Kingdom of Bhutan

Department of Surface Transport

Project for Capacity Development on Countermeasures of Slope Disaster on Roads in Bhutan

Project Completion Report

July 2024

Japan International Cooperating Agency

Kokusai Kogyo Co., Ltd.

Earth System Science Co., Ltd.

OYO Corporation

IM
JR
24-095

Exchange rate (at the time of commencement of project: December 2018) BTN 1.00 = JPY 1.626

Source: JICA, https://www.jica.go.jp/Resource/announce/manual/form/consul_g/ku57pq00000kzv7m-att/rate_2018.pdf

Photos


1st JCC (Jan 31, 2019)


3rd JCC (Feb 4, 2020)


5th JCC (May 16, 2022)


6th JCC (Oct 31, 2022)


7th JCC (Apr 21, 2023)


8th JCC (Nov 28, 2023)


9th JCC (May 29, 2024)


1st Open Seminar (Feb 5, 2020)

Photos


2nd Open Seminar (Apr 21, 2023)

3nd Open Seminar (May 28, 2023)


First training in Japan: visit to the Road Control Center (Sep 24, 2019)

First training in Japan: Action plan presentation (Sep 27, 2019)


2nd training in Japan: Infrastructure Museum (Oct 30,2023)

2nd Training in Japan: Action plan presentation (Nov 2, 2023)


Group Photo of 3nd Open Seminar (May 28, 2023)

Hand over of Guidelines and Handbook (May 29, 2024)

Photos


Output 1: Rain gauge and local communication base station (Apr 26, 2019)


Output 1: Technical transfer seminar on installation of inclinometer (Apr 26, 2019)


Output 1: Exercise of ex-ante traffic control (Jun 6, 2023)


Output 1: Exercise of ex-ante traffic control (Jun 7, 2023)


Output 1: 2nd Technical transfer seminar (May 22, 2023)


Output 1: Maintenance of slope observation equipment (Apr 15,2024)


Output 1: Indoor exercise for rainfall advance traffic control (Apr 30, 2024)


Output 1: Exercise of rainfall advance traffic control (Apr 30, 2024)

Photos

Output 2: Vegetative engineering germination test (Jun 8, 2019)

Result 2: Completion of the first test construction of vegetation works (Oct 31, 2020)

Result 2: Start of the second test construction (Jan 25, 2023)

Result 2: Construction status of drainage works (Mar 25, 2023)

Output 2: Completion of the second test construction (May 3, 2023)

Output 2: Installation of site description signage (Sep 7 2023)

Result 2: Status of the third test construction (Apr 1, 2024)

Output 2: Completion of the third test construction (Apr 13, 2024)

Photos

Output 3: Training on handling geological survey tools (Nov 4,2019)

Output 3: Seismic survey measurement (Jun 3, 2022)

Output 3: Technical training on SRT (Feb 14,2023)

Output 3: Technical training for installation of hinges (Feb 16, 2023)

Output 3: 5th Technical Seminar (Sep 27, 2023)

Output 3: JICA headquarters construction site visit (Mar 6, 2023)

Output 3: Completion of cut-and-fill construction site (Apr 27, 2023)

Output 3: Installation of site description signage (Aug 30, 2023)

Photos

Result 4: Rock slope survey (Jun 25, 2019)

Result 4: Construction of rockfall prevention work (May 7, 2020)

Output 4: Completion of rockfall prevention work (May 8, 2020)

Output 4: Confirmation of bedrock properties (May 4 2020)

Output 4: Inspection by Prof. Yashima of Gifu University (Jun 14, 2023)

Output 4: Panoramic view of Tekizampa site (Dec 13, 2023)

Output 4: Guidance for construction of spraying works (Mar 27, 2024)

Output 4: Completion of spraying work (Apr 28, 2024)

Photos

Output 5: Debris flow Stream Survey (Apr 15, 2019)

Result 5: Construction for countermeasures against debris flows (Aug 5, 2020)

Output 5: Completion of culvert construction (May 8, 2020)

Output 5: Investigation of unstable sediment volume in the stream (May 9, 2022)

Result 5: Construction of left and right bank abutments (Feb 23, 2023)

Output 5: Completion of culvert construction (May 5, 2023)

Output 5: Study meeting on countermeasures against debris flow (Feb 2, 2023)

Output 5: Study Session on Debris flow Control Works (Apr 25, 2023)

Photos

Output 6: Road Information Acquisition Using Drive Recorders (Dec 2, 2019)

Output 6: Technical Transfer Seminar, Data Collection for GIS Database (Dec 2, 2019)

Output 6: Handover ceremony for drone equipment (Oct 31, 2022)

Output 6: Automatic Drone Navigation Training, Trongsa (Nov 14, 2022)

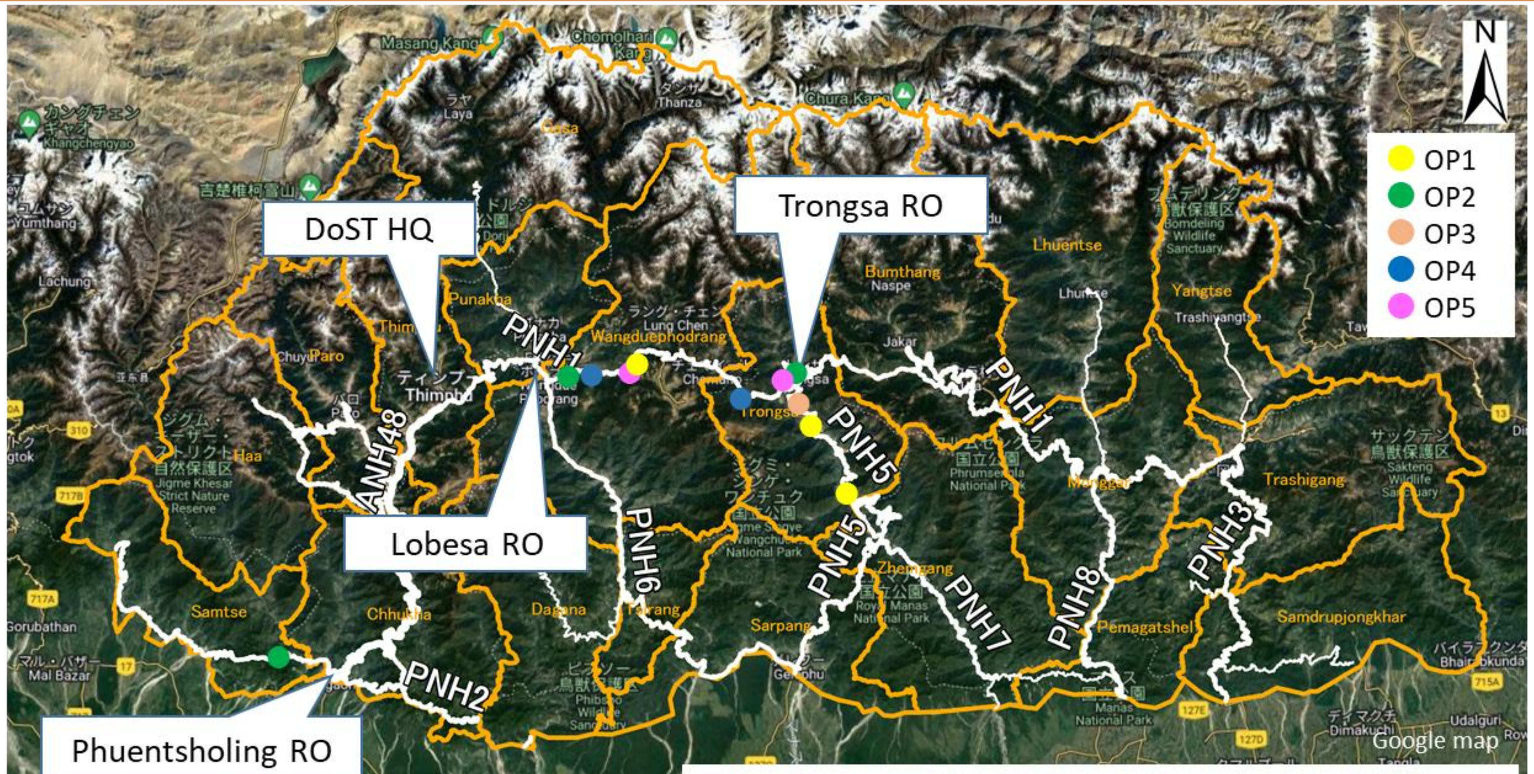
Output 6: Horizontal development of drone utilization (Mar 16, 2023)

Output 6: BRS system development consultation (Jul 17, 2023)

Output 6: 3D model of Samtse based on drone measurements

Output 6: Operation seminar for BRS App in HQ (May 7, 2024)

Capacity Development on Countermeasures of Slope Disaster on Roads in Bhutan, Summary of Project Completion Report



Location map of Pilot Site, DoST Headquarter (HQ) and Regional Offices (RO)

OP2 : Bio-Engineering

- Bio-Engineering works were piloted at the following three sites.
- In 2020, Ghangtangkha, Lobesa RO, PNH1.
- In 2023, Yangkhil, Trongsa RO, PNH1.
- In 2024, Gopini, Phunentsholing RO, PNH2.

OP3 : Cutting Slope

- Geological surveys were conducted in 2020 to establish standard cut slope angles.
- Cutting slope works were piloted at Teleganchu, PNH5, Trongsa RO in 2023.
- Seminars and practical guidance were held in each RO using the developed guidelines.

OP1 : Ex-ante Traffic Control

- Installed the observation systems, and collected the information on the amount of rainfall and the occurrence of collapses.
- Based on these information, set a rainfall threshold for ex-ante traffic control.
- A system was established to issue warnings when the rainfall exceeded the threshold amount based on rainfall observation information.
- Conducted mock drills for ex- ante traffic control.

OP4 : Rock Slope Failure (Rockfall)

- Pilot construction of rockfall protection works at Chendebji, PNH1, Trongsa RO in 2020.
- Detailed design was carried out at Tekizampa, Lobesa RO, PNH1 in 2022-23.
- Pilot construction of rock slope failure countermeasures at Tekizampa during two dry seasons from 2023 to 2025.

OP6 : Road Information System

- Improved Bhutan Road Safety system.
- GIS data related to road management was created and centralized as Road GIS data.
- Drone operation training sessions were held in various ROs.
- 3D topographic model of slopes were created using drones, and used to survey, design some countermeasures for target slopes.

OP5 : Debris Flow

- In 2020, a pilot project of Debris Flow countermeasures was carried out at Bjee, Trongsa RO, PNH1.
- In 2023, a pilot construction of Debris Flow countermeasures was carried out at Khelekha, Lobesa RO, PNH1.
- Seminars were held in all ROs using the developed guidelines.
- DoST has started horizontal deployment with its own budget.

QR code/URL for PDF data of Guidelines/Handbook created by C-Slope Project

https://www.moit.gov.bt/en/publications/acts/

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Abbreviations

abbreviation	English text
ADB	Asian Deveopment Bank
BBS	Bhutan Broadcasting Service
BCAA	Bhutan Civil Aviation Authority
BL	Base Line
BRS	Bhutan Road Safety
BTTV	BTTV
C/P	Counter Part
COVID-19	Coronavirus Disease 2019
CREST	Construction Resources for Environmentally Sustainable Technologies
CST	College of Science and Technology
DCC	Director Coordination Committee
DEM	Digital Elevation Model
DF	Debrtis Flow
DGM	Department of Geology and Mines
DoFPS	Department of Forest and Park Services
DoL	Department of Livestock
DoST	Department of Surface Transport
DoST-RO	Department of Surface Transport-Regional office
EC	Electric Conductivity
G2C	Government to Citizen
GIS	Geographic information system
GISDB	Geographic Information System Data Base
GMT	Greenwich Mean Time
GPS	Global Positioning System
ICL	International Consortium on Landslides
ICT	Information and Communication Technology
IR	Inception Report
JCC	Joint Coordinating Committee
JNEC	Jigme Namgyel Engineering College
JET	JICA Expert Team
JICA	Japan International Cooperating Agency
JV	Joint Venture
KY	Activities to prevent accidents (“Kiken Yochi” in Japanese)
KUENSEL.	KUENSEL.
LS	Land Slaide
MoAF	Ministry of Agriculture and Forests
MoIT	Ministry of Infrastracture and Transport
MS	Monitoring Sheet
NEXCO	Nippon Expressway Company Limited
NGO	Non-governmental organizations
Nu	Ngultrum
ODA	Official Development Assistance
OJT	On the Job Training
PC	Personal Computer
PDM	Project Design Matrix
PNH	Primary National Highway
PO	Plan of Operation
PPT	Power Point
PR	Progress Report
R/D	Record of Discussion
RAMS	Road Asset Management System
RF	Rock Fall
RSTA	Road Safety and Transport Authority
RTK	Real Time Kinematic
SDGs	Sustainable Development Goals
SDMD	Slope Disaster Management System
SF	Debris Slope Failure
SMS	Short Message Service
UAV	Unmanned aerial vehicle

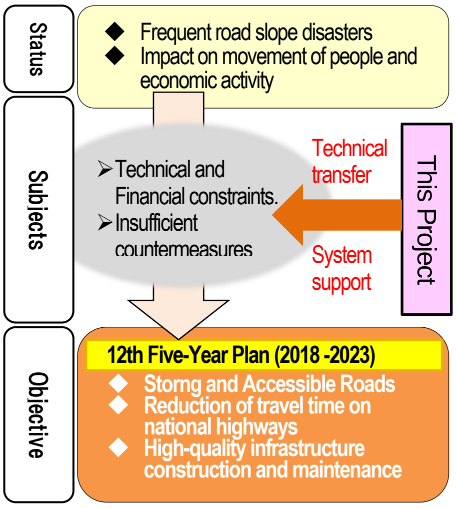
UNDP	United Nations Development Programme
WB	World Bank
WP	Work Plan
WG	Working Group
WLF	World Landslide Forum

Chapter 1. Project background and objectives

1.1 Project background

Bhutan's roads are scattered with many slope disaster risk areas due to topographical and geological conditions, and slope disasters such as slope failures and debris flows occur frequently, especially during the rainy season. These disasters frequently occur along the Primary National Highway (hereinafter referred to as PNH), including National Highway No. 1, which runs east-west across the country, and National Highways No. 2 to No. 5, which run south to the Indian border, and have been hampering the movement of people and economic activities. In response, the Japan International Cooperation Agency (hereinafter referred to as JICA) implemented the "Master Plan Study on Road Slope Management (July 2014 - March 2017)" (hereinafter referred to as the "Master Plan Study"), a development study-type technical cooperation project, to transfer technology related to road slope management.

Subsequently, Bhutan's 12th Five Year Plan (2018 - 2023) identified "strong and accessible roads regardless of weather conditions," "reduction of travel time on national highways," and "quality infrastructure construction and maintenance" as development indicators, and the Department of Surface Transport (hereinafter referred to as "DoST") of the Ministry of Infrastructure and Transport (hereinafter referred to as "MoIT") has implemented road slope measures that combine bio-engineering and countermeasures, but have not been sufficient due to technical and financial constraints. Against this background, JICA decided to implement a technical cooperation project (hereinafter referred to as "the Project") to support DoST as a counterpart (hereinafter referred to as "C/P") to transfer technology related to slope monitoring and construction of simple and inexpensive countermeasures for road slope control, and to prepare design and construction management guidelines.



(Source: JET)

Figure. 1.1-1 Role of this work in Bhutan road development

1.2 Outline of the Project

(1) Project Name

Project for Capacity Development on Countermeasures of Slope Disaster on Roads in Bhutan

Target country: Bhutan

Project period: from December 28, 2018 to July 31, 2024 (approximately 67 months)

(2) Overall Goal

Slopes on roads in Bhutan are properly developed and managed by using countermeasures improve in the Project.

(3) Project Purpose

Capacity of DoST for countermeasures of slope disaster on roads is improved.

(4) Expected Outputs

Output 1: Conditions of ex-ante traffic control are clarified.

Output 2: Suitable bio-engineering works are selected against "debris slope failure."

Output 3: Standards for cut slope angles for "debris slope failure" and "rock slope failure" are revised.

Output 4: Suitable countermeasure works are implemented for "rock slope failure (rock fall)."

Output 5: Suitable drainage works and facilities are installed for "debris flow."

Output 6: Information system on slope disasters and traffic controls on roads is improved.

(5) Summary of Activities

Output 1: Conditions of ex-ante traffic control are clarified.

1.1 Select target sections and slopes based on the results of slope disaster inspection

1.2 Plan monitoring of displacement and rainfall

1.3 Acquire basic data by the monitoring of displacement and rainfall

1.4 Analyze and evaluate the acquired basic data to establish sections and threshold rainfall for the ex-ante traffic control

1.5 Establish proper operation system (headquarters and regional offices) for the ex-ante traffic control by analyzing current issues on the traffic control system

1.6 Implement ex-ante traffic control drill on the selected sections

1.7 Develop a manual on the monitoring of displacement/rainfall and the ex-ante traffic control

Output 2: Suitable bio-engineering works are selected against "debris slope failure."

2.1 Select target sections and slopes based on the results of slope disaster inspection

2.2 Investigate and evaluate vegetation on current slopes, and organize issues

2.3 Examine suitable bio-engineering works against "debris slope failure" in Bhutan

2.4 Implement the suitable bio-engineering works on pilot sites as trial

2.5 Develop a design/implementation guideline and a standard unit price table on the bio-engineering works

Output 3: Standards for cut slope angles for "debris slope failure" and "rock slope failure" are revised.

3.1 Select target sections and slopes based on the results of slope disaster inspection

3.2 Evaluate geology and slope stability by reconnaissance etc.

3.3 Develop a manual on classification of rocks and geology

3.4 Examine standards for cut slope angles on each geological type

3.5 Develop a design/implementation guideline and a standard unit price table on the standards for cut slope angles in Bhutan

3.6 Supervise based on developed desing/implementation guideline

Output 4: Suitable countermeasure works are implemented for "rock slope failure (rock fall)."

4.1 Select target sections and slopes based on the results of slope disaster inspection

4.2 Investigate, analyze and evaluate on topography and geology for selection of countermeasure works

4.3 Select suitable countermeasure works for the target sections and slopes

4.4 Plan and design the selected countermeasure works

4.5 Implement the selected countermeasure works

4.6 Implement safety management activities on the construction for the selected countermeasure works

4.7 Develop a design/implementation guideline and a standard unit price table on the selected countermeasure works

4.8 Develop a countermeasure handbook for slope failures

Output 5: Suitable drainage works and facilities are installed for "debris flow."

5.1 Select target sections and slopes based on the results of slope disaster inspection

5.2 Investigate and evaluate on topography and geology for the selected debris flow streams

5.3 Collect and analyze information of drainage system on roads for the selected debris flow streams

5.4 Plan and design drainage works and facilities

5.5 Implement the drainage works and facilities

5.6 Implement safety management activities on the construction for the drainage works and facilities

5.7 Develop a design/implementation guideline and a standard unit price table on the drainage works and facilities

Output 6: Information system on slope disasters and traffic controls on roads is improved.

6.1 Conduct training on basics of GIS

6.2 Improve the existing DoR GIS database and information sharing mechanism between DoR headquarters and regional offices after clarifying the current situation and issues.

6.3 Improve data acquiring system of the road information at the DoR reginal offices

6.4 Improve data input/management system of the road information into the GIS database at DoR headquarters

6.5 Improve sharing system of the road information utilizing the GIS database

6.6 Develop a manual on the road information system utilizing the GIS database

1.3 Scope of Project

(1) Target Area

All over Bhutan / National Highways in Lobesa and Trongsa ROs (total length: approx. 600 km)*

*Model project (pilot survey and pilot construction) sites are selected, and the Lobesa and Trongsa regional offices serve as model ROs.

(2) Related government agencies and institutions

The core C/Ps for the Project is DoST Maintenance, Design, Construction, and Bridge Divisions, as well as the regional office engineers in all nine locations. Two of the regional offices, Lobesa and Trongsa, are model regional offices.

Direct beneficiaries: DoST

Indirect beneficiaries: Bhutanese nationals

(3) Outputs

The following reports and technical cooperation documents are prepared

Table 1.3-1 Reports to be prepared

deliverables	Time of Submission	Number of copies submitted	Descriptions and Remarks
Work Plan (Jp)	After the conclusion of the contract within 10 days	Japanese 2 copies	· Outline of Operations · Project Implementation Policy · Contractor's Work Implementation Structure
Work Plan (En)	Jan, 2019	English 3 copies	· Introduction (history and results of previous projects, background and history of the implementation, purpose, and scope of this project) · Implementation Policy/ Implementation Plan/ Implementation Method/ Implementation Structure/ Staffing Plan · Others (equipment and materials required for field survey, items to be borne by C/P)
Monitoring Sheet Ver. 1 - 9 (MS)	Feb and Aug, 2019 Feb and Sep, 2020 Apr and Oct, 2022 Apr and Oct, 2023 May, 2024	English 3 copies	· Activity reports - Status of Outputs · Implementation issues/concerns to be resolved · External factors that positively or negatively affect project progress and Outputs
Project Progress Report	Dec, 2020 Dec, 2022 Dec, 2023	Japanese 2 copies	· Progress report
Project Completion Report	Jul, 2024	English 17 copies Japanese Sum 7 copies EnglishCD-R 5 JapaneseCD-R 5	· Project Summary ･Project Results · Review of results ･Achievement of Impacts · Other pending matters
Project Implementation Report	Jul, 2024	Japanese 3 copies	· Summary of project completion report · Activity (survey) · Activities (Technology Transfer) ･Important issues in project implementation and operation · Devices/Lessons Learned · Project Implementation Schedule · Proposal to materialize the proposed work implementation plan

(Source: JET)

Table 1.3-2 Materials prepared for technical cooperation (manuals, handbooks, etc.)

Technical Cooperation Materials	activity	Activity End Date	Time of Submission	Submission Method
Manual for surface displacement and rainfall monitoring and ex-ante traffic control	1-7	December 2023	June 2024	Attached to the project completion report
Design and construction management guidelines and standard unit price list for bio-engineering	2-5	June 2024	June 2024	Attached to the project completion report
Rock Quality and Geology Classification Manual	3-3	June 2023	October 2023	Attached to MS
Design and construction management guidelines and standard unit price list for standard cut slope	3-5	December 2023	June 2024	Attached to MS
Design and construction management guidelines and standard unit price list for slope countermeasure works	4-7	June 2024	June 2024	Attached to the project completion report
Slope Failure Prevention Handbook	4-8	June 2024	June 2024	Attached to the project completion report
Design and construction management guidelines and standard unit price list for drainage works and drainage facilities	5-7	December 2023	June 2024	Attached to the project completion report
Manual for GISDB-based road information system	6-6	June 2024	June 2024	Attached to MS

(Source: JET)

Chapter 2. Project Achievements

The following table shows the actual personnel input from the start of the work to the completion of the work.

Table 2-1 Actual Personnel Input for Work on Site (January 11, 2019 - July 31, 2024)

JICA Expert Team (Responsibilities)	Number of trip	Travel schedule	Days	Total days (Overall plan)	Person-month (Overall plan)
Tomoharu Iwasaki (Chief adviser/Slope Monitoring 1)	6	January 11 - February 24, 2019 May 1 - May 31, 2019 August 2 - September 1, 2019 January 10 - February 7, 2020 April 24 - May 24, 2022 (Of which, April 26 - April 30 Quaritine due to COVID-19) October 7 - November 12, 2022	45 31 31 29 26 37	199 (199)	6.63 (6.63)
Tomohiro Nishimura (Chief adviser/Successor)	2	April 15 - 24, 2023 December 1 - December 19, 2023 April 9 - May 3, 2024 May 18 - June 6, 2024	10 19 25 20	74 (74)	2.47 (2.47)
Masanori Tozawa (Slope Monitoring 1/ Successor)	2	May 10 - June 16, 2023 November 16 - December 19, 2023	38 34	72 (72)	2.40 (2.40)
Takeshi Kuwano (Vice Chief adviser/ Slope monitoring)	3	January 11 - February 3, 2019 April 1 - April 21, 2019 October 10 - November 7, 2019	24 23 29	74 (74)	2.47 (2.47)
Takashi Hara (Rock Slope disaster countermeasure Measures1)	8	January 24 - February 22, 2019 September 25 - November 9, 2019 January 6 - 30, 2020 April 24 - May 17, 2022 (Of which, April 26 - April 30 Quaritine due to COVID-19) October 4 - October 25, 2022 January 9 - February 2, 2023 June 6 - June 23, 2023 December 7 - 24, 2023	30 46 25 19 22 25 18 18	203 (203)	6.77 (6.77)
Atsushi Yashima (Rock Slope disaster countermeasure Measures 2)	1	June 11 - 17, 2023	7	7 (7)	0.23 (0.23)
Shoji Muramoto (Rock Slope disaster countermeasure Measures 3)	3	April 24 - May 17, 2022 (Of which, April 26 - April 30 Quaritine due to COVID-19) January 9 - February 2, 2023 December 7 - 24, 2023	19 25 18	62 (62)	2.07 (2.07)
Kiyoharu Hirota (Bio-engineering/Landscape consideration)	9	January 29 - February 27, 2019 May 7 - June 20, 2019 September 30 - October 24, 2019 February 9 - 28, 2020 April 24 - May 24, 2022 (Of which, April 26 - April 30 Quaritine due to COVID-19) August 18 - September 17, 2022 January 14 - 30, 2023 August 29 - September 17, 2023 December 13 - 19, 2023 February 8 - 29, 2024 April 18 - April 16, 2024	30 45 25 20 26 31 17 20 38 22 30	304 (304)	10.13 (10.13)

JICA Expert Team (Responsibilities)	Number of trip	Travel schedule	Days	Total days (Overall plan)	Person-month (Overall plan)
Kengo Ohashi (Geological survey/Analysis)	8	April 14 - June 8, 2019 October 21 - December 9, 2019 February 24 - March 21, 2020 May 1 - June 28, 2022 (Of which, May 3 - May 7 Quaritine due to COVID-19) September 6 - September 26, 2022 February 6 - 25, 2023 April 1 - April 30, 2023 March 23 - April 18, 2024	56 50 27 54 21 20 30 27	285 (285)	9.50 (9.50)
Masaaki Aizawa (Rock Survey and Analysis)	5	June 14 - July 28, 2019 January 6 - February 1, 2020 October 17 - December 19, 2022 January 10 - 29, 2023 (Of which, January 21 - January 25: Quaritine due to COVID-19) April 8 - April 21, 2024	45 27 54 15 14	165 (165)	5.50 (5.50)
Sueo Hirose Debris slope failure)	10	January 23 - February 13, 2019 April 19 - May 28, 2019 January 20 - March 21, 2020 September 5 - September 30, 2022 January 10 - 31, 2023 April 5 - May 1, 2023 September 11 - October 10, 2023 December 11 - December 28, 2023 February 4 - March 9, 2024 April 10 - April 27, 2024	22 40 62 26 22 27 30 18 35 18	300 (300)	10.00 (10.00)
Yuichi Mukonakano (Monitoring system1)	3	February 16 - March 11, 2019 April 10 - May 19, 2019 November 16 - December 5, 2019	24 40 20	84 (84)	2.80 (2.80)
Tao Naoning (Monitoring system1/ Successor)	1	April 11 - April 21, 2024	11	11 (11)	0.37 (0.37)
Tomohiro Nishimura (Debris flow)	10	January 29 - February 27, 2019 March 26 - April 24, 2019 September 29 - October 28, 2019 February 9 - March 24, 2020 April 24 - May 24, 2022 August 29 - September 24, 2022 January 10 - February 11, 2023 February 22 - March 24, 2023 April 8 - May 7, 2023 November 25 - December 20, 2023	30 30 30 45 31 27 33 31 20 7	284 (284)	9.47 (9.47)
Chizuru Sugihara (Cost estimation)	9	May 1 - May 31, 2019 June 15 - July 13, 2019 September 28 - November 14, 2019 May 1 - May 24, 2022 August 29 - September 28, 2022 October 10 - 16, 2022 December 1 - January 17, 2022 April 1 - April 30, 2023 July 1 - July 25, 2023	31 29 57 24 31 7 7 30 25	235 (235)	7.83 (7.83)
Masahide Tanaka (Construction management)	3	November 16 - December 10, 2023 January 9 - February 25, 2024 March 18 - March 31, 2024	25 48 14	87 (87)	2.90 (2.90)
Yasuhisa Suganuma (Contract management/Constrcution Supervision1)	4	January 17 - March 1, 2020 January 6 - February 2, 2023 November 6 - December 20, 2023 February 25 - March 27, 2024	45 28 45 32	150 (150)	5.00 (5.00)
Tomoaki Tsugawa (Construction Supervision 2)	1	February 24 - March 24, 2020	30	30 (30)	1.00 (1.00)

JICA Expert Team (Responsibilities)	Number of trip	Travel schedule	Days	Total days (Overall plan)	Person-month (Overall plan)
Yasuyoshi Kawaguchi (Construction Supervision 2/ Successor)	2	January 23 - February 22, 2023 December 23, 2023 - February 4, 2024	59 44	103 (103)	3.43 (3.43)
Soshi Mikami (GIS database)	8	April 24 - May 23, 2019 November 18 - December 17, 2019 January 20 - February 16, 2020 July 18 - August 17, 2022 October 25-November 30, 2022 June 20, 2023 - July 30, 2023 November 15 - December 24, 2023 January 2 - February 3, 2024	45 30 28 31 37 41 40 33	270 (270)	9.00 (9.00)
Takashi Saito (Road information management)	8	January 18 - February 11, 2019 October 26 - December 4, 2019 June 10 - July 9, 2022 August 4 - August 29, 2022 October 8 - October 20, 2022 November 10 - December 3, 2022 June 14 - July 13, 2023 October 23 - December 13, 2023 April 22-June 11, 2024	25 40 30 14 13 24 30 52 49	276 (276)	9.20 (9.20)
Ryota Hasegawa (Project coordinator/Monitoring1)	5	January 11 - March 11, 2019 (January 11 - January 20, regular assignment) March 26 - April 20, 2019 August 2 - 24, 2019 (August 2 - August 11, regular assignment) November 3 - December 8, 2019 January 8 - February 21, 2020 (January 8 - January 17, regular assignment)	10 10 10	30 (30)	1.00 (1.00)
Hiroko Otake (Project coordinator/Monitoring1)	4	April 24 - May 24, 2022 (Of which, April 26 - April 30 Quaritine due to COVID-19) (Regular assignment from April 24 to April 25 and May 1 to May 8) October 18-November 19, 2022 (Regular assignment from October 18 to October 27) April 8 - May 7, 2023 (Regular assignment from April 8 to April 17) November 16 - December 3, 2023 (Regular assignment from November 16 to November 25)	10 10 10 10	40 (40)	1.33 (1.33)
Kosuke Uzawa (Project coordinator/Monitoring1/Successor)	0	No record of travel	0	0 (0)	0.00 (0.00)
Mitsuko Nakamura (Project coordinator/Monitoring 2/Successor)	1	May 18 - June 6, 2024	20	20 (20)	0.67 (0.67)
TOTAL				3365 (3365)	112.17 (112.17)

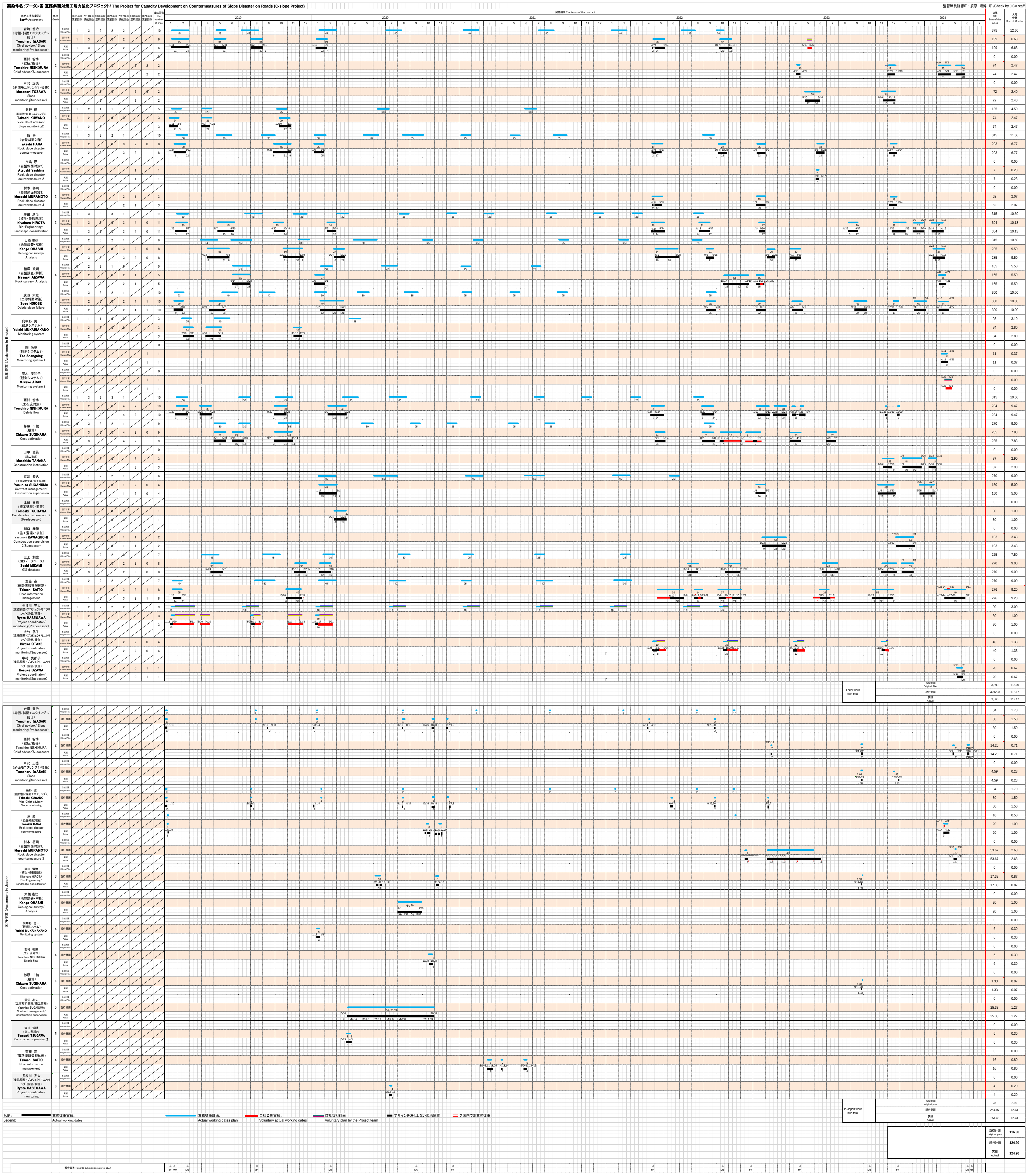
(Source: JET)

Table 2-2 Actual Personnel Input for Domestic Work (January 1, 2019 - July 30, 2024)

JICA Expert Team (Responsibilities)	Working period	Days	Total days (Overall plan)	Person-month (Overall plan)
Tomoharu Iwasaki (Chief adviser/Slope Monitoring 1)	January 1 - 10, 2019 September 10 - 11, 2019 January 3 - 4, 2020 August 10 - 13, 2020 October 26 - October 31, 2020 December 1 - December 2, 2020 April 14 - 15, 2022 September 29 - September 30, 2022	10 2 2 4 6 2 2 2	30 (30)	1.50 (1.50)
Tomohiro Nishimura (Chief adviser/Successor)	February 13 - 14, 2023 September 4, 2023, September 11, 2023 May 9 - 13, 2024 June 10 - June 21, 2024	2 2 2 8.2	14.2 (14.2)	0.71 (0.71)
Masanori Tozawa (Slope Monitoring 1/Subsequent)	September 11 - 13, 2023 December 25 - December 26, 2023	2.66 1.93	4.59 (4.59)	0.23 (0.23)
Takeshi Kuwano (Vice Chief adviser/ Slope monitoring)	January 1 - 10, 2019 August 1 - 2, 2019 January 3 - 4, 2020 August 10 - 11, 2020 October 26 - October 31, 2020 December 7 - December 8, 2020 June 6 - June 7, 2022 September 29 - September 30, 2022 February 6, 2023, February 7, 2023	10 2 2 2 6 2 2 2 2	30 (30)	1.50 (1.50)
Takashi Hara (Rock Slope disaster countermeasure Measures1)	January 5 - 9, 2019 October 8, 15, 19, 2020 November 5, 12, 19, 2020 April 17 - April 30, 2024	5 3 3 9	20 (20)	1.00 (1.00)
Shoji Muramoto (Rock Slope disaster countermeasure Measures 3)	December 13 - December 16, 2022 February 9 - June 20, 2023 May 13 - May 16, 2024	4 46 3.67	53.67 (53.67)	2.68 (2.68)
Kiyoharu Hirota (Bio-engineering/Landscape consideration)	June 8 - 12, 2020 June 15 - 19, 2020 November 5 - 10, 2020 September 19 - 20, 2023	5 5 6 1.33	17.33 (17.33)	0.87 (0.87)
Kengo Ohashi (Geological survey/Analysis)	Within August 1 - September 30, 2020	20	20 (20)	1.00 (1.00)
Yuichi Mukonakano (Monitoring system1)	January 12 - 17, 2020	6	6 (6)	0.30 (0.30)
Tomohiro Nishimura (Debris flow)	October 19 - 24, 2020	6	6 (6)	0.30 (0.30)
Chizuru Sugihara (Const Estimation)	September 19 - 20, 2023	1.33	1.33 (1.33)	0.07 (0.07)
Yasuhisa Suganuma (Contract management/Constrcution Supervision1)	March 30 - October 31, 2020	25.33	25.33 (25.33)	1.27 (1.27)
Tomoaki Tsugawa (Construction Supervision 2)	March 29-April 3, 2020	6	6 (6)	0.30 (0.30)
Takashi Saito (Road information management)	March 1 - 5, 2021, March 11, 18, 25 April 13 - April 14, 2021 June 9 - 11, 2021, June 14 - 16, 2021	8 2 6	16 (16)	0.80 (0.80)
Ryota Hasegawa (Project coordinator/Monitoring1)	July 13 - July 16, 2020	4	4 (4)	0.20 (0.20)
TOTAL			254.45 (254.45)	12.73 (12.73)

(Source: JET)

Table 2-3: Table of Actual Input of Personnel (January 2019 - July 2024)



(Source: JET)

Chapter 3. Project Activities

This work strengthens DoST's capacity for road slope control in Bhutan by clarifying conditions for ex-ante traffic control, developing capacity for countermeasures against debris and rock slope failure and debris flow, and improving information systems for road disasters and traffic control, thereby contributing to appropriate development and maintenance of road slopes. This contributes to the appropriate development and maintenance of road slopes.

3.1 Overall activities

(1) Preparation of Work Plan

As domestic work prior to visit to Bhutan, a project plan and a draft work plan (hereinafter referred to as "WP") were prepared in English. In each document, JET summarized the basic policy, activities, implementation structure, and process of this project, as well as the activity plan and methodology for the site activities. Prior to the first visit, a policy meeting was held at JICA Headquarters to explain and discuss the contents of the activities. The work plan was submitted to JICA Headquarters in January 2019.

After arriving in Bhutan, JET also paid a courtesy call to Dasho Tenzin, Director General of DoST, on January 15, 2019, and briefed him on the project outline with the WP. The WP was approved by DoST at the first JCC meeting held on January 31, 2019, and was subsequently submitted to JICA in February 2019. In addition, the business contracts for the 1st through 5th modifications were prepared and submitted to JICA in accordance with the 5 contract modifications that have been implemented. The sixth contract modification was concluded on January 26, 2024, and through discussions with the lead department, it was confirmed that the submission of the work plan for the sixth modification was not required.

Table 3.1-1 Reporting documents prepared and submitted

deliverables	Time of Submission	Number of copies submitted
Work plan Work plan (1st revise) Work Plan (2nd revise) Work Plan (3rd revise) Work Plan (4th revise) Work Plan (5th revise)	January 2019 February 2019 March 2019 December 2019 April 2021 January 2023	2 copies in Japanese
WP	January 2019	3 copies in English

(Source: JET)

(2) Preparation of the Monitoring Sheets

The monitoring sheet (hereinafter referred as “MS”) is prepared in collaboration with the C/Ps and experts, and is reviewed and approved by the JCC, including the status of data collection on indicators, progress of activities, results achieved, issues and concerns, and external factors affecting the activities.

The first edition of MS I & II, 'ver. 1', was prepared in January 2019 and has since been prepared approximately every 6 months in conjunction with the JCC meetings with the proactive involvement of the C/P. In conjunction with the 2nd JCC meeting in August 2019, MS ver. The MS ver. 2 was prepared in time for the 2nd JCC meeting in August 2019, explained to and discussed with the C/P side, and approved. MS ver. 3 was prepared in February 2020, and the WG confirmed and approved the progress of the work and the future direction of the project. The fourth JCC was postponed to December 2020 due to the spread of the new coronavirus. Due to ongoing travel difficulties, the 4th JCC was held online for the first time, where MS ver. 4 was also approved. After a two-year hiatus due to the spread of coronavirus infection, travel resumed in April 2022, and the 5th JCC was held there in May 2022. MS ver.5 was developed based on the revised PDM and PO. MS ver.6 was developed in October 2022, and the contents were confirmed and approved at the 6th JCC held in the field. MS ver.7 and MS ver.8 were prepared in April 2023 and November 2023, respectively, and were reviewed and approved by the 7th and 8th JCCs held locally.

(3) Establishing PDM indicators

The finalization of the indicators listed in the PDM and the specific figures for the items not yet set were discussed with JICA and then with the C/P and decided in August 2019. The deadline for the activities was revised due to the extension of the construction period by 1.5 years, which was decided in May 2022.

Table 3.1-2 List of PDM indicators set (indicators and deadlines set after the start of project in **bold)**

Objectives and Outputs	Indicator
Overall Goal: Slopes on roads in Bhutan are properly developed and managed by using countermeasures improved in the Project.	More than 4 countermeasures by using the technology installed/improved in the Project are implemented in the 2 target regional offices (Lobesa and Trongsa).
	More than 7 countermeasures by using the technology installed/improved in the Project are implemented in all of the other 7 regional offices.
Project Purpose: Capacity of DoST for countermeasures of slope disaster on roads is improved.	More than 4 countermeasure works by using the technology installed/improved in the Project are implemented by DoST.
	More than 70% of DoST engineers is able to implement ex-ante traffic control according to the developed manuals.
	Budget for countermeasures by using the technology installed/improved in the Project is incorporated into the annual budget plan in DoST.
Output 1: Clarification of conditions for advance traffic control	Sections of ex-ante traffic control are selected **(by December 2022)**
	Threshold rainfall of ex-ante traffic control is established.
	A manual on the monitoring of displacement/rainfall and the ex-ante traffic control is developed and approved by DoST (MoIT) **(by December 2023)**
Output 2: Suitable bio-engineering works are selected against “debris slope failure”.	At least two engineers in the DoST headquarters and each regional office are able to select suitable bio-engineering works and to supervise implementation of the works
	A design/implementation guideline and a standard unit price table on the bio-engineering works are developed and approved by DoST (MoIT) **(by June,2024)**
Output 3: Standards for cut slope angles for “debris slope failure” and “rock slope failure” are revised.	At least two engineers in the DoST headquarters and each regional office are able to select suitable cut slope angle on each geological type and to supervise implementation of the works
	A design/implementation guideline and a standard unit price table on the standards for cut slope angles are developed and approved by DoST (MoIT) **(by December, 2023)**
Output 4: Suitable countermeasure works are implemented for “rock slope failure (rock fall)”.	At least two engineers in the DoST headquarters and each regional office are able to select suitable countermeasure works for “rock slope failure (rock fall)”.
	At least two engineers in the DoST headquarters and each regional office are able to understand the selected countermeasure works and to supervise implementation of the works.
	A design/implementation guideline, a standard unit price table on the countermeasure works for “rock slope failure (rock fall)” and a countermeasure Handbook are developed and approved by DoST (MoIT) **(by June,2024)**.
Output 5: Suitable drainage works and facilities are installed for “debris flow”.	At least two engineers in the DoST headquarters and each regional office are able to investigate and design suitable drainage works and facilities and to supervise implementation of the works.
	A design/implementation guideline and a standard unit price table on the drainage works and facilities are developed and approved by DoST (MoIT) **(by December, 2023).**
Output 6: Information system on slope disasters and traffic controls on roads is improved.	Road information system with the existing GIS database is improved.
	Necessary data for maintenance and traffic control on roads are periodically collected by regional offices.
	Manual on the road information system utilizing the GIS database is developed and approved by DoST (MoIT) **(by June,2024)**

(Source: JET)

(4) JCC

The Joint Coordinating Committee (hereinafter referred to as "JCC") held its first meeting on January 31, 2019, followed by its second meeting on August 28, 2019, third meeting on February 4, 2020, fourth meeting on December 4, 2020, and fifth meeting on May 16, 2022. The JCC confirmed the progress and MS of the Project as a whole and of each Output, and discussed future activity plans, concerns about the Project's progress, and measures to address these concerns. At the 5th JCC, which agreed to extend the construction period of the Project, it was approved to change the number of meetings from the initial total of eight to a total of nine.

