CHAPTER 6 ENGINEERING GEOLOGY ON SELECTED STRUCTURAL MEASURE SITES

6.1 Oeste Dam

Detailed site investigation and drilling survey of 3 points were performed in this project. The location of drilling points and outcrop, geological structure and distribution of geology are shown in the Figure 6.1.1. Drilling survey was performed at the left side of the existing concrete dam body (No: FBO-01, Total depth: 30.6m), the central base dam (No: FBO-02, Total depth: 26.0m) and the right side of the existing concrete dam body (No: FBO-03, Total depth: 25.5m) with standard penetration tests, that were performed before reaching to the bedrock. Geological cross section along and across the dam body are shown in Figure 6.1.2 and Figure 6.1.3. Geological structure and distribution around the Oeste Dam is shown in Table 6.1.1.

Table-6.1.1 Stratigraphy around the Oeste Dam

Geological timescale		Stratigraphy		Lithology	Geological structure and distribution
Period Período	Epoch Época	Symbol	Layer name		
Quaternary Quaternary	Holocene Holoceno	AT	Embankment Aterro	Consisted of brown sandy cohesive soil. Water content is moderate. N values show 6-10.	Distributed at around the surface. Thickness is 11.2m at FBO-01.
		CO	Concrete Concreto	Consisted of ordinary portland cement concrete. An aggregate content is about 40% vol. No degradation was found both aggregate and cement.	Distributed at the existing dam body. Founded on fresh rock at the central bank.
		Q2a-are	Holocene sand Holocino areia	Consisted of soft silty fine sand.	Distributed below flood level at the upper stream area.
		Q2a-arg	Holocene clay Holocino argila	Consisted of soft sandy silt.	Partially distributed below flood level at the upper stream area.
		Q2r	Residual soil (Highly weathered rock) Os solos residuais (Altamente intemperismo de rochas)	Consisted of red brown sandy cohesive soil. Rock structure remains, but easyily crushed by finger. N values show 14-33. Water content is low.	Distributed at the surface or under the embankment. Lower limit of this stratum is GL-15.6m for the F-BO-01 and GL-16.7m for the F-BO-03.
Permian Permian		P1rb-Fo	Shale Folhelho	Consisted of medium strong rock, unconfined compression strength is about 30MN/m^2 by hammer sounding.	Gentle bedding plane (5 to 10 degree) is generally observed. N-NW dip is observed at the left side, W-SW dip is observed at the right side.
		P1rb-Si	Siltstone Siltito		

Source: JICA Survey Team

The unconfined compression strength of fresh bedrock is estimated about 30MN/m^2, classified as medium strong rock. In crack zone, crack spacings are more than 5cm. According to the existing result of shearing test for similar rock, shear strength is estimated as $\tau=1.0 + \sigma\tan38°$ (MN/m^2).

The characteristics of each layer are shown below.

Embankment: AT

Source: JICA Survey Team

Photo (left) shows standard penetration test sample of GL-9m at the borehole F-BO-01 in the left side, which is consisted of brown sandy cohesive soil. The layer was filled after concrete placement of the existing dam body, which is distributed at the both side of dam body and the lower area of down stream side of dam body with founded on the bedrock. The thickness is 11.2m at F-BO-01.

Concrete: CO

Source: JICA Survey Team

Photo (left) shows ordinary portland cement concrete of the existing dam body.

Content of aggregate is approximately 40% in volume and no degradation was found between aggregate and cement.

Holocene sand: Q2a-are

Source: JICA Survey Team

Photo (left) shows panoramic view of dam body from left side of upper stream side, the layer is distributed below the flood water level (the area where some flood woods were deposited in the left photograph).

Residual soil (Highly weathered rock): Q2r

Photo (left) shows sample of GL-11m at F-BO-01

Source: JICA Survey Team

Source: JICA Survey Team

Photos (left) shows outcrop at the left side of dam body.

The 3-meter-height cliff was observed tentatively at the down of dam body.

Shale: P1rb-Fo

Source: JICA Survey Team

Photos (left) shows outcrop of sandy shale at the left side of dam body.

Medium strong rock, whose unconfined compression strength is about 30MN/m2 by hammer sounding, was observed.

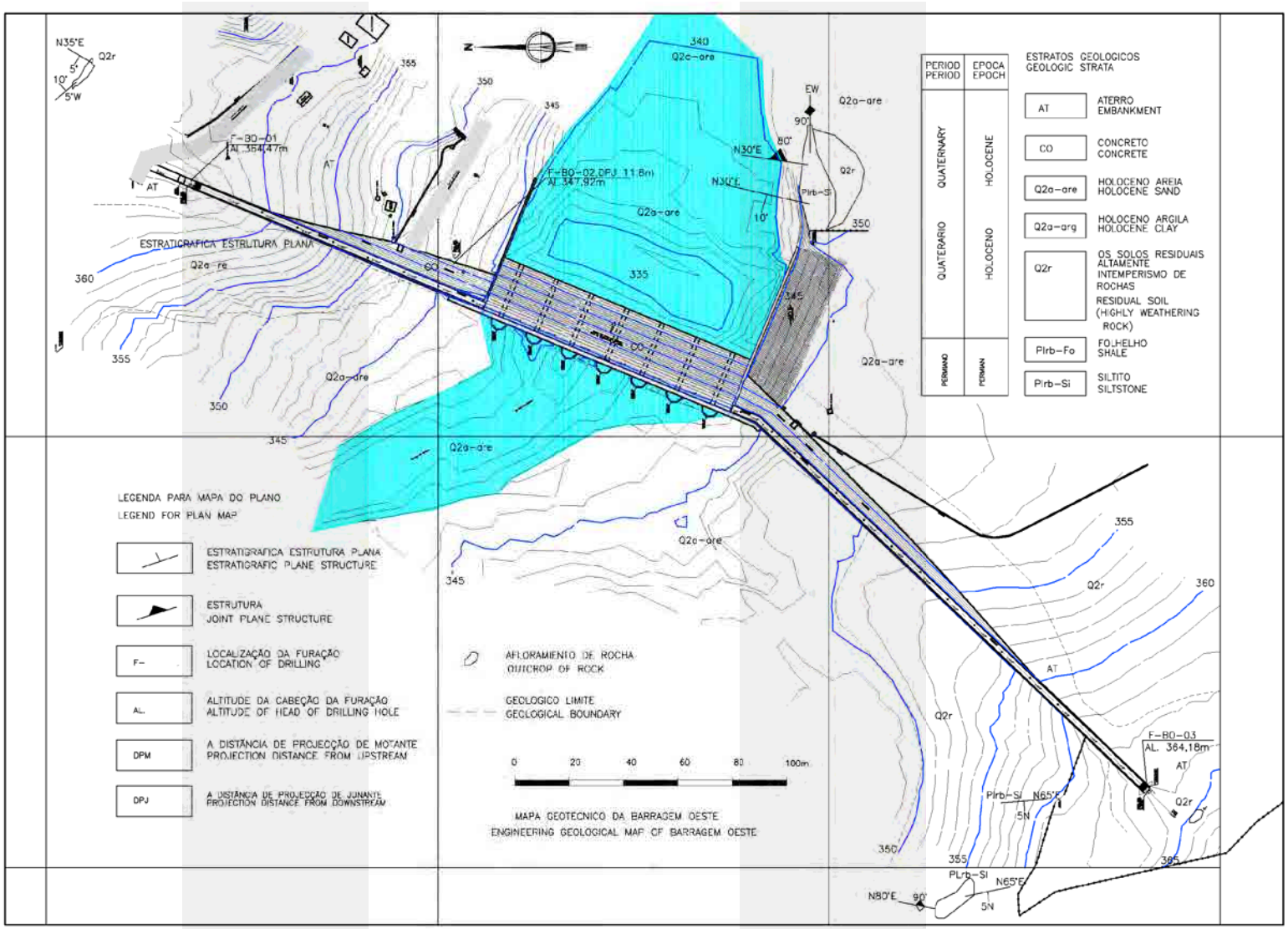
Steep cracks are developed at outcrop.

Siltstone: P1rb-Si

Source: JICA Survey Team

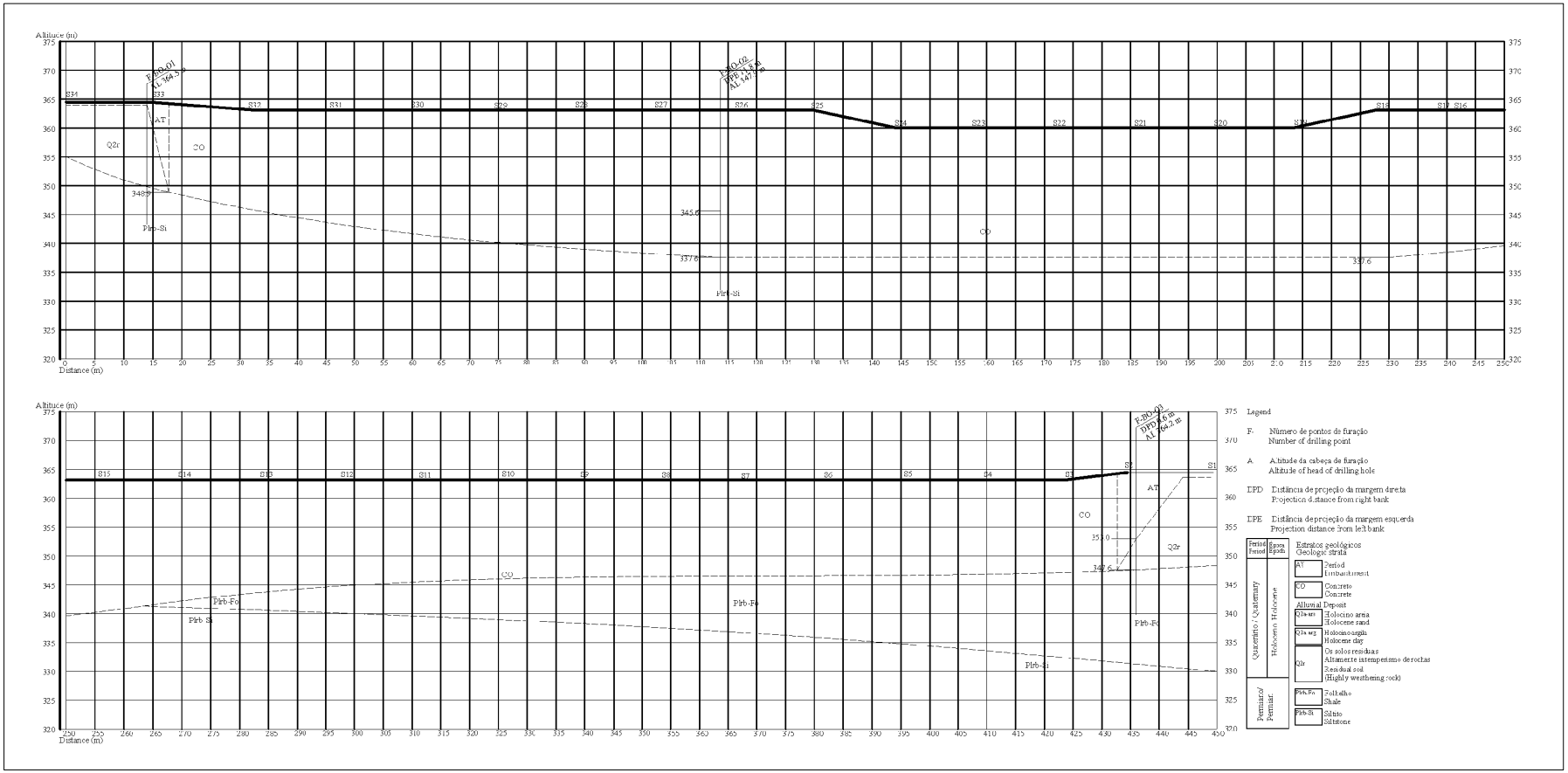
Photo (left) shows siltstone at GL-27m of F-BO-01. Medium strong rock, whose unconfined compression strength is about 20MN/m2 by hammer sounding, was observed.

Low angled cracks for bedding plane are closely adhered with no degradation.



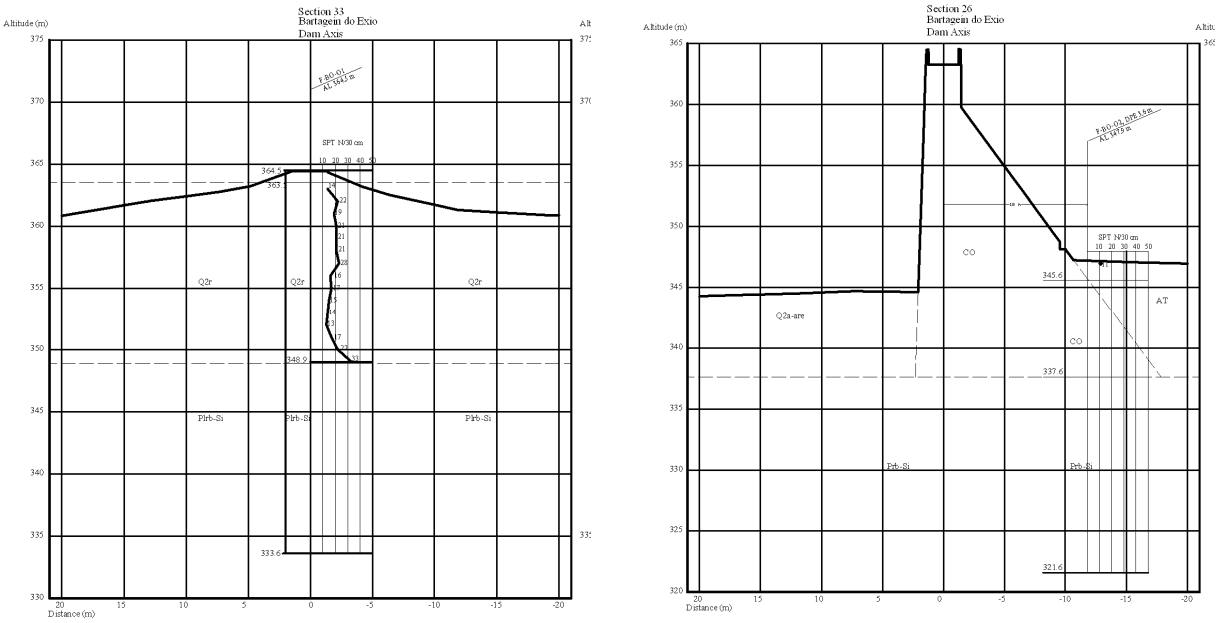
Source: JICA Survey Team

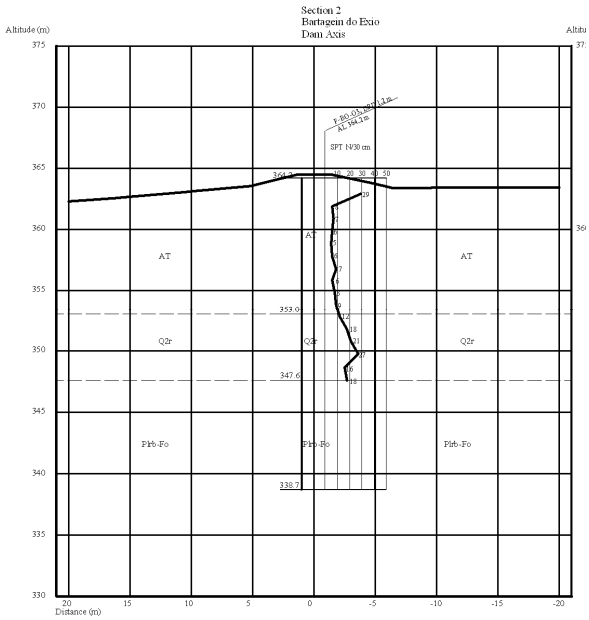
Figure 6.1. 1 Geological Map for the Oeste Dam



Source: JICA Survey Team

Figure 6.1.2 Geological Cross Section along the Oeste Dam Body





Legend

F-	Number of drilling point
AL.	Ground Level of drilling hole
DPD	Projected distance from right side
DPE	Projected distance from left side

Geological Strata

A	Embankment
CO	Concrete
Q2a-are	Holocene sand
Q2a-arg	Holocene clay
Q2r	Residual soil
Plrd-Fo	Shale
Plrb-Si	Siltstone

Source: JICA Survey Team

Figure 6.1.3Geological Cross Section across the Oeste Dam Body

6.2 Sul Dam

Detailed site investigation and drilling survey of 1 point were performed in this project. The location of drilling point and outcrop, geological structure and distribution of geology are shown in the Figure 6.2.3. The drilling was performed at the top of spillway (No: F-BS-01, Total depth: 20.0m) in order to verify the quality of concrete and condition of bedrock at the spillway.

Geological cross section at the spillway is shown in Figure 6.2.2, and Geological map of the Sul Dam is shown in Table 6.2.1.

Table 6.2.1 Stratigraphy around the Sul Dam

Geological timescale		Strarigraphy		Lithology	Geological structure and distribution
Period Período	Epoch Época	Symbol	Layer Name		
Quaternary Quaternary	Holocene Holoceno	AT-r	Rock embankment Aterro de rocha	Consisted of medium strong sandstone and siltstone aggregates. Diameter of aggregates are 30 - 80 cm.	Distributed at the riprap, right side slope in upper stream side of spillway (approx.35m long) and riverbed.
		AT-sp	Embankment of gravel soil Aterro de solo pedregoso	Consisted of gravel and soil. Gravel is poor-sorted, 1-200 cm diameter. Matrix is silty sand, slightly sticky.	Distributed at the lower area than AL.385m at the dam body.
		CO	Concrete Concreto	Consisted of ordinary portland cement concrete. An aggregate content is about 40% vol. No degradation was found both aggregate and cement.	Distributed at the spillway. Founded on the fresh rock of the central bank at GL-15.2m in F-BS-01.
		Q2a-cas	Holocene gravels Holoceno cascalhos	Consisted of medium strong sandstone and siltstone. Gravels are well-rounded, whose diameters are 2 - 20 cm.	Distributed at the riverbed and river bank.
		Q2r	Residual soil (Highly weathered rock) Os solos residuais (Altamente intemperismo de rochas)	Consisted of red brown sandy cohesive soil. Rock structure remains, but easily crushed by fingers. Water content is low.	Distributed at right side of spillway and both sides of upper stream side from dam body.
Permian Permian		P1rb-Si/Are	Siltstone, Sandstone Siltito,Arenito	Consisted of sandy siltstone and sandstone alteration. Unconfined compression strength is about 30MN/m^2, by hammer sounding, classified as Medium strong rock.	The bed strikes N 40°-70°W and dips 5 to 25°N (right side of upper stream side).

Source: JICA Survey Team

The unconfined compression strength of fresh bedrock is estimated about 30MN/m^2, medium strong rock. In crack zone, crack spacings are more than 5cm. According to the existing result of shearing test for similar rock, the strength of shear is estimated as $\tau=1.0 + \sigma\tan38°$ (MN/m^2).

The characteristics of each layer are shown below.

Rock embankment : AT-r

Source: JICA Survey Team

Photo (left) shows deposited mass of rocks for the purpose of slope protection or erosion prevention, located at the right side in upward of spillway and riverbed. The rock is consisted of medium-strong sandstone rubbles with diameter of 30-80cm.

Source: JICA Survey Team

Photo (left) shows riprap of slope protection at dam body, which is located at the back of the building.

Embankment of gravel soil: AT-sp

Source: JICA Survey Team

Embankment of gravel soil at the right and down stream side of dam body.

Diameter of gravel is heterogeneous, 1 to 200 cm. Matrix is silty sand.

Concrete: CO

Source: JICA Survey Team

Photo (left) shows dam body concrete of the existing spillway at the right side.

Source: JICA Survey Team

Photo (left) shows dam body concrete of the existing spillway at the F-BS-01.

Aggregates are consisted of medium strong sandstone and siltstone with diameter of 1 to 3 cm, containing 40% approx. in volume.

Holocene gravels: Q2a-cas

Source: JICA Survey Team

Photo (left) shows Gravelly soil (Q2a-cas) distributed at the down of spillway. Gravels are medium strong sandstone and siltstone with the diameter of 2 to 20 cm.

Residual soil (Highly weathered rock): Q2r

Source: JICA Survey Team

Photos (left) show outcrops observed at the right down stream side of dam body. Original is sandstone and structures are remaining. The layer is deeply weathered and easily broken by hammer; therefore excavation by ripper might be easy.

Siltstone, Sandstone: P1rb-Si/Are

Source: JICA Survey Team

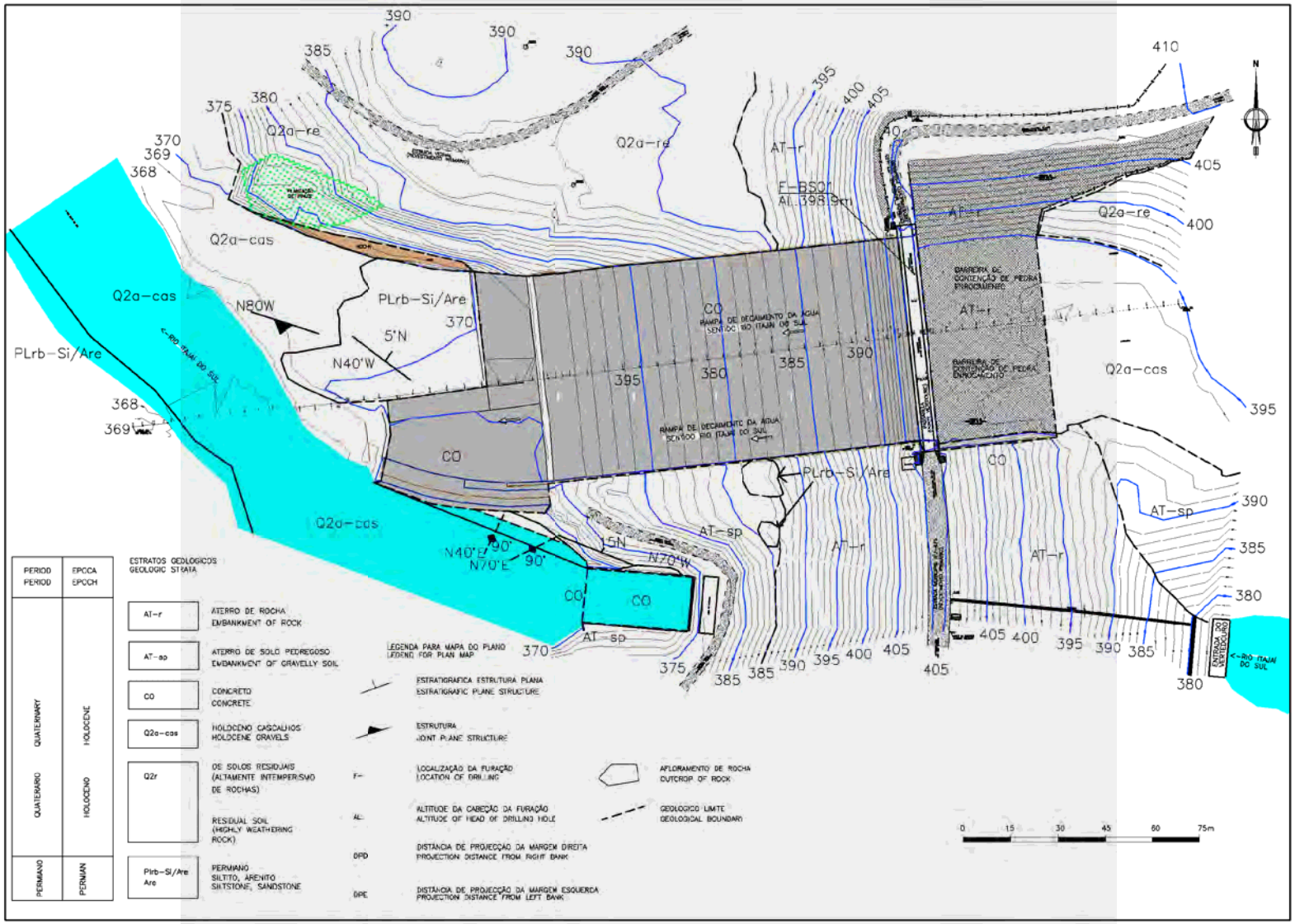
Photo (left) shows outcrop at the down stream side of the spillway.

Medium strong rock whose unconfined compression strength is about 30MN/m2 by hammer sounding was ovserved.

Steep cracks are developed.

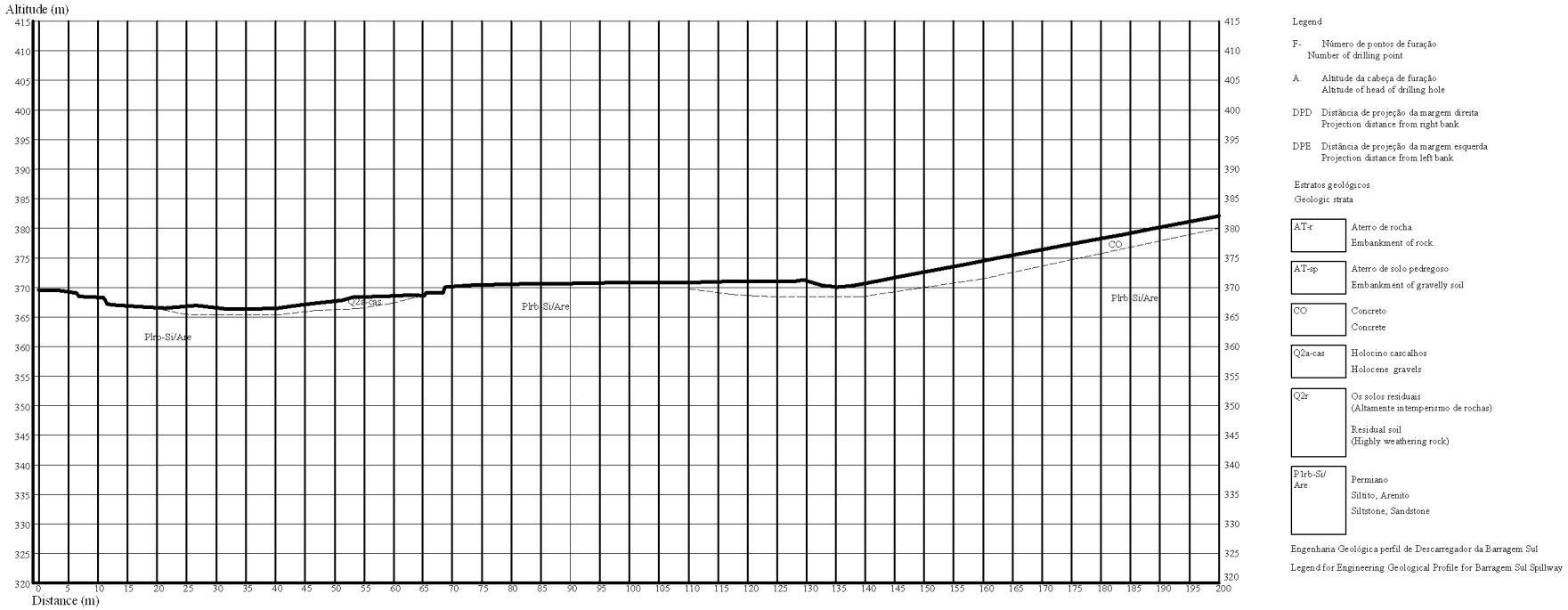
Source: JICA Survey Team

Photo (left) shows sandstone founded on dam body concrete, found at GL-15.2m in F-BS-01.



