Geotechnical Assessment Report

September 25

1. Parking Structure:

1.1. Scouring of the foundations:

The foundations of the retaining walls of the parking structure are located adjacent to a river channel and have been exposed due to active scour along the bank. Although the structure is likely founded on rock, persistent erosion has created visible voids that pose a risk of undermining (Figure 1), particularly during high-flow conditions. Immediate stabilization is necessary to safeguard the structure, while long-term protection measures should be developed based on detailed hydraulic and geotechnical investigations.



Figure 1: Scouring Under the Foundations of RW at the Parking Structure

The BOT operator shall undertake immediate stabilization works, to stabilize the exposed foundations and safeguard the riverbank as outlined below.

1. Identify and fill all voids or undercut zones around the exposed foundation using underwater-grade concrete (e.g., tremie concrete) or cementitious grout or controlled low-strength material (CLSM), as applicable
2. The material shall be placed carefully to restore support beneath the foundation without disturbing the existing rock or soil base.
3. Ensure no material placement significantly intrudes into the river's hydraulic section.

4. Perform the works during the dry season or use temporary measures as needed to control water flow or turbidity during filling (e.g., silt curtains, localized diversion).
5. Construct a thin concrete beam to protect the existing foundation from future erosion. The beam shall be constructed along the base of the exposed wall extending a minimum of 1.0 meter below bottom of foundation.
6. Carry out regular visual inspections and reconnaissance surveys of the retaining walls, the surrounding areas, and all other structures at risk of scour with increased frequency during high-flow seasons (e.g., winter and early spring), focusing on new or widening cracks in the walls, signs of movement (tilting or settlement), soil loss or erosion behind the wall, or reappearance or progression of voids or scour features. A baseline photographic and measurement record shall be established, followed by periodic updates after each major rainfall or flood event.

Due to the site's immediate proximity to the river, any remedial or protective measures must be carefully implemented and designed to avoid reducing the hydraulic cross-section. It is necessary to highlight that the provided measures are immediate fixes and shall be accompanied with long term solutions to provide engineered, durable, and sustainable solutions that account for changing flow patterns. These solutions shall be provided following detailed hydraulic modelling, geotechnical, structural and environmental assessments.

1.2. Basement Wall

During site inspection, it was observed that the retaining wall within the basement terminates before fully enclosing the area, leaving a vertical rock face directly exposed (Figure 2). The exposed rock surface appears fractured and unsupported. No reinforcement, bolting, or surface treatment (e.g., shotcrete or mesh) is currently in place.

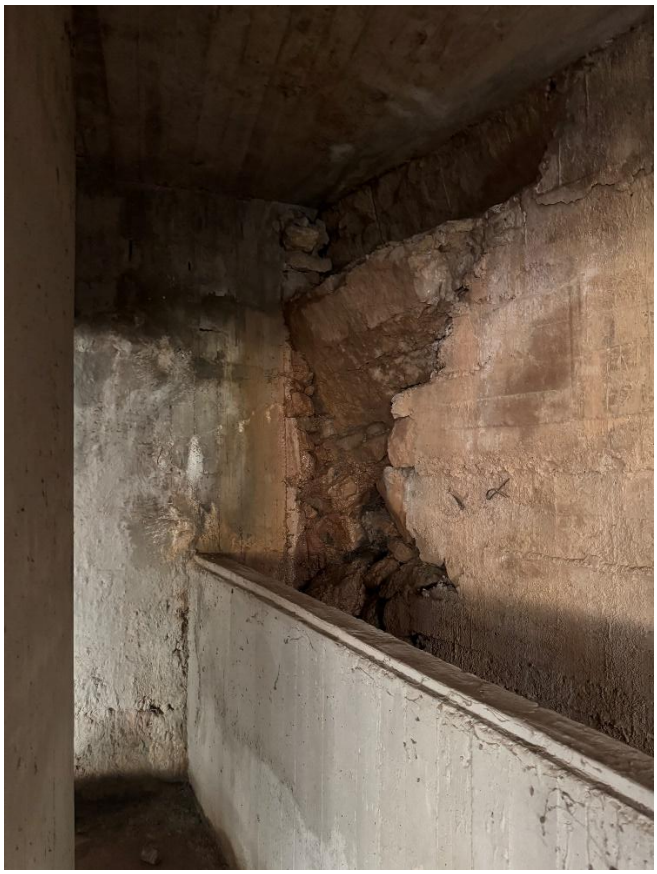


Figure 2: Conditions of Existing Basement Wall at Parking Structure

The BOT operator shall undertake the following tasks as part of immediate mitigation and detailed assessment of the exposed basement rock face:

