Appendix 3.1.9

Procedure of the maintenance

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
MINISTRY OF PUBLIC INFRASTRUCTURE AND LAND TRANSPORT (MPI)

TECHNICAL COOPERATION PROJECT: LANDSLIDE ADVISER FOR MAURITIUS

Procedure of the Maintenance for Landslide Countermeasures

September 2017

KOKUSAI KOGYO CO., LTD.

Contents

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Appendix

1 Introduction

The conditions of landslide countermeasure works are grasped through inspection work, and the maintenance work is carried out based on the information thus obtained. Moreover, efforts must be made to keep the landslide countermeasure works in good condition at all times, whereby the re-occurrence of disasters can be prevented. Therefore, when deformation and/or problems are confirmed on the landslide countermeasure works through inspection work, it is essential to repair these immediately.

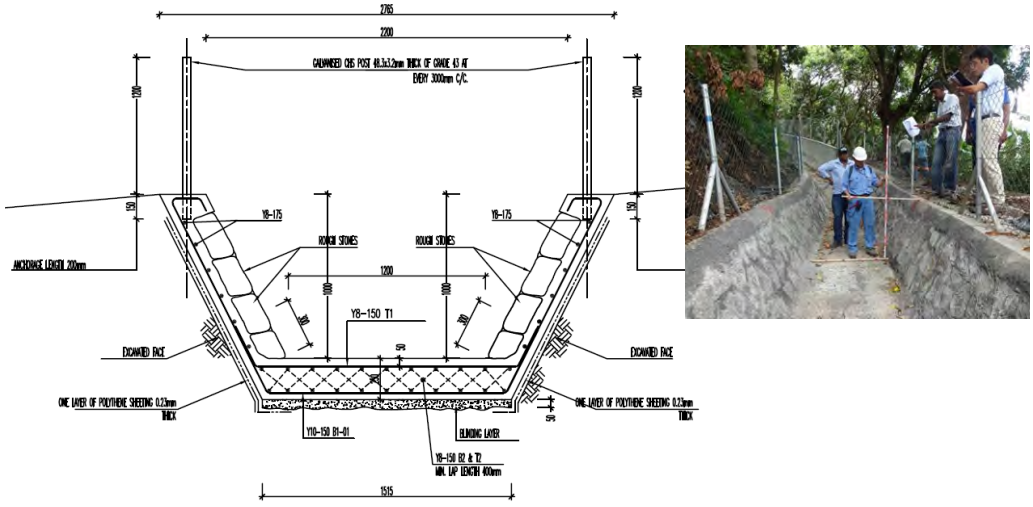
There are many kinds of landslide countermeasure works; however, this manual describes the maintenance methods of the surface drainage and horizontal drainage systems (perforated PVC pipe) — which were constructed in the Chitrakoot area.

2 Surface drainage system

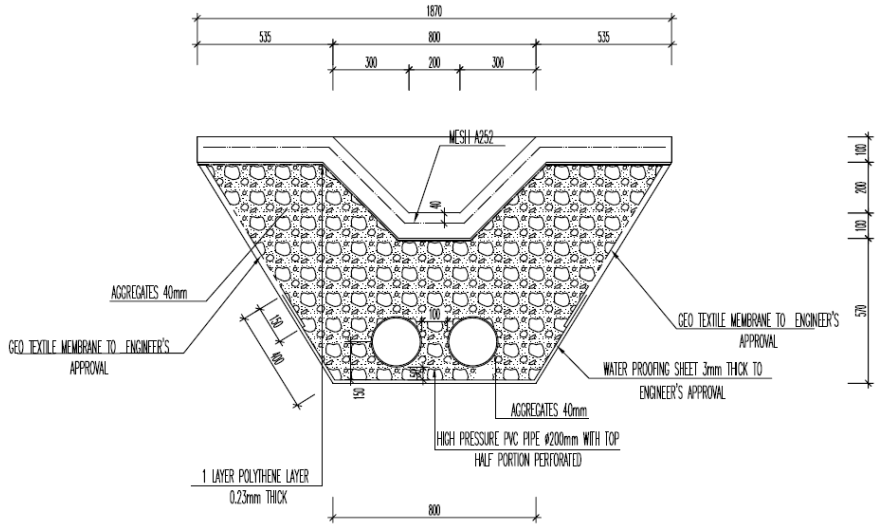
2.1 Purpose of the surface drainage system

The surface drainage system is constructed to drain out the surface water of the landslide area in areas with no risks. The structure is simple, but plays an important role in preventing landslides.

Open-blind ditch is one kind of surface drainage system. This open-blind ditch is a structure combined with a drainage pipe, which is installed at the lower part of the surface drainage. The purpose of this system is to drain the very shallow groundwater and surface water to areas outside the landslide area.



a. Surface drainage system



b. Open-blind ditch

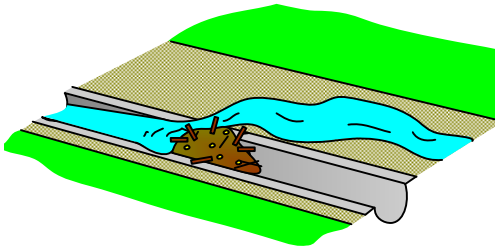
Figure 2.1.1 Examples of the surface drainage system and open-blind ditch in Chitrakoot (Source: MPI)

2.2 Maintenance method

During maintenance of the surface drainage system, the drainage is cleaned and the damaged parts are restored. The inspection must be carried out regularly, and the necessary repair work must be conducted based on the inspection results.

[Cleaning in the drainage]

When the surface water flows into the drainage, other materials (soils, rocks, branches, leaves and garbage) often flow in at the same time. These materials may flow down with water, but the bigger sized materials remain in the drainage. These sedimentation materials disturb the drainage, and can cause water overflow.



(Source: JICA expert team)

Therefore, the sedimentation material (soils, rocks, branches, leaves and garbage) in the drainage must be removed regularly, and it should be carried out especially before the wet season when a large quantity of water flows down. In addition, the sedimentation material accumulated in the water catch basin, installed in the same section, must be removed as well.

[Restoration of damaged parts]

In cases where gaps and cracks occur – common in joints – in a surface drainage system, the designed drainage capacity of the drain cannot be expected. Therefore, cracks and gaps need to be repaired immediately.

2.3 Periodical inspection for surface drainage system

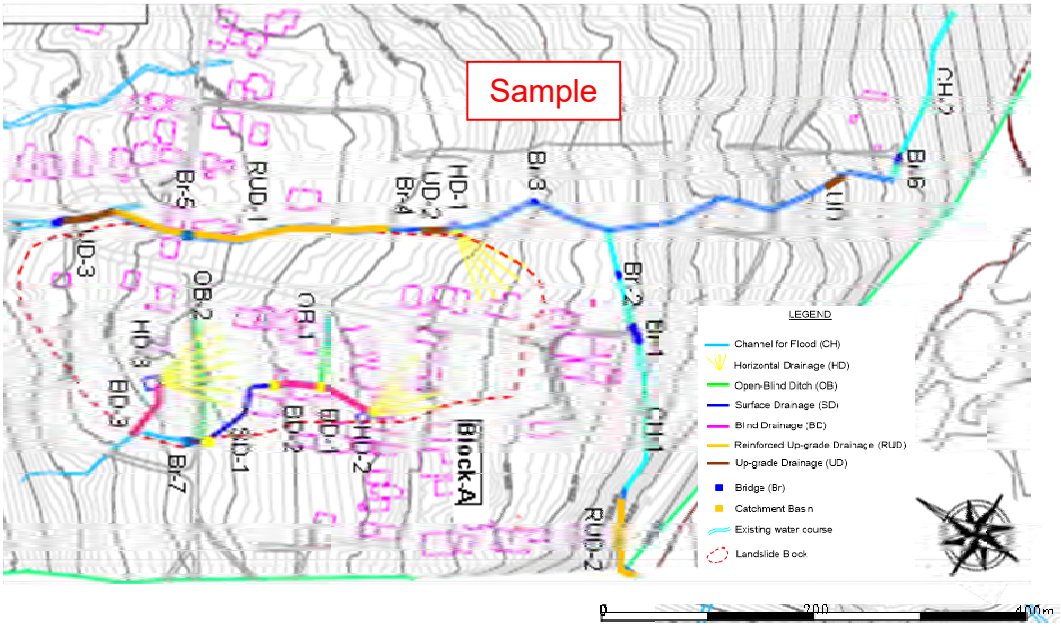
Periodical inspection is required for the maintenance of surface drainage system. The frequency of inspection shall usually be once a month, and it should be increased (twice a month or more) in the wet season, when the landslide area becomes active. In the case that the landslide activity has been confirmed, the frequency of inspection must be increased depending on the situation. The specific inspection items are shown in the inspection sheet (Figure 2.3.1 and appendix).

Table 2.3.1 The frequency of inspection (Source: JET)

Inspection in dry season	Once a month
Inspection in the wet season, when the landslide area becomes active.	Twice a month or more

Inspection Sheet	Surface Drainage / Ditch			
	Name of Inspector :		Date of Inspection :	

< Location map>



a) There is an obstruction stopping the surface water flowing into the drainage. No , Yes (➡ Go to a1-a4)	a1) Name or No. of the drainage		a3) Repair method	
	a2) Location	[m]	a4) Repair amount	
b) There is an obstacle causing overflow in the drainage. No , Yes (➡ Go to b1-b4)	b1) Name or No. of the drainage		b3) Repair method	
	b2) Location	[m]	b4) Repair amount	
c) There is a crack and/or water leak in the drainage. No , Yes (➡ Go to c1-c9)	c1) Name or No. of the drainage		c8) Repair method	
	c2) Location	[m]	c9) Repair amount	
	c3) Width of the crack	[mm]		
	c4) The crack is new	Yes , No		
	c5) There is the displacement along the crack	Yes , No		
	c6) Cause of the crack	Yes , No		
	c7) There is the drainage from a blind ditch.	Yes , No		

Figure 2.3.1 Example of an inspection sheet for surface drainage and ditch system (Source: JET)

An inspection sheet is made every time and is filed and kept in the office so that past inspection results can be referred to easily. After the inspection, the damaged parts are repaired based on the inspection results.

2.4 Repair of the surface drainage system

(1) Backfill of the crack

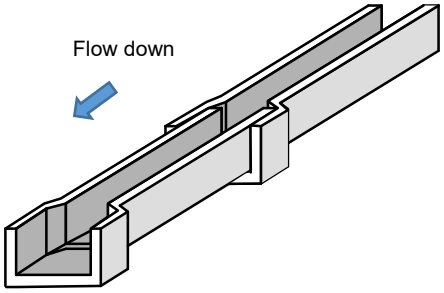
The crack is filled with fill material (mortar and others) immediately to prevent a water leak from an open crack.

