ENGINEERING OF SLOPE
Planning, Design, Construction & Maintenance Considerations

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http://www.gnpgeo.com.my

G&P Geotechnics Sdn Bhd (www.gnpgroup.com.my)
CONTENTS

• Introduction
• Policies & Legislation
• Planning of Hill-Site Development
• Analyses & Design of Slopes
• Design of Slope Strengthening Works
• Construction Control & Site Supervision
• Maintenance of Slopes
• Conclusion
INTRODUCTION
Soil Nailed Slope Failure
Policies and Legislation
Source of Hillsite Development Guidelines

Governmental & Private Agencies

- IKRAM
- DOE
- JMG
- IEM
- MPAJ (Local Authority)

- Urban & Rural Planning Department (JPBD)
- Ministry of Housing & Local Government (MHLG)

Source:
- G&P Geotechnics Sdn Bhd
- www.gnpgroup.com.my
### Simplified Slope Classification

<table>
<thead>
<tr>
<th>Classifications</th>
<th>Gradient of Natural Terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Insitu terrain $&lt; 15^\circ$</td>
</tr>
<tr>
<td>Class II</td>
<td>Insitu terrain $15^\circ - 25^\circ$</td>
</tr>
<tr>
<td>Class III</td>
<td>Insitu terrain $25^\circ - 35^\circ$</td>
</tr>
<tr>
<td>Class IV</td>
<td>Insitu terrain $&gt; 35^\circ$</td>
</tr>
</tbody>
</table>
Policies and Legislation

• These guidelines & regulations:
  – are conflicting & unclear
  – are too complicated for implementation
  – are subjected to various interpretations

• IEM has formulated policies and procedures for landslide risk mitigation on hillsite developments
## Position Paper for Mitigating the Risk of Landslide on Hill-Site Development

<table>
<thead>
<tr>
<th>Class</th>
<th>Total Height ($H_T$)</th>
<th>Global Angle ($\alpha_G$)</th>
<th>Localised Height ($H_L$)</th>
<th>Localised Angle ($\alpha_L$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CLASS 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Low Risk)</td>
<td>≥ 15 m</td>
<td>&lt; 19°</td>
<td>&lt; 3 m</td>
<td>&lt; 27°</td>
</tr>
<tr>
<td></td>
<td>6 m – 15 m</td>
<td>&lt; 27°</td>
<td>&lt; 3 m</td>
<td>&lt; 30°</td>
</tr>
<tr>
<td></td>
<td>&lt; 6 m</td>
<td>-</td>
<td>-</td>
<td>&lt; 34°</td>
</tr>
<tr>
<td><strong>CLASS 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Medium Risk)</td>
<td>&gt; 15 m</td>
<td>19° – 27°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6 – 15 m</td>
<td>≥ 27°</td>
<td>≥ 3 m</td>
<td>27° – 30°</td>
</tr>
<tr>
<td></td>
<td>&lt; 6 m</td>
<td>-</td>
<td>≥ 3 m</td>
<td>≥ 30°</td>
</tr>
<tr>
<td><strong>CLASS 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(High Risk)</td>
<td>&gt; 15 m</td>
<td>&gt; 27°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>≥ 3 m</td>
<td>≥ 30°</td>
<td></td>
</tr>
</tbody>
</table>

**The Institution of Engineers, Malaysia**

**Position Paper for Mitigating the Risk of Landslide on Hill-Site Development**
**Legend:**

- $H_T$ = Total height of slope
- $H_L$ = Localised height
- $\alpha_G$ = Global angle of slope
- $\alpha_L$ = Localised angle of slope
Current Status

• JKR – Guidelines for Slope Design, 2010

• DBKL – Guidelines for Planning of Hilly & Sloping Areas, 2010

• Negeri Selangor – Guidelines for Hillsite Development
PLANNING STAGE
Planning Stage

- Desk Study (e.g. geological map, aerial photos)
- Site Reconnaissance

Geological Input

- Terrain Mapping
  - Terrain Classification (JMG)
- Geological Mapping
  - Rock Type
- Surface Hydrogeological Assessment, Natural Water Course
  - Joints
  - Weathering grades
- Erosion & Instability Evaluation
  - Geohazard & Geological Constraints
Groundwater Regime

