Government of Nepal
Ministry of Physical Infrastructure and Transport
Department of Roads
Planning and Design Branch
Geo-Environment and Social Unit (GESU)

Supplementary Guide to

Roadside Geotechnical Problems:

A Practical Guide to Their Solution

August 2023

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Foreword

The existing document "Roadside Geotechnical Problems: A Practical Guide to their Solution" was prepared in 2007 by the Department of Roads (DOR) under the Road Maintenance and Development Project funded by the World Bank. It is widely practiced by the DOR Divisions, Consultants and Contractors working in the road sectors. In course of time, DOR has successfully implemented additional successful methodologies and solutions in stabilizing slopes including in Narayanghat Mugling road upgrading works funded from the World Bank. So, the compilation of these additional experiences based on successful results is expected to benefit of DOR engineers, Consultants and all the practitioners dealing with not only the roadside geotechnical problem but other infrastructures facing similar problems. The Department of Roads is glad to add this document as "Supplementary Guide" from the lessons learned through implementation of measures in slope and riverbank protection to the existing "Roadside Geotechnical Problems: A Practical Guide to their Solution". I believe that this "Supplementary Guide" will be very useful for the Engineers and Geotechnical Engineers and practitioners working in the field.

This Supplementary Guide will add value to requirements for the necessary planning, assessment, investigation, design and implementation of adequate/ appropriate measures/ solutions which could be sustainable. Apart from geotechnical solutions, some innovations on investigations and instrumentation are also included in this Supplementary Guide.

I take this opportunity to thank the study team from ITECO Nepal and the World Bank team for their efforts in creating this Supplementary Guide under the Grant received from the Quality Infrastructure Investment Partnership that jointly hosted by the Government of Japan and the World Bank. I advise all the Road Engineers, Geotechnical Engineers, and practitioners from the DOR and related sectors to use the available guidelines and this Supplementary Guide to improve the quality and effectiveness of the slope protection work.

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Sushil Babu Dhakal

Director General

Department of Roads

Kathmandu, August 2023

Acknowledgements

The study team duly acknowledges the guidance of the Department of Roads and the World Bank team while carrying out the assignment “Climate Change Vulnerability and Risk Assessment along Nagdhunga-Naubise-Mugling-Narayanghat (NNMN) Road Corridor and a Network Level Climate Change Vulnerability and Risk Mapping”, and preparation of this Supplementary Guide.

This Supplementary Guide is prepared based on the experiences in assessment, observation, investigation methods applied to understand the problem roots, design of proper stabilization/ mitigation measures, implementation and monitoring instrumentation applied on the slopes along Narayanghat-Mugling road corridor.

This Supplementary Guide is part of the DOR’s “Roadside Geotechnical Problems: A Practical Guide to their Solution, 2007” and contains only additional information which is complementing to the original document.

The Consultant’s team would like to express gratitude to all the concerned agencies, officials and experts in this field including the World Bank.

Tuk Lal Adhikari

Team Leader

Kathmandu, August 2023

CONTENTS

List of Tables and Figures

Supplementary Guide to "Road-side Geotechnical Problems: A Practical Guide to Their Solution, 2007"

1 ADDENDUM TO MAIN TEXT

This Supplementary Guide is part of the "Road-side Geotechnical Problems: A Practical Guide to Their Solution, 2007" and consists of additional information on possible investigations and design measures for slope protection and river training works.

Table A-1 below consists of description of successful investigation, stabilization or mitigation measures.

Table A-1: List of Successful Investigation, Stabilization or Mitigation Measures

Description of Investigations and Stabilization / Mitigation Measures	Degree of Noted Success in implementation experiences in various sites	Available in Existing "Practical Guide"	Added in This "Supplementary Guide"
Stabilization/ Mitigation Measures			
Soil Nailed Walls	Excellent	Available	
Gabion Walls	Mostly successful	Available	
Cement Masonry Walls	Successful	Available	
Gabion Check Dams	Successful	Available	
Cement Masonry Check Dams	Successful	Available	
RCC Crib Walls	Highly successful	Available	
Bank Protection Concrete or Cement Masonry Walls	Mostly successful	Available	
Bank Protection Gabion Walls	Less successful	Available	
Concrete Armor Blocks with Flexible Connection Using Steel Ropes	Mostly successfully	Available	
Concrete Armor Blocks with Semi-Rigid Articulation with Rebars	Successful		Added
Inverted Cantilevers	Successful	Available	
Trap Walls	Successful	Available	
Bioengineering Solutions	Mostly successful	Available	
Horizontal Drains	Less successful	Available	
Normal Rock Netting with	Mostly successful		Added

Description of Investigations and Stabilization / Mitigation Measures	Degree of Noted Success in implementation experiences in various sites	Available in Existing "Practical Guide"	Added in This "Supplementary Guide"
Gabion Net and Cables			
Soil Nails with Self Drilling and Grouting Bars	Successful		Added
Reinforced Earth with Terramesh Facing	Successful		Added
Investigation Methods			
Drone Survey and Mapping	Successful		Added
Bathymetric Survey across River	Successful		Added
Piezometric Monitoring	Successful		Added
Extensometer Monitoring	Successful		Added
Inclinometer Monitoring	Successful		Added

Notes:

1. *The experiences considered are from various road slope stabilization measures investigated and implemented in Lamosangu Jiri road, Arniko Highway, Tribhuvan Highway, Naubise- Mugling, and recently completed Narayanghat- Mugling Road works.*
2. *The degree of success is judged as: excellent = performing well without maintenance and repairs, highly successful = performing well with minor maintenance and repair, successful = performing well with normal maintenance and repairs, mostly successful = most part of the measure performing well with normal maintenance and repair but partially damaged, and less successful = performance substandard, less effective = purpose of the measure not served as intended.*

However, after the assessment of the performance of the investigations and works applied in various roads under various interventions, the following investigation methodologies and measures are identified less effective, which require further study and research to include in the present Guide:

- Gabion walls for bank protection works in boulder stage.
- Spurs and spur heads in narrow mountain streams.
- Isolated concrete armor blocks without connection or articulations.
- Dealing with connection and mitigation of effect of local road constructions on highways.

2 ADDENDUM TO ANNEX B: GEOTECHNICAL ASSESSMENT PROCEDURES

A comprehensive set of geotechnical assessment procedures is available in Annex B of the guide “Roadside Geotechnical Problems: A Practical Guide to Their Solution”. In course of more than one and half decade, some more geotechnical procedures are being used in Nepal and the successful examples of such procedures from these experiences are added in this section.

B11 Drone Survey and Mapping

Drone surveying is the process of surveying an area of land with a high-resolution camera mounted in an unmanned aerial vehicle (UAV). The drone (UAV) takes hundreds of overlapping pictures through high definition (HD) camera mounted on it, as it moves over the area. Then, with the help of computer software utilizing “Structure from Motion” (SFM), the images are processed to create a 3D model of the site.

Here are some steps to follow for drone surveying:

- Check everything that you need on site before you leave the office.
- Prepare a plan of your flight paths to cover the entire area.
- Establish ground control points using differential global positioning system (DGPS) at an interval of 300 to 500m spacing.
- Prepare appropriate set up for the flight in the field.
- Fly and collect images.

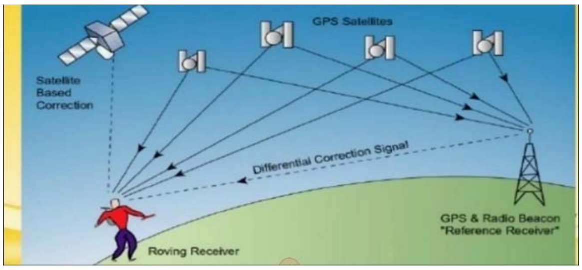
The drone surveyed images must be processed in the following steps to make the survey meaningful and useful for engineering and site assessment purposes:

- Ortho-rectification of the mosaiced images to convert into orthographic plan and orthophoto maps.
- Preparation of 3D surface at ground level excluding trees, building and cables above the ground.
- Generation of digital elevation model of the site
- Generation of elevation map, slope map and aspect map
- Extraction of slope cross sections for stability assessment
- Extraction of river cross sections for hydraulic simulation
- Enhancement of land use map overlay of orthophoto map
- Overlay with geological, soils and hydrological maps
- Development of hazard, susceptibility and risk maps
- Evaluation of temporal variation and climate change effects

For more complete reference on drone surveying, reference should be made to applicable drone survey manuals and processing methods. Some Software for drone data processing are Drone Deploy, Agisoft, Pix4D Mapper, Drone Deploy Enterprise 3D Map etc. Freeware (e.g., Open Drone Map) is also available but may not offer full functionality for data processing.

The maps generated from drone surveys will generally be accurate within ±10 cm. This level of accuracy is good for all sorts of feasibility studies and alternative analysis but need to be augmented with field surveys using total stations for sections particularly in thickly forested areas and areas where bridges/houses affect the accuracy of the Digital Terrain Model (DTM). To minimize the errors, drones must fly at low heights and hence more flight paths may be required to ensure adequate overlaps.

Flight Paths for UAV Survey

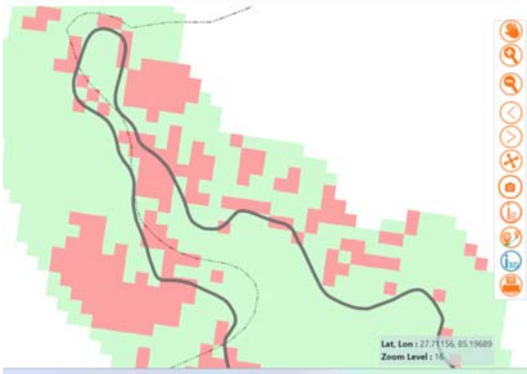


DGPS Survey and Data Processing

Orthophoto Map developed from Drone

Contour Map developed from Drone

Landslide Hazard Map



Landslide Risk Map

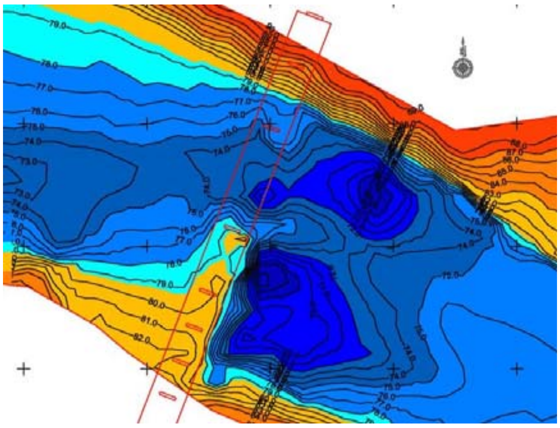
Figure B-11: Procedure for Drone Survey, DGPS and Thematic Maps Generation

B12 Bathymetric Survey across River

Bathymetric surveys with SONAR (sound navigation and ranging) allow us to measure the depth of a water body as well as map the underwater features of a water body. Multiple methods can be used for bathymetric surveys including single-beam and multi-beam sonar, Acoustic Doppler Current Profiler (ADCP), sub-bottom profilers, and the Eco mapper Autonomous Underwater Vehicle or boats with DGPS positioning.

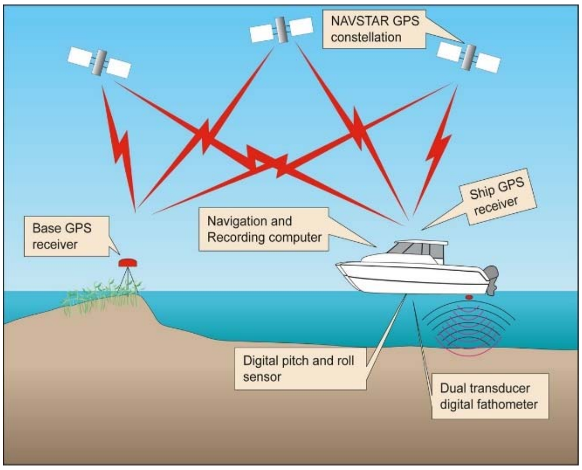
The methodology applied for bathymetric survey at km 17 of Narayanghat Mugling road can be used as reference for similar future bathymetric surveys for other river cross sections.