1. Clear loose, detached rock debris
2. Apply shotcrete over the exposed rock face combined with anchored high-tensile mesh or wire netting to stabilize loose fragments, seal cracks, and provide surface confinement. The mesh shall be securely fixed using bolts or plates, and all work shall follow specified standards for durability and structural performance.

1.4. Loose Fragmented Rockface

2nd parking underground on the end left corner: 33°56.6107'N,35°38.3699'E.

Loose fragments have been observed originating from a weathered/ fractured limestone bedding plane (Figure 3), with newly fallen blocks indicating fresh surface exposure on the outcrop. While the overall outcrop is stable, these small-scale detachments pose a risk of rockfall and require localized treatment. It is recommended manually removing or scaling

unstable fragments posing an immediate fall risk and stabilizing the surface with anchored wire mesh or netting over the affected zone to contain future detachment.



Figure 3. Field condition of locality 5.

2. Open Areas:

2.1 Locality 1: Wedge Stability/ Loose blocks

Directly above the entrance where security stands: 33°56.6296'N,35°38.4003'E

The rock formation in this location (Figure 4) consists of hard limestone, which exhibits significant fracturing. These fractures increase the risk of rock falls, particularly during periods of rainfall. Given these geological conditions, the severity of this site is assessed as

high. It is required to reinforce the rock face through installing a double steel mesh with possible rock bolts.



Figure 4. Field condition of locality 1.

1.2. Locality 2: Poorly Constructed Gravity wall

Above the snack of Jeita Grotto: 33°56.6293'N,35°38.4431'E.

The limestone outcrop surrounding this area (Figure 5) is structurally stable. A gravity retaining wall constructed from dry-stacked cobbles and boulders without mortar has been identified above the rock outcrop. This construction method offers minimal resistance to lateral earth pressure, especially under wet conditions or surcharge loads, posing a high risk of localized collapse, or rock falls. It is required to dismantle the existing sections of the gravity wall and reconstruct them with mortared stone masonry with proper drainage to allow flow of water.



Figure 5. Field condition of locality 2.

1.3. Locality 3: Wedge Stability/ Loose blocks

To the right side of the snack: 33°56.6256'N,35°38.4660'E.

The limestone outcrop in this area exhibits significant fracturing, with large blocks present. As illustrated in Figure 6, rock and block falls have been observed causing local damage. The BOT operator shall undertake the following tasks:

- Inspect and document the rockfall location, including size and source of dislodged blocks.
- Remove fallen debris from the toe area to clear access and eliminate hazards.
- Manually scale loose or unstable fragments from the outcrop face within the immediate vicinity of the fall.
- Install localized wire meshes with anchors over the affected area to contain future minor rockfalls.
- Reinstate the parapet wall and damaged utilities
- Provide basic surface drainage if water ingress is observed contributing to weathering or detachment.



Figure 6. Field condition of locality 3.

1.4. Locality 4: Wedge Stability/ Loose blocks/ Rockfalls

Above train parking: 33°56.6212'N,35°38.4660'E.

Although previous mesh reinforcement has been installed in the area (Figure 7), it does not fully cover the identified risk zone. As a result, the region remains exposed to a medium to high risk of rock falls. The mesh should be continued to cover the inner rock faces.



Figure 7. Field condition of locality 4.

1.5. Locality 5: The Garden

The garden wall (Figure 8) is currently composed of loosely placed boulders and cobbles, forming a dry-stacked structure along the riverbank. This type of wall construction presents a safety concern, especially during heavy rain or flash floods. The flowing water can gradually erode the base of the wall, causing the rocks to shift or collapse over time. Without proper reinforcement or a concrete foundation at the bottom, the wall is much more vulnerable to being washed out or destabilized by the river.

