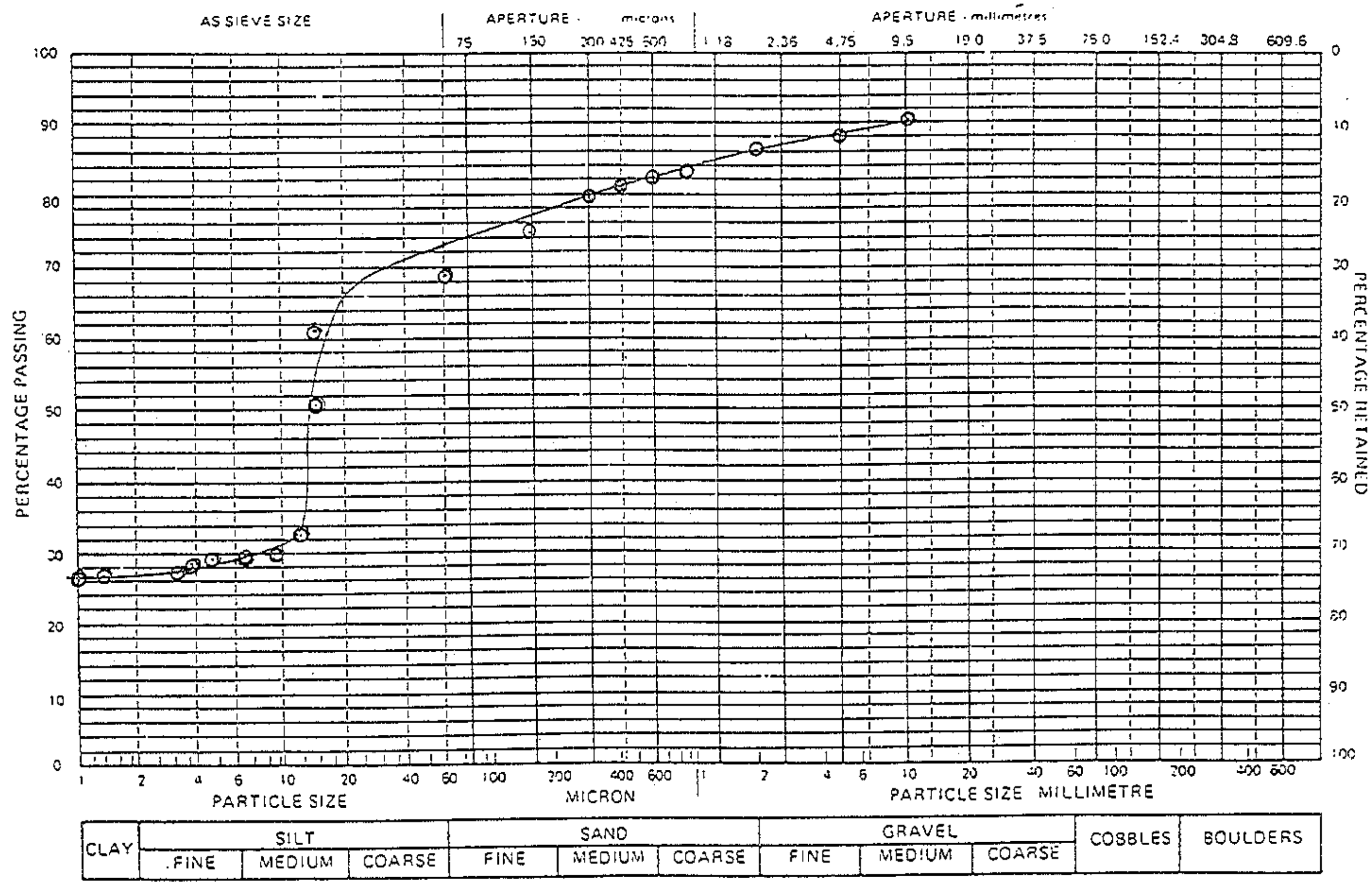
Fig. I.2.5-4

Tested by .... Plotted by .... Checked by .... SAMPLE NO. ...

Date .... Date .... Date .... REGISTRATION ....



D_{10} .... D_{30} .... D_{60} .... C_u .... C_c .... Classification ....

Description of material ....

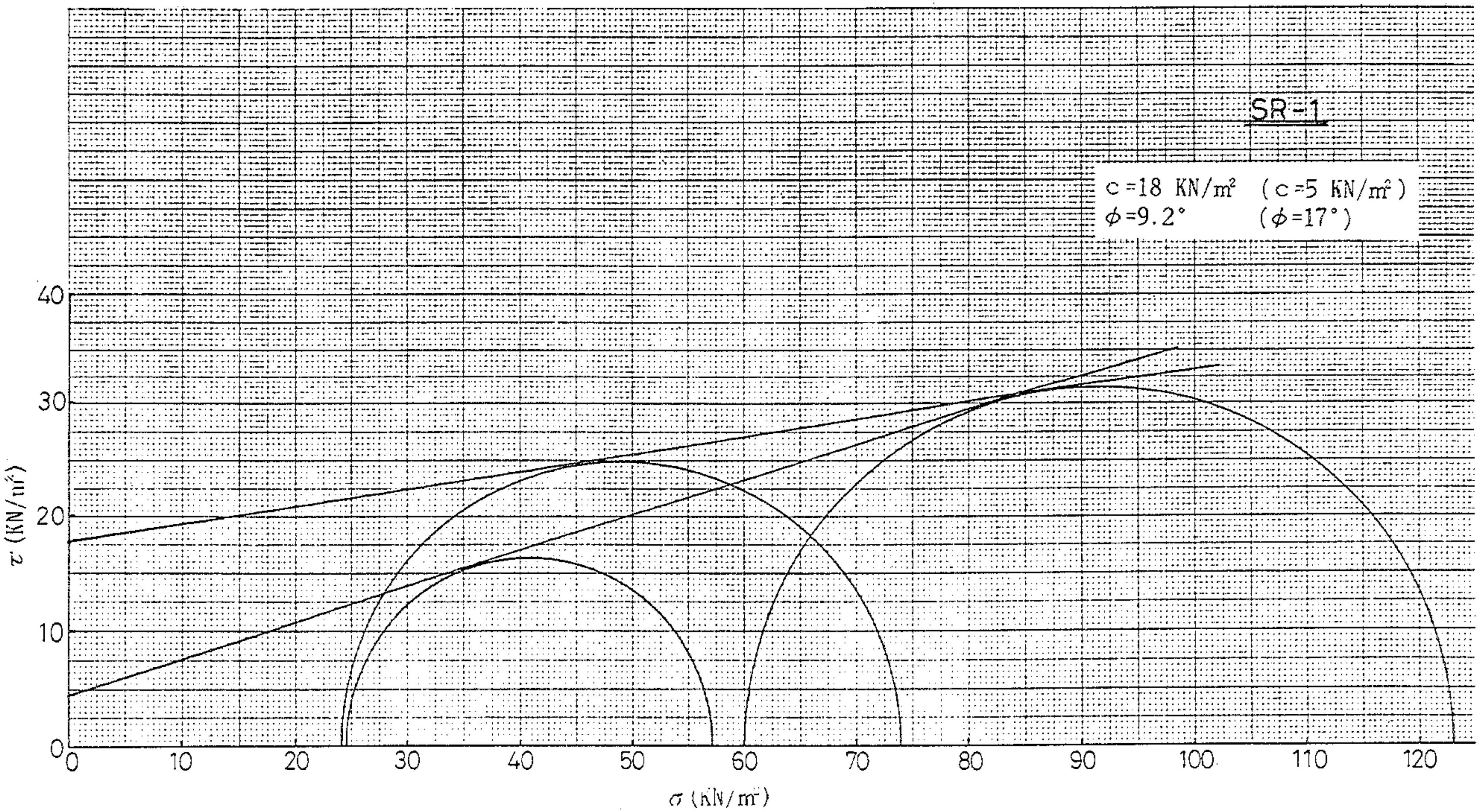
Report No. .... Sheet ....

