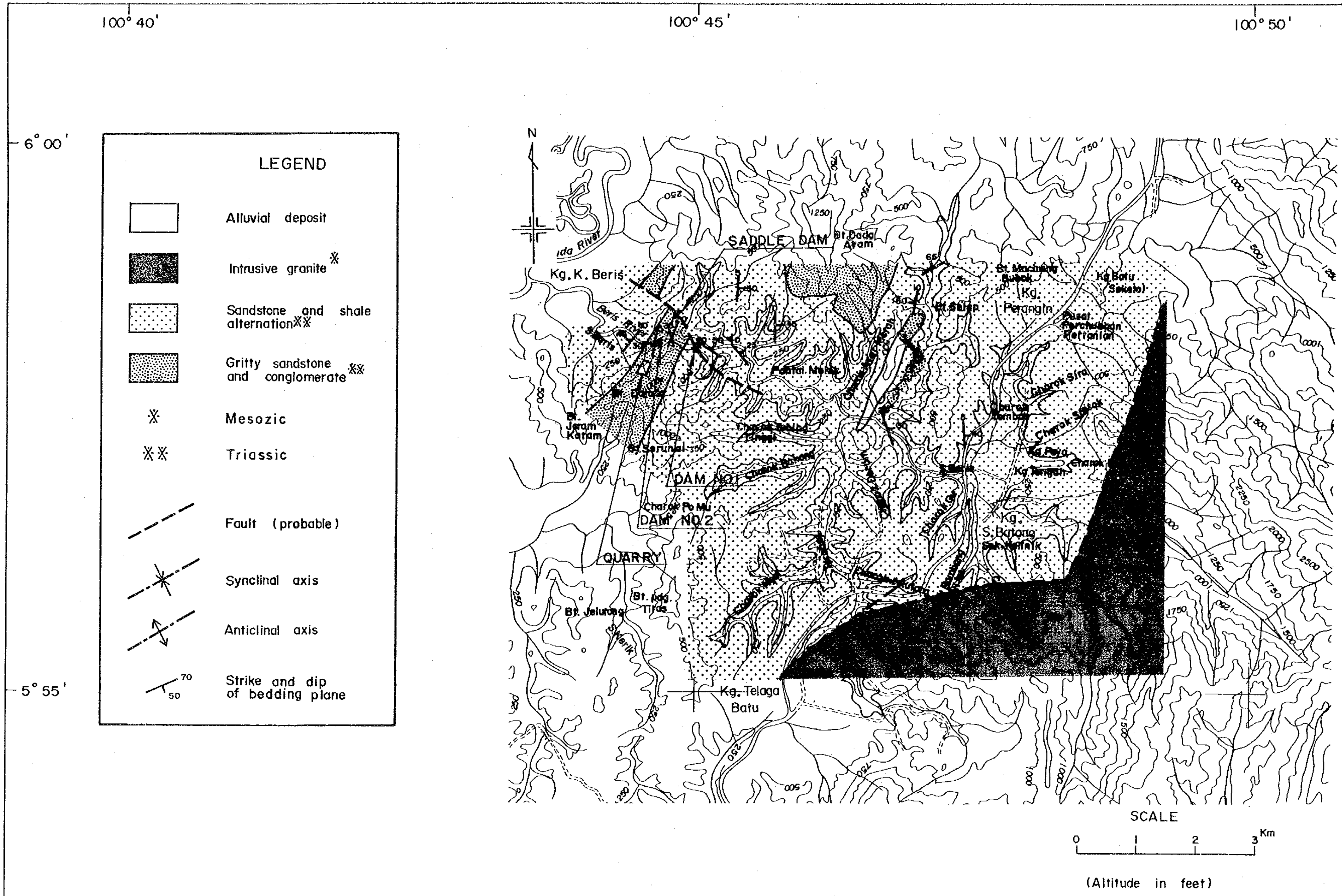
PLATE NO. 13



Geological Map of Dam and Reservoir Area, Beris

100° 50'

100° 40'

100° 45'

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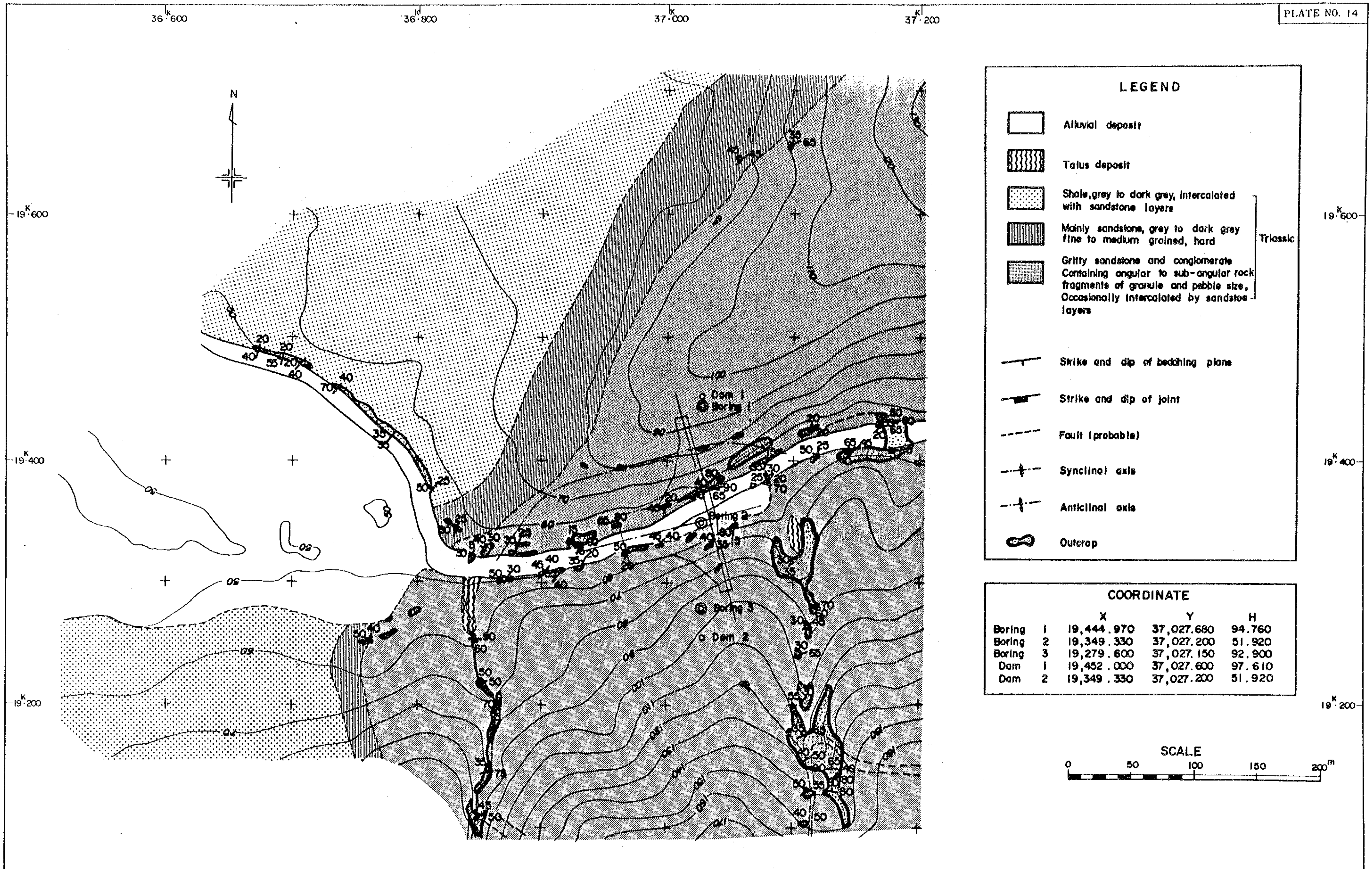
PLATE NO. 14



COORDINATE

		X	Y	H
Boring	1	19,444.970	37,027.680	94.760
Boring	2	19,349.330	37,027.200	51.920
Boring	3	19,279.600	37,027.150	92.900
Dam	1	19,452.000	37,027.600	97.610
Dam	2	19,349.330	37,027.200	51.920

Geological Map of Dam Site, Beris No. 2

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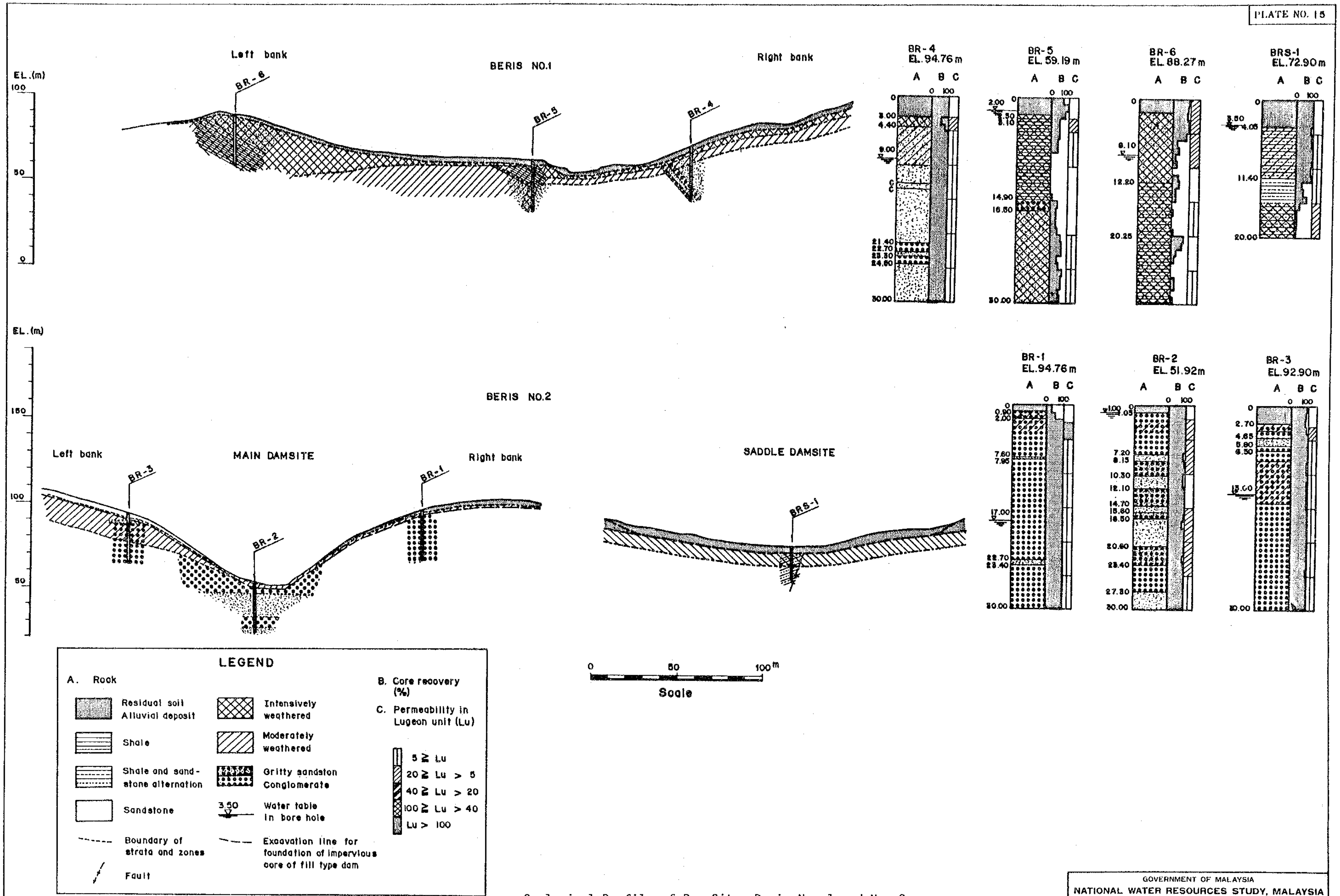

Geological Profile of Dam Site, Beris No. 1 and No. 2

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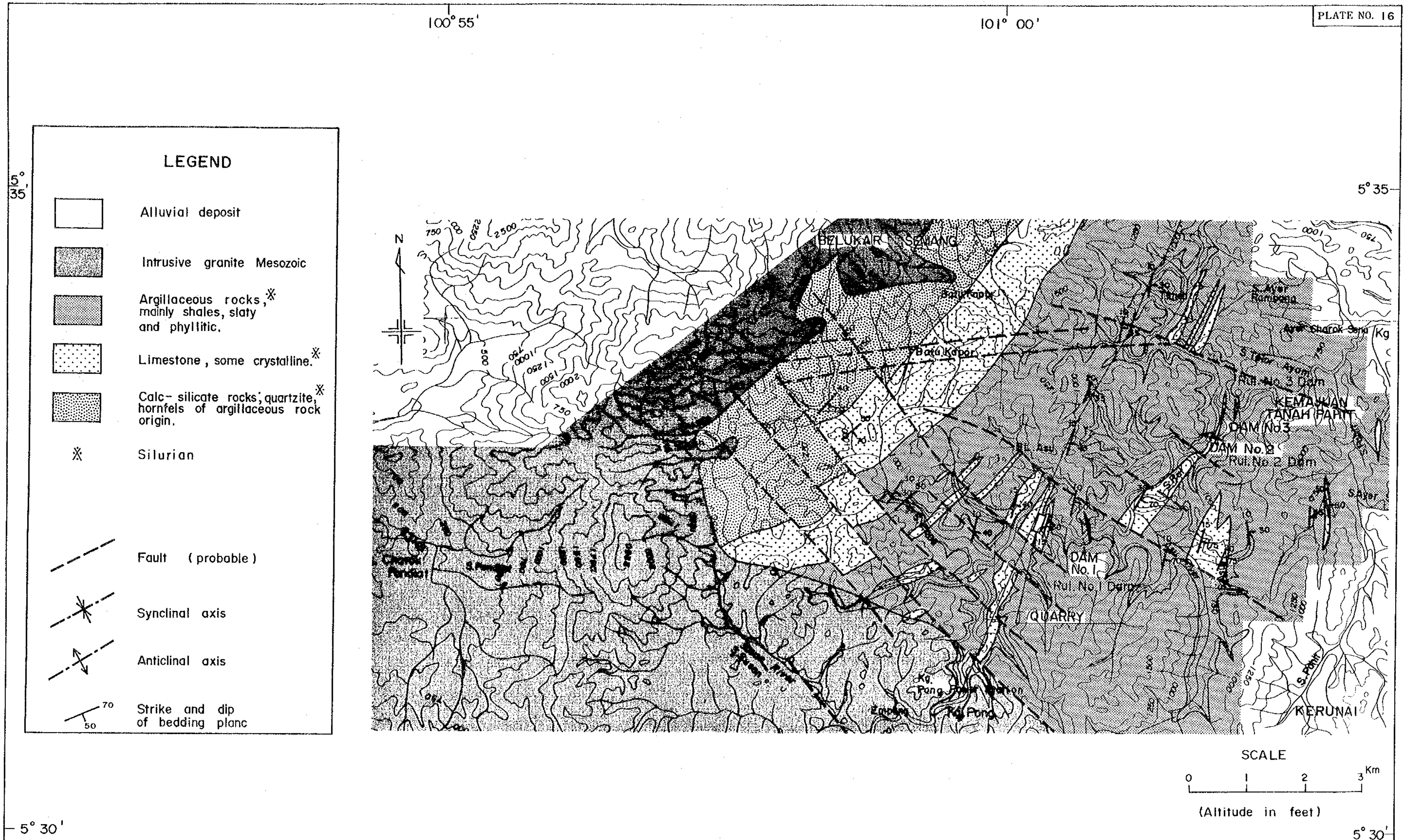
PLATE NO. 16



Geological Map of Dam and Reservoir Area, Rui

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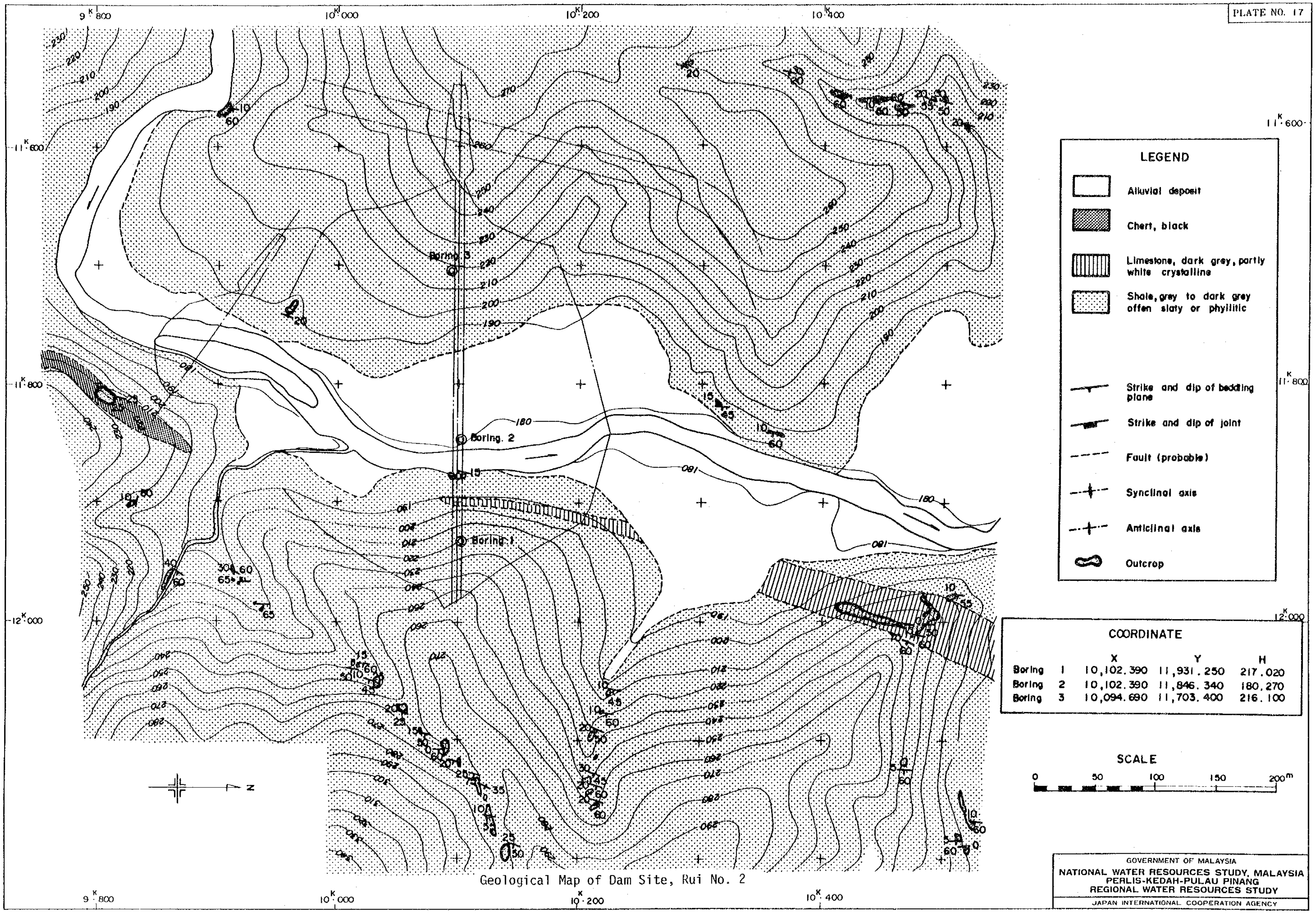
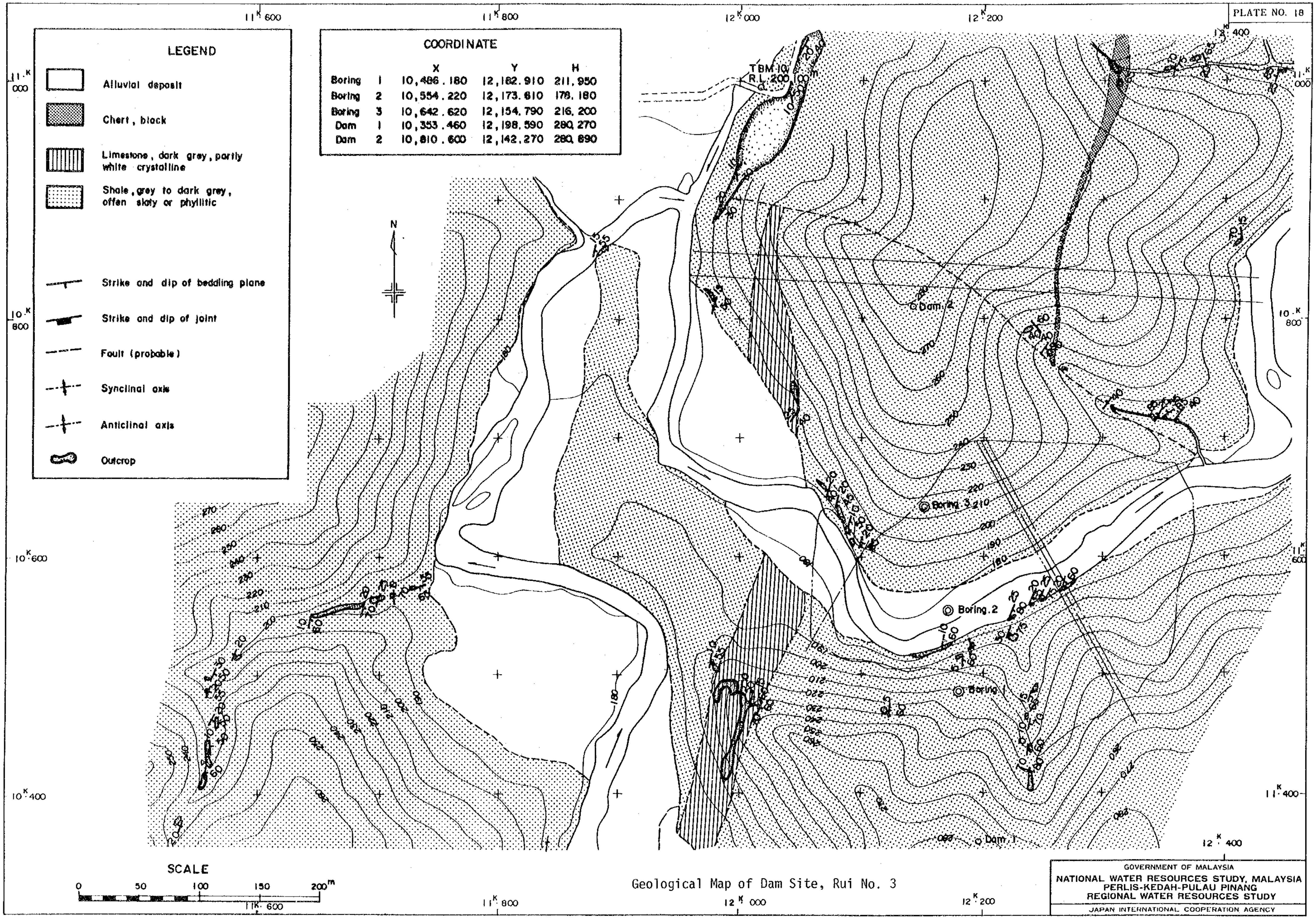