The below shall be performed:

1. Excavation and Foundation Preparation: Carefully remove vegetation and dismantle the existing wall. Excavate a shallow trench for foundation installation along the exposed length of the river-facing side.

2. Construction of Concrete Toe Wall: Construct a reinforced concrete base or toe wall along the lower portion of the slope to provide scour resistance and foundation stability. Ensure the concrete wall extends below the expected scour depth and is properly keyed into the ground.

3. Mortar Pointing and Rebuilding of Upper Wall: Rebuild the upper portion of the wall using the existing boulders, but with cement mortar bonding between stones to lock them in place and prevent displacement. Apply proper compaction and interlocking of stones during rebuilding to improve long-term stability.

4. Erosion and Drainage Protection: Install weeps or surface drains as needed to relieve hydrostatic pressure behind the wall. Apply vegetation trimming and slope cleaning to maintain visibility and access for future inspections.
5. Visual Monitoring and Maintenance: Conduct regular inspections, particularly after storms or high-flow events, to ensure integrity of the structure and detect any early signs of movement or erosion.



Figure 8. Field condition of locality 5.

1.6. Rock-Fall Hazards

The grotto is situated at the base of a steep natural slope, where previous rockfall incidents have been reported. The area is exposed to weathered rock masses and overhangs, with seasonal rainfall accelerating erosion of softer materials, increasing the likelihood of detachment. In addition, ongoing construction activities near the top of the slope may further aggravate rockfall risk due to vibrations and disturbance of already fragile zones.

A comprehensive rockfall hazard assessment is required to evaluate the site and develop long-term protection measures. This detailed study should be performed by a qualified specialist and lies outside the scope of the BOT operator.

The BOT operator should, however, carry out precautionary tasks to maintain safety prior to implementing permanent measures. These include:

1. Basic Visual Walkthrough: Walk the accessible areas near and above the grotto to check for obvious loose rocks, fallen debris, or visible signs of instability.
2. Flag and Mark Hazardous Areas using basic materials such as warning tape or cones to mark areas beneath any suspect overhangs or debris zones. Do not intervene or attempt to stabilize any part of the slope.
3. Photo Documentation and Notification.
4. Periodic Re-checking: Repeat this task occasionally or after strong rainfall and report any visible changes.



Figure 9. Field condition of locality 6.

3. Lower Grotto Observations

3.1. Locality 7

Entrance of the grotto (above the door)

The marly limestone formation in this area exhibits significant weathering and fracturing, with visible oxidation present. Additionally, several rocks are unstable, posing a potential hazard that may require further assessment/ mitigation. It is recommended to install localized protection, such as anchored wire mesh over the affected zone.

