

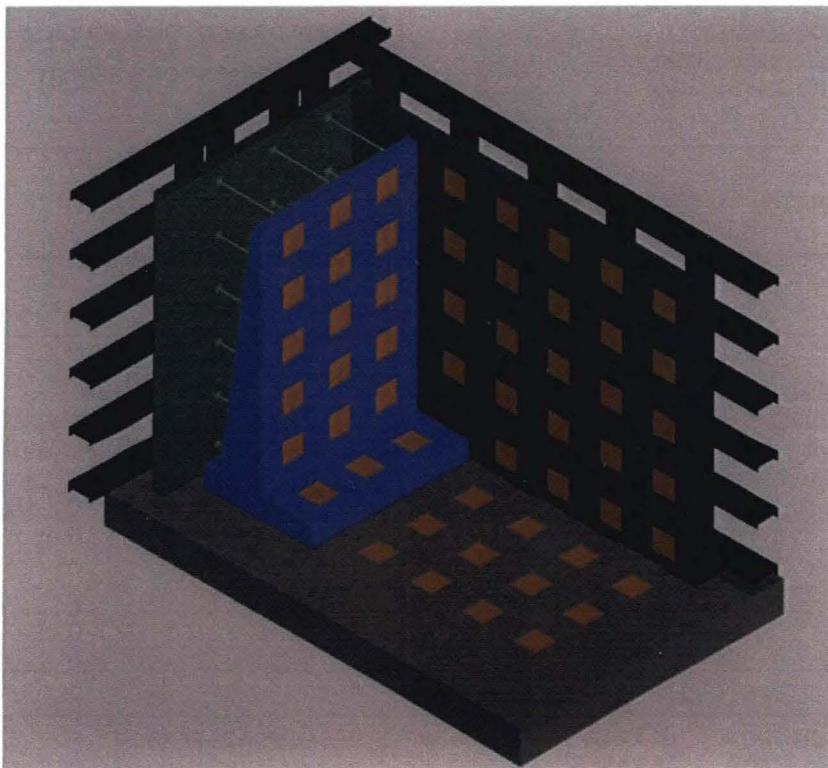
RECLAMATION

Managing Water in the West

Report DSO-2013-03

Soil-Structure Interaction Phase 3 Feasibility Level Design Full-Scale Retaining Wall Shake Table Testing

Dam Safety Technology Development Program



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

August 2013

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14. ABSTRACT This ongoing research will help answer the questions that continue to arise as Reclamation is faced with detailed analysis and modifications of spillways and other earth-retaining structures subjected to significant seismic loading. The objective of this research is a better analytical tool to predict the seismic lateral earth pressures for configurations that include groundwater, cohesion, non-horizontal zone, and compaction/in-place density effects under various ground accelerations. This report represents the conclusion to the third phase (Feasibility Level Design Phase 3) of this research project. The ultimate project purpose is to complete a full scale shake table test of a concrete cantilever retaining wall.					
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Dam Safety Technology Development Program

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**U.S. Department of the Interior
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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Dam Safety Technology Development Program
Waterways and Concrete Dams Group, 86-68130

DSO-2013-13

Soil-Structure Interaction
Phase 3 Feasibility Level Design
Full-Scale Retaining Wall Shake Table Testing

APG

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9-27-2013

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ACRONYMS AND ABBREVIATIONS

ft	feet
g	acceleration of gravity
kg	kilograms
kg/m ³	kilograms per cubic meter
lb/ft ³	pounds per cubic foot
m	meter
Hz	hertz
LHPOST	Large High Performance Outdoor Shake Table
LVDT	linear variable differential transformers
MN	million Newtons
MN-m	million Newtons meters
Mlb	million pounds
Mlb-ft	million pounds feet
PI	Principal Investigator
UCSD	University of California, San Diego

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Appendix C – LHPOST Testing Task and Expense Breakdown
Appendix D – LHPOST Experimental Equipment

EXECUTIVE SUMMARY

This report presents feasibility level designs and cost estimates for a retaining wall system Shake Table: i) pilot testing program, and ii) representative full-scale test series. In these experiments, emulation of actual in-situ backfill soils and compaction/placement procedures is of primary interest (including considerations such as soil cohesion and soil-gravel mixtures). Budget estimates for performing these experiments are developed and presented. Appendices provide the underlying details. An additional appendix is included as well with background information related to the equipment at the testing laboratory.

INTRODUCTION

The objective of Reclamation's current soil-structure interaction research is to develop guidelines for computing dynamic lateral earth pressures for earth retaining structures that are more representative of field conditions. Reclamation has numerous structures currently in issue evaluation and conceptual design alternatives stages where soil-structure interaction plays a significant role on the stability of the structure and the type of modification required. Other dam owners throughout the United States are faced with the same concerns.

Having completed the Scoping Phase 1 [1] and the Planning Phase 2 [2] of this research, additional studies are reported herein towards completion of the Feasibility Design Phase 3 by:

1. Developing feasibility designs, test procedures and instrumentation requirements for a full-scale shake table test using the University of California, San Diego (UCSD) Large High Performance Outdoor Shake Table (LHPOST) facilities, and for an optional pilot testing program prior to the full-scale test using the UCSD campus shake table.
2. Development of feasibility level design cost estimates for the pilot testing program and for the full- scale testing based on the feasibility designs.
3. Coordinating with Reclamation throughout the entire study.

Prior related work on the UCSD LHPOST includes the work reported by Dr. Patrick Wilson in his PhD dissertation [3]; in which dynamic earth pressure experiments were conducted on a full-scale bridge abutment wall. Figure 1 presents an overview of the elements involved in this experimental investigation [3]. For such testing, instrumentation to acquire data potentially includes:

- Strain Gages deployed on reinforcing bars within the reinforced concrete retaining wall

- Displacement Transducers to measure relative displacement between two points in space (e.g., string pots and Linear Variable Differential Transformers (LVDT's))
- Accelerometers to record the input acceleration signal as well as horizontal and vertical acceleration elsewhere throughout the surface of the model and embedded within the soil model at various selected locations of interest.
- Pressure Transducers and Tactile Pressure Sensors which are devices that monitor local pressure where installed and might be used to record static as well as dynamic normal pressures during the shaking experiment. Of particular interest are the pressures exerted by the soil on the wall as well as pressures on the base and sides of the soil container.
- Shape Tape which is a flexible column of piezoelectric displacement and rotation sensors designed to report translation along the deployed direction. The shape tape is typically deployed along the model height so as to record lateral displacements (static and dynamic).
- Digital Cameras which may be used to monitor evidence of soil surface disturbance. Image processing techniques may be used to detect motion relative to original position (essentially by image subtraction).

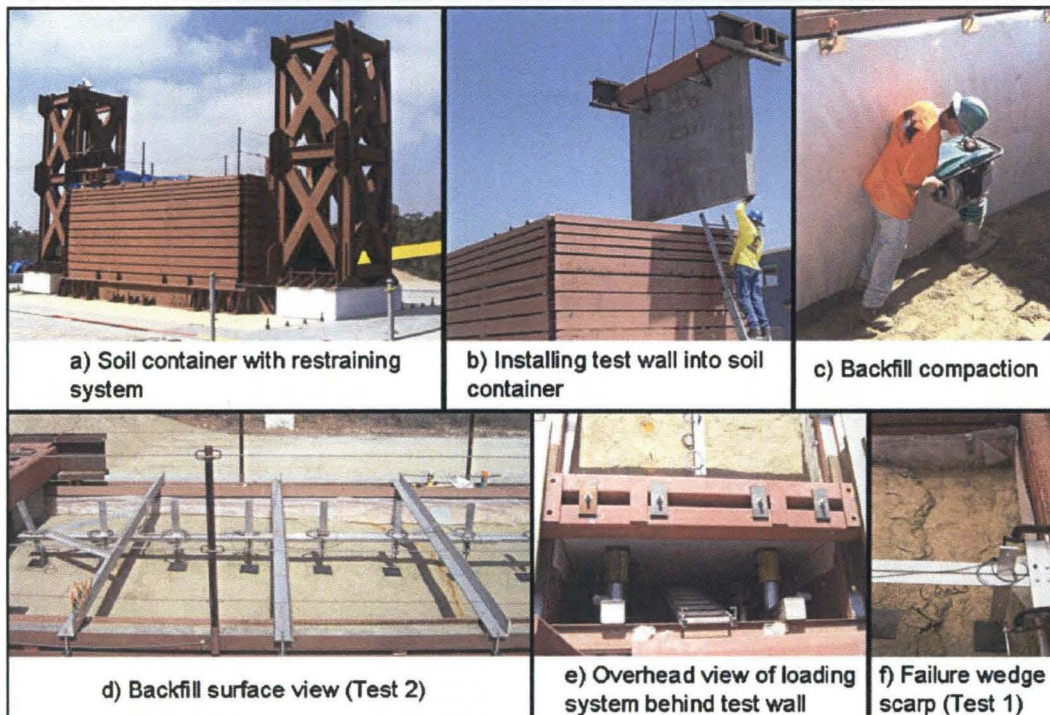


Figure 1. - Experimental configuration [3]: a) Restrained laminar soil container rigidly connected to the UCSD LHPOST base (Platen), b) Reinforced concrete test wall installation inside the container, c) Backfill soil compaction inside the container, d) Ground surface with deployed instrumentation to monitor vertical displacements at different locations behind the wall, e) Hydraulic jacks employed to exert passive loading conditions when specified, f) Ground surface passive wedge scarp in the backfill.

OUTLINE OF REPORTED EFFORTS

As such, this document will mainly address:

1. Full-Scale Test Feasibility Design: Development of a 60-percent-level (feasibility-level) design for a full-scale retaining wall shake table test at the LHPOST facilities.
2. Pilot Test Program Feasibility Design: Development of a 60-percent-level (feasibility-level) design for a suggested pilot testing program to be completed prior to the full-scale test. The pilot test will be conducted using the UCSD on-campus shake table to establish a basis for conducting the full-scale test.

As part of the above, cost estimates are prepared for both the pilot testing program and full-scale test program including construction expenses, material quantities, unit pricing, equipment, instrumentation, test monitoring, test post-processing, report preparation and recommended contingencies.

In the following sections, material will be presented as relates to:

- The representative backfill soils.
- The proposed pilot testing program.
- The LHPOST large-scale experimental program.

SOIL MATERIAL

A local quarry near UCSD (Vulcan Materials) provided a soil sample that is potentially viable as a soil backfill with a small but significant percentage of fines (about 7%). Soil from this quarry was employed in earlier UCSD tests [3]. Upon compaction at the optimum moisture content (OMC) to 95% relative density, peak friction angle was estimated to be above 45 degrees with a cohesion intercept of about 2.18 lb/in² (15 kPa) (residual friction angle was in the range of 36 degrees with a cohesion intercept of about 1.45 lb/in² (10 kPa)).

If additional fines and clay content is needed for a particular test, this soil will be mixed with an appropriate percentage of such soils (to be procured as needed). Handling of this soil mixture (mixing, placement, and compaction) will require additional effort in trials in order to achieve a robust mixture that can be consistently reproduced with the desired mechanical properties.

The sample provided by Vulcan Materials (known as Fill Sand 15) included about 10% of relatively large particles in excess of approximately ¾-inch (20 mm) in size (Figure 2), with the largest particles being of the order of 1.5 inches in size (about 40 mm). Grain size distribution for this soil is shown in Figure 3. Such soil might be desirable for certain situations where the native actual prototype backfill soil contains large size particles.



Figure 2. – Vulcan Materials Fill Sand 15 with largest particles of about 1.5 inches in size.

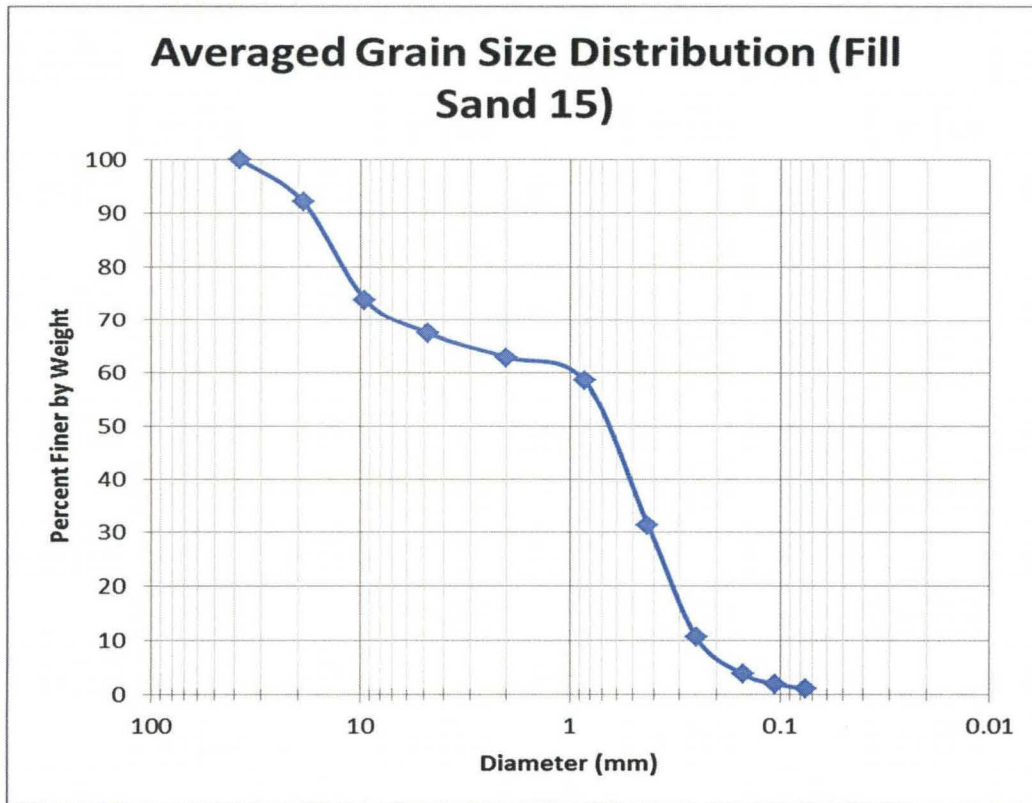


Figure 3. – Vulcan Materials Fill Sand 15 grain size distribution.