The procedure includes planning of the boat paths prior to surveying both longitudinally and transversely. The boats generally follow predetermined paths, but their exact positions are established with the help of DGPS. Once the coordinate of the sonar is determined at the point of sounding, the depth can reliably be measured. A large number of depth measurements are taken so that the DTM of the riverbed can be generated which subsequently provides cross sections and profiles at required locations.

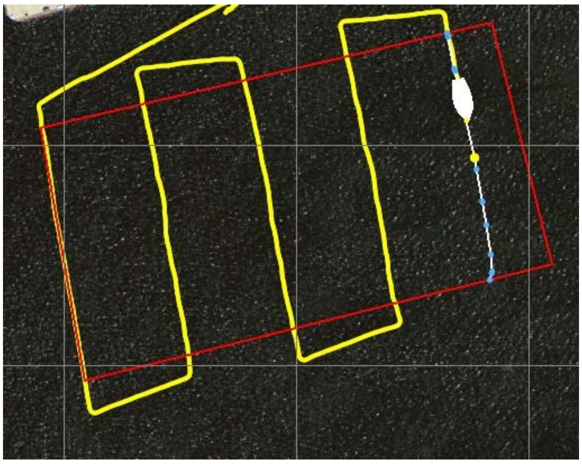


Bathymetric Survey Output

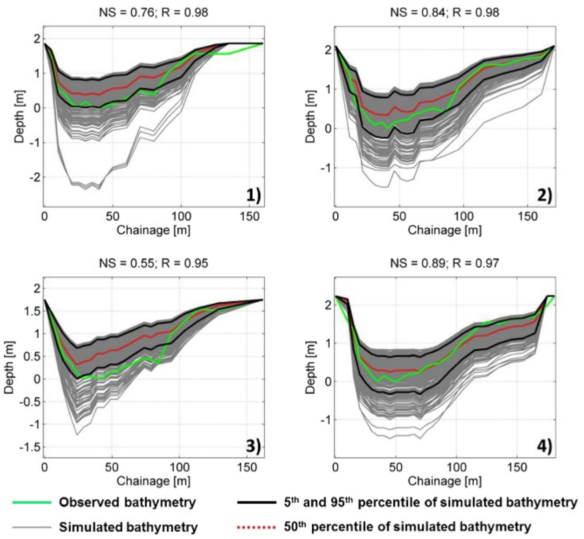
Bathymetric Survey Method



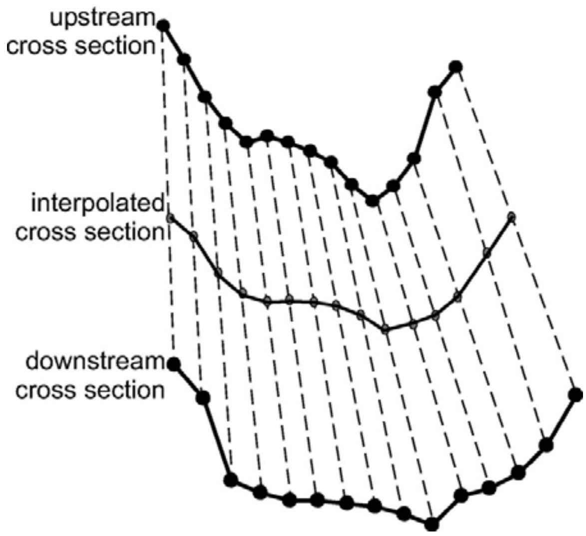
Bathymetric Survey with Positioning System



Navigation Routes for Bathymetric Survey



River Sections from Bathymetric Survey for Hydraulic Modeling



Channel Cross Sections from Bathymetric Survey

Figure B-12: Procedure for Bathymetric Survey and Generation of Profiles

B13 MAM Survey of Foundation and Slope

A MAM survey is a type of geophysical survey that uses the mise-a-la-masse (MAM) method to map the electrical conductivity of subsurface structures. MAM surveys are useful for exploring mineral deposits, geothermal reservoirs, groundwater aquifers, and other geological features.

The steps of a MAM survey are as follows:

- A current electrode is inserted into a borehole or on the ground surface that intersects the target structure, and a return electrode is placed at a distant location on the surface.
- A direct current is applied between the electrodes, creating an electric potential difference across the structure and the surrounding rocks.
- An array of potential electrodes is deployed on the surface along a profile or a grid, and the electric potential at each electrode is measured using a voltmeter.
- The potential data is processed and interpreted to obtain the shape, size, orientation, and depth of the target structure.

The instruments and accessories used for a MAM survey include:

- A current source, such as a battery or a generator, to provide the direct current.
- A current electrode, such as a metal rod or a wire, to supply the current into the borehole.
- A return electrode, such as a metal plate or a wire, to complete the current circuit on the surface.
- A voltmeter, such as a digital multimeter or a data logger, to measure the electric potential at each potential electrode.
- Potential electrodes, such as metal stakes or wires, to record the electric potential on the surface.
- Cables and connectors, such as coaxial cables or banana plugs, to connect the electrodes and the voltmeter.
- A GPS receiver, a compass, and a measuring tape, to locate and orient the electrodes and the borehole.
- A computer and a software, such as MATLAB or Surfer, to process and interpret the potential data,

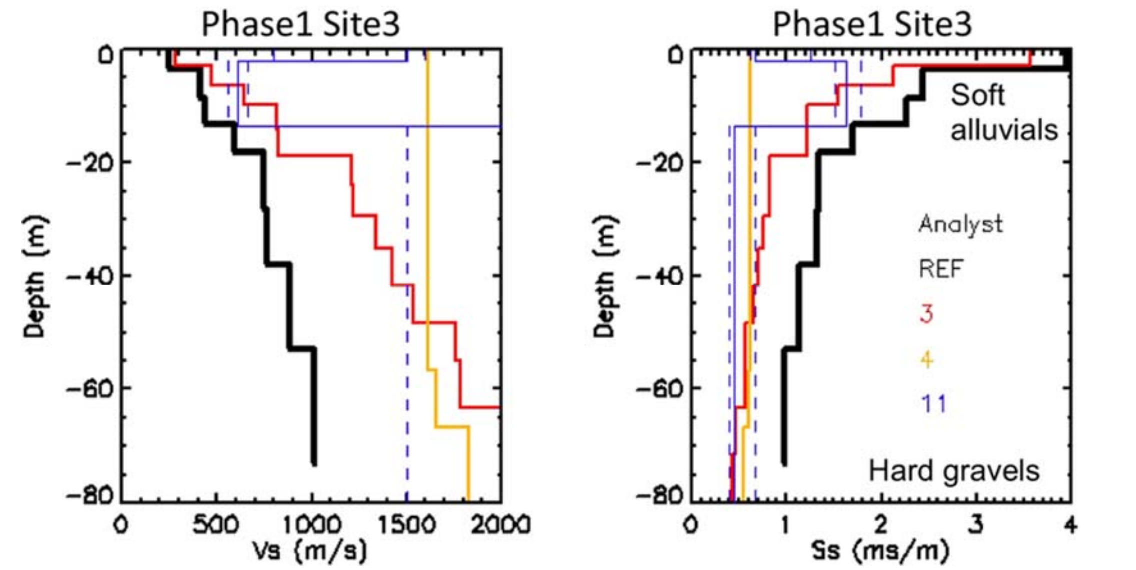
MAM survey is a Microtremor Array Measurement (MAM), which is a non-invasive surface wave survey technique for mapping soil/rock interfaces. The survey is similar to Multichannel Analysis of Surface Waves (MASW), which is a seismic method for determining the shear wave velocity profile of the subsurface. The latter requires active sources of tremors while the MAM uses passive sources, and it does not need an artificial source of tremors.

MAM survey data is a type of seismic data that can be used to estimate the soil/rock interface depth and the shear wave velocity profile of the subsurface. This can be useful for geotechnical and environmental applications, such as site investigation, earthquake hazard assessment, or ground improvement.

We can estimate the shear wave velocity profiles of soil and rock layers using MAMs, which are a type of passive surface wave survey. MAMs use the natural vibrations of the ground to measure the phase velocities of surface waves at different frequencies. By applying an inversion algorithm, we can obtain the shear wave velocity profiles from the dispersion curves.

One of the challenges of using MAMs is to determine a suitable array configuration for the sensors, which depends on the site conditions, depth range, and resolution of interest. Another challenge is to select a suitable criterion for identifying the soil/rock interface, which may vary depending on the geological formation and the definition of rock. For example, a shear wave velocity of 500 m/s is recommended as a guide value for estimating the soil/rock interface.

Alternatively, we can also use other geophysical methods such as refraction, reflection, multichannel analysis of surface waves (MASW), ground penetrating radar, electromagnetic surveys, and electrical resistivity approaches for bedrock mapping, but each of those methods has limitations as well.



Microtremor Array Survey Process

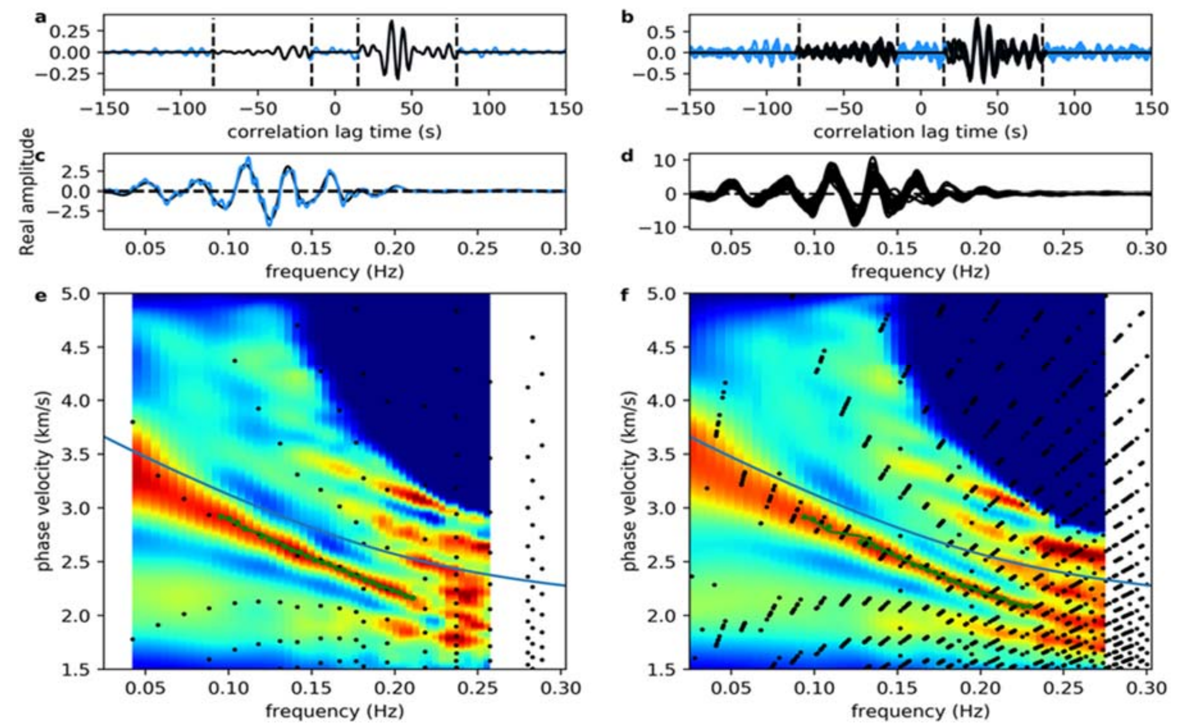
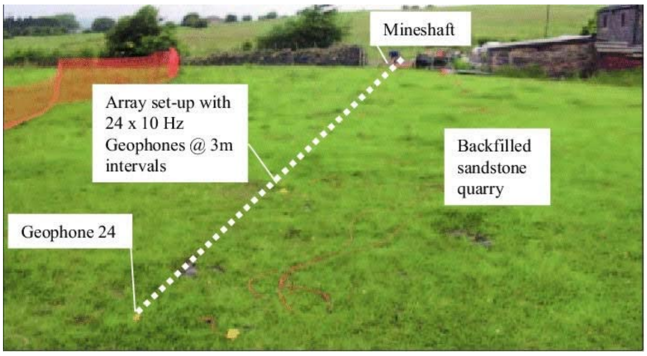


