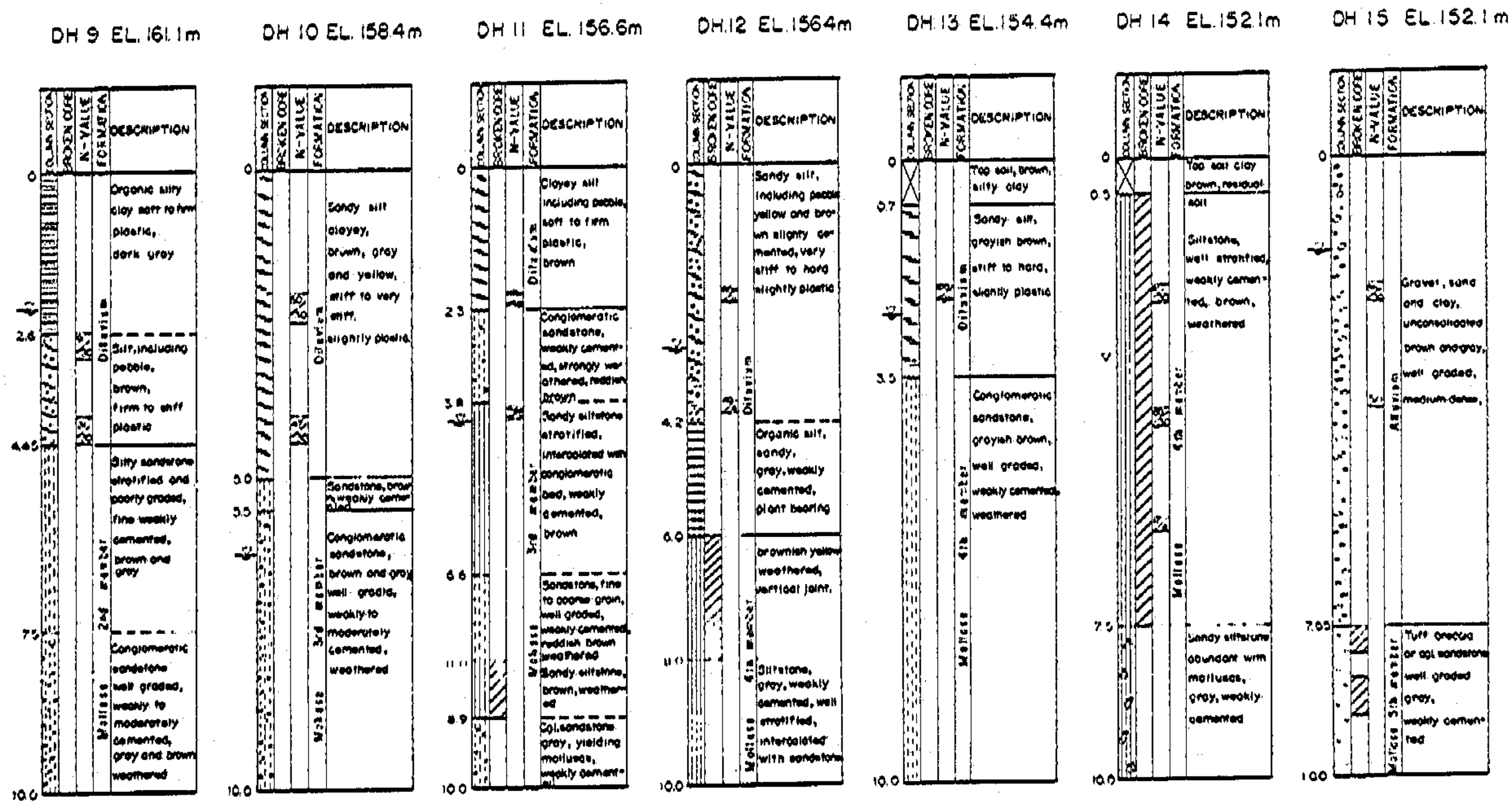


Fig. II.4.7 <u>SUMMARIZED COLUMN SECTION OF AMING SECONDARY CANAL (2/4)</u>

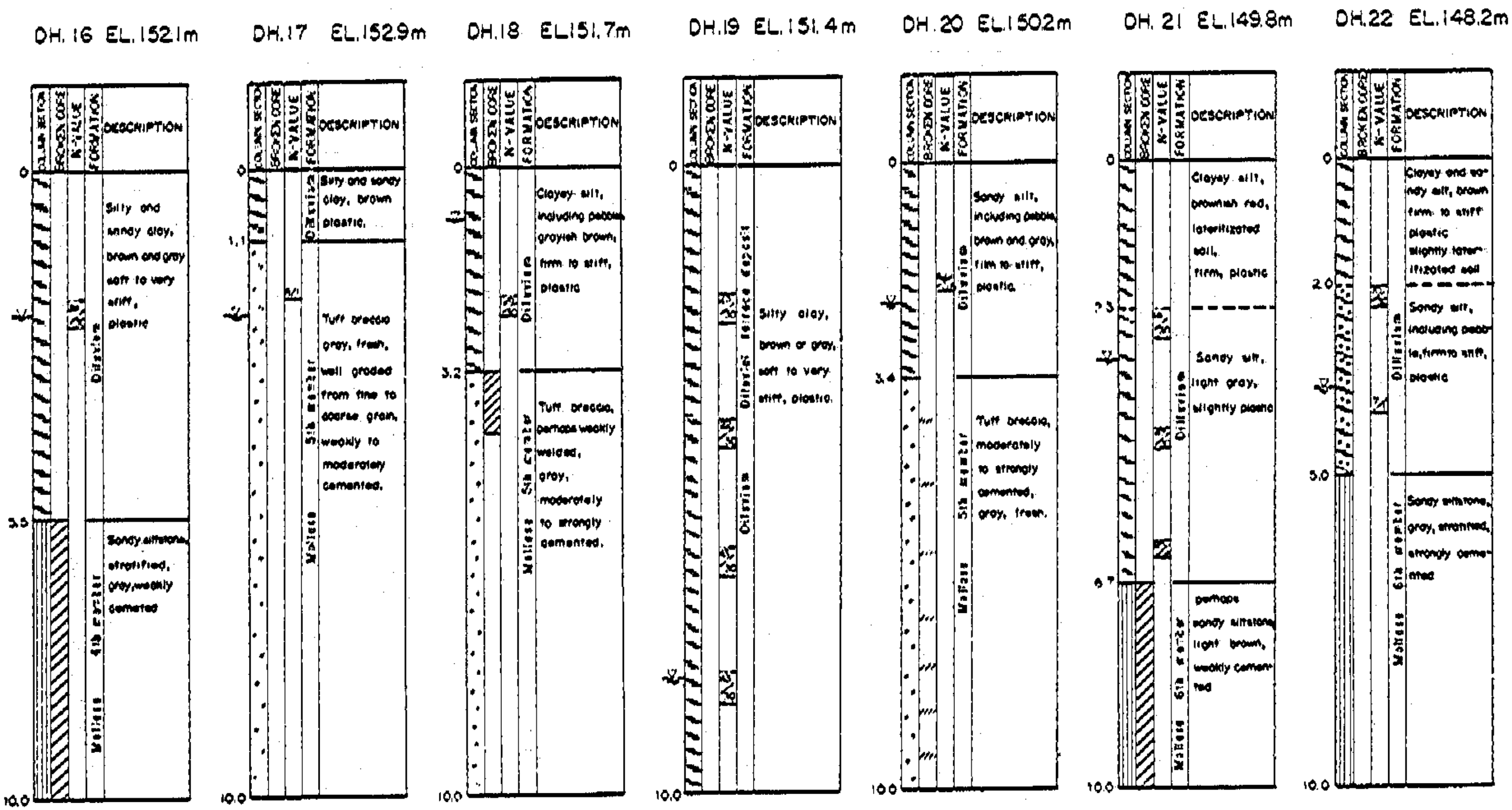


Fig. II.4.7 SUMMARIZED COLUMN SECTION OF AMING SECONDARY CANAL (3/4)

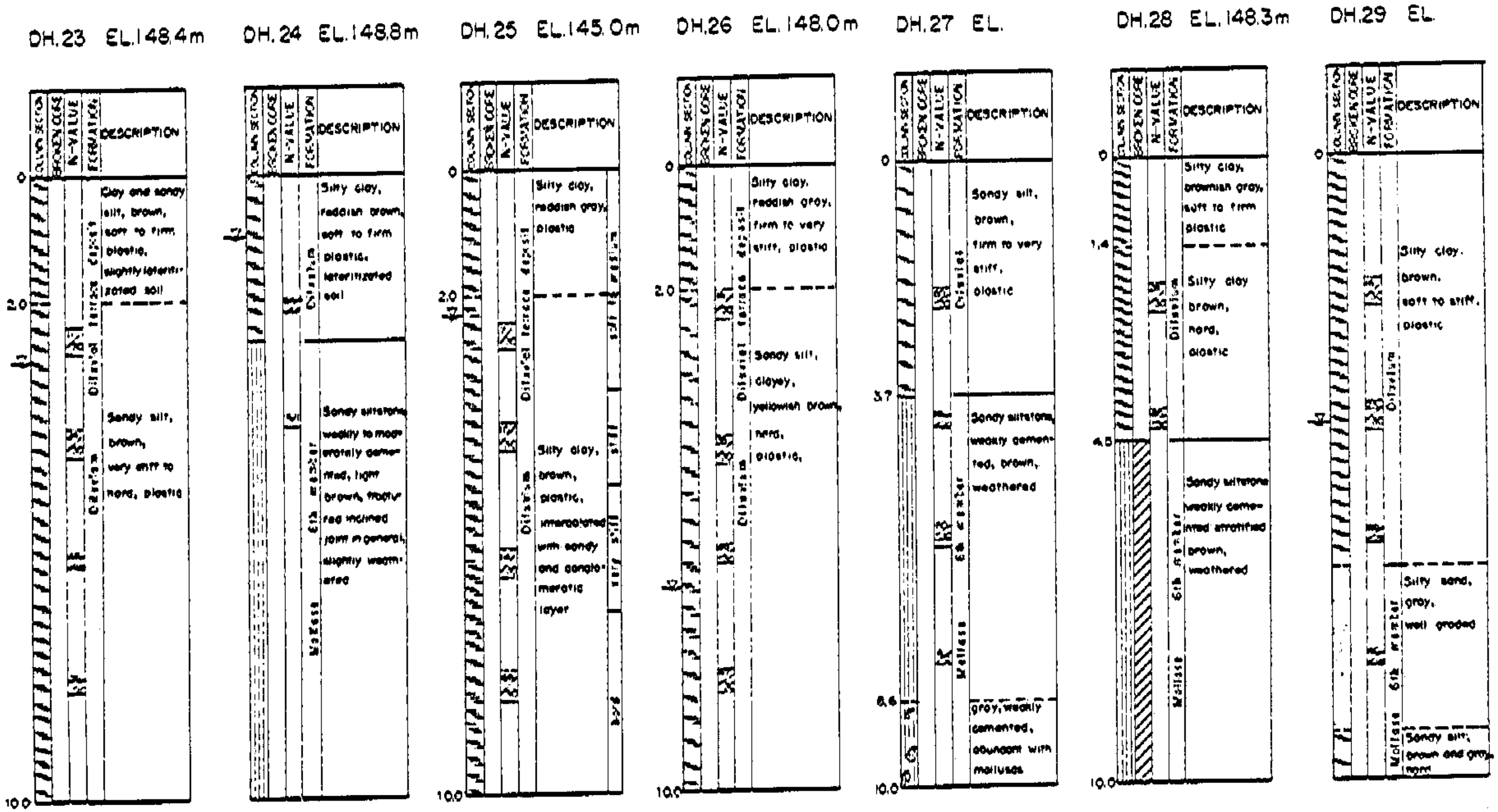


Fig. II.4.7 SUMMARIZED COLUMN SECTION OF AMING SECONDARY CANAL (4/4)

ANNEX - III

SOIL MECHANICS

ANNEX - III SOIL MECHANICS

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ANNEX - III SOIL MECHANICS

1. INTRODUCTION

The present soil mechanical survey consists of the field investigation along the main and secondary canal routes and the construction material survey. The field investigation along the main and secondary canal routes aims at clarifying:

(1) the physical and mechanical properties of soil materials along the canal routes,

(2) the foundation conditions along the proposed main and secondary canal routes, and

(3) the availability and suitability of construction materials for canal embankment.

The main purposes of the construction material survey for the proposed major structures including closing dike, intake structures and aqueducts are:

(1) to clarify the physical characteristics of concrete aggregates at the proposed structures sites,

(2) to select the borrow area(s) for impervious materials to be used for construction of closing dike,

(3) to check and confirm the results of the past investigation conducted by the Government, and

(4) to estimate the design values for stability analysis of the closing dike.

2. INVESTIGATION

2.1 General

The following field investigations and laboratory tests were made:

(1) Field investigation

(Unit: nos.)

Investigation Item	Main Canal	Aming Secondary Canal	Palaka-Parota Secondary Canal	Major Structure Site	Total
Test Pit	5	15	5	-	25
Auger Boring	5	15	4	-	24
Swedish Sounding Test	1	3	3	-	7
Cone-penetration Test	3	13	3	-	19
Sampling					
- Soil	2	7	2	-	11
- Gravel & Sand	-	-	-	5	5

(2) Laboratory tests

(a) Soil mechanical test

(Unit: nos.)

Test Item	Main Canal	Aming Secondary Canal	Palaka-Parota Secondary Canal	Total
Water content	2	7	2	11
Specific gravity	2	7	2	11
Grain size analysis	2	7	2	11
Atterberg limit	2	7	2	11
Compaction test	2	7	2	11
Triaxial compression	2	3	1	6
Consolidation	2	1	1	4

(b) Concrete aggregate test

(Unit: nos.)

Test Item	Main Canal	Aming Secondary Canal	Palaka-Parota Secondary Canal	Total
Specific gravity	2	1	2	5
Percentage of absorption	2	1	2	5
Grain size analysis	2	1	2	5

2.2 Field Investigation

2.2.1 Foundation condition

(1) Main canal route

The main canal route runs along the skirts of southern gently sloping hills. A total of 14 test pits were dug up to 3.0 m along the canal route and the detailed profile descriptions of each pit were already prepared by DOI. In the present field investigation, a number of additional profile observations were made, as shown in Fig. III.2.1.

The top layers observed along the skirts of gently sloping hills are mainly composed of moderately weathered baserocks such as silt stone and sandy tuff, except around Haradda area where the top layer is clay hardpan originated from the residual riverbed sediments. The top layer around intake weir site is hard baserocks of silt stone and sandy tuff.

The results of sounding tests and cone penetration tests are summarized in Tables III.2.1 and III.2.2. According to the results of Swedish sounding tests and cone penetration tests, the weathered deposit layers around Haradda area have a insufficient bearing capacity for the foundation of heavy and/or rigid canal structures, showing the N-value of less than 10 within 2.5 m from ground surface. The foundation below 2.5 m, however, has moderately sufficient bearing capacity for canal structures with the N-value of more than 10.

The hard baserocks of silt stone and sandy tuff extending around intake weir site have very sufficient bearing capacity for the foundation of canal structures. Use of dynamite will be needed for excavation of the canal in this area. Most of the baserocks along the main canal route are, however, moderately weathered sandy tuff or alternation of sandy tuff and silty tuff. These are generally firm foundations which have moderately sufficient bearing capacity for heavy canal structures.
The excavation of these weathered deposits could be made at least 2.0 m by using back-hoe-shovel.

(2) Aming secondary canal route

Aming secondary canal route is laid out along the foot of the eastern hills in connection with the main canal. A total of 26 test pits observations were made along the canal route by DOI. All these test pits were checked and confirmed through field investigation and also a number of additional profile observations were carried out. Locations of additional observation sites are given in Fig. III.2.1. Most of the top layers observed along the canal routes are moderately weathered, and are mainly composed of alternate layers of sandy and silty tuff and/or weathered deposits of sandy tuff and silt stone. The alternate layers of sandy and silty tuff are generally extend along the canal route with the thickness of 1.5 - 3.0 m on the top of the weathered deposits of silt stone and sandy tuff.

According to the results of sounding tests, these alternate layers have N-value of more than 10. The upper parts of the alternate layers are generally highly weathered, and show N-value of less than 10. These insufficient bearing layers are limited within 1.5 m from the surface. It is, therefore, recommended that in order to keep the sufficient bearing capacity, the excavation be made up to 1.5 m in depth.

The canal route runs across the paddy fields in some sections. The soil profiles observed in the paddy fields are mainly composed of blackish or greyish alluvial deposits with the thickness of 1.5 - 2.0 m. The bearing capacity of these deposits is very small with N-value of less than 5.

(3) Palaka-Parota secondary canal route

Palaka-Parota secondary canal route starts from intake weir site, and runs along the foot of the western mountains. Eight (8) test pits were already made along the canal routes by DOI. Additional 5 test pits and 4 auger borings were executed in the present field investigation.

The firm and hard baserocks generally outcrop on the ground surface from intake weir site to the point passing across the Sanrego river. The top layers near to the intake weir site are mainly silt stone and slate which have sufficient bearing capacity for canal structures. These stones are generally cracked. The massive and fresh sandy tuff is observed around the place passing across the Sanrego river. It has a sufficient bearing capacity for the foundation of canal structure. The top layers observed after the Sanrego river to the end of canal are mainly moderately weathered sandy tuff of silty tuff. These have a sufficient bearing capacity.

2.2.2 Construction materials

(1) Materials for main canal embankment

The canal embankment would be executed by maximum use of the in-site materials excavated from canal section. The available materials along the canal route are classified into four groups as mentioned below:

(a) Strongly weathered alternate layers of sandy and silty tuff

This material which appears from Maradda to the end of main canal, mainly consist of silty sand and silty clay. The gravel content is less than 10%. This material has a characteristic of high plasticity and high dry strength. The soil colour in moist condition is yellowish brown or brownish light grey. This material under natural condition has nearly optimum water content and is well compacted. The material seems to be sufficiently imperviousness. This material is judged to be suitable for canal embankment.

(b) Sandy tuff

This material is mainly distributed between the intake weir site and Maradda area. Most of the material are taken from the weathered layer of sandy tuff and mainly consist of silty and clayey sands. This material is generally sandy. Although it could be well compacted, sufficient imperviousness would not be sustained. The original layer of sandy tuff is very hard and is hardly excavated with back-hoe-shovel. Another heavy equipment would be required. This material is not suitable for canal embankment due to its pervious nature. If it would be used for canal embankment, some measures like canal lining or impervious facing should be required.

(c) Silt stone

The hard silt stone occurs around the intake weir site. It is very hard rock and dynamite will be needed for excavation. Although the excavated materials could be used for canal embankment, some measure would be necessary due to their perviousness to water. The weathered deposits of silt stone are found under the alternate layers of sandy and silty tuff. These could be excavated by back-hoe-shovel and moderate imperviousness be expected if would be well compacted.

(d) Highly plastic clay

The clayey materials obtained around Maradda area have a characteristics of high plasticity, high dry shrinkage and high dry strength. The materials are mainly strongly weathered riverbed deposits. The colour of surface soil in moist condition is dark grey and the lower layers show light brownish grey. The dark grey surface soils are generally soft and sticky with high water content. The surface materials are not suitable for canal embankment. The materials from lower layers are suitable for canal embankment. Since these materials tend to show high dry shrinkage, many deep cracks may develop on the embankment when canal is dried for a long time. Special care for canal maintenance will be required if these materials are used for canal embankment.

(2) Materials for Aming secondary canal embankment

The representative materials available along Aming secondary canal route are as follows:

(a) Weathered deposits of sandy and silty tuff

Most of the surface layers observed along the canal route are the weathered deposits of sandy and silty tuff. The thickness of the layers is about 1.5 - 2.0 meters. The materials are fine and/or cohesive soils with some mixture of gravel. The strongly weathered part of the materials has a property of high plasticity and high dry strength. The soil colour of the strongly weathered part is mainly yellowish brown. The moderately weathered part which contains many silty sand, has a characteristic of medium plasticity. Its colour in moist condition is light greyish brown or brownish light grey. The materials under natural condition have nearly optimum water content for compaction. The materials are sufficiently impervious. These are generally good for canal embankment.

(b) Sandy tuff

The weathered deposits of sandy tuff occur around Desa Massila. The materials are considerably weathered and are mainly composed of fine sand and silty sand with almost no plasticity. The soil colour in moist condition is yellow brownish light grey. The materials have no problem for compaction, but due to their sandy nature, the materials are generally pervious to water.

(c) Silty stone

Silty stones and their weathered materials are mainly found under the weathered alternate layers of sandy and silty tuff. The base-rocks of silt stones occur around Desa Massila, immediately under the surface soils. The weathered layer of silt stone contains very little fine soils components like silt and/or sandy silt, and sufficient imperviousness would not be expected. The baserocks of silt stones could also be utilized for canal embankment. These have no problem for stability, but impervious material facing will be essential.

(d) Reddish brown coloured soils

These soils are broadly developed over the eastern hilly region. The materials are geologically same as the weathered materials of sandy and silty tuff. The soil mechanical properties of the materials are also same. However, this material has a bit lower water content. The soil colour in moist condition shows reddish brown.

(3) Materials for Palaka-Parota secondary canal embankment

The available materials along Palaka-Parota secondary canal route are as follows:

(a) Silt stone-slate

These are rock materials with average specific gravity of about 2.1 - 2.2. Since many cracks are developed, the maximum grain size of the materials to be excavated from canal section would be less than 100 mm in diameter, and the minimum grain size be more than 2.0 mm. The colour in moist condition is grey. The materials are obviously pervious to water, but show high stability for embankment.

(b) Sandy tuff

The sandy tuff materials are divided, by degree of weathering, into two types: one is slightly weathered rock material, and the other is strongly weathered material composed of fine soils. The rock materials would be good for slope embankment, but impervious material facing should be essential. The fine soil material mainly consist of sandy clay and silty clay. These have general characteristics of high or medium plasticity, high dry strength and medium dry shrinkage. The soil colour in moist condition is light greyish yellow brown to yellow brownish light grey. The fine soil materials are suitable for canal embankment.