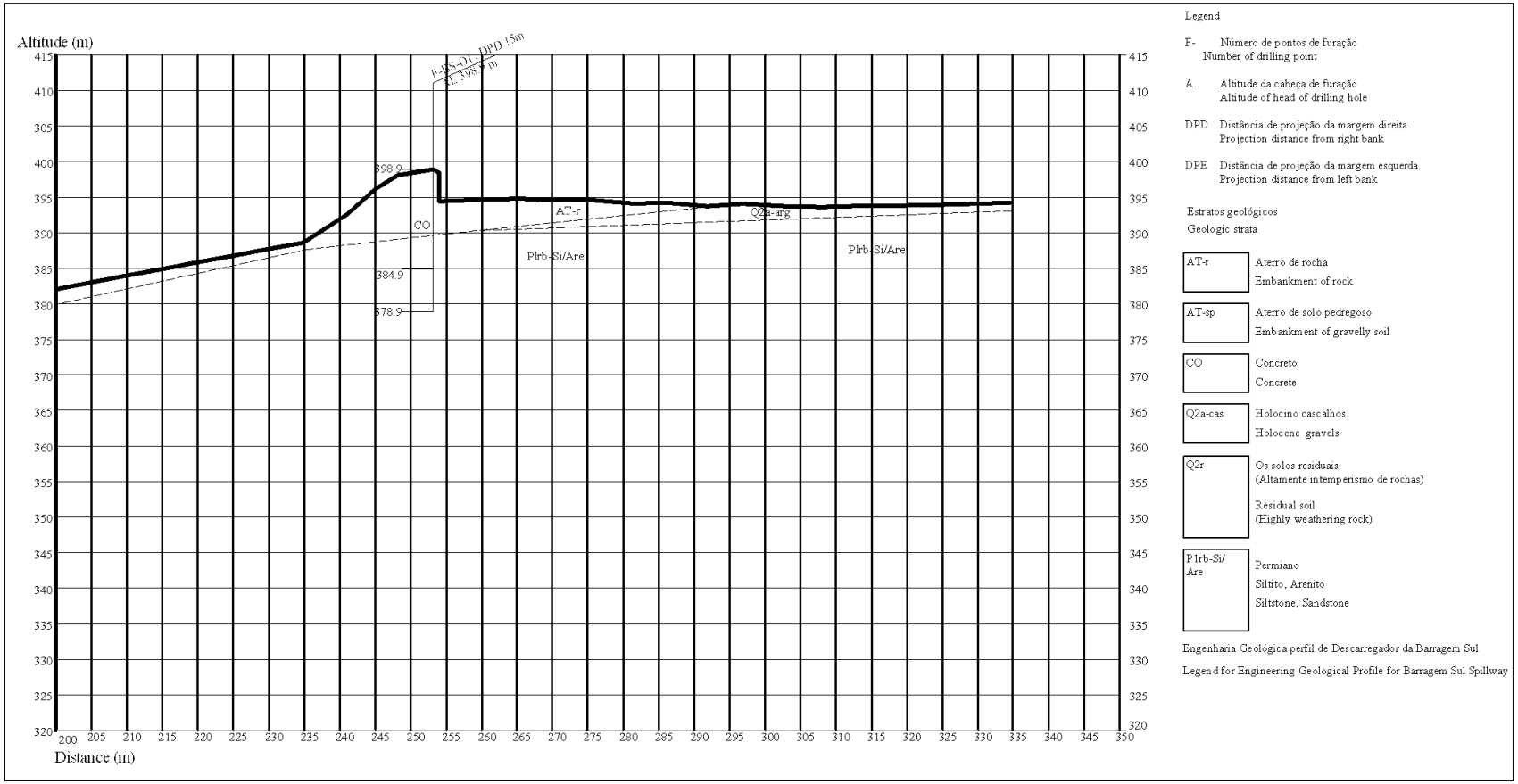
Source: JICA Survey Team

Figure 6.2.1 Geological Map of the Sul Dam



Source: JICA Survey Team

Figurr 6.2.2 Geological Cross Section at the Spillway of the Sul Dam 1/2（Upper stream side and top side）



Source: JICA Survey Team

Figure-3.2.x6 Geological Cross Section at the Spillway of the Sul Dam 2/2（Down stream side and energy dissipater side）

6.3 Itajai Mirim Upstream Gate

The proposed gate site is in the alluvial plan beside the Old Itajai Mirim River. And directory 6.5km southwest from river mouth of Itajai-Acu River, and directory 5.4km South-Southeast from river mouth of Itajai Mirim River into Itajai-Acu River.

Ground ingredient is almost flat, and altitude of the site is around 2.5 meter. The 38 meter depth drilling investigation was conducted in this survey as shown in location map of Figure 6.3.1.

The geology is alluvial deposit in Quaternary System from surface to more than 38 meter depth; the depth of bottom of the alluvial deposit is not confirmed. The detailed geological strata are found out by the drilling and described in Table 6.3.1. The engineering geological profile is shown in Figure 6.3.2.

Table 6.3.1 Geological Starta of Proposed Itajai Mirim Upstream Gate

Period	Epoch	Symbol	Name of strata	Feature of strata	Summary of stranded penetration test (SPT) result, N-value
Quaterário / Quaternary	Holoceno Holocene	Q2aj-are3	Jovem Holocino areia 3 Young Holocene sand 3	Fine sand with silt and clay, brown and loose. Recent flood deposit.	Minimum 4 Maximum 5 Average 5
		Q2aj-arg2	Jovem Holocino argila 2 Young Holocene clay 2	Clay with sand, brown, gray and green.	Minimum 2 Maximum 3 Average 2
		Q2aj-are2	Jovem Holocino areia 2 Young Holocene sand 2	Fine sand, gray and green.	Minimum 5 Maximum 12 Average 8
		Q2aj-arg1	Jovem Holocino argila 1 Young Holocene clay 1	Clay, dark gray, with shells.	Minimum 2 Maximum 3 Average 2
		Q2aj-are1	Jovem Pleistoceno areia 1 Young Holocene sand 1	Medium sand, gray and green.	Minimum 12 Maximum 21 Average 16
		Q2am-arg	Médio Holoceno argila Medium Holocene clay	Clay, brown and dark gray	Minimum 2 Maximum 5 Average 4
		Q2aa-are	Antigo Holoceno areia Old Holocene sand	Not distributed in this site.	-
	Pleistoceno Pleistocene	Q1a-arg/ped	Pleistoceno argila Pleistocene clay	Silt with clay with boulder, light gray	Minimum 23 Maximum 300 Average 109
		Q1a-are/ped	Pleistoceno areia Pleistocene sand	Not distributed in this site.	-

Source: JICA Survey Team

Dipper than 32.9 m depth and Altitude -30.4 m, 'Q1a-arg/ped: Pleistocene clay with boulder' is distributed. It is silt clay with boulder. It is considerably the basal alluvial gavels which formed around 18,000 years ago at last glacial maximum (LGM) in late Ulm glacial stage, the sea level altitude of LGM is around -130 m. Under the glacial climate, the gravel yield is big in the mountains due to freeze-thaw cycle.

Thick blown and gray clay layer of ‘middle Holocene cay’ overlay ‘old Holocene clay’ from 13.8 m to 32.9 m depth (altitude from -30.4 m to -11.3 m). It is fresh water or brackish clay in deeper area judging from the blown color and marine clay in shallower than 25.8 m (altitude -23.3 m) judging from the gray color. The sea level rise was occurred after LGM until around 5,000 years ago. The clay is considerably accumulated in wetland or in shallow marine. It is 9500 years ago when sea level is above -30 m altitude. Therefore age of middle Holocene clay considerably younger than it.

The young Holocene sand and clay layers are distributed in alternation in depth of shallower than -11.3 m (altitude 8.8 m). The dark gray clay from 9.0 m to 11.9 m depth (altitude -6.5 m to -11.9 m) include seashell and might be accumulated in shallow inner bay. The clay from 5.0 m to 2.6 m depth (altitude -2.5 m to + 0.1 m) is greenish color, and it indicates the clay is fresh water sediment. The high sea level in Holocene is +2 m altitude at around 5000 years ago called Flandrian, Holocene, or Jomon (in Japan) transgression, in that time this site might be costal. The sand from 1.9 m to 0.0 m depth (altitude 0.6 m to 2.5 m) is flood continental deposit and it might be younger than 5000 years ago of the transgression.

Engineering property of each stratum is determined by calculation from standard penetration test results: N-value as follows.

The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. The test procedure is described in the British Standard BS EN ISO 22476-3, ASTM D1586 and Australian Standards AS 1289.6.3.1.

The test uses a thick-walled sample tube, with an outside diameter of 50 mm and an inside diameter of 35 mm, and a length of around 650 mm. This is driven into the ground at the bottom of a borehole by blows from a slide hammer with a weight of 63.5 kg (140 lb) falling through a distance of 760 mm (30 in). The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm (6 in) up to a depth of 450 mm (18 in) is recorded. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance" or the "N-value". In cases where 50 blows are insufficient to advance it through a 150 mm (6 in) interval the penetration after 50 blows is recorded. The blow count provides an indication of the density of the ground, and it is used in many empirical geotechnical engineering formulae.

N-values adopted for each geological stratum are minus one-half standard deviations from the average generally. Only for Pleistocene clay with boulder (Q1a-are/ped), minimum N-value is adopted to assess the strength of the clay matrix and to escape the effects of gravels and boulders mixed.

Cohesion is the force that holds together molecules or like particles within a soil for cohesive soils or clay type soils. Cohesion, c can be determined by following formula from Terzaghi, K., Peck, R. B. and Mesri, G., Soil Mechanics in Engineering Practice, 3rd Ed. Wiley-Interscience (1996) ISBN 0471086584.

$c = 6.25N$ (kN/m^2), and maximum value is 100 kN/m^2.

Where;

c = Cohesion (kN/m^2)

N = N-value of standard penetration test

Angle of internal friction for sand is the angle on the graph (Mohr's Circle) of the shear stress and normal effective stresses at which shear failure occurs. Angle of Internal Friction, φ, can be determined by the following relationship between, φ, and N-value for sands from Peck 1974, Foundation Engineering Handbook and following formula can be utilized.

$$\boldsymbol{\varphi} = 27 + 0.3\ N$$

Where;

φ = Angle of internal friction (degree)

N = N-value of standard penetration test

Unit weights of soil are the determined by following empirical values shown in Table 6.3.2 based on the N-value.

Table 6.3.2 Empirical Values for Unit weight γ, of Granular Soils based on the Standard Penetration Test N-value

SPT Penetration, N-Value (blows/ 30cm)	Unit weight γ (kN/m^3)
0 - 4	11- 16
4 - 10	14 - 18
10 - 30	17 - 20
30 - 50	17 - 22
>50	20- 24

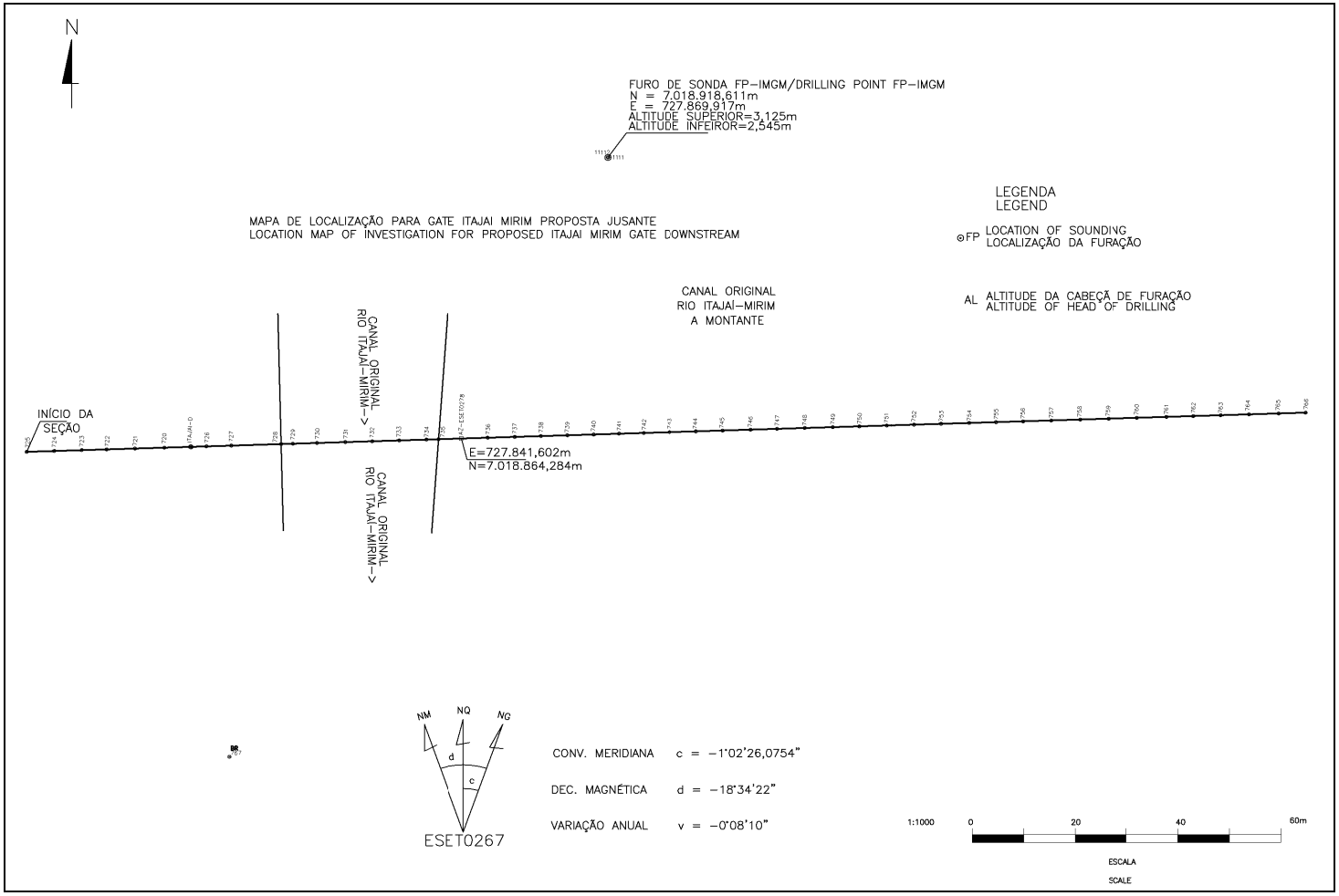
Source: modified from Bowels, Foundation Analysis of United State of America

Engineering properties of each stratum are determined and shown in Table 6.3.3.

Table 6.3.3 Determined Engineering Property of Each Stratum for the Itajai Mirim Upstream Gate

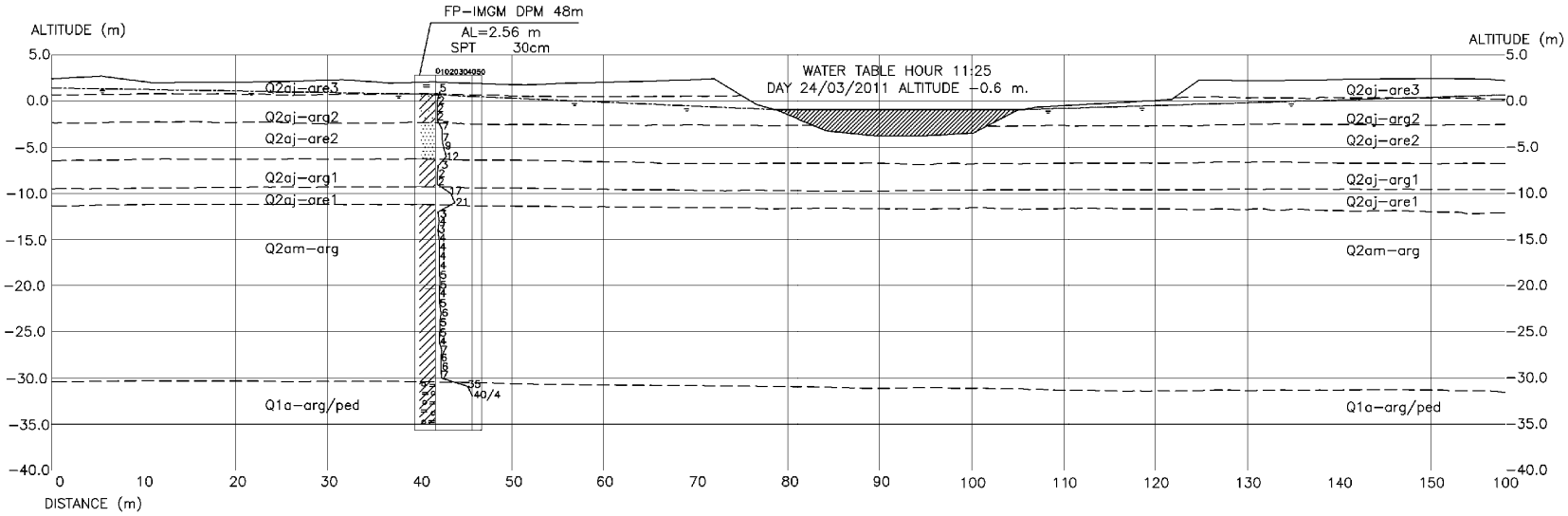
Symbol	Name of strata	SPT N-Value Average (blows/ 30cm)	SPT N-Value Standard deviation (blows/30cm)	SPT N-value Adopted (blows/ 30cm)	Soil Strength c: cohesion (kN/m^2) φ: angle of internal friction (degrees)	Unit weight saturated γ_{sat} kN/m^3
Q2aj -are3	Young Holocene sand 3	4.5	0.7	4.2	C=0 φ=28	15
Q2aj-arg2	Young Holocene clay 2	2.2	0.4	2.0	C=13 φ=0	18
Q2aj-are2	Young Holocene sand 2	7.6	2.3	6.5	C=0 φ=29	16
Q2aj-arg1	Young Holocene clay 1	2.2	0.4	1.8	C=11 φ=0	17
Q2aj-are1	Young Holocene sand 1	16	4	14	C=0 φ=31	18
Q2am-arg	Medium Holocene clay	4.5	1.2	3.9	C=24 φ=0	19
Q1a-arg/ped	Pleistocene clay	109	130	23	C=100 φ=0	21

Source: JICA Survey Team



Source: JICA Survey Team

Figure 6.3.1 Location Map of the Itajai Mirim Upstream Gate



ENGINEERING GEOLOGICAL PROFILE OF ITAJAI MIRIM GATE (UPSTREAM)

LEGEND FOR ENGINEERING GEOLOGICAL PROFILE

LOG

- CLAY
- SILT
- SAND
- COBBLE/BOULDER
- CLAYEY, WITH CLAY
- SILTY, WITH SILT
- SANDY, WITH SAND
- GRAVELLY, WITH GRAVEL
- WITH COBBLE/BOULDER

FP-	NUMBER OF DRILLING POINT
SP-	NUMBER OF SOUNDING POINT
AL.	ALTITUDE OF HEAD OF DRILLING HOLE
DPM	PROJECTION DISTANCE FROM UPSTREAM
DPJ	PROJECTION DISTANCE OF DOWNSTREAM
— —	BOUNDARY OF GEOLOGICAL STRATA
—·—▽	GROUND WATER TABLE

GEOLOGICAL STRATA

AT	EMBANKMENT
ALLUVIAL DEPOSIT	
Q2aj-are3	YOUNG HOLOCENE SAND 3
Q2aj-arg2	YOUNG HOLOCENE CLAY 2
Q2aj-are2	YOUNG HOLOCENE SAND 2
Q2aj-arg1	YOUNG HOLOCENE CLAY 1
Q2aj-are1	YOUNG HOLOCENE SAND 1
Q2m-are	MIDDLE HOLOCENE SAND
Q2m-arg	MIDDLE HOLOCENE CLAY
Q2aa-are	OLD HOLOCENE SAND
Q1a-arg/ped	PLEISTOCENE CLAY WITH BOULDER
Q1a-are/ped	PLEISTOCENE SAND WITH BOULDER

Source: JICA Survey Team

Figure 6.3.2 Engineering Geological Profile of Itajai Mirim Upstream Gate

6.4 Itajai Mirim Gate (Down Stream)

The proposed gate site is in the alluvial plan beside the Old Itajai Mirim River 180 meter upstream from the confluence with Itajai Mirim Channel. It is directory 5.0 km southwest from river mouth of Itajai-Acu River, and directory 5.4km South-Southeast from river mouth of Itajai Mirim River.

Ground ingredient is almost flat, and altitude of the river bank of the site is around 3 meter. The proposed site is located just downstream of the Brasilia Bridge of the Davi Adao Schimitt Road. The 40 meter depth drilling investigation was conducted by this survey, and three (3) existing sounding (standard penetration test holes) for New Brasilia Bridge was conducted by Itajai City as shown in location map of Figure 6.4.1.

The geology is alluvial deposit in Quaternary System from surface to deeper than around 40 meter depth; the depth of the alluvial deposit bottom is not clear. The geological strata are found out by the drilling and existing data of three (3) sounding holes as described in Table 6.4.1. The engineering geological profile is shown in Figure 6.4.2.

Table 6.4.1 Geological Strata of Proposed Itajai Mirim Downstream Gate

Period	Epoch	Symbol	Name of strata	Feature of strata	Summary of stranded penetration test (SPT) result, N-value
		AT	Aterro Embankment		
Quaterário / Quaternary	Holocene	Q2aj-are3	Jovem Holocino areia 3 Young Holocene sand 3	Fine sand with silt and clay, brown and loose. Recent flood deposit.	Minimum 4 Maximum 8 Average 6
		Q2aj-arg2	Jovem Holocino argila 2 Young Holocene clay 2	Clay with sand, brown, gray and green.	Minimum 0.3 Maximum 4 Average 2
		Q2aj-are2	Jovem Holocino areia 2 Young Holocene sand 2	Fine sand, gray and green.	Minimum 4 Maximum 17 Average 8
		Q2aj-arg1	Jovem Holocino argila 1 Young Holocene clay 1	Clay, dark gray, with shells.	Minimum 2 Maximum 7 Average 3
		Q2am-are	Médio Holoceno areia Medium Holocene sand		Minimum 9 Maximum 143 Average 57
		Q2am-arg	Médio Holoceno argila Medium Holocene clay	Clay, brown and dark gray	Minimum 2 Maximum 8 Average 5
		Q2aa-are	Antigo Holoceno areia Old Holocene sand		Minimum 10 Maximum 35 Average 21
		Q2aa-arg	Antigo Holocene argila Old Holocene clay	Silt with clay with boulder, light gray	Minimum 5 Maximum 7 Average 6
	Pleistocene	Q1a-are/ped	Pleistocene sand with boulder		Minimum 25 Maximum 59 Average 41

Source: JICA Survey Team

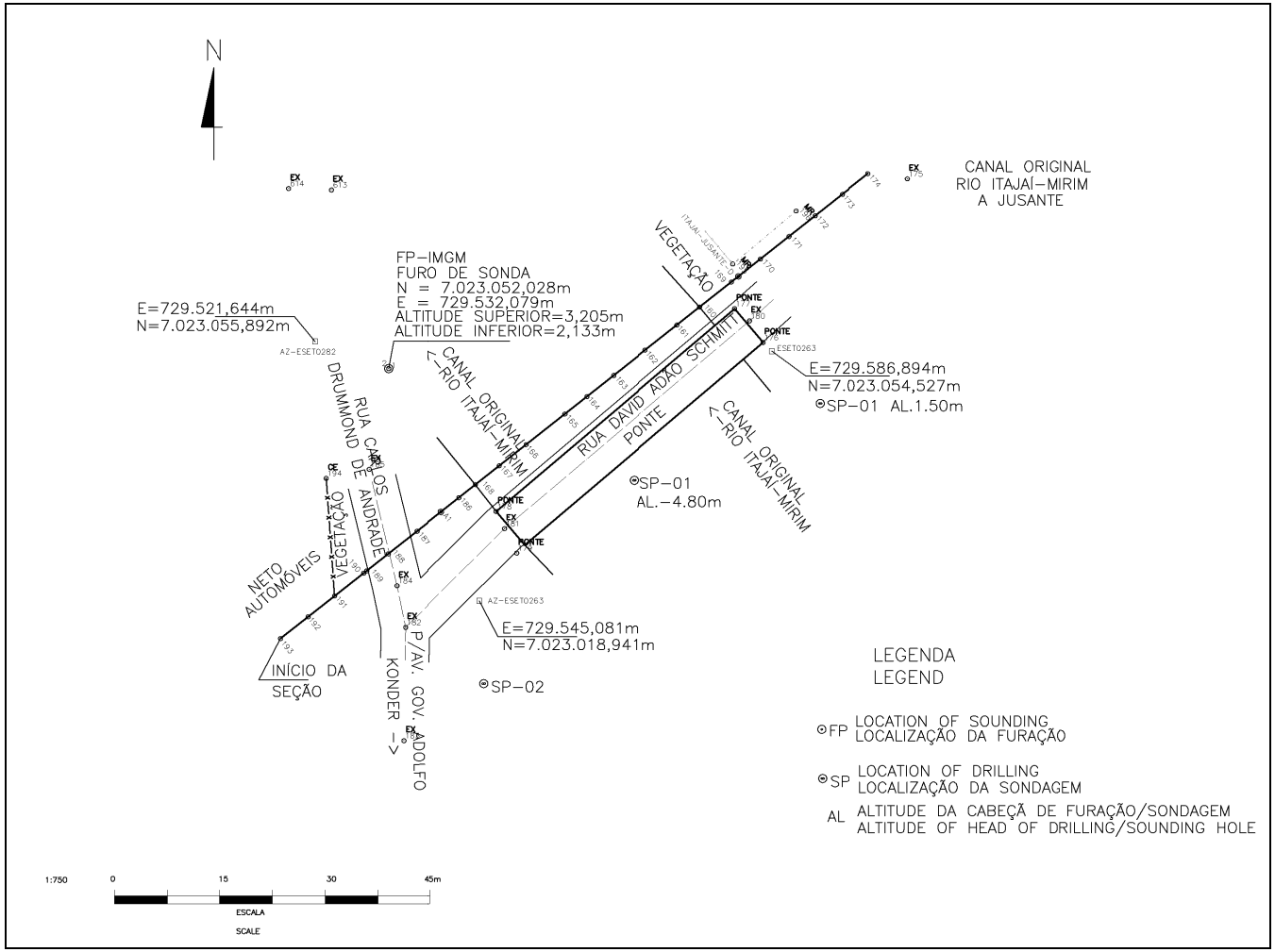
Engineering property of each stratum is determined by calculation from standard penetration test results: N-value as explained in section (1) Itajai Mirim Upstream Gate.

Engineering properties of each stratum are determined and shown in Table 6.4.2.