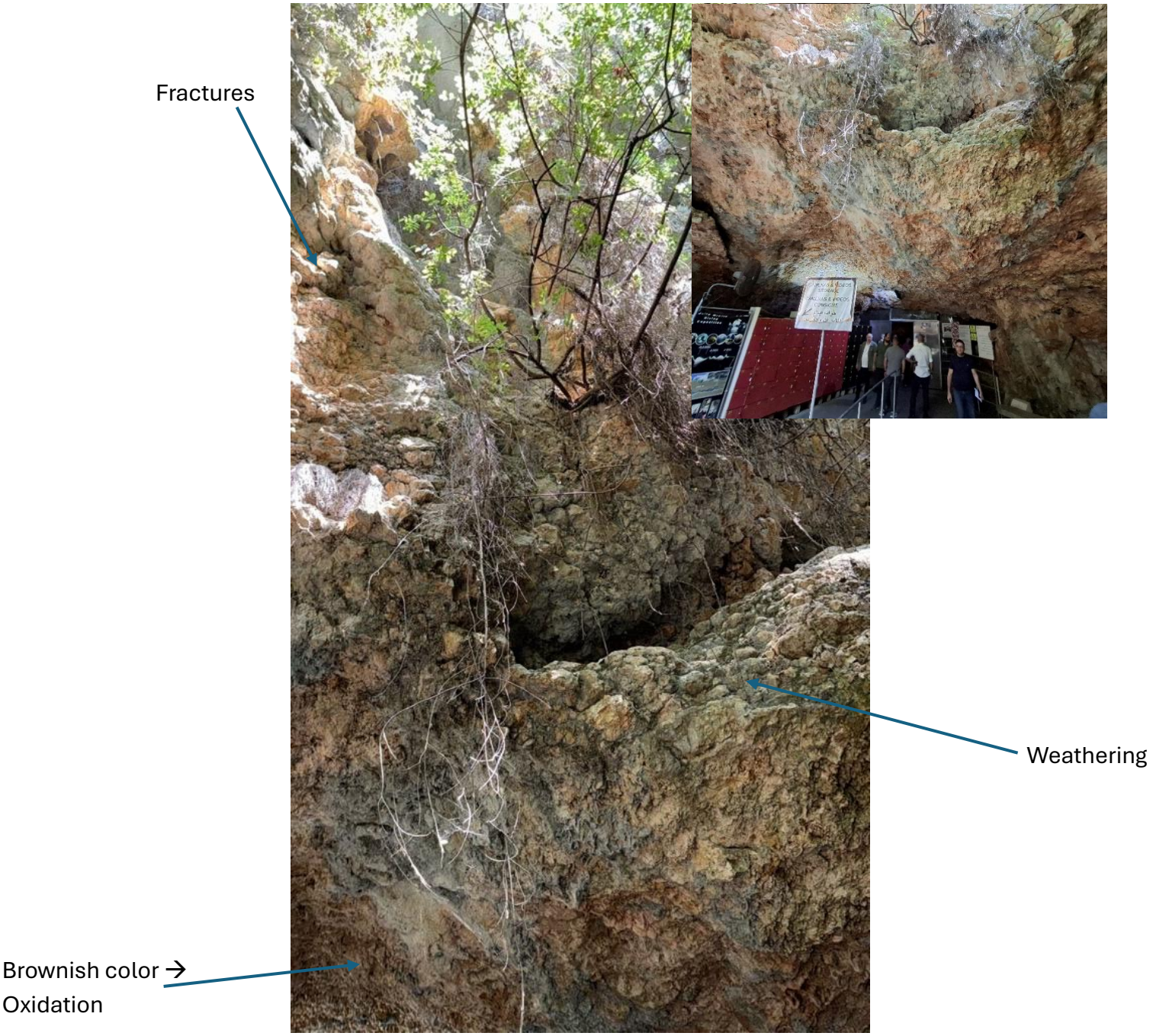


Figure 10. Field condition of locality 7.

3.2. Locality 8

Inside the grotto, before reaching the boats.

The stalactites and stalagmites (Figure 11) in this area exhibit horizontal fractures and noticeable tilting. These structural weaknesses may hinder their continued growth and increase the likelihood of instability, potentially leading to their detachment. preliminary

observations suggest the need for specialized geotechnical and geological assessment to determine the underlying causes and appropriate stabilization measures.