Geological Map of Dam Site, Rui No. 2

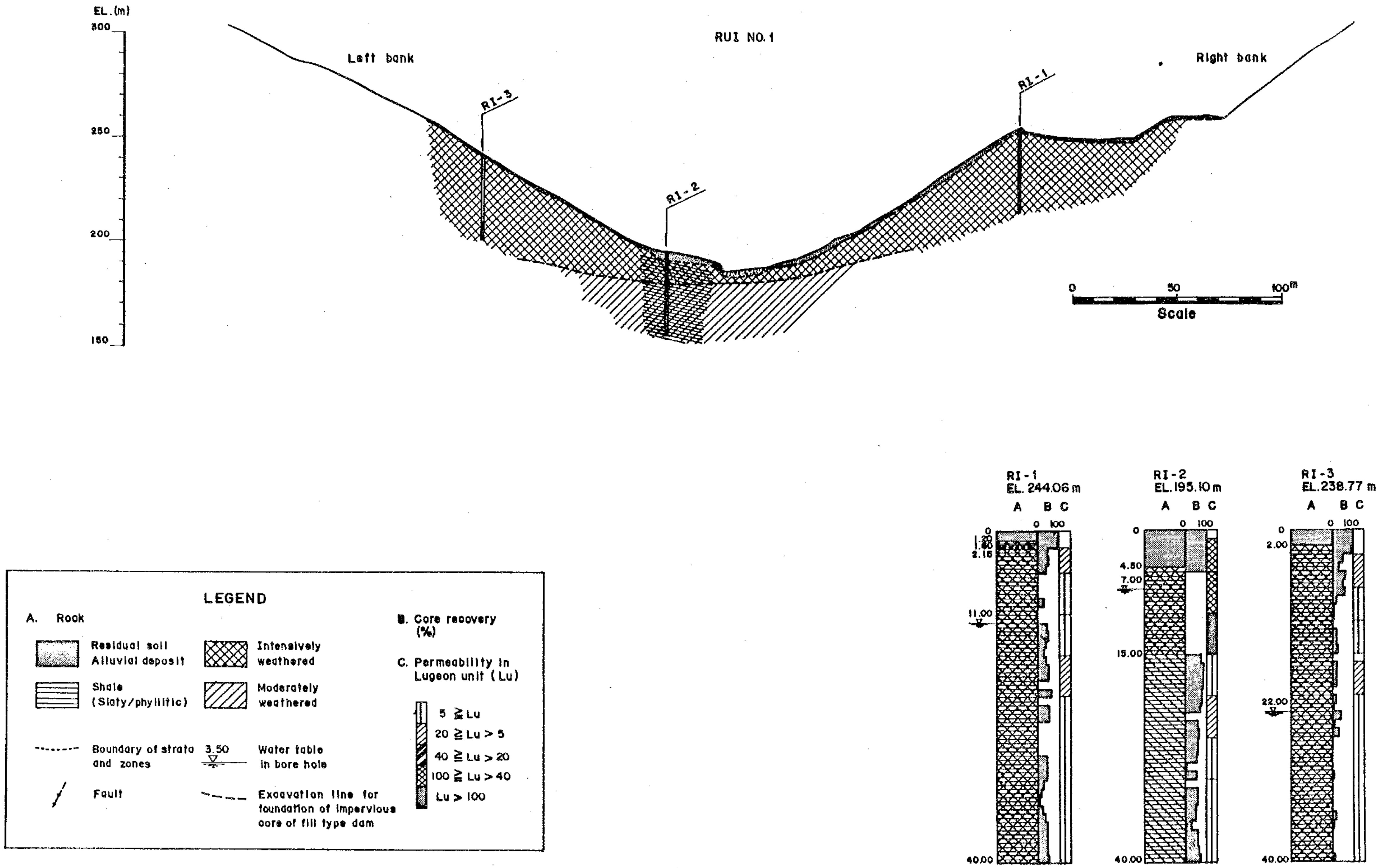


COORDINATE

		X	Y	H
Boring	1	10,486.180	12,182.910	211,950
Boring	2	10,554.220	12,173.610	178.180
Boring	3	10,642.620	12,154.790	216.200
Dam	1	10,353.460	12,198.590	280.270
Dam	2	10,810.600	12,142.270	280.890

Geological Map of Dam Site, Rui No. 3

PLATE NO. 19



Geological Profile of Dam Site, Rui No. 1

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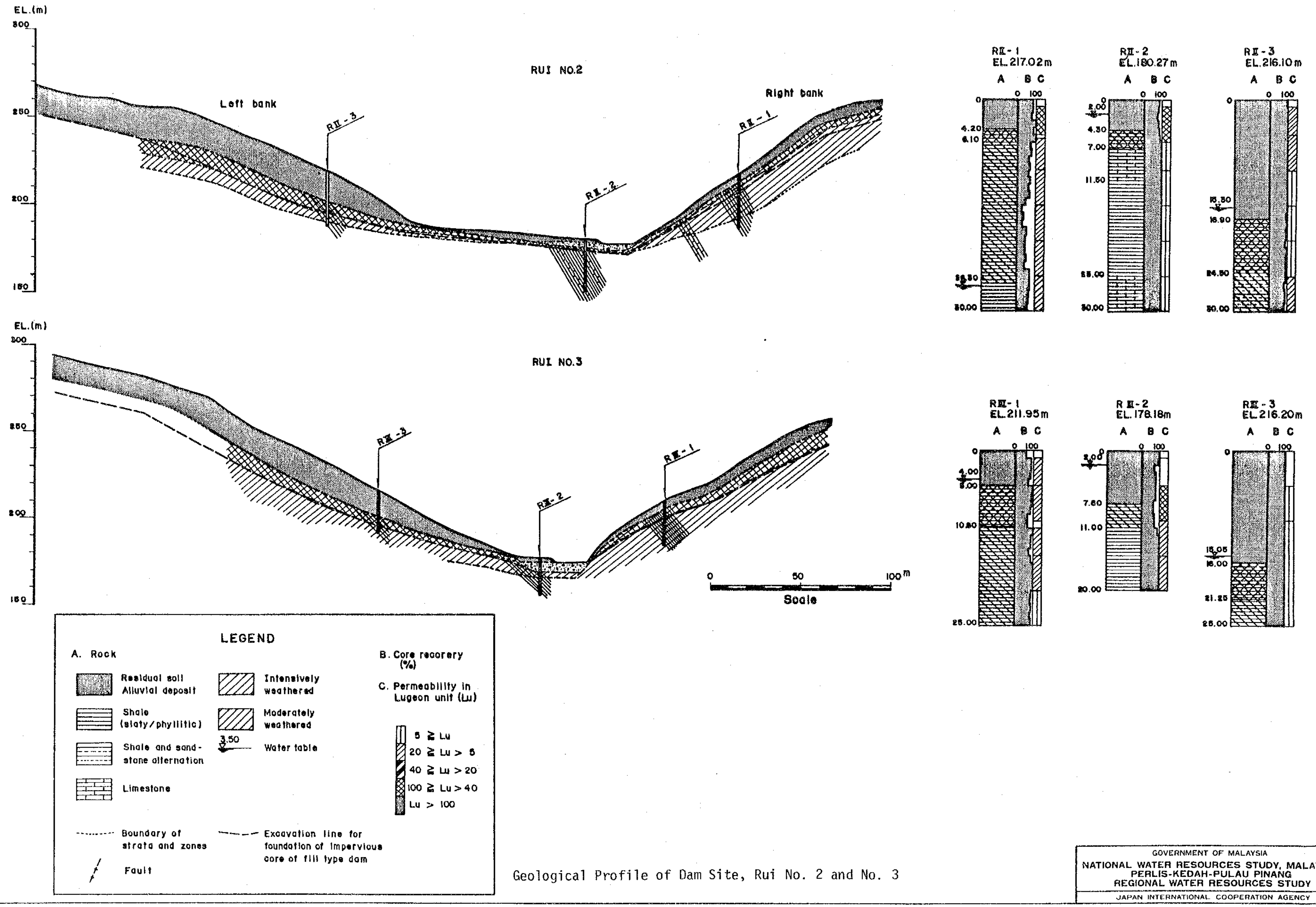

Geological Profile of Dam Site, Rui No. 2 and No. 3

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ANNEX K

CONSTRUCTION MATERIAL

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1. INTRODUCTION

The objective of the construction material survey is to find adequate sources of soil, sand and rock materials for earth structures and aggregates and rock materials for concrete and rock structures involved, to estimate reserved quantity and available amount, and to evaluate quality of the materials from engineering standpoint.

The study area, the Perlis-Kedah-Pulau Pinang region includes the Perlis, Kedah, Merbock, Muda and Perai river systems, and the Rui river basin of the Perak river system. The investigation was focused on the proposed six dam sites and their alternative sites; that is, Badak-Temin, Sari, Durian, Tawar-Muda, Beris and Rui.

The investigation is composed of three parts; accordingly; field survey, laboratory tests for earth materials and engineering analysis and evaluation. The reconnaissance of site conditions and sampling for the laboratory tests was done from December 17, 1982 to February 20, 1983. A series of laboratory soil mechanical tests were executed by the DID research laboratory in Kuala Lumpur. The physical and chemical property tests and the Proctor compaction test were done from the beginning of February to the end of March, 1983. The mechanical property tests were carried out from March to July, 1983. Supplemental tests were done to examine the soil property test results and to check the swelling behavior of the cohesive soils at the Nippon Koei research laboratory in Japan from April to May, 1983.

Section 2 describes the site conditions and alternative and proposed quarry sites and borrow pits. Section 3 presents the laboratory testing schedule for the fine grained soils and their test results. Section 4 describes the characteristics of the residual soils around the project sites and evaluates the mechanical properties required for rolled earth dams. Section 5 summarizes the investigation results of concrete aggregates and filter material.

2. CONSTRUCTION MATERIAL SOURCES

2.1 Requirement of Non-manufactured Construction Materials

The site reconnaissance was done to find the sources of non-manufactured construction materials required for fill or concrete dams and their auxiliary structures. The material sources are classified into three setout below:

(1) Rock quarry; rock for fill dams and masonry, fine and coarse aggregates for concrete dams and the other concrete structures, and filter and drain materials for fill dams and other structures.

(2) Borrow-pit for cohesive soil; impervious core material for fill dams, earth material for earth embankment structures, and backfill materials.

(3) Borrow-pit for sand and gravel; filter and drain materials for fill dams and other structures, fine and coarse aggregates for concrete dams and the other concrete structures.

2.2 Site Conditions and Alternative Quarry Sites and Borrow-Pits

The project area and the proposed 6 dam sites are shown in Fig. 1. The topographic and geological conditions of these dam sites are summarized in Tables 1 - 3. The details of the topographic and geologic site conditions are presented in the Annex J, Engineering Geology.

After the first stage site reconnaissance, one dam axis was precisely investigated for the Badak-Temin, Sari and Durian sites. Two alternative axes for the Tawar-Muda and Beris sites and 3 alternative axes for the Rui site were investigated. The location of the alternative sources of construction materials is shown in Plate 1 for the Badak-Temin site, Plate 2 for the Sari and Durian sites, Plate 3 for the Tawar-Muda site, Plate 4 for the Beris site and Plate 5 for the Rui site, in which rock quarry, borrow-pit for cohesive soil, and borrow-pit for sand and gravel are denoted as Q, B and S respectively. The distance, quality and quantity of the prospective reserves of construction materials are summarized in Tables 4 - 10.

2.3 Test Pits

The total number of 26 test pittings was done for cohesive soil, sand and gravel to observe the subsurface conditions of the deposits and to take samples for laboratory tests. The diameter of the test pit was 1.5 - 2.0 m and the depth was 1.0 - 3.0 m depending on the site conditions. The slope cut for road construction and outcrop of sand and gravel were also observed. The number of test pits are set out below:

Badak-Temin	(4)	= BT-B1, B2, B3 and BT-S1
Sari	(6)	= SR-B1, B2, B3, B4 and SR-S1, S2
Durian	(3)	= DR-B1, B2, B3
Tawar-Muda	(5)	= TM-B1, B2, B3 and TM-S1, S2
Beris	(3)	= BR-B1, B2, B3
Rui	(5)	= RI-B1, B2, B3, B4 and RI-S1

The location of these pits is shown in Plates 1 - 5.

2.4 Proposed Quarry-sites and Borrow-pits

2.4.1 Accuracy of reserved quantity

The reserved quantity of soil, sand and gravel deposits is estimated by using the field notes and the one inch/one mile maps (Scale 1/63,360). The quantity values are therefore rather notional and are subject to further investigation.

2.4.2 Badak-Temin site

(1) Quarry site

Of the two alternative quarry sites, Q1 and Q2, the BT. Bendang Bongsu quarry, Q1 where is 2 km west from the dam site by road is proposed. The yield rate of the BT. Telipong quarry, Q2 is better but the distance to the site is too long. The rock is siliceous sand stone and its yield rate may be about 50% because of thick top soil cover. The reserved quantity is estimated more than 10×10^6 m^3.

(2) Borrow-pit for cohesive soil

The residual soil around the dam site is reddish and lateritic clay. Of the three alternative borrow-pits for cohesive soil, B1, B2 and B3, both B1 and B2 are proposed. The B1 is located around BT. Bendang Bongsu and 1 km south from the dam site by road distance. The B2 is located 0.5 - 2 km east from the dam site in the reservoir area. The soil of B1 is CH or CL in the Unified Soil Classification (see Table 22) and that of the B2 is CH or MH. The soil property of B1 seems to be better for the impervious core material than that of B2, but the B2 has the advantage of location. The reserved quantity of B1 and B2 is some 2×10^6 m^3 or more respectively.

(3) Borrow-pit for sand and gravel

No deposit of gravel was found but a sand deposit of thin layer, S1 (1 - 2 m) was found in and around the river channels of the Badak and Temin rivers. The deposit within 3 km upstream from the dam site can be used for fine aggregate or filter material, but it is mostly submerged. The sand is poorly graded and is classified SP in the Unified Soil Classification. The reserved quantity is estimated some 20×10^3 m^3.

2.4.3 Sari site

(1) Quarry site

The quarry Q1 which is within 1 km on the right bank of the dam site is proposed. The rock is hard sandstone covered with rather thin top soil. The yield rate may be some 70%. The quantity is estimated more than 2×10^6 m^3.

(2) Borrow-pit for cohesive soil

Of the two alternative borrow-pits for cohesive soil, B1 and B2, the B1 which is located on the rolling right bank of the Sari river, 0.7 - 1.3 km northwest from the dam site is proposed. The B1 deposit is brownish sedimentary soil (CL) intercalated with thin sand layers (SP-SW) of about 0.5 m each. The depth of the reserve is estimated around 3 - 5 m. The quantity is estimated some 2×10^6 m^3.

This soil, which is classified into CL in the Unified Soil Classification, is considered being good material for rolled earth dams.

(3) Borrow-pit for sand and gravel

Both the S1 and S2 borrow-pits are proposed. However the S1 being minor deposit, the S2 is the primary deposit despite long distance. The S1 deposit, which is a mixture of sand (SP-SW) and gravel, is a thin layer in and around the river channel of the Sari river, 1 - 2 km upstream from the dam site. The quantity of S1 is estimated some 20×10^3 m^3 but the most part is submerged in the river water.

The S2 is the spill bank dredged from the tin mining near Kelian Pintu Wang, 6 km northwest by road from the dam site. It is composed of sand (SW-SP), gravel, cobbole and boulder. The reserved quantity is estimated some 100 - 200 $\times 10^3$ m^3. Since the gravel contains heavily weathered rock, it is subject to further study to use it for concrete aggregate.

2.4.4 Durian Site

(1) Quarry site

The quarry Q1, which is on the southern ridge of Bt. Boh Lembu, 3.3 km north (upstream) by road from the dam site, is proposed. The rock is siliceous sandstone. The yield rate may be some 70%. The reserved quantity is estimated more than 5 x 10^6 m^3.