An additional sample with particles above about 10 mm in size (a little less than 0.5 inches) screened out (removed) was also procured (Figure 4) from Vulcan Materials (known as screened Fill Sand 15). Grain size analysis for this material was conducted using the wash sieve technique to remove fines and was found to match the data provided by Vulcan Materials (Figure 5).



Figure 4. – Vulcan Materials Screened Fill Sand 15.

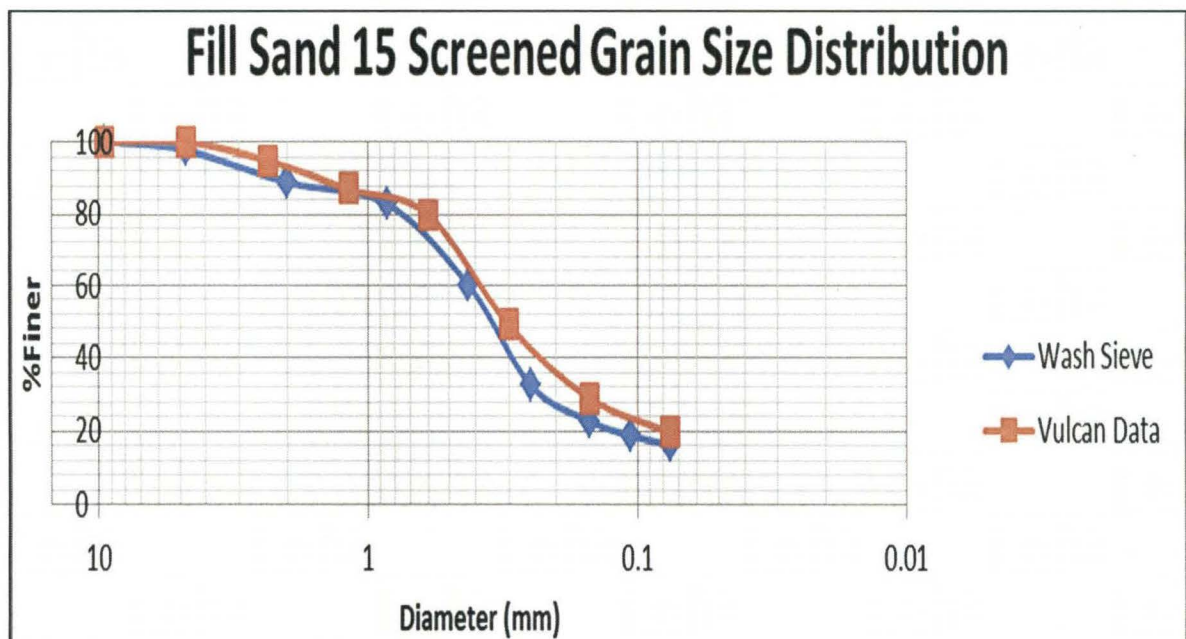


Figure 5. – Vulcan Materials Screened Fill Sand 15 grain size distribution.

PILOT TESTING: 6.7 FT (2 M) HEIGHT WALLS

A number of exploratory pilot experiments are proposed as a possible prelude towards the large-scale LHPOST experimentation program. For that purpose, the UCSD on-campus shake table and an available soil container to accommodate 6.7 ft (2 m) high walls can be used (Figure 6-8).

With lower cost and faster construction time, a number of different wall-backfill scenarios can be tested efficiently using this UCSD on-campus shake table. Benefits from such pilot testing are potentially fourfold:

1. provide data sets to shed light on the salient response mechanisms of interest,
2. permit preliminary computational model calibrations for additional insights into the LHPOST expected outcomes,
3. allow for drawing final conclusions as relates to the most effective and informative LHPOST testing configurations, and
4. test and verify the intended wall-backfill configuration schemes, the relevance and value of different input dynamic base excitations and sequences, soil types including placement/compaction procedures, and the necessary informative instrumentation layouts (sensor types and spatial locations).

Conducted on a smaller scale relative to the large full-scale LHPOST experiments, this pilot testing program aims to:

1. Define the range of effective and robust soil placement and soil compaction procedures that can be efficiently and confidently employed during the LHPOST testing phase.
2. Contribute to the final decisions related to instrumentation types and instrumentation placement locations and techniques in order to further enhance the quality and quantity of reliable accurate data during the LHPOST testing phase.
3. Allow for testing a number of potentially relevant geometric wall-backfill configurations, thereby aiding in the final definition of the most appropriate geometric/material LHPOST experimental setups.
4. Furnishing pilot data sets for preliminary development and calibration of computational models, towards employment for the LHPOST experiments and subsequent prototype full-scale assessments and evaluations.



Figure 6. – UCSD on-campus shake table container to accommodate 6.7 ft (2 m) high walls.

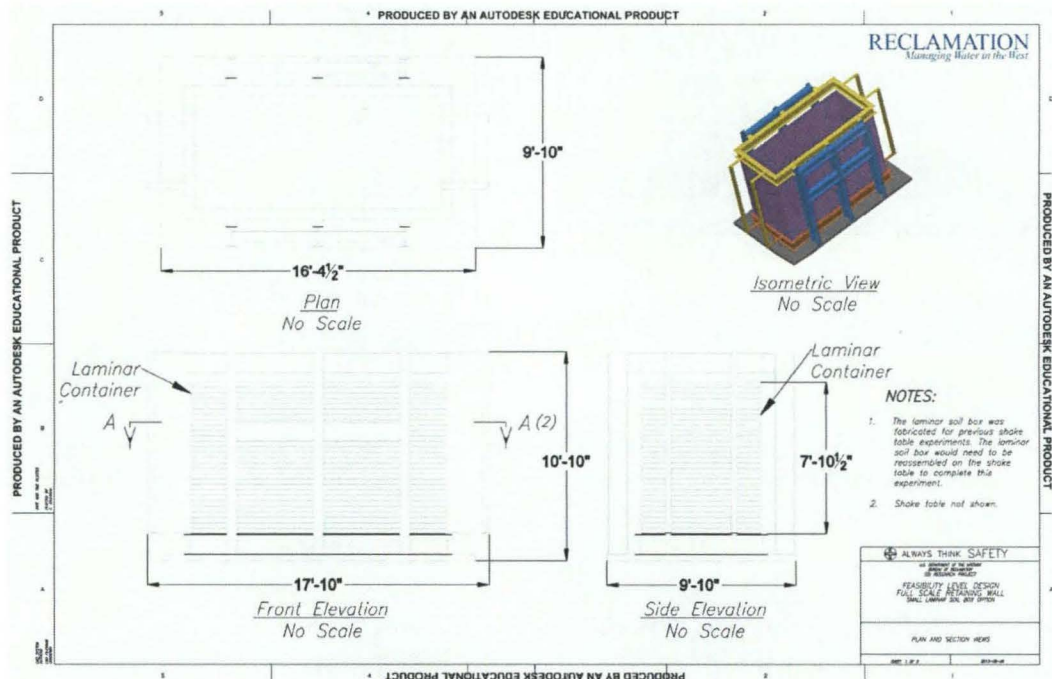
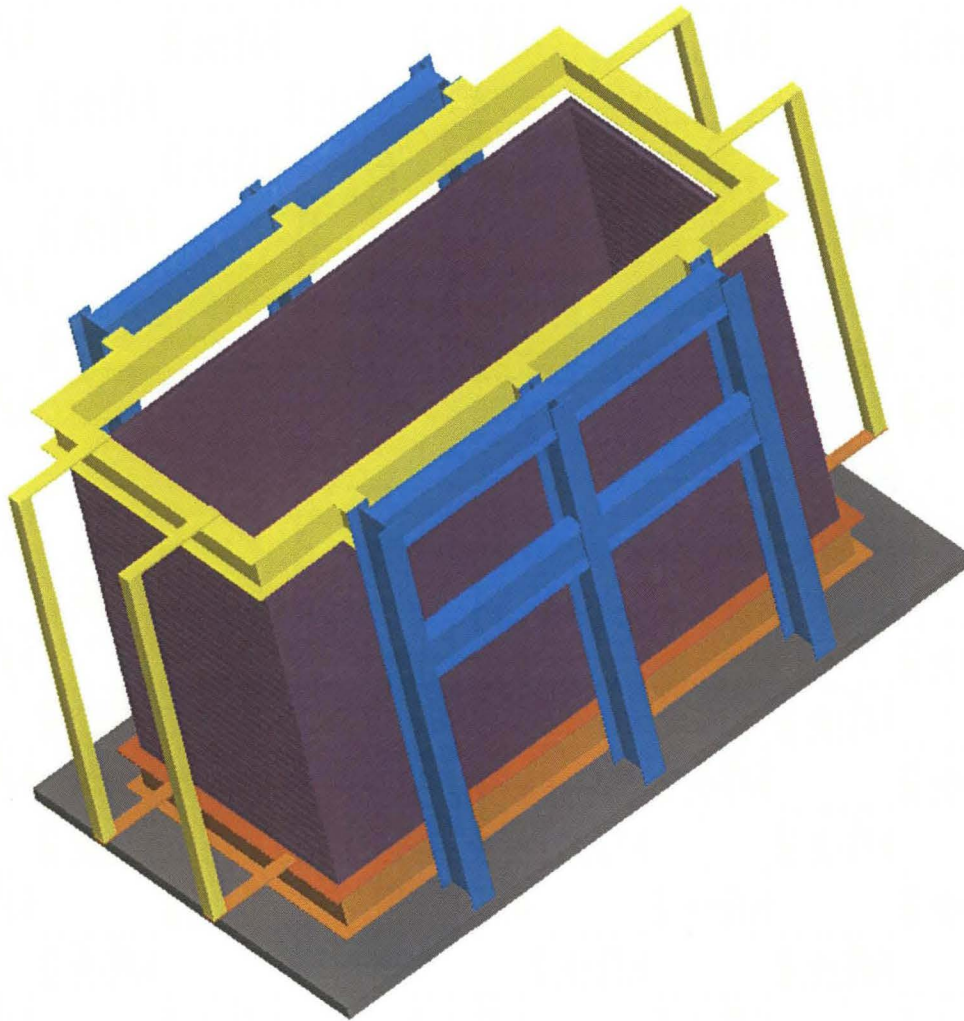


Figure 7. – UCSD on-campus shake table container plan and elevations.



Isometric View
No Scale

Figure 8. – Three dimensional schematic of small laminar soil box.

Potential Pilot Testing Configurations

Schematics for possible physical and/or numerical simulation are shown in Figure 9. Anticipated base shaking motions for the pilot testing program include:

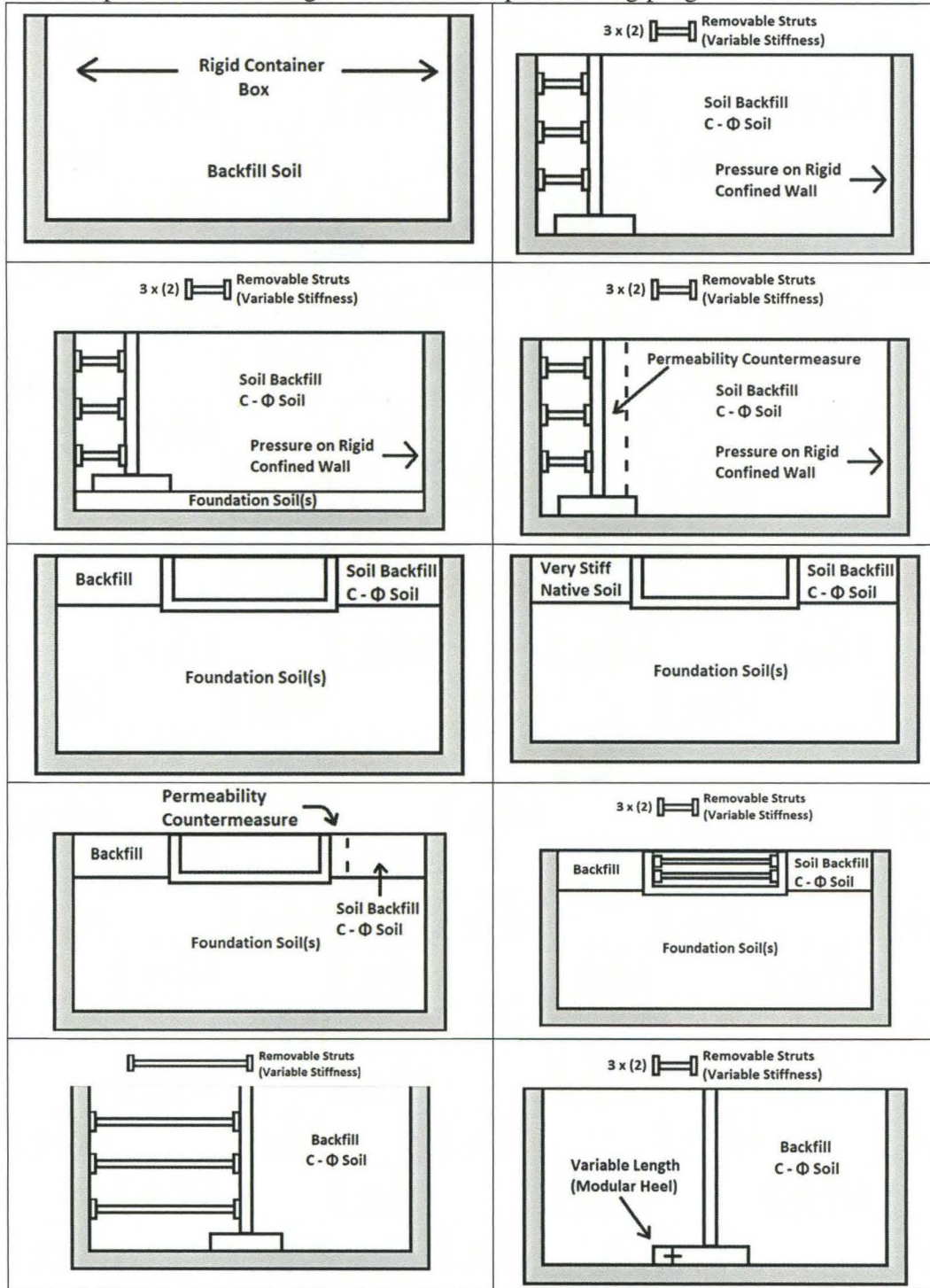


Figure 9. – Schematic of potential configurations for physical and/or numerical simulation.

i) low peak acceleration broadband (in terms of frequency content) motions to document the system nearly linear dynamic response characteristics (e.g., system resonances, soil shear wave profile), ii) low and high amplitude earthquake-like motions (0.1g-1.0g or more) to measure the range of potential dynamic forces on the wall, and iii) harmonic excitation if needed in order to focus on a steady-state response characteristic if interest (as needed).