Figure 2.4.1 Example of repairing of crack on the surface drainage system (Source: JET)

(1) Restoration of surface drainage system

In the case that a surface drainage is damaged by continuous landslide activity, it is necessary to carry out radical measures. The section of a damaged surface drainage is repaired using the flexible materials such as corrugated pipe. If the acquisition of flexible materials is difficult, the joints of conventional drainage materials should be overlapped.

Restoration using corrugated pipe



Overlapped joint

Figure 2.4.2 Examples of surface drainage system restoration (Source: JET)

3 Horizontal drainage system

3.1 Purpose of the horizontal drainage system

The increase of groundwater is one of main causes of landslide activity. The purpose of the horizontal drainage system is to remove the groundwater in a landslide mass. A drainage pipe (perforated PVC pipe) is installed in the underground to drain out the groundwater around the pipe. Generally, it is a countermeasure applied for shallow groundwater.


Figure 3.1.1 Horizontal drainage system in Chitrakoot, Block A (Source: JET)

3.2 Maintenance method

The maintenance items for the horizontal drainage system are 1) pipe cleaning, and 2) restoration of incidental facilities. The inspection must be carried out regularly, and the necessary repair work must be conducted based on the inspection results.

< Pipe cleaning>

In the case that groundwater flows into the drainage pipe, the neighboring soil often flows in at the same time, and the soil remains in a drainage pipe. The drainage discharge volume by drainage pipes decreases because of these accumulated soils. Therefore, if a decrease in drainage is confirmed by a periodical check, the drainage pipe cleaning must be carried out.

＜Restoration of incidental facilities＞

Retaining walls, made in concrete and Gabion, are constructed to an outlet of a horizontal drainage system. In the case that damages of these retaining walls are confirmed, these should be repaired promptly. In addition, the accumulated soil in the surface drainage ditch and the catchment measures, which are located near to the outlets of horizontal drainage system, should be removed.

Figure 3.1.2 Example of retaining walls for outlets of horizontal drainage systems (Source: JET)

3.3 Periodical inspection for horizontal drainage system

Periodical inspection is required for the maintenance of the surface drainage system. The frequency of inspection should usually be once a month, and it should be increased (twice a month or more) in the wet season, when landslide activity becomes active. In the case that the landslide activity has been confirmed, the frequency of inspection must be increased depending on the situation. The specific inspection items are shown in the inspection sheet (Figure 3.3.1 and appendix).

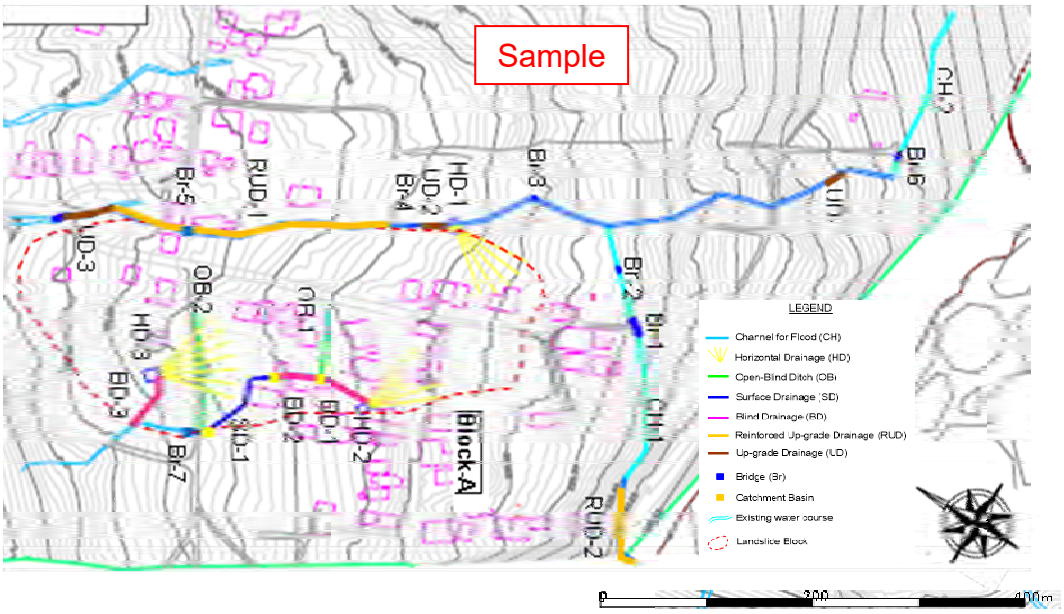
Table 3.3.1 The frequency of inspection (Source: JET)

Inspection in dry season	Once a month
Inspection in the wet season, when the landslide area becomes active	Twice a month or more

The inspection sheet is made every time and is filed and kept in the office so that past inspection results can be referred to easily. After the inspection, the damaged parts are repaired based on the inspection results.

Inspection Sheet	Horizontal Drainage			
	Name of Inspector :		Date of Inspection :	

< Location map>



a) Volume of drainage water. (ml/min) The volume has decreased compared to the volume recorded in the last inspection Yes, No （➡ Go to a1-a4）	a1) Name or No. of the horizontal drainage system		a3) Repair method	
	a2) Location		a4) Repair amount	
b) Deformation and/or damage to the drainage pipe. No , Yes （➡ Go to b1-b4）	b1) Name or No. of the horizontal drainage system		b3) Repair method	
	b2) Location of the pipe		b4) Repair amount	
c) Blockage of pipe outlet No , Yes （➡ Go to c1-c4）	c1) Name or No. of the horizontal drainage system		c3) Repair method	
	c2) Location of the pipe		c4) Repair amount	
d) Water leak from pipe outlet No , Yes （➡ Go to d1-d4）	d1) Name or No. of the horizontal drainage system		d3) Repair method	
	d2) Location of the pipe		d4) Repair amount	
e) Damage to the retaining wall for outlets of the horizontal drainage system No , Yes （➡ Go to e1-e9）	e1) Name or No. of the horizontal drainage system		e3) Repair method	
	e2) Location of the damage		e4) Repair amount	

Figure 3.3.1 Example of an inspection sheet for surface drainage and ditch system (Source: JET)

3.4 Pipe cleaning

According to the inspection results, if it is confirmed that the drainage pipe (perforated PVC pipe) is blocked because of the accumulated soil, the drainage pipe will be cleaned by a high-pressure water jet, to restore its drainage capacity.

Table 3.4.1 Materials and machinery for cleaning drainage pipes (Source: JET)

Jet water nozzle	High pressure pump	Generator	High pressure hose
There are some jet water outlets towards front and the lateral - rear.	35-70 ℓ/min, 14 MPa	9000W, 120/240V 30A	100R 2/2 L=90m
			

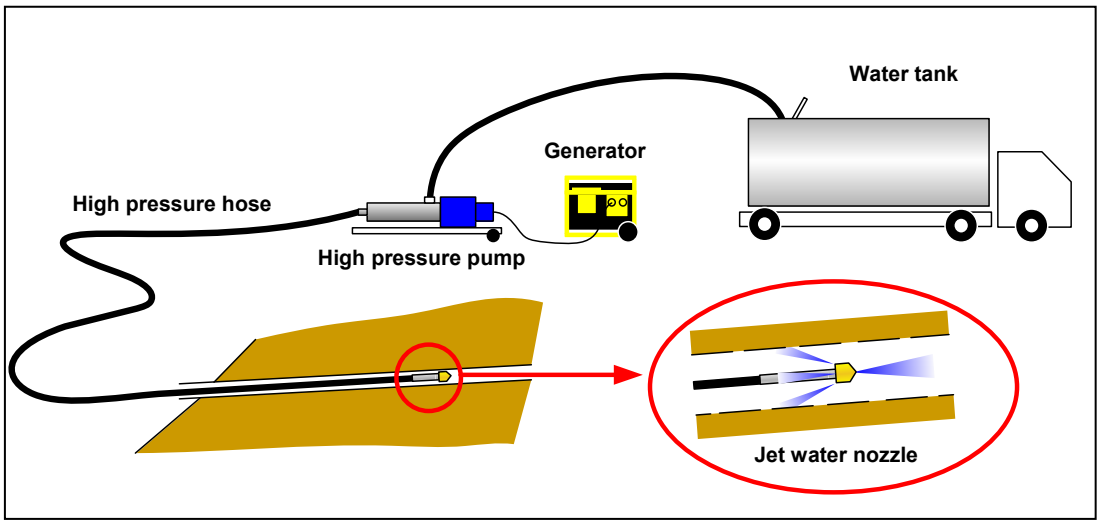


Figure 3.4.1 System (materials/machinery) for cleaning drainage pipes (Source: JET)

[Notice] Do not use the high-pressure water jet at the same part for a long time, because the soil outside the drainage pipe will be washed out as well.

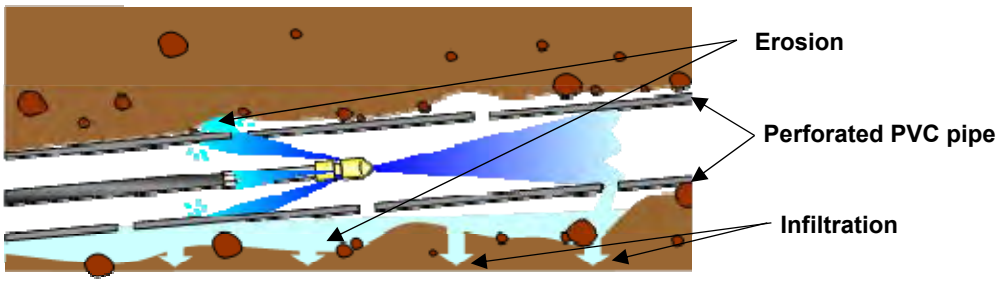


Figure 3.3.1 Washing out the soil outside the drainage pipe by a high-pressure water jet (Source: JET)

4 Drainage well

＜Soil Removal>

When the drainage pipe is buried by a large quantity of soil deposits at the bottom of the well, it is necessary to remove the soil of the bottom immediately, and to clean the pipe after that.