(2) Borrow-pit for cohesive soil

Of the two alternative borrow-pits, B1 and B2, the B1 which is on the right and left bank of the Durian river, 1 - 1.5 km south (downstream) by road from the dam site is proposed. The B1 is mixture of reddish and gray residual soils. The grain size distribution varies sample by sample and therefore its classification varies as CH-MH, CL or SC. The reserved quantity is estimated some 2 x 10^6 m^3.

(3) Borrow-pit for sand and gravel

No major deposit of sand and gravel was found except S1, a very thin sand layer in and around the river channel of the Durian river. Although the quantity in the river channel within 2 km upstream from the dam site is estimated some 10 x 10^3 m^3, it is mostly submerged in the river water and therefore it cannot be used practically.

2.4.5 Tawar-Muda Site

(1) Quarry site

The quarry Q1 which is the hill near Kg. Tanjong Piring on the left bank of the Muda river, 1 km south (downstream) from the dam site is proposed. The rock is moderately hard sandstone. The yield rate may be some 70%. The reserved quantity is estimated more than 2 x 10^6 m^3.

(2) Borrow-pit for cohesive soil

Of the two alternative borrow-pits, B1 and B2, the B1 which is the hill on the right bank of the Muda river, 1 km northwest in the reservoir area from the No. 1 dam site is proposed. The B1 is yellowish or reddish residual soil. It is lateritic and is classified MH or CH. The soil reserve to the depth of about 3-5 m can be used for rolled earth dams and therefore the quantity is estimated some 1.5 x 10^6 m^3.

(3) Borrow-pit for sand and gravel

Of the two alternative borrow-pits, S1 and S2, the S1 which is a thin layer of 2 - 3 m on the left bank of the Muda river near Kg. Tanjung Piring, 0.5 - 1.0 km downstream from the No. 1 dam site is proposed. The S1 is a mixture of sand (SP) and gravel (GP) and is submerged below 2 m from the ground surface. The reserved quantity is estimated some 100 - 200 x 10^3 m^3. The S2 is the same sand and gravel deposit as the S1 but is subject to further study.

2.4.6 Beris site

(1) Quarry site

Of the two alternative quarries, Q1 and Q2, the Q1 which is within 1 km on the left bank of the No. 2 dam site, north ridge of Bt. Damar is proposed. The Q2 is better in terms of distance but the estimated quantity (some 500 x 10^3 m^3) is not reliable. The Q1 is composed of Grit, conglomerate and sandstone. The yield rate may be some 80%. The reserved quantity is estimated more than 2 x 10^6 m^3.

(2) Borrow-pit for cohesive soil

The only borrow-pit B1 which is on the right bank of the Beris river, 0.7 - 1.5 km west (downstream) from the No. 2 dam site is proposed. The soil of B1 is yellowish or reddish residual soil intercalated with white clay or coarse sand. It is lateritic and is classified into CH or MH in the Unified Soil Classification. The soil reserve to the depth of about 3 - 5 m can be used for rolled impervious core materials, and thus the quantity is estimated some 500 x 103 m^3.

(3) Borrow-pit for sand and gravel

No deposit of sand and gravel was found in the Beris river. The deposit in the downstream of the Muda river from the junction at the Beris river may be subject to further investigation.

2.4.7 Rui site

(1) Quarry site

The quarry Q1 which is an outcrop on the right bank of the Rui river, 1 km west from the No. 1 dam site (3.2 km southwest from the No. 2 dam site) is the only fresh rock source in the Rui reservoir area. The matrix is limestone. The yield rate may be some 70%. The reserved quantity is estimated some 2 x 10^6 m^3. The shale on the right and left bank of the alternative dam axes is weathered to some extent and slaking is probable.

(2) Borrow-pit for cohesive soil

Of the four alternative borrow-pits, B1, B2, B3 and B4, the B2 is proposed for the Rui 3 site and the B3 is proposed for the Rui 2 site. The B2 is on the left (B2-1) and right (B2-2) banks within 0.5 km upstream from the existing tailing dam. The B2-1 is the reddish or grey residual soil weathered from slaty shale and is classified into ML or CL. The B2-2 is the reddish and residual soil weathered from shale and is classified into ML or CL. Both soils are lateritic. The B3 is on the left (B3-1) and right (B3-2) bank of the Rui river, within 0.5 km upstream from the Rui 2 site. Both the B3-1 and B3-2 are considered being reddish and residual soil though no test pitting was done due to very thick vegetation. The soil may be ML or CL and lateritic and is subject to further investigation. The reserved quantity of B2-1, B2-2, B3-1 and B3-2 is estimated some 1×10^6 m^3 respectivety assuming the depth of 3 m. The B4, which is on the left bank of the Rui river, 0.5 km downstream from the Rui 1 dam site is proposed for the Rui 1 site, but the Rui 1 site is judged to be abandoned.

(3) Borrow-pit for sand and gravel

The S1 borrow-pit, which is in the tailing area for the tin mine in operation, 2 - 3 km northwest (upstream) by road from the existing tailing dam, is proposed. The tailing sand from the tin mining is well graded sands containing little fines (SW). The organic content, however is rather high (4%) and is subject to further investigation.

The S2 borrow-pit is a thin layer of shale gravel submerged in the channel of the Rui river, within 1 km upstream and downstream from the Rui 2 dam site. The reserved quantity is estimated some 5×10^3 m^3 but is not reliable.

3. LABORATORY TESTS

3.1 Laboratory Test Schedule and Specifications

The principal objective of the laboratory soil mechanical tests is to evaluate the engineering properties of the prospective fill dam materials in and around the proposed 6 dam sites in the stage of pre-feasibility study.

The testing schedule was planned so as to figure out the physical, chemical and mechanical properties roughly within the given time and budget constraint. The soil test items and their sample numbers in Table 11 except the supplementary tests were executed at the DID laboratory. For all the cohesive soils sampled from the test pits, the gradation analysis (particle size distribution), specific gravity, insitu moisture content, Atterberg limits, and pH tests were done as the series of physical and chemical property tests. As for mechanical property test, the Proctor compaction test for moisture-density relation using a rammer was done for all the cohesive soil samples. The particle size distribution after the compaction test was also measured. The permeability test with variable head, the unconfined compression test, the tri-axial compression test (CU) with sample diameter of 38 mm, the consolidation test with sample diameter of 75 mm were done for the selected 10 samples only.

For sand material only the particle size distribution, the specific gravity and the organic content were measured. A gravel sample was taken at the Tawar-Muda site only, and the gradation test and the specific gravity test were done.

The sieve analysis was done under the condition of water washing. A same naturally dried sample was used repeatedly in the process of getting the optimum moisture content (OMC) for the purpose of time saving because the cohesive soils were considered being non-volcanic. The samples for the permeability, unconfined compression, tri-axial compression and consolidation tests were compacted under the OMC in order to figure out the mechanical properties required for the embankment compacted with the OMC condition. The tri-axial compression tests were executed under consolidated and undrained (CU) condition after the samples were satulated, and the pore water pressure was also measured so as to obtain the effective-stress parameters.

The particle size distribution, specific gravity, the liquid limit and the plastic limit of some samples from the Tawar-Muda, Beris and Rui sites were checked by the supplemental test. The swelling behavior of the samples from the Beris and Rui sites was measured by the supplemental test since very high clay content had been measured by the DID's gradation analysis. Both the supplemental tests were executed at the Nippon Koei research laboratory. These test items and their sample numbers are shown in Table 11.

The DID laboratory executed all the tests by the use of the testing methods specified by the British Standard, BS 1377 - 1975.

The Nippon Koei laboratory executed with the Japanese Industrial Standard, JIS A1202-A1206 and A1217.

3.2 Test Results

All the laboratory test results are summarized in Tables 12 - 17 and these results are compiled as set out below in order to analize the soil mechanical characteristics.

(1) Particle size distribution of cohesive soils before and after Proctor compaction by project site: Figs. 3 & 4.
Particle size distribution of sand and gravel: Fig. 4.

(2) Plasticity chart for Unified Soil Classification of fine grained soils by project site: Fig. 5.

(3) Moisture-dry density relation by Procter compaction for cohesive soils: Fig. 6.

(4) Shear stress-principal stress relationship and stress-strain relationship by tri-axial compression $\overline{CU}$ test: Figs. 7 - 11.

(5) Void ratio-consolidation pressure relationship of cohesive soils: Figs. 12 & 13, and Tables 18 - 21.

(6) Pressure-void ratio relationship in swelling process: Fig. 14.

(7) Dry density-shear stress-permeability relationship: Fig. 15

The test results are presented by using the international system of units (SI). The units used and the conversion factors from SI to the system of metric gravity units are listed in Table 24.

4. EMBANKMENT MATERIALS

4.1 Residual Soils Around the Project Sites

No predominant deposit of sedimentary soils were found around the proposed dam sites except some minor deposits on the both banks along the river channels. That is, the cohesive soils are mostly residual soils which are the product of rock weathering accumulated in place.

The profile of the residual soils and their parent rocks in the project area forms the typical three zones:

(a) the upper zone (residual soil) where there is a high degree of weathering and removal of material by wind or water flow; from the ground surface to the depth of 0.5 - 5 m,

(b) the intermediate zone (intensively weathered rock) where there is intensive weathering at the top part of the zone, but also some deposition toward the bottom part of the zone; from the bottom of the upper zone to the depth of 3 - 10 m, and

(c) the partially weathered zone where there is the transition from the partially weathered material to the unweathered parent rock; from the bottom of the intermediate zone to the depth of 8 - 20 m.

The upper and intermediate zones were investigated as the prospective sources for fill materials. The parent rocks of the residual soils are considered being shale, sandstone and alternation of shale and sandstone which are the predominant rock formations in the project area. The main component of the residual soils seems to be reddish soil, namely lateritic clay. The particle size distribution differs significantly site by site even in the same area. The particle size distribution depends on the degree of weathering and the matrix of the parent rock. The factors influencing the rate of weathering and nature of the products of weathering are climate (temperature and rainfall), time, type of source rock, vegetation, drainage and bacterial activity. It is impossible to clarify the main factors which cause the variation of particle size distribution, but it can be inferred that the sand content may be high in the area having predominant sandstone formation while the silt and clay content may be high in the area having the predominant shale formation.

4.2 Evaluation of Soil Mechanical Properties of Residual Soils

4.2.1 Physical and chemical properties

(1) Particle size distribution

The particle size distribution is compiled by dam site and is shown in Figs. 3 & 4. The content of silt and clay is very high (30 - 80%) and the particle size distribution varies significantly depending on the soil layer even at the same test pit.

(2) Consistency and Unified Soil Classification

The plasticity charts for the Unified Soil Classification (defined in Table 22) of the fine grained soils in the project area are shown in Fig. 5. The range of the liquid limit (Wl), plasticity index (Ip) and the group symbols are set out below.

Soils	Wl (%)	Ip (%)	Unified Soil Classification
Badak-Temin	30 - 85	15 - 55	CH, CL or CH-MH
Sari	35 - 75	15 - 35	CL or CH-MH
Durian	45 - 60	15 - 35	CH-MH, CL or ML
Tawar-Muda	45 - 80	20 - 35	MH, CH or CL-ML
Beris	50 - 100	20 - 75	CH or MH
Rui	35 - 90	15 - 55	ML, CL, CH or MH
Average	40 - 80	17 - 48	

(3) Specific gravity

The specific gravity is considered in the range of 2.6 - 2.8 though the smaller values of less than 2.5 were obtained in the test.

If the smaller values are adopted, the dry densities with the saturation degree of 100% do not meet the prospective zero-void curve (see Fig. 6). For example the specific gravity of BR-B2-2 should be 2.73 instead of 2.19. The zero-void point is obtained at the moisture content of 33% with the specific gravity of 2.73 but the dry density is 1.27 Mg/m^3 instead of 1.43 for the same moisture content if the specific gravity of 2.19 is used.

(4) Field moisture content

The field moisture content is 12 - 40%, mostly less than 30% and is less than or equal to the optimum moisture content (OMC). The OMC is 11 - 36%. The sampling was done in the dry season and thus the field moisture content in the wet season is subject to the further study.

(5) Organic content and pH value

No organic substance was found by eye observation, but the organic content of 1 - 4% was measured in the laboratory test. The value of smaller than 1% is considered being inorganic. The values of larger than 1% and smaller than 4% were measured from the 11 samples, SR-B1 - B4, SR-S2, DR-B1 & B3, TM-S1 & S2, BR-B1 & B2, R1-S1. These values seem to be too high and are subject to further study.

The pH value is 3 - 5 and all the soils are considered being acid soils.

(6) Dry density and OMC

The maximum dry density and the optimum moisture content were obtained by the standard Proctor compaction test with the standard compaction energy. These values are set out below.

Soils	Maximum Dry Density (Mg/m^3)	OMC (%)
Badak-Temin	1.5 - 1.8	14 - 28
Sari	1.5 - 1.9	13 - 29
Durian	1.6 - 1.9	11 - 21
Tawar-Muda	1.5 - 1.7	18 - 24
Beris	1.4 - 1.8	14 - 30
Rui	1.3 - 1.7	18 - 36

4.2.2 Assessment of mechanical properties required for rolled earth dams

It has been reported about the residual soils (lateritic clay) in the project area where the trafficability is very bad in the rainy season while it is easy to handle in the dry season. The degree of lateritization is deemed to be not high, the specific behaviours of the local residual soil, which supported the verbal evidence, were observed in the laboratory tests. In this section, the workability, shear strength, permeability and compressibility are evaluated in order to assess whether these residual soils are adequate to the requirement of rolled earth dams or not. The results are summarized in Table 23.

(1) Workability

The workability will be poor at any site. According to the Unified Soil Classification that of the soils in the Sari, Durian, Tawar-Muda and Rui sites might be fair but the possibility of being poor is high.

(2) Shear strength

In the effective stress condition the cohesion (C') is 25 - 110 kPa and the angle of internal friction (ø') is 18 - 34°. The cohesion of larger than 100 kPa seems too high. The internal friction angle of less than 30° is classified poor and that of larger than and equal to 30° is classified fair.

The pore water pressure is relatively too low except BR-B2-2. It can be guessed that the samples were not completely saturated or the specified compaction energy was not enough.

The tri-axial compression test was done in three multi-stages (see Figs. 7 - 11). This method has the advantage of time saving but has the disadvantage of resulting on less shear strength. The single stage tri-axial test is recommended in the detailed study.

(3) Permeability

The permeability coefficient in the range of $1 \times 10^{-3} - 10^{-4}$ cm/s is classified semi-pervious and that of less than 1×10^{-4} cm/s is classified impervious. All the residual soils in the project area must be impervious according to the content of silt and clay though the rest results show semi-pervious. The values of higher than 10^{-4} cm/s may be unreliable. The causes are considered being:

(a) the optimum moisture content of the sample was much drier than saturation, and thus shell was still hard and was not collapsed well by compaction; and

(b) the Proctor compaction was done with the standard compaction energy (say E), but this energy was not large enough for these weathered rock materials.

The coefficient of permeability, therefore would be made smaller to the level of less than 1×10^{-5} cm/s, if the compaction energy of around 3E level were applied and the moisture control were done well.

(4) Compressibility

The consolidation coefficient and coefficient of compressibility are shown in Tables 18 - 20. The void ratio and compressibility are estimated by using the consolidation test results shown in Figs. 12 & 13 and are listed in Table 21. The compressibility is high, 2 - 4% under 200 kPa and 3 - 5% under 400 kPa. The values of TM-B3-2 (18.9%), BR-B2-2 (28.2%) and R1-B3-1 (19.8%) are abnormally high. The test results infer that the standard compaction energy was not enough to collapse the shell particle and saturation collapse occurred in the consolidation saturation process. The slaking and swelling were observed. The swelling pressure of less than 30 kPa was observed as shown in Fig. 14. This value is considered being rather low, but high swelling pressure can be induced if higher compaction energy is applied. In general the denser soils are compacted, the higher swelling pressure is developed (Ref. 1). The rate of swell is generally higher on the wet side of OMC, too. The high compressibility and swelling would result in cracking and displacement of earth structures.

(5) Dry density-shear strength-permeability relationship

The dry density-shear strength-permeability relationship shown in Fig. 15 suggests that inconsistent relation is observed and these test results involve errors to some extent.

4.2.3 Conclusion and recommendation

The test results describe that all the residual soils in the proposed dam are poor as the material for rolled embankment dams. Especially the workability, compressibility and swelling are considered being very poor, and thus some difficulties would be involved in the homogeneous earthfill dam. These materials, however, can be used for the impervious core material of the central core fill dam because the requirement for workability and structural stability is eased for this type.

In this stage it is hasty to conclude definitely because the number of sample was not enough and the testing method and condition were not necessarily best.

This kind of material is being considered poor and the practice of rolled embankment dams is little in the USBR. It, however, does not mean useless. Practices of more serious materials are frequently conducted with contrivable countermeasure in these decade. Significant soil behaviour is observed and thus the prudent study on the items setout below is highly recommended.

(a) Analyses of clay mineral content and soluble salt content.

(b) Workability (sensitivity by the unconfined compression test).

(c) Proctor compaction test with higher compaction energy in the range of 2E - 4E. The diameter of a mold be 15 cm or larger.

(d) Tri-axial compression test (CU) with single stage loading for the samples compacted with higher energy.

(e) Permeability, consolidation and swelling tests for the samples compacted with higher energy.

(f) Effect of compaction moisture content (±OMC) on the foregoing mechanical characteristics.

5. CONCRETE AGGREGATES

Major deposits of sand and gravel were not found around the proposed dam sites except Sari site. Most part of concrete aggregates and filter material, therefore will have to be produced from quarried rocks by a crushing plant system as set out below:

	Sand		Gravel	
Site	Reliability of Deposit	Requirement of Production by Plant	Reliability of Deposit	Requirement of Production by Plant
Badak-Temin	S1: a little	mostly	none	100%
Sari	S1: a little S2: high	minor portion	S1: a little S2: high	minor portion need of study
Durian	S1: less	100%	none	100%
Tawar-Muda	S1: some S2: some	major portion need of study	S1: some S2: some	major portion need of study
Beris	none	100%	none	100%
Rui	S1: high need of study	minor portion	S2: less	100%

The quality and quantity of sand and gravel are subject to further investigation.