(5) Equipment procurement

Materials and equipment necessary for the implementation of the project were procured and provided to the C/P. The table below shows the materials and equipment procured in Japan and locally.

Table 3.1-3 Materials and Equipment Procured in Japan

Product	Qty.	Purpose
Soil hardness tester	3	Output 2: Measuring soil densities
Soil sampler	3	Output 2: Soil samples were collected to investigate the condition of the topsoil.
pH meter	3	Output 2: Measurement of soil pH value
Conductivity meter	3	Output 2: Evaluation of salt content, etc., by measuring soil conductivity
Simple penetration tester	3	Output 3: Evaluation of strata compaction by measuring Nd values of sediment slopes and bedrock.
Handy Elastic Wave Velocimeter	3	Output 3/Output 4: Quantitative evaluation of the degree of weathering of bedrock by measuring the P-wave velocity of the bedrock
clinometer	3	Output 3: Investigation of geological properties and geological structure of cut slope
laser range finder	3	Output 3/Output 5: Measurement of slope and height of cut slope, slope of stream, topographical conditions, etc.
Schmidt Hammer	3	Output 4: Rock strength is measured and rock mass classification is evaluated.
drive recorder	7	Output 6: Acquisition of field location coordinates and field photo/video data
rain gauge	3	Output 1: Slope monitoring to measure rainfall
Ground surface tilt sensor	30	Output 1: Slope monitoring to detect slope changes and timing of collapse
Measuring equipment parent unit (mobile communication station)	3	Output 1: Slope monitoring data is consolidated and sent to the headquarters server
Alarm and database server	1	Output 1: Slope monitoring data analyzed and warnings issued
mainframe of a drone	2	Output 6: Acquisition and surveying of road and road slope information
Flight Simulator License	2	Output 6: Training in manual drone flight
Software for orthoimaging and topographic mapping and analysis	1	Output 6: Analysis of drone-captured images
Levels and slant levels	20	Output 3: For the construction of the slope using the specified cut slope.
4G modem	3	Output 1: Slope monitoring data is consolidated and sent to the headquarters server via 4G

(Source: JET)

Table 3.1-4 Procured Materials and Equipment in Bhutan

Product	Qty.	Purpose
Helmet	60	To be used by specialists and C/Ps during field work
Safety vest	60	To be used by specialists and C/Ps during field work
Multifunction machine	1	To print, copy, and scan materials necessary for the project
Small printer	2	To print documents during field trips in Bhutan, one each at Lobesa Regional Office and Trongsa Regional Office.
Laptop	2	For use by local mercenaries in project activities
Office software, etc. (Word, Excel, etc.)	2	Installed on the two notebook computers mentioned above and used for creating documents and analyzing data.
Projector	1	For use in conferences and seminars
Desktop PC for analysis	1	Output 6: To operate software for orthoimaging and topographic mapping and analysis.

(Source: JET)

(6) Subcontract with local companes

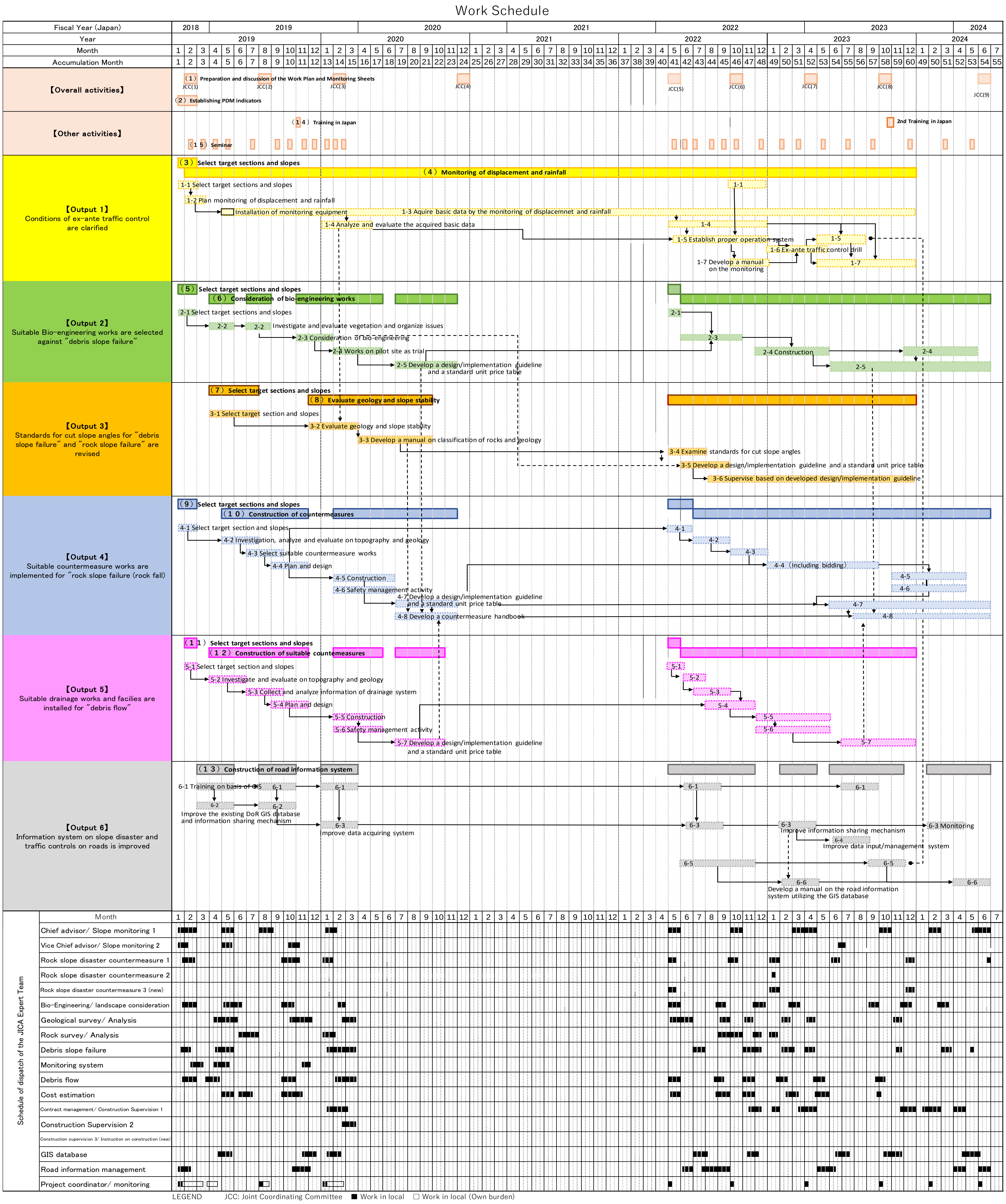
In this project, works related to the installation of slope monitoring equipment, the first through third Bio-engineering construction test runs, and the development of the Bhutan Road Safety (hereinafter referred to as "BRS") application were performed under a local re-commissioning. The following is a summary of the completed field re-commissioning work.

Table 3.1-5 Results of On-Site Recommissioning Operations

Items	Dscription	Period	Selection Method	Service provider
Slope monitoring Equipment Installation	Output 1: Installation of slope monitoring sensors, rain gauges, and local communication stations for monitoring in Razhau, Dzongkalom, and Reotala districts, Bhutan	3/28/2019 ~ 5/20/2019	Collating quotations	M/S Trophel Construction Rep: Mr. Nimala Trophel
1st vegetation work test construction	Result 2: Pilot Construction of Vegetation Works in Ghantangkha District, Bhutan	1/29/2020 ~ 6/15/2020	Collating quotations	Nor-Lha Construction Rep: Sonam Tashi
2nd vegetation work test construction	Result 2: Construction of Vegetation Works in Trongsa District, Bhutan	12/16/2022 ~ 4/30/2023	Collating quotations	M/s Sonam Construction Rep: Sangay Tenzin
BRS application development work	Output 6: BRS application development work	12/29/2023 ~ 5/31/2024	Collating quotations	ngn technologies private limited Rep: Dawa Sonam
3rd vegetation works test construction	Output 2: Construction of Vegetation Works in Gopini District, Bhutan	1/16/2024 ~ 4/15/2024	Collating quotations	Norbu Yeabar Construction Rep : Sonam Yezer

(Source: JET)

Table 3.1-6 Flowchart of work implementation



3.2 Output 1: Conditions of ex-ante traffic control are clarified.

Activity 1-1: Select target sections and slopes based on the results of slope disaster inspections

Through the results of road disaster prevention inspections, field checks, and discussions with the C/P, the best target routes and slopes for exante trafic control were selected within the jurisdiction of the model regional offices (Lobesa and Tongsa) through the first to third phases of study described below.

Table 3.2-1 Considerations for selection of target routes and slopes

Selection Considerations	
➢ Slopes requiring countermeasures identified in the road disaster prevention inspections conducted in the preceding projects. ➢ C/P requests (rheotara, box cut landslides, etc.) ➢ Actual damage situation, sections with many slope failures and road blocks, long slopes ➢ Typical slope disaster that collapses during heavy rainfall (mostly landslide slope failure) ➢ Cooperation with monitoring established or planned by weather bureaus and universities ➢ Areas where real-time automatic measurement using cellular communication is possible	**Target Slope**  Slope in Reotara(Source JET)

(Source: JET)

Phase 1: From the 16 slopes with high priority for countermeasures detected in the master plan study of the preceding project, slopes that are appropriate as slopes to be monitored for Output 1 are selected as "candidates for selection".

Phase 2: The **"target slopes**" for monitoring are selected from the two slopes selected as candidates in Phase 1 and the slopes newly identified as "Rank 1" by the field survey.

Phase 3: Establish a **"targeted section" for** exante trafic control in the area containing the selected slopes to be monitored.

Below are the results of each phase of the study.

(1) Phase 1

The 16 slopes with high priority for countermeasures detected in the prior case master plan study are evaluated to determine if they are appropriate as slopes to be monitored for Output 1. The two evaluation items are as follows.

<u>Evaluation Item 1</u>: The type of disaster is "Debris Slope Failure (SF)".

Since exante trafic control is based on rainfall thresholds, the monitoring equipment installed for Output 1 was targeted for "Debris Slope Failure (SF)[1]" that occurs in relation to rainfall.

On the other hand, rock fall, which is a form of RF (Rock Slope Failure), does not necessarily occur during rainfall, but can also occur due to seismic motion, wind, and weathering of the basement.

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[1] SF stands for Surface Failure, but as part of this form of surface failure, a slope composed of collapsed soil and rocks (Debris) collapses (Failure), which is expressed as Soil Slope Failure SF.

In addition, most LS (landslides) are triggered by groundwater increase[2] , but there is a time lag between rainfall and groundwater increase[3] , and the relationship between the amount of rainfall and groundwater increase is not uniquely determined. Therefore, "RF (Rock Slope Failure)" and "LS (Landslide)" are not subject to exante trafic control based on the rainfall threshold[4] . The occurrence of "DF (debris flow)" is related to the amount of rainfall and is therefore subject to advance traffic regulation based on the rainfall threshold. However, since most of the typical slope failures that occur during heavy rainfall in Bhutan are "landslide slope failures", they are not included in the monitoring of this project.

<u>Assessment Item 2</u>: Select slopes with large amounts of sediment on the slope

In Debris Slope Failure (SF), the collapsed soil[5] left on the slope may be sediment-dominated or boulder-dominated. Both are subject to exante trafic control based on rainfall thresholds. In order to prevent variations in data due to temperature changes, the slope sensor is supposed to be buried in the ground, so "slopes with a large amount of sediment on the slope" that are suitable for sensor burial are selected and the slope sensor is buried there. Slopes with a small amount of collapsed soil remaining on the slope and slopes with mainly boulders are excluded from monitoring.

It is noted that TPP0122160 and TPP0120180 were eliminated because their hazard rank is no longer R1 due to road widening work.

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[2] Rock failure and landslide phenomena are caused by the interaction between predisposing factors, which are natural elements that constitute the slope morphology (e.g., material conditions such as bedrock and soil, and constitutive factors such as slope angle and strata structure), and triggers that have physical effects on the predisposing factors such as groundwater levels due to rainfall and inertial forces due to earthquakes. become slippery or, conversely, stable.

[3] Rainfall causes water to seep into the ground and become groundwater, and as the groundwater surface rises, the ground becomes unstable (effective stress in the ground decreases). This sequence of events is described as having a time lag.

[4] For example, the total amount of rainfall after *** hours from the beginning of the rainfall will be ＊＊＊＊ mm, which is a standard value to be used as a basis for determining the implementation of advance traffic restrictions.

[5] It refers to the sediment and rocks that accumulate at the bottom of a slope once the slope collapses.

Table 3.2-2 Phase 1; results of the study of the 16 slopes identified in the prior project.

Road No.	Supervisory office	Control No.	Disaster classification	Evaluation item: Type of disaster: SF	Evaluation item: Large amount of sediment on the slope	Result
1	Lobesa	WPP0121170	DF (Debris flow)			Not subject (to)
1	Lobesa	WPP0120980	RF (Rock Slope Failure)			Not subject (to)
1	Lobesa	WPP0120270	SF (Soil Slope Failure)	✓	✓	**candidate slope**
1	Trongsa	TPP0122160	RF (Rock Slope Failure)	Road widening work has resulted in a hazard rank of Rank 1.		Not subject (to)
1	Trongsa	TPP0121700	LS (Landslide)			Not subject (to)
1	Trongsa	TPP0120850	SF (Soil Slope Failure)			Not subject (to)
1	Trongsa	TPP0120440	DF (Debris flow)			Not subject (to)
1	Trongsa	TPP0120400	SF (Soil Slope Failure)	✓		Not subject (to)
1	Trongsa	TPP0120370	SF (Soil Slope Failure)	✓		Not subject (to)
1	Trongsa	TPP0120180	RF (Rock Slope Failure)	Road widening work has resulted in a hazard rank of Rank 1.		Not subject (to)
1	Trongsa	TPP0120130	DF (Debris flow)			Not subject (to)
4	Trongsa	TRP0450490	DF (Debris flow)			Not subject (to)
4	Trongsa	TRP0450470	DF (Debris flow)			Not subject (to)
4	Trongsa	TRP0450290	DF (Debris flow)			Not subject (to)
4	Trongsa	TRP0450070	LS (Landslide)			Not subject (to)
4	Trongsa	TRP0420160	SF (Soil Slope Failure)	✓	✓	**candidate slope**

(Source: JET)

(2) Phase 2

The following items are evaluated for the two slopes identified as candidates in the first phase (both Rank 1) and for the slope newly determined to have a new hazard rank of "Rank 1" based on the field survey (slope survey sheet and slope chart are newly prepared).

Evaluation Item 1: The type of disaster is "Debris Slope Failure (SF)".

Same as evaluation item 1 in phase 1.

Evaluation Item 2: The slope has a large amount of sediment on the slope

Same as evaluation item 2 in phase 1.

Evaluation Item 3: Degree of impact on roads due to collapsed soil

Large impact" refers to a situation in which the entire road is covered by collapsed soil, while "impact" refers to a situation in which approximately half of the road is covered by collapsed soil.

Evaluation Item 4: Slopes to be monitored are representative slopes in the target section.

Based on the results of monitoring on the target slope, exatne traffic control is implemented in the target reach that includes the target slope. The slope monitored should be a model slope representative of the section subject to exante trafic control. For example, slopes with a hazard rank of "Rank 1" but for which some countermeasures have already been implemented and the timing of collapse may be different (i.e., the effect of the countermeasures may delay the onset of collapse) compared to slopes in the same section that have not yet been countermeasured should be excluded.

<u>Evaluation Item 5</u>: There is a strong demand from DoST

Slopes that are judged to be "suitable (✓)" in all of the above evaluation items 1-4, and for which DoST has a strong request to conduct monitoring.As a result of the Phase 2 study, the following three slopes were selected as monitoring slopes for Output 1.

Table 3.2-3 Slopes selected for monitoring slopes for Result 1 (3 slopes)

Road No.	section	control number	pilot number	Place Name	Management Office	GPS coordinates	
						latitude (nav.)	slight degree
1	S-1	**WPP0120610**	S-1-3	Razhau.	Lobesa	N 27 31 56.4	E 90 6 13.5
5	S-2	-	S-2-7	Dzongkalom*	Tonsa	N 27 27 50.2	E 90 29 59.5
5	S-3	TRP0420160	S-3-2	Reotala	Tonsa	N 27 14 22	E 90 36 45.7

(Source: JET) * Slopes with a hazard risk rank of "Rank 1" due to road widening

The results of the Phase I and Phase II studies are summarized in the following table, and the locations of the selected slopes to be monitored are shown in Figure 3.2-1.

(Source: JET)

Figure 3.2-1 Location of slopes to be monitored

Table 3.2-4 Summary table of results for selection of target slopes for Output 1.

List of the Nominated for Target Slopes

No.	Management No.	Site Name	Section	Regional Office	Hazard Rank		Types of Landslide	Judgement of target slope	Memo
					Last time	This time			
S-1-1	WPP0120930	Khelokha	S-1	Lobesa	R3	R1 *	SF(Debris slope failure)	Not Good	The amount of debris left on the slope is small.
S-1-2	WPP0120690	Khelokha	S-1	Lobesa	R3	R1 *	SF(Debris slope failure)	Good	Although this slope is suitable for monitoring, it is not a model slope of this section.
S-1-3	WPP0120610	Manikyangsa	S-1	Lobesa	R3	R1 *	SF(Debris slope failure)	Target Slope	This slope is suitable for monitoring, and it is a model slope of this section.
S-1-4-1	WPP0120270		S-1	Lobesa	R1	R1	SF(Debris slope failure)	Not Good	This slope is too large for monitoring, and additionally, a cut slope other than the road widening work is being constructed, so it is not suitable for monitoring of ex-ante traffic control.
S-1-4-2	WPP0120260		S-1	Lobesa	R2	R1 *	SF(Debris slope failure)	Not Good	The amount of debris left on the slope is small.
S-1-5	WPP0120110	Nubding	S-1	Lobesa	R1	R1	SF(Debris slope failure)	Not Good	The amount of debris left on the slope is small.
S-1-6	-	Rukubji	S-1	Lobesa	Non	R1 *	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-1-7	-	Chazam	S-1	Lobesa	Non	R1 *	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-1-8-1	-	Chuserbu	S-1	Lobesa	Non	R1 *	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-1-8-2	-	Chuserbu	S-1	Lobesa	Non	R1 *	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-2-1	-	Chuserbu	S-2	Trongsa	Non	R1 *	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-2-2	-	Chendebji	S-2	Trongsa	Non	R1 *	SF(Debris slope failure)	Not Good	The amount of debris left on the slope is small.
S-2-3	-	Chendebji	S-2	Trongsa	Non	R1 *	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-2-4	-		S-2	Trongsa	Non	R1 *	SF(Debris slope failure)	Not Good	The amount of debris left on the slope is small.
S-2-5	WPP0121330		S-2	Trongsa	R1	R1	RF(Rock slope failure)	Not Good	It is not Debris Slope Feilure.
S-2-6	-		S-2	Trongsa	Non	R1 *	RF(Rock slope failure)	Not Good	It is not Debris Slope Feilure.
S-2-7	-		S-2	Trongsa	Non	R1 *	SF(Debris slope failure)	Target Slope	This slope is suitable for monitoring, and it is a model slope of this section.
S-2-8	-		S-2	Trongsa	Non	R1 **	SF(Debris slope failure)	Good	This slope is suitable for monitoring, but this slope is located outside the target section.
S-2-9	-		S-2	Trongsa	Non	-	BF (Back Fill Feilure)	Not Good	It is not Debris Slope Feilure.
S-3-1	-		S-3	Trongsa	Non	R1 **	RF(Rock slope failure)	Not Good	It is not Debris Slope Feilure.
S-3-2	TRP0420160	Reutala	S-3	Trongsa	R1	R1	SF(Deblis slope failure)	Target Slope	This slope is suitable for monitoring, and it is a model slope of this section.

* Due to road widening work, the hazard risk rank of this slope had become "Rank 1".

**Through this site investigation, the risk rank of this slope was judged to be "Rank 1".

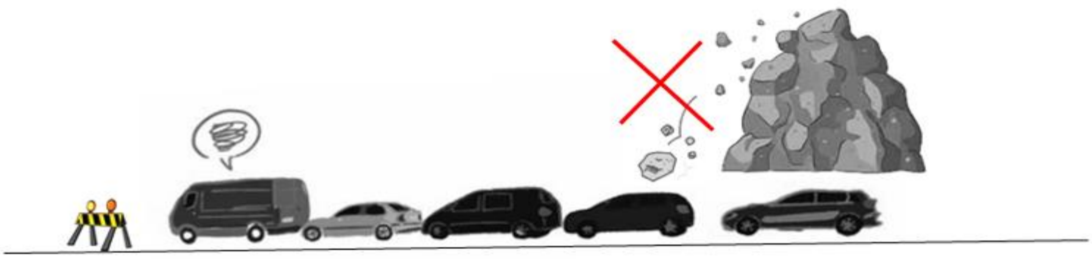
(Source: JET)

(3) Phase 3

The sections subject to exante trafic control were selected one by one within the jurisdiction of the model regional offices (Lobesa and Tongsa) after considering the following requirements for selecting the sections subject to exante trafic control through field inspections and discussions with C/Ps.

<Requirements for selecting the target section>

- ✓ Since the exante trafic control is implemented using rain gauge measurements, the "target area" of the exante trafic control must be set in an area that includes the "target slope" of the monitoring selected in Phase2.
- ✓ The pre-traffic control exercise to be conducted in this project is the first attempt for the DoST, and various problems may occur during the exercise. In order to accurately identify and immediately address such problems, it is desirable that the section to be covered by the pre-training exercise not be too long. Therefore, the length of the pre-traffic control section for the Project is no longer than a few hundred meters.
- ✓ Several vehicles are temporarily stopped at the beginning and end of the pre-restricted zone. The start and end points of the pre-restricted zone should be set at locations where there is no danger of falling rocks or collapsing shoulders for these stopped vehicles.



(Source: JET)

Figure 3.2-2 Establishing the beginning and ending points of the pre-passage control zone at locations where there is no danger of falling rocks or shoulder collapse.

As a result of the above considerations, two advance passage control zones were established, one in the jurisdiction of the Lobesa Office and one in the jurisdiction of the Tongsa Office. The table below shows the locations of the restricted areas.

Table 3.2-5 Locations of pre-passage restricted sections

National Road No.	monitoring Target Slope	RO	Target Section/Starting Point		Target section/termination point	
			latitude (nav.)	longitude	latitude (nav.)	longitude
1	Razhau.	Lobesa	27°31'53.78" n	90° 6'13.06" E	27°32'0.36 "N	90° 6'16.44 "E
5	Dzongkalom	Trongsa	27°27'49.92 "N	90°29'59.64 "E	27°27'38.59 "N	90°29'45.51 "E

(Source: JET)

[Section of prior traffic control in the jurisdiction of Lobesa Office].

(Source: JET)

Figure 3.2-3 Pre-restricted traffic section: Razhau, Lobesa-RO

(Source: JET)

Photo 3.2-1 View of the beginning of the pre-passage restricted section: Razhau, Lobesa-RO

(Source: JET)

Photo 3.2-2 View of the end of the pre-passage restricted section: Razhau, Lobesa-RO

The section of the Tongsa Office that is under the jurisdiction of the Tongsa Office is restricted for traffic in advance.

(Source: JET)

Figure 3.2-4 Exante trafic control section: Dzongkalom, Trongsa

(Source: JET)

Photo 3.2-3 View of the beginning of the pre-passage restricted section: Dzongkalom, Trongsa

(Source: JET)

Photo 3.2-4 View of the end of the pre-controlled road section: Dzongkalom, Trongsa

Activity 1-2 Develop a displacement and rainfall monitoring plan

Develop an optimal monitoring plan by reviewing and selecting the best equipment in terms of both cost and quality for Bhutan's exante trafic control.

(1) Selection of displacement and rainfall monitoring equipment

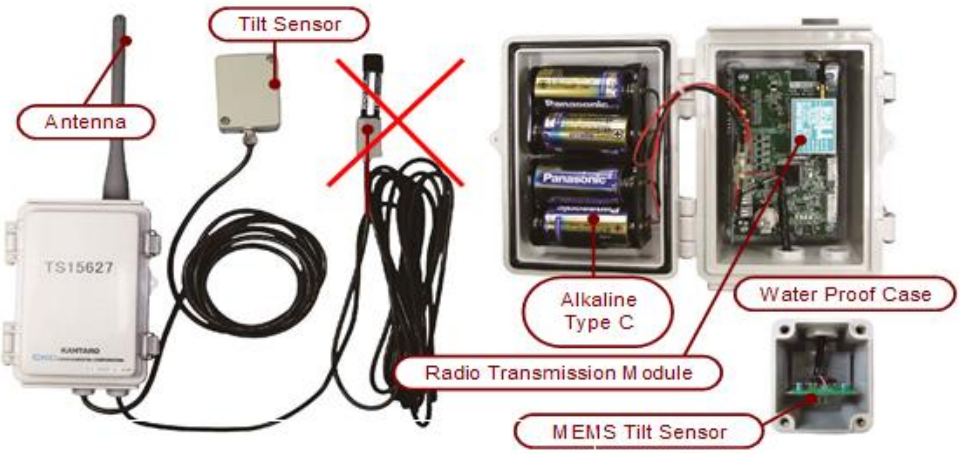
The specifications and procured equipment and quantities required for the displacement and rainfall monitoring equipment are as follows

1) Various displays and manuals of measurement equipment must be compatible with English.
2) Resolution of ground surface inclination sensor: 0.005° or better; same/accuracy: ±0.05° or better (because reference value must be set in 0.1° increments)
3) Ability to automatically transfer measurement data to alarms and databases via local mobile communications
4) Server must be able to be installed and operated in Bhutan (Web servers in Japan are not acceptable).
5) The server shall have database and alert functions (e.g.,email and SMS)
6) The server must be able to be customized for web functions and linkage with other devices and systems according to the local customer's needs.
7) Knowledge and basic data to be able to set the reference value of the inclination sensor.
8) Experience in installing sensors and servers in Bhutan or neighboring countries such as India.

Table 3.2-6 Equipment procured and quantity

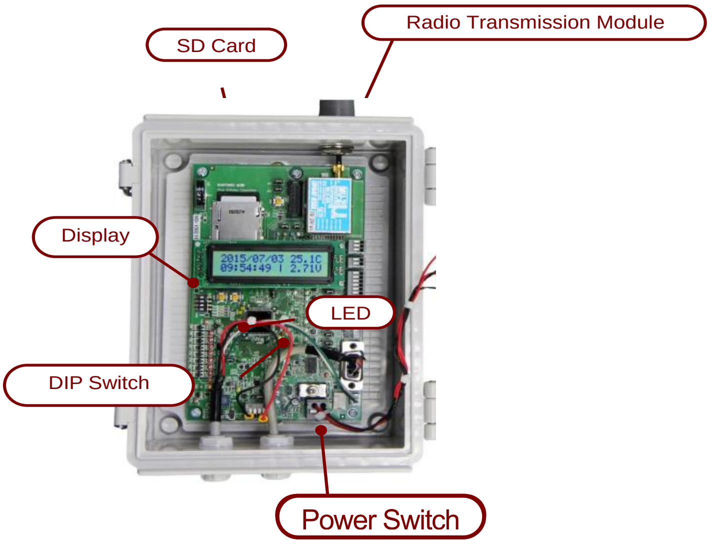
Product	Purpose	Qty.
Rain gauge	Measuring rainfall	3
Ground surface tilt sensor	Measuring the ground surface slope of a road slope	30
Measuring equipment parent unit (mobile communication station)	Transferring data from rain gauge and ground surface tilt sensor to server via cellular phone communication	3
Alarm and database server	Installed at DoST headquarters for centralized management of rainfall and surface slope data and issuance of warnings	1

(Source: JET)



(Source: JET)

Figure 3.2-5 Ground surface inclination sensor



(Source: JET)

Figure 3.2-6 Measuring equipment parent unit (mobile communication station)

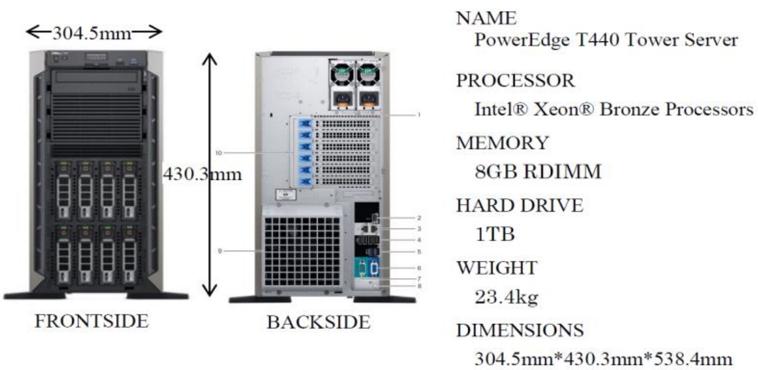
Table 3.2-7 Rain gauge specifications

Subject	Remarks
Method	Tilt Type Rain Gauge
Diameter/Area	φ:200mm, A:314 ㎠
Signal Output	Make contact output with magnetic lead switch
Output pulse width	0.1 to 0.15 second
Contact capacity	15VA (Within DC50V x 0.3A)
Resolution	1 tilt = 0.5mm
Range	MAX 100mm/h
Accuracy	Less than 20mm/h: ±0.5mm / Over 20mm/h: ±3
Outside diameter	φ210mm x H:450mm
Weight	3.2kg
Temperature limit	1 to 50°C

(Source: JET)

Figure 3.2-7 Rain gauge

(Source: JET)



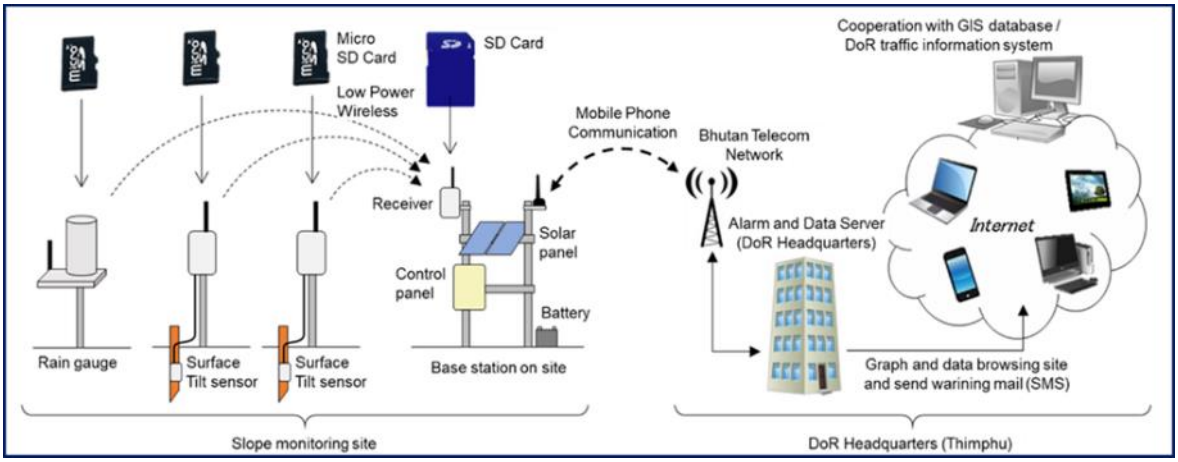
(Source: JET)

Figure 3.2-8 Alarm and database server

(2) Monitoring System Structure

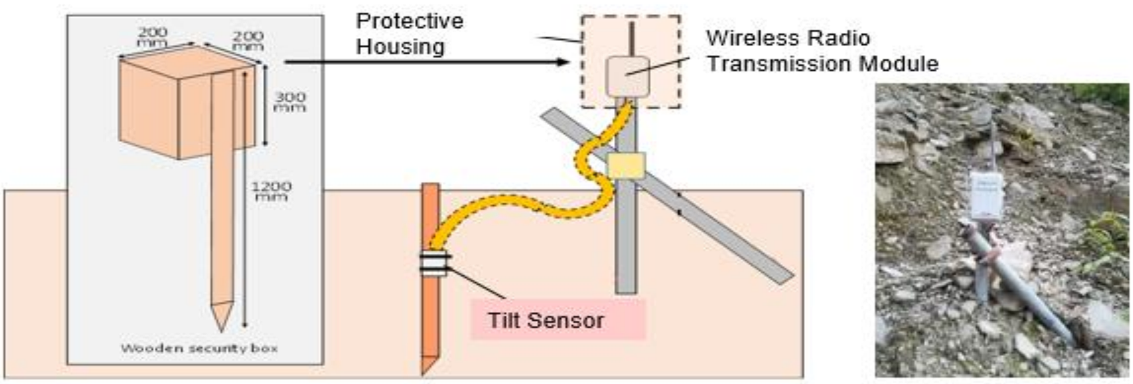
Configuration of the monitoring system installed in this project in Figure3.2.-9. The measured data from the ground surface inclination sensors installed on the three slopes to be monitored are transmitted every 10 minutes by low-power radio to a base station installed beside the slopes to be monitored.

The base station consists of a rain gauge and instrumentation parent unit (mobile communication station). The base station receives data from the ground surface tilt sensor every 10 minutes and automatically transmits the data, along with the rain gauge observation data, to the alert and database server located at the DoST headquarters in the capital city of Thimphu via cellular phone lines. The alert and database server can send alert emails and SMS to the cell phones and PCs of the concerned parties when rainfall or ground surface tilt angle exceeding the preset measurement threshold is observed.



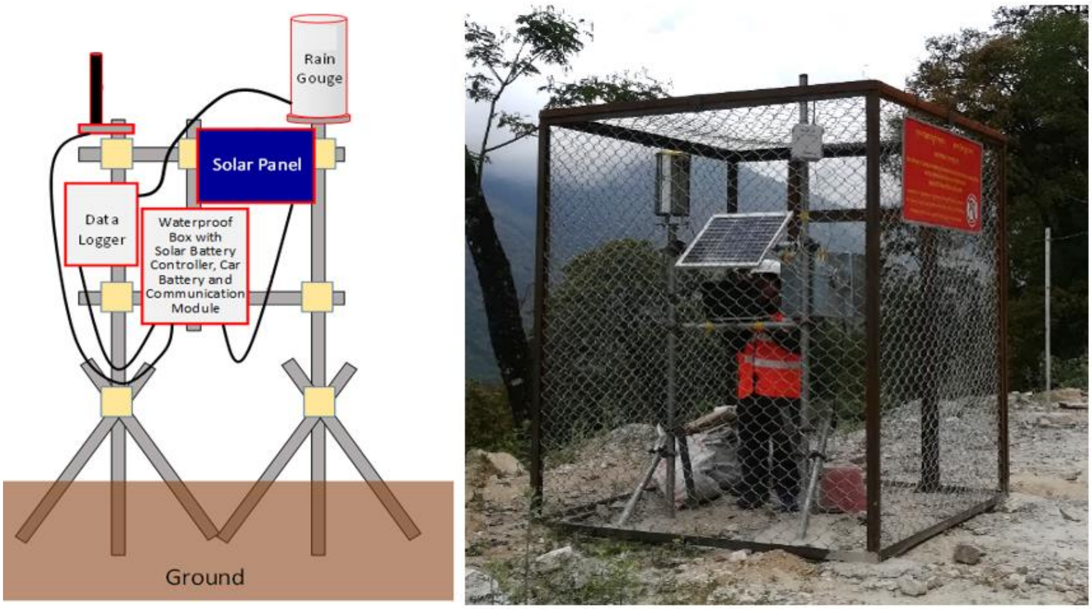
(Source: JET)

Figure 3.2-9 Monitoring System Configuration



(Source: JET)

Figure 3.2-10 Installation configuration of ground surface inclination sensor



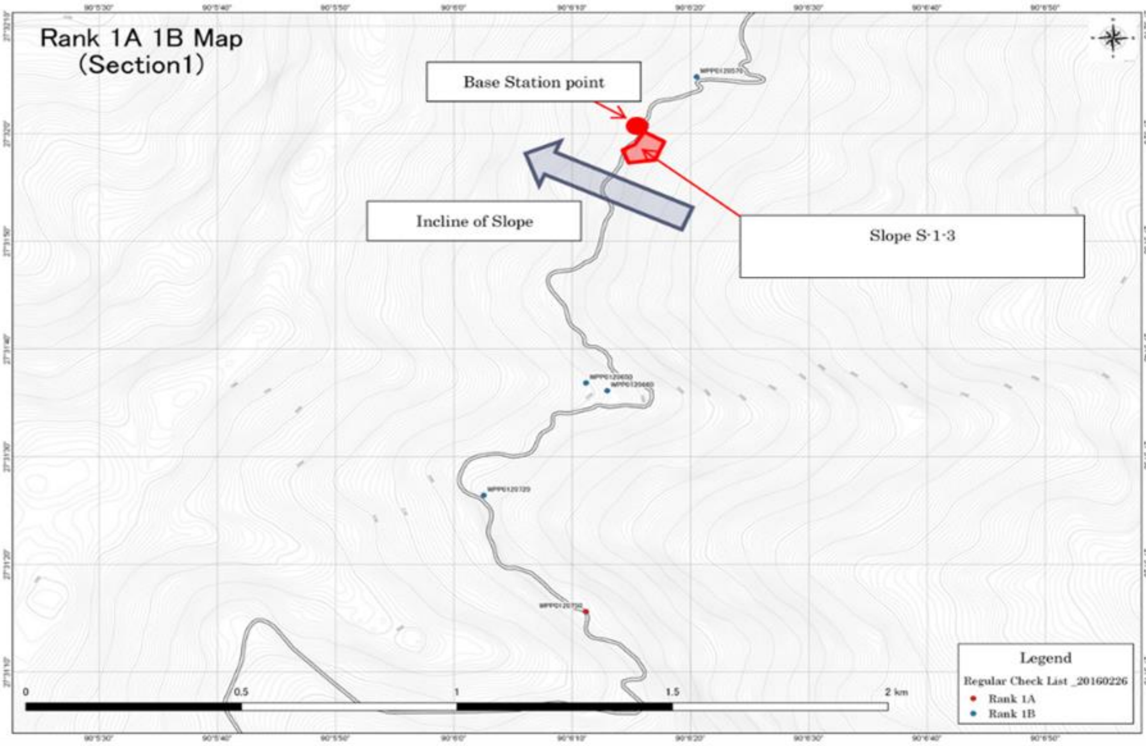
(Source: JET)

Figure 3.2-11 Base Station Installation Configuration Diagram

(3) Layout plan for displacement and rainfall monitoring equipment

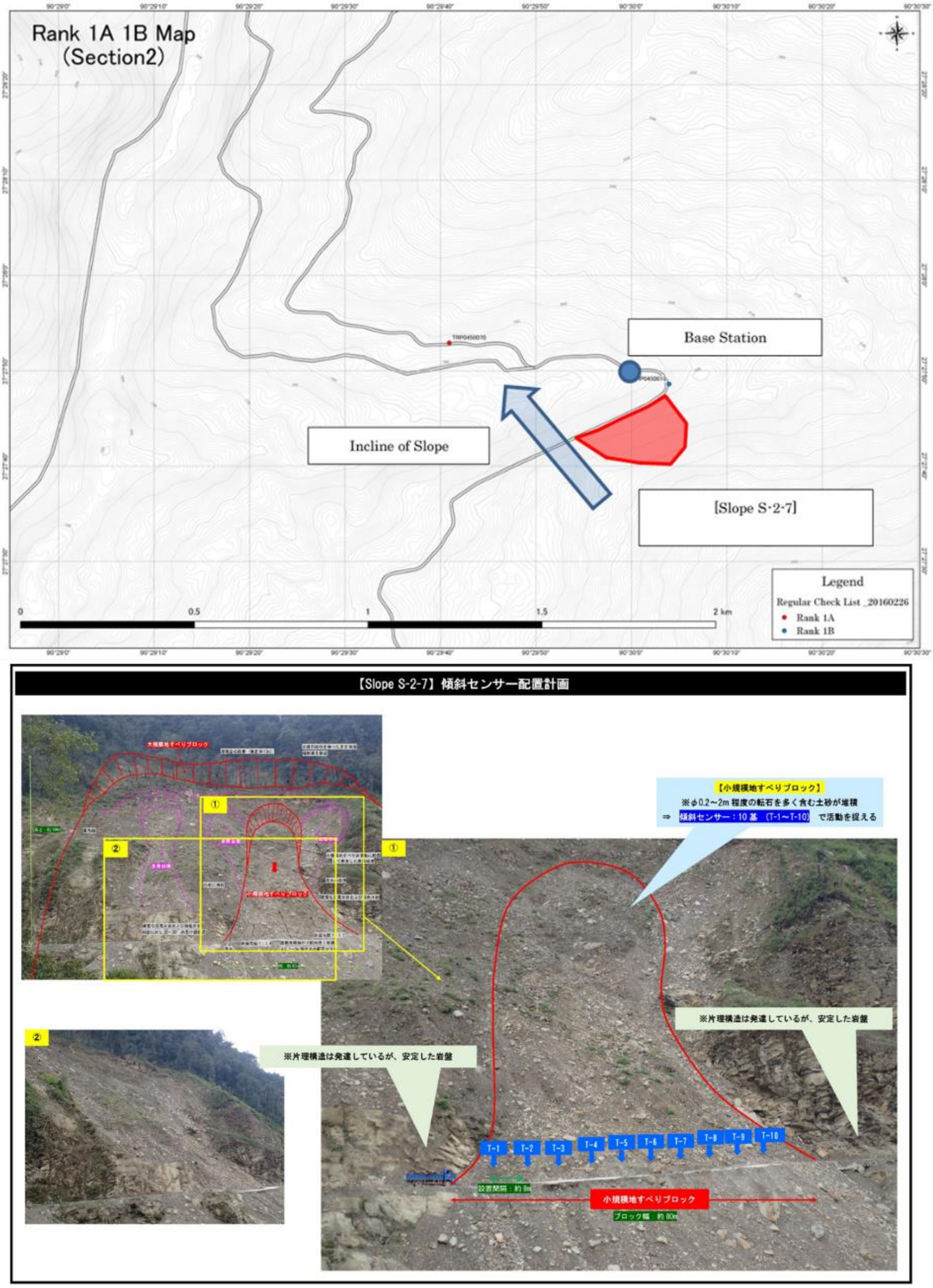
The placement of monitoring equipment was planned based on a field survey. Surface slope sensors were installed at locations where surface failures were expected to occur, to ensure that rainfall-related surface failures could be detected. The base stations, which consisted of rain gauges and the parent unit of the measurement equipment (mobile communication station), were installed on stable ground outside the area affected by the slope failure. In planning the location of the base station, JET selected a location where the radio waves from the surface slope sensor on the slope would be sufficiently far away and the reception of the cell phone signals used to transmit data to the server would be as good as possible.

Planning the placement of displacement and rainfall monitoring equipment at three measurement sites indicated in Figure.3.2-12, 13, 14.