Pilot Testing Program Cost Estimates

Below is a breakdown of the cost estimate components for the Pilot Testing Program. The first experiment in the series involves soil procurement and testing, computational effort setup, and other site/experiment preparation expenses as presented in Table 1. Subsequent Pilot Test configurations could be performed at lower costs as shown in Table 2. Detailed cost breakdowns for each Work Element are included in Appendix B.

Table 1 - First Pilot Test Estimated Costs

Work Element 1 - Soil Procurement	\$6,200.00
Work Element 2 - Soil Preparation	\$10,143.20
Work Element 3 - Computational Framework Setup/Calibration/Predictive Estimates	\$31,000.00
Work Element 4 - Container Preparation, Setup and CIP Retaining Wall Construction	\$24,204.00
Work Element 5 - Instrumentation (install and test)	\$47,746.00
Work Element 6 - Soil Placement	\$20,181.00
Work Element 7 - Shake Table Testing	\$3,410.00
Work Element 8 - Soil Removal	\$4,011.40
Work Element 9 - Demobilization and Model Dismantling	\$5,846.60
Work Element 10 - Data Analysis & Report Preparation	\$38,796.50
Subtotal - First Test	\$191,538.70
Design Contingencies (10%)	\$19,153.87
Contract Cost – First Test	\$210,692.57
Construction Contingencies (15%)	\$31,603.89
Field Cost – First Test	\$242,296.46

Table 2 – Subsequent Pilot Tests Estimated Costs

Work Element 1 - Soil Procurement	\$6,200.00
Work Element 2 - Soil Preparation	\$4,439.20
Work Element 3 - Computational Framework Setup/Calibration/Predictive Estimates	\$0.00
Work Element 4 - Container Preparation, Setup and CIP Retaining Wall Construction	\$0.00
Work Element 5 - Instrumentation (install and test)	\$3,565.00
Work Element 6 - Soil Placement	\$15,717.00

Work Element 7 - Shake Table Testing	\$682.00
Work Element 8 - Soil Removal	\$4,743.00
Work Element 9 - Demobilization and Model Dismantling	\$1,500.00
Work Element 10 - Data Analysis & Report Preparation	\$15,097.00
Subtotal (Subsequent Test)	\$51,943.20
Design Contingencies (10%)	\$5,194.32
Contract Cost (Subsequent Test)	\$57,137.52
Construction Contingencies (15%)	\$8,570.63
Field Cost (Subsequent Test)	\$65,708.15

LHPOST TESTING

The primary objective is to develop benchmark large-scale retaining wall system seismic response data sets. This experimental response would be a main basis for calibration of numerical computational tools. With such data sets and calibrated numerical tools, assessments and evaluations can be conducted for prototype scenarios of interest.

Salient additional information regarding the LHPOST experimental facility and available soil containers may be found in Appendix C of this report. The wall-soil model may be constructed in: i) the rigid-wall container (Figure 10-15), or ii) the laminar container, constrained to perform in a rigid-wall configuration (Figure 16-19). The preferred soil container configuration decision can be finalized based on logistical considerations associated with effort and time needed for preparation, deployment, testing and dismantling.

The rigid-wall soil box consists of rigid concrete panels connected by steel posts and surrounded by steel perimeter bracing. Upon assembly, the container acts as a rigid monolith and requires no additional external supports to perform in this manner. The large laminar container consists of relatively rigid steel I-section perimeter frames (laminates) stacked on top of one another, with either: i) rollers in between the laminates for use as a 1-dimensional (1D) flexible shear beam container, or ii) wood-block spacers instead of the rollers when used as a rigid container. In the rigid-wall configuration, additional external massive rigid steel towers are used on either side (in the direction of shaking/laminate motion) to constrain relative motion between the laminates. Additional details regarding the rigid soil box container and the large laminar box container are included in Appendix A.

Among the advantages of the rigid soil box over the large laminar container are the possibilities of modeling larger width (e.g., to help further reduce friction along the lateral boundaries (in the shaking direction), taller wall and backfill configurations, and easier deployment of pressure sensors along the inner side of the container vertical walls. The advantages of the large laminar soil box

(constrained to act as a rigid container) over the rigid soil box emanate mainly from the smaller (but still substantial) overall size and include the relatively lower effort and cost to assemble/dismantle the container and to build the soil backfill, potential for higher peak input base accelerations, and easier control over model height for shorter walls (just by using fewer laminates).

Instrumentation needs for testing in any of the above soil containers is quite similar. This includes pressure cells and/or tactile pressure sensors to record soil pressure where needed, accelerometers to track inertial forces, strain gauges to monitor axial deformation of the concrete wall reinforcement bars at selected locations, and displacement transducers to measure lateral and/or vertical displacements locally at any desired location (relative to the rigid container frame).

LHPOST Full-Scale Retaining Wall Cost Estimates

Below is a breakdown of the cost estimate components. The first experiment in the series involves additional setup, site preparation, soil procurement, and dismantling expenses as shown in Table 3. After the first test, additional experimental setups can be studied at reduced cost and time as shown in Table 4. Detailed cost breakdowns for each Work Element are included in Appendix C.

Table 3 – First LHPOST Test Estimated Costs¹

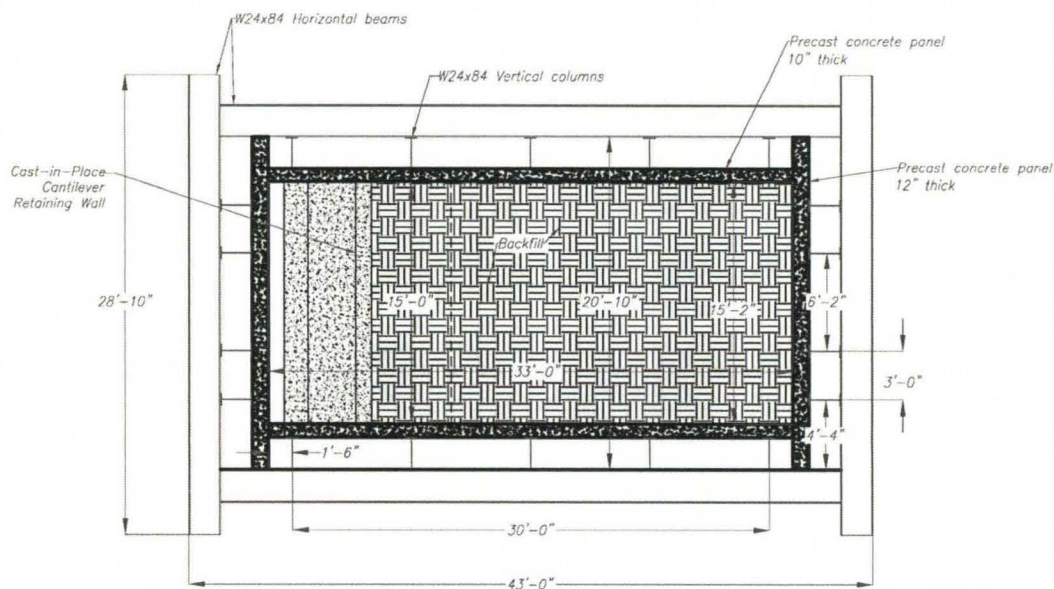
Work Element 1 - Soil Procurement	\$33,548.20
Work Element 2 - Soil Preparation and RC wall construction	\$14,458.40
Work Element 3 - Computational Framework Setup/Calibration/Predictive Estimates	\$46,500.00
Work Element 4 - Container Preparation, Setup and CIP Retaining Wall Construction	\$131,972.00
Work Element 5 - Instrumentation (install and test)	\$185,798.00
Work Element 6 - Soil Placement	\$152,225.50
Work Element 7 - Shake Table Testing (2 months testing duration)	\$213,292.80
Work Element 8 - Soil Removal	\$33,759.00
Work Element 9 - Demobilization and Model Dismantling	\$101,494.00
Work Element 10 - Data Analysis & Report Preparation	\$114,080.00
Subtotal - LHPOST First Test	\$1,027,127.90
Graduate Student Funding and PI Support ²	\$200,000.00
Design Contingencies (10%)	\$102,712.79
Contract Cost – LHPOST First Test	\$1,329,840.69
Construction Contingencies (15%)	\$199,476.10
Field Cost – LHPOST First Test	\$1,529,316.79

Table 4 – Subsequent LHPOST Tests Estimated Costs¹

Grand Total - LHPOST First Test	\$1,027,127.90
Subtract \$100,000 from Facility usage in Work Element 7 (1 month only to conduct test)	-\$100,000.00
Subtract expenses from Work Elements 1 and 3 (soil procurement and computations)	-\$80,048.20
Subtract major portion of Container Building and Dismantling Work (Elements 4 and 9)	-\$200,000.00
Subtract \$50,000 in Dev Tech and Student Expenses (due to reduction in testing time)	-\$50,000.00
Subtract \$70,000 in Work Element 10 (Data Analysis Report)	-\$70,000.00
Reduction in Expenses for Subsequent Test	-\$500,048.20
Subtotal – LHPOST Subsequent Test	\$527,079.70
Design Contingencies (10%)	\$52,707.97
Contract Cost – LHPOST Subsequent Test	\$579,787.67
Construction Contingencies (15%)	\$86,968.15
Field Cost – LHPOST Subsequent Test	\$666,755.82

Notes

1. Estimated time on LHPOST needed for conducting First Test = 2 months (2 weeks to build box, 3 weeks to build model + Instrumentation, including 3 days of testing, 1 week for model removal, and 2 weeks to remove container). Estimated time for conducting each subsequent test is 1 month.
2. Graduate student funding and Principal Investigator (PI) support for 2 additional years suggested to employ the recorded data and to explore various additional prototype scenarios (PhD Thesis effort) at an estimated expense of about \$200,000.

**Figure 10. – Plan of rigid soil box container configuration.**

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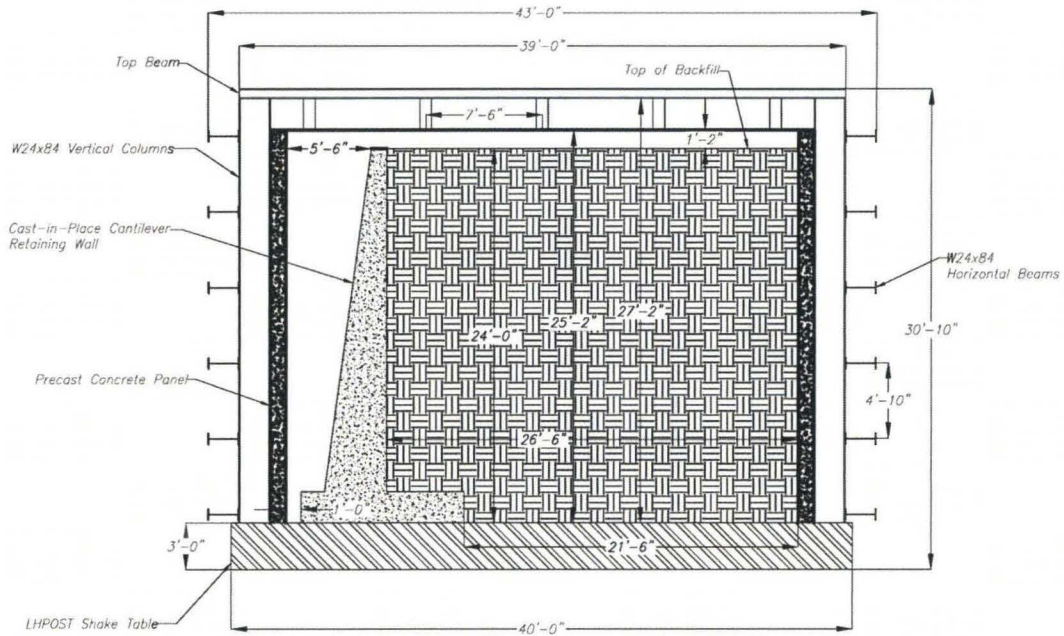


Figure 11. – Typical section of rigid soil box container.