REFERENCES

1. EARTH MANUAL, 1974, A Water Resources Technical Publication, Second Edition, USBR

TABLES

Table 1 CONDITIONS OF BADAK-TEMIN, SARI AND DURIAN DAM SITES

Site Conditions	Badak-Temin	Sari	Durian
River System	Kedah river	Kedah river	Kedah river
Latitude and Longitude	6°26'50" N 100°28'28" E	6°22'20" N 100°38'10" E	6°23'00" N 100°42'45" E
Catchment Area	112 km^2	61 km^2	74 km^2
Site Topography	Flat and wide valley (1.2 km) between low ridges	V-shaped valley (0.3 km)	Flat valley (0.8 km) between gentle ridges
Foundation Geology	Sandstone (thick) on right bank and shale on left bank, Devonian-Triassic, Fractures on left bank	Sandstone with shales, hard, Triassic/ Jurassic	Sandstone and shale, moderately hard, Triassic/ Jurassic, Fractures in the riverbed
Alternative Dam Type	Fill types only	Fill types or concrete gravity	Fill types only

Table 2 CONDITIONS OF TAWAR-MUDA AND BERIS DAM SITES

Site Conditions	Tawar-Muda 1 (Upstream)	Tawar-Muda 2 (Downstream)	Beris 1 (Upstream)	Beris 2 (Downstream)
River System	Muda river	Muda river	Muda river	Muda river
Latitude and Longitude	6°03'30" N 100°47'00" E	6°03'30" N 100°47'00" E	5°58'45" N 100°44'44" E	5°58'45" N 100°44'44" E
Catchment Area	129 km^2	130 km^2	114 km^2	116 km^2
Site Topography	Gentle V-shaped valley (0.9 km)	Gentle V-shaped valley (0.8 km)	Gentle V-shaped valley (0.6 km)	V-shaped valley (0.3 km)
Foundation Geology	Sandstone and shale, Triassic	Shale with sandstone, moderately hard, Triassic, some fractures on the left bank	Sandstone and shale, Triassic, fractured zone runs	Grit, breccia, and sandstone, hard, Triassic, fractured zone through the saddle dam site
Alternative Dam Type	Fill types only	Fill types only	Fill types only	Fill types or concrete gravity

Table 3 CONDITIONS OF RUI DAM SITE

Site Conditions	Rui 1 (Upstream)	Rui 2 (Middle)	Rui 3 (Downstream)
River System	Perak river	Perak river	Perak river
Latitude and Longitude	5°34'00" N 101°00'50" E	5°34'50" N 101°01'50" E	5°34'50" N 101°02'50" E
Catchment Area	259 km^2	278 km^2	305 km^2
Site Topography	V-shaped valley (0.5 km) having thin left abutment	Gentle V-shaped valley (0.7 km)	Gentle V-shaped valley (0.8 km)
Foundation Geology	Slaty shale and limestone, hard, Silurian, deep fractures	Slaty shale and limestone, hard, Silurian, deeply weathered	Slaty shale, hard, Silurian, deeply weathered
Alternative Dam Type	Fill types only	Fill types only	Fill types only

Table 4 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND BADAK-TEMIN SITE

Dam Site	Location	Quality	Quantity
1. Rock Quarry:			
Q1	Bt. Telipong, 12 km west from the dam site by road distance	Siliceous sandstone, covered with thin top soil, yield rate of about 70 - 80%	Abundant, more than 20 x 10^6 m^3
Q2	Bt. Bendang Bongsu, 2 km west from the dam site by road distance	Siliceous sandstone, covered with thick top soil, yield rate of about 50%	Abundant, more than 10 x 10^6 m^3
2. Borrow-Pit for Cohesive Soil:			
B1	Around Bt. Tunggal, 1 km south from the dam site by road distance	Reddish residual soil, lateratic clay, Unified Soil Classification of CH - CL	Some 2 x 10^6 m^3
B2 & B3	B2 is 0.5 - 2 km east from the dam site in the reservoir area. B3 is 2 - 3 km north from the dam site in the reservoir area.	Reddish residual soil, lateratic clay, Unified Soil Classification of CH - MH	More than 2 x 10^6 m^3 in B2 and more than 5 x 10^6 m^3 in B3
3. Borrow-Pit for Sand and Gravel:			
S1	Sand; Thin layer in and around river channel of the Badak and Temin rivers 1 - 3 km upstream from the dam site. Gravel; No deposit was found.	Poorly graded sands, Unified Soil Classification of SP	Minor deposit of some 20 x 10^3 m^3, mostly submerged

Table 5 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND SARI SITE

Dam Site	Location	Quality	Quantity
1. Rock Quarry:			
Q1	Within 1 km on the right bank of the dam site	Hard sandstone, yield rate of about 70%	More than 2×10^6 m^3
2. Borrow-Pit for Cohesive Soil:			
B1	Rolling right bank of the Sari river, 0.7 - 1.3 km northwest from the dam site	Brownish sedimentary soil (CL) with thin (0.5 m) sand layers (SP-SW)	Some 2×10^6 m^3
B2	Rolling left bank of the Sari river, 1.3 - 2.0 km northwest from the dam site	Mixture of reddish and brown residual soils, CL or CH - OH	Some 2×10^6 m^3
3. Borrow-Pit for Sand and Gravel:			
S1	Thin layer in and around river channel of the Sari river 1 - 2 km northwest from the dam site	Mixture of sand (SP-SW) and gravel	Minor deposit of some 20×10^3 m^3 mostly submerged
S2	Tin mining near Kelian Pintu Wang, 6 km northwest by road from the dam site	Mixture of sand (SW-SP), gravel, cobbole and boulder; gravel contains soft weathered rock	Major deposit of some 0.1 - 0.2 $\times 10^6$ m^3

Table 6 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND DURIAN SITE

Dam Site	Location	Quality	Quantity
1. Rock Quarry:			
Q1	The southern ridge of Bt. Boh Lembu, 3.3 km north (upstream) by road from the dam site	Siliceous sandstone, yield rate of 70%	Abundant, more than 5 x 10^6 m^3
2. Borrow-Pit for Cohesive Soil:			
B1	The right and left bank of the Durian river, 1 ~ 1.5 km south (downstream) by road from the dam site	Mixture of reddish and gray residual soils, CH ~ MH, CL, SC	Some 2 x 10^6 m^3
B2	The right bank of the Durian river, 2.5 km north by road from the dam site	Mixture of reddish and brownish residual soils, CL ~ SC	Some 0.5 x 10^6 m^3
3. Borrow-Pit for Sand and Gravel:			
S1	Sand; Thin layer (1 m) in and around river channel of the Durian river 1 ~ 2 km upstream from the dam site. Gravel; No deposit was found.	Fine sand	Very thin deposit of some 10 x 10^3 m^3, mostly submerged

Table 7 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND TAWAR-MUDA SITE

Dam Site	Location	Quality	Quantity
1. Rock Quarry:			
Q1	The hill near Kg. Tanjong Piring on the left bank of the Muda river, 1 km south (downstream) from the dam site	Moderately hard sandstone, yield rate of 70%	More than 2×10^6 m^3
2. Borrow-Pit for Cohesive Soil:			
B1	The hill on the right bank of the Muda river in the reservoir area, 1 km north-west from the No. 1 dam site	Yellowish-reddish residual soil, lateratic clay, MH, CH	Some 1.5×10^6 m^3
B2	The hill on the right bank of the Tawar river in the reservoir area, 0.5 - 1.0 km northwest from the secondary dam site	Reddish residual soil, lateratic clay, MH	Some 1×10^6 m^3
3. Borrow-Pit for Sand and Gravel:			
S1	Thin layer (2 - 3 m) on the left bank of the Muda river near Kg. Tanjung Piring, 0.5 - 1.0 km downstream from the No. 1 dam site	Mixture of sand (SP) and gravel (GP), submerged below 2 m depth	Some 0.1 - 0.3 $\times 10^6$ m^3
S2	Thin layer (2 - 3 m) on the left and right bank along the Muda river, within 2 km up-stream (north) from the No. 1 dam site	Mixture of sand (SP) and gravel (GP), submerged below 2 m depth	Some 0.1 - 0.3 $\times 10^6$ m^3

Table 8 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND BERIS SITE

Dam Site	Location	Quality	Quantity
1. Rock Quarry:			
Q1	Within 1 km on the left bank (south) of the No. 2 dam site, north ridge of Bt. Damar	Grit, conglomerate and sandstone, yield rate of 80%	Abundant, more than 2 x 10^6 m^3
Q2	Within 0.5 km on the right bank (northeast) of the No. 2 dam site	Grit, conglomerate and sandstone, yield rate of 70%	Some 0.5 x 10^6 m^3
2. Borrow-Pit for Cohesive Soil:			
B1	The right bank of the Beris river, 0.7 - 1.5 km west (downstream) from the No. 2 dam site	Yellowish - reddish residual soil with white clay or coarse sand, CH, MH	Some 0.5 x 10^6 m^3
3. Borrow-Pit for Sand and Gravel:			
	No deposit of sand and gravel was found.	—	—

Table 9 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND RUI SITE (1/2)

Dam Site	Location	Quality	Quantity
1. Rock Quarry:			
Q1	Outcrop on the right bank of the Rui river, 1 km west from the No. 1 dam site (3.2 km southwest from the No. 2 dam site)	Limestone, yield rate of 70%	Some 2×10^6 m^3
2. Borrow-pit for Cohesive Soil:			
B1	The right bank of the tributary, 2.2 km northwest (upstream) by road from the existing tailing dam	Reddish residual soil, lateratic clay, MH	Some 1×10^6 m^3
B2 (B2-1 & B2-2)	The left (B2-1) and right (B2-2) banks within 0.5 km upstream from the existing tailing dam	Reddish residual soil weathered from shale (B2-2), reddish-grey soil weathered from slaty shale (B2-1) ML, CL	Some 1×10^6 m^3 for each site
B3 (B3-1 & B3-2)	The left (B3-1) and right (B3-2) bank of the Rui river, within 0.5 km upstream from the No. 2 dam site	Reddish residual soil, ML, CL	Some 1×10^6 m^3 for each site
B4	The left bank of the Rui river, 0.5 km downstream from the No. 1 dam site	Brownish - reddish residual soil, MH, CH	Some 0.5×10^6 m^3

Table 10 CONDITIONS OF CONSTRUCTION MATERIAL RESERVES AROUND RUI SITE (2/2)

Dam Site	Location	Quality	Quantity
3. Borrow-Pit for Sand and Gravel:			
S1	2 - 3 km north-west (upstream) by road from the existing tailing dam in the tailing area for tine mine	Tailing sand from tine mine, SW	Some 1 x 10^6 m^3
S2	Thin layer of gravel in the channel of the Rui river within 1 km upstream and downstream from the No. 2 dam site	Shale	Minor deposit of some 5 x 10^3 m^3, all submerged

Table 11 LABORATORY SOIL TEST ITEMS FOR SOIL, SAND AND GRAVEL MATERIALS

Test Item	Number of Samples
COHESIVE SOIL	
A. Physical and Chemical Property Tests	Total 27 for tests a1 - a6;
a1) Gradation Analysis	Badak-Temin (4), Sari (4), Durian (5), Tawar-Muda (4), Beris (6) & Rui (4)
a2) Specific Gravity	
a3) Insitu Moisture Content	
a4) Atterberg Limits	
a5) pH	
a6) Organic Content	
B. Mechanical Property Test	Total 27 for tests b1 - b2;
b1) Proctor Compaction Test for Moisture Density Relation Using Rammer	Badak-Temin (4), Sari (4), Durian (5), Tawar-Muda (4), Beris (6) & Rui (4)
b2) Gradation Analysis after b1 Test	
b3) Permeability with Variable Head	Total 10 for tests b3 - b6;
b4) Unconfined Compression	Badak-Temin (1), Sari (2), Durian (1), Tawar-Muda (2), Beris (2) & Rui (2)
b5) Tri-axial Compression ($\overline{CU}$), 3 Multi-stage	
b6) Consolidation (ø75 mm)	
C. Supplemental Test	Total 5 for tests c1 & c2;
c1) Gradation Analysis	Tawar-Muda (1), Beris (2) & Rui (2)
c2) Liquid and Plastic Limits	
c3) Specific Gravity	Total 3 for tests c3 & c4;
c4) Swelling	Beris (1) & Rui (2)
SAND	Total 6 for tests s1 - s3;
s1) Gradation Analysis	Badak-Temin (1), Sari (2), Tawar-Muda (2) & Rui (1)
s2) Specific Gravity	
s3) Organic Content	
GRAVEL	Only 1 for tests g1 & g2;
g1) Gradation Analysis	Tawar-Muda (1)
g2) Specific Gravity	

Table 12 SUMMARY OF SOIL MECHANICAL TESTS FOR THE BADAK-TEMIN SITE

	Sample No.				
	BT-B1-1	BT-B1-2	BT-B2-1	BT-B3-1	BT-S1-1
Sample Depth (m)	2	0.7	2	3	Outcrop
Particle Size Distribution					
Maximum Size (mm)	14	14	14	14	10
Gravel (2 - 50 mm) (%)	19	3	17	7	3
Sand (0.06 - 2 mm) (%)	25	46	9	5	95
Silt (0.002 - 0.06 mm) (%)	24	33	27	31	2
Clay (<0.002 mm) (%)	32	18	47	57	0
Consistency					
Linear Shrinkage (%)	25.0	15.2	23.2	23.7	-
Liquid Limit (WL %)	71.2	31.2	85.0	84.6	-
Plasticity Index (Ip %)	48.2	12.8	44.1	50.3	-
Unified Soil Classification	CH	CL	MH	CH	SP
Specific Gravity	2.65	2.54	2.43	2.51	2.63
Field Moisture Content (%)	20.2	16.2	17.1	18.7	-
Organic Content (%)	0.81	0.26	0.10	0.13	0.0
pH Value	3.40	3.31	3.44	3.40	-
Proctor Compaction Test					
Max. Dry Density (γd Mg/m^3)	1.64	1.79	1.50	1.64	-
OMC (%)	21.7	14.2	27.8	23.0	-
Unconfined Compression					
Strength (UU), Cu (kPa)	48.8	-	-	-	-
Tri-axial Compression (CU)					
Cohesion C' (kPa)	41	-	-	-	-
Internal Friction Angle ø' (degree)	26	-	-	-	-
Cohesion C (kPa)	43	-	-	-	-
Internal Friction Angle ø (degree)	25	-	-	-	-
Permeability (10^{-8}cm/s)	2.33	-	-	-	-
Consolidation					
Compression Index, Cc	See Table 18	-	-	-	-

Table 13 SUMMARY OF SOIL MECHANICAL TESTS FOR THE SARI SITE

	Sample No.							
	SR-B1-1	SR-B1-2	SR-B2-1	SR-B2-2	SR-B3-1	SR-B4-1	SR-S1-1	SR-S2-1
Sample Depth (m)	2	1	1.5	1.5 - 2	Outcrop	Outcrop	Outcrop	Outcrop
Particle Size Distribution								
Maximum Size (mm)	14	10	14	14	14	10	No Record	14
Gravel (2 - 50 mm) (%)	27	4	10	24	42	10		42
Sand (0.06 - 2 mm) (%)	67	40	4	3	57	5		30
Silt (0.002 - 0.06 mm) (%)	6	23	45	52	1	61		28
Clay (<0.002 mm) (%)	0	33	41	21	0	24		0
Consistency								
Linear Shrinkage (%)	-	13.2	15.8	19.1	-	26.8	-	-
Liquid Limit (WL %)	-	33.6	65.8	50.0	-	73.6	-	-
Plasticity Index (Ip %)	-	12.1	33.8	24.4	-	34.9	-	-
Unified Soil Classification	SW-SP	CL	CL or CH - OH	CL or CH - OH	Sand	MH - OH	Sand	SW-SP
Specific Gravity	2.60	2.63	2.40	25.8	-	2.63	-	2.66
Field Moisture Content (%)	17.5	15.0	23.2	SR-B2-1	-	-	-	-
Organic Content (%)	0.92	0.85	4.15	4.60	-	1.83	-	1.03
pH Value	4.36	3.59	3.34	3.50	-	3.34	-	-
Proctor Compaction Test								
Max. Dry Density (γd Mg/m^3)	1.92	1.79	1.56	1.70	-	1.45	-	-
OMC (%)	13.0	15.0	25.0	16.8	-	29.4	-	-
Unconfined Compression								
Strength (UU), Cu (kPa)	-	64.8	-	-	-	-	-	-
Tri-axial Compression (CU)								
Cohesion C' (kPa)	-	40	-	-	-	-	-	-
Internal Friction Angle ϕ' (degree)	-	19	-	-	-	-	-	-
Cohesion C (kPa)	-	30	-	-	-	-	-	-
Internal Friction Angle ϕ (degree)	-	20	-	-	-	-	-	-
Permeability (10^{-8}cm/s)	-	0.292	-	-	-	-	-	-
Consolidation								
Compression Index, Cc	-	See Table 18	-	-	-	-	-	-

Table 14 SUMMARY OF SOIL MECHANICAL TESTS FOR THE DURIAN SITE

	Sample No.				
	DR-B1-1	DR-B1-2	DR-B2-1	DR-B2-2	DR-B3-1
Sample Depth (m)	2	0.8	1	0.5 - 0.7	1.4
Particle Size Distribution					
Maximum Size (mm)	10	10	14	10	14
Gravel (2 - 50 mm) (%)	19	7	18	5	40
Sand (0.06 - 2 mm) (%)	52	23	48	43	27
Silt (0.002 - 0.06 mm) (%)	11	35	21	27	18
Clay (< 0.002 mm) (%)	18	35	13	25	15
Consistency					
Linear Shrinkage (%)	19.4	15.6	17.8	17.5	18.6
Liquid Limit (WL %)	60.6	55.6	43.9	46.0	48.3
Plasticity Index (Ip %)	32.3	26.6	19.8	14.6	21.7
Unified Soil Classification	CH or SC	CH - MH	CL or SC	ML	CL or SC
Specific Gravity	2.66	2.63	2.64	2.70	2.79
Field Moisture Content (%)	18.1	21.5	9.8	13.8	15.0
Organic Content (%)	0.39	2.36	0.20	0.29	1.00
pH Value	4.30	4.59	4.86	4.72	3.69
Proctor Compaction Test					
Max. Dry Density (γd Mg/m^3)	1.84	1.64	1.84	1.70	1.88
OMC (%)	13.9	21.2	11.4	20.0	16.0
Unconfined Compression					
Strength (UU), Cu (kPa)	30.1	-	126.0	-	-
Tri-axial Compression (CU)					
Cohesion C' (kPa)	25	-	51	-	-
Internal Friction Angle ϕ' (degree)	32.5	-	30.5	-	-
Cohesion C (kPa)	30	-	56	-	-
Internal Friction Angle ϕ (degree)	28.5	-	30.5	-	-
Permeability (10^{-8}cm/s)	543,000	-	246,000	-	-
Consolidation					
Compression Index, Cc	See Table 18	-	See Table 18	-	-

Table 15 SUMMARY OF SOIL MECHANICAL TESTS FOR THE TAWAR-MUDA SITE

	Sample No.							
	TM-B1-1	TM-B2-1	TM-B3-1	TM-B3-2	TM-B3-2*	TM-S1-1	TM-S2-1	TM-S2-1
Sample Depth (m)	Outcrop	2	1.2	2.9	2.9	Outcrop	2.3	1 - 2
Particle Size Distribution								
Maximum Size (mm)	20	20	28	28	10	10	14	14
Gravel (2 - 50 mm) (%)	24	39	28	26	22	3	14	15
Sand (0.06 - 2 mm) (%)	8	27	13	4	9	94	19	83
Silt (0.002 - 0.06 mm) (%)	40	34	26	44	49	3	67	2
Clay (<0.002 mm) (%)	28	-	33	26	20	0	0	0
Consistency								
Linear Shrinkage (%)	18.1	-	30.2	23.2	-	-	-	-
Liquid Limit (WL %)	44.8	-	80.5	55.2	56.0	-	-	-
Plasticity Index (Ip %)	17.9	-	35.6	22.5	31.0	-	-	-
Unified Soil Classification	CL - ML	MH or SC	MH	MH	CH	SP	GP	SP
Specific Gravity	2.55	2.42	2.22	2.51	2.86	2.63	2.57	2.63
Field Moisture Content (%)	13.3	15.2	26.0	22.5	-	-	-	-
Organic Content (%)	0.17	-	0.30	0.09	-	3.25	-	3.72
pH Value	3.84	-	4.71	4.53	-	-	-	-
Proctor Compaction Test								
Max. Dry Density (γd Mg/m^3)	1.65	-	1.50	1.62	-	-	-	-
OMC (%)	18.0	-	24.0	23.0	-	-	-	-
Unconfined Compression								
Strength (UU), Cu (kPa)	67.8	-	-	151.1	-	-	-	-
Tri-axial Compression (CU)								
Cohesion C' (kPa)	30	-	-	110	-	-	-	-
Internal Friction Angle ϕ' (degree)	29	-	-	18	-	-	-	-
Cohesion C (kPa)	35	-	-	90	-	-	-	-
Internal Friction Angle ϕ (degree)	29	-	-	19	-	-	-	-
Permeability (10^{-8}cm/s)	22,350	-	-	32,400	-	-	-	-
Consolidation								
Compression Index, Cc	See Table 19	-	-	See Table 19	-	-	-	-