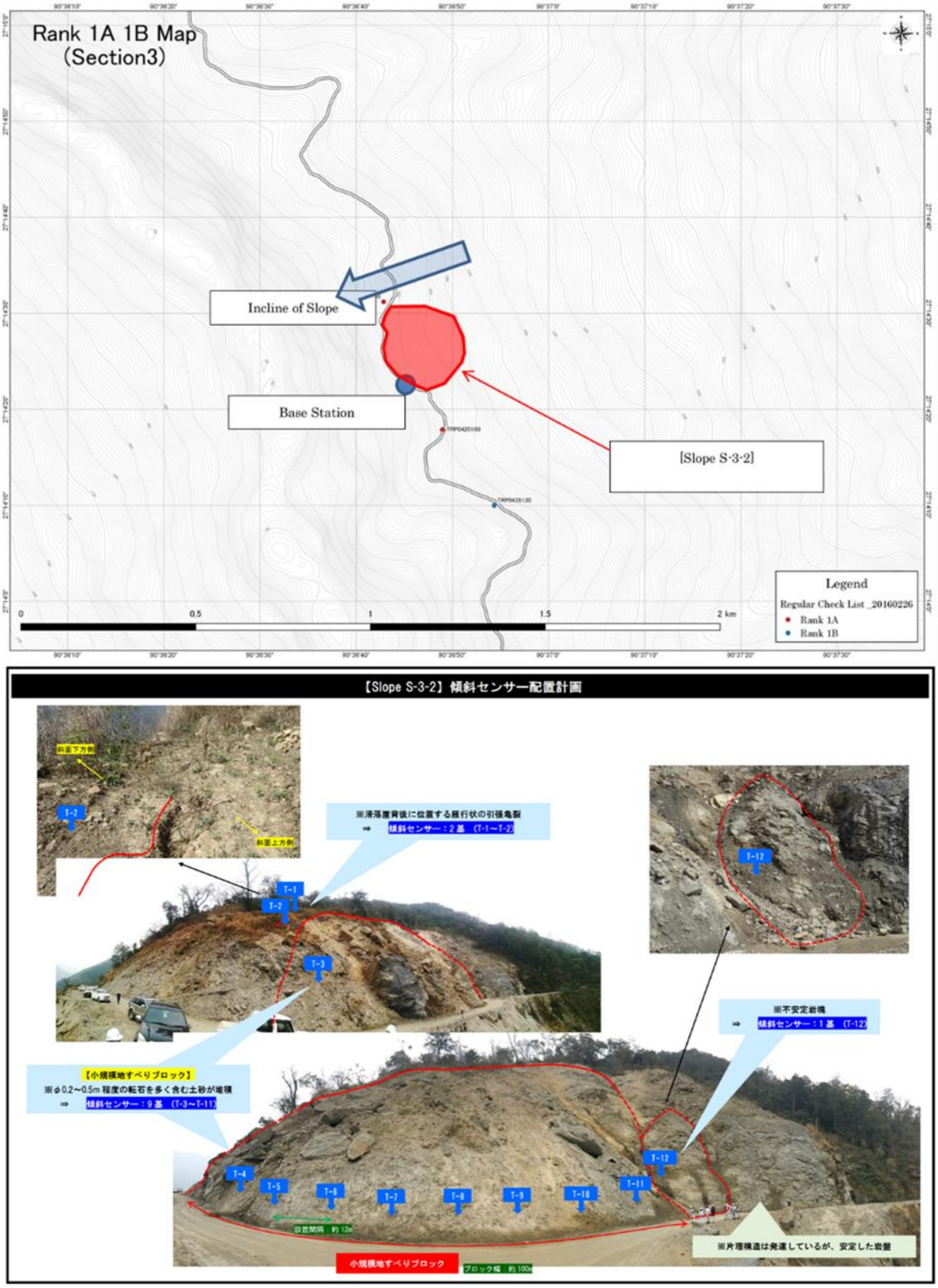
(Source: JET)

Figure 3.2-12 Deployment plan for base station and ground surface tilt sensor
(Razhau, Lobesa office)



(Source: JET)

Figure 3.2-13 Deployment plan for base station and ground surface tilt sensor (Dzongkhalom, Tongsa office)



(Source: JET)

Figure 3.2-14 Deployment plan of base stations and ground surface tilt sensors
(Reotala, Tonsa office)

Activity 1-3. Obtain basic data from displacement and rainfall monitoring

The displacement and rainfall monitoring equipment was installed by May 2019, prior to the first year rainy season (June-September 2019), and rainfall and surface slope sensor data were acquired during the first year rainy season. The installation was handled by a local re-commissioning of the project.

Basic data from displacement and rainfall monitoring has been automatically obtained since May 2019, when the displacement and rainfall monitoring equipment was installed, and stored on a server located at the DoST headquarters.

Table 3.2-8 Item quantity table for installation

Item	Unit	Qty.	Remarks
Installation of rain gauges and instrumentation parent units	Counter for machines, incl. vehicles	3	The instrumentation parent unit includes a solar panel, solar battery controller, battery, communications modem, antenna for the modem, and a foundation on which to install these devices.
Installation of fence to prevent theft of rain gauges and measurement equipment parent units	Place	3	Fenced on all sides, including top
Installation of ground surface displacement meter	Counter for machines, incl. vehicles	30	Includes anti-theft wooden box
Installation of signs calling for theft prevention	Counter for installed or mounted objects (e.g. stone lanterns, gravestones, satellites)	6	One unit on each side of each slope

(Source: JET)

Installation of monitoring equipment

Digging to install the tilt sensor

Setting up the protective fence

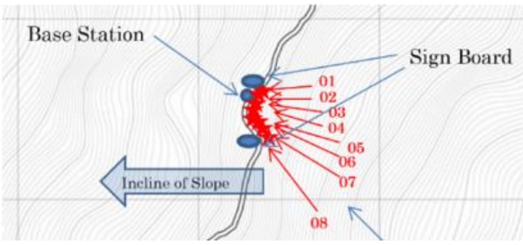
Install the tilt sensor

Transfeering the handling the observation

(Source: JET)

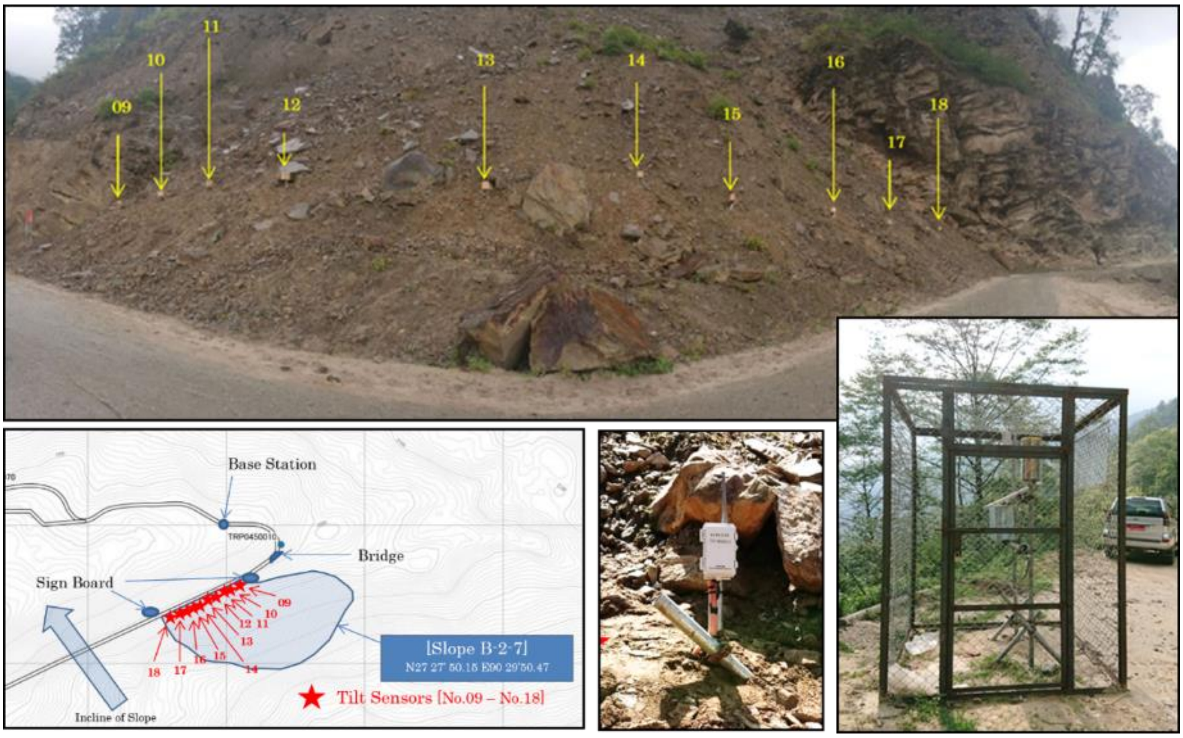
Photo 3.2-5　Installation of monitoring equipment in action, case study of Dzongkalom

Installation status of monitoring equipment



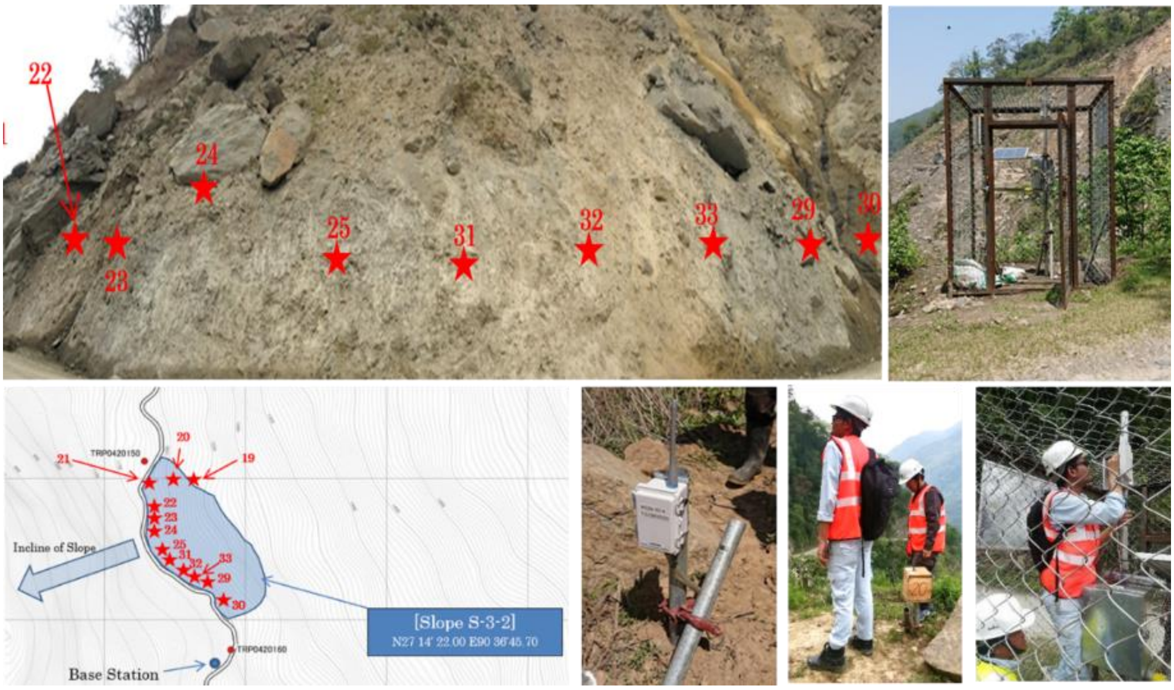
(Source: JET)

Figure 3.2-15　Deployment of base stations and ground surface tilt sensors (Razhau)



(Source: JET)

Figure 3.2-16 Deployment of base station and ground surface tilt sensor (Dzongkalom)



(Source: JET)

Figure 3.2-17 Deployment of base stations and ground surface tilt sensors (Reotala)

(Source: JET)

Photo 3.2-6　Deployment of alarm and database servers
(Located at DoST headquarters in Thimphu)

In addition, as for the system (RSWS), the ability to send out gmail via third-party application programs is considered a security issue when the gmail account resides at the Google® headquarters, and Google's policy of restricting the ability to send gmail (in May 2023) has resulted in the restriction of the sending of alerts via email, which was previously possible. [6]Due to this policy, the sending of alerts by email, which had previously been possible, is now restricted. Therefore, a new account was set up (ckc-alert@ckcnet.co.jp) and a new server port number was assigned (changed to 587) to restore the ability to send emails (April 29, 2024).

[6] Email Sender Guidelines, Google, https://support.google.com/a/answer/81126?hl=ja

Table 3.2- 9 Items modified (results of on-site response on April 15-17, 2024)

Item	S-1: Razhau	S-2: Dzongkhalum	S-3: Reutala
Mobile SIM Single Access performance with mobile communication network	Tashi cell 4G was not received 3G was unstable Response: The carrier was changed to Bhutan Telecom and relocated to Nobdin.	Bhutan Telecom 4G was received Response: The status quo was maintained.	Tashi cell 4G was not received 3G was not received Response: The carrier was changed to Bhutan Telecom and moved to Panzur.
Datalogger Observation and Recording Performance	OK	Rain gauge ID was wrong (00000004). Response: Changed to 00000002.	OK
Solar Panel Solar panel	OK	OK	OK
Charge Controller Voltage converter	OK	Exchanged Response: Replaced.	NG, Exchanged Response: Replaced.
Car Batteries battery	Exchanged Response: Replaced.	Exchanged Response: Replaced.	Exchanged Response: Replaced.

(Source: JET)

As of April 29, 2024, for each monitoring instrument, taking into consideration the outflow of the tiltmeter (Leotara) due to the slope collapse in 2020, the change of mobile communication network standard (from 3G to 4G), and the ease of maintenance (distance from each regional office), the Rachau station (rain gauge) was moved to the DoST office site in Nubding The Rachau station (rain gauge) was moved to the DoST office site in Nubding, and the Leotara station was moved to the DoST office site in Pangzur.

(Source: JET)

Photo 3.2-7 Relocation of the observatory (April 15-17, 2024, Rachau, Leotara relocation and testing)

Activity 1-4 Analyze and evaluate basic data to establish traffic control zones and standard rainfall values for traffic control

Slope failures supplemented by surface tilt sensors during the 2019 rainy season at the three measurement sites were reviewed with monitoring data from surface tilt sensors and rain gauges.During the 2019 rainy season, 13 slope failures were observed by tilt sensors, as shown below.

Table 3.2- 10 Time of occurrence of slope failures supplemented by surface slope sensors during the 2019 rainy season.

Measurement Site Name	Ground surface inclination sensor No.	Time of slope failure
Razhau.	4	2019/7/24 14:10
Dzongkalom	17	Jul 11, 2019 13:00
	18	2019/7/11 14:10
Reotala	21	2019/7/8 11:10
	22	2019/5/29 08:40
	23	5/28/2019 19:20
	24	2019/5/29 05:30
	25	2019/7/8 07:00
	29	2019/5/4 17:40
	30	2019/5/4 09:20
	31	2019/7/8 06:20
	32	2019/5/2/28 01:20
	33	2019/6/26 11:00

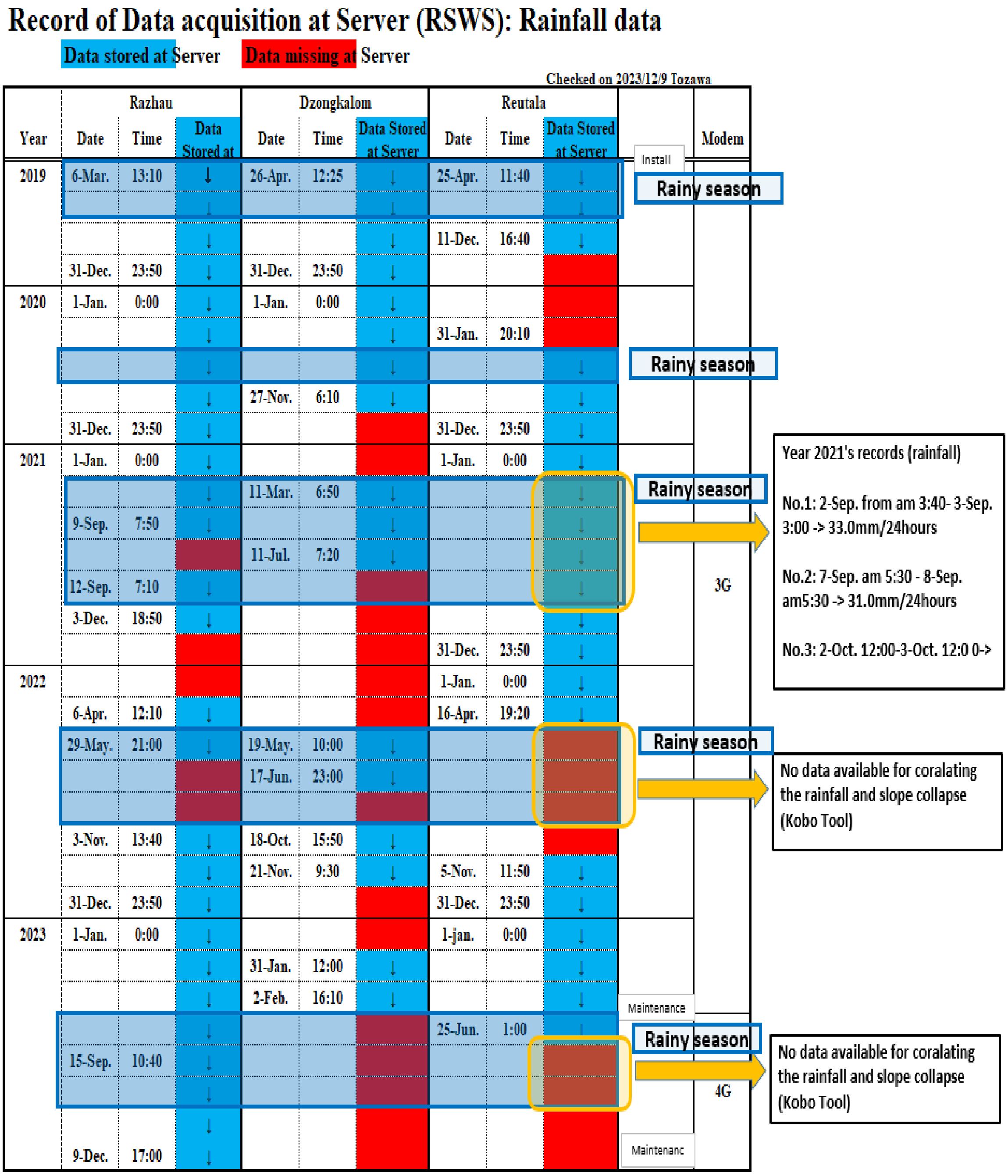
(Source: JET)

Of these slope failures, those that were clearly related to rainfall were analyzed and evaluated as follows. The results of this analysis and evaluation are taken into account when determining the threshold values for the implementation of exante trafic control in the future. However, since the number of measured data of slope failure is small at this point, it is necessary to continue to accumulate measured data and to consider the determination of threshold values.

The table below summarizes the status of observation data records from the time of installation (April 2019) to December 2023. This shows the status of the data observed by the rain gauges and tiltmeters installed in each regulated section, relayed from each reference station via mobile communication network, and stored in the DoST-managed server. since the installation in 2019, problems related to maintenance (maintenance) of observation equipment and base stations (for example, storage battery deterioration of storage batteries, short circuits caused by water intrusion into the wiring of the power conditioner (an inverter [DC-AC converter], a machine that converts the DC power generated by the solar cell module into AC power so that AC loads such as wireless modules can be used), and other maintenance-related external factors) have occurred, The impact on the reliability of the observation data stored on the DoST-managed server (no missing data) was considered. As for the establishment of a maintenance system, JET decided to continue its search for a maintenance system while continuing to accumulate observation data (e.g., distributors of electrical parts, suppliers of storage batteries, etc.) because there were no optimal suppliers of materials and equipment in the vicinity of the observatory.

Phenomena related to maintenance (external factors: factors that threaten the preservation of observation records) include the following events.

1. In Reotala, the regulated slope collapsed, and the tiltmeter installed there was washed away into the valley, making measurement impossible.
2. 2020 project interruption due to the Corona disaster caused a voltage drop in the batteries, making it impossible to supply power.
3. Due to the update of mobile communication network standards (3G→4G: 4th Generation/Long Term Evolution), the communication standard of the wireless module could not be supported and data communication became impossible, so the module was changed to a standard-compliant wireless module.
4. Recording operation was temporarily interrupted due to a server switchover caused by a change in the server's management entity.



Record of Data acquisition at Server (RSWS): Rainfall data

Data stored at Server | Data missing at Server

Checked on 2023/12/9 Tozawa

Year	Razhau Date	Razhau Time	Razhau Data Stored at	Dzongkalom Date	Dzongkalom Time	Dzongkalom Data Stored at Server	Reutala Date	Reutala Time	Reutala Data Stored at Server		Modem
2019	6-Mar.	13:10	↓	26-Apr.	12:25	↓	25-Apr.	11:40	↓	Install / Rainy season	
			↓			↓			↓		
			↓			↓	11-Dec.	16:40	↓		
	31-Dec.	23:50	↓	31-Dec.	23:50	↓					
2020	1-Jan.	0:00	↓	1-Jan.	0:00	↓					
			↓			↓	31-Jan.	20:10			
			↓			↓			↓	Rainy season	
			↓	27-Nov.	6:10	↓			↓		
	31-Dec.	23:50	↓				31-Dec.	23:50	↓		
2021	1-Jan.	0:00	↓				1-Jan.	0:00	↓		
			↓	11-Mar.	6:50	↓			↓	Rainy season	
	9-Sep.	7:50	↓			↓			↓		
				11-Jul.	7:20	↓			↓		
	12-Sep.	7:10	↓						↓		3G
	3-Dec.	18:50	↓						↓		
							31-Dec.	23:50	↓		
2022							1-Jan.	0:00	↓		
	6-Apr.	12:10	↓				16-Apr.	19:20	↓		
	29-May.	21:00	↓	19-May.	10:00	↓				Rainy season	
				17-Jun.	23:00	↓					
	3-Nov.	13:40	↓	18-Oct.	15:50	↓					
			↓	21-Nov.	9:30	↓	5-Nov.	11:50	↓		
	31-Dec.	23:50	↓				31-Dec.	23:50	↓		
2023	1-Jan.	0:00	↓				1-jan.	0:00	↓		
			↓	31-Jan.	12:00	↓			↓		
			↓	2-Feb.	16:10	↓			↓	Maintenance	
			↓				25-Jun.	1:00	↓	Rainy season	
	15-Sep.	10:40	↓								
			↓								4G
			↓								
	9-Dec.	17:00	↓							Maintenanc	

Year 2021's records (rainfall)

No.1: 2-Sep. from am 3:40- 3-Sep. 3:00 -> 33.0mm/24hours

No.2: 7-Sep. am 5:30 - 8-Sep. am5:30 -> 31.0mm/24hours

No.3: 2-Oct. 12:00-3-Oct. 12:0 0->

No data available for coralating the rainfall and slope collapse (Kobo Tool)

No data available for coralating the rainfall and slope collapse (Kobo Tool)

(Source: JET)

Table 3.2-9 Status of data acquisition since the time of installation (April 2019)
(Data storage status at the DoST management server / ↓ indicates that records are stored)

Therefore, when it was not possible to obtain measurement data at the time of slope failure, JET extracted disaster cases that occurred close to the section where exante trafic control was implemented from the traffic interruption records in the Kobo Tool system (a management system that records road traffic interruption information) separately managed by DoST. The standard rainfall for the regulation was determined by identifying the time of occurrence and verifying the correlation between the time of occurrence and the observed rainfall. The basic concept is described below.

From the data of disaster events that occurred in the vicinity of each station, JET extracted disaster events that were judged to have occurred close to the rain gauge from the database after 2019, when Kobo Tool started recording, and identified the top 10 disaster events (the top events are those closest to the rain gauge, with the closest distance to the rain gauge as No. 1). The top 10 disaster events (the one closest to the rainfall monitoring station is ranked first) are identified using the time occurrence of the event, and the rainfall data (continuous rainfall) observed at the same time. The relationship between disaster events and continuous rainfall is compared on a graph using the temporal change in continuous rainfall. This was done with data from each observation station to search for threshold values. As a result of the analysis, it was found that, for example, in Trongsa (Dzongkarom station/regulation section), the location of disaster events falls within an area of about 10 km from the rain gauge installation point, and the correlation between disaster events and continuous rainfall was validated (the dominant area of the rain gauge where rainfall observation and its prediction are valid is about 5 to 10 km)[7]. (Due to the influence of topographic rainfall, the extent of the dominant area with the same rainfall for the same rain gauge varies between plains and mountains).

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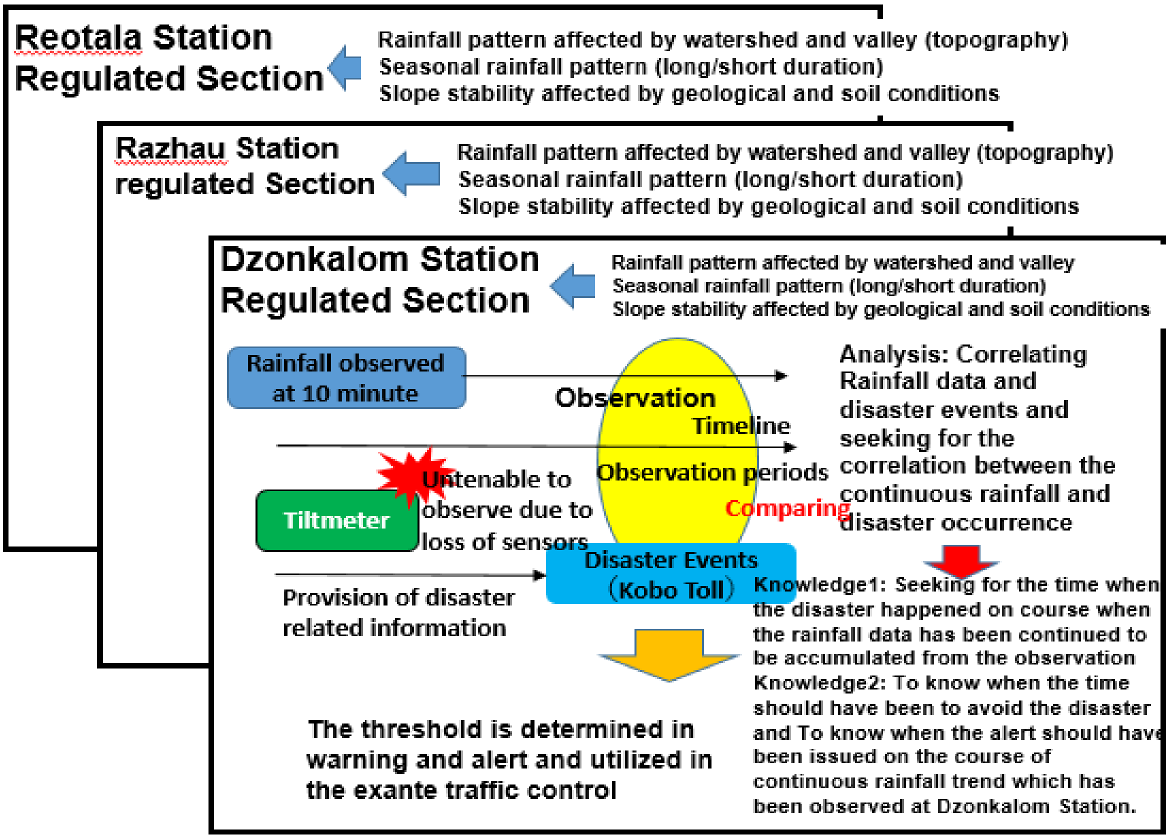
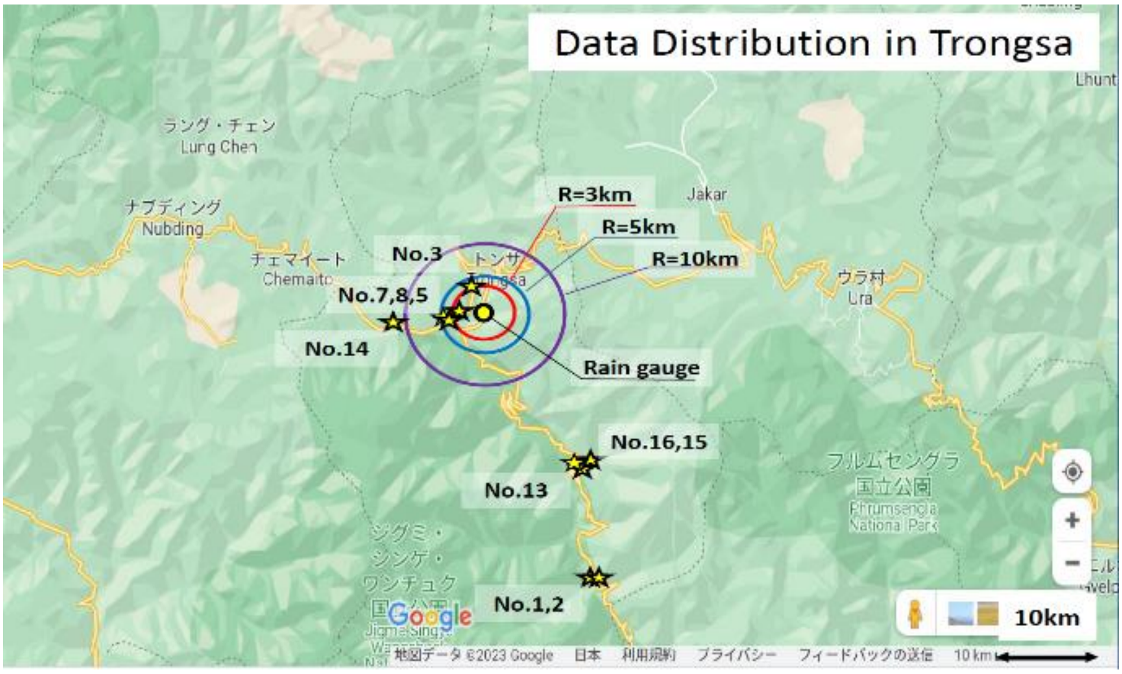
[7] Miyake: Density of rainfall stations and observed density of area rainfall, https://www.jstage.jst.go.jp/article/suirikagaku/17/4/17_57/_pdf/-char/ja





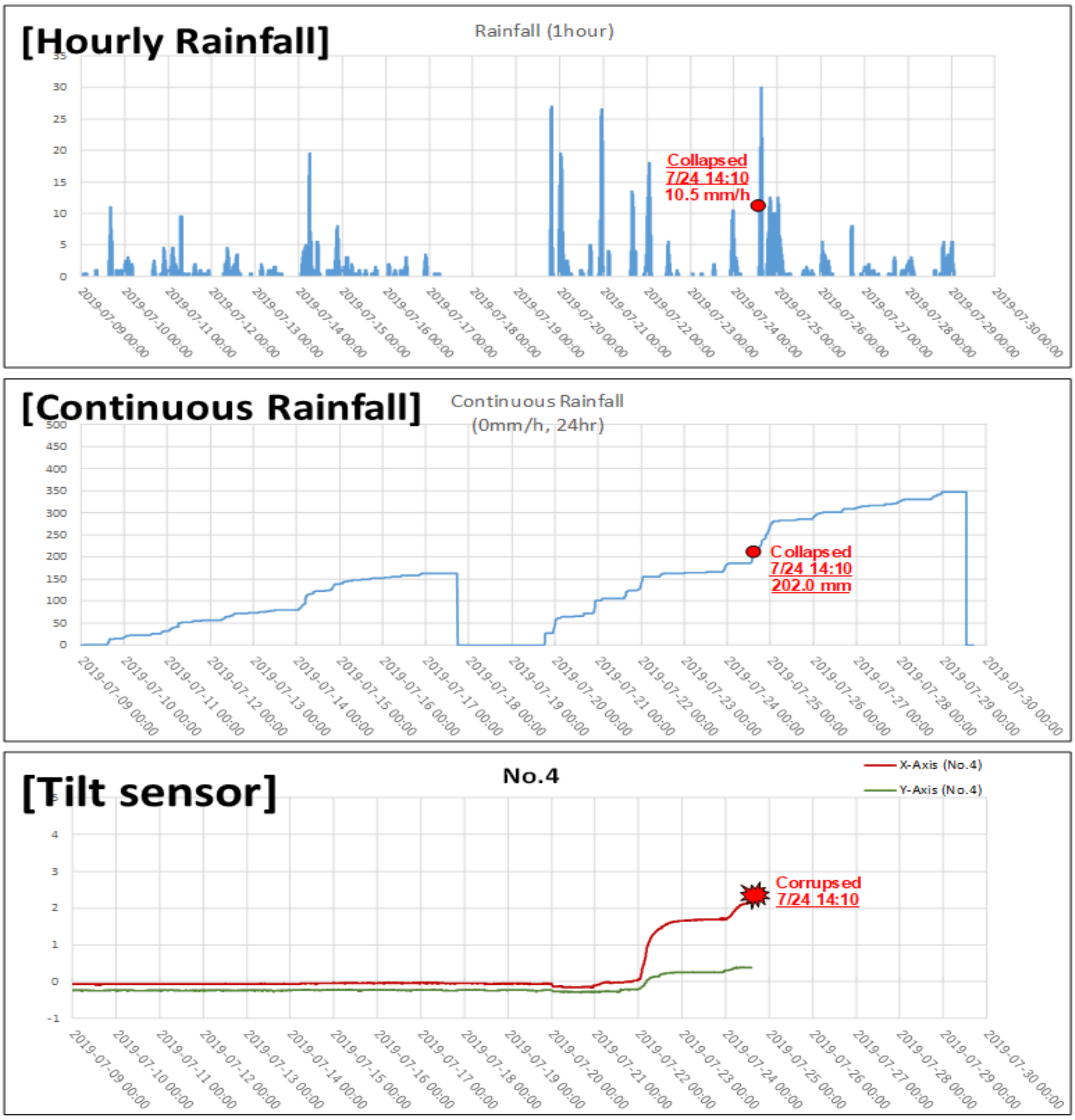
(Source: JET)

Figure 3.2- 18 How to determine thresholds, distribution of disaster events and rainfall observations

(1) Razhau.

Slope failure occurred at Sensor No. 4 on July 14, 2019 at 14:10. The following figures show the rainfall and surface slope sensor measurements before and after the occurrence of the slope collapse. The upper graph shows the hourly rainfall (also called rainfall intensity), the middle graph shows the continuous rainfall (however, if there is no rainfall for 24 hours, the accumulation is stopped), and the lower graph shows the ground surface tilt angle. The time of slope failure is indicated by a red dot in each figure.

These graphs show that the continuous rainfall and hourly rainfall at the time of slope failure were 202.0 mm and 10.5 mm / h, respectively. In determining the thresholds for future exante trafic control, JET used 202.0 mm of continuous rainfall and 10.5 mm / h of hourly rainfall.



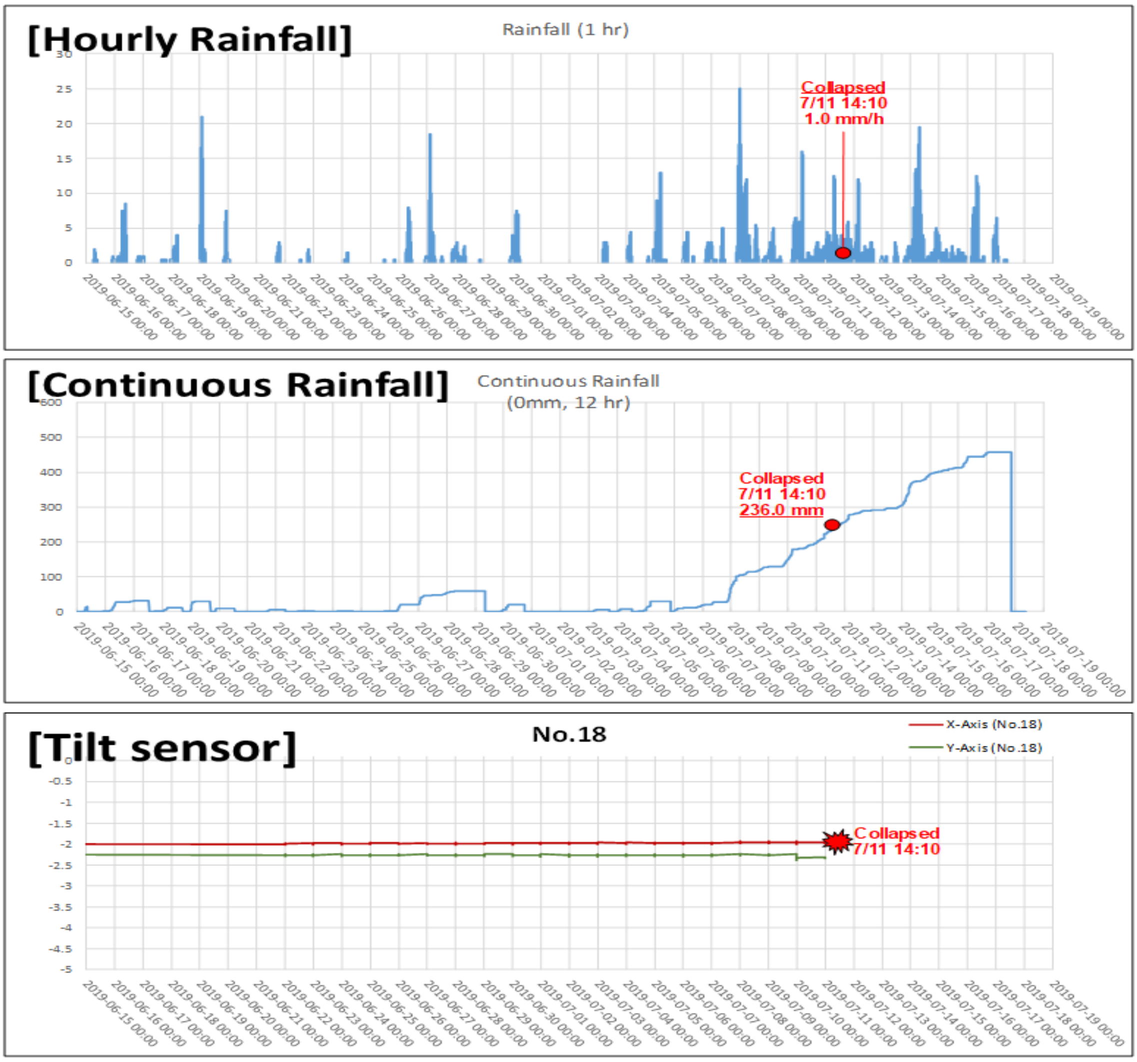
(Source: JET)

Figure 3.2- 19 Onset results of slope failures supplemented by surface slope sensors during the 2019 rainy season (Razhau).

(2) Dzongkalom

Slope failure occurred at Sensor No. 18 on July 11, 2019 at 14:10. The following figures show the rainfall and surface slope sensor measurements before and after the occurrence of the slope collapse. The upper graph shows the hourly rainfall (also called rainfall intensity), the middle graph shows the cumulative rainfall (however, if there is no rainfall for 12 hours, the accumulation is stopped), and the lower graph shows the ground surface tilt angle. The time of slope failure is indicated by a red dot in each figure.

From these graphs, the continuous rainfall at the time of slope failure is 236.0 mm and the hourly rainfall is 1.0 mm / h. This is a guideline for setting the regulatory standard rainfall.



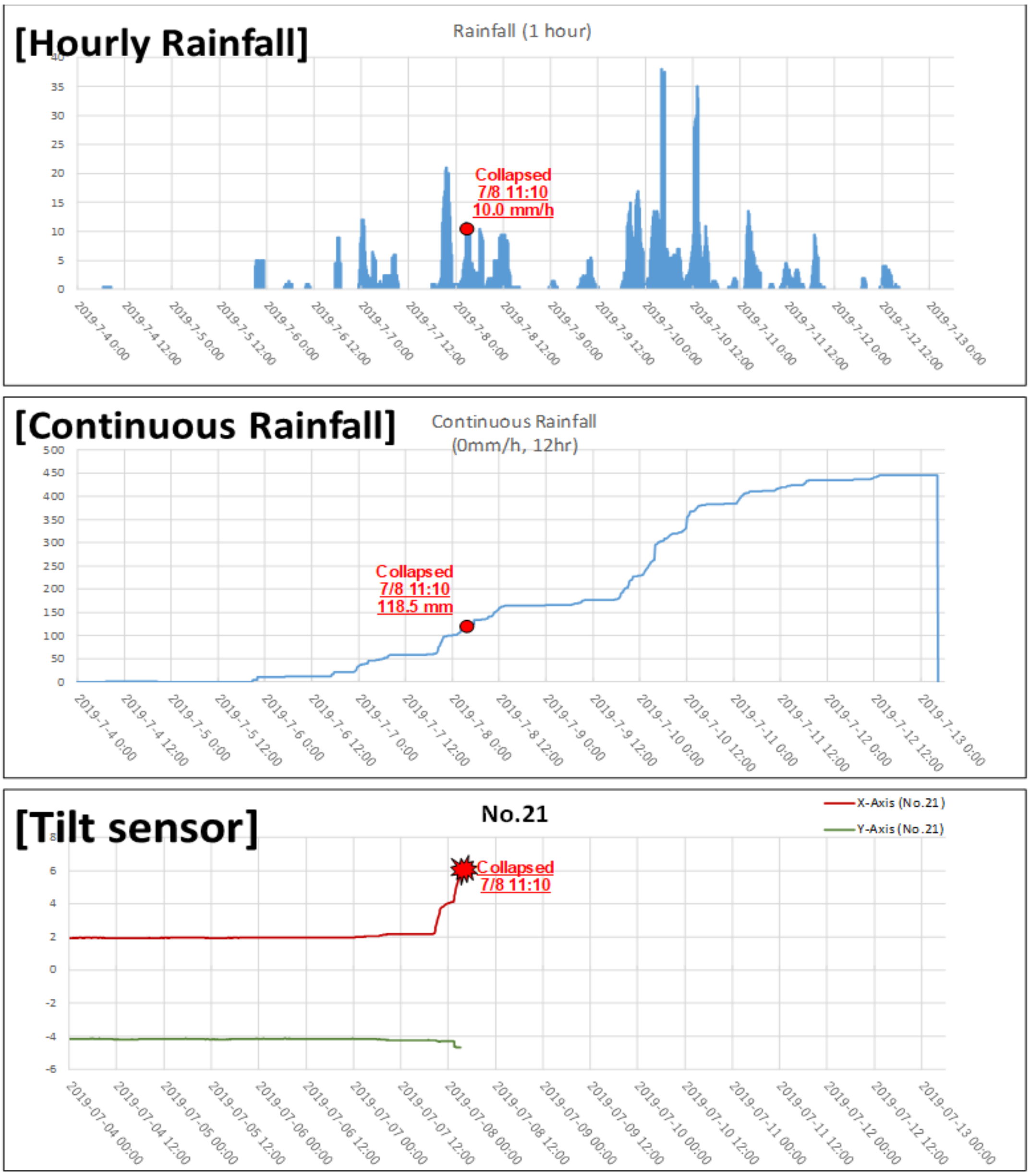
(Source: JET)

Figure 3.2- 20 Onset results of slope failures supplemented by surface tilt sensors during the 2019 rainy season (Dzongkalom).

(3) Reotala

Slope failure occurred at Sensor No. 18 at 11:10 a.m. on July 8, 2019. The following figures show the rainfall and surface slope sensor measurements before and after the occurrence of the slope collapse. The upper graph shows the hourly rainfall (also called rainfall intensity), the middle graph shows the cumulative rainfall (however, if there is no rainfall for 12 hours, the accumulation is stopped), and the lower graph shows the ground surface tilt angle. The time of slope failure is indicated by a red dot in each figure.

These graphs indicate that the continuous rainfall at the time of slope failure was 118.5 mm and the hourly rainfall was 10.0 mm / h. This is a guideline for setting the regulatory standard rainfall.



(Source: JET)

Figure 3.2- 21 Onset results of slope failures supplemented by surface tilt sensors during the 2019 rainy season (Reotala)

(4) Considering the Threshold

Observation have continued after the 2019 rainy season, but the analysis and evaluation of basic data acquired after 2020 and the determination of thresholds for exante trafic control were conducted by DoST and JET, and were decided at the 7th JCC in June 2023. Note that since the installation in April 2019, due to the loss of tiltmeters due to slope failure (Reotala) and the cessation of tiltmeter functionality due to the interruption of maintenance work caused by the coronal disaster, for Razhau and Dzonkalom, the road slope management system (KoboTool Box), managed by DoST, has been used to observe that the threshold value for Roetala was determined by comparing the data from the surface slope sensor and the rain gauge. The threshold values for Roetala were not used for the threshold for exante traffic control in the field due to the small number of reference data, and the accumulation of future observations was used to improve the accuracy of determining the threshold values.

Table 3.2-10 Thresholds for each interval

Segment			Razhau.	Dzonkalom	Reutala
Threshold for preparing regulations: Yellow	A=0.8*C	Continuous [mm].	62	76	94
Threshold to initiate regulation:.Red	B=0.9*C	Continuous [mm].	70	85	106
Thresholds correlated with collapse	C	Continuous [mm].	78	95	118

(Source: JET)

Razhau searched for relationships between the observations (rainfall) that could be obtained since the installation in April 2019 and the top 10 collapse phenomena regarded to be rock failures by the KoboTool Box, using the coincidence on the time axis as a key. These were plotted in the combinations of (rainfall, collapse) on the graph, and the scatter of the plots. The minimum continuous rainfall [mm] at the time the collapse event actually occurred was examined excluding plots that were biased based on the scatter of the plots. As a result, it was determined that the minimum continuous rainfall [mm] at which a collapse event would begin to occur was 78 [mm].

Dzonkalom searched for relationships between the observations (rainfall) that could be obtained since the installation in April 2019 and the top 10 collapse phenomena determined to be rock failures by the KoboTool Box, using the coincidence on the time axis as a key, and plotted the combination of (rainfall, collapse) on the graph, scattering the plots. The data were plotted on the graph and the minimum continuous rainfall [mm] at the time the collapse event actually occurred was examined, it was determined that 95 [mm] was the minimum continuous rainfall at which a collapse event would begin to occur.