(c) Black soil

The black soils which extend around the end of canal are fine and cohesive, and contain some roundish calcareous gravels of 5.0 mm in diameter. In general, they show high plasticity and high dry shrinkage. The soil colour in moist condition is black or grey and partly light grey. The materials, if compacted with natural water content, would be very firm. However, if dried, many cracks will be caused by drying shrinkage.

(4) Material for closing dike

The ground foundation of closing dike mainly consists of silt stone and sand stone which have sufficient bearing capacity for the foundation of fill-type dam. However, according to the results of permeability tests executed at intake weir site, the foundation is very permeable, showing the coefficient of permeability from 1×10^{-3} to 1×10^{-4} cm/sec. In order to minimize the seepage through foundation, the closing dike with rather wide bottom of impervious zone is designed; that is, the homogeneous materials would use for dam embankment and make the creep length longer.

Since the foundation is permeable, the embankment materials tend to cause piping at the boundary face to the foundation. It is generally known that the soils with plasticity index of more than 15% have sufficient resistance against piping phenomena. Therefore, the embankment materials for clsing dike sould be cohesive clayey soils of a high plasticity and also these should have sufficient shearing strength for stability of fill-type dam.

(5) Borrow pit materials

Two borrow areas for obtaining the embankment materials of closing dike are selected at the southwestern hilly area, located 1 - 3 km southeast from the intake weir site.

The materials in the borrow areas are mainly composed of blackish clayey deposits and brownish strongly weathered materials of sandy and/or silty tuff. The blackish deposits are fine clay soils and contain some roundish calcareous gravels. The gravel content tends to lower with the depth. The thickness of the clayey deposits ranges from 3.0 meter to 4.5 meter. These materials have characteristics of high plasticity and high dry shrinkage.

The brownish strongly weathered materials of sandy and/or silty tuff are fine cohesive soils. These also have high plasticity and high dry strength. They are generally impervious to water. The thickness of the materials is approximately 1.5 m. The materials below 1.5 m are not well weathered and generally sandy. The permeability of the sandy materials shows 1×10^{-4} cm/sec. It is recommended that the materials should be carefully taken without mixing them with lower sandy materials. These available materials to be taken from the borrow areas are highly plastic with the plasticity index of over 15% and have high resistance against piping.

Available volumes in the borrow areas are estimated at about 500,000 m^3 in total, 300,000 m^3 at 3 km apart and 200,000 m^3 at 1 km apart from the intake weir site. The estimate available volume will be sufficiently enough for embankment of the closing dike, because the required volume for embankment of closing dike is around 300,000 m^3.

(6) Concrete aggregates

Major structures for the Project are planned in Sanrego, Biru and Macinaga rivers. The riverbed of these rivers are covered with sand, gravel and cobbles. These riverine deposits are favourable for the aggregates of concrete and masonry and also for the construction of gabions. According to the results of grain size analysis (see Fig. III.2.2), the riverbed materials near the major structures sites are mostly sands and fine gravels.

(a) Sanrego river

To examine the quality of gravel, the percentage of absorption and specific gravity tests are performed on the samples taken from the riverbeds. The results are, together with the standard requirement of ASTM, shown below:

Item	Tested Data			ASTM Standard Requirement
	Lowest	Highest	Middle	
Percentage of absorption (%)	2.74	2.87	2.77	less than 3.00
Specific gravity	2.58	2.60	2.60	more than 2.50

The results on both tests show that the samples have the sufficient characteristics for the standard requirement of ASTM. In view of the quality of gravel, gravels from the Sanrego river are suitable for the aggregates for concrete, masonry and gabion.

(b) Biru river (near by Maradda)

In the downstream of the existing Maradda intake weir, there exists a large amount of cobbles, gravel and sand of which average grain size is sufficient for concrete coarse and fine aggretates. They are of high quality. According to the result of grain size analysis test, there is a large amount of particles of which grain size is finer than #200 sieve (74 μ). Sand containing many particles under 74 μ is not suitable for concrete aggregates, because strength of concrete become small if such sands are used. Available volumes of concrete aggregates are estimated at about 3,000 m^3.

(c) Macinaga river

The Macinaga river flows mainly from east to west. Riverbeds of this river are thinly covered with sands and gravels. The riverbed deposits contain many fine particles under 74 μ; these are not suitable for concrete aggregate. According to the results of grain size analysis tests, the aggregates scarcely contain cobbles. If cobbles are required for structures, cobbles must be brought into the site from the another places. The estimated volume of the available concrete aggregate is about 10 - 30 m^3.

2.3 Laboratory Test

2.3.1 Soil physical test

To clarify physical properties of soil materials extending in the Project area, laboratory tests were made for soil samples taken from the test pits made along the main and secondary canal routes. Test items are as follows:

(a) Specific gravity test,

(b) Grain size analysis test,

(c) Water content test, and

(d) Atterberg limit test.

The physical tests mentioned above were carried out based on the ASTM Standard. The detailed test quantities are shown in Table III.2.3 The laboratory tests were undertaken by the Government on September/October, 1982 at Bina Marga Laboratory, Ujung Pandang. The results are described hereunder (Table III.2.4, to be referred):

(1) Specific gravity test

The results of specific gravity test for soil particles are:

Soil	Lowest	Highest	Mean
Main canal			
- Strongly weathered alternate layers of sandy and silty tuffs	-	-	2.75
- Strongly weathered silt stone	2.66	2.76	2.71
Aming secondary canal			
- Strongly weathered alternate layers of sandy and silty tuffs	2.73	2.77	2.75
- Sandy tuff	-	-	2.68
- Strongly weathered silt stone	-	-	2.68
- Reddish brown soil	2.60	2.76	2.68
Palaka-Parota secondary canal			
- Strongly weathered alternate layers of sandy and silty tuffs	-	-	2.71
- Black soil	-	-	2.62

The mean values of specific garvity range from 2.62 to 2.75. Those values are almost same as the generally acknowledged value for inorganic soil (ranging 2.6 to 2.8).

(2) Grain size analysis test

All samples used for the grain size analysis are natural graded soil. Their gradations coincide with their natural ones. However, they are considered to be different from their natural ones by the method of sampling of soils for grain size analysis. Therefore, gradations would have to be synthetically judged from the test pits observation and the results of soil test. In this study, soils staying 4.76 mm sieve (#4) are classified as gravels.

The results of grain size analysis are shown in Fig. III.2.3. The values of Rp (percent of the grains finer than No. 200 sieve) for each sample are summarized as follows:

(Unit: %)

Soil	Percent Finer than No.200 (74μ)		
	Lowest	Highest	Mean
- Strongly weathered alternate layers of sandy and silty tuffs	44.1	71.8	55.7
- Sandy tuff	-	-	45.3
- Strongly weathered silt stone	50.5	84.8	66.3
- Reddish brown soil	73.5	78.2	75.9
- Black soil	-	-	53.1

The Rp value is one of the indications for judging appropriateness of soil materials for the impervious zone of embankment. In general, the materials with Rp of over 20% are judged to be appropriate, but cracking will occur on the materials which have extremely high Rp value.

According to the results of grain size analysis test, the materials extending along the canal routes hardly contain gravels of which grain size is greater than 4.76 millimeter. However, judging from observation of test pit profiles, soil materials in natural condition are some mixture with gravels.

(3) Water content test

The results of water content test are summarized in the following table. The samples tested are those passing 4.76 mm sieve.

(Unit: %)

Soil	Water Content		
	Lowest	Highest	Mean
- Strongly weathered alternate layers of sandy and silty tuffs	20.3	42.0	30.1
- Sandy tuff	-	-	24.8
- Strongly weathered silt stone	32.6	42.8	36.9
- Reddish brown soil	30.6	36.5	33.5
- Black soil	-	-	25.6

With regard to natural water content, no great difference is seen among these soils, except for sandy tuff and black soil of which water content is about 25%, show a little lower water content than others. In general, soils contained a lot of fine particles have higher water content. As sandy tuff and black soil less contain particles under 74 μ in size than other, and seem to have low water content.

(4) Atterberg limit test

The results of Atterberg limit test for the samples passing 0.42 mm sieve are summarized below:

(Unit: %)

Soil	Liquid Limit			Plastic Limit		
	Lowest	Highest	Mean	Lowest	Highest	Mean
- Strongly weathered alternate layers sandy and silty tuffs	39.0	63.2	49.9	21.0	47.1	32.8
- Sandy tuff	-	-	39.2	-	-	26.3
- Strongly weathered silt stone	53.6	71.8	60.7	23.1	41.1	31.9
- Reddish brown soil	64.9	72.0	68.4	37.8	43.6	40.7
- Black soil	-	-	41.8	-	-	21.1

The quality of fine-grained soil shows a little high plasticity. It is generally known that the soil with plasticity index of over 15% have high resistance against piping phenomena. Most of the soils, except for soil materials of moderately weathered sandy tuff, in the Project area meet to this criteria.

2.3.2 Soil mechanical test

To know mechanical properties of soil materials extending in the Project area, laboratory tests were made for representative soil samples taken from the test pits made along the canal routes.

The items are:

(a) Compaction test,

(b) Triaxial compression test, and

(c) Consolidation test.

The mechanical tests were carried out based on the ASTM Standard. In addition, the following specifications for the soil mechanical tests were applied:

(a) Compaction test

(i) Compaction is made with standard energy. (following standard Proctor compaction test)

(ii) Cone-penetration test is made on the compacted specimen after weighing the specimen.

(b) Triaxial compression test

(i) The lateral pressures (σ^3) of the test are 1.0, 2.0 and 3.0 km/cm^2.

(ii) The pore water pressure is also measured during the compression time.

(iii) The pre-consolidation pressure for the CU-test is same as the lateral pressure on the specimen.

(c) Consolidation test

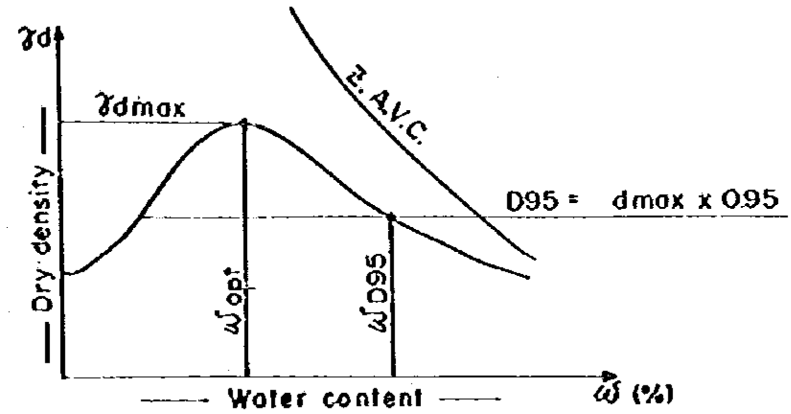
The specimen is saturated under the surcharged condition of 0.1 kg/cm^2.

(d) Test condition

Soil mechanical tests such as triaxial compression test and consolidation test are carried out for the respective specimen to be prepared for the following two conditions:

(i) γdmax and Wopt

(ii) γdmax x 0.95 = D95 and WD95



The results of these tests are summarized in Table III.2.5. The major results are described hereunder:

(1) Compaction test

The results of standard Proctor compaction test are shown below, in which mean values are indicated for all items.

Soil	γdmax	Wopt	γdD95	WD95	Wf-WD95
	(t/m^3)	(%)	(t/m^3)	(%)	(%)
- Strongly weathered alternate layers of sandy and silty tuffs	1.47	22.3	1.40	27.6	2.8
- Sandy tuff	1.53	24.7	1.45	29.3	-4.4
- Strongly weathered silt stone	1.30	31.5	1.24	35.4	0.9
- Reddish brown soil	1.24	29.7	1.18	32.1	1.5
- Black soil	1.61	19.6	1.53	24.1	1.5

Remarks: γdmax: maximum dry density

Wopt: optimum water content

γdD95: dry density to obtain 95 percent of γdmax

WD95: highest water content to obtain 95 percent of γdmax

Wf: natural water content

If the value of (Wf - WD95) is positive, in general, the materials in natural condition are inadequate for canal embankment. From the above results, the values of (Wf - WD95) of the materials tested are mostly positive but very small. Therefore, these materials would be used for canal embankment paying attention to water content control in the field.

(2) Triaxial compression test

The results of triaxial compression tests on remolded samples are shown below (see Table III.2.5 and Fig. III.2.4). The size of specimens is 10 cm high and 5 cm diameter

Soil	Specimen Condition		Shearing Strength	
	W	γd	c	φ
	(%)	(t/m³)	(kg/cm²)	(deg)
- Strongly weathered alternate layers of sandy and silty tuffs	22.4	1.58	1.15	14.0
- Strongly weathered silt stone	35.2	1.29	0.60	24.0
- Reddish brown soil	33.4	1.29	2.40	21.0
- Black soil	20.1	1.62	1.80	14.5

Remarks: W: water content
γd: dry density
c: cohesion
φ: angle of internal friction

From the above results, the materials extending along the canal routes have sufficient high shearing strength. The larger cohesion (c) and angle of internal friction (φ) would give the more sufficient resistant force against shearing force.

(3) Consolidation test

Results of consolidation tests on remolded samples are summarized in Table III.2.5. According to the results of consolidation tests, the coefficients of consolidation (Cv) range from 2×10^{-4} to 1×10^{-2} cm^2/sec, and the compression indexes (Cc) range from 0.05 to 0.12. The value of Cc indicates the quantity of consolidation. From view point of deformation of canal embankment, the larger value of Cc will give a large consolidated settlement after embankment. Judging from the value of Cv, a fairly long lapse of time would be expected before getting 90% degree of consolidation on the embankment. However, as canal embankment is not so high, the quantity of settlement is not so large too.

2.3.3 Concrete aggregate test

To examine the quality of concrete aggregate, laboratory tests were made for sand and gravel samples taken from the riverbeds near the major structure sites. Test items are:

(a) Specific gravity test,

(b) Grain size analysis test, and

(c) Percentage of absorption test.

The aggregate tests were carried out based on the ASTM Standard. The detailed test results are shown in Table III.2.6.

(1) Specific gravity test

The results of specific gravity test for sands and gravels are shown below:

Location	Bulk Specific Gravity	
	Saturated Surface-dry	Oven-dry
R. Macinaga	2.60	2.49
R. Biru (Haradda)	2.66	2.60
R. Sanrego (Intake)	2.60	2.53
R. Sanrego (Teko)	2.58	2.51
R. Sanrego (Sanrego)	2.60	2.53

According to the standard of ASTM, the specific gravity of concrete aggregate required 2.5 or over. The results shown in the above table meet this standard value. These aggregates is judged to be suitable for concrete aggregate.

(2) Grain size analysis test

The results of grain size analysis test for aggregates are summarized below. In this study, particles staying 4.76 millimeter sieve (#4) are classified into gravels.

(Unit: %)

Location	Content of Gravel	Content of Fine-grain
	No Passing 4.76 mm Sieve	Passing 74μ Sieve
R. Macinaga	29.5	26.3
R. Biru (Haradda)	60.5	17.5
R. Sanrego (Intake)	85.3	7.3
R. Sanrego (Teko)	72.0	10.4
R. Sanrego (Sanrego)	73.0	8.5

From the above results, riverbed deposits contain more than 50% of gravels staying 4.76 mm sieve, except for riverbed materials of the Macinaga river. These materials are suitable for the aggregates of concrete, masonry and gabion. If the aggregates contain a lot of particles passing 74 μ sieve, such fine particles should be excluded from the original materials, because the mortar would become weak if such fine particles are used.

(3) Percentage of absorption test

The results of percentage of absorption test for sand and gravel are shown below:

(Unit: %)

Location	Percentage of Absorption
R. Macinaga	4.44
R. Biru (Maradda)	2.12
R. Sanrego (Intake)	2.87
R. Sanrego (Teko)	2.74
R. Sanrego (Sanrego)	2.77

According to the standard of ASTM, the percentage of absorption of concrete aggregate should be less than 3.0%. As riverbed deposits of the Macinaga river have a large amount of fine particles, their percentage of absorption shows a little high value of 4.44%. Other materials are suitable for concrete aggregate as they meet this standard value.

3. ANALYSIS

3.1 Soil Classificaton

Based upon the results of grain size analyses and Atterberg limit tests, the soil classification is made as follows:

(1) Canal routes

(a) Strongly weathered alternate layers of sandy and silty tuff;

These materials are classified into CL, MH and SC, depending on the different degree of weathering and thickness of each layer.

(b) Sandy tuff;

This material is mainly classified as SC. But the strongly weathered parts will belong to CH.

(c) Strongly weathered silt stone;

Most of strongly weathered silt stones are classified as CH. The liquid limit and plastic limit of these materials vary, depending on the degree of weathering.

(d) Reddish brown soil;

Reddish brown soils are classified into MH and CH. However, the natural soils under field condition contain some amount of gravels. Such soils will be classified as SC.

(e) Black soil;

Black clay soils are classified into ML and CL. These generally contain calcareous gravels. The calcareous gravels could be crushed with finger tips, and show sandy texture.

(2) Concrete aggregate

As Atterberg limit tests for riverbed materials were not carried out in the laboratory, soil classification is made by use of the results of grain size analyses. Riverbed materials of Macinaga river will be classified as GM, and those of Biru and Sanrego rivers classified into G-M.

(3) Borrow area material

There are two kinds of borrow area materials available; one is blackish or greyish coloured and has a characteristic of high plasticity, and the other is yellowish brown or brown in colour and has a high or medium plasticity.

The soils coloured in black or grey are classified as CH. The soils coloured yellowish brown or brown are classified into CH, CL and ML.

Yellowish brown coloured soils are strongly weathered materials of sandy tuff or silty tuff. In the borrow areas, the degree of weathering deffers with depth. The soil classification, therefore, ranges from CH for surface soils to ML for sub-surface soils.

3.2 Stability of Slopes

3.2.1 Closing dike

(1) Design values

The design values on the optimum condition are applied to the DOI design works of closing dike. However, the water content of soil in natural condition is higher than its optimum. Therefore, the shearing strength of embankment materials will become less than its optimum value. With this in view, the design values are determined through the review of the soil mechanical tests made by DOI.

The results of soil mechanical tests carried out by DOI are summarized in Table III.3.1. From these results, the design values of black coloured soils are presumed as follows:

Black soil

- Steady state seepage

Based on the effective stress value of triaxial compression test (C - U test), it is decided:

$$C' = (0.58 + 1.38 + 0.39)\ kg/cm^2 \div 3 \times 90\%^{/1} \times 80\%^{/2} \doteqdot 5.0\ t/m^2$$

$$\phi' = (\tan 10° + \tan 3.25° + \tan 15°) \div 3 \times 90\% \times 80\% \doteqdot 7°\text{-}00'$$

$Wf = 36.3\%$

$Gs = 2.602$

$\gamma d = (1.532 + 1.160 + 1.245) \div 3 = 1.31\ t/m^3$

$\gamma t = 1.31 \times (1 + 0.363) = 1.79\ t/m^3$

$$e = \frac{Gs}{\gamma d} - 1 = 0.986$$

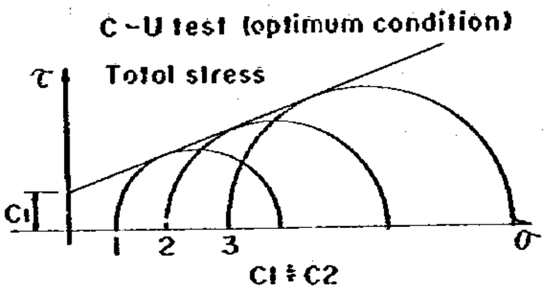
$$\gamma sat = \frac{Gs + e}{1 + e} = 1.81\ t/m^3$$

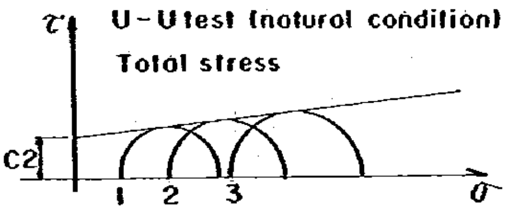
$\gamma sub = \gamma sat - \gamma w = 0.81\ t/m^3$

Remarks: /1; conversion factor for natural condition
/2; safety factor of design value

- During construction

Based on the total stress value of triaxial compression tests (U - U test and C - U test), it is decided:





$C = (0.5 + 1.35 + 0.48)\ kg/cm^2$
$\div 3 \times 80\%^{/3} \doteqdot 7.0\ t/m^2$

$\phi \leq 5°$ that is, $\phi \doteqdot 3°\text{-}00'$

Remarks: /3; safety factor for design value

The design values of dark brown or yellowish brown coloured material which are strongly weathered of sandy tuff or silty tuff are also presumed as follows:

Strongly weathered sandy tuff or silty tuff

- Steady state seepage (effective stress)

$C' = (0.70 + 0.40 + 0.15) \div 3 \times 90\% \times 80\% \doteqdot 3.0\ t/m^2$

$\phi' = (\tan 9° + \tan 28.75° + \tan 24.5°) \div 3 \times 90\% \times 80\% \doteqdot 15°\text{-}00'$

$Wf = 33.52\%$

$Gs = 2.597$

$$\gamma d = (1.545 + 1.320 + 1.178) \div 3 = 1.35\ t/m^3$$

$$\gamma t = 1.35 \times (1 + 0.3352) = 1.80\ t/m^3$$

$$e = \frac{2.597}{1.35} - 1 = 0.924$$

$$\gamma sat = \frac{Gs + e}{1 + e} = 1.83\ t/m^3$$

$$\gamma sub = \gamma sat - 1 = 0.83\ t/m^3$$

- During construction (total stress)

$$C = (0.7 + 0.4 + 0.28) \div 3 \times 80\% \doteqdot 3.0\ t/m^2$$

$$\phi = (\tan 6° - 50' + \tan 22° - 50' + \tan 15°) \div 3 \times 90\% \times 80\% \doteqdot 11°\text{-}00'$$

The two design values are calculated as mentioned above. Judging from the results of field investigation in the borrow areas, the major embankment materials for closing dike are black soils. Therefore, the design value of black soils is applied to stability analysis for closing dike.

