Annexure II

Specification for:

Laboratory Pullout Testing Setup for Embedded Soil Reinforcements under Cyclic Loading

Specification for Laboratory Pullout Testing System for Embedded Soil Reinforcements under Static and Cyclic Loading:

A purpose-built laboratory pullout testing system is proposed to be developed for evaluating the interaction and pullout behaviour of embedded soil reinforcements subjected to static and cyclic loading conditions. The system shall be capable of independently or simultaneously applying vertical static/cyclic surcharge loading at the soil surface and horizontal or inclined pullout loading to the embedded reinforcement. The experimental system shall simulate the combined stress conditions experienced by reinforced soil structures subjected to traffic-induced, repeated, or variable surcharge loading.

1. **Purpose:** The purpose of the proposed laboratory testing system is to evaluate the pullout and interface response of embedded soil reinforcements, including geogrids, geotextiles, geostrips, soil anchors, and soil nails, under static and cyclic surface loading conditions.
   The setup shall simulate reinforced soil wall systems subjected to traffic-induced or repeated surcharge loading, as well as soil anchor and soil nail systems used in slope stabilization and retaining structures.
   The system shall enable controlled vertical static and cyclic loading through a loading plate, followed by or combined with horizontal/inclined pullout testing, as required by the test protocol.
   The setup shall be capable of measuring pullout load, displacement response, load-displacement behaviour, post-cyclic pullout resistance, and deformation characteristics of the reinforced soil system, with provision for image-based monitoring through acrylic observation faces.