Figure B-13B: Typical Output of MAM Survey



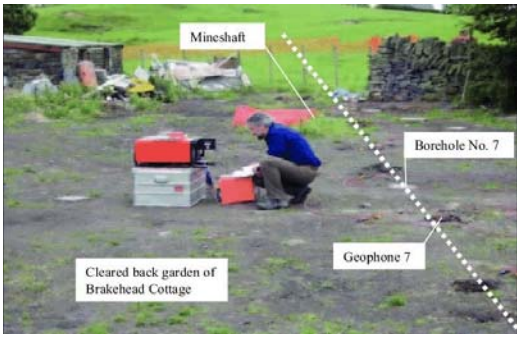


Figure B-13A: Procedure for Micro Tremor Survey example

B14 Piezometric Monitoring

A piezometer is a device that measures the water pressure or groundwater level in the soil. There are different types of piezometers, such as standpipe, vibrating wire, hydraulic, and pneumatic. The installation process of a piezometer on the slope depends on the type of piezometer and the site conditions. The general procedure is as follows:

- A borehole is drilled to the desired depth on the slope, using a drill rig and a suitable drilling method (such as rotary, auger, or core drilling).
- A piezometer tip or slotted/perforated filter, which contains the sensing element and the filter, is attached to a cable or a tubing and lowered into the borehole. The piezometer tip should be placed at the target depth where the water pressure or groundwater level is to be measured.
- The borehole is backfilled with a suitable material, such as sand, gravel, bentonite, or grout, depending on the type of piezometer and the site conditions. The backfill material should provide good contact between the piezometer tip and the surrounding soil and prevent any leakage or contamination of the water in the borehole.
- The cable or the tubing is routed to the surface and connected to a readout device, such as a data logger, a voltmeter, or a pressure gauge, depending on the type of piezometer. The cable or the tubing should be secured and protected from damage or vandalism.
- The piezometer is calibrated and tested to ensure its proper functioning and accuracy.

The equipment, accessory and materials required for piezometer installation may vary depending on the type of piezometer and the site conditions. However, some common items are:

- A drill rig, a water truck, and a support truck, with the necessary accessories to drill the borehole and handle the drill cuttings.
- A piezometer tip or slotted/perforated filter, a cable or a tubing, and a readout device, compatible with the type of piezometer and the site conditions.
- A grout pump, a water pump, hoses, and mixing tanks, to prepare and inject the backfill material into the borehole, if needed.
- A tremie pipe, to place the backfill material at the bottom of the borehole without segregation or dilution, if needed.
- A pressure washer, to clean the equipment and the site after the installation.
- A GPS receiver, a compass, a whistler and a measuring tape, to locate and orient the borehole and the piezometer.
- A computer and software, to process and interpret the piezometer data.

Standpipe piezometers are a type of piezometers used to measure pore water pressure and/or groundwater level in vertical boreholes. They consist of a porous filter tip (made of plastic, ceramic or stainless steel) and a riser pipe that extends to the surface. The filter tip is surrounded by a sand filter zone and a bentonite seal to isolate the water pressure at the tip from the rest of the borehole. The water level or pressure inside the riser pipe can be measured using a water level meter (also called a dip meter) or a pressure gauge. Standpipe piezometers are simple, cheap and reliable instruments that can be used to study the pore water pressure of a specified depth below ground, to estimate the permeability of the soil, or to monitor the quality and quantity of the groundwater.

A possible specification of a standpipe piezometer is:

- Plastic pipe: 50 mm diameter, PVC or HDPE material, with threaded joints
- Perforated tip: 100 mm long, with 0.5 mm diameter holes spaced at 10 mm intervals, made of porous plastic or ceramic material.
- Riser pipe: same as plastic pipe, with sufficient length to reach the surface.
- Sand: clean and well-graded, with a grain size of 0.5 to 2 mm
- Cement/bentonite grout: mixed in a ratio of 1:4 by weight, with a water-cement ratio of 0.5
- Bourdon gauge: range of 0 to 100 kPa, accuracy of ±1 kPa, with a flexible hose connection to the piezometer

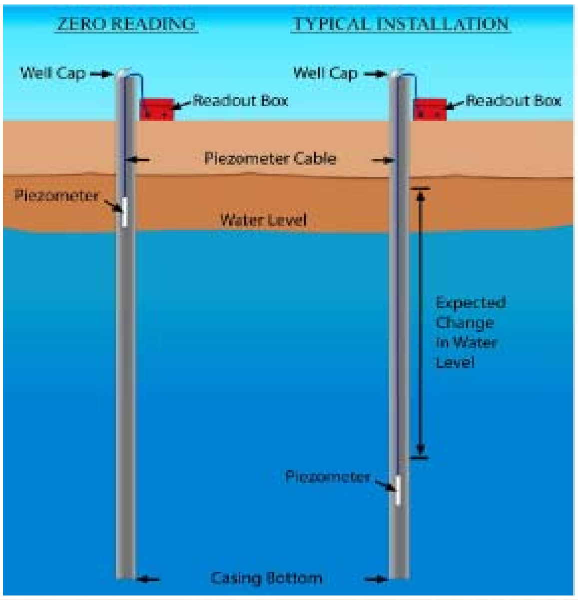
The piezometers can provide the correct level of water table. However, for ensuring the correctness of the data, the technician monitoring the water table must take precautions as follows:

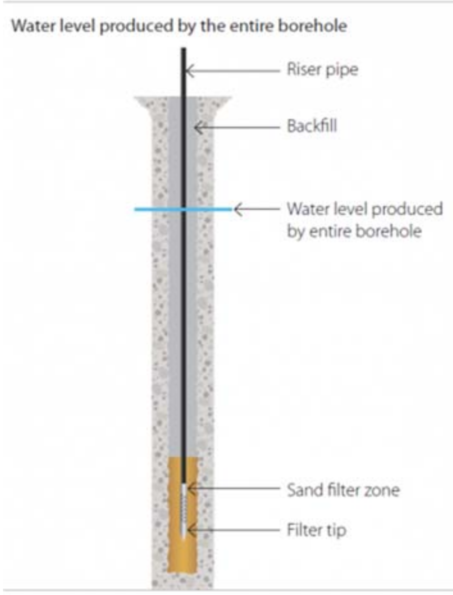
- Make sure that there is no infiltration of surface water around the piezometer. The ground around the piezometer must always be sealed by clayey soil. If surface water penetrates to the level of filter, the measurement may show water table larger than that caused by ground water seepage.
- The sounding instrument or buzzer must be calibrated periodically in the laboratory for correctness of the measurement.
- The cap of the piezometer must be sealed so that no water enters the tube. The cap must be opened only for measurement and must remain tightly closed and locked the rest of the time.
- In active landslides, the piezometer tube may get blocked and may indicate water level that is trapped above the point of blockage. So, for active landslides, the piezometer tube needs to be checked for non-blockage up to the filter level.

Once these precautions are taken, the water table can be accurate within ±10 cm. For more complete reference, reference should be made to vendor's specifications.

Piezometric monitoring of landslides is typically carried out on a regular basis, such as weekly or monthly. The frequency of monitoring depends on the level of risk and the resources available. Piezometric data is typically recorded and analyzed using a data logger.

Illustrative Sketches:





Piezometer test at Km 17 of Narayanghat Mugling Road

Figure B-14: Installation Procedure of Standpipe Piezometers

B15 Extensometer Monitoring

An extensometer is a device that measures the deformation or displacement of a material or a structure under stress. There are different types of extensometers, such as contact, non-contact, video, and magnetic. The installation process of an extensometer fixed on the soil nailed wall or the slope depends on the type of extensometer and the site conditions. However, a general procedure is as follows:

- A borehole is drilled to the desired depth on the wall or the slope, using a drill rig and a suitable drilling method.
- An extensometer tip, which contains the sensing element and the filter, is attached to a cable or a tubing and inserted into the borehole. The extensometer tip should be placed at the target depth with respect to which the deformation or displacement is to be measured.
- The borehole is backfilled with a suitable material, such as sand, gravel, bentonite, or grout, depending on the type of extensometer and the site conditions. The backfill material should provide a good contact between the extensometer tip and the surrounding soil or rock and prevent any leakage or contamination of the water in the borehole.
- The cable or the tubing is routed to the surface and connected to a readout device, such as a data logger, a voltmeter, or a pressure gauge, depending on the type of extensometer. The cable or the tubing should be secured and protected from damage or vandalism.
- The extensometer is calibrated and tested to ensure its proper functioning and accuracy.

The equipment, accessory and materials required for extensometer installation may vary depending on the type of extensometer and the site conditions. However, some common items are:

- A drill rig, a water truck, and a support truck, with the necessary accessories to drill the borehole and handle the drill cuttings.
- An extensometer tip, a cable or a tubing, and a readout device, compatible with the type of extensometer and the site conditions.
- A grout pump, a water pump, hoses, and mixing tanks, to prepare and inject the backfill material into the borehole.
- A tremie pipe, to place the backfill material at the bottom of the borehole without segregation or dilution.
- A pressure washer, to clean the equipment and the site after the installation.
- A GPS receiver, a compass, and a measuring tape, to locate and orient the borehole and the extensometer.
- A computer and software, to process and interpret the extensometer data.

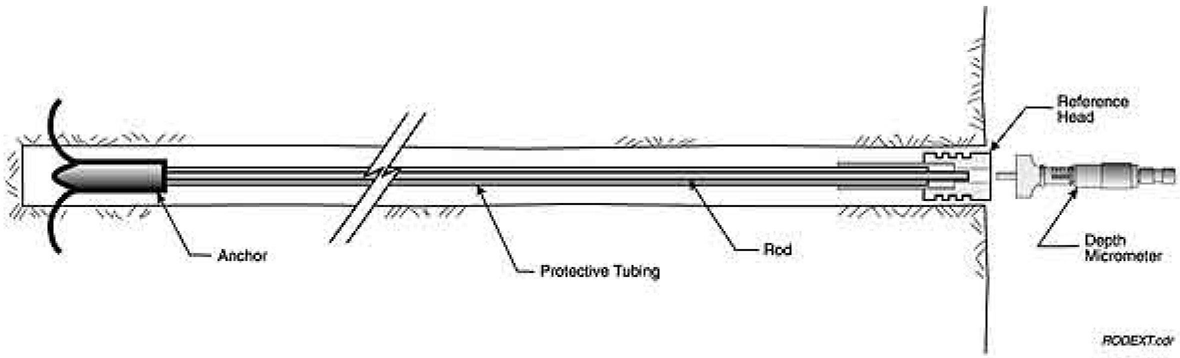
An extensometer is a device that is used to measure changes in the length of an object. It is useful for stress-strain measurements and tensile tests. Extensometers can be used to monitor the movement of the slope on the surface by measuring the relative distances between pairs of reference points.

In creeping and unstable slope, different points within the soil mass may move differently depending on the mode of movement or slippage. Along the installed extensometer, the points at different distance from the head point may move differently. The measured change in length can help locate the points within the ground where slip is likely to occur. The data on strains at different depths will help to better understand the slope movement process.

One type of extensometer that can be used for slope monitoring is a tape extensometer. Tape extensometer is used for fast and accurate measurement of relative distances between pairs of reference points on the surface of structures, including radial movements and convergence of tunnels, linings, shafts and caves.