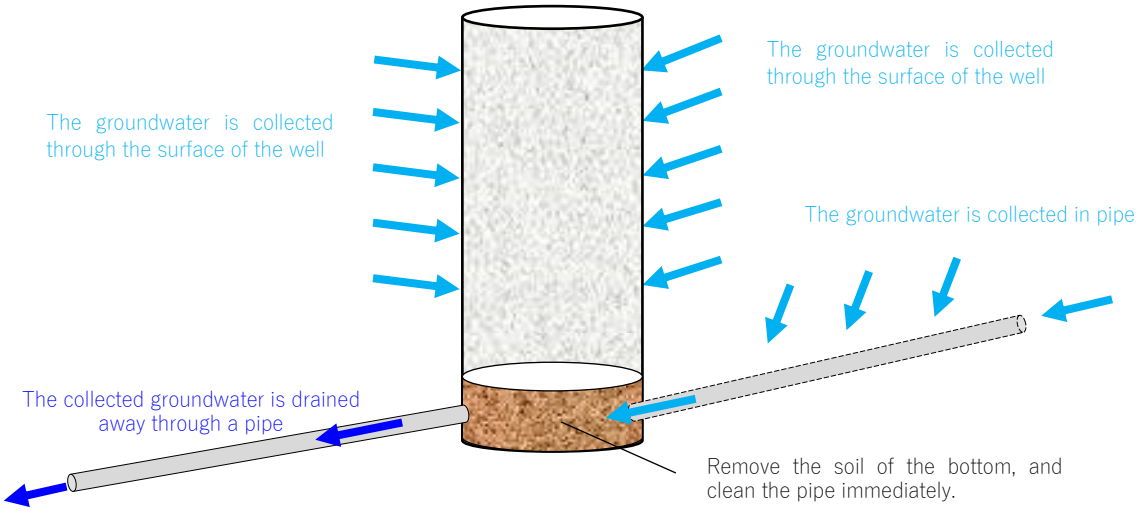


Figure 4.1.1 The removal of the soil deposits at the bottom of the drainage well (Source: JET)

＜Pipe cleaning＞

The cleaning method of pipes in a drainage well is the same as that of the horizontal drainage system. After cleaning the pipes, the soil collected at the bottom of the drainage well should also be removed.

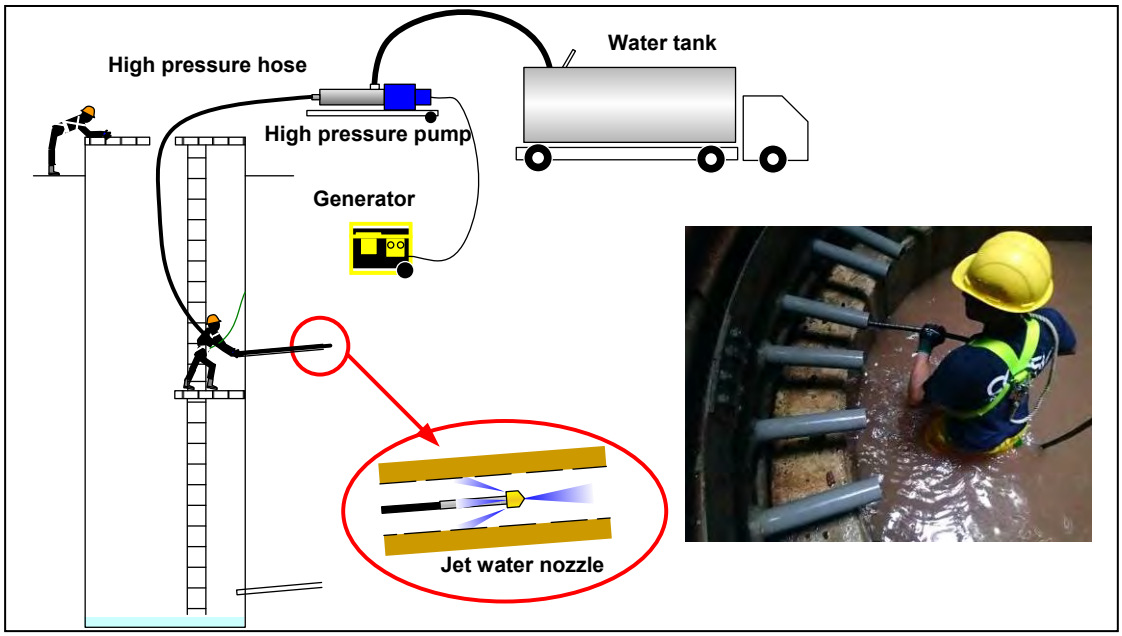


Figure 4.1.2 System (materials/machinery) for cleaning drainage pipes in a drainage well (Source: JET)

Appendix

Inspection sheet for surface drainage/Ditch

Inspection sheet for horizontal drainage

Inspection Sheet	Surface Drainage / Ditch			
	Name of Inspector :		Date of Inspection :	

< Location map>

a) There is an obstruction stopping the surface water flowing into the drainage. No , Yes（➡ Go to a1-a4）	a1) Name or No. of the drainage		a3) Repair method	
	a2) Location	[m]	a4) Repair amount	
b) There is an obstacle causing overflow in the drainage. No , Yes（➡ Go to b1-b4）	b1) Name or No. of the drainage		b3) Repair method	
	b2) Location	[m]	b4) Repair amount	
c) There is a crack and/or water leak in the drainage. No , Yes（➡ Go to c1-c9）	c1) Name or No. of the drainage		c8) Repair method	
	c2) Location	[m]	c9) Repair amount	
	c3) Width of the crack	[mm]		
	c4) The crack is new	Yes , No		
	c5) There is the displacement along the crack	Yes , No		
	c6) Cause of the crack	Yes , No		
	c7) There is the drainage from a blind ditch.	Yes , No		

Inspection Sheet	Horizontal Drainage			
	Name of Inspector :		Date of Inspection :	

< Location map>

a) Volume of drainage water. (ml/min) The volume has decreased compared to the volume recorded in the last inspection Yes, No（ ➡ Go to a1-a4）	a1) Name or No. of the horizontal drainage system		a3) Repair method	
	a2) Location		a4) Repair amount	
b) Deformation and/or damage to the drainage pipe. No , Yes（ ➡ Go to b1-b4）	b1) Name or No. of the horizontal drainage system		b3) Repair method	
	b2) Location of the pipe		b4) Repair amount	
c) Blockage of pipe outlet No , Yes（ ➡ Go to c1-c4）	c1) Name or No. of the horizontal drainage system		c3) Repair method	
	c2) Location of the pipe		c4) Repair amount	
d) Water leak from pipe outlet No , Yes（ ➡ Go to d1-d4）	d1) Name or No. of the horizontal drainage system		d3) Repair method	
	d2) Location of the pipe		d4) Repair amount	
e) Damage to the retaining wall for outlets of the horizontal drainage system No , Yes（ ➡ Go to e1-e9）	e1) Name or No. of the horizontal drainage system		e3) Repair method	
	e2) Location of the damage		e4) Repair amount	

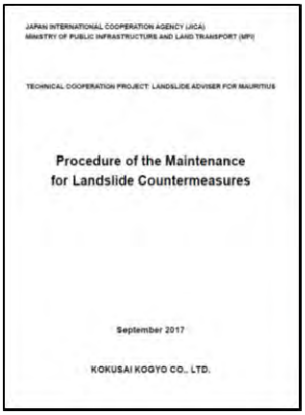
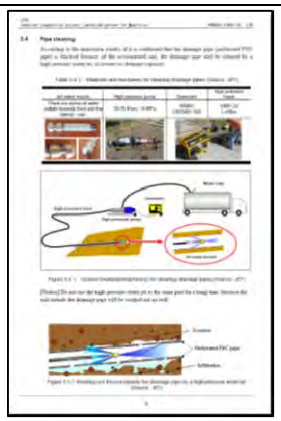
Appendix 3.1.10

Technical meeting for procedure manual of the maintenance of landslide countermeasures

Technical meeting for procedure manual of the maintenance of landslide countermeasures

Technical meeting for procedure of the maintenance of landslide countermeasures was held on 17 October 2017 by MPI/LMU and JET.

Table 1 Technical meeting for procedure manual of the maintenance of landslide countermeasures, 17th October 2017 (Source: JET)

Date	17th October 2017
Venue	MPI, Phoenix
Stakeholder	Mr. T. Parbhunath Director, Civil Engineering Section, MPI Mr. Chinasamy Chief Engineer, Civil Engineering Section, MPI- LMU Mr. Mosaheb Engineer/ Senior Engineer, Civil Engineering Section, MPI Mr. Damonsing Engineer/ Senior Engineer, Civil Engineering Section, MPI Mr. Gobin Engineer/ Senior Engineer, Civil Engineering Section, MPI Mr. Iwasaki JICA Expert Team, JET Mr. C.K. Bhuckory Project Coordinator, JET (Ag. Secretary)
Objectives	✓ Generally, in Mauritius, the landslide countermeasure is maintained by municipalities. Therefore MPI and the JICA experts have prepared the maintenance procedure of a landslide countermeasure for municipalities. ✓ MPI will be able to teach a procedure of the maintenance to the municipalities by using this document.
Manual	  

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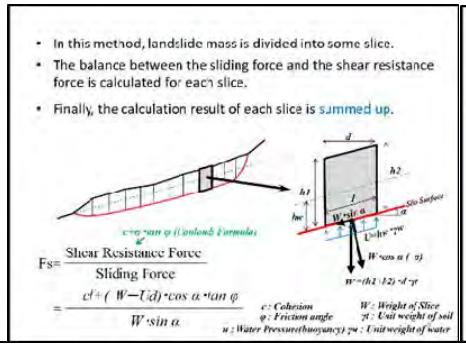
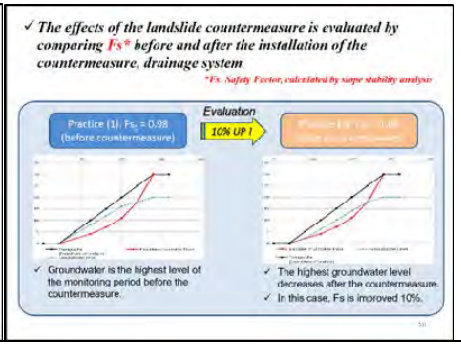
Appendix 3.1.11

Technical workshop for evaluation of the effects of the countermeasure work

1 Technical workshop for evaluation of the effects of the countermeasure work

Table 1 Technical workshop for evaluation of the effects of the countermeasure work, 4th October 2017 (Source: JET)

Date	4th October 2017
Venue	MPI, Phoenix
Stakeholder	**Technical Workshop on Slope Disasters.** **On 04 September 2017, Ministry of Public Infrastructure and Land Transport, Phoenix at 14.00 hrs.** (Name / Designation / Contact / Signature) 1. KIRAN BHURTH — TECHNICAL OFFICER — 57566726 2. GOOBASAHIB Irfaan — Technical Officer — 57504143 3. LUCHYRAM Cheyneigh — Trainee Engineer — 59157500 4. MAHADEO Ritesha — Technical Officer — 57530491 5. Hoobeh Muzaffar — Trainee Engineer — 57057722 6. JUGOO Ismaal — Trainee Engineer — 57947995 7. MOHAMOOBALLY Mohamen — Trainee Engineer — 59182015 8. Ujoodha Yashveer — Trainee Engineer — 57636322 9. UNGNOO Soobeernathsingh — Trainee Engineer — 5976 5039 10. JEEBODH Ashish — Trainee Engineer — 59172880 11. Hedisth Ramlachun — Trainee Engineer — 59810371 12. Allia Naseeven — Trainee Engineer — 57582141 13. JOOMUN Zahirali — Trainee Engineer — 57523051 14. Khalid Mahabeth — Trainee Engineer — 59709016 15. M. Gobin — Engineer/Senior Engineer — 601 1600 16.
Objectives	<Purpose of this workshop> After completion all Landslide counter measure in Chitrakoot, MPI/LMU has to evaluate the effect of the landslide countermeasures without an JICA Expert Team. Therefore, in this workshop, the lecture about the evaluation method for the landslide countermeasure is conducted so that MPI/LMU can evaluate it by self.  
Photo	 

2 Procedure for evaluation of the effects of the countermeasure work

2.1 Work flow for Evaluation by the stability analysis

The effects of the landslide countermeasure works are evaluated by the stability analysis, in accordance with the work flow shown below, after completion of the countermeasure, Phases I and II, in Chitrakoot.