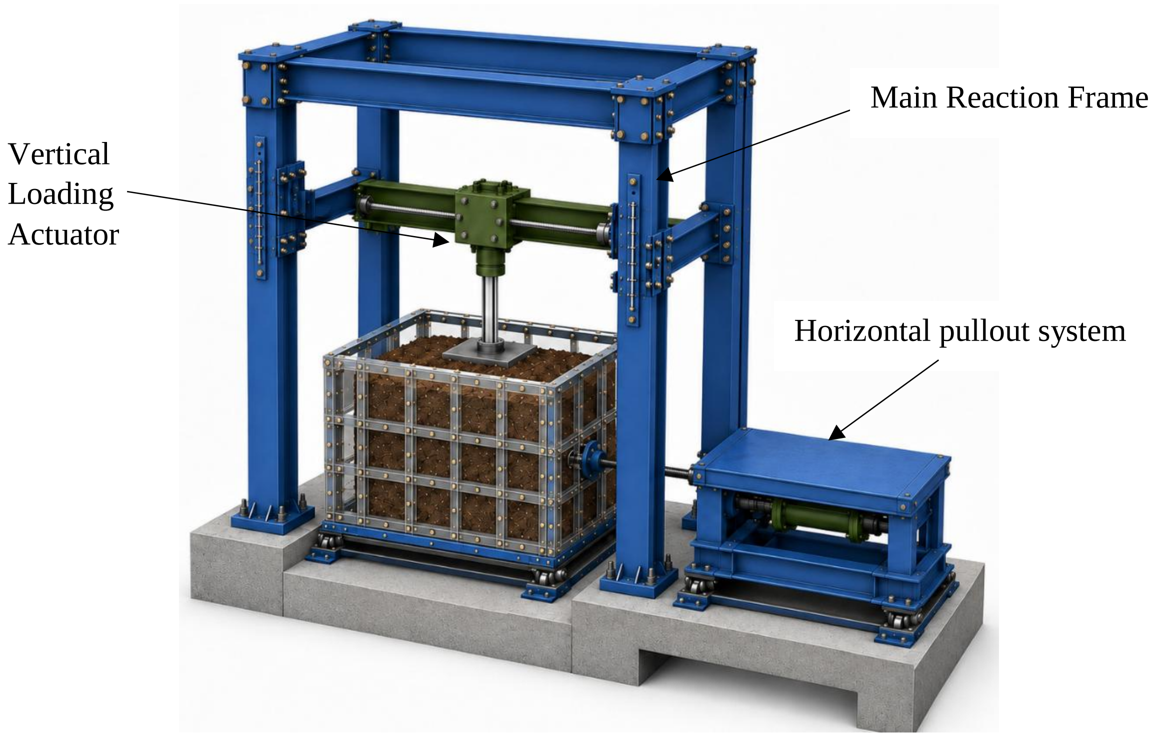
2. **Major components required:**

The proposed laboratory testing system shall be ***supplied as a complete, purpose-built, single integrated turnkey package*** comprising a rigid four-column structural reaction frame, vertically adjustable loading system, horizontally traversing actuator carriage, soil-filled test tank mounted on an independent rail system, vertical static/cyclic loading system, horizontal/inclined pullout system, hydraulic power pack, gripping and coupling arrangements, foundations, anchorages, instrumentation supports, guides, locking devices, instrumentation, controller, data-acquisition system, computer, control software, and all associated fixtures and accessories required for complete operation. The supplier shall ensure full compatibility, structural adequacy, alignment, synchronized operation, installation, commissioning, and overall performance of the complete system. The entire assembly shall be designed to safely withstand the specified vertical static and cyclic loads, horizontal and inclined pullout loads, and any governing combined loading condition without excessive deformation, vibration, instability, connection slip, loss of alignment, or deterioration in measurement accuracy or operational reliability.

2.1 Structural Reaction and Loading Frame

The system shall include a rigid four-column structural reaction frame capable of safely resisting the maximum specified vertical static and cyclic loads, horizontal and inclined pullout loads, and any governing combined loading condition without excessive deformation, vibration, instability, connection slip, or loss of alignment. The frame shall accommodate the soil-filled test tank, vertical static/cyclic actuator, loading plate, horizontal/inclined pullout system, load cells, displacement sensors, instrumentation, and all associated fixtures required for complete testing.

The main reaction frame shall comprise four vertical structural-steel columns and four major top beams, forming a rigid three-dimensional reaction structure. The principal columns and major beams shall be fabricated from ISMB 250 sections or sections of higher structural capacity, as required by detailed structural design. Suitable stiffeners, connection plates, gusset plates, bracing, and other strengthening elements shall be provided wherever required to ensure adequate strength, stiffness, and stability under the specified loading conditions. The frame shall provide a minimum clear height of 2.7 m measured from the existing finished floor level to the underside of the major top beam, and the spacing between adjacent principal columns shall be not less than 3.0 m centre-to-centre, or greater where required to accommodate the tank, rail movement, loading systems, instrumentation, and safe working clearances.



Representative schematic of the proposed laboratory pullout testing setup.

Two vertically adjustable side cross-beams, one on each side of the reaction frame, shall be provided between the corresponding pairs of vertical columns. These side cross-beams shall be fabricated from ISMB 250 or higher-capacity sections and shall be capable of being raised or lowered along the columns to accommodate different test-tank heights, soil levels, loading-plate elevations, specimen configurations, and actuator stroke requirements. The side cross-beams shall be guided during adjustment and shall be securely fixed at the selected elevation using properly designed high-strength bolted connections, locking pins, mechanical clamps, or an equivalent positive locking system capable of preventing unintended vertical movement, rotation, vibration, or loss of alignment during static and cyclic loading.