The procedure for installation and operation of a tape extensometer may vary depending on the manufacturer and model, but generally it involves the following steps:

- Selecting suitable locations for the reference points on the slope surface. The reference points should be stable and accessible and should cover the area of interest.
- Installing anchors or brackets at the reference points. The anchors or brackets should be firmly attached to the slope surface using bolts, nails, screws or glue.
- Attaching the tape extensometer to the anchors or brackets. The tape extensometer consists of a steel tape with a hook at one end and a spring-loaded reel at the other end. The hook is attached to one anchor or bracket, and the reel is attached to another anchor or bracket. The tape should be kept taut between the two points.
- Reading the tape extensometer. The tape extensometer has a scale on the reel that indicates the length of the tape between the two points. The length can be read directly from the scale or recorded by a digital display or a datalogger. The length should be measured periodically or continuously to monitor any changes in the slope movement.
- Interpreting the data. The changes in the length of the tape indicate the relative displacement between the two points. The direction and magnitude of the displacement can be calculated using trigonometry or geometry. The rate and pattern of the displacement can be used to assess the stability of the slope and identify any potential hazards.



Extensometer test at km 26 of Narayanghat Mugling Road

Figure B-15: Installation Procedure of Extensometers

B16 Inclinometer Monitoring

An inclinometer is a device that measures the deformation or displacement of a material or a structure under stress. There are different types of inclinometers, such as contact, non-contact, video, and magnetic. The installation process of an inclinometer on the slope or the embankment slope depends on the type of inclinometer and the site conditions. However, a general procedure is as follows:

- A vertical or sub-vertical borehole is drilled to the desired depth on the slope or the embankment, using a drill rig and a suitable drilling method.
- An inclinometer tip, which contains the sensing element and the filter, is attached to a cable or a tubing and lowered into the borehole. The inclinometer tip should be placed at the target depth with respect to which the deformation or displacement is to be measured.
- The borehole is backfilled with a suitable material, such as sand, gravel, bentonite, or grout, depending on the type of inclinometer and the site conditions. The backfill material should provide a good contact between the inclinometer tip and the surrounding soil or rock and prevent any leakage or contamination of the water in the borehole.
- The cable or the tubing is routed to the surface and connected to a readout device, such as a data logger, a voltmeter, or a pressure gauge, depending on the type of inclinometer. The cable or the tubing should be secured and protected from damage or vandalism.
- The inclinometer is calibrated and tested to ensure its proper functioning and accuracy.

The equipment, accessory and materials required for inclinometer installation may vary depending on the type of inclinometer and the site conditions. However, some common items are:

- A drill rig, a water truck, and a support truck, with the necessary accessories to drill the borehole and handle the drill cuttings.
- An inclinometer tip, a cable or a tubing, and a readout device, compatible with the type of inclinometer and the site conditions.
- A grout pump, a water pump, hoses, and mixing tanks, to prepare and inject the backfill material into the borehole.
- A tremie pipe, to place the backfill material at the bottom of the borehole without segregation or dilution.
- A pressure washer, to clean the equipment and the site after the installation.
- A GPS receiver, a compass, and a measuring tape, to locate and orient the borehole and the inclinometer.
- A computer and software, to process and interpret the inclinometer data.

The inclinometer is an instrument that measures angles of slope, elevation, or depression of an object or the ground with respect to gravity. It can also measure horizontal displacements along a borehole. It is used to monitor and evaluate the deformation and stability of natural slopes, embankments, retaining walls, slurry walls, and deep excavations.

An inclinometer consists of a casing with orthogonal grooves and a trolley device that is lowered to depth and takes measurements at regular intervals. The commonly used inclinometers have two accelerometers and use a biaxial probe that measures the tilt in both horizontal directions.

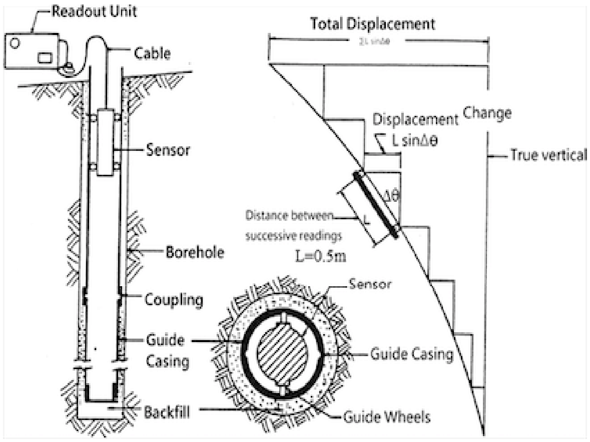
The functions and specifications of inclinometers in slope movement monitoring depend on the type and purpose of the instrument. There are two main types of inclinometers: vertical and horizontal. Vertical inclinometers are used to monitor the lateral movements of slopes or embankments along a borehole. Horizontal inclinometers are used to monitor the settlement or heave of structures or foundations along a horizontal plane. The specifications of inclinometers include the range, resolution, accuracy, and sensitivity of the measurements. These vary depending on the manufacturer and model of the instrument. For example, some inclinometers have a range of ±15°, a resolution of 0.001°, an accuracy of ±0.02°, and a sensitivity of 0.0005°.

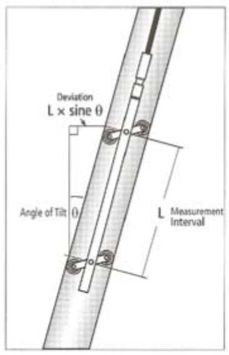
As there are different instruments such as extensometer, piezometer and inclinometers to monitor slope, the instruments must be recommended for specific purpose such as:

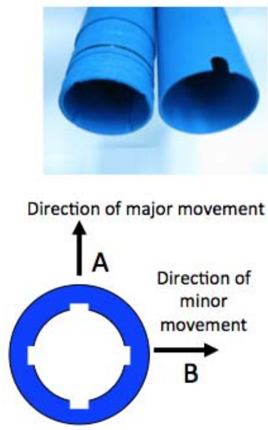
- The piezometer can be used only to measure water table and must be used only in situations where water table is anticipated to aggravate slope instability.
- Inclinometers are very well suited to measure horizontal displacement within the soil mass throughout the depth. This is very useful information and is helpful to pinpoint the slip zone or high deform zone.
- Extensometers are suitable to monitor horizontal movement at a few pre-designated fixed points within the soil mass along horizontal line. This may indicate the zone of major movement but cannot precisely locate the slip surface or rupture zone.
- Based on the ease of operation, cost and skill required for monitoring inclinometers may provide better idea on the subsurface movement more precisely and hence must be given preference.

For more complete reference, reference should be made to vendor's specifications.

Illustrative Sketches:







Inclinometer test at Km 17 of Narayanghat Mugling Road

Figure B-16: Installation **Procedure** of Inclinometers

B17 Use of Hydrodynamic Modeling and Simulation

Hydrodynamic modeling and simulation using HEC-RAS software is a complex process that involves several steps and tools. According to the Introduction to HEC-RAS, the software allows to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations and water temperature/water quality modeling. The software has a graphical user interface (GUI) that provides file management, data entry/editing, river analyses, tabulation and graphical displays of input and output data, inundation mapping, reporting facilities, and online help.

To perform hydrodynamic modeling and simulation using HECRAS software, the following steps must be followed:

- Define the geometry of the river system, including the cross sections, bridges, culverts, levees, storage areas, etc.
- Define the flow data, such as steady or unsteady boundary conditions, lateral inflows, diversions, etc.
- Define the simulation options, such as the computational method, the output frequency, the tolerance values, etc.
- Run the analysis and review the results using tables, graphs, maps, or animations.

Depending on the type of analysis you want to perform (steady or unsteady flow), the user may need to use different components of HECRAS software. For example, for unsteady flow analysis, one needs to use the Unsteady Flow Analysis System (UFAS) component that allows to simulate time-varying flow conditions.

For more complete reference, reference should be made to
https://www.hec.usace.army.mil/software/hec-ras

Illustrative Sketches:

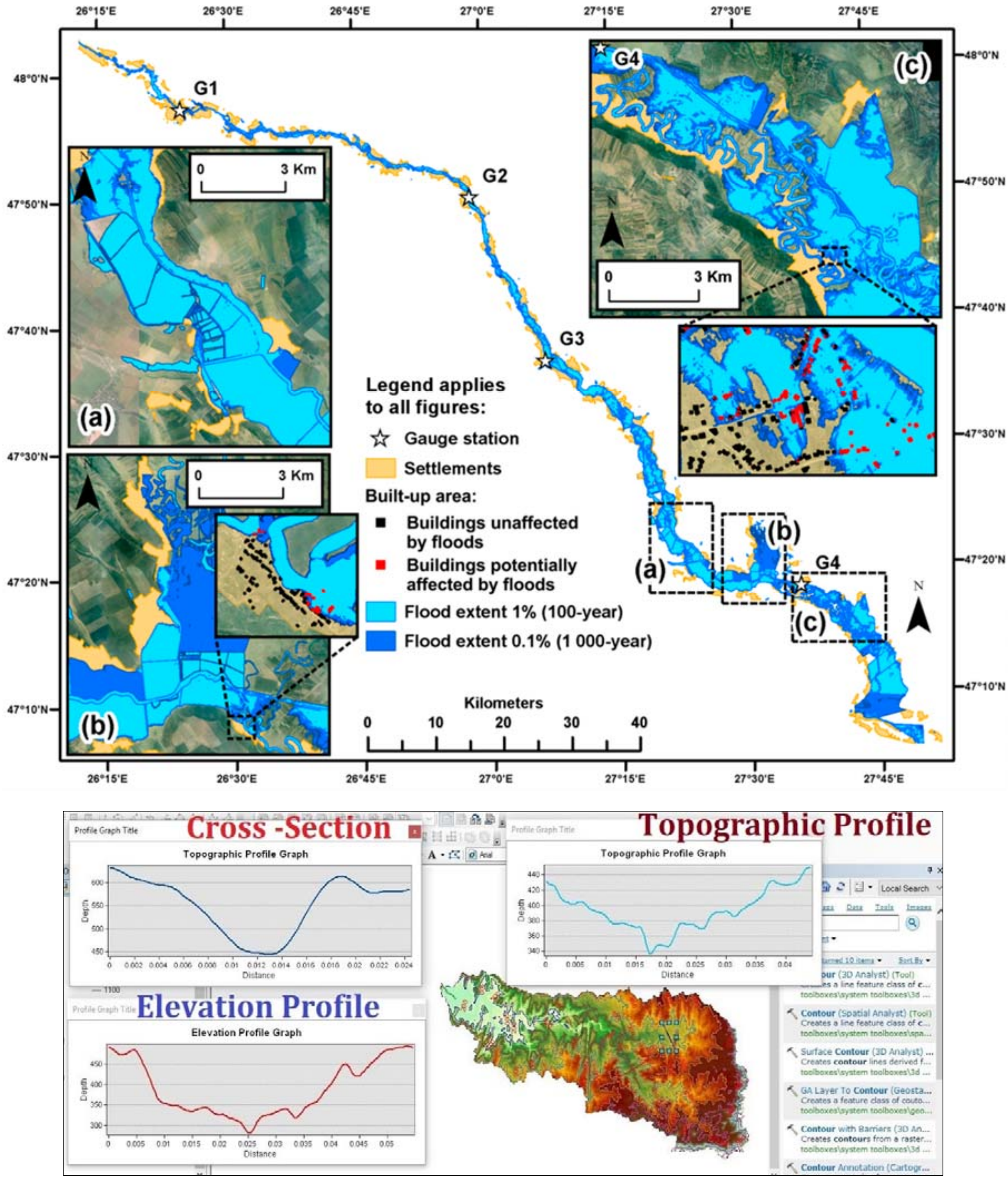


Figure B-17: Procedure of Hydrodynamic Modelling and Simulation

B18 Pile Integrity Test (PIT)

A pile integrity test (PIT) is a non-destructive method to check the quality, dimension and length of foundation piles. It involves applying a small impact on the pile head and measuring the resulting motion or force with an accelerometer or an instrumented hammer. The recorded data can reveal any defects or changes in the pile cross-section along the shaft.