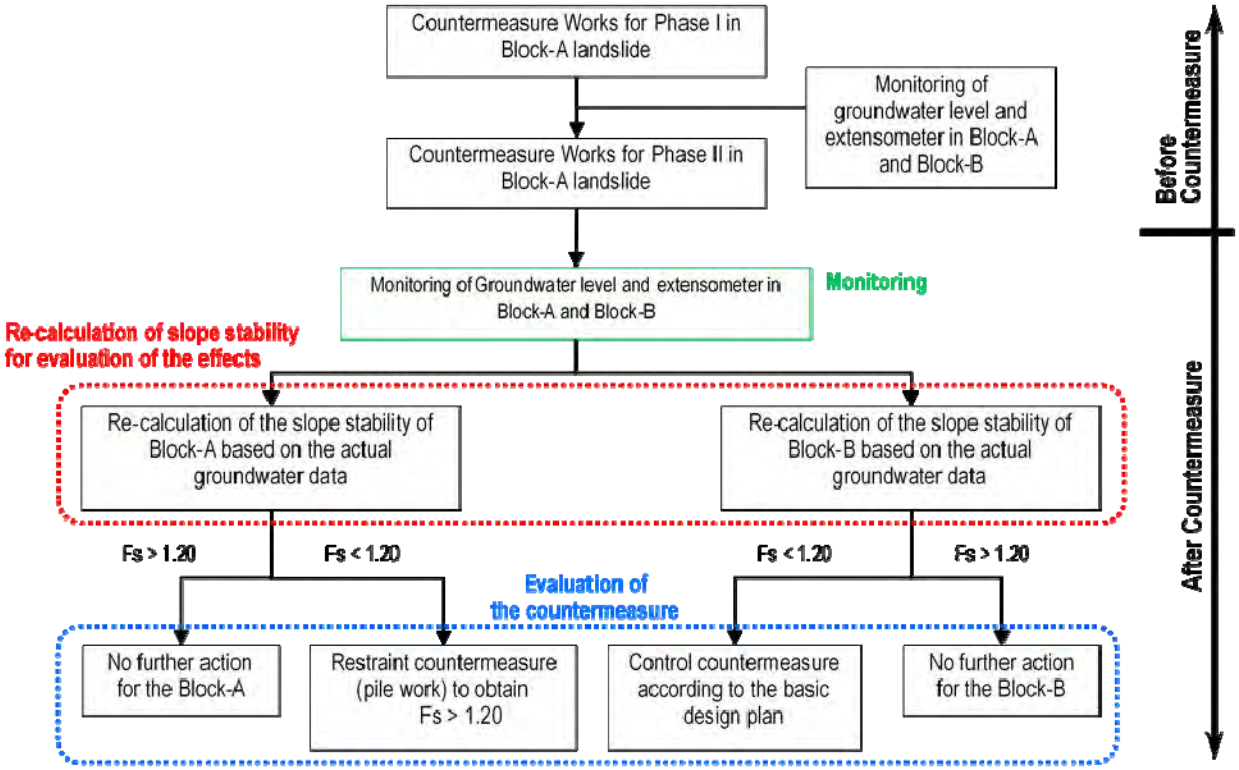


Figure 1 Flow chart for re-calculation of slope stability for the evaluation of the effects of landslide countermeasure works in Chitrakoot Area (Source: JET)

After completion of the works of Phase II, groundwater level and landslide activity shall be confirmed by monitoring. Regarding the stability analysis to check the factor of safety of the landslide after completion of the countermeasure works, the landslide analysis model used during the design stage shall be used. The parameters for the analysis, such as cohesion, internal friction angle or unit weight, shall not be changed except for groundwater level, which will be re-established as the highest level measured during the rainy season.

2.2 Monitoring of Groundwater level and extensometer

After completion of the works of Phase II, groundwater level and landslide activity shall be confirmed by monitoring. MPI/LMU has to monitor groundwater level in wet season after the countermeasure completion, 2018-2020, and get the highest groundwater level of the monitoring period for each year.

Water level meter: [Block-A] BPP 16, BPP 11, W-2, BPP 8, [Block-B] B-P1, B-P2, BPX-2

Extensometer: [Block-A] E(5), E-C1, [Block-B] E(1), E(2)

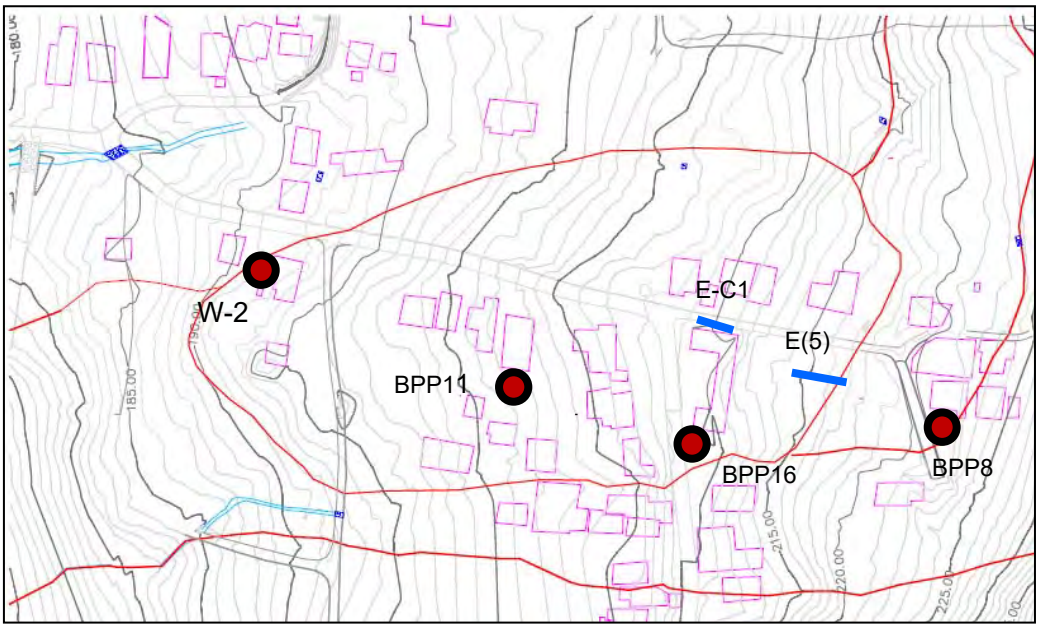


Figure 2 Location of monitoring for Block-A landslide (Source: JET)

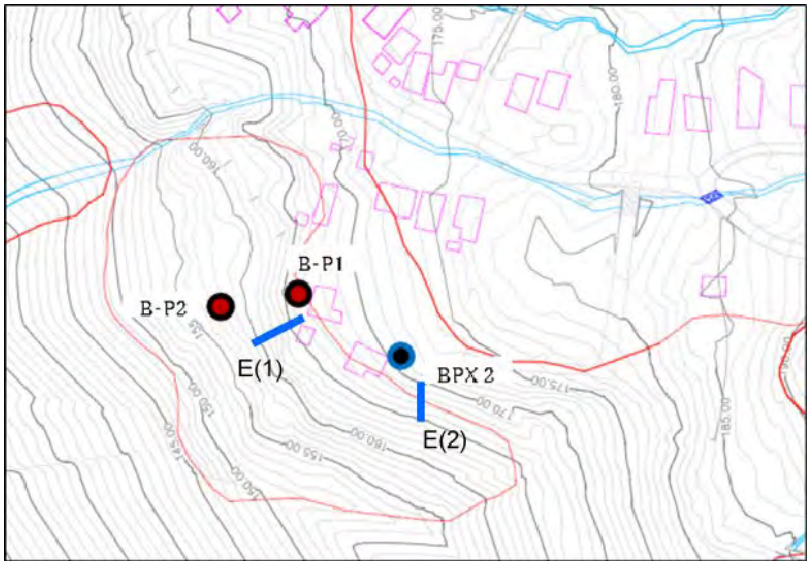


Figure 3 Location of monitoring for Block-B landslide (Source: JET)

2.3 Evaluation of the landslide countermeasure

The stability analysis must be carried out using the highest water level after the countermeasure, and the effect of the countermeasure is evaluated based on the result of stability analysis.

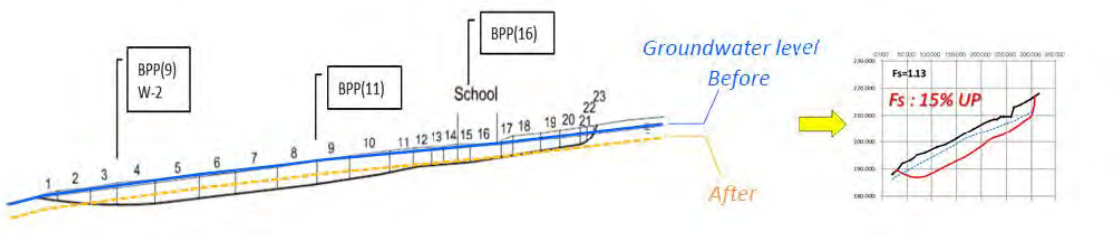


Figure 3 Concept of the evaluation of the countermeasure based on the stability analysis (Source: JET)

Fs after the countermeasure is evaluated as follows,

Table 2 Evaluation of Fs after the landslide countermeasure work

Fs, after countermeasure	**Necessary measure, additional countermeasure**
$Fs_1 < 1.05$	The additional countermeasure should be carried out.
$1.05 < Fs_1 < 1.20$	The additional countermeasure should be planned. (If the landslide is active again, the additional countermeasure can be installed quickly.)
$1.20 < Fs_1$	The additional countermeasure is not necessary.

Attendance Sheet

Technical Workshop on Slope Disasters.

On 04 September 2017, Ministry of Public Infrastructure and Land Transport, Phoenix at 14.00 hrs.