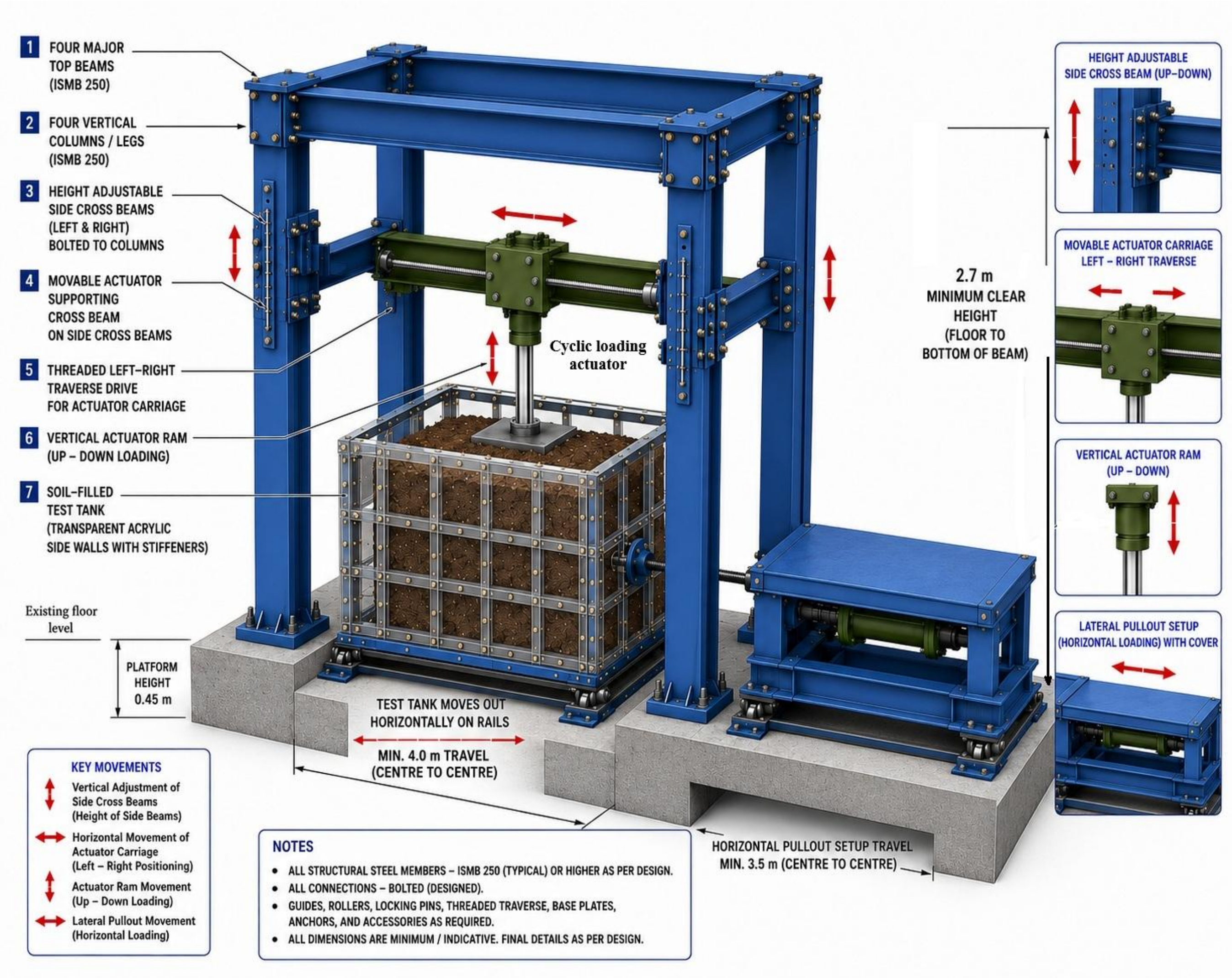
A transverse actuator-supporting crosshead shall span between and be structurally supported by the two adjustable side cross-beams. The vertical actuator shall be mounted on a movable actuator carriage supported by this crosshead. The carriage shall permit controlled horizontal movement in both left and right directions along the crosshead so that the actuator centreline can be positioned accurately at the required loading location. Horizontal positioning shall preferably be achieved through a threaded screw or lead-screw traverse mechanism, together with suitable guide rails, bearings, rollers, sliding elements, end stops, and a positive locking arrangement. The actuator carriage shall be rigidly locked at the selected position before application of static or cyclic loading.

The vertical actuator shall provide independent extension and retraction of its ram or piston for application and removal of the test load. The actuator ram shall act through the specified loading plate directly onto the prepared soil surface or test specimen, and the actuator centreline, loading plate, and intended loading point shall remain properly aligned throughout the loading stroke. The loading system shall therefore permit independent vertical adjustment of the side cross-beams, horizontal positioning of the actuator carriage, and vertical movement of the actuator ram.