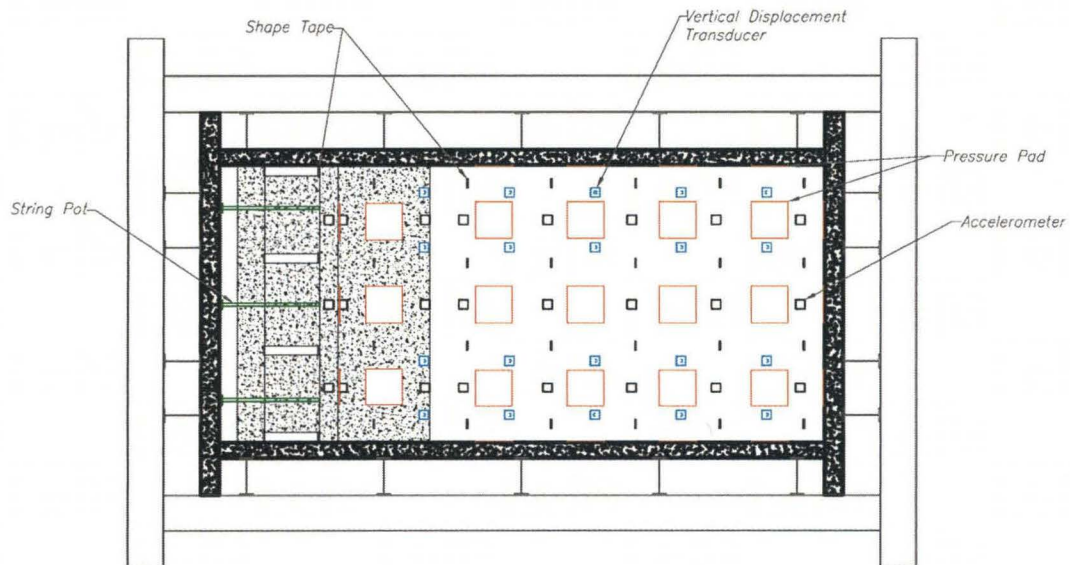


Figure 12. – Plan of rigid soil box container showing instrumentation layout

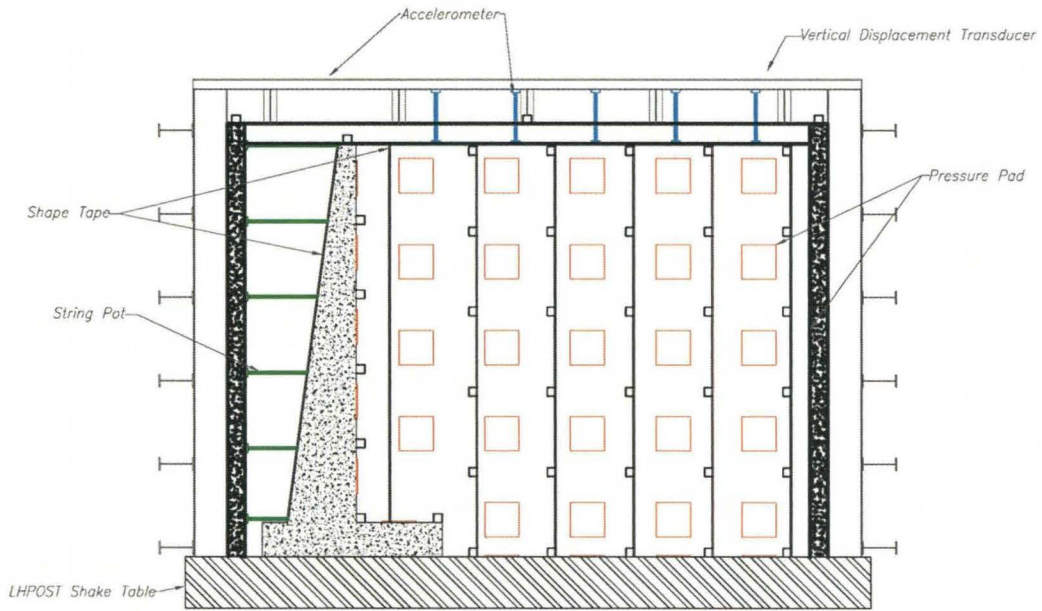


Figure 13. – Typical section of rigid soil box container showing instrumentation layout.

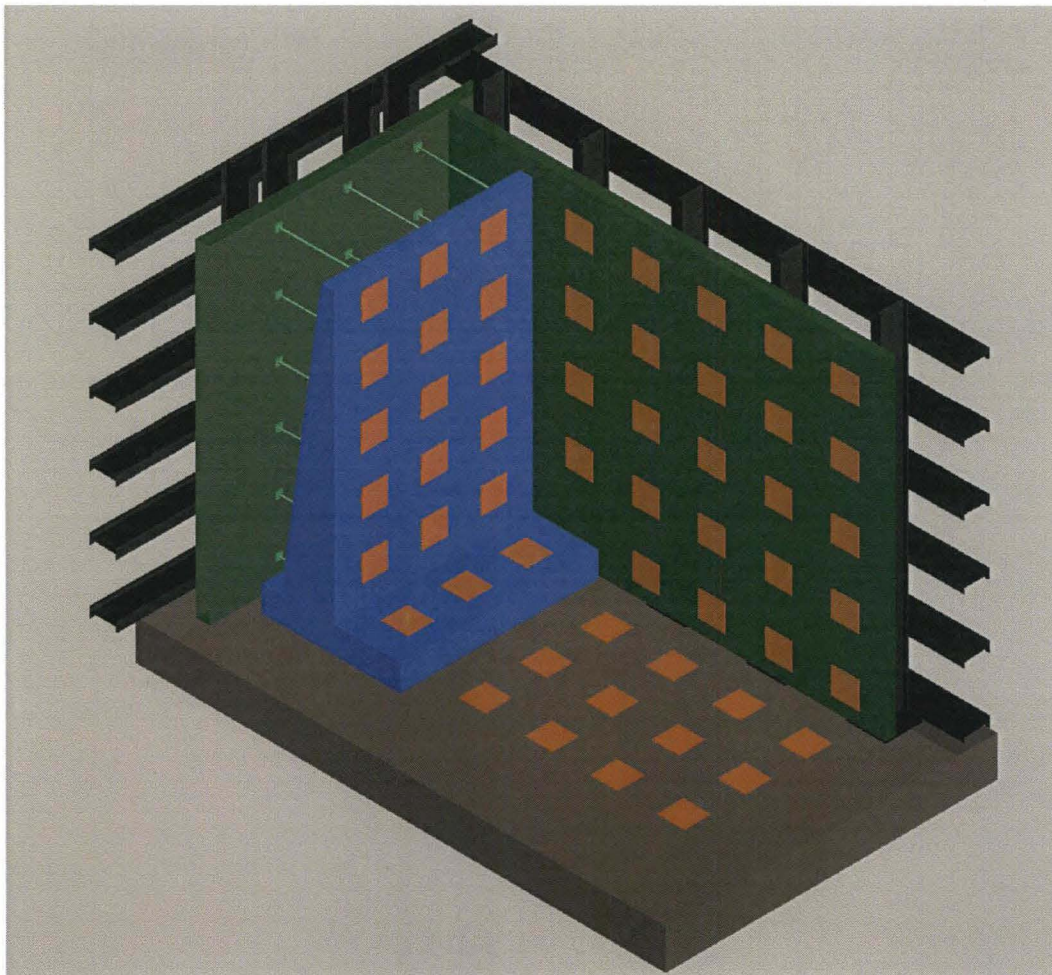


Figure 14. – Isometric solid model view of rigid soil box container experiment.

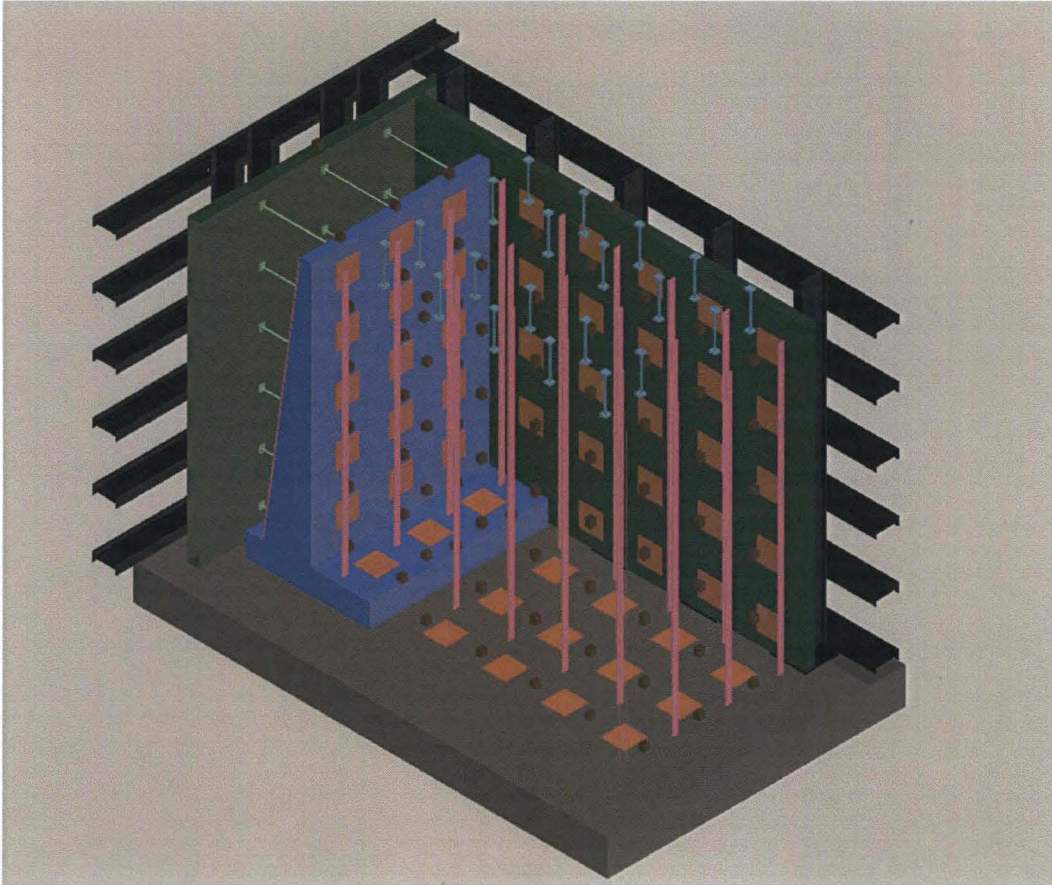


Figure 15. – Schematic layout of LHPOST experiment in rigid soil container showing instrumentation requirements.

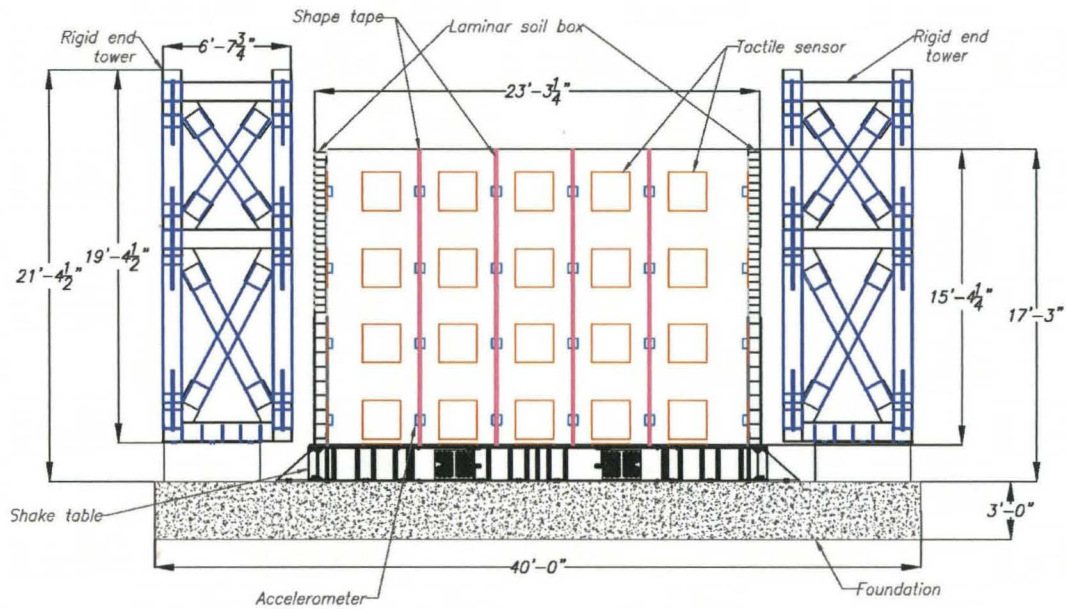


Figure 16. – Typical section of LHPOST large laminar soil box experiment.

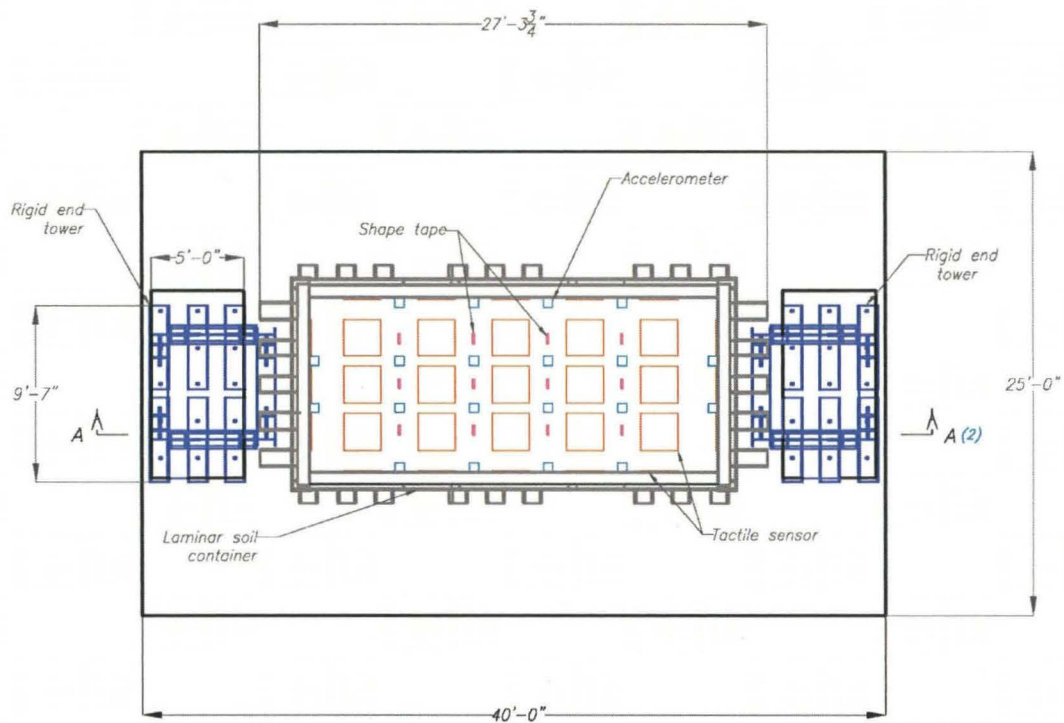


Figure 17. – Typical section plan of LHPOST large laminar soil box experiment including instrumentation layouts.