Table 6.4.2 Determined Engineering Property of Each Stratum for the Itajai Mirim Downstream Gate

Symbol	Name of strata	SPT N-Value Average (blows/ 30cm)	SPT N-Value Standard deviation (blows/ 30cm)	SPT N-value Adopted (blows/ 30cm)	Soil Strength c: cohesion (kN/m^2) φ: angle of internal friction (degrees)	Unit weight saturated γ_{sat} kN/m^3
AT/ Q2aj -are3	Embankment/ Young Holocene sand 3	5.8	1.4	5.1	c=0 φ=29	15
Q2aj-arg2	Young Holocene clay 2	2.1	0.9	1.7	c=11 φ=0	17
Q2aj-are2	Young Holocene sand 2	8.4	4.5	6.2	c=0 φ=29	15
Q2aj-arg1	Young Holocene clay 1	3.3	1.2	2.7	c=17 φ=0	18
Q2am-are	Medium Holocene sand	57	29	43	c=0 φ=40	20
Q2am-arg	Medium Holocene clay	4.9	1.5	4.2	c=26 φ=0	18
Q2aa-are	Old Holocene sand	21	6.8	18	c=0 φ=32	18
Q2aa-are	Old Holocene clay	6.0	1.4	5.3	c=33 φ=0	18
Q1a-are/ped	Pleistocene sand with boulder	41	14	25	c=0 φ=35	19

Source: JICA Survey Team



Source: JICA Survey Team

Figure 6.4.1 Location Map of the Itajai Mirim Downstream Gate

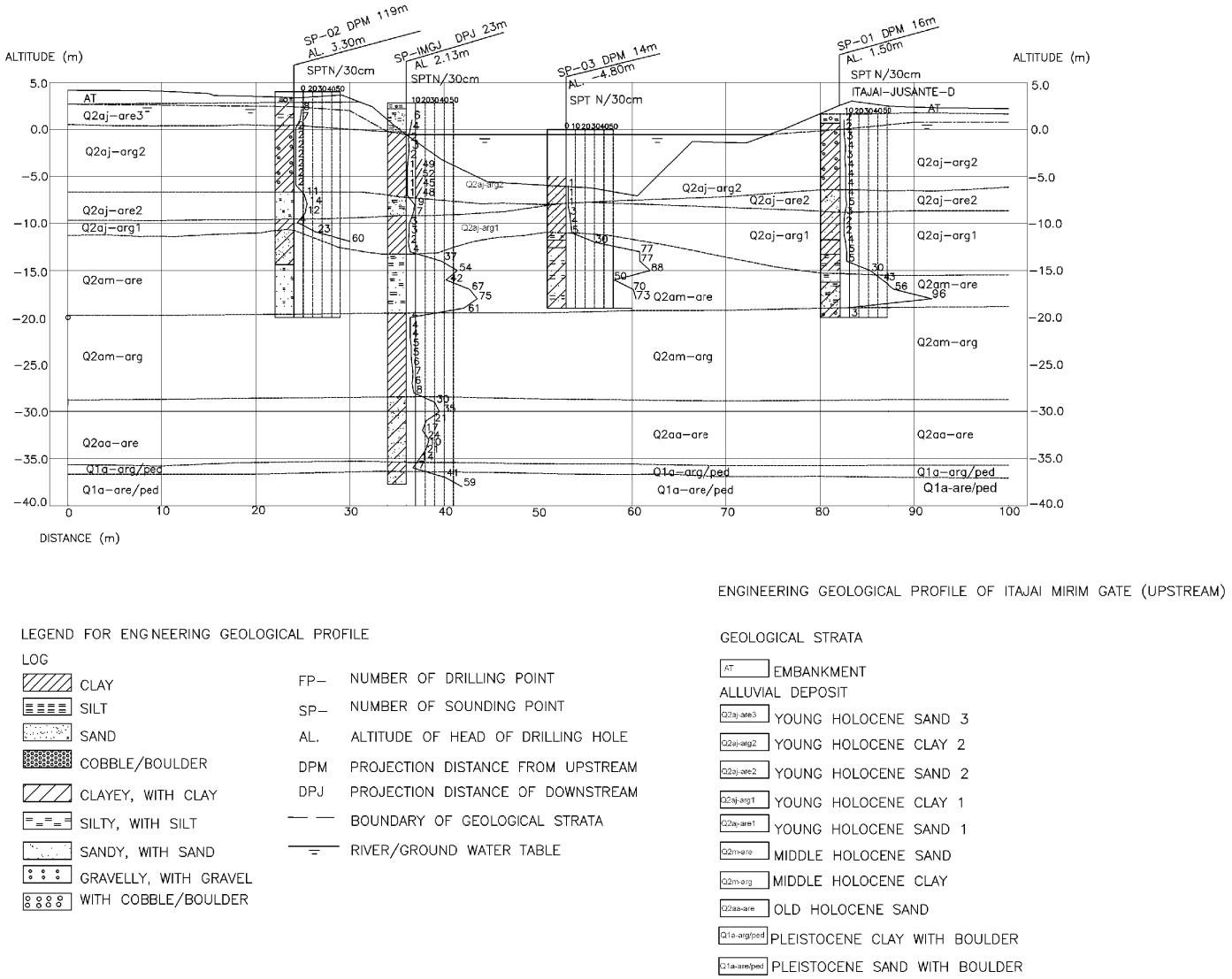


Figure 6.4.2 Engineering Geological Profile of the Itajai Mirim Downstream Gate

6.5 Sites for Structural Measures for Landslide

6.5.1 Site for Structural Measures for Landslide and Engineering Geological Investigations

(1) Location of 13 sites

Locations of priority 13 sites are shown in Table 6.5.1 and Figure 6.5.1, 6.5.2, and 6.5.3.

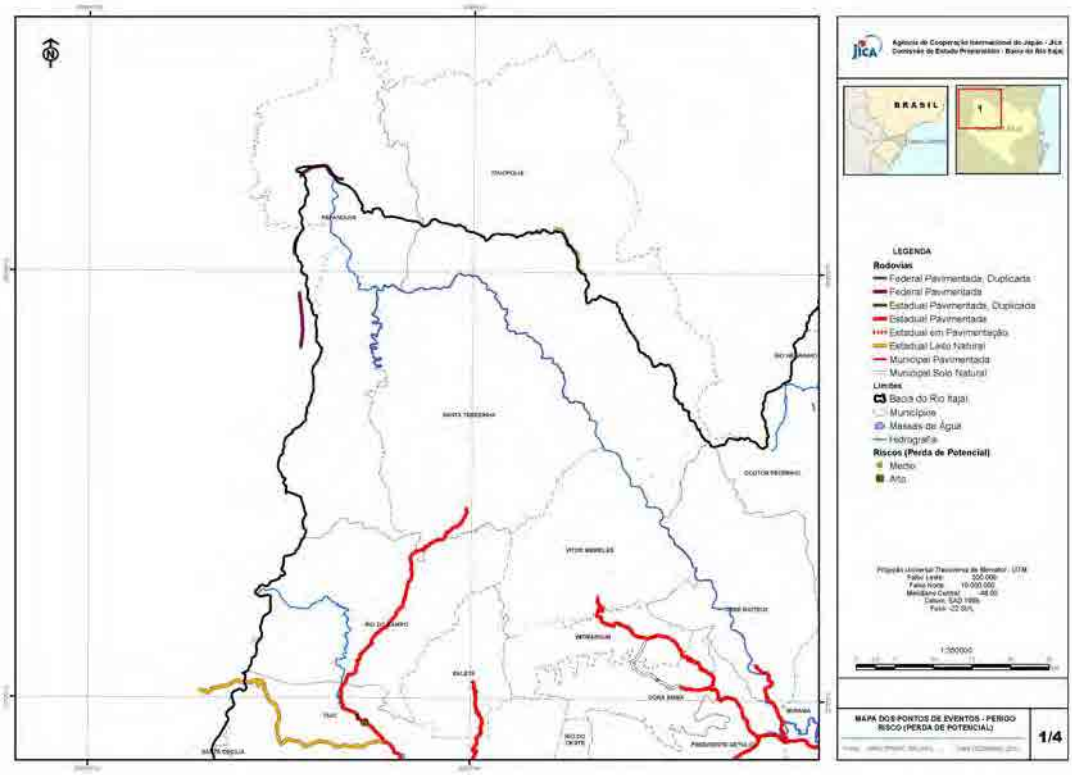
Table 6.5.1 List of 13 Priority Sites for Landslide Structural Measures

No.	Name of location	The south latitude			The west longitude			SDR	Municipality
		Degree	Minute	Second	Degree	Minute	Second		
1	SC 302 Taio-Passo Manso-5	27	1	45	50	8	18	Taio	Taio
2	SC470 Gaspar River Bank	26	55	2	48	58	37	Blumenau	Gaspar
3	Blumenau -Av Pres Casrelo Branco	26	55	7	49	3	58	Blumenau	Blumenau
4	SC418 Blumenau - Pomerode	26	51	32	49	9	18	Blumenau	Pomerode
5	SC474 Blumenau-Massaranduba 2	26	44	18	49	4	18	Blumenau	Blumenau
6	Gaspar - Luiz Alves, Gaspar 9	26	47	38	49	0	16	Blumenau	Gaspar
7	Gaspar - Luiz Alves, Luiz Alves 6	26	44	26	48	57	52	Blumenau	Luiz Alves
8	SC470 Gaspar Bypass	26	55	56	48	57	21	Blumenau	Gaspar
9	SC477 Benedito Novo - Dutor Pedrinho 1	26	46	50	49	25	6	Indaial	Benedito Novo
10	SC418 Pomerode - Jaraguá do Sul 1	26	40	29	49	8	35	Blumenau	Pomerode
11	Gaspar - Luiz Alves, Luiz Alves 4	26	46	38	48	59	31	Blumenau	Luiz Alves
12	SC474 Blumenau-Massaranduba 1	26	46	38	48	59	31	Blumenau	Blumenau
13	SC 302 Taio-Passo Manso 4	27	6	26	50	4	7	Taio	Taio

Source JICA Survey Team

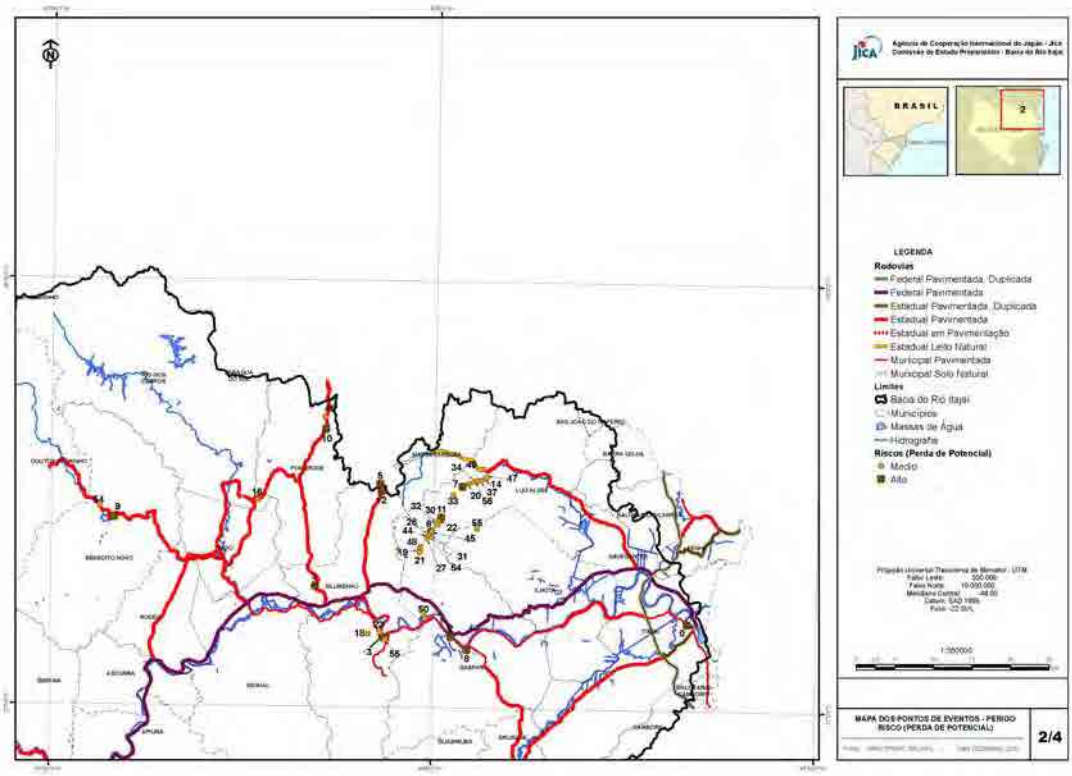
(2) Investigation Items

Items of topographic surveys and geological investigations are shown in Table 6.5.2. Result of field observation and investigation are compiled in plan engineering geological maps and some engineering geological profiles.



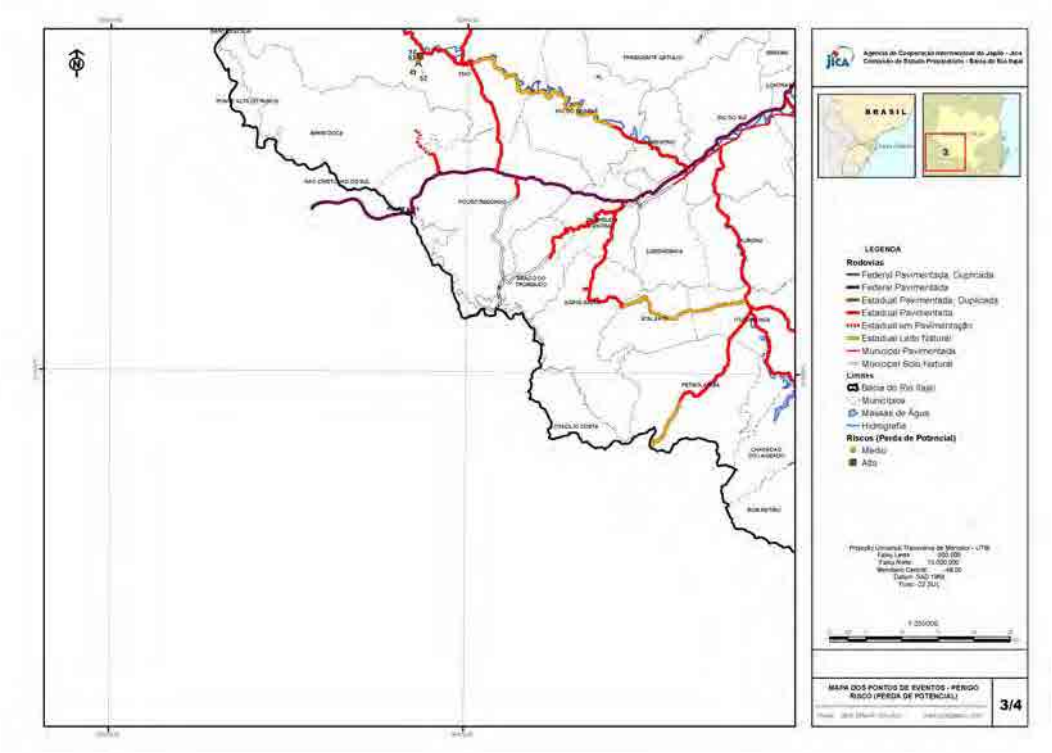
Source: JICA Survey Team

Figure 6.5.1 Location of Priority 13Landslide Risk Sites (1)



Source: JICA Survey Team

Figure 6.5.2 Location of Priority 13 Sites for Landslides (2)



Source: JICA Survey Team¥

Figure 6.5.3 Location of Priority 13 Sites for Landslides (3)

Table 6.5.2 List of 13 Priority Sites for Landslides

No.	Name of Site	Topographic cross section Survey	Drilling, standard penetration tests, and pipe strain gauge monitoring	Simplifued dynamic cone penetration test
1	SC 302 Taio-Passo Manso-5	212 m	2 vertical drilling 6,0 m, 5,4 m	-
2	SC470 Gaspar River Bank	50 m	-	-
3	Blumenau -Av Pres Casrelo Branco	66 m		2 sites
4	SC418 Blumenau – Pomerode	74 m	-	1 sites
5	SC474 Blumenau-Massaranduba 2	85 m	-	-
6	Gaspar - Luiz Alves, Gaspar 9	84 m	-	-
7	Gaspar - Luiz Alves, Luiz Alves 6	105 m	-	2sites
8	SC470 Gaspar Bypass	60 m	-	-
9	SC477 Benedito Novo - Dutor Pedrinho 1	112 m	2 vertical drillings, 14.5 m, 13.5m	-
10	SC418 Pomerode - Jaraguá do Sul 1	163 m	-	1 site
11	Gaspar - Luiz Alves, Luiz Alves 4	111 m	-	1 site
12	SC474 Blumenau-Massaranduba 1	85 m	-	--
13	SC 302 Taio-Passo Manso 4	98 m	-	-
Total		1,305m	4 vertical drilling, 39.4 m	7 sites

Source JICA Survey Team

(3) Pipe Strain Gauge Monitoring

The purpose of strain gauges with PVC (Polyvinyl chloride) pipes installment in drilling holes is to detect the depth of slip surface.

When PVC pipes, which installed in a drilling holes, is bent by the movement of a landslide, one side of PVC pipes is compressed, and another side is extended. Strain gauges with PVC pipes are measuring instruments which can judge a slip surface and determine the degree of displacement of strain gauge by measurement of small changes in electric resistance value caused by the bending of PVC pipes. A set of two strain gauges were put on PVC pipes at 1 meter intervals depths.

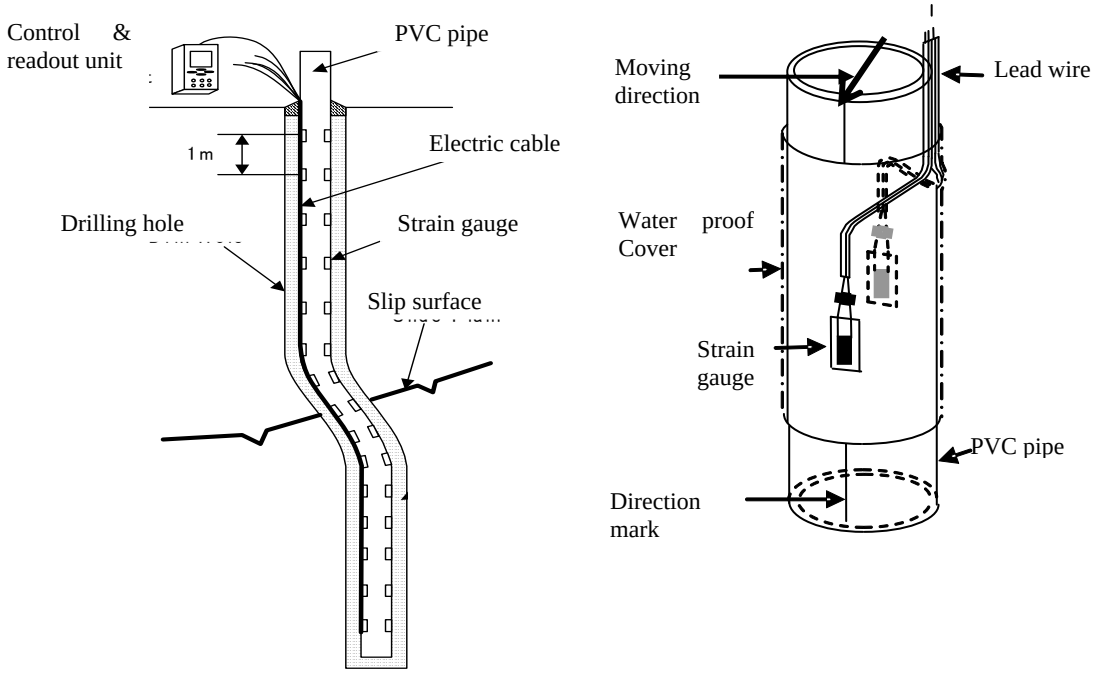


Figure 6.5.4 Strain Gauges with PVC Pipes

An example of graph of strain gauges monitoring is shown below. In this graph, the value of strain increases at the depth of slip surface.

If a landslide moves, the value of strain will be accumulated. Data not accumulated (only one time movement) is just accidental.

Evaluation of data of strain gauges is shown in the next table.

Table 6.5.3 Criteria for Evaluation of Data of Strain Gauges in Japan

Activity lank	Value of accumulation (μ/month)	Variability Characteristics		Geographic possibility of existence of slip surface	Overall judgments	
		Tendency of accumulation	Status of moving		Classification of slip surface	Activity and Type of landslide
A	More than 5,000	Very High	Accumulative	Possible	Deterministic	Active landslide-
B	More than 1,000	High	Accumulative	Possible	Qusi-deterministic	Slowly moving creep
C	More than 100	Low	Accumulative/intermissive/destabilizing/regressive	Possible	Potential	Impossible to conclude existence of slip surface. Need to continue observation.
D	More than 100 (Short term)	None	Intermissive/destabilizing/regressive	None	Abnormal	Slip surface is not existent. Caused by other factors, except landslide.

Source: JICA Survey Team

6.5.2 Engineering Geology on Selected Structural Measure Sites

(1) SC301 Taio -Passo Manso-5

Active landslide block of 80 m width 60 m length is recognized. Pavement has been broken recurrently due to landslide. Drilling investigation shows that bed rock surface is shallow (2.7 m -3.0 m depth) and groundwater table is shallow (1.0 m -2.6 m). Pipe strain gauge monitoring does not indicate sharply-defined slip surface.

General view from Taio side

General view from Passo Manso side

Shale rock, bedding is almost flat

Landslide scarp on mountain side slope

Landslide scarp on mountain side slope

Damaged pavement

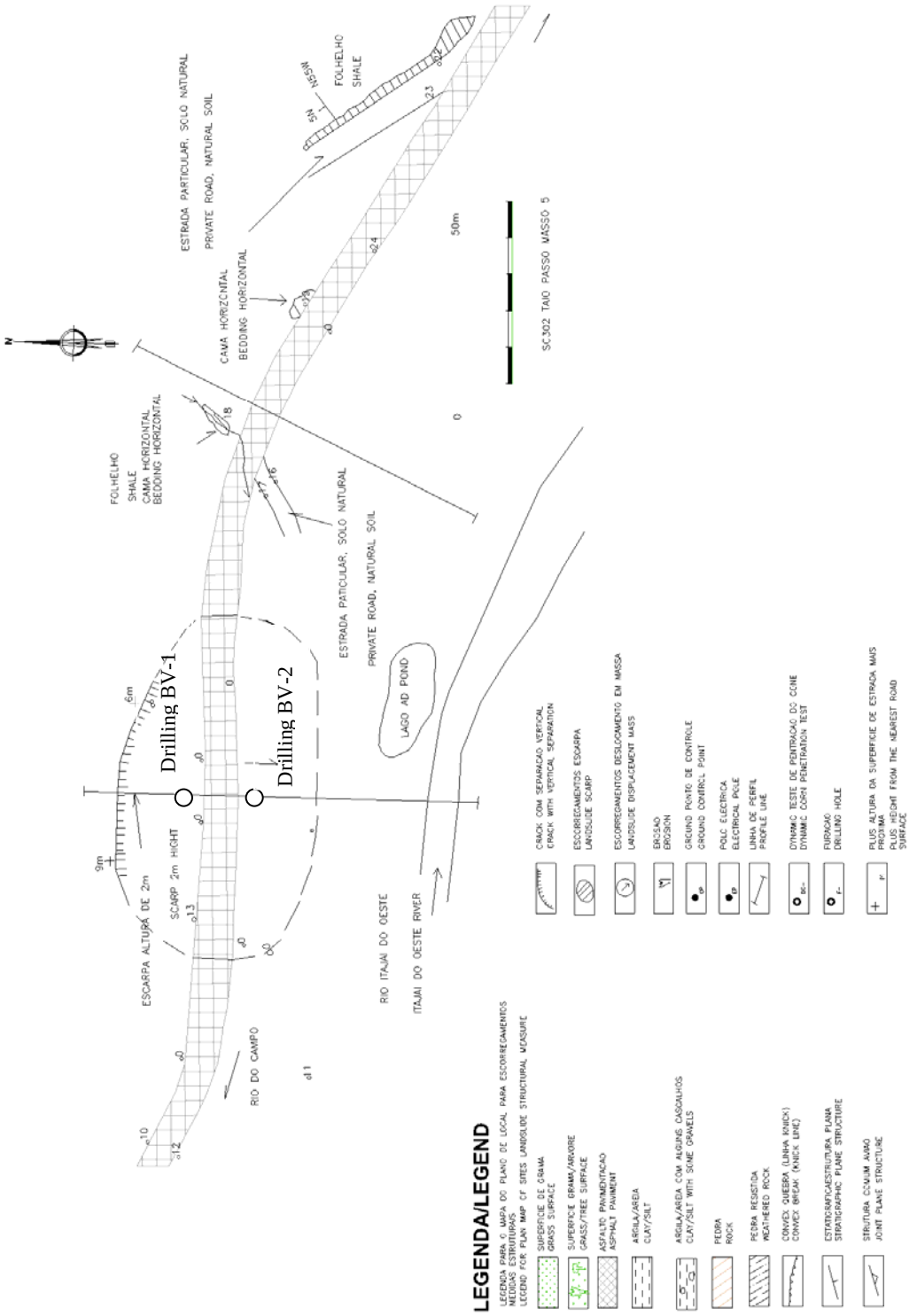
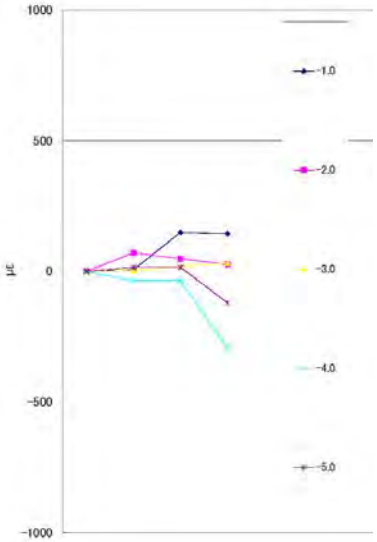
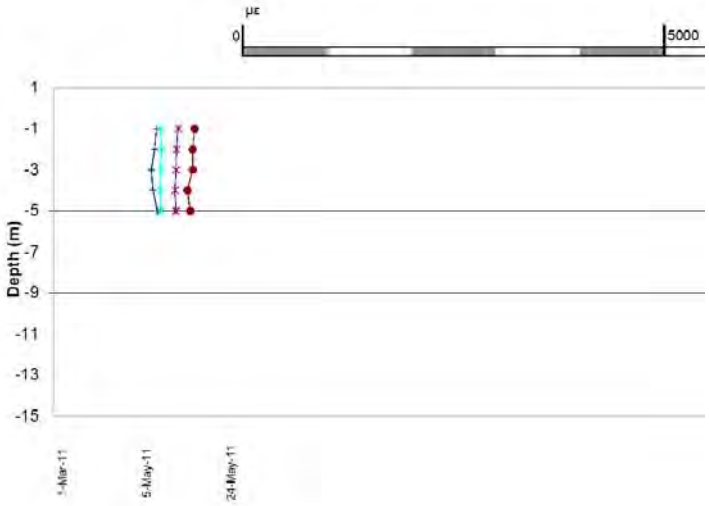


Figure 6.5.4 Engineering Geological Map for SC301 Taio -Passo Manso-5

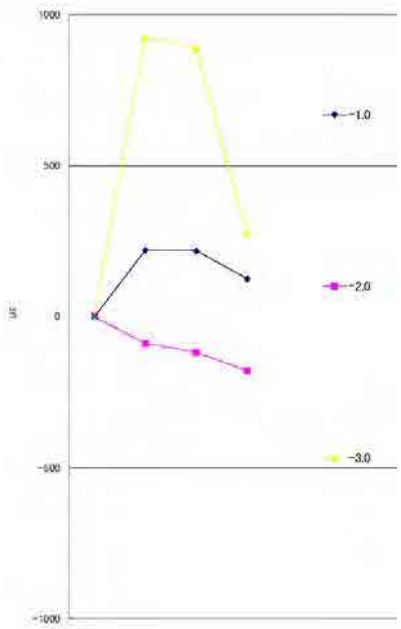
BV-1



Depth from Ground Line	28-Apr-11	5-May-11	14-May-11	24-May-11
	40661	40668	40677	40687
-1.0	0	6	150	145
-2.0	0	71	49	27
-3.0	0	4	18	32
-4.0	0	-36	-35	-292
-5.0	0	16	16	-120



BV-2



Depth from Ground Line	28-Apr-11	5-May-11	14-May-11	24-May-11
	40661	40668	40677	40687
-1.0	0	221	219	126
-2.0	0	-88	-117	-179
-3.0	0	927	891	277