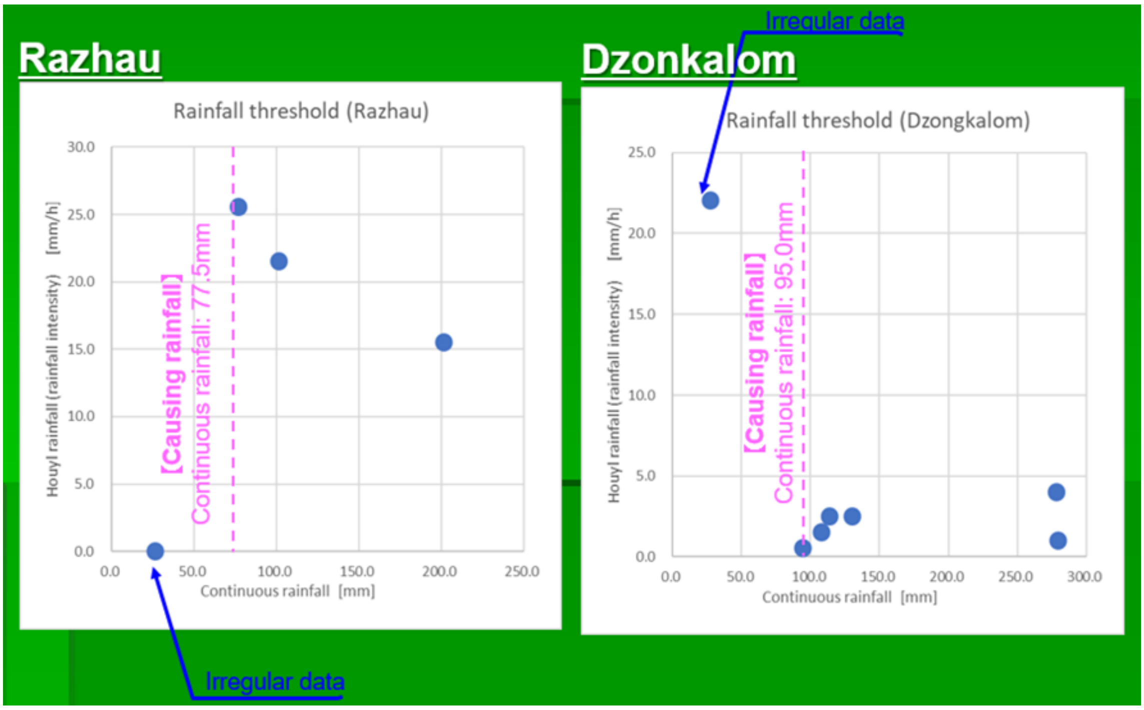
Reotala extracted cases where the observed (rainfall) surface tiltmeters that could be obtained since their installation in April 2019 were determined to have collapsed, and determined that the continuous rainfall at which the collapse event occurred was 118 [mm] (this is only a reference value due to the small sample size sufficient to be reliable).

The threshold for preparing regulations (A : Yellow value) was set at 80% of the threshold (C) at which collapse is assumed to begin, and the threshold for initiating regulations (B : Red) was set at 90% of the threshold (C) at which collapse is assumed to begin. The reason for this is to take into account the time required for DoST regional office staff to gather at the office and the time required to retrieve equipment and materials (poles, bars, and cones) from the warehouse and load them onto trucks before leaving for the site, taking into account the time required for continuous rainfall to monotonically increase. The rate settings for A and B are to be continuously improved through operation.

The thresholds were changed prior to the simulated drill (April 29-30, 2024) due to system modifications and relocation of the observatory on April 15-17, 2024.

At Razhau, the warning (Yellow) was set at 26 mm and the alert (Red) at 45 mm,

In Dzonkalom, the thresholds were changed to 13 mm for Yellow and 36 mm for Red.



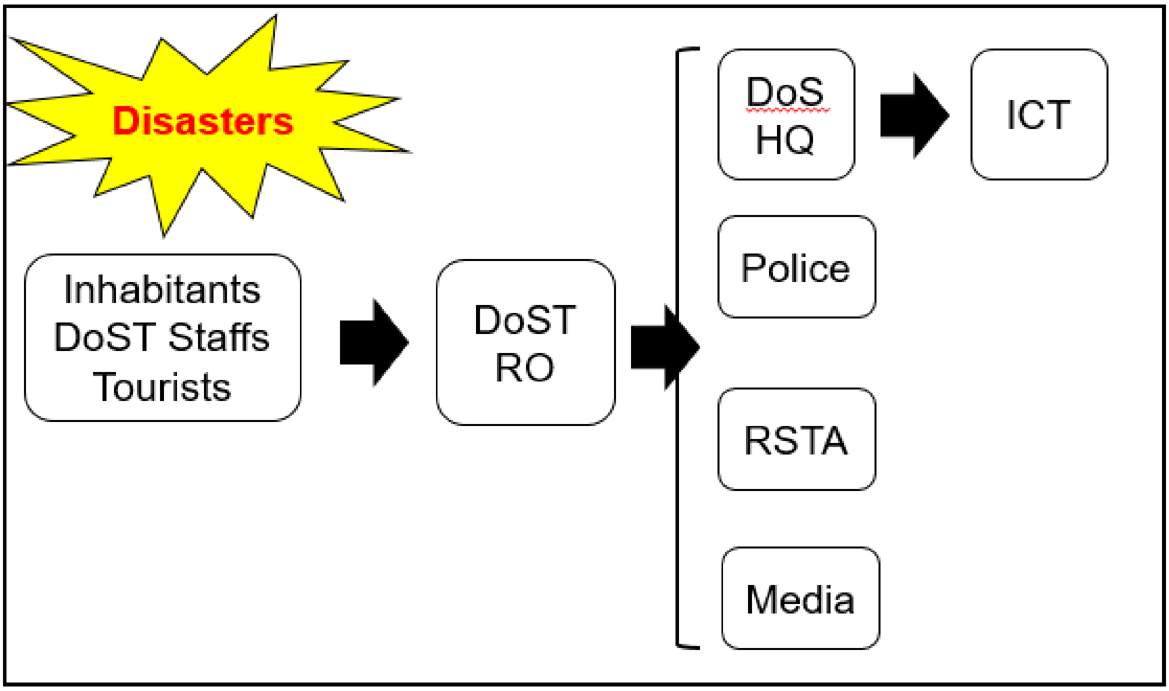
(Source: JET)

Figure 3.2- 22 Continuous rainfall as a basis for setting thresholds in the Razhau and Dzonkalom sections.

Activity 1-5. Analyze the current issues of the exante trafic control system (headquarters and regional offices) and establish an appropriate system

(1) Current status of exante trafic control system

To date, the DoST had no experience with exante trafic control and had not established a system for this purpose. Until now, the system shown in the figure below was established for traffic control starting immediately after the occurrence of a slope disaster.



(Source: JET)

Figure 3.2- 23 Regulatory regime after a slope disaster

- ✓ Information on the occurrence of road slope disaster was obtained from residents living near the site of the slope disaster, residents, workers, travelers, travel guides, DoST staff, and police passing by the site, and from reports to the RO of the DoST.
- ✓ The RO of the DoST communicates information on the occurrence of a road slope disaster to the DoST headquarters, police, RSTA, etc., and initiates road rehabilitation.
- ✓ The DoST headquarters communicated information obtained from ROs on the occurrence of road slope disasters and the resulting restrictions on passage (road closures) to the ICT (Information and Communication Technology Department) for data entry into the road information system.

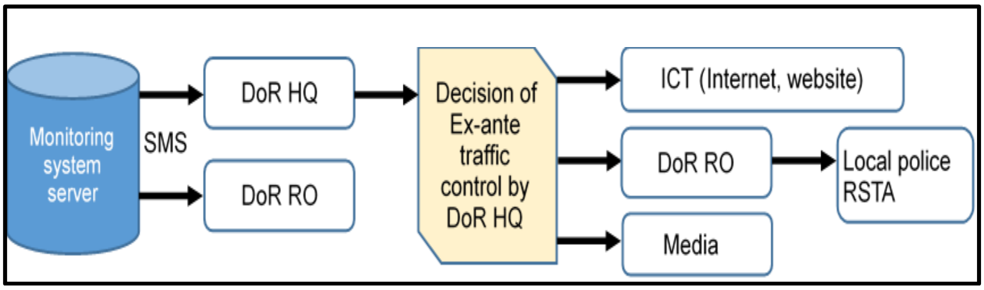
(2) Image of exante trafic control system that needs to be developed in the future

In this study, JET proposed the establishment of an exante trafic control regim based on rainfall thresholds. The figure below shows an exante trafic control regime that is envisioned to be established in the future, with reference to the existing regime for road slope disasters. This proposal has the following effects.

1. Consistency of information distribution is established, whereby information on the actual occurrence of road slope hazards is centralized at the road administrator and then transmitted to the road user side via the road

administrator's decision on whether or not to implement the regulation. Therefore, they are able to know the information about the regulation before entering the regulated section, which gives efficiency to their decision to travel and their behavior after the decision is made (behavior change) from the road user's perspective.

2. On the road administrator's side, the decision to implement or lift the regulation is made proactively based on the information (threshold values) that predicts slope failure, while considering the condition of road traffic in the pre-rainfall regulation section. Therefore, it is expected that the road administrator, as the entity that provides traffic services to society on national roads including the regulated section, is more aware of the need to preserve road earthwork structures and drainage facilities (slope preservation) by being accountable for the implementation of regulatory measures for road traffic.



(Source: JET)

Figure 3.2- 24 Image of exante trafic control system

- ✓ When the rainfall exceeds the rainfall threshold, the monitoring system server sends an SMS or email notification to the DoST headquarters and DoST-RO officials to initiate exante trafic control.
- ✓ The DoST HQ reviews the monitored rainfall and determine whether or not to restrict traffic in advance.
- ✓ If DoST HQ decides to implement exante trafic control, DoST HQ instructs DoST-RO to implement exante trafic control, and also informs ICT and the media of the start of exante trafic control.
- ✓ Upon receiving instructions from the DoST Headquarters, the DoST-RO contacts the RSTA and the police to instruct them to implement traffic restrictions at the site, and also goes to the site to confirm the current situation, direct the restoration work, and decide whether to lift the restrictions.

Activity 1-6. Conduct mock drills for local traffic control in the selected restricted areas.

After setting the rainfall thresholds as described above, an implementation system was established, and a mock training for advance rainfall control was conducted on June 6, 2023 in the regulated section of Dzonkalom for employees of the Trongsa RO, and on June 7, 2023 in the regulated section of Razhau for employees of the Lobesa RO. In addition, a mock drill based on the manual (Ver 3) was conducted in Dzonkalom on April 29-30, 2024.

First, for the 2023 mock drill, the manual was reviewed in the morning to confirm the division of roles among the DoST, local police, and RSTA, as well as action procedures according to the timeline. After that, the DoST headquarters reviewed the implementation of regulations, the DoST regional office received instructions, and the DoST contacted the local police and RSTA to initiate advance rainfall restrictions for the restricted areas in the area. In the criteria for regulation implementation, an alert (SMS, email) would be issued according to the set rainfall threshold as described above, and the regulations would be implemented in the field according to the predetermined information distribution flow. As for the criteria for lifting the restrictions once implemented, the DoST staff makes a decision based on the following information sources (1) and (2) in the mock drill. Specifically, for information (1), DoST staff monitored the rainfall information observed by the RSWS. When the current rainfall reached the lifting criteria (e.g., rainfall of 2 mm or less per hour for 3 consecutive hours), and for information (2), RO staff with jurisdiction over the restricted area observed the slopes to be lifted based on the slope conditions in the checklist. The information (2) is that the information obtained from the on-site staff when the items indicating the condition of the slope based on the checklist were determined to be stable on site. Based on this information, the DoST headquarters shall make the decision to lift the regulation. In Dzonkalom, the actual time of lifting was 8 minutes behind the target time for lifting, compared to the target time for lifting. This was mainly due to the fact that the staff, while monitoring the slope in the restricted area, could not see the actual slope and make an immediate decision on whether or not to lift the restriction. Also, in Razhau, the actual time of release was 7 minutes ahead of the target time (earlier than planned). The implementation of the project is shown below.

(Source: JET)

Photo 3.2-8 Mock drill in the Dzonkalom section (June 6, 2023, report, local regulation in place, results)

		Plan	Actual
Yellow Alert	Be ready	10:30	10:30
Red Alert	Road Block prepared	10:35	10:37
Decision		10:38	10:39
Instruct		10:40	10:40
Dispatch		10:42	10:41
Arrived at section		11:42	11:45
Setting up the Barigade		11:47	11:50
Termination mail received		12:02	12:06
Instruction to site investgstion		12:05	12:10
Decided to Terminate		12:15	12:14
Get order to terminate		12:18	12:15
Police/RSTA terminated		12:23	12:16

(Source: JET)

Photo 3.2-9 Mock drill in the Razhau section (June 7, 2023, on-site regulation in place, results)

The following items were noted during the review seminar (responses to the points raised are in parentheses). Some of the points raised were addressable and have been reflected in the manual.

The following comments were attached to the mock drill conducted at Dzonkalom. In parentheses are reactions from JET.

1. There is a hotline that is utilized locally (hotline shared between DoST RO and police). JET would like to see this utilized (it is difficult to incorporate this system since the applications and circuit systems are different.This would require system modification costs and reliability verification, and would be a capital investment for the DoST, so it should be considered in organizational management).
2. Simplify the checklist (simplify checklist items and consider alternatives).
3. The criteria for lifting the regulation should be clarified (for example, the regulation may be lifted when the hourly rainfall is 2 mm or less for 3 hours). As an alternative measure, a drone could be used to simultaneously photograph the slope from above from a bird's eye view, and the staff could use the video to judge the degree of danger and safety of the slope and lift the restrictions (A means to conduct the lifting of restrictions is also worth considering).

The simulated training conducted at Razhau was as follows.

1. An alarm issuance should be by SMS (SMS is the basic method since it is a push type notification).
2. Simplify the release criteria (simplify the checklist. Also, as an alternative measure, a drone could be utilized, and a system to determine the collapse risk and safety level of slopes based on images of the slopes taken by the drone could be considered).

In addition, the 2024 mock drill demonstrated the effects of the previous experience and was conducted as per procedure without significant time loss. The training was recorded and edited as a video of the field activities and uploaded to You Tube® for viewing anytime, anywhere, especially as an off-JT material for the staff of the regional office who could not participate in the mock drill.

(Source: JET)

Photo 3.2-10 Mock drill in the Dzonkalom section (April 30, 2024)

Activity 1-7. Prepare manuals for displacement and rainfall monitoring and exante trafic control

The table of contents of the manual for displacement and rainfall monitoring and advance passage control is listed below. This manual was refined and updated through the pre-passage control exercise held in April-May 2023 and reviewed and revised by DoST officials on June 10, 2023. The latest manual was then revised on April 30, 2024 in response to comments at the Director Coordination Committee (hereinafter referred as "DCC") held on April 16, 2024, which was released as the official version, Ver. 1.

Guideline for "Ex-ante traffic control"

Contents

3.3 Output 2: Suitable bio-engineering works are selected against “debris slope failure.”

Activity 2-1: Select target sections and slopes based on the results of slope disaster inspections.

In Activity 2-1, three sites were selected as test slopes for vegetation construction (also called pilot sites): one in each of Lobesa and Tongsa regional offices, which are the model regional offices for this project, and one in the southern regional office, where the climatic conditions are very different from those in Lobesa and Tongsa regional offices. The three sites are located in Lobesa and Tongsa regional offices.

At the start of this project (January 2019), the plan was to select the three target slopes for Activity 2-1 at one time, but based on the spread of the new coronavirus and changes in the status of road expansion work in DoST, the first target slope for the first test construction was selected in 2019. The second test slope was selected in 2022, and the third test slope in 2023, after consultation with the C/P, based on the local conditions at the time. The results of the selection of these three slopes for test construction are reported below.

Activity 2-1-1 Selection of the first test slope to be constructed (in 2019)

The target slopes for the vegetation construction test are those cut slopes that are subject to erosion during rainfall and are mainly formed by sediments.

The slopes were selected from Route 1 and Route 4 proposed in the detailed planning study within the jurisdiction of the model regional offices (Lobesa and Tongsa Regional Offices) based on the preceding master plan study and discussions with the C/P. The actual slope selection process was conducted by a field survey involving the C/P and an engineer from the DoFPS station of the MoAF who is familiar with vegetation. The actual slope selection process was conducted through a field survey that included engineers from the C/P and the DoFPS Bureau of the MoAF, who are familiar with vegetation. The target slopes were selected in the following three phases

Phase 1: A survey is conducted on a total of 15 slopes on Route 1 and Route 4 proposed in the detailed planning study and in the vicinity of two model regional offices to identify 20 to 30 slopes in need of vegetation work.

Phase 2: From the slopes selected in Phase 1, select about 6 suitable slopes for test construction, which are small, easy to conduct test construction, and easily observed from the two model regional offices.

Phase 3: From the slopes selected in Phase 2, one site is selected from the jurisdiction of the Lobesa Regional Office or Tongsa Regional Office as the first test slope to be constructed.

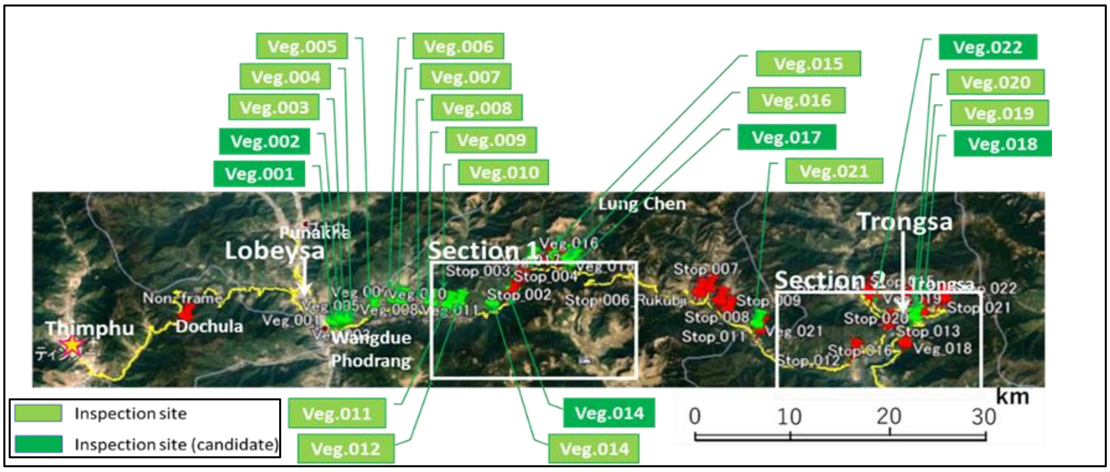
(1) Results of Phase 1 Selection

A total of 15 sites on Route 1 and Route 4 proposed in the detailed formulation study and two slopes near the model regional office were surveyed by WG members in Output 2 to identify "slopes in need of vegetation works" that meet the following conditions.

<Conditions>

1) The earth slope shall be formed by cut-and-fill construction.
2) Slopes with partial collapse history or high potential for collapse
3) Slopes where gully erosion is observed or where erosion damage is possible.

Below are the 22 slopes selected from the results of the survey study.



(Source: JET, base map: Google Earth)

Figure3.3-1 Location of the 22 slopes extracted in the first phase

(2) Results of Phase 2 Selection

From the 22 slopes identified in the first phase, six slopes were selected as suitable for test construction.

1) Considering the direction of slopes that affect vegetation growth, select 2 slopes facing south, 2 slopes facing north, and 2 slopes facing east or west.
2) Select slopes within the jurisdiction of both regional offices that are close to the two model regional offices and easily observed.
3) Select at least one location from the two-model regional office jurisdictions.

Location maps and site conditions for the six selected sites are shown in the following figures. In addition, the results of the field survey conducted for the selection are shown in the table.

(Source: JET, base map: Google Earth)

Figure 3.3-2 Location of the six slopes extracted in phase 2.

Table 3.3-1 List of survey results for candidate slopes for test construction of Output 2

No.	Vegetation (survey)	jurisdiction (Office)	Test Imple.	latitude [E]	longitude [N]	altitude (m)	slope facing direction E	W	S	N	spring water etc. (present/ no)	Slope failure (present/ no) This slope	nearby	Status check	Purpose of test vegetation Purpose
1	Veg. 001	Lobesa	◎	89.9047	27.4847	1,193			✓		no	partial	(rock)	There is some surficial slope failure. The Lobesa Regional Office plans to install gabions in the future. It is necessary to cut the slope and create vegetation.	Germination test Protection for surficial erosion
2	Veg. 002	Lobesa	○	89.9141	27.4857	1,202			✓		no (dry)	partial	(rock)	The bioengineering was done cuttings and was ineffective due to gully erosion. Replacement of the upper channel and recutting of the slope were required.	Germination test Protection for surficial erosion
3	Veg. 003	Lobesa		89.9158	27.4869	1,334			✓		no	surficial	(rock)	A lot of rock debris, making it unsuitable for vegetation work.	
4	Veg. 004	Lobesa		89.9185	27.4875	1,303			✓		no	surficial	(rock)	Gabions at the foot of the slope. The rock slope is likely to exfoliate, and the slope height is high. Not suitable for vegetation.	
5	Veg. 005	Lobesa		89.9459	27.4987	1,353	✓				no	surficial	(rock)	Southeast slope. Rock debris present. Partial vegetation recovery.	
6	Veg. 006	Lobesa		89.9692	27.5058	1,337				✓	present	shallow	vulnerable	Northeast slope. A small debris flow. The slope is gentle but unstable.	
7	Veg. 007	Lobesa		89.9771	27.5041	1,430			✓		(semi-dry)	surficial	(rock debris)	A lot of rock debris and the surface is enfoliation. Not suitable for vegetation work.	
8	Veg. 008	Lobesa		90.0075	27.5034	1,523				✓	no	surficial	(rock)	Gabions at the foot of slope. Erosion is progressing on surface layer , and the slope is high. Not suitable for vegetation.	
9	Veg. 009	Lobesa		90.0257	27.5002	1,632				✓	no	surficial	(rock)	Debris and contains large rocks. Large-scale cut slope is required for vegetation to grow. Not suitable for vegetation.	
10	Veg. 010	Lobesa		90.0369	27.5019	1,659				✓	(wet)	surficial	vulnerable	Rock debris. Erosion is accelerating on the slope. Houses nearby. The slope needs to be recut to accommodate vegetation.	
11	Veg. 011	Lobesa		90.0719	27.5025	1,863				✓	(semi-dry)	shallow	vulnerable	North-northeast slope. Gabions which is loose at the foot of slope.	
12	Veg. 012	Lobesa		90.093	27.5153	2,088				✓	(semi-dry)	shallow	(rock)	North-northwest slope. Erosion of the surface layer progresses on the steep slope.	
13	Veg. 013	Lobesa		90.1119	27.544	2,387		✓			(semi-dry)	surficial	(rock)	Northwest slope. Debris slope, containing large rock blocks.	
14	Veg. 014	Lobesa	◎	90.1361	27.5479	2,518				✓	(semi-dry)	no	no	North slope, stable under current conditions. Candidate for a vegetation test site in a severe climate environment.	Germination test Protection for surficial erosion
15	Veg. 015	Lobesa		90.1501	27.5452	2,519		✓			(semi-dry)	surficial	no	Southwest slope. If cutting slope is done in the future, vegetation work will be suitable.	
16	Veg. 016	Lobesa		90.1544	27.5419	2,680			✓		(wet)	loose surface	no	Debris flow deposits, natural recovery of vegetation.	
17	Veg. 017	Lobesa	○	90.1563	27.5424	2,625				✓	(semi-dry)	partial (surface)	no	Stable under current state. Low elevation. Candidate site for vegetation works under severe climatic conditions in the future.	Germination test Protection for surficial erosion
18	Veg. 018	Trongsa	○	90.5009	27.4639	2,040		✓			(semi-dry)	partial (surface)	(rock)	Southwest slope. If cutting slope is done in the future, vegetation work will be suitable.	Germination test Protection for surficial erosion
19	Veg. 019	Trongsa		90.5106	27.4877	2,053		✓			(wet)	shallow	(rock)	Debris flow deposits, natural recovery of vegetation.	
20	Veg. 020	Trongsa		90.5127	27.4941	2,094			✓		(semi-dry)	spalling	vulnerable	The current state is stable. The vegetation is recovering naturally. The slope surface is loose a bit. Houses nearby.	
21	Veg. 021	Trongsa		90.3463	27.4811	2,473		✓			no	surficial	vulnerable	The surface to shallow layers of the slope are unstable. When cutting is performed, a long slope is formed.	
22	Veg. 022	Trongsa (Bjeepam)	◎	90.4791	27.4989	2,028		✓			(semi-dry)	no	partial	Northwest-north slope, small slope failure on the west side, with gabions.	Germination test Protection for surficial erosion

(Source: JET)

(3) Results of Phase 3 Selection

From the slopes extracted in the second phase, one slope was selected from the jurisdiction of the Lobesa Regional Office as the first test construction slope. The second test construction slope (within the jurisdiction of the Tongsa Regional Office) and the third test construction slope (in the southern region) were selected after the first test construction was completed and the results were evaluated.

The following points were considered for Veg. 001 and Veg. 002 slopes that were selected as candidates for the first test construction slope in the jurisdiction of Lobesa Regional Office during the second stage, and Veg. 001 (place name: Gangthangka) was finally selected as the first test construction slope. The selection table for the first test construction slope is shown below.

1) Slopes of a scale that makes it easy to conduct test construction on a small scale and keep construction costs within budget
2) South-facing slopes with good growth potential.
3) Location for easy observation (close to office)

Table 3.3-2 Selection table for the first test construction slope.

Item	Veg. 001, Gangthangka	Veg. 002 slope
Site photograph		
Current status	Small sediment slope constructed by cut-and-fill construction. Although the slope is relatively new, partial surface collapse and erosion are already evident. Early implementation of vegetation work is desirable.	Large sediment slope constructed by cut-and-fill construction. Gully erosion is very advanced, and retaining wall construction has been installed at the end of the slope by DoST. The channel at the top of the slope is damaged and needs to be replaced and the slope needs to be re-cut.
Jurisdiction	Lovesa Regional Office	Lovesa Regional Office
Latitude and Longitude	27.4847, 89.9047	27.4857, 89.9141
Location	Close to JET office, within 5 km	Close to our office, within 5 km
Scale	Small slope approximately 30m wide and 15m high	Large scale slope approximately 100m wide and 35m high
Slope-facing	facing south	facing south
Judgment	**Selection** Small slope, facing south, close to the office, ideal for the first test slope.	**Rejection (of an application)** The slope scale was too large to be the subject of the first test construction, so it was not selected.

(Source: JET)

Activity 2-1-2 Selection of the second test construction slope

(1) Candidate for 2nd test construction

For the selection of the second test slope, JET initially planned to select a slope within the jurisdiction of the Tongsa Regional Office, which was considered during the selection of the first test slope, namely Veg. 022

(first candidate) or Veg. 018 (second candidate), but JET could not obtain permission to use them because they are both on private land. Therefore, after consultation with C/P, it was decided to select a suitable site again from T-veg.001 to T-veg.008 (Previous candidate sites in the figure), but during the stagnation period of the project (from around March 2020 to April 2022) due to the spread of corona infection, these sites were not selected. Road widening work on the slopes was completed and generally stabilized. Therefore, it was decided at the DCC held on June 6, 2022, to exclude these slopes from the candidates for the second test construction slopes. In addition, the C/P newly identified six slopes from T-veg.009 to T-veg.014 (New candidate sites in the figure below) as candidates for the second test construction slopes.

(Source: JET, base map: Google Earth)

Figure 3.3-3 Location map of candidate slopes for the second test construction in the jurisdiction of the Tongsa Regional Office.

			
T-veg.001: Nyala	**T-veg.002**: Nyala	**T-veg.003**: Nyala	**T-veg.004**: Sakachawa
			
T-veg.005: Sakachawa	**T-veg.006:**Tshering Drupchhu	**T-veg. 007:**Tashiling.	**T-veg.008:** Tshangkha

(Source: JET)

Photo 3.3-1 Slopes excluded from the second round of testing (Previous candidate sites)

(2) Selection of the second test construction slope

The second test slope was selected from the six newly shortlisted slopes T-veg.009 to T-veg.014 based on the results of the field survey. The results of the field survey are presented below. The following points were considered during the field survey.

<Item for consideration>

- ✓ Workability of cut slope: Can the ease of construction and slope stability be ensured when the current cut slope is cut and shaped with the "standard cut slope" that is currently being transferred as part of the technology transfer under Output 3?
- ✓ Availability of stockyards: Is a stockyard (temporary storage) for construction materials available in the vicinity?
- ✓ Securing water for construction: Ease of securing water for use in construction.
- ✓ Construction safety: Can the project ensure the safety of road traffic during and after construction?

In addition to these considerations, the final evaluation included a determination of the suitability of the slope as a test slope for this project, including the scale, construction period, cost, topography, and geological conditions.

Table 3.3-3 Selection Table for the Second Test Construction Slope

No.	Latitude/ Longitude	Cut soil workability	Availability of stockyards	Securing water for constructio n	Constructi on safety	Rating*.	Suitability as test construction slope
T-veg. 009	27°30'16.44 "N/ 90°32'5.68 "E	Yes	Yes	Yes	No	△	It is difficult to select this slope as a test slope for vegetation work because of the landslide terrain behind it and the need to confirm the degree and scale of the landslide activity in advance.
T-veg. 010	27°30'18.95 "N/ 90°32'7.27 "E	No	Yes	No	No	X	The base rock is very shallow from the ground surface, leaving little topsoil after the cut is made, making it unsuitable for vegetation work.
T-veg. 011	27°30'19.06 "n/ 90°31'41 "e	No	Yes	No	No	X	The cut-and-cover shaping of the slope interfered with traffic on the road above. The large scale of the embankment shaping, slope stabilization, etc., and the large construction cost and time frame make it unsuitable for the test construction of Output 2.
T-veg. 012	27°30'13.43 "n/ 90°32'4.69 "e	No	Yes	No	Yes	X	Large-scale cut-and-fill and slope stabilization measures are required, construction costs are high, and the construction period may take more than one year, making it unsuitable for the test construction of Output 2.
T-veg. 013	27°30'29.4 "N/ 90°30'57.52 "E	No	No	No	Yes	X	Direct vegetation work is not possible due to the rocky slope.
T-veg. 014	26°56'44.15 "n/ 90°31'56.36 "e	Yes	Yes	Yes	Yes	○	Inadequate drainage of the fields above the slope makes the surface layer prone to collapse during heavy rainfall. Future slope erosion and slope failure could have a significant impact on road traffic. The application of vegetation works in conjunction with slope molding and drainage works is appropriate for the test construction of Output 2 because it can ensure the safety of the slope.

*Rating: ○Appropriate, △Not inappropriate but difficult to select , ×Inappropriate. (Source: JET)

		
T-veg.009	**T-veg.010**	**T-veg.011**
		
T-veg.012	**T-veg.013**	**T-veg.014**

(Source: JET)

Photo 3.3-2 New candidate sites for the second test construction.

Based on the results of the field survey, T-veg. 014 (slope east of Yangkhil Resort) was selected as the second test construction slope. This slope is located east of the Yangkhil Resort Hotel and includes private land as well as road land, but consent has been obtained from the landowners related to the construction site. The current status of the second test slope is shown below.

The subject slope had experienced slope failure and surface erosion over a width of 40 m after road widening. The cause is considered to be the lack of drainage treatment from the rice paddies behind the slope as well as the inappropriate cut slope, and it is inferred that the collapse was caused by the large amount of surface water and groundwater supplied into the slope during the rainy season. Therefore, the slope should be treated not only with vegetation, but also with cut-and-fill (re-cut to standard cut-and-fill grade) and surface and groundwater drainage. This is ideal for the transfer of technology for a comprehensive slope control method that combines not only vegetation work, but also standard cut slope and drainage work.

(Source: JET, base map: Google Earth)

Figure3.3-4 Current status of the second test slope (T-veg. 014: slope east of Yangkhil Resort) in the jurisdiction of the Tongsa District Office.

Activity 2-1-3 Selection of the third test construction slope

The selection of the third test slope was decided on Gobipi in Samtse after three stages of consideration following consultation with the DCC.

(1) Selected sites in Phase 1: Candidate Site Darachu, Sarpang, Bhutan

The following results summarize the potential sites for the third vegetation test construction.

The study route and Darachu sites are listed below.

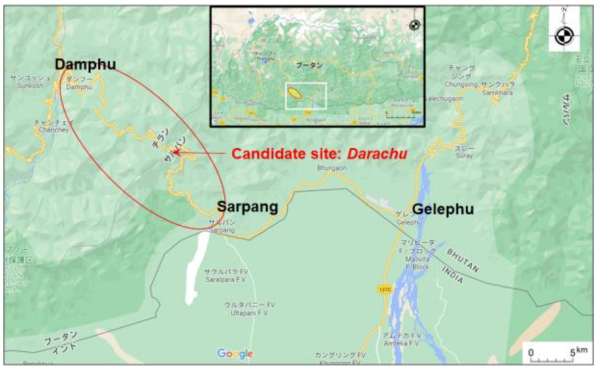


Figure3.3-5 Observation route of Damphu-Sarpang in PNH-5 (modified from Google Earth Map).

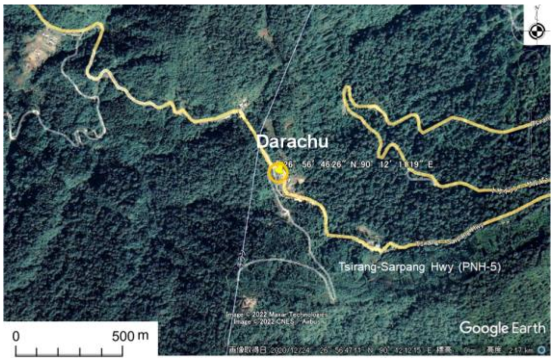


Figure3.3-6 Observation route of Damphu-Sarpang in PNH-5 (modified from Google Earth Image).

The following figure shows the study area and the location of the germination test sites.

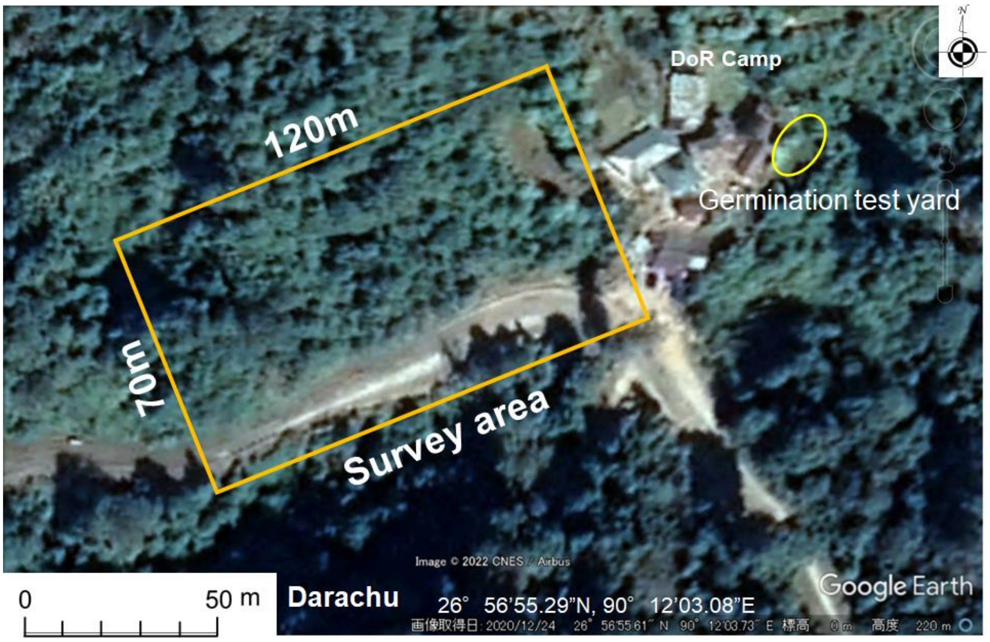


Figure3.3-7 Prospective survey area and the germination test yard (added Google Earth Image: 26°56'55.29 "N, 90°12'03.08 "E).

Photo 3.3-3 Panoramic view of the cut slope of the site Darachu.

Photo 3.3-4 The one aspect of the slope with several gully erosion.

Photo 3.3-5 The drain at the foot of the slope.

Photo 3.3-6 The prospective germination test yard
(Left: anterior of the yard, right whole view of the yard).

The process of site selection in Sarpang is explained here.

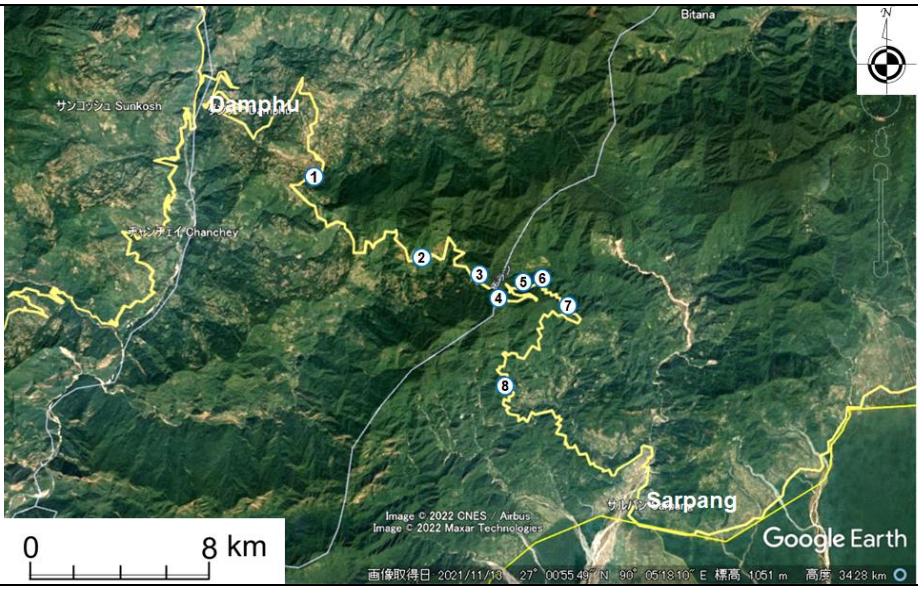
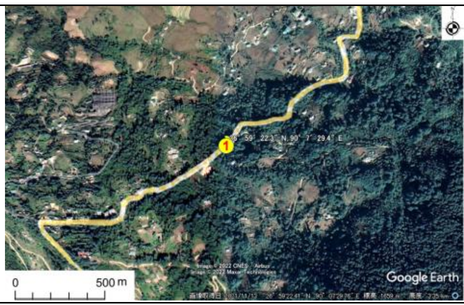
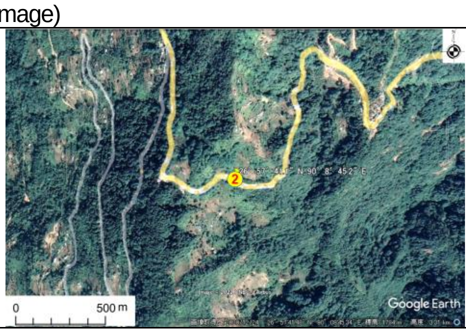
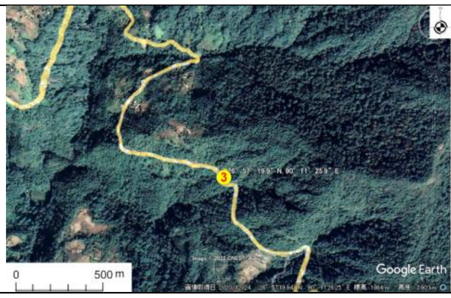
	Sar-veg.001: SITE-1 Sar-veg.002: SITE-2 Sar-veg.003: SITE-3 Sar-veg.004: SITE-4 Sar-veg.005: SITE-5 6）Sar-veg.006: SITE-6 Sar-veg.007: SITE-7 8）Sar-veg.008: SITE-8

Figure3.3-8 Location of the candidate sites (modified from Google Earth Image).

	
① Sar-veg.001:SITE-1	SITE-1 (added the point 1 on Google Earth Image)
	
② Sar-veg.002: SITE-2	SITE-2 (added the point 2 on Google Earth Image)

	
③ Sar-veg.003: SITE-3	SITE-3 (added the point 3 on Google Earth Image)

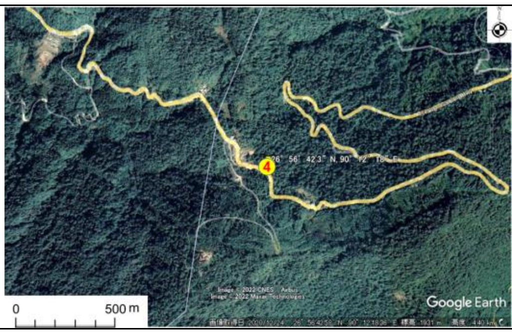
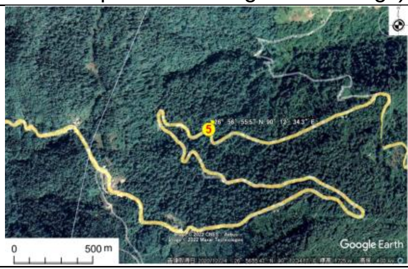
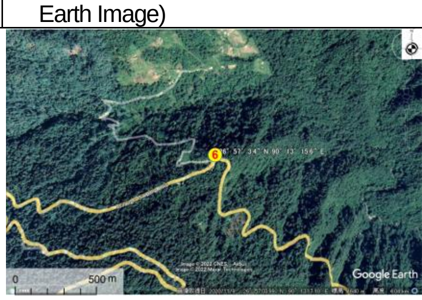
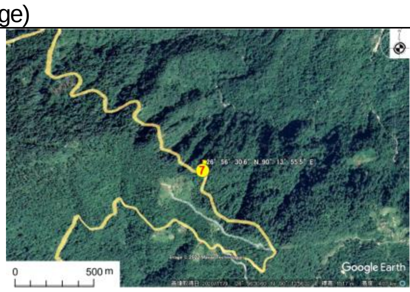
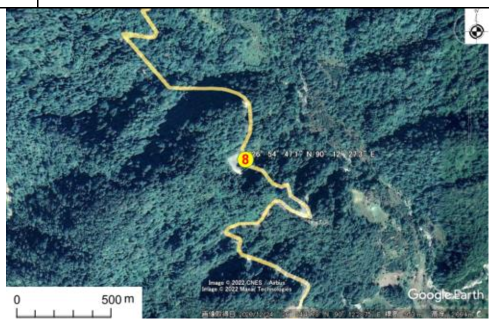
	
④ Sar-veg.004: SITE-4 *Darachu*	SITE-4 (added the point 4 on Google Earth Image)
	
⑤ Sar-veg.005: SITE-5	SITE-5 (added the point 5 on Google Earth Image)
	
⑥ Sar-veg.006: SITE-6	SITE-6 (added the point 6 on Google Earth Image)
	
⑦ Sar-veg.007: SITE-7	SITE-7
	
⑦ Sar-veg.008: SITE-8	SITE-8

Figure3.3-9 Status of each candidate site.

The table also summarizes the results of site observations and confirmations, which were conducted with an emphasis on the workmanship of the construction.

Table 3.3-4 Selection sheet of eight candidate sites (*: *see* caption, **: *see* explanation).

Number (S-veg.)	Site name (Slope direction)	Latitude/ Longitule	Land use*	Workability *	Stock yard	Status (Hight, Vegetation, etc.)	Note**	Eval.*
001	SITE-1 (Northwest)	26°59'22.3"N/ 90°07'29.4"E	×	×	○	Low, Natural vegetation, Crack on the curb	1	×
002	SITE-2 (South)	26°57'41.1"N/ 90°08'45.2"	×	○	×	Low, Natural vegetation	2	×
003	SITE-3 (South)	26°57'19.9"N/ 90°11'29.9"E	○	△	○	Low, Natural vegetation, Debris	3	△
004	SITE-4 (Southwest)	26°56'55.29"N/ 90°12'03.08"E	○	○	○	Moderate, Cut slope, Gully erosion	4	○
005	SITE-5 (South)	26°56'55.5"N/ 90°12'34.4"	○	△	○	Low, Stable, Natural vegetation	5	△
006	SITE-6 (South)	27°57'3.4"N/ 90°13'15.6"E	○	△	○	Low, Stable, Natural vegetation, Rocks	6	△
007	SITE-7 (Southwest)	26°56'30.6"N/ 90°13'55.5"E	○	△	○	Low, Stable, Natural vegetation, Rocks	7	△
008	SITE-8 (West)	26°54'47.1"N/ 90°12'27.3"E	○	×	△	High, Natural vegetation, Rocks	8	×

*Workability (Easy to cut):○High, △Moderate, ×Low, *Land **use**: ○Public, △Unclear, ×Private**.** Bad.