The soil-filled test tank shall be mounted on an independent horizontal rail system, and only the test tank shall move on this rail system. The main reaction frame and horizontal/inclined pullout reaction arrangement shall remain fixed. The tank rail shall extend sufficiently beyond the outermost reaction-frame columns to enable the complete tank to be moved laterally entirely outside the four-column frame for filling, soil compaction, specimen preparation, instrumentation, and maintenance, and subsequently pushed back into the required testing position beneath the vertical actuator. An indicative tank travel of approximately 4.0 m centre-to-centre or greater shall be provided, subject to the final tank dimensions and requirement for complete clearance of the reaction-frame footprint. Heavy-duty rails, rollers or wheels, bearings, lateral guides, end stops, anti-derailment provisions, and positive tank-position locking devices shall be included.

A separate fixed horizontal/inclined pullout reaction arrangement shall be provided adjacent to the test tank for mounting and aligning the horizontal or inclined pullout actuator and for safely resisting the corresponding pullout reaction forces. The pullout arrangement shall include appropriate reaction supports, actuator mounting provisions, load-cell and displacement-sensor fixtures, coupling and gripping arrangements, alignment devices, and protective cover. The horizontal pullout assembly shall remain independent of the movable tank rail and shall be positioned so that the pullout load is applied along the intended test axis without significant eccentricity or unintended bending.

Each of the four principal reaction-frame columns shall be securely supported on a properly designed reinforced-concrete foundation. The minimum foundation depth below the existing floor level shall be 600 mm, unless a greater depth is required by structural or geotechnical design. Each column shall be connected to the foundation using suitably designed base plates, anchor bolts, holding-down bolts, stiffeners, levelling arrangements, and non-shrink grout. The foundation and anchorage system shall be designed to safely resist axial forces, shear, uplift, overturning moments, eccentric loads, cyclic loading effects, and vibration generated during vertical and horizontal testing.



Representative Schematic Photo of proposed laboratory pullout testing setup

All above schematic dimensions are indicative and the Section 2 dimensions govern.

A separate ***rigid horizontal/inclined pullout reaction frame*** shall be provided adjacent to the test tank and shall remain fixed independently of the movable tank system. The frame shall provide suitable mounting and alignment provisions for the horizontal pullout actuator, load cell, gripping/coupling assembly, displacement transducers, alignment guides, and protective cover. The actuator support shall permit adjustment of the pullout axis in elevation and, where required, inclination so that the applied load remains collinear with the embedded reinforcement or test element. Suitable slotted plates, bolted brackets, adjustable supports, guide rails, or equivalent mechanisms shall be provided for this purpose.

The pullout actuator shall be securely connected to the reaction frame through properly designed bolted structural connections, mounting plates, stiffeners, and anchorages. The complete arrangement shall safely transfer the full actuator reaction to the supporting frame and foundation without connection slip, excessive local deformation, instability, vibration, or loss of alignment. Positive locking arrangements shall be provided after positioning and alignment to prevent unintended movement during static or cyclic pullout testing.

The pullout reaction frame shall be fabricated from suitable structural steel sections of adequate capacity, with appropriate stiffeners and bracing, and shall be supported on a suitably designed reinforced-concrete foundation or structural platform using base plates and anchor bolts. The frame and foundation shall be designed for the governing axial reaction, shear, overturning moment, eccentricity, cyclic effects, and any vertical component arising from inclined pullout loading. The pullout system shall remain structurally independent of the movable test tank while maintaining accurate alignment with the test specimen throughout the full loading stroke.

The final sizes and detailing of all structural members, stiffeners, connection plates, bolts, welds, base plates, anchorages, guide systems, locking arrangements, rail components, and foundation elements shall be established through detailed structural design for the actual actuator capacities and governing static, cyclic, horizontal, inclined, and combined loading conditions. All structural steel members, reaction beams, adjustable cross-beams, actuator-supporting crosshead, connections, foundations, anchorages, base plates, bolts, welds, guides, rails, rollers, locking devices, safety provisions, and all other accessories required for complete and safe operation of the system shall be included within the supplier's scope.