PARTICLE SIZE DISTRIBUTION CHART, D/W-2

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

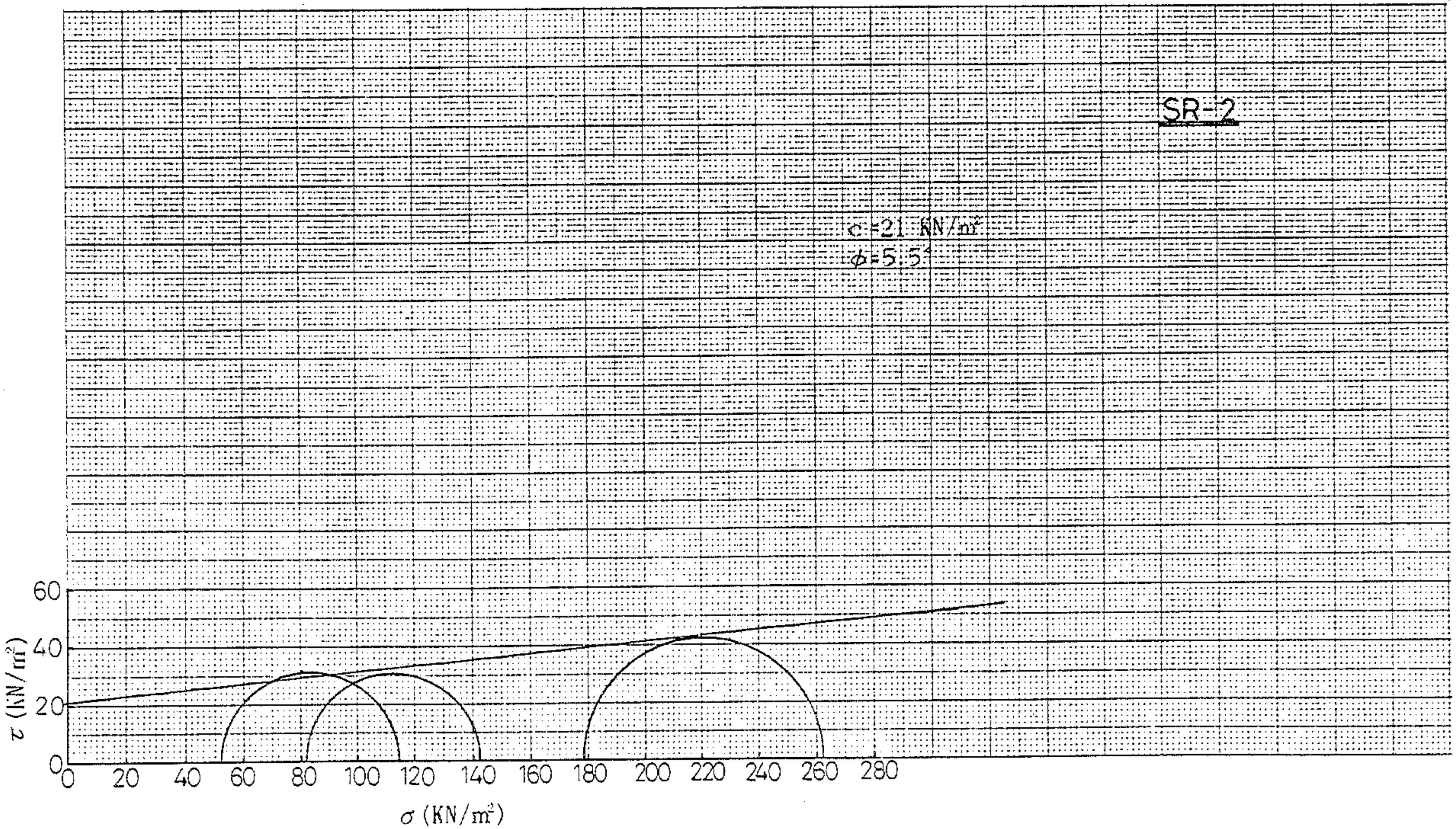
Fig. I.2.5-5



MOHR'S CIRCLE, S/R-1

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

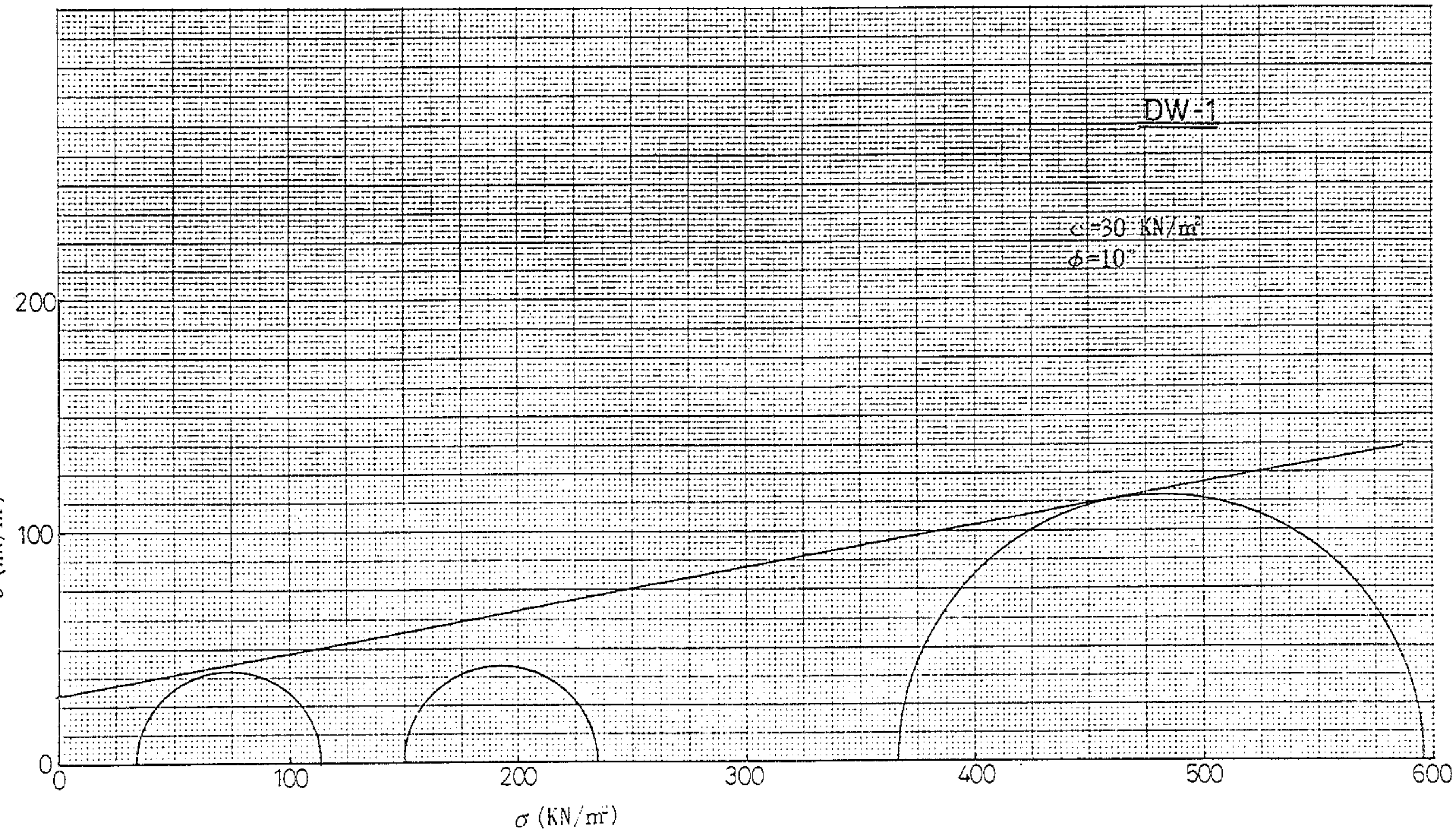
Fig. I.2.5-6



MOHR'S CIRCLE, S/R-2

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

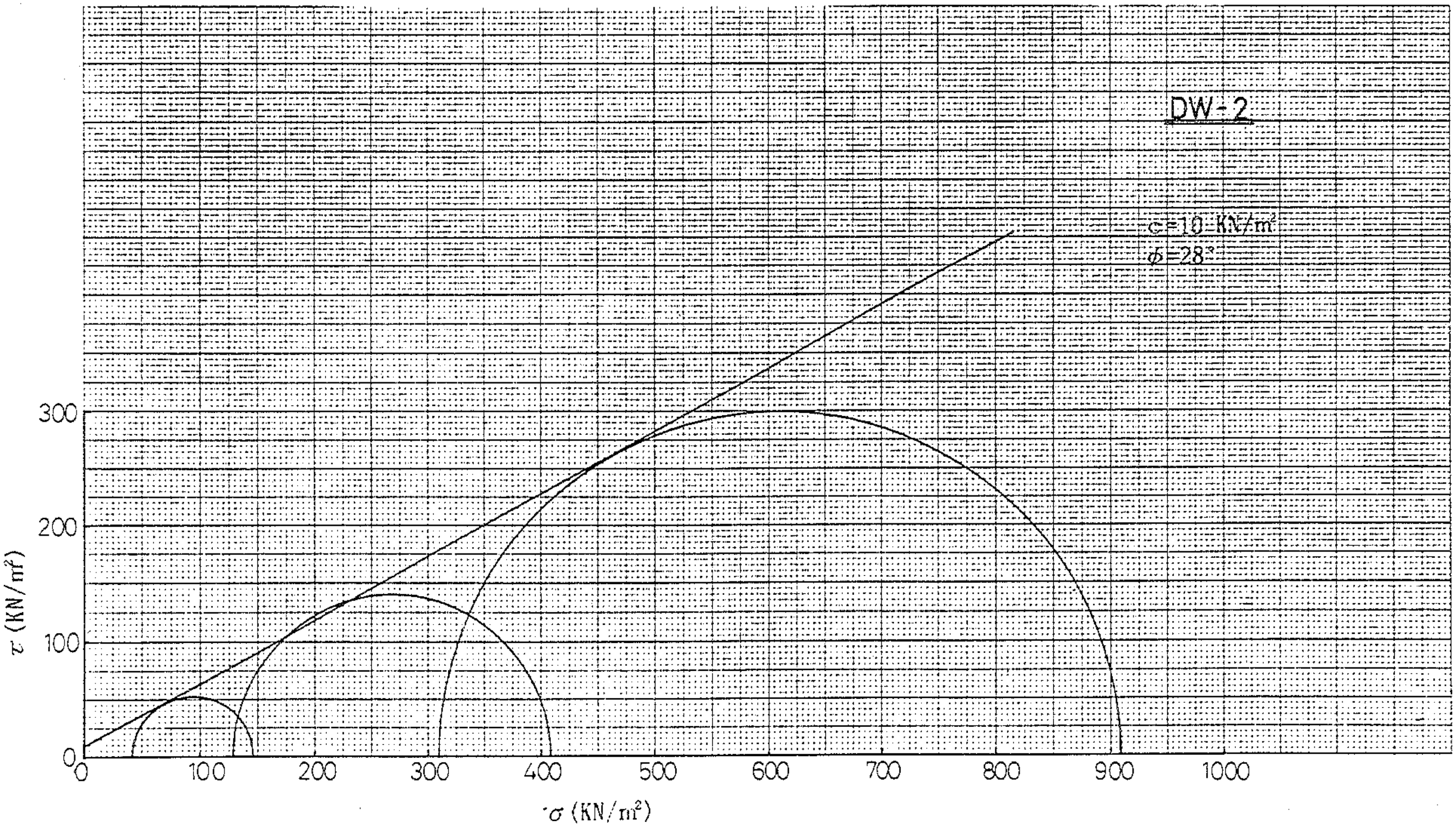
Fig. I.2.5-7



MOHR'S CIRCLE, D/W-1

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

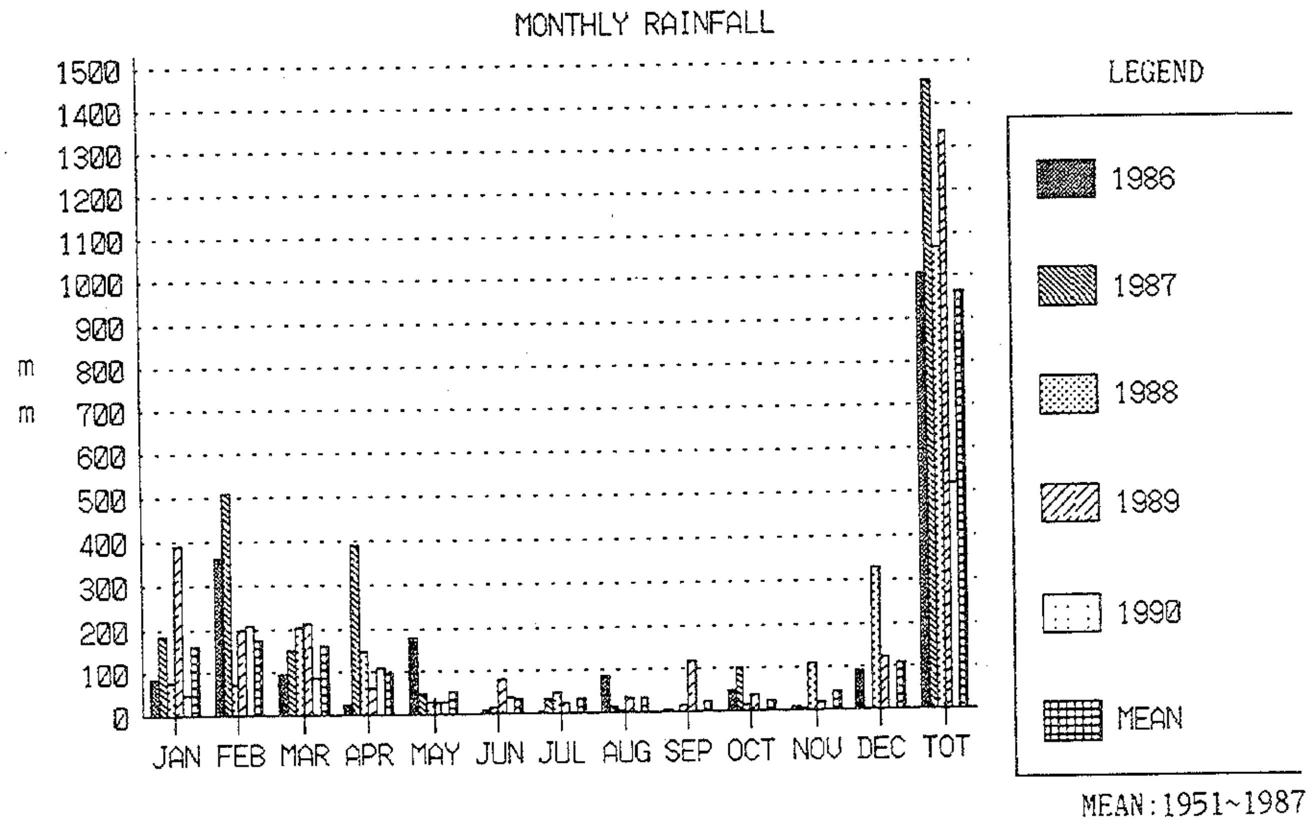
Fig. I.2.5-8



MOHR'S CIRCLE, D/W-2

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-1

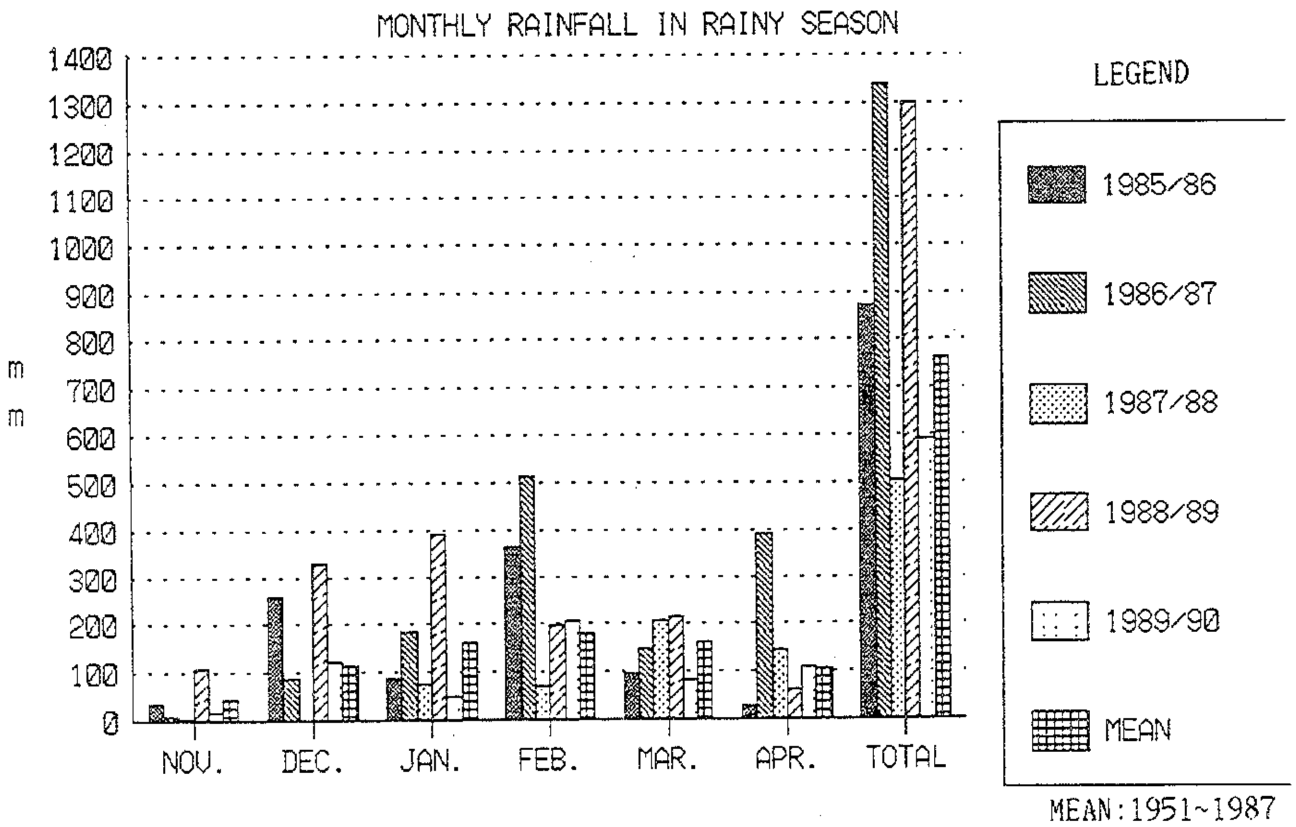


MONTHLY RAINFALL FROM 1986 TO 1990

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-2

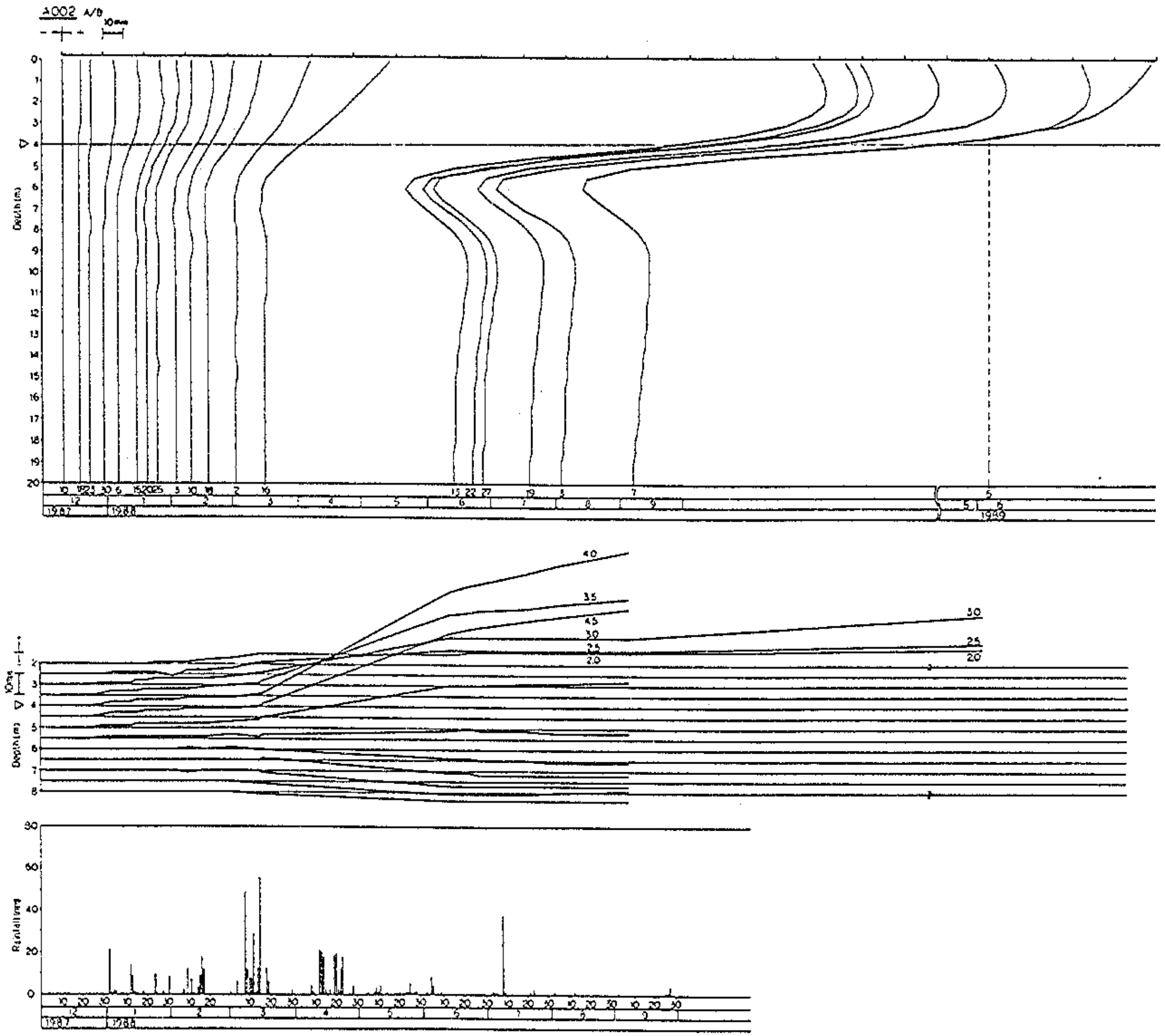


MONTHLY RAINFALL IN RAINY SEASON FROM 1985 TO 1990

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-3

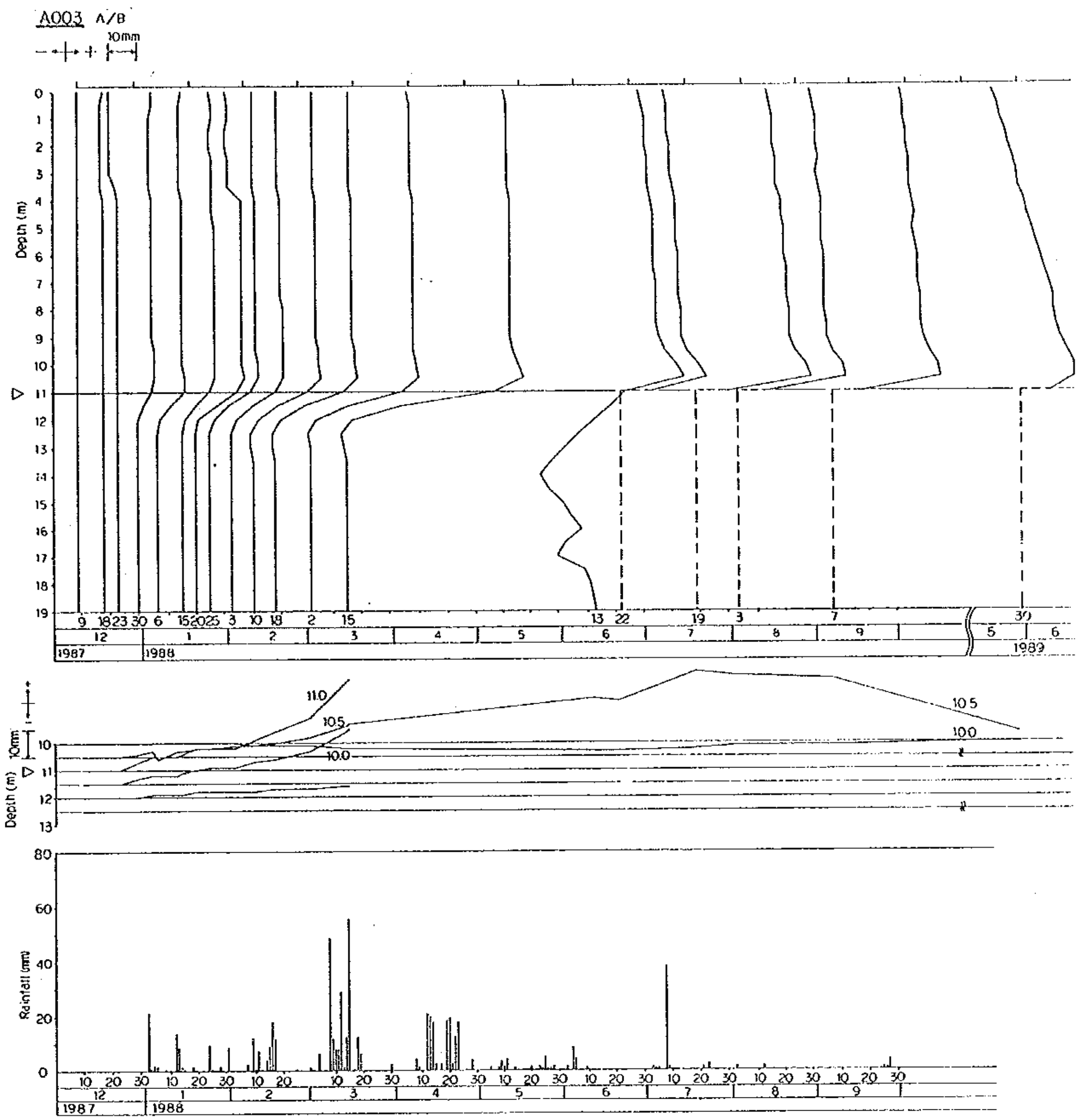


DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, A002

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-4

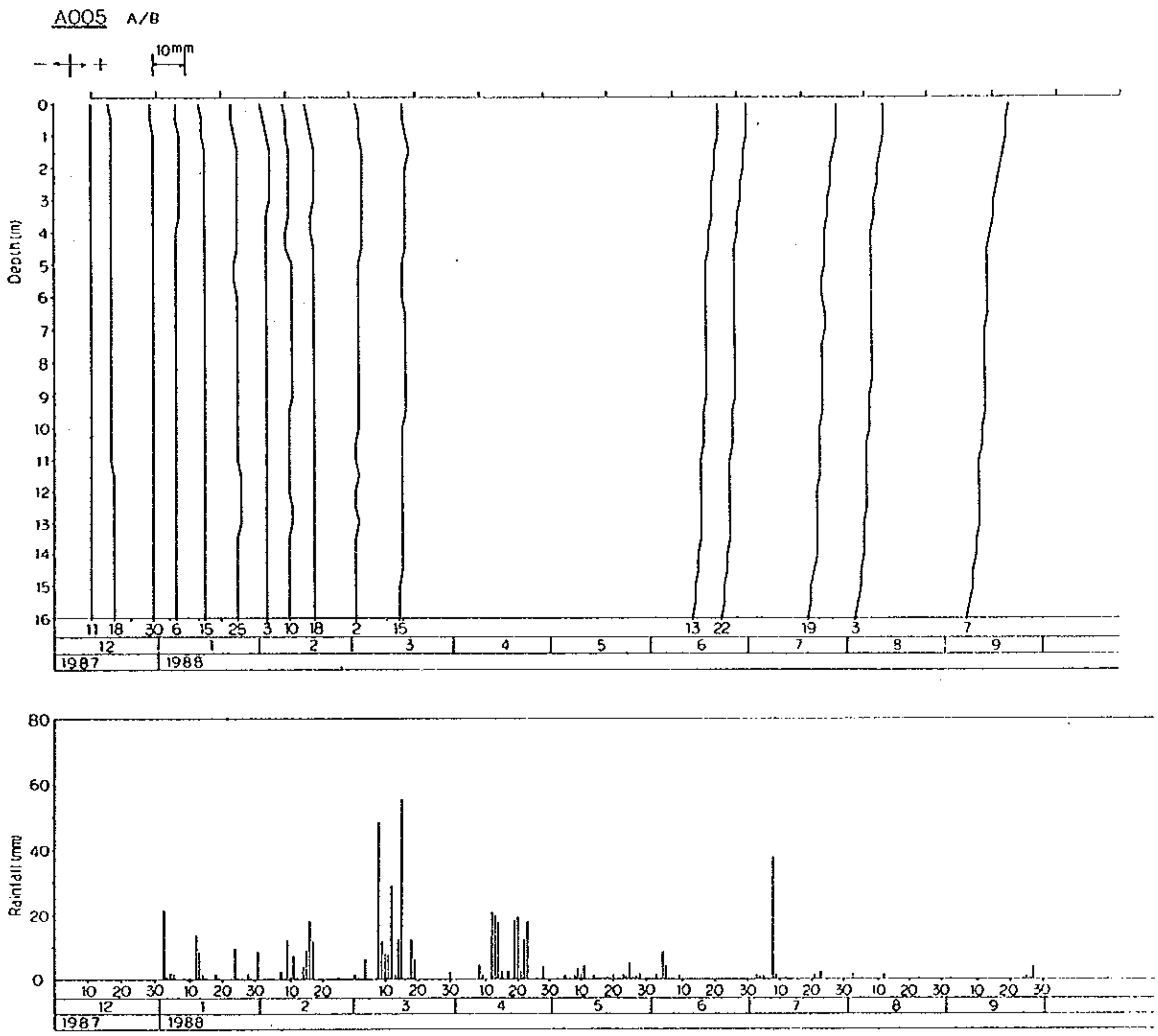


DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, A003

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-5

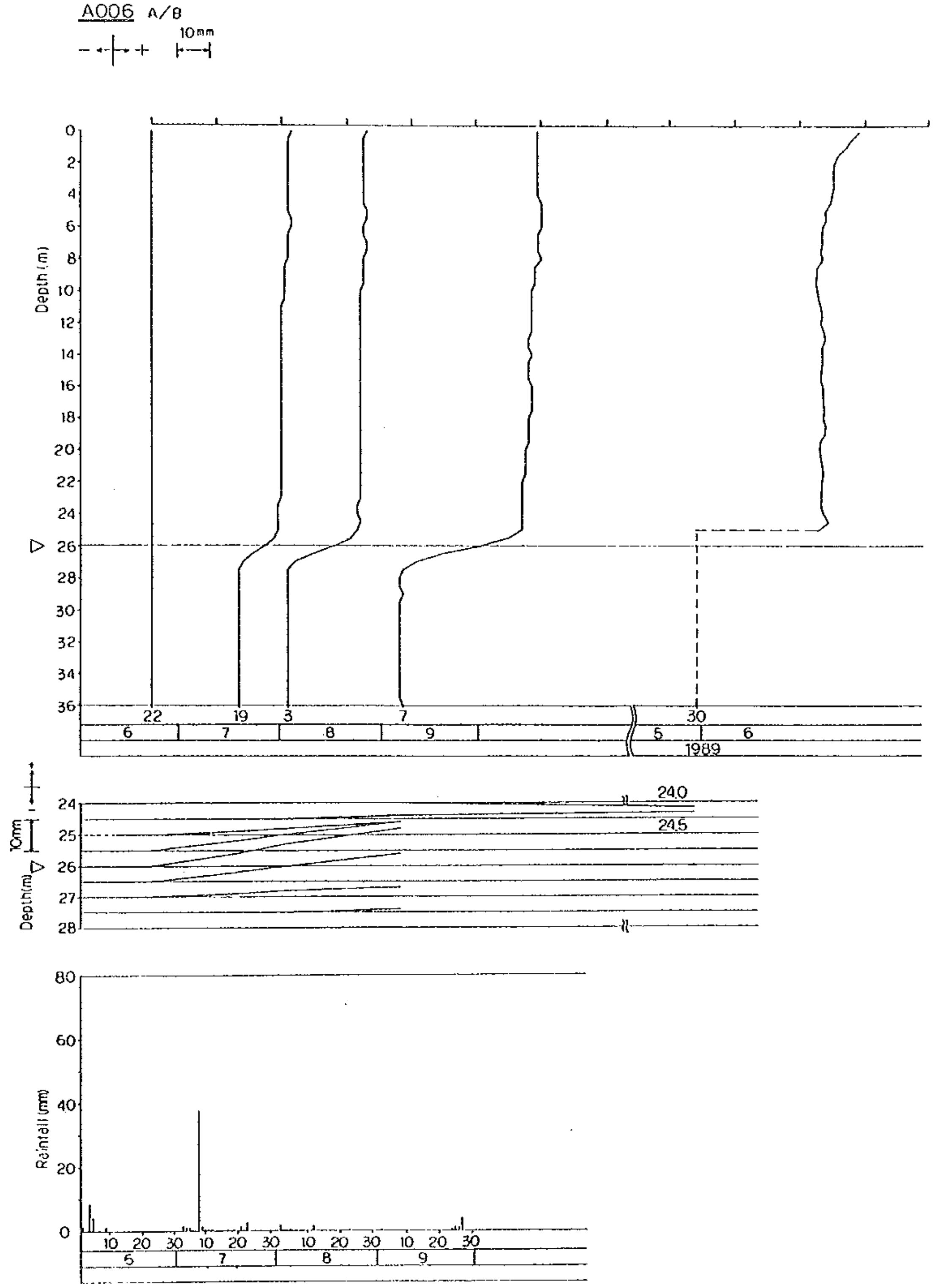


DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, A005

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

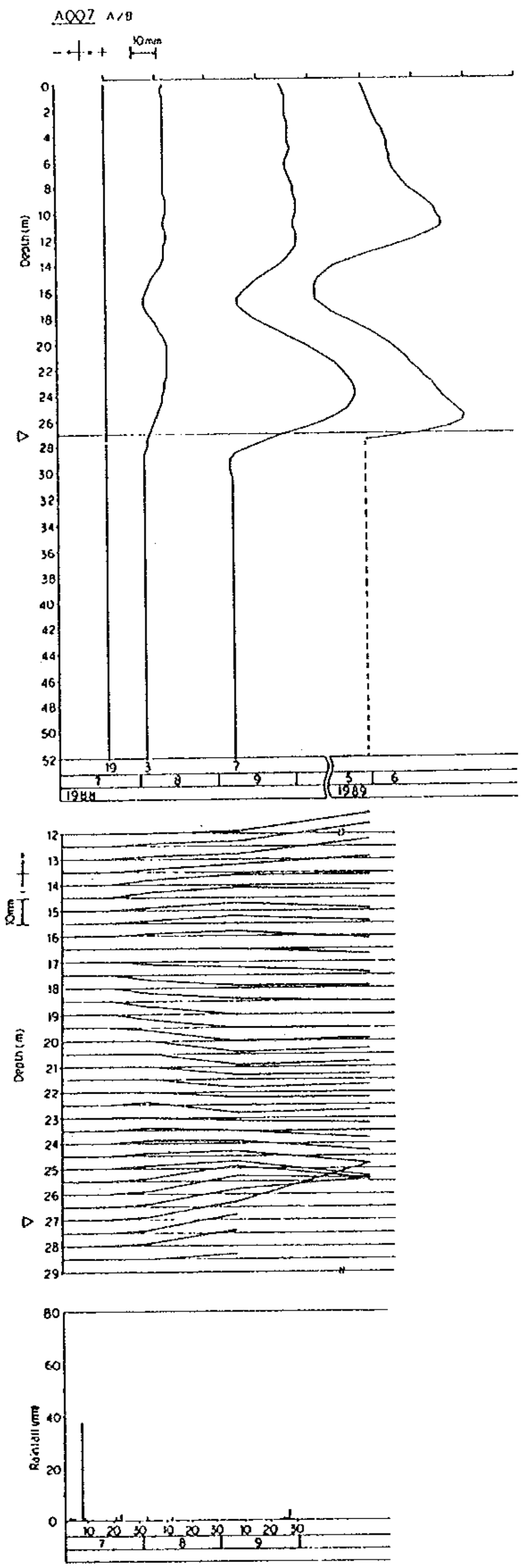
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-6



DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, A006	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY

