Structural Assessment of Existing Facility

Operator Scope of Work

December 2025

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PART 1 - INTRODUCTION:

DAR was requested to conduct an observation-based inspection and structural condition assessment of the existing buildings and structures within the Jeita Grotto Facility. The objective of this assessment is to evaluate the current structural condition of the facility and to determine an appropriate rehabilitation and reinstatement strategy that would allow for its safe reuse.

In general, regardless of the level of visible damage, the structural detailing of the connections between various structural and façade elements, the cantilevered columns supporting the cable car, and the design and reinforcement of the basement walls must be adequate to resist seismic actions in accordance with the latest Lebanese seismic codes, especially given that the Jeita area is susceptible to severe earthquakes.

However, considering the limited available budget and the extensive scope of work required to upgrade the structural systems of the various blocks to meet current seismic standards, this aspect of retrofitting will not be addressed in the current report. Nonetheless, it is strongly recommended that seismic strengthening measures be studied and implemented at the earliest opportunity.

PART 2 - VISUAL INSPECTION

A visual inspection was conducted on 13 June 2025 and was limited to the exploration of the site perimeter, as well as the examination of exposed and accessible structural elements across all blocks, including both the lower and upper grotto areas.

The detailed findings of the Visual Inspection are provided in a separate report.

PART 3 - TESTING SCOPE OF WORK AND METHODOLOGY

3.1 Testing Campaign:

Following the visual inspection findings detailed above, the new investor should engage a testing agency to conduct the require testing campaign.

The new facility investor shall engage a reputable, independent testing agency that is approved by the Engineer and the Authorities having jurisdiction, to perform a comprehensive inspection of the structural elements. This agency shall provide mapped documentation of observed defects and a detailed report outlining the current condition of construction materials and the extent of deterioration in the structural elements.

The purpose of the testing campaign is to assess the current condition of the existing structures.

Detailed as-built structural drawings are not available for all structures; therefore, an in-situ geometrical and topographical survey was already conducted, and its findings will be made available to the appointed testing agency.

To finalize the assessment, an in-situ detailed survey of the strength of structural members is required to understand the behavior of the existing structures and consequently check their ability to support safely the intended service loads.

The detailed survey will consist generally of:

1. Defining the existing conditions of the structures including reviewing available information and assessing/considering the conducted geometric and visual surveys.
2. Conducting in-situ and laboratory tests for accurate evaluation.
3. Preparing and submitting a comprehensive report that includes description of procedures and findings.
4. Identifying any structural defect by performing detailed inspection and testing of the structural elements.
5. Checking the integrity and strength of the structural elements by conducting mechanical and chemical tests on them.
6. Recommendations for future courses of action.

3.2 Extent of Testing Scope:

For the existing concrete structures, the appointed laboratory or testing agency shall carry out the necessary field and laboratory tests as required. The scope of work shall include, but not be limited to, the following:

A. Defects Mapping: Assess the condition of the concrete elements, identifying all signs of distress, including but not limited to the existence of cracks (type, pattern, width), delamination, deflection, rebars corrosion, concrete spalling, concrete carbonation and the like. Furthermore, steel reinforcement and anchors shall be inspected to determine rate of corrosion and other defects. All findings shall be mapped on the topographical survey drawings that will be handed to the testing agency, and documented in details along with photos and sketches in the initial and final report to be submitted to the Client.

   The same should be done for steel structures, mainly the steel columns supporting the cable cars and the steel boat-docking platforms, where the testing agency should inspect steel members in accordance with ASCE Manual 130 for corrosion (to ISO 9223), rust staining, pitting, deformations (bending, buckling, wrapping), cracking or joint separation, coating failures (to ISO 12944), grating, decking supports, bracing elements, accumulated silt, debris, and vegetation, sections loss due to rust or abrasion, and condition of welds and connections.