(2) Method of stability calculation

Stability calculation for closing dike is made by using slip-circle method. The safety factor against sliding for an assumed circle is computed by the equation as shown below (see Fig. III.3.1):

$$Fs = \frac{\Sigma\{(N - U - Ne) \cdot \tan\phi + C.L\}}{\Sigma(T + Te)}$$

where,

Fs: safety factor

C: cohesion

ϕ: angle of internal friction

L: length of arc of slip circle

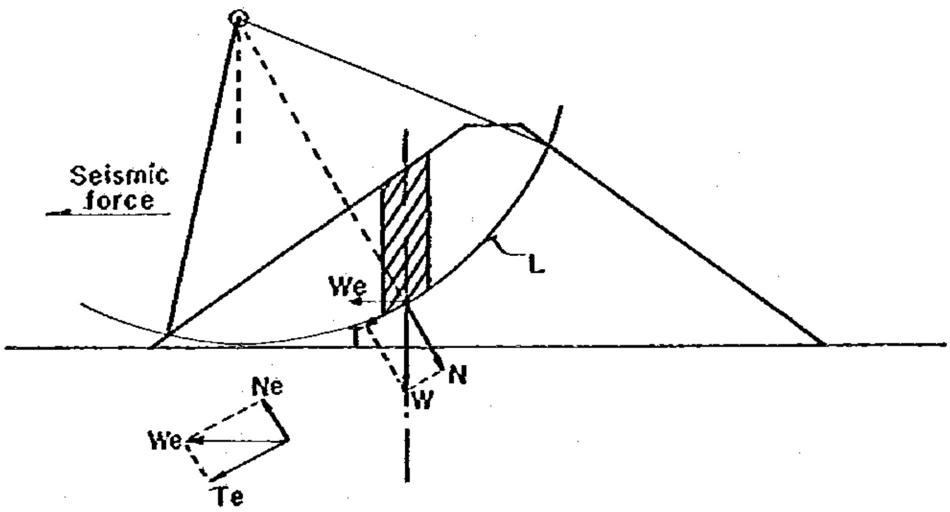
N: normal force along the arc

T: tangential force along the arc

Ne: normal force for seismic force along the arc

Te: tangential force for seismic force along the arc

U: uplift force due to pore water pressure along the arc



(3) Result of calculation

The stability calculation is carried out for the original section proposed by DOI. The results are shown in Table III.3.2 and Fig. III.3.2. It should be noted that calculation was made on the assumption of steady state seepage with earthquake of 0.15 horizontal seismic coefficient.

According to the results of calculation, minimum safety factor for slope of upstream is 1.605. This surely meet the standard value of more than 1.1. On the other hand, minimum safety factor for downstream slope is 1.06. The factor does not meet the standard value. It is recommended that for the downstream slope, the original design be modified to sustain the enough stability.

3.2.2 Embankment slope for canal

To examine the stability of canal embankment slope, the shearing strength parameters; cohesion and angle of internal friction, are usually determined from the results of shear strength test. In order to determine the shear strength, the triaxial compression tests are made in the present study. The results are shown below:

Soil	Shearing Strength Parameter	
	Cohesion C (kg/cm^2)	Angle of Internal Friction ϕ (deg.)
- Strongly weathered alternate layers of sandy and silty tuffs	1.2	14° - 00'
- Sandy tuff /1	0.3	15° - 00'
- Strongly weathered silt stone	0.6	24° - 00'
- Reddish brown soil	2.4	21° - 00'
- Black soil	1.8	14° - 30'

Remarks: /1; the values of sandy tuff are assumed, making reference to results of borrow area material.

The critical height of embankment is calculated by Tailor's method (refer to Fig. III.3.4). In the calculation, input parameter of cohesion (c) is modified taking into account the conversion factor of 0.9 for natural condition and safety factor of 0.8 of design value for the above results, and angle of internal friction is regarded as zero (0), besides, the safety factor of stability is set at 1.5.

The results of the calculation shown in Table III.3.4 seem to indicate that steep embankment slope is allowable to almost any kind of soils. But further more, it should be considered that the canal embankment would frequently face to alternate repetition of drying and swelling which will cause failure of steep slope. It is, therefore, recommended that the slope angle of embankment for main and secondary canals be designed with 34 degrees (1:1.5).

3.2.3 Cut slope for canal

The sounding and cone penetration tests are carried out on natural soils by use of a Swedish sounding apparatus and a portable cone-penetrometer. From these two tests, the undrained strength qu and the cohesion for zero angle of internal friction C are estimated by using following two equations:

$$qu = 0.0045\ Wsw + 0.0075\ Nsw$$

$$C = 1/2 \cdot qu = 1/10 \cdot qc$$

where,

qu: unconfined compressive strength (kg/cm^2)

Wsw: load (kg)

Nsw: half turning numbers per meter (times)

C: cohesion (kg/cm^2)

qc: cone bearing capacity (kg/cm^2)

However, judging from the results of soil test and profile observation at test pits, as natural residual soils contain some amounts of gravels, their angles of internal friction is not considered to be zero. In view of the above, the shearing strength parameters are assumed for cuts of canal as follows:

Soil or Rock	Cohesion C (kg/cm^2)	Design Angle of Cut Slope	Remarks
Soft soil	0.25 - 0.3	34° (1:1.5)	Strongly weathered soil, High plastic soil and Residual soil
Medium to firm soil	0.5 over	34° to 45° (1:1.5 to 1:1.0)	Sandy tuff or Silty tuff strongly weathered
Weathered rock		45° (1:1.0)	Silt stone and Sandy tuff
Rock		45° to 63° (1:1.0 to 1:0.5)	Silt stone and Sandy tuff

From the results of slope stability analysis made by using Tailor's method, it is presumed that the vertical cut in natural soft soil still have much safety even with considerable height. However, it is also recommended that cut slope in soft soil be designed with 34 degrees (1:1.5) as well as embankment slope. In addition, the recommended design angles of cut slope for another firm soils and rocks are as in the above table.

3.3 Leakage

(1) Leakage through closing dike

According to the results of permeability test, coefficient of permeability of embankment material is smaller than 5×10^{-6} m/sec. As closing dike is proposed to be a homogeneous fill dam, the seepage through embankment is assumed to be very small.

The permeability on foundation of closing dike ranges from $k = 1 \times 10^{-3}$ to 10^{-4} cm/sec. The quantity of leakage through foundation is negligible small for the discharge of the Sanrego river (see ANNEX-VII).

(2) Leakage through canal embankment

According to the results of gradation, soil materials extending along the canal routes are assumed to have low permeability, being less than 1×10^{-6} cm/sec. However, if the rock materials are used for canal embankment, the permeability will be very high. In such case, canal embankment will have to be covered with impervious facing.

The water contents of embankment materials are desired to be kept at the optimum water content. If the water content of the embankment materials differs from the optimum, embankment will have higher permeability than the expected. This problem is, however, easily settled by watering the materials during embankment works.

(3) Leakage through foundation of canal

According to the test pits observations, the permeability on the canal foundation is estimated to be 1 x 10^{-5} cm/sec, except weathered sandy tuff, silt stone and partly of talus deposits of which foundations are anticipated to have high permeability. To prevent high leakage from these foundations, it is recommended that they should be covered with such impervious facing as wet stone masonry or clay for sloping portion.

4. RECOMMENDATION

4.1 Stability of Closing Dike

(1) Safety factor of closing dike

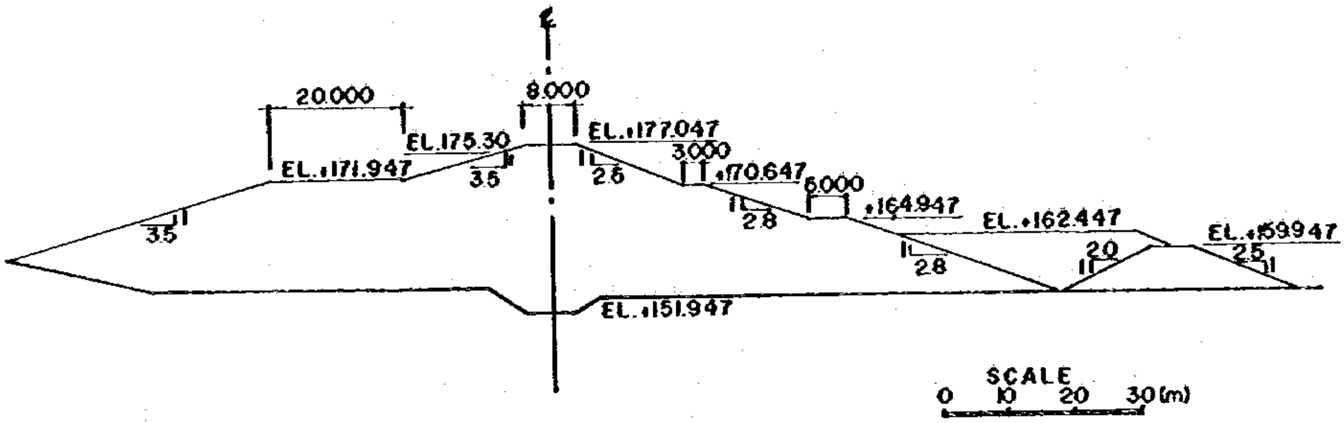
The results of stability calculation for closing dike with circular slip method are summarized below (for details, vide Table III.3.2, Table III.3.3, Fig. III.3.2 and Fig. III.3.3):

Original Section				Modified Section	
Upstream		Downstream		Downstream	
Radius (m)	Safety Factor	Radius (m)	Safety Factor	Redius (m)	Safety Factor
20.0	2.702	24.0	1.384	32.0	1.313
25.0	3.628	32.0	1.135	40.0	1.195
35.0	2.204	39.0	1.092	42.0	1.663
36.8	1.695	42.0	1.305	49.5	1.198
60.0	1.769	60.0	1.087	60.0	1.384
88.0	1.605	75.0	1.060	70.0	1.819

The calculation results indicate that the safety factor for downstream slope of closing dike designed by DOI is less than 1.1. In order to increase its safety factor, the downstream slope is modified to a some extent as shown in Fig. III.3.3.

(2) Standard section of closing dike

Based on the results of stability calculation of slopes, the standard design section of closing dike is proposed as follows:



(3) Recommendation

Taking the results of soil mechanical investigation and stability calculation into consideration, it is recommended that:

(a) standard section of closing dike be modified as shown above,

(b) highly plastic materials with plasticity index of more than 15 must be used at the boundary face between foundation and embankment,

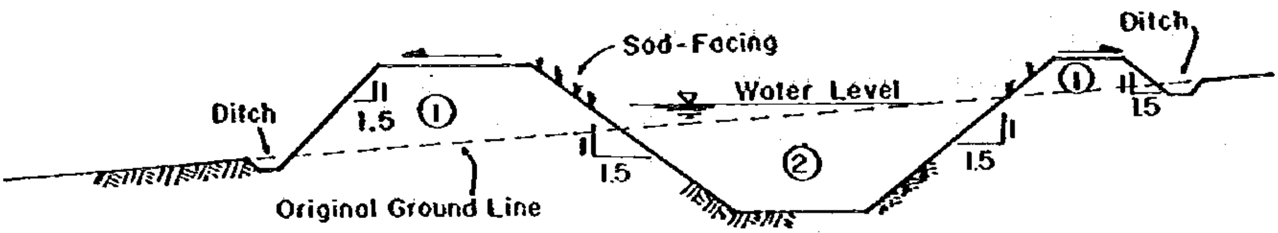
(c) the shearing strength of borrow area materials be confirmed under natural condition,

(d) the brown materials contained sandy part are embanked on the surface of closing dike, because black soils tend to make many cracks by drying shrinkage, and

(e) the rock materials might be used for embankment on the surface part of closing dike, exclusively for the downstream slope.

4.2 Typical Section of Canals

Based upon the results of soil test, detailed field investigation and stability analysis slopes, a typical design section of canal is proposed as shown below:



(1) Embankment

Cobbles larger than 10 cm, are removed to prevent seepage from embankment material. If cobbles are encounted in canal excavation, they are used for the counter weight of the canal embankment or road-metalling to get high resistance against sliding of outer slope. The embankment should be well compacted to keep high resistance against drying shrinkage, swelling and sliding.

The portion above wetted perimeter of canal should be sodded to protect canal facing from shrinkage and erosion.

(2) Excavation

If the foundation of canal is much gravelly or cracky and porous, it should be covered with an impervious material and/or concrete materials.

The catch drain should be provided along the foot of the embankment. At the boundary of the cut and the natural slope, the shoulder ditch is desired to be constructed to protect the cut slope from erosion.

Table III.2.1 Swedish Sounding Tests

Load Nsw	Location: Maradda (Main Canal)			Auger Boring 20 (Aming Secondary)			TP-24 (distance of 3.0m) (Parota Secondary)			Auger Boring 24 (Parota Secondary)			Auger Boring 21		
	Depth D	N	qu	Depth D	N	qu	Depth D	N	qu	Depth D	N	qu	Depth D	N	qu
(kg)	(m)		(kg/cm^2)	(m)		(kg/cm^2)	(m)		(kg/cm^2)	(m)		(kg/cm^2)	(m)		(kg/cm^2)
100	0.55	-	-	0.25	6	0.84	0.045	-	-	0.015	-	-	0.05	-	-
100	0.58	-	-	0.50	7	1.06	0.295	4	0.63	0.265	7	1.00	0.30	4	0.57
100	0.83	4	0.59	0.75	8	1.14	0.545	5	0.74	0.515	10	1.38	0.325	-	-
100	1.08	4	0.63	1.00	8	1.23	0.795	4	0.64	0.52	-	-	0.575	5	0.70
100	1.15	-	-	1.27	7	1.09	1.045	4	0.58	0.80	10	1.36	0.825	7	1.02
100	1.40	4	0.53	1.52	6	0.93	1.055	-	-	1.09	6	0.89	0.965	21	3.13
100	1.41	-	-	1.77	6	0.91	1.305	4	0.57	1.34	4	0.67			
100	1.66	4	0.54	2.05	5	0.79	1.555	4	0.60	1.59	9	1.20			
100	1.91	4	0.58	2.30	5	0.75	1.90	6	0.96	1.84	12	1.59			
100	2.16	5	0.68				2.15	4	0.65						
100	2.41	6	0.87				2.40	7	1.05						
100	2.52	9	1.34				2.65	8	1.14						
Place	Paddy			Field (Top of Hill)			Paddy or Field			Field			Paddy		
Surface Condition	Dry - Moisture			Dry			Dry - Moisture			Dry			Dry		

Remarks: Nsw: Half turning numbers per meter (Nsw = Na/L x 100)

N: N-value (gravel, sand or sandy soil) N = 2 + 0.067 · Nsw
(clay or cohesive soil) N = 3 + 0.05 · Nsw

qu: Unconfined compressive strength qu = 0.0045 · Nsw + 0.0075 · Nsw

Table III.2.2 Cone Penetration Test

Depth	Location																	
	Aug. 1	Aug. 2	Aug. 5	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Agu. 10	Aug. 11	Aug. 13	Aug. 14	Aug. 15	Aug. 16	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 23
(m)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)	qc (kg/cm²)
0.3							2.6											
0.4							2.9											
0.5	13.4	5.9	13.4			6.7	3.4				14.4 over	7.2 over	3.9		14.4 over	14.4 over		
0.6				6.5			3.4	13.4 over		10.3			3.6	7.2 over			7.2	
0.7					6.7		3.6		9.8	12.4			3.9					
0.8							3.4		10.3	11.3			3.7					
0.9							3.4		10.1	11.3			3.8					
1.0	13.9	6.2	13.4	6.6	7.0	7.0	3.7	14.4 over	11.4	13.9	14.4 over	7.8 over	3.6	7.2 over		14.4 over	7.2 over	5.2
1.1							3.9		10.1	15.5			3.7					5.9
1.2							4.4		11.3				3.6		14.4 over			6.2
1.3							4.2		12.4				3.4					5.9
1.4							4.9		10.8				3.9					7.2 over
1.5	15.5 over	7.8 over	14.4	6.2			5.7		12 4	15.5 over			4.7	7.2 over		14.4 over	7.2 over	
1.6	15.5 over						6.7	14.4 over	11.1			7.8 over	6.7		14.4 over			
1.7							6.7		12.9				7.2 over					14.4 over
1.8							7.0		13.9									
1.9							7.2											
2.0		7.8 over								15.5 over					14.4 over	14.4 over	7.2 over	
2.1								14.4 over										
2.2													7.2 over					
Place	Hill Side	Paddy	Paddy	Hill Side	Hill Side	Paddy	Paddy	Paddy	Paddy	Hill Side	Top of Hill	Hill Side	Paddy	Paddy & Field	Paddy	Top of Hill	Paddy	Paddy
Surface Condi- tion	Moist	Moist	Moist	Dry ~ Moist	Dry	Dry ~ Moist	Moist	Dry	Moist	Moist	Dry	Dry	Dry ~ Moist	Dry ~ Moist	Dry ~ Moist	Dry ~ Moist	Moist	Moist

Table III.2.3 Laboratory Test Items and Quantities

Sample Name / Test Items	Water Content	Specific Gravity	Grain Size Analysis	Atterberg Limit	Percentage of Absorption	Compaction	Triaxial Compression	Consolidation
TP - 1 2.3 m	1	1	1	1		1	1	2
TP - 4 2.0 m	1	1	1	1		1	1	2
TP - 6 1.0 m	1	1	1	1		1	-	-
TP - 8 1.3 m	1	1	1	1		1	1	2
TP -12 2.5 m	1	1	1	1		1	-	-
TP -13 1.5 m	1	1	1	1		1	-	-
TP -14 2.0 m	1	1	1	1		1	1	-
TP -18 1.5 m	1	1	1	1		1	1	-
TP -20 1.0 m	1	1	1	1		1	-	-
TP -22 1.5 m	1	1	1	1		1	-	-
TP -24 1.5 m	1	1	1	1		1	1	2
R. Sanrego (Intake)		1	1		1			
R. Sanrego (Sanrego)		1	1		1			
R. Sanrego (Teko)		1	1		1			
R. Macinaga		1	1		1			
R. Biru (Maradda)		1	1		1			
T o t a l	11	16	16	11	5	11	6	8

Table III.2.4 The Result of Soil Physical Tests

Hole Number	Depth (m)	Geological Classification	Unified Classification	Field Moisture Content Wf (%)	Specific Gravity Gs	Consistency L.L. (%)	Consistency P.L. (%)	Consistency P.I.	Gradation: Passed Percentage (%) 4.76 mm	2.00 mm	0.42 mm	0.074 mm	0.005 mm	Particle Size (mm) D_{60}	D_{30}	D_{10}	Cu	Cc
TP- 1	2.3	Alternation	CL	21.04	2.75	43.80	21.00	22.80	-	100	93.26	55.78	25.0	0.085	0.011	-	-	-
TP- 4	2.0	Silt stone	CH	35.40	2.76	56.80	31.63	25.17	-	100	65.38	50.52	42.0	0.104	-	-	-	-
TP- 6	1.0	-do-	CH	32.60	2.66	53.60	23.13	30.47	-	100	92.68	63.68	26.0	0.060	0.006	-	-	-
TP- 8	1.3	-do-	CH	42.76	2.68	71.80	41.08	31.72	-	100	98.88	84.78	25.0	0.026	0.012	-	-	-
TP-12	2.5	Sandy tuff	SC	24.83	2.68	39.18	26.30	12.89	-	100	94.12	45.28	34.0	0.105	0.012	-	-	-
TP-13	1.5	Alternation	MH	37.20	2.73	63.20	47.06	16.14	-	100	93.76	71.84	21.0	0.021	0.010	-	-	-
TP-14	2.0	-do-	MH	42.03	2.77	53.50	34.14	19.38	-	100	98.44	51.20	25.0	0.085	0.015	-	-	-
TP-18	1.5	Reddish brown soil	CH	30.61	2.60	64.90	37.81	27.09	-	100	85.34	78.18	55.6	0.009	-	-	-	-
TP-20	1.0	-do-	CH	36.48	2.76	71.95	43.55	28.40	-	100	87.16	73.54	54.5	0.010	-	-	-	-
TP-22	1.5	Alternation	SC	20-26	2.71	39.00	29.00	10.00	-	100	49.80	44.12	33.0	0.950	-	-	-	-
TP-24	1.5	Black soil	CL	25.58	2.62	41.75	21.05	20.70	-	100	72.84	53.06	45.6	0.280	-	-	-	-

Table III.2.5 The Results of Soil Mechanical Tests

Number of Test Pit	Field Moisture Content Wf	Compaction Test				Triaxial Compression Test: Initial Condition of Specimen		Triaxial Compression Test: Shearing Strength		Consolidation Test: Initial Condition of Specimen		Consolidation Test: Index	Consolidation Test: Coefficient
		γ_{dmax}	Wopt	D95	WD95	W	γ_d	C	ϕ	W	γ_d	Cc	Cv
	(%)	(t/m3)	(%)	(t/m3)	(%)	(%)	(t/m3)	(kg/cm2)	(deg)	(%)	(t/m3)		(cm2/sec)
TP- 1	21.04	1.63	18.0	1.55	25.4	20.23	1.64	1.25	6°30'	19.20 20.73	1.604 1.568	0.049 0.057	5.45×10^{-3} 5.56×10^{-3}
TP- 4	35.40	1.30	31.3	1.24	36.9	34.67	1.29	0.90	17°00'	32.27 33.06	1.318 1.263	0.061 0.103	5.52×10^{-3} 5.79×10^{-3}
TP- 6	32.60	1.38	29.6	1.31	32.4								
TP- 8	42.76	1.22	33.7	1.16	37.0	35.64	1.29	0.30	31°00'	34.84 39.76	1.222 1.265	0.123 0.074	5.64×10^{-3} 5.31×10^{-3}
TP-12	24.83	1.53	24.7	1.45	29.3								
TP-13	37.20	1.33	22.1	1.26	27.1								
TP-14	42.03	1.42	22.9	1.35	26.0	24.63	1.51	1.05	21°00'				
TP-18	30.61	1.27	30.0	1.21	32.6	33.39	1.29	2.40	21°00'				
TP-20	36.48	1.20	29.3	1.14	31.5								
TP-22	20.26	1.49	26.0	1.42	31.8								
TP-24	25.58	1.61	19.6	1.53	24.1	20.13	1.62	1.80	14°30'	21.80 25.04	1.557 1.482	0.046 0.054	1.82×10^{-3} 6.21×10^{-3}