Remarks: *; Supplementary test

Table 16 SUMMARY OF SOIL MECHANICAL TESTS FOR THE BERIS SITE

	Sample No.							
	BR-B1-1	BR-B1-2	BR-B1-2*	BR-B2-1	BR-B2-2	BR-B2-2*	BR-B3-1	BR-B3-2
Sample Depth (m)	1.5	2.8 - 3	2.9	2.8 - 3	3	3	1.2	2.8 - 3
Particle Size Distribution								
Maximum Size (mm)	5	10	19	10	10	9.5	10	14
Gravel (2 - 50 mm) (%)	4	21	26	14	8	7	15	38
Sand (0.06 - 2 mm) (%)	45	46	34	45	22	16	34	10
Silt (0.002 - 0.06 mm) (%)	23	12	26	10	20	37	22	21
Clay (< 0.002 mm) (%)	28	21	14	31	50	40	29	31
Consistency								
Linear Shrinkage (%)	15.6	20.4	-	25.8	22.6	-	16.0	20.2
Liquid Limit (WL %)	52.5	61.6	66.5	87.2	98.2	103	54.6	57.2
Plasticity Index (Ip %)	27.5	30.9	40.6	42.9	69.4	72.5	27.7	22.8
Unified Soil Classification	CH	CH	CH	MH	CH	CH	CH	MH
Specific Gravity	2.46	2.65	2.65	2.22	2.19	2.73	2.35	2.51
Field Moisture Content (%)	12.5	12.3	-	18.4	29.4	-	13.5	19.7
Organic Content (%)	1.41	0.15	-	1.06	0.27	-	0.99	0.73
pH Value	3.73	4.52	-	4.67	4.85	-	3.45	3.59
Proctor Compaction Test								
Max. Dry Density (γ_d Mg/m^3)	1.76	1.82	-	1.67	1.43	-	1.69	1.61
OMC (%)	14.7	13.8	-	23.8	29.5	-	18.4	23.2
Unconfined Compression								
Strength (UU), Cu (kPa)	-	44.2	-	-	59.9	-	-	-
Tri-axial Compression (CU)								
Cohesion C' (kPa)	-	109	-	-	35	-	-	-
Internal Friction Angle ø' (degree)	-	34	-	-	26	-	-	-
Cohesion C (kPa)	-	110	-	-	30	-	-	-
Internal Friction Angle ø (degree)	-	34	-	-	28	-	-	-
Permeability (10^{-8}cm/s)	-	34,400	-	-	58.15	-	-	-
Consolidation								
Compression Index, Cc	-	See Table 19	-	-	See Table 19	-	-	-
Swelling Pressure (kPa)	-	-	-	-	-	22.5	-	-

Remarks: *; Supplementary test

Table 17 SUMMARY OF SOIL MECHANICAL TESTS FOR THE RUI SITE

	Sample No.						
	RI-S1-1	RI-B1-1	RI-B1-1*	RI-B2-1	RI-B3-1	RI-B3-1*	RI-B4-1
Sample Depth (m)	Tailing Area	2 - 3	2 - 3	Outcrop	2 - 3	2 - 3	2 - 3
Particle Size Distribution							
Maximum Size (mm)	5	14	5	10	5	5	5
Gravel (2 - 50 mm) (%)	14	5	1	11	2	2	4
Sand (0.06 - 2 mm) (%)	80	5	3	18	10	7	15
Silt (0.002 - 0.06 mm) (%)	6	47	56	71	50	73	37
Clay (< 0.002 mm) (%)	0	43	40	-	38	18	44
Consistency							
Linear Shrinkage (%)	-	28.9	-	-	18.6	-	33.4
Liquid Limit (WL %)	-	78.0	85.0	-	38.9	38.0	91.4
Plasticity Index (Ip %)	-	29.7	53.1	-	13.3	16.6	37.0
Unified Soil Classification	SW	MH	CH	-	ML - CL	CL	MH
Specific Gravity	2.74	2.16	2.76	2.38	2.23	2.71	2.04
Field Moisture Content (%)	-	2.69	-	-	21.3	-	40.6
Organic Content	3.98	0.08	-	-	0.21	-	0.11
pH Value	-	3.73	-	-	3.60	-	3.99
Proctor Compaction Test							
Max. Dry Density (γd Mg/m^3)	-	1.44	-	-	1.68	-	1.34
OMC (%)	-	31.0	-	-	18.0	-	36.1
Unconfined Compression							
Strength (UU), Cu (kPa)	-	100.4	-	-	73.5	-	-
Tri-axial Compression (CU)							
Cohesion C' (kPa)	-	45	-	-	36	-	-
Internal Friction Angle ϕ' (degree)	-	28	-	-	31	-	-
Cohesion C (kPa)	-	55	-	-	34	-	-
Internal Friction Angle ϕ (degree)	-	23	-	-	30.5	-	-
Permeability (10^{-8}cm/s)	-	6,120	-	-	8,385	-	-
Consolidation							
Compression Index, Cc	-	See Table 20	-	-	See Table 20	-	-
Swelling Pressure (kPa)	-	-	7.64	-	-	29.4	-

Remarks: *; Supplementary test

Table 18 CONSOLIDATION COEFFICIENT AND COEFFICIENT OF COMPRESSIBILITY (1/3)

		Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Sample No.	BT-B1-1			
Initial void ratio	0.589	0 - 25	11.5	2.82
Specific gravity	2.65	25 - 50	11.8	0.293
Natural moisture content	24.7% dry wt.	50 - 100	6.53	0.185
Dry density	1.66 t/m^3	100 - 200	5.90	0.121
Degree of saturation	100%	200 - 400	0.62	0.101

		Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Sample No.	SR-B1-2			
Initial void ratio	0.388	0 - 25	6.40	1.07
Specific gravity	2.63	25 - 50	5.35	0.107
Natural moisture content	14.7% dry wt.	50 - 100	7.50	0.207
Dry density	1.89 t/m^3	100 - 200	7.05	0.093
Degree of saturation	99.3%	200 - 400	49.1	0.055

		Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Sample No.	DR-B1-1			
Initial void ratio	0.395	0 - 25	17.2	0.392
Specific gravity	2.66	25 - 50	13.3	0.290
Natural moisture content	15.2% dry wt.	50 - 100	25.3	0.104
Dry density	1.91 t/m^3	100 - 200	12.8	0.282
Degree of saturation	100%	200 - 400	8.92	0.101

		Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Sample No.	DR-B2-1			
Initial void ratio	0.326	0 - 25	2.18	0.301
Specific gravity	2.64	25 - 50	17.0	0.468
Natural moisture content	12.9% dry wt.	50 - 100	4.78	0.419
Dry density	1.99 t/m^3	100 - 200	10.6	0.308
Degree of saturation	90.1%	200 - 400	14.2	0.230

Table 19 CONSOLIDATION COEFFICIENT AND COEFFICIENT OF COMPRESSIBILITY (2/3)

Sample No.	TM-B1-1	Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Initial void ratio	0.471	0 - 25	25.5	1.17
Specific gravity	2.55	25 - 50	14.5	0.111
Natural moisture content	21.2% dry wt.	50 - 100	18.4	0.160
Dry density	1.73 t/m^3	100 - 200	50.1	0.110
Degree of saturation	100%	200 - 400	23.4	0.067

Sample No.	TM-B3-2	Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Initial void ratio	0.621	0 - 25	7.92	2.42
Specific gravity	2.51	25 - 50	1.94	1.80
Natural moisture content	23.0% dry wt.	50 - 100	12.6	0.712
Dry density	1.63 t/m^3	100 - 200	10.9	0.623
Degree of saturation	92.6%	200 - 400	14.3	0.320

Sample No.	BR-B1-2	Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Initial void ratio	0.390	0 - 25	36.3	0.491
Specific gravity	2.65	25 - 50	27.5	0.395
Natural moisture content	15.0% dry wt.	50 - 100	7.91	0.305
Dry density	1.91 t/m^3	100 - 200	12.6	0.121
Degree of saturation	97.1%	200 - 400	27.5	0.071

Sample No.	BR-B2-2	Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Initial void ratio	0.934	0 - 25	25.1	5.13
Specific gravity	2.65	25 - 50	2.18	1.46
Natural moisture content	31.2% dry wt.	50 - 100	6.87	1.06
Dry density	1.48 t/m^3	100 - 200	1.83	0.831
Degree of saturation	87.0%	200 - 400	12.6	0.687

Table 20 CONSOLIDATION COEFFICIENT AND COEFFICIENT OF COMPRESSIBILITY (3/3)

		Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Sample No.	RI-B1-1			
Initial void ratio	0.504	0 - 25	36.1	0.613
Specific gravity	2.16	25 - 50	16.8	0.159
Natural moisture content	31.9% dry wt.	50 - 100	14.7	0.129
Dry density	1.43 t/m^3	100 - 200	16.3	0.809
Degree of saturation	100%	200 - 400	14.2	0.054

		Pressure (kN/m^2)	Consolidation Coefficient Cv (m^2/yr)	Coefficient of Compressibility Mv (m^2/MN)
Sample No.	RI-B3-1			
Initial void ratio	0.300	0 - 25	25.3	1.51
Specific gravity	2.23	25 - 50	15.7	1.10
Natural moisture content	18.3% dry wt.	50 - 100	22.1	0.894
Dry density	1.78 t/m^3	100 - 200	23.4	0.572
Degree of saturation	100%	200 - 400	20.8	0.314

Table 21 VOID RATIO AND COMPRESSIBILITY OF COHESIVE SOILS

Sample No.	Initial		Pressure 200 kPa		Pressure 400 kPa	
	Void Ratio	Porosity	Void Ratio	Compressibility (%)	Void Ratio	Compressibility (%)
Badak-Temin						
BT-B1-1	0.490	0.329	0.438	2.4	0.410	3.8
Sari						
SR-B1-2	0.388	0.280	0.323	3.6	0.307	4.5
Durian						
DR-B1-1	0.395	0.283	0.326	3.7	0.300	5.2
DR-B2-1	0.326	0.246	0.287	2.3	0.267	3.5
Tawar-Muda						
TM-B1-1	0.428	0.300	0.398	1.5	0.379	2.5
TM-B3-2	0.620	0.383	0.325	13.8	0.240	18.9
Beris						
BR-B1-2	0.390	0.281	0.323	3.7	0.305	4.7
BR-B2-2	0.930	0.482	0.430	18.1	0.250	28.2
Rui						
R1-B1-1	0.504	0.335	0.454	2.3	0.438	3.0
R1-B3-1	0.300	0.231	0.100	14.0	0.033	19.8

Table 22 GROUP SYMBOLS AND DESCRIPTION OF UNIFIED SOIL CLASSIFICATION

Group Symbols	Typical Names
GW	Well graded gravels, gravel-sand mixtures, little or no fines
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
GM	Silty gravels, poorly graded gravel-sand-silt mixtures
GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
SW	Well graded sands, gravelly sands, little or no fines
SP	Poorly graded sands, gravelly sands, little or no fines
SM	Silty sands, poorly graded sand-silt mixtures
SC	Clayey sands, poorly graded sand-clay mixtures
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
OL	Organic silts and organic silt-clays of low plasticity
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
CH	Inorganic clays of high plasticity, fat clays
OH	Organic clays of medium to high plasticity
Pt	Peat and other highly organic soils

Remarks; Soils possessing characteristics of two groups are designated by combinations of symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.

Source; Earth Manual (Ref. 1)

Table 23 ASSESSMENT OF SOIL PROPERTIES REQUIRED FOR ROLLED EARTH DAMS

Borrow-Pit and Soils	Workability	Shear Strength	Permeability	Compressibility and Swelling
Badak-Temin B1 & B2: CH (CL or CH-MH)	Poor	C' = 41 kPa ø' = 26° Poor	2×10^{-8} cm/s Impervious	High (4% at 400 kPa)
Sari B1: CL (CH or OH)	Fair (Possibly poor)	C' = 40 kPa ø' = 19° Poor	0.3×10^{-8} cm/s Impervious	High (5% at 400 kPa)
Durian B1: CH, CL (or SC)	Fair (Possibly poor)	C' = 25 kPa ø' = 28.5° C' = 51 kPa ø' = 30.5° Fair	3×10^{-3} cm/s 5×10^{-3} cm/s Semi-pervious	High (5% at 400 kPa) High (4% at 400 kPa)
Tawar-Muda B1: CL-ML (MH or SC)	Fair (Possibly poor)	C' = 30 kPa ø' = 29° C' = 110 kPa ø' = 18° Fair	2×10^{-4} cm/s 3×10^{-4} cm/s Semi-pervious	Medium (3% at 400 kPa) High (19% at 400 kPa)
Beris B1: CH (or MH)	Poor	C' = 109 kPa ø' = 34° C' = 35 kPa ø' = 26° Fair	3×10^{-4} cm/s 6×10^{-7} cm/s Impervious	High (5% at 400 kPa) High (28% at 400 kPa) Swelling = 23 kPa
Rui				
B2 & B3: CL, ML, MH	Fair (Possibly poor)	C' = 36 kPa ø' = 31° Fair	8×10^{-5} cm/s Impervious	High (20% at 400 kPa) Swelling = 29 kPa
B4: MH, CH	Poor	C' = 45 kPa ø' = 28° Fair	6×10^{-5} cm/s Impervious	Medium (3% at 400 kPa) Swelling = 8 kPa

Table 24 INTERNATIONAL SYSTEM OF UNITS (SI)

Prefix

M	:	mega- = 10^6
k	:	kilo- = 10^3
c	:	centi = 1/100

Mass

g	:	gram
kg	:	kilogram = 10^3 g

Force

N	:	Newton = 1 $kg \cdot m/s^2$

Pressure

Pa	:	Pascal = 1 N/m^2

Length

m	:	meter

Time

s	:	second

Conversion factor

1 kgf/m^2 = 9.80665 Pa

1 kPa = 1/98 kgf/cm^2

1 N = 10^5 dyn

FIGURES

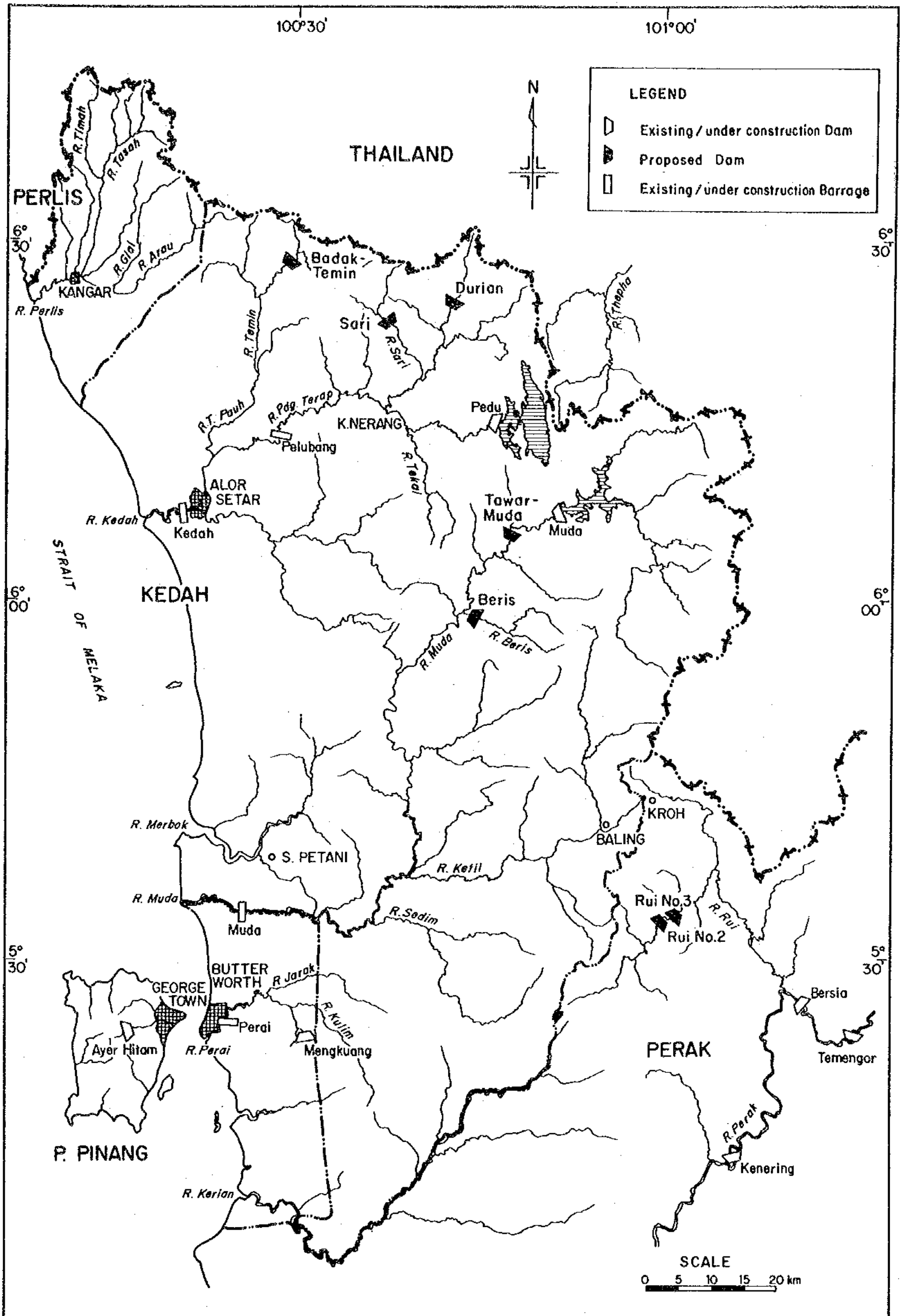

Fig. 1 The Project Area and Proposed 6 Dam Sites

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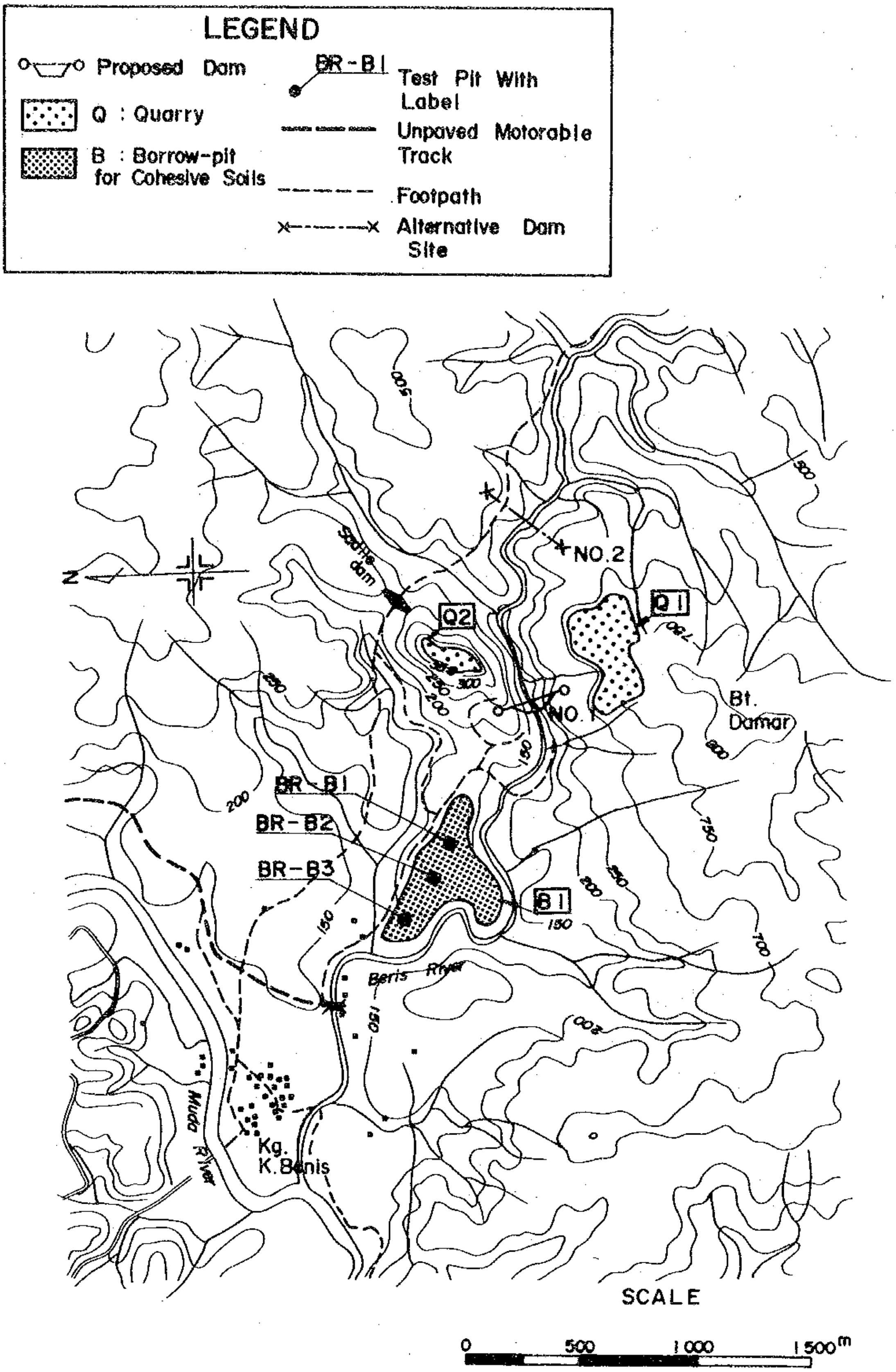