   For the steel columns supporting the cable car, a thorough inspection of the isolated footings and their surroundings should be carried out. The scope shall include a detailed visual survey of the steel columns, base plates and reinforced-concrete footings, checking for cracks, spalling, rust staining, misalignment, loose connections and any visible signs of vibration-related distress. The areas around the footings should be examined for soil scouring or loss of embedment, and, if needed, local geotechnical checks (trial pits and/or in-situ tests) may be carried out in line with EN 1997-2 or similar accepted practice. The anchor bolts and nuts should be inspected visually and by simple mechanical checks (hammer sounding and torque verification), and, where justified, non-destructive testing such as magnetic-particle or ultrasonic testing should be used in accordance with ASTM E709 and ASTM E114 / E213 to detect possible defects. The condition of the concrete foundations should be assessed similarly to other reinforced concrete elements, using the destructive and nondestructive tests listed below. All findings, including measurements and photos, shall be reported part of the defects mapping report, then used to judge the current safety and serviceability of the footings/columns and to identify any need for remedial or strengthening measures.

B. Destructive Tests:

   1. Concrete Coring: The concrete coring is the process of drilling or cutting through concrete, shells, walls, slabs, columns, and ceilings for assessment of the compressive strength and chemical composition of concrete, and the extent of deterioration due to

weathering during the last decades. The number, size and location of core samples will be selected to permit all necessary laboratory tests.

2. Core samples should be extracted from the walls, columns, suspended slabs, and beams to evaluate the structural integrity and safety of the existing reinforced concrete, and to define the extent of the required rehabilitation measures. A minimum of four (4) sets of cores should be taken from each block, and one (1) set for the foundation of each steel column supporting the cable car, with each set consisting of three (3) cores, as follows:

    a. One set from external columns and walls
    b. One set from deteriorated slabs and beams
    c. One set from main internal columns and walls
    d. One set from basement walls, foundations, and ground beams (where accessible)

    Additional core samples may be taken based on the recommendations of the testing agency, depending on site conditions and findings during the investigation.
    Three cores (one set) shall be taken from each isolated foundation for the steel columns supporting the cable car.

3. Reinforcement Samples: Reinforcement bars will be extracted from selected locations in the structures for testing, especially from the Parking Block. Requirements for specimen length, preparation, testing, and determination of the yield strength shall be as provided in ASTM A370. Samples and site measurements will also be used to determine the level of corrosion and section loss of the bars. The results of tensile strength, elongation, and section measurements will be documented in details with photos in the final report.

C. Non Destructive Tests:

1. Cover meter survey: In place test to locate the rebars buried in concrete as well as the corresponding cover and size/spacing of reinforcement in accordance with BS 1881 Part 204. This test is required for base slab, columns, walls, beams and slabs as follows:

    a. Suspended Slabs: Top and bottom reinforcement in both directions (including beams' longitudinal and transverse reinforcement, if any).
    b. Vertical elements: Vertical and horizontal reinforcement of columns and walls.

    In case cover meter fails to provide the above-mentioned requirements, sub-consultant should suggest alternative test methods to the engineer's approval.

2. Half-cell potential and linear polarization resistance: Half-cell potential measurement in accordance with ASTM C876 should be carried out to establish the probability of corrosion of rebar. Results of the potential map will provide base line comparison data and assist in determining most anodic areas for embedded reference electrode placement. Corrosion rates are to be valuated using linear polarization resistance (LPR) according to ASTM G59.
3. Schmidt hammer (ASTM C805) and/or ultrasonic pulse velocity test (ASTM C597): non-destructive tests used to check the compressive strength of concrete. The testing agency should plot a graph between compressive strength of concrete cores and results from Schmidt hammer or direct UPV tests (at least 9 samples per block) to minimize the number of cores to be extracted from the structure.
4. Select critical steel structural members, especially the columns supporting the cable car, for ultrasonic thickness testing to detect section loss (to ASTM E797 or ISO 16809), magnetic particle (to ASTM E709 or ISO 9934-1) or dye penetrant testing (to ASTM E165 or ISO 3452-1) for surface cracks, ultrasonic testing (UT) or radiography

(to ASTM E1030 or ISO 17636) for internal flaws detection, and coating thickness gauge for remaining protection layer (to ISO 2808 or ASTM D7091).