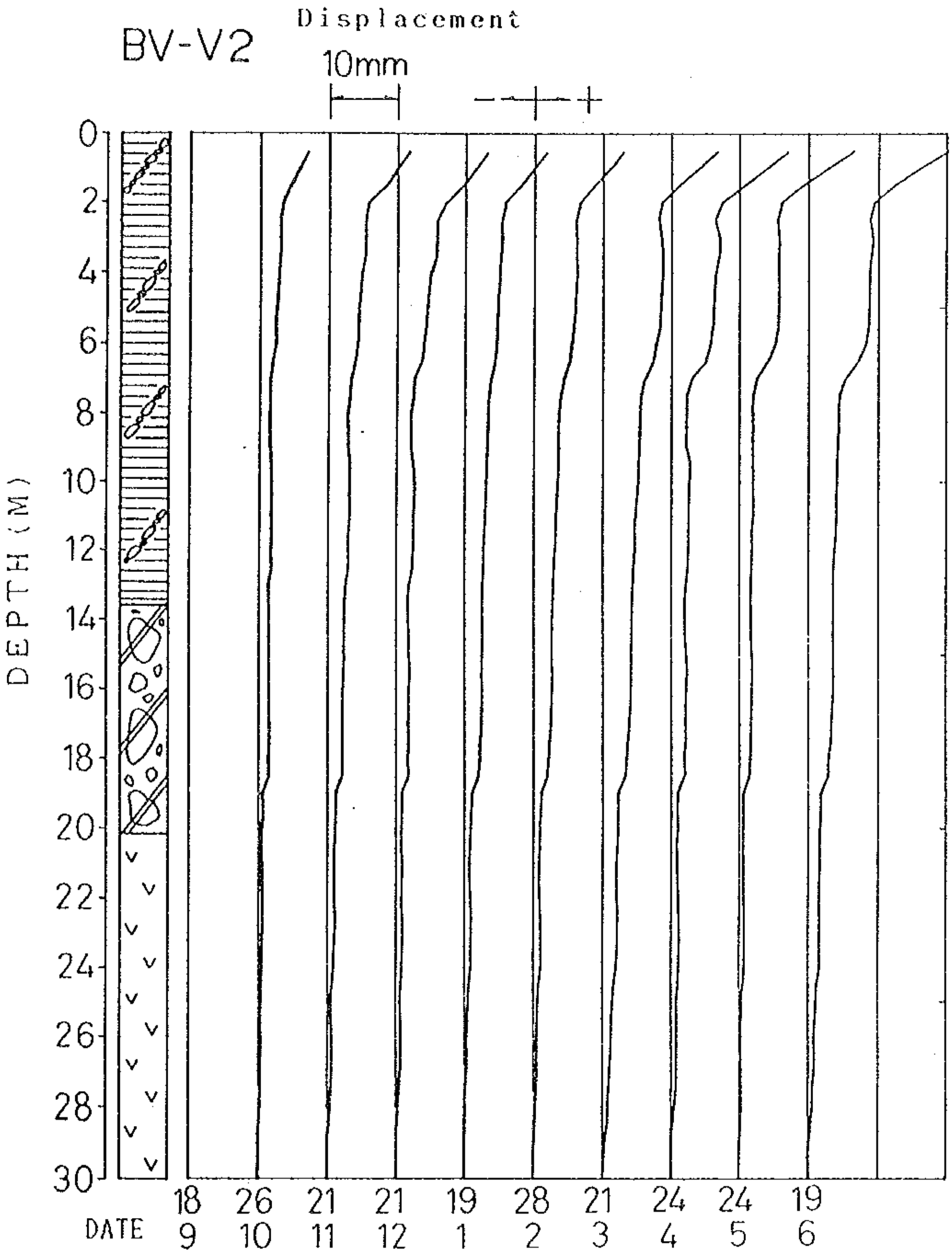
Fig. I.2.6-7



DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, A007

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

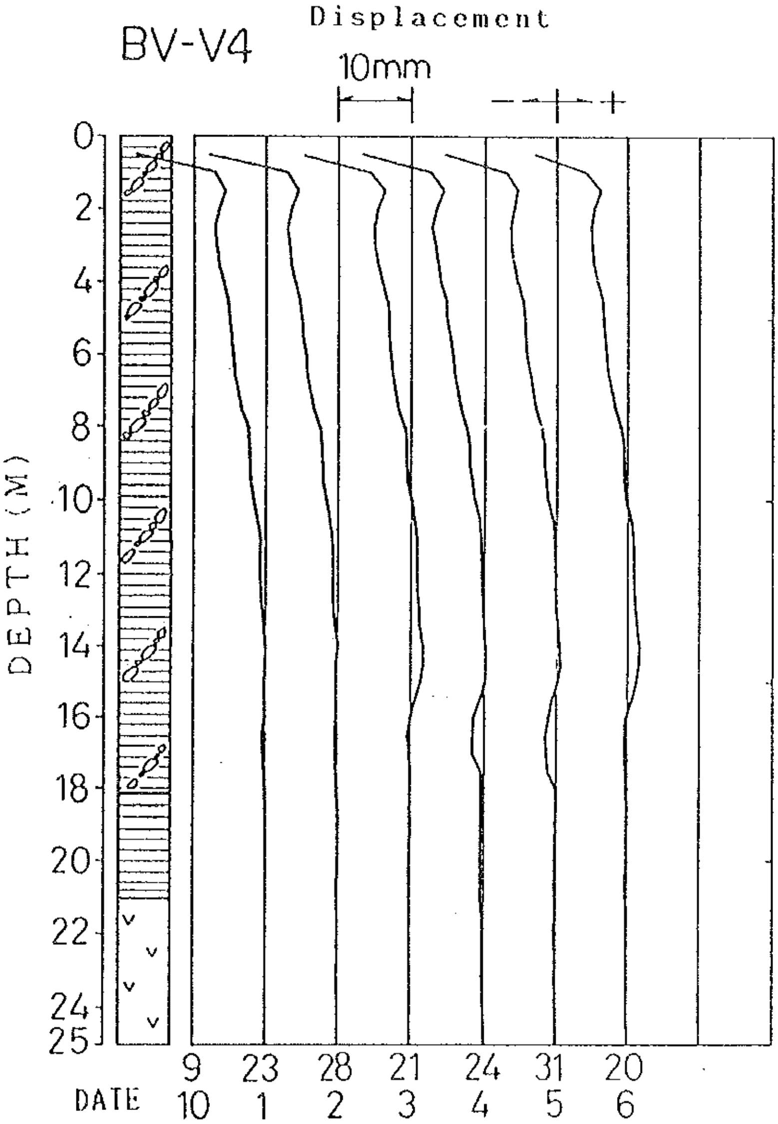
JAPAN INTERNATIONAL COOPERATION AGENCY



DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-V2

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

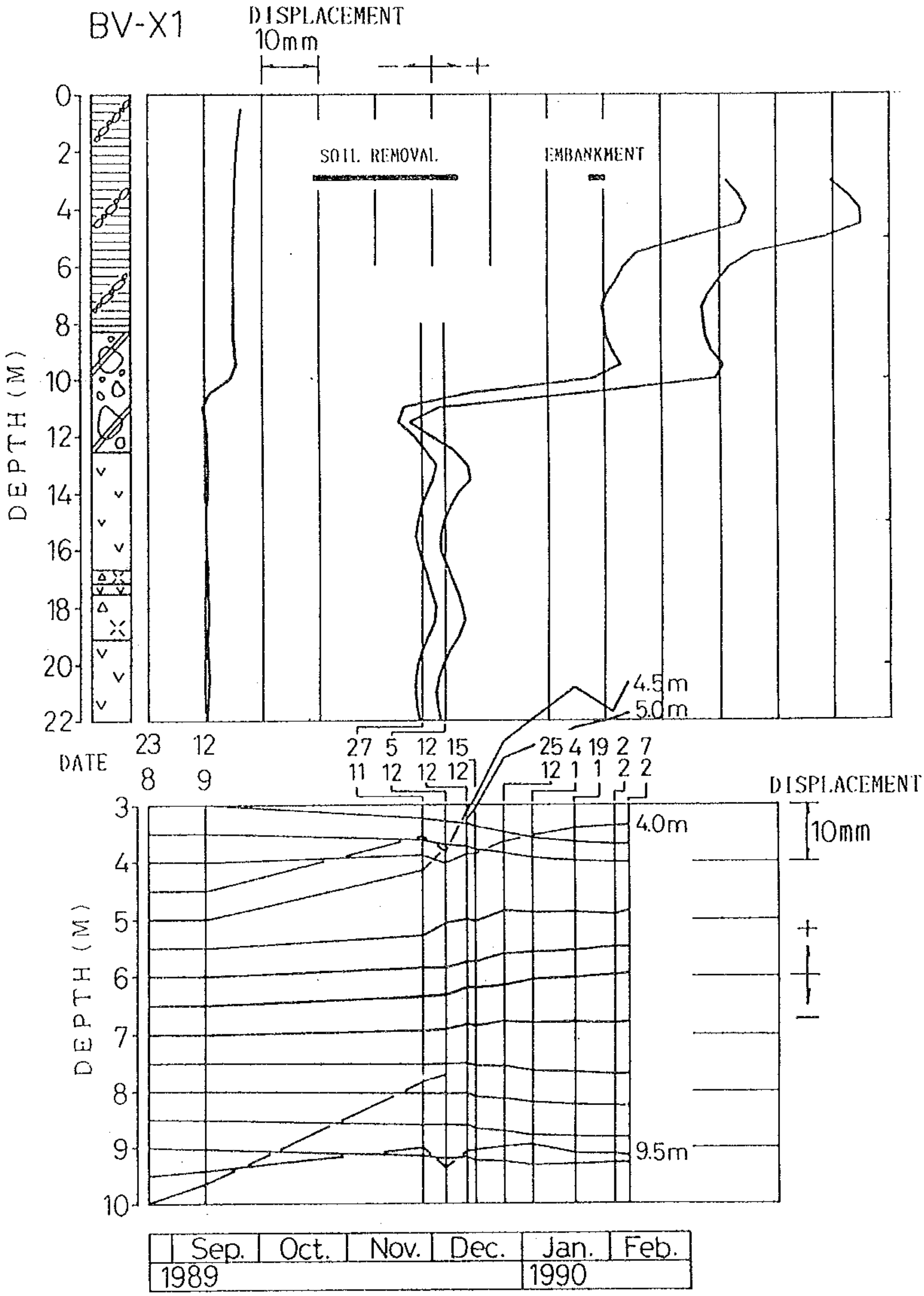


DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-V4

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-10

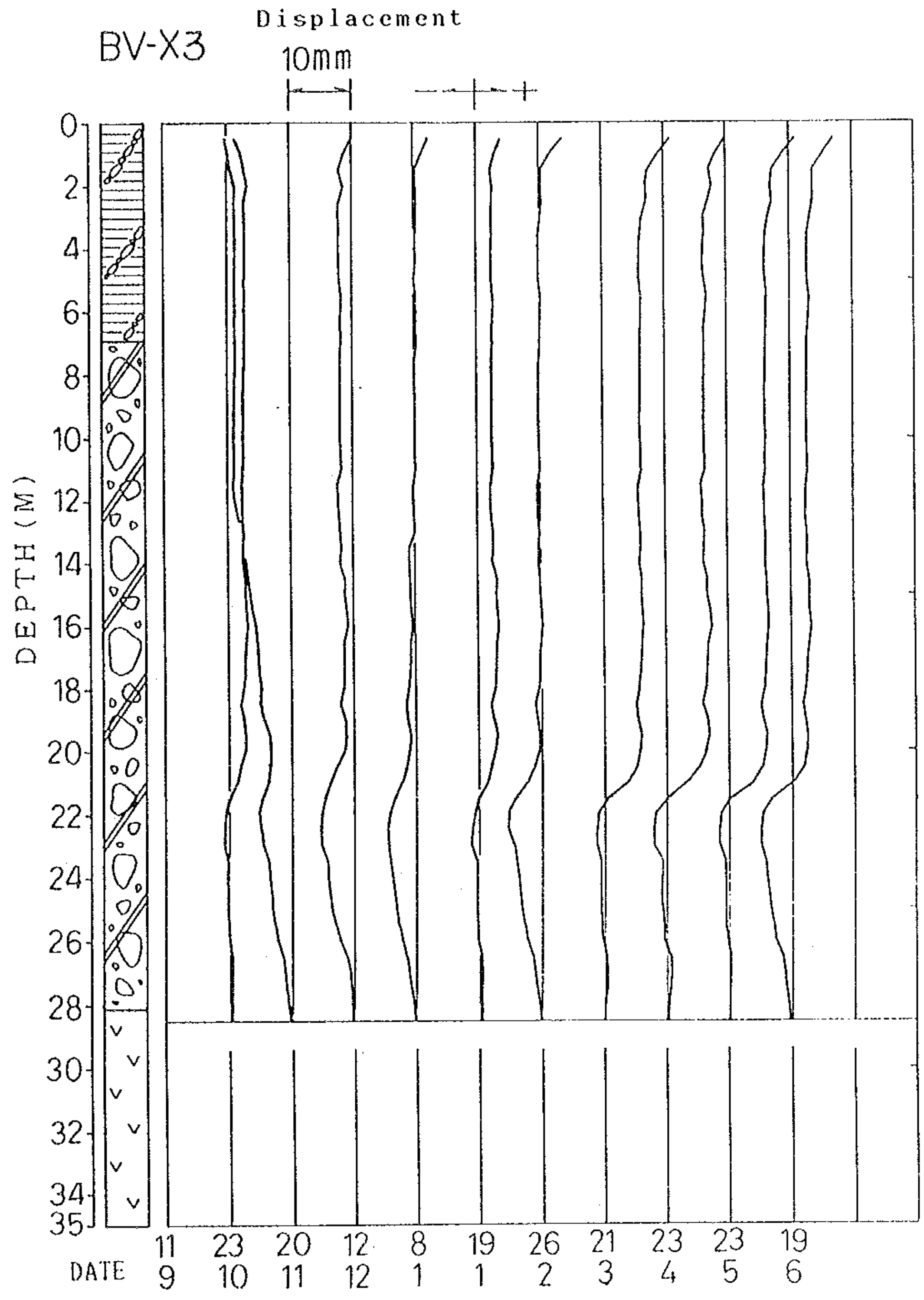


DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-X1

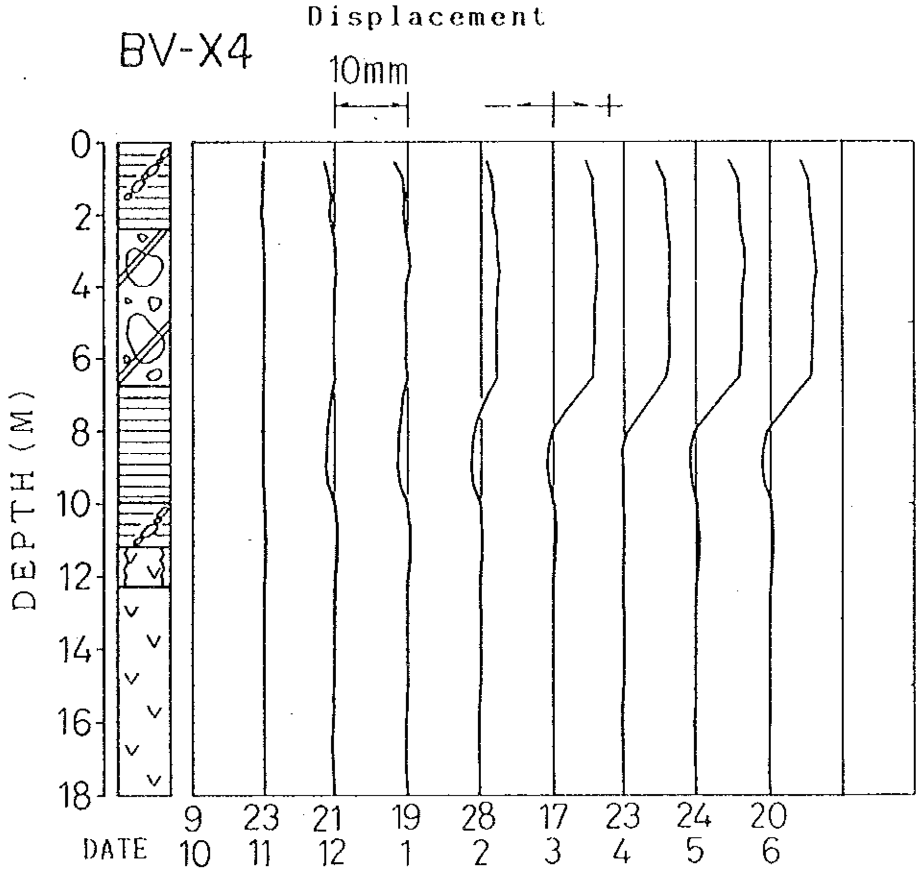
GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-11



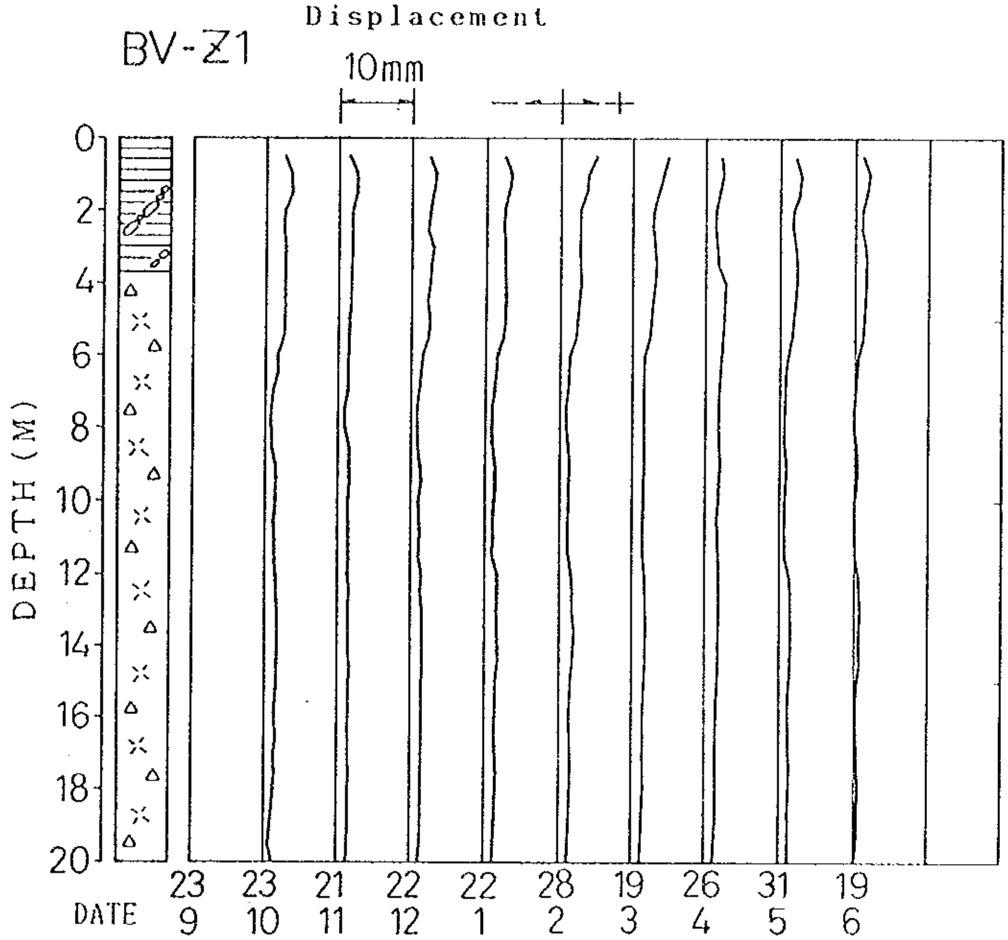
DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-X3	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY



DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-X4

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

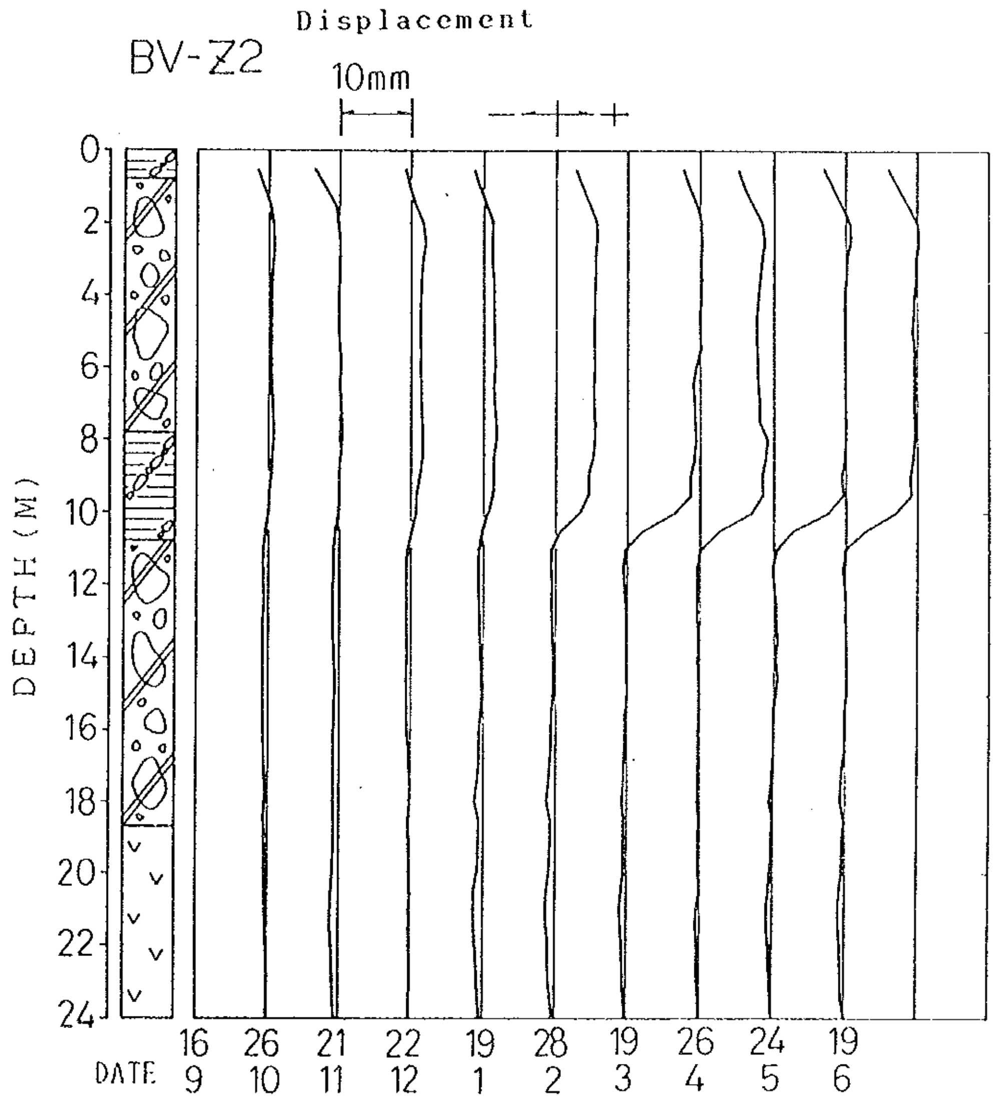
JAPAN INTERNATIONAL COOPERATION AGENCY



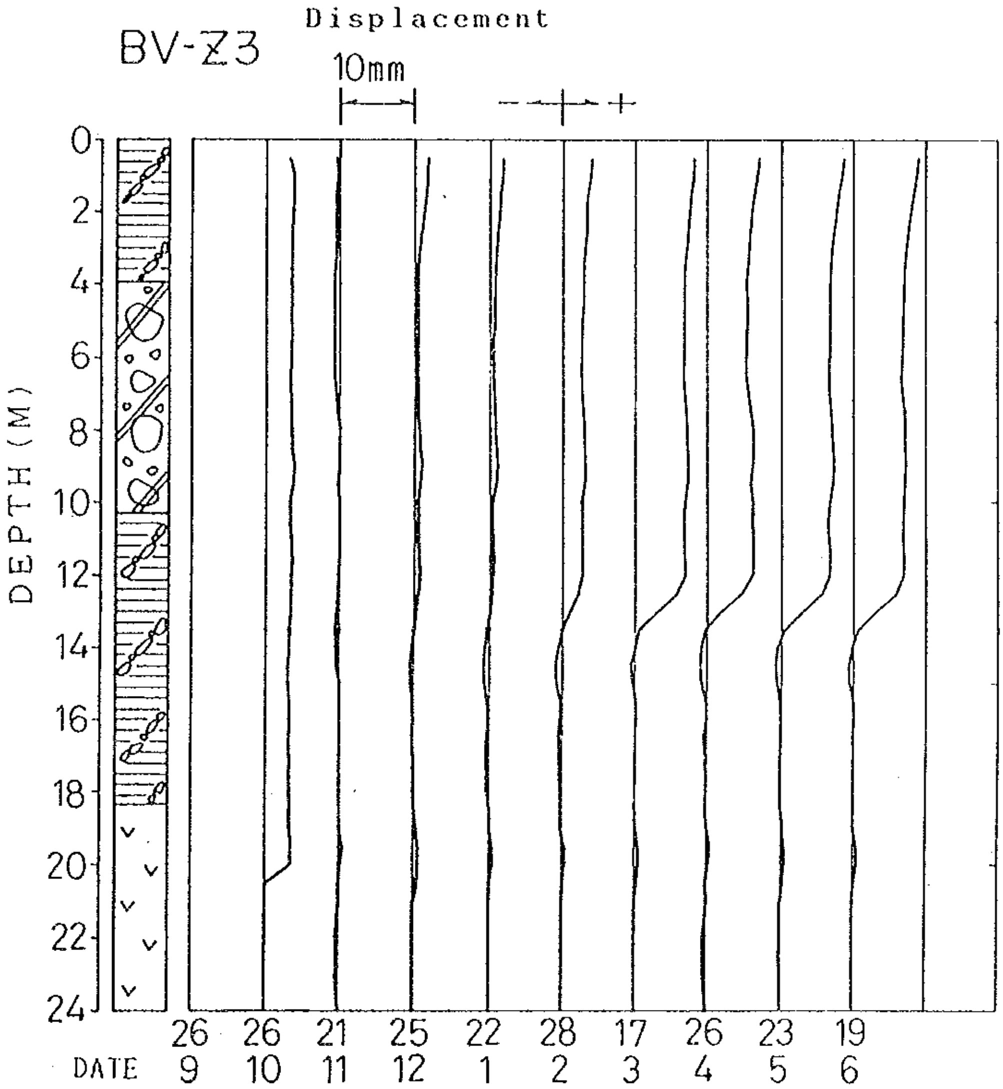
DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-Z1

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY



DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-Z2	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY

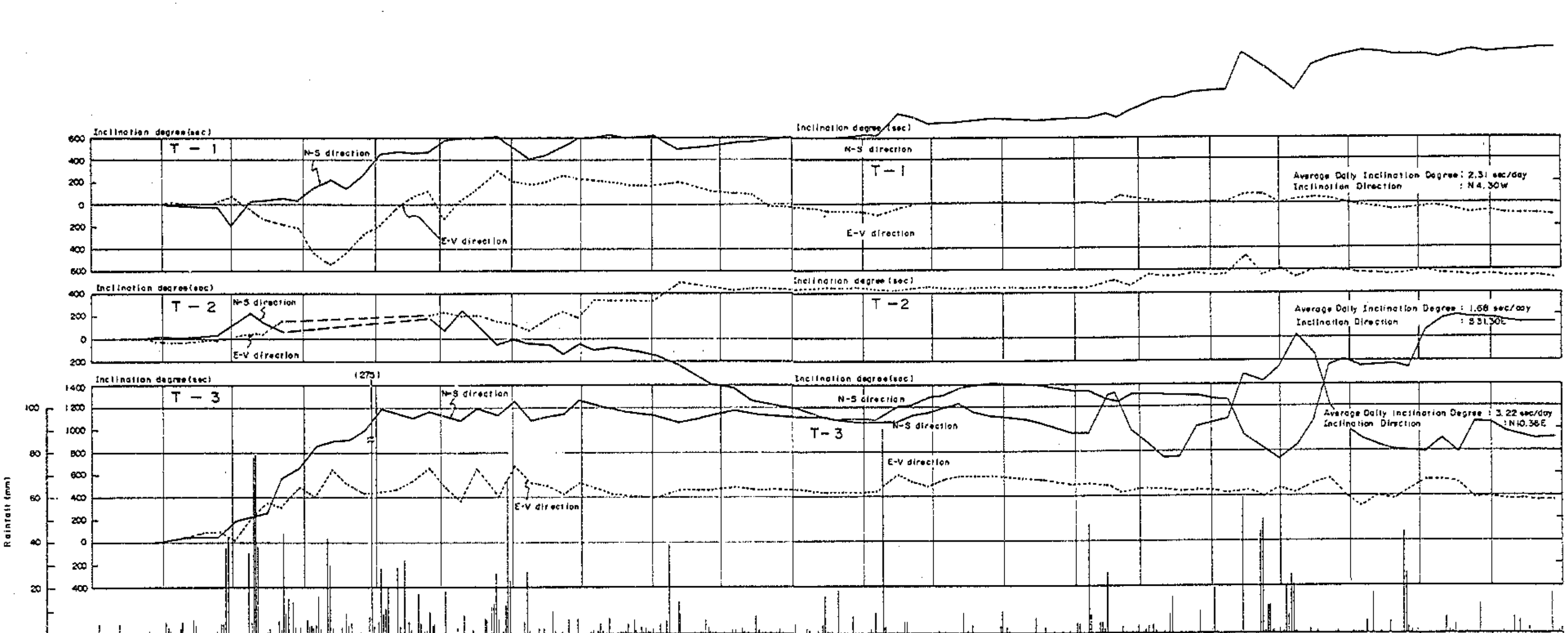


DISPLACEMENT OF BOREHOLE INCLINOMETER IN BOREHOLE, BV-Z3

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-16

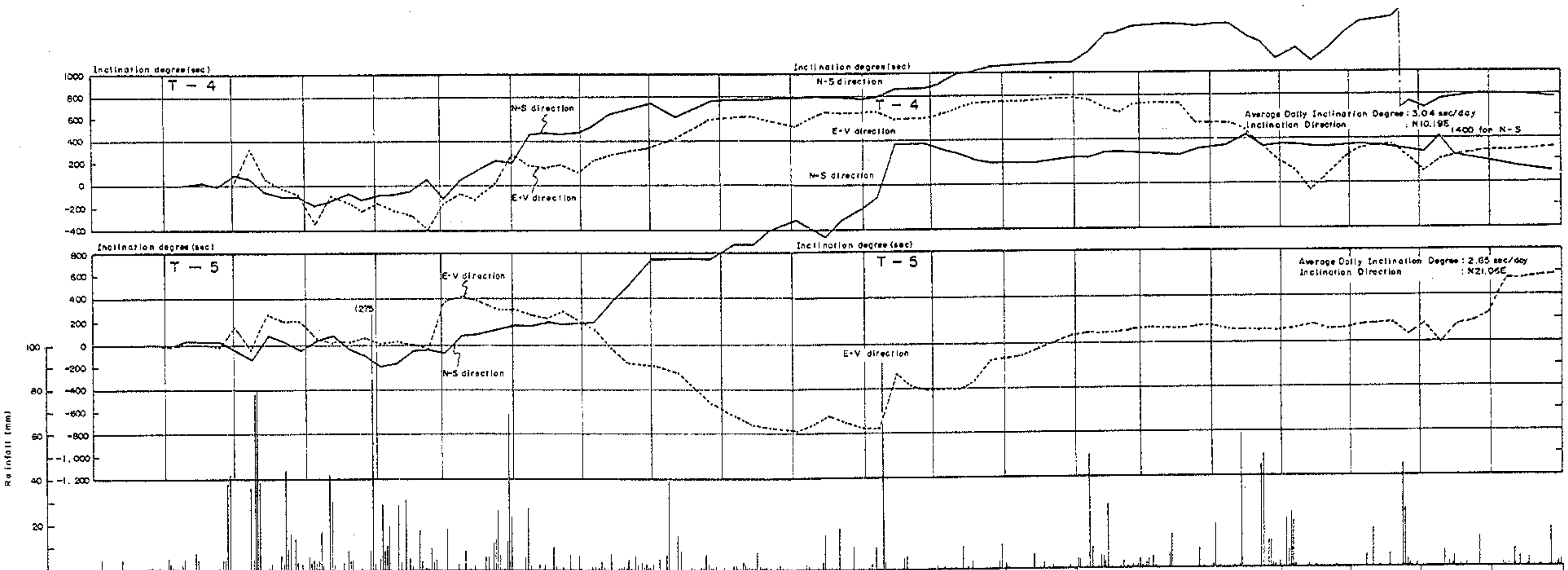


Date	Oct. '88	Nov.	Dec.	Jan. '89	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug. '89	Sep	Oct.	Nov.	Dec.	Jan. '90	Feb.	Mar.	Apr.	May	Jun.
Rainfall	14.0	108.2/122.2	330.4/452.6	388.1/840.7	197.8/1038.5	215.1/1253.6	61.5/1315.1	28.8/1343.9	83.2/1427.1	23.4/1450.5	36.1	120.8	36.6	17.9	123.7	46.5	208.1	84.4	109.7	30.1	41.0

DISPLACEMENT OF TILTMETERS, T1～T3

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6–17

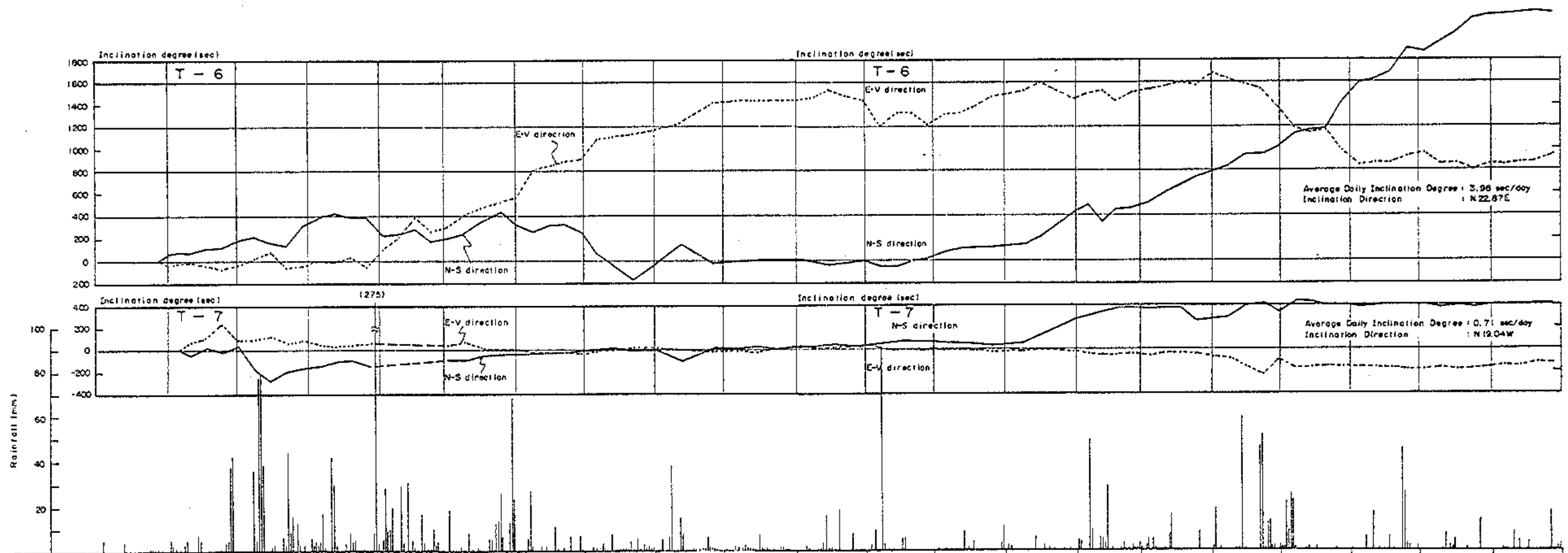


Date	Oct. '88	Nov.	Dec.	Jan. '89	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug. '89	Sep.	Oct.	Nov.	Dec.	Jan. '90	Feb.	Mar.	Apr.	May	Jun.
Rainfall	14.0	108.2/122.2	330.4/452.6	388.1/840.7	197.8/1038.5	215.1/1253.6	61.5/1315.1	28.8/1343.9	83.2/1427.1	23.4/1450.5	36.1	120.8	36.6	17.9	123.7	46.5	208.1	84.4	104.7	30.1	41.0

DISPLACEMENT OF TILTMETERS, T4～T5

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-18

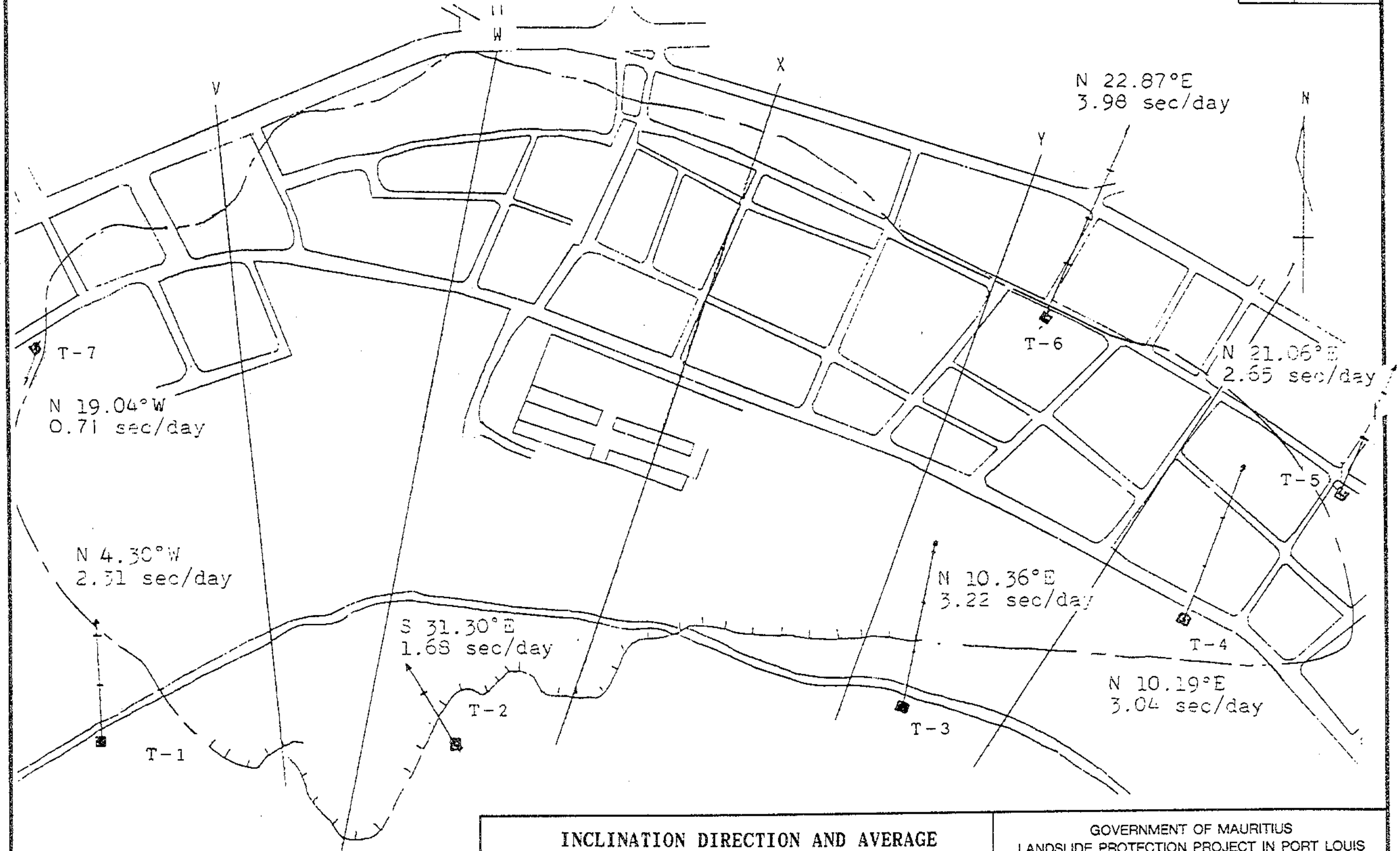


Date	Oct. '88	Nov.	Dec.	Jan. '89	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug. '89	Sep	Oct.	Nov.	Dec.	Jan. '90	Feb.	Mar.	Apr.	May	Jun.
Rainfall	14.0	106.2/122.2	330.4/452.6	388.1/040.7	197.8/10385	215.1/1253.6	61.5/1315.1	28.8/1343.9	83.2/1427.1	23.4/1450.5	36.1	120.8	36.6	17.9	123.7	46.5	208.1	84.4	109.7	30.1	41.0