2.2. Test Tank

The test tank shall be a rigid, soil-filled structural container designed for repeated vertical loading and horizontal/inclined pullout testing without excessive wall deformation, leakage, distortion, or loss of alignment. The tank shall be fabricated using a suitably stiffened structural-steel frame, with the principal observation side provided as a fully transparent acrylic panel to permit clear visual observation of soil deformation, reinforcement movement, shear-zone development, and specimen behaviour during testing. The acrylic face shall be adequately supported by vertical and horizontal steel stiffeners, perimeter framing, clamping plates, and sealed bolted connections, with the final acrylic thickness and stiffener spacing determined from the governing lateral earth pressure, surcharge, cyclic loading, and tank dimensions. The front face of the tank shall remain structurally closed, except for specifically designed and sealed provisions required for the pullout connection or instrumentation. The tank shall permit placement and controlled compaction of soil to the specified test level and shall provide suitable provisions for reinforcement installation, load-transfer elements, sensors, drainage where required, and internal dimensional reference markings. The complete tank shall be mounted on the independent rail system so that it can be moved fully outside the four-column reaction frame for specimen preparation and subsequently repositioned accurately beneath the vertical actuator for testing. Suitable lifting points, handling provisions, locking arrangements, end restraints, and safety features shall be incorporated, and the tank structure shall be designed to safely resist the combined effects of soil self-weight, compaction pressure, surcharge, vertical actuator loading, horizontal pullout forces, and repeated cyclic loading.

Item	Specification
Tank type	Rigid steel tank with a strong base frame and provision for transparent acrylic observation faces on two opposite faces.
Indicative model size	Approximately 1.5 m wide × 1.5 m high × 1.5 m long, with two transparent acrylic faces.
Observation faces	Transparent acrylic panels on three sides for visual monitoring, digital image correlation, and image-based deformation analysis. Acrylic panels shall be of adequate thickness and stiffness to safely resist soil pressure and test-induced deformation
Drains	Bottom drainage outlets shall be provided to drain accumulated water from the tank. Provided with removable covers.
Reinforcement installation	Provision for slots, clamps, or guide arrangements to place geosynthetic reinforcement layers at selected vertical spacing and embedment lengths.
Anchor / nail installation	Provision for installing embedded nails or grouted anchors in horizontal and inclined orientations.
Tank shall allow easy soil filling, compaction, instrumentation installation, reinforcement placement, and dismantling after testing.	
Tank shall be placed over, trolley-mounted movable base with guided horizontal movement over a minimum travel length of minum 3m away from frame, with suitable positive locking arrangements for safe positioning and restraint during static, cyclic, and pullout testing	

2.3. Vertical Static and Cyclic Loading System

Item	Specification
Loading system	Servo-hydraulic or equivalent controlled vertical loading system with hydraulic servo power pack.
Static actuator capacity	Minimum 250 kN. or Higher
Dynamic actuator capacity	Minimum ± 150 kN dynamic capacity or Higher (with minimum stroke of ± 150 mm, (300 mm total stroke))
Frequency range	0.1 Hz to 10 Hz
Loading mode	Load-controlled and displacement-controlled operation for static, repeated, sinusoidal, triangular, haversine, and user-defined loading histories.
Loading plate	Rigid loading plate / loading assembly for applying surface surcharge on the soil surface.
Vertical load cell	250 kN capacity, calibrated, accuracy preferably +/- 0.5 percent or better.
LVDTs	Minimum two LVDTs shall be provided for measuring the vertical settlement/displacement response of the soil surface/loading plate during static and cyclic loading. The LVDTs shall be positioned suitably, preferably on opposite sides of the loading plate, to enable determination of average settlement and identification of any differential movement or tilting.