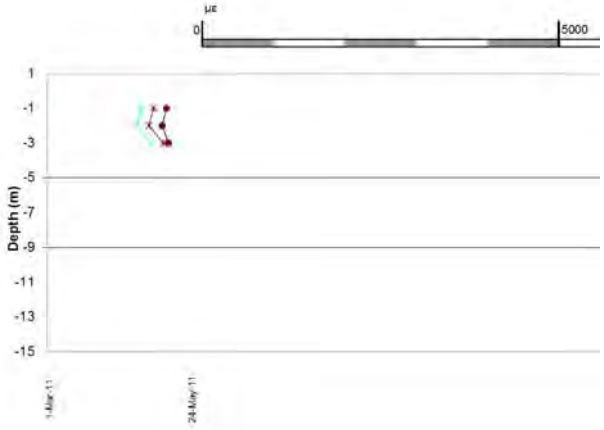


Figure 6.5.5 Pipe Strain gauge Monitoring for SC301 Taio -Passo Manso-5

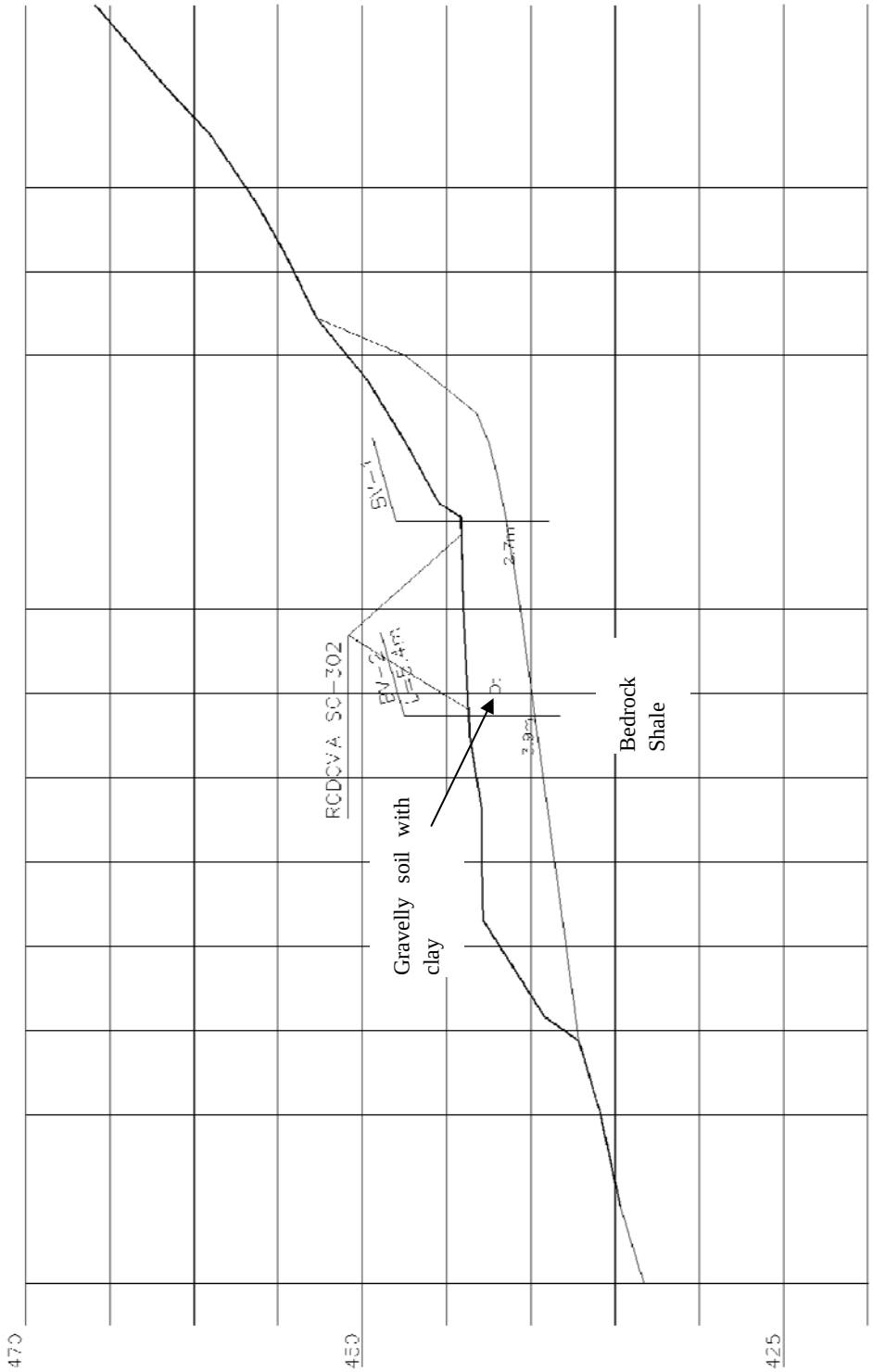


Figure 6.5.6 Engineering Geological Profile for SC301 Taio -Passo Manso-5

(2) SC470 Gaspar River Bank

The slope was collapsed by heavy rain in November 2008. The slope was temporally restored and protected by gabion. But deformation of road shoulder is progressing. It is a possibility of destruction of pipe culverts which go across the road. In that case, the water leakage may cause a further road slope failure.

General view from Gaspar side

General view from Blumenau side

Cracks on road pavement

Temporary slope protection by gabion

Temporary slope protection by gabion

Slope situation of the most deformed portion
Cross section line shown in Figure 6.5.7.

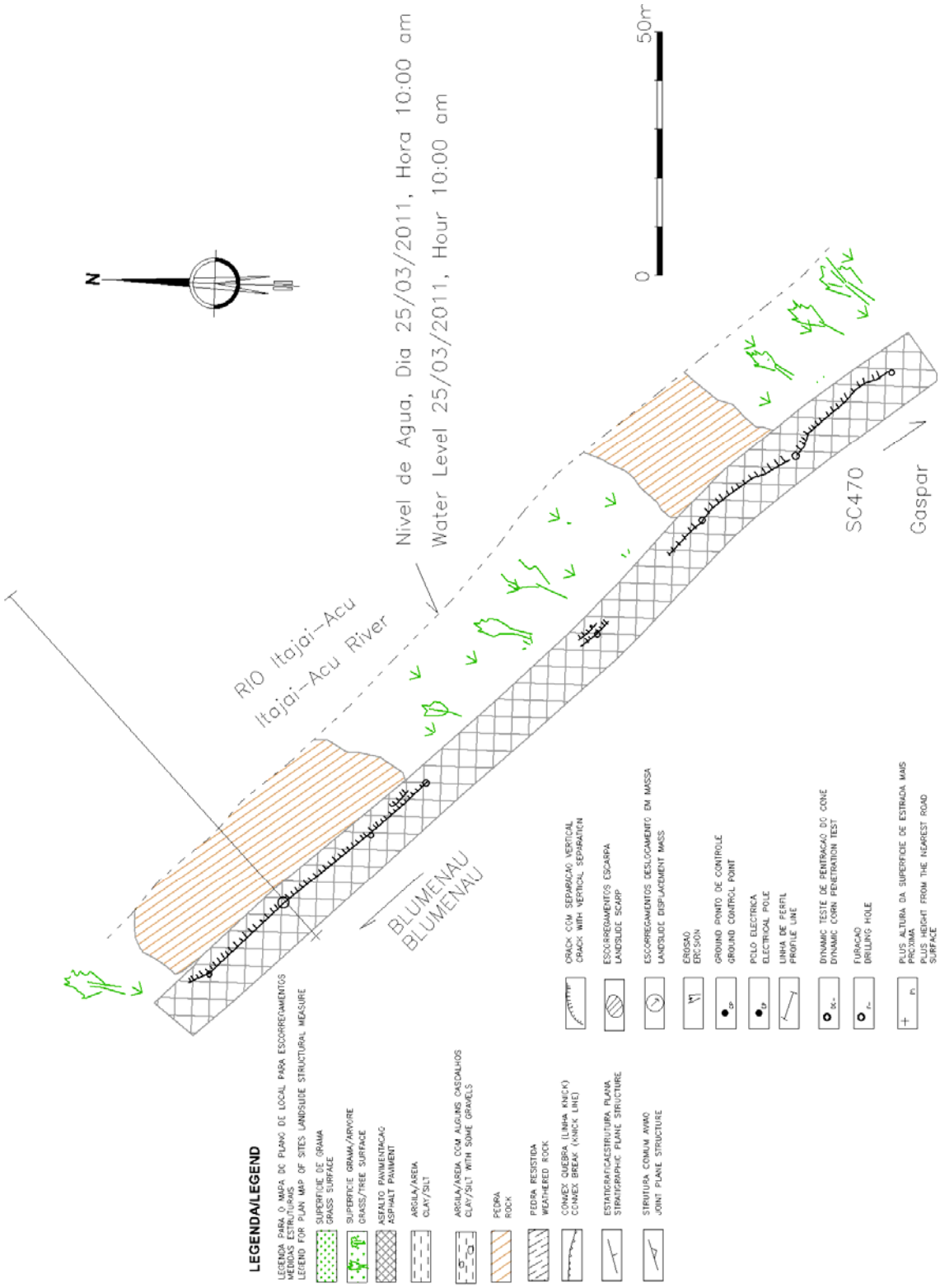


Figure 6.5.7 Engineering Geological Map for SC470 Gaspar River Bank

(3) SC470 Blumenau-Av Pres Castero Branco

Cracks and deformation is recognized on the road. The slope deformation with 10-20 cm height miner scarps of river bank is also recognized. Dynamic corn penetration test shows that soft clay is distributed of the slope surface with more than 3 meter depth.

General view from the opposite side of the Itajai-Acu River

Road side portion of the slope, sounding by dynamic corn penetration

Cracks on road pavement

Cracks on road pavement

Road side portion of the road side

22nd April 2011
The watermark level is 1meter

General view of the river side

Bedrock beside the river
hard and massive,
,Granulated Pyroxenite
Santa Catarina Granulite Complex, Archean.

Rubble work on talus deposit
(fine-grained soil with some gravels and cobles, some gravels and cobbles are weathered and soft.

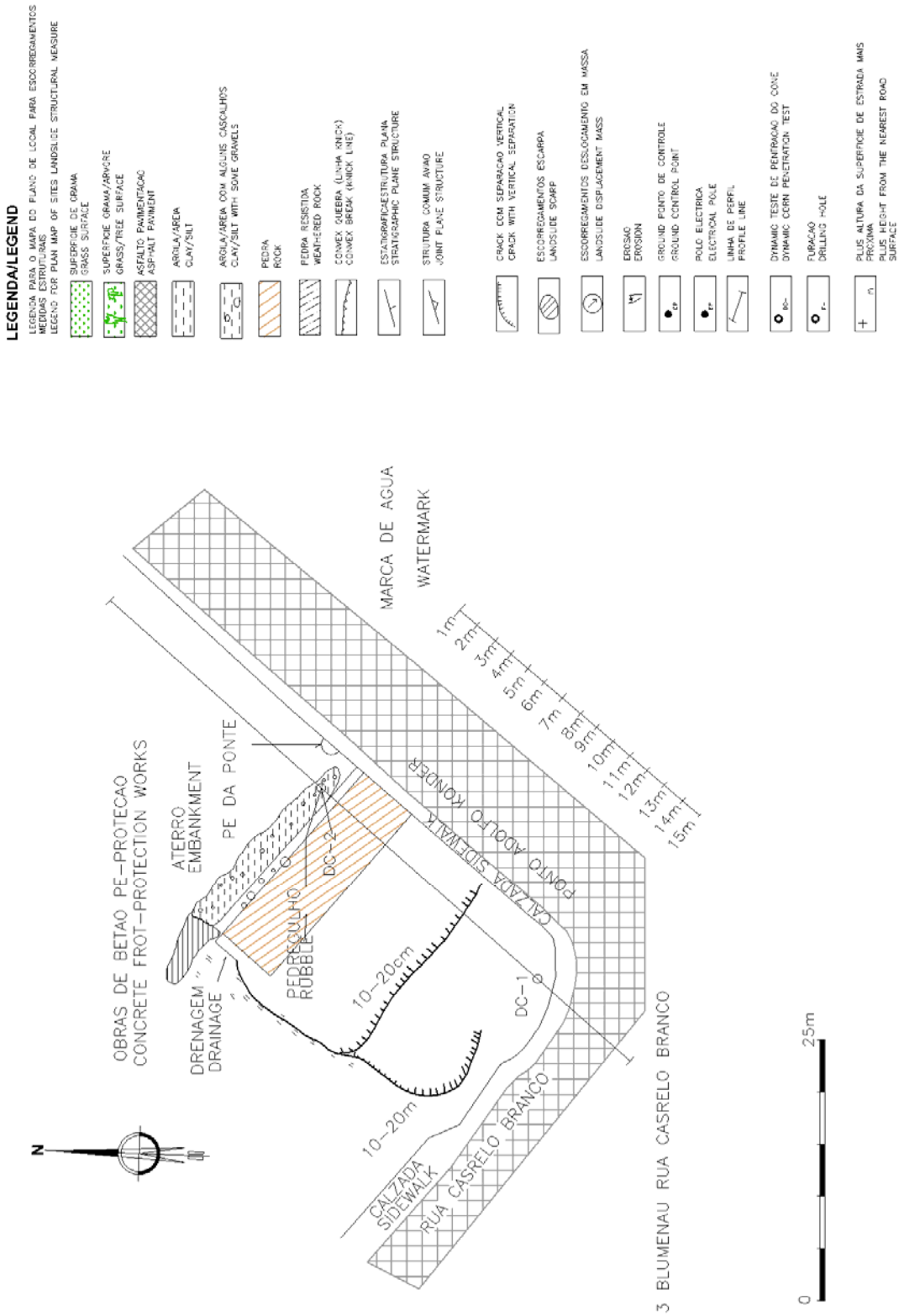


Figure 6.5.8 Engineering Geological Map for SC470 Blumenau-Av Pres Castero Branco

(4) SC418 Blumenau - Pomerode

Soil collapses have been occurred intermittently due to heavy rain. Crack which extend parallel to the road on the slope. Seepage out of water is found out.

Dynamic corn penetration test shows that very soft red clay is distributed of the slope surface with more than 3 meter depth.


General view from Blumenau side




Soil collapse and erosion of the center portion


Crack which extend parallel to the road on the slope. Seepage out of water is found out.


Crack which extend parallel to the road on the slope.

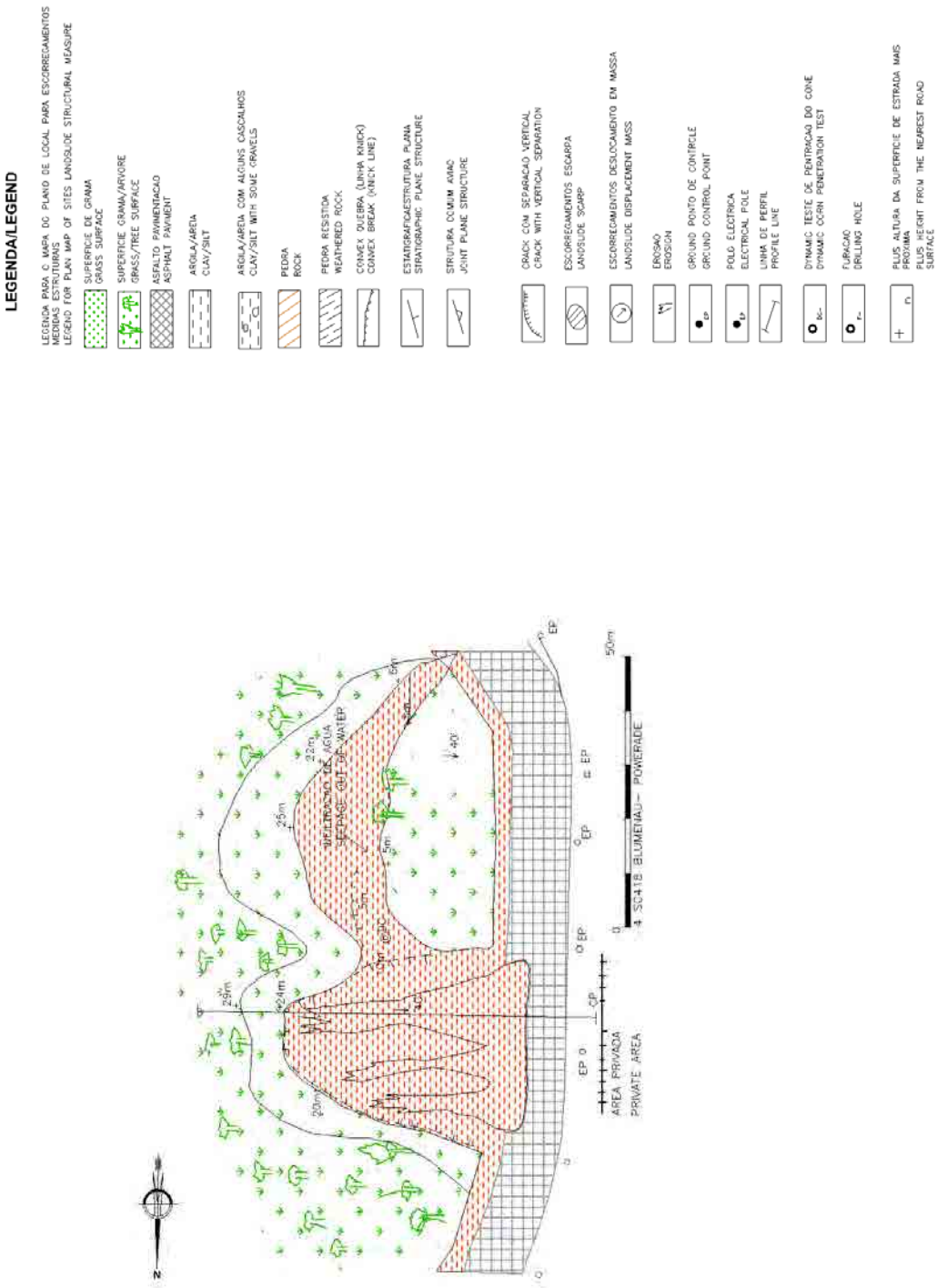


Figure 6.5.9 Engineering Geological Map for SC418 Blumenau-Pomerode

(5) SC474 Blumenau – Massaranduba 2

Soil collapses have been occurred intermittently due to heavy rain.

General view of the Blumenau City side soil collapse

Landslide portion of the center of the slope

Collapse prone portion of the slope, Massaranduba City side

Stable slope of the slope end of Massaranduba City side.
Hard rock, gneisses are distributed along the road.

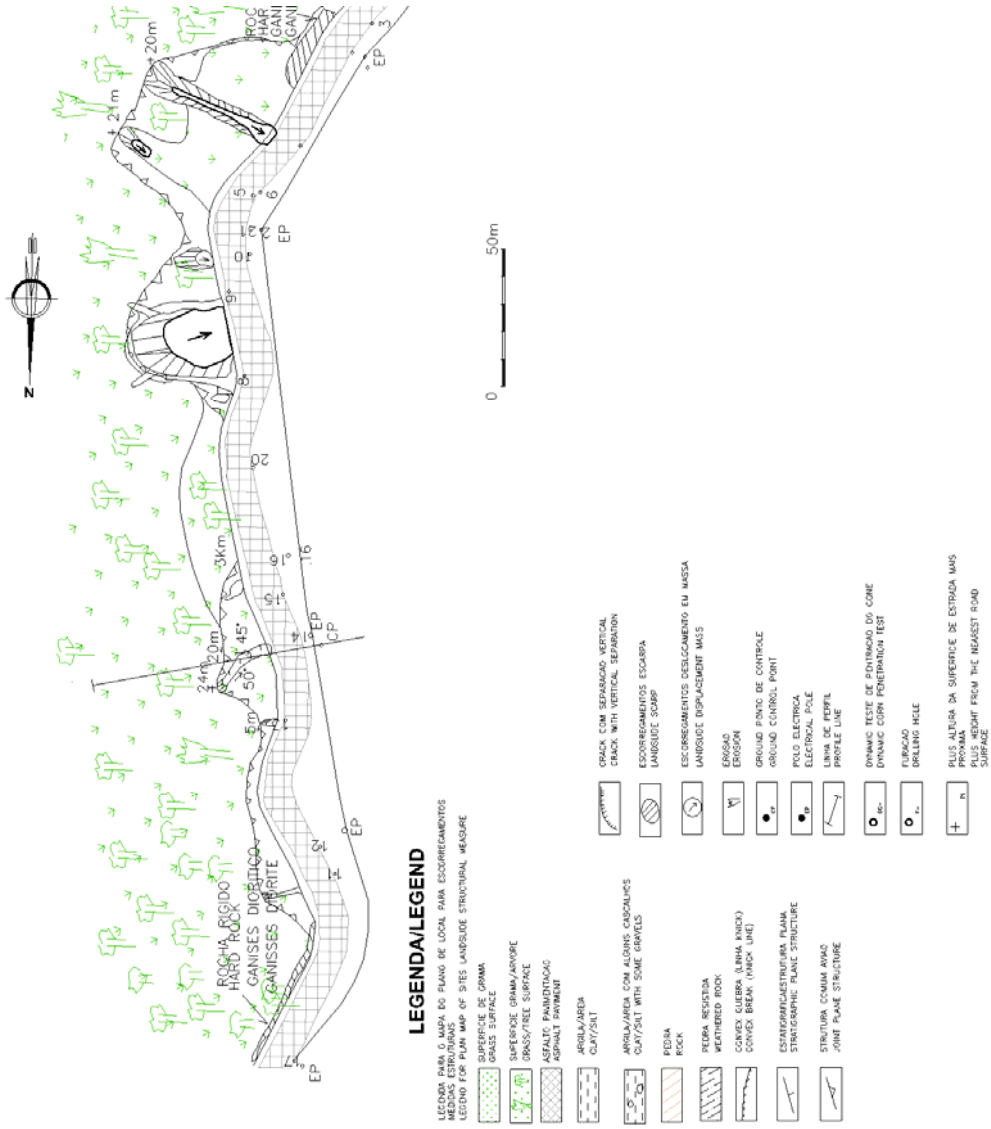


Figure 6.5.10 Engineering Geological Map for SC474 Blumenau – Massaranduba 2

(6) Gaspar-Luiz Alves, Gaspar 6

Soil collapses have been occurred intermittently due to heavy rain. Serious erosion is progressing in the side of valley, and Gaspar. Dynamic corn penetration test shows that very soft red clay is distributed of the slope surface with more than 3 meter depth.

General view of mountainside slope

Mountainside slope of Gaspar side

Mountain side Profile line

Valley side

Existing cut slope in Luiz Alves side

Slope open ditch 60 cm width, 60 cm depth.

Valley side slope of Luiz Alves side portion.

Erosion of valley side slope in Gaspar side portion.

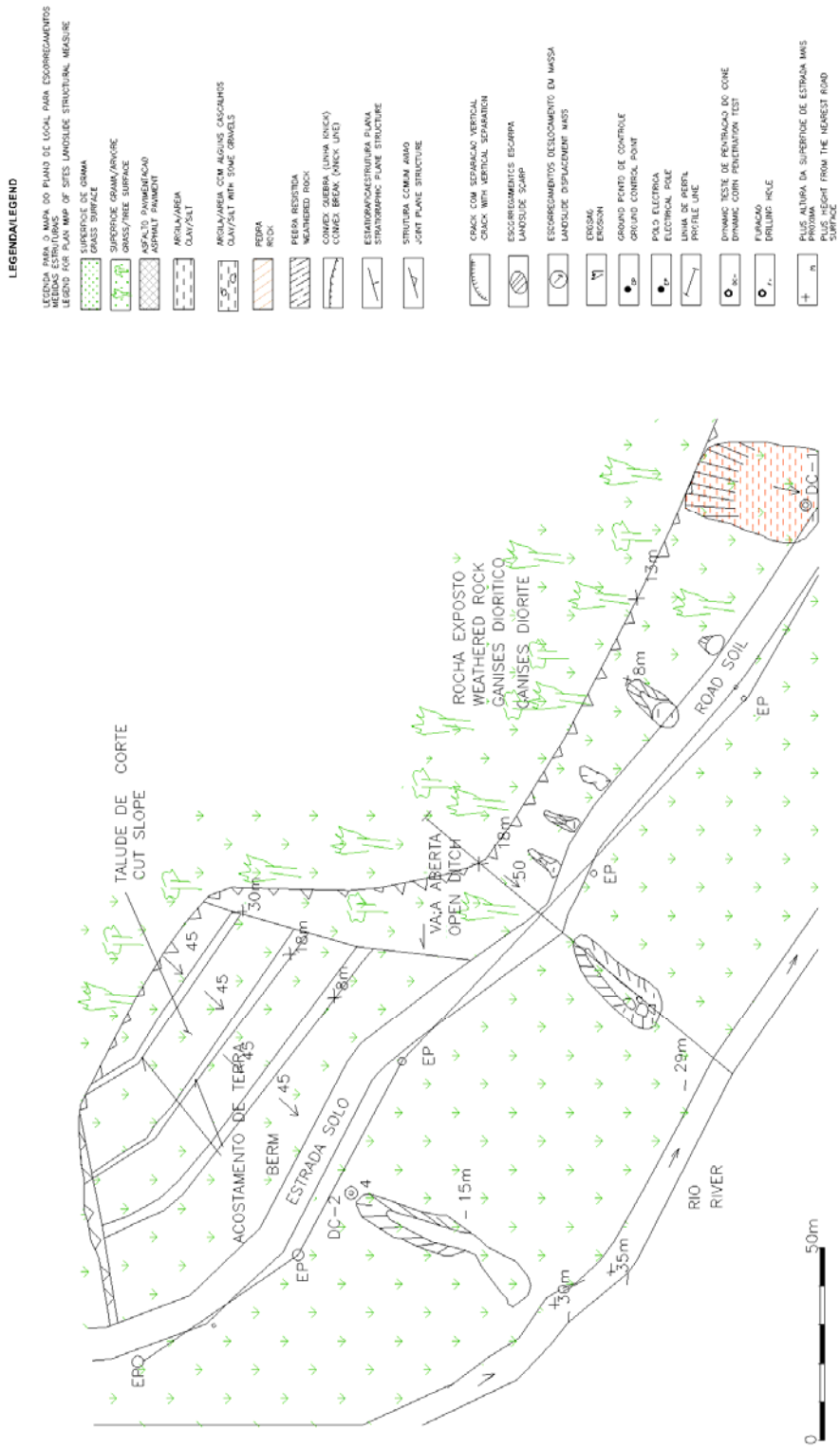


Figure 6.5.11 Engineering Geological Map for Gaspar-Luiz Alves, Gaspar 6

(7) Gaspar-Luiz Alves, Luiz Alves 6

Soil collapses have been occurred intermittently due to heavy rain. There is a possibility of rock slope collapse in center portion.