Fig. 2 Detailed Construction Material Sources Around Beris Dam Site

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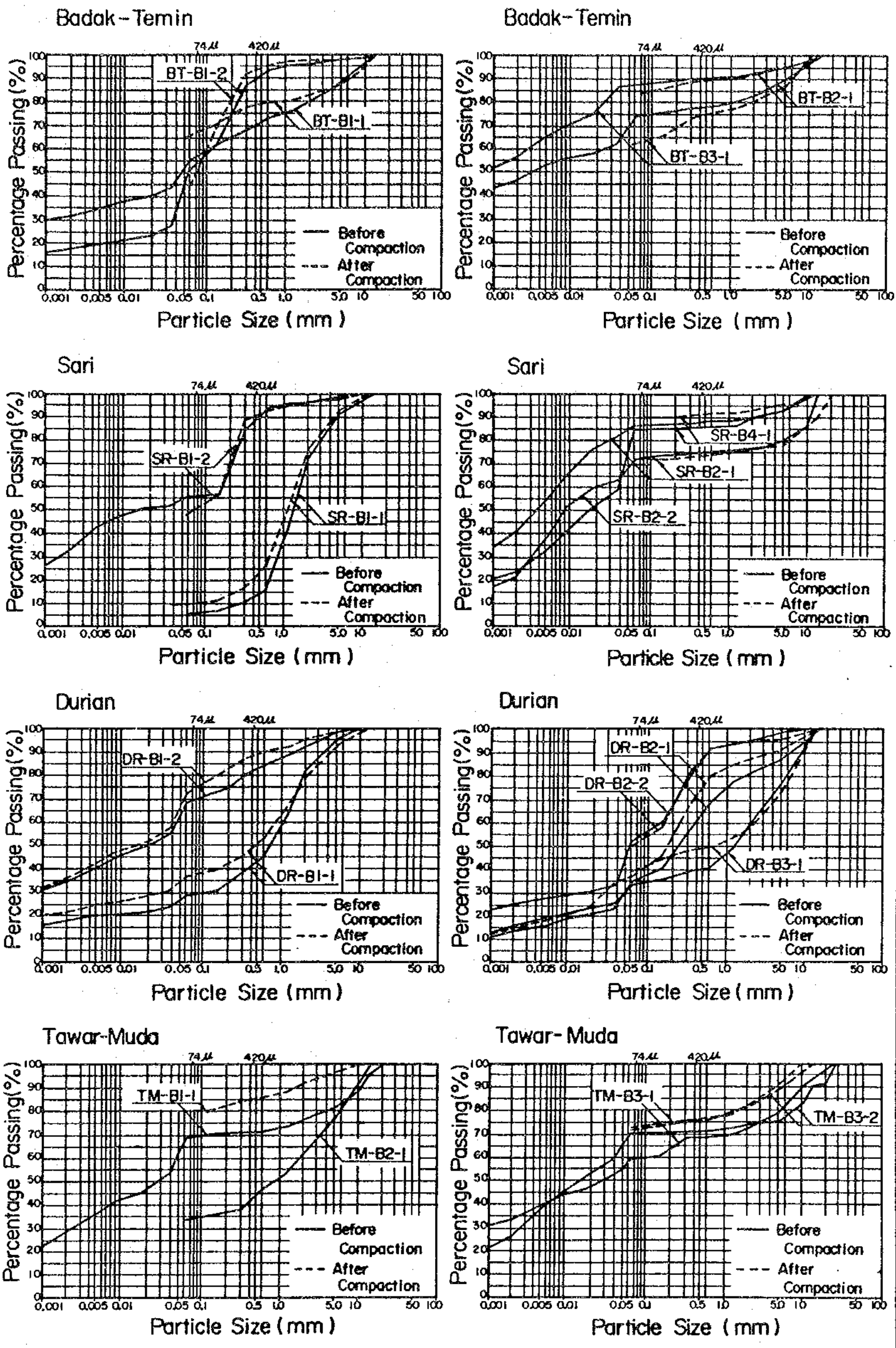

Fig. 3 Particle Size Distribution of Fine Grained Soils in Project Area (1/2)

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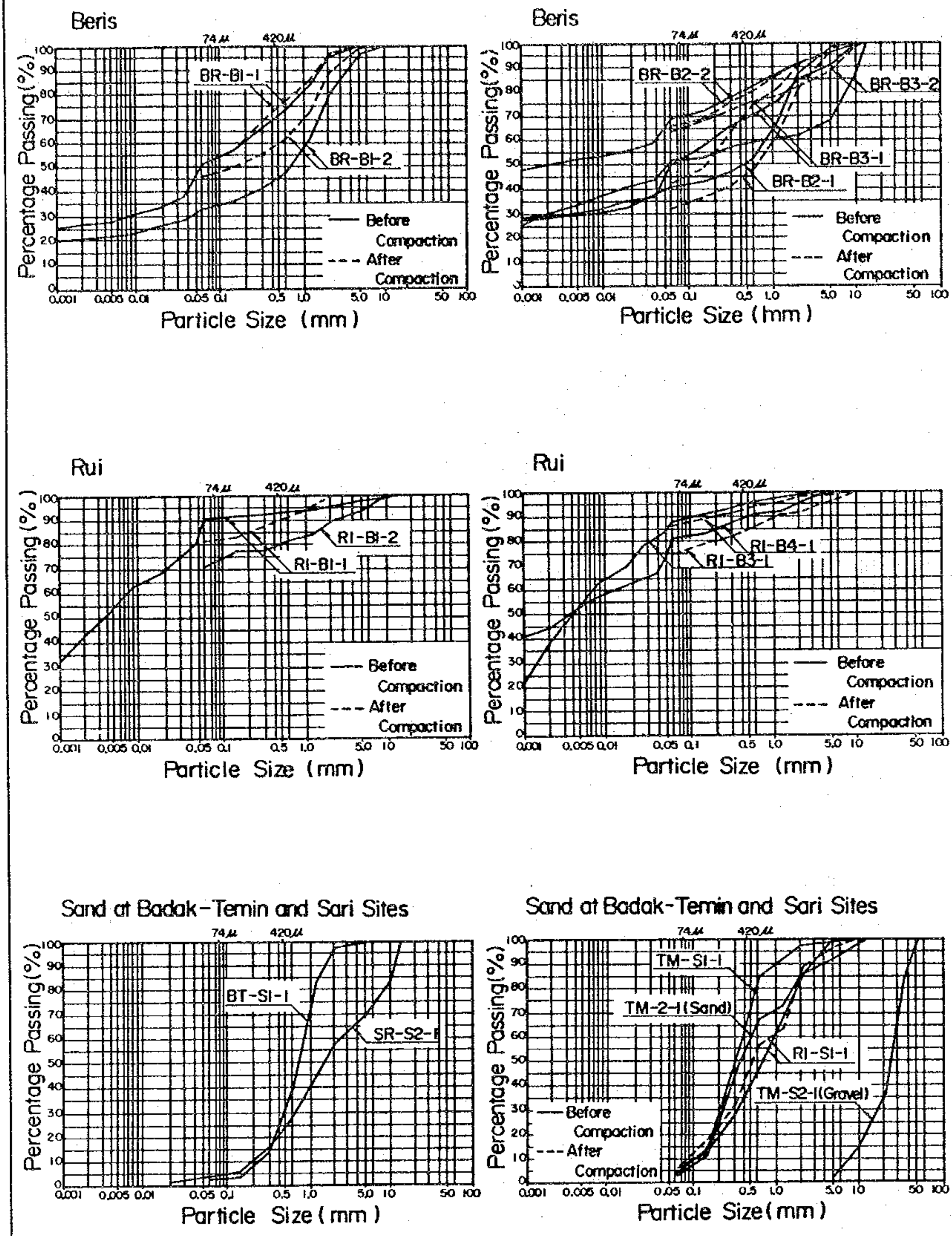

Fig. 4 Particle Size Distribution of Fine Grained Soils in Project Area (2/2)

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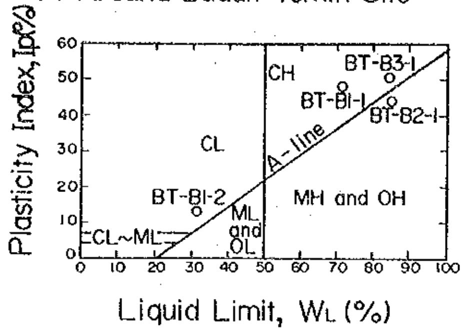
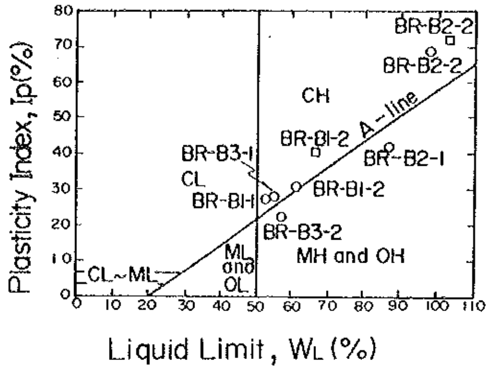
Soil Around Badak-Temin Site

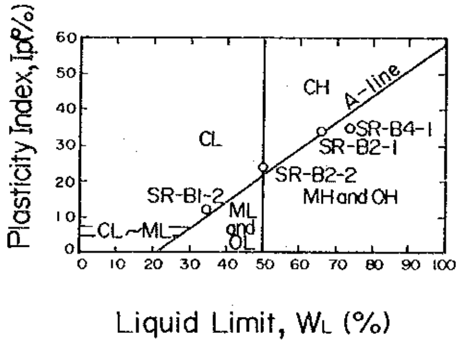


Soil Around Beris Site

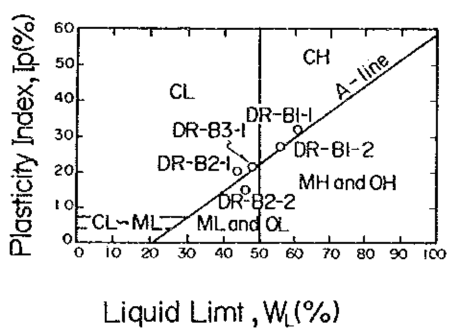


Remarks : O = Tests by DID
□ = Supplementary tests

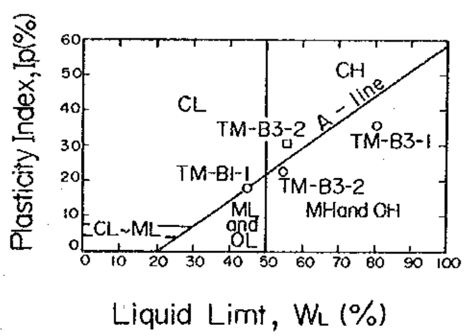
Soil Around Sari Site



Soil Around Durian Site



Soil Around Tawar-Muda Site



Soil Around Rui Site

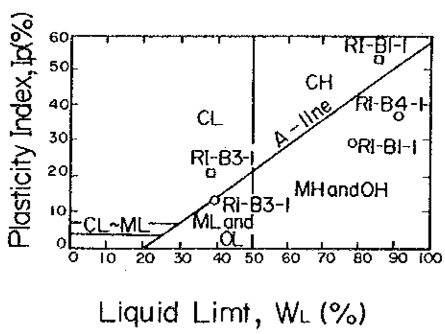


Fig. 5 Plasticity Chart for Unified Soil Classification of Fine Grained Soils in Project Area

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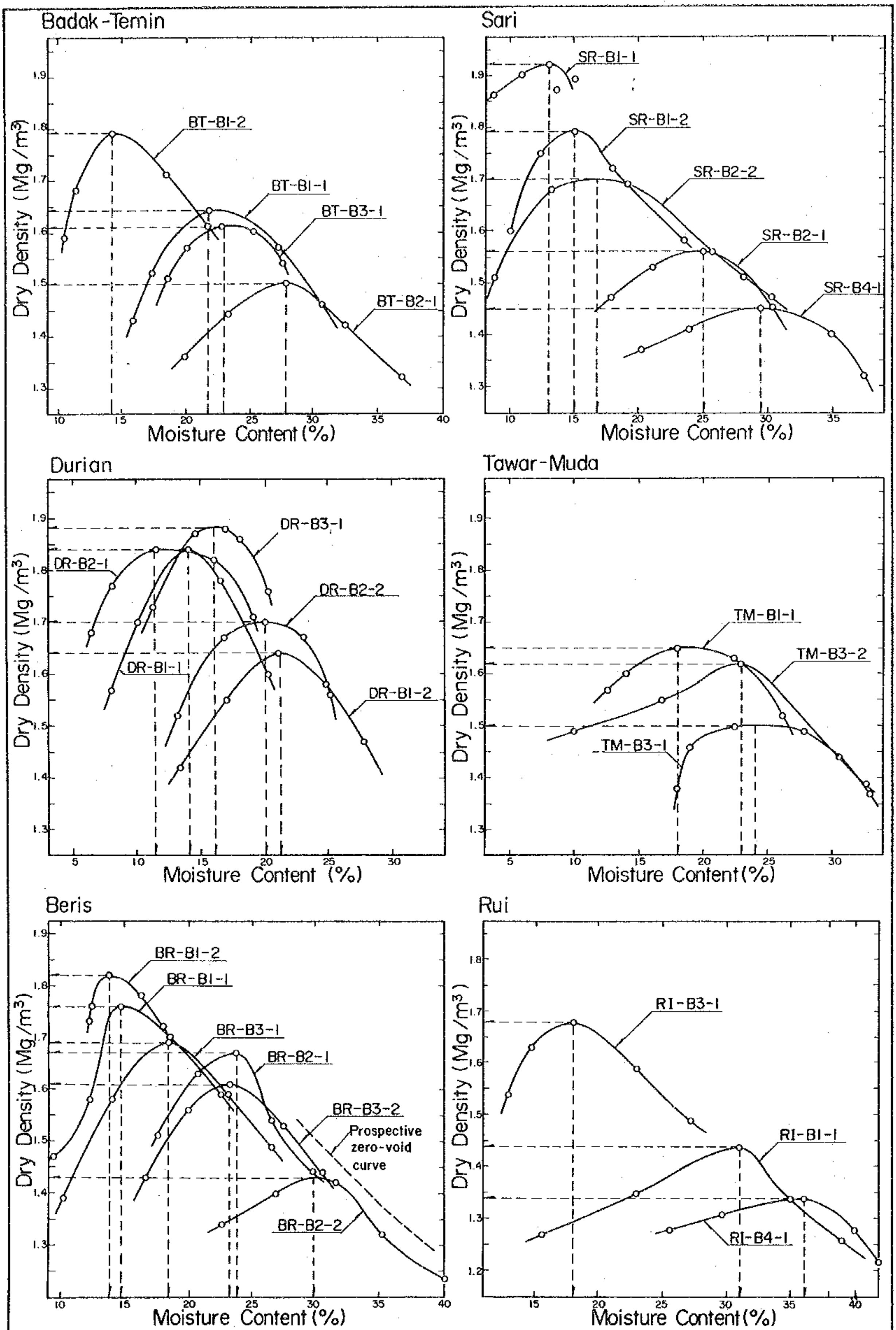

Fig. 6 Moisture-Dry Density Relationship of Cohesive Soils in Project Area

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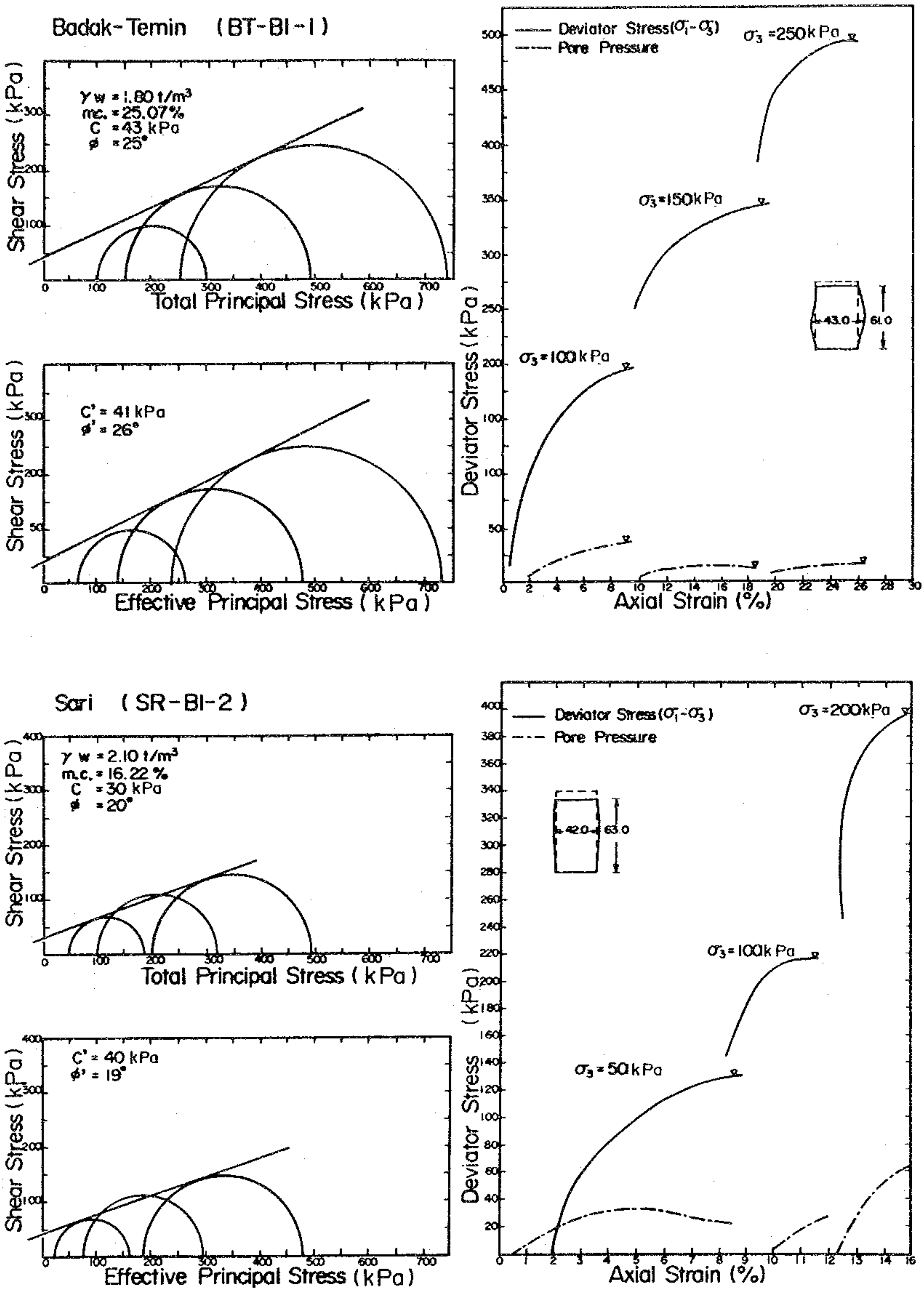