Table III.2.6 The Results of Concrete Aggregate Tests

Grain Size Test

Sample No.	Maximum Grain Size	Passing Rate of Distribution (%)												
		- 100	2" 50.8	1 1/2" 38.1	1" 25.4	3/4" 19.1	3/8" 9.52	# 4 4.96	#10 2.0	#20 0.84	#40 0.42	#80 0.25	#100 0.105	#200 0.074
	(mm)	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
R. Macinanga	38.1	-	-	100	99.12	97.23	84.63	70.50	50.29	33.95	28.38	27.25	26.99	26.30
R. Biru (Maradda)	100	100	89.0	80.1	69.7	61.7	48.4	39.5	31.5	22.5	22.4	18.5	18.2	17.5
R. Sanrego (Intake)	250	91.0	67.5	54.0	36.1	28.2	18.0	14.7	11.8	10.6	9.3	8.8	8.2	7.3
R. Sanrego (Teko)	200	96.0	78.3	70.3	58.0	50.9	35.6	28.0	21.6	14.9	12.2	11.2	11.0	10.4
R. Sanrego (Sanrega)	100	100	81.0	66.5	57.9	50.5	37.3	27.0	15.6	12.4	9.3	8.9	8.9	8.5

Specific Gravity Test

Sample No.	Classification	Specific Gravity			Percentage of Absorption
		Saturated Surface-Dry	Oven-Dry	Apparent	(%)
R. Macinanga	GM	2.603	2.492	2,802	4.442
R. Biru (Maradda)	G - M	2.659	2.604	2.756	2.115
R. Sanrego (Intake)	G - M	2.604	2.532	2.730	2.869
R. Sanrego (Teko)	G - M	2.580	2.512	2.697	2.74
R. Sanrego (Sanrega)	G - M	2.603	2.533	2.724	2.768

Table III.3.1 <u>The Results of Soil Mechanical Test for Borrow Pit Material (1/2)</u>

No. of Test Pit	Color	Natural Condition	Compaction Test	Triaxial Test	Field Moisture Content (%)	Specific Gravity
'80TP-2	Black	Wf=25.47%	Wopt=20.00%	C=0.58(0.5)Kg/cm2	42.00	2.601
(1.45m)		γd=1.568 t/m3	γdmax=1.595 t/m3	Ø=10°00'(10°30')	25.47 ●	2.634
		(1.532 t/m3)	Đ95 =1.515 t/m3		51.03	2.584
					45.71 ●	2.622
'80TP-5	Black	Wf=45.71%	Wopt=29.07%	C=1.38(1.35)Kg/cm2	35.22	2.576
(2.5m)		γd=1.128 t/m3	γdmax=1.352 t/m3	Ø=3°25'(3°30')	45.29	2.599
		(1.160 t/m3)	Đ95 =1.284 t/m3		37.74 ●	2.588
					40.36	2.614
'80TP-8	Grey	Wf=37.74%	Wopt=24.00%	C=0.39(0.48)Kg/cm2	Wf=36.3%	Gs=2.602
(2.4m)		γd=1.274 t/m3	γdmax=1.518 t/m3	Ø=15°00'(12°30')		
		(1.245 t/m3)	Đ95 =1.442 t/m3			

Where,
- Wf ; Field moisture content
- γd ; Dry density, the value in ( ) is the result of compaction test
- Wopt ; Optimum water content
- γdmax ; Maximum dry density
- Đ95 ; Dry density to obtain 95 percent of γdmax
- C ; Cohesion, the value in ( ) is total stress value
- Ø ; Angle of internal friction, the value in ( ) is total stress value.

Table III.3.1 The Results of Soil Mechanical Test for Borrow Pit Material (2/2)

No. of Test Pit	Color	Natural Condition	Compaction Test	Triaxial Test	Field Moisture Content (%)	Specific Gravity
'80TP-13	Dark	Wf=23.55%	Wopt=24.80%	C=0.70(0.70)Kg/cm2	35.62	2.616
(2.0m)	Brown	γd=1.501 t/m3	γdmax=1.527 t/m3	Ø= 9°00' (6°50')	38.95	2.546
		(1.545 t/m3)	Ɖ 95 =1.451 t/m3		35.66	2.648
					40.67	2.615
'80TP-17	Yellowish	Wf=34.97%	Wopt=17.00%	C=0.40(0.40)Kg/cm2	30.73	2.593
(1.2m)	Brown	γd=1.304 t/m3	γdmax=1.732 t/m3	Ø=28°75' (22°50')	32.88	2.628
		(1.320 t/m3)	Ɖ 95 =1.645 t/m3		27.26	2.586
					30.11	2.610
'80TP-19	Yellowish	Wf=42.59%	Wopt=24.00%	C=0.15(0.28)Kg/cm2	23.55	2.603
(2.2m)	Brown	γd=1.178 t/m3	γdmax=1.545 t/m3	Ø=24°30' (15°00')	38.32	2.592
		(unknown)	Ɖ 95 =1.468 t/m3		31.76	2.542
					24.69	2.580
					34.97	2.573
					28.57	2.551
					42.59	2.660
					40.05	2.609
					$\overline{Wf}$=33.52%	$\overline{Gs}$=2.597

Where,

- Wf ; Field moisture content
- γd ; Dry density, the value in ( ) is the result of compaction test
- Wopt ; Optimum water content
- γdmax ; Maximum dry density
- Ɖ 95 ; Dry density to obtain 95 percent of γdmax
- C ; Cohesion, the value in ( ) is total stress value
- Ø ; Angle of internal friction, the value in ( ) is total stress value

Table III.3.2 Result of Stability Analysis for Closing Dike Designed by DOI (1/2)

Case		Inter-Angle	Length of Circular arc	N-Force			T-Force			Ne/4	Te/5	Fs/6
Slope	Radius			Area I /1	Area II /2	N-Force /3	Area I /1	Area II /2	T-Force /3			
Up Steram	25.00m	87°00'	37.96m	-	145.0	117.5	-	47.5	38.5	5.8	17.6	3.628
Up Stream	35.00m	92°00'	56.20m	25.0	355.0	332.3	25.0	62.5	95.4	14.3	49.8	2.204
Up Stream	36.80m	108°00'	69.37m	155.0	446.7	639.3	92.5	-15.0	153.4	23.0	95.9	1.695
Up Stream	20.00m	138°00'	46.08m	297.5	15.0	267.8	42.5	12.5	56.8	8.5	40.2	2.702
Up Stream	88.00m	61°00'	93.69m	590.0	241.0	909.3	82.5	61.7	222.1	33.3	136.4	1.605
Up Stream	60.00m	66°00'	69.12m	451.7	72.5	495.6	12.5	135.0	153.8	23.0	14.3	1.769

Note : /1 ; Moist area (unit m2)
/2 ; Submerged area (unit m2)
/3 ; Area I x wet density + Area II x submerged density (unit ton)
/4 ; (T-Force) x (horizontal seismic coefficient) (unit ton)
/5 ; (N-Force) x (horizontal seismic coefficient) (unit ton)
/6 ; Safety factor $= \frac{(N - Ne) \cdot \tan \phi + c.L}{T + Te.}$

where ; ϕ ; internal friction angle
C ; Cohesion

γt = 1.79 t/m3
γsub = 0.81 t/m3
C = 5.0 t/m2
ϕ = 7°00'

Table III .3.2 Result of Stability Analysis for Closing Dike Designed by DOI (2/2)

Case		Inter-Angle	Length of Circular arc	N-Force			T-Force			Ne/4	Te/5	Fs/6
Slope	Radius			Area I /1	Area II /2	N-Force /3	Area I /1	Area II /2	T-Force /3			
Down Stream	60.00m	69°30'	72.78m	532.5	-	953.2	164.5	-	294.5	44.2	143.0	1.087
Down Stream	75.00m	60°00'	78.54m	737.5	35	1348.5	172.5	12.5	318.9	47.8	202.3	1.060
Down Stream	39.00m	99°30'	67.73m	577.5	20	1049.9	145.0	18.0	266.0	39.9	157.5	1.092
Down Stream	32.00m	118°00'	65.90m	542.5	50	1011.6	125.0	25.0	244.0	36.6	151.7	1.135
Down Stream	24.00m	116°00'	48.59m	305.0	-	545.9	78.3	-	140.1	21.1	81.9	1.384
Down Stream	42.00m	80°00'	58.50m	342.5	-	613.1	105.0	-	187.95	28.19	92.0	1.305

Note : /1 ; Moist area (unit m2)

/2 ; Submerged area (unit m2)

/3 ; Area I x wet density + Area II x submerged density (unit ton)

/4 ; (T-Force) x (horizontal seismic coefficient) (unit ton)

/5 ; (N-Force) x (horizontal seismic coefficient) (unit ton)

/6 ; Safety factor $= \dfrac{(N - Ne) \cdot \tan \phi + c.L}{T + Te.}$

where : ϕ ; internal friction angle

C ; Cohesion

$\gamma t = 1.79$ t/m3

$\gamma sub = 0.81$ t/m3

C = 5.0 t/m2

$\phi = 7°00'$

Table III.3.3 Result of Stability Analysis for Modified Section of Closing Dike

Case		Inter-Angle	Length of Circular arc	N-Force			T-Force			Ne/4	Te/5	Fe/6
Slope	Radius			Area I /1	Area II /2	N-Force /3	Area I /1	Area II /2	T-Force /3			
Down Stream	49.50 m	94°00'	81.21 m	696.0	12.5	1256.0	151.0	6.0	275.2	41.3	188.4	1.198
Down Stream	40.00 m	107°00'	74.70 m	633.0	30.0	1157.4	135.0	15.0	253.8	38.1	173.6	1.195
Down Stream	42.00 m	100°00'	73.30 m	472.0	-	853.8	85.8	-	153.6	23.0	128.1	1.663
Down Stream	70.00 m	79°30'	97.13 m	632.5	-	1132.2	96.0	-	171.8	25.8	169.8	1.819
Down Stream	60.00 m	86°00'	90.06 m	684.0	-	1224.4	138.0	-	247.0	37.1	183.7	1.384
Down Stream	32.00 m	123°00'	68.70 m	592.5	75.0	1121.3	99.0	22.5	195.4	29.3	168.2	1.313

Note : /1 ; Moist area (unit m2)
/2 ; Submerged area (unit m2)
/3 ; Area I x wet density + Area II x submerged density (unit ton)
/4 ; (T-Force) x (horizontal seismic coefficient) (unit ton)
/5 ; (N-Force) x (horizontal seismic coefficient) (unit ton)
/6 ; Safety factor $= \frac{(N - Ne) \cdot \tan \phi + c.L}{T + Te.}$

where : ϕ ; internal friction angle
C ; Cohesion

$\gamma t = 1.79$ t/m3
$\gamma sub = 0.81$ t/m3
$C = 5.0$ t/m2
$\phi = 7°00'$

Table III.3.4 Required Slope Angle for Safety Factor Fs = 1.5

Application of Embank. & Cut	Soil	Height of Slope (m)	Angle of Slope
Embankment and Cut	Strongly weathered alternate layers of sandy silty tuffs (γt = 1.79t/m^3)	4.0	90° (1=0.0)
		5.0	90° (1=0.0)
		6.0	90° (1=0.0)
		10.0	90° (1=0.0)
Embankment and Cut	Sandy tuff (γt = 1.87t/m^3)	4.0	90° (1=0.0)
		5.0	74° (1=0.29)
		6.0	52° (1=0.78)
Embankment and Cut	Strongly weathered silt stone (γt = 1.68t/m^3)	4.0	90° (1=0.0)
		5.0	90° (1=0.0)
		6.0	90° (1=0.0)
Embankment and Cut	Reddish brown soil (γt = 1.56t/m^3)	4.0	90° (1=0.0)
		5.0	90° (1=0.0)
		6.0	90° (1=0.0)
Embankment and Cut	Black soil (γt = 1.90t/m^3)	4.0	90° (1=0.0)
		5.0	90° (1=0.0)
		6.0	90° (1=0.0)

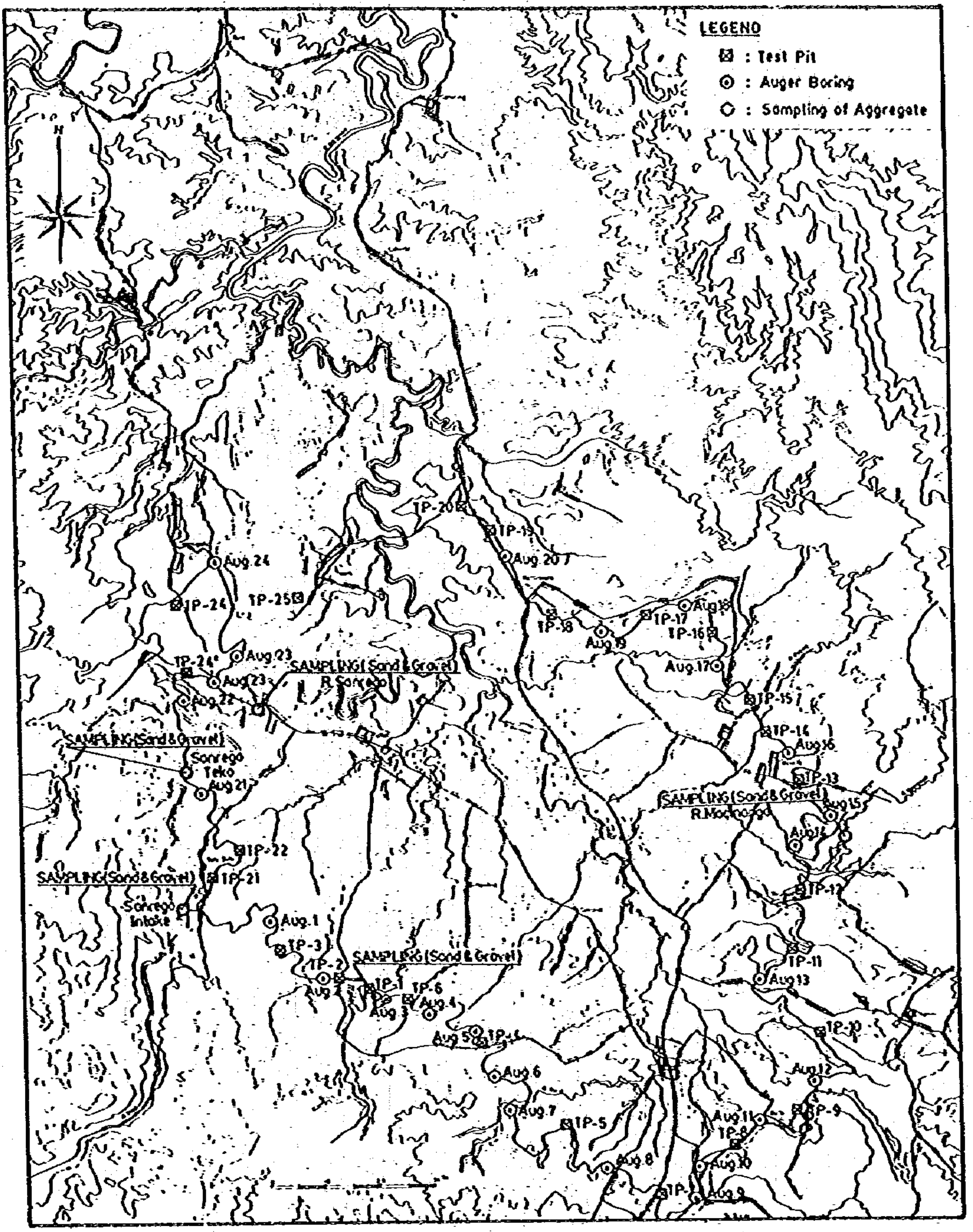


Fig. III.2.1 LOCATION MAP OF SOIL MECHANICS SURVEY

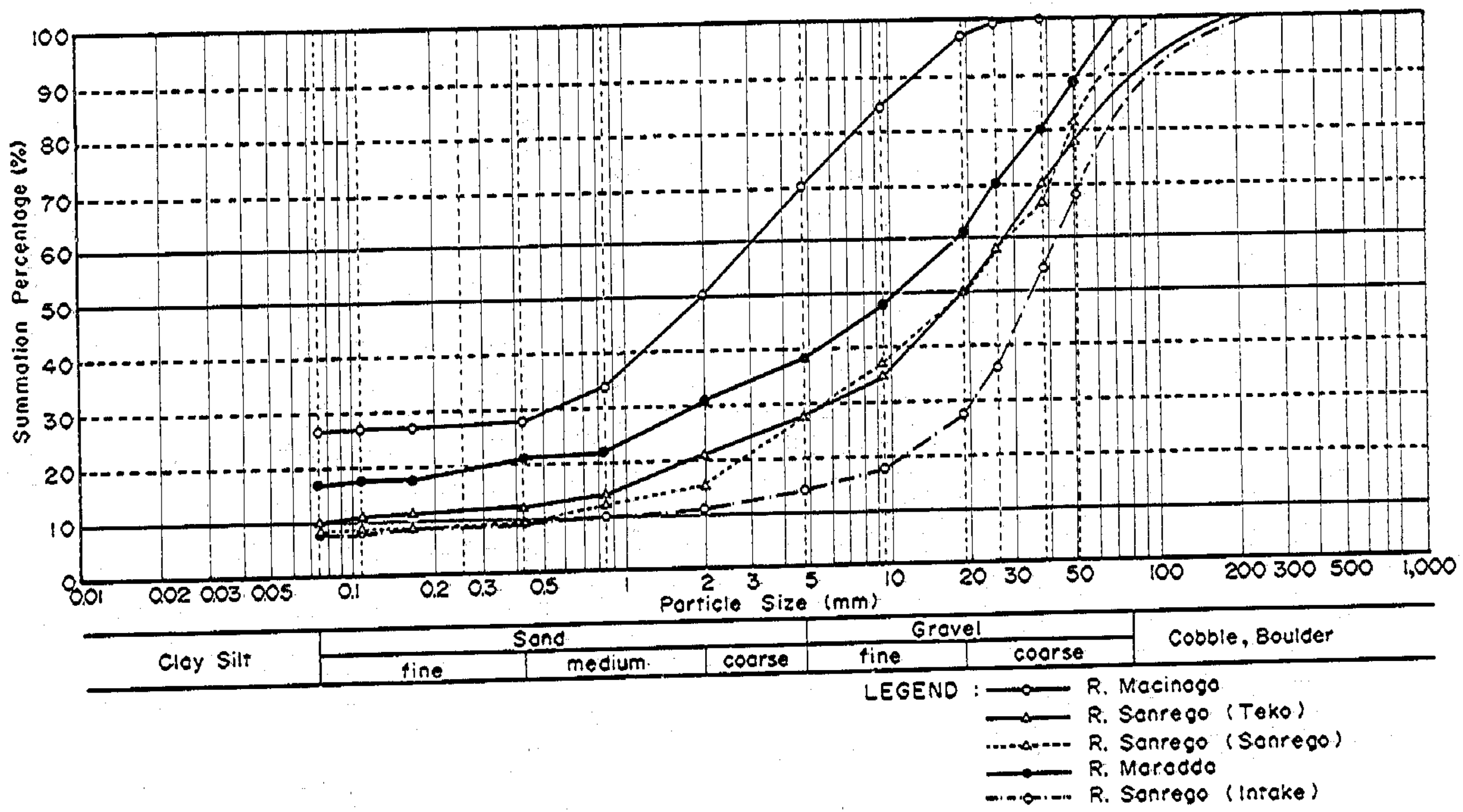


Fig. III.2.2 PARTICLE SIZE ACCUMULATION CURVE (CONCRETE AGGREGATE)

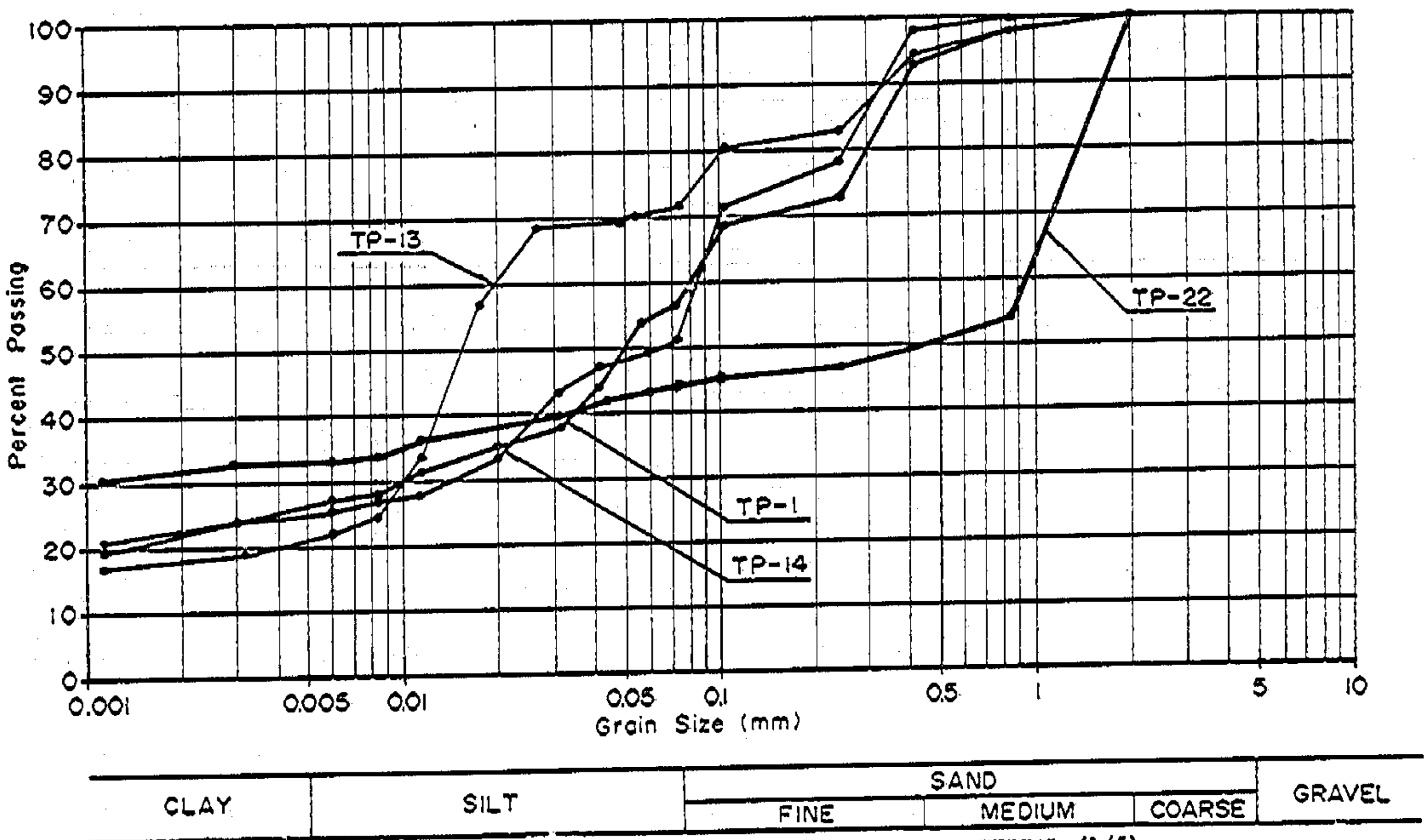


Fig. III.2.3 GRAIN SIZE ACCUMULATION CURVE OF EMBANKMENT MATERIAL (1/5)
(Strongly Weathered Materials of Alternate Layers of Sandy and Silty Tuffs)