<table>
<tr><th>Item</th><th>Specification</th></tr>
<tr><td>Safety and control</td><td>Overload protection, stroke limit, emergency stop, and closed-loop feedback control shall be provided.</td></tr>
<tr><td colspan="2">Actuator with Servo valve manifold having Double acting double ended fatigue rated hydrostatic piston rod bearing with axial load cell (Capacity ± 150 kN) with an overload capacity of 150% of the rated load and built-in LVDT (Coaxially mounted displacement transducer; 300mm (±150mm) having swivel base assembly with following provision/fixing.
The vertical actuator shall be a double-acting, fatigue-rated servo-hydraulic actuator equipped with a servo-valve manifold, hydrostatic or equivalent low-friction bearing arrangement, axial load cell and coaxially mounted LVDT.</td></tr>
<tr><td colspan="2">Providing and fixing of interchangeable loading plates at the bottom end of the actuator piston rod. The loading plates shall comprise circular plates of Ø150 mm and Ø300 mm, or square plates of 150 × 150 mm and 300 × 300 mm, as finalized, with a minimum thickness of 30 mm. The bottom surface of each loading plate shall be provided with a suitable rubber pad/base.</td></tr>
<tr><td colspan="2">The suitable Cooling arrangement must be provided to maintain the temperature of the hydraulic oil to run the whole machine continually for 2 million cycles.</td></tr>
<tr><td colspan="2">Hydraulic Power Pack with necessary cable, hose pipes, fittings and accessories for the operation of the actuator system with anti-vibration mounting. The noise rating of complete system should be less than 70 dB at peak performance. The hydraulic power flow, maximum operating pressure, power rating of motor and oil tank capacity suitable to run the actuator under dynamic/cyclic loading of different waveform with above mentioned frequency ranges and under static loading in the form of ramp signal.</td></tr>
</table>

Note: Servo-hydraulic power pack compatible with the vertical actuator capacity and dynamic frequency range. Hydraulic pressure and flow capacity shall be sufficient to operate the actuator under the specified static and cyclic loading conditions without overheating. Power pack shall include suitable cooling, filtration, oil level indicator, pressure gauge, and safety relief valve.

2.4. Horizontal and Inclined Pullout System

Item	**Specification**
Pullout Actuation type	Servo-controlled electromechanical or hydraulic push-pull loading system capable of both tensile pullout and compressive pushing operations.
Loading control	Both displacement and load control
Pulling capacity	Minimum 100 kN or higher
Variable displacement rate	Stable control shall be ensured for practical pullout rates of 0.01 to 15 mm/min.
Horizontal load cell	100 kN capacity, calibrated, accuracy preferably +/- 0.5 percent or better.
Pullout stroke	Minimum 150 mm, preferably extendable to 200 mm or more

Item	Specification
Horizontal displacement measurement	Two LVDTs with 150 mm travel for pullout displacement, wall-facing displacement, and reinforcement/nail head movement.
Inclined pullout	Arrangement shall permit inclined pullout of soil nails or embedded anchors. Required angle range 0 to 10 degrees.
Nail / anchor sample diameter	Provision for testing 20 mm and 32 mm diameter nails or anchors with suitable adapters and couplers.
Alignment	Pulling or pushing axis shall remain aligned with the reinforcement or nail axis to minimize bending, eccentricity, and boundary friction effects.
Control and synchronization:	The horizontal/inclined pullout system shall be integrated with or synchronizable through the common controller, data-acquisition system, and control software for coordinated operation with the vertical static/cyclic loading system.

2.5. Gripping, Coupling, and Fixture Requirements

Item	Specification
Geosynthetic grips	Wide mechanical wedge, roller, or clamping grips suitable for geogrid, geotextile, and geostrap without slippage or local tearing.
Soil nail couplers	Threaded couplers, collet grips, jaw grips, or adapter plates suitable for 20 mm and 32 mm diameter nails or anchors.
Interchangeability	Fixtures shall be interchangeable for geosynthetic pullout, nail pullout, and nail pushing tests.

2.6. Computerized Control, Data Acquisition, and Software System

a) The system shall include a computer with monitor and minimum one-year OEM warranty for controlling the test setup and collecting test data. The computer shall have, at minimum, an Intel i7 or higher processor, original licensed Windows operating system, 2 TB SSD/HDD storage, 32 GB RAM, keyboard, optical mouse, minimum six USB ports, 32-inch monitor, compatible data acquisition interface, and waveform generation facility for actuator control. A colour laser printer and 1 kVA UPS with minimum 30 minutes backup shall also be provided.

b) A 32-channel data acquisition system shall be provided for collecting data from strain gauges, load cells, pressure cells, displacement transducers, LVDTs, actuator feedback sensors, and other compatible instrumentation during testing.

c) Control software shall be provided for actuator control and data acquisition. The software shall enable static loading, cyclic loading, pullout testing, displacement-controlled and load-controlled operation, real-time data display, data storage, and data export. Software updates required for compatibility with the computer operating system shall be the responsibility of the supplier during the warranty period.