Fig. 7 Tri-Axial Compression Test Results, $\overline{CU}$, 38 mmφ, 3 Multi-Stage (1/5)

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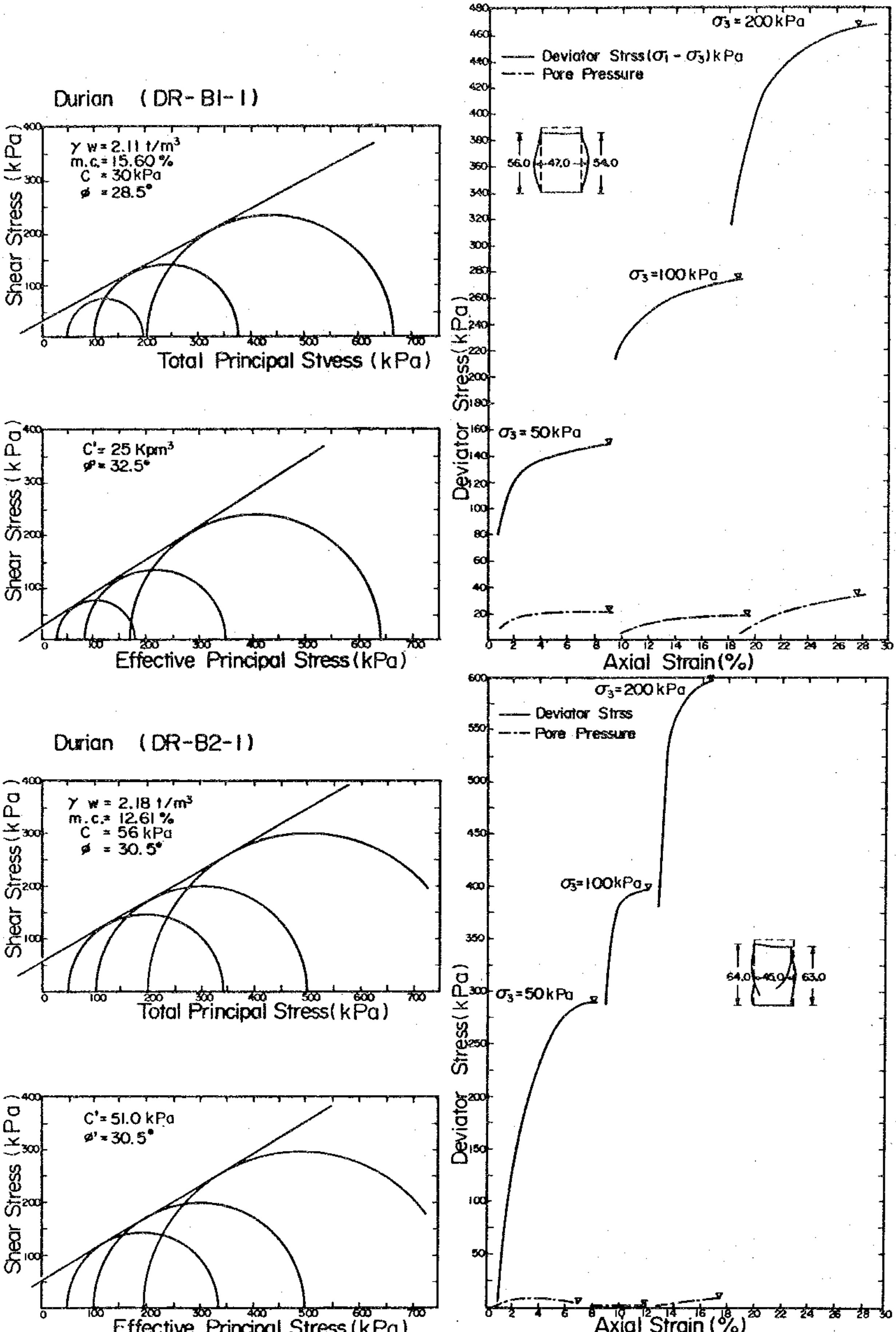

Fig. 8 Tri-Axial Compression Test Results, $\overline{CU}$, 38 mmø, 3 Multi-Stage (2/5)

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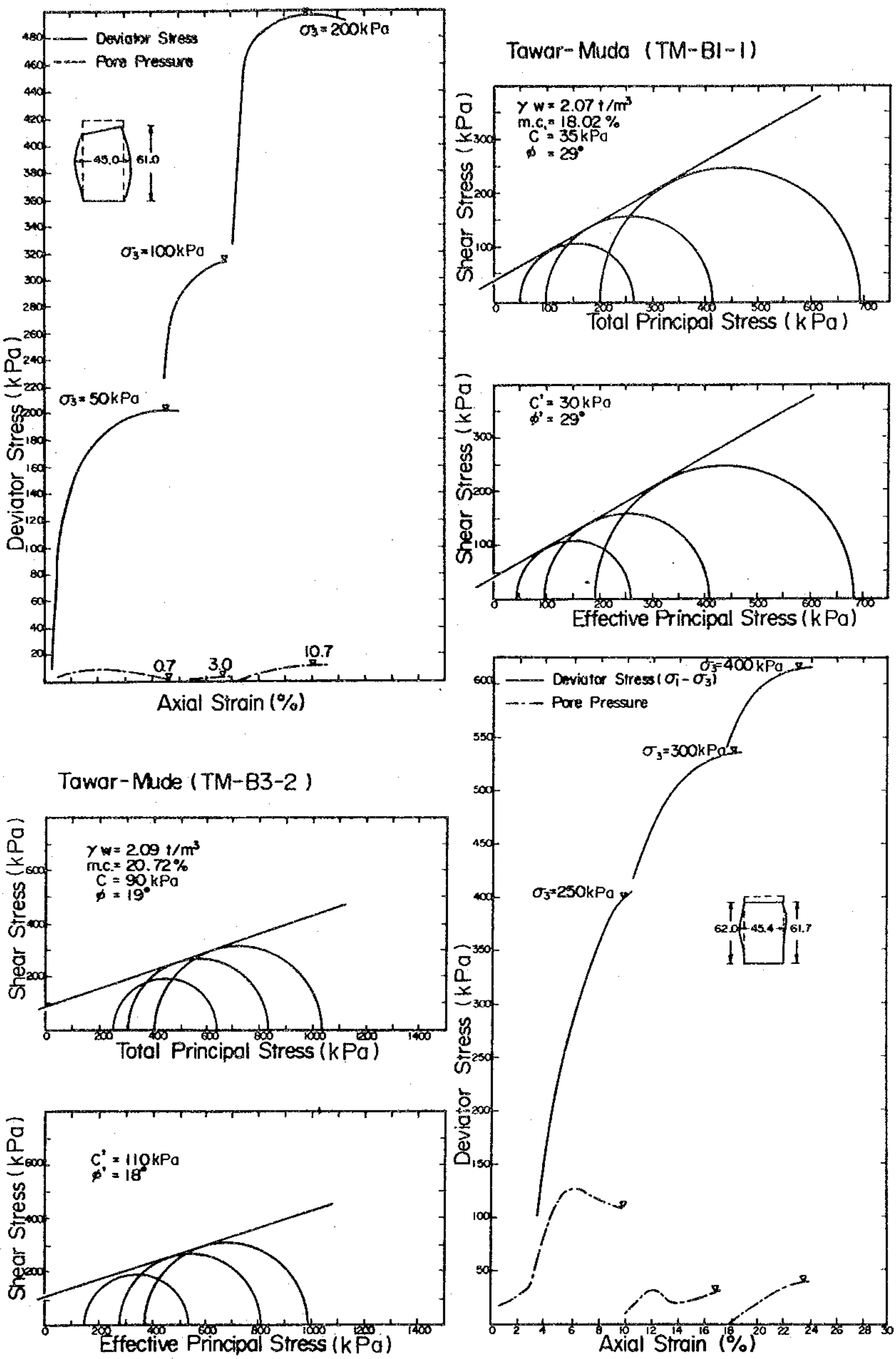

Fig. 9 Tri-Axial Compression Test Results, $\overline{CU}$, 38 mmφ, 3 Multi-Stage (3/5)

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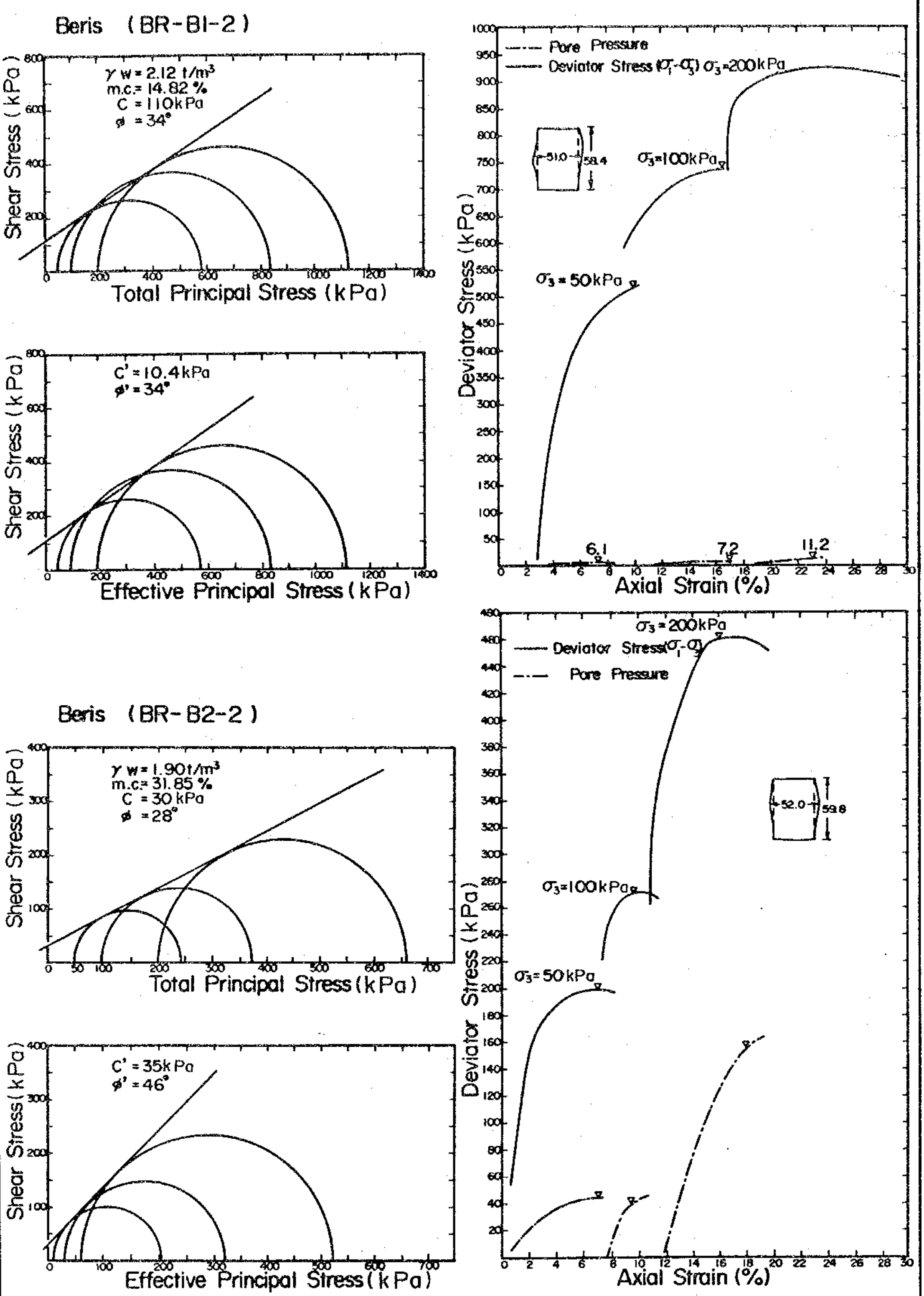

Fig. 10 Tri-Axial Compression Test Results, $\overline{CU}$, 38 mmφ, 3 Multi-Stage (4/5)

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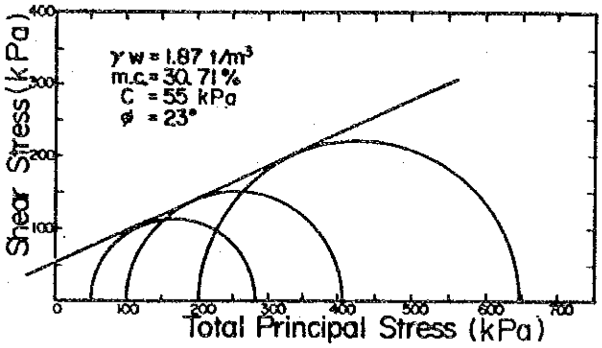
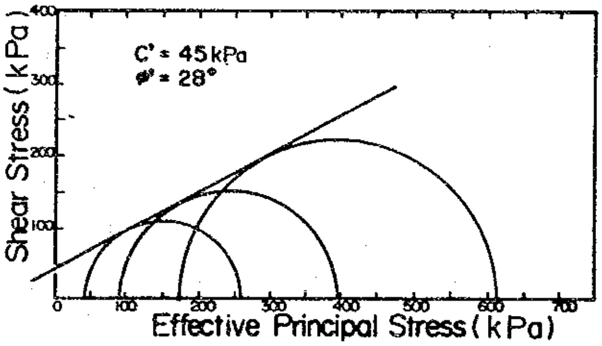
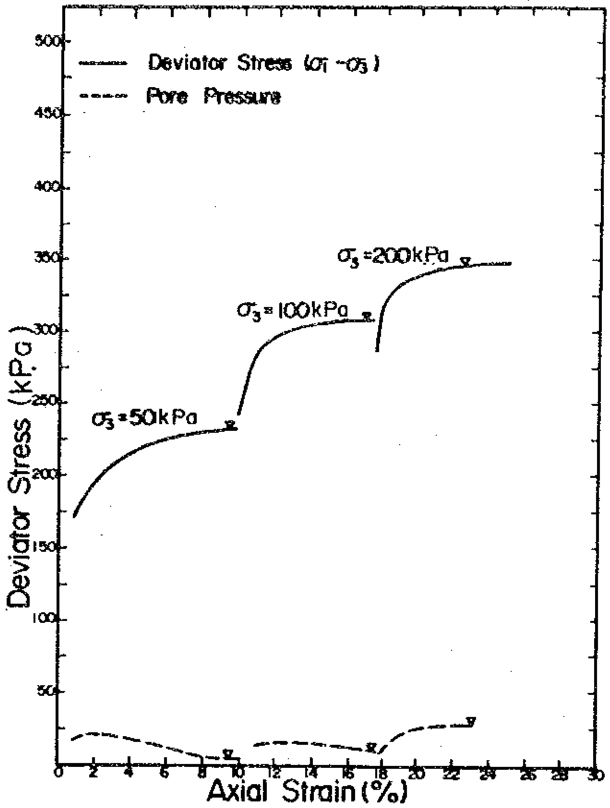
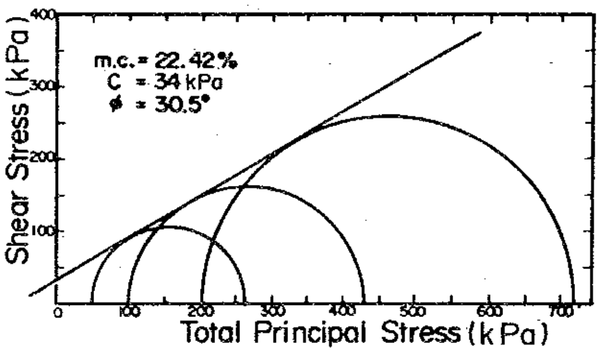
Rui (RI-B1-1)

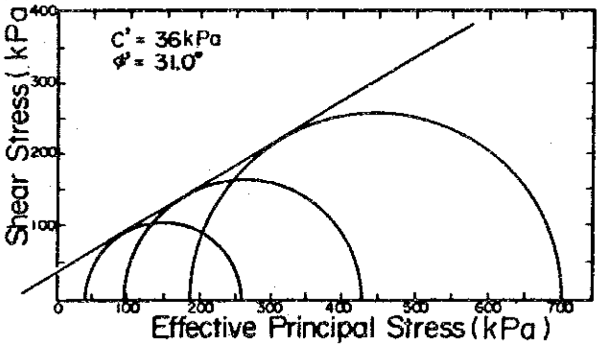






Rui (RI-B3-1)





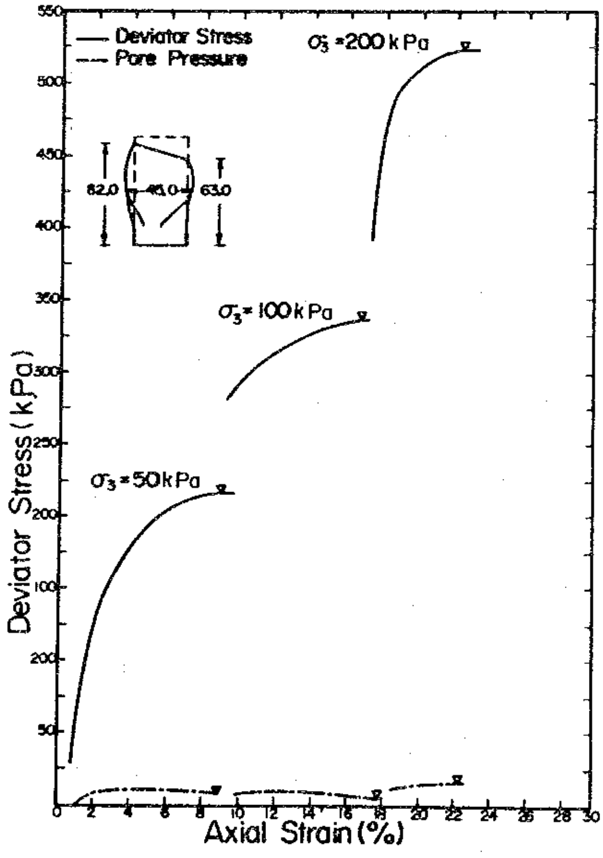


Fig. 11 Tri-Axial Compression Test Results, $\overline{CU}$, 38 mmφ, 3 Multi-Stage (5/5)