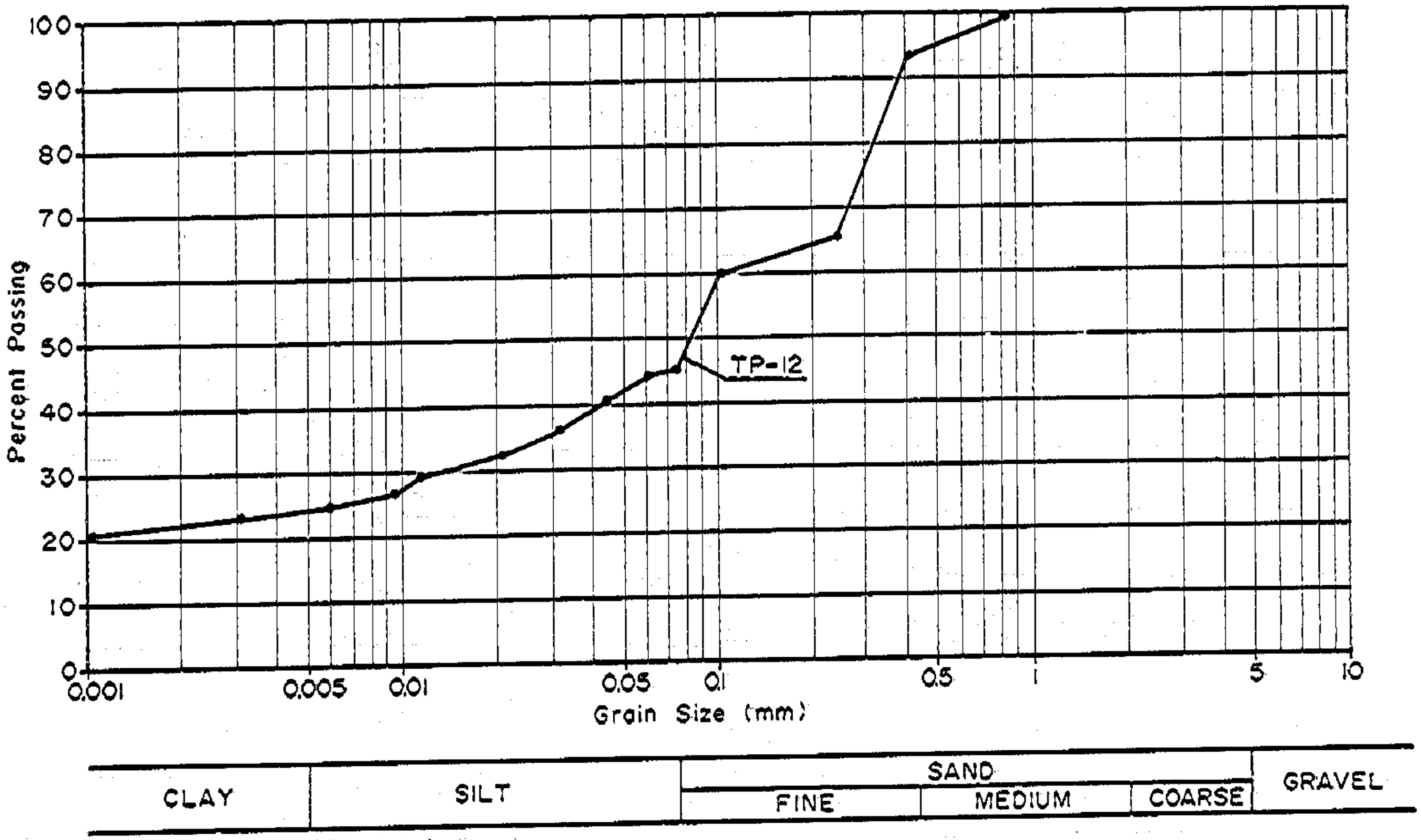


Fig. III.2.3 GRAIN SIZE ACCUMULATION CURVE OF EMBANKMENT MATERIAL (2/5)
(Sandy Tuff)

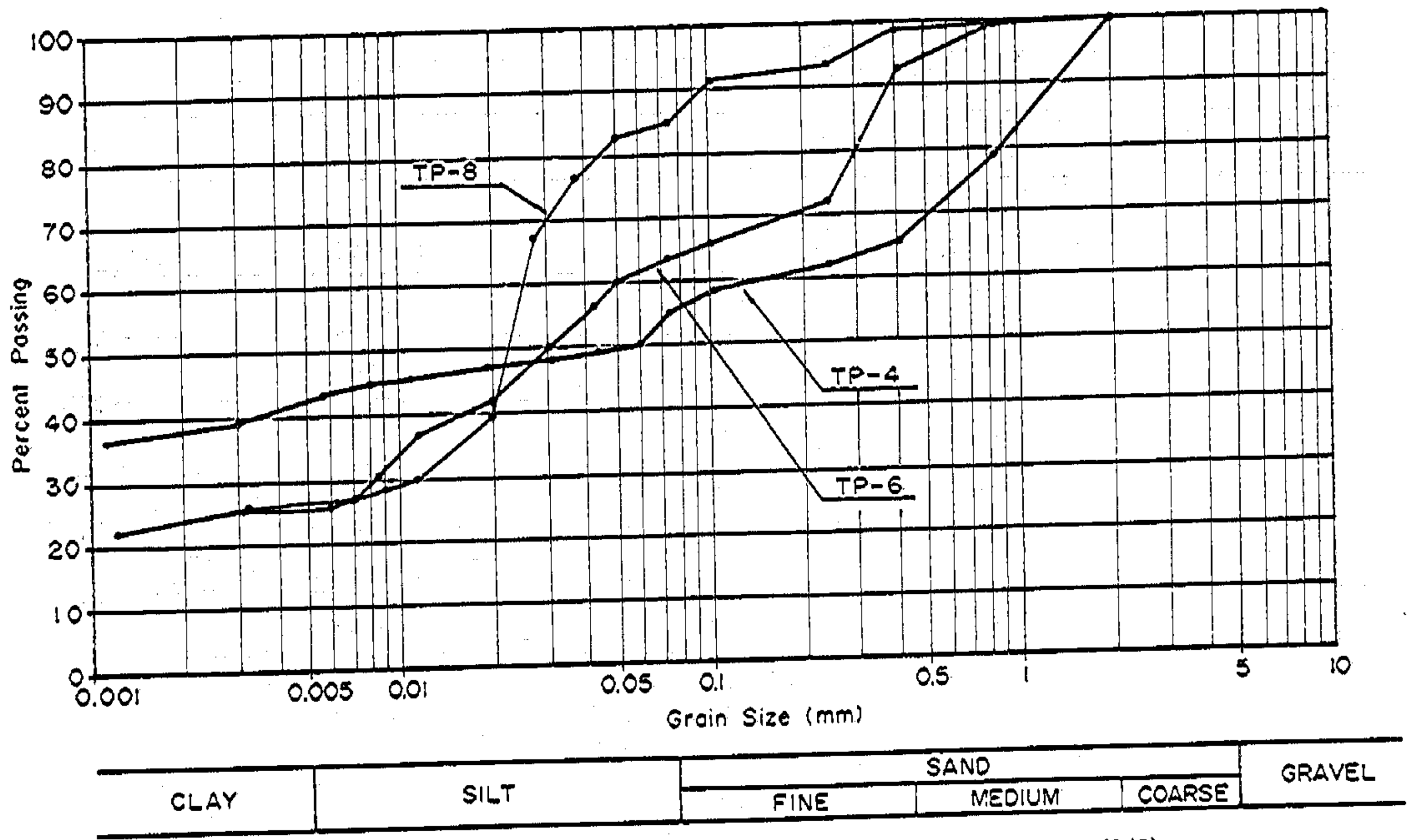


Fig. III.2.3 GRAIN SIZE ACCUMULATION CURVE OF EMBANKMENT MATERIAL (3/5)
(Strongly Weathered Silt Stone)

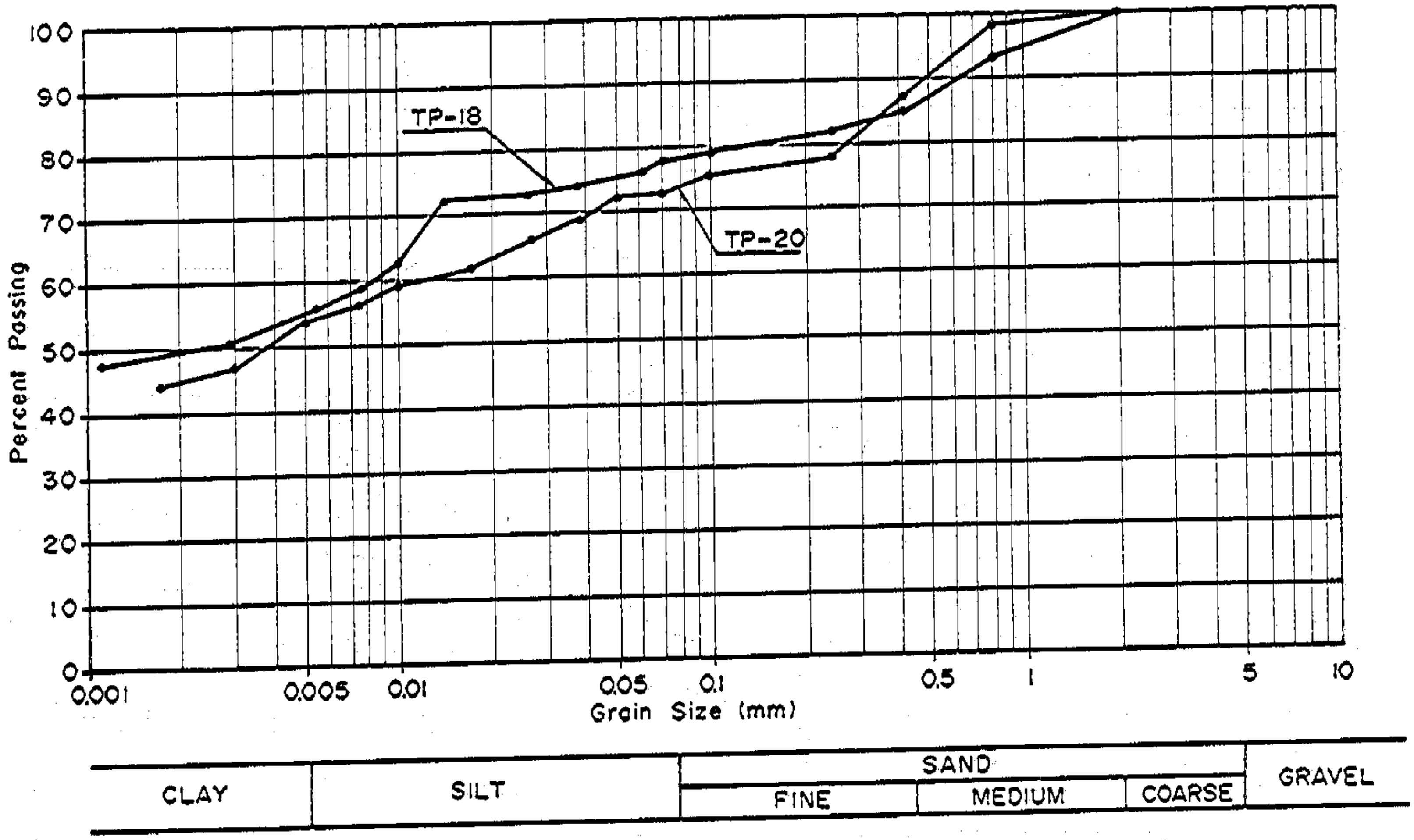


Fig. III.2.3 GRAIN SIZE ACCUMULATION CURVE OF EMBANKMENT MATERIAL (4/5)
(Reddish Brown Soil)

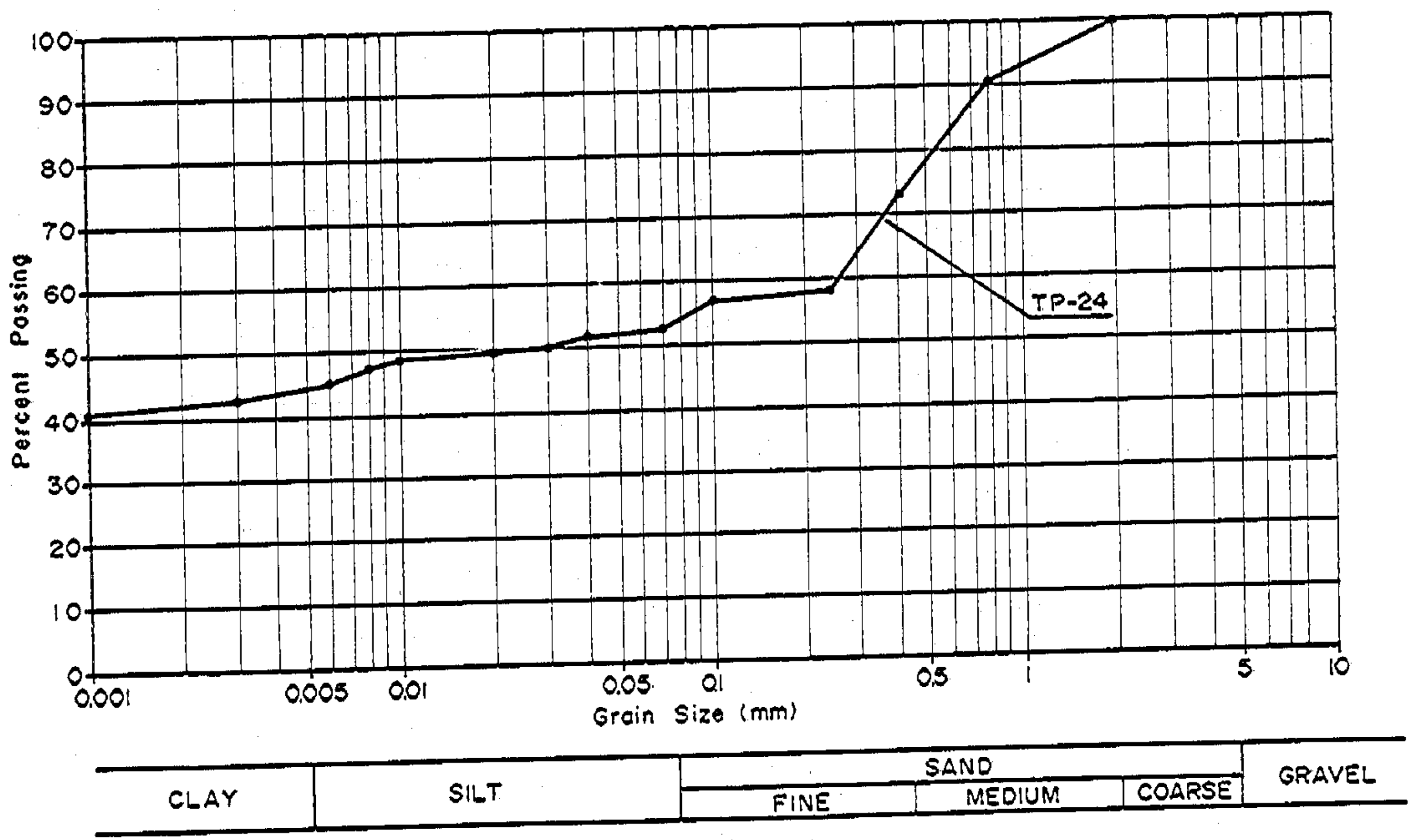


Fig. III.2.3 GRAIN SIZE ACCUMULATION CURVE OF EMBANKMENT MATERIAL (5/5)
(Black Soil)

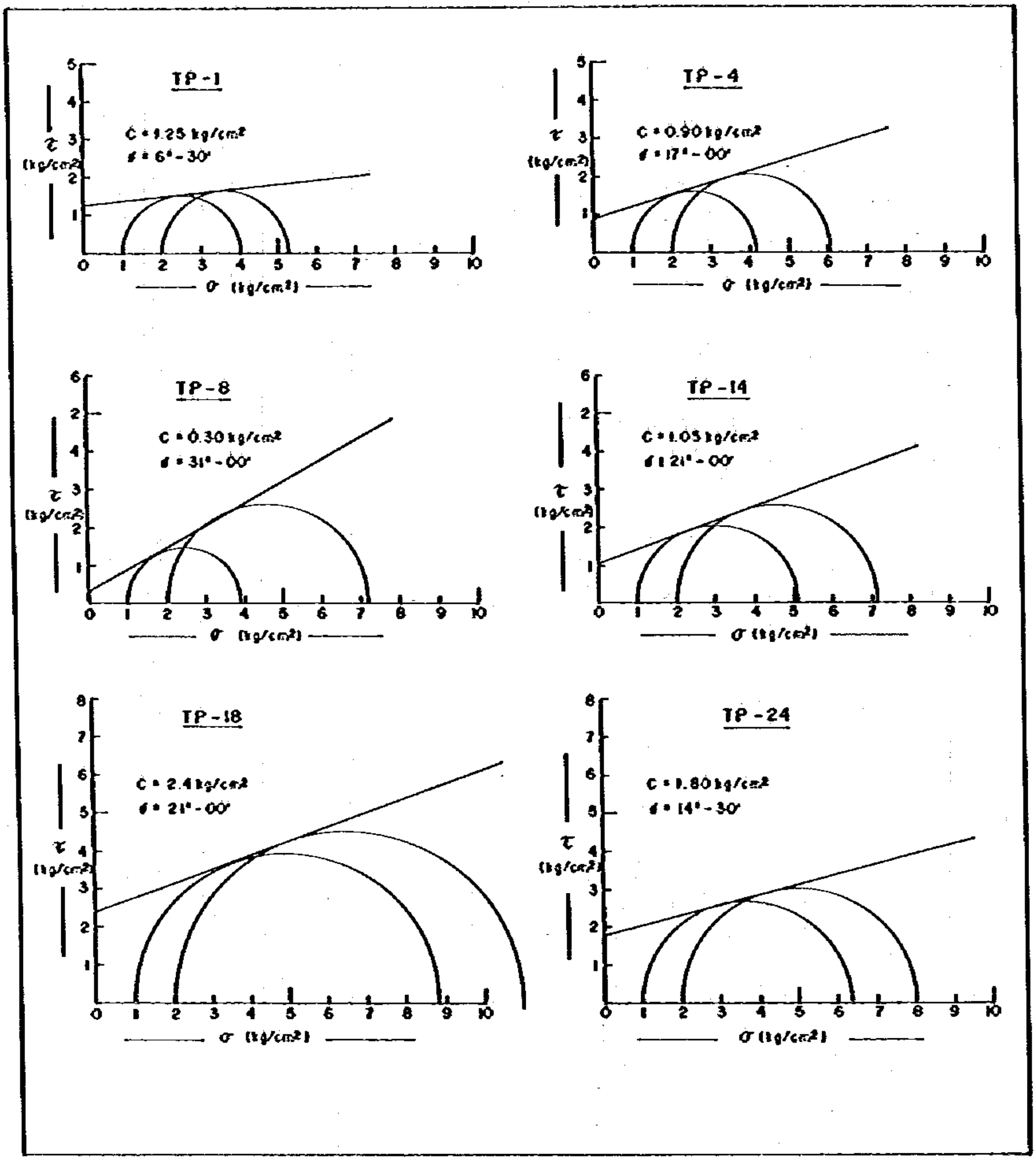


Fig. III.2.4 RESULT OF TRIAXIAL COMPRESSION TEST (MOHR'S CIRCLE)