General view from Gaspar City side

General view of Gaspar City side to center

General view of center portion

Soil collapse on Gaspar side portion

Rock slope 60 degree, on center portion

Structure of joint is N10W 70Wdip, gentle oblique to slope surface. Granulite, hard rock

Ruiz Alves side portion , Soil collapse of Luiz Alves side portion

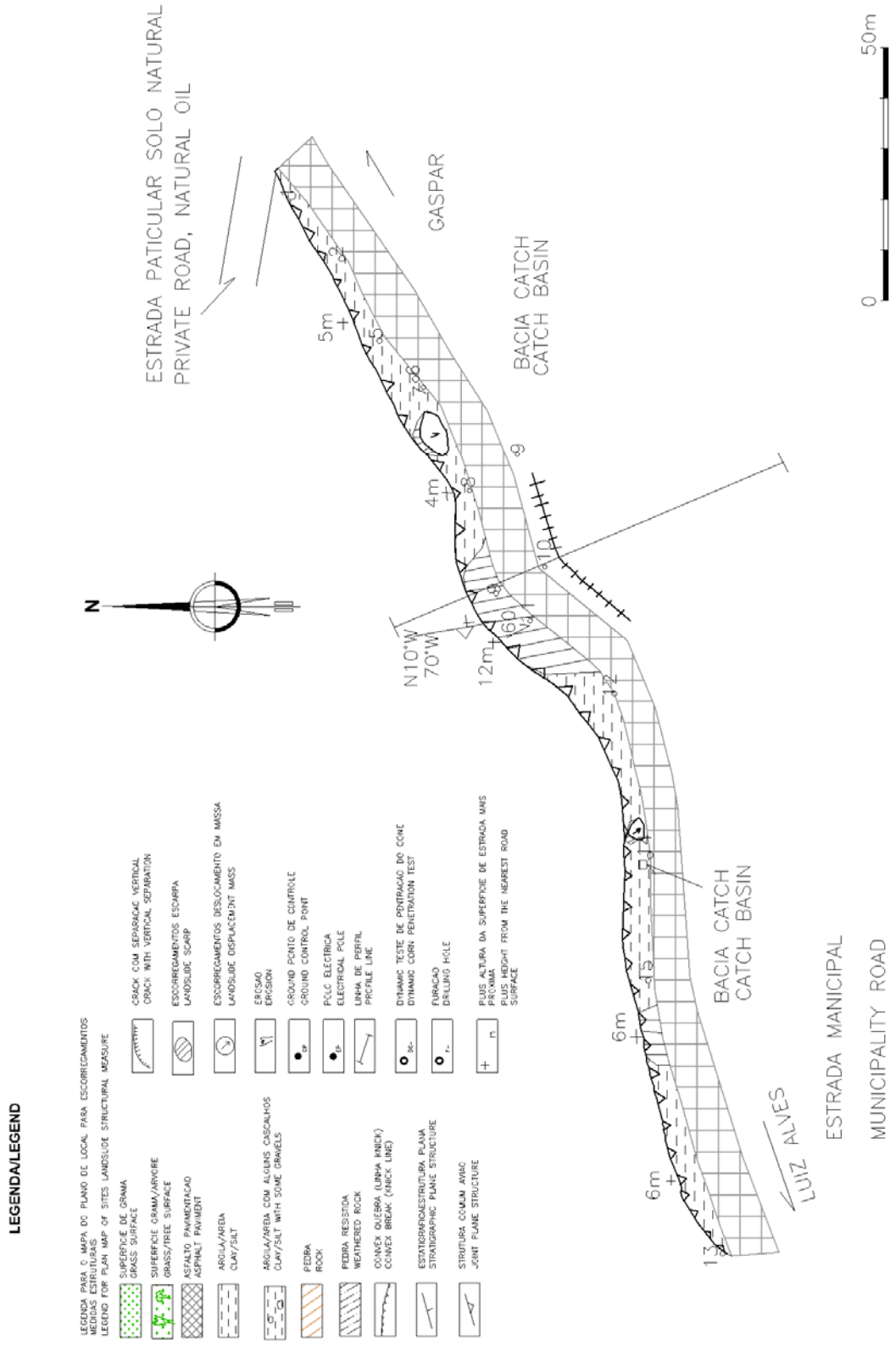
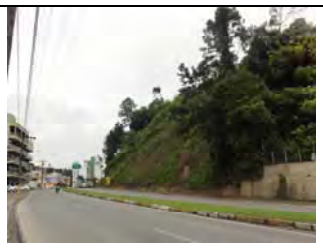


Figure 6.5.12 Engineering Geological Map for Gaspar-Luiz Alves, Luiz Alves 6

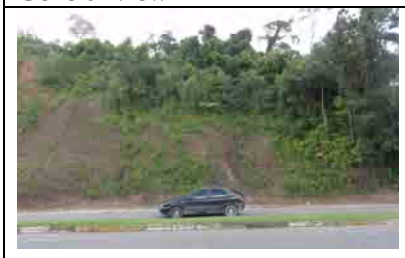
(8) SC470 Gaspar Bypass

Under the heavy rain In November 2008, road closure disaster of whole width was occurred due to soil collapse. And the possibility of soil collapse is still remaining.

General view



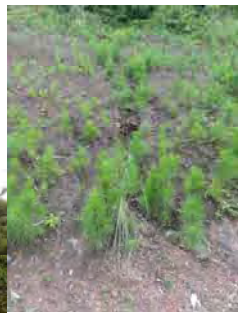
General View of Itajai City side



General view of Itajai City side

Center to Itajai City side portion.

Center portion, Photo of right side is disaster situation in November 2011



Center to Blumenau side portion.

Crack rich rock which recognized in Blumenau side portion.

Granulitic pyroxenite

Figure 6.5.13 Engineering Geological Map for SC470 Gaspar Bypass

(9) SC 477 Benedito Novo - Doutor Pedrihho 1

Landslide block of 60 m width 50 m length with 2 m height scarp is recognized. Drilling investigation shows that bed rock surface is deep (10 m -12 m depth) and groundwater table is also deep (9.5m at road side, 3.2m at valley side). Pipe strain gauge monitoring does not indicate sharply-defined slip surface.

General view from Doutor Pedrihho side

General view from Benedito Novo side

landslide scarp

Pavement damage due to water seepage

Drilling core of bed rock, Granulite, hard rock

Doutor Pedrihho side end of the landslide mass

Slope situation of valley side of the landslide mass

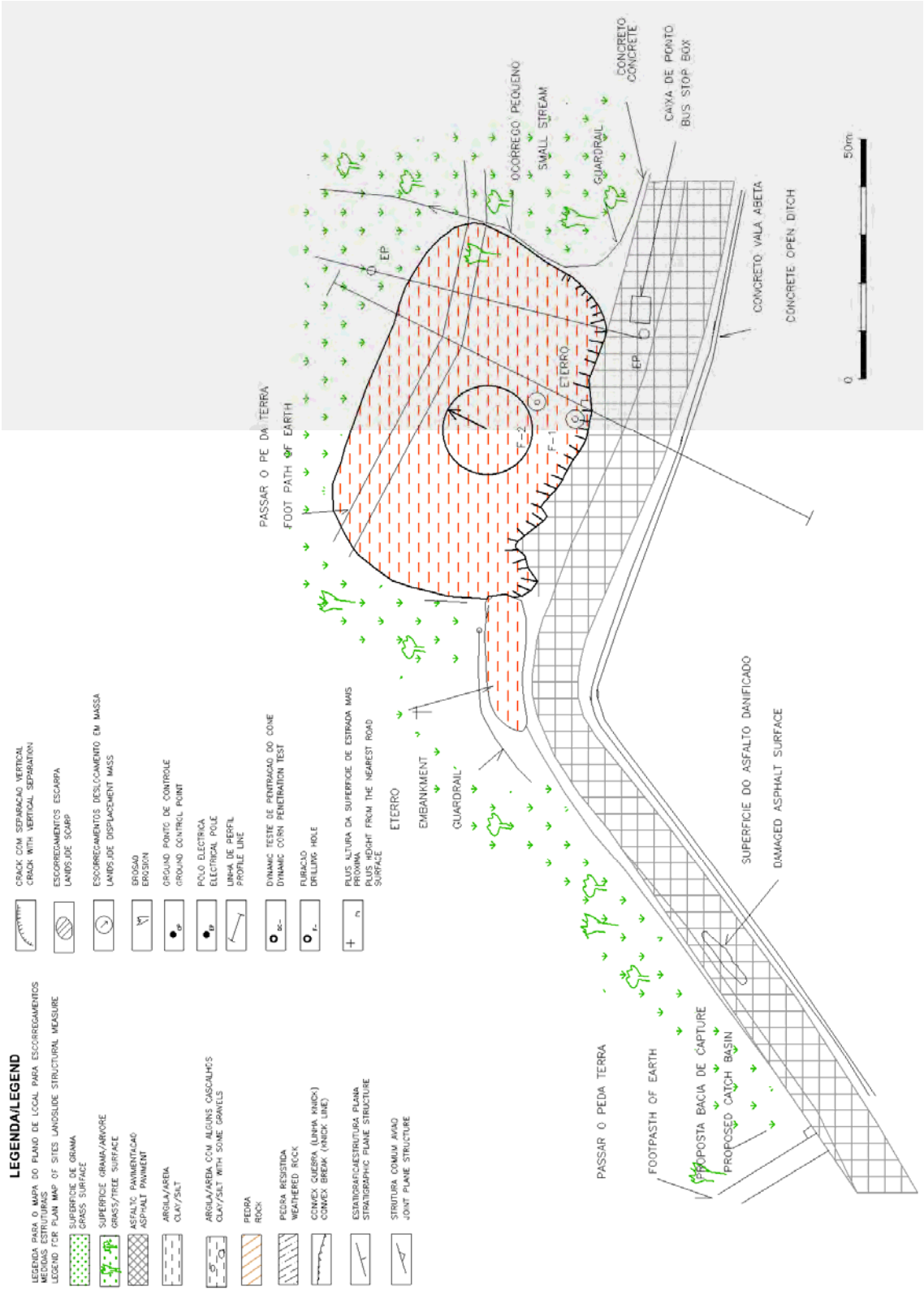


Figure 6.5.13 Engineering Geological Map for SC 477 Benedito Novo - Doutor Pedrihho 1

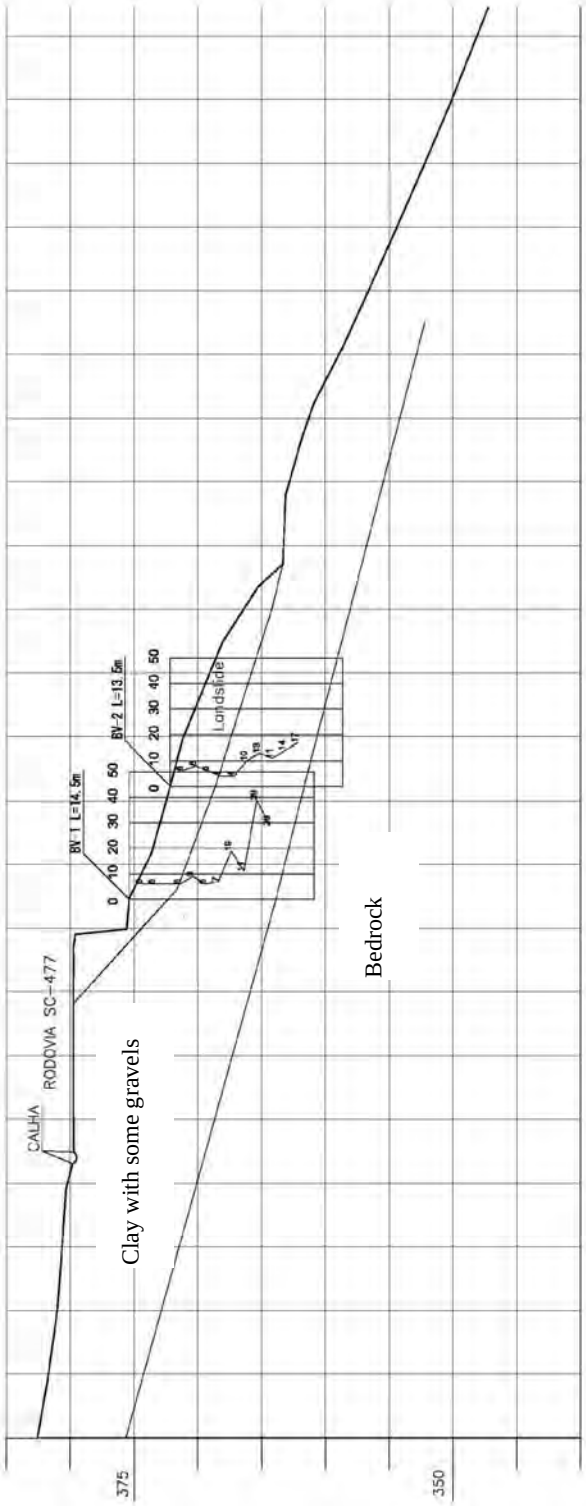
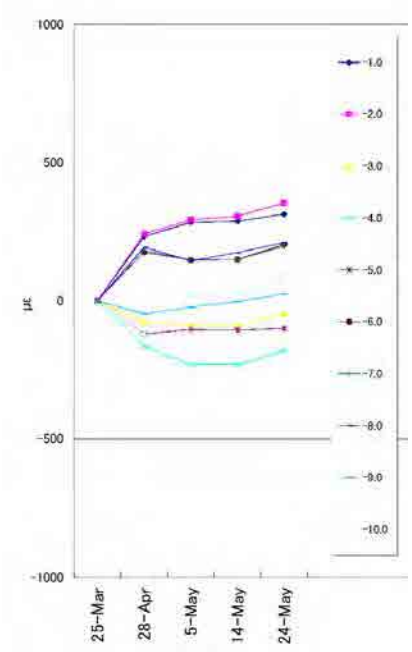
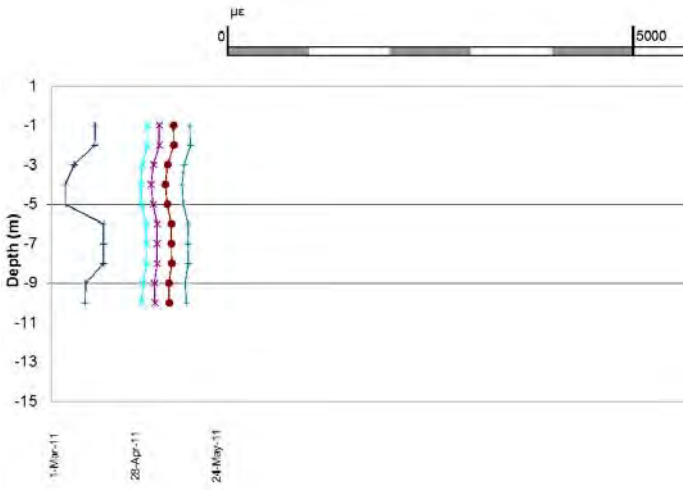


Figure 6.5.14 Engineering Geological Profile for SC 477 Benedito Novo - Doutor Pedrihho 1

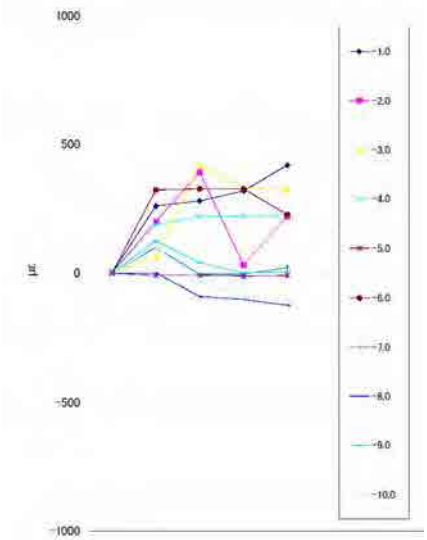
BV-1



Depth from Ground Line	25-Mar-11	28-Apr-11	5-May-11	14-May-11	24-May-11
	40627	40661	40668	40677	40687
-1.0	0	232	284	288	314
-2.0	0	241	293	306	355
-3.0	0	-76	-88	-92	-44
-4.0	0	-164	-232	-232	-182
-5.0	0	-120	-104	-106	-100
-6.0	0	176	148	150	204
-7.0	0	183	146	150	197
-8.0	0	194	144	174	210
-9.0	0	-47	-23	-3	25
-10.0	0	-122	16	14	90



BV-2



Depth from Ground Line	25-Mar-11	28-Apr-11	5-May-11	14-May-11	24-May-11
	40627	40661	40668	40677	40687
-1.0	0	261	281	320	420
-2.0	0	201	393	32	222
-3.0	0	62	422	331	326
-4.0	0	188	220	221	228
-5.0	0	-8	-8	-12	-8
-6.0	0	324	328	328	228
-7.0	0	100	-4	-3	22
-8.0	0	1	-88	-100	-122
-9.0	0	125	42	1	6
-10.0	0	105	-32	-88	-98

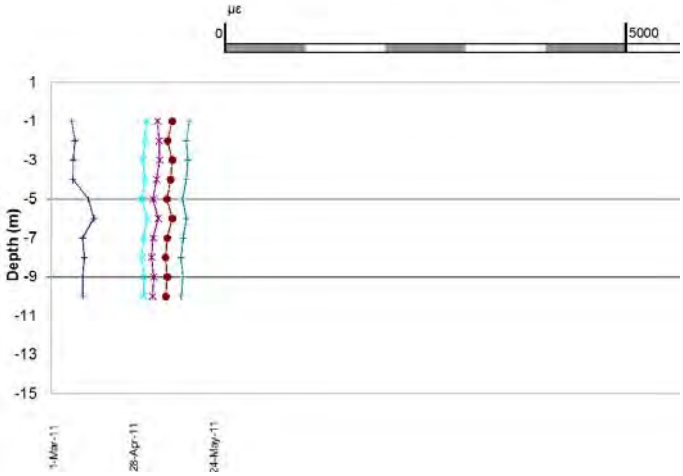


Figure 6.5.15 Pipe Strain gauge Monitoring for SC 477 Benedito Novo - Doutor Pedrihho 1

(10) SC 418 Pomerode - Jaragaua do Sul 1

Both side of road embankment shoulder is deformed by sliding. Dynamic corn penetration test shows that soft clay with some gravel is distributed of the slope surface with more than 3 meter depth.

General view from Pomerode City side

General view from Jaragaua do Sul City side

Deformation of East side slope

Seepage out of water

Situation of East side slope

Paddy field of outside of east side slope

Erosion of valley side slope in Gaspar side portion.

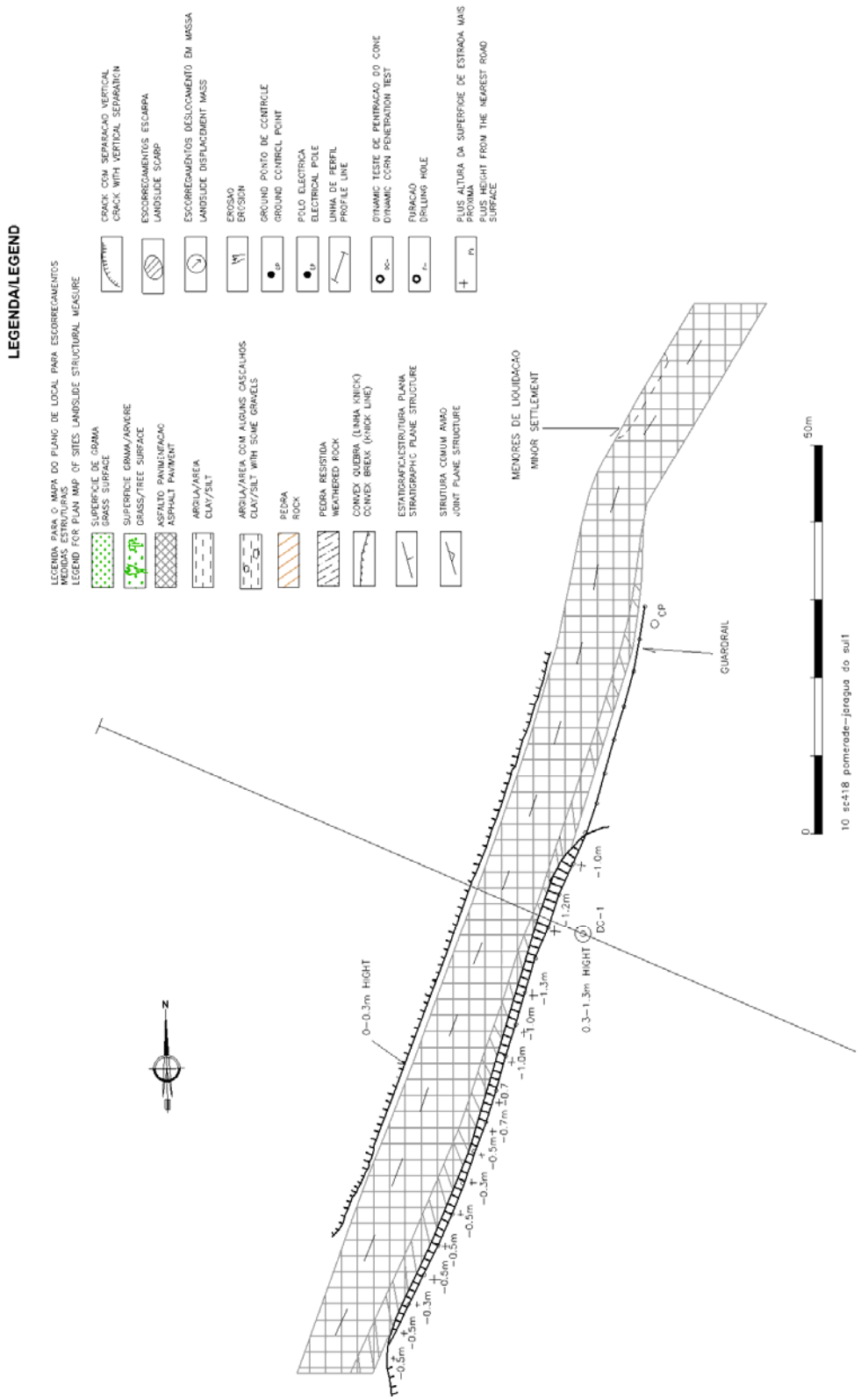


Figure 6.5.16 Engineering Geological Map for SC 418 Pomerode - Jaragaua do Sul 1

(11) Gaspar-Luiz Alves, Luiz Alvez 4

Soil collapses have been occurred intermittently due to heavy rain. Serious erosion is progressing in the mountainside of center portion. Dynamic corn penetration test shows that very soft red clay is distributed of the slope surface with more than 3 meter depth.

General view (Left side Ruiz Alves, Right side Gaspar)

General view of Gaspar side slope from Ruiz Alves side

General view of Gaspar side slope from Ruiz Alves side from Gaspar side

General view of center portion of the slope. Under testing of dynamic corn penetration

Big erosion of fine grained soil of the center portion of the slope

Mother rock, Granulite, hard rock.

General view of Luiz Alves side of the slope

Slope toe of Luiz Alves side of the slope

General view of Luiz Alvez side slope

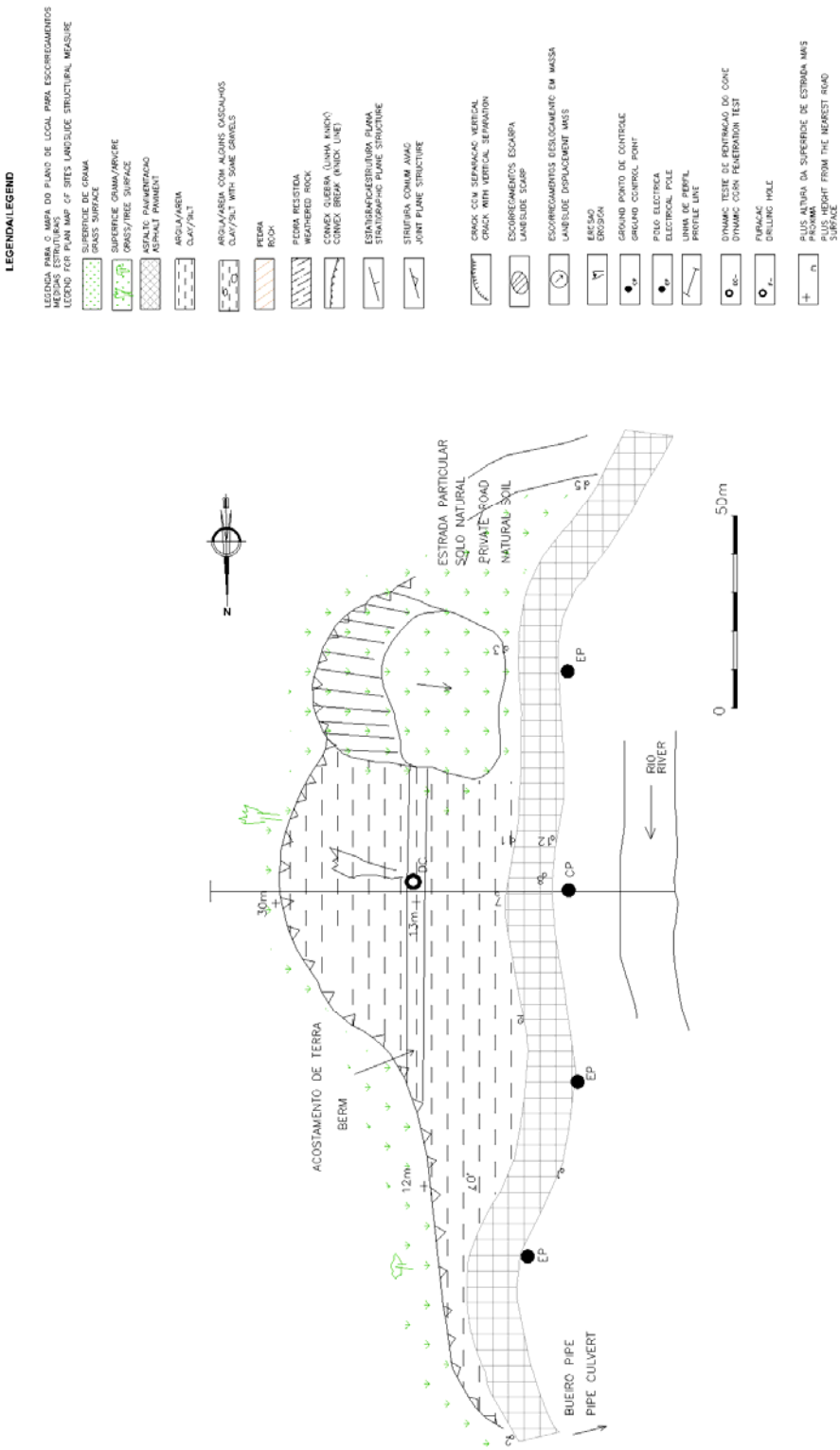


Figure 6.5.17 Engineering Geological Map for Gaspar-Luiz Alves, Luiz Alvez 4

(12) SC474 Blumenau-Massaranduba 1

Soil collapses have been occurred intermittently due to heavy rain. Soil is reddish and very soft when it is saturated.