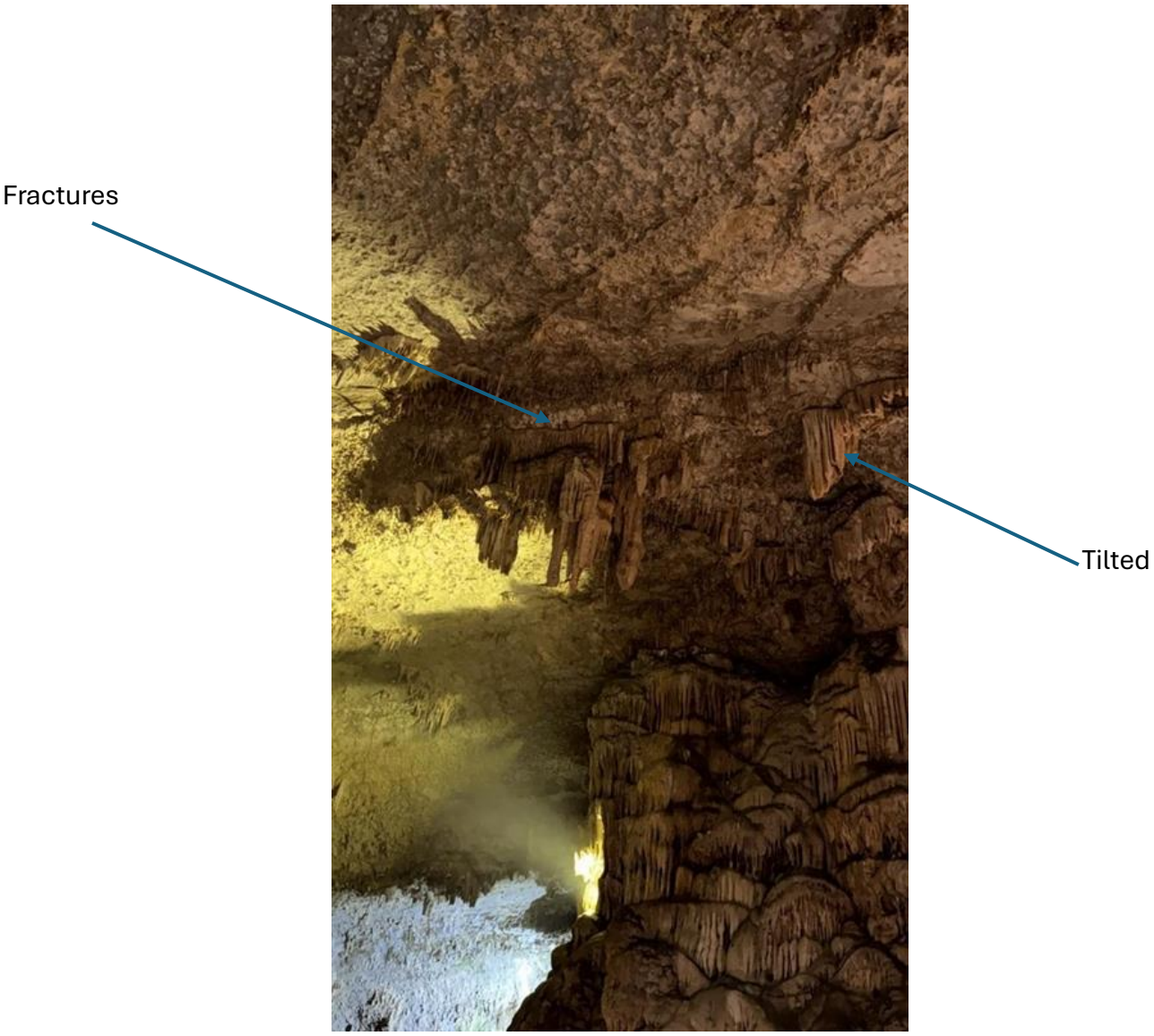


Figure 11. Field condition of locality 8.

<u>The scope of work of the BOT shall include:</u>

1. Preliminary Visual Inspection and Documentation:
    - Conduct a visual inspection of all visibly tilted stalactites within accessible zones.

- Document each case with photographs and approximate location mapping.
- Report findings to the project authority for further evaluation.

2. Immediate Safety Measures
    - Temporarily isolate zones located directly beneath or adjacent to significantly tilted formations.
    - Install visible signage to warn visitors and staff of potential overhead hazards.
    - Restrict visitor access to affected areas as a precautionary measure.
3. Specialist Study Requirement
    - A detailed geological and structural assessment shall be carried out by a specialized team (not under BOT scope), including:
        - Geological mapping of ceiling rock conditions.
        - Structural stability evaluation of each tilted stalactite.
        - Monitoring and instrumentation (if required).
        - Design of stabilization or removal measures based on risk classification.
    - The BOT contractor shall fully cooperate with the appointed specialists and provide access and support as needed.
4. Reporting
    - Submit a preliminary incident report summarizing observed cases, actions taken, and areas isolated.
    - Include recommendations for any urgent safety concerns requiring immediate intervention by specialists.