Soil-Structure Interaction
Phase 3 Feasibility Design
Full-Scale Retaining Wall Shake Table Testing

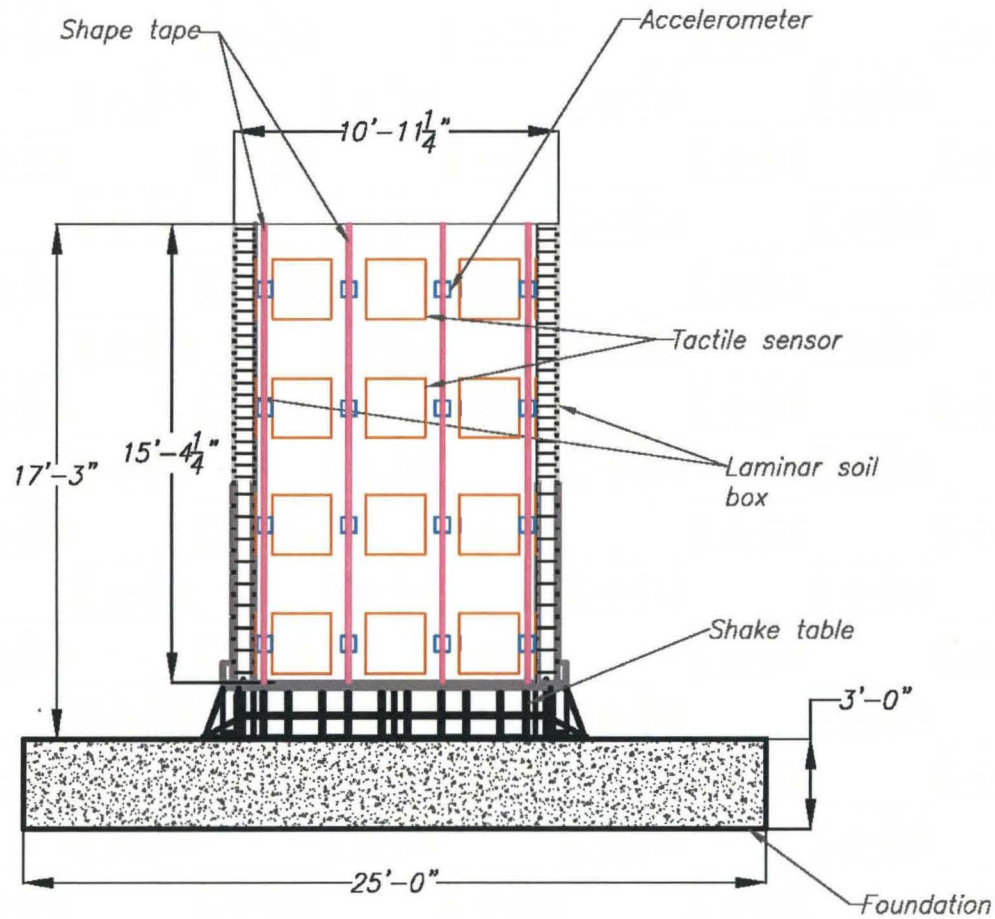


Figure 18. – Typical section of LHPOST large laminar soil box experiment including instrumentation layouts.

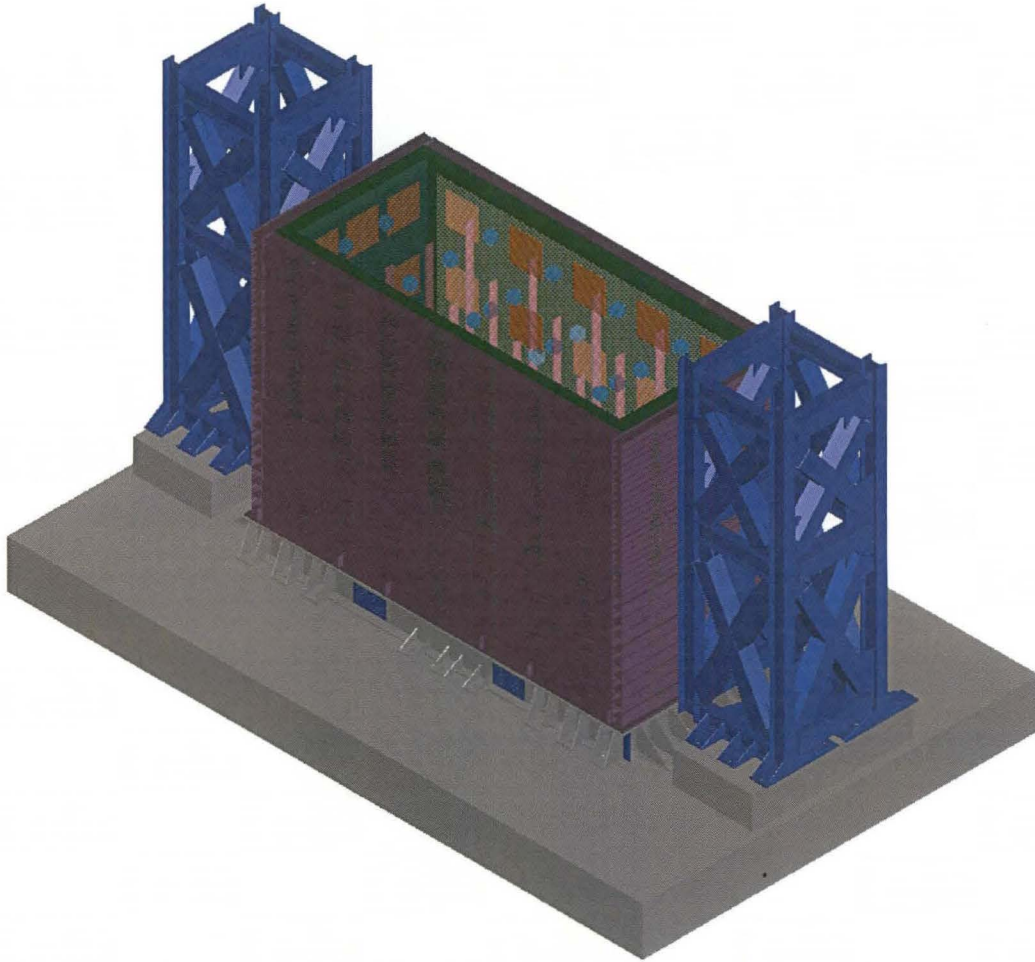


Figure 19. – Schematic layout of LHPOST experiment in large laminar soil box constrained to perform in rigid container mode.

Potential for LHPOST First Test Cost Reductions

Some potential cost savings for completing the first full-scale test on the LHPOST include:

1. Subtract \$200,000 if the US National Science Foundation (current main sponsor of the LHPOST) agrees to include this effort under the Network for Earthquake Engineering Simulation (NEES) consortium framework. If so, all recorded data sets must be freely available in the public domain within 1-year of testing.
2. Subtract \$120,000 if Tactile Sensors are not used (rely on conventional pressure sensors only).
3. Subtract \$80,000 if experiment is conducted in the laminar container (restrained to perform in rigid-container mode) due to the simpler assembly/dismantling efforts.
4. Subtract \$80,000 if rigid foam is used to limit width and increase level of peak input base acceleration (for the wide 19 ft rigid-container configuration and 25 ft wall height, peak input base acceleration would be in the range of 0.7 g (at about 1 Hz frequency), and in the range of 1 g (at about 3 Hz and higher). Narrower rigid container configurations will allow for lower overall weight and permit significantly higher peak input acceleration (e.g., depending on width of the model, 1.2 g or more).

ACKNOWLEDGEMENTS

This report discusses preparations for a research effort to be conducted under the direction of UCSD Professors A. Elgamal, P. J. Fox and J.E. Luco. Professors Fox and Luco provided the necessary materials for key sections of this report. In addition, a number of UCSD co-workers and researchers contributed to the reported cost estimation efforts and to the preparation of various editorial/graphical materials including Mr. Dan Radulesco, Mr. Paul Greco, Dr. Michael Fraser, Mr. Christopher Giacalone, Mr. Andrew Sander, Mr. Xiang Li, and Mr. John Li.

REFERENCES

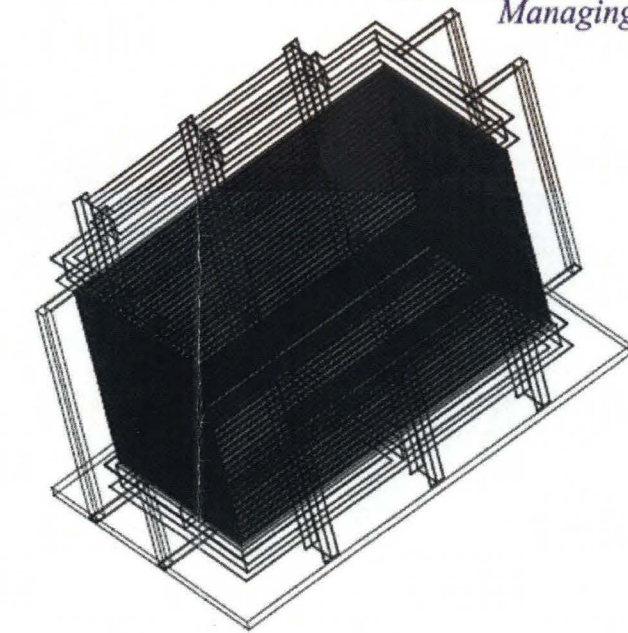
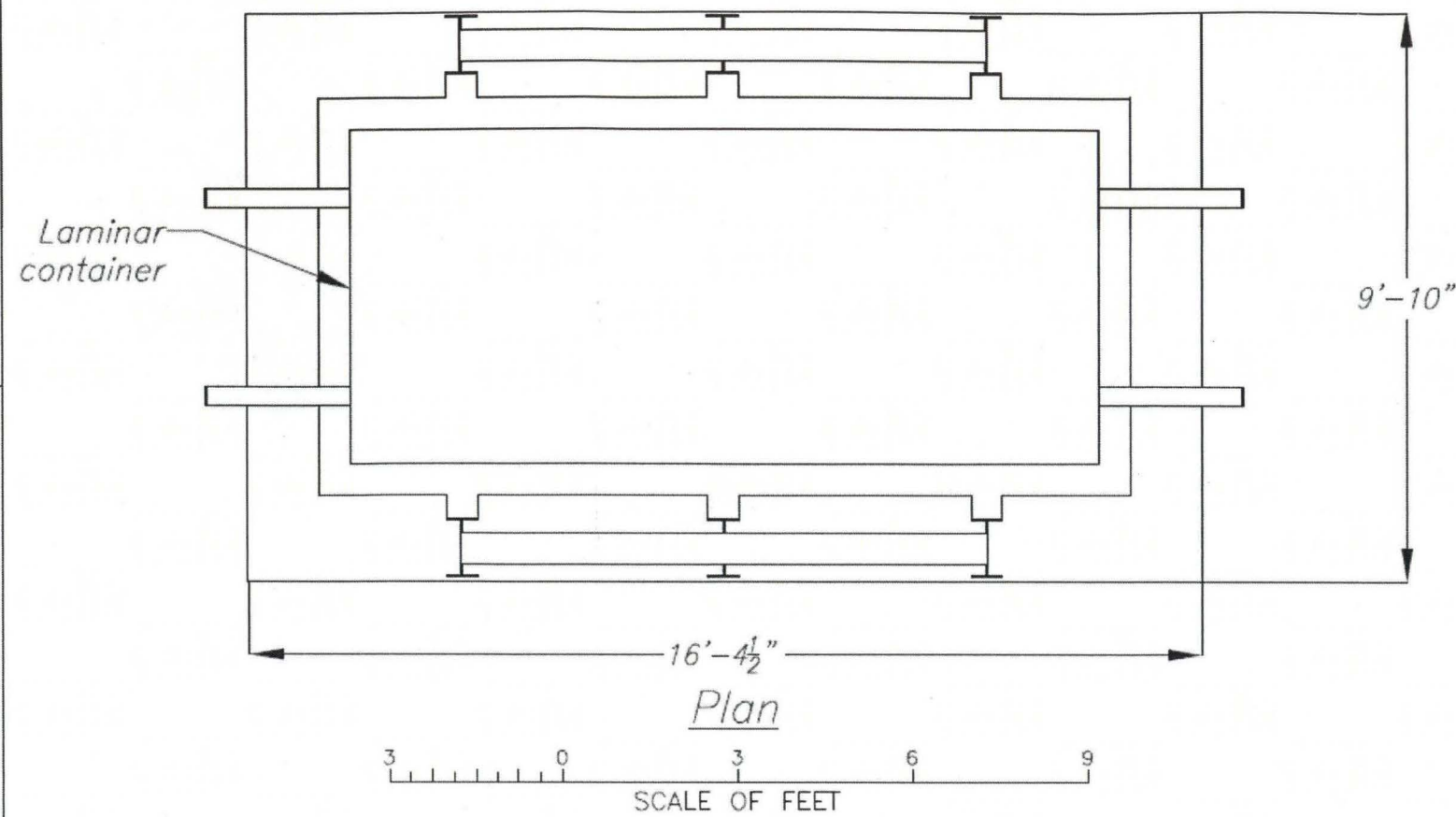
1. Dominic, S., and Liu, M. 2009. "Soil-Structure Interaction - Scoping Phase 1." Dam Safety Technology Development Program, Report DSO-10-01, U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado.
2. Dominic, S., and Nuss, L. 2010. "Soil-Structure Interaction-Planning Phase 2 LHPOST Site Visit." Dam Safety Technology Development Program, Report DSO-11-02, U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado.
3. Wilson, P. 2009. "Large scale passive force-displacement and dynamic earth pressure experiments and simulations." Ph.D. thesis, Dept. of Structural Engineering, University of California, San Diego, La Jolla, California.