General view of Blumenau City side

General view of Blumenau City side and center portion

Head portion of new collapse

Head portion of new collapse, and water seepage out is admitted

General view of center portion

General view of Massaranduba side

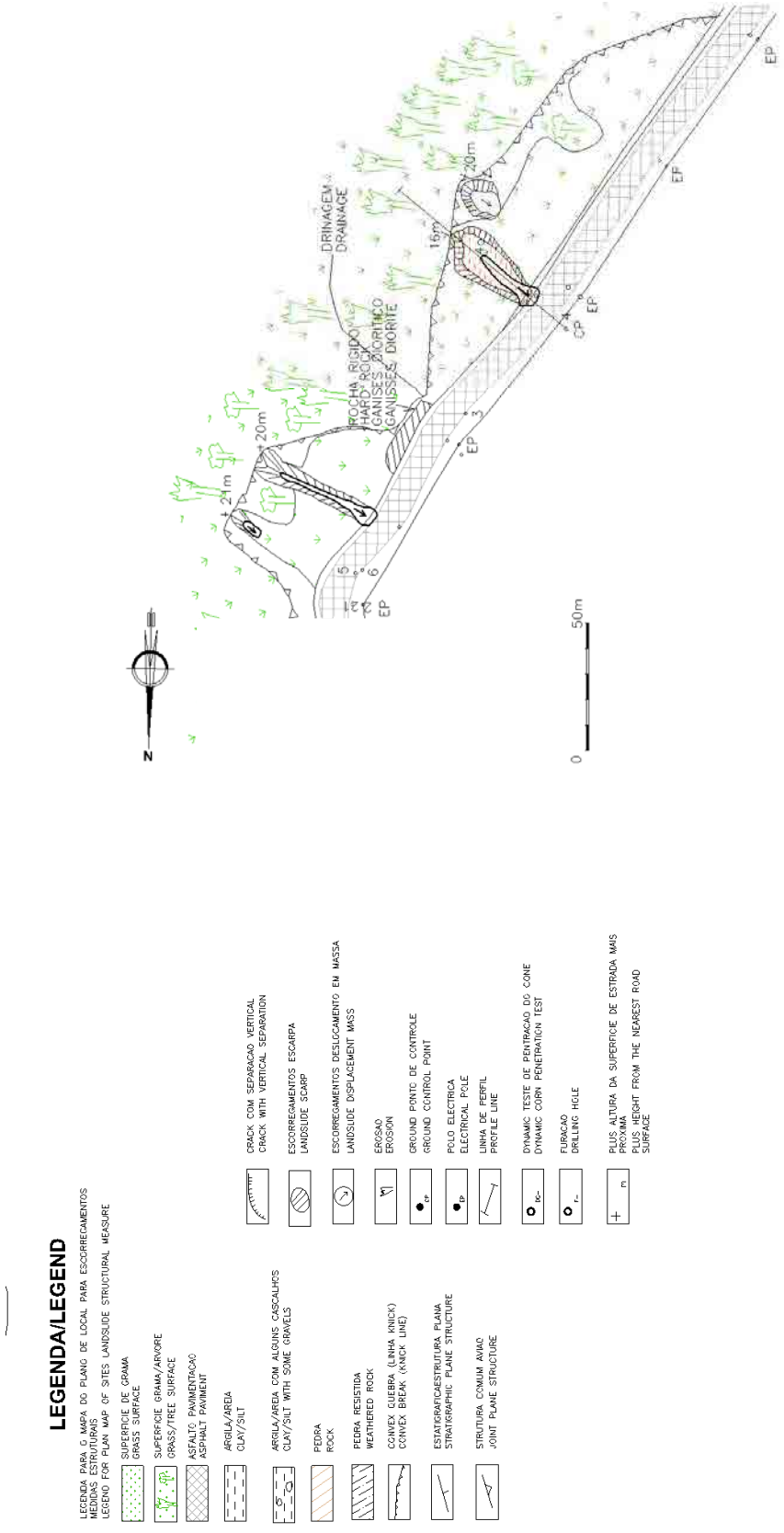


Figure 6.5.18 Engineering Geological Map for SC474 Blumenau-Massaranduba 1

(13) Taio-Passo Manso 4

Soil collapses have been occurred intermittently due to heavy rain. Depth of soil is mostly shallower than 1 meter on lower portion, and thicker than 3 meter on higher portion of the slope.

General view from Passo Manso side

General view of Taio side

General view of Passo Manso side

Collapsed portion of Passo Manso side

Small spring from the slope toe

Silt stone of lower portion of the slope

Silt stone and shale of lower portion of the slope

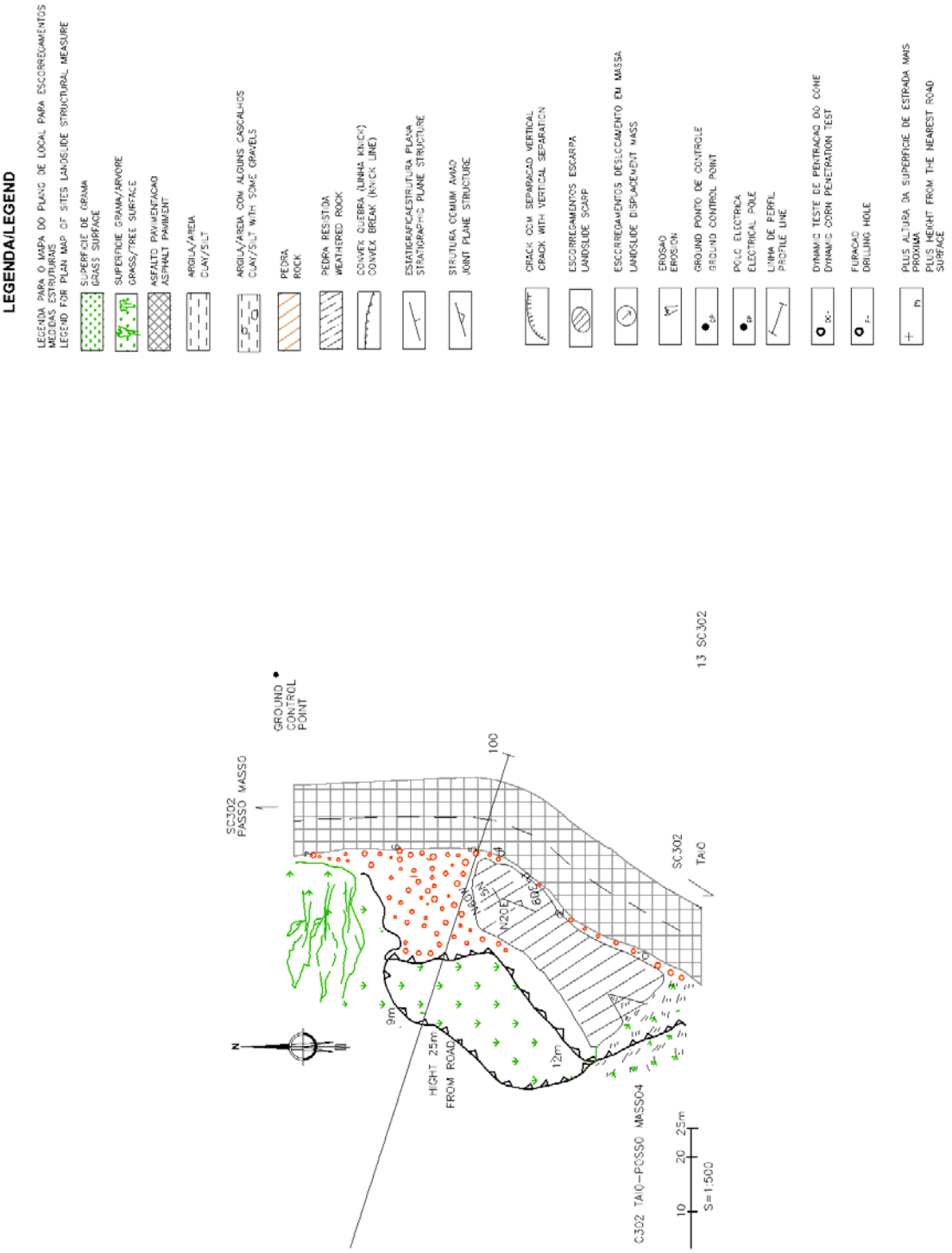


Figure 6.5.19 Engineering Geological Map for Taio-Passo Manso 4

CHAPTER 7 FEASIBILITY STUDY OF STRUCTUAL MEASURE FOR LANDSLIDE

7.1 General

The 13 priority sites (potential annual loss is more than R$500 thousand) are selected for structural measures. The safety target of the structural measure is to ensure full functionality of the infrastructure and/or buildings/lands against heavy rain of 60 years return period, or heavy rain level of in November 2008 at Blumenau Municipality (hereinafter referred to as '60 years heavy rain') . All of the priority sites are road slops, and the structural measures will be planed to ensure full width road traffic against 60 years heavy rain.

In the master plan, safety target is set to ensure half width road traffic against 60 years heavy rain. In this feasibility study, safety target is changed to ensure full width road traffic against 60 years heavy rain, because that high possibility of human lives lost is recognized on 13 priority sites by new finding of the field survey and comprehensible consideration as summarized in follows.

- The partial width road closure is expected even structural measures have been conducted to ensure half width road traffic against 60 years heavy rain. In that case, the landform characteristics indicate that rapid slope collapse which directly attack road users, or tumble down of road users due to sudden road foundation failure.
- Annual average daily traffic (AADT) of the priority 13 sites is relatively higher and from 1,800 to 43, 000 vehicles per day. The high traffic may increase possibility of direct hit by disasters; even they are partial width road closure.
- Especially, 7 sites are Aregisso Vermelho-Anarelo (red-yellow soils) which has the character of remarkable strengths deterioration by water contains. The shallow slide deformations were recognized on sod facing cut slopes on Aregisso Vermelho-Anarelo by the inspection in April 2011. The deformations had been progressive by the comparison with the inspection in May 2010; even the slopes had not suffered by 60 years heavy rains. The new finding shows that cutting slopes of 7 meter height or more on Aregisso Vermelho-Anarelo have a high possibility of collapse by a 60 year heavy rain, because they are slightly deformed even with sod facing without 60 year heavy rains. In the master plan stage, reinforced earth of cut slop is planed on slopes on 15 meter height or more, because these slopes can not secure the half width road traffic when they are collapsed. In the feasibility study, reinforced earth on cut slope is adopted on more widely on cut slopes of 7 meter or more to avoid human lives loss and to secure whole width road traffic for 60 year heavy rains.

Type for measures will be selected by learning form existing measures of similar condition slopes, which have not been occurred disaster even under 60 years heavy rain. It is also referred that technical norm in Brazil, NORMA BRASILEIRA ABNT (Associação Brasileira de Normas Técnicas), NBR (Número de referéncia) 11682, Estabilidade Encostas (Slope Stabilization).

The road drainage will be planed by using rainfall intensity- duration curve of 10 years return period, according to the practices of DEINFRA.

Following three methods have not utilized in Itajai River basin. It means that they has not be untried of 60 years heavy rain. In referring experience of similar slopes in Japan, they are also selected as alternative methods for this feasibility study.

- Lightweight embankment of expanded polystyrene (EPS)
- Reinforced earth of polypropylene (PP) fiber/cement/sand mixture
- Connecting concrete blocks revetment which enable covering soil and vegetation

Landslides cause sediment discharge also, and it cause negative influence of flood, flash flood, further landslide process, and infrastructure function. Therefore vegetation and drainage ditch will be utilized to protect erosion. In no risk place of falling trees, the trees will be planted. The tree plantation will contribute to the carbon fixation and the improvement of global environment, also.

7.2 Landslide Type and Selection of Type of Structural Measures

7.2.1 Classification of Landslide Type

Appropriate structural measures are different by type of landslide movement and landslide location from preservation object generally. In this feasibility study, types of landslide are a as Table 7.2 .1 for the selection of the appropriate structural measures.

Table 7.2.1 Type of Landslide

Landslide location from preservation object	Type of landslide movement
Mountainside slope	Collapse
Vallyside slope	
River bank slope	
-	Slide
-	Flow

Source: JICA Survey Team

The selected 13 priority sites and types of landslide are summarized in Table 7.2.2.

Table 7.2.2 Selected 13 Priority Sites and Type of Landslide

No. of priority order	Site	Municipality	Management	Potential annual loss mil R$/year	Type of landslide
1	SC 302 Taio-Passo Manso-5	Taio	State	1,255	Slide
2	SC470 Gaspar River Bank	Gaspar	State	1,095	River bank collapse
3	Blumenau -Av Beira Rio	Blumenau	Municipality	1,021	River bank collapse
4	SC418 Blumenau – Pomerode	Pomerode	State	989	Slide
5	SC474 Blumenau-Massaranduba 2	Blumenau	State	907	Mountainside collapse
6	Gaspar - Luiz Alves, Gaspar 9	Gaspar	Municipality	774	Slide, Mountainside, and valley side collapse
7	Gaspar - Luiz Alves, Luiz Alves 6	Luiz Alves	Municipality	700	Mountainside collapse
8	SC470 Gaspar Bypass	Gaspar	State	689	Mountainside collapse
9	SC477 Benedito Novo - Doutor Pedrinho 1	Benedito Novo	State	680	Slide
10	SC418 Pomerode-Jaragua do Sul 1	Pomerode	State	651	Vallyside collapse
11	Gaspar - Luiz Alves, Luiz Alves 4	Luiz Alves	Municipality	629	Mountainside collapse
12	SC474 Blumenau - Massaranduba 1	Blumenau	State	601	Mountainside collapse
13	SC 302 Taio - Passo Manso 4	Taio	State	526	Mountainside collapse

Source: JICA Survey Team

7.2.2 Selection of Measure against Mountainside Collapse

The selection criteria of measure structural type's alternatives against mountainside collapse are formulated by the policy described in section 7.1.1 and shown in Table 7.2.3. The vegetation works, and open ditch are included in basic measures to prevent sediment discharge.

There are many existing gabion retaining walls on slope foots with slope vegetation in the Itajai river basin. It is enough against 60 years heavy rain for the slope less than 7 m height. But in case of slope height is more than 7m, some slopes occurs deformation as shown in following photo.

Slope deformation in cut slopes which higher than 7 m on SC 474 Blumenau - Massaranduba road in Blumenau Municipality.

Source: JICA Survey Team

Table 7.2.3 Structural Measures against Mountainside Collapse

Slope condition		Typical measure alternatives	Common items
Stable cutting gradient is Not secured		Rock bolts, anchor works.	Open ditch, vegetation
There is rock falls probability		Removal of unstable rock, foot protection, rock protection fence, rock catch/cover net.	
Stable cutting gradient for deep collapse is secured	Slope height is more than 7 m.	Cutting of unstable portion, slope reinforcement works.	
	Slope height is less than 7 m	Cutting of unstable portion, vegetation net, and gabion on slope foot.	

Source: JICA Survey Team

Structural measures types are selected against mountainside collapse as Table 7.2.4. To prevent erosion or sediment discharge due to rainfall or springs, open ditch and vegetation are planed for all selected sites.

Table 7.2.4 Selected Measures for Mountainside Collapse

No. of priority order	Site	Height Gradient	Soil or rock type	Spring recognized	Selected structural measure
5	SC474 Blumenau-Massaranduba 2	15 m height 40 degree	Weathered rock	In rainfall time	1. Cutting of unstable portion 2. Open ditch 3. Slope reinforcement works 4. Vegetation
6	Gaspar - Luiz Alves, Gaspar 9	15 m height 45 degree	Clay, sand, or weathered rock		
7	Gaspar - Luiz Alves, Luiz Alves 6	10-20 m 60 degree	Clay, sand, or weathered rock		
8	SC470 Gaspar Bypass	20 m 50 degree	Weathered rock		
11	Gaspar - Luiz Alves, Luiz Alves 4	15 m 25 degree	Clay, sand, or weathered rock		
12	SC474 Blumenau-Massaranduba 1	30 m 50 degree	Weathered rock		
13	SC 302 Taio-Passo Manso 4	20 m 50 degree			

Source: JICA Survey Team

Comparison of alternatives of slope reinforcement measure for 1,000 m^2 is carried out and shown in Table 7.1.4. Reinforced earth method of PP fiber/ cement/sand is recommendable, because it is advantage of all evaluation items of the cost, construction period, and landscape.

- Crib works (shotcrete crib)
- Crib works (cast-in-place concrete crib)
- Reinforced earth of PP fiver/cement/sand mixture

7.2 .3 Selection of Measure against Valley side Slope Collapse

The selection criteria of measures alternatives against valley side slope collapse are formulated by the policy described in section 7.1.1 and shown in Table 7.2.5. The vegetation works, and open ditch is included in basic measures to prevent sediment discharge.

7.2.4 Selection of Measure against River Bank Collapse

Selections of measures for two river bank slope collapse (priority No.2 SC 470 Gaspar River Bank, priority No.3 Blumenau - AV. Pres Casrelo Branco) are conducted by considering river flow rate and advantage for environment preservation.

The flow rates are calculated by river cross section at the sites using height - quantities relation of river discharge at studied sites.

Table 7.2.5Comparison of Alternatives of Slope Reinforcement Measure

	Shotcrete crib works	Cast-in-place concrete crib works	Reinforced earth of PP fiver/cement/sand mixture
Example photo			
Constriction date estimation date estimation for 1000 m^2	Sub-work items day/1000 m^2 Cleaning slope 5 Wire mesh 8 Crib works 25 Vegetation 5 otal 43	Sub-work items Day/1000 m^2 Cleaning slope Crib works including curing term Vegetation Total	Sub-work items day/1000 m^2 Cleaning slope Anchor bar Drainage Reinforced earth of PP Vegetation Total
Unit cost,	Sub-work items R$/$m^2$ Cleaning slope 15 Wire mesh 45 Crib works 300 Vegetation 65 Total 425	Sub-work items R$/$m^2$ Cleaning slope 15 Crib works 340 Vegetation 65 Total 420	Sub-work items R$/$m^2$ Cleaning slope 15 Anchor bar 50 Drainage 35 Reinforced earth of PP 235 Vegetation 75 Total 410
Evaluation	Not recommendable - 2nd long construction period - Highest construction cost - Not good landscape	Not recommendable - Longest construction period - 2nd low cost Construction - Not good landscape	Recommendable alternative - Shortest construction period - Lowest construction cost - Good landscape

Source: JICA Survey Team

Table 7.2.6 Structural Measures against Valley Side Collapse

Slope condition			Typical measure alternatives	Common item
Height (H) of collapse H>10	Height (H) and width (W) of collapse H/W > 0.5		Pilling, or large block placing	Tree planting Open ditch
	Height (H) and width (W) of collapse H/W ≦0.5		Gully filling by gabion and longitudinal drainage	
Height (H) of collapse H≦10	Height (H) and width (W) of collapse H/W > 0.5	Embankment on slope foot is Possible	Embankment	
		Embankment on slope foot is Impossible	Pilling, or large size block placing	
	Height (H) and width (W) of collapse H/W ≦0.5		Gully filling by gabion and longitudinal drainage	

Source: JICA Survey Team

Table 7.2.7 Selected Measures for Valley side Collapse

No. of priority order	Site	Height of collapse	Width of collapse	Embankment possibility	Selected Measure
6	Gaspar - Luiz Alves, Gaspar 9	30m	3m	Impossible	Gully filling by gabion and longitudinal drainage, tree planting
10	SC418 Pomerode – Jaragua do Sul 1	8m	30m	Possible	Embankment, open ditch, tree planting

Source: JICA Survey Team

Table 7.2.8 Height - Quantities Relation of River Discharge at Studied Sites

Discharge (m^3/s)	Priority No.2 SC 470 Gaspar River Bank	Priority No.3 Blumenau AV. Beira Rio	Remark
500	1.98	2.41	
1,000	3.01	3.94	
1,500	4.13	5.37	
2,000	5.28	6.71	
2,500	6.29	7.88	
3,000	7.25	8.92	
3,500	8.27	9.96	
3,700	8.58	10.30	Discharge return period 10 year
4,000	9.04	10.81	
5,000	10.44	12.36	
5,500	11.09	13.06	Discharge return period 50 year
6,000	11.74	13.77	

Source: JICA Survey Team

Flow rate is calculated as shown in Table 7.2.9. Compensating rate of both sites is adopted 1.0, because Priority No.2 SC 470 Gaspar site is straight river course, and Priority No.3 Blumenau AV. Pres Casrelo Branco is fixed bed of solid rock and the radius of the river is about 2km.

Table 7.2.9 Design Flow Rate

Site	Return Period or Max value	Design discharge (m3/S)	Sectional area (m2)	Flow rate (m/s)	Straight or Incurve	Bed condition	Compensating rate	Design flow rate (m/s)
Gaspar	50	5,500	3,543	1.55	Straight	Fixed	1.0	1.55
	Max	5,609	3,995	1.40	Straight	Fixed	1.0	1.40
Blumenau	50	5,500	2,069	2.65	Curve	Fixed	1.0	2.65
	Max	6,008	2,182	2.75	Curve	Fixed	1.0	2.75

Source: JICA Survey Team

Experimentally applicable condition of revetment types for slope conditions shown in Table 7.2.10.

For priority No.2 SC 470 Gaspar River Bank, gabion revetment is applicable as shown in Table 7.2.11.

For priority No.3 Blumenau AV. Pres Casrelo Branco, revetment of connecting concrete blocks with cover soil and vegetation is applicable as shown in Table 7.2.12.

Table 7.2.10 Applicable Condition of River Revetment Types

River Revetment Type		Experimentally applicable condition	
		Design Flow Rate (m/sec) 2 3 4 5 6 7	The other condition
Vegetation	Sodding	Gaspar site	Area for higher than ordinary water level
Sheet	Geotextile	Blumenau site	Without area for gravels/cobbles sediments. Without water impact part.
	Block matt		
Wood material	Log crib works		Without area for gravels/cobbles sediment. Area where lower than ordinary ground level of area protected by levee
	Brushwood crib works		
	Woodpile fence		
Stone material	Dry stone pitching (without mortar)		In case of stone material is available near the site. Area where lower than ordinary ground level of area protected by levee
	Wet stone pitching (with mortar)		
Gabion	Wirer-cylinder		Without area for gravels/cobbles sediment. Area where lower than ordinary ground level of area protected by levee
	Flat gabion placing		
Concert material	Connecting concrete blocks		It is applicable at area of gravels/cobbles sediment
	Concert block pitching		

Legend

	Applicable range
	Applicable, but more low cost alternative is applicable.

Source: JICA Survey Team referring web-page of Ministry of Land Transportation and Infrastructure ,Japan

Table 7.2.11 Selection Result for Priority No.2 SC 470 Gaspar River Bank

Type of Revetment		Adaptabilitas
Vegetation	Sodding	NOT applicable. The site is broken portion by 60 year heavy rain. Local rapid flow rate might be occurred.
Sheet	Geotextile	
	Block matt	
Wood material	Log crib works	NOT applicable. Wood materials will be deteriorated in 10 years.
	Brushwood crib works	
	Woodpile fence	
Stone material t	Dry stone pitching (without mortar)	NOT applicable. It is difficult to stable cover soil as vegetation base.
	Wet stone pitching (with mortar)	
Gabion	Wirer-cylinder	Applicable. It is good landscape harmony with both side of stream by using cover soil.
	Flat gabion placing	
Concrete	Connecting concrete blocks	Applicable and Not Advantage in cost.
	Concert block pitching	NOT applicable. It is require the special type block material for stable soil covering as vegetation base

Source: JICA Survey Team

Table 7.2.12 Selection Result for priority No.3 Blumenau AV. Pres Casrelo Branco

Type of Revetment		Adaptabilitas
Vegetation	Sodding	NOT applicable. It is NOT stable against design flow rate.
Sheet	Geotextile	NOT applicable. The site is beside the bridge pier and possibility of rapid flow rate.
	Block matt	
Wood material	Log crib works	NOT applicable. Wood materials will be deteriorated in 10 years.
	Brushwood crib works	
	Woodpile fence	
Stone material	Dry stone pitching (without mortar)	NOT applicable. It is difficult that stable cover soil placing as vegetation base.
	Wet stone pitching (with mortar)	
Gabion	Wirer-cylinder	NOT applicable It is not harmony with continuous landscape with upstream and down stream. The landscape of the site is important for Blumenau Municipality.
	Flat gabion placing	
Concrete	Connecting concrete blocks	Applicable. It shall be adopted the type of connecting concrete block revetment which available soil as vegetation base.
	Concert block pitching	NOT applicable. It is not available stable soil covering as vegetation base

Source: JICA Survey Team

Table 7.2.13 Selected Measures for Valley Side Collapse

No. of priority order	Site	Height of slope	Average slope gradient Horizontal: Vertical	Design flow rate (m/sec)	Selected Measure
2	No.2 SC 470 Gaspar River Bank	30m	1: 0.7 35 degree	1.6	Gabion revetment, cover soil, vegetation
3	No.3 Blumenau AV. Pres Castelo Branco	8m	1:0.6 31 degree	2.8	Connecting concrete blocks revetment, cover soil, vegetation

Source: JICA Survey Team

7.2.5 Selection of Measures against Slide

(1) Factor of Safety of Sliding

Stability analysis is conducted for determination of the scale and quantity of structural measure to maintain the stability of the sliding slope by ensuring the design factor of safety.

The Swedish slice method is used for stability analysis of a landslide slope, as follows:

$$Fs = \frac{(\Sigma N - \Sigma U) \times \tan\phi + C \times \Sigma L}{\Sigma T}$$

Where,

N(kN/m) = Normal force along sliding surface by gravity of slice, N=Wcosα

T(kN/m) = Tangential force along sliding surface by gravity of the slice, T=Wsinα

α（°） = Angle of the base of the slice to the horizontal

U(kN/m) = Uplift due to pore pressure acting on sliding surface of the slice

L（m） = Length of sliding surface acting on the slice

C(kN/m^2) = Cohesion of sliding surface

φ（°） = Internal friction angle of sliding surface

Table 7.2.14 Determination of Initial Factor of Safety (IFS)

Initial factor of safety	Movement conditions
IFS = 0.95	• A large number of obvious potential slide topography such as scarps, bulges, stepped land, ponds and swamps; and • Many visible ongoing and active movements of cracks, subsidence, upheaval, toe erosion, or small toe collapse as well as springs.
IFS = 0.98	• Obvious potential slide topography such as bulges, stepped land, ponds and swamps, but • Few or small ongoing movements of cracks, subsidence, upheaval, or small toe collapse.
IFS = 1.00	• Potential slide area is at rest, and • Cracks, subsidence, upheaval, or small toe collapse are visible, but not progressing.

Source: Modification from MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction Japan, November 1997

The design factor of safety (DFS) is the target value for enhancing the slope stability by structural measures as shown in Table 7.2.15.

Table 7.2.15 Determination of Design Factor of Safety (DFS)

Design factor of safety	Condition
DFS = 1.10 to 1.20	• Sudden and severe movement is expected; and • Slide prone cause significant damage to, houses, buildings infrastructures, and/or human lives.
DFS = 1.05 to 1.10	• A slide have little effect on houses, buildings or infrastructures; or • The proposed prevention works are temporary countermeasures.

Source: Modification from MANUAL FOR RIVER WORKS IN JAPAN, Published by River Bureau, Ministry of Construction Japan, November 1997.

The design factor of safety indicates multiplication ratio to the initial factor of safety IFS after completion of structural measures.

The slide slopes of this feasibility study, and initial/target factor of safety are determined in accordance with Table 7.2.14 and Table 7.2.15, and shown in Table 7.2.16.

Table 7.2.16 Object Slopes against Slide and Initial/Target Factor of Safety

Priority No.	Site	Initial factor of safety (IFS)	Design factor of safety (DFS)
1	SC 302 Taio-Passo Manso-5	1.00	1.15
4	SC418 Blumenau – Pomerode	1.00	1.15
6	Gaspar - Luiz Alves, Gaspar 9	1.00	1.15
9	SC477 Benedito Novo - Doutor Pedrinho 1	1.00	1.15

Source: JICA Survey Team

(2) Selection of Structural Measure Types

Table 7.2.17 shows the general structural measures for slides. The structural measure types are selected by flow as shown in Figure 7.2.1.

The selected structural measures for 4 slides sites are shown in Table 7.2.18.