The above shall cover both grottos with emphasis on accessible areas to visitors and personnel.

3.3. Locality 9

Near the end of the steep stairs.

The rock formation appears to be stable (Figure 12); however, it exhibits significant weathering and fracturing. Due to these conditions, periodic inspections are recommended to assess any potential changes or risks that may arise over time.



Figure 12. Field condition of locality 9.

4. Upper Grotto

4.1. Locality 11

Above the entrance of the tunnel.

The rock formation exhibits significant fracturing. A rock failure has developed with visible signs of instability and damaged steel mesh. This hazard is particularly evident in the third image, highlighting the need for careful assessment and potential mitigation measures. Immediate stabilization is required to prevent collapse and restore slope safety.



Figure 13. Field condition of locality 11.

It is required to:

1. Establish safe access (e.g., manlift, scaffolding, or rope access) to inspect the wedge geometry and net conditions.
2. Carefully remove loose debris and weathered material around the wedge to reduce additional loading.

3. Remove failed or damaged mesh to prepare for reinstallation.
4. Drill and install rock bolts across the wedge body and into stable surrounding rock to prevent detachment.
5. Install new high-tensile steel mesh, fixed with anchor plates and edge ropes, ensuring it is properly tensioned and covers the entire affected area.
6. Secure the area below the work zone during operations.
7. Maintain temporary protective barriers or debris catchment netting until full stabilization is confirmed.

4.2. Locality 12

Near the study panel on the right side.

The rock formation exhibits significant weathering and fracturing. All loose or detached material shall be carefully removed to prevent uncontrolled detachment and ensure a stable surface for any subsequent stabilization measures.



Figure 14. Field condition of locality 12.

Estimated Area for stabilization:25 m^2

4.3. Locality 13

Near the end of the path, before reaching the stairs by 20m.

The rock formation is heavily weathered (Figure 15) and exhibits extensive fracturing throughout the entire bedding. While no immediate major risks have been identified, regular inspections are necessary to proactively mitigate potential hazards and ensure long-term stability.



Figure 15. Field condition of locality 13.

4.4. Locality 14

At the end of the grotto, visitors are not allowed to pass.

The geological formation transitions from limestone to sandy limestone, indicating the presence of softer material. Below the bridge, sliding has been observed, accompanied by extensive fracturing in the more complex rock. The image to the left depicts the area above the bridge, while the picture on the right corresponds to the section below the bridge. It is important to monitor these fractures and fissures over time to assess whether movement is occurring. Monitoring can be done through applying epoxy (or plaster) or tell-tales across selected cracks. Regular visual inspections (e.g., monthly or post-rainfall/winter) shall be

performed and any signs of crack widening, new fractures, or rock spalling shall be documented, to assess the need for further investigations or stabilization methods.

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Figure 16. Field condition of locality 14.

5. Upper and Lower Grotto: General Requirement

The safety and stability of the grotto must be thoroughly assessed, particularly considering that construction works are ongoing directly above. It is essential to evaluate whether these activities are causing changes in environmental conditions or stress distribution, such as increased vibrations, surface loading, or shifts in moisture and humidity that may compromise the grotto's internal stability.

This assessment lies outside the scope of the BOT operator and should be carried out by a specialized team with expertise in geology, geotechnical engineering, and speleology. The

specialist study shall also include the stability assessment of internal cave formations, including tilted stalactites and other ceiling features that may pose a falling hazard to visitors and staff. Detailed monitoring, structural evaluation, and design of stabilization or mitigation measures shall be performed exclusively by the appointed specialists.

The BOT operator is responsible for routine safety surveillance and shall:

1. Conduct regular safety walkthroughs and visual inspections of the grotto.
2. Monitor key visible cracks (as indicated above) using simple methods such as plaster or epoxy tell-tales.
3. Visually inspect and document any significantly tilted stalactites or signs of ceiling distress.
4. Photograph and record all observed changes, deteriorations, or potential hazards.
5. Immediately report any signs of instability or unsafe conditions—whether related to rock mass, formations, or environmental shifts—to the supervising team for further action.