D. Laboratory Tests:

1. The following tests should be conducted on the extracted cores, with rates as recommended by the testing agency:

   a. Compressive Strength as per ASTM C39 or BS EN 12390 on all cores
   b. Depth of Carbonation as per BS EN 14630 or ACI 222.R
   c. Chloride Content Test as per BS 1881-124
   d. Sulfate Content Test as per BS 1881-124

2. Tensile strength and elongation of reinforcement steel, according to ASTM A370.

All tests shall be performed in accordance with international codes and standards.

Once above testing campaign is completed, the testing agency will prepare and submit for the approval of the Engineer, a detailed report collecting findings, results and interpretation presenting the existing facility structural condition and stability assessment together with the recommendations and way forward.

3.3 Deliverables:

A. Testing Agency Initial Report: This report shall mainly include the following:

1. Data collection including the structural systems of the existing structures.
2. Defects mapping, as described above.
3. Identification of the tests to performed and proposing their related location in the existing structures.
4. Works schedule for the tests and inspection works, including the time required for the inspection and testing.

B. Testing Agency Final Report: This report shall mainly include the following:

1. Presentation of Inspection and testing results.
2. Analysis/assessment on the surveys and testing findings.

PART 4 - REHABILITATION SCOPE OF WORK AND METHODOLOGY

Based on the findings of the Testing Campaign and the recommendations outlined in the Testing Agency's Final Report, the Operator shall proceed with the execution of all necessary reinstatement and retrofitting works required to restore the structural integrity, safety, and long-term durability of the affected structural systems across the various blocks.

The Operator shall engage a specialized and certified Contractor, with a proven track record in structural rehabilitation and retrofitting works, to carry out these activities. The Contractor shall:

Submit to the Engineer a detailed methodology statement for the rehabilitation works, including:

1. Step-by-step procedures
2. Health, safety, and environmental (HSE) provisions
3. Access and protection measures
4. Monitoring and quality control procedures

Propose suitable materials, products, and technologies for the Engineer's review and approval, including product datasheets, material certifications, and method of application.

Ensure that all works are carried out in full compliance with relevant international standards and codes, such as ACI 562, EN 1504, or other applicable national or local standards.

The rehabilitation strategy shall be performance-based, addressing not only the restoration of structural capacity but also long-term durability, corrosion protection, and serviceability under future loading and environmental conditions.

4.1 Spalling, Voids, and Delamination:

In areas where concrete spalling, delamination, or surface deterioration is observed due to carbonation, water ingress, or corrosion of embedded reinforcement and steel elements, the following repair procedures shall be executed:

A. Delaminated and unsound concrete shall be removed to sound substrate, with edges saw-cut to a minimum depth to avoid feathering (per EN 1504-10, ACI 562).

B. Exposed reinforcement shall be cleaned to bare metal using mechanical tools (grinding, sandblasting) to achieve a SA 2½ finish (as defined in ISO 8501-1).

C. Bars with a reduction in diameter beyond acceptable limits (typically >20–25%) shall be replaced or supplemented with new reinforcement bars anchored into the surrounding concrete using approved rebar anchoring systems (per ACI 355.4, EN 1504-6).

D. The cleaned and treated reinforcement shall be coated with a corrosion-inhibiting primer.

E. Electrochemical treatment methods (e.g., re-alkalization) may be proposed in cases of widespread corrosion, subject to Engineer's approval.

F. Rebuilding of the concrete section shall be performed using structural-grade R4 repair mortars or flowable micro-concrete conforming to EN 1504-3 and BS EN 12190.

G. Curing shall follow manufacturer specifications and site conditions.

4.2 Cracks in Reinforced Concrete Elements:

Cracks in concrete elements, whether due to structural loads, shrinkage, or environmental exposure, shall be addressed as follows:

A. Structural cracks shall be injected using low-viscosity epoxy resins, ensuring complete penetration and bonding across the crack width, following EN 1504-5 and ACI 503R.

B. Non-structural cracks or those associated with water ingress shall be sealed using flexible polyurethane (PU) resins or elastomeric sealants, depending on site conditions and crack movement.