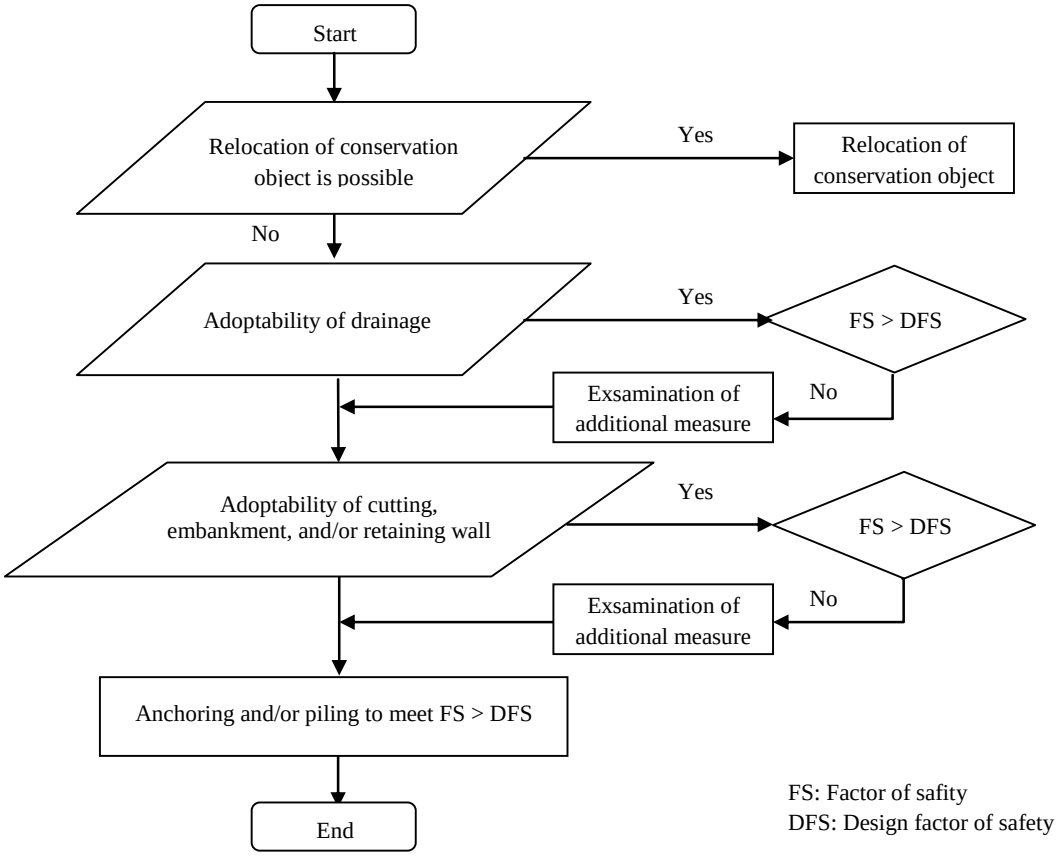
The effects of groundwater level lowering by installation of drainage are set experimentally as shown in Table 7.2.19.

For the site of the priority No. 9 SC477 Benedito Novo - Doutor Pedrinho 1, groundwater drainage is not appropriate; because groundwater table is initially low. Light weight embankment by EPS (Expanded polystyrene) is appropriate for the site condition of deep foundation rock and low groundwater.

Table 7.2.17 General Structural Measures for Slides

Classification		Type of Structural Measure
1. Drainage	Surface Drainage	Open ditch
	Underground Drainage	Closed conduit with open ditch
		Horizontal drainage drilling
		Drainage wells
		Drainage tunnels
2. Cutting and Embankment		Cutting of slide head
		Embankment of slide foot
		Light weight embankment of slide head
3. Retaining wall		Gabion walls
		Retaining walls
4. Anchoring		Rock bolts
		Ground anchors
5. Piling		Steel pipe piles
		Shaft work

Source: JICA Survey Team



Source: JICA Survey Team

Figure 7.2.1 Flowchart of Selection of Structural Measures for Slide

Table 7.2.18 List of Structural Measures and Result of Stability Analysis

No. of priority order	Site	IFS: Initial factor of Safety	DFS: Design factor of safety	Safety factor after groundwater drainage or light weight embankment	Measure
1	SC 302 Taio-Passo Manso-5	1.00	1.15	1.14 by 1.0 m lowering of groundwater table. 1.20 by 1.5 m lowering of groundwater table.	Horizontal drainage drilling Gabion retaining wall
4	SC418 Blumenau - Pomerode	1.00	1.15	1.15 by 0.5 m lowering of groundwater table.	Closed conduit with open ditch, Gabion retaining wall
6	Gaspar - Luiz Alves, Gaspar 9	1.00	1.15	1.150 by 1.0 m lowering of groundwater table.	Horizontal drainage drilling Gabion retaining wall
9	SC477 Benedito Novo - Doutor Pedrinho 1	1.00	1.15	1.15 by lightweight embankment.	Lightweight embankment

Source: JICA Survey Team

Table 7.1.19 Effects of Groundwater Level Lowering by Installation of Drainage

Type of Work	Lowering of groundwater table
Closed conduit with open ditch	-0.5m
Horizontal drainage drilling	From -1.0 to - 1.5m

Source: JICA Survey Team

7 .3 Feasibility Design on Structural Measures for the Selected Site

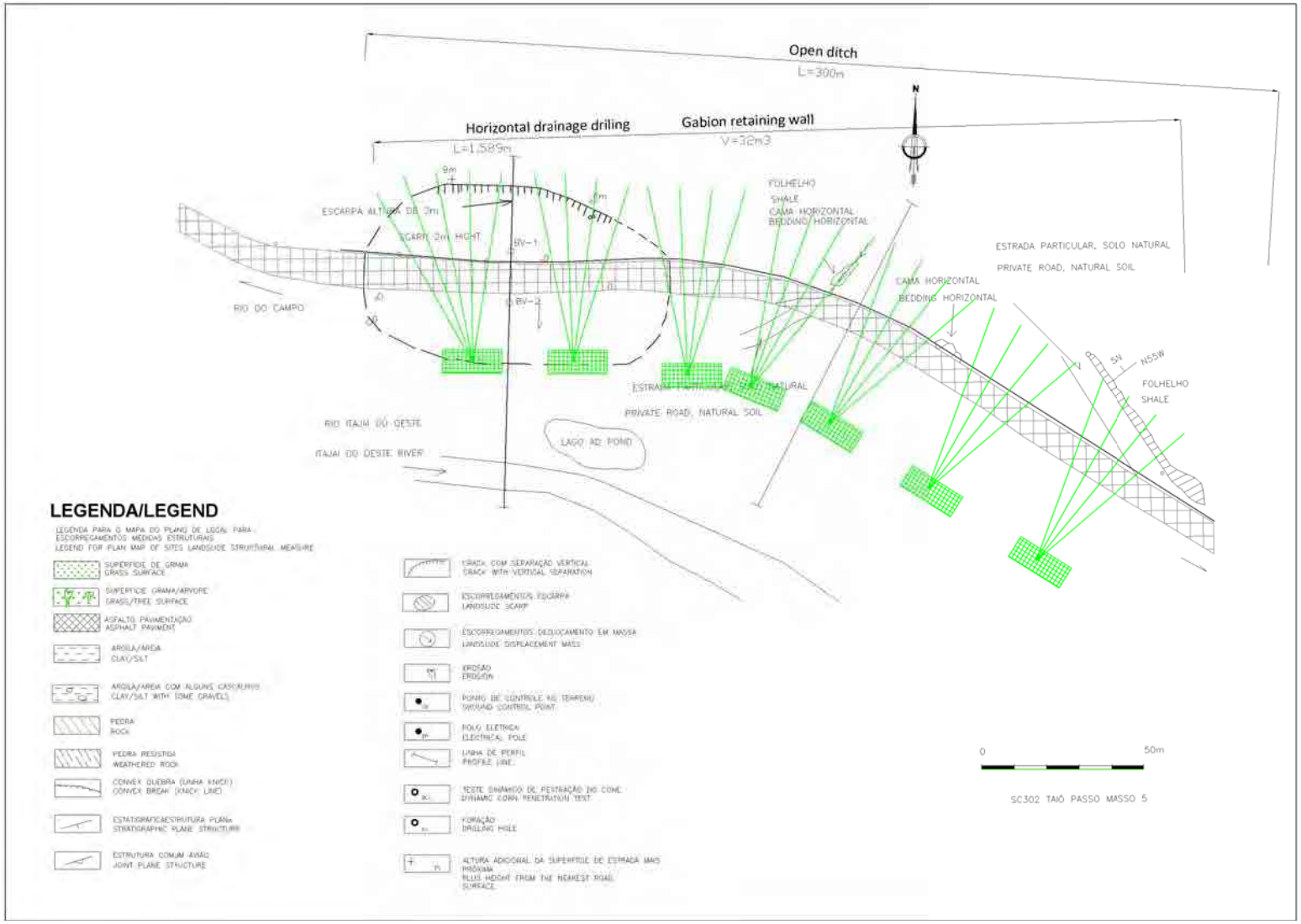
The work quantities of structural measures are summarized in Table 7.3.1. Layout of the structural measures of priority No.1 Taio-Passo Manso is shown in Figure 7.3.1 and 7.3.2.

Table 7.3.1 Work Quantities of Structural Measures

No. of priority order	Site name	Type of countermeasure	Unit	Quantities
1	SC 302 Taio-Passo Manso-5	Horizontal Drainage drilling	m	1,589
		Gabion retaining wall	m^3	32
		Open ditch	m	300
		Land acquisition (rural area)	m^2	7,000
2	SC470 Gaspar River Bank	Cutting, excavation	m^3	16,660
		Embankment	m^3	16,660
		Pavement	m^2	700
		Gabion retaining wall	m^3	2,000
		Nursery planting	m^2	3,400
		Concrete culvert pipe placing	M	27
3	Blumenau – Av Pres Castelo Branco	Sheet pile	m^2	598
		Connecting concrete block	m^2	4,852
		Geotextile	m^2	4,852
		Cutting	m^3	150
		Sodding	m^2	4,852
4	SC418 Blumenau – Pomerode	Closed conduit with open ditch	m	373
		Gabion retaining wall	m^3	238
		Open ditch	M	95
		Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	3,112
5	SC474 Blumenau-Massarandub a 2	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	6,986
6	Gaspar - Luiz Alves, Gaspar 9	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	5,560
		Gabion open ditch	m^3	572
		Waterproof sheet	m^2	312
		Open ditch	m	282
		Horizontal Drainage drilling	m	160
		Gabion retaining wall	m^3	100
		Nursery planting	m^2	14,952
		Land acquisition (rural area)	m^2	14,629
7	Gaspar - Luiz Alves, Luiz Alves 6	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	2,662
		Open ditch	M	240
8	SC470 Gaspar Bypass	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	5,151
		Open ditch	M	182
9	SC477 Benedito Novo - Doutor Pedrinho 1	Lightweight embankment by EPS(Expanded polystyrene)	m^3	1,930
		Cutting, excavation	m^3	1,930
		Open ditch	M	234
		Pavement	m^2	863
		Temporary Scaffold	m^3	450
		Land acquisition (rural)	m^2	500

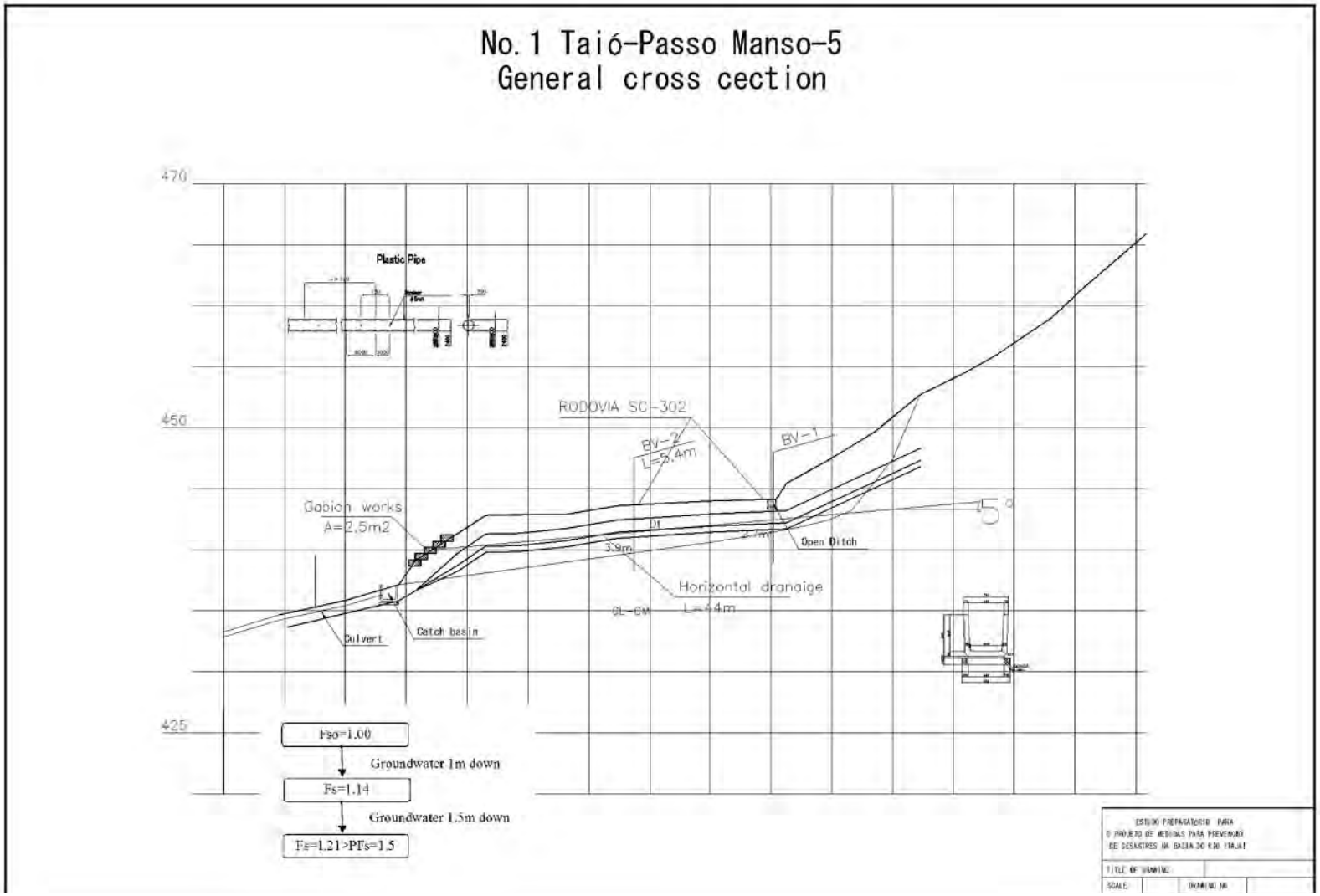
10	SC418 Pomerode - Jaragua do Sul 1	Gabion retaining wall	m^3	764
		Embankment	m^3	10,216
		Nursery planting	m^2	5,930
		Pavement	m^2	404
		Open ditch	m	340
		Land acquisition (rural)	m^2	6,713
11	Gaspar - Luiz Alves, Luiz Alves 4	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	6,930
		Open ditch	m	260
12	SC474 Blumenau-Massarandub a 1	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	967
13	SC 302 Taio-Passo Manso 4	Reinforced earth of polypropylene fiber/cement/sand mixture with vegetation	m^2	2,182
		Open ditch	m	82

Source: JICA Survey Team



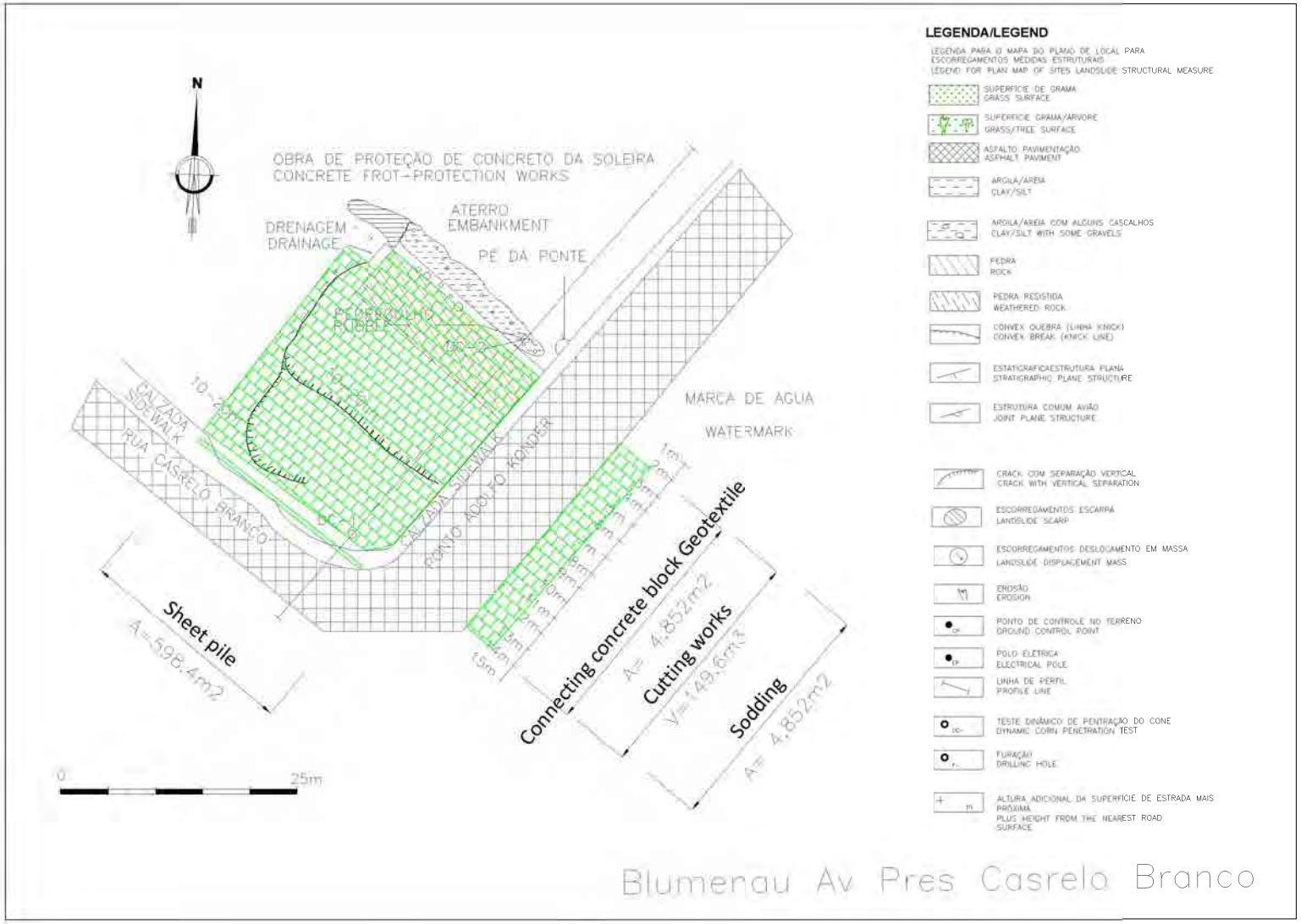
Source: JICA Survey Team

Figure 7.3.1 Plan Layout of Structural Measure for Priority No.1 Landslide SC 302 Taio-Passo Manso-5



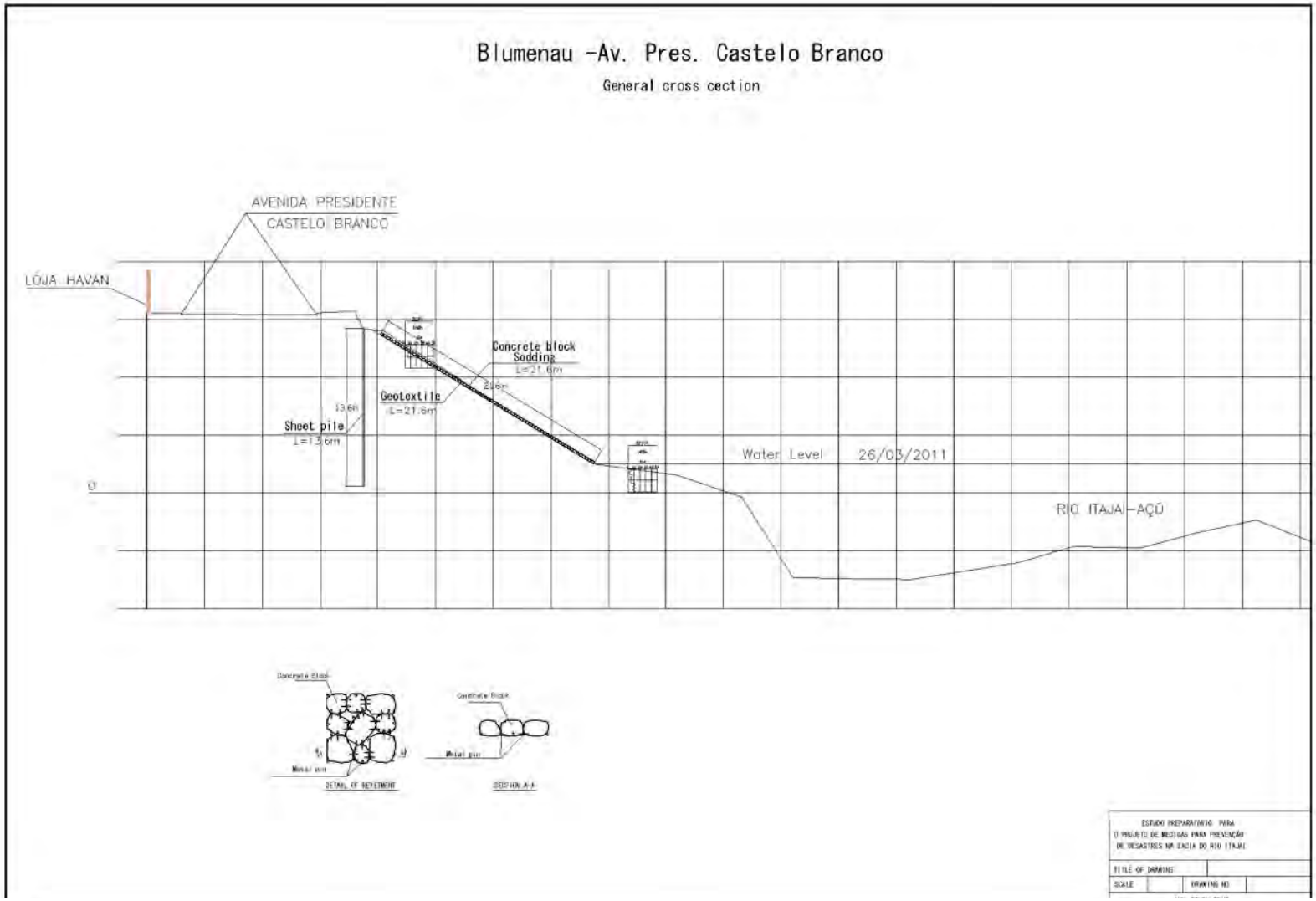
Source: JICA Survey Team

Figure 7.3.2 Profile Layout of Structural Measure for Priority No.1 Landslide SC 302 Taio-Passo Manso-5



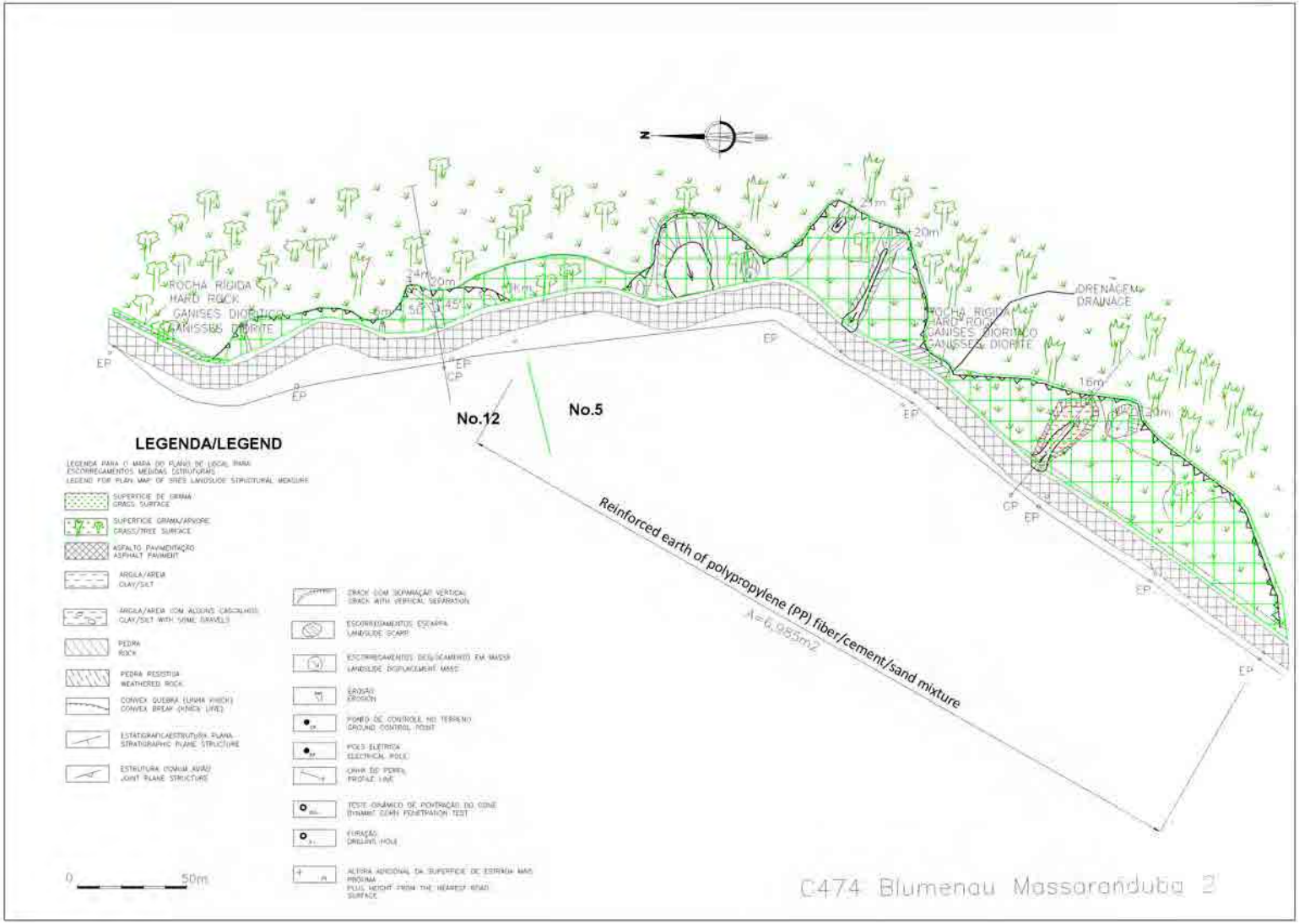
Source: JICA Survey Team

Figure 7.3.3 Plan Layout of Structural Measure for Priority No.3 Blumenau –Av Pres Casrelo Branco