APPENDIX A: FEASIBILITY DESIGN DRAWINGS

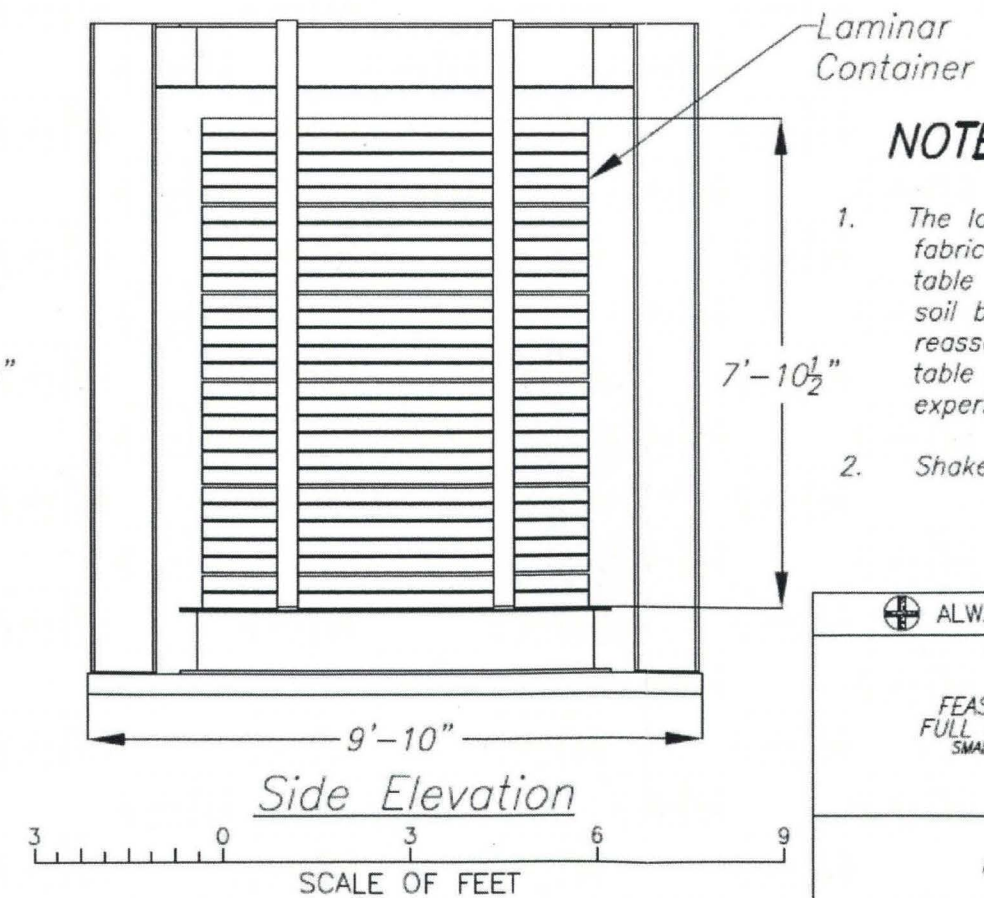
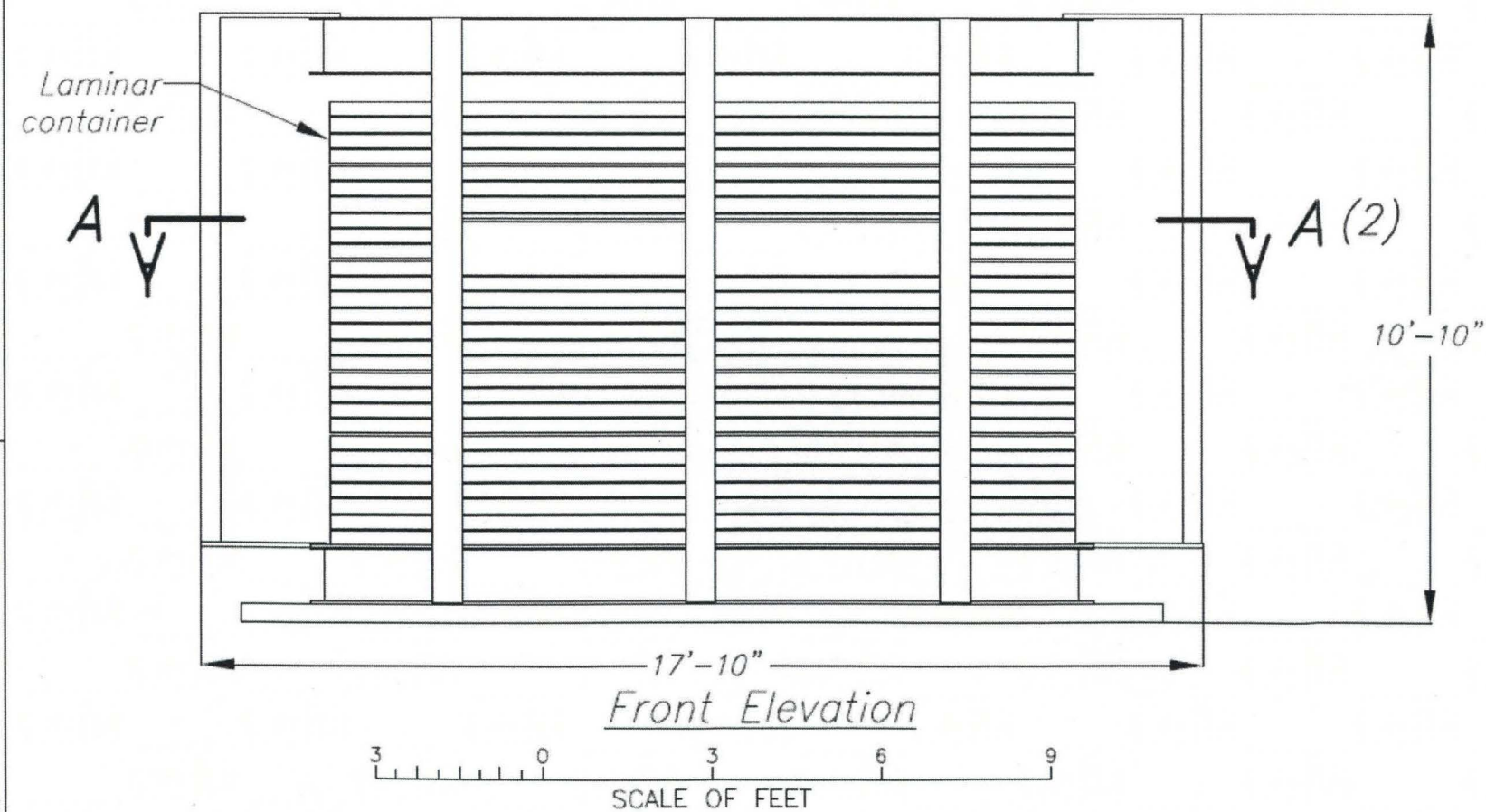
Small Laminar Container

Large Rigid Box

Large Laminar Box



Isometric View
No Scale



NOTES:

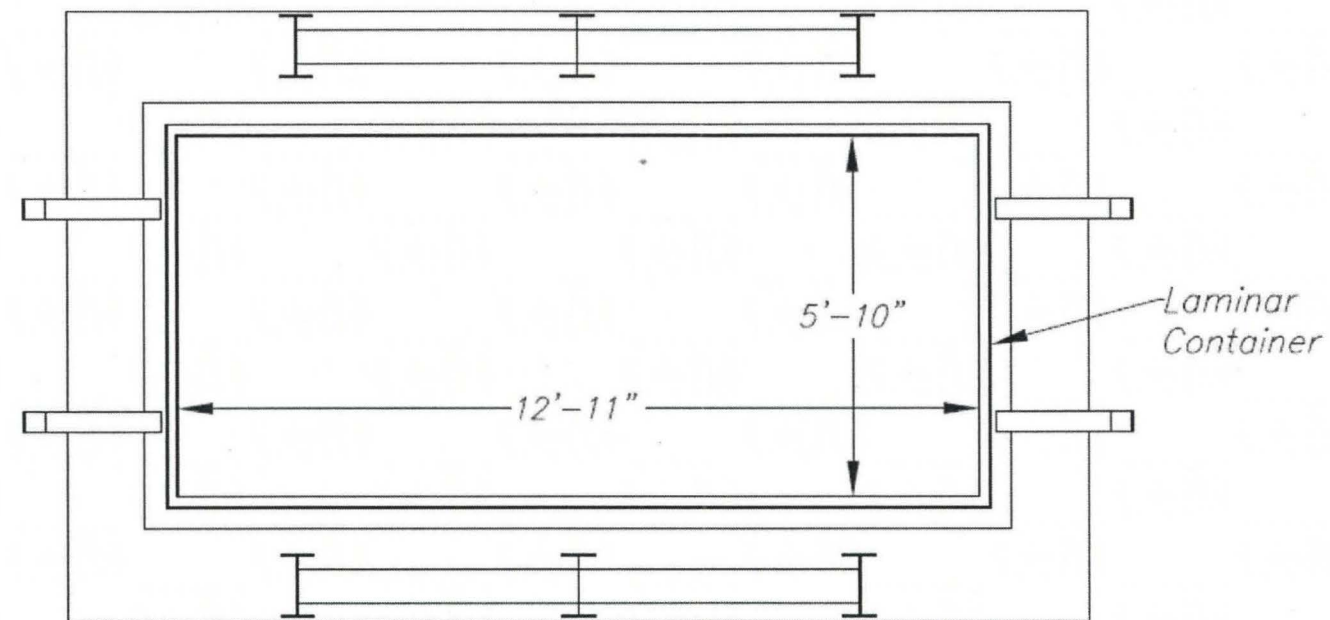
1. The laminar soil box was fabricated for previous shake table experiments. The laminar soil box would need to be reassembled on the shake table to complete this experiment.
2. Shake table not shown.

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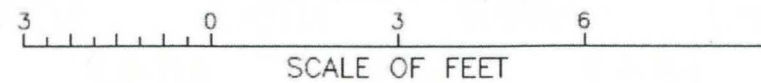
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SSI RESEARCH PROJECT

FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
SMALL LAMINAR SOIL BOX OPTION

PLAN AND ELEVATIONS



Section A-A (1)



NOTES:

1. The retaining wall, backfill, and sensors are not shown.

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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
SMALL LAMINAR SOIL BOX OPTION

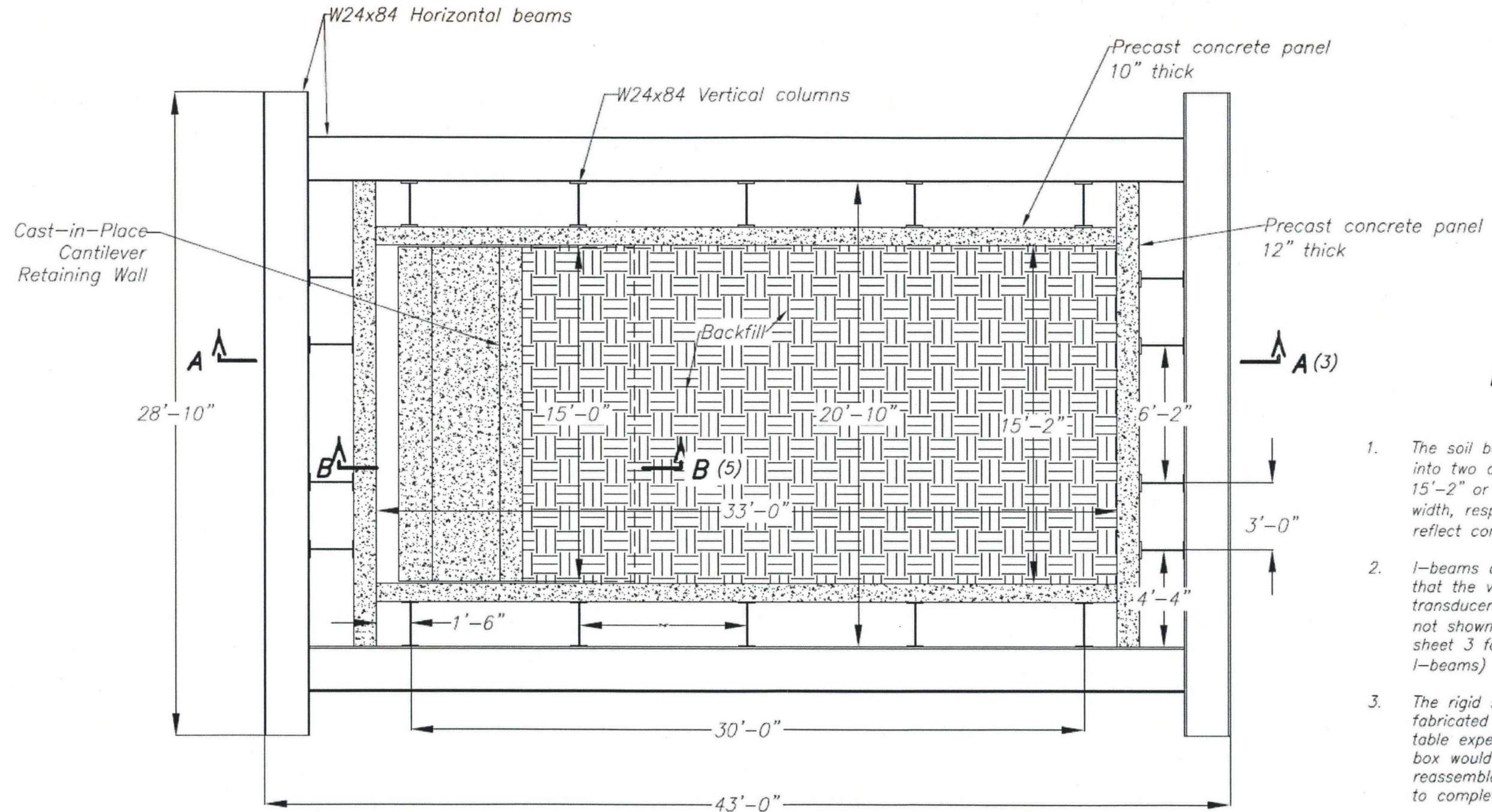
TYPICAL SECTIONAL PLAN

SHEET 2 OF 2

2013-08-09

DATE AND TIME PLOTTED
PLOTTED BY
C. G. G. G.

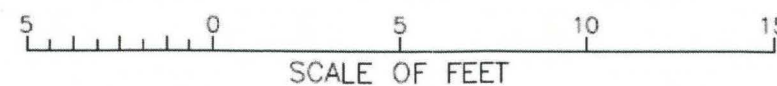
OLD SYSTEM
AUTOMATIC
PLOTTER
UNIVERSITY



NOTES:

1. The soil box can be adjusted into two configurations (A and B), 15'-2" or 19'-2" of internal width, respectively. (Drawings reflect configuration A)
2. I-beams on top of the soil box that the vertical displacement transducers are attached to are not shown for clarity. (Refer to sheet 3 for details of top I-beams)
3. The rigid soil box container was fabricated for previous shake table experiments. The rigid soil box would need to be reassembled on the shake table to complete this experiment.