DISPLACEMENT OF TILTMETERS, T6～T7

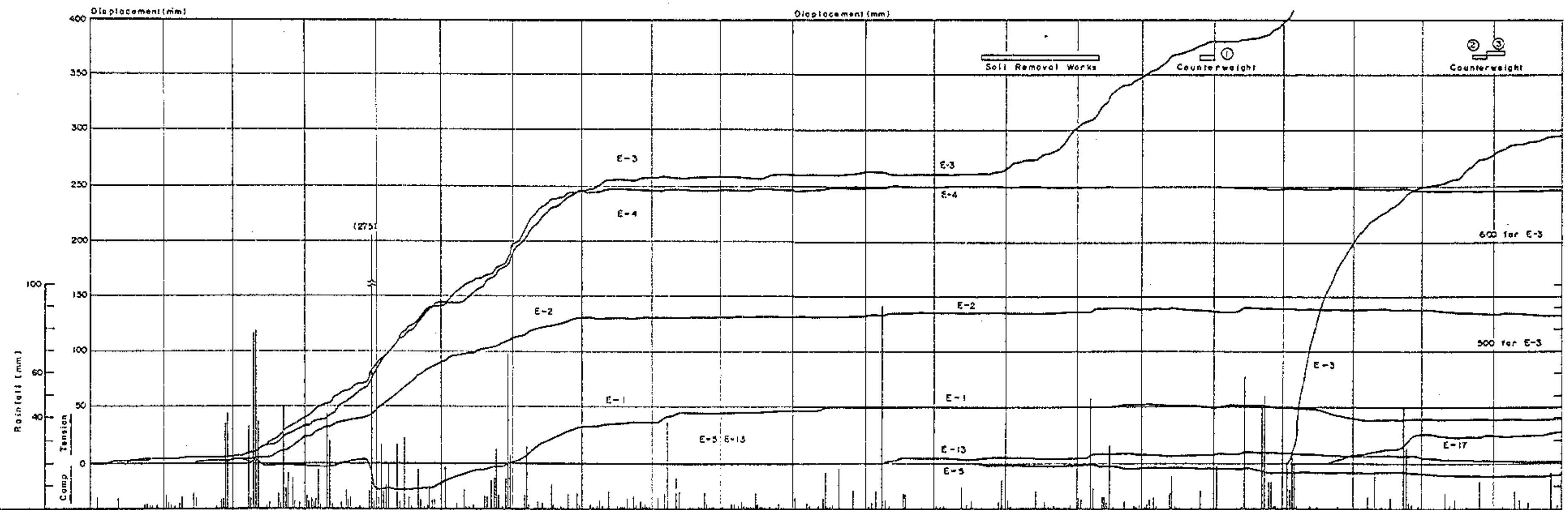
GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6–19



INCLINATION DIRECTION AND AVERAGE ANGLE OF TILTMETER RECORD

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY



Date	Oct. '88	Nov.	Dec.	Jan. '89	Feb.	Mar.	Apr.	May	Jun.	Jul.
Monthly Rainfall	14.0	108.2/122.2	330.4/452.6	388.1/840.7	197.8/1038.5	215.1/1253.1	61.5/1315.1	28.8/1343.9	83.2/1427.1	23.4/1450.5

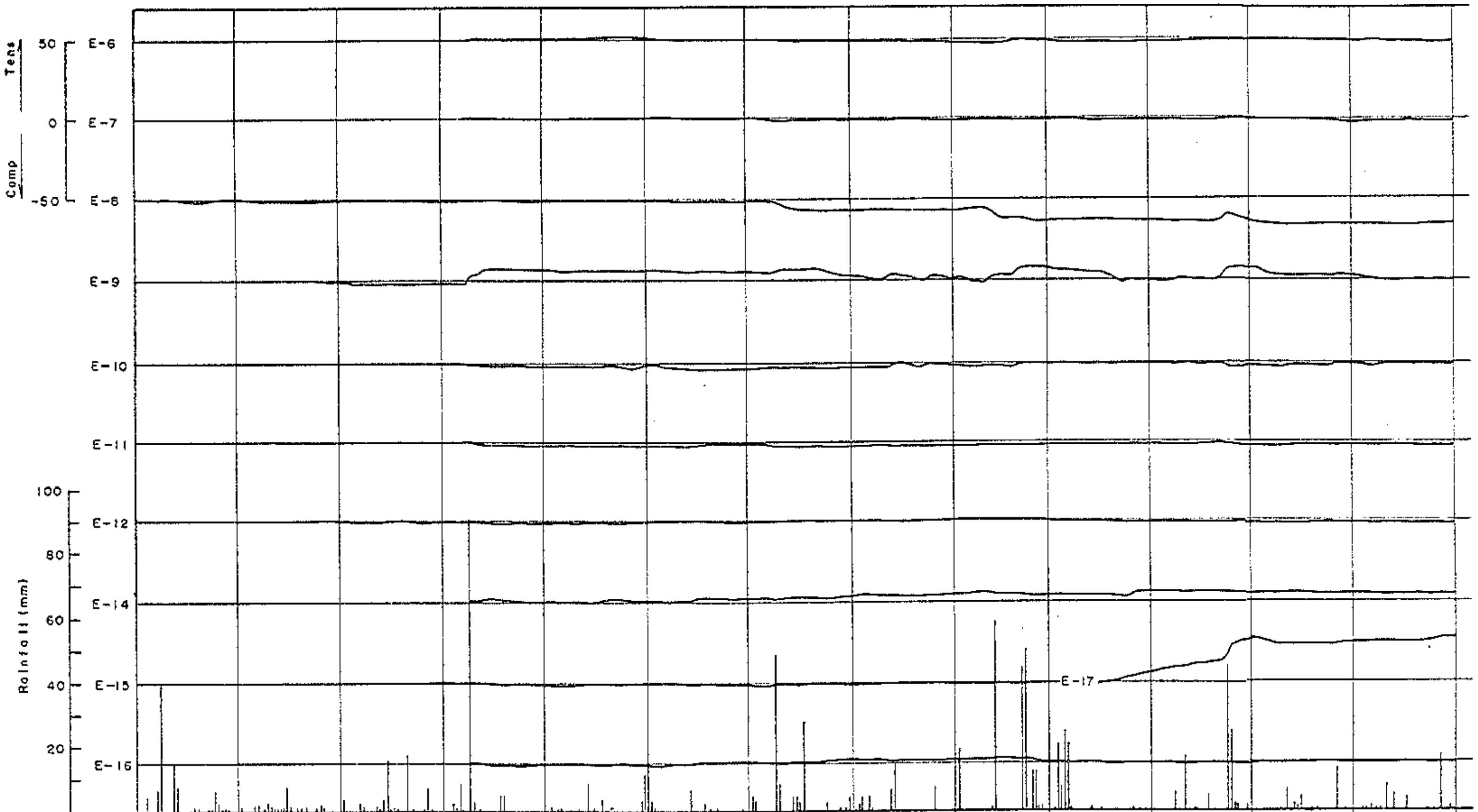
Date	Aug. '89	Sep.	Oct.	Nov.	Dec.	Jan. '90	Feb.	Mar.	Apr.	May	Jun.
Monthly Rainfall	36.1	120.8	36.6	17.9	123.7	46.5	206.1	84.4	109.7	30.1	41.0

DISPLACEMENT OF EXTENSOMETER AT CROWN PORTION OF LANDSLIDE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-21



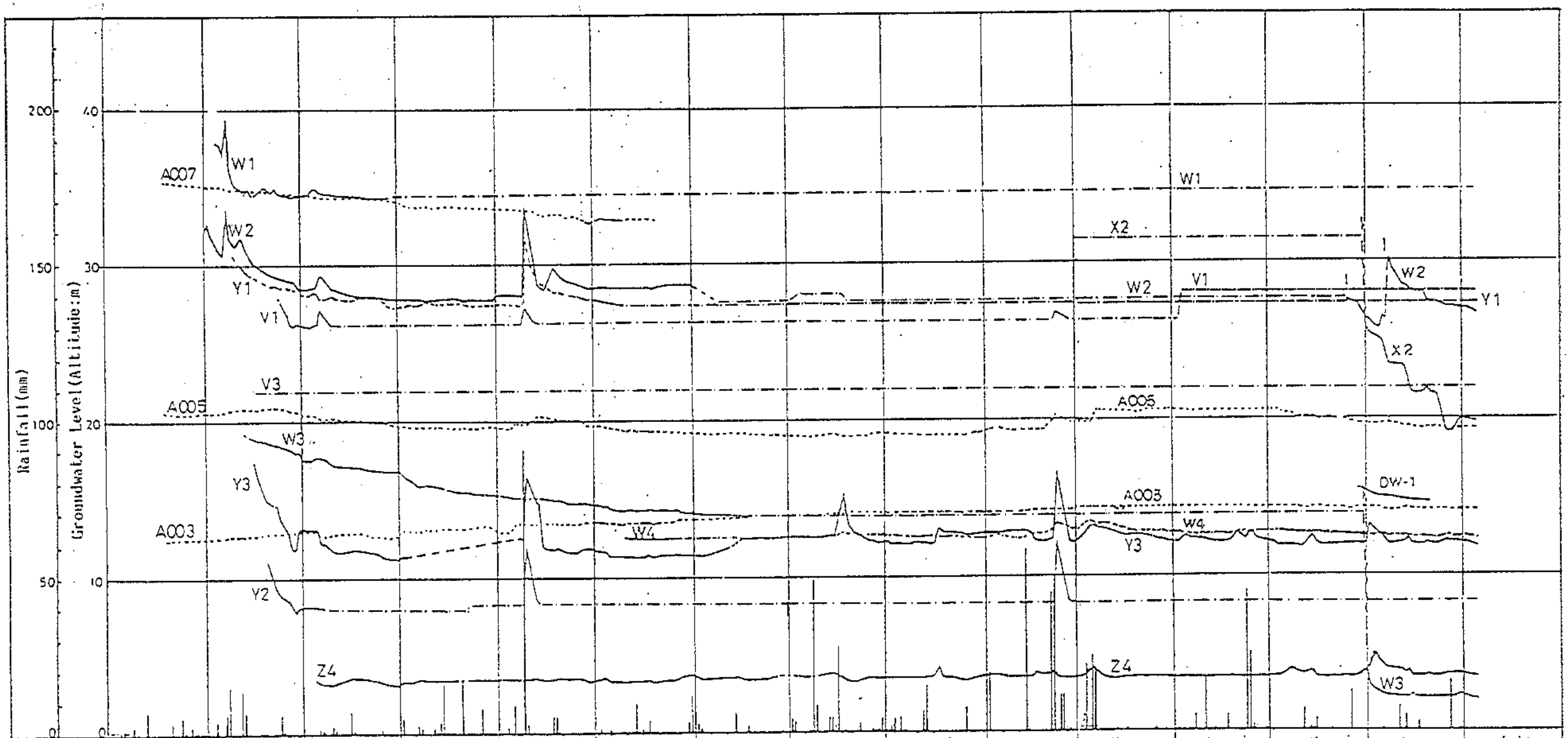
Date	Jun. '89	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. '90	Fev.	Mar.	Apr.	May	Jun.
Monthly Rainfall	83.2	23.4	36.1	120.8	36.6	17.9	123.7	46.5	208.1	84.4	109.7	30.1	41.0

DISPLACEMENT OF EXTENSOMETER AT CENTRAL AND TOE PORTIONS OF LANDSLIDE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-22



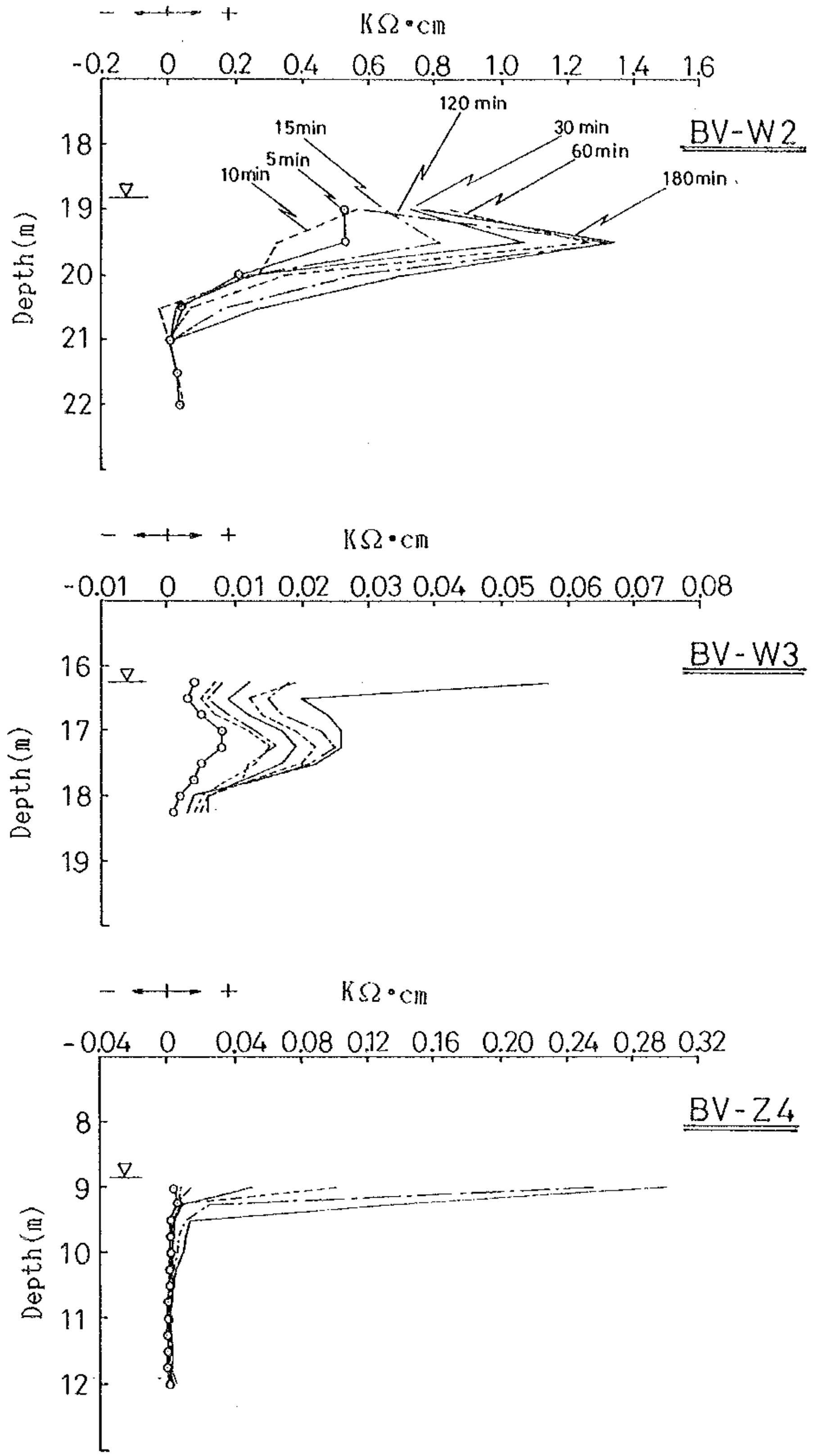
Date	May.'89	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.'90	Feb.	Mar.	Apr.	May	Jun.	Jul.
Rainfall Monthly(mm)	28.8	83.2	23.4	36.1	120.8	36.6	17.9	123.7	46.5	208.1	84.4	109.7	30.1	41.0	

—·—·— :Groundwater level is deeper than the bottom of borehole

OBSERVATION RESULTS OF GROUNDWATER LEVEL IN BOREHOLES

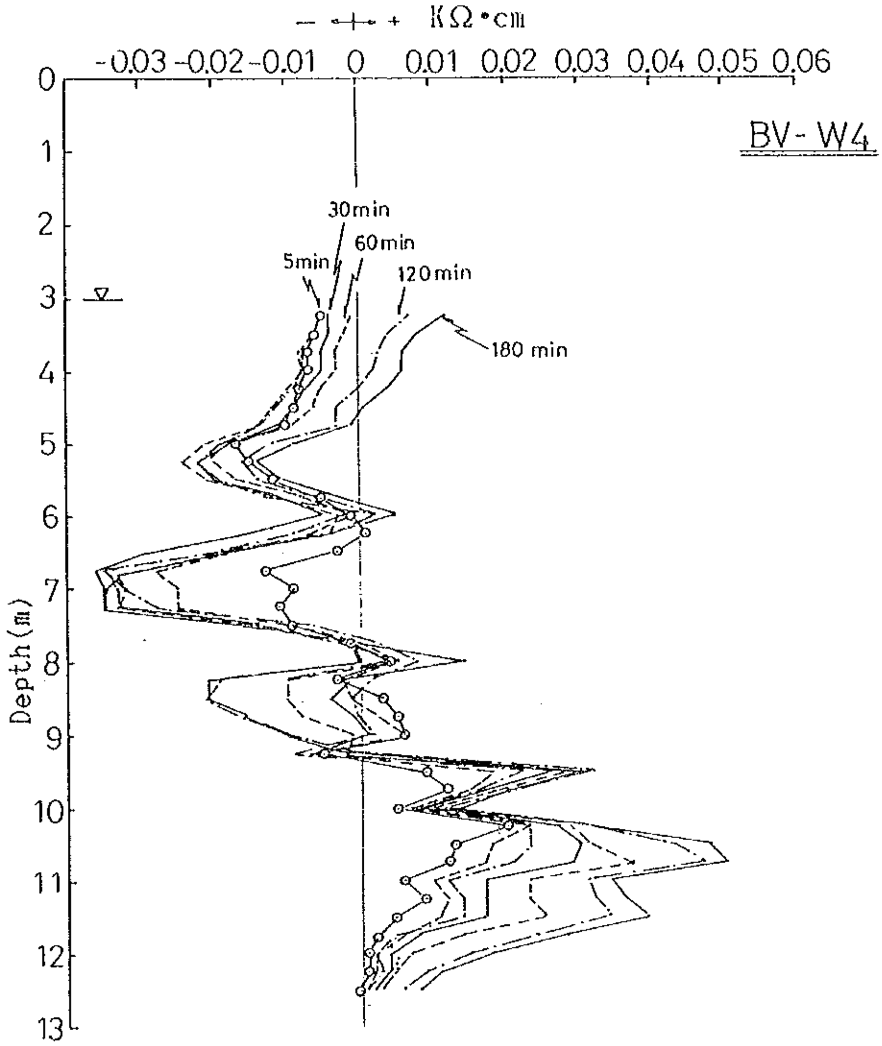
GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.6-23



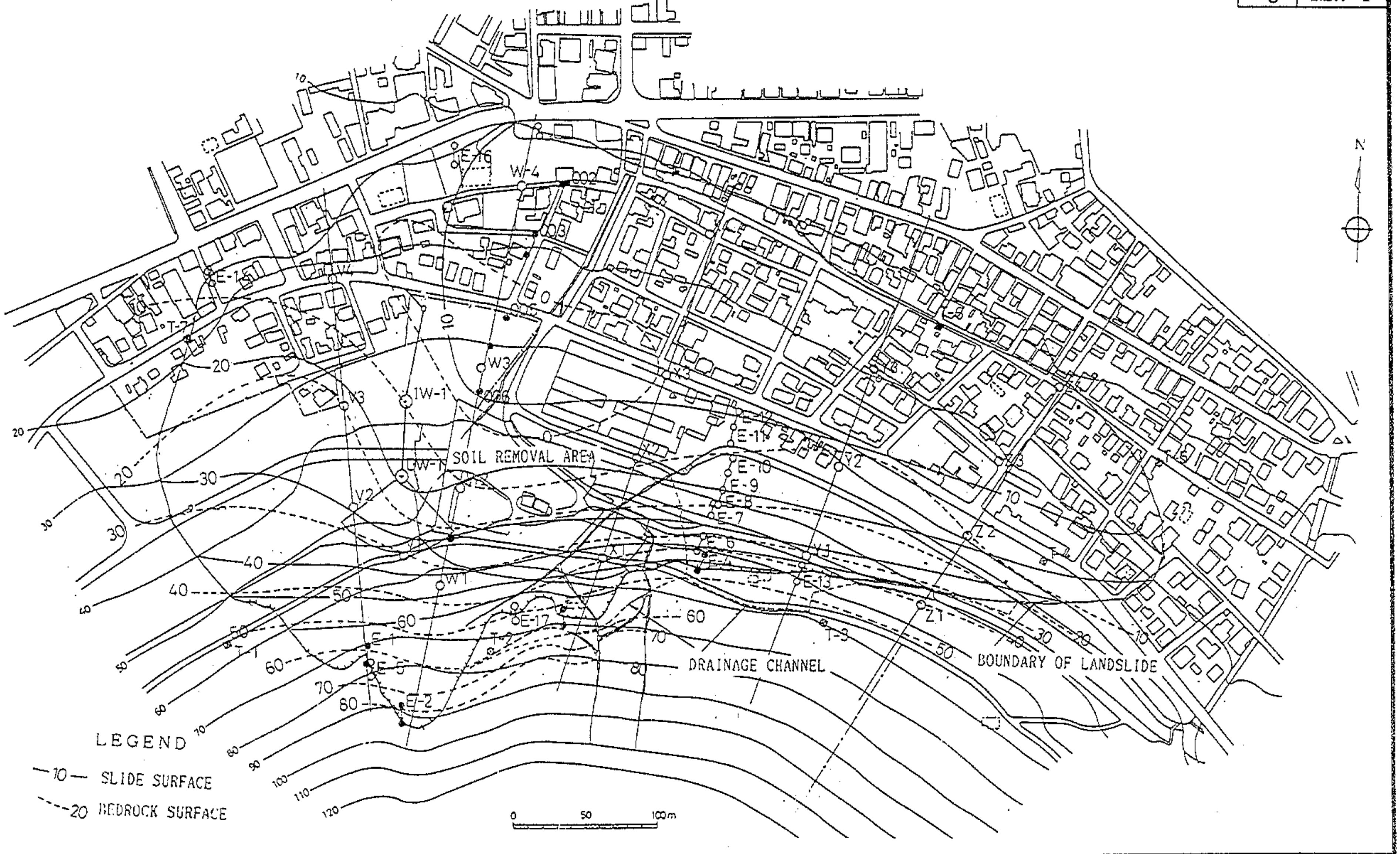
OBSERVATION RESULT OF RESISTIVITY OF GROUNDWATER IN BOREHOLE, BV-W2, BV-W3 AND BV-Z4

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY



OBSERVATION RESULT OF RESISTIVITY OF GROUNDWATER IN BOREHOLE BV-W4	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.7-1