Subsoil Material Properties

Geological Weak Zones

Bedrock Depth

Hard Stratum

Subsoil Depth

SI Planning
Planning of Development Layout

- Geotechnical input in early stage
- Maximise environmental preservation by clustering development
Planning of Development Layout

• Allow **higher density** development within minimum plinth area
• **Leave green** on hill slope

Photo courtesy of www.lushhomemedia.com
ANALYSIS & DESIGN
OF SLOPES
Analysis & Design of Slopes

• ACT 133 & UBBL

• Natural slopes adjacent to development shall be assessed on its existing slope safety.

• In-line with judgement by Justice James Foong in the Highland Tower case.
KUALA LUMPUR: Justice James Foong held that Block One was brought down by a "rotational retrogressive slide emanating from the high wall behind the second-tier car park."

The judge noted that the wall had stood 10 years without failing.

"We have evidence that the suspected area of failure consisted of sandy soil.

"With 10 days of continuous rainfall in the area before the failure of this wall, surely the ground on which it stood would be saturated with water when the drainage system of the slope was either insufficient or inadequate to accommodate water.

"When this happens, the pore water pressure in the soil will increase to cause the soil to be less resistant to slide.

"This must have played a very major role in causing the ground on which this high wall stood to fail."

Justice Foong said he found that water must have been a major factor in causing the collapse of the high wall and the landslide that followed.

As for the source of the water, the judge said that it came from rainfall and runoff water that was washed along the surface.

"With the internal drains on the Arab-Malaysian land, the (runoff) water would be directed down the slope in a controlled manner.

"But these drains were neither sufficient nor efficient or maintained to carry the load.

"Substantial part was earth drains and this permitted easy percolation of water into the soil to saturate it.

"Some were blocked or with vegetation growing over them.

"Such blockage must have caused severe overflow on the terraced slope," he added.

Justice Fong said that the second source was water from the East Stream which was directed into a pipe culvert but the pipe culvert was in very poor condition and damaged.
IMPORTANT Slope Stability Factors

- Soil Properties
- Slope Geometry
- Groundwater table
- Slope Maintenance
IMPORTANT Slope Stability Factors

• Soil Properties

Steep Rockface  Gentle Beach
**IMPORTANT** Slope Stability Factors

- **Slope Geometry**

- Steep Slopes Has Higher Risk of Failing

- Steep Slopes Has Higher Risk of Failing
IMPORTANT Slope Stability Factors

• Groundwater table

Low Groundwater Table

High Groundwater Table

• High Groundwater Increases Risk of Failure
Groundwater Table

- Rainwater = Runoff + Infiltration
  - Erosion
  - Rise in Water Level

- Design for 10-yr ARI or representative groundwater level.
- Slopes of High Risk-to-Life →
  - check sensitivity of water level.
SLOPE STABILITY ANALYSIS
Methods of Stability Analysis

Analyse as SOIL = Grade IV to VI

Methods :- (Should check both)

(A) Circular Slip Failure (e.g. Simplified Bishop)
    - for deep layer without structural features.

(B) Non-Circular or Wedge Slip Failure

    (e.g. Janbu, Morgenstern & Price)
    - failures often at relict joints or boundaries between weathering zone.
External Loading

• Loadings from :-
  – Traffic
  – Building Foundations
  – Retaining Wall
  – Spoil heaps
FACTOR OF SAFETY