C. Crack monitoring may be required prior to injection to assess whether the crack is active or dormant.

D. All products used must meet ISO 11600 for movement capability and EN 14188-2 for sealing performance.

4.3 Structural Strengthening – RC Jacketing and CFRP Wrapping:

Where structural elements are deemed inadequate due to loading demands or degradation, the following strengthening options shall be implemented:

A. For RC Jacketing:

1. Columns, beams, or walls shall be enlarged using additional layers of reinforced concrete with dowels and connectors to ensure monolithic action.
2. Substrate shall be roughened or scabbled and treated with bonding agents per ACI 364.1R, EN 1504-4, and FIB Model Code 2010.
3. New reinforcement shall be detailed to match the design requirements and tied securely to existing steel.
4. Steel rebar dowels shall be anchored into the substrate concrete using approved rebar anchoring systems (per ACI 355.4, EN 1504-6).
5. Pouring of jacket concrete shall be done using non-shrink, high-strength repair concrete or micro-concrete with minimum shrinkage.

B. For CFRP Wrapping:

1. CFRP or other FRP systems shall be applied for confinement, flexural, or shear strengthening as needed.
2. Surface preparation includes smoothing, cleaning, and priming using compatible epoxy systems.
3. Application of CFRP sheets or laminates shall follow ACI 440.2R, EN 1504-4, and FIB Bulletin 14, ensuring fiber orientation and anchorage detailing match design intent.
4. Pull-off bond strength tests (in accordance with EN 1542) shall be conducted to verify adhesion.

4.4 Structural Monitoring of RC Elements Cast into Rock Formation to Support Pedestrian Passages at the Upper Grotto:

The reinforced-concrete elements cast directly into the rock manmade cavities should be monitored regularly to detect any movement, cracking, slippage, or signs of distress. The monitoring program should include a periodical visual inspection of all exposed concrete surfaces and contact interfaces with the rock, looking for new cracks, widening of existing cracks, changes in alignment, spalling, or any signs of detachment.

Reference marks should be installed on both the concrete and the adjacent rock faces so that any relative displacement or rotation can be measured over time. In areas where access allows, crack gauges or simple tell-tales may be placed to track the development of critical cracks. All observations should be photographed, recorded, and compared to previous inspection cycles to identify trends. Any sudden movement or progressive deterioration should be reported immediately, as these elements play a direct role in supporting the pedestrian passages inside the grotto.

4.5 Soil Scour Under Footings:

To rectify the scour issue affecting the foundation of the circular retaining wall at the west side of the parking structure, the remediation must address both the loss of soil support and the exposure of the foundation to river flow. The goal is to stabilize the existing foundation, prevent further erosion, and protect against future scouring.

A. Site Preparation and Access Control

1. Divert the local river flow using temporary cofferdams, sheet piles, or sandbag walls to create a dry or low-flow work zone around the exposed foundation (as per ACI 350.4R guidelines on working near hydraulic structures).
2. Establish safe access platforms and install temporary support or shoring if necessary.
3. Carry out a visual and topographical survey to assess the full extent of scour and exposed areas.

B. Geotechnical and Structural Assessment: Perform a detailed inspection of the exposed foundation base and adjacent soil.

C. Concrete Injection and Pressure Grouting

1. Drill grout holes at selected locations beneath and adjacent to the exposed footing area.
2. Inject non-shrink, cementitious grout or microfine cement slurry under controlled pressure to fill voids left by scouring and Reinstate soil contact with the base of the foundation.
3. Grouting materials shall comply with EN 1504-5 (Injection products and systems) or ASTM C1107 (High-performance, non-shrink grout).
4. Confirm effectiveness by grout take monitoring and use ground-penetrating radar (or sounding) to verify void closure.

D. Construction of Reinforced Concrete Ground Beam

1. Excavate in front of the existing foundation to prepare for a protective ground beam or toe beam along the base of the wall or column. The depth of the beam shall not be less than 1m below the bottom of the foundation level.
2. Design the beam to act as a protective apron resisting hydraulic erosion and as additional lateral restraint to the base of the wall (refer to EN 1992-1-1 for design).
3. Connect the new beam to the existing wall or column footing using epoxy-bonded dowels (anchorage system compliant with ACI 355.4).
4. Cast the beam using durable, water-resistant concrete (min. Grade C40/50), incorporating waterproofing admixtures and corrosion inhibitors.
5. Ensure proper curing using moisture-retaining blankets or curing compounds in accordance with ACI 308.1.