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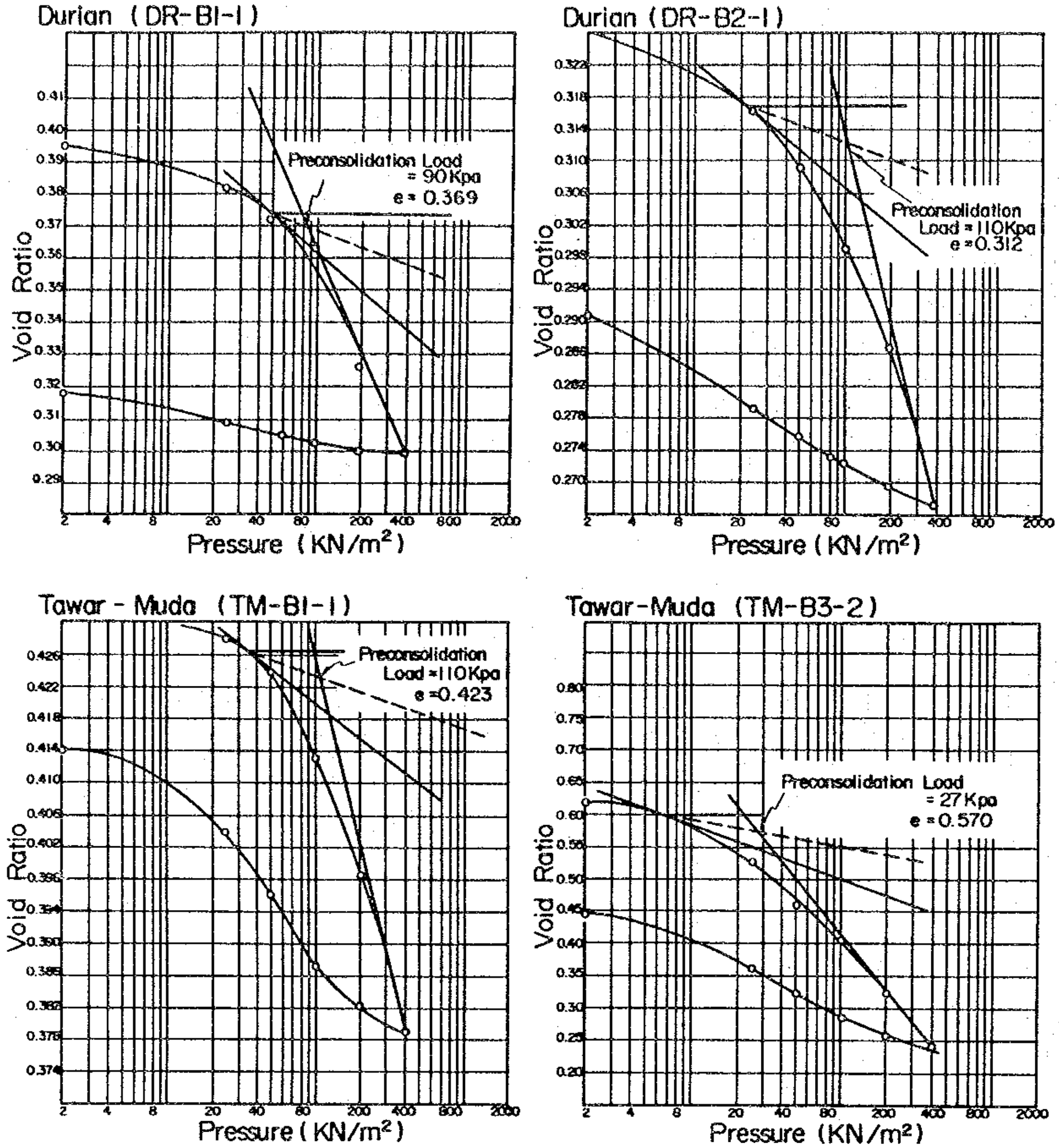

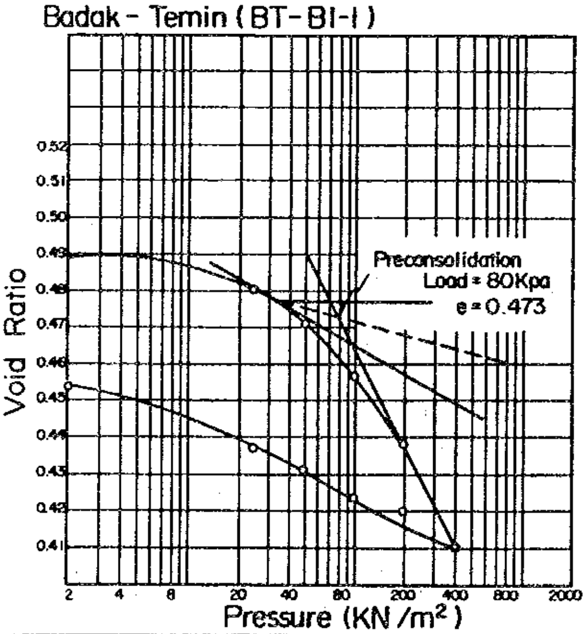

Fig. 12 Void Ratio-Consolidation Pressure Relationship of Cohesive Soils in Project Area (1/2)

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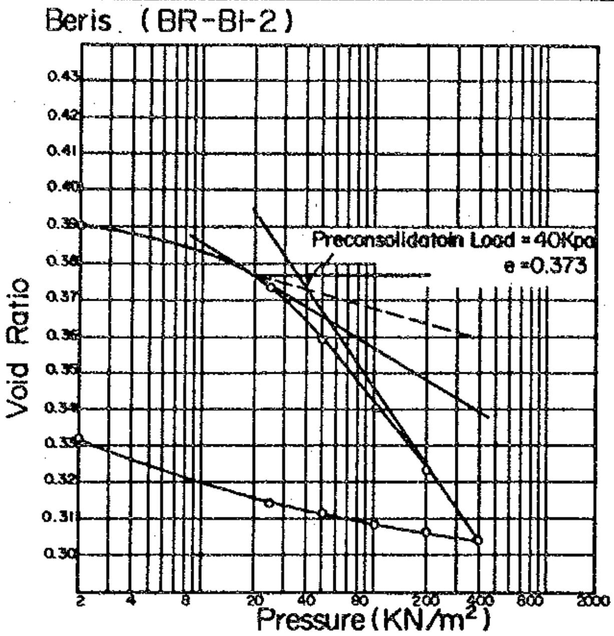

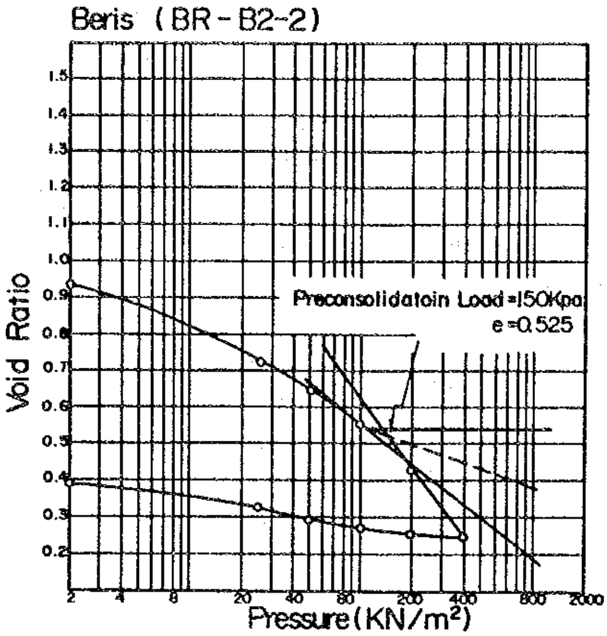

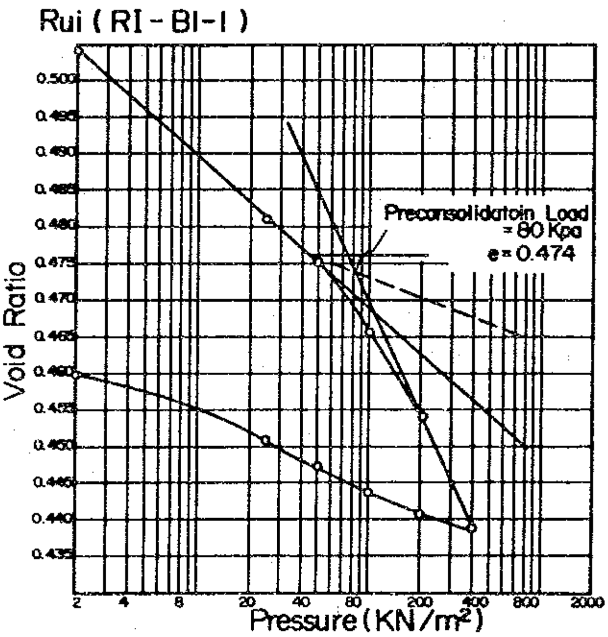

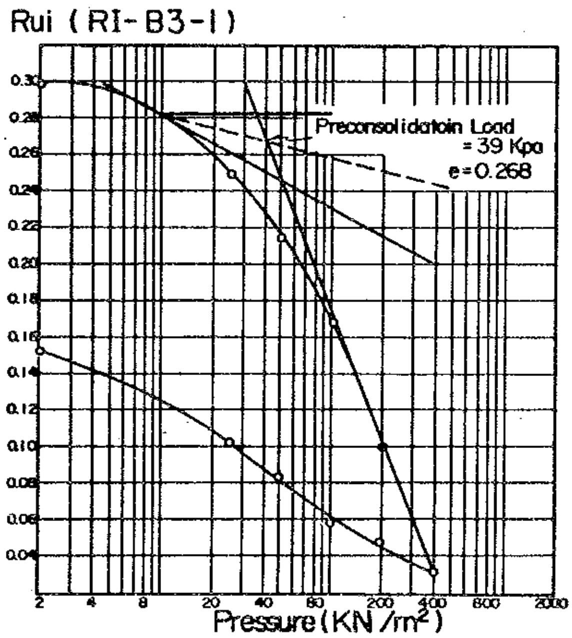

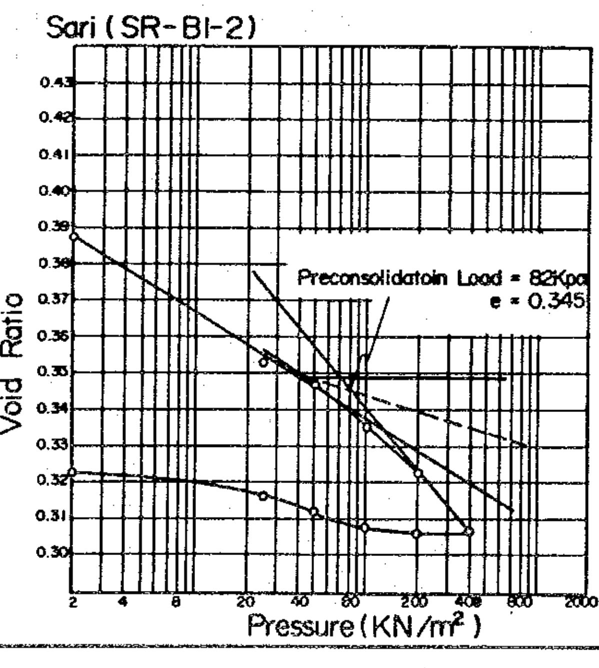

Fig. 13 Void Ratio-Consolidation Pressure Relationship of Cohesive Soils in Project Area (2/2)

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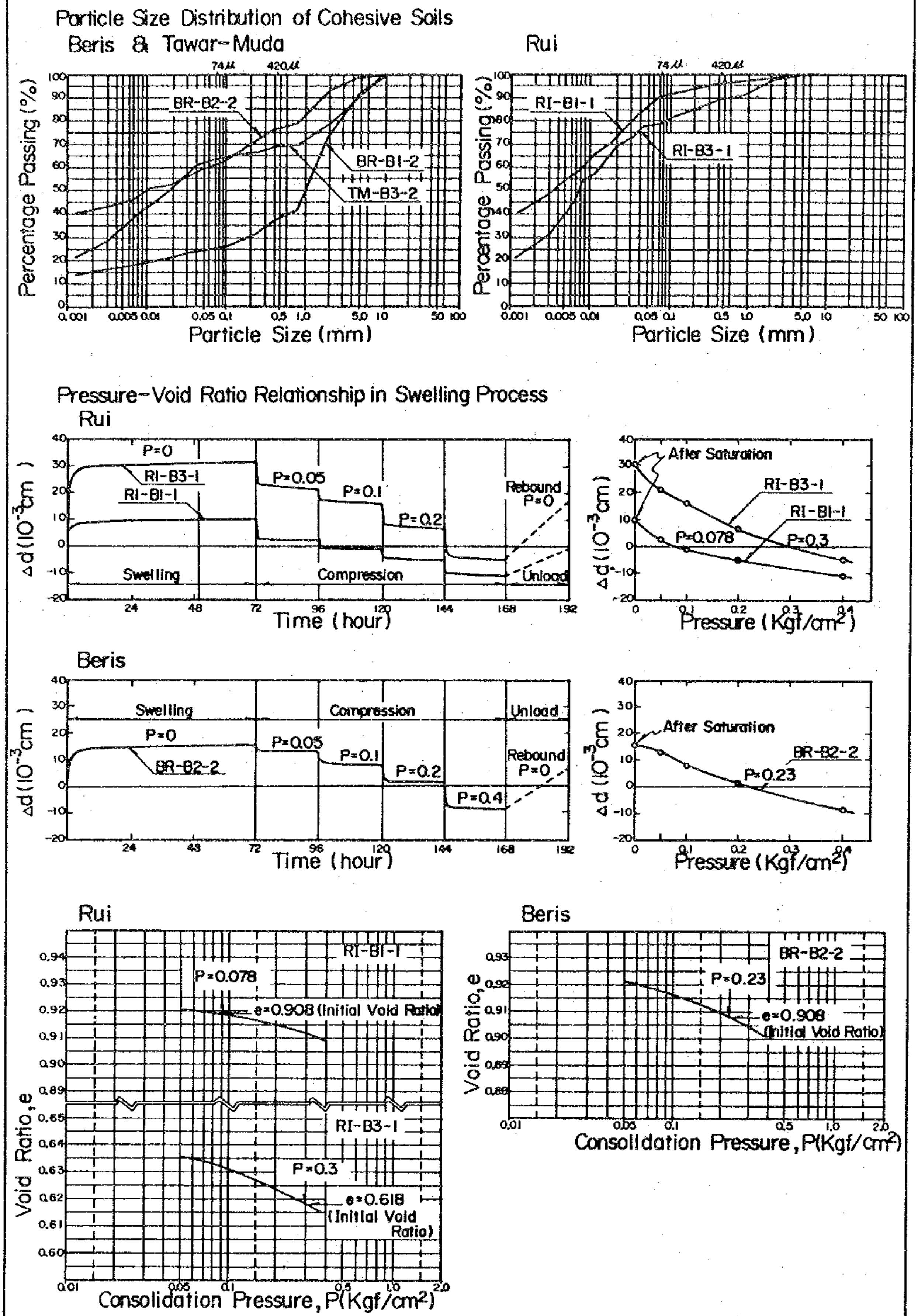

Fig. 14 Results of Supplementary Tests

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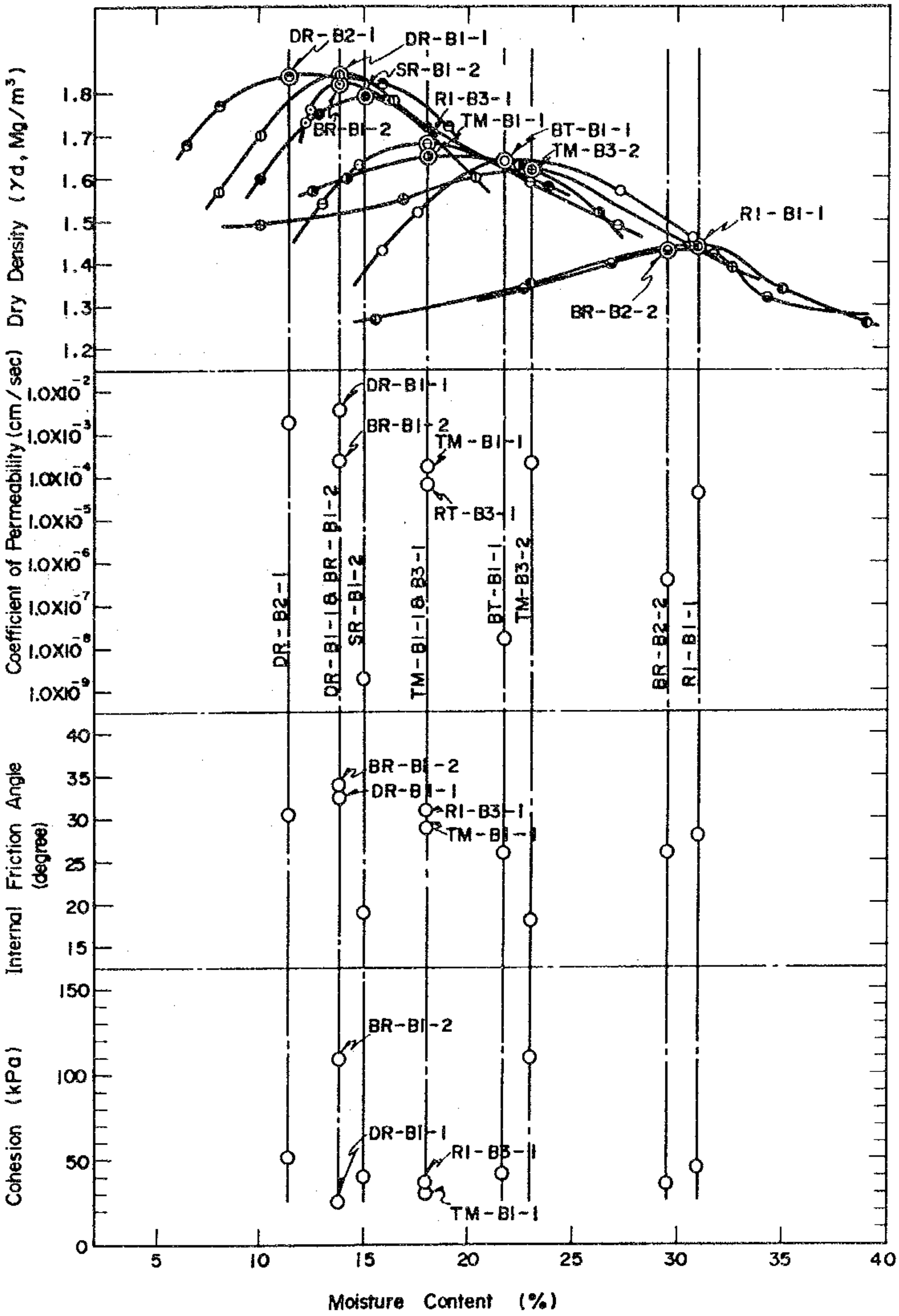

Fig. 15 Dry Density-Shear Strength-Permeability Relationship

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