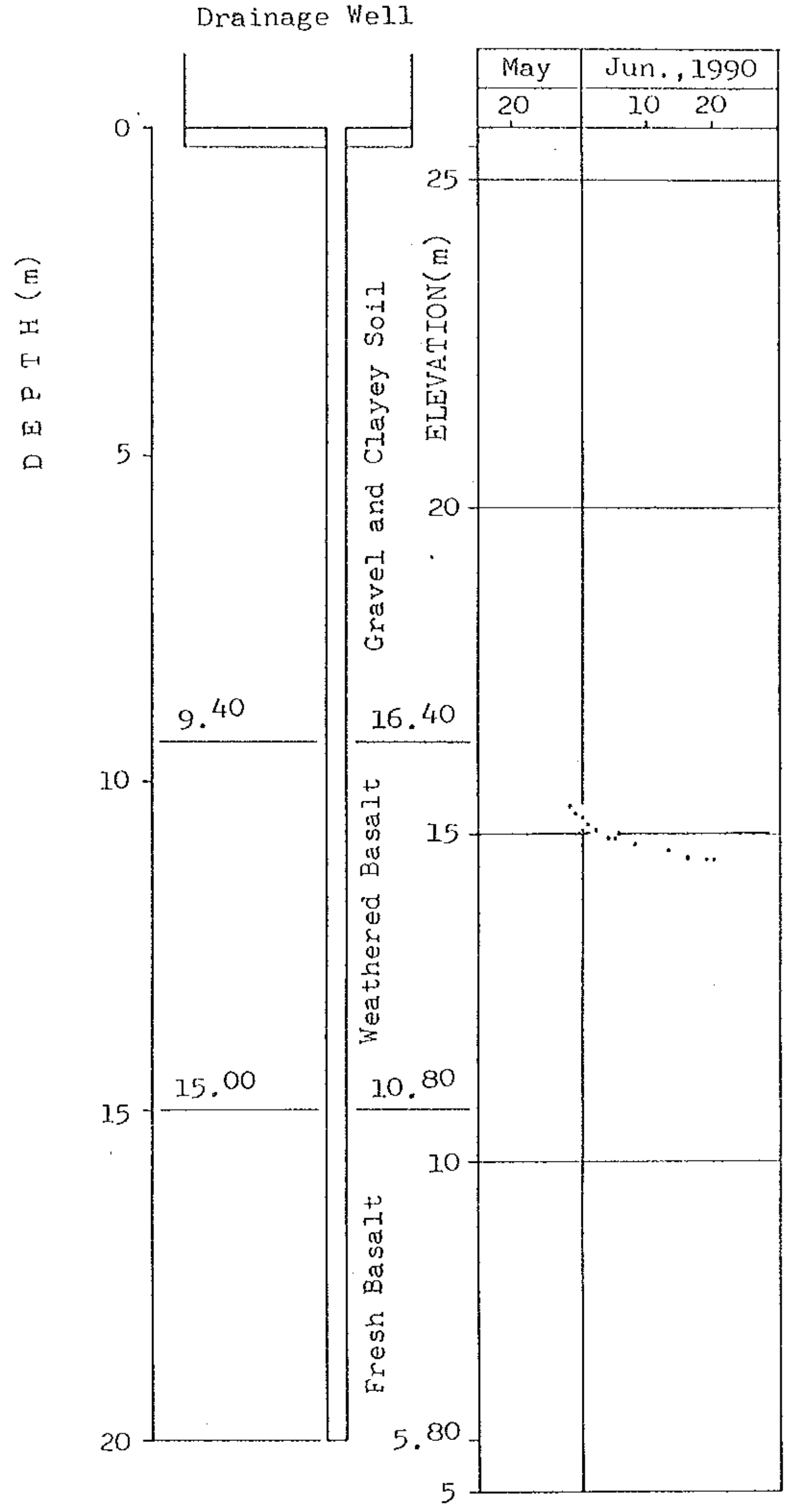


CONTOUR MAP OF ASSUMED SLIDE SURFACE AND BEDROCK SURFACE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 1.2.7-2

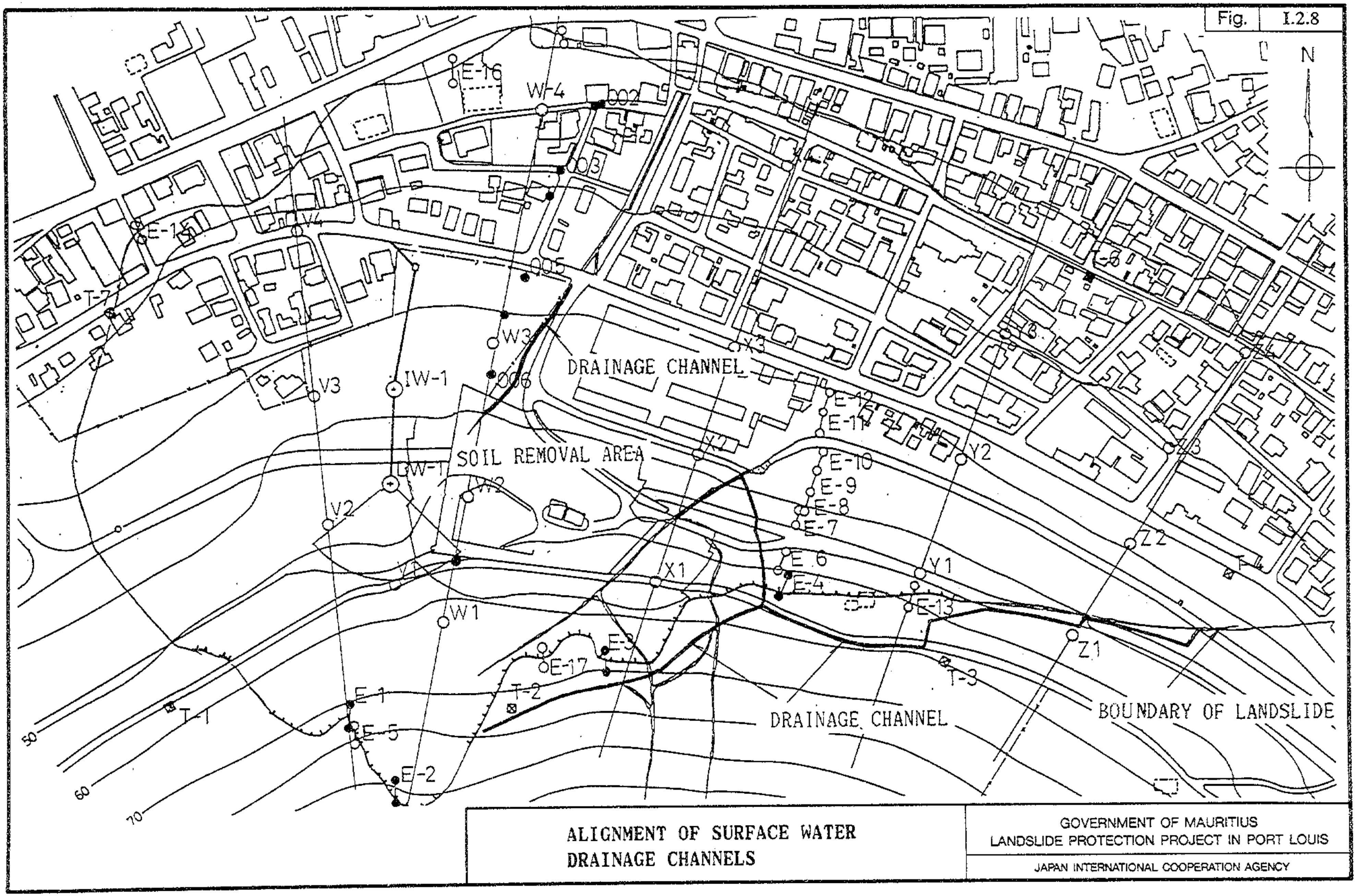


GROUNDWATER LEVEL AROUND DRAINAGE WELL

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.2.8

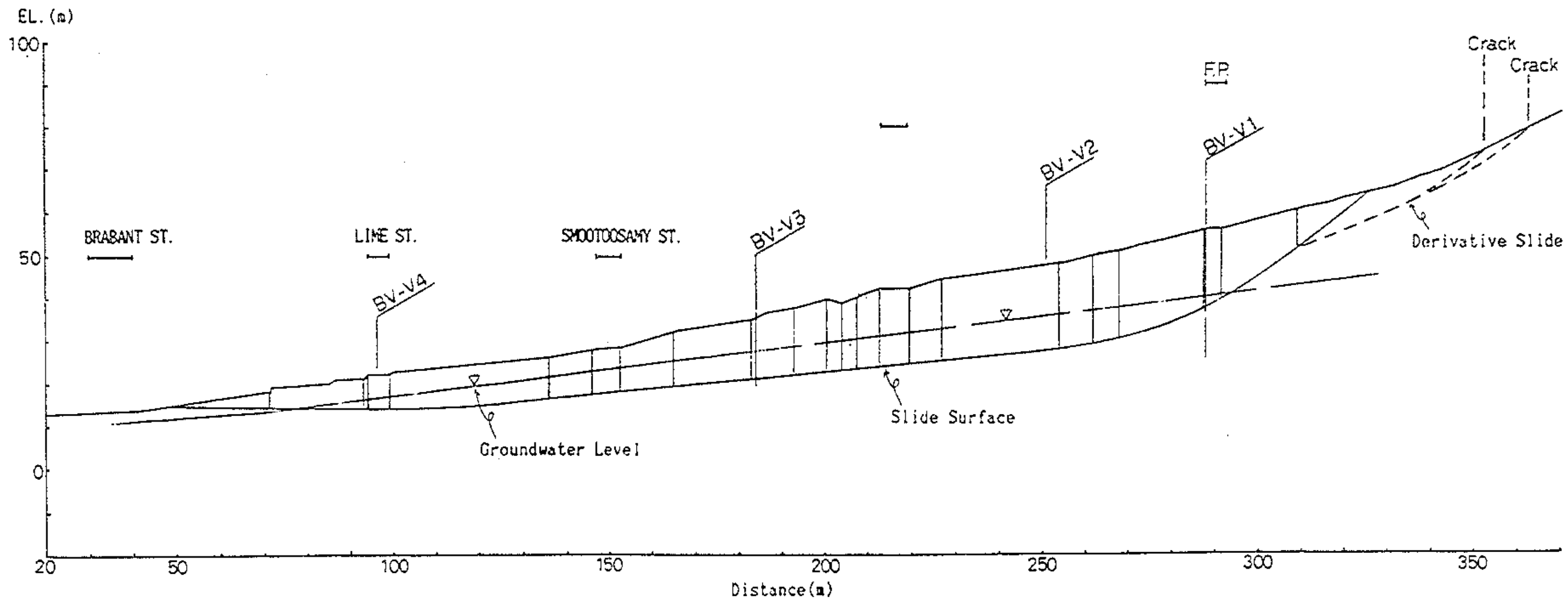


ALIGNMENT OF SURFACE WATER DRAINAGE CHANNELS

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.1-1

Cohesion of Slide Surface	c=1.0 t/m²
Internal Friction Angle of Slide Surface	ϕ=9.4° (tanϕ=0.16478)
Safety Factor before Counter Measures	Fs=1.00
Safety Factor after Conpletion of Drainage Well (Experimental Investigation)	Fs=1.071

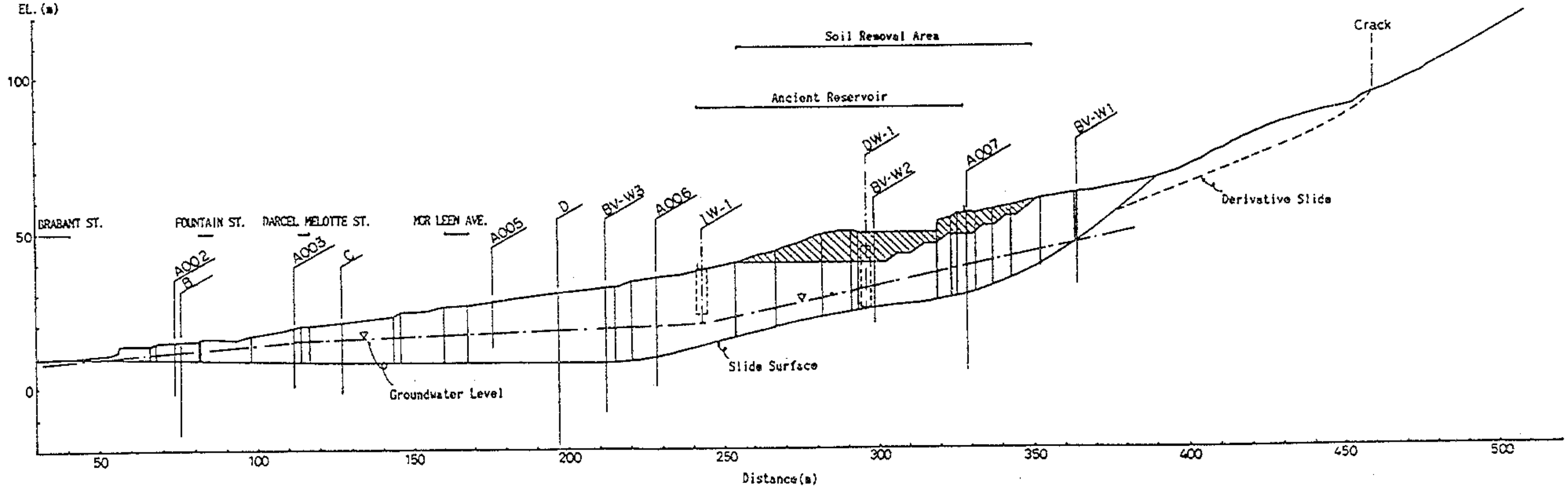


PROFILE OF STABILITY ANALYSIS ALONG V-LINE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.1-2

Cohesion of Slide Surface		$c=1.0\ t/m^2$
Internal Friction Angle of Slide Surface		$\phi=9.7°$ ($\tan\phi=0.1708$)
Safety Factor before Counter Measures		Fs=1.00
Safety Factor after Conpletion of Soil Removal Works		Fs=1.031
Safety Factor after Conpletion of Soil Removal Works and Drainage Well(Experimental Investigation)		Fs=1.092



PROFILE OF STABILITY ANALYSIS ALONG W-LINE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

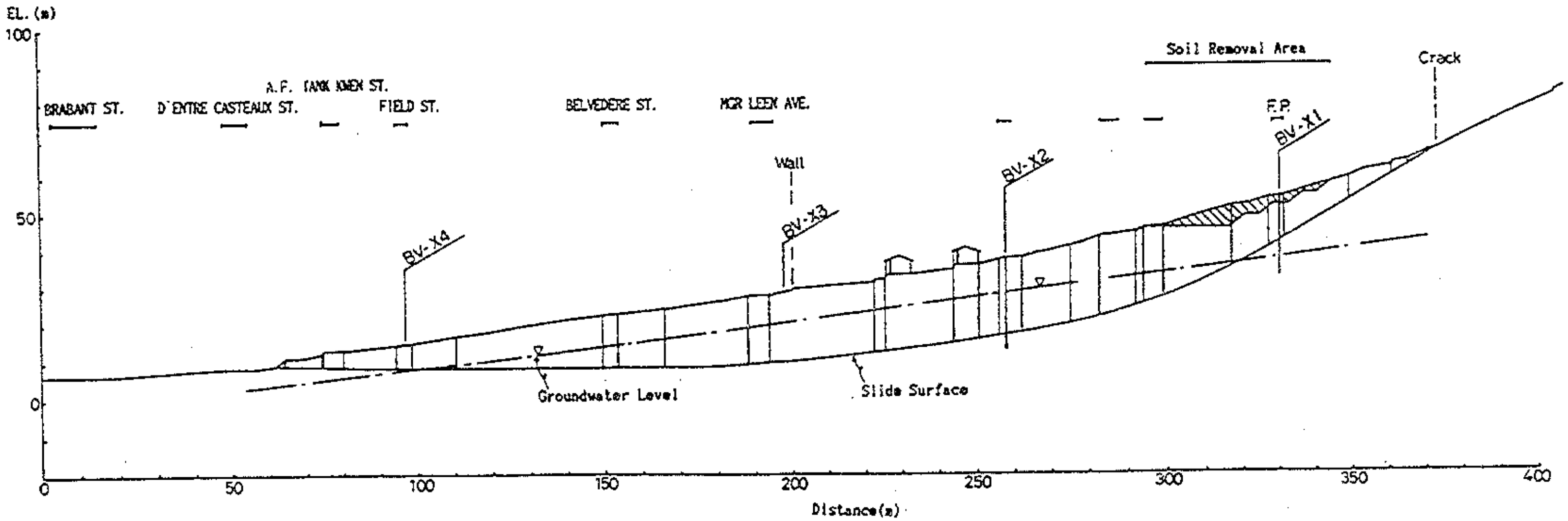
Fig. I.3.1-3

Cohesion of Slide Surface — $c=1.0\ t/m^2$

Internal Friction Angle of Slide Surface — $\phi=9.9°$ ($\tan\phi=0.1740$)

Safety Factor before Counter Measures — Fs=1.00

Safety Factor after Conpletion of Soil Removal Works — Fs=1.071



PROFILE OF STABILITY ANALYSIS ALONG X-LINE

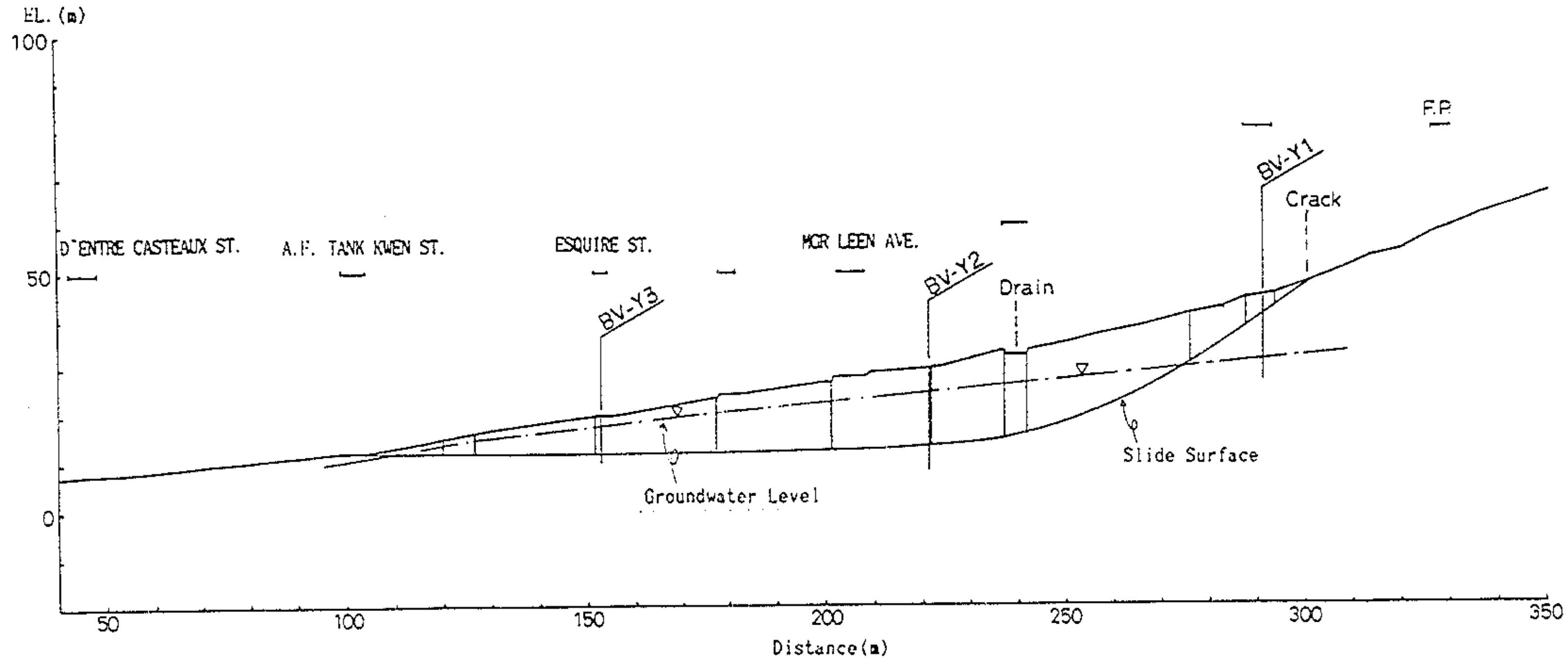
GOVERNMENT OF MAURITIUS

LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.1–4

Cohesion of Slide Surface	$c=1.0\ t/m^2$
Internal Friction Angle of Slide Surface	$\phi=8.8°\ (\tan\phi=0.155)$
Safety Factor before Counter Measures	$Fs=1.00$

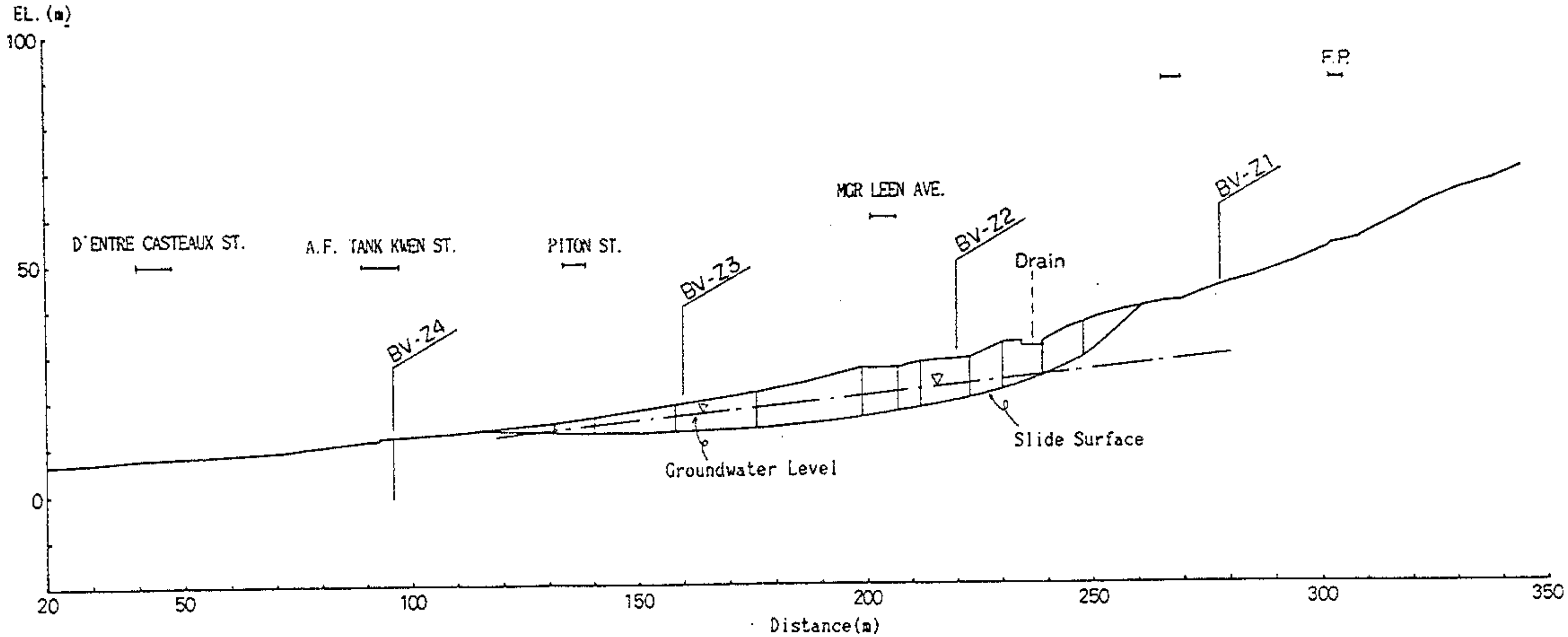


PROFILE OF STABILITY ANALYSIS ALONG Y-LINE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.1-5

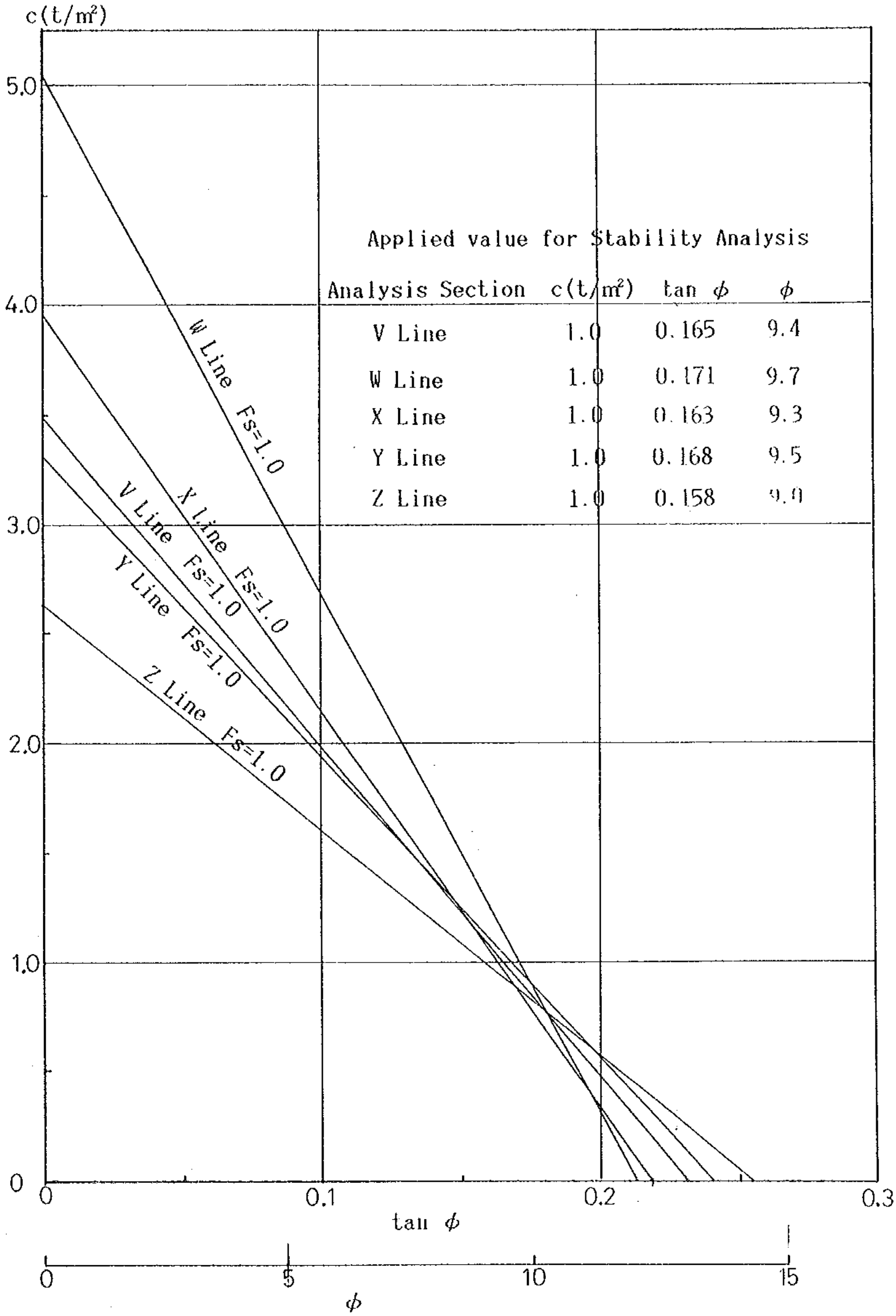
Cohesion of Slide Surface	$c=1.0\ t/m^2$
Internal Friction Angle of Slide Surface	$\phi=6.9°$ ($\tan\phi=0.121$)
Safety Factor before Counter Measures	$Fs=1.00$



PROFILE OF STABILITY ANALYSIS ALONG Z-LINE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.1-6



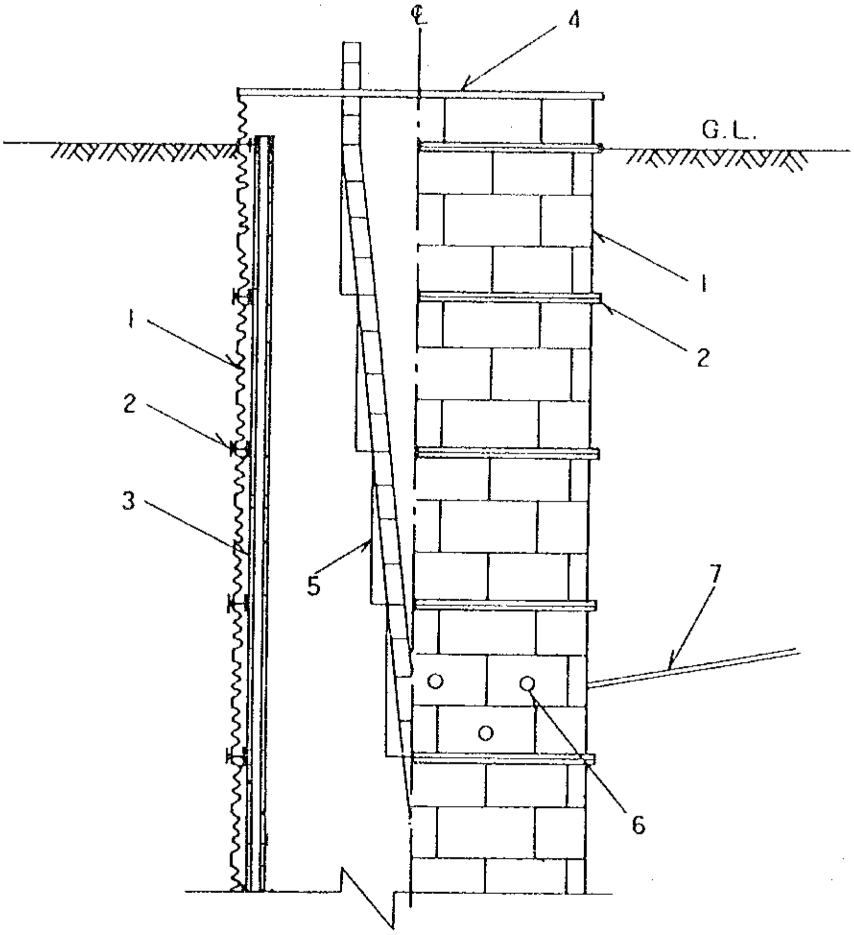
Applied value for Stability Analysis

Analysis Section	c(t/m²)	tan φ	φ
V Line	1.0	0.165	9.4
W Line	1.0	0.171	9.7
X Line	1.0	0.163	9.3
Y Line	1.0	0.168	9.5
Z Line	1.0	0.158	9.0

RELATION BETWEEN INTERNAL FRICTION ANGLE AND COHESION OF MATERIALS ON SLIDE SURFACE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY



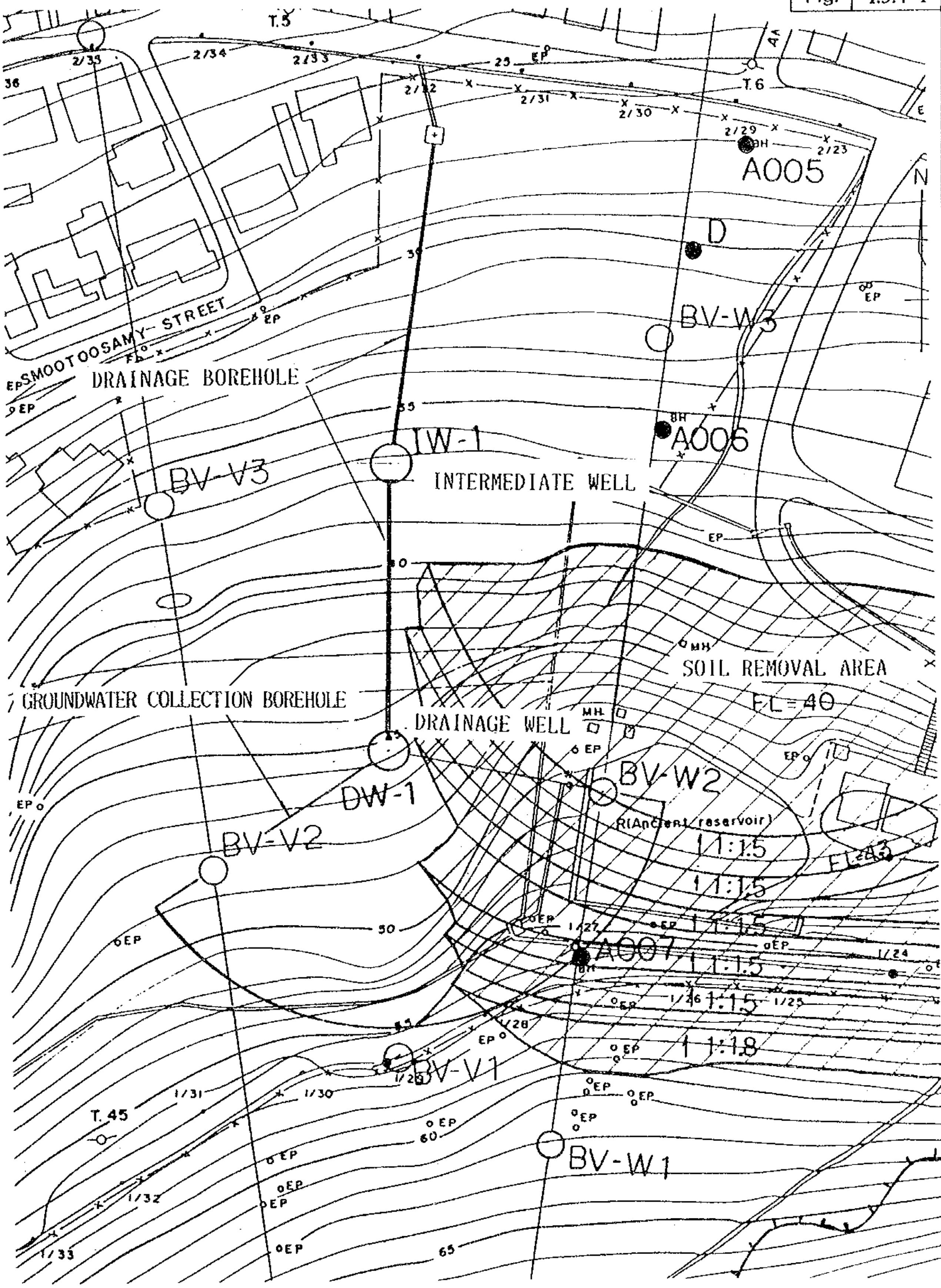
1. AN-TYPE LINER PLATE
2. STIFFENER RING
3. VERTICAL STIFFENER
4. COVER(EXPANDED METAL)
5. LADDER
6. WATER COLLECTION HOLES
7. GROUNDWATER COLLECTION BOREHOLE

STRUCTURE OF DRAINAGE WELL

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

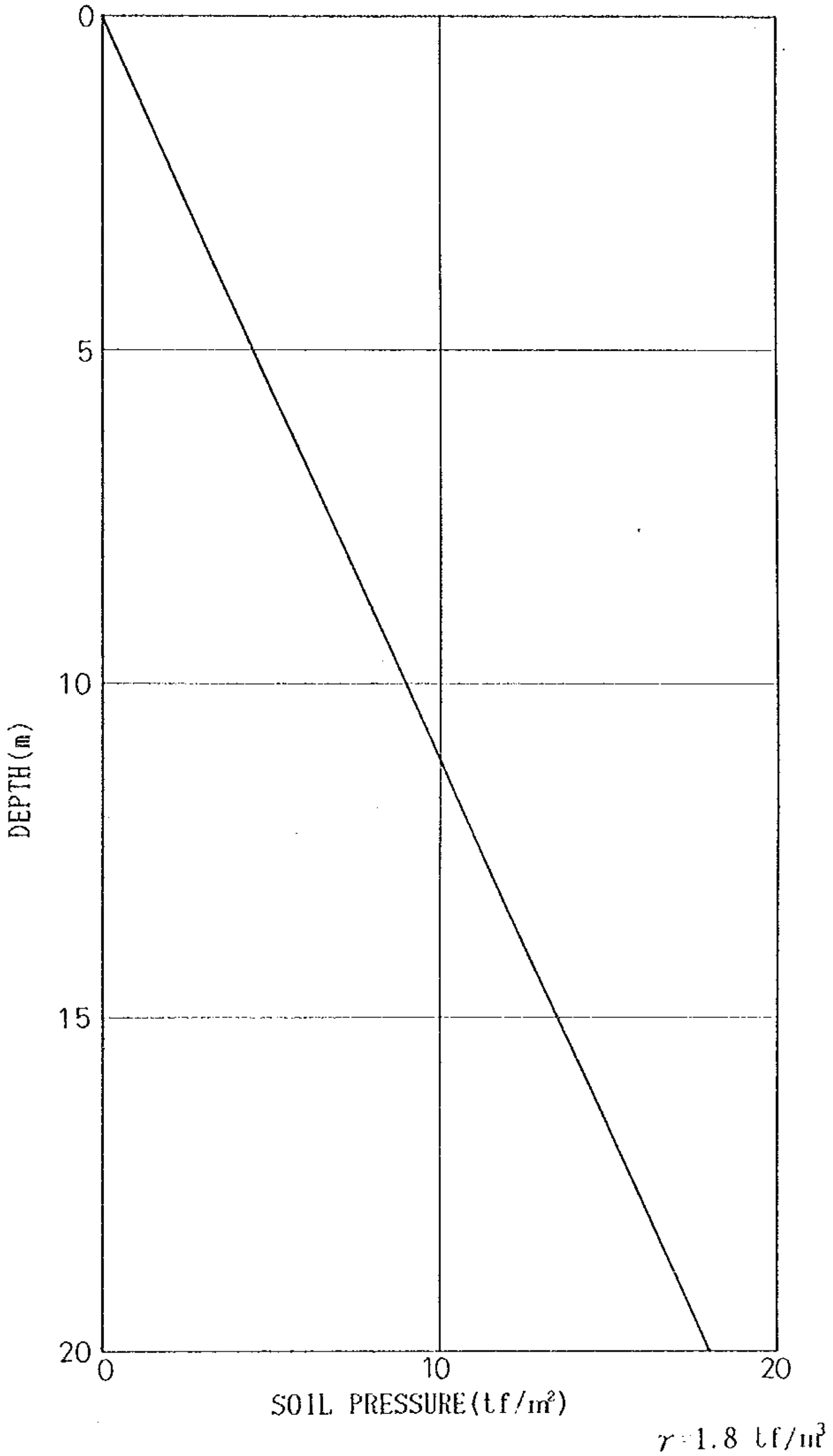
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-1



LOCATION OF EXPERINENTAL INVESTIGATION SITES	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-2



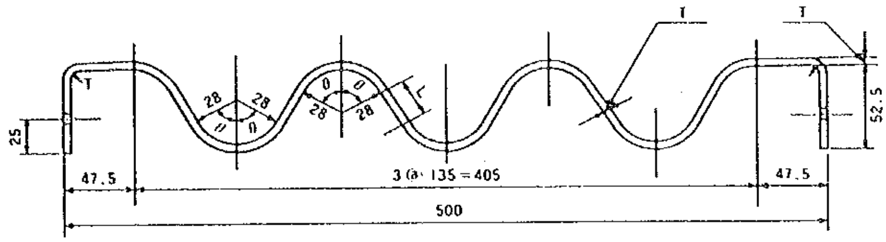
DISTRIBUTION OF UNIFORM SOIL PRESSURE

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

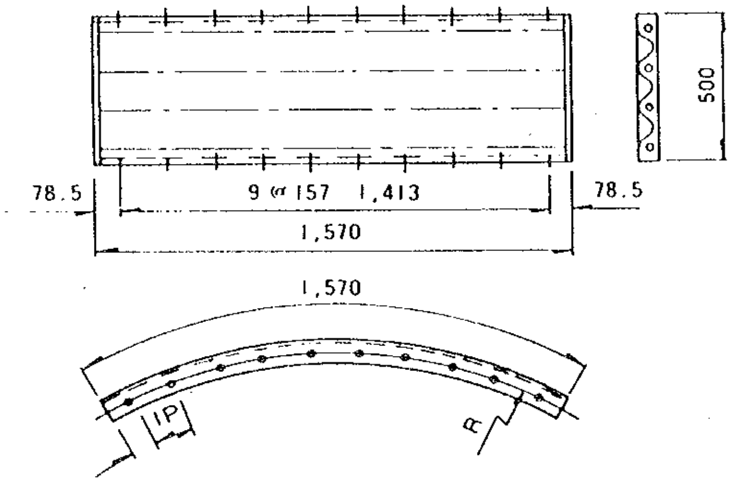
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-3

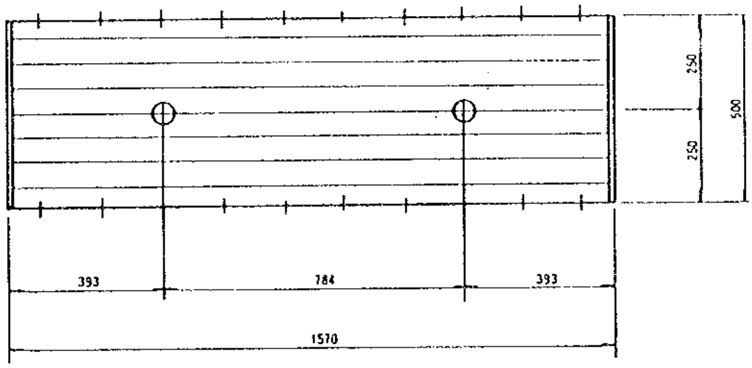
AN-TYPE LINER PLATE (SS34)



P10 SECTION

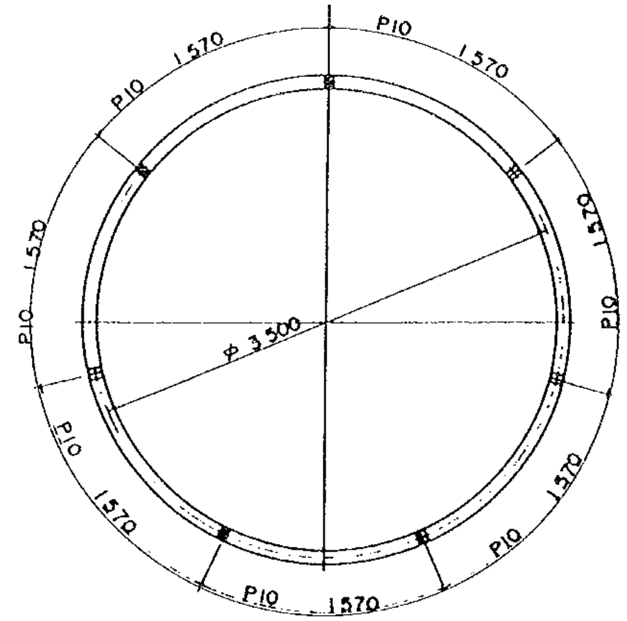


P10 SECTION

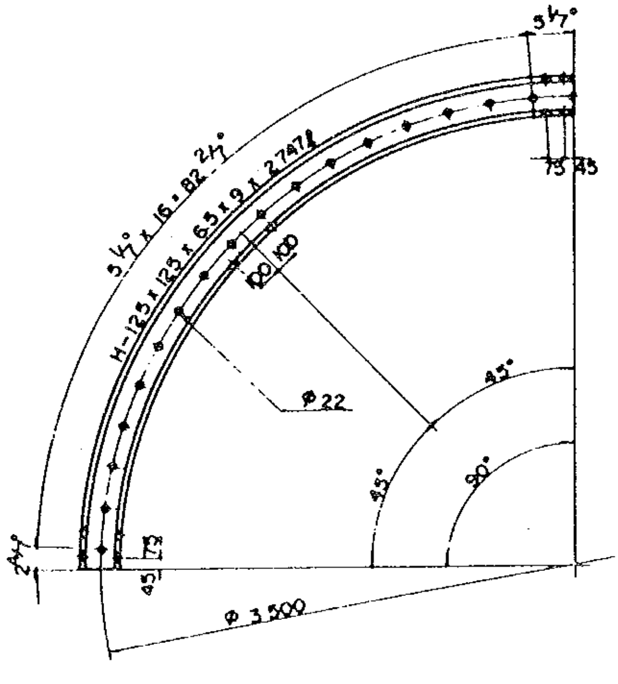


DETAIL OF LINER PLATE	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-4



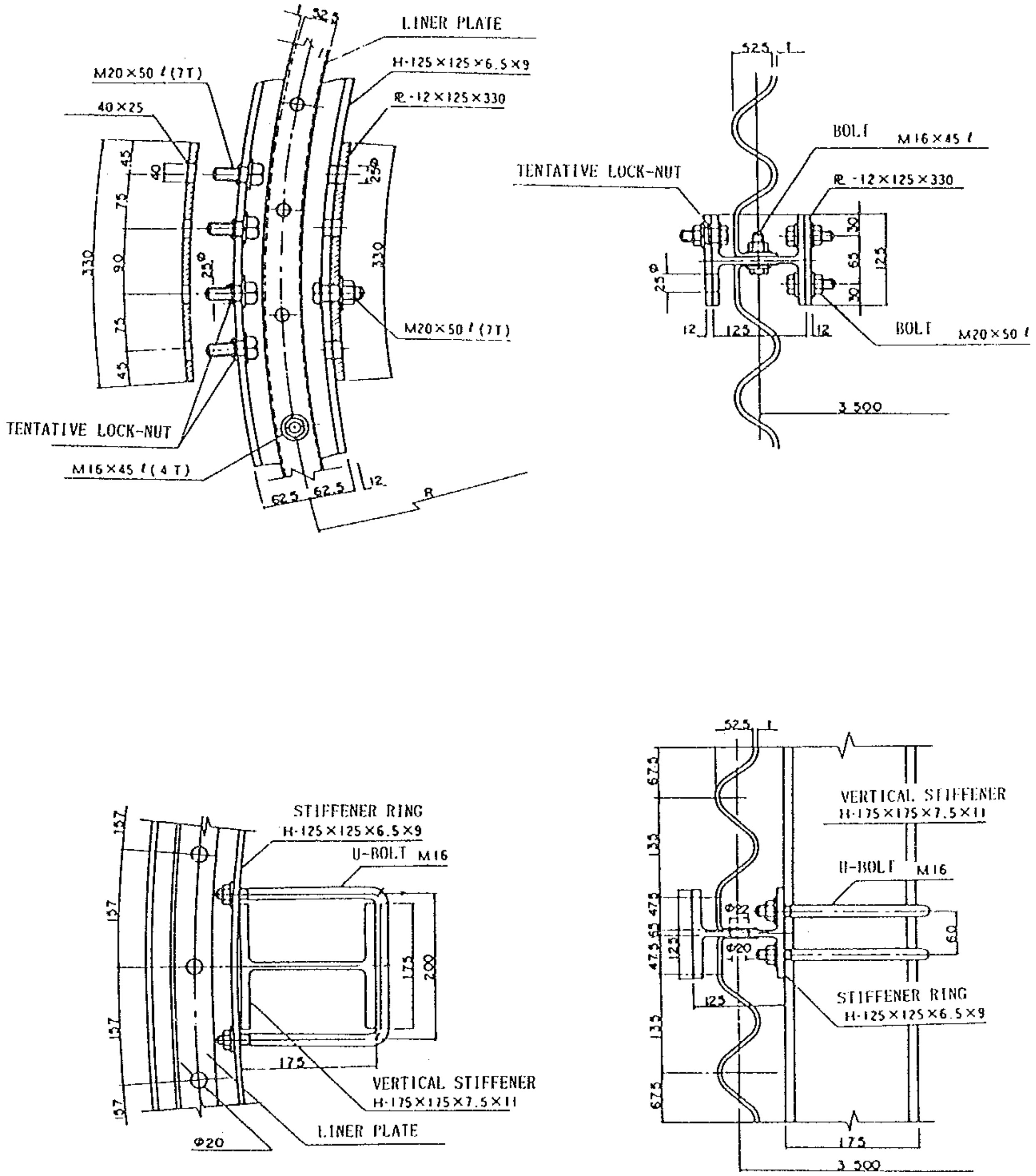
a) LINER PLATE



b) STIFFENER RING

LINER PLATE AND STIFFENER RING	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-5

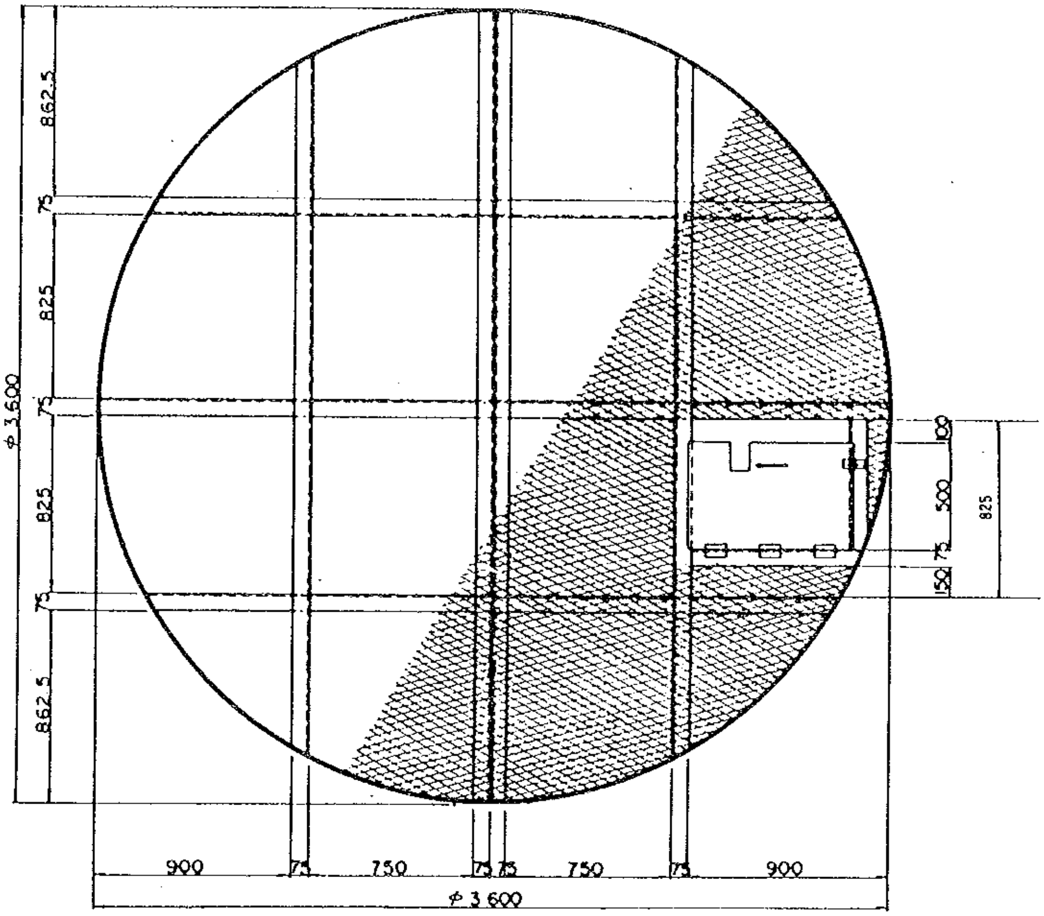


CONNECTION OF STIFFENER
AND FIXING OF VERTICAL STIFFENER

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

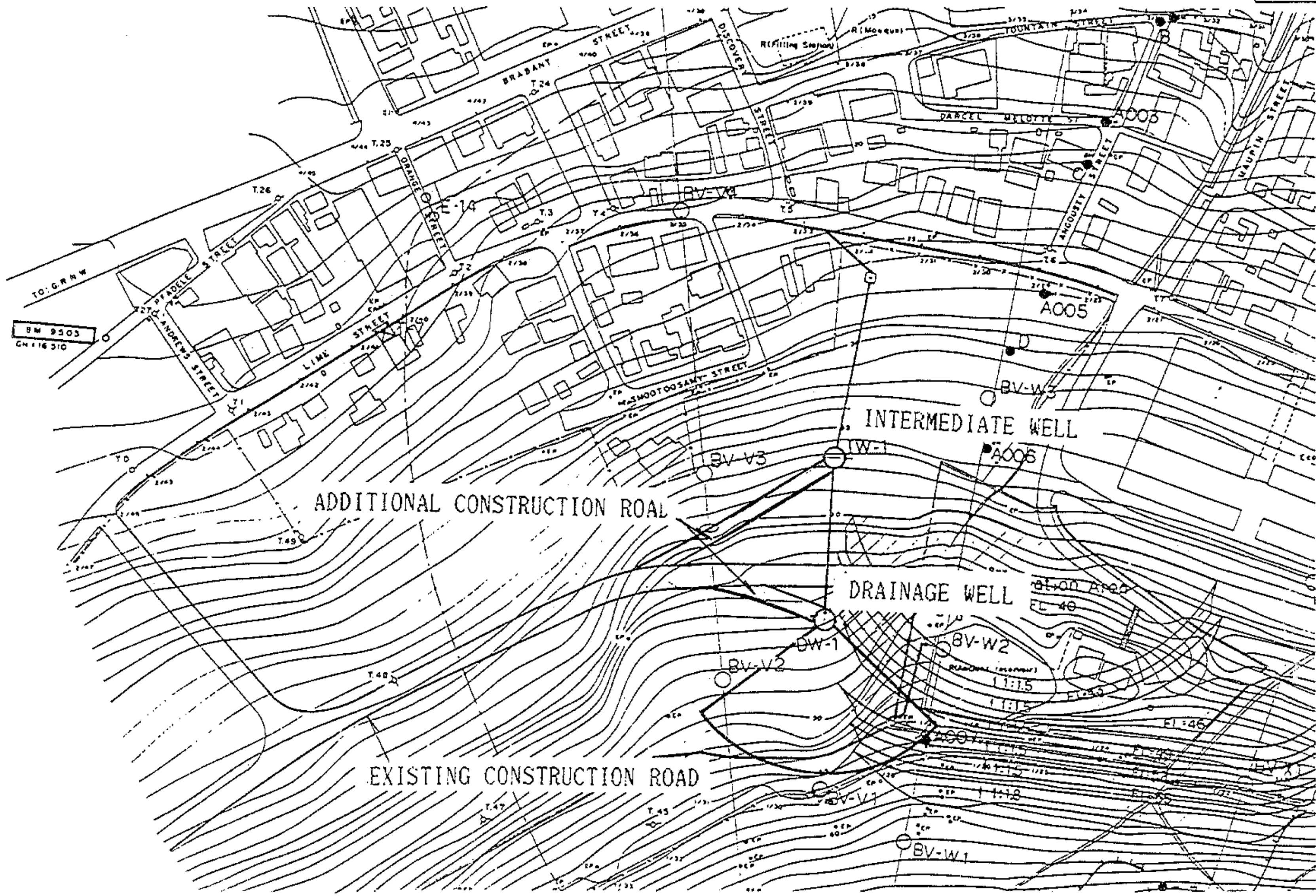
JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-6



COVER OF DRAINAGE WELL	GOVERNMENT OF MAURITIUS LANDSLIDE PROTECTION PROJECT IN PORT LOUIS
	JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4-7



CONNECTION ROAD

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

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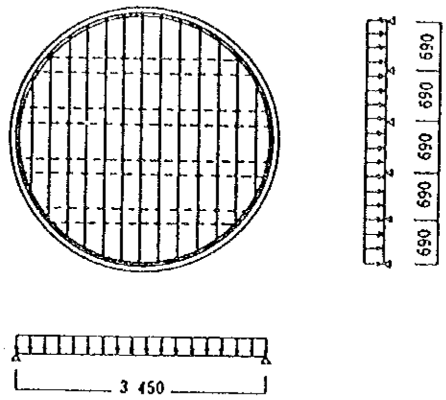
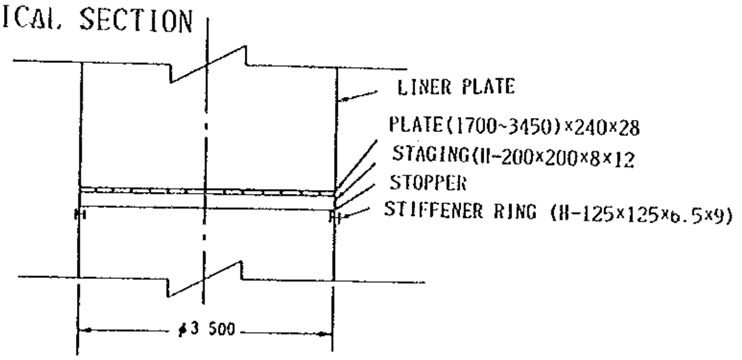
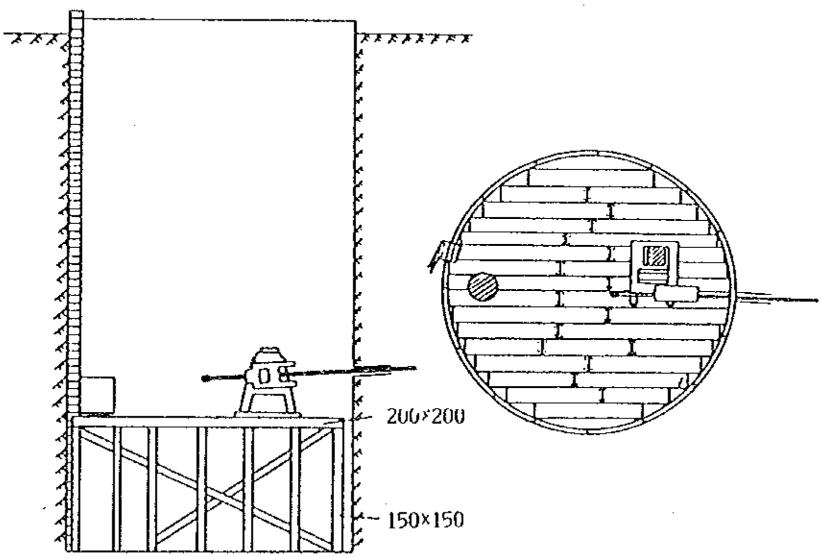
Fig. I.3.4-8

HORIZONTAL SECTION



VERTICAL SECTION





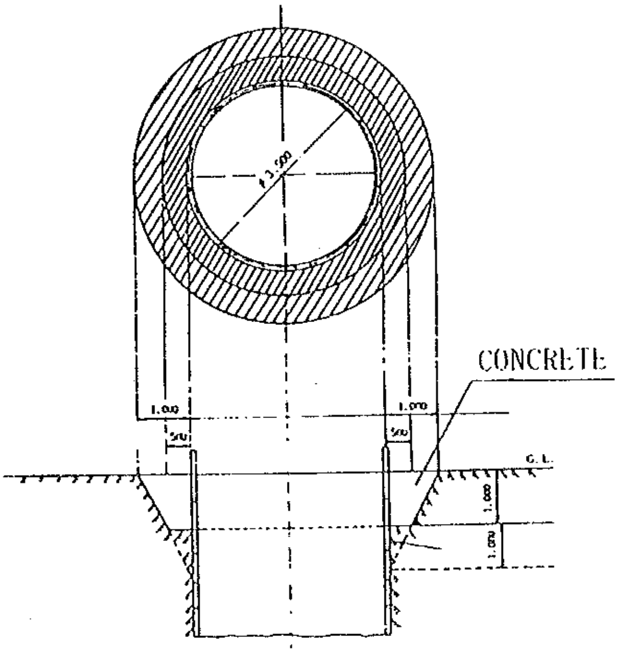
UNIT:mm

WORKING STAGE FOR DRILLING OF GROUNDWATER COLLECTION AND DRAINAGE BOREHOLES

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. I.3.4–9



FIXING OF CONCRETE CAP

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

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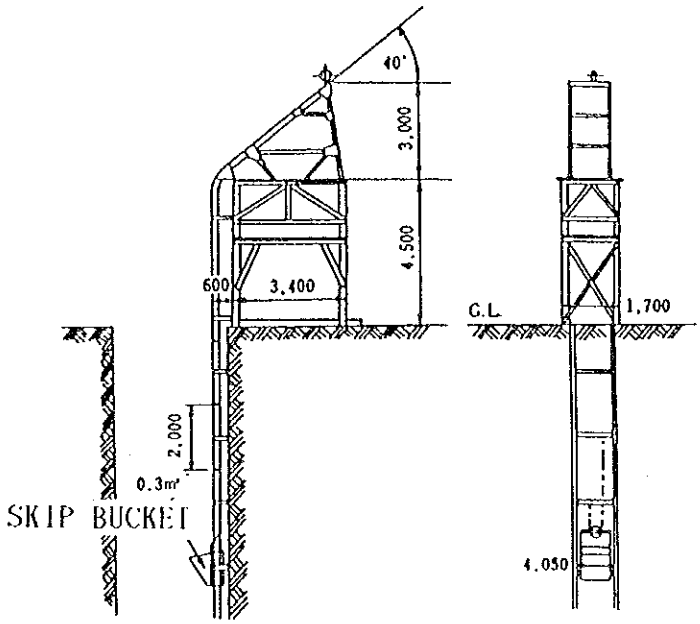
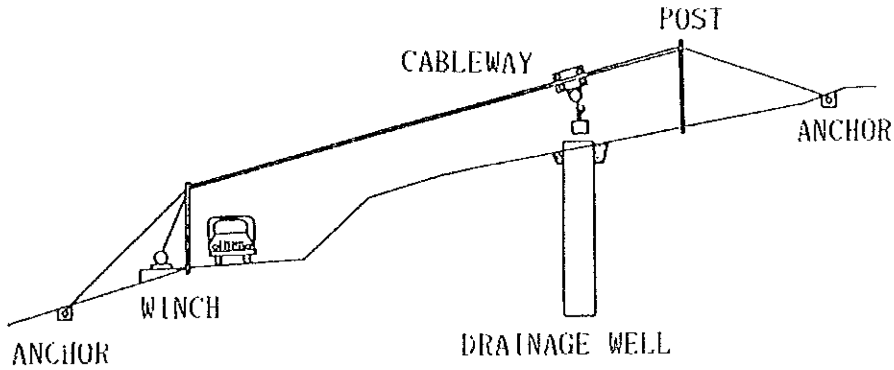
Fig. I.3.4-10





EXAMPLE OF MUCKING FROM DRAINGE WELL

GOVERNMENT OF MAURITIUS
LANDSLIDE PROTECTION PROJECT IN PORT LOUIS

JAPAN INTERNATIONAL COOPERATION AGENCY

SUPPORTING II

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II.1 INTRODUCTION

II.1.1 General

The natural conditions of the area surrounding the landslide area were clarified by the field investigations conducted in the first stage. Based on the results obtained in the first stage study, construction of a drainage well was considered to be effective for mitigation of landslide movement by decreasing groundwater levels.