To perform a PIT on RCC piles at riverbed, the following equipment and accessories are required:

- A pile integrity tester device with a built-in data acquisition and interpretation system.
- A sensitive accelerometer or an instrumented hammer with a rubber tip.
- An adhesive material to attach the accelerometer to the pile head.
- A laptop or a tablet with PIT software for data analysis and reporting.
- A power source or a battery for the device and the laptop/tablet.
- A level and a cleaning tool to prepare the pile head surface.

Additionally, the RCC piles should be cured to at least 80% of their ultimate compressive strength and cut off to the desired level before testing. The riverbed aggregates used for concrete should be free from dirt, silt, clay, and other deleterious substances. The aggregates should conform to the specifications of IS: 383-1970245.

The PIT is a technique that can be used to check the quality and shape of the pile shaft, both for cast-in-situ and prefabricated piles. It is a non-destructive type of testing that involves striking the pile head with a hammer and recording the response of the pile using a sensor.

The general procedure for PIT is as follows:

- Before the test, the pile head should be smoothened at a minimum of three locations of an equally divided quadrant of the entire pile circular cross-section.
- The concrete of cast-in-situ piles should be cured to at least 80% of its ultimate compressive strength, which is usually reached after 7 days of pile installation.
- The pile head should be at the cut-off level and free of debris or loose material.
- The sensor (accelerometer) should be fixed to the pile head using wax or adhesive, and the gap between the point of impact of the hammer and the sensor should be 300 mm in every quadrant/part of the pile cross-section.
- The hammer blow should be applied perpendicular to the pile head, and it should produce a compressive sonic wave of length between 2m to 3m and speed 3500 to 4500 m/s along the pile shaft.
- The hammer weight and wave speed should be appropriate for the depth and size of the pile, and they should be mentioned in the test report.
- The test data should be recorded by a data acquisition device and analyzed by software such as PIT-W-2009 or updated software.

The test results can be interpreted by various methods, such as the Unloading Point Method (UPM) for determination of the compressive pile behavior. The test can reveal defects such as cracks, necking, bulging, soil inclusions, or changes in cross-section along the pile length. However, PIT has some limitations, such as:

- It cannot measure the bearing capacity or load-displacement behavior of the pile.

- It cannot detect defects near the pile toe or below a major defect.
- It may not be reliable for piles with complex geometry or variable soil conditions.
- It may be affected by external noise or environmental factors.

Therefore, PIT should be used in conjunction with other methods of pile testing and inspection to ensure the quality and safety of the pile foundation.

Illustrative Sketches:

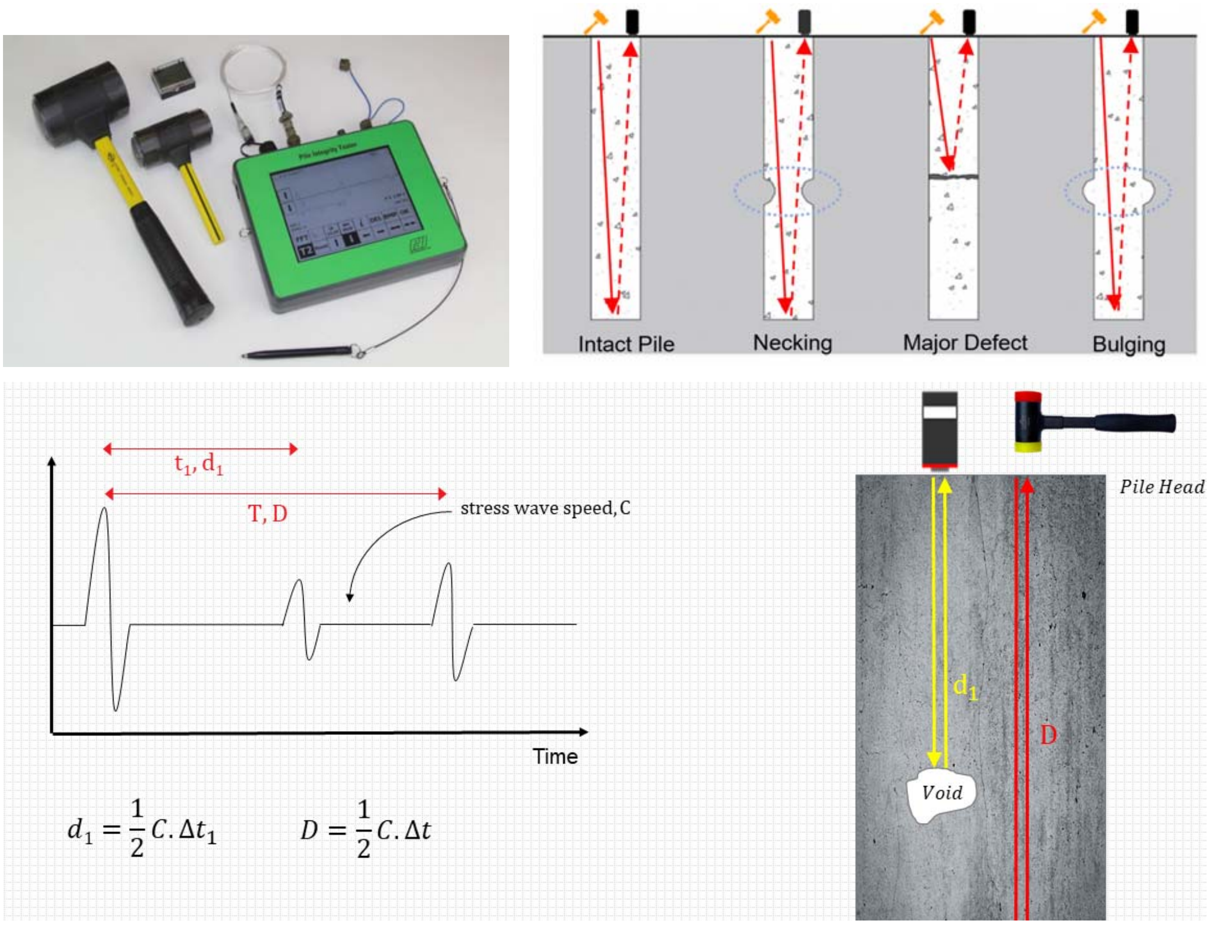


Figure B-18: Procedure for Pile Integrity Testing

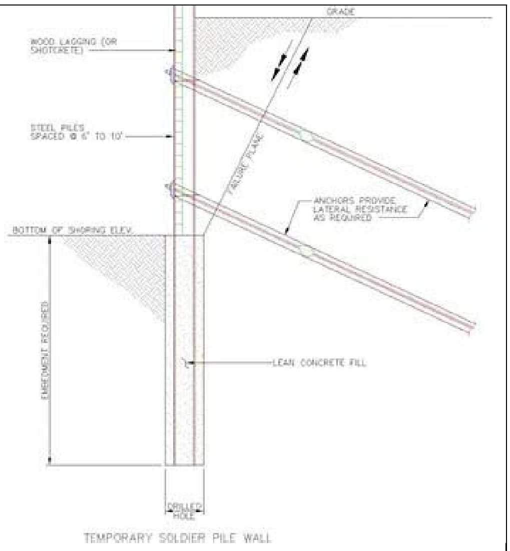
3 ADDENDUM TO ANNEX C: STANDARD GEOTECHNICAL SOLUTIONS

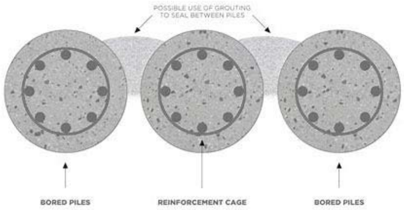
A comprehensive set of geotechnical solutions is available in Annex C of the guide "Roadside Geotechnical Problems: A Practical Guide to Their Solution". In course of more than one and half decade, some more geotechnical solutions in slope stabilization are being used in Nepal in various important road corridors. The successful slope protection measures and techniques used in river protection works experiences are added in this section.

C15 RCC Pile Wall for Riverbank Protection Work

Name of Measure: ***Pile Wall***	**Symbol:**
Purpose / Function: A pile wall is a type of retaining structure that is used to support soil or water in deep excavations. A pile wall is formed by installing piles (circular structural elements) in the ground, either by driving or drilling them. There are different types of pile walls depending on how the piles are arranged and reinforced. Some common types are: • Secant pile wall: This is formed by constructing intersecting reinforced concrete piles. The piles are reinforced with either steel rebar or steel beams and are drilled under mud. The secant pile wall has increased stiffness and can be installed in difficult ground conditions[1]. • Tangent pile wall: This is similar to secant pile wall, but the piles are constructed flush to each other without overlap. The tangent pile wall requires all piles to be reinforced and usually has a pile cap to ensure a more homogenous behavior[1]. • -Contiguous pile wall: This is formed by constructing piles with a spacing between them. This type of pile wall is mainly used in coherent (fine-grained) materials where there is no risk of material collapse between the piles. The contiguous pile wall is quicker, cheaper and simpler to perform compared to other types of pile walls[2].	**Advantages:** The main advantages of pile walls are: • They can provide stability and support the toe of the slope • They can prevent soil erosion at toe of slope • They can adapt to different soil conditions and alignment requirements • They are required where the river besides the road is deep and where river cuts the toe of the bank **Disadvantages:** The main disadvantages of pile walls are: • They may have verticality tolerances and waterproofing issues for deep piles • They may require additional protection or support for high loads or unstable soils • They may have environmental impacts due to soil disturbance and disposal • They may require steel liner at locations where flow of debris and sediment is anticipated.
Design/Considerations: Some of the factors that affect the design and construction of pile walls are: • Loads from the superstructure: The pile wall should be able to support the vertical and horizontal loads imposed by the structure above it, as well as any surcharge or seismic loads.	**Limitations:** • They may be difficult to install in hard or rocky soils or in areas with high groundwater levels. • They may have limited load capacity and settlement control compared to other types of foundations. • They may require high verticality tolerances and precise alignment to

• Condition of the soil: The pile wall should be designed based on the geotechnical properties of the soil, such as strength, stiffness, permeability, compressibility, etc. The soil condition also affects the construction method and equipment selection for pile installation. • Condition of the rock: The pile wall should be designed to penetrate into a suitable bearing stratum that can carry the load transferred by the piles. The rock condition also affects the drilling and grouting techniques for pile installation. • The cost of construction: The pile wall should be designed to optimize the material, labor and equipment costs, as well as the construction time and quality. The cost of construction also depends on the availability and accessibility of the site, the clearances from the boundaries, and the limitation of the vibrations and sound levels. • The type of pile wall: The pile wall should be selected based on the project requirements, site conditions and design criteria. Different types of pile walls have different advantages and disadvantages in terms of performance, durability, constructability and aesthetics. Some common types of pile walls are secant pile wall, tangent pile wall, contiguous pile wall and sheet pile wall[234].	ensure proper overlap and interlock between piles. • They may not provide complete seepage control at the joints between piles. • They may be more expensive and time-consuming than sheet pile walls or other shallow foundations. • They may need steel lining at areas exposed to high-speed flows to protect the concrete from abrasive effect of debris or sediment flow.
Illustrative photos: River training works at Km 17 of Narayanghat Mugling Road based on Piles  Other examples:	