• Considers **TWO** Main Factors:
  – Risk-to-Life
  – Economic Risk

• **Three** Level of Risks:
  – Negligible, Low, High
<table>
<thead>
<tr>
<th>Risk-to-Life</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-air recreation, Country Parks</td>
<td>Negligible</td>
</tr>
<tr>
<td>Roads of low traffic</td>
<td>Negligible</td>
</tr>
<tr>
<td>Storage Compound</td>
<td>Negligible</td>
</tr>
<tr>
<td>Densely used playgrounds, car parks.</td>
<td>Low</td>
</tr>
<tr>
<td>Roads with high traffic</td>
<td>Low</td>
</tr>
<tr>
<td>Public waiting areas (bus stops, petrol stations, railway platforms)</td>
<td>Low</td>
</tr>
<tr>
<td>Occupied Buildings (residential, etc)</td>
<td>High</td>
</tr>
<tr>
<td>Storage of Dangerous Goods</td>
<td>High</td>
</tr>
<tr>
<td>Economic Risk</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Open-air recreation, Country Parks</td>
<td>Negligible</td>
</tr>
<tr>
<td>Roads of low traffic &amp; not sole access</td>
<td>Negligible</td>
</tr>
<tr>
<td>Open air car parks</td>
<td>Negligible</td>
</tr>
<tr>
<td>Rural Roads + Primary Distributor Roads</td>
<td>Low</td>
</tr>
<tr>
<td>Essential services (temporary loss = power, water, gas mains etc.)</td>
<td>Low</td>
</tr>
<tr>
<td>Roads of Strategic importance</td>
<td>Low</td>
</tr>
<tr>
<td>Essential services (extended period)</td>
<td>High</td>
</tr>
<tr>
<td>Excessive structural damages</td>
<td>High</td>
</tr>
</tbody>
</table>
Cut & Fill Soil Slopes

- Mainly follows Geotechnical Manual for Slopes of Hong Kong
  - Vertical height of slopes: 5m - 6m ($\leq 7.5m$)
  - Berm width $\geq 1.5m$

- Topsoil to be properly removed.

- No buried water-carrying services to be embedded on the crest of fill slopes
  - To prevent saturation of fill slopes due to pipe leakage.
Burst irrigation pipe believed to be at root of fatal Merano landslide

Investigation focuses on irrigation system for nearby orchard after mudslide causes commuter train to crash, killing nine passengers.

By Declan Lynch

Investigators are focusing their attention on a faulty irrigation system which is thought to have triggered the landslip which led to April’s fatal train crash in Italy.

Nine people died and 30 were injured when a mudslide set off by a sudden water flow slammed into a commuter train near the town of Merano in the Bolzano province in the foothills of the Dolomites.

“Natural groundwater seems not to be the main trigger of the landslide,” said Bolzano Province, lead technical investigator Rinaldo Cenonev.

Province of Bolzano transport adviser Thomas Widmann agreed and added that the first tests proved that huge quantities of water must have “spilled out” from the irrigation system.

Investigators began work on site on 16 April. This has so far involved drilling four boreholes and installing piezometers to study the strata and hydrogeology of the site. In addition, investigators have carried out some field experiments on the burst pipe, which is part of an irrigation system that serves an adjacent apple orchard.

Local press reports said the orchard owner had admitted that water had leaked from its irrigation system, but that natural aquifers in the subsoil could have caused long-
Bukit Antarabangsa Failure 2008
Bukit Antarabangsa Failure 2008

PIPE FAILURE
Bukit Antarabangsa Failure 2008
Fill Slopes

- Encourage robust system

Rock Toe
Surface Drainage

- **Cast-in-situ** RC berm drains instead of precast drain.
Fill Slopes Over Valleys

- To have catchment study
- To have adequate surface and subsurface drainage
DESIGN OF SLOPE
STRENGTHENING WORKS
DESIGN OF SOIL NAILED SLOPE
SLOPE CHASING

Required Space
• Common design reference
DESIGN CONCEPT - FRICTION

• Ultimate Unit Friction
  \[ f_{su} = 4\sim6 \, N_{SPT} \]

• Ultimate Friction for Each Nail
  \[ f_{su} A_s L \]
  \( A_s = \text{Surface Area of Nail} \)
  \( L = \text{Length of Nail} \)
DESIGN CONCEPT - FRICTION

- Ultimate Unit Friction
  - $f_{su} = 4\sim6 \text{ } N_{SPT}$

- Ultimate Friction for Each Nail
  - $f_{suCL}$
    - $C = \text{Circumference of Nail}$
    - $L = \text{Length of Nail}$
DESIGN CONCEPT - STEEL