PLAN - RIGID SOIL BOX OPTION

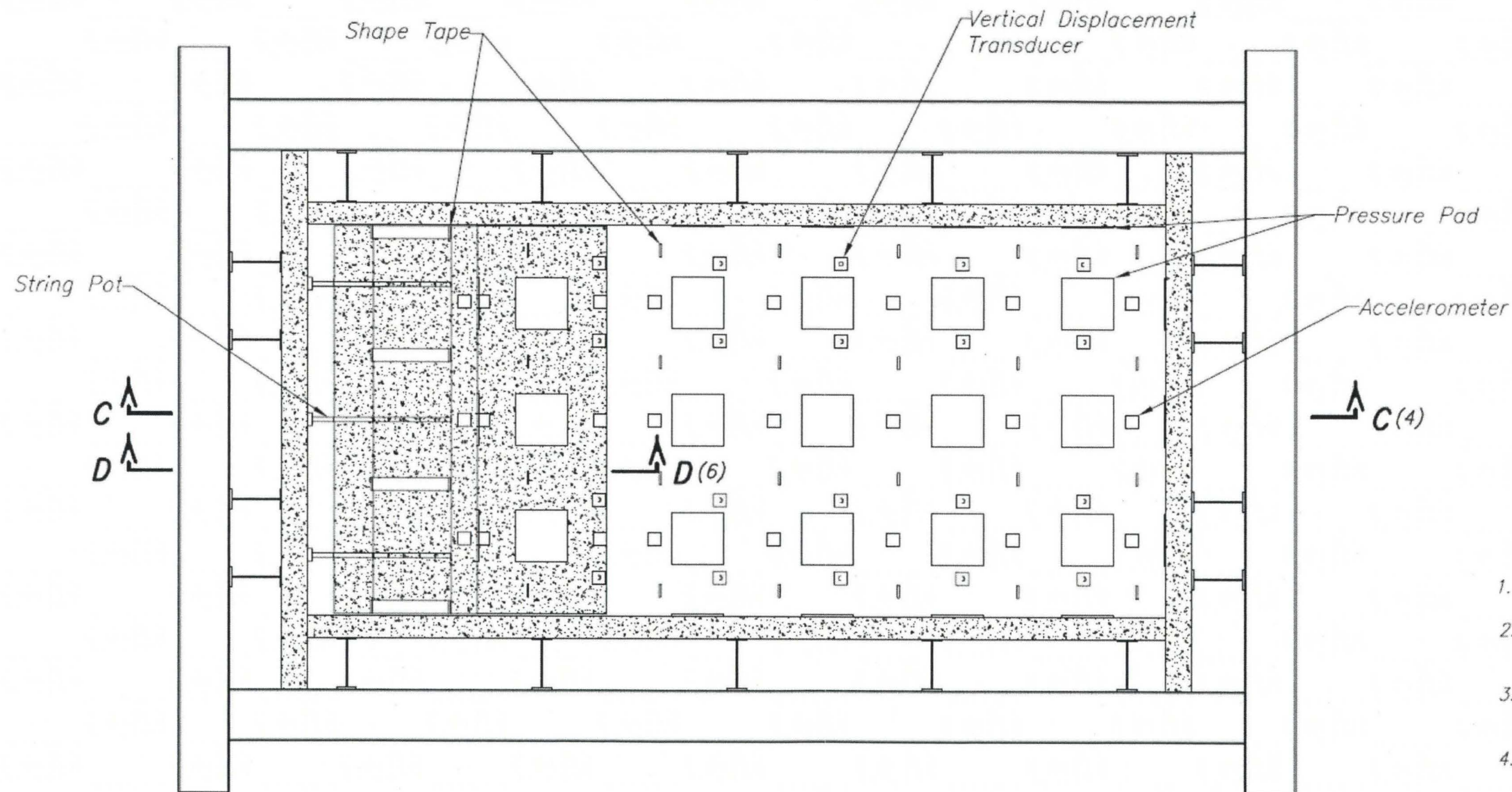


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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
RIGID SOIL BOX OPTION

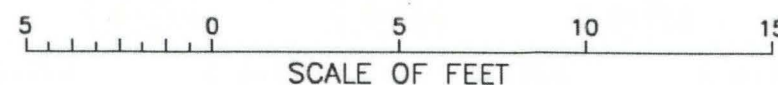
PLAN (GEOMETRY)



NOTES:

1. Sensors are not drawn to scale.
2. Sensors will be placed based on the final soil box configuration.
3. Soil hatch patterns are not shown for clarity.
4. See Sheet 1 for soil box dimensions.

INSTRUMENTATION PLAN - RIGID SOIL BOX OPTION

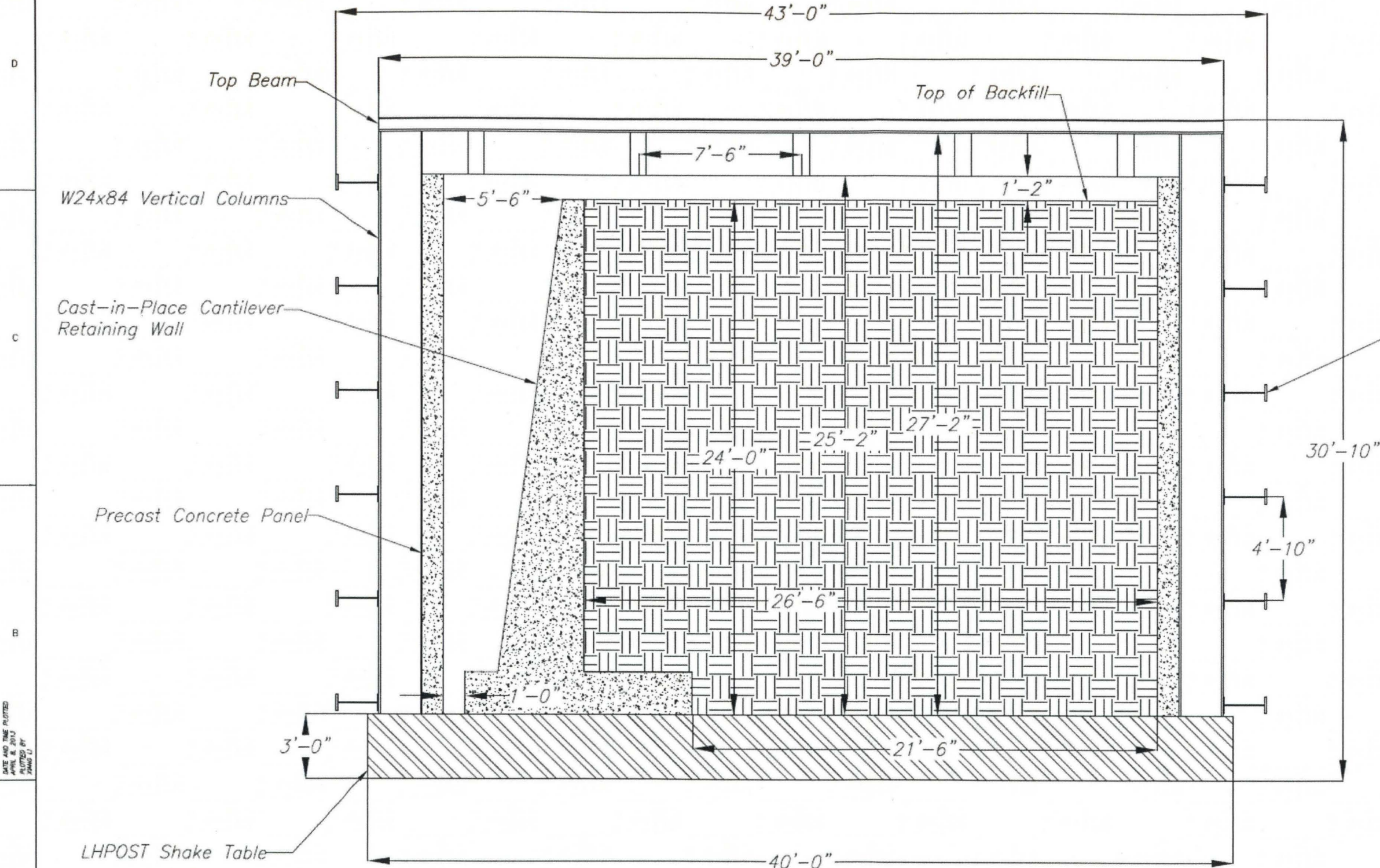


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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
RIGID SOIL BOX OPTION

PLAN (SENSORS)



NOTES:

- 1. Reinforcement not shown.
- 2. Place and compact backfill in 12 inch lifts.

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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
RIGID SOIL BOX OPTION

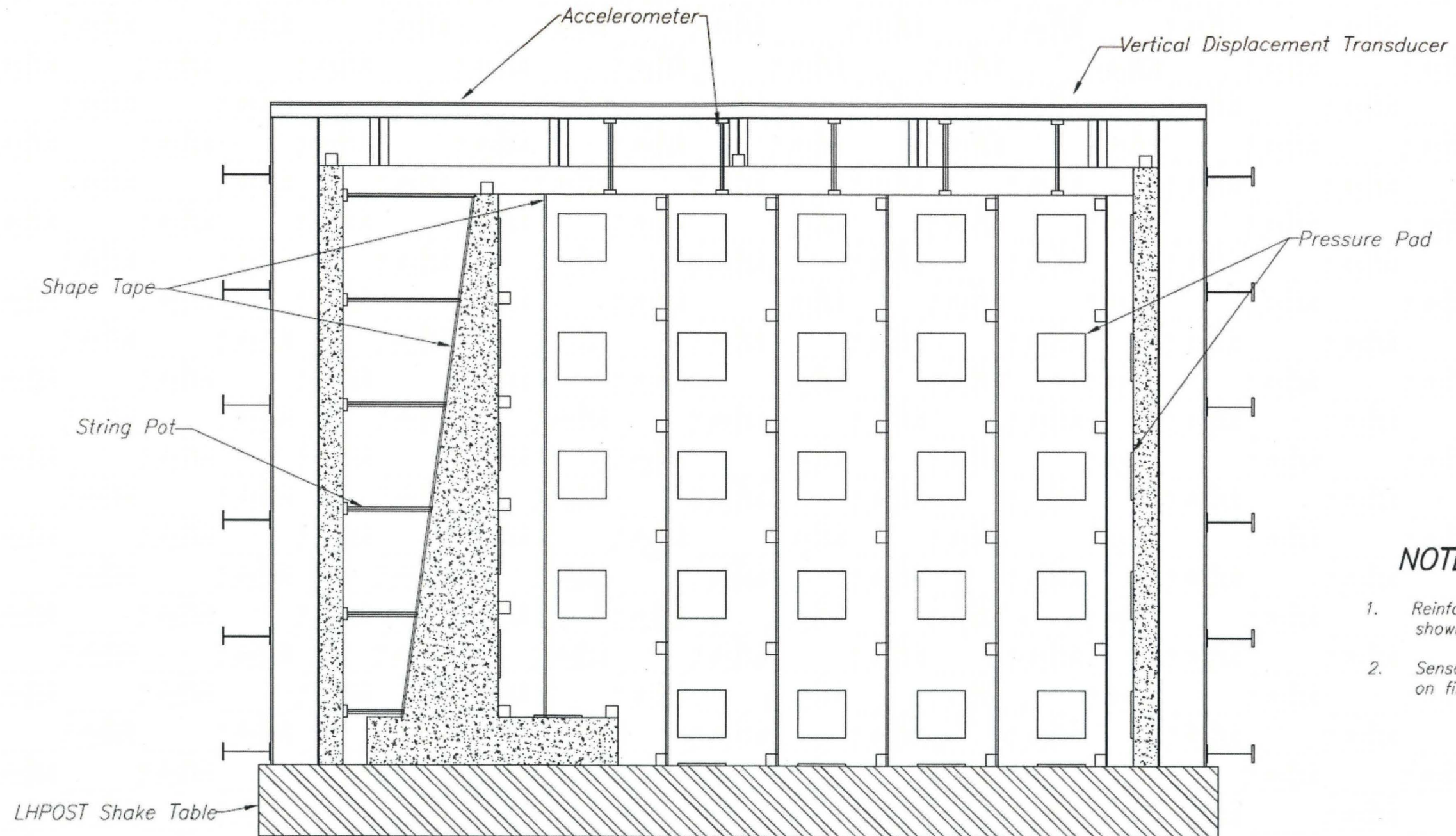
TYPICAL SECTION (GEOMETRY)

SHEET 3 OF 6

2013-08-09

DATE AND TIME PLOTTED
APRIL 8, 2013
PLOT BY
PANDU

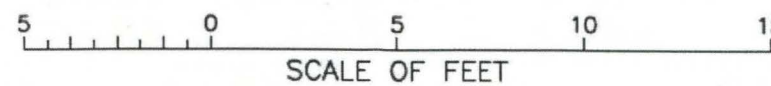
CAD SYSTEM
AUTOCAD
LAYOUT



NOTES:

1. Reinforcement and backfill not shown.
2. Sensors will be placed based on final soil box configuration.

SECTION C-C (2)