[**Note]

1. Slope is private property and cannot be constructed.
2. Slopes and roads cannot be constructed because they are on private property.
3. Cut and fill is easy, but the slope is stable due to natural vegetation and does not require construction for bioengineering.
4. Cut slope with partial gully erosion. Run slope of schist surface: N52W57N (without declination correction). Geology: albite schist. Suitable location for bioengineering.
5. Slope is too low to cut and bedrock exists at the base of the slope. Not suitable for bioengineering.
6. Natural vegetation, stable slopes, and no bioengineering required.
7. Natural vegetation, stable slopes, and no bioengineering required.
8. Long slopes and natural vegetation make it difficult to assess the situation.
9. Not suitable as a candidate site for bioengineering due to the potentially huge amount of logging.

(2) Phase 2: PNH4 Sarpang-Tsiran route

Regarding the third vegetation engineering test site for Output 2, the DCC within the DoST on June 6, 2022 recommended the Serkem site (PNH5: Gelephu-Trongsa) as opposed to the Darachu site (PNH4: Sarpang-Tsiran) proposed by JET. Serkem site locates as described in the following figure (Figure 3.3-10).

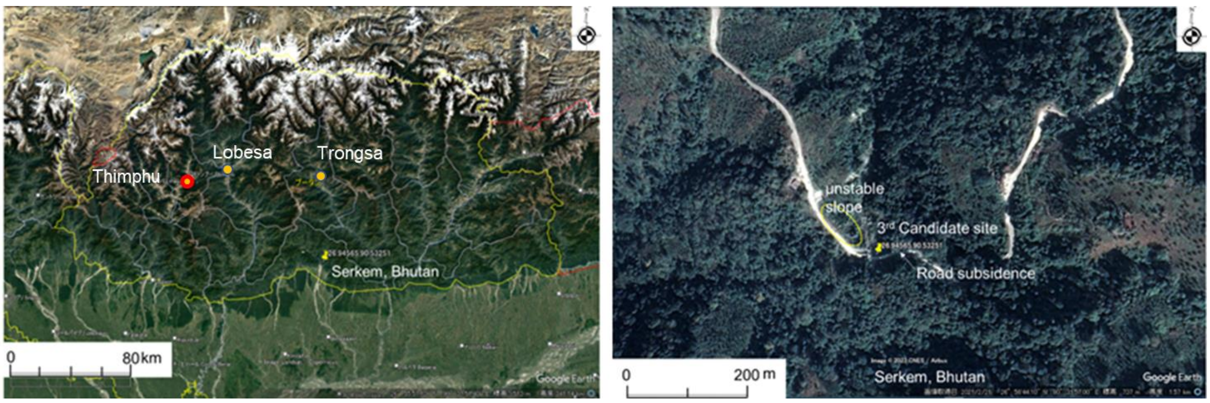


Figure3.3-10 Serkem, the third vegetation engineering test site candidate (from Google Earth Image).

1. Local status (coordinates 26.94565,90.53251 from Yonten Phuntsho 20220707)

The site is a bedrock cut slope with road subsidence due to a landslide in an adjacent area. Regarding the surrounding conditions, the surface of the slope under the road in the direction of Gelephu is unstable.

Photo 3.3-7 Distant view of the candidate slope (Road slope in front is unstable).

Photo 3.3-8 Nearby view of the proposed site.

Photo 3.3-9 Third candidate site for vegetation work.

Photo 3.3-10 3Settlement of the road on the east side of the slope.

2. Confirmation and discussion with the person in charge of the Outputs2 at DoST HQ
DoST HQ: January 27, 2023
Participation: Mr. Hirota (JET), DoST-Yonten Phuntsho & Thinley Wangchuk (Maintenance Division)

The plan is to construct a rock greening system. An example in Japanese case such as net with mortar bags attached horizontally is presented. This method is used to cover the slope for revegetation. Inside the mortar bag is powder, which hardens with rainwater over time. The mortar bags are attached to the slope by anchor pins made of deformed steel bars (D10, l=20cm).

Photo 3.3-11 Rock greening work (East of Tenjin IC, Kochi Expressway).
33°32′34.99″N, 133°25′55.9″E

Photo 3.3-12 Rock Revegetation Work on Steep Slope (Hasuike, Tosa City).
33°29′7.75″n, 133°24′20.11″e

Through the discussion, it was decided that, if the project is to be carried out at the candidate site in Bhutan, a construction method that is adapted to the site should be planned, such as net + sandbag (containing guest soil + seed + fertilizer) to adhere to the slope, stairway vegetation construction (constructing a stairway-shaped frame and filling it with guest soil + seed + fertilizer), and so on.

(3) Phase 3: PNH2 route (Phuentsholing)

After the Serkem site was selected in the second phase, the possibility arose that the section in question would become an abandoned section due to the construction of a bypass due to frequent landslides, and it became necessary to select the site again to the extent that these sections were excluded.

Since the 7th JCC instructed the committee to consider the site between Phuentsholing and Samtse as well, a field survey was conducted along the PNH2 route and the Gopini slope in Samtse was selected from among four candidate sites.

Although the surface layer is covered with rock debris, there are many similar slopes in Bhutan, and if this test construction goes well, it can be expected to be applied as an effective vegetation work.

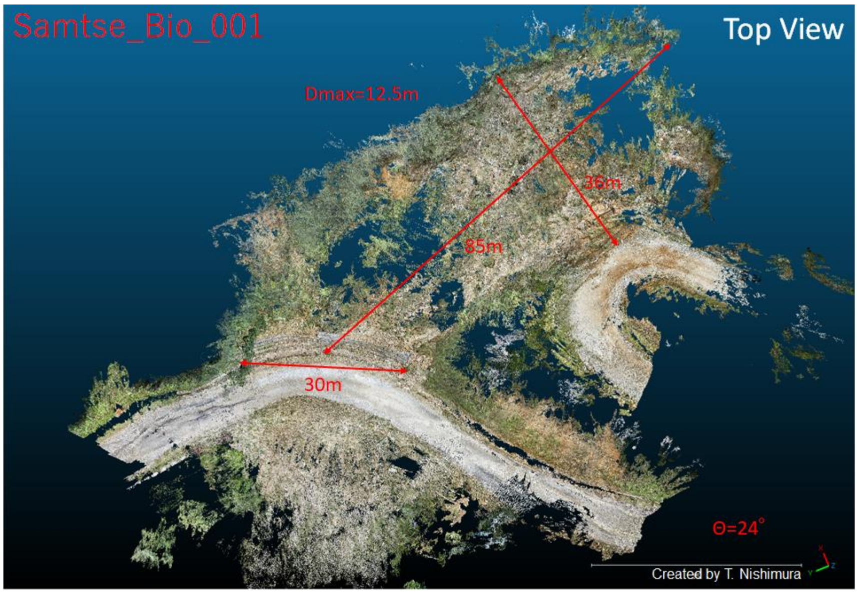


Figure3.3-11 3D terrain model by SfM.

Activity 2-2: Investigate and evaluate vegetation on current slopes, and organize issues.

In consideration of the local ecosystem, it is desirable to use plants and topsoil native to the area or used for agriculture in vegetation construction. Here, JET investigated the materials (soil, seeds, sheets, etc.) necessary for vegetation construction prior to designing the vegetation works.

(1) Greening materials Seeds

In order to conduct vegetation engineering in Bhutan, JET investigated native plants and seeds that are transported for agriculture and are available. The DoL office and seed warehouse are shown below.

(Source: JET)

Photo 3.3-13 View of the DoL Office (left) and inside the DoL seed warehouse (right)

Table 3.3-5 shows a list of pasture grasses and other local grasses available for purchase at the DoL's National Seed Centre. This table shows that 29 types of seeds are available for purchase at the DoL and can be used in Bhutan by the Ministry of Agriculture and Forestry of Bhutan. Of these, the DoL confirmed the availability of 9 types of seeds (circled in red in the table) that it has determined to be suitable for road slope vegetation work. The DoL also recommended a GM mixed seed (No. 11 and 12 in the table), and JET determined that a total of 10 types of seed were available, including this mixed type. The DoL also informed that Sl No. 1 and 16 had already been used for vegetation work on road slopes in Bhutan. However, the specific location and results are unknown as no records were kept.

It was confirmed that the applicability of these 10 species (especially Sl No. 1 and 16, which have a good track record) should be studied in the future to realize vegetation works suitable for Bhutan.

Table 3.3-5 List of seeds available in Bhutan as provided by DoL

Sl No.	Variety	Year release	Releasing Agency	Yield Potential (Dry Matter	Maturity for grazing	Recommended Agro-Ecology (MaSL)
1	Paspalum Atratum Var.CIAT 26986	2002	RC-Jakar	2.0-3	1 yr (Perennial)	<1500
2	Palisade Grass	2002	RC-Jakar	3.2-3.6	1 yr (Perennial)	<1500
3	Lucerne Var.Eureka	2002	RC-Jakar	1.6-2.5	1 yr (Perennial)	1000-2800
4	Swede Var.Ostega	2002	RC-Jakar	2.0-2.5	1 yr (Annual)	2500-2700
5	Oat (FOB)	2002	RC-Jakar	2.0-3.0	1 yr (Annual)	20-4000
6	Oat (Naked)	2004	RC-Jakar	2.0-3.0	1 yr (Annual)	200-4000
7	Oat (Sampede)	2004	RC-Jakar	2.2-4.0	1 yr (Annual)	200-4000
8	Fodder Beet (Alba)	2004	RC-Jakar	1.5-3.0	1 yr (Annual)	2000-3500
9	Gautemala Grass	2004	RC-Jakar	1.2-2.4	1 yr (Annual)	<1500
10	White Clover Var.Ladino	2002	RC-Jakar	3.2-4.4	1 yr (Perennial)	1700-3300
11	Italian Rye grass Var. Lipo	2002	RC-Jakar	1.2-2.2	1 yr (Perennial)	2000-3000
12	Cocks foot.,Var Amba	2002	RC-Jakar	0.8-1.2	1 yr (Perennial)	2000-3500
13	Tall Fescue Var.Barcel	2002	RC-Jakar	1.5-3.0	1 yr (Perennial)	2000-3500
14	Willow (Fodder tree)	2001	RC-Jakar	0.8-2.2	3 yr (Perennial)	1700-2800
15	Molases grass	2002	RC-Jakar	1.6-2.4	1 yr (Perennial)	<2000
16	Ruzi grass	2002	RC-Jakar	2.8-3.2	1 yr (Perennial)	500-2000
17	Sugarcane	2002	RC-Jakar	16.0-20.0	1 yr (Annual)	<1200
18	Fig (Fodder tree)	2001	RC-Jakar	3.0-3.5	2-3 yrs (Perennial)	300-2000
19	Fodder peanut	2002	RC-Jakar	1.1-2.0	1 yr (Perennial)	<1500
20	Stylo Var. CIAT 184	2002	RC-Jakar	4.0-12.0	1 yr (Perennial)	<1200
21	Kikiyu grass	2001	RC-Jakar	4.0-6.0	1 yr (Perennial)	1000-2300
22	Napier grass	2002	RC-Jakar	4.0-6.0	1 yr (Perennial)	<2000
23	Greenleaf desomodium	2002	RC-Jakar	2.0-2.5	1 yr (Perennial)	<1500
24	Guinea grass	2007	RC-Jakar	2.4-3.2	1 yr (Perennial)	>1000
25	Setaria sphacelata Var.	2016	RC-Jakar	3.2	1 yr (Perennial)	<1500
26	Gamba grass Var. Gayanus	2016	RC-Jakar	2.2-3	1 yr (Perennial)	at 900
27	Vicia villosa Var. Indian hairy vetch	2016	RC-Jakar	1.48-1.76	1 yr (Annual)	>2000
28	Desmodium uncinatum Var. Silverleaf	2016	RC-Jakar	1.2-2	1 yr (Perennial)	<1000
29	Centrosema pubescens Var. Centro	2016	RC-Jakar	1.2-1.8	1 yr (Perennial)	<900

*1 The circled "0" indicates seeds that were actually available.
*2 Darkly colored items indicate seeds that have been used as vegetation construction in Bhutan.
(Source : Research and Development Centre, modified from DoL's sheets of seeds)

(2) Greening materials [Soil and fertilizers]

Cut slopes generated during road construction often have a certain degree of hardness (soil hardness) even when they are earth slopes, and therefore, when vegetation work is carried out, it is often necessary to apply soil and fertilizer to the slopes along with the seeds for the seeds to be deposited. Therefore, a survey was conducted in Bhutan to determine what kind of soil and fertilizer can be used for vegetation planting.

As for the guest soil, Bhutan currently has frequent road construction and widening projects in and around the region, and it was found to be very easy to use site-generated soil as the guest soil for vegetation works.

Organic fertilizers, such as livestock manure, are not readily available, and farmers are dependent on self-sufficiency and do not sell them on the market. However, general chemical fertilizers are available at the DoL's National Seed Centre and can be used for vegetation engineering.

Table 3.3-6 List of chemical fertilizers distributed in Bhutan.

No.	Item	unit	Revised selling price (Nu./pack)
1	Suphala (NPK 15:15:15): Vegetable fertilizer (nitrate-based)	50 kg pack	1870
2		20 kg pack	780
3		10 kg pack	400
4		5 kg pack	205
5	Urea (46% N): Nitrogen 46% granular urea	50 kg pack	990
6		20 kg pack	420
7		10 kg pack	220
8		5 kg pack	115
9	SSP (16% P20): Phosphate fertilizer	50 kg pack	985
10	MOP (60% K20): Potassium chloride fertilizer	50 kg pack	2145
11	Borax (20% Brown min): Borate fertilizer	5 kg pack	945
12	Bone Meal: Bone meal fertilizer	50 kg pack	2840

(Source : MoAF, http://www.moaf.gov.bt/revised-selling-price-of-the-fertilizers/)

(3) Condition of the slope at the time of construction

The target slopes for vegetation work are cut slopes generated by road construction, and earth slopes where erosion damage due to rainfall is a concern after construction. It is not possible to implement vegetation work on bedrock slopes or slopes with many boulders and fallen rocks. For example, according to Japanese standards, the hardness of the cut slope surface is important to implement vegetation work on an earth slope, and the type of vegetation work should be changed after a measurement of 25 to 27 mm using a soil hardness meter. In addition, the pH value of the soil must be suitable for the growth of grasses (pH>4.0).

Based on the above, the important conditions for implementing vegetation works on road slopes in Bhutan are that the slope should be a sediment slope, the hardness of the soil should be appropriate for the type of vegetation works to be assumed, and the pH value of the soil should be above 4.0.

(4) Organizing Issues

Based on the above survey results, the issues to be addressed in implementing appropriate vegetation works in Bhutan are summarized as follows.

Table 3.3-7 Challenges in implementing vegetation works on road slopes

Anticipated Issues	**Greening materials [Seeds** : Of the available seeds, confirm whether the seeds are suitable for revegetation work on road slopes. **Greening Materials [Soil and Fertilizer**: It is necessary to confirm that the available fertilizers are actually effective for revegetation work on road slopes. **Slope conditions at the time of construction**: Slope surface hardness should be measured with a soil hardness meter and soil pH should be measured in order to implement an appropriate vegetation design.

(Source: JET)

Activity 2-3: Examine suitable bio-engineering works against "debris slope failure" in Bhutan.

(1) Seed Selection

Based on the results of germination tests conducted in advance of the three test installations and the test installations using seeds that are easily available in Bhutan, which were investigated in Activity 2-2 (1) Greening Materials [Seeds], seeds that can "tolerate drought" or "tolerate cold" were selected as suitable for road slope vegetation work in Bhutan. or "cold tolerant" seeds suitable for road slope vegetation construction in Bhutan were selected based on the results of germination tests conducted in advance of the three test installations and test installations. The following is a description of the seed selection method and the results of the study at the first test site (in Lobesa District Office), the second test site (in Trongsa District Office), and the third test site (in Phuntsholing District Office).

a. Within the jurisdiction of Lobesa Office (elevation: generally 1100m to 1500m)

Phase 1: [Narrowing down the seeds to be used].

From the survey results in Activity 2-2 (1) Greening Materials [Seeds], it was found that 29 types of seeds are available and usable in Bhutan, and 10 of them are readily available. Therefore, based on the DoL's advice, JET selected 2 or 3 types of seeds from these 10 types that were suitable for the altitude, climate, and other conditions of the test construction site. In the first test construction, the following conditions were taken into consideration in narrowing down the selection.

<Refine criteria>.

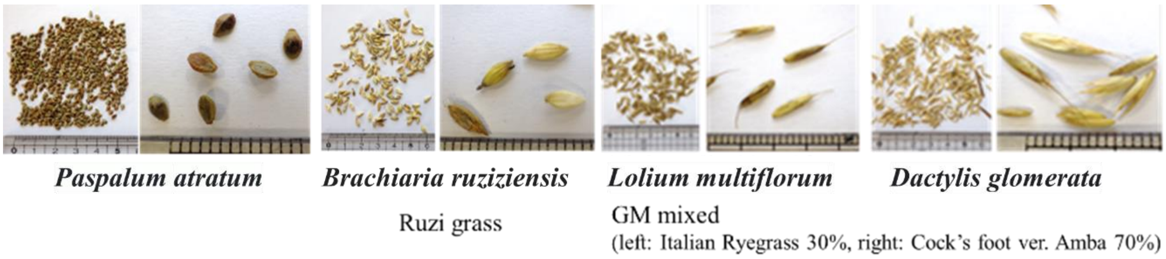
1) Type suitable for the elevation of the first test construction site (1,193 m).
2) Must be a perennial
3) Preference is given to species that have a proven track record of use as vegetation works in Bhutan.
4) Try the mixed species (GM mixed) recommended by the DoL.

In light of the above conditions, JET narrowed down the 10 seed types in Activity 2-2 to the following three types (Paspalum atratum, Ruzi grass, and GM mixed) and decided to use these three seed types in the second stage of germination tests.

Table 3.3-8 Summary of seeds used in germination tests

Seed name	Applicable elevation [m]	Single year/Multi-year	Reasons for selection
Paspalum atratum	<1500	perennial plant	It is a perennial herb and adapted altitude. It has been used in Bhutan as a vegetation worker and is recommended by the DoL.
Ruzi grass	500<2000	perennial plant	It is a perennial herb and adapted altitude. It has been used in Bhutan as a vegetation worker and is recommended by the DoL.
GM mixed (Italian Ryegrass 30%, Cock's foot ver. Amba 70%)	2000<3000	perennial plant	It is a perennial herb, but its adaptive altitude is slightly higher than that of the first test construction. However, according to DoL, it is the most used species in Bhutan, including around the first pilot installation.

(Source: JET)



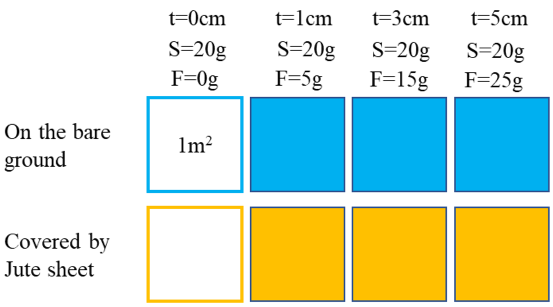
(Source: JET)

Figure3.3-12 Seeds selected for germination tests
(From left to right: Paspalum atratum, Ruzi grass, GM mixed).

Phase 2: [Germination test].

The DoST land near the test construction site was secured, and germination tests of the seeds selected in the first step were conducted prior to the test construction. Seeds with sufficient germination rate and growth rate from the germination test results were used in the test construction.

Prior to the first test, a germination test at the yard was conducted at the Lobesa Regional Office site near the site. For the germination test, three types of seeds (Paspalum atratum, Ruzi grass, and GM mixed) were used, and four different thicknesses t of manure-impregnated soil (0 cm, 1 cm, 3 cm, and 5 cm) were applied on the soil pile. The seed quantity was set at 20 g/m2 regardless of the thickness of the guest soil. In addition, the test was conducted on the assumption that the surface would be covered with jute netting (hemp netting) to prevent seeds and other materials from flowing out of the vegetation on the slope. Therefore, the test was conducted with the surface covered with jute netting. Therefore, as shown in Figure 3.3-13, germination tests were conducted in eight different plots for one seed type. Note that the fertilizer used was Suphala (NPK) 15:15:15, which is the most used fertilizer for horticultural use in Bhutan based on discussions with the DoL.



t: thickness of the client soil, S: weight of the spread seeds, F: weight of the fertilizer contained in the client soil.

(Source: JET)

Figure3.3-13 Germination test patterns for one seed (8 patterns).

<Germination test procedure>

1) Water daily for one week from the day the seeds are sown.
2) From the second week, the observation is made once a week.
3) Watering is done once a week at the time of observation.
4) The examination shall begin on June 7.
5) Fertilizer is Suphala (NPK) 15:15:15, the most used fertilizer for horticulture in Bhutan.

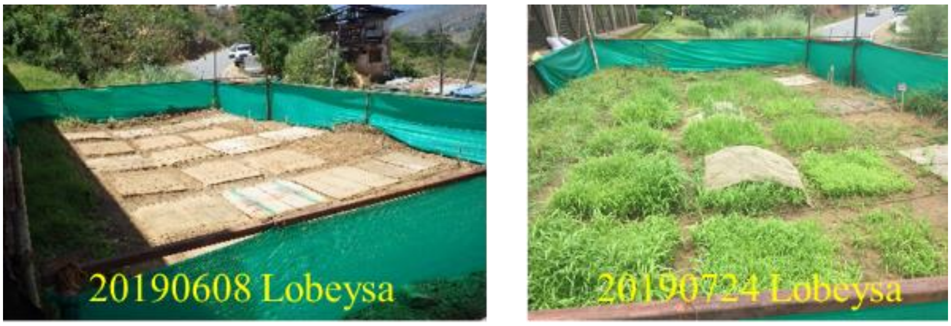
(Source: JET)

Photo 3.3-14 Construction yard for germination tests at the Lobesa Regional Office site (left) and observation of germination conditions (right).

<Germination test results>

Observations from germination tests are shown in Photo 3.3-15 and Table 3.3-9. A summary of the test results is as follows.

1) The highest coverage was *Paspalum* atratum→ Ruzi grass→ GM mixed, and although the difference in coverage among the three types was small, GM mixed was the lowest because it was located at a higher elevation than the test site.
2) The thickness of the guest soil should be at least t = 3 cm.
3) *Paspalum atratum* and Ruzi grass are considered to be less affected by the presence or absence of jute netting.



(Source: JET)

Photo 3.3-15 ermination trials at Lobesa Regional Office site
(Left: at the start of the test, Right: 1.5 months after the start of the test)

Table 3.3-9 Observations of germination tests (July 24, 2019)

Paspalum atratum		Ruzi grass		GM mixed	
Thickness of the client's soil (t)	Coverage (%)	Thickness of the client's soil (t)	Coverage (%)	Thickness of the client's soil (t)	Coverage (%)
t=0cm	10	t=0cm	0	t=0cm	3
t=1cm	45	t=1cm	85	t=1cm	60
t=3cm	90	t=3cm	96	t=3cm	85
t=5cm	90	t=5cm	76	t=5cm	69
t=0cm +JS	-	t=0cm +JS	-	t=0cm +JS	-
t=1cm +JS	90	t=1cm +JS	63	t=1cm +JS	26
t=3cm +JS	-	t=3cm +JS	-	t=3cm +JS	-
t=5cm +JS	100	t=5cm +JS	90	t=5cm +JS	30

(Source: JET) t: thickness, JS: jute sheet

Based on the results of the above germination test at the Lobesa Regional Office, the following origin is established for the first test construction.

1) *Paspalum* atratum and *Ruzi* gras.
2) When placing soil on the slope surface, ensure that the thickness of the soil is at least t=3 cm.
3) It is possible to cover the slope surface with jute netting if necessary

b. Within the jurisdiction of the Tongsa Office (elevation: approximately 2,000 m to 2,500 m)

Phase 1: [Narrowing down the seeds to be used].

a. The same method was followed for seed selection for the first test installation in the jurisdiction of the Lobesa office.

Phase 2: [Germination test].

The DoST land near the Tonsa office was secured and tested for germination of the seeds selected in phase 1. The conditions for the tests were the same as those in the jurisdiction of the a. Lobesa office.

<Germination test results

The results of the pot test conducted as a preliminary stage of the germination test in the jurisdiction of the Tonsa Regional Office are shown in the table below. Ten species of seeds selected in the first stage were vegetated in pods (flowerpots) and observed for germination. Many of the species germinated and grew well within the jurisdiction of the Lobesa Regional Office, which is at an altitude of about 1,200 m. However, only Tall Fescue (germination rate: 53%, followed by steady growth) germinated and grew well within the jurisdiction of the Tonsa Regional Office, which is at a higher altitude (2,000 m to 2,500 m), as shown in the following table. Therefore, germination tests were conducted in the test yard using only Tall Fescue.

Table 3.3-10 Table of germination test results using pods (flowerpots)

No.	Seeds	Photo.	Trongsa R. O. Pot
1	*Paspalum astarum*		70% dead
2	Oat (FOB)		89% dead
3	Oat (Stamped)		85% dead
4	Italian reyegrass		18% dead
5	Cock's foot		5% dead
6	Tall Fescue		53% live
7	Molases grass		1% dead
8	Ruzi grass		4% live
9	Stylo		0%
10	GM mixed (No.4-30%, No.5-70%)		13% 70%dead

(Source : JET)

The results of the germination test in the test yard are shown in Photo 3.3-16. A summary of the test results is shown below.

- ✓ Seed selection: Tall Fescue germinated and grew without problems in the yard test.
- ✓ The thickness of the guest soil should be at least t = 3 cm.
- ✓ Germination occurred with and without jute netting, but the germination rate was higher without jute netting.

At the beginning of the yard test (7/16/2021) Two months after the start of the yard test (9/9/2021)
(Source: JET)

Photo 3.3-16 Status of germination yard tests in the jurisdiction of the Tonsa Regional Office
(In the left and right photos, foreground: with jute net, background: without jute net)

c. Gopini within the jurisdiction of Phuntsholing Office (elevation: approximately 1500 m)

Phase 1: [Narrowing down the seeds to be used].

a. The same method was followed for seed selection for the first test installation in the jurisdiction of the Lobesa office.

Phase 2: [Germination test].

Germination tests of two types of seeds, Paspalum atratum and Ruzi grass, which are commonly available in Bhutan, were conducted on the target slope of Gopini, a potential vegetation construction site (test site elevation of approximately 1,500 m).

[Period] August 19 to September 4, 2023. The results of the germination test showed that both species germinated well.

[Methods and Materials]

1) Seeds: *Paspalum atratum* and Ruzi grass (see Figure3.3-14).

2) Fertilizer: NPK=1:1:1 (trial: 5g/t=1cm/m^2) t: soil thickness [cm]

3) Soil: Use soil near the germination test site. Sieve the soil.

Soil is sieved using a 5 mm mesh sieve.

4) Wooden crates: 1 m square, 5 cm high.

5) Target germination rate: 60% (at post-germination observation)

	
Paspalum atratum	Ruzi grass: *Brachiaria ruziziensis*

Figure3.3-14 Selected seeds
(*Paspalum atratum*, Ruzi grass: *Brachiaria ruziziensis*).

[Germination test]

Test Site

The germination test site, Gopini, is located within the jurisdiction of the Samtse Branch of the Phuntsholing Regional Office, approximately 200 km south-southwest of Thimphu via road.

Figure3.3-15 3rd Stage Germination Test Site, Gopini.
(26° 53′ 46.00″N, 89° 12′ 49.62″E, Altitude: 1,500 m: Samtse sub-division office, Phuentsholing R.O.)

Testing period: July 12, 2023 to September 4, 2023

Progress and results of germination tests

1) July 12, 2023: Germination tests begin
2) July 19, 2023: Observation of germination test status
3) July 27, 2023: Observation of germination test status
4) August 4, 2023: Observation of germination test status
5) September 4, 2023: Observation of germination test status completed

Both Ruzi grass and Paspulm grew well, although the germination test area using jute bags was buried by runoff from the slope surface.

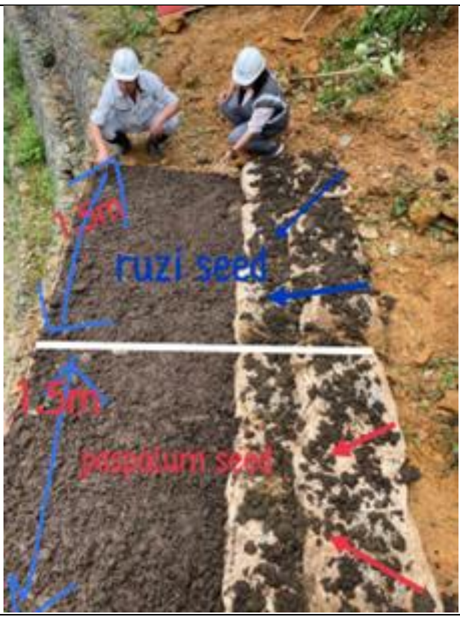


Photo 3.3-17 Start of germination test (July 12, 2023: from left to right, Paspalum atratumand , Ruzi grass).

Photo 3.3-18 Germination observation (July 19, 2023).

Photo 3.3-19 Progress (July 27, 2023)

Photo 3.3-20 Continuous observation of germination status (August 4, 2023).

Photo 3.3-21 End of observation of germination status (September 4, 2023).

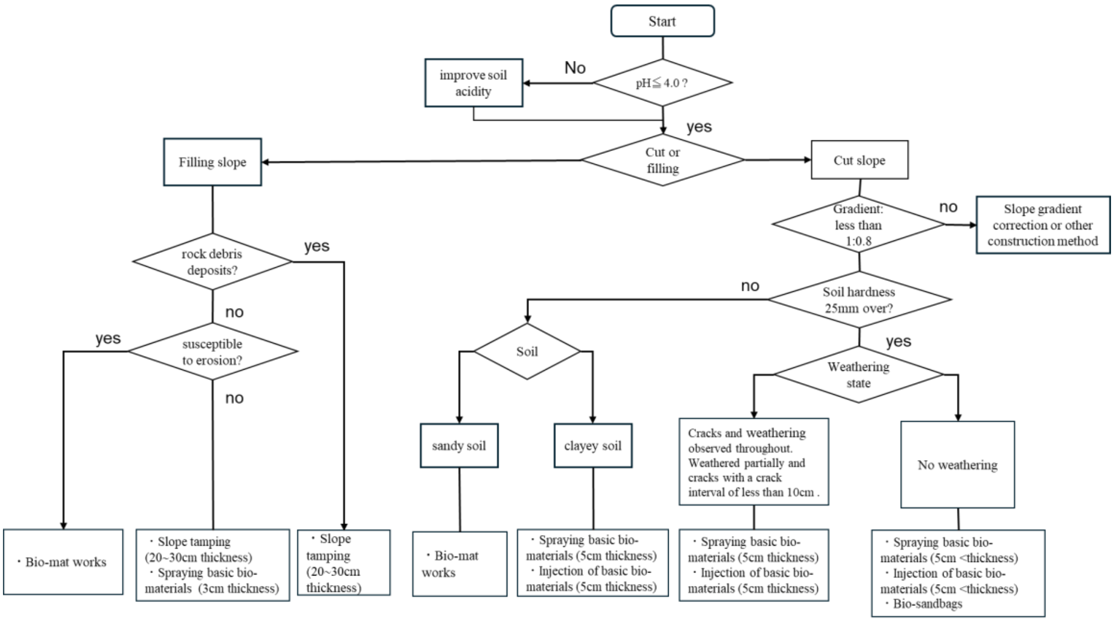
The germination test was conducted on the gabions (to the left of the person standing)

Photo 3.3-22 Panoramic view of germination test site (4 September 2023)

Both Ruzi grass and Paspalum species germinate well, but Ruzi grass seed, which is more readily available locally, is selected for use in the third vegetation engineering test site, Gopini.

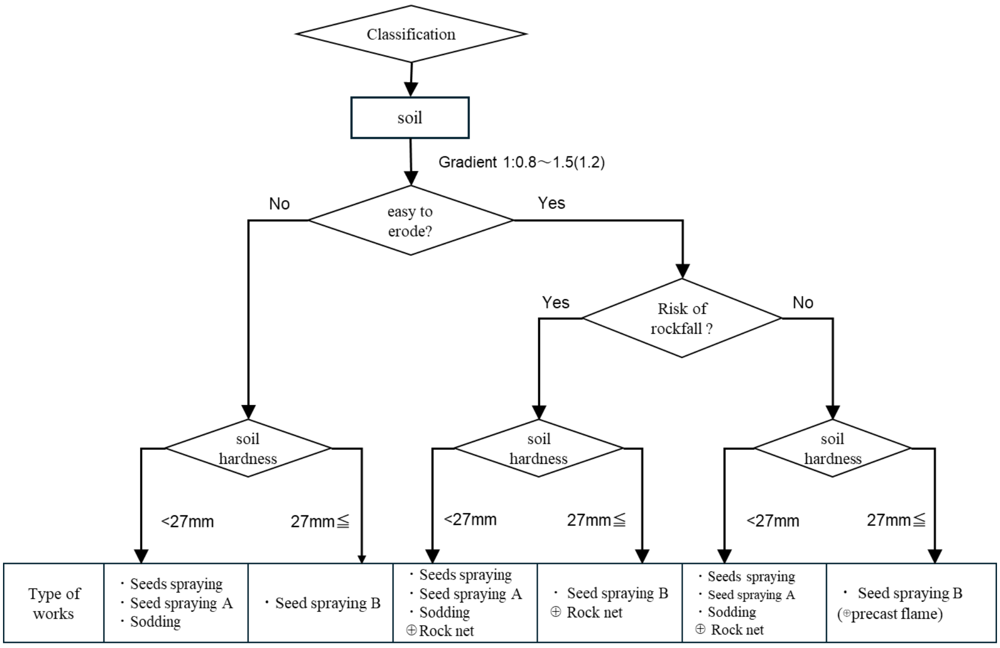
(2) Selection of construction method

The Japanese Ministry of Land, Infrastructure, Transport and Tourism (hereinafter referred as “MLIT”) and NEXCO have established a selection flow for vegetation work on road cut slopes based on their long experience in this field. The selection flow for vegetation work by the MLIT and the selection flow by NEXCO are shown below.



(Source: From the Ministry of Land, Infrastructure, Transport and Tourism, National Institute for Land and Infrastructure Management, Document No. 734)

Figure3.3-16 Ministry of Land, Infrastructure, Transport and Tourism, Japan: Selection Flow of Vegetation Work Types for Road Slopes.



(Source: NEXCO Design Guidelines, Vol. 1, Civil Engineering, excerpts from the "Earth and Sediment" section)

Figure3.3-17 NEXCO in Japan: Selection Flow of Vegetation Work Types for Road Slopes.

Although the construction method selection flow applied in Japan described above is not necessarily optimal for Bhutan, a construction method using inexpensive materials readily available locally was adopted for the selection of the construction method for the test construction of Output 2, with reference to the construction method selection flow in Japan. Finally, through the test construction, a selection flow for the best vegetation construction method for Bhutan was developed together with C/P, and the technology was transferred to C/P through field surveys and seminars.

(3) slope (incline) of a cut

In order to prevent landslides on cut slopes, it is necessary to determine the appropriate slope before vegetation work is performed. The selection of the appropriate cut slope should follow the standard cut slope discussed in Output 3.

Activity 2-4: Implement the suitable bio-engineering works on pilot sites as trials.

The construction of the vegetation works is expected to be carried out with planting and seed application taking place around October to the following May during the dry season, and the plants are expected to flourish during the subsequent rainy season (June to September). Therefore, the first test construction was conducted around January to April 2020. For the same reason, the second and third installations were conducted from January to February in 2023 and 2024, when the effects of the corona spread had subsided. The proposed timing of the test construction for the vegetation works is shown in the table.

Table 3.3-11 Draft Timing of Test Construction for Vegetation Works

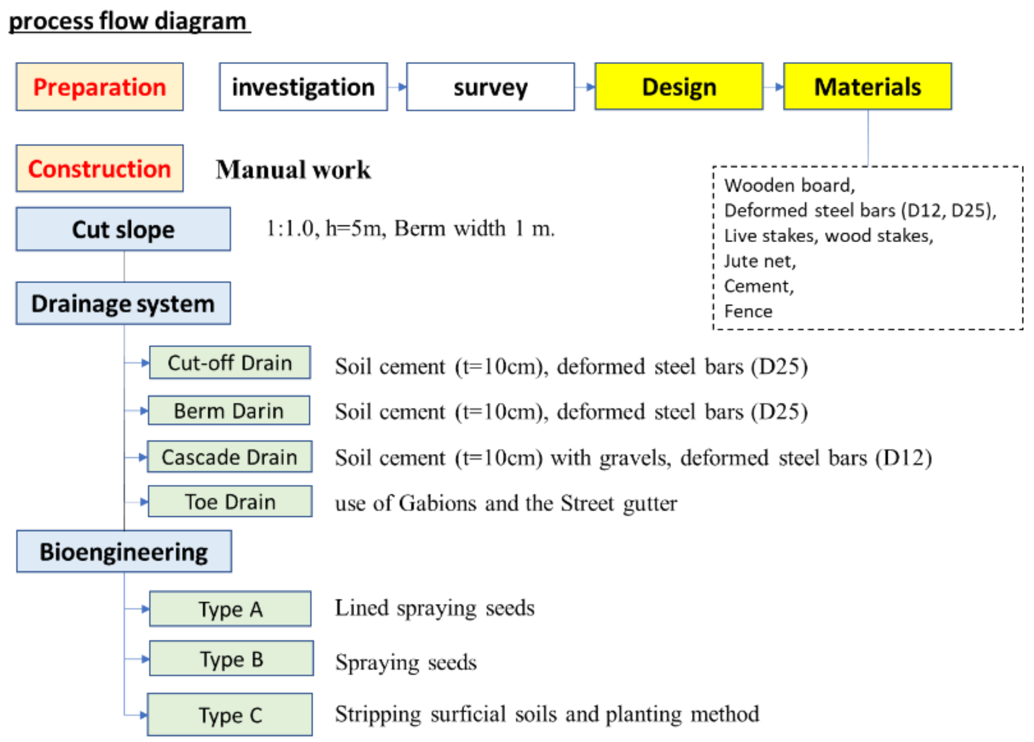
Test construction	implementation period	Construction Area	Adoption
1st	January - April 2020	Within the jurisdiction of the Lobesa Regional Office	Selected Veg. 001, Gangthangka
2nd	January - April 2023	Within the jurisdiction of Trongsa Regional Office	T-veg.014, east slope of Yangkhil Resort
3rd	January - April 2024	Phuentsholing Regional Office Jurisdiction	

(Source: JET)

Activity 2-4-1 First test construction

The first test construction was conducted at Veg. 001, Gangthangka, within the jurisdiction of the Lobesa Regional Office from January to April 2020.

(1) Work procedure for the first test construction



(Source: JET)

Figure3.3-18 Construction Process of Vegetation Works.

(2) Field survey for the first test construction

Prior to the design work for the first test construction, the following field investigations were conducted.

Field survey: A field survey was conducted to understand the site conditions necessary for the design. The field survey was conducted to understand the condition of the subject slope and the current status of surrounding structures such as waterways and roads, as well as to define the scope of the survey to be conducted later and to set boundary stakes to indicate the construction area.

Upper path and waterway Slope and upper path seen from the east Road condition Road valley side slope
(Source: JET)
Photo 3.3-23 Situation of field traning before vegetation engineering test.

A small diameter and a channel are located above the subject cut slope, but both are outside the construction area and were found to be unaffected. Slope slopes are approximately 45° at the top of the slope and 30° in the middle to bottom of the slope, with slopes exceeding 45° (48-52°) above the small diameter above the upper slope.

The survey area was set at 60m x 90m around the perimeter, including the construction area, and cross-sectional surveys were conducted every 5m in the section where the vegetation work was to be implemented. The survey area for the vegetation work design is shown below.

(Source: JET, base map :Google Earth)
Figure3.3-19 Surveyed area for vegetation engineering design.

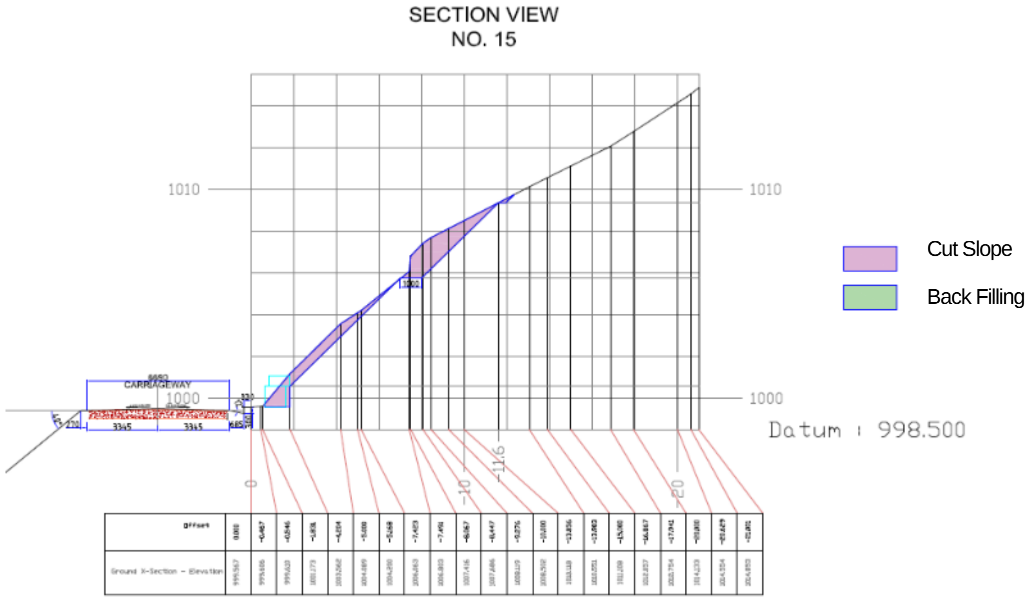
Field Tests] Various field tests were conducted to determine the field conditions necessary for the design of the project. The items of the field tests were soil hardness test, soil pH test, and electrical conductivity measurement. The measurement results are shown in "Activity 2-3 (2) Selection of Construction Methods".

Meeting at Lobesa Regional Office Confirmation of target slope Field test
(Source: JET)
Photo 3.3-24 Field survey prior to testing vegetation works (Lobesa Regional Office)

The surveying work was performed to determine the site conditions necessary for the design. The surveying work was performed by DoST in plan and 5m pitch cross sectional surveying, and the plan and cross sectional drawings required for the design were produced.

(3) Detailed design for the first test construction

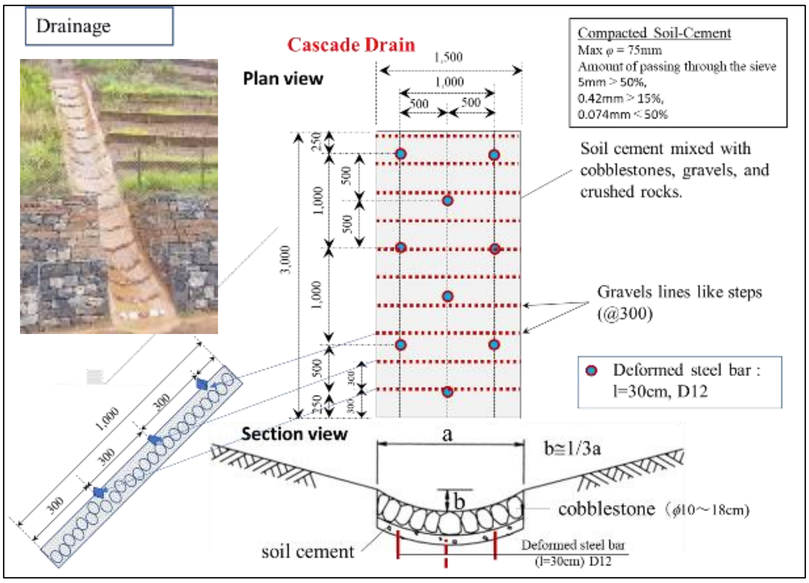
Prior to the vegetation work, the subject slope was cut and shaped to an appropriate slope according to the results of the study in Output 3. The cross-sectional shape is shown below. At the end of the slope, a 2m-high retaining wall was installed, and the slope above the wall was cut and shaped to a slope of 1:1.0 (45 degrees), with a small step on the slope.