- BS8110 (Ultimate) : \( T_N = 0.87 \times f_y \times A_s \)
- FHWA (Allowable) : \( T_N = 0.55 \times f_y \times A_s \)
- Steel Elements/Connection : BS5950
- Reinforced Concrete : BS8110
MODE OF FAILURES

• Three Modes of External Stability

- SLIDING
- TOPPLING
- BEARING CAPACITY
a) Face Failure

Failure Mode –
Face Failure and “Active” Zone Sliding Off Front of Nails

b) Pullout Failure

Failure Mode –
Nails Pull Out of Resistant Zone
Failure Mode –
Tensile Failure of Tendon

MINIMUM FOS: 1.40
Soil Nails

Grid Beam System
(allow landscaping around the soil nail)

Typical soil nail slope configuration with shotcrete/Gunite facings
(for slope steeper than 1V:1H)
Soil Nails

Commonly used

Steeply cut slopes of 25m - 30m (4V:1H gradient) Fully Shotcrete Soil Nail Slope
Individual Nail Head System
Grid Beam System
Soil Nails

- Proper design of the soil nail facing is important when gradient $\geq 60^\circ$

Example of facing failure

**CORRECT**
- Main reinforcement at back of steel plate

**INCORRECT**
- Main reinforcement in front of steel plate
DESIGN OF ROCK STRENGTHENING
INTRODUCTION

• Used to stabilize weak rock mass.

• Acts in the same manner as soil nail.
TYPES OF FAILURES - SLIDING

SINGLE BLOCK/SINGLE PLANE SLIDING

MULTIPLE BLOCKS/MULTIPLE PLANE SLIDING
SLIDING FAILURE

Planar Failure
TYPES OF FAILURES - WEDGE

SINGLE WEDGE

SINGLE WEDGE /MULTIPLE INTERSECTING PLANES

- crest of slope
- slope face
- direction of sliding
- planes corresponding to centres of pole concentrations
WEDGE FAILURE
TYPES OF FAILURES - TOPPLING

Toppling failure in hard rock which can form columnar structure separated by steeply dipping discontinuities.

- Crest of slope
- Slope face
- Planes corresponding to centre of pole concentration
TOPPLING FAILURE
STEREOGRAPHIC PLOT ANALYSIS

Wedge Failure Zone

Toppling Failure Zone
STRENGTHENING OPTIONS

- **Shotcreting**
  - To prevent *loose rocks* from falling

- **Scaling**
  - To *chisel* off small loose rocks

- **Rock Bolt**
  - To *stabilize* large rock mass
NETTING
SCALING
SHOTCRETING
ROCK BOLT
CONSTRUCTION CONTROL & SITE SUPERVISION
CONSTRUCTION CONTROL

• **Site Supervision & Coordination:**
  - Site personnel with sufficient **knowledge & experience**
  - Close coordination & **communication** with design engineers
  - Maintain detailed **site records**
SUSTAINABLE HILLSITE DEVELOPMENT

- Creation of **Standard Operating Procedures (SOP)**

- Formation of a **centralised institution/agency** for hillside development
SUSTAINABLE HILLSITE DEVELOPMENT

• Simply it is more effective

• Far more difficult to overthrow while policies can easily be changed due to change of political parties
SUSTAINABLE HILLSITE DEVELOPMENT

- Important to ensure sustainable hillsite development even after the issue is no longer ‘hot’

- Promises can easily be broken while institutions often last and are more difficult to overthrow
Applies For Temporary & Permanent Works

Contractor to be Penalised for Non-compliance

BOQ Item for Temporary Slope Protection Works

Legal Provision: Earthworks Specification

CONSTRUCTION CONTROL

Via Contractual Measures
SPECIFICATION & BOQ
12.0 TEMPORARY WORKS

12.1 The Contractor shall allow in the tender for the cost of providing the necessary design, statutory submission, construction, testing and monitoring of all temporary works, including the subsequent removal of all recoverable temporary structures, for the satisfactory completion of the earthworks. He shall be responsible for the temporary works shall comply with requirements of BS 5975.

12.2 Temporary works means all planning and works carried out by the Consultant complying with all specifications, drawings, laboratory tests, temporary tracks, excavation, filling, protection works, necessary temporary drainage, pumping of water, strengthening measures, methodology and method statements.