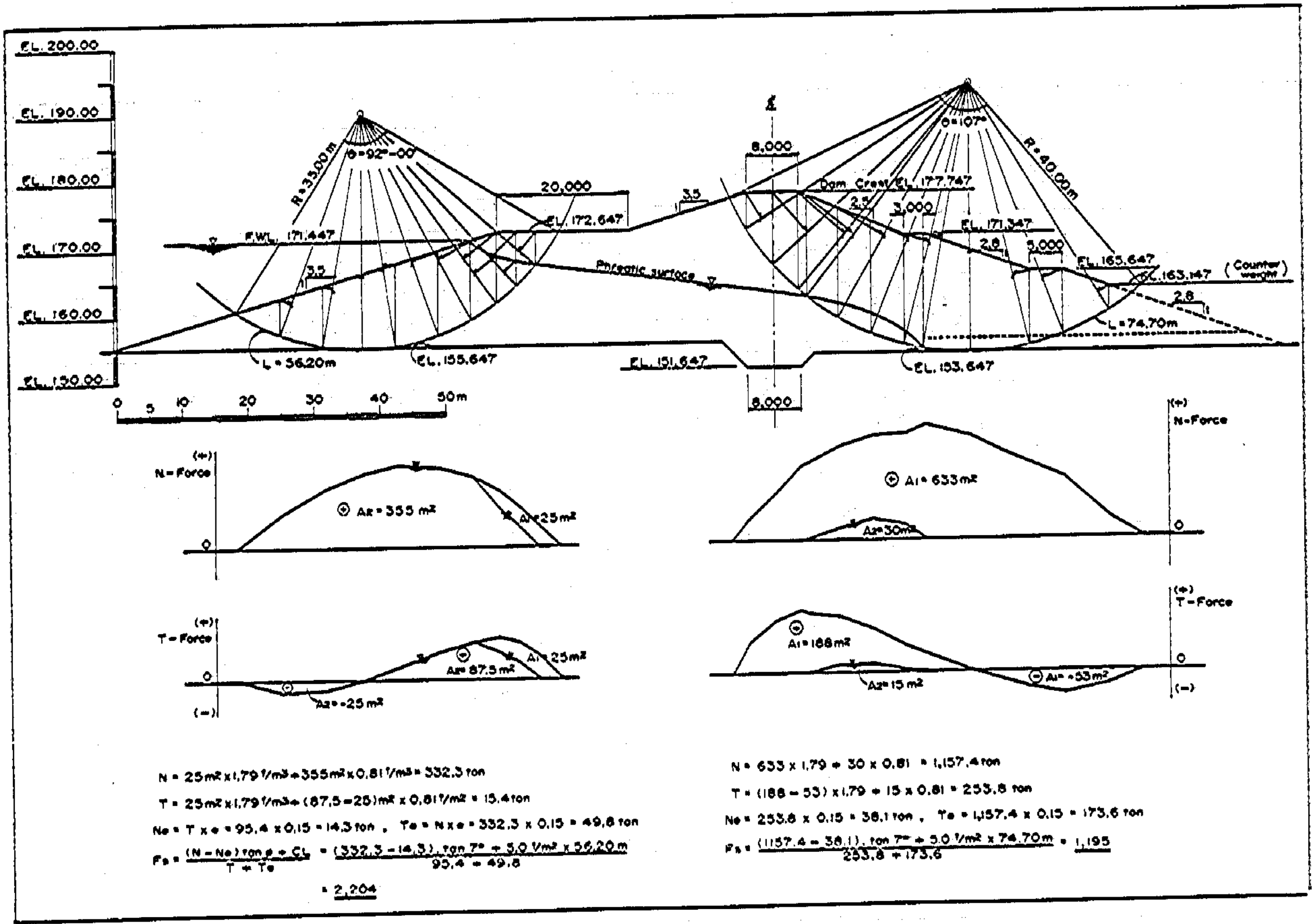


Fig. III.3.1 STABILITY CALCULATION BY CIRCULAR SLIP METHOD

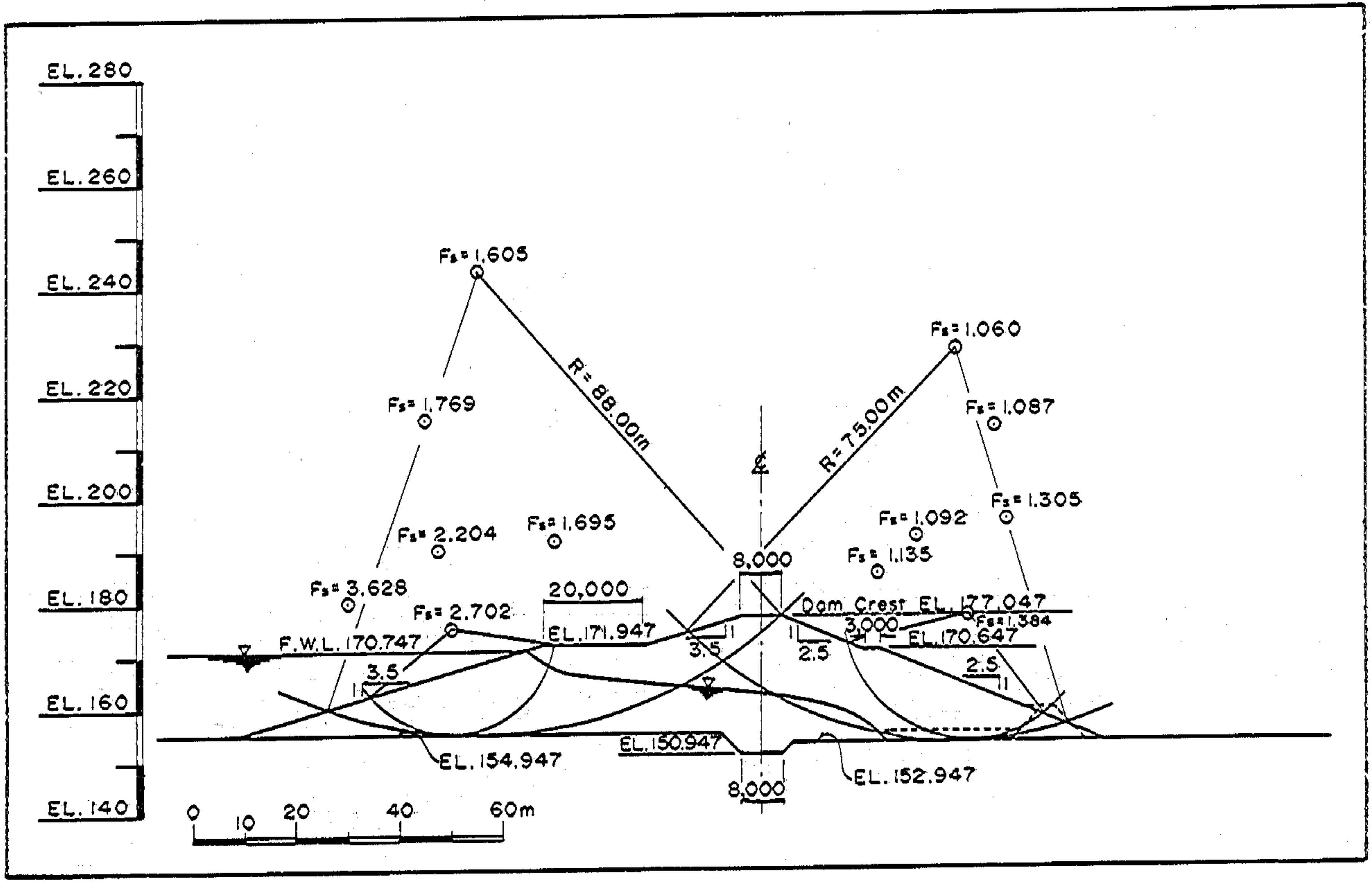


Fig. III.3.2 RESULT OF STABILITY ANALYSIS FOR CLOSING DIKE DESIGNED BY DOI

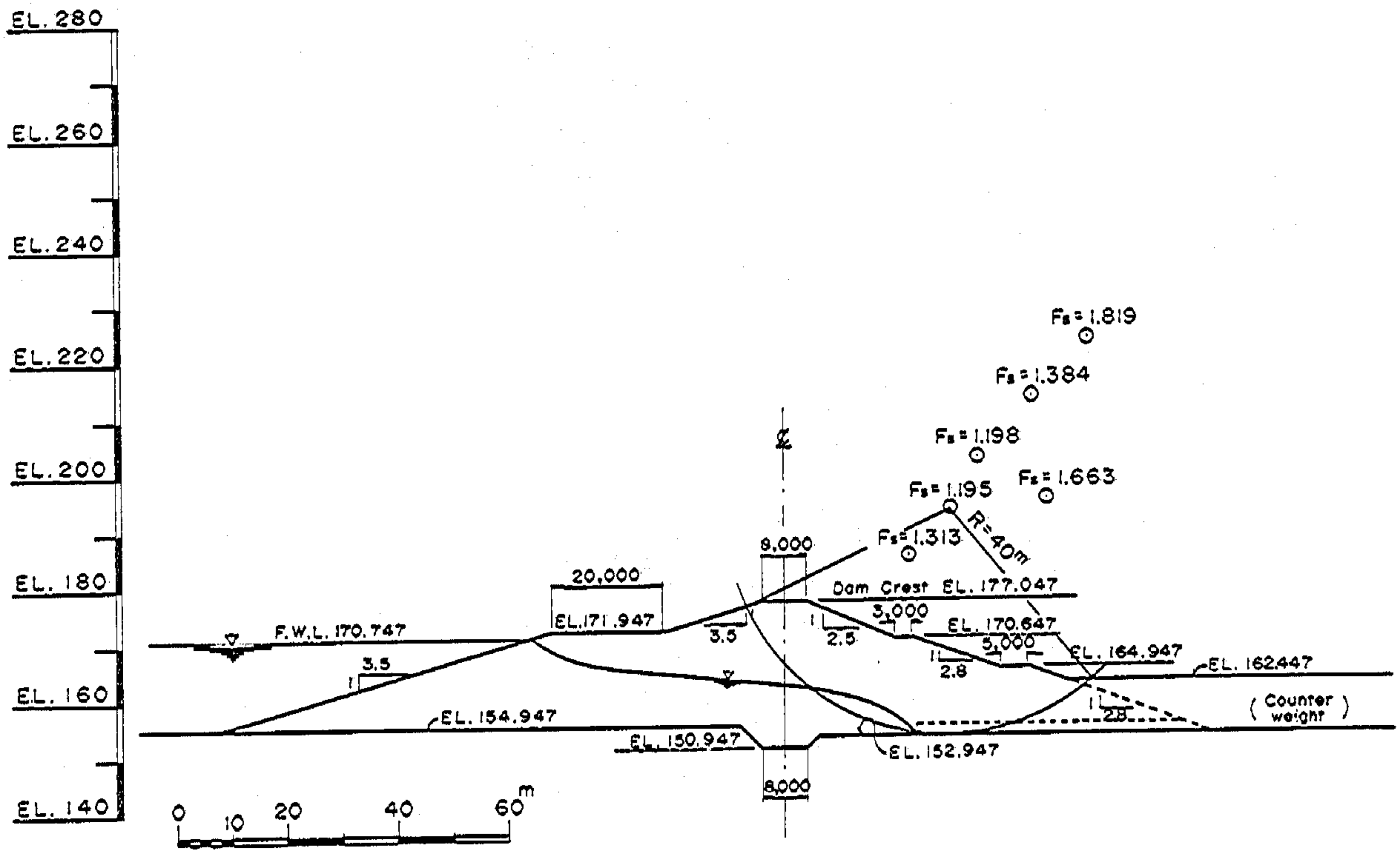
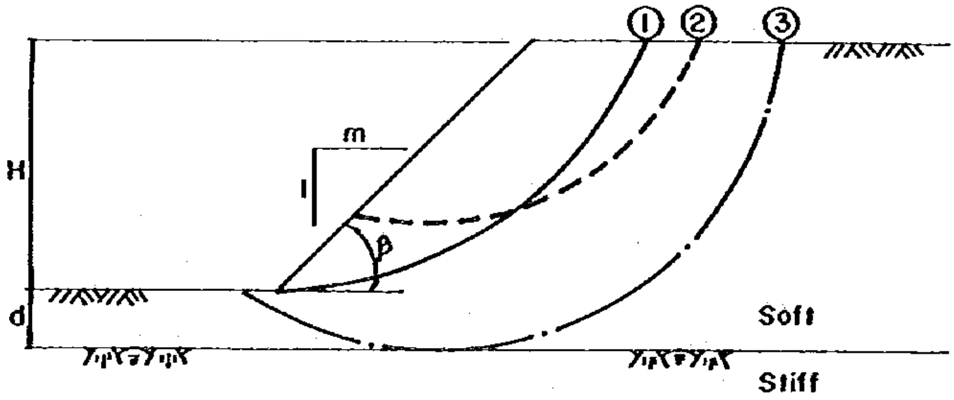
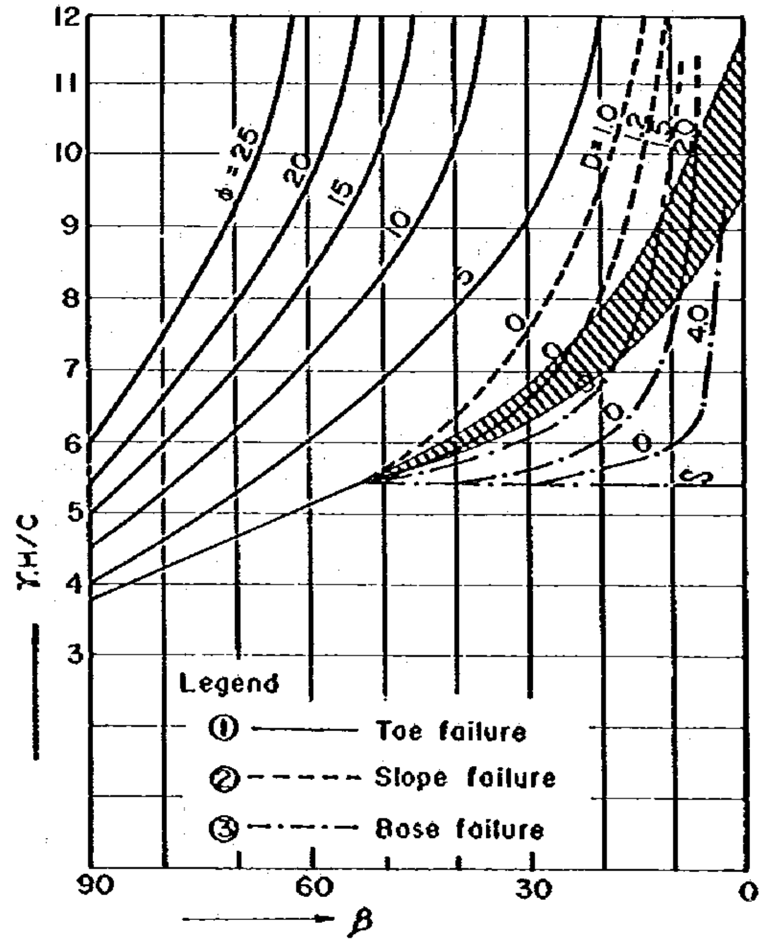


Fig. III.3.3 RESULT OF STABILITY ANALYSIS FOR MODIFIED SECTION





Explanation

γ.H/C ; reciprocal of stability number

γ : density

H : height

C : cohesion

β ; angle of slope, $\tan\beta = 1/m$

D ; (d + H) H, coefficient of depth

φ ; angle of internal friction

Fig. III.3.4 TAYLOR'S SLOPE STABILITY CHART

LIST OF REFERENCES

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2. "Geological and Soil Mechanical Investigation on Canal Routes and Major Structure Sites", WIRATMAN Cabang Ujung Pandang. ("Penyelidikan Geologi Tehnik dan Mekanika Tanah Pada Bangunan Perlintasan dan Saluran").

3. "Geological and Soil Mechanical Investigation on Canal Routes and Major Structure Sites of Sanrego Irrigation Project, South Sulawesi Province", WIRATMAN Cabang Ujung Pandang. ("Penyelidikan Geologi Tehnik dan Mekanika Tanah Pada Bangunan Perlintasan dan Saluran di Daerah Irigasi Sanrego Propinsi Sulawesi Selatan").

4. "Design of Small Dams" A Water Resources Technical Publication.

5. "Earth Manual" A Water Resources Technical Publication.

6. "Method of Soil Mechanical Test" Japanese Society of Soil and Foundation Engineering.

7. "Method of Soil Mechanical Survey" Japanese Society of Soil and Foundation Engineering.

8. "Planning and Design Criteria for Land Reclamation Irrigation Project -- Design of Dam --" Ministry of Agriculture, Forestry and Fisheries, Japan.

ANNEX - IV

SOIL AND LAND CLASSIFICATION

ANNEX - IV SOIL AND LAND CLASSIFICATION

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ANNEX - IV   SOIL AND LAND CLASSIFICATION

1. GENERAL

The study area for the Sanrego Irrigation Project is defined, in the agreed "Scope of Works", as the lands lying along the Walanae and Sanrego rivers of about 17,500 ha (10,000 ha in net irrigation area) which have been delineated by the Master Plan.

The findings of the reconnaissance land resources survey for the study area are presented in two preceding study reports:

(1) Reconnaissance land resources survey in the South Sulawesi area, soil map (scale: 1/500,000), 1968, Soil Research Institute, Bogor.

(2) Master Plan for the Central South Sulawesi Water Resources Development Project, Soil Map (scale: 1/50,000), 1980, Japan International Cooperation Agency, Tokyo.

The present soil study aims at identifying major soil groups and their distribution in the study area through the review of the past studies and substantial field investigation, and also examining the suitability of each soil group for irrigation farming on the basis of the study on governing factors for land capability.

The present report deals with the procedure of the field investigation and studies, and final results of the soil studies including major characteristics and land capability classes of the soil groups identified in the study area.

2. SOILS

2.1 Procedure of Soil Survey

The physiographical condition of the study area was first examined, prior to the actual field survey, by using the topographic maps scaled 1/25,000 and two series of aerial photoes; one was taken in March, 1977 on a scale of 1/25,000 and the other was a new series taken in August, 1982 on a scale of 1/10,000. The study results were compiled on the topographic maps scaled 1/25,000 as the preliminary land-form unit maps.

The preliminary soil survey was then carried out over the study area of about 17,500 ha and the land-form unit map was checked and adjusted in the field. The auger boring observations were then made at the rate of three (3) observations per every 100 ha. The results of these field activities indicate that the land-form units have different soil characteristics. This means that the land-form is well correlated with the soil condition in the study area.

The soil profile survey was carried out on the basis of the information obtained through auger boring observations. Special attention was given to the land-forms for selection of soil test pits. A total of 32 pits were dug to a depth of about one meter or bedrock or gravel layer. Each soil profile was observed in accordance with the standards described in the "Guidelines for Soil Profile Description" of FAO. Furthermore, more than 100 test boring observations were additionally practiced for further adjustment of provisional boundaries of each soil group.

For physico-chemical analyses in laboratory, a total of 30 soil samples were taken from the distinguishable horizons of eight (8) representative soil profiles in the study area. These soil samples were analyzed at the Chemical Research Institute (BALAI PENELITIAN KIMIA), Ujung Pandang. The items of physico-chemical analyses are (1) pH (H_2O, N-KCl), (2) total carbon, (3) total nitrogen, (4) available phosphate, (5) cation exchange capacity (CEC), (6) exchangeable bases (Ca, Mg, Na, K), (7) free iron and (8) soil particle size distribution. The procedures and methods of these analyses are shown in Table IV.2.1 and the results are given in Table IV.2.2.

2.2 Results of Soil Survey

2.2.1 Land-form

From the physiographic viewpoints, the lands of the study area are classified into six (6) land-form categories (see Fig. IV.2.1):

	Land-form Category	Area (ha)	Proportional Extent (%)
(1)	flat lowland of recent alluvium	1,800	10.3
(2)	lower terraces of semi-recent alluvium	4,600	26.3
(3)	higher terraces of old alluvium	5,400	30.8
(4)	high terraces of Pleistocene deposits	3,500	20.0
(5)	dissected isolated hills	1,400	8.0
(6)	dissected erosion surface and mountains	800	4.6
	Total	17,500	100.0

The flat lowland is developed on the recent fluvial deposits conveyed from the surrounding terraces and hills, and mainly extends along the rivers and streams. The lower part of this land-unit is annually subject to the flash flooding.

The undulating riverine terraces are developed mainly over the alluvial lands in-between the Sanrego and Walanae rivers. These alluvial terraces are divided into two land-form units. One is lower terraces of semi-recent alluvium, extending over the northern part of the study area. The land relief is slightly undulating with slope of less than 3%. The soils are generally deep. The semi-recent low terraces occur in-between the elevations of 110 - 140 m. The other is higher terraces of old alluvium, which is developed over the southern part of the study area. This land-unit extends on slightly elevated lands with elevation of 140 - 180 m. The land relief is gently undulating with slope range of 3 - 6%. The surface soils are generally shallow due to annual soil erosion caused by rapid surface runoff.

The high terraces of pleistocene deposits occur in the eastern part of the study area. These are developed on long and narrow interhills extending from north to south, with average width of about 4 km and approximate length of 15 km. This land-unit has gently undulating topography with average slope of 3 - 8%. The soils are generally reddish brown colored and moderately deep.

The dissected isolated hills are sporadically found in the alluvial terraces developed in-between the Sanrego and Walanae rivers. These are not irrigable due to their steep topography. The soils are generally very shallow with the effective soil depth of less than 15 cm.

The dissected erosion surface and mountains extend on the western and southern boundaries of the study area. The soils are generally stony and shallow. The land relief is steeply dissected. These lands are not irrigable.

2.2.2 Soil classification

In the light of the physiographic condition in the study area, together with the morphological characteristics of the representative soil groups and result of physico-chemical analysis, the soils of the study area are classified into seven (7) soil units, according to the FAO/UNESCO soil classification system. They are:

Land-form Category	Soil Unit	Area (ha)
(1) flat lowland of recent alluvium	- Eutric Gleysols (Ge)	1,800
(2) lower riverine terraces of semi-recent alluvium	- Eutric Fluvisols (Je)	4,600
(3) higher riverine terraces of old alluvium	- Dystric Fluvisols (Jd)	5,100
	- Pellic Vertisols (Vp)	300
(4) high terraces of pleistocene deposits	- Eutric Nitosols (Ne)	3,500

Land-form category	Soil Unit	Area (ha)
(5) dissected isolated hills	- Dystric Cambisols (Bd)	1,400
(6) dissected erosion surface and mountains	- Lithosols (I)	800
Total		17,500

Eutric Gleysols (Ge) or Grey Alluvial and Greyish Brown Alluvial Soils in Indonesian classification system are the poorly drained soils in the low-lying areas and/or in depressions. These soils formed from unconsolidated sediment materials. These soils are influenced by high groundwater tables and/or periodic stagnant water by seasonal floods and heavy rainfalls, and therefore show hydromorphic properties of gleyzation. These soils have a reducing condition in lower part of soil profile because of continuously saturated condition with the water. The effective soil depth is generally deep. These soils have (A)-Ag-Cg horizons with greyish color in general and the texture is generally clay to silty clay. The structure is massive. The pH value ranges from 4.5 to 6.2. The cation exchange capacity is over 20 meq/100 g. The base saturation degree averages more than 60%. These soils are used for paddy cultivation at present. Although these soils are suitable for irrigated paddy cultivation, drainage improvement is essential for sustaining the good yield. These soils occupy 1,800 ha in total or 10.3% of the study area.