(Source: JET)

Figure3.3-20 Design cross section of cut and bedding basket construction for vegetation construction - N0.15 cross section in the center of the slope.

Drainage works] From the viewpoint of preventing erosion of slopes, drainage works were installed in small drainage channels and around the slopes to prevent rainwater from flowing into the slopes and eroding the cut slope surfaces. In Japan, it is common to use U-shaped ditches and bellows pipes for drainage works on cut slopes, but in Bhutan, these materials are difficult and expensive to obtain. Therefore, JET adopted an inexpensive drainage channel construction method using soil cement and natural stones generated locally.



(Source: JET)

Figure3.3-21 Design cross section of cut and bedding basket construction for vegetation construction - N0.15 cross section in the center of the slope.

The hardness of the slope and the pH of the soil were measured on site when selecting the type of vegetation work to be done in the test construction. The hardness and Ph values of the first test construction site are shown in the table. As a Output, it was found that the hardness of the slope at the first test construction site was generally less than 27 mm, and the construction type was selected according to NEXCO's selection flow for vegetation construction types. A simplified survey is shown below.

Table 3.3-12 Hardness and pH values of the first test construction site

Slope hardness (measured with a soil hardness meter)

Position/measuring line	No.5 (Center of slope - 10m)	No.10 (Center of slope - 5m)	No. 15 (Slope center)	No. 20 (Slope center + 5m)	No. 25 (Slope center + 10m)
Upslope	-	21.8	25.3	24.2	-
middle of a slope	-	23.6	25.4	23.9	-
Downslope	no suitable place	15.8	30.1	21,18	26.4

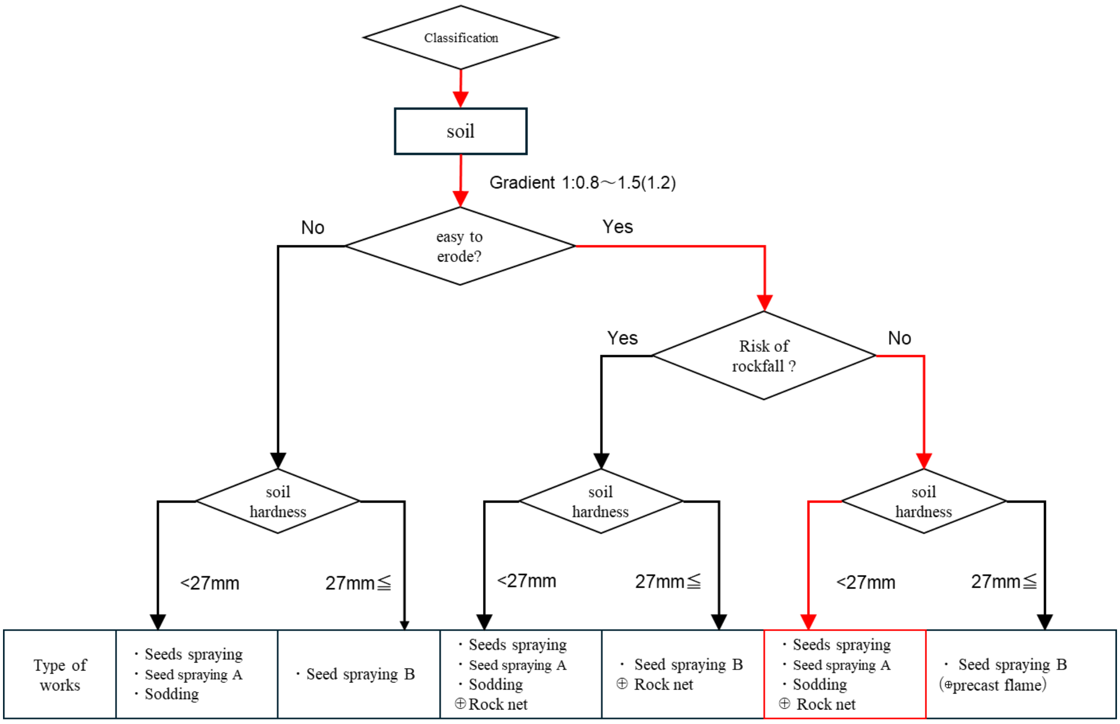
*Other measured values: Soil pH value = 7.55, electrical conductivity = 0.20 mS/cm, temperature at measurement = 24.7° C

(Source: JET)

(Source: JET)

Photo 3.3-25 Simplified surveying (left: pole surveying, middle: surveying with distance meter, right: soil hardness measurement)

Based on the above, using NEXCO's vegetation type selection flow, it was determined that seed spreading, seed spraying, and turfing would be appropriate for the first test construction site. For the actual test construction, JET proposed the most appropriate construction method based on these types of work, taking into consideration the materials available in Bhutan and the construction techniques that could be implemented.



(Source: NEXCO Design Guidelines, Vol. 1, Civil Engineering, with additions and modifications)

Figure3.3-22 NEXCO: Selection of vegetation types for the first test construction using the Selection Flow for Vegetation Types for Road Slopes.

The following results were obtained through activities 2-3. The design of the vegetation works was based on these results, and the most appropriate method was proposed considering the materials available in Bhutan and feasible construction techniques.

<Activity 2-3 Results>

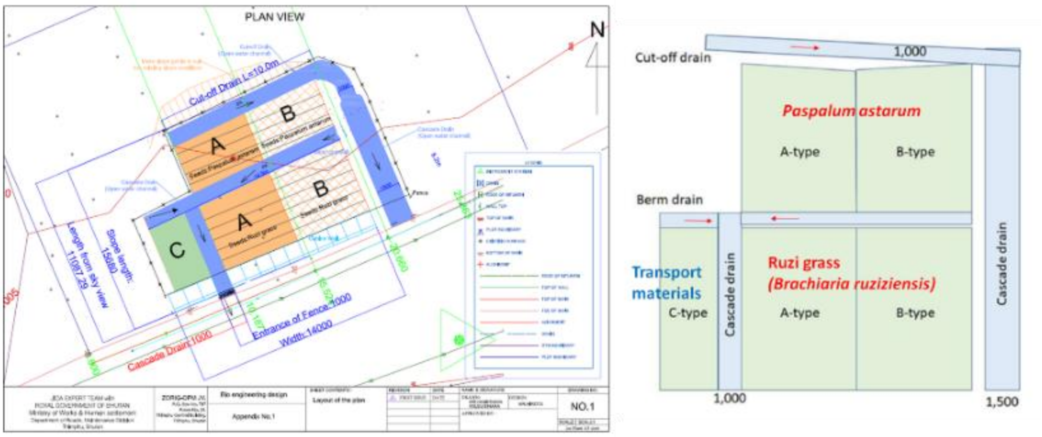
1) *Paspalum* atratum and *Ruzi* gras.
2) When placing soil on the slope surface, ensure that the thickness of the soil is at least t=3 cm.
3) It is possible to cover the slope surface with jute netting if necessary
4) Seed spreading, seed spraying, and turfing are appropriate based on the vegetation type selection flow in Japan.

In Bhutan, there is no technology or equipment for spraying seeds and substrate materials using a compressor, which is commonly practiced in Japan. In addition, materials such as vegetation mats and sheets for fixing seeds and substrate on slopes are difficult and expensive to obtain. Therefore, in the first pilot project, JET proposed and implemented a seed spreading method using coarse jute nets, which are inexpensive and available in Bhutan. In addition, JET conducted a trial of using a strip of jute net (Type A) and a jute net applied to the entire slope surface (Type B). In addition, a trial of turfing using vegetation grown in a germination test (Type C) was also conducted. The two types of seeds used were Paspalum atratum and Ruzi gras. The following is a summary of each vegetation type.

Table 3.3-13 Three types of vegetation works to be implemented in the first test construction

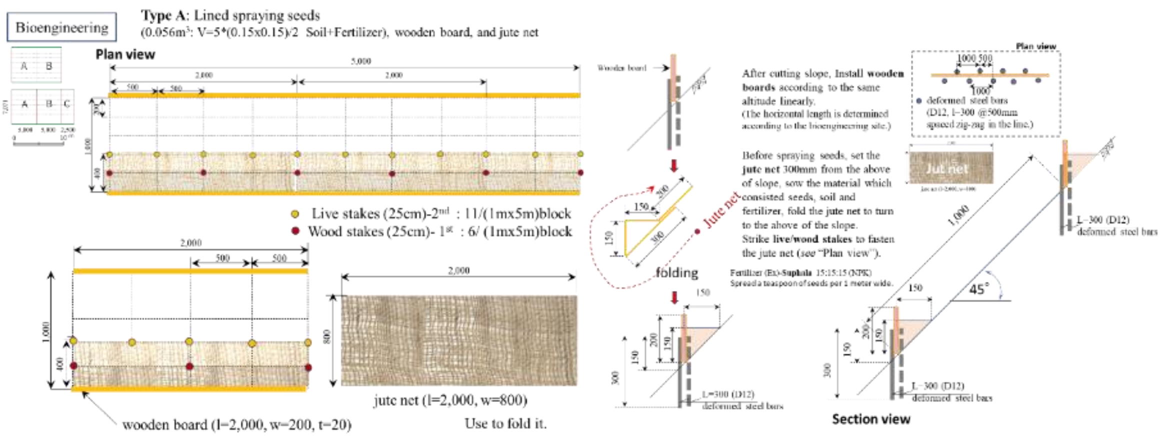
type of works	Method Name	summary	Seeds to be used	substrate
Type A	Strip seed spreader	A seed dispersal method in which the seed to be dispersed and the base material are fixed with a jute net that is applied in a strip on the slope.	<Slope top *Paspalum atratum* ＜Lower part of the slope Ruzi gras <Spraying amount Spray 20 g per 1 m^3	Substrate thickness: 5 cm Topsoil collected at the site was mixed with 25 g of fertilizer Suphala per 1 m^3.
Type B (blood, influenza, hepatitis, etc.)	Whole surface seed dispersal	A seed dispersal method in which the seed and substrate to be dispersed are established by applying a jute net over the entire slope surface.		
Type C	Turfenter	Cutting vegetation grown in germination tests and applying turf on slopes	*Paspalum atratum*, Ruzi gras, GM mixed	Included in Zhangzhi

(Source: JET)



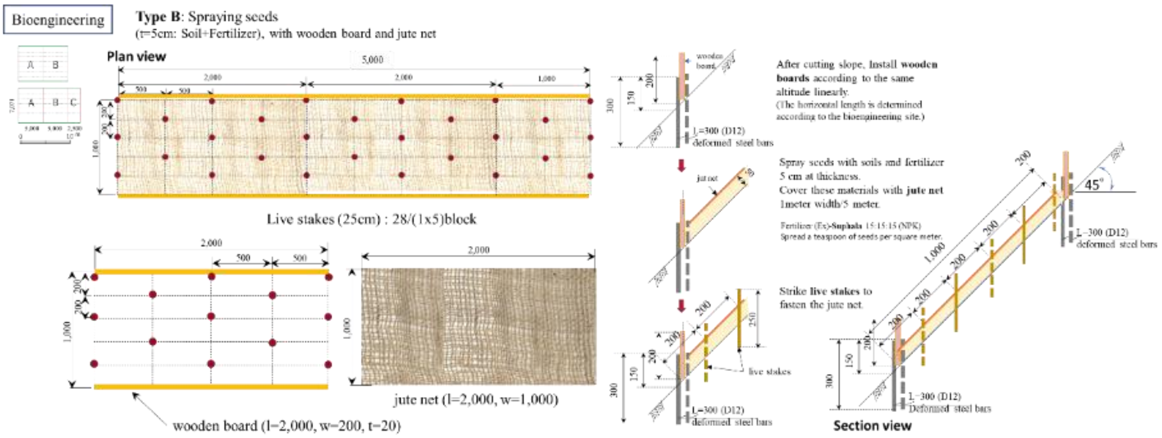
(Source: JET)

Figure3.3-23 Modified vegetation construction layout plan
(left: design documents, right: conceptual drawing).



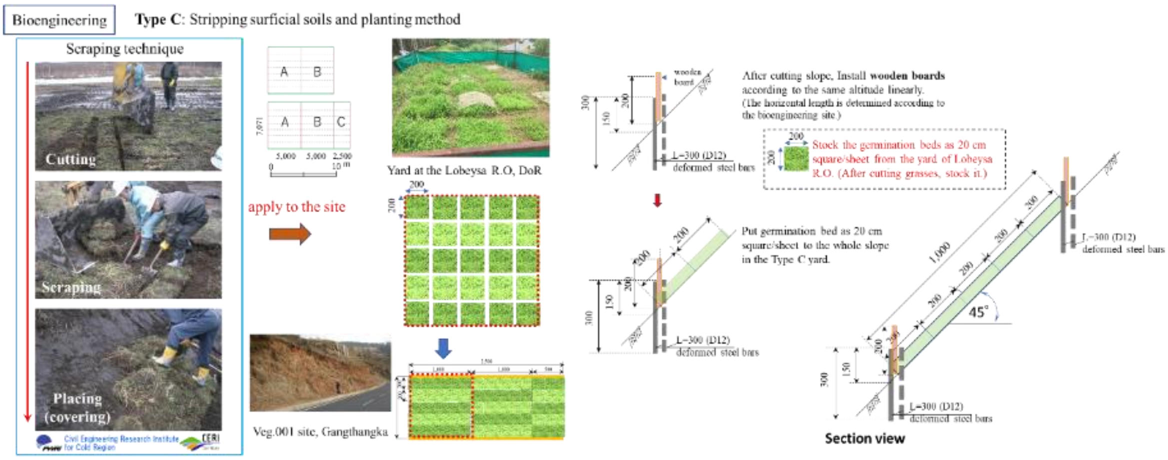
(Source: JET)

Figure3.3-24 Vegetation work Type A: banded seed dispersal.



(Source: JET)

Figure3.3-25 Vegetation work Type B: Seed dispersal.



(Source: JET)

Figure3.3-26 Vegetation work Type C: Turfing.

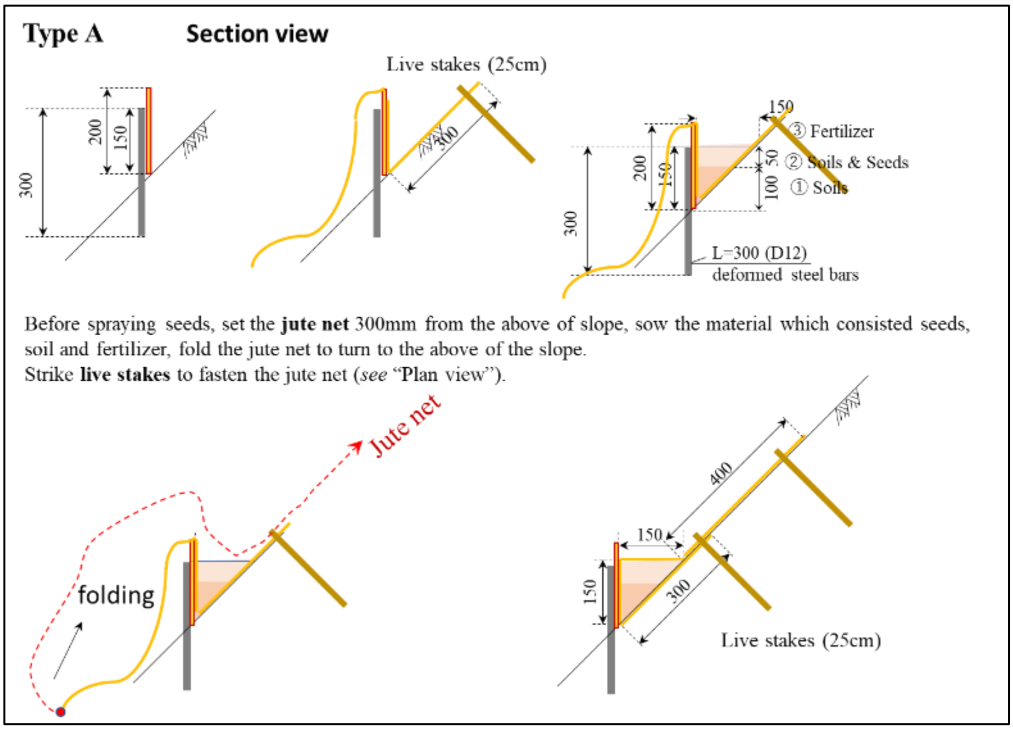
Table 3.3-14 Table of quantities for vegetation work in the first test construction

(Data) item	Unit	Volume	Remarks
Advance preparation for equipment delivery and accommodations	Equation	1	Costs associated with bringing in materials and equipment necessary for construction, setting up accommodations, and hiring traffic controllers and slope monitors.
Cut and fill construction	Equation	1	Includes costs related to the disposal of generated soil.
Construction of drainage system (slope shoulder and small slope side vertical drainage)	Equation	1	Includes anti-theft wooden box
closet maker	M	13	One unit on each side of each slope
Installation of fences to prevent animals from entering	Equation	1	Surrounding the construction area from all sides
Construction of vegetation works A	Equation	1	Spread soil containing seed and fertilizer horizontally 15 cm wide and cover with jute netting. This should be done at 1 m intervals.
Construction of vegetation works B	Equation	1	Cover all surfaces with soil containing seed and fertilizer and cover with jute netting.
Construction of vegetation works C	Equation	1	Transplant "germination mats" that have germinated in the yard.

(Source: JET)

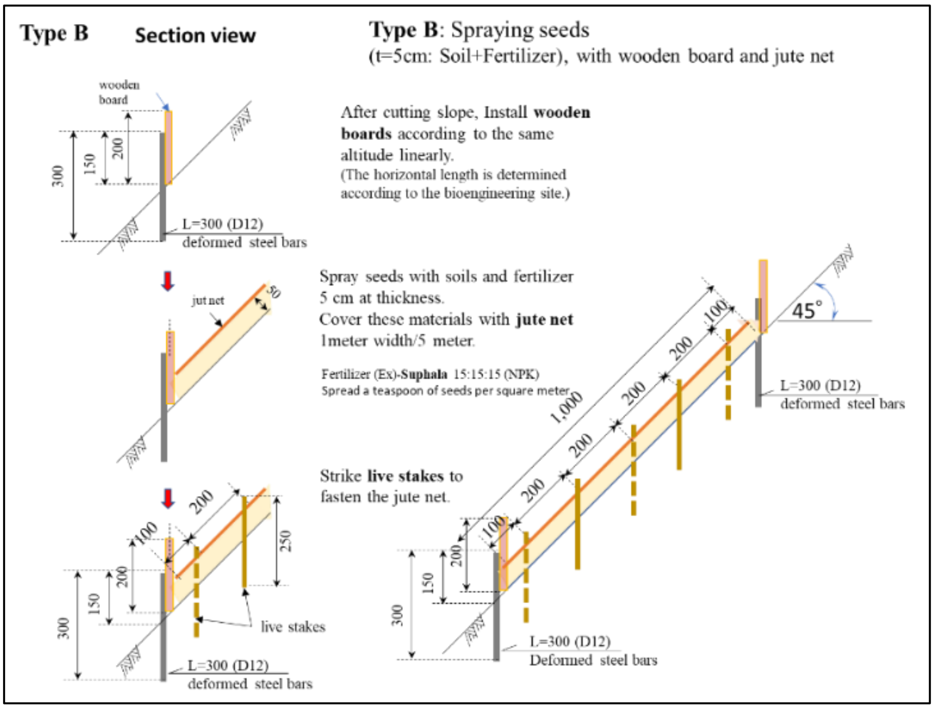
(4) On-site installation of the first test construction

For on-site installation, JETs prepared materials illustrating the installation method and provided direct on-site installation guidance. In addition, since on-site guidance by JETs was no longer possible after March 2020 due to COVID-19, video materials on construction procedures were prepared to facilitate visual understanding among construction personnel and DoST staff, and technical guidance and construction management were conducted remotely from Japan via the Web (Skype) on a regular basis. The construction procedures are described below. The construction procedures are shown below.



(Source: JET)

Figure3.3-27 Construction Procedure for Vegetation Work Type A.

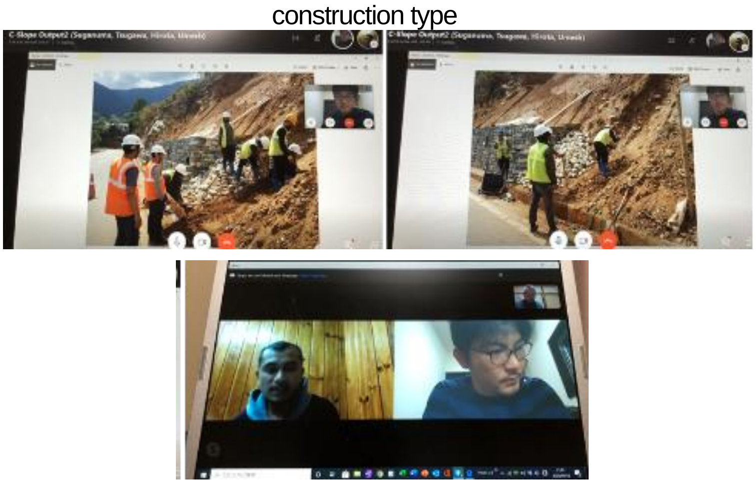


(Source: JET)

Figure3.3-28 Construction Procedure for Vegetation Work Type B.

(Source: JET)

Photo 3.3-26 Part of the Video material showing the construction procedure for each vegetation construction type



(Source: JET)

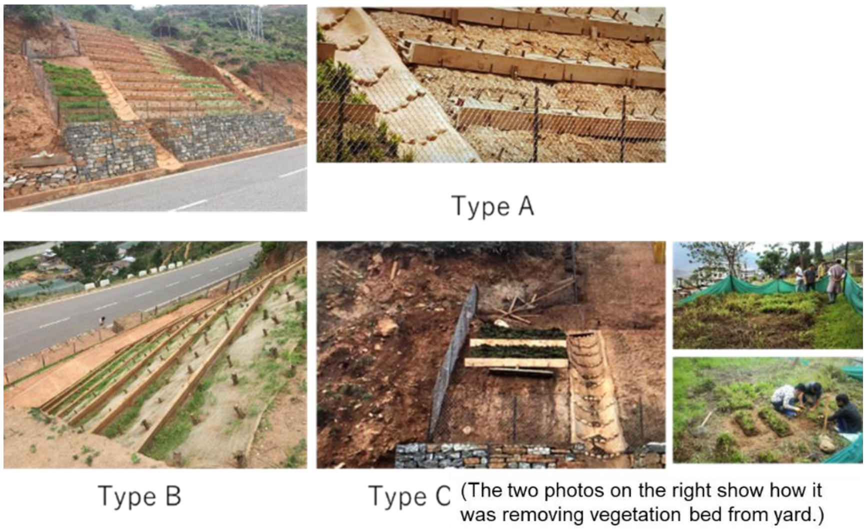
Photo 3.3-27 Technical guidance and construction management via the web using Skype

(Source: JET)

Photo 3.3-28 Drainage construction status

(Source: JET)

Photo 3.3-29 Vertical drainage (cascade drain) under construction (2020/5/26)

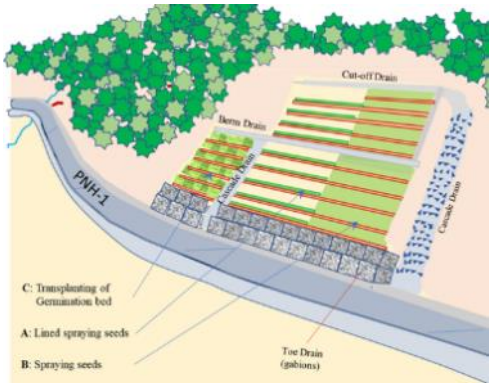


(Source: JET)

Photo 3.3-30 Construction status of Type A, B, and C

(5) Post-construction status of the first test construction

For the first test construction, which was completed at the end of May 2020, the figure shows the overall view of the plan and the condition of the slope after the completion of the test construction. The photo shows the condition of the slope approximately 3 months after the completion of the construction (September 26, 2020). At this point, the vegetation is thriving best in Type B: full surface seed application (jute netting), followed by Type C: turfing, and although Type A: strip seed application has germinated, it is considerably inferior to the lower part of Type B and Type C. The photo shows that the vegetation is thriving well in Type B, but not in Type C.



(Source: JET)

Figure3.3-29 Overall view of the project (left), slope immediately after vegetation construction (right) (May 31, 2020).

(Source: JET)

Photo 3.3-31 Slope conditions about three months after vegetation construction (September 26, 2020)

Based on the above results, in the jurisdiction of the Lobesa District Office, where the first trial construction was conducted, it is considered effective to use either Type B: full surface seed application (jute netting) or Type C: turfing. However, in the case of Type C, a large farm for turf cultivation would be required in addition to the construction site, but it is difficult to secure such a large area of farmland in Bhutan, which is a mountainous country. Considering the current situation, it is concluded that Type B is the most realistic vegetation construction method in Bhutan.

(6) Impact of COVID-19

Due to the spread of COVID-19, the following issues were encountered and addressed during the first test construction.

1) JICA experts can no longer travel to Bhutan

Problems: Inability to provide direct on-site guidance and adequate technical guidance and construction management.

Countermeasures:

(i) Supervised the progress of the site through Skype with a local mercenary (technical assistant) and provided technical guidance to the DoST and local workers.

(ii) Backup for construction management was provided through the creation and use of Video materials on the construction procedures for vegetation work.

2) Unable to obtain materials from India.

Problems: Some construction materials could not be imported from India.

Countermeasures:

Similar materials were gathered in Bhutan for the construction. The dimensions of the materials were slightly different and the price was also high.

The creation and use of Video materials

Devising Video materials:

- ✓ When creating the Video in Japan, JET selected materials as close as possible to those used in Bhutan.
- ✓ It was also created to carefully explain each of the construction procedures.
- ✓ JICA experts also participated via Skype to provide advice during the viewing of the video materials.

C/P (DoST) Response:

- ✓ It was recognized by Lobesa and Tonsa office personnel as easy to understand.
- ✓ The Sarpang office requested to use it as an educational tool for young engineers.
- ✓ Since this video can be freely viewed within DoST, JET received the opinion that it is very useful for horizontal deployment of the technology.

Activity 2-4-2 Second test construction

The second test construction was conducted on the eastern slope of T-veg. 014, Yangkhil Resort in the jurisdiction of DoST Trongsa Regional Office.

(1) Field survey for second test construction

Prior to the design work for the second test construction, the following field investigations were conducted.

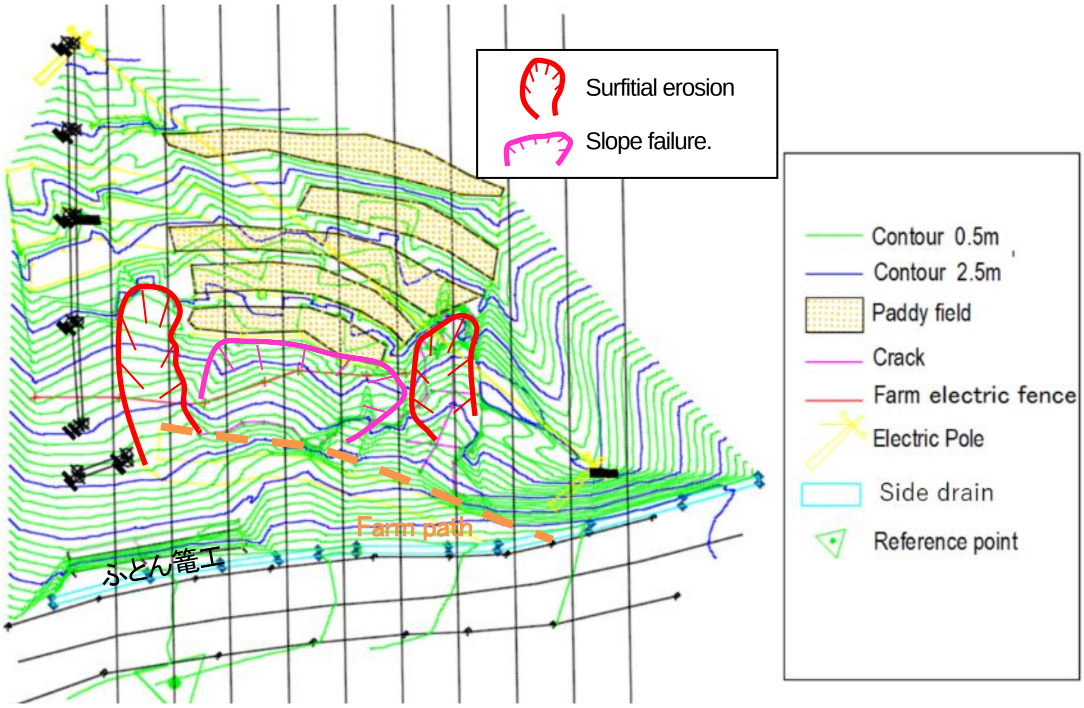
A field survey was conducted to understand the local conditions necessary for the design of the project. The field survey was conducted to understand the condition of the subject slope, the surrounding surface water and its drainage, and to determine the scope of the survey to be conducted later. The following are photographs and plans of the site.

Large-scale surface erosion (with collapse in the eastern part) is observed on both sides of the subject slope, and surface slope failure is also observed in the central part of the slope. There are rice paddies above the slope, but there are no drainage works, and precipitation and water from the rice paddies flow freely down the slope along the topography. It is assumed that the large amount of surface water is causing surface erosion of the slope, and that some of the surface water is recharged as groundwater, triggering the surface slope failure.

In the center of the slope, there are the remains of an agricultural trail, and on the left side of the slope, a futon basket was constructed as a countermeasure to a previous slope failure.

(Source: JET)

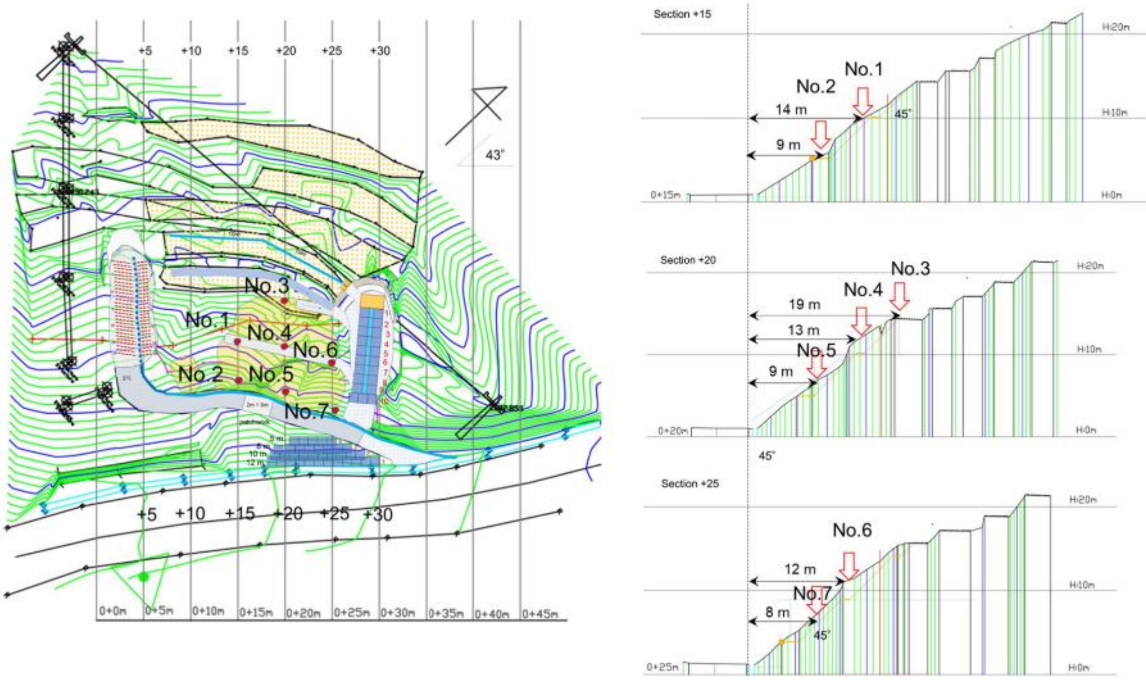
Photo 3.3-32 Local conditions of the slope adjacent to the east of the second test slope (T-veg. 014, Yangkhil Resort)



(Source: JET)

Figure3.3-30 Plan of the slope adjacent to the east of the 2nd test construction slope (T-veg. 014, Yangkhil Resort).

Field Tests] Simple penetration tests were conducted in the slope to determine the geological conditions necessary for the design. Simplified penetration tests were conducted at a total of seven locations, No. 1 through No. 7, as shown in the figure below.



(Source: JET)

Figure3.3-31 Field survey prior to vegetation engineering test (Lobesa Regional Office).

The results of the simple penetration test on the second test construction slope are shown in the table below. Based on the test results, the standard cut slope for this slope was found to be 1:1 to 1:1.2 at the top of the slope and 1:1 at the middle and bottom of the slope, according to the guideline developed in Output 3.

Table 3.3-15 Table of Simple Penetration Test Results for the Second Test Construction Slope

Slope position	test position	depth	Simple Penetration Test Site Nc Value	Standard cut slope
Upper part of slope	No.3	Depth 1m	4 - 5	1:1 - 1:1.2
		Depth 2m	4 - 7	1:1 - 1:1.2
mid-slope	No.1, 4, 6	Depth 1m	2 - 12	1:1
		Depth 2m	11 - 18	1:1
Lower part of the slope	No.2, 5, 7	Depth 1m	4- 19	1:1
		Depth 2m	5 - 40 or more	1:1

(Source: JET)

The surveying work was conducted in order to grasp the local conditions necessary for the design. Based on the field survey, the survey area was set at 55m x 50m, including the construction area, and cross-sectional surveys were conducted every 5m in the section where the vegetation work was to be implemented. The surveyed area for the design of vegetation works is shown below. The surveying work was performed by DoST and the necessary plan and cross sectional drawings were prepared for the design.

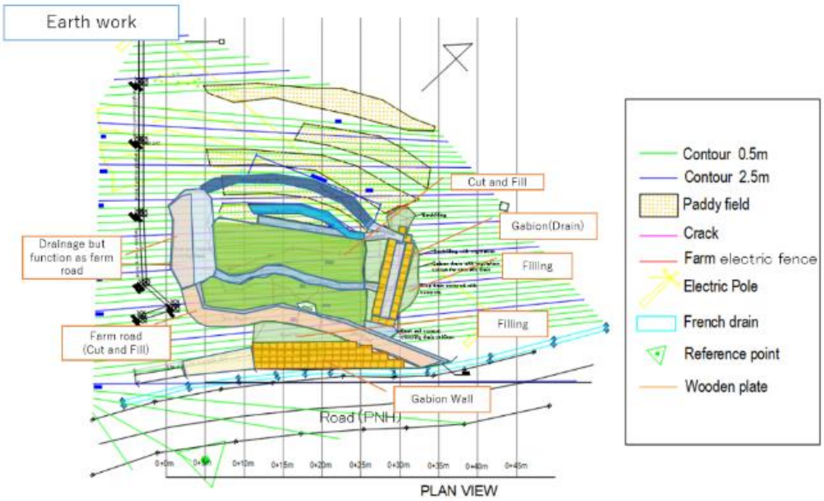
(Source: JET)

Figure3.3-32 Surveyed area for design of vegetation works on the second test slope.

(2) Detailed design for second test construction

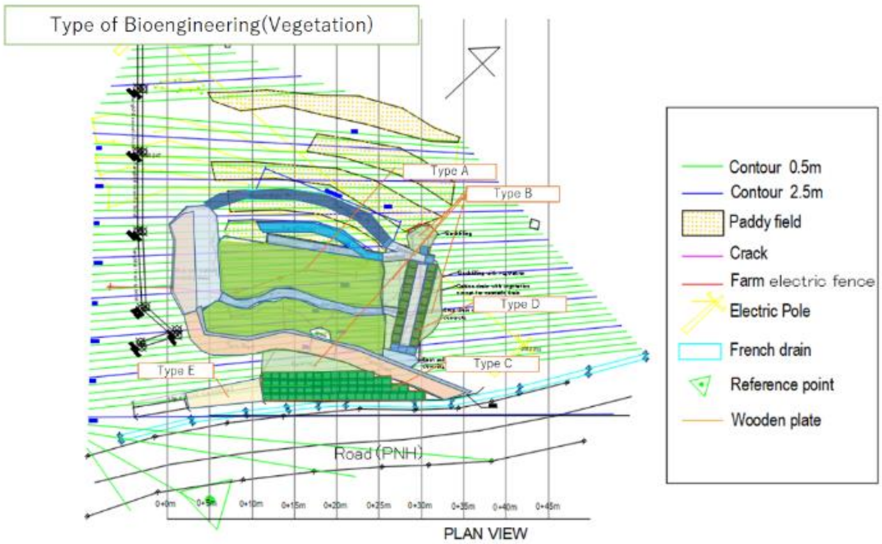
The overall construction plan for the entire slope is shown in the figure below. The slope failure area in the center of the slope was shaped to a standard cut slope by cut-and-fill construction, and vegetation work were carried out. The surface erosion areas located at the right and left ends of the slope were designed as stand-up drainage channels, while surface drainage channels and culvert drains (French drains) were installed at the top and behind the slope, and a small drainage channel was installed in the middle of the slope. The end of the slope is equipped with four tiers. At the end of the slope, four tiers of futon baskets were placed and backfilled to serve as counterweights against large-scale slope failure, and agricultural trails were placed on the embankment for the convenience of local residents.

The design was also designed to maximize environmental considerations as well as to ensure slope stability by increasing the revegetation rate of the entire slope by planting vegetation on the tops of the many futon baskets to be installed.



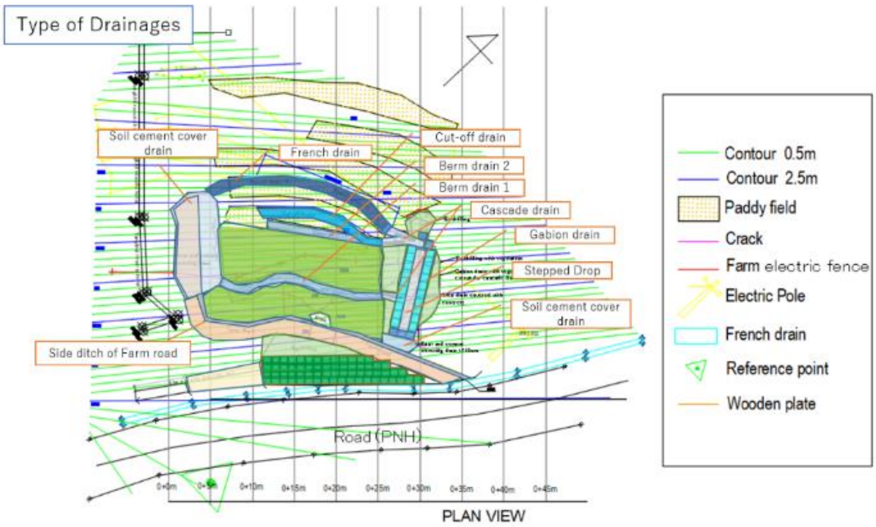
(Source: JET)

Figure3.3-33 Layout of earthwork (cut and fill) for the second test construction.



(Source: JET)

Figure3.3-34 Layout of vegetation works for the second test construction.

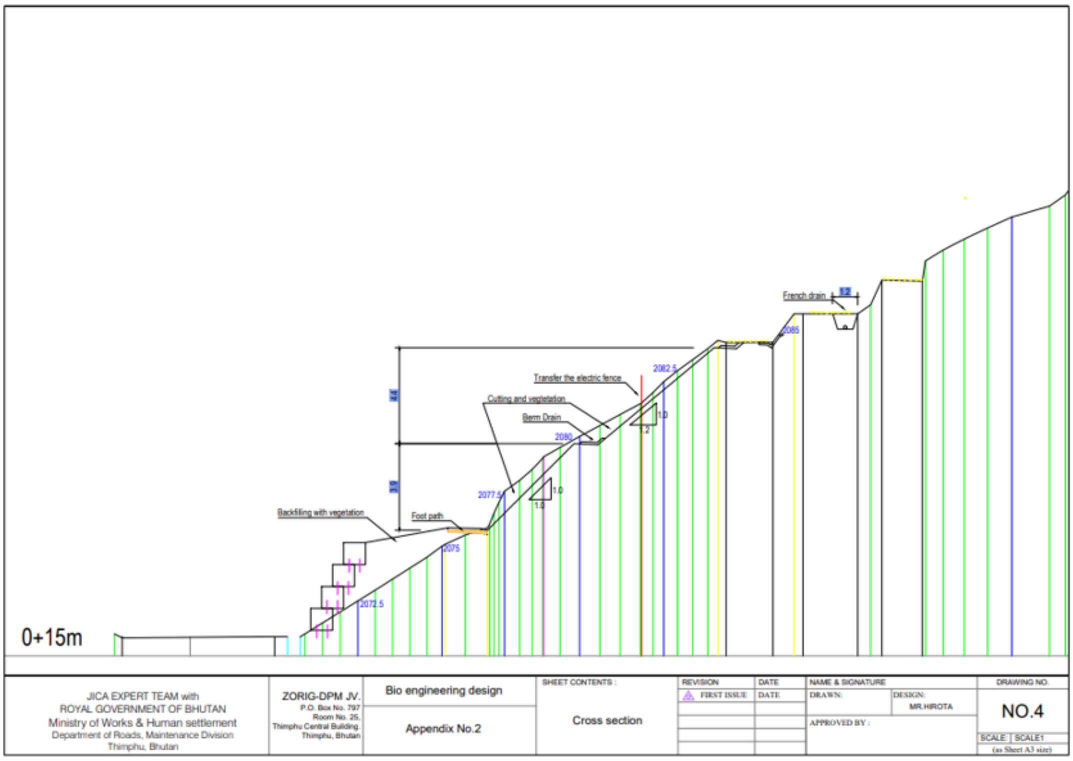


(Source: JET)

Figure3.3-35 Layout of drainage works for the second test construction.

The slope is formed by earthwork (cut and fill) prior to vegetation work. The cross-sectional shape is shown in the figure below.

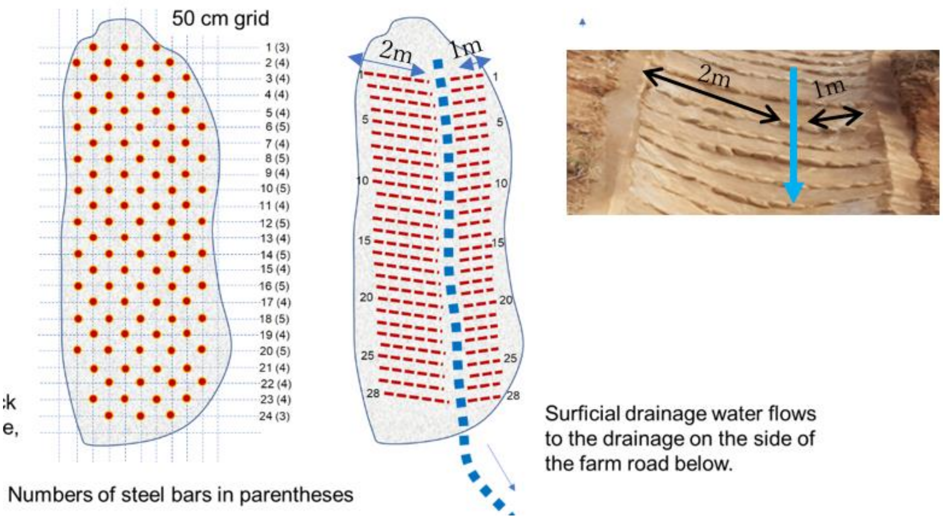
At the end of the slope, a 4-meter-high retaining wall with a bedding cage was installed, and an agricultural trail was constructed on the embankment behind the wall. For the cut-and-cover construction with the agricultural trail at the end of the slope, the slope was cut and shaped to an appropriate slope according to the results of the simple penetration test and the results of the study in Output 3. The slope at the bottom of the slope is sloped 1:1.0 (45 degrees), and the slope from the middle to the top of the slope is sloped slightly more gently at 1:1.2 to ensure the safety of the slope.