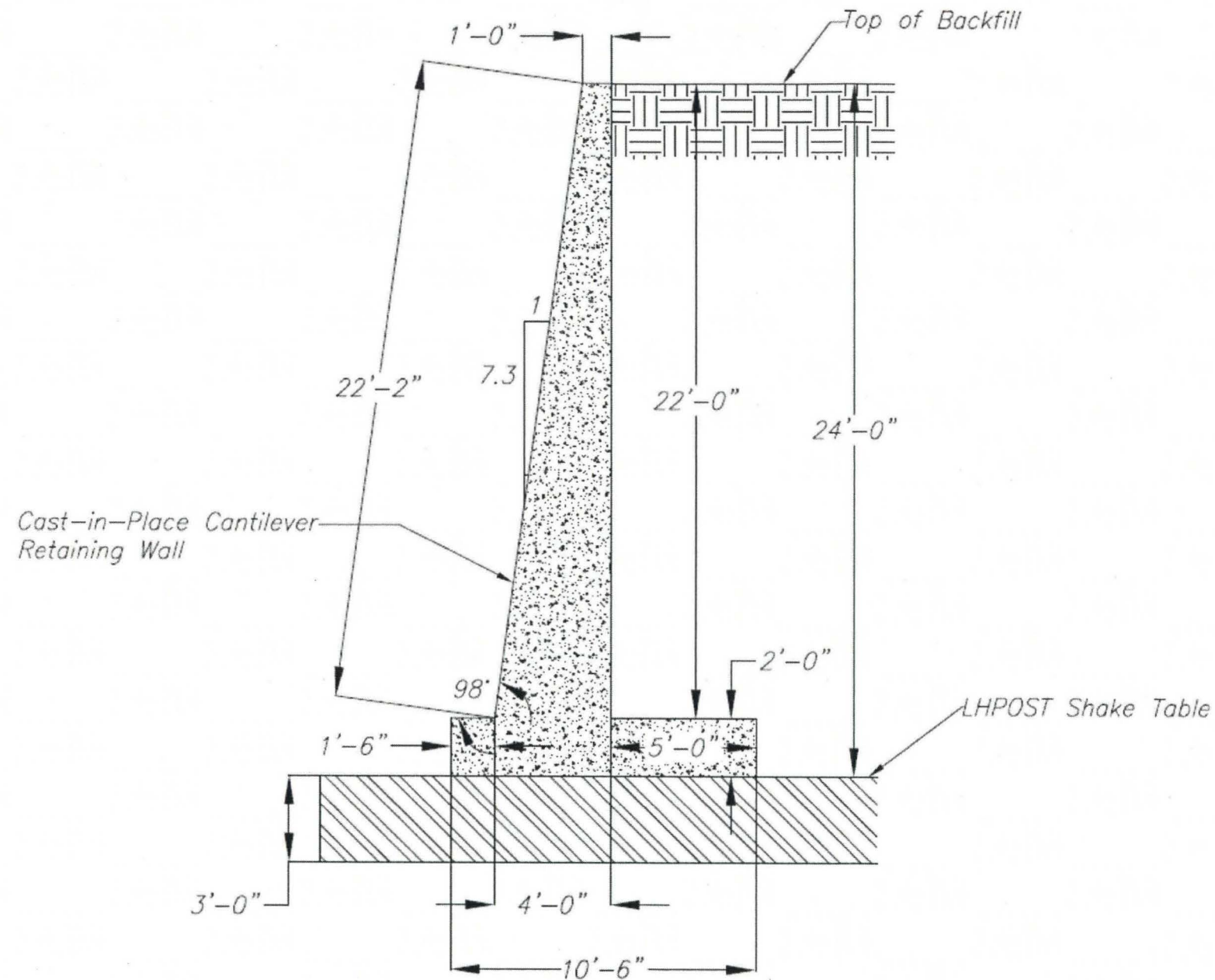


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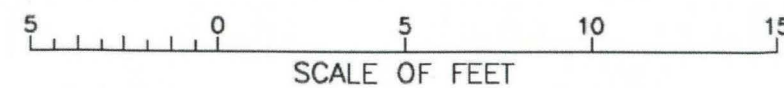
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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
RIGID SOIL BOX OPTION

TYPICAL SECTION (SENSORS)



SECTION B-B (1)



NOTES:

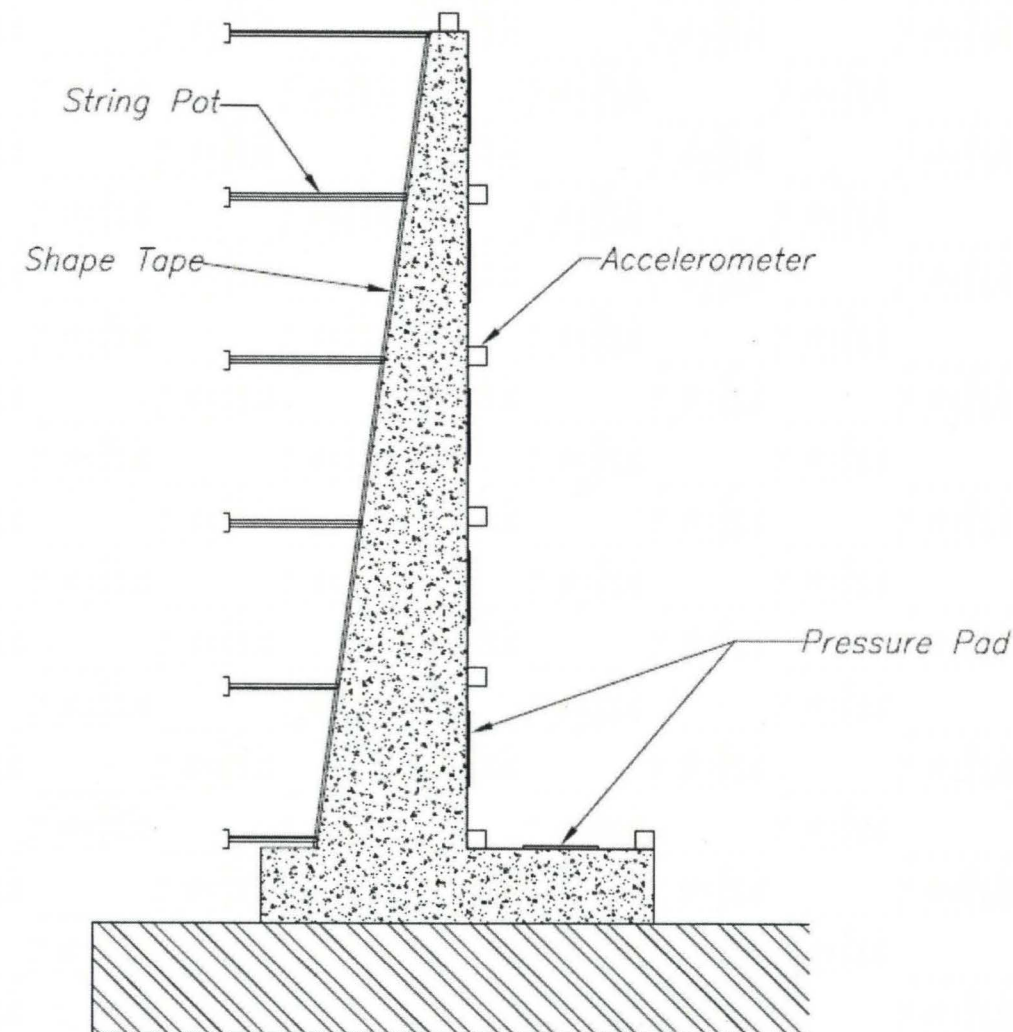
1. Reinforcement not shown.

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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
RIGID SOIL BOX OPTION

CANTILEVER RETAINING WALL SECTION (GEOMETRY)



SECTION D-D (2)

5 0 5 10 15
SCALE OF FEET

NOTES:

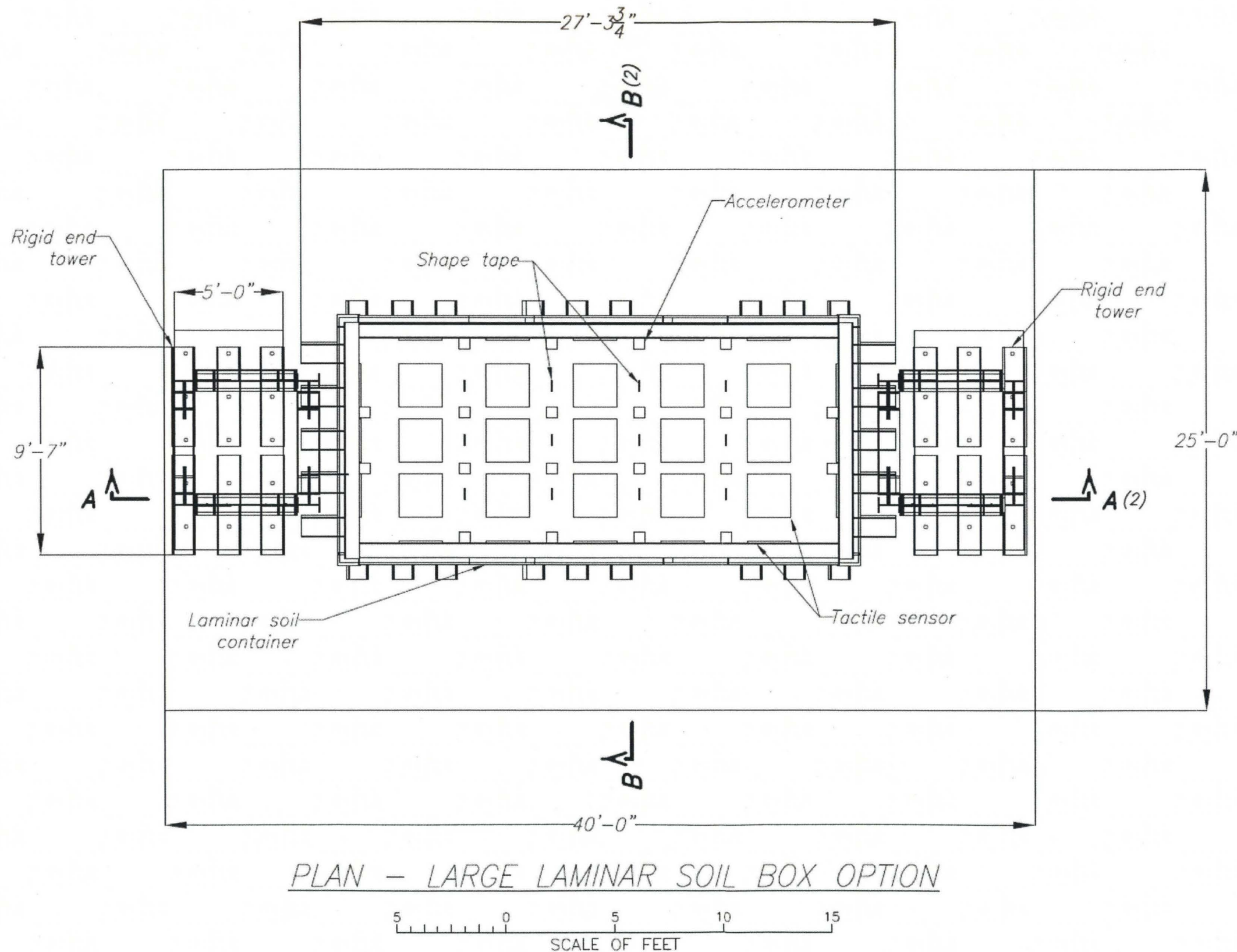
1. Reinforcement and backfill not shown.
2. Sensors are not drawn to scale.
3. Sensor placement may vary depending on final configuration of soil box.

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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
RIGID SOIL BOX OPTION

Cantilever Retaining Wall Section (Sensors)



NOTES:

1. The retaining wall and backfill are not shown
2. The laminar soil box container was fabricated for previous shake table experiments. The rigid soil box would need to be reassembled on the shake table to complete this experiment.

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FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
LARGE LAMINAR SOIL BOX OPTION

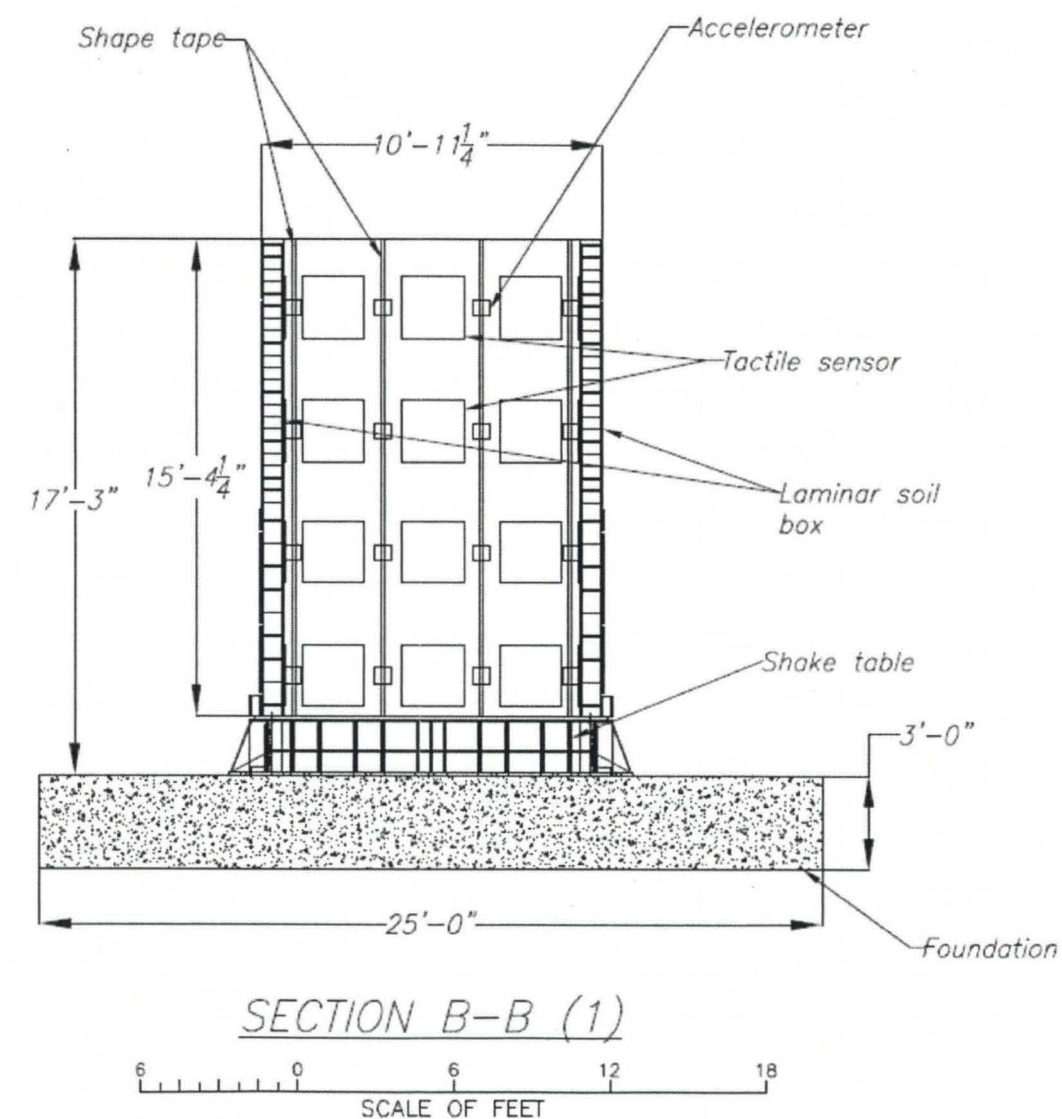