Eutric Fluvisols (Je) or Brown Alluvial Soils mainly extend over the lower riverine terraces developed in-between the Sanrego and Walanae rivers. These soils are developed on the semi-recent alluvial deposits and generally immature with no predominant morphological characteristics. The effective soil depth is generally deep. In general, these soils have A-(B)-C horizons with dark brown to yellowish brown color. The soil texture is clay to loamy clay. The soil structure varies with location, ranging from structureless massive to weakly developed fine to medium angular blocky structure. As for chemical properties, pH value of these soils ranges from 4.3 to 6.8 showing the tendency to increase in lower horizons. The cation exchange capacity is generally less than 20 meq/100 g with more than 60% of the base saturation degree. The most of these soils are presently put under cultivation of rainfed paddy. These soils are generally good agricultural potential and often intensively used. The soils are suitable not only for irrigated rice but also for a wide range of crops. These soils occupy about 4,600 ha or 26.3% of the study area.

Dystric Fluvisols (Jd) or Low Humic Gley Soils occur on the higher riverine terraces of old alluvium, extending over the southern part of the study area. These soils are generally immature in profile development, with shallow to moderate soil depth. The soil texture is medium to fine in surface soil and fine in sub-soils. The soil structure is generally structureless massive to weakly developed fine angular blocky structure. These soils are generally pale in color and moderately leached of nutrients. These soils have A-(B)-C horizons. The pH value is around 5.0 throughout the profile. The cation exchange capacity is less than 15 meq/100 g with less than 50% of base saturation degree. Most of these soils are presently used for rainfed paddy cultivation. The soils are generally suitable for irrigated rice cultivation. Adequate fertilization and some measures to prevent the soil erosion like terracing and laying out of small plots will be needed for best use of these soils. These soils occupy 5,100 ha or 29.1% of the study area.

Pellic Vertisols (Vp) or Grey Grumsols develop over the higher riverine terraces extending on the middle western part of the study area. The soils have the grey or black heavy clayey surface soils formed on calcareous alluvium. These soils have swelling clay properties which cause them to be sticky when soils become wet, and to be hard, dry and deeply cracked when dry. As the results, micro-relief so-called gilgai is developed at the surface. This "vertic" surface soils are not very deep, generally within 30 cm from the ground surface. The subsoils underlaying vertic surface vary with the location from gravelly to clayey alluvial deposits. They are neutral to slightly alkaline in soil reaction. The cation exchange capacity shows more than 20 meq/100 g with more than 70% of base saturation degree. The average clay component is around 50%. The land covered with these soils are presently used for paddy cultivation. Adequate water supply is the key to utilization of these soils. These soils occupy 300 ha or 1.7% of the study area.

Eutric Nitosols (Ne) or Dark Reddish Brown Latosols develop on the pleistocene high terraces which extend mainly on the eastern part of the study area. These soils are originated from highly whethered diluvial deposits. The soils are generally deep having an argillic B horizon, and well drained. These soils are dark reddish brown to red in color, medium to fine textured, slightly sticky and plastic. The soil structure is generally structureless to fine subangular blocky structure. As for chemical features, the soil reaction is strongly acid showing the pH value of less than pH 5. The cation exchange capacity is less than 10 meq/100 g with more than 60% of base saturation degree. Most of these soils are left as grassland, and a very limited area is being used for cultivation of estate crops including clove, coconuts and kemiri. Agricultural potential of these soils is generally high for field corps, especially good for sugar cane growing. However, these are marginal to rice cultivation. Adequate fertilizer application will be essential for any kind of land use. Eutric Nitosols occupy 3,500 ha or 20.0% of the study area.

Dystric Cambisols (Bd) or Brunizems occur on the isolated hills, which are sporadically found on the alluvial terraces. These soils are formed on the residual deposits. They have very shallow depth, rather low base saturation degree and slight acidity. The soil erosion is generally serious due to their steep topography. Most of the soils are presently used for orchard and/or cultivation of upland crops. These soils are not irrigable and are excluded from the Project area. These soils occupy 1,400 ha or 8.0% of the study area.

Lithosols (I) cover the most of western and southern mountains and the dissected foothills. They are very shallow in depth and generally stony. Lithosols have almost no agricultural value.

The results of the present soil classification studies are illustrated on Fig. IV.2.2. The typical soil profile of each soil unit is shown in Table IV.2.3.

3. LAND CAPABILITY

3.1 Land Classification System

Three major land classification systems have been applied for the water resources development project in Indonesia. They are:

(1) USDA land capability classification system/1

(2) USBR land classification system/2

(3) FAO land suitability classification system/3

The USDA system is most widely used, but it does not meet the particular requirement for irrigation project. It is mainly used for rainfed agriculture in rainfed. The USBR system was devised originally for irrigated land use. However, the basic concept of the USBR system is generally to assess the lands under arid climate and/or assess land productivity for dry field crops like wheat, barley, cotton, etc. Some modification of this system is required under Indonesian condition due to the different requirements for irrigated paddy cultivation under humid climate. Although several approaches to the modification have been made by various study groups, none of them has been fully authorized at present. The FAO system is more flexible than US ones and can be applied to the full range of environments. It is the system that the Soil Research Institute, Bogor, recommends for use in Indonesia. This system is, however, still under development and does not serve the detailed criteria for suitability assessment on the irrigated paddy cultivation.

Considering all these, it is conceived that the Japanese land classification standard/4 for paddy can be applied to the feasibility study on the Sanrego Irrigation Project. The Japanese system is devised

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Remarks: /1: Land Capability Classification, Agricultural Handbook No. 210, 1961, Soil Conservation Services, USDA.

/2: Bureau of Reclamation Manual Vol. 5, Irrigated Land Use, Part 2: Land Classification, 1953, USBR.

/3: A Framework for Land Evaluation, 1976, FAO

/4: Outline of Land Classification based on Soil Survey in Japan, 1977, National Institute of Agricultural Science, Tokyo.

originally for paddy cultivation and its classification criteria are detailed enough for land capability assessment on a feasibility study level. In the Japanese system, lands are classified into 4 capability classes, i.e., I, II, III and IV. Each class is defined as follows:

(1) Class I : Land has almost no limitation for crop production and/or no risk of soil conservation. It is naturally fertile and has a great potential for crop production without any improvement practices of soils.

(2) Class II : Land has some limitations for crop production and/or some risks of soil conservation, and requires some soil improvement practices for normal crop production.

(3) Class III: Land has many limitations for crop production and/or is likely subject to risks of soil conservation, and fairly intensive improvement practices are required.

(4) Class IV : Land has great natural limitations than these in Class III, but can be utilized for cultivation of some specific crops under very careful management.

In the USDA system, lands are classified into 8 classes and the lower 4 classes from V to VIII are ranked as "not suitable for agricultural production". The USBR system has 6 classes, I to III being arable, IV being suitable only for special uses and VI non-arable. Class V is reserved for undecided suitability, but in practice this class is often omitted. The Japanese system, 4 class classification of arable land, is, therefore, correlative with these US systems.

The FAO system for land suitability classification is used for assessment of lands in terms of their relative suitability for a specific type of use. The Sanrego Irrigation Project aims at increasing rice production under irrigated condition and the land use type envisaged is double cropping of paddy as described in ANNEX-V. In the FAO system, the land suitability classes for each specific utilization type reflect degrees of suitability or of limitation, i.e., S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (currently not suitable, having limitations which are considered unsuitable with existing knowledge at currently acceptable cost) and N2 (permanently unsuitable). It is considered that the suitability classes from S1 to N1 nearly correspond to 4 classes described in the Japanese system.

In view of above consideration, the Japanese system seems to be most suitable for land capability classification for paddy fields due to its detailed specification and 4 classes rating which can be correlative with other systems.

3.2 Specification of Land Capability Classification

In the Japanese system, there are 13 factors for assessment of land capability as shown below:

(1) thickness of top soil
(2) effective soil depth
(3) gravel content in top soil
(4) easiness of plowing
(5) permeability under submerged condition
(6) state of redox potential
(7) wetness of land/1
(8) inherent fertility
(9) content of available nutrient
(10) degree of hazard
(11) frequency of hazard
(12) slope/1
(13) erosion

The specifications of land capability class are explained as follows:

(1) Thickness of top soil (code: t)

Top soil is the first horizon where plant roots can easily penetrate, and generally corresponds to the plowed layer. The classes are grouped according to the thickness of top soils as follows (when effective depth of soil (d) is placed to class IV, this factor also is placed to class IV):

t	Class		
	Paddy	Upland	Orchard
(cm)			
more than 25	I	I	I
25 - 15	I	II	I
less than 15	II	III	III

Remarks: /1: Factors for upland crops only

(2) Effective depth of soil (code: d)

Effective depth of soil is the depth up to bedrock, hard pan and gravel layer which plant roots can not penetrate. The classes are grouped, according to thickness of the effective soil depth, as follows:

d	Class		
	Paddy	Upland	Orchard
(cm)			
more than 100	I	I	I
100 - 50	I	II	II
50 - 25	II	III	III
15 - 25	III	III	IV
less than 15	IV	IV	IV

(3) Gravel content in top soil (code: g)

Gravel contents in top soil are expressed by the percentage of the exposed surface area of gravel on the soil profile, and are graded into the following classes:

g	Class		
	Paddy	Upland	Orchard
(%)			
less than 5	I	I	I
5 - 10	I	II	I
10 - 20	I	II - III	I - II
20 - 50	I - II	III - IV	II - III
more than 50	IV	IV	IV

(4) Easiness of plowing (code: p)

Easiness of plowing largely depends upon the quantity and quality of clay and organic matter and moisture condition. In order to estimate the class of this factor, the following 4 sub-factors are used:

(a) Soil texture of top soil;

		Content of clay	Content of sand
1.	coarse	less than 15%	more than 85%
2.	medium	less than 15%	less than 85%
3.	fine	15 - 25%	-
4.	very fine	more than 25%	-

(b) Stickness of top soil;

1. none and/or slightly sticky
2. sticky
3. very sticky

(c) Consistence when dry;

1. loose
2. hard
3. very hard

These sub-factors are combined altogether to determine capability classes as follows:

Sub-factors a	b	c	Class	Criteria
1	1	(2)/1	I	Easy to slightly difficult
2	2	2	I	
2	2	2	I	
2	2	3	II	Moderately difficult
3	3	3	II	
2	2	3	III	Very difficult
3	3	3	III	

Remarks: /1: limitation by dry condition

(5) Permeabiligy under submerged condition (code: 1)

This factor affects irrigation water requirement, soil temperature, and leaching of the nutrients or development of reduced condition of the soil. This standard factor is evaluated mainly by the combination of soil texture and the presence of compact layer within 50 cm from the surface, as sub-factors:

(a) Soil texture;

	Content of clay	Content of sand
1. very fine	more than 5%	-
2. fine	25 - 15%	-
3. medium	less than 15%	less than 85%
4. coarse	less than 15%	more than 85%

(b) Compactness;

1. compact: more than 14.0 kg/cm^2 by hardness meter
2. medium : 14.0 - 1.4 kg/cm^2 by hardness meter
3. loose : less than 1.4 kg/cm^2 by hardness meter

Sub-factors a	Sub-factors b	Class Paddy	Criteria
1	1	I	Poorly to imperfectly permeable
1	2	I	
2	2	II	Moderately to well permeable
3	2	II	
3	3	III	Well to excessively permeable

(6) State of redox potential (code: r)

This factor indicates the risk of root damage owing to the strong reduction of soil, resulting in low rice production. The following sub-factors are used for the evaluation of this factor.

(a) Content of easily decomposable organic matter in top soil;

1. low : less than 10 mg NH_4-N/100 g
2. medium: 10 - 20 mg NH_4-N/100 g
3. high : more than 20 mg NH_4-N/100 g

(b) Content of free iron oxides in top soil;

1. high : more than 1.5% for dry soil
2. medium: 1.5 - 0.8%
3. low : less than 0.8%

(c) Degree of gleyzation;

1. weak : no gley horizon within 50 cm from the surface
2. medium: gley horizon exists within 50 cm
3. strong: gley horizon exists throughout profile or exists below plowing layer

Sub-factors a	Sub-factors b	Sub-factors c	Class	Criteria (Risk of root damage)
1	1	2	I	None to weak
1	3	2	I	
2	1	2	I	
1	1-2	3	II	Moderate to strong
1	3	3	II	
2	1-2	3	II	
3	1	2	II	
2	3	3	III	Very strong
3	2	2	III	
3	1	3	III	
3	3	2	III	

(7) Wetness of land (code: w; wet condition, (w); dry condition)

This factor is only applied to upland and orchard. This factor is used for the estimation of wet or drought injury of upland crops and trees, and is evaluated by the combination of the following 3 sub-factors:

(a) Permeability;

1. high
2. medium
3. low

(b) Water holding capacity (evaluated by maximum water-holding capacity);

1. high : more than 80
2. medium: 80 - 40
3. low : less than 40

(c) Moisture condition;

(2). dry/1
1. slightly moist
2. moist
3. wet

Sub-factors			Class	Criteria (Risk of drought or wetness)
a	b	c		
1	3	(2)	(IV)	High possibility of drought
1	3	1	(III)	Possibility of drought
1	2	1	(II)	Low possibility of drought
1	1	1	I	None
2	2	2	II	Low possibility of overwetness
1-3	1	3	III	Possibility of overwetness
3	2	3	IV	High possibility of overwetness

Remarks: /1: limitation by dry condition

(8) Inherent fertility (code: f)

Inherent fertility is evaluated by the combination of the following 3 sub-factors:

(a) Nutrient holding capacity (evaluated by CEC);

1. high : more than 20 meq/100 g
2. medium: 20 - 6 meq/100 g
3. low : less than 6 meq/100 g

(b) Nutrient fixation power (evaluated by coefficient of P_2O_5 absorption;

1. very low: less than 700
2. low : 700 - 1,500
3. medium : 1,500 - 2,000
4. high : more than 2,000

(c) Base status in soil (evaluated by base saturation degree);

1. good : more than 50%
2. medium : 50 - 30%
3. poor : less than 30%

(i) For paddy

Sub-factors a	b	c	Class	Criteria
1	1-2	2	I	Fertile
2	1-2	1	I	
1	1-2	3	II	Medium
1	3-4	2	II	
2	1-2	2	II	
3	1	2	II	
2	3-4	3	III	Infertile
3	2	2	III	
3	3-4	3	III	

(ii) For upland and orchard

Sub-factors a	b	c	Class	Criteria
1	2	1	I	Fertile
2	1	2	I	
1	2	3	II	Medium
2	1	3	II	
1	3	1	II	
1	3	2	II	
1	3	3	III	Infertile
3	1	1	III	
2	4	2	II - III	

(9) Content of available nutrients (code: n)

Content of available nutrients in soil are closely related to the inherent soil fertility, and are evidently influenced to cultivation practices. The capability class is evaluated by the combination of the following sub-factors:

(a) Content of exchangeable calcium;

1. high : more than 200 CaO mg/100 g
2. medium: 200 - 100 CaO mg/100 g
3. low : less than 100 CaO mg/100 g

(b) Content of exchangeable magnesium;

1. high : more than 25 MgO mg/100 g
2. medium: 25 - 10 MgO mg/100 g
3. low : less than 10 MgO mg/100 g

(c) Content of available potassium;

1. high : more than 15 K_2O mg/100 g
2. medium: 15 - 8 K_2O mg/100 g
3. low : less than 8 K_2O mg/100 g

(d) Content of available phosphate;

1. high : more than 10 P_2O_5 mg/100 g
2. medium: 10 - 2 P_2O_5 mg/100 g
3. low : less than 2 P_2O_5 mg/100 g

(e) Content of available nitrogen;

1. high : more than 20 N mg/100 g
2. medium: 20 - 10 N mg/100 g
3. low : less than 10 N mg/100 g

(f) Content of available silica;

1. high : more than 15 SiO_2 mg/100 g
2. medium: 15 - 5 SiO_2 mg/100 g
3. low : less than 5 SiO_2 mg/100 g

(g) Content of micro-elements (evaluated by the risk of deficiency;

1. none and/or weak
2. medium
3. serious

(h) Acidity (evaluated by pH);

Paddy	Upland & Orchard		
1	1	weak :	more than 6.0
2	2	medium :	6.0 - 5.0
3	3	strong :	5.0 - 4.5
3	4	very strong:	less than 4.5

Class	Criteria
I	High
II	Medium
III	Low

(10) Degree of hazard (code: i)

This factor means limitation caused by the presence in excess of substances such as sulphur compounds, soluble salts, heavy metals, etc. Dependent sub-factors for this factor are as follows:

(a) Presence of harmful substances;

(i) Harmful sulphur compounds

1. none
2. slightly
3. moderately
4. seriously

(ii) Salts content (evaluated by chlorine content as an indicator)

1. low : less than 0.1% for dry soil
2. medium: 0.1 - 0.3%
3. high : more than 0.3%

(iii) Heavy metals

1. none
2. slightly
3. moderately
4. seriously

(iv) Irrigation water quality

		Temp. (°C)	pH	Total N (ppm)	Salts Content (ppm)
1.	good	20	6.0-7.5	less than 1.0	less than 500
2.	medium	20-15	4.0-6.0 or 7.5-8.5	1.0-5.0	500-2,000
3-4.	polluted	15	less than 4.0 or more than 8.5	more than 5.0	more than 2,000

(b) Physical hazard;

Presence of bedrock, pan, compact layer or gravel layer that disturb root development within 50 cm of the surface, and difficult of their removal:

1. none
2. slightly difficult
3. very difficult

The class of this factor is decided by the lowest grade among the dependent sub-factors.

Class	Criteria
I	None
II	Slightly
III	Moderately
IV	Seriously

(ii) Frequency of hazard (code: a)

This factor is mainly influenced by natural environmental condition. The class of this factor is determined by the combination of the following two dependent sub-factors:

(a) Risk of overhead flooding inundation;

1.	none and/or rarely	:	no risk if rainfall with high intensity occurs
2.	moderately	:	even if inundation occurs due to high rainfall intensity, excess water is drained out in a short period
3.	frequently	:	inundation continuous for a long period if rainfall with high intensity occurs

(b) Risk of land creep;

1. none and/or rarely
2. moderately
3. frequently

The class of this factor is determined by the lowest grade of two dependent sub-factors.

Class	Criteria
I	None to rarely
II	Moderately
III	Frequently

(12) Slope (code: s)

This factor is applied to upland and orchard only. The class of this factor is decided by the combination of the following sub-factors:

(a) Natural slope as a main dependent sub-factors: 5 grades as shown in the following table.

(b) Direction of slope.

(c) Artifical slope.

Steepness of Slope		Class	
(°)	(%)	Upland	Orchard
less than 3	less than 6	I	I
3 - 8	6 - 14	II	I - II
8 - 15	14 - 28	III	I - III
15 - 25	28 - 47	IV	II - III
more than 25	more than 47	IV	IV

(13) Erosion (code: e)

The class of this factor is determined by the combination of the following sub-factors:

(a) Occurrence of rill or gully;

		Occurrence of Rill	Occurrence of Gully
1.	none	none	none
2.	rarely	rarely	none
3.	moderately	sometimes	none
4.	frequently	frequently	exist

(b) Resisting power to water erosion;

1. strong
2. medium
3. weak

(c) Resisting power to wind erosion;

1. strong
2. medium
3. weak

Class	Criteria
I	None or very slightly
II	Slightly
III	Seriously
IV	Very seriously

The specification of Japanese land capability class is summarized in Table IV.3.1.

3.3 Land Capability

The land is evaluated by using the assessment factors mentioned above. The land capability class is determined at the lowest class of the factors. Limitation on suitability of land due to 13 factors are indicated by use of codes like "t", "g", "d" either individually and collectively, as shown in the following example.

Factor	Code	Paddy	Upland
1. thickness of top soil	t	I	III
2. effective soil depth	d	I	I
3. gravel content in top soil	g	I	I
4. easiness of plowing	p	II (3,3,2)	II (2,2,2)
5. permeability under submerged condition	l	II (1,3)	-
6. state of redox potential	r	II (2,1,3)	-
7. wetness of land	w	-	-
8. inherent fertility	f	I (1,2,2)	III (1,2,3)
9. content of available nutrient	n	II (2,1,1,1, 2,2,2,2)	III (3,3,3, 3,3,3)
10. degree of hazard	i	I (1,1)	I (1,1)
11. frequency of hazard	a	I (1,1)	I (1,1)
12. slope	s	-	I (1,S,1)
13. erosion	e	-	I (1,1.1)

Land capability class: Paddy ; IIplrn
Upland; IVw

With four (4) land classes for rice and upland crops and with each class having 13 sub-classes, a great number of combinations of land class symbols is possible if much variation occurs in the study area. Actually, however, only different composite land class symbols are used for the arable lands in the study area, as shown below:

Soil Unit	Land Capability (Paddy/Upland)	Study Area (ha)	Irrigable Area (ha)
Eutric Gleysols	IIpfna/IIIdgpna	1,200	1,000
	IIgpfna/IIIg	600	400
Eutric Fluvisols	IIpfn/IItdpse	3,700	2,500
	IItdpfn/IIItd	900	700
Dystric Fluvisols	IItdpfn/IItdwse	4,000	3,100
	IItdpfn/IIItdse	1,100	700
Pellic Vertisols	IIpn/IIpwne	300	200
Eutric Nitosols	IIIpn/IItdgpwfnse	3,500	1,400
Dystric Cambisols	IVtdi/IVtdse	1,400	-
Lithosols	IVtdgi/IVtdgi	800	-
Total		17,500	10,000

The correlation between soil unit and land class is shown in Table IV.3.2.

The land classification map is shown in Fig. IV.3.1. The general features of each class, together with suggested land use, are summarized in Table IV.3.3. The soils of the Project area are generally suitable for double cropping of paddy due to their general characteristics of heavy texture and slow percolation. The soils, however, tend to develop many cracks in the dry season and require a bit more irrigation water to saturate the cracks.