(Source: JET)

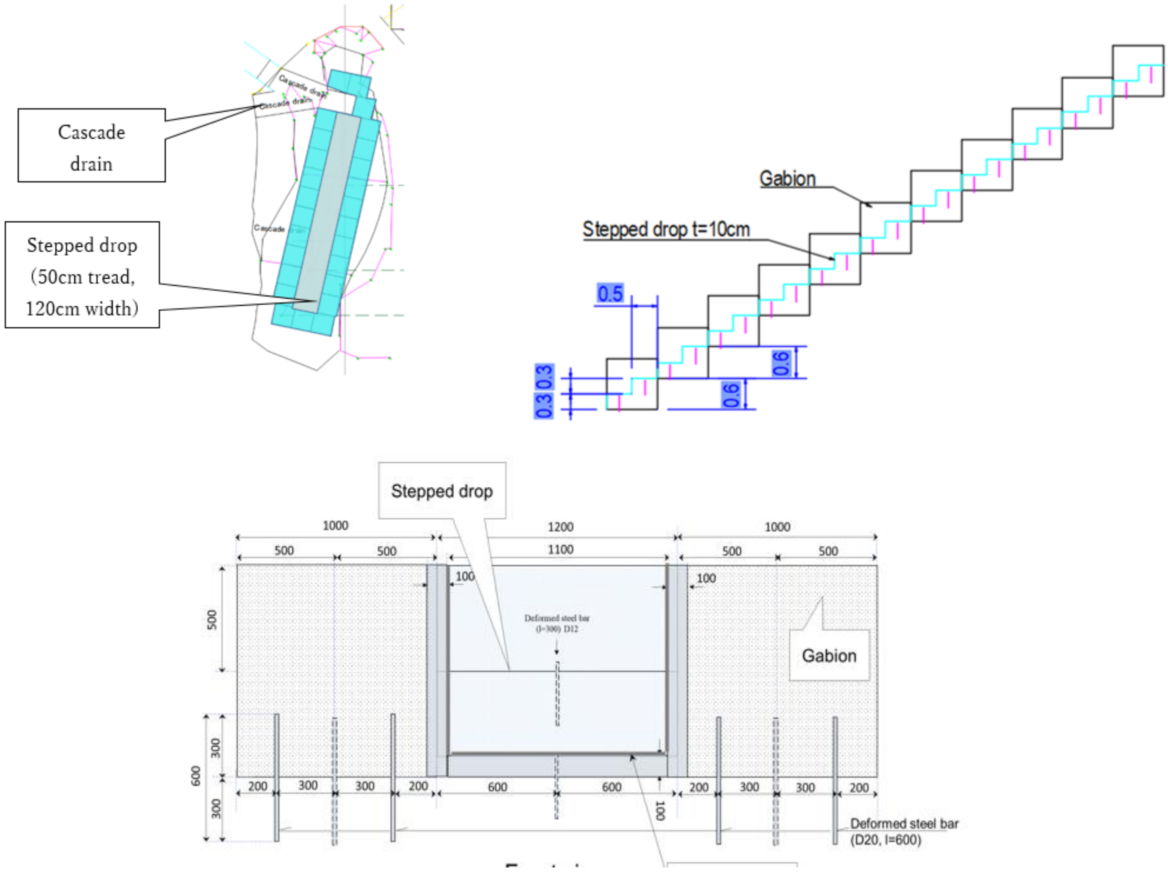
Figure3.3-36 Design cross section of cut and bedding basket construction for vegetation construction - N0.15 cross section in the center of the slope.

Drainage works] From the viewpoint of preventing erosion of the slope and eliminating the groundwater level within the slope, drainage works were designed to prevent surface water from flowing into the slope and eroding the cut soil surface, as well as to reduce the supply of groundwater to the slope. Specifically, the surface erosion sites located at the right and left edges of the slope were constructed as drainage works, and drainage works and culverts were installed on a small step on the slope and behind the slope. In Japan, it is common to use U-shaped ditches and bellows pipes for drainage works on cut slopes, but in Bhutan, these materials are difficult and expensive to obtain. Therefore, an inexpensive drainage channel construction using soil cement made from locally generated soil and natural stones was adopted.



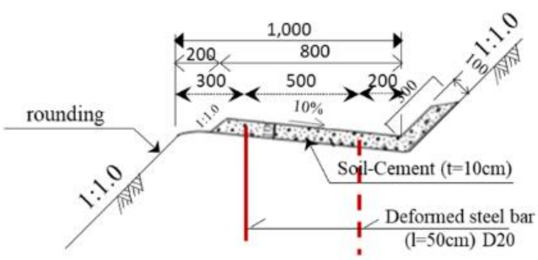
(Source: JET)

Figure3.3-37 Structure of vertical drainage works (left side of slope) for vegetation works.

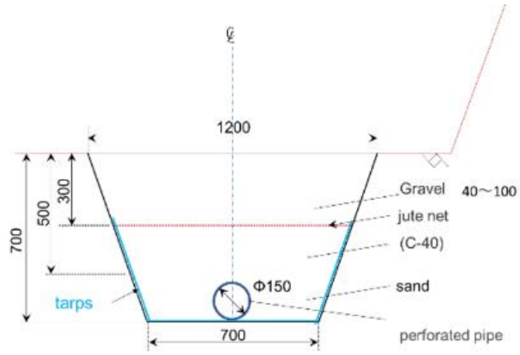


(Source: JET)

Figure3.3-38 Structure of vertical drainage works (right side of slope) for vegetation works.



Cross-sectional view of small drainage works



Cross-sectional view of culvert works

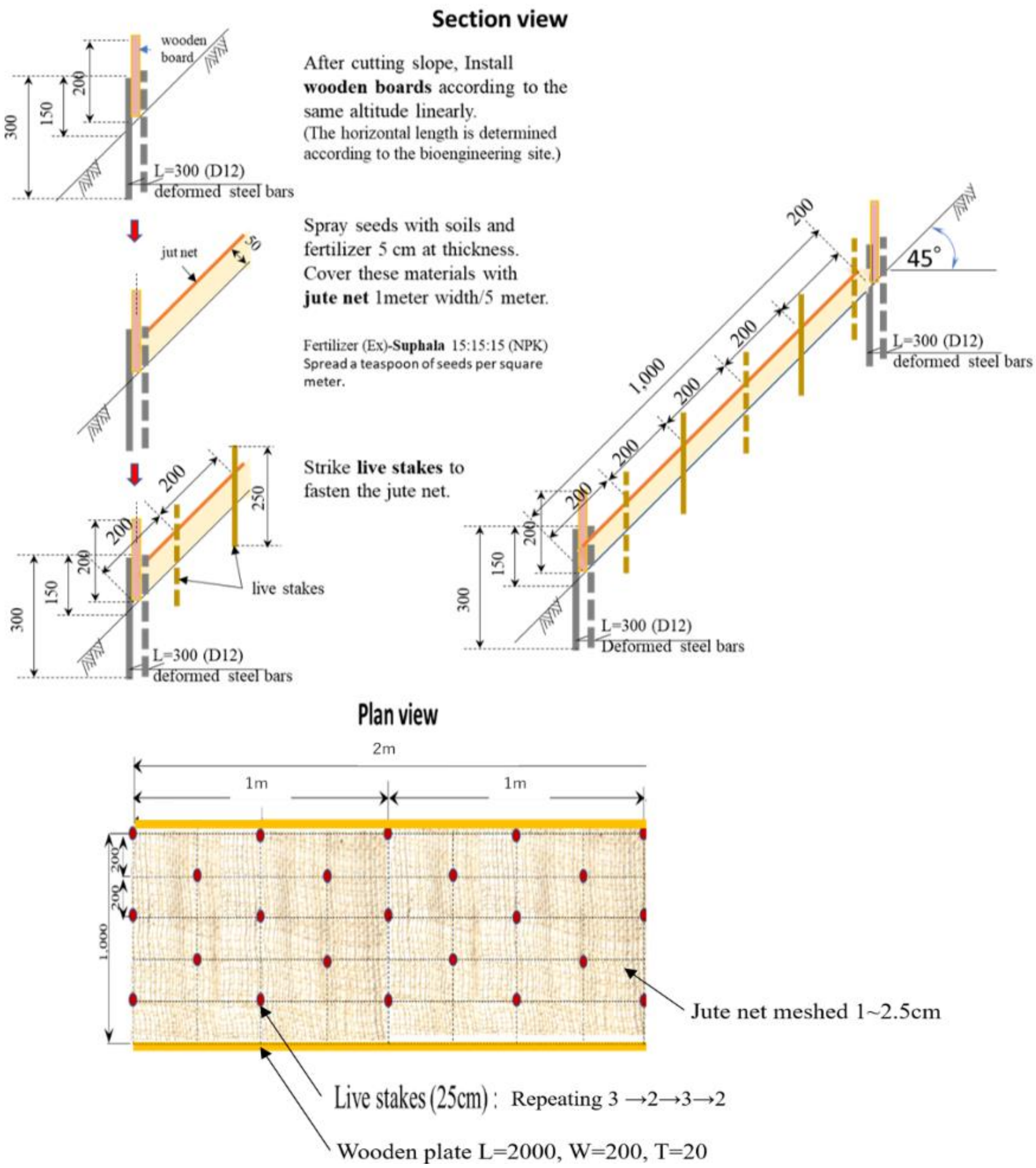
(Source: JET)

Figure3.3-39 Small stage drainage for vegetation works (left figure) and culvert works behind the slope (right figure).

The design of the vegetation works was based on the results of the first trial construction and Activity 2-3, and the most appropriate construction method was selected considering the materials available in Bhutan and feasible construction techniques.

- ✓ Tall Fescue seeds that have germinated and grown well even in the high altitude Tonsa Regional Office jurisdiction (2000m to 2500m) is used.
- ✓ When placing soil on the slope surface, ensure that the thickness of the soil is at least t = 3 cm.
- ✓ Cover the slope surface with jute nets to prevent scattering and runoff of topsoil and seeds (Type B of the first test construction is used).

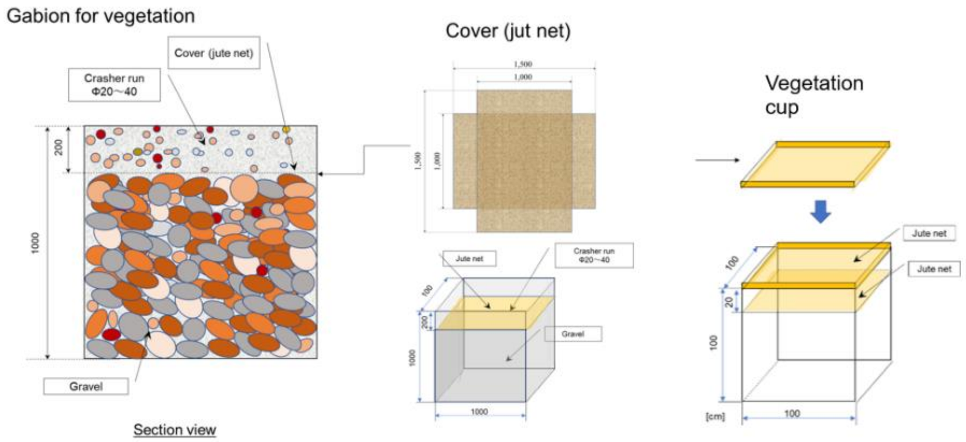
In the first test construction, a seed dispersal method using coarse jute nets, which are available inexpensively in Bhutan, was proposed and implemented. The jute netting and the application to the entire slope (Type B) were judged to be appropriate, and this method was adopted for the second test construction.



(Source: JET)

Figure3.3-40 Structural drawing of the vegetation work on the glide surface.

In the second test construction, a number of futon baskets were installed. By installing vegetation on the tops of the many cages, the revegetation rate of the entire slope was increased, and the design was designed to not only ensure the stability of the slope, but also to give maximum consideration to environmental aspects. The figure below shows the structure of the vegetation work on the futon cage. The vegetation on the top surface of the futon basket is also secured by using Tall Fescue seeds with a minimum thickness of t=3cm.



(Source: JET)

Figure3.3-41 Structural drawing of the vegetation work on the glide surface.

(3) On-site installation of the 2nd test construction

The second test construction was conducted from January to May 2023.

	
Photo 3.3-33 Gabion construction vegetation and channel ((March 25, 2023).	Photo 3.3-34 Vegetation construction completed (May 3, 2023).
	
Photo 3.3-35 Test construction completed (May 3, 2023).	Photo 3.3-36 Greening Status (August 2, 2023).

Observation of the slope conditions three months after completion of the vegetation work shows that revegetation is proceeding smoothly.

Photo 3.3-37 Revegetation status of staircase channel and top of Gabion (September 2, 2023).

Photo 3.3-38 After installation of signage (September 3, 2023).

Activity 2-4-3 Third test construction

The third test construction was conducted on the north slope of Gopini in Samtse, within the jurisdiction of the Phuentsholoing Regional Office. The site consists of a slope sloping more gently than 45 degrees, and the ground surface is covered with debris due to past landslides. In the 7th JCC meeting held in April 2023, it was decided to conduct the 3rd pilot project in Samtse and Phuentsholing districts. In May 2023, four sites along PNH 2 between Phuentsholing and Samtse were selected as candidate sites. After examining the topography, constructability, and other factors, Gopini was determined to be the most suitable site, and after obtaining approval from DoST, a detailed field survey and surveying was conducted in September 2023. Based on the results of these surveys, detailed design, costing, and special specifications were reviewed for the vegetation works and associated slope disaster prevention works, which are expected by DoST to be applied to similar slopes in challenging locations as vegetation works construction.

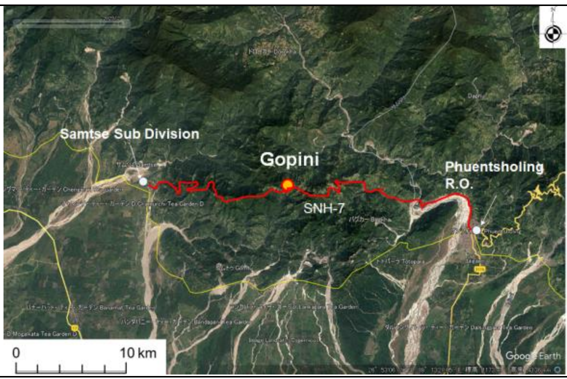
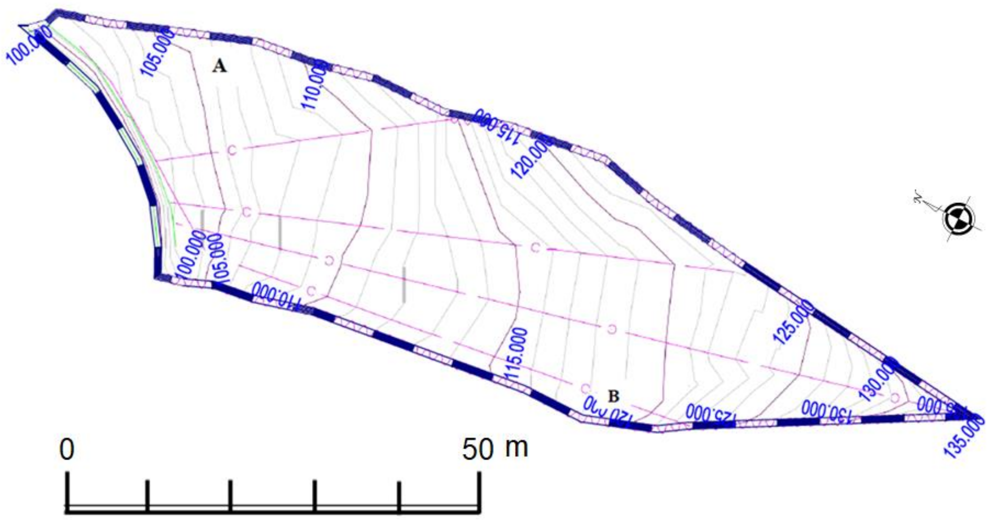


Figure3.3-42 Test Construction Slope Location.

Photo 3.3-39 Panoramic view of test slope.

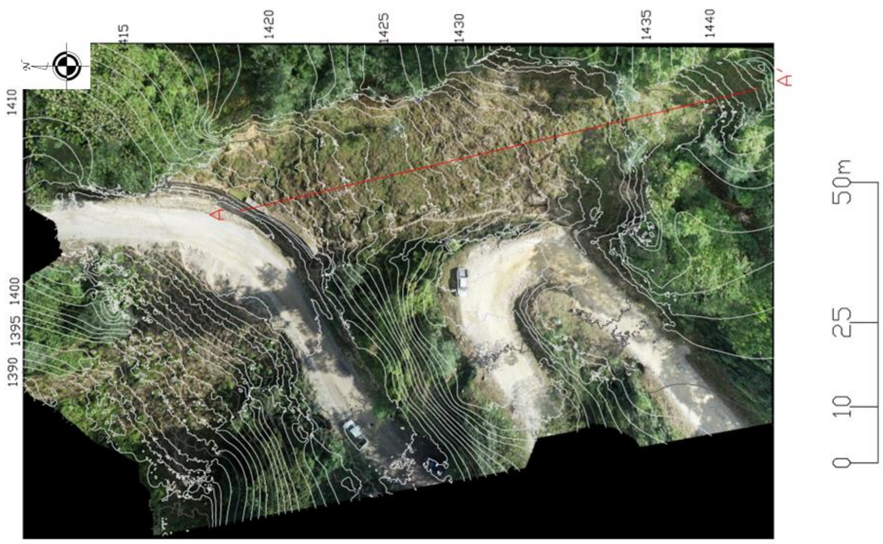
(1) Field survey for the third test construction

Prior to the design work for the third test construction, a surface survey was conducted and a survey was made with the cooperation of Samtse Sub-division. The surface of the third test site is covered with rock debris and the slope is about 20 degrees, so the ground surface was shaped and the drainage system was sufficiently prepared before the vegetation was installed.

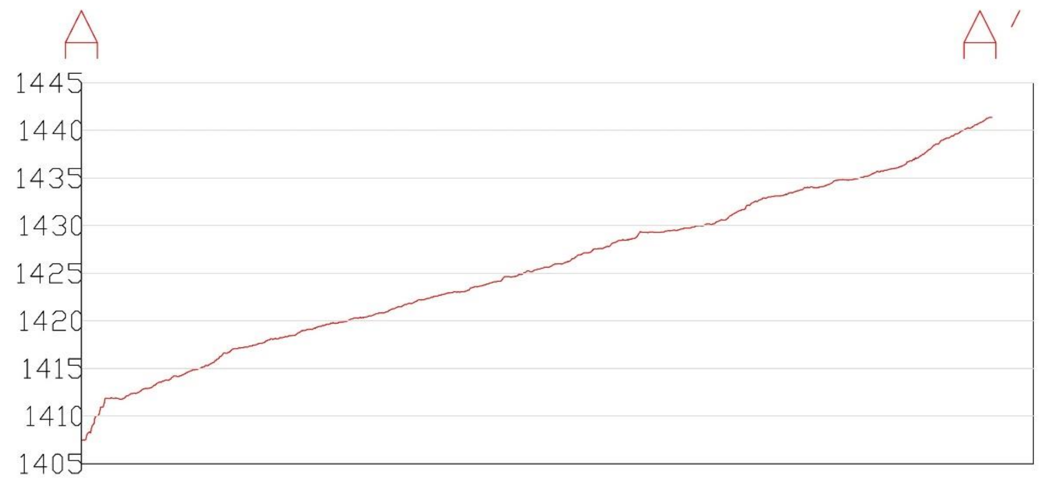


(Source: JET)
Figure3.3-43 Survey plan (additions to the data provided by Samtse Sub-division).

In addition, JET and C/P took on-site drone images as necessary for construction management (workmanship control) and maintenance management.



(Source: JET)
Figure3.3-44 Drone shot (with contour lines . (A-A' is the cross-sectional line).

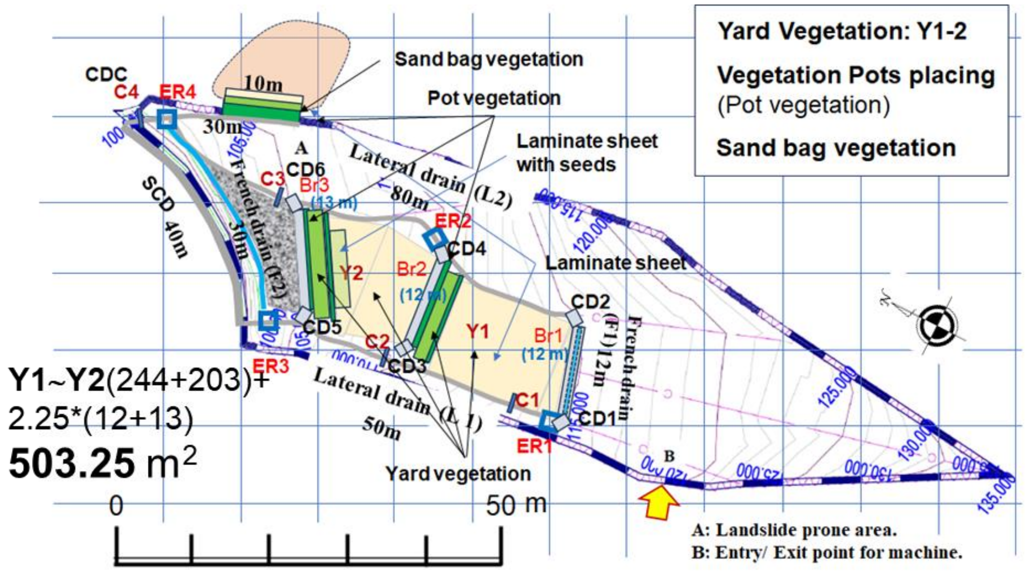


(Source: JET)

Figure3.3-45 The figure is based on a drone shot. A-A' is the cross section.

(2) Detailed design for 3rd test construction

The construction plan for the entire slope is shown in the figure below.



(Source: JET)

Figure3.3-46 Vegetation works and drainage system.

Main construction facilities: The following is a list of the main drainage and vegetation construction types.

Table 3.3-16 List of major drainage and vegetation works.

Drainage System	Unit	volume	Remarks	Vegetation engineering	Unit	Volume	Remarks
Berm drain (Br)	m	37.0	Conduit	Yard vegetation	m^2	503.3	447+ 2.25 between pots x (12+13)
Lateral drain (L)	m	160.0	Vertical drainage	Vegetation pots placing	pcs	133	**23** pieces on the Br2,. **25** pieces on the Br3 **12** pieces at Y1 **13** pieces at Y2 **60** pieces at Landslide prone area
Cascade drain (C)	m	12.0	Connection from the receiving channel to the vertical drainage	Sand bag vegetation	pcs	400	Landslide prone area **200** bags with seeds and **200** bags without seeds
French drain (F)	m	42.0	Underdrainage				
Check dam (CD)	pcs	6	Streamflow Reduction				
Energy reducer (ED)	pcs	4	Streamflow Reduction				

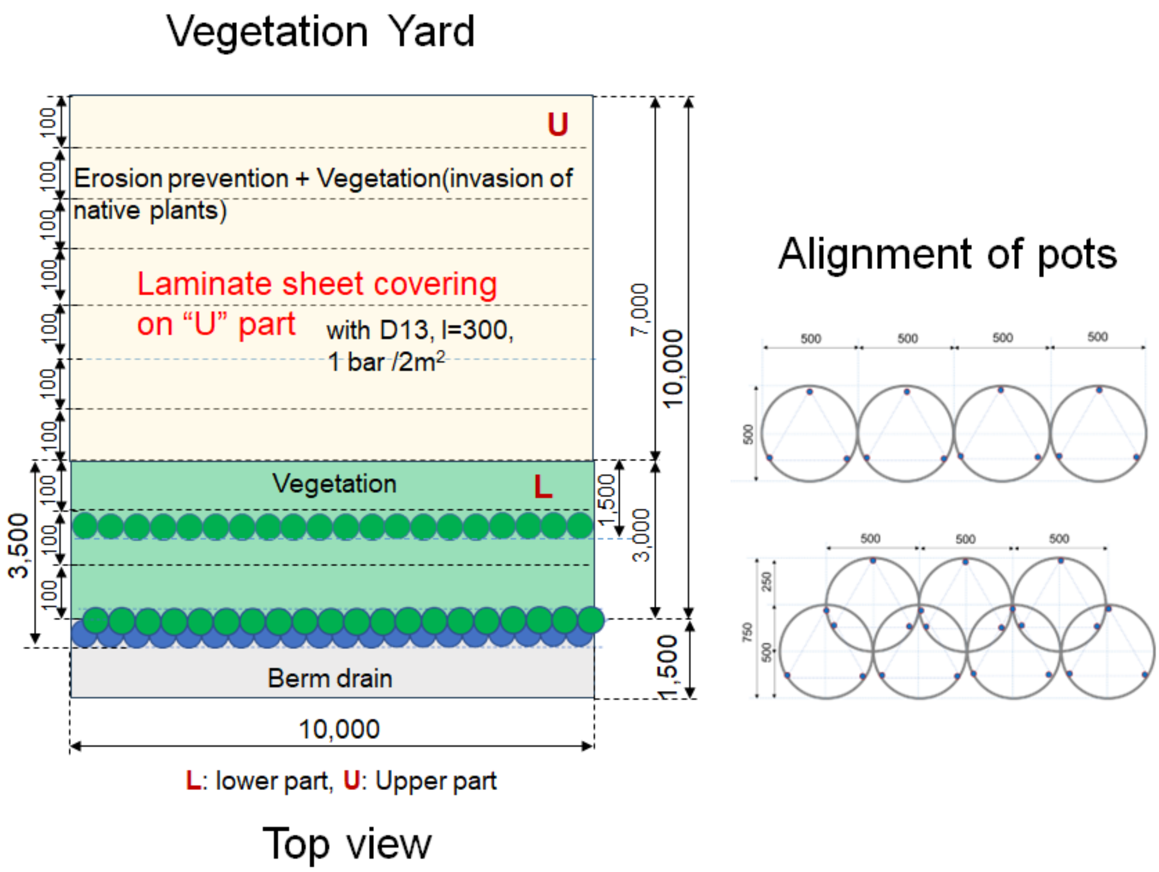
(Source: JET)

Vegetation work plan

Details of vegetation construction:

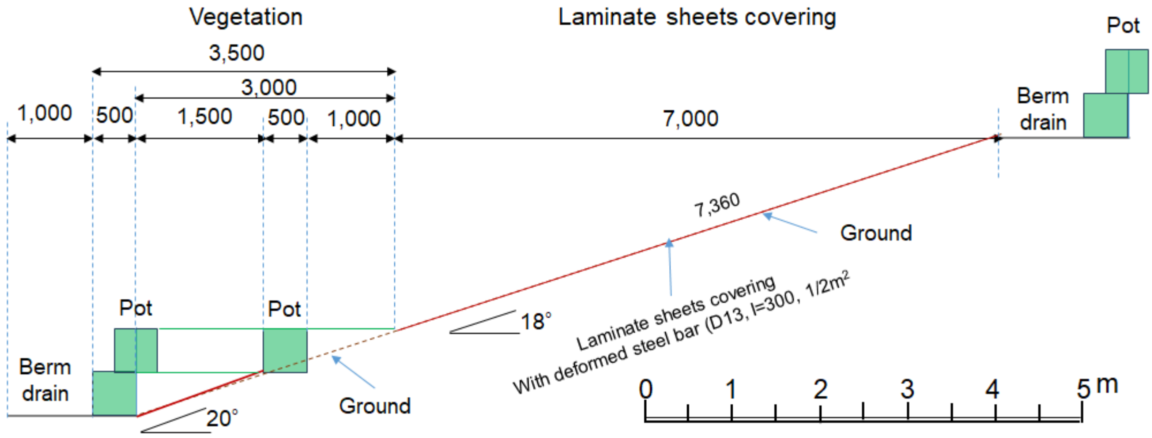
Yard vegetation

The area to be seeded in the yard is the area between the pot rows (top and bottom width 1.25 m + 1.0 m) .



(Source: JET)

Figure3.3-47 Typical plan of vegetation works (left: 10 m square yard + bearing channel) and pot arrangement (right)

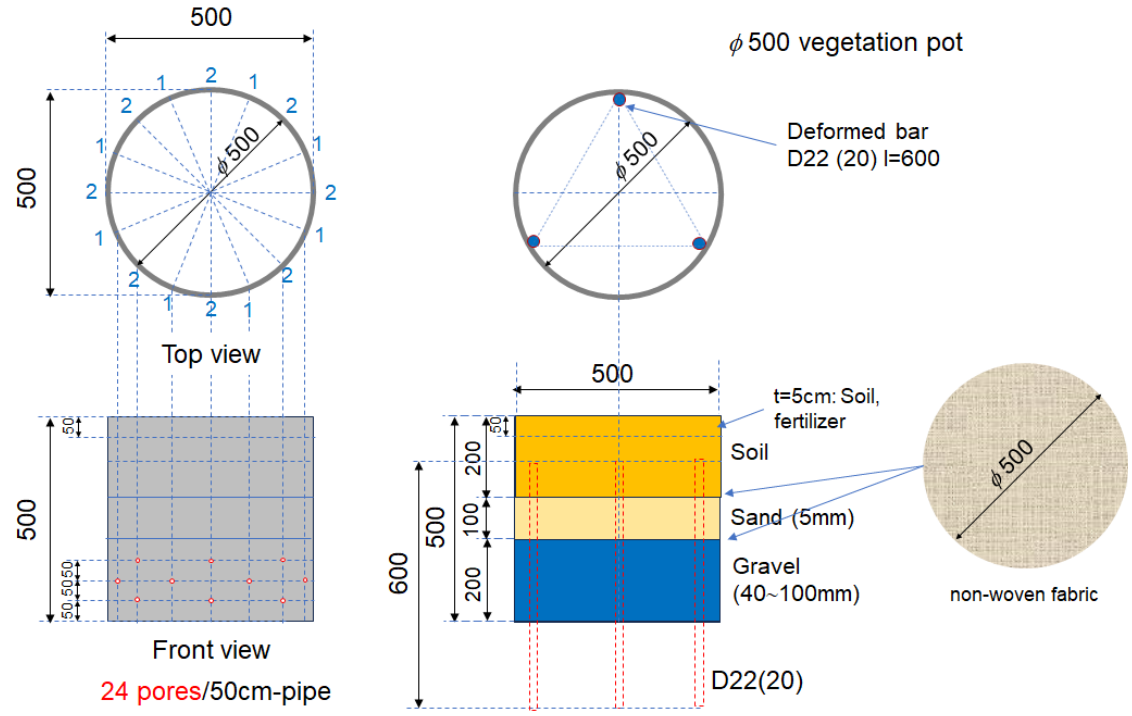


(Source: JET)

Figure3.3-48 Standard cross section of vegetation work at the yard and the yard's bearing channel layout.

Vegation pots placing

Cut 50 cm diameter tubes (of any material as long as they are strong) into 50 cm lengths and prepare vegetation pots. In each pot, three steel bars (D22) are inserted first, then filled with crushed stone (40-100 mm), sand (5 cm, top and bottom bordered by non-woven fabric), and soil (20 cm), starting from the bottom.



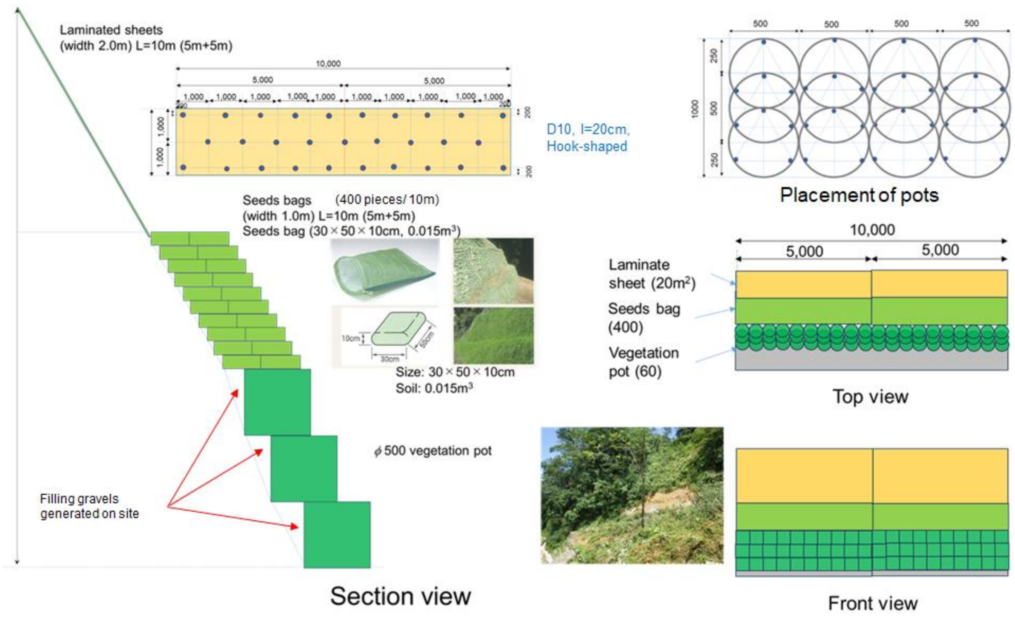
(Source: JET)

Figure3.3-49 Structure of vegetation pots.

Sandbag vegetation

Sandbag revegetation was performed on the east slope where surface collapse is observed at the test site. Vegetation work at this location was done in combination with other vegetation work that uses pots and laminated sheets.

The sandbag vegetation installation consists of double bags. The 400 bags were planned for this site, and 10 g of ruzi grass was seeded on the inside top surface of the 200 bags that were exposed. The first step is to fill a jute bag with soil and place it in a plastic mesh bag with the seeds attached to the top of the bag. The double bags are then stacked in two rows of 10 layers in a 10-cm-wide section.

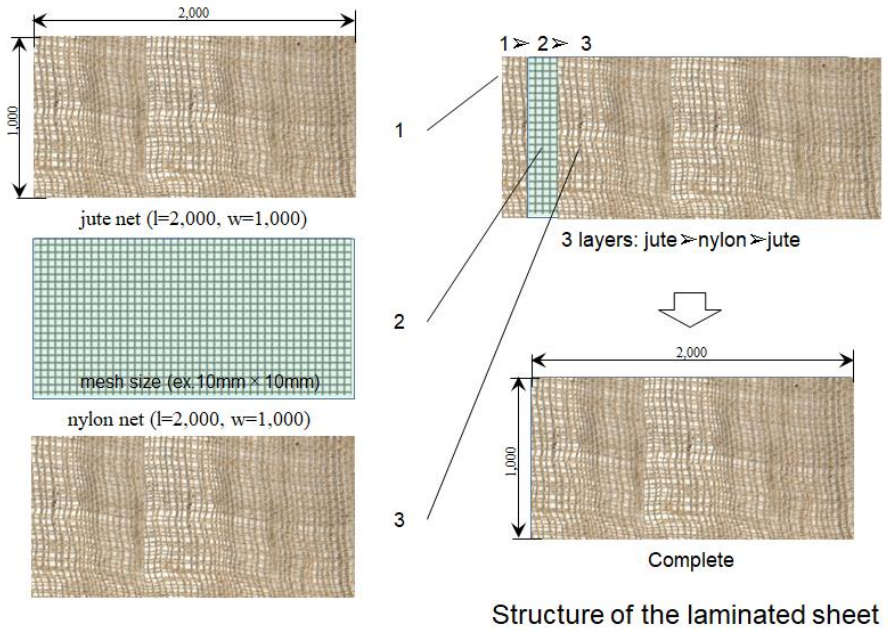


(Source: JET)

Figure3.3-50 Vegetation works in small collapsed areas (sandbag vegetation works included).

Laminate sheet covering

Vegetation work with flying species uses laminated sheets. This is created by sandwiching plastic mesh sheets between jute sheets. It also serves to prevent erosion of the surface layer. The laminated sheet allows some soil to be deposited on top.



(Source: JET)

Figure3.3-51 Composition of Laminated Sheet.

Plants to be employed: seeds were Ruzi grass. In the pots, Ruzi grass were used in the surface-slip areas, but Madagascar periwinkle (Catharanthus roseus L.) and Boat Lily (Tradescantia spathacea) were planted alternately in the pot rows in the yard. .

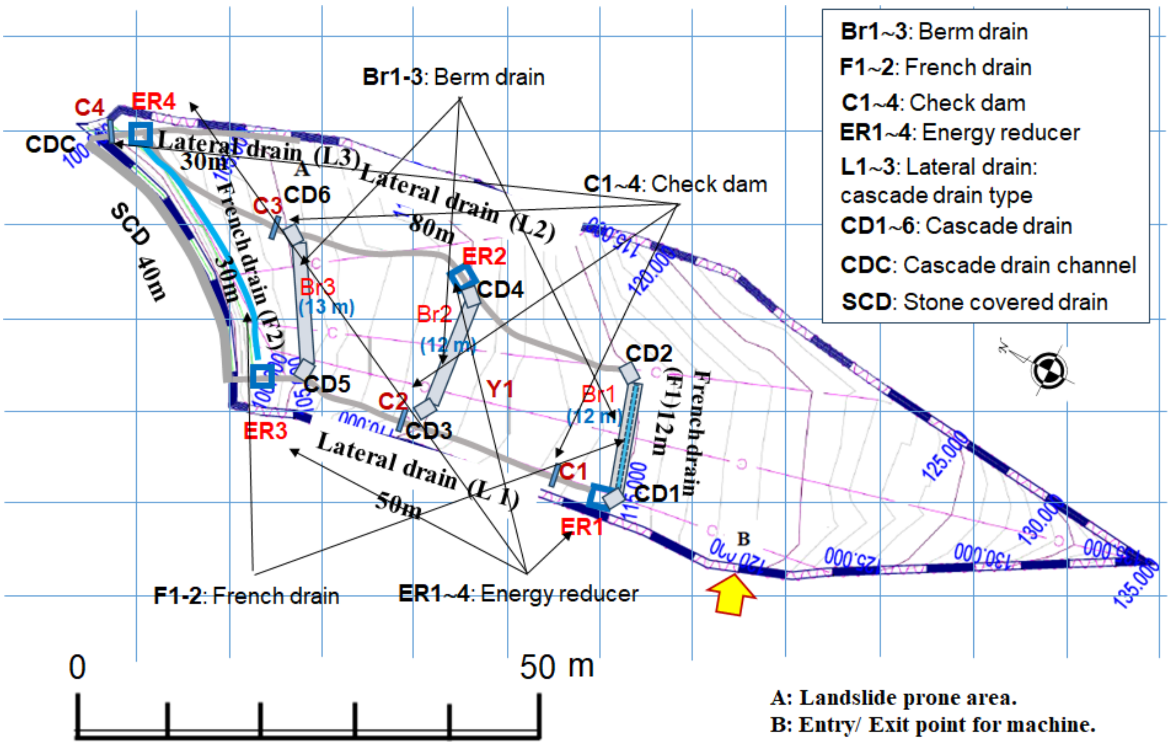
		
Ruzi grass (*Brachiaria ruziziensis*)	Madagascar periwinkle (*Catharanthus roseus* L.)	Boat Lily (*Tradescantia spathacea*)

(Source: JET)

Figure3.3-52 Plants used in vegetation construction.

Drainage Plan

The drainage system should be installed before the vegetation work is done.

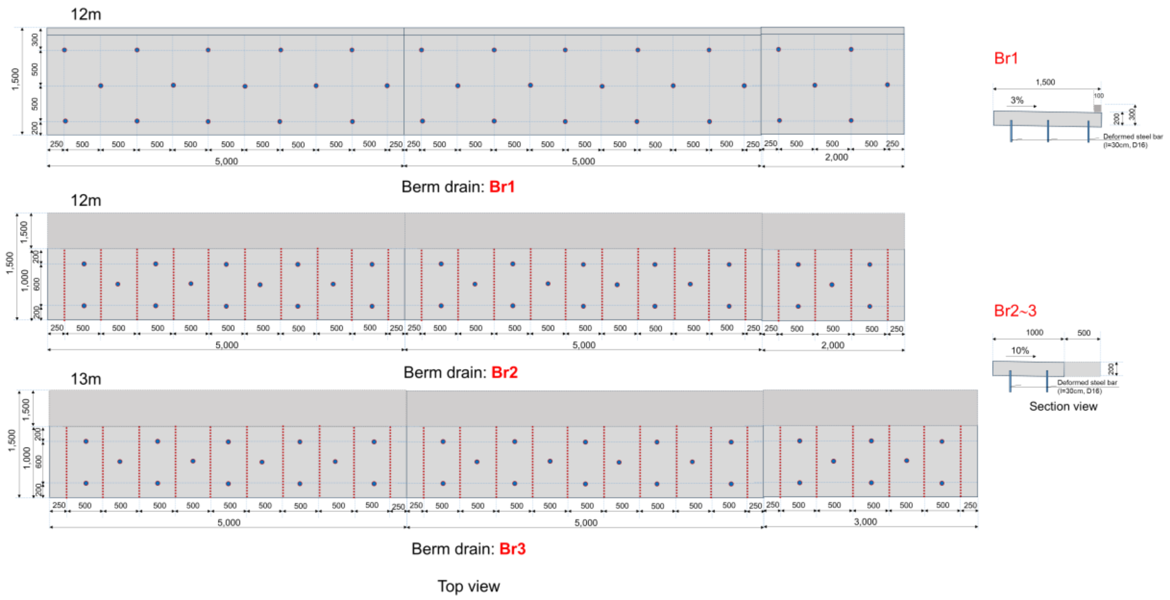


(Source: JET)

Figure3.3-53 Drainage Systems and Types of Drainage Works.

Details of each drainage system type

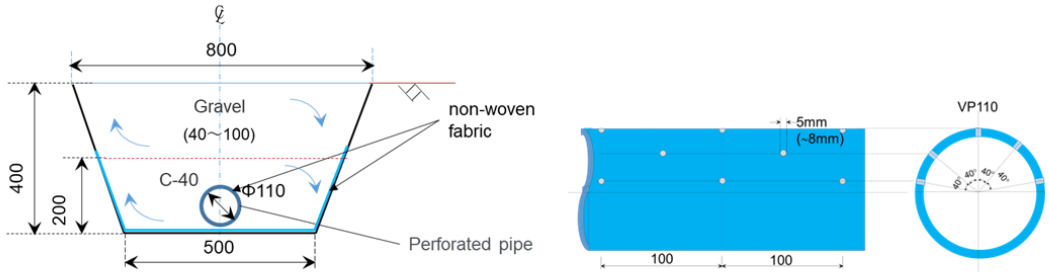
Berm drains (Br1, Br2, Br3): receive surface water flowing down the slope and drain it into vertical drains (Lateral drains L1, L2). Finally, it is drained out of the slope by the roadside ditch (Stone covered drain SCD) below the slope.



(Source: JET)

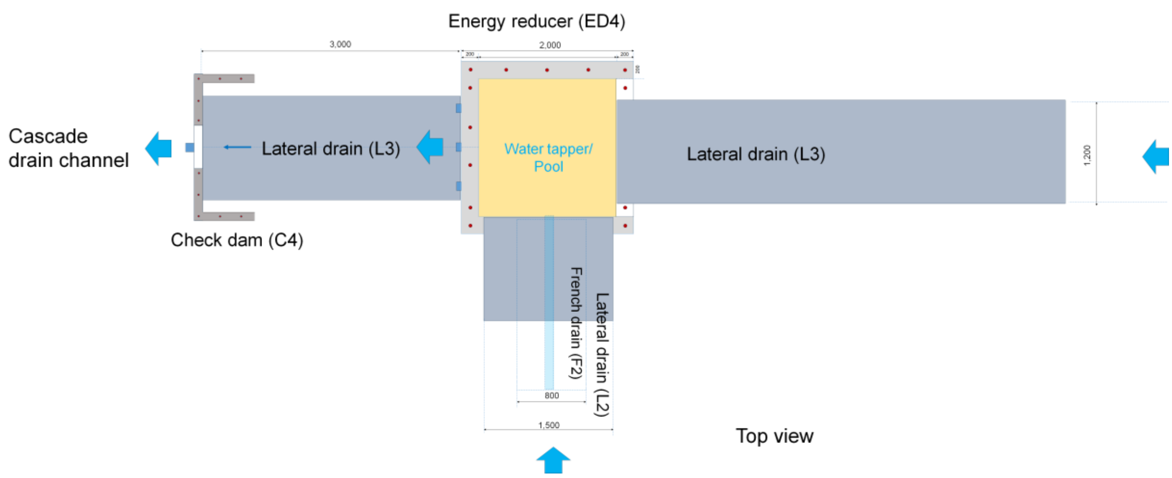
Figure3.3-54 Plan of the bearing channel (Br1: 12m, Br2: 12m, Br3: 13m).

French drain F1 and F2: Drainage of surface water and rising groundwater. This water is led to a vertical drainage channel for drainage.



(Source: JET)

Figure3.3-55 Culvert drainage cross section and pipe used.