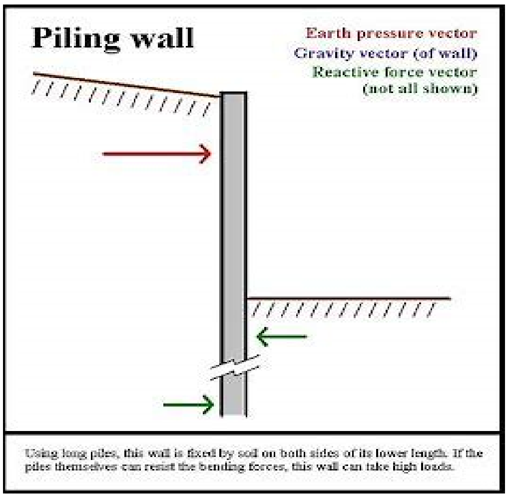


Figure C-15: Illustrative Sketches of Pile Walls for Bank/ Slope Protection

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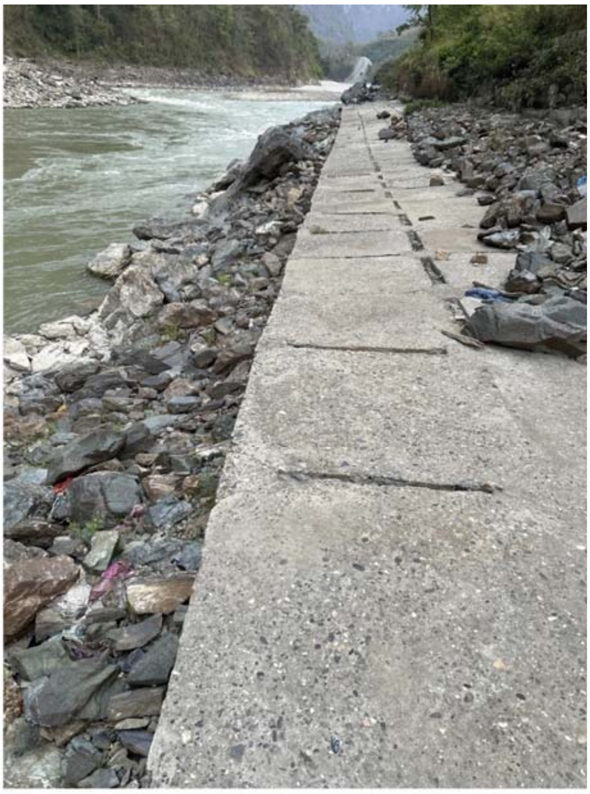
(a) Pile foundations – Design, Construction and Testing Guide. https://www.structuralguide.com/pile-foundations/.
(b) Specifications for the Construction of Secant and Tangent Pile Wall .... https://semspub.epa.gov/work/07/30323382.pdf.
(c) Foundation Design and Construction - CEDD. https://www.cedd.gov.hk/filemanager/eng/content_148/ep1_2006.pdf.
(d) Secant and Tangent Pile Walls – Deep Excavation. https://www.deepexcavation.com/en/resources/retaining-systems/secant-pile-walls.

C16 Concrete Armour Blocks with Semi-Rigid Articulation with Rebars/ Cables

Name of Measure: Concrete Armour Blocks with Semi-Rigid Articulation with Rebars	**Symbol:**
Purpose / Function: Articulated concrete armour-blocks are a type of revetment that are used to protect riverbanks and beds from erosion caused by waves and flow energy. They are made of concrete blocks that are connected by strong cables, forming a flexible mat that can conform to the shape of the slope or bed. The purpose of these blocks is to absorb the impact of the water and reduce the shear stress on the bank or bed material They also allow some water and sediment to pass through, maintaining the natural hydrology and ecology of the river. Typical sizes of blocks, bars and cables are as follows: Concrete blocks – M20 concrete 1.5m x 1.5m x 1.0m with lifting arrangement and articulation installation. Reinforcement for articulation – 25 mm Fe415 steel Cable – 16 mm high strength steel cable.	**Advantages:** - They provide an erosion-resistant overlay with specific hydraulic performance characteristics. - They allow infiltration and exfiltration of water while retaining the soil subgrade. - They are flexible and porous and can conform to changes in subgrade while remaining interlocked. - They are easy to install, simple to produce, and environmentally friendly. - They can support vegetation growth through vertical cores and spaces. - They have excellent resistance to hydraulic shear and overtopping conditions. **Disadvantages:** - It may be less stable than other methods such as rock riprap or poured concrete riprap. - It may be more expensive than other methods depending on the availability and transportation of concrete blocks. - It may be less effective in curved river reaches or in areas with high water levels, flow velocities or wave conditions.
Design/Considerations: - The hydraulic stability of the armour concrete block (ACB) system as a function of site-specific hydraulic conditions and unit characteristics. - The factor of safety method that involves balancing the driving and resisting forces, including gravity, drag and lift. - The geotextile filter and/or subgrade filter design to prevent soil migration through the ACB system. - The minimum installation guidelines and toe treatments to ensure proper performance of the ACB system. - The geomorphic considerations for ACB design such as channel alignment, slope, curvature, roughness, and sediment transport.	**Limitations:** - They require a site-specific geotextile and geogrid selection based on the gradation and permeability of the surface soils. - They may not be suitable for high-velocity flows (> 6 m/s) or steep slopes that exceed the hydraulic stability of the ACB system. - They may require additional anchoring or termination methods to prevent uplift or displacement of the blocks. - They may be affected by geomorphic factors such as sediment transport, channel migration, and vegetation growth.

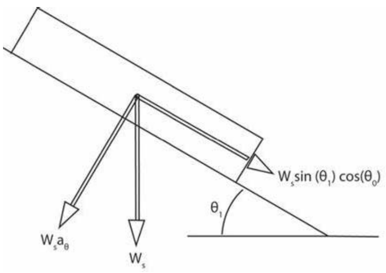
Illustrative photos:

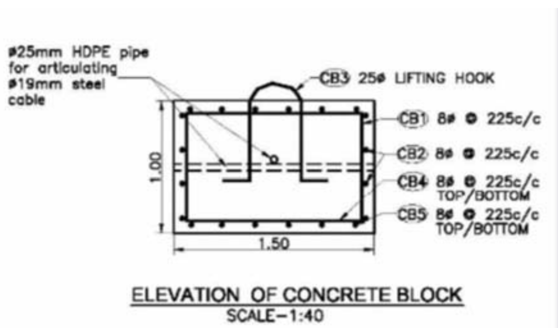


Latitude: 27.82081518° N
Longitude: 84.48664624° E
Elevation: 162.513m

Latitude: 27.82080359° N
Longitude: 84.48723494° E
Elevation: 167.639m

Example of Articulated Concrete Blocks Apron





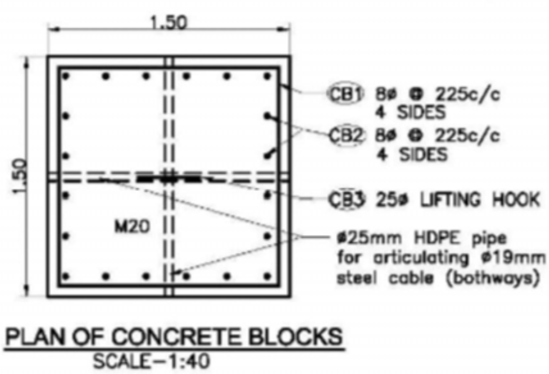


Figure C-16: Illustrative Sketches of Concrete Armor Blocks with Articulation

Bibliography:

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(2) Chapter 6 - Coastal Revetments for Wave Attack - Pile Buck Magazine. https://pilebuck.com/highways-coastal-environment-second-edition/chapter-6-coastal-revetments-wave-attack/.

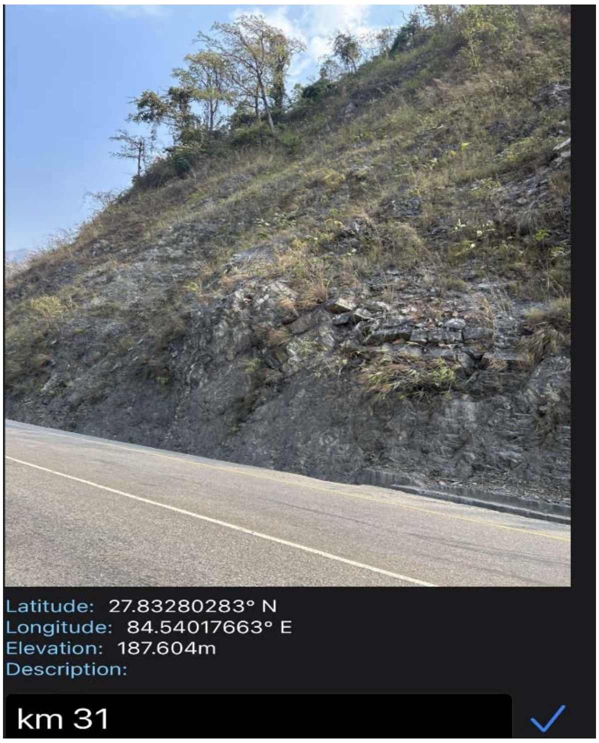
(3) Riverbank stabilization using rock riprap falling aprons. https://www.researchgate.net/publication/230288704_River_bank_stabilization_using_rock_riprap_falling_aprons.

C17 Rock Netting with Gabion Net and Cables

Name of Measure: Rock Netting with Gabion Net and Cables	**Symbol:**
Purpose / Function: Rock netting is a type of slope protection that uses wire mesh, steel ropes and anchors to secure unstable slopes and prevent rockfalls. It is designed to enhance the stability of the slope and reduce the possibility of slope failure, thereby protecting the public and infrastructure from slope failure damages. Rock netting can adapt to the topography and allow free drainage and vegetation growth. It can also be cheaper and more environmentally friendly than concrete or shotcrete construction. Typical sizes of cables are as follows: Steel Cable – 16 mm high strength steel cable Spacing – 2,5m x 2.5m Cable Direction – Vertical only for drapery system to permit flow of debris within net, both vertical and horizontal where debris are to be retained in place avoiding flow within the net. *Alternatively, high performance net can be used as per requirement for longer life and larger load capacity*.	**Advantages:** - It is fast and easy to install using lightweight equipment. - It imparts tensile strength almost immediately. Where higher tensile strength is needed, steel cables are used with 2-3 m panels. - It is flexible to match existing slopes and rock profiles. - It does not inhibit vegetation regeneration, allowing the slope to return to its natural state. - It is cost-effective with low maintenance requirements. **Disadvantages:** - It can be time-consuming to install and maintain. - It can interfere with the natural drainage and vegetation of the slope. It may require proper drainage and bioengineering measures in the slope to improve the slope condition. - It may not be effective for very large or heavy rocks, or for slopes that are very steep or unstable. For such critical cases, high performance nets may be applied instead of gabion nets.
Design/Considerations: - The extent and depth of the unstable rock face, which can be determined by field observations, geo-mechanical models or back analysis. - The geometric and mechanical properties of the rock mass and the soil cover, such as cohesion, friction angle, density, weathering, etc. - The performance features of the anchors and the mesh, such as breaking load, stiffness, corrosion resistance, etc. - The safety factors for both the ultimate limit state (verification of breaking loads of the system components) and the serviceability limit state (maximum permissible deformation of the facing), which depend on the slope morphology, the additional loads (such as snow or ice) and the level of risk. - The installation problems, such as access,	**Limitations:** - It may not be effective for large boulder sizes or thick layers of loose material. High performance nets must be used in such cases. - It may require frequent maintenance and inspection to ensure its integrity. Proper design and specification may reduce the maintenance requirement. - It may interfere with the natural drainage and vegetation of the slope. So, proper drainage and bioengineering inside the netting must be applied where needed. - - It may not be aesthetically pleasing or compatible with the surrounding environment.

vegetation, aesthetics and environmental issues or regulations, which can affect the cost and feasibility of the project. Choice of appropriate system at appropriate location will reduce problems during installation, designer should take consideration of all aspects related to cost, environment and access to the site.