	Name	Designation	Contact	Signature
1.	KIRAN BHUREETH.	TECHNICAL OFFICER.	57585726	
2.	GOOPASAHIB Irfaan	Technical Office	57504143	
3.	LUCKYRAM Cheryngsingh	Trainee Engineer	59157500	
4.	MAHADEO Ritisha	Technical Officer	57530491	
5.	Hoobash Muzaffar	Trainee Engineer	57057722	
6.	JUGOO Ismaail	Trainee Engineer	57947995	
7.	MOHAMOOD ALLY M.Hassen	Trainee Engineer	59132015	
8.	Ujoodha Yashveer	Trainee Engineer	57636322	
9.	UNGNOO Soobeernathsingh	Trainee Engineer	5976 5039	
10.	JEEBODH Aalish	Trainee Engineer	59242880	
11.	Hedisth Ramlochun	Trainee Engineer	59810371	
12.	Allia Naseeven	Trainee Engineer	57584141	
13.	JOOMUN Zahirali	Trainee Engineer	57525651	
14.	Khalid Mohabuth	Trainee Engineer	59709016	
15.	M. Gobin	Engineer / Senior Engineer	601 1600	
16.				

Technical Workshop for MPI / LMU

Evaluation method for effects of the landslide countermeasure by using “Stability Analysis”

4th Oct, 2017 (Wed) 14:00 - 16:00

Dr. Tomoharu IWASAKI
JICA Expert Team

1

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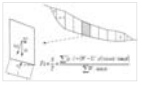
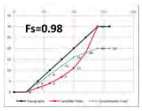
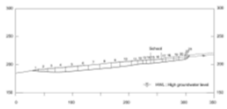
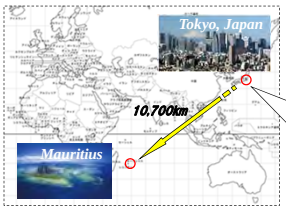





4

Self-Introduction

Tomoharu IWASAKI (51)
岩崎 智治



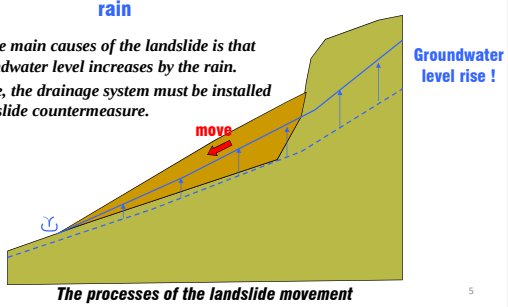
I studied ….
- University : Civil Engineering
- Graduate school : Geotechnical Eng

My Family

2

1. How to evaluate the effect of the landslide countermeasure

- ✓ ***One of the main causes of the landslide is that the groundwater level increases by the rain.***
- ✓ ***Therefore, the drainage system must be installed as a landslide countermeasure.***



The processes of the landslide movement

5

Purpose of this workshop

The landslide countermeasures are installted in Chitrakoot, Landslide Block-A.

- ✓ Phase 1 had been completed in 2014.
- ✓ Phase 2 is under construction, it will be completed at the end of 2017.

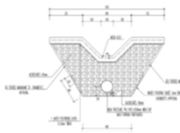
After completion it, MPI/LMU has to evaluate the effect of the landslide countermeasures without an JICA Expert Team.

Therefore, in this workshop, the lecture about the evaluation method for the landslide countermeasure is conducted so that you can evaluate it by yourself.

3

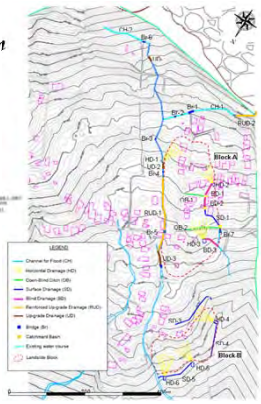
- ✓ ***In Chitrakoot, Many drainage system are installed as a landslide countermeasure.***

Channel CH-1



Open-Blind Ditch

Horizontal Drainage HD-1



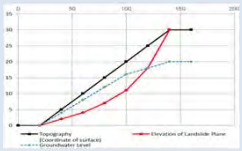
6

✓ ***The effects of the landslide countermeasure is evaluated by comparing Fs* before and after the installation of the countermeasure, drainage system.***

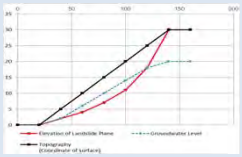
**Fs: Safety Factor, calculated by slope stability analysis*

Evaluation

Fs_0 = 0.98 (before countermeasure) → 10% UP ! → Fs_1 = 1.08 (after countermeasure)



✓ Groundwater is the highest level of the monitoring period before the countermeasure.

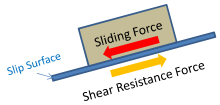


✓ The highest groundwater level decreases after the countermeasure.
✓ In this case, Fs is improved 10%.

7

2. Slope Stability Analysis (Modified Fellenius Method)

- The Modified Fellenius Method is an ordinary method, also called a "Simple Method", usually used for landslide analysis.
  (If you begin to study about a stability analysis, this method is a best for you.)
- It is based on the balance between "Sliding Force" and "Shear Resistance Force" along the slip surface.



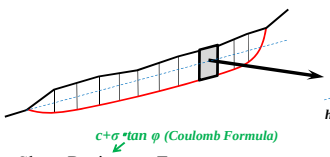
$$Fs=\frac{\text{Shear Resistance Force}}{\text{Sliding Force}}$$

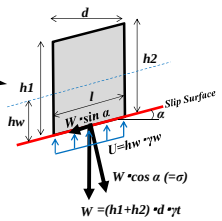
- The safety factor (Fs) is the ratio of these force.

Fs = 1.00 : Just balance between Sliding Force and Resistance Force
Fs < 1.00 : Unstable, Slide
Fs > 1.00 : stable

8

- In this method, landslide mass is divided into some slice.
- The balance between the sliding force and the shear resistance force is calculated for each slice.
- Finally, the calculation result of each slice is summed up.





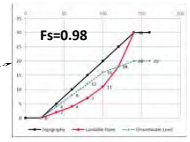
$c+\sigma \cdot \tan\varphi$ *(Coulomb Formula)*

$$Fs=\frac{\text{Shear Resistance Force}}{\text{Sliding Force}}=\frac{\sum cl+(W-Ud)\cdot\cos\alpha\cdot\tan\varphi}{\sum W\cdot\sin\alpha}$$

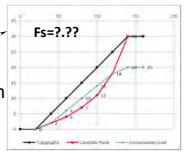
c : Cohesion *W : Weight of Slice*
φ : Friction angle *γt : Unit weight of soil*
u : Water Pressure(buoyancy) *γw : Unit weight of water*

3. Practice of the stability analysis

・Practice (1):
To make an analysis model
= Initial condition



・Practice (2):
To decrease a groundwater level
= After the countermeasure, drainage system



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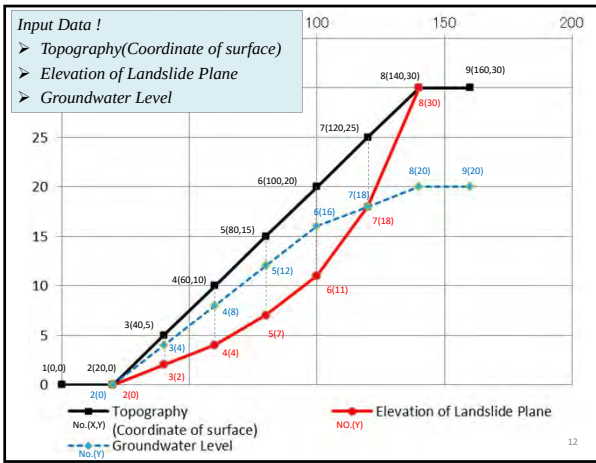
Practice (1): To make an analysis model
= Initial condition

Please open "Practice.xls "

11

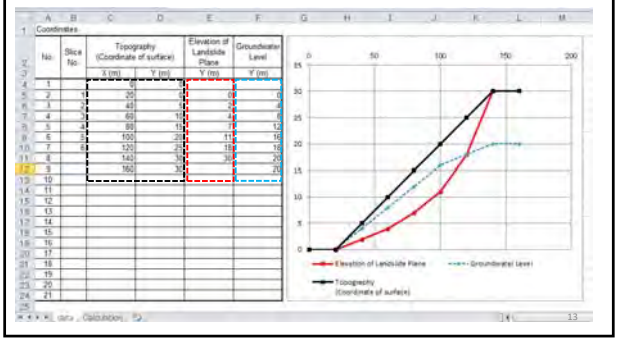
Input Data !
- *Topography(Coordinate of surface)*
- *Elevation of Landslide Plane*
- *Groundwater Level*



12

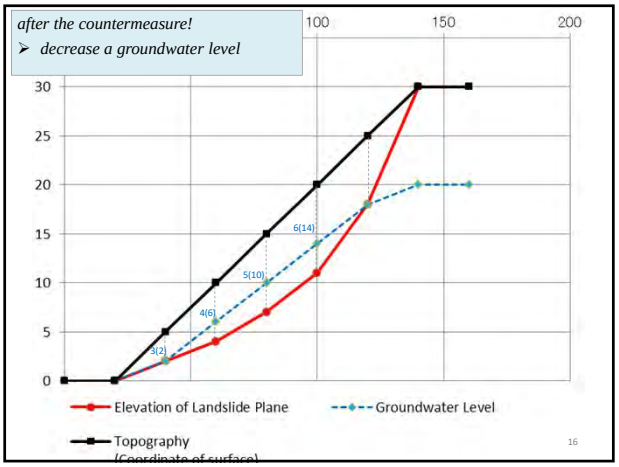
Input Data !

- *Topography(Coordinate of surface)*
- *Elevation of Landslide Plane*
- *Groundwater Level*



after the countermeasure!

- *decrease a groundwater level*



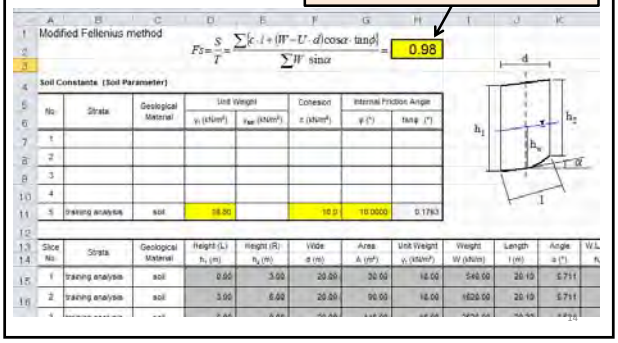
Input Soil Parameter !