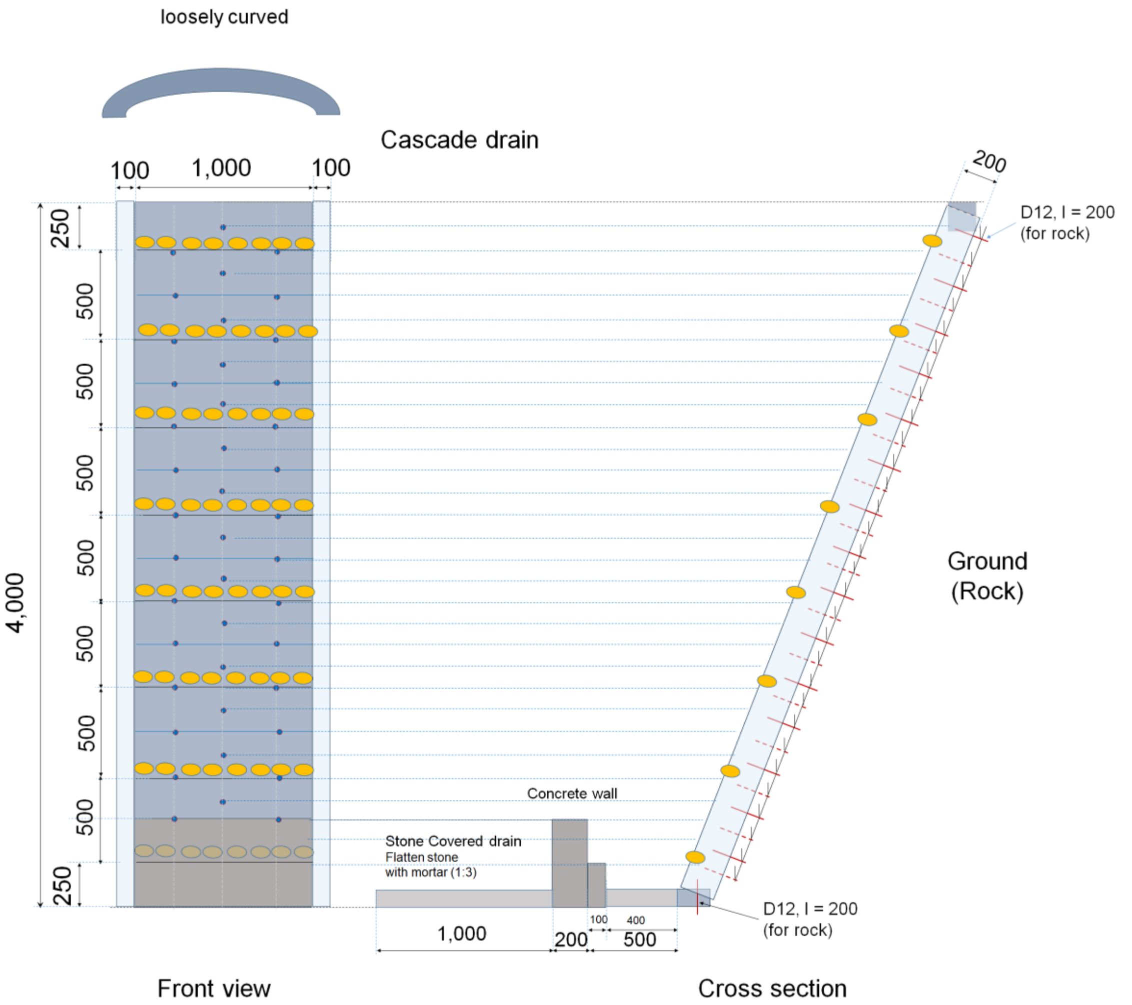


(Source: JET)

Figure3.3-56 Relationship of drainage to vertical drainage channels, catch basins, culvert drainage channels and abatement works (plan view).

Lateral drains (L1, L2, L3): Drain water downslope from a channel or culvert.

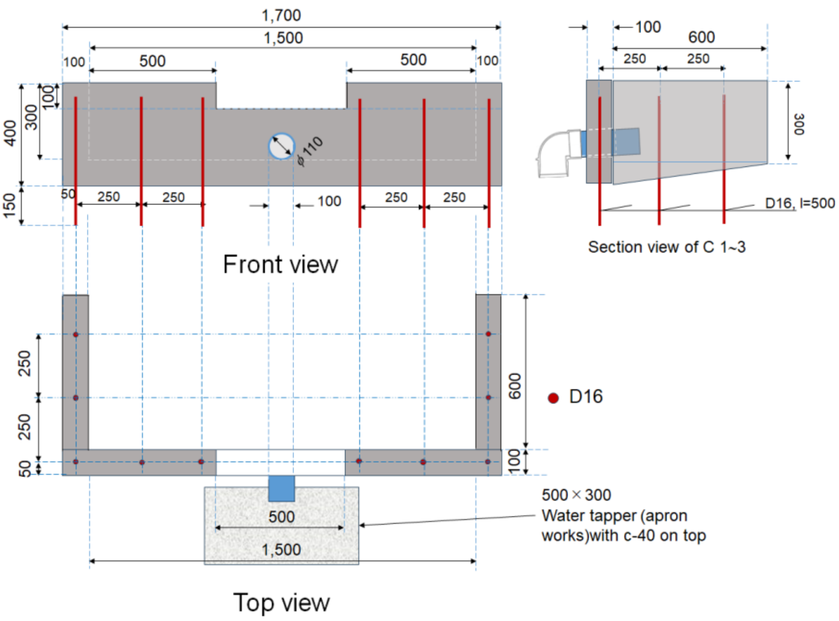
Energy reducers ER1, ER2, ER3, ER4, Check dam C1, C2, C3, C4, and Cascade drain channel CDC: These work to reduce the force of water being directed from the longitudinal drainage channel and prevent it from flowing down the road below while retaining its hydraulic force.



(Source: JET)

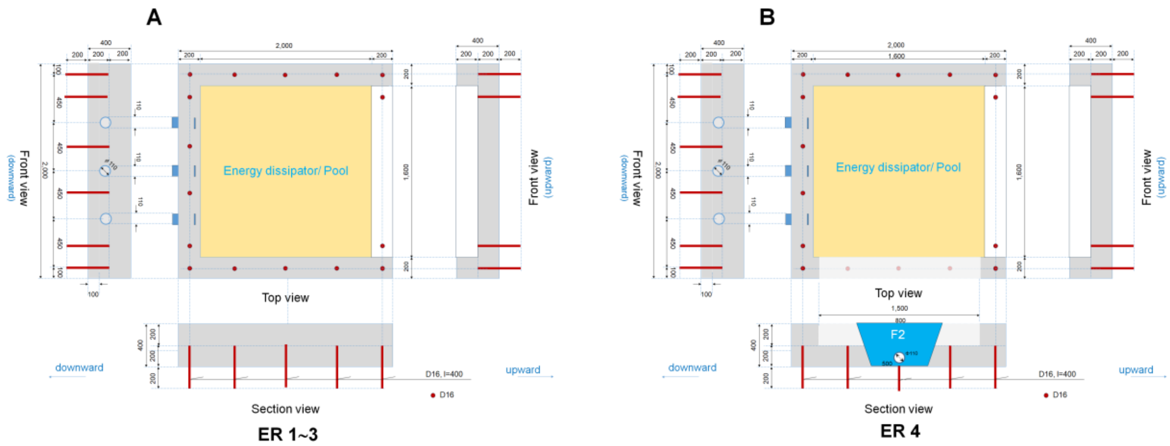
Figure3.3-57 Cascade drain channel (CDC) located at the end of the vertical drainage works.

Check dams control the flow of water in vertical drainage.



(Source: JET)

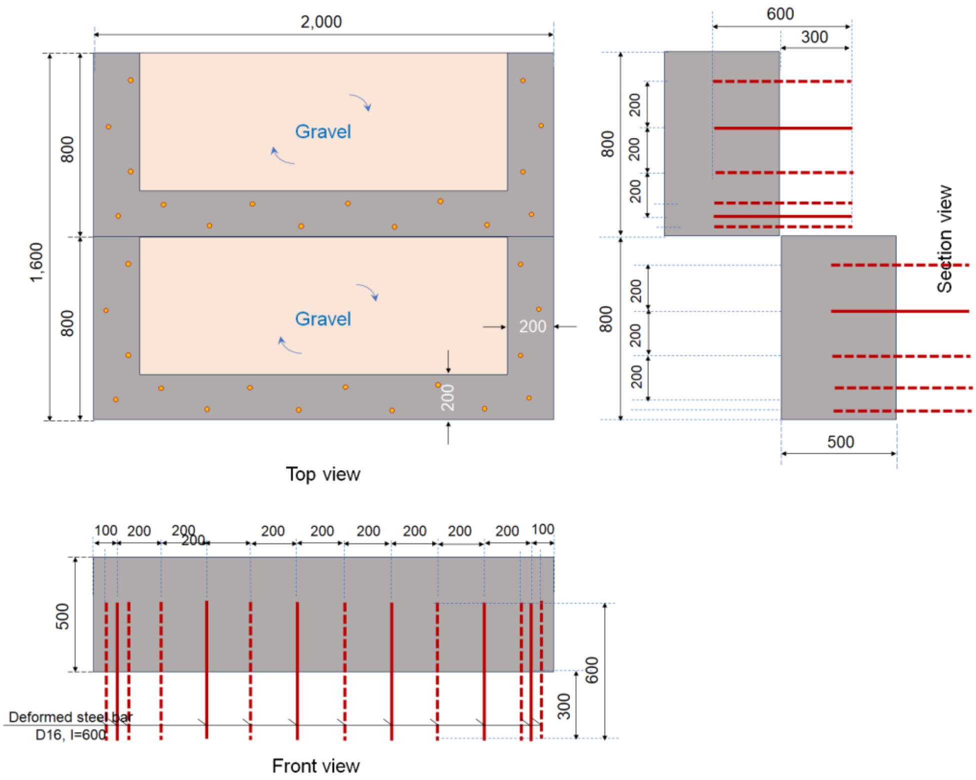
Figure3.3-58 Check dams and water tapping.



(Source: JET)

Figure3.3-59 Reduction works (left: standard, right: receiving channel, culvert-drainage channel confluence).

The staircase type reduction works were installed at the end of the drainage works on the right side towards the slope. It is enclosed by a concrete wall, the bottom of which is exposed to the surface of the ground.

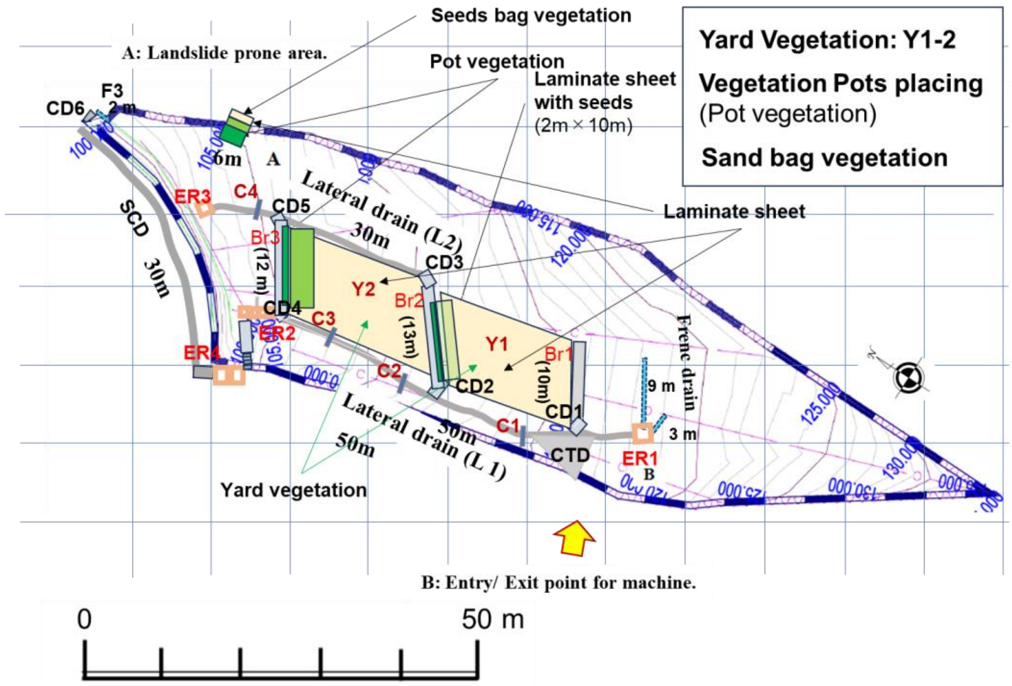


(Source: JET)

Figure3.3-60 Staircase Drainage (Reduction).

(3) Construction based on changes due to on-site resurvey after drone imaging (special specifications)

After confirming and measuring the drone images listed in Figure 3.3-44 in the field, the design details and quantities were reviewed (Figure 3.1-61).



(Source: JET)

Figure3.3-61 Review of quantities and placement of vegetation works and drainage systems.

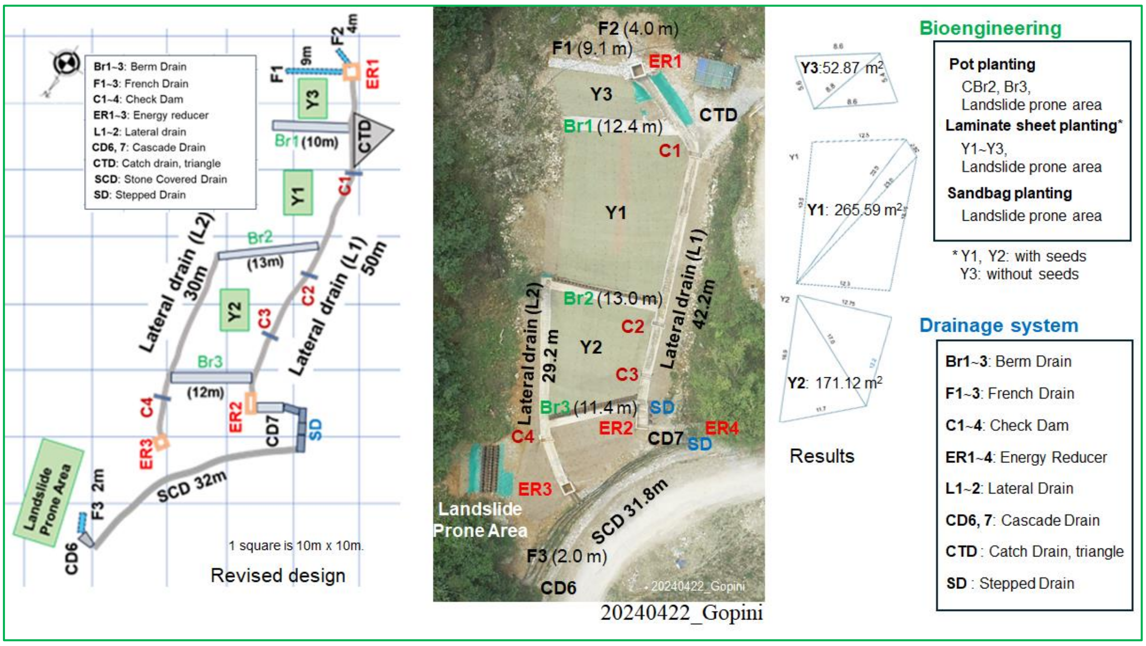
The changes in vegetation placement, etc., are as follows.

Fill and Laminate sheet with seeds were eliminated in the lower part of -Y1. This is because the slope after leveling is gentle.

This is because no steps occurred in the

-Y3 was newly established and Laminate sheet with seeds was laid here.

-Seeds bag vegetation location in the Landslide prone area was placed at the base of the slope. To stabilize the slope.



(Source: JET)

Figure3.3-62 Plain changes during construction (left) and placement as seen in drone-photographed images after completion (right).

Here JET lists the three test vegetation construction sites (Gangthanka, Yangkhil, and Gopini) and describe the contents of the Gopini site.

Table 3.3-17 Construction methods used from the first test slope to the third test slope for Bioengineering.

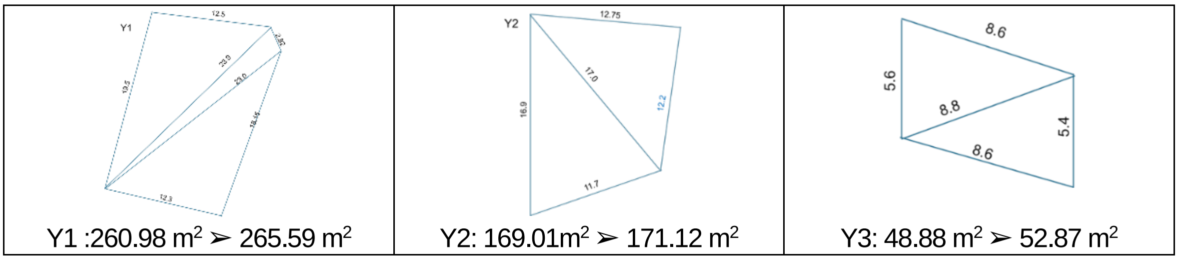
Vegetation work/ methods	1st test slope Gangthanka	2nd test slope Yangkhil	3rd trial slope Gopini	Memo
1) Linearly planting	**Linearly planting**	-	-	Vegetation for long term
2) Overall planting	**Overall planting**	**Overall planting** with jute net,. **Overall planting** with laminate sheet (no seeds)	**Overall planting** with laminate sheet (with seeds, no seeds)	Highly versatile, Highly versatile, Highly versatile, Highly versatile Long term Effective
3) Transplantation of a germination bed	**Transplantation of a germination bed**	-	-	Effective
4) Cap planting	-	**Cap planting** on gabion	-	Effective
5) Stepped planting	-	**Stepped planting**	-	Effective
6) Pot planting	-	-	**Pot planting**	Effective
7) Sandbag planting	-	-	**Sandbag planting**	Effective

(Source: JET)

Vegetation work/ methods

Overall planting

Full revegetation at the Gopini site was done in Y1, Y2, and Y3, each with an area of 265.59 m2 in Y1, 171.2 m2 in Y2, and 52.87 m2 in Y3 at completion.



(Source: JET)

Figure3.3-63 Area occupied by each yard (Y1, Y2, Y3) (initial ➢ done).

Overall planting with laminate sheet (sith seeds)

Full surface revegetation with seeds was done at Y3.

(Source: JET)

Photo 3.3-40 Overall planting done in Y3.

Overall planting wit laminate sheet (no seeds)

Full surface revegetation without seeds, expecting seed dispersal from adjacent areas, was done in Y1 and Y2. In addition, only the jute net was covered on the unplanned slope surface (Y2 on the right, jute net covering on the unplanned slope on the two left sides, and vegetation work on the Landslide prone area in the distant view).

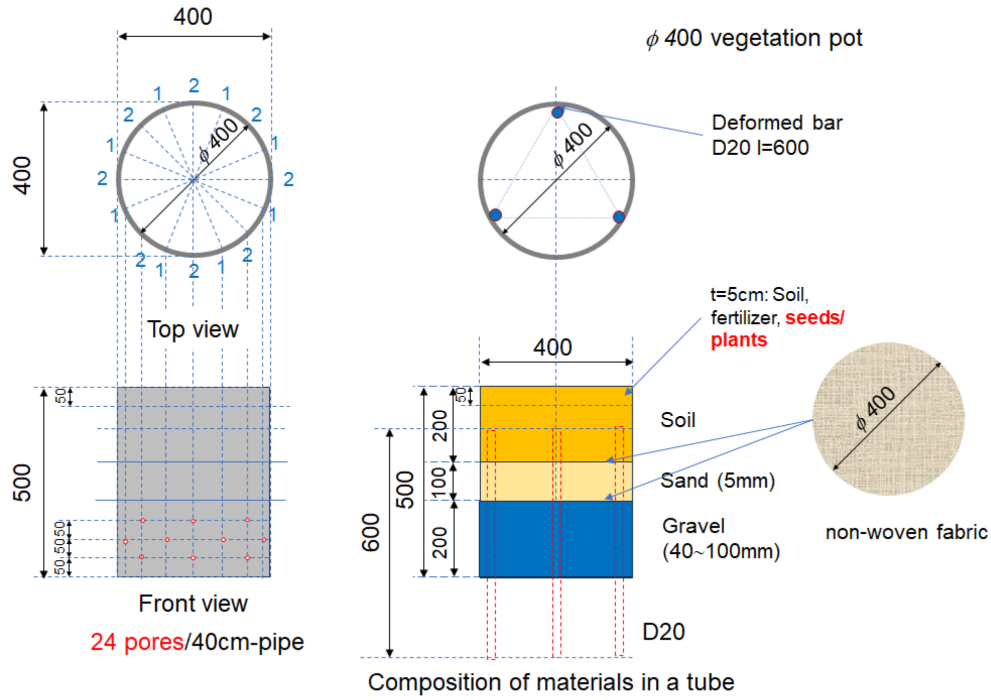
(Source: JET)

Photo 3.3-41 Overall planting at Gopini site. (Y2: right side of the picture).

Pot planting

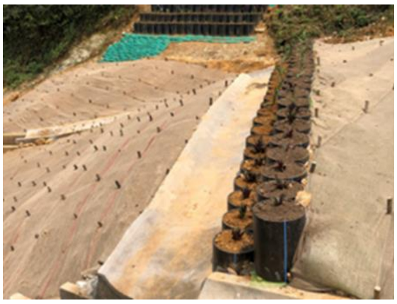
Pot plantings were prepared with 400-diameter tubes at a height of 500 and fixed with three D20s, as shown in Figure 3.3-87, for soil pressure control and vegetation construction.

The construction sites were used above Berm drains Br2 and Br3 at the bottom of Yard Y1 and Y2, and in the landslide prone area.



(Source: JET)

Figure3.3-64 Structure of vegetation pot (ex. Gpini site).



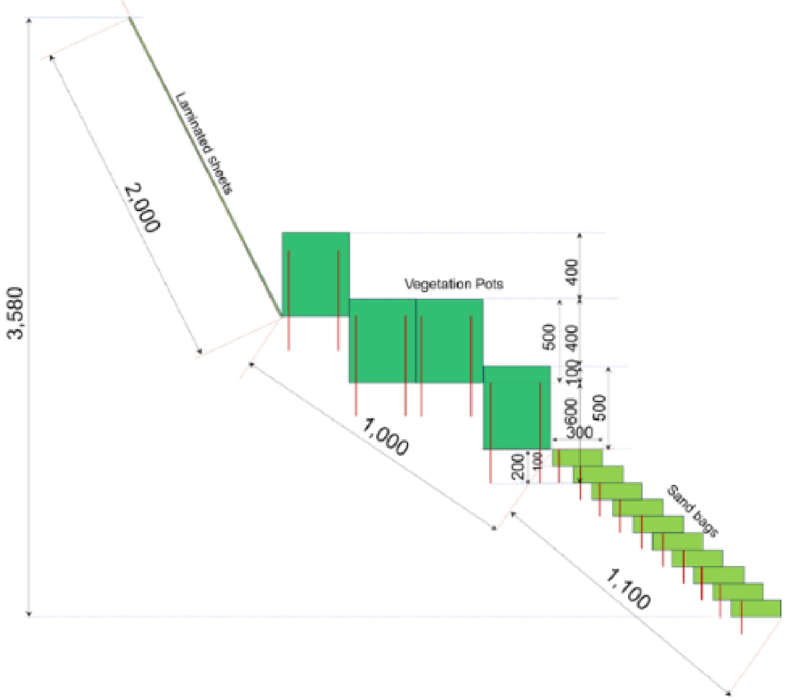
Pot planting (Berm drain 3, Y2)
Row of vegetation pots 50 pots ➢ 56 pots
(site of stepped drain: 3pots)
(Source: JET)

Pot planting (Berm drain 2, Y1)
Row of vegetation pots 32 pots ➢ 30 pots

(Landslice prone area)
pot installation status.
60 pots ➢64 pots
different diameters

Photo 3.3-42 Pot planting (ex. Gpini site). Total pots: 153 pots

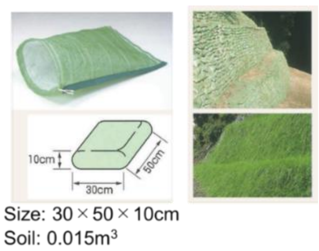
Sandbag planting



(Source: JET)

Figure3.3-65 Vegetation work in Landslide prone area (cross section).
Sandbag planting is in the yellow-green range, sandbag (120 ➢ 129 bags)

The bag used for sandbag planting was a double-layered bag with a jute sack on the inside and a plastic mesh sack on the outside.



Sandbag planting.

(Source: JET)

Sandbag installation status.

Sandbag with some germination.

Photo 3.3-43 Sandbag planting.

Table 3.3-18 Drainage system as ancillary work to Bio-engineering.

Drainage system	1st test slope Gangthanka	2nd test slope Yangkhil	3rd test slope Gopini	Memo
1) Cut-off drain	**Cut-off drain**	**Cut-off drain**	-	
2) Berm drain	**Berm drain**	**Berm drain**	**Berm drain**	
3) Cascade drain	**Cascade drain** with cobble stone	**Cascade drain** (joint type)	**Cascade drain**,. Lateral drain (Cascade drain)	Lateral is used due to placement
		Catch drain (slightly concaved)	Catch drain (slightly concaved)	Surficial
		Stepped drain	Stepped drain	
4) French drain	-	**French drain**	**French drain**	
5) Energy dissipator (Energy reducer, sump) *	-	Energy reducer (Box type)	Energy reducer (Box type,. U-shaped)	
		Check dam	Check dam	
		(stepped drain)	(stepped drain)	Function
6) Toe drain	Gabions to Road gutter	Gabions to Road gutter	Stone covered drain as Road gutter	

*: Names in parentheses are synonymous.

Drainage system

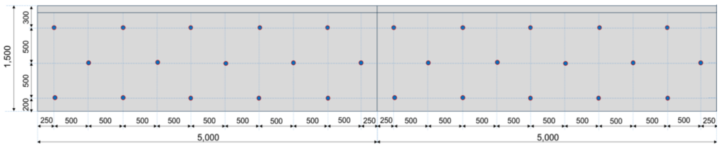
Each type of work in the Drainege system is as follows

Berm drain

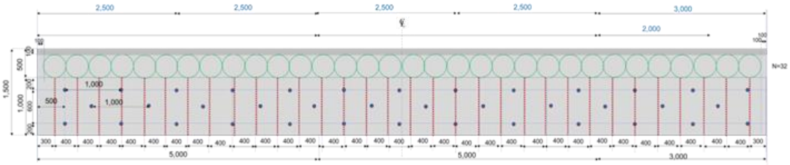
(Source: JET)

Photo 3.3-44 Berm drain from construction site information (Br 1 and Br 2 are visible).

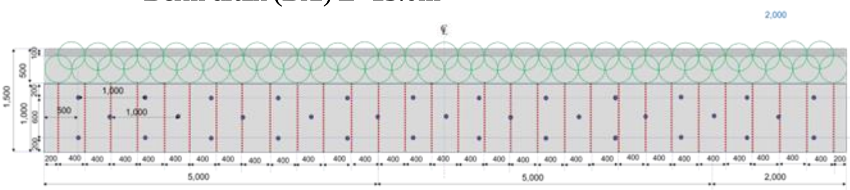
Berm drain (Br1, Br2, Br3)



Berm drain (Br1) L=10.0m ➢12.4m

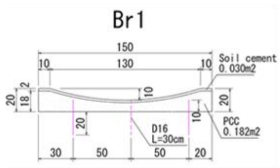


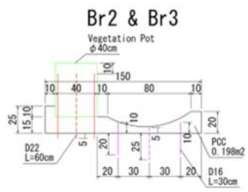
Berm drain (Br2) L=13.0m



Berm drain (Br3) L=12.0m ➢11.4m

section





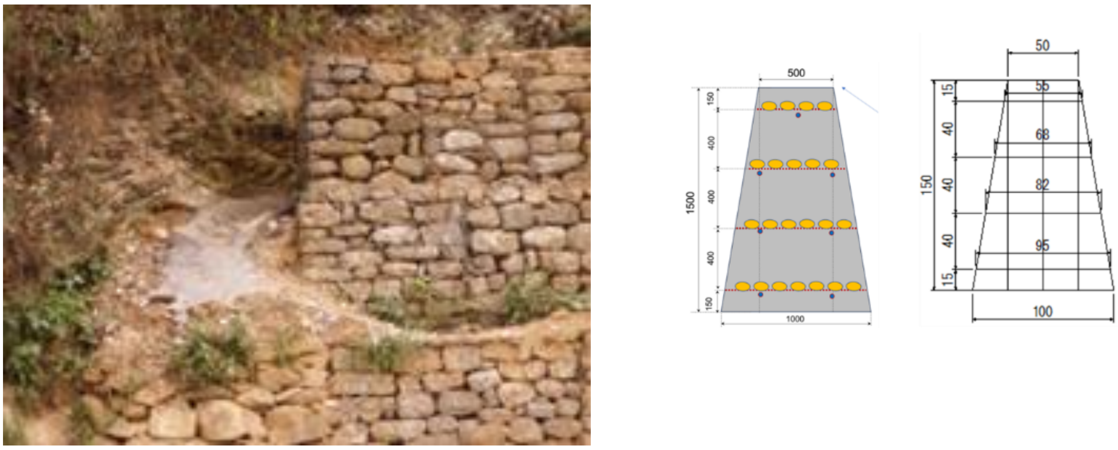
(Source: JET)

Figure3.3-66 Berm drain in Bioengineering.

Cascade drain

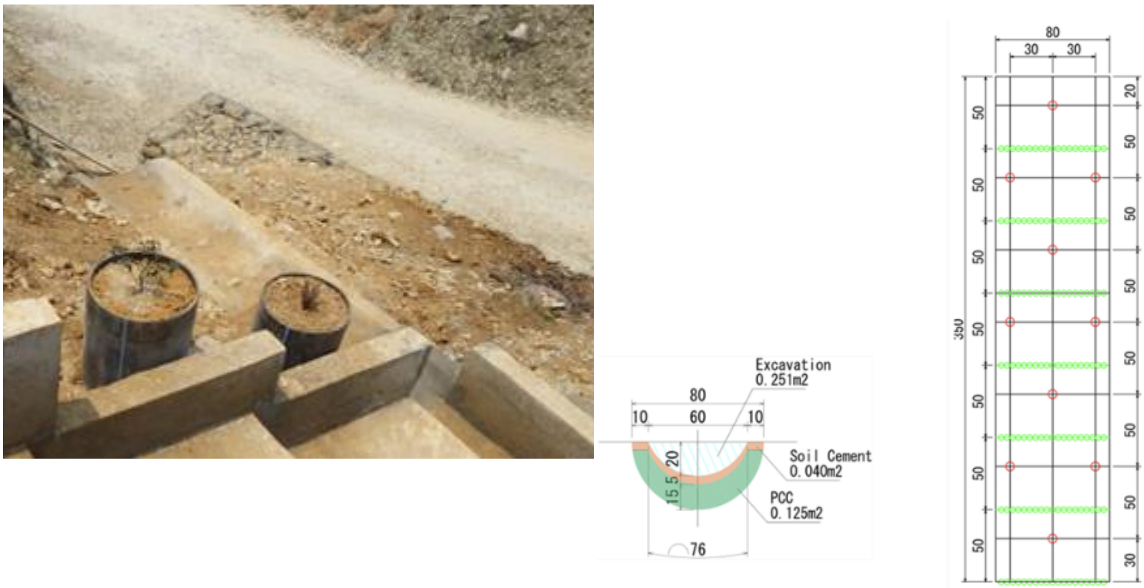
Cascade drain, (CD,6 CD7)

Cascade drains CD1 to CD5 designed have installed as continuous drainage because there was little head difference between them, and berm drains at the time of construction. Therefore, CD1-CD-5 disappeared and became part of Berm drain.



(Source: JET)

Figure3.3-67 Cascade drain (CD6) 0.5~1.0 (W)×1.50 (L) ➢0.47m (W)× 1.84m(L).



(Source: JET)

Figure3.3-68 Cascade drain (CD7) 0.8 (W)×3.50m ➢ 0.8 (0.77straight)×3.28m.

Lateral drain (Cascade drain)

Lateral drains are represented by L1 and L2 in Figure 3.3- 86 above.

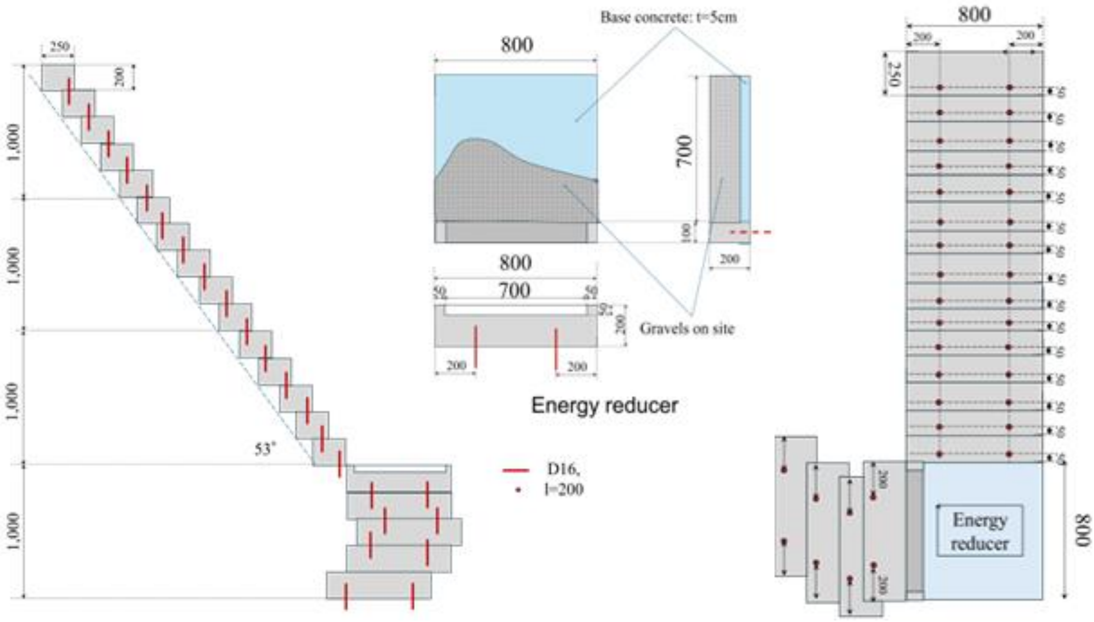
Catch drain (slightly concaved)

(Source: JET)

Figure3.3-69 Catch drain (CTD)   6.0, 7.2, 6.4 6.048 ➢5.9 (concave), 7.2, 6.4, 6.1,

Stepped drain

Stepped drains are seen at two locations at the construction site, the one following the Stone covered drain at the end of the stream is shown below.



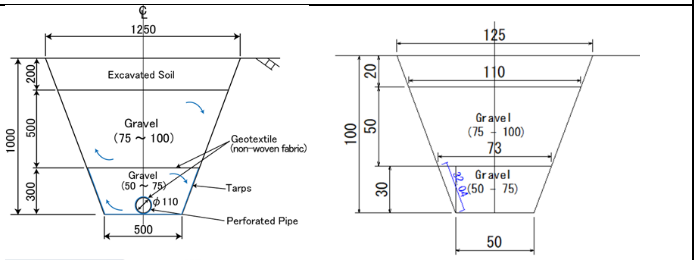
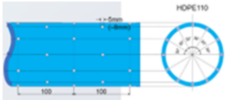
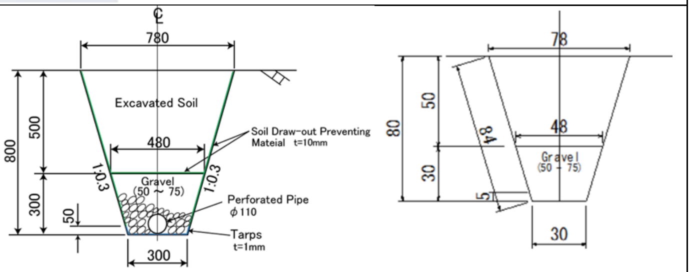
(Source: JET)

Figure3.3-70 Stepped drain.

Stepped drain Energy reduction (ER4) is a staircase landing where the flow path changes. The shape is triangular in the construction situation, with no base, and is filled with local crushed stone.

French drain

French drain (F1, F2, F3)

Type of work	Formula	Remarks
French drain (F1)	L=9.0m ➢9.1m	
French drain (F2)	L=4.0m ➢4.0m	
French drain (F3)	L=2.0m ➢2.0m	

(Source: JET)

Figure3.3-71 French drain (cross section).

Energy dissipator

Energy dissipators are available in box type and U-shaped type.

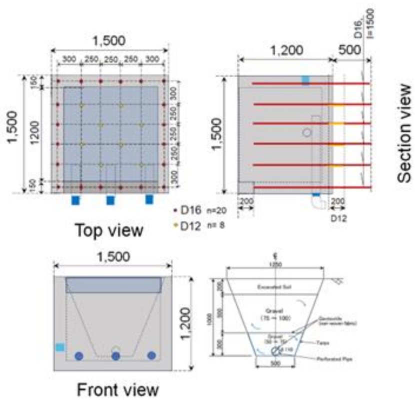
Energy reducer (Box type)

Energy reducer (U-shaped)

Energy reducer (ER1, ER2, ER3)

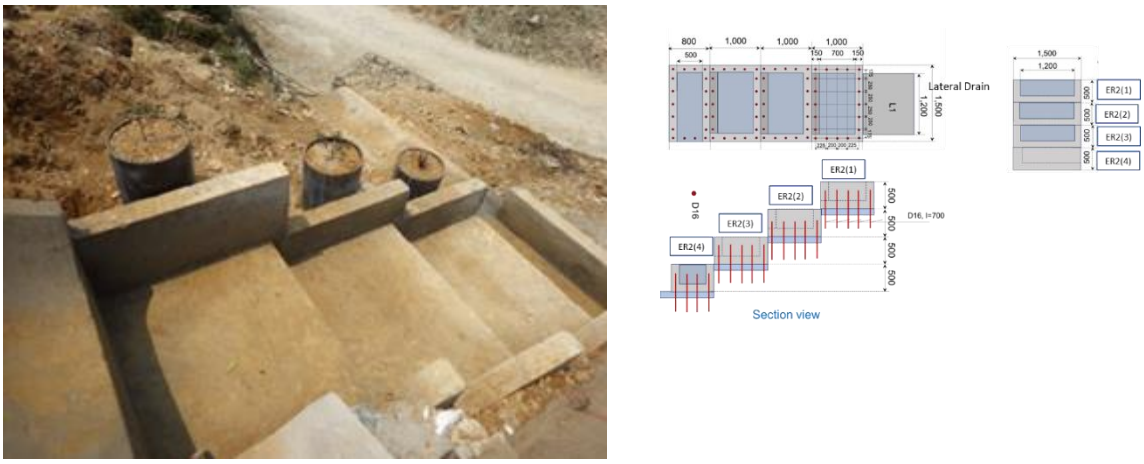
Photos

Figures



(Source: JET)

Figure3.3-72 Energy reducer (ER1) Box type , 1,500×1,500, ➢1,520×1,500, Thickness: 15~16cm.

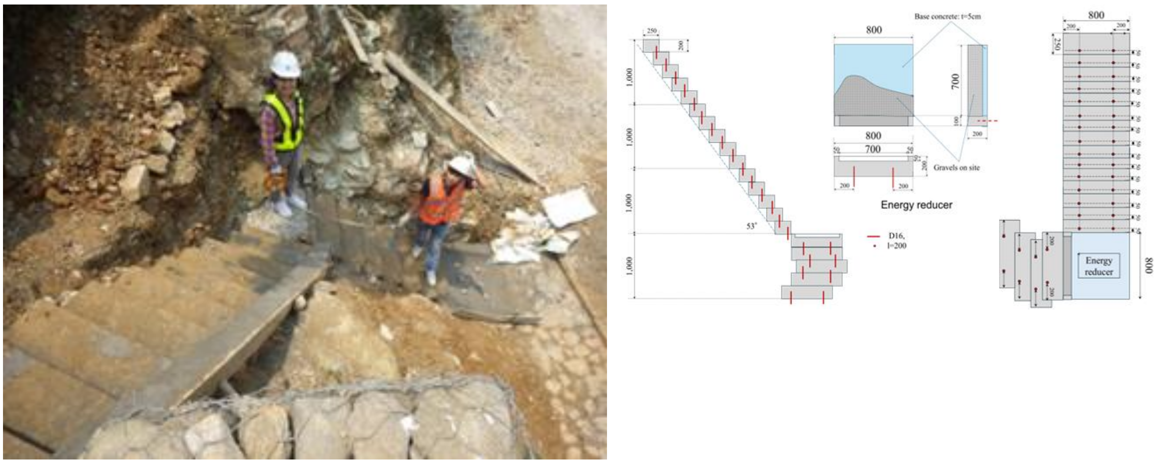


(Source: JET)

Figure3.3-73 Energy reducer (ER2), U-shaped type. The end of the stepped drain is ER2..

(Source: JET)

Figure3.3-74 Energy reducer (ER3), Box type, Pipe 3.0m×2➢3.0m×2.

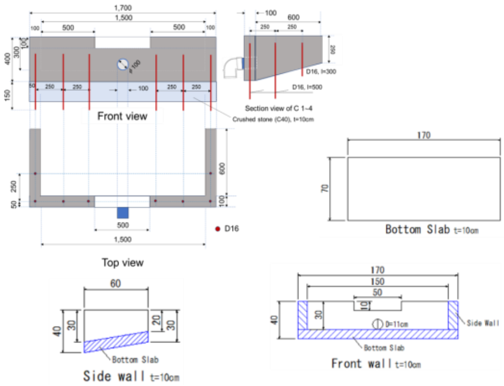


(Source: JET)

Figure3.3-75 Energy reducer (ER 4).

Check dam

Check dam (C1, C2, C3, C4)



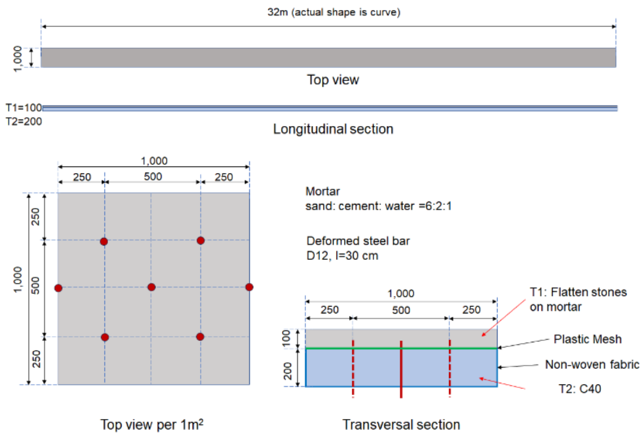
(Source: JET)

Figure3.3-76 Check dam (C1~C4).

Toe drain

Stone covered drain as Road gutter.

Stone Covered drain (SCD)



(Source: JET)

Figure3.3-77 Stone Covered drain (SDC) L=32.0m ➢31.8m.

Handing over the completion inspection certificate

Installation of construction signage

construction signs

(Source: JET)

Photo 3.3-45 Installation of signboard.

Activity 2-5: Develop a design/implementation guideline and a standard unit price table on the bio-engineering works.

The contents of the guidelines are intended to cover the processes of "planning," "investigation," "design," "construction," and "maintenance" of vegetation works. Seminars were held to promote understanding of vegetation engineering and to transfer technology to enable planning and construction of vegetation engineering. The table below lists the contents of the guidelines for vegetation design and construction management.

Table 3.3-19 Table of Contents of Design Guidelines for Vegetation Works (Ver. 1)

Chapter 1 General rules
1.1 Background of formulation of the Bioengineering guidelines
1.2 Purpose of the Bioengineering Guidelines
1.3 Vegetation work as a slope protection work
Chapter2 Overview of Bioengineering
2.1 Types and characteristics of vegetation work
2.2 Selection of vegetation work
Chapter3 Design of Bioengineering in Bhutan
3.1 Selection of slopes for bioengineering
3.2 Types of vegetation work and selection of vegetation methods
3.3 Bio Bioengineering design
Chapter4 Vegetation work construction and maintenance
4.1 Vegetation work construction plan
4.2 Construction of vegetation work
4.3 Maintenance of vegetation work
Appendix１：Examples of Bioengineering （Lobeysa R.O., Trongsa R.O., Sarpang R.O.）
Appendix２：Cost of vegetation work and standard unit price

(Source: JET)

Table 3.3-20 Table of Contents of Construction Management Guidelines for Vegetation Works (Ver. 1)

Chapter-1 Construction Plan
1 Description
2 Requirement

Chapter-2 Quality Control
1 Quality Control for each work
2 Field Checklist
3 As Built Control
4 Progress Control

Chapter-3 Safety Control
1 Preface
2 Prevention of occupational accidents due to slope failure in cut slope construction
3 Safety Plan
4 Meeting with the Client
5 Dairy Works
6 Work Item
7 Field Checklist

Appendix-1: Sample of Construction Plan
Appendix-2: A Field Checklist on Quality Control for Construction (DRAFT)
Appendix-3: Sample of Weekly Meeting Report
Appendix-4: Sample of Daily Construction Report

(Source: JET)