12.3 The scope of temporary construction shall include:
   (a) Life safety measures such as hoardings, barricades, netting, etc.
   (b) Ground improvement and/or ground water cut off systems.
   (c) Ground water recharging systems, surfacing and ground levelling.
   (d) All other measures necessary for the safe performance of the works.

12.4 Temporary works shall be the sole responsibilities of the Contractor. Contractor's approval or consent of Contractor's methodology statement on all temporary works shall not relieve the Contractor's sole responsibility to ensure all temporary works comply with good engineering practice, and Contractor's own time and cost to rectify any defects, non-compliance with good engineering practice or possible long term instability/failure and serviceability problems of the temporary works.

12.5 The Contractor shall employ a Professional Engineer to design and supervise the construction of the temporary works. A certified copy of the design calculations and construction drawings shall be made available to the S.O. for the purposes of record.

12.6 The Contractor shall make all necessary statutory submissions to the local Authority the required clearances under the local Regulations governing his design and construction of the temporary works may be imposed from time to time during the tenure of the contract.

12.7 All temporary works, especially but not limited to temporary accesses and temporary earthworks (temporary cut or temporary fill) shall not cause failure and shall not induce instability or serviceability problems in the long term. All temporary cut and fill by Contractor that will be left behind after completion of permanent works shall have the same Factor of Safety on stability and Serviceability conditions as permanent works. These temporary works by Contractor shall also comply with all requirements, specifications, drawings and workscope applicable for similar type of permanent works (e.g. slope angle, compaction of fill, surface drainage, retaining structures, strengthening measures if necessary, etc).
Borrow Pit

24.3 The Contractor shall be responsible for locating borrow pits. Designated borrow pits shown on the Drawings only indicate to the Contractor potential areas for borrow. Whether the Contractor obtains materials from the designated or his own borrow pit, it shall be his responsibility to ascertain the suitability of the pit with respect to the quantity and quality of the materials, which shall be subject to the approval of the S.O. The Contractor shall pay all necessary fees, taxes or royalties to the appropriate authorities and observe all relevant regulations. The Contractor shall keep the borrow pits free from ponding water and the excavation neat and tidy and shall carry out necessary erosion and environmental protection measures following the agreed method statement or as instructed by the S.O.

24.4 The contractor shall submit method statement on cutting or filling and turfing at the borrow pit or dump site for approval of the S.O.. After cutting or dumping, all the slopes shall be formed to a stable gradient and close turfed or protected by other approved surface protection method. Provision of drainage, siltation pond and preventive measures of pollution shall also be included in the method statement.
Turfing shall be carried out *within seven (7) days* after formation of the final slope profile as shown in the Drawings and/or where directed by the Engineer. Otherwise, the Engineer reserves the right to engage external party to carry out the work and deduct the additional cost incurred accordingly from the contract. The type of turf shall be as indicated in the Drawings or other alternative type as approved by the Engineer and shall be free of lallang and essentially free of weeds.

**Penalty**

The Contractor who fails to implement the Works as per above Sub-sections 2.2.8.1, 2.2.8.2 and 2.2.8.3 shall bear the time and cost of turfing/hydroseeding works carried out by others under the direction of the S.O.
Requirements on Temporary Works included in BOQ
### BOQ

**BILL NO. 1 - TEMPORARY WORKS (CONT’D)**

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Description</th>
<th>Unit</th>
<th>Quantity</th>
<th>Rate</th>
<th>Amount RM</th>
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</thead>
<tbody>
<tr>
<td>2.0</td>
<td><strong>Borrow Pit</strong></td>
<td></td>
<td></td>
<td></td>
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</table>

The contractor shall submit method statement on cutting or filling and turfing at the borrow pit (within or beyond project site) or dump site for approval of the S.O. After cutting or dumping, all the slopes shall be formed to a stable gradient and close turfed or protected by other approved surface protection method. Provision of drainage, siltation pond and preventive measures of pollution shall also be included in the method statement. Failure to implement the Works as per specification shall bear the time and costs of turfing/hydraseeding works carried out by others under the direction of the S.O.