- *γt : 18 [kN/m3]*
- *c : 10.0 [kN/m2]*
- *Φφ : 10.0 [deg]*

Fs=1.00 : Just balance between Sliding Force and Resistance Force

Fs<1.00 : Unstable, Slide

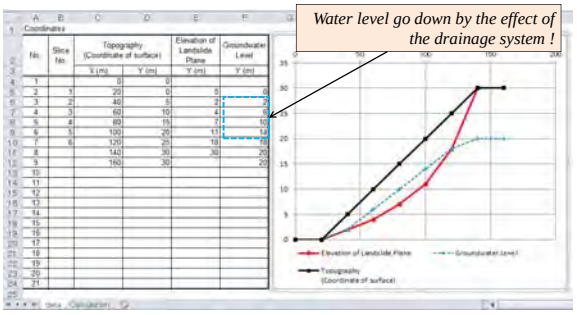
Fs>1.00 : stable



after the countermeasure!

- *decrease a groundwater level*

Water level go down by the effect of the drainage system !



Practice (2):

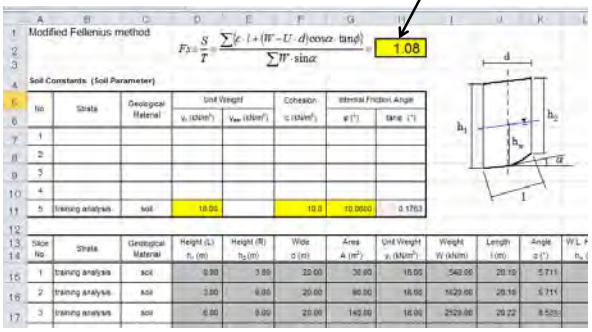
To decrease a groundwater level

= After the countermeasure, drainage system

after the countermeasure!

- *decrease a groundwater level*

By an effect of the drainage system, Fs improved 0.1 from before countermeasures



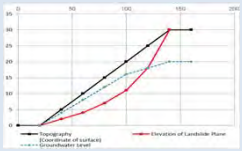
✓ ***The effects of the landslide countermeasure is evaluated by comparing Fs* before and after the installation of the countermeasure, drainage system.***

****Fs: Safety Factor, calculated by slope stability analysis***

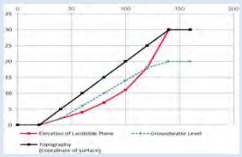
Practice (1): Fs_0 = 0.98 (before countermeasure)

Evaluation: 10% UP !

Practice (2): Fs_1 = 1.08 (after countermeasure)



✓ Groundwater is the highest level of the monitoring period before the countermeasure.



✓ The highest groundwater level decreases after the countermeasure.
✓ In this case, Fs is improved 10%.

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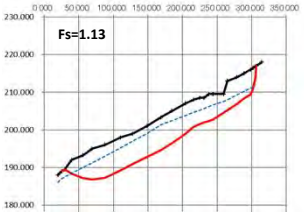
After the countermeasure : 20XX

✓ The highest water level decreases after the installation of the countermeasure.
✓ For example, in the case of groundwater level decrease 2m

➡ Fs_1 = 1.13

✓ As an evaluation result,

Fs = 1.08 ➡ 1.13
➡ Fs is improved 15%.



Refer to "Chitrakoo_A-Block_After.xls"

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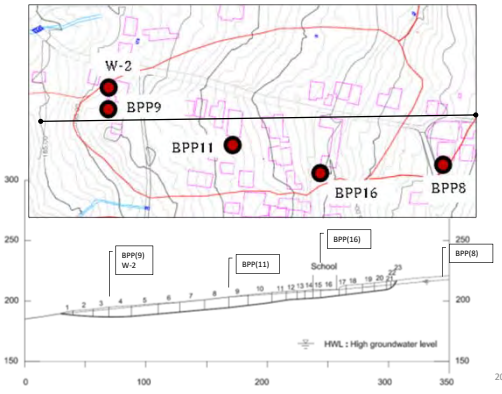
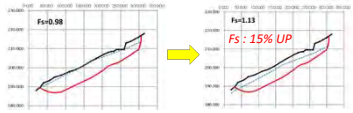
4. Countermeasure in Chitraskoot, Block-A



20

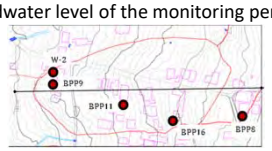
Conclusion

✓ The effects of the landslide countermeasure is evaluated by comparing Fs before and after the countermeasure



✓ MPI/LMU has to monitor groundwater level in wet season after the countermeasure completion, 2018-2019 in Chitrkoot, and get the highest groundwater level of the monitoring period.

<Monitoring point>
BPP8
BPP16
BPP11
BPP9 and W-2



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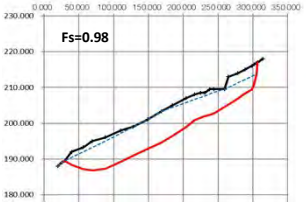
Before the countermeasure : 2014

✓ Stability analysis model was prepared based on the result of the landslide-investigation / monitoring in previous JICA project, 2014.
✓ Groundwater is the highest level of the monitoring period, in rain season in 2014.

➡ Fs_0 = 0.98



Refer to "Chitrakoo_A-Block_Before.xls"

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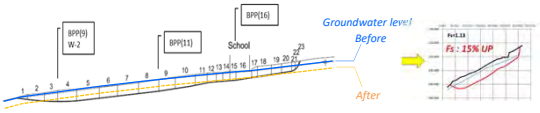
✓ The stability analysis must be carried out using the highest water level after the countermeasure, and the effect of the countermeasure is evaluated based on the result of stability analysis .



✓ Fs after the countermeasure is judged as follows,

Fs, after countermeasure	Necessary measure, additional countermeasure
Fs_1 < 1.05	The additional countermeasure should be carried out.
1.05 < Fs_1 < 1.20	The additional countermeasure should be planned. (If the landslide is active again, the additional countermeasure can be installed quickly.)
1.20 < Fs_1	The additional countermeasure is not necessary.

5. Next Technical Workshop

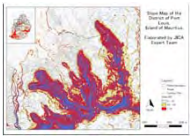
Technical Workshop for MPI / LMU

Slope Angle Map by QGIS

11th Oct, 2017 (Wed)
14:00 - 16:00

Venue: MPI, Phoenix
JICA Expert : Dr.Iwasaki,

- ✓ In this workshop, the making method of the slope angle map by the free GIS, QGIS, is explained by JICA expert team.



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Appendix 3.1.12

Evaluation method for effects of the landslide countermeasure by using Stability Analysis

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
MINISTRY OF PUBLIC INFRASTRUCTURE AND LAND TRANSPORT (MPI)

TECHNICAL COOPERATION PROJECT:LANDSLIDE ADVISER FOR MAURITIUS

Evaluation method for effects of the landslide countermeasure by using Stability Analysis

September 2017

KOKUSAI KOGYO CO., LTD.

Contents

Purpose

The landslide countermeasures are installed in Chitrakoot, Landslide Block-A.

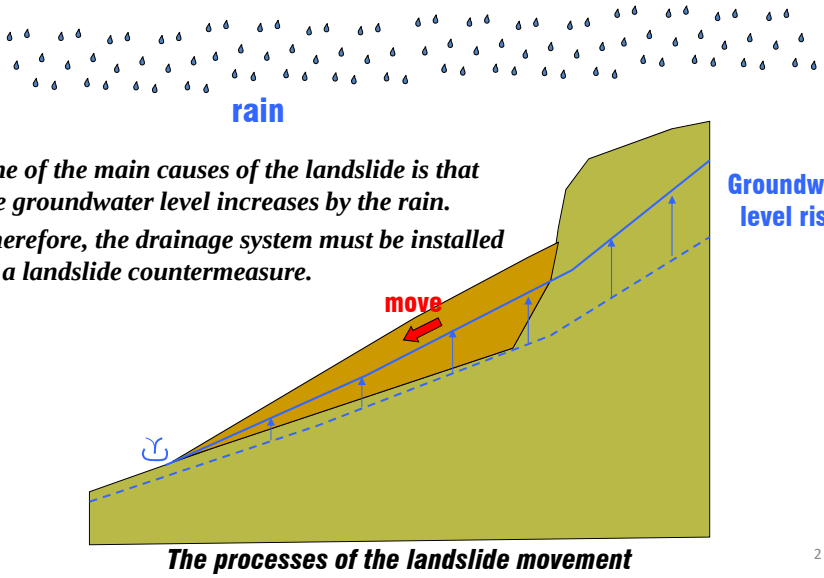
- ✓ Phase 1 had been completed in 2014.
- ✓ Phase 2 is under construction, it will be completed at the end of 2017.

After completion it, MPI/LMU has to evaluate the effect of the landslide countermeasures without an JICA Expert Team.

Therefore, the lecture about the evaluation method for the landslide countermeasure is conducted so that you can evaluate it by yourself.

1

1. How to evaluate the effect of the landslide countermeasure



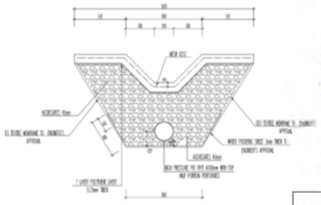
- ✓ ***One of the main causes of the landslide is that the groundwater level increases by the rain.***
- ✓ ***Therefore, the drainage system must be installed as a landslide countermeasure.***

The processes of the landslide movement

2

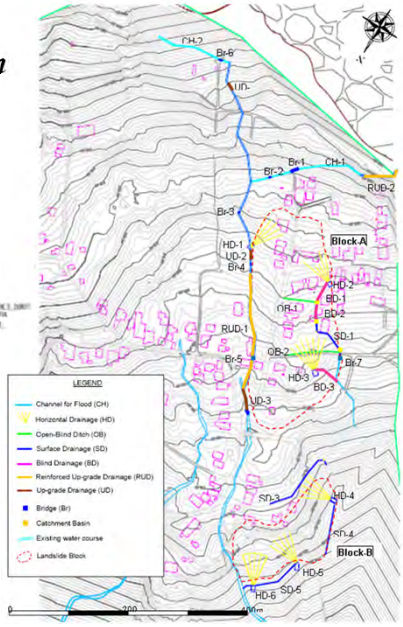
✓ ***In Chitrakoot, Many drainage system are installed as a landslide countermeasure.***

Channel CH-1



Open-Blind Ditch

Horizontal Drainage HD-1



3

✓ ***The effects of the landslide countermeasure is evaluated by comparing Fs* before and after the installation of the countermeasure, drainage system.***

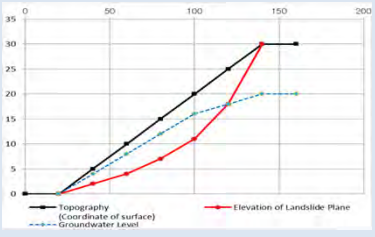
****Fs: Safety Factor, calculated by slope stability analysis***

$Fs_0 = 0.98$ (before countermeasure)

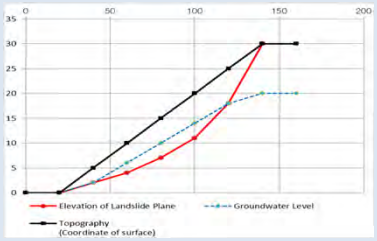
Evaluation

10% UP !