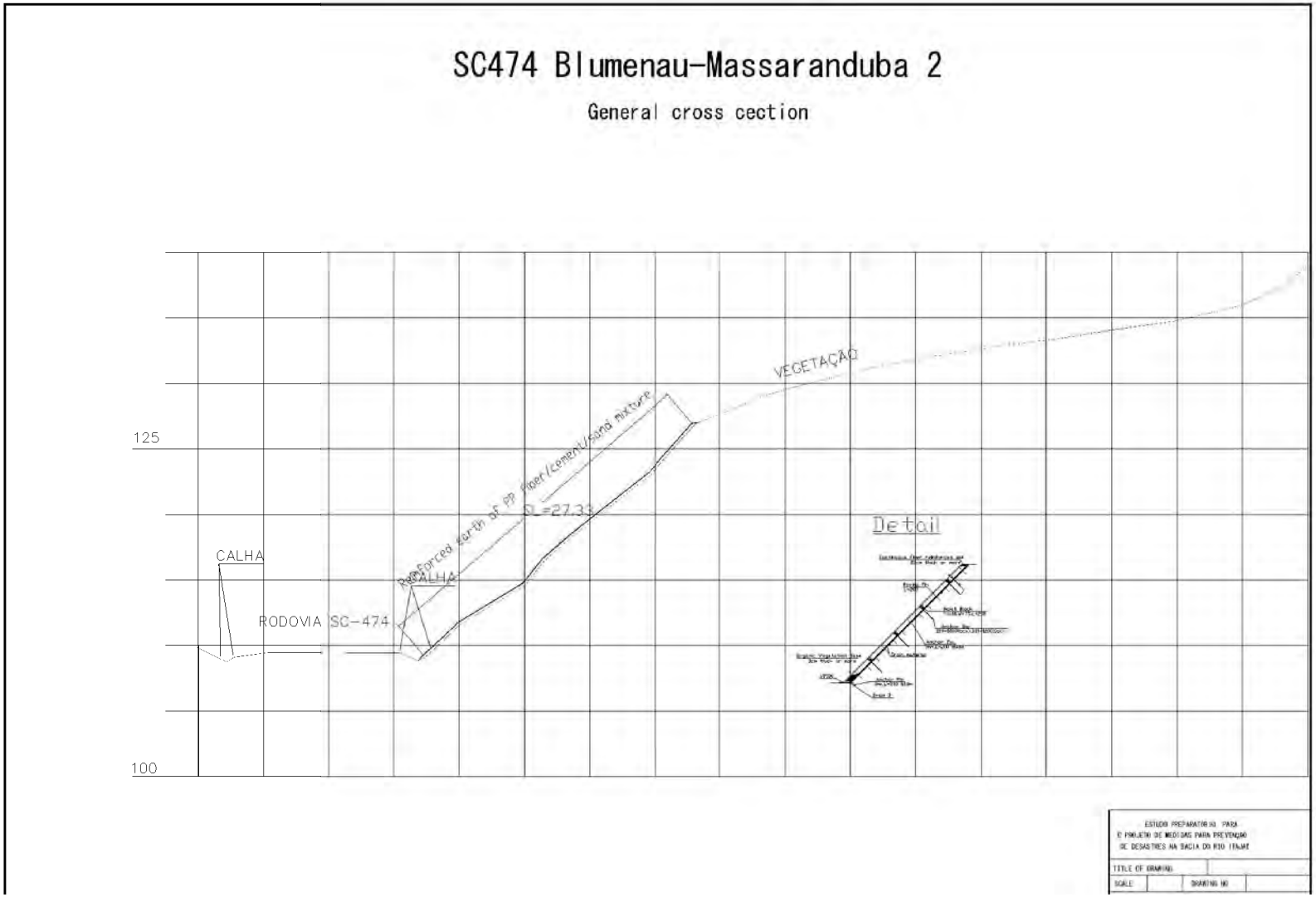
Source: JICA Survey Team

Figure 7.3.4 Profile Layout of Structural Measure for Priority No.3 Blumenau –Av Pres Casrelo Branco



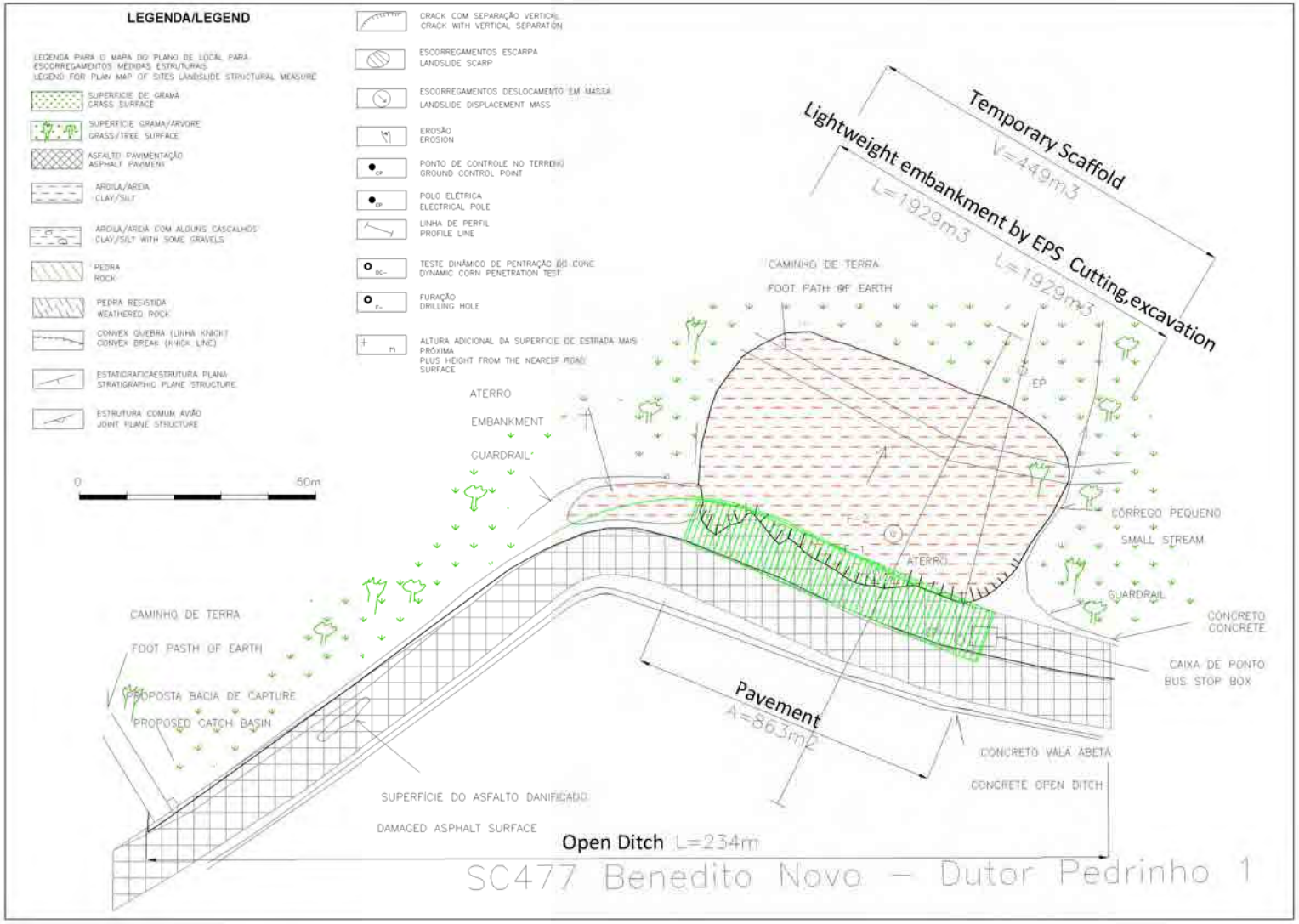
Source: JICA Survey Team

Figure 7.3.5 Plan Layout of Structural Measure for Priority No.5 SC474 Blumenau-Massaranduba 2



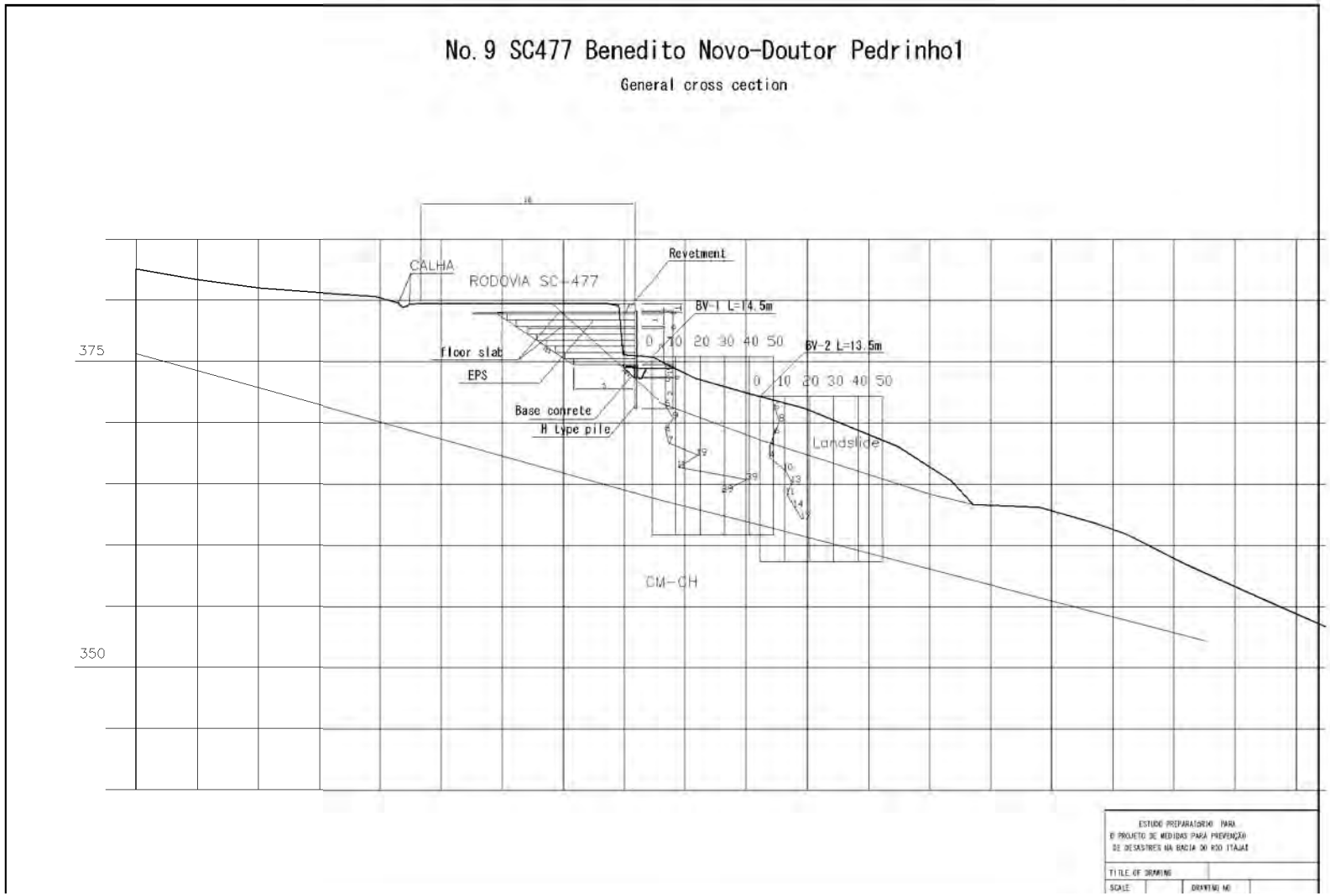
Source: JICA Survey Team

Figure 7.3.6 Profile Layout of Structural Measure for Priority No.5 SC474 Blumenau-Massaranduba 2



Source: JICA Survey Team

Figure 7.3.7 Plan Layout of Structural Measure for Priority No.9 SC477 Benedito Novo - Dutor Pedrinho 1



Source: JICA

Figure 7.3.8 Profile Layout of Structural Measure for Priority No.9 SC477 Benedito Novo - Dutor Pedrinho 1

CHAPTER 8 FEASIBILITY STUDY OF EARLY WARNING SYSTEM FOR LANDSLIDE AND FLASH FLOOD

8.1 General

The effectiveness and sustainability of the early warning system for landslide/flash flood are studied regarding following items.

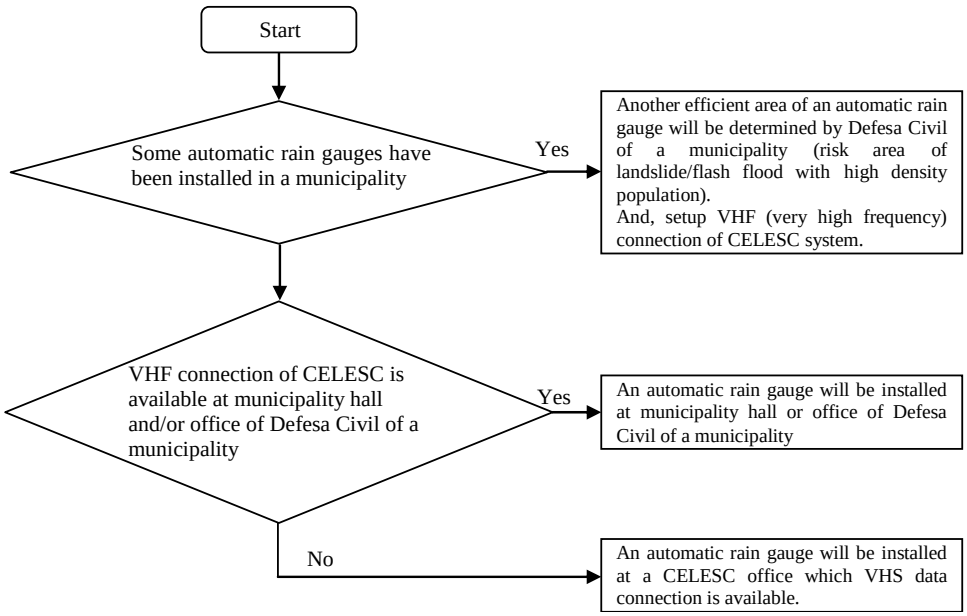
- Rainfall monitoring and data communication/repository
- Criteria of rainfall index for attention/alert
- Management of information, calculation of rainfall index, issue/announce of attention/alert
- Evacuation order and disaster education
- Road traffic regulation for risk avoidance

8.2 Rainfall Monitoring, Data Communication, and Repository

An automatic rain gauge will be installed in each municipality (293 municipalities in Santa Catarina State) for the early warning purpose.

Defesa Civil-SC is a responsible organization for establishment and maintenance of automatic rain gauges and equipments for data communication/repository. EPAGRI/CIRAM and each municipality are implementation organization for the rainfall monitoring, data communication and repository.

Location of automatic rain gauge will be determined by following procedure. Redundant data communication will be established by both of VHS (very high frequency connection) of CELESC system and GPRS (general packet radio services) to secure information communication even under stormy condition.



Source: JICA Survey Team

Figure 8.2.1 Flowchart to Determination Location of Automatic Rain Gauges

8.3 Criteria of Rainfall Index for Attention/Alarm

Criteria of rainfall index for attention/alarm will be set by Defesa Civil-SC by support of EPAGRI/CIRAM.

It is not available landslide/flash flood database with exact time and location of occurrence. The rainfall monitoring stations are sparse, so locations of landslide/flash flood are mostly more than 10 km distance.

Therefore the appropriate criteria setting by the following indexes are not possible so far, it shall be conduct when exact disaster database is furnished.

Accuracy on prediction of disaster occurrence:

$$\text{Correct\_Prediction\_Index} = \frac{\text{Number\_of\_disasters\_over\_the\_warning\_criterion\_value}}{\text{Total \_number\_of\_disasters}} \ (\%)$$

Efficiency on prediction of disaster occurrence:

$$\text{Efficiency Index} = \frac{\text{Total hours for early warning}}{\text{Number of disasters over the warning criterion value}} \ \text{(Hours / Numbers of disasters)}$$

The soil water index (SWI) is used for landslide early warning criteria in Japan as described in the section 9.2.3 of Main Report Part 1 Master Plan.

The Japan methodological agency analyzed that 93 % of fatality due to landslide was caused by most big SWI in past 10 years. The analysis was conducted by 53 thousand landslides data from 2001 to 2009. In case of the storm in November 2011 in the Itajai River basin, the fatalities were occurred only in area of SWI was more than 20 years return period. Therefore, the SWI of 10 years return period is appropriate for alert criteria as the initial setting.

The rainfall index criteria for attention are appropriate to be set once a year level. The purpose of the attention is preparation for alert level storm, reorganization of the warning system by inhabitants, checking of functions of the warning system, and training opportunity for risk avoidance activities.

8.4 Management of Information, Calculation of Rainfall Index, Issue/Announce of Attention/Alarm

Defesa Civil-SC is responsible organization for management of information, calculation of rainfall index, issue of attention/alarm.

The attention and alert are issued by Defesa Civil-SC formally. Because, the early information for the public is important, Defesa Civil-SC delegates EPAGRI/CIRAM the announcement of the rainfall level of attention/warning by web-page and/or mass media, as a part of routine or emergency weather report. The computer system of the early warning shall be included the function of automatic sending electronic mail to Defesa Civil-SC, mayor/defesa civil staff of each municipality, and EPAGRI/CIRAM staffs in charge.

8.5 Evacuation Order and Disaster Education

Municipalities/mayors are responsible official for evacuation order. Evacuation will be ordered for risk houses designated which shall be evacuated when rainfall index is alert level. The evacuation will be also ordered if visible processes of disasters are found out.

The Defesa Civil of municipalities will prepare the detailed hazard map (S=1:10000), and will designate the risk areas/houses, emergency evacuation building such as schools and/or churches,

evacuation route. The disaster education about the evacuation will be also conducted. Santa Catarina State shall clarify the responsibility of the municipalities/mayors about evacuation order in a law.

The capacity of a municipality is not enough for the evacuation order generally. The Defesa Civil-SC shall coordinate the support of the municipalities, using human resources of universities, engineer of public/private, and/or international technical assistance. The early warning system shall be started as soon as possible. And then, the risk areas/houses which shall be evacuated would be designated one by one by the maximum effort of municipalities to make mature the early warning system.

The summary of evacuation order and disaster education is shown in Figure 8.5.1.

SDS-SC
Preparation of map of S = 1:10000 with DEM (digital elevation model)
(Aero photographing was started from April 2010)

↓

Defesa Civil of municipalities supported by the Defesa Civil-SC.
To prepare hazard map by 1:10000 maps,
To designate area/houses shall be evacuated when rainfall index is alert level and/or alert is issued.
To designation of emergency evacuation building/evacuation route.
To conduct disaster education about the evacuation.

↓

Evacuation order by municipalities/mayors for
- High risk houses designated beforehand which shall be evacuated when rainfall index is alert level.
- Houses when visible processes of disasters are found out.

Source: JICA Survey Team

Figure 8.5.1 Evacuation Order and Disaster Education

8.6 Road Traffic Regulation for Risk Avoidance

The structural measures for landslide will be conducted from high risk (big potential annual loss) slopes. But, there are many landslide/flash flood prone road sections mostly on low traffic volume mountainous road. The potential annual losses of road slopes on low traffic volume are generally not high and not prioritized even they are disaster-prone. Therefore it is required that the road traffic regulation for risk avoidance on disaster prone road segments.

Traffic regulation will be ordered to disaster prone road section designated when rainfall index is alert level. The traffic regulation will be ordered when disaster process associate with landslide/flash flood is found out. The disaster prone road sections would be designated one by one by the maximum effort to make mature the early warning system. After the completion of the structural measures, the designations of disaster prone road sections for early warning will be removed.

Municipality is responsible for municipality roads; DEINFRA is responsible for state roads for the road traffic regulation for risk avoidance. The capacity of a municipality is not enough for the traffic regulation order generally. The Defesa Civil-SC shall coordinate the support of the municipalities, using human resources of universities, engineer of public/private, and/or international technical assistance.

CHAPTER 9 COST AND BENEFIT FOR LANDSLIDE MANAGEMANT

9.1 Structural Measures for Sediment Disaster Prevention

The structural measures for sediment disaster prevention will be implemented at the 13 priority places (with annual potential loss more of R$ 500.000). In following Table, the direct costs of each works are shown;

Table 9.1.1 Direct Cost of Structural Measure for Landslide Disaster Mitigation

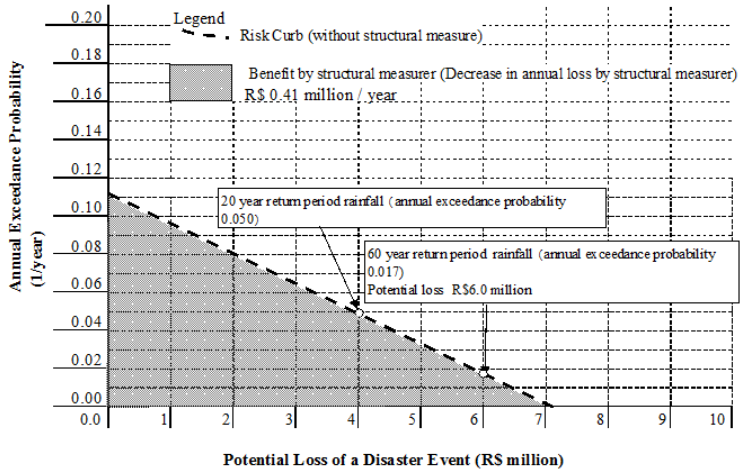
Priority	Local	Direct Cost R$ (x 10^3)
1	Road SC 302 Taio-Passo Manso-5	387
2	Road SC470 Gaspar River Bank	2,062
3	Blumenau- Av. Pres Casrelo Branco	2,849
4	Road SC418 Blumenau – Pomerode	1,851
5	Road SC474 Blumenau-Massaranduba 2	3,724
6	Road Gaspar - Luiz Alves, Gaspar 9	3,399
7	Road Gaspar - Luiz Alves, Luiz Alves 6	1,448
8	Road SC470 Gaspar Bypass	2,768
9	Road SC477 Benedito Novo - Doutor Pedrinho 1	1,026
10	Road SC418 Pomerode - Jaraguá do Sul 1	878
11	Road Gaspar - Luiz Alves, Luiz Alves 4	3,726
12	Road SC474 Blumenau-Massaranduba 1	515
13	Road SC 302 Taio-Passo Manso 4	1,173
Total		**25,806**

Source: JICA Survey Team

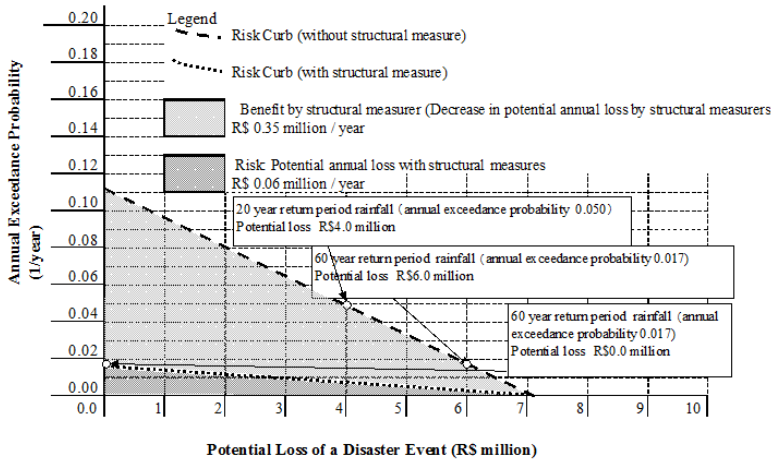
9.2 Cost and Benefit Analysis of Structural Measures for Landslide

The 13 priority landslide risk sites (potential annual loss is more than R$500 thousand) are selected to study the feasibility of structural measures. The safety target of the structural measure is to ensure full functionality of the infrastructure and/or buildings/lands against heavy rain of 60 years return period, or heavy rain level of in November 2008 at Blumenau Municipality (hereinafter referred to as ‘60 years heavy rain’) . All of the priority sites are road slops, and the structural measures will be planed to ensure full width road traffic against 60 years heavy rain.

An annual benefit of structural measures is evaluated by using the risk curve on a relation chart of annual exceedance probability and loss of a disaster event as shown in Figure 11.2.x. An annual benefit of structural measures is calculated as area between risk curve of with and without structural measures on the chart. A risk curve with structural measures is drown from point of ‘x axis of 0 potential loss of a disaster event, y axis of 0.017 annual exceedance probability(60 year probability)’ to point of ‘x axis of maximum potential loss of a disaster event , y axis of 0 annual exceedance probability.



Without Structural Measures



With Structural Measures

Source: JICA Survey Team

Figure 9.2.1 Example of a Benefit by Structural Measurers for Landslide

Feasibility indicators of benefit/cost ratio (BCR), economic net present value(ENPV), and economic internal rate of return are calucurated by12％ discount rate and 20 years evaluation period, which are practice for road investment evaluation of DEINFRA.

Summary of cost and benefits of the 13 priority landslide risk sites are shown in Table 9.2.1.

Table 9.2.1 Selected 13 Priority Sites and Type of Landslide

No. of priority order	Site	Potential annual loss (R$ x 10^3/year)	Total cost (direct and indirect) (R$ x 10^3)	Benefit: decrease in potential annual loss (R$ x 10^3/year)	Feasibility index		
					BCR: Benefit cost ratio	ENPV: Economic net present value (R$ 10^3)	EIRR: Economic internal rate of return (%)
1	Road SC 302 Taio-Passo Manso-5	1,255	542	1,062	14.6	7,388	196
2	Road SC470 Gaspar River Bank	1,095	2,810	581	1.5	1,533	20
3	Blumenau –Av Pres Castelo Branco	1,021	3,883	654	1.3	1,002	16
4	Road SC418 Blumenau - Pomerode	989	2,522	841	2.5	3,763	33
5	Road SC474 Blumenau-Mass aranduba 2	907	5,075	641	0.9	-286	11
6	Road Gaspar - Luiz Alves, Gaspar 9	774	4,664	653	1.0	215	13
7	Road Gaspar - Luiz Alves, Luiz Alves 6	700	1,974	591	2.2	2,440	30
8	Road SC470 Gaspar Bypass	689	3,772	402	0.8	-768	9
9	Road SC477 Benedito Novo - Doutor Pedrinho 1	680	1,399	575	3.1	2,894	41
10	Road SC418 Pomerode-Jaragua do Sul 1	651	1,210	553	3.4	2,916	46
11	Road Gaspar - Luiz Alves, Luiz Alves 4	629	5,078	532	0.8	-1,107	8
12	Road SC474 Blumenau - Massaranduba 1	601	702	425	4.5	2,470	60
13	Road SC 302 Taio - Passo Manso 4	526	1,599	446	2.1	1,734	28
Total of the 13 risk sites		10,516	35,231	7,956	1.7	24,196	22

Source: JICA Survey Team

CHAPTER 10 RECOMMENDATION FOR LANDSLIDE MANAGEMENT

Installation of Early Warning System for Landslide and Flashflood:

i) The study area of master plan is the Itajai River Basin, however, the early warning system shall be installed to the entire state of Santa Catarina and rationalize the cost of system development. In all municipalities have risks of landslide and flash flood, even risk levels are different, then at least one automatic rain gauge shall be installed in each municipality.

ii) The rainfall index for warning system should be processed by simple rainfall amount (eg, 30 minutes rainfall amount), ie, the rainfall index would not be coupled to two values (for example, 90 days rainfall amount and 48 hours rainfall amount), it is desirable that a single value can express this index. If you take a single numeric value, return period can be calculated to assess disaster occurrence potential. In case of warning statement, the people shall be feel the danger realistically by the statement such as 'It is highest dangerous situation for landslide and flashflood in last ten years'.

iii) This system is newly installed, and the organization for the evacuation shall be same as flood forecasting and warning system.

iv) The municipality shall designate the areas of disaster risk of flash floods and landslides, establish in advance the evacuation sites and routes for the warning, perform the training of the residents and related institutions, to avoid human lives lost securely. The detailed hazard maps by the Blumenau City is preparing are useful basic material for this system. The Ilhota City assigns the responsible persons for communication and action during dangerous situation for each district. Such actions should be extended to other municipalities.

Enhancement of the Land Development Project Management to Reduce Sediment Yield and Disasters:

v) It shall be strengthened that the projects executed by the contractors (projects of state and municipal) in relation to slope stabilization and sediment yield mitigation. It is required that the training of engineers of construction design and supervision.

vi) Preparation of norms and administrative direction shall be required for the regulation facilities for rainfall runoff about land development not to encourage flashflood and flood.

Rationalization of Structural Measures

vii) Structural measures for landslide disaster shall be planed to reduce sediment yield securely. Bare slopes shall be vegetated. Tree planting shall be conducted at slopes where there is no danger of falling trees or road valley side slopes as measures of climate change by fixing carbon.

viii) The effective measures against the sediment yield are reforestation of bare collapsed slopes and restoration of riparian forests to prevent river erosion. Its main goal is the preservation of water resources, forests and environment. The forestation also contributes to the mitigation of sediment yield. It shall be promoted that the programs to recovery of riparian vegetation, conservation program of watershed areas. The programs are part of the master plan of water resources, prepared by the Committee of Itajai in March 2010.

ix) Within the Itajai River Basin, the Port of Itajai has the largest economic losses due to sediment discharge. But the volume of sedimentation and the volume of dredging were never monitored. The monitoring is required to clarify the mechanism of sedimentation, including sediment by the tide. It is an idea the research will be sublet to research institute of hydrology such as UNIVALI University. Based on the research, effective measures to reduce sediment at Itajai Port shall be formulated.