**Requirements on Borrow Pit included in BOQ**
### 3.0 Protective Vegetation For Erosion Control

Turfing shall be carried out within seven (7) days after formation of the final slope profile as shown in the Drawings and/or where directed by the Engineer. Otherwise, the Engineer reserves the right to engage an external party to carry out the work and deduct the additional cost incurred accordingly from the contract. The type of turf shall be as indicated in the Drawings or other alternative type as approved by the Engineer and shall be free of laliang and essentially free of weeds.

If due to unforeseen circumstances turfing or hydroseeding cannot be carried out within the duration as specified hereafter, temporary protection/cover (e.g., plastic sheets or equivalent) shall be laid on exposed slopes by the Contractor.

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**Requirements on Turfing included in BOQ**
CUT SLOPES
CUT SLOPES & EARTH EXCAVATION

- Existing Ground Profile
- Earth to be cut and removed
- Area not to be disturbed
- Cast in-situ cut-off drain
CUT SLOPES & EARTH EXCAVATION

Important to **turf & construct berm drain** every berm
CUT SLOPES & EARTH EXCAVATION

EXISTING GROUND PROFILE

EARTH TO BE CUT AND REMOVED

CAST IN-SITU BERM DRAIN

CAST IN-SITU CUT-OFF DRAIN

CLOSE TURFING

CUT SLOPE PROFILE
CUT SLOPES & EARTH EXCAVATION
FILL SLOPES
FILLING OF PLATFORM & SLOPES

AREA NOT TO BE DISTURBED

EXISTING GROUND PROFILE

AREA NOT TO BE DISTURBED
FILLING OF PLATFORM & SLOPES

- Temporary Earth Bund
- Top Soil/Unsuitable Material to be Removed
- Temporary Earth Drain
- Existing Ground Profile
FILLING OF PLATFORM & SLOPES

- **Temporary Earth Bund**
- **Temporary Earth Drain**
- **Slope Benching**
- **Existing Ground Profile**

300mm THK. x 500mm WIDTH FREE DRAINING MATERIAL (CRUSHER RUN) WRAPPED WITH GEOTEXTILE KET1.1 OR EQUIVALENT AT 4.5m c/c

SEE DETAIL 'A'

5%
FILLING OF PLATFORM & SLOPES

- **Temporary Earth Bund**
- **Slope Benching**
- **Temporary Earth Drain**
- **Existing Ground Profile**

300mm THK. x 500mm WIDTH FREE DRAINING MATERIAL (CRUSHER RUN) WRAPPED WITH GEOTEXTILE KET11 OR EQUIVALENT AT 4.5m c/c
FILLING OF PLATFORM & SLOPES
FILLING OF PLATFORM & SLOPES

- Trim back to final fill slope profile
- Close turfing
- Toe drain
- Temporary earth drain
- Existing ground profile
- Slope benching

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FILLING OF PLATFORM & SLOPES
FILLING OF PLATFORM & SLOPES

- Trim back to final fill slope profile
- Berm drain
- Close turfing
- Toe drain
- 0.5m
- 5%
- 1.5m
- 2m
Surface Protection of Slopes

- Closed turfing within 7 days
- Encouraged Horizontal groves
SLOPE MAINTENANCE MANUAL
Maintenance

Our experience:

Formation of rills and gullies which caused erosion and localized landslips
Maintenance

• Referred to the guidelines from Hong Kong GEO
  – Routine Maintenance Inspections by laymen
  – Engineer’s Inspections

• Maintenance scheme has more emphasis recently
Poorly Maintained Drains
Poorly Maintained Drains

A: U-channel along Crest of Slope

B: U-channel along Berm of Slope
Well Maintained Drains

A: U-channel and Catchpit
B: U-channel along Toe of Slope
Poorly Maintained Drains

C: Catchpit at Toe of Slope

D: Catchpit at Crest of Slope
Well Maintained Drains

C: U-channel and Catchpit

D: Stepped-channel

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Well Maintained Drains

Close Turfing

Proper Drainage System
Poorly Maintained Slopes
Well Maintained Slopes
THANK YOU FOR YOUR ATTENTION