$Fs_1 = 1.08$ (after countermeasure)



✓ Groundwater is the highest level of the monitoring period before the countermeasure.



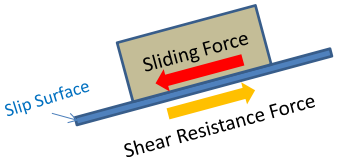
✓ The highest groundwater level decreases after the countermeasure.

✓ In this case, Fs is improved 10%.

4

2. Slope Stability Analysis (Modified Fellenius Method)

- The Modified Fellenius Method is an ordinary method, also called a “Simple Method”, usually used for landslide analysis.
  (If you begin to study about a stability analysis, this method is a best for you.)
- It is based on the balance between "Sliding Force" and "Shear Resistance Force" along the slip surface.



$$Fs=\frac{\text{Shear Resistance Force}}{\text{Sliding Force}}$$

- The safety factor (Fs) is the ratio of these force.

Fs = 1.00 : Just balance between Sliding Force and Resistance Force
Fs < 1.00 : Unstable, Slide
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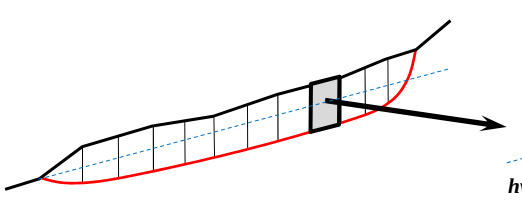
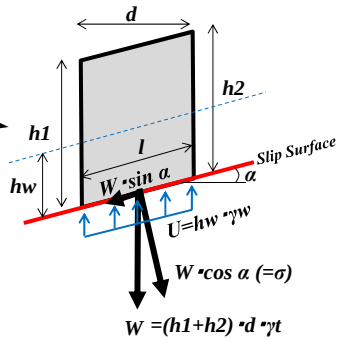
5

- In this method, landslide mass is divided into some slice.
- The balance between the sliding force and the shear resistance force is calculated for each slice.
- Finally, the calculation result of each slice is summed up.





$c+\sigma \cdot \tan\varphi$ *(Coulomb Formula)*

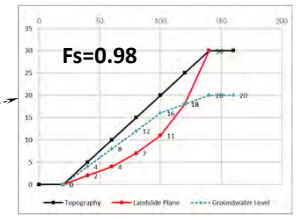
$$Fs=\frac{\text{Shear Resistance Force}}{\text{Sliding Force}}=\frac{\sum cl+(W-Ud)\cdot\cos\alpha\cdot\tan\varphi}{\sum W\cdot\sin\alpha}$$

c : Cohesion *W : Weight of Slice*
φ : Friction angle *γt : Unit weight of soil*
u : Water Pressure(buoyancy) *γw : Unit weight of water*

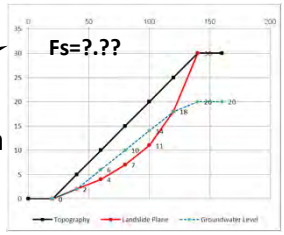
6

3. Practice of the stability analysis

・Practice (1):
To make an analysis model
= Initial condition



・Practice (2):
To decrease a groundwater level
= After the countermeasure, drainage system



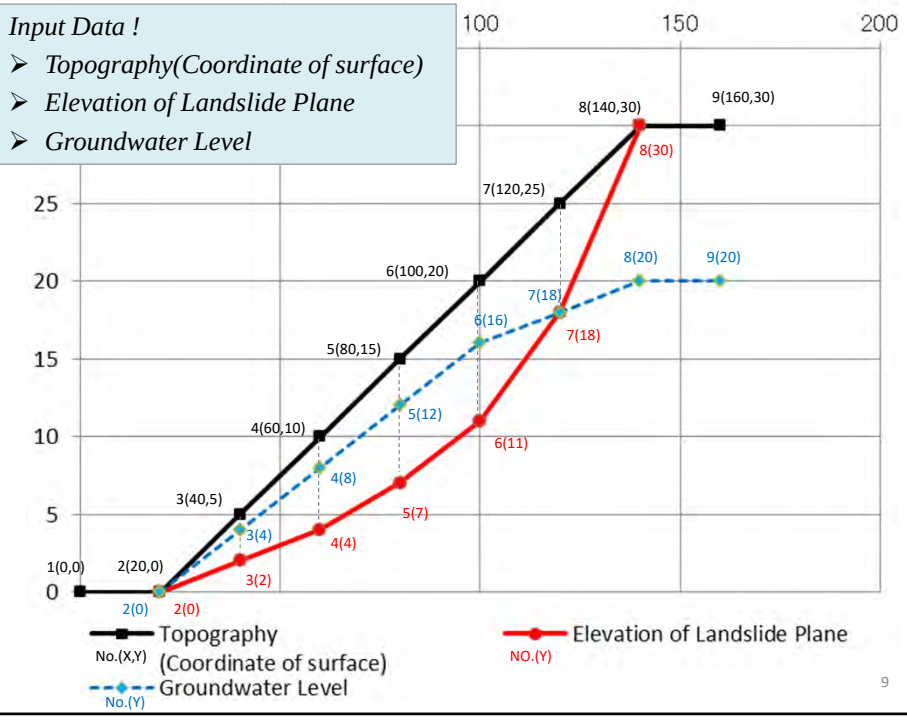
7

Practice (1): To make an analysis model
= Initial condition

8

Input Data !

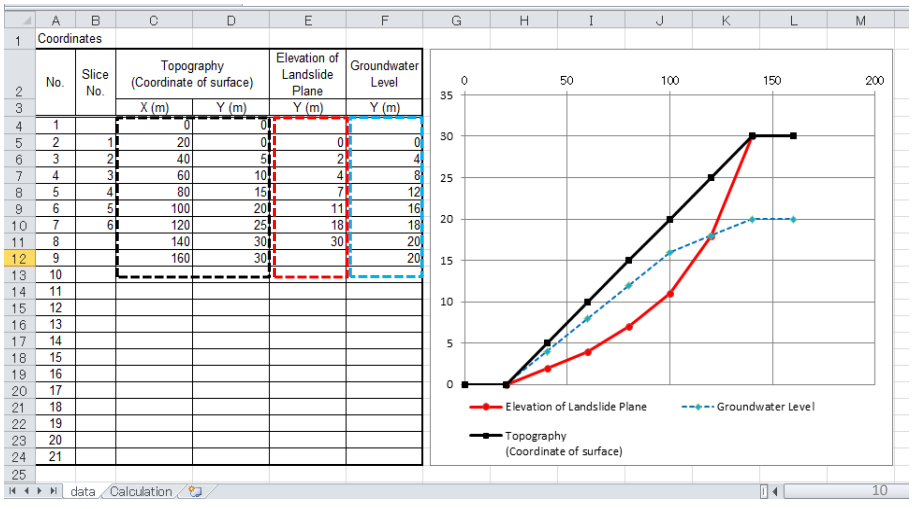
- *Topography(Coordinate of surface)*
- *Elevation of Landslide Plane*
- *Groundwater Level*



9

Input Data !

- *Topography(Coordinate of surface)*
- *Elevation of Landslide Plane*
- *Groundwater Level*



	A	B	C	D	E	F
1	Coordinates					
2	No.	Slice No.	Topography (Coordinate of surface)		Elevation of Landslide Plane	Groundwater Level
3			X (m)	Y (m)	Y (m)	Y (m)
4	1		0	0		
5	2	1	20	0	0	0
6	3	2	40	5	2	4
7	4	3	60	10	4	8
8	5	4	80	15	7	12
9	6	5	100	20	11	16
10	7	6	120	25	18	18
11	8		140	30	30	20
12	9		160	30		20
13	10					
14	11					
15	12					
16	13					
17	14					
18	15					
19	16					
20	17					
21	18					
22	19					
23	20					
24	21					
25						

10

Input Soil Parameter !

- *γt : 18 [kN/m3]*
- *c : 10.0 [kN/m2]*
- *Φφ : 10.0 [deg]*

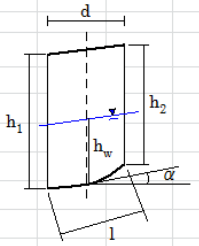
Fs=1.00 : Just balance between
Sliding Force and Resistance Force

Fs<1.00 : Unstable, Slide

Fs>1.00 : stable

Modified Fellenius method

$$Fs = \frac{S}{T} = \frac{\sum\{c \cdot l + (W - U \cdot d)\cos\alpha \cdot \tan\phi\}}{\sum W \cdot \sin\alpha} = 0.98$$



Soil Constants (Soil Parameter)

No.	Strata	Geological Material	Unit Weight γ_t (kN/m³)	Unit Weight γ_{sat} (kN/m³)	Cohesion c (kN/m²)	Internal Friction Angle φ (°)	Internal Friction Angle tanφ (°)
1							
2							
3							
4							
5	training analysis	soil	18.00		10.0	10.0000	0.1763

Slice No.	Strata	Geological Material	Height (L) h_1 (m)	Height (R) h_2 (m)	Wide d (m)	Area A (m²)	Unit Weight γ_t (kN/m³)	Weight W (kN/m)	Length l (m)	Angle α (°)	W.L h_w
1	training analysis	soil	0.00	3.00	20.00	30.00	18.00	540.00	20.10	5.711	
2	training analysis	soil	3.00	6.00	20.00	90.00	18.00	1620.00	20.10	5.711	

11

Practice (2):

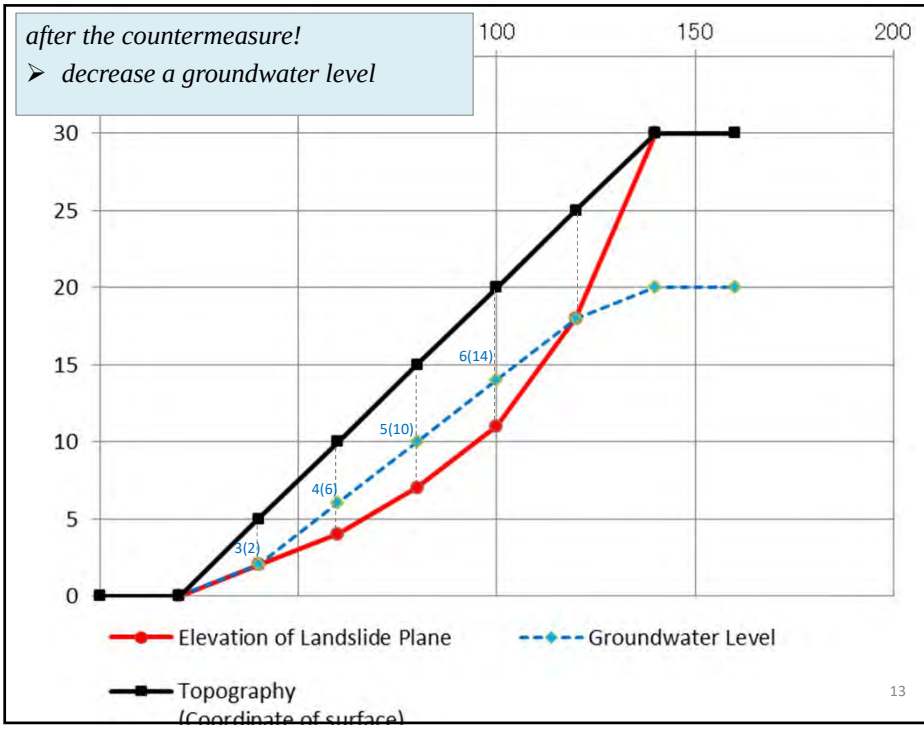
To decrease a groundwater level

= After the countermeasure, drainage system

12

after the countermeasure!