2.7. Technical Specification for Controller, Control software & data acquisition system

The controller, control software, and data acquisition system shall have the following minimum features:

i. The system shall have provision for PID-based servo control with auto-zeroing, auto-tuning, and auto-adjustment features for stable actuator operation.
ii. The system shall allow computer-controlled operation for starting, stopping, holding, pausing, and resuming the actuator during the test.
iii. Load and displacement measurement accuracy shall be ±1% or better; individual load cells and LVDTs shall preferably have ±0.5% accuracy or better..
iv. The vertical actuator shall be capable of applying both dynamic cyclic loading and static ramp loading.
v. The horizontal pullout system shall be capable of performing load-controlled, displacement-controlled / strain-controlled pullout tests, as applicable.
vi. The software shall allow programmable loading parameters, including load, displacement, frequency, amplitude, waveform, loading rate, number of cycles, hold time, and unloading rate.
vii. The system shall be capable of defining and executing user-programmable test sequences for static loading, cyclic loading, pullout testing, and combined loading conditions.
viii. The system shall allow individual and simultaneous application and recording of vertical cyclic loading and controlled horizontal pullout, wherever required, including synchronized measurement of vertical load, horizontal pullout load, actuator displacement, LVDT readings, frequency, amplitude, number of cycles, and time-history data.
ix. Software shall support real-time monitoring, load-displacement plots, cycle count, load history, displacement history, data storage, export to CSV/Excel, and generation of test reports.
x. The software shall provide programmable safety limits for load, displacement, actuator stroke, frequency, amplitude, and number of cycles.
xi. The system shall allow controlled modification of load, frequency, and amplitude during the test, wherever required by the test protocol.
xii. The software shall provide facilities for data storage, database backup, restore, and retrieval after completion of the test.
xiii. The system shall provide online display of load versus displacement, load versus time, displacement versus time, number of cycles, actuator position, and readings from additional instrumentation channels.
xiv. The data from each channel shall be stored in user-defined files or directories and shall be exportable in formats compatible with Microsoft Excel and analysis software.
xv. The data acquisition system shall be capable of recording readings from load cells, pressure sensors, LVDTs, displacement transducers, strain gauges, actuator feedback sensors, and other compatible channels during static, cyclic, and pullout testing.

Channel-wise data shall be stored in user-defined files or directories and shall be exportable to Excel-compatible and analysis software formats.

2.8. Calibration, Warranty, Training, and Documentation

i. Calibration certificates shall be provided for load cells, LVDTs, actuators, and data acquisition channels at the time of delivery.
ii. On-site training and demonstration shall be provided for installation, operation, data acquisition, cyclic loading, pullout testing, and safety procedures.
iii. Minimum One-year warranty from the date of installation against manufacturing defects and poor workmanship.
iv. Supplier shall provide operation manuals, maintenance manuals, electrical and hydraulic circuit diagrams, calibration records, software manual, and safety instructions.
v. Performance demonstration shall be carried out after installation for vertical cyclic loading, horizontal pullout, inclined pullout, nail pushing, sensor recording, and data export.
vi. Essential spares, hydraulic seals, cables, connectors, sensor mounts, and fixture adapters shall be included or quoted separately.
vii. The supplier/manufacturer shall be responsible for the complete design, fabrication, supply, installation, fixing, welding, alignment, connection, mounting, commissioning, and integration of the structural reaction frame, test tank, vertical and horizontal loading systems, actuators, hydraulic system, pullout assemblies, sensors, fixtures, controller, data-acquisition system, computer, software, and all associated accessories required for a fully functional laboratory testing system. All necessary fabrication, installation, electrical, hydraulic, mechanical, and integration works shall be included in the supplier's scope and cost.