Table IV.2.1 Procedures and Methods of Soil Analysis

Soil Properties	Procedures and Methods
1. pH	Using the grass electrode method with soil/solution ratio of 1/2.5
2. Total carbon	Tyurin method (back titration of carbon consumed by oxidation of chromic acid with H_2SO_4)
3. Total nitrogen	Converting nitrogen to NH_4 by Kjeldahl digestion, and measuring the amount of NH_4 by back titration after addition of acid solution
4. Available phosphate	Extracting phosphate by NH_4F solution, colouring by molybdophosphoric method and measuring by spectrophotometer
5. Cation exchange capacity (CEC)	Saturating exchange sites with NH_4, extracting NH_4 absorbed and measuring the NH_4 by neutrization titration
6. Exchangeable bases	Extracting Ca, Mg, Na and K by N-NH_4OAc, (1) measuring Ca and Mg by EDTA titration and (2) measuring by flame-photometer
7. Free iron	Extracting by dithionite ($Na_2S_2O_4$), coloring by orthophenanthroline and measuring by spectrophotometer
8. Texture	Fractionating using sieves and taking suspensions by the application of Stokes' equation

Reference: M.L. Jackson, 1967, Soil Chemical Analysis.

Table IV.2.2 Result of Soil Analysis

Sample No.	pH		Total Carbon	Total Nitrogen	Available Phosphate	Cation Exchange Capacity	Exchangeable Base					Base Saturation Degree	Free Iron	Soil Particle Size Distribution			
	H_2O	KCl	(%)	(%)	(ppm)	(me/100gr)	Ca	Mg	Na	K	Total	(%)	(%)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
							(me/100gr)										
1. Dystric Fluvisols																	
1/1	5.3	3.6	1.75	0.10	5.40	15.8	3.13	2.35	0.04	0.64	6.16	39	0.24	29.73	55.30	13.45	1.52
1/2	4.7	3.7	0.93	0.07	7.58	14.0	3.52	2.05	0.04	0.69	6.30	45	0.08	40.82	54.56	2.47	2.15
1/3	4.8	3.6	0.45	0.06	3.52	19.0	4.23	2.81	0.07	0.87	7.98	42	3.52	45.22	53.01	1.77	-
1/4	4.8	4.0	0.24	0.06	8.60	17.3	3.87	3.38	0.06	0.82	8.13	47	0.04	53.14	38.18	-	8.68
1/5	4.9	3.6	0.05	0.09	6.36	16.5	4.56	2.92	0.09	1.01	8.58	52	0.04	62.16	37.84	-	-
1/6	4.9	4.2	0.09	0.07	14.12	4.3	1.24	0.98	0.08	0.86	3.14	73	0.03	61.96	35.21	2.51	0.32
11/1	4.7	3.3	1.25	0.11	4.16	11.0	1.86	1.71	0.07	0.90	4.54	41	0.20	61.31	31.88	6.53	0.28
11/2	4.9	3.3	0.28	0.08	14.85	16.9	4.37	2.22	0.11	1.21	7.91	47	0.02	76.98	16.68	8.11	6.23
11/3	4.8	3.8	0.15	0.07	8.22	9.2	2.04	1.56	0.10	1.14	4.84	53	0.01	73.96	25.05	0.99	-
2. Eutric Fluvisols																	
4/1	4.3	3.6	1.39	0.1	17.05	13.6	7.86	3.72	0.04	0.46	12.1	89	0.03	22.63	60.06	16.23	0.28
4/2	5.6	5.0	0.33	0.05	10.39	15.5	6.82	4.35	0.03	0.27	11.5	74	0.16	27.89	46.48	23.64	1.99
4/3	5.8	5.3	0.69	0.11	3.99	16.6	8.12	4.71	0.03	0.25	13.1	79	0.12	31.51	47.19	20.61	0.69
4/4	5.9	5.1	0.48	0.06	2.60	18.5	7.97	6.24	0.20	0.77	15.2	82	0.03	67.74	8.38	19.52	4.36
4/5	6.3	5.1	0.20	0.05	2.09	13.2	3.87	4.80	0.06	0.24	8.98	68	0.03	49.87	25.93	23.22	0.98
10/1	6.0	4.7	0.27	0.04	6.88	18.8	8.31	3.98	0.05	0.52	12.86	68	0.08	31.85	58.65	9.50	-
10/2	6.0	4.6	1.44	0.11	8.21	18.9	9.82	4.99	0.11	0.53	15.42	82	0.22	33.04	61.98	2.47	2.51
10/3	6.8	5.2	1.22	0.08	2.30	8.5	4.96	1.08	0.04	0.16	6.24	73	0.07	31.08	65.37	2.52	1.03
3. Eutric Gleysols																	
9/1	6.2	5.0	0.42	0.1	5.98	17.4	8.21	5.35	0.05	0.68	14.29	82	0.04	51.94	11.41	6.77	29.88
9/2	4.5	3.3	1.07	0.05	14.22	12.8	5.76	2.18	0.05	0.39	8.38	65	0.76	50.29	36.65	12.59	0.47
9/3	5.2	3.6	0.24	0.05	6.26	8.3	3.88	1.55	0.04	0.39	5.86	71	0.24	36.34	36.51	18.08	9.07
4. Pellic Vertisols																	
12/1	5.8	4.7	1.39	0.14	9.77	22.8	15.64	4.76	0.09	0.30	20.8	91	0.02	85.73	7.47	6.80	-
12/2	6.3	5.0	0.95	0.07	4.20	27.9	21.27	4.53	0.07	0.22	26.1	94	0.02	90.03	7.67	2.30	-
12/3	7.6	6.2	0.20	0.06	2.60	10.9	5.82	1.78	0.07	0.30	7.97	73	0.01	53.96	36.06	3.92	6.06
5. Eutric Nitosols																	
29/1	4.6	3.9	2.97	0.14	19.73	7.7	1.96	2.73	0.02	0.21	4.93	64	0.10	26.82	24.51	31.92	16.75
29/2	4.4	3.8	0.85	0.07	13.80	6.6	2.31	3.22	0.02	0.13	5.68	86	0.16	42.19	26.53	7.08	24.20
29/3	4.5	3.8	0.66	0.06	8.54	4.2	1.80	1.04	0.04	0.19	3.07	73	0.03	62.01	15.44	6.14	16.41
29/4	4.5	3.7	0.04	0.07	5.05	8.7	3.63	2.91	0.04	0.33	6.91	79	0.03	67.66	30.04	1.10	1.20
6. Distric Cambisols																	
30/1	5.1	4.6	0.49	0.07	2.57	13.1	1.77	2.61	0.04	0.27	4.69	36	0.01	16.22	62.28	18.50	-
30/2	6.0	4.6	0.24	0.06	2.14	12.5	2.93	3.55	0.08	0.21	4.77	54	0.02	31.82	49.40	17.76	1.02

Table IV.2.3 Soil Profile Description (1/6)

1. Profile Number	No. 9
2. Date of Examination	25 August, 1982
3. Soil Name	
1) FAO/UNESCO, 1974 /1	Eutric Gleysol
2) National, 1976 /2	Grey Alluvial Soils or Greyish Brown Alluvial Soil
4. Location	Tengnge, DS.Palakka, KEC.Libureng
5. Elevation	110 m
6. Land Form	Flat low land of recent alluvium
7. Vegetation or Land Use	Rainfed paddy field
8. Drainage Condition	Poorly drained
9. Profile Description	

A	0-20 (cm)	Brown (10YR 4/6) dry; clay; structureless; slightly sticky, plastic; few small spherical gravel (0.2 - 1.5 m) of weathered iron stone lower, common fine roots; clear or abrupt irregular boundary; pH 6.2.
B	20-50 (cm)	Brown (7.5YR 4/4) moist; clay; structureless; sticky, slightly plastic; few fine roots; gradual irregular boundary; pH 4.5.
Cg	50-100 (cm)	Light gray (10YR 7/1) moist; clay loam; structureless; slightly sticky, slightly plastic; few or common fine faint bright yellowish brown (10YR 6/8) mottle; gradual irregular boundary; pH 5.2.

Remarks : /1 ; Soil Map of the World, Legend (volume 1), FAO/UNESCO, 1974

/2 ; Jenis tanah di Indonesia, SRI, Bogor, 1976.

Table IV.2.3 Soil Profile Description (2/6)

1. Profile Number	No. 4
2. Date of Examination	7 September, 1982
3. Soil Name	
1) FAO/UNESCO, 1974 /1	Eutric Fluvisol
2) National, 1976 /2	Brown Alluvial Soil
4. Location	Cenranae, DS.Cenrana, KEC.Kahu
5. Elevation	130 m
6. Land Form	lower riverine terrace of semi-recent alluvium
7. Slope	Almost flat
8. Vegetation or Land Use	Rainfed paddy
9. Drainage Condition	Moderately well drained
10. Profile Description	

A1	0- 9 (cm)	Grayish yellow brown (10YR 6/2) dry; silt loam; structureless; slightly sticky, slightly plastic, slightly hard dry; common fine roots; diffuse wavy boundary; pH 4.3.
A2	9-17 (cm)	Grayish yellow brown (10YR 5/2) wet; clay loam; common fine faint bright brown (7.5YR 5/8) mottles; structureless; slightly sticky, slightly plastic; common fine roots; gradual wavy boundary; pH 5.6.
B1	17-24 (cm)	Brownish gray (10YR 4/1) wet; clay loam; few small spherical gravel (0.5 - 2cm) of weathered iron stone; few medium distinct reddish brown (5YR 4/6) mottles, structureless; slightly sticky, slightly plastic; few fine roots; clear wavy boundary; pH 5.8.
B2	24-38 (cm)	Brownish gray (10YR 5/1) wet; clay; weak medium brocky; sticky, slightly plastic, firm moist, hard dry; gradual irregular boundary; pH 5.9.
C	38-100(+) (cm)	Dark grayish yellow (2.5YR 5/2) wet; clay; weak medium blocky; sticky, slightly plastic, firm moist, extremely hard dry; gradual irregular boundary; pH 6.3.

Remarks : /1 ; Soil Map of the world, Legend (volume 1), FAO/UNESCO, 1974

/2 ; Jenis tanah di Indonesia, SRI, Bogor, 1976.

Table IV.2.3 Soil Profile Description (3/6)

1. Profile Number	No. 1
2. Date of Examination	31 August, 1982
3. Soil Name	
1) FAO/UNESCO, 1974 /1	Dystric Fluvisol
2) National, 1976 /2	Brown Alluvial Soils
4. Location	Carima, DS.Cenrana, KEC.Kahu
5. Elevation	155 m
6. Land Form	Higher riverine terrace of alluvium
7. Vegetation or Land Use	Rainfed paddy field
8. Drainage Condition	Well drained
9. Profile Description	

A	0-11 (cm)	Dull brown (7.5YR 3/2) dry, silty clay loam, weakly massive, slightly sticky, slightly plastic, frequent fine roots, clear wavy boundary, pH 5.3
AB	11-17 (cm)	Grayish brown (7.5 YR 4/2) moist, silty, clay, moderate medium granular, slightly sticky, slightly plastic, slightly hard dry, frequent fine roots, clear irregular boundary, pH 4.7
B11	17-32 (cm)	Brownish gray (10YR 5/1), clay, common medium distinct red mottle (10R 4/8), moderate medium angular blocky, sticky, plastic, slightly hard wet, very hard dry, frequent fine roots, gradual irregular boundary, pH 4.8
B12	32-65 (cm)	Brownish gray (10YR 6/1), clay, many coarce bright yellowish brown (10YR 6/6) mottle, moderate medium blocky, sticky, very plastic, firm moist, very hard dry, few fine roots, clear irregular boundary, pH 4.8
B2	65-83 (cm)	Brownish gray (10YR 6/1),clay, moderate medium blocky, very sticky, very plastic, firm moist, very hard dry, clear irregular boundary, pH 4.9
C	83-100(+) (cm)	Grayish yellow brown (10YR 6/2), many coarce prominent bright yellowish brown (10YR 6/6) mottle, moderate medium blocky, slightly sticky, plastic, firm moist, extremely firm, weathered clay stone or tuff, pH 4.9.

Remarks : /1 ; Soil Map of the World, Legend (volume 1), FAO/UNESCO, 1974

/2 ; Jenis tanah di Indonesia, SRI, Bogor, 1976.

Table IV.2.3 Soil Profile Description (4/6)

1. Profile Number	No. 12
2. Date of Examination	31 August, 1982
3. Soil Name	
1) FAO/UNESCO, 1974 /1	Pellic Vertisol
2) National, 1976 /2	Grey Grumusol
4. Location	Tompongpatu, DS.Senrego, KEC.Kahu
5. Elevation	160 m
6. Land Form	Low riverine alluvial terrace
7. Vegetation and Land Use	Rainfed paddy field
8. Drainage Condition	Moderately well drained
9. Profile Description	

A	0-31 (cm)	Reddish black (7.5YR 7/1); heavy clay; strong medium blocky; very sticky, very plastic, very firm moist, extremely hard dry; diffuse irregular boundary; common fine roots; pH 5.8.
B	31-40 (cm)	Brownish black (10YR 2/2); heavy clay; very few fine faint yellowish mottles; strong massive, very sticky, very plastic, firm moist, extremely hard dry; few fine roots, clear wavy boundary; pH 6.3.
C	40-100 (cm)	Dark brown (10YR 2/2); heavy clay; many medium prominent light gray (2.5Y 8/1) mottles; moderate fine granular; few small, hard, spherical, white, lime concretion; moderate fine granular; very sticky, very plastic, friable wet, extremely hard dry, clear wavy boundary; pH 7.6.

Remarks : /1 ; Soil Map of the world, Legend (volume 1), FAO/UNESCO, 1974

/2 ; Jenis tanah di Indonesia, SRI, Bogor, 1976.

Table IV.2.3 Soil Profile Description (5/6)

1. Profile Number	No. 29
2. Date of Examination	7 September, 1982
3. Soil Name	
1) FAO/UNESCO, 1974 /1	Eutric Nitosol
2) National, 1976 /2	Dark Reddish Brown Latosol
4. Location	Polewali, DS.Polewali, KEC.Libureng
5. Elevation	150 m
6. Land Form	High terrace of diluvial deposits
7. Vegetation	Orchard (Cashew Nuts), grass land
8. Drainage Condition	Well drained
9. Profile Description	

A	0-10 (cm)	Dark reddish brown (2.5YR 3/2) dry; clay loam; structureless; non sticky, non plastic, friable moist, hard dry, few fine roots; gradual irregular boundary; pH 4.6.
B1	10-30 (cm)	Dark red (10R 3/4) dry; clay; structureless; many medium prominent red (10R 5/8) mottles; slightly sticky, slightly plastic, friable moist, hard dry; very few fine roots, gradual irregular boundary; pH 4.4.
B2t	30-150(+) (300) (cm)	Red (7.5R 4/8) moist; clay; structureless; many medium prominent red (10R 5/8) mottles; continuous thin cuton of clay with sesquioxide; slightly sticky, slightly dry; gradually irregular boundary; pH 4.5.

Remarks : /1 ; Soil Map of the World, Legend (volume 1), FAO/UNESCO, 1974

/2 ; Jenis tanah di Indonesia, SRI, Bogor, 1976.

Table IV.2.3 Soil Profile Description (6/6)

1. Profile Number	No. 30
2. Date of Examination	7 September, 1982
3. Soil Name	
1) FAO/UNESCO, 1974 /1	Dystric Cambisol
2) National, 1976 /2	Brunizems
4. Location	Batu Batu, DS.Biru, Kec.Kahu
5. Elevation	170 m
6. Land Form	Dissected isolated hills
7. Vegetation	Grass land
8. Drainage Condition	Well drained
9. Profile Description	

A	0-12 (cm)	Dull yellow orange (10YR 7/2) dry; silt loam; structureless; few fine faint brown (7.5YR 4/4) mottles; non sticky, non plastic, friable moist, slightly hard dry; few fine roots above 5 cm; gradual or clear smooth boundary; pH 5.1
C	12-100(+) (cm)	Grayish yellow brown (10YR 5/2) moist; silty clay loam; weak medium blocky; non sticky, slightly plastic, firm moist, very hard dry; gradual or clear smooth boundary; pH 6.0.

Remarks : /1 ; Soil Map of the World, Legend (volume 1), FAO/UNESCO, 1974

/2 ; Jenis tanah di Indonesia, SRI, Bogor, 1976.

Table IV.3.1 Specification of Japanese Land Classification System

Item	Code	Class I Paddy	Class I Upland	Class I Orchard	Class II Paddy	Class II Upland	Class II Orchard	Class III Paddy	Class III Upland	Class III Orchard	Class IV Paddy	Class IV Upland	Class IV Orchard
1. Thickness of top soil	t	> 15 cm	> 25 cm	> 15 cm	< 15 cm	25 - 15 cm	-	-	< 15 cm		-	-	-
2. Effective depth of soil	d	> 50 cm	> 100 cm		50 - 25 cm	100 - 50 cm		25 - 15 cm	50 - 15 cm	50 - 25 cm	< 15 cm		< 25 cm
3. Gravel content in top soil	g	< 20 %	< 5 %	< 10 %	20 - 50 %	5 - 20 %	10 - 50 %	-	10 - 50 %	20 - 50 %	> 50 %	> 20 %	> 50 %
4. Easiness of plowing	p	Easy to slightly difficult			Moderately difficult			Very difficult			-	-	-
5. Permeability under submerged condition	l	Poorly to imperfectly permeable	-	-	Moderately to well permeable	-	-	Well to excessively permeable	-	-	-	-	-
6. State of redox potentiality (Risk of root damage)	r	None to weak	-	-	Moderate to strong	-	-	Very strong	-	-	-	-	-
7. Wetness of land (Risk of drought or wetness)	Wet: W Dry: (W)	- -	None None		- -	Low possibility of over wetness Low possibility of drought		- -	Possibility of over wetness Possibility of of drought		- -	High possibility of over wetness High possibility of drought	
8. Inherent fertility	f		Fertile			Medium			Infertile		-	-	-
9. Content of available nutrients	n		High			Medium			Low		-	-	-
10. Degree of hazard	i		None			Slightly			Moderately			Seriously	
11. Frequency of hazard	a		None to rarely			Moderately			Frequently		-	-	-
12. Slope	s	-	< 3°	< 15°	-	3 - 8°	8 - 25°	-	8 - 15°	15 - 25°	-	> 15°	> 25°
13. Erosion	e		None or very slightly			Slightly			Seriously			Very seriously	

Table IV.3.2 Soil Unit and Land Classification Class

	Factor		Eutric Gleysols		Eutric Fluvisols		Dystric Fluvisols		Pellic Vertisols		Eutric Nitosols		Dystric Cambisols		Lithosols	
			Paddy	Upland	Paddy	Upland	Paddy	Upland	Paddy	Upland	Paddy	Upland	Paddy	Upland	Paddy	Upland
(1)	Thickness of top soil	(t)	I	I	I-II	II-III	I-II	II-III	I	I	II	II	IV	IV	IV	IV
(2)	Effective soil depth	(d)	I	II	I-II	II-III	I-II	II-III	I	I	II	II	IV	IV	IV	IV
(3)	Gravel content in top soil	(g)	I-II	II-III	I	I	I	I	I	I	II	II	II	II	IV	IV
(4)	Easiness of plawing	(p)	II	II	II	II	II	II	II	II	III	II	III	III	III	III
(5)	Permeability under submerged condition	(l)	I	-	I	-	I	-	I	-	II	-	II	-	I	-
(6)	State of redox potential	(r)	I	-	I	-	I	-	I	-	I	-	I	-	I	-
(7)	Wetness of land	(w)	-	I	-	I	-	II	-	II	-	II	-	II	-	II
(8)	Inherent fertility	(f)	II	I	II	I	II	I	I	I	II	II	II	III	II	III
(9)	Content of available fertility	(n)	II	II	II	II	II	II	II	II	III	II	II	III	II	III
(10)	Degree of hazard	(i)	I	I	I	I	I	I	I	I	I	I	IV	III	IV	IV
(11)	Frequency of hazard	(a)	II	II	I	I	I	I	I	I	I	I	II	III	III	III
(12)	Slope	(s)	-	I	-	I-II	-	II-III	-	I	-	II	-	IV	-	III
(13)	Erosion	(e)	-	I	-	I-II	-	II-III	-	II	-	II	-	IV	-	IV
Land Classification Class (paddy/upland)			IIpfna/IIdgpna IIgpfna/IIIg		IIpfn/IItdpse IItdpfn/IIItd		IIpfn/IItdwse IItdpfn/IIItdse		IIpn/IIpwne		IIIpn/IItdgwfnse		IVtdi/IVtdse		IVtdgi/IVtdgie	

Table IV.3.3 Agricultural Limitations and Suggested Land Use for Each Land Class

Soil Unit Land Class (Paddy/Upland)	Area (ha)	Agricultural Limitation	Suggested Land Use	Management Factors
Eutric Gleysols				
IIpfna/IIdgpna IIgpfna/IIIg	1,200 600	Heavy texture, low fertility presence of gravel, flash flooding	Double cropping of rice or rainy season paddy and polowijo crops rotation under irrigation	Drainage improvement, use of fertilizers on the basis of experiment and rotational cropping aimed at up-grading the fertility level of soil
Eutric Fluvisols				
IIpfn/IItdpse IItdpfn/IIItd	3,700 900	Low fertility, uneven topography, erosion, cracking	- do -	Application of fertilizers, land levelling and bench terracing, rotational cropping, pre-irrigation to close cracks for dry season cropping
Dystric Fluvisols				
IItdpfn/IItdwse IItdpfn/IIItdse	4,000 1,100	Shallow soil, low fertility uneven topography, erosion	- do -	Deep ploughing, adequate fertilization, land levelling, rotational cropping
Pellic Vertisols				
IIpn/IIpwne	300	Heavy texture, poor workability, low fertility, cracking	Double cropping of irrigated rice	Application of fertilizers, drainage improvement, pre-irrigation to close cracks for dry season paddy
Eutric Nitosols				
IIIpn/IItdgpwfnse	3,500	Low fertility, strongly acidity undulating topography	Large scale sugar cane plantation, orchard, perennial crops like clove and coconut.	Deep ploughing, liming, adequate fertilization, mulching
Dystric Cambisols				
IVtdi/IVtdse	1,400	Shallow soil, soil erosion, gravelly low fertility	Perenial crops such as coconut, cashewnut, upland crops like cassava, sweet potato	Erosion control, regreening, adequate fertilization
Lithosols				
IVtdgi/IVtdgi	800	Shallow, stony, high susceptibility to soil erosion	Forest	Reforestation
Total area	17,500			