- *decrease a groundwater level*



13

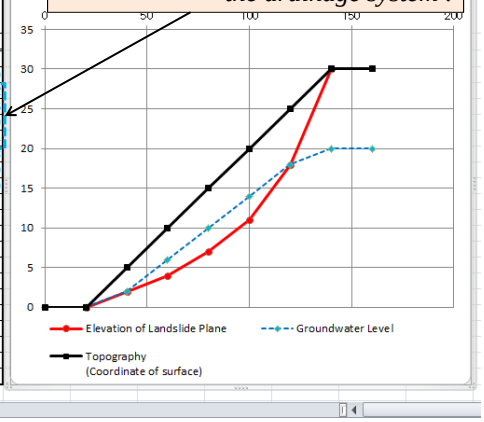
after the countermeasure!

- *decrease a groundwater level*

	A	B	C	D	E	F
1	Coordinates					
2	No.	Slice No.	Topography (Coordinate of surface)		Elevation of Landslide Plane	Groundwater Level
3			X (m)	Y (m)	Y (m)	Y (m)
4	1		0	0		
5	2	1	20	0	0	0
6	3	2	40	5	2	2
7	4	3	60	10	4	6
8	5	4	80	15	7	10
9	6	5	100	20	11	14
10	7	6	120	25	18	18
11	8		140	30	30	20
12	9		160	30		20
13	10					
14	11					
15	12					
16	13					
17	14					
18	15					
19	16					
20	17					
21	18					
22	19					
23	20					
24	21					
25						

data / Calculation

Water level go down by the effect of the drainage system !



14

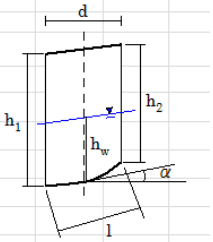
after the countermeasure!

- *decrease a groundwater level*

By an effect of the drainage system,
Fs improved 0.1 from before countermeasures

Modified Fellenius method

$$Fs = \frac{S}{T} = \frac{\sum\{c \cdot l + (W - U \cdot d)\cos\alpha \cdot \tan\phi\}}{\sum W \cdot \sin\alpha} = 1.08$$



Soil Constants (Soil Parameter)

No.	Strata	Geological Material	Unit Weight γ_t (kN/m³)	Unit Weight γ_{sat} (kN/m³)	Cohesion c (kN/m²)	Internal Friction Angle φ (°)	Internal Friction Angle tanφ (°)
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2							
3							
4							
5	training analysis	soil	18.00		10.0	10.0000	0.1763

Slice No.	Strata	Geological Material	Height (L) h_1 (m)	Height (R) h_2 (m)	Wide d (m)	Area A (m²)	Unit Weight γ_t (kN/m³)	Weight W (kN/m)	Length l (m)	Angle α (°)	W.L. H h_w (
1	training analysis	soil	0.00	3.00	20.00	30.00	18.00	540.00	20.10	5.711	
2	training analysis	soil	3.00	6.00	20.00	90.00	18.00	1620.00	20.10	5.711	
3	training analysis	soil	6.00	8.00	20.00	140.00	18.00	2520.00	20.22	8.531	

- ***The effects of the landslide countermeasure is evaluated by comparing Fs* before and after the installation of the countermeasure, drainage system.***

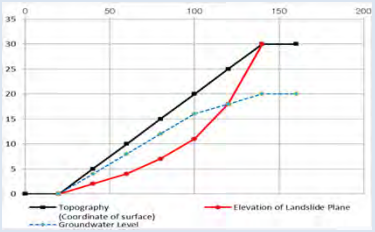
Fs: Safety Factor, calculated by slope stability analysis

Practice (1): Fs_0 = 0.98 (before countermeasure)

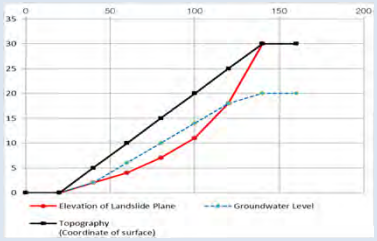
Evaluation

10% UP !

Practice (2): Fs_1 = 1.08 (after countermeasure)



- ✓ Groundwater is the highest level of the monitoring period before the countermeasure.



- ✓ The highest groundwater level decreases after the countermeasure.
- ✓ In this case, Fs is improved 10%.

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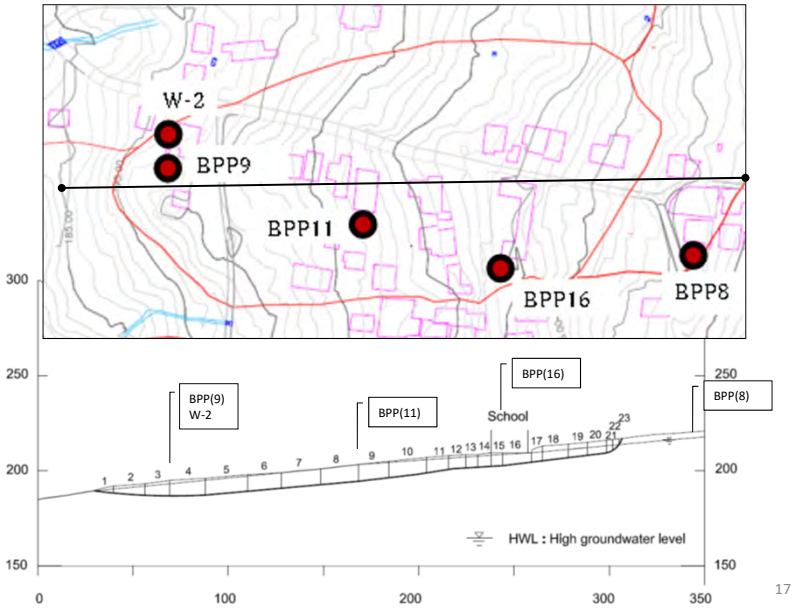
4. Countermeasure in Chitraskoot, Block-A

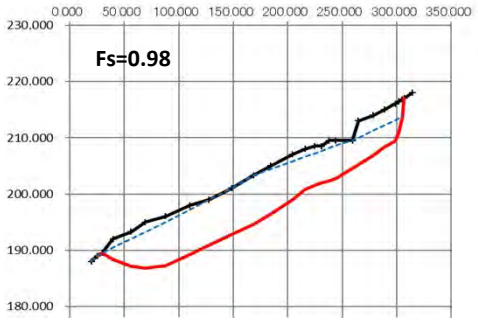


17

Before the countermeasure : 2014

- ✓ Stability analysis model was prepared based on the result of the landslide-investigation / monitoring in previous JICA project, 2014.
- ✓ Groundwater is the highest level of the monitoring period, in rain season in 2014.

➡ Fs_0 = 0.98



Refer to "Chitrakoo_A-Block_Before.xls"

18

After the countermeasure : 20XX

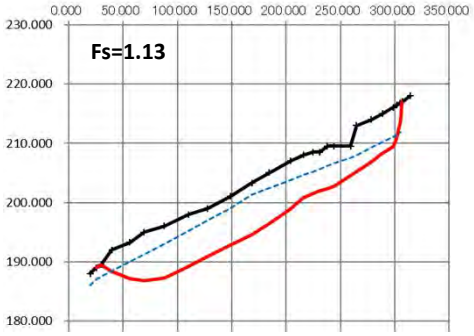
- ✓ The highest water level decreases after the installation of the countermeasure.
- ✓ For example, in the case of groundwater level decrease 2m

➡ Fs_1 = 1.13

- ✓ As an evaluation result,

Fs = 1.08 ➡ 1.13

➡ Fs is improved 15%.



19

Refer to "Chitrakoo_A-Block_After.xls"

Conclusion

- ✓ The effects of the landslide countermeasure is evaluated by comparing Fs before and after the countermeasure

- ✓ MPI/LMU has to monitor groundwater level in wet season after the countermeasure completion, 2018-2019 in Chitrkoot, and get the highest groundwater level of the monitoring period.

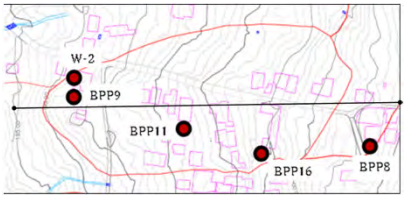
<Monitoring point>

BPP8

BPP16

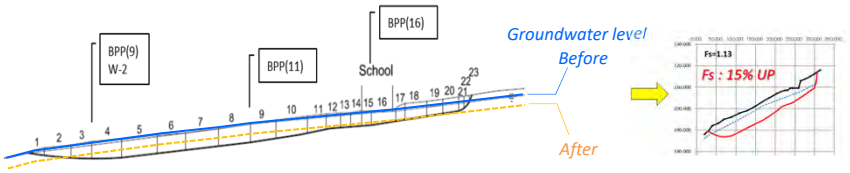
BPP11

BPP9 and W-2



20

✓ The stability analysis must be carried out using the highest water level after the countermeasure, and the effect of the countermeasure is evaluated based on the result of stability analysis .



✓ Fs after the countermeasure is judged as follows,

Fs, after countermeasure	Necessary measure, additional countermeasure
$Fs_1 < 1.05$	The additional countermeasure should be carried out.
$1.05 < Fs_1 < 1.20$	The additional countermeasure should be planned. (If the landslide is active again, the additional countermeasure can be installed quickly.)
$1.20 < Fs_1$	The additional countermeasure is not necessary.