Illustrative Photos: NM road sites using gabion nets and cables



Example: use of High-performance nets

Figure C-17: Illustrative Sketches for Rock Netting with Gabion Nets and Cables

Bibliography:

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(2) GEO Technical Guidance Note No. 10 (TGN 10) Enhancement of Rock Slope .... https://www.cedd.gov.hk/filemanager/eng/content_427/TGN%2010_4.pdf.

(3) Rockfall Netting Philippines - Brown & Greenfield Engineering. https://brownandgreenfield.com/slope-protection/rockfall-netting/.

(4) Rockfall Netting — Soil Engineering Construction, Inc. https://www.soilengineeringconstruction.com/services/rockfall-netting.

C18 Reinforced Earth Wall/ Slope with Terra Mesh Facia

Name of Measure: Reinforced Earth Wall/ Slope with Terra Mesh Facia	**Symbol:**
Purpose / Function: The reinforced earth slopes with terra mesh facia are a type of Mechanically Stabilized Earth (MSE) structures and Reinforced Soil Slopes (RSS) that use pre-assembled units of double twist wire mesh (8×10 type) as geogrid reinforcement. The units are filled with suitable stone or soil fill and connected to form a slope or a wall. The facia can be gabion, vegetated or architectural depending on the desired appearance. The purpose and functions of these structures are to provide stability, erosion control, drainage and aesthetics for various applications such as road embankments, retaining walls, bridge abutments, etc. Geogrid reinforcement is a technique that uses geogrids, which are geosynthetic materials made from polymers such as polypropylene, polyethylene or polyester. Geogrids are used to reinforce soils and similar materials by transferring forces to a larger area of soil and providing stabilization and filtration. Geogrids have openings called apertures that allow soil to strike through and provide confinement and interlock. Geogrids can be used for various applications such as retaining walls, pavements, embankments, foundations, mining and hardscaping.	**Advantages:** They are more cost effective than the mass gravity gabion wall in case of very high walls because of the speed of installation and reduced rock fill requirements. They are environmentally friendly and can allow natural vegetation cover. They are durable and can withstand the most aggressive environmental conditions. **Disadvantages:** They require high quality structural backfill and suitable fill behind the front face to ensure stability and performance. They may not be suitable for very steep slopes or walls that require high bearing capacity or seismic resistance. They may need regular maintenance to prevent erosion, corrosion or damage to the wire mesh units. This can be reduced by use of polymer coated facia.
Design Considerations: Design considerations for reinforced slopes with terra mesh facia depend on various factors, such as the soil properties, the slope angle, the load conditions, the environmental conditions and the aesthetic preferences. According to[1], some of the common challenges faced when altering soil slopes are: - Bearing capacity: weak soils that need to support high loads or many loading and unloading cycles require precise design and quality materials. - Fast installation: productivity on construction sites and emergency situations demand a rapid installation process. - Challenging topography: retaining walls and soil reinforcement solutions sometimes need to reach	**Limitations:** Some of the limitations of reinforced earth slopes with terra mesh facia are that they may be susceptible to the coupling effect of rainfall and earthquake, which can affect the dynamic response, pore pressure and tensile stress distribution of the reinforcement. They may also require special design considerations for drainage, erosion control, facing connection and reinforcement length. Additionally, they may have higher installation costs than other facing options such as geocells or geotextiles in case of

great heights while keeping a small ground footprint. - Availability of materials: scarcity of materials and limited access to the construction site can affect the choice of soil reinforcement structures. - High durability: solutions need to have the longest design life and withstand aggressive climates. - Environmental impact: solutions need to combine great performance with environmental integration. Another aspect of the design of reinforced slopes is the facing system, which includes the surface erosion protection and the secondary reinforcement. The erosion protection facilitates the establishment of vegetation and/or provides structural support for the forming of "over-steepened slopes. The secondary reinforcement provides additional stability and prevents sloughing of the slope face.	low height walls/ slopes.
Illustrative Sketches/ photos: NM Road km 17	Examples:

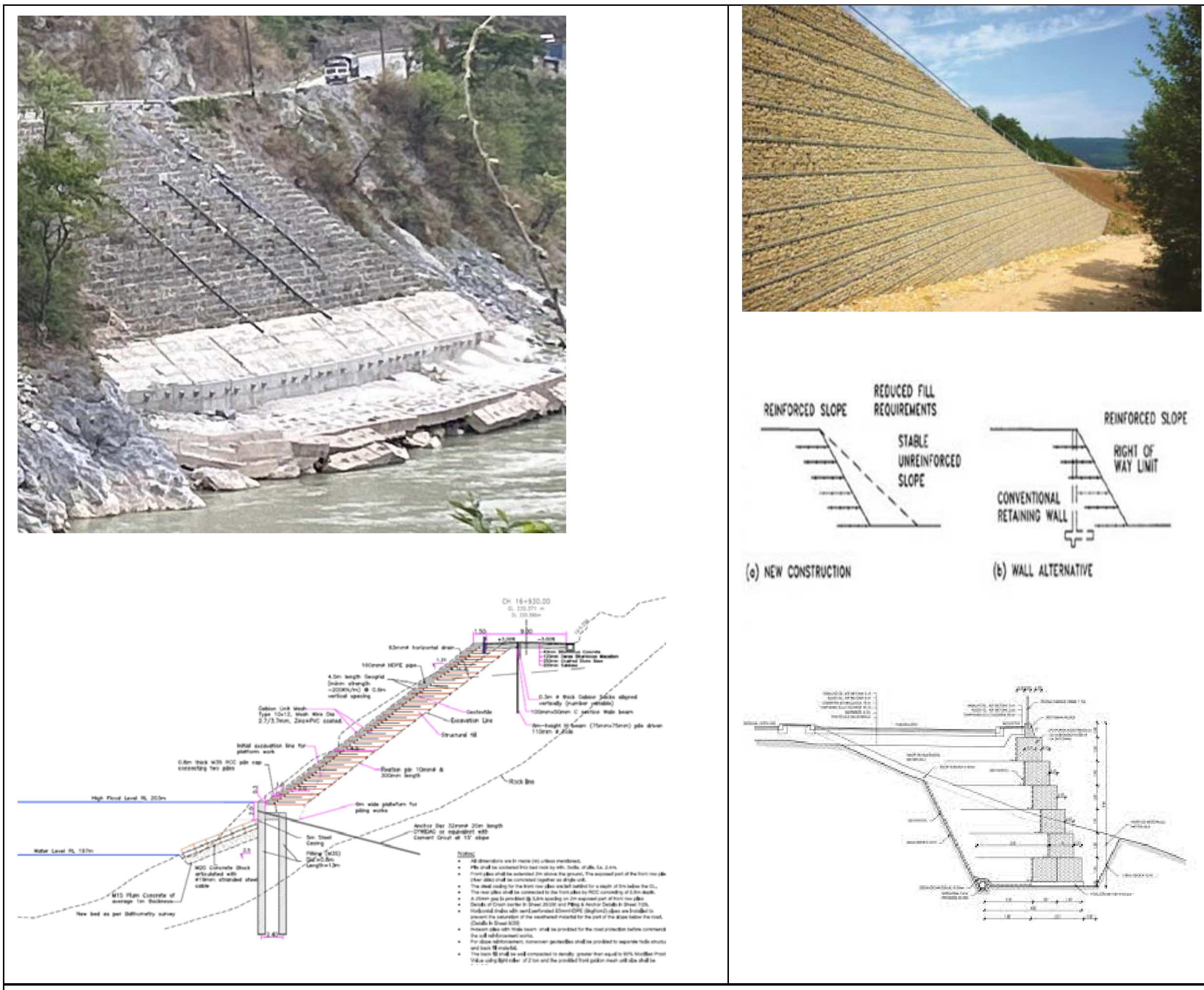


Figure C-18: Illustrative Sketches for Reinforced Earth Wall/ Slope with Terra Mesh Facia

Bibliography:

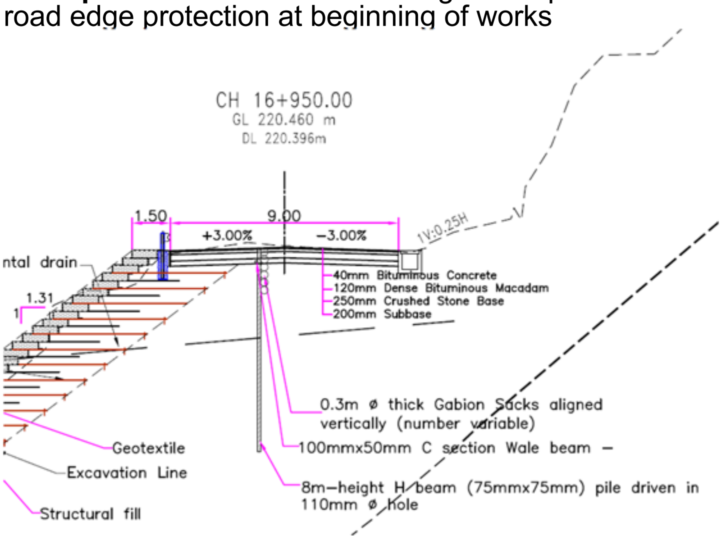
(1) Reinforced soil walls - Terramesh® | Maccaferri Corporate. https://www.maccaferri.com/products/terramesh/.

(2) Terramesh® | Reinforced Soil Slopes and Walls - Maccaferri Uk & Ireland. https://www.maccaferri.com/uk/products/terramesh-5/.

(3) Maccaferri® Terramesh® & Green Terramesh® | Geofabrics. https://www.geofabrics.co/products/maccaferri®-terramesh®-green-terramesh®.

C19 H-Piles/ I-Piles for Slope Stabilization

Name of Measure: H Piles for Slope Stabilization	**Symbol:**
Purpose / Function: H piles are steel beams that can be used for slope stabilization by acting as shear dowels across the potential failure surface. They can resist the lateral pressure of the sliding soil mass and prevent further movement of the slope. Some factors that affect the design and performance of H piles are: - The subsurface conditions and soil properties of the slope - The distribution of lateral load along the pile length - The spacing and layout of the piles - The p-multiplier, which is a reduction factor for the soil resistance along the pile due to group effects - The pile tip fixity, which depends on the embedment depth and soil stiffness - The moment and shear capacity of the pile section[2] Grouting depends on the type of H pile, the soil conditions, and the design requirements. Some types of H piles that use grouting are: Socketed H piles: These are installed by forming a pre-bored hole in the ground with a socket in the rock, placing a steel H section in the pre-bored hole and subsequently filling it with cement grout. The loading capacity of socketed H piles comes from the skin friction between the grout and rock. Where the slope is likely to fail in one direction only, I pile can also be used for H piles. I pile of equivalent section has a larger moment of resistance in load direction and lower moment of resistance in other direction.	**Advantages:** - H piles can provide effective shear resistance across the potential failure surface of a slope by acting as dowels. - H piles can be installed quickly and easily with minimal disturbance to the slope. - H piles can be designed to resist both lateral and axial loads. - H piles can be used in various soil types and conditions. **Disadvantages:** - H piles may not be able to mobilize the full passive resistance of the soil due to flow-around failure or soil arching. - H piles may require additional measures such as tiebacks or grouting to enhance their stability and performance. - H piles may be affected by corrosion or deterioration over time.
Design/Considerations: Some factors that affect the design and performance of H piles are: - The subsurface conditions and soil properties of the slope - The distribution of lateral load along the pile length - The spacing and layout of the piles - The p-multiplier, which is a reduction factor for the	**Limitations:** - H piles are limited by the availability and capacity of the driving equipment. - H piles are limited by the depth and strength of the stable soil layer below the sliding mass. - H piles are limited by the geometry and configuration of the slope and

soil resistance along the pile due to group effects - The pile tip fixity, which depends on the embedment depth and soil stiffness - The moment and shear capacity of the pile section	the failure surface. - Need heavy equipment/special equipment for pile driving, drilling - Require adequate working space - Costly and needs special construction supervisions and trained manpower
Example: Km 17 of NM road using 8 m H piles for road edge protection at beginning of works 	