For confirmation of effectiveness of the drainage well in the rainy season, one drainage well 20 m deep was constructed with 1000 m of groundwater collection boreholes (20 holes) and one intermediate well 15 m deep.

About 50000 m^3 of soil removal works was also carried out in parallel with construction of the drainage well. The soil removal works were done also for mitigation of landslide movement by decreasing the weight of sliding masses from the upper slope of the landslide area.

An emergency counterweight embankment was made for mitigation of a small landslide that occurred near extensometer, E-3. This small landslide appeared to be secondary to the main landslide and caused by the soil removal works.

This Supporting Report (II) describes the planning and design of the drainage well and the concerning works, planning and execution of the soil removal works, and planning and execution of the emergency counterweight for the small landslide. The locations of the soil removal area and the drainage well are shown in Fig.II.1.1.

II.1.2 Experimental Investigations and Emergency Protection Measures

(1) Experimental investigations

The designing of the drainage well was based on calculation of earth pressure with consideration to allowable stress intensity, buckling pressure, compressive stress and so on. Based on these calculations, a combination of steel liner plate of 1570x500x2.7 mm in size and stiffener rings of H-125x125x6.5x9 mm in size was confirmed to be sufficient for the estimated earth pressure from the sliding earth masses.

The required quantity of the main materials for the drainage well and the intermediate well consisted of 504 steel liner plates and 36 sections of stiffener rings.

Availability of local materials was examined in the study period but it was found that the main materials and machines had to be brought from Japan. The manpower was confirmed to be available easily but no experienced manpower was available.

The work plan for construction of the wells was prepared accordingly. Working hours were assumed to be 7 hours per day and 30 days a month. However, the actual work was carried out by continuous 24 hours working to save time.

The cost estimate was made in Japanese yen for direct construction costs, indirect costs and general supervision costs. The construction cost was estimated for Phase-I for construction of one 20 m drainage well and drilling of groundwater collection boreholes and for Phase-II for construction of one 15 m intermediate well, drilling of 120 m of drainage boreholes, and installation of drainage facilities. The total construction cost was estimated to be 69.9 mill. yen for phase-I and 21.5 million for phase-II.

(2) Emergency protective measures

Soil removal works to reduce weight from the upper sliding masses was considered to be effective for mitigation of landslide movements in future rainy seasons. Therefore, planning and designing of soil removal works were prepared during the course of the field investigations.

The amount of earth materials to be removed was designed to be about 50000 m^3 from the area covering 150 m x 100 m in size. Slope excavation was designed at 1.0 to 1.5 between vertical length and the horizontal length. The slopes were designed to be half circles in shape, forming six steps accompanied by 3 m wide berms between each excavated slope. The soil removal works were performed during the period from October to December 1989 just before the rainy season.

Stability analysis for the soil removal works was made on the observation lines, Line-W and Line-X, which cross the designed soil removal work site from south and north. The expected safety factors for the lines are 1.03 for Line-W and 1.08 for Line-X after completion of the soil removal works, increasing by about 3 % and 8 % the safety factors before the soil removal works for both lines.

A small landslide occurred during the soil removal works around extensometer, E-3, in the central upper part of the landslide area. Movement of this small landslide continued with increasing rainfall in December 1989.

For mitigation of this landslide a counterweight was planned and executed in January 1990, and the movement ceased in short period. These movements seem to have been caused by further development of slide surfaces with increasing of rainfalls in February 1990, and significant movement continued afterwards. Additional counterweights were planned and executed in the period from the end of May to the beginning of June 1990. The movements ceased after the completion of the counterweights and with decreasing of rainfall.

Although the movement of the small landslide has ceased, there is the possibility that the stability of the small landslide would be decreased by continuous rainfall in the future. Therefore, providing steel piling works will be required for stabilization of this small landslide for long term protective measure.

II.2 EXPERIMENTAL INVESTIGATION

II.2.1 Designing of Experimental Investigation

(1) Designing of drainage well and intermediate well

Designing of the drainage well and the intermediate well were made in accordance with the following general concepts.

1) Outline of design

The diameter of the drainage well and the intermediate well is 3.5 m. Protection of the well wall is secured by steel liner plates. The depth of the drainage well is 20 m which is about 2 m shallower than the assumed depth to the slide surface. The depth of the intermediate well is 15 m. Based on the calculation of design earth pressure and allowable stress of the steel liner plate, the design of the drainage well was made for securing sufficient safety against buckling of the wells and compressive stress on the circular section.

2) Calculation of design earth pressure

Stress expected to act on the drainage well was considered to be only earth pressure. This earth pressure is estimated to be uniform at a certain horizon when the drainage well does not penetrate the sliding plane, and shearing movement does not affect the well. Water pressure which may act on the drainage well is not considered except when predominant groundwater remains in the shallow parts.

The calculation method based on static earth pressure was adopted for the calculation of uniform earth pressure which was considered to act on the drainage well. The equation for calculation of the static earth pressure is as follows:

$$q = K \times (d \times H)$$

where, q : horizontal earth pressure (t/m^2) at depth of H
H : depth from the ground surface (m)
d : unit weight of soil (t/m^3, d=1.8)
K : coefficient of earth pressure at calculation of static earth pressure (k=0.5)

The distribution of uniform earth pressure which seems to act on the drainage well was calculated by using the above equation and is shown in Fig.II.2.1-1, and the obtained static earth pressures are summarized as follows. The calculated results of static earth pressure are shown in Table II.2.1-1, in a series of depths from the ground surface.

STATIC EARTH PRESSURE

DEPTH OF WELL	STATIC EARTH PRESSURE
15 m	13.5 t/m^2
20 m	18.0 t/m^2

3) Allowable stress intensity and physical characteristics of steel plates and stiffeners

The drainage well, which is a steel structure, is a permanent structure mainly for its drainage function. No work will be done in the well after its completion. The well will not lose its function even if slight deformation happens to the well structure, and moreover the well has a flexible structure against deformation stress. Therefore, the allowable stress intensity of the materials used for the drainage well for a short term is allowed to be about 1.5 times larger than the long term allowable stress.

The materials used for the drainage wells are a type of SS34, which were planned to be utilized for steel supports of which the long term allowable stress is 1200 kg/cm^2. The allowable bending stress and compressive stress (Ca) is 1800 kg/cm^2 (= 1200 kg/cm^2 x 1.5) as the design value.

The thickness of steel plates ranges from 2.7 mm to 7.0 mm. 2.7 mm steel plate was required for the experimental investigation for economy and ease of construction. However, H-shaped steel stiffeners was considered to be required when the steel plates were insufficient in strength. The steel plates and stiffeners will make a monolithic structure, and the design strength of the structure had to be taken as combined value. The physical and mechanical properties of the steel plates and stiffener rings are shown below.

PROPERTY OF STEEL PLATE

Thickness (mm)	Area of section (cm^2) A	Section moment of inertia (cm^4) I	Section modulus (cm^3) Z
2.7	39.76	141.0	45.98

PROPERTY OF STIFFENER RING

Size (mm)	Area of section (cm^2)	Section moment of inertia (cm^4)		Section modulus (cm^3)	
	A	Ix	Iy	Zx	Zy
H-125x125x6.5/9	30.31	847	293	136	47.0

4) Examination on buckling of circular section

Critical buckling pressure under homogeneous pressure which seems to act on circular section is shown in the following equation.

$$Pcr = 3 \times E \times I / r^3$$

where, Pcr : critical buckling pressure (t/cm^2)

E : modulus of elasticity = 21×10^6 (t/m^3)

I : moment of inertia of steel plate for unit depth (m^4/m)

r : radius of drainage well (m)

The critical buckling stress is about 3 to 9 times larger than the static water pressure when the circular section is apt to buckle in the soil. The allowable buckling strength, Pa, of the steel drainage well was calculated by the following equation with taking the safety factor of 1.5.

$$Pa = 3 \times E \times I \,/\, f \times r^3$$

where, f : safety factor (f=1.5)

The examination of the materials for the drainage well had to be made in the condition that the allowable buckling strength, Pa, is larger than the design earth pressure, Pt.

The calculation results of allowable external forces are shown in Table II.2.1-2 for combination of steel plates of 2.7 mm and 3.2 mm in thickness with the stiffeners of H-125. The moment of inertia (I) for the perforated steel plates was selected at the value of 0.8 x I according to Japanese technical standard.

The safety combination of steel plates and stiffeners for buckling is summarized as follows:

SAFETY COMBINATION OF STEEL PLATE AND STIFFENER

Depth	Steel plate	Stiffener
until 3.0 m	2.7 mm without perforation	---
until 9.0 m	2.7 mm without perforation	---
until 18.0 m	2.7 mm with perforation	2 m interval stiffener ring
until 20.0 m	2.7 mm without perforation	2 m interval stiffener ring

The examination on buckling of the drainage well was made by calculation as follows:

Depth until 9.0 m (using 2.7 mm steel plate without perforation)

$$Pa = 3 \times E \times I / f \times r^3$$
$$= 3 \times 21000000 \times 0.000001128 / 1.5 \times 1.75 \times 1.75 \times 1.75$$
$$= 8.84\ (t/m^2) > q = 8.10\ (t/m^2)$$ ------------------------ ok

Depth until 20.0 m (using 2.7 mm steel plate with perforated plus H-125 stiffener at 2 m interval)

$$Pa = 3 \times E \times I / f \times r^3$$
$$= 3 \times 21000000 \times 0.000005363 / 1.5 \times 1.75 \times 1.75 \times 1.75$$
$$= 42.03\ (t/m^2) > q = 18.00\ (t/m^2)$$ ------------------------ ok

5) Examination of compressive stress on circular section

According to the following procedure, compressive stress and bending moment were examined on the drainage well.

a. Compressive stress

Compressive strength of the circular structure under uniform earth pressure was calculated by the following equation.

$$N = q \times r$$

where, N : compressive strength (t/m)
q : uniform earth pressure (t/m^2)
r : radius of the drainage well (m)

Compressive stress intensity was examined by the following equation.

$$C = N / A < Ca$$

where, C : compressive stress intensity (kg/cm^2)
A : section area of steel plate for unit depth (cm^2/m)
Ca : allowable compressive stress intensity (kg/cm^2)

b. Bending moment

The bending moment was calculated by the following equation.

$M\ max = N \times s / (1 - q / Pcr)$

where, M max : maximum bending moment (tm/m)

N : compressive strength (t/m)

s : maximum strain to the direction of center (m)

Pcr : critical buckling stress (t/m^2)

The maximum strain to the direction of the well center was considered to be about 1 % of the radius, that is s = 0.01 x r. The maximum compressive stress intensity (C) was examined by comparing with the allowable stress intensity (Ca). The maximum compressive stress intensity (C) is composed of the total stress intensity of the maximum bending moment (M max) and the compressive strength (N). That is shown below:

$$C = M\ max / Z + N / A < Ca$$

Z : section modulus (cm^3/m)

c. Examination on structure of drainage well

The Strength of drainage structure was examined in the following for several cases using different materials.

* Well depth until 9.0 m (using 2.7 mm thick perforated steel liner plates)

In the case that only compressive stress was considered.

$N = q \times r = 8.1 \times 1.75 = 14.18$ (t/m)

$A = 39.76$ (cm^2/m)

$C = N / A = 14.18 \times 1000 / 39.76$

$= 356.64$ (kg/cm^2) $<$ $Ca = 1800$ (kg/cm^2) --------------- ok

In the case that bending moment was considered.

$s = 0.01 \times r = 0.01 \times 1.75 = 0.0175$ (m)

$Pcr = 3 \times E \times I / r^3$

$= 3 \times 21000000 \times 0.000001128 / 1.75 \times 1.75 \times 1.75$

$= 13.26$ (t/m^2)

$$M\ max = N \times s / (1 - q / Pcr)$$
$$= 14.18 \times 0.0175 / (1 - 8.1 / 13.26)$$
$$= 0.638\ (tm/m)$$
$$C = M\ max / Z + N / A$$
$$= 0.638 \times 100000 / 45.98 + 14.18 \times 1000 / 39.76$$
$$= 1744.2\ (kg/cm^2) < Ca = 1800\ (kg/cm^2)$$ --------------- ok

* Well depth until 20.0 m (using 2.7 mm perforated steel liner plates plus stiffener rings at 2 m interval)

In the case that only compressive stress was considered.

$$N = q \times r = 18.00 \times 1.75 = 31.5\ (t/m)$$
$$A = 39.76 + 30.31 / 2 = 54.92\ (cm^2/m)$$
$$C = N / A = 31.5 \times 1000 / 54.92$$
$$= 573.56\ (kg/cm^2) < Ca = 1800\ (kg/cm^2)$$ ---------------- ok

In the case that bending moment was considered.

$$s = 0.01 \times r = 0.01 \times 1.75 = 0.0175\ (m)$$
$$Pcr = 3 \times E \times I / r^3 = 3 \times 21000000 \times 0.000005363 / 1.75 \times 1.75 \times 1.75 = 63.04\ (t/m^2)$$
$$M\ max = N \times s / (1 - q / Pcr)$$
$$= 31.5 \times 0.0175 / (1 - 18.0 / 63.04) = 0.772\ (tm/m)$$
$$C = M\ max / Z + N / A$$
$$= 0.772 \times 100000 / 113.98 + 31.50 \times 1000 / 54.92$$
$$= 1250.87\ (kg/cm^2) < Ca = 1800\ (kg/cm^2)$$ ------------------ ok

As calculated above, the drainage well made of perforated (with strainer) steel liner plates with thickness of 2.7 mm plus stiffener rings at 2 m interval was considered to be sufficiently strong until the depth of 20.0 m with taking compressive stress and bending moment into consideration.

The examination of the strength of intermediate well was also performed by the same procedure for the drainage well.

(2) Specification and quantity of materials for wells

The materials for the drainage well and the intermediate well were specified as follows, and the summary of the required quantity of materials is shown in Tables II.2.1-3.

1) Steel liner plate

The well of 3.5 m in diameter will have 7 liner plates for one section. The liner plate will have to be galvanized and perforated for groundwater collection. Every two perforated holes for groundwater collection were required to be arranged for each one plate at 80 cm interval. The drawing of liner plate is shown in Fig.II.2.1-2. The liner plates for the wells are summarized as follows.

Specification	: SS34 (JIS G3101)
Standard	: p-10 section (circle 1570 mm round; height 500 mm; thickness 2.7 mm)
Quantity	: 7 plates/section/50cm x (20.5 m + 15.5 m) = 504 plates (perforated type, 210 plates for 15 m)
Weight	: 27.43 kg / plate x 504 plates = 13824.7 kg

2) Stiffener

Stiffeners were composed of H-shape steel, stiffener rings, and vertical stiffener. These were designed to be fixed with bolts. The stiffeners are summarized as follows. The drawing of liner plate and the stiffener ring are shown in Fig.II.2.1-3.

Specification:	SS41 (JIS G3101)	
Standard :	stiffener ring	H-125x125x6.5x9mm, L=2747.5mm
	vertical stiffener	H-175x175x7.5x11mm, L=6m, 4.5m
	connecting plate	330x125x12mm, 340x175x12mm, 340x140x6mm
Quantity :	stiffener ring	4 x 9 sections (drainage well 6 + intermediate well 3) = 36
	vertical stiffener	I=6m(4), I=4.5m(4)
	connecting plate	drainage well (64) + intermediate well (24) = 88
Weight :	stiffener ring	65.4x36=2354.4kg
	vertical stiffener	241.2 to 180.9x8=1688.4 kg
	connecting plate	2.24 to 5.6x88=342.8 kg

3) Bolt and nut

Based on the thickness of liner plates and stiffeners, bolts and nuts which fix liner plates with stiffeners, were selected. The detail of connection of liner plates with stiffener rings is shown Fig.II.2.1-4.

Specification:	M16 - M20
Strength :	4T(tension strength, 41 to 50 kg/mm^2), 7T(70 kg/mm^2)
Quantity :	drainage well (4524pcs) + intermediate well (3160pcs) = 7684 pcs.
Weight :	0.146 to 1.07 kg x 7684 = 1273.8 kg (for drainage well 783.2 kg)

4) Cover

Covers were required to be provided for prevention of falling materials into the wells. The cover is shown in Fig.II.2.1-5.

Specification:	expansion metal
Standard :	outer diameter 3600 mm
Quantity :	2(drainage well 1, intermediate well 1)
Weight :	610x2=1220 kg

5) Ladder

Specification:	steel
Standard :	spiral type (H=1 to 2m, width 0.5m) ladder type (H=2 to 4m, width 0.5m)
Quantity :	2 sets (spiral type for drainage well, ladder type for intermediate well)
Weight :	spiral type 688.4 kg, ladder type 215.0 kg

(3) Availability of local material

1) Construction material

The availability of local materials was examined to assess the possibility that the required amount could be supplied on time without any exception. According to the examination result, it was confirmed that there were some suppliers of H-shape steel, gas pipes, and bits. However, reliability was poor for supplying sufficient materials at any time, and these materials were supposed to be supplied from abroad. The available construction materials in Mauritius are cement, sand, timber, and fuel (light oil, gasoline, electric power, etc.). Electric power is obtainable from C.E.B (Central Electricity Board). The construction materials required for the experimental investigation are shown in Table II.2.1-4.

2) Construction machine

Most of the required construction machines were available locally except for the horizontal boring machine and the facility for mucking. The local contractors had relatively sufficient bulldozers, backhoes, and dump trucks, and they were available. However, rental fee was relatively high because there is no rental firm which rents out these machines for short periods normally. The machines had to be rented from a local contractor. Though compressors, generators, pumps, and blowers belonging to the local contractors were limited in number. The contractor for the experimental investigation was considered to supply them from abroad because they seem not to be available at any time. The main construction machines required for the experimental investigation are shown in Table II.2.1-5.

3) Laborers for construction

Manpower was easily available but there was no experienced manpower for excavation of the designed deep wells and drilling of horizontal boreholes. Therefore, assistance of experts from the successful contractor was required. Additional payment was required to consider for the work in the drainage well.

The standard working day was considered to be 8 hours between 7:00 a.m. and 5:00 p.m. on week days, and 5 hours between 7:00 a.m. and 2:00 p.m. on Saturdays. Work outside these standard working hours, and holiday work, was considered to subject to overtime. The kind of works required for the experiment investigation is shown in Table II.2.1-6.

4) Transportation of construction material and machine

The construction materials and construction machines from abroad was planned to be transported to Port Louis by ship, and they were considered to be transported to La Butte by trucks or trailers. No problem on the transportation between Port Louis and la Butte was expected because the road is asphalt paved and the distance is very short.

In the case of transportation from Japan, it was assumed to be about 30 days to Port Louis; about 7 days for customs clearance; one day from Port Louis to La Butte. The total transportation period from Japan to La Butte was estimated to be about 40 days after shipping.

5) Examination on ability of local contractor

There are several relatively big local construction firms such as General Construction Co.Ltd., Civic Ltd., etc. However, they have no experience in the construction of drainage wells and the drilling of horizontal boreholes. Therefore the experimental investigation should be performed by experienced foreign contractors, or as a joint venture between the foreign contractors and the local contractors.

(4) Plan of construction

1) Plan of work process

Work process of the drainage well is as follows:

WORK PROCESS OF DRAINAGE WELL

PREPARATORY WORKS	--- preparation, construction materials and machines supply, and transportation
TRANSPORTATION	--- transportation of materials and machines
	--- loading and unloading of materials and machines
	--- local transportation

TEMPORARY WORK ---- construction road
--- land clearing and scaffolding
--- water supply and drainage
--- electricity supply
--- ventilation installation
--- site office preparation

SAFETY FACILITY --- security measure
--- measure for night work

CONSTRUCTION
TRANSPORTATION --- dismantling temporary facility
--- local transportation
--- removal

CLEARING WORK

The outline of construction work is shown below.

WORK PROCESS OF DRAINAGE WELL CONSTRUCTION

WORK ITEM	ACTUAL WORK	WORK PURPOSE
EXCAVATION WORK	Excavation	Drainage
		Mucking
METAL WORKS	Liner Plate Installation	Assembling of stiffener Assembling of ladder
CONCRETE WORKS FOR PLATE FIXING	Excavation	Mucking
	Concrete Works	
DRILLING OF GROUNDWATER COLLECTION BOREHOLE	Machine Installation	Drilling
		Protection of borehole

DRAINAGE CHANNEL CONSTRUCTION	Excavation	Drainage
	Masonry Works	Mucking
CONCRETE WORKS	Concrete Placing	
RELATED WORKS		Installation of cover Installation of protective fence

The time schedule for the experimental investigation is shown in Fig.II.2.1-6, and the total working period from the initial material supply was estimated to be 14 months. The rainy season in Mauritius starts in November, and the construction of drainage well was required to be completed before the rainy season. From this point of view the work had to be started as soon as possible after starting the second investigation. One month was counted as 30 days and a working day was considered to be 7 hours for the examination of the schedule, and one holiday was considered for a week in this connection.

The drainage well was scheduled to be completed in November, 1989. After the completion of the drainage well, groundwater collection boreholes were planned to be drilled from the inside of drainage well. Dewatering from the drainage well was planned to be made by pumping until completion of the intermediate well and drainage boreholes.

2) Plan for transportation to the site

Most of the required materials and machines for the construction of the drainage well were expected to be transported from abroad by shipping services. Transportation between Port Louis and La Butte was considered through public roads. For the transportation in the vicinity of the construction site it seemed to be possible to use a 4 m wide trail by which old water pipes were removed recently. The drainage well and the intermediate well were designed to face each other across this trail. Extension roads connecting between the trail and two wells were required for about 100 m in a total length. Partial averaging was necessary because the trail was partly steep, and gravel spreading was required for the whole section of this trail. The required connection roads are shown in Fig.II.2.1-7.

3) Land clearing and scaffolding

The construction site of the drainage well and the intermediate well had to be horizontal or gently sloped. Land-leveling was required after land-clearing by cutting trees and bushes to guarantee sufficient spaces for installation of machines for construction of the wells and for stocking necessary materials. The required size of the space was about 15 m x 18 m.

Though drilling of groundwater collection boreholes was planned to be made in the drainage well on different steps, at about 13 m and 18 m below the ground surface, a working stage was considered to be necessary when the drilling was planned to be made on the upper step. The working stage, which was planned to be prepared using stiffener rings, was required to be strong enough for vibration and weight of the boring machine. The working stage for drilling is shown in Fig.II.2.1-8.

Drilling of two drainage boreholes was planned made at about 19 m below the ground surface in the drainage well and at 14 m below the ground surface in the intermediate well. Lower groundwater collection boreholes and drainage borehole were designed to be drilled at about 18 m below the ground surface, about 2 m higher than the bottom of the drainage well.

4) Drilling works

For attaining effective groundwater collection and from the relation between the length of boreholes and the location of aquifers, the drainage well was designed to dig the groundwater baring zone in general. The location of drainage well for the experimental investigation was selected with the assumption that the drainage well would be situated in the groundwater baring zone.

The construction period of the wells was scheduled in dry season but a heavy rainfall was considered to be encountered occasionally and groundwater level might be increased suddenly. increase suddenly. Therefore, sufficient counter measures were planned prepared for the excavation of the drainage and intermediate wells. During the excavation of the intermediate well, water stored in the drainage well was required to remove by pumping. The pump was required to have sufficient pumping head and capacity; the capacity of more than 600 l/min was required. Pump installation is shown in Fig.II.2.1-9.

Drainage of the surface water was planned to be made along concave topography directed to the north from location of the drainage well for easy draining. Drilling water for the groundwater collection boreholes and the drainage boreholes was planned to be supplied from a water tank stationed on the ground beside the wells. Drainage of drilling water was also planned to be made by pumping.

5) Fixing of liner plate

Fixing the first section of liner plates in vertical position was considered to be very important at the start of liner plates assembling. If this fixing is not in the right position, the wells might be inclined or self sinking might be occurred. Therefore, the structure for fixing of the first section was planned to be vertical and sufficiently strong for the weight. The fixing of the first section of liner plates was considered to be performed by using H-shape steel or logs and/or concrete placing. Though the concrete placing is a most reliable way for plate fixing, the concrete placing was planned to be executed for the experimental investigation.

Excavation of the ground surrounding the liner plate in a cone shape for about 2 m in depth was required for the liner plate fixing by concrete placing. After excavation in a cone shape, the liner plates for 2.5 m in height were planned to be assembled vertically. Crashed stones were planned to be back-filled under compaction for about 1 m and then concrete placing was designed to be made in upper 1 m zone. The liner plate fixing by using concrete placing is shown in Fig.II.2.1-10.

6) Electric power

a. High voltage receiving facility

There was a transmission line of 6.6 kv belonging to CEB at about 40 m south of the proposed location of the drainage well. The electricity was considered to be available from this transmission line. The area including several transmission poles was required to excavate for the soil removal works. Therefore, the route of transmission lines were planned to be changed slightly by CEB. The electric power supply was considered to be obtainable until construction site with a voltage of 400 V with three phases. The receiving facility of 400 V with three phases was considered to be supplied by CEB.

The cost for the electric power supply was estimated at about Rs.100000, and it was estimated to be about one month until the electric power was available. One transformer was required near the construction site for receiving electricity.

b. Loading

Electric load on drilling work are as follows:

ELECTRIC LOAD ON DRILLING WORK

Machine	Specification	Capacity (KW)	Unit	Total capacity (KW)
Drill rig		30	1	30
Drill pump	200 l/min	11	1	11
Submergible pump	600 l/min, H=30 m	7.5	2	15
Blower	50 m_3/min	0.75	1	0.75
Winch		5.5	1	5.5
Lightning	500 W	0.5	9	4.5
Reserve		10		10
Total				76.75

Though electric energy for excavation of the drainage well was considered to be smaller than the works for drilling works, the capacity of transformer was decided by the capacity of the drilling machine.

c. Decision of capacity of transformer

Though required voltage of drill rigs from abroad was estimated to be 200 V with three phases, the installation of transformers was required for sufficient capacity to convert from 400 V with 3 phases to 200 V with 3 phases. The required transformer was 100 KVA x 1 unit (400V with 3 phases to 200V with 3 phases).

d. Emergency generator

For electricity failure during the construction, a diesel generator (25KVA x 1unit) was required to install pumps, blowers, winches, etc.