E. Erosion Protection and Riverbank Stabilization

1. Place geotextile separation fabric over the compacted riverbed and backfill areas to prevent soil loss through voids.
2. Install riprap, gabion mattresses, or revetment concrete blocks around the foundation and beam to dissipate water energy and resist future erosion.
3. Where higher hydraulic velocities are anticipated, use grouted riprap or reinforced concrete protection pads.
4. All protective works shall follow the guidance of FHWA HEC-18 and EN 13383-1 (for rock materials in hydraulic works).

F. Monitoring: Install survey markers or inclinometers to monitor potential wall movement or settlement post-repair.

G. Quality Control and Documentation

1. The Contractor shall:

    a. Submit shop drawings, material datasheets, and grout mix designs for Engineer approval.

b. Perform trial grout injections if required to calibrate pressure and volume.
c. Maintain detailed records of grout volumes and pressures, reinforcement and dowel installation, and concrete placement and curing.

2. A final inspection report shall be prepared summarizing works, test results, and photographic documentation of all stages.

4.6 Surface Protection – Anti-Carbonation and Waterproofing Coatings:

Exposed concrete surfaces vulnerable to carbonation or chloride ingress, particularly at facades, podiums, and exposed reinforced concrete surfaces, shall be treated as follows:

A. Surfaces shall be cleaned, repaired, and dried before coating application.

B. An anti-carbonation coating with a CO_2 diffusion resistance ($Sd \geq 50$ m) shall be applied, per EN 1504-2 and EN 1062-6.

C. Where water ingress is a concern, liquid-applied waterproofing membranes or elastomeric coatings shall be applied, selected based on crack-bridging performance (EN 1062-7) and UV resistance.

D. All coatings shall be applied per the manufacturer's system requirements, including primers, base coats, and topcoats.

4.7 Steel Columns Supporting the Cable Car Rehabilitation:

Possible rehabilitation measures for the steel columns supporting the cable car may include:

A. Tightening or replacing deteriorated anchor bolts and nuts,

B. Repairing or re-welding any cracked or weakened welds,

C. Treating areas showing signs of corrosion through cleaning and protective recoating.

D. Where needed, localized strengthening plates or collars can be added around the base plate or column shaft.

E. Once all repairs are completed, the exposed steel surfaces should receive a suitable protective coating system designed for outdoor exposure, to guard against UV radiation, moisture, and long-term corrosion.

4.8 Steel Docking Structures Rehabilitation:

A. Remove Marine Growth and Rust using high-pressure water jetting or mechanical brushing or with abrasive blasting to ISO 8504-2 (as needed).

B. Degrease and Clean prior to applying any repair materials. Light to moderate rust should be treated with mechanical cleaning or water jetting. No need to use abrasive blasting unless deep pitting exists.

C. Cut and replace severely corroded or deformed members with more than 30% section loss, with equivalent or improved steel sections. Reinforce with stiffeners or plates as needed. Weld replacement parts to AWS D1.1.

D. Apply a 3-layer paint system: zinc-rich primer + epoxy intermediate + polyurethane or acrylic topcoat, in accordance with ISO 12944.

E. Re-perform NDT on all critical repairs.

F. Establish a maintenance cycle (e.g., visual inspections every 2 years, full reassessment every 5 years).

4.9 Execution, Quality Control, and Documentation:

All rehabilitation works shall be supervised and documented under a comprehensive QA/QC framework. The Contractor shall:

A. Submit detailed method statements for each intervention, including work sequences, materials, safety measures, and control points.

B. Provide technical datasheets, material certifications, and installation manuals for all proposed products, to be reviewed and approved by the Engineer.

C. Carry out trial applications or mock-ups for surface repairs, coatings, or CFRP systems as required.

D. Conduct all required testing, including:

1. Core testing (per EN 12504-1)
2. Pull-off adhesion tests (per EN 1542)
3. Visual inspections and photographic documentation

E. Maintain a record of all repairs, materials used, and results in a Repair Logbook, forming part of the final handover documentation.