Illustrative Sketches:

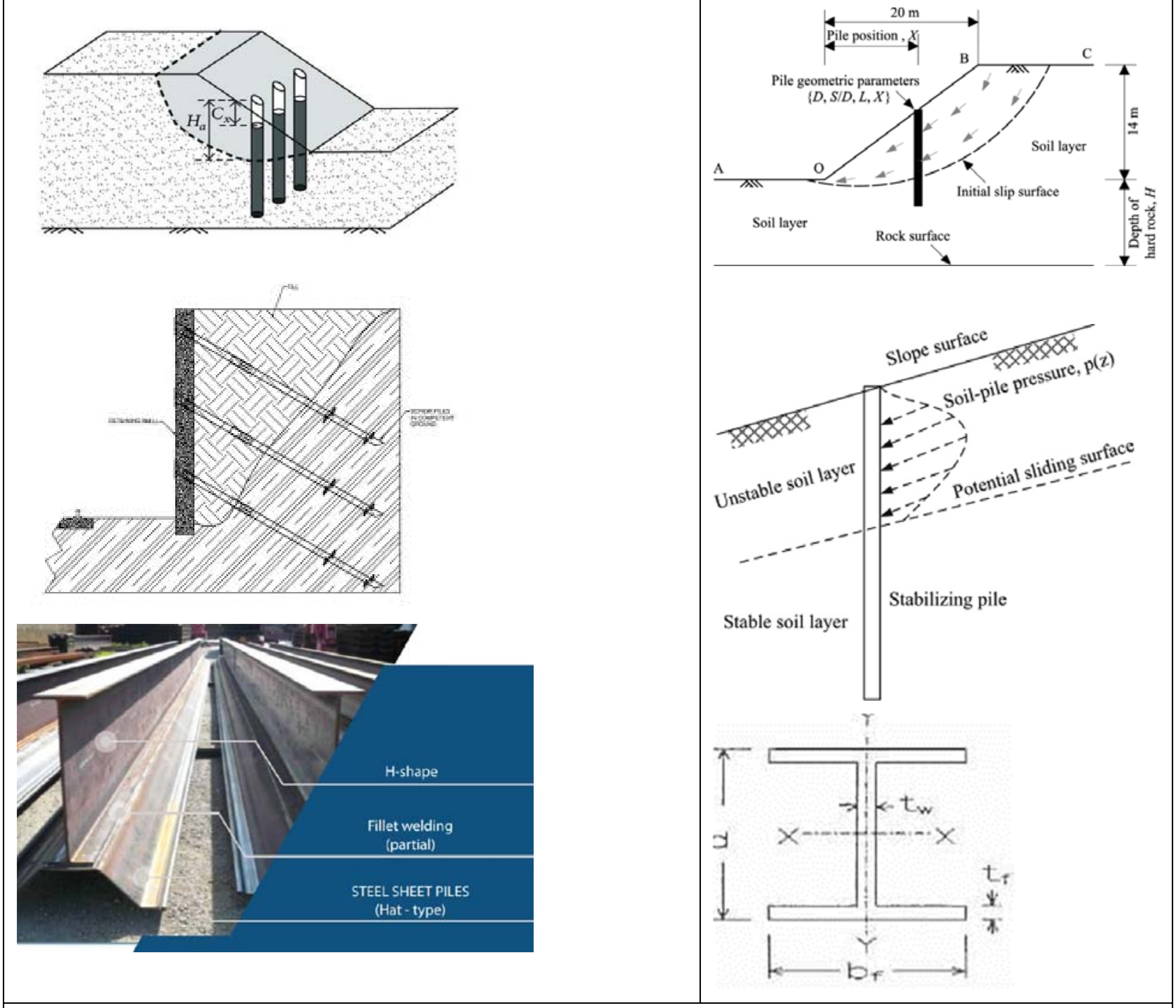


Figure C-19: Illustrative Sketches for H-Piles/ I-Piles for Slope Stabilization

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C20 Soil Nails with Double Corrosion Protection (DCP) with Appropriate Facial Elements

Name of Measure: Soil Nails with Double Corrosion Protection (DCP)	**Symbol:**
Purpose / Function: Soil nails with double corrosion protection are a type of reinforcement system for stabilizing slopes, cuttings and excavation walls. They consist of threaded bars that are inserted into pre-drilled holes and grouted with cement. The bars are protected from corrosion by a corrugated plastic sheath that covers the entire length of the bar and is filled with grout. The purpose of this system is to provide enhanced durability and performance for soil nails that are exposed to aggressive environments or require a long service life. Some of the advantages of soil nails with double corrosion protection are: - They can be used for temporary and permanent applications - They can be installed in restricted access areas - They can be cut and coupled at any point along the length - They can be post-grouted for bond stress enhancement Double corrosion protection (DCP) is a factory pre-grouted encapsulation of the steel tendons within a corrugated plastic sheath. It ensures durability and consistent long-term performance of the soil nails in aggressive environments or for permanent applications. The strength classes of soil nails with DCP depend on the type and diameter of the steel tendons used. For example, the Minova DCP ATB thread bar system has different strength classes ranging from 160 kN to 2209 kN for yield load and from 175 kN to 2430 kN for ultimate load. The strength classes also meet three internationally recognized design standards: EN1537:2013, EN14199:2015 and EN14490:2010. Alternate Types of Facia: Apart from the RCC facia applied in NM Road, consideration must be made for alternative facia	**Advantages:** They provide enhanced durability and long-term performance in aggressive environments. They offer a rapid and economical method for stabilizing slopes and battered cuttings, often being more cost-effective than installing traditional excavation supports. They are suitable for areas where access is restricted and can be used for both temporary and permanent applications. They are easy to install and test, with simple components and assembly. They allow for cutting and coupling the bar at any point along its length, for easy on-site length adjustments. **Disadvantages:** They require open hole drilling and grouting, which may not be possible in some soil conditions or locations. They are a passive system that relies on the mobilization of soil shear strength, which may not be sufficient in some cases. In such cases longer soil nails can be chosen. They may not be able to accommodate large deformations or movements without compromising the integrity of the system. They may require post-grouting tubes or valves for bond stress enhancement in some cases.

where appropriate from among the following types: Shotcrete facia: This is the most common type of facia, which involves spraying a layer of concrete or mortar on the soil surface. The thickness of the shotcrete facia usually ranges from 50 to 150 mm. Panel facia: This type of facia consists of precast concrete or steel panels that are attached to the soil surface using anchors or bolts. The panel facia can also provide additional structural support to the soil nailed structure. Wrap-around facia: This type of facia uses geosynthetic materials, such as geotextiles or geomembranes, to wrap around the soil surface and the nail heads. Hybrid facia: This type of facia combines two or more of the above types to achieve the desired functions and appearance.	
Design/Considerations: They should be designed according to the relevant standards and codes of practice, such as EN 1537:2013, EN 14199:2015, EN 14490:2010, BS 8004:2015 + A1:2020, BS EN 1997-1:2004 + A1:201323. They should be selected based on the required service life and the aggressivity of the environment, taking into account factors such as soil type, groundwater level, pH, chloride content, sulfates, carbonates, etc. They should be installed with adequate spacing, inclination, length and diameter to ensure sufficient load transfer and stability. They should be tested for pull-out resistance, grout quality and corrosion protection before and after installation. They should be monitored for performance and maintenance during their service life.	**Limitations:** - They may not be suitable for soils with high water content or low cohesion. - They require open hole drilling and grouting, which may not be feasible in some conditions. - They may not prevent surface erosion or weathering of the slope face. Appropriate types of facial element must be chosen to prevent surface erosion and weathering. - They may not be able to accommodate large deformations or movements of the slope. Where large deformations are anticipated, more flexible types of facial element must be chosen.

Example: Km 17 of NM road using Soil nails in river training pile structures 	 **Example:** Km 26 of NM road using Soil nails in retaining structures 

Illustrative Sketches:

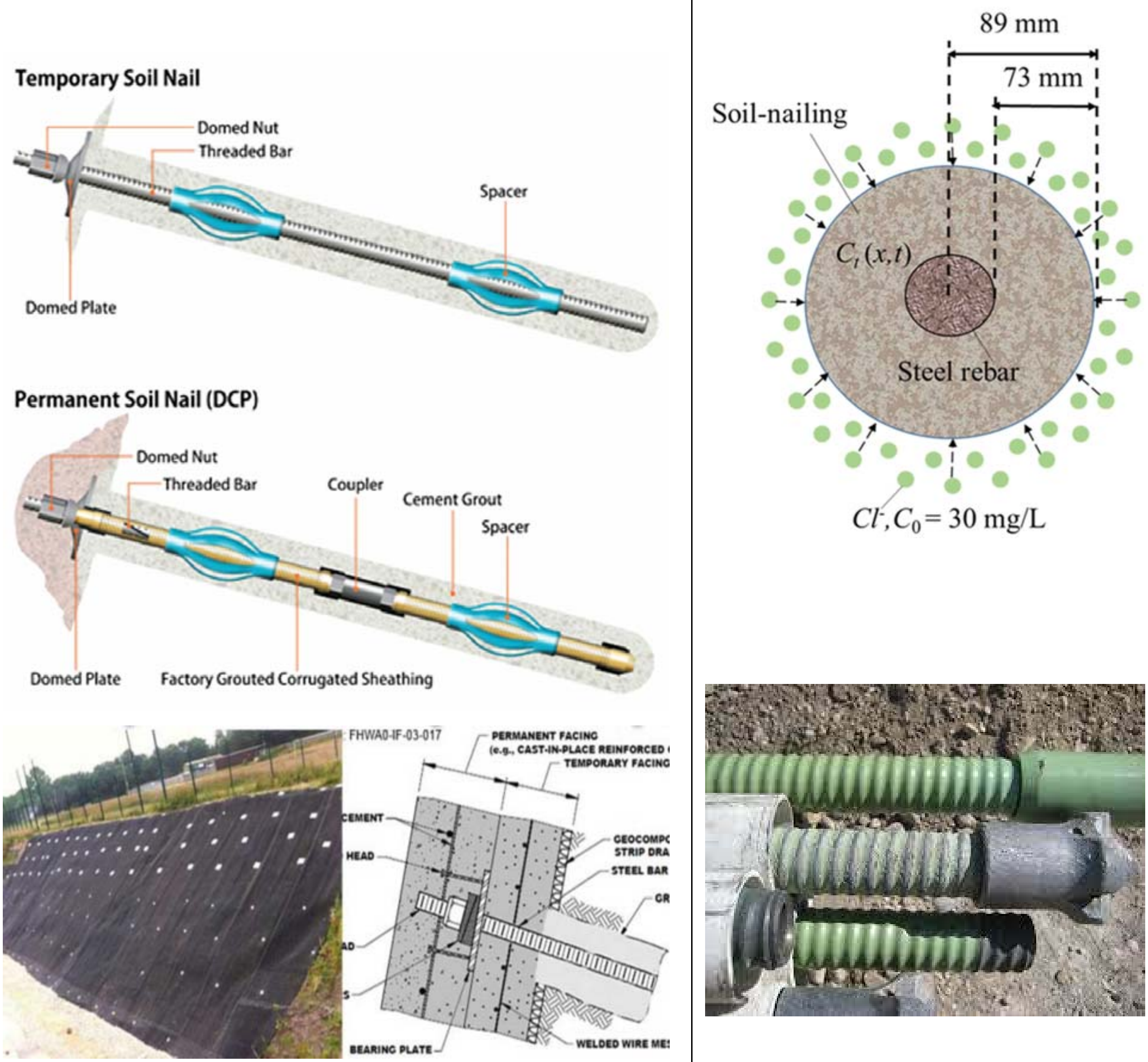

Figure C-20: Illustrative Sketches for Soil Nails with Double Corrosion Protection (DCP) with Appropriate Facia Elements

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