7) Plan for excavation of drainage well

After fixing the first section of liner plates, excavation of inside drainage well was planned to be started. The excavation was considered to be made mainly by manpower using breakers and pick hammers. Excavation for one section of liner plates, 50 cm in depth, was planned to be performed ahead of the one section liner plate assembling. Immediately after the excavation for one section, assembling of liner plates is performed for protective of well walls. Confirmation of perpendicularity of the well and measurement of the well deformation were required during excavation.

Mucking of the excavated soil and gravel materials was required to made by using skid buckets, cables, and cranes in general. The excavated materials were planned to be transported to spoil bank and flattened. An example of mucking from the drainage well is shown in Fig.II.2.1-11.

The most dangerous work in the drainage well and the intermediate well was considered to be mucking of the excavated materials. A mucking bucket was designed to be moved up and down along guide ropes. Protection nets and stages were planned to be provided also in the wells. A skip tower and a winch were required to be fixed tightly by anchors against floating, sliding, and sinking. Density measurement of oxygen and gases was required to be made before entering into the wells, and ventilation was planned to be performed by blowers during excavation works.

When the depth was reached to 20 m for the drainage well and 15 m for the intermediate well, concrete placing for 30 cm in thickness was designed to be made at the bottom of the well for prevention of water leakage.

8) Installation of liner plates in drainage well

The drainage well excavation and liner plate installation were scheduled to be performed section by section. Each liner plate is set in staggered position without spaces in vertical or horizontal directions. For fixing liner plates, bolts and nuts were required. When stiffeners of H-shape steel were fixed, the liner plates were designed to be assembled in a circular shape with connecting plates, and flanges were designed to be fixed with bolting when lower liner plates were assembled.

Ladders were designed to be installed with progress of excavation. A spiral type ladder was designed to be installed in the drainage well for securing the safety of excavation works and inspection works after completion of the well. On the other hand, vertical ladder type steps were designed to be installed in the intermediate well because inspection of the intermediate well was not expected after completion of the well.

After assembling liner plates and stiffener rings, H-shape steel vertical stiffeners was designed to be connected with the stiffener rings by using U-bolts in four directions. The vertical stiffeners were designed to be installed for reinforcement of the well structure with attention focused on the safety for the later inspection.

After completion of the drainage well, a steel cover made of expanded metals was designed to be set up for preventing materials from falling in and securing a light into the wells, and the cover was planned to be locked. After completion of all the works, fences enclosing the drainage well and the intermediate well were provided for safety.

9) Groundwater collection boreholes and drainage boreholes

Groundwater collection boreholes, or horizontal boring, and drainage boreholes were for draining groundwater from the landslide area to the outside of the landslide. For the experimental investigation a lot of boreholes were designed to be drilled. The quantity of drilling consisted of groundwater collection boreholes for 1000 m, drainage boreholes between the drainage well and the intermediate well for 45 m, and the drainage borehole between the intermediate well and the ground surface for 75 m.

a. Groundwater collection borehole

The groundwater collection boreholes were designed to be drilled into the mountain side from the drainage well for collecting groundwater. The boreholes were planned to be drilled for 50 m, penetrating 10 m into bedrocks through the assumed sliding planes. Taking the effectiveness of draining water into consideration, boreholes were planned to be drilled from three stages at the depths of 14.6 m, 17.8 m and 18.8 m from the ground surface. The arrangement of boreholes is shown in Table II.2.1-4 and Fig.II.2.1-5.

The angle of elevation of drainage boreholes was designed to be horizontal to 5 deg. in general. The location of the drainage well was between Line-V and Line-W and the drainage boreholes were designed to penetrate into bedrocks for 10 m with the inclination of 5 deg. Perforated pvc pipes with inner diameter of 40 mm and outer diameter of 48 mm were designed to be inserted into drilled boreholes for protection of boreholes.

For covering a wide area for groundwater collection in the landslide area, in which groundwater flow paths seemed to be complicated, the lateral opening of each borehole was planned to be 15 deg. with a fan shape.

b. Drainage borehole

Drainage boreholes (116 mm in diameter), which are planned to be connected the drainage well with the intermediate well, was for draining groundwater to the ground surface. Protection of the drainage boreholes is assured by use of steel pipes of SGP90A.

The intermediate well was planned to be situated in the middle of the section between the drainage well and the outlet of drainage borehole. The inclinations of boreholes were designed to be 3 deg. in the section between the drainage well and the intermediate well and about 2 deg. between the intermediate well and the ground surface.

The section between the drainage pit and the Lime street for about 30 m was designed to be open-cut and the channel is protected by masonry works.

10) Safety management

The work was considered to be performed safely following Mauritian Law and other related regulations. The main items of safety management are listed as follows.

a. Disaster prevention from person to fall into the wells
b. Disaster prevention during transportation and material handling
c. Disaster prevention from material falling
d. Disaster prevention of structural corrosion
e. Disaster prevention of accident causing from machine operation
f. Disaster prevention from electric shock
g. Disaster prevention of traffic accident
h. Disaster prevention of fire and explosion
i. Disaster prevention from poisoning of gases and other chemical materials
j. Disaster prevention of oxygen starvation
k. Disaster prevention from accident to the public

(5) Cost estimate

1) Condition of cost estimate

The construction cost was estimated in Japanese Yen for supplying materials and equipment from abroad and in Mauritian Rupees for supplying materials and equipment in Mauritius.

2) Labor, material and machine

It was considered that the labors, materials and equipment for the construction works should be supplied locally as far as possible.

3) Escalation ratio

No escalation ratio was considered because the period between the cost estimate (May, 1989) and the commencement of construction (September, 1989) was very short.

4) Cost estimate system

The standard for cost estimate prepared by the Ministry of Construction, which was generally applied for cost estimate in Japan, was adopted for the cost estimate for the experimental investigation works. The main points of the standard are as follows:

a. Direct construction cost

The direct cost was calculated by accumulation based on production rate.

b. Indirect construction cost

* Temporary work cost

The cost for preparation, transportation , and temporary work were made up by accumulation, and others were made up by calculation based on percentage.

* Site supervision cost

The cost was made up by calculation based on percentage.

c. General supervision cost

The cost was made up by calculation based on percentage.

5) Exchange rate

The exchange rate between Japanese Yen and Mauritian Rupees was based on the rate in May, 1989 as follows:

US$ 1.00 = Yen 135.0 = Rs. 15.3

6) Basic unit price

The basic unit price, which was used for accumulation of production rates, was classified into labor unit price, materials unit price, and equipment unit price.

a. Material unit price

* Supply from abroad

Prices related to the liner plates were adapted to the examination results obtained in Japan. Other prices of materials were based on the prices featured in the year book "Construction Cost, March in 1989". The transportation cost was included into the indirect cost.

* Local supply

The basic price was the average of the prices obtained from government offices and local contractors.

b. Equipment unit price

* Supply from abroad

The equipment unit price was decided to be the lower price comparing the converted unit hour price featured in "Table for Calculation of Construction Equipment Rental Cost, 1988" and the price was calculated by multiplying equipment purchasing cost to unit hour rental cost which appears in the same table. Transportation cost was included into the indirect cost.

c. Local supply

The basic unit price had been decided to be the average price of the examination results obtained from the local contractors.

d. Labor cost

The labor cost was decided as the average price of the standard daily unit prices obtained from government offices and local contractors. The cost for the work in wells was increased by 50 %.

The construction materials were considered to be supplied locally as far as possible. However, the materials were expected from abroad if sufficient materials could not be supplied on time locally. The construction equipment, which were brought from abroad, was considered to be brought back again, and the transportation cost was calculated for both ways.

7) Production rate

Based on "Standard Cost Estimate, 1989, MOW" and "Standard Cost Estimate Data, Japan Geological Investigation Association", all production rates and percentages for the calculation of direct construction cost and indirect construction cost were calculated, and unit cost were calculated by using these production rates and percentages. The production rate for the drainage well had to be revised because there was no experienced laborers for these works in Mauritius. In this cost estimate, the cost for expatriate labor was included into the direct construction cost without revision of the production rate.

8) Construction cost

The construction cost was estimated for Phase-I and Phase-II separately. The cost for Phase-I was mainly composed of the costs for the preparatory works, temporary works, transportation, construction of the drainage well for 20 m and drilling of groundwater collecting boreholes. The cost for Phase-II was mainly composed of construction of the intermediate well, drilling of drainage boreholes for 120 m, outlet works, and other related works. The costs estimated are summarized as follows:

SUMMARY OF COST FOR EXPERIMENTAL INVESTIGATION

PHASE	YEN PORTION	Rs. PORTION	TOTAL
Phase-I	53537871 yen	Rs.1849879	69853803 yen
Phase-II	12485674 yen	Rs.1025305	21528864 yen

* Exchange rate: 1 Rs. = 8.82 Yen

II.2.2 Execution of Experimental Investigation

(1) Construction of drainage well

1) Purpose of the work

Groundwater levels were measured in most of the boreholes drilled in the period from April to July 1989. The depths ranged from 7 m to 30 m, equivalent to the depth from 35 m and 3 m respectively in elevation. Generally, higher groundwater levels are believed to accelerate sliding movement above sliding surfaces by increasing the pore pressure in the ground masses. Thus high groundwater levels can directly cause instability of a landslide.

Construction of drainage wells accompanied by drilling of groundwater collection boreholes will decrease groundwater levels in a landslide area and thus mitigate landslide movements. Drawdown of groundwater levels by construction of drainage wells is therefore one of the most useful measures for securing stabilization of landslides by changing the natural condition. Construction of an experimental drainage well was therefore planned accordingly.

2) Location and Dimensions of the Drainage Well

In this experimental investigation, a drainage well was sited between the survey lines, V and W at 45.5 m in elevation. The location of the drainage well is shown in Fig.II.1.1. At this part bedrock surfaces and the sliding surfaces are confirmed to be deepest in the concerned landslide area. Selection of the drainage well location was considered to be very important for the stability of this landslide.

According to the specification prepared by JICA study team, the drainage well with the size of 3.5 m in diameter and 20.0 m in depth was constructed with using steel liner plates. The sketch of the drainage well is shown in the Figs.II.2.2-1, II.2.2-2 and II.2.2-3.

From the drainage well groundwater collection boreholes were drilled for 1000 m in total length for draining groundwater through perforated pvc pipes of 40 mm in diameter. Boreholes were arranged to be 500 m (50 m x 10 holes) in total length in the direction of the mountain side with 10 to 15 degrees of lateral opening angles between each borehole. The boreholes were drilled towards the mountain side at an angle of elevation of 0 deg. to 5 deg. The sketch of arrangement of drilled boreholes is shown in Fig.II.2.2-4 and Fig.II.2.2-5.

3) Progress of the work

Excavation work of the drainage well was started at the end of October 1989 and was completed by the beginning of December 1989. Construction of the 20.0 m x 3.5 m dia. drainage well took about 40 days. Since there was no heavy rainfall construction there were no interruptions.

Circular shaped steel liner plates in seven sections, 0.5 m in height and all tightly bolted together, were fixed after every 0.5 m excavation.

Based on the stability analysis, stiffening rings in four sections were installed below 10 m depth to allow for the higher soil pressures. The stiffening rings were further supported by four vertical stiffeners of 10 m in length.

After completion of the drainage well excavation, installation of steel liner plates and stiffeners, 30 cm concrete was placed at the bottom of the drainage well for protective against water leakage. Concrete was also placed for 2.0 m above the bottom of the drainage well, covering the inside wall of the drainage well. Drilling of groundwater collection boreholes was commenced after completion of these works.

4) Subsurface geology

Subsurface materials observed during excavation of the drainage well were loose talus deposits which were composed of subangular boulders and gravels with clayey soil. The geological profile of the drainage well is shown in Fig.II.2.2-6. The content of the gravel materials did not change greatly from the ground surface to the bottom of drainage well but it seemed to be slightly greater below 13 m. The gravels and boulders were composed of very hard basaltic volcanic lavas, which seemed to have been derived from outcrops on the higher mountain slopes by weathering. The average size of gravels/boulders excavated from the drainage well was 20 cm to 50 cm, and the maximum size was more than 2 m in diameter.

Clayey materials appeared to be light to dark brownish in general. The water content of the clayey materials was relatively higher in the shallow zones, less than 5 m in depth. Cohesion of clayey materials seem to be decreased below about 13 m. Excavation in the drainage well was rather smooth in the deeper zones because of less cohesiveness of the clayey materials.

Water seepage was not observed during the excavation of the drainage well. This indicates that groundwater levels were deeper than the bottom of the drainage well in the landslide area. Groundwater levels were measured in the boreholes drilled at the beginning of the the first stage study. However, a large drawdown of groundwater levels seems to have occurred during the long dry period after the rainy season in early 1989.

(2) Construction of the intermediate well

Construction of the intermediate well, drilling of drainage boreholes, and construction of the outlet works were carried out as a part of the experimental investigation.

1) Purpose of the work

The drainage well, which was for collection of groundwater through groundwater collection boreholes, was constructed in the central part of the landslide prone area.

Drilling of a drainage borehole between the drainage well and the ground surface is for gravitational drainage of the collected groundwater from the drainage well to the ground surface. Horizontal boring for about 120 m is so long that the borehole seemed not able to reach to the accurate position. Construction of one intermediate well was required on the line between the drainage well and the ground surface for dividing the long section into two sections accordingly.

The purpose of the intermediate well was to facilitate drainage of the drainage well because the maximum length for the accurate horizontal drilling is only about 50 m. After completion of the intermediate well the drainage borehole connecting the drainage well to the intermediate well was 45 m. and the drainage borehole connecting the intermediate well with the ground surface was 75 m.

2) Location and dimension of the intermediate well

The location of the intermediate well is shown in Fig.II.1.1. The wall of the intermediate well was protected by steel liner plates of 2.7 mm thick like the drainage well except without the drain holes, together with stiffener rings 10 m.

The depth of the intermediate well was fixed as 15 m so that the well should not penetrate the slide surface of the landslide, and the groundwater from the drainage well could be drained gravitationally to the ground surface through the drainage borehole in the lower section.

3) Progress of the work

Excavation of the intermediate well, by the same method as for the drainage well was completed within a half month by 24 hours continuous working during May 1990. The design of the intermediate well is shown in Fig.II.2.2-7 to Fig.II.2.2-9. The materials used for the construction of the intermediate well are summarized in Table II.2.2-1.

After completion of intermediate well until the target depth, additional one more section of liner plates were assembled above the ground surface, and a steel cover using expanded metal is put on them for preventing foreign materials from falling into the well. The intermediate well is surrounded by wire net fences having the height of 2 m for preventing outsiders from entering into the structure site. Vertical ladders accompanied by guide rings are installed in the intermediate well for the future maintenance works.

4) Subsurface geology around the intermediate well

Materials, which were observed during excavation of the intermediate well, were similar to them found in the drainage well. The geological profile of the intermediate well is shown in Fig.II.2.2-10. There was no clear difference on the included materials from the top to the bottom of the well. However, the contents of gravels seem to be increased slightly with the depth in the well section.

Gravels were blackish to dark grayish and their size ranged from 10 cm to 30 cm in general. Although large boulder were not found frequently, there were occasional boulders bigger than 50 cm. The maximum size of the boulder encountered during the excavation was about 2 m. Joints were developed frequently on this big boulder and it was easily broken by breakers.

The clayey soil was dark brownish in general. The moisture content of the clayey soil seems was relatively low, and the soil becomes very stiff and cracks developed when it was dried. Slickensides, which were considered to develop under intensive stress in the previous stage, were observed frequently along the boundary between the clayey soil and gravels and in clayey soil itself.

Since there was no water seepage from the side walls of the intermediate well during the construction, deeper water table was estimated during the excavation of the intermediate well. There was some rainfall during construction of the well, and the rain water immediately infiltrated into the bottom of the well. This seems to imply that the materials surrounding the intermediate well have relatively high permeability.

(3) Drilling of groundwater collection boreholes

1) Purpose of the work

Since rising groundwater levels are believed to accelerate landslide movements by increasing the pore pressure of materials in the sliding masses, groundwater levels have to be reduced by draining groundwater to outside of the sliding areas for mitigation of landslide movements. The purpose of drilling the groundwater collection boreholes was, therefore, to decrease the groundwater levels in the landslide area by drainage.

All the groundwater collection boreholes were drilled from the drainage well for 50 m into the mountain side. Groundwater was expected to drain into these groundwater collection boreholes throughout their length because perforated pvc pipes were inserted throughout the full length of the boreholes.

2) Arrangement of boreholes

For effective drainage of groundwater from wider areas, the groundwater collection boreholes were arranged to reach or to cross the assumed sliding surfaces because groundwater was expected predominantly in the zone above the sliding surfaces. The boreholes were drilled from three stages, 14.60 m, 17.80 m and 18.80 m in depth, after placing a concrete seal in the bottom of the drainage well. The arrangement of groundwater collection boreholes is shown in Fig.II.2.2-4 and Fig.II.2.2-5.

At the beginning of drilling, the boreholes were drilled with lateral opening angle of 15 deg. However, the angle between boreholes was changed to 10 deg. for effective collection of groundwater for the long term protective measures. The boreholes at different levels were staggered position.

The boreholes were drilled to slope towards the drainage with at an angle of approximately 5 deg. For the protective of the boreholes, perforated pvc pipes of 40 mm in diameter were inserted into the drilled boreholes.

3) Progress of the work

The drilling of groundwater collection boreholes was started at beginning of December 1989 and was completed by the end of March 1990. The groundwater collection boreholes were drilled after placing of the concrete seal and provision of stages for drilling works. The main equipment used for the drilling works was as follows:

Drill rig : TONE TOP-M

Compressor : HOKUETSU PDS-3903

The boreholes were drilled by bits of 66 mm in diameter with 86 mm casing pipes installed at the same time. Materials drilled were basaltic gravels with clayey soil. Progress of the drilling was slowed down in the predominantly clayey zones by a hammer bit. However, the relatively favorable work progress was attained in the zones where gravels are predominated.

There was no great difference in geological conditions between the boreholes drilled from the upper stage and the lower stage. Very soft zones were confirmed between 44.5 m and 45.5 m in borehole, No.6, which was drilled from the lower stage. This soft zone was judged to include slide surfaces from the drilling conditions and the slime obtained during drilling. No soft zones similar to the materials in No.6 were confirmed in boreholes, No.7 to No.10 but these boreholes were nevertheless considered to have penetrated the assumed slide surface from the results obtained from the field investigation, in the the first stage study.

Drilling progress was decreased in clayey materials and increased in gravel zones or bedrock zones in general. Drilling works continued 24 hours/day with two shifts in general. The minimum progress of drilling was 50m/9days, and the maximum was 50m/3days. The average progress was 50m/5.8days.

4) Effect of the work

Drilling of the groundwater collection boreholes were performed in the rainy season, November to March. However, only light rainfall was recorded in this rainy season in the landslide area. No water drainage was observed from the drilled groundwater collection boreholes because groundwater levels in the area were deeper than the bottom of the drainage well during the borehole drilling. The effects of drilling of the groundwater collection boreholes have therefore not been clearly confirmed.

The movement of the landslide was accelerated with increasing rainfall in the rainy season in late 1988, and it decelerated with decreasing of rainfall in May 1989. The groundwater collection boreholes were drilled for mitigating landslide movements by draining groundwater in the rainy season. Permeability coefficients of talus deposits in the landslide area are of the order from $x10^{-3}$ cm to $x10^{-4}$ cm, indicating relatively high permeability coefficients. Therefore, drainage of groundwater may be expected when groundwater levels increase after heavy rainfall.

The effects of groundwater collection boreholes are not very clear in this study because of the relatively small amount of rainfall in the rainy season from 1989 to 1990. The effects, however, are expected to be confirmed by groundwater drainage from the groundwater collection boreholes when groundwater levels increase after heavy rainfalls.

(4) Drilling of drainage boreholes

1) Purpose of the work

The drainage boreholes were drilled for gravitational drainage of the collected groundwater to the ground surface through groundwater collection boreholes. The layout of the intermediate well, the drainage boreholes, and the outlet works are shown in Fig.II.2.2-11. The quantity and the size of drainage boreholes is summarized in Table II.2.2-2.

The length of drainage boreholes is 45 m in the upper section and 75 m in the lower section. For protective of drainage boreholes, steel pipes which have the diameter of 114.3 mm were inserted into the borehole after completion of the drilling. The diameter of the steel pipes used is considered to be sufficient for smooth drainage of groundwater.

The section between the end of drainage boreholes and the MGR. Leen Avenue was excavated for about 18 m as an opencut drainage channel. The surface of the opencut section is protected by masonry works.

2) Location and dimension of the drainage boreholes

The drainage boreholes were aligned to the direction of the maximum slope of the ground surface to minimize the length of the drainage boreholes. The alignment of the drainage boreholes is shown in

Fig.II.2.2-11.

The drainage borehole in the upper section is 45 m in length. Steel pipes inserted into the drainage boreholes have a thickness of 4.5 mm and the diameter of 114.3 mm. The inclination of drainage borehole in the upper section is about 2 deg. between the entrance of the drainage borehole in the drainage well and the outlet in the intermediate well. The depth of the entrance of the drainage borehole is 18.6 m (El.26.9 m) and the outlet is 13.7 m (El.25.3 m). One meter long steel pipes were used to make up the target length. The profile of the drainage boreholes is shown in Fig.II.2.2-12.

Drainage borehole in the lower section is 75 m in length and the quality of the steel pipes inserted into drainage boreholes are the same as the upper section. The inclination of the drainage boreholes in the lower section is about 0.8 deg. between the entrance in the intermediate well and the outlet of the drainage borehole. The height of the entrance of the drainage borehole is El.25.2 m and the outlet is El.24.2 m.

3) Progress of the work

The drainage boreholes were drilled by a boring machine which was set in the intermediate well. Drill bits of 110 mm in diameter and casing bits of 130 mm were used for drilling of drainage boreholes. Drilling of the upper section of drainage borehole was started at the beginning of June 1990 and completed by the middle of June 1990. Nine days were taken for completion of drilling of the upper section by 24 hours continuous drilling. The average progress of the drilling was equivalent to about 5 m/day in ordinary working hours.

The materials encountered during the drilling of the drainage borehole in the upper section were basaltic gravels, of which maximum size was about 2 m, with clayey soil. The drainage borehole was drilled almost in a straight line without encountering any water spring or water loss.

Drilling of the lower section of the drainage boreholes was started at the middle of June and completed by the end of June 1990. Twelve days were taken for the drilling work by 24 hours continuous drilling. The average progress of the drilling was about 6.2 m/day in ordinary working hours.

Basaltic gravels with clayey soil were encountered during the drilling of the drainage borehole in the lower section. No large size boulders were encountered during the drilling.

(5) Construction of outlet works of drainage borehole

1) Purpose of the work

After completion of drilling of the drainage borehole in the lower section for 75 m, an opencut drainage channel was trenched for about 18 m. The opencut drainage channel connects the outlet of drainage borehole to the ditch along MGR Leen Avenue. The design of the outlet works is shown in Fig.II.2.2-13. The materials used for the outlet works are summarized in Table II.2.2-3.

A small pit of 0.5 m x 0.5 m was dug at the outlet of the drainage borehole as a trap pit for clayey materials or other foreign materials which may flow from the drainage well and/or the intermediate well. The trenched surface of the opencut channel was protected by masonry works from erosion.

The groundwater collected into the drainage well will be drained finally to the underdrain along Brabant Street through the drainage boreholes, the opencut drainage channel, the ditch along MGR Leen Avenue, the underdrain passing MGR Leen Avenue, and the open channel along Discovery Street.

2) Location and dimension of the outlet works

Outlet works including the outlet of drainage borehole, the small pit, and opencut channel are situated near the survey point, 2/32, along MGR Leen Avenue. The direction of the drainage channel is to the northwest, intersecting the direction of the drainage borehole with the angle of about 110 deg. The layout of the drainage boreholes and the outlet works are shown in Fig.II.2.2-11.

The width of drainage channel is about 0.5 m at the bottom. The length is about 18 m between the outlet of drainage borehole and the ditch along MGR Leen Avenue. The inclination of drainage channel is about 1/90 in this section. The inclination of the excavated slope of drainage channel is decided to be 1/0.7 from the location of the opencut drainage channel. The surface of the opencut channel is protected by masonry works of 30 cm in thickness.

The pit at the outlet of the drainage boreholes is for trapping clayey soil and foreign materials which might be included into drainage water. Therefor, the bottom of the pit is designed to be about 25 cm deeper than the bottom of the drainage channel. The bottom of the drainage channel is covered by 30 cm thick masonry works.

3) Progress of the work

The construction of the outlet works was started at the end of June and completed at the beginning of July 1990. When the drilling of the drainage borehole was completed for 75 m in the lower section, the ground surface around the outlet of the drainage borehole was dug by an excavator. The accurate location of the end of drainage borehole was measured by ground survey works after confirming the end of drainage borehole by digging.

The intersection point between the opencut drainage channel and the ditch along MGR Leen Avenue was decided from the survey results on elevations of the outlet of the drainage borehole and the ditch. After these preparatory works digging of the channel was carried out along the surveyed alignment. The maximum height of the opencut channel is about 2.8 m near the trap pit.

At the end of the experimental investigation work trial water a flow test was made by pouring water into the drainage well. The water flow to the outlet works through the intermediate well and the drainage boreholes was confirmed at the end of June 1990.

II.3 EMERGENCY PROTECTIVE MEASURE

II.3.1 Soil Removal Works

(1) Planning and execution of soil removal works

1) Purpose of the work

In landslide areas upper soil masses always act to push down the lower soil masses along slide surfaces. Therefore, reduction of the weight of upper soil masses is believed to be effective for stabilization of slide movements directly. Soil removal works from upper slopes in landslide areas is one of protective measures to mitigate landslide movement with changing natural condition.

From this point of view, the soil removal work of about 50000 m^3 was executed by Mauritian government in accordance with the work plan prepared by JICA study team in the first stage of this study. The location of the soil removal area and the dumping area is shown in Fig.3.1.

2) Location and dimensions of soil removal area

The soil removal work site was selected in the area between survey lines, W and X, including some parts surrounding these lines. Based on the stability analysis, the soil removal work is expected to increase the safety factor by about 3 % along the survey line, W and about 8 % along the line, X.

The soil removal area is situated at the foot of Signal mountain and occupies an irregularly shaped area of about 150 m in width and about 100 m in length. The design of the soil removal area is shown in Fig.II.3.1-1. Excavation slopes were designed to be curved for smooth contact with surrounding mountain slopes.

Excavation works for the soil removal were made in the part between El. 60 m and El. 40 m, divided into six steps providing 3 m wide berms between each slope in general. The inclination of excavating slopes was designed to be in the ratio of 1.0 : 1.8 between the vertical length and the horizontal length for the highest slope between El. 60 m and El. 55 m. The ratio of 1.0 : 1.5 is adopted for other slopes below El. 55 m. The height of the slope was designed to be 3 m except for the highest slope of which the height range 5 m to less than 1 m.

The excavation works were performed in accordance with the prepared design. At the bottom of the soil removal area a large flat area was created in the shape of a half circle about 120 m in diameter. Drainage channel networks are provided in the area, covering the whole area along the foot part of the excavated slopes. The total length of the drainage channel network is about 1500 m.

The dumping site for the excavated soil materials was selected on the bare land facing to Caudan basin. The location of the dumping site is shown in Fig.II.3.1-2. The distance from the soil removal area to this site is less than 1 km in a straight line. After completion of the soil removal works, a large flat area of about 20000 m^2 was created at the dumping site.

3) Progress of the work

Soil removal works were started at the end of October 1989 and completed by the beginning of December except for the drainage channel installation and vegetation planting on the excavated slopes. The drainage channel installation was completed by the end of January 1990, and vegetation planting was completed by the middle of February 1990.

Soil removal work progressed from the upper portion to the lower portion in a step by step sequence, following the design for excavation. Gravels and boulders with clayey soil materials were mainly excavated from the soil removal area. Poor quality concrete was excavated from the base of the abandoned reservoir in the central part of the soil removal area. Though the average size of removed boulders ranges from 0.5 m to 1.0 m in general, the maximum size of the boulder was more than 2.0 m in diameter.

Frequently developed slickensides like smooth planes were observed in excavated clayey soil materials at several 10 cm intervals. This seems to imply that earth masses above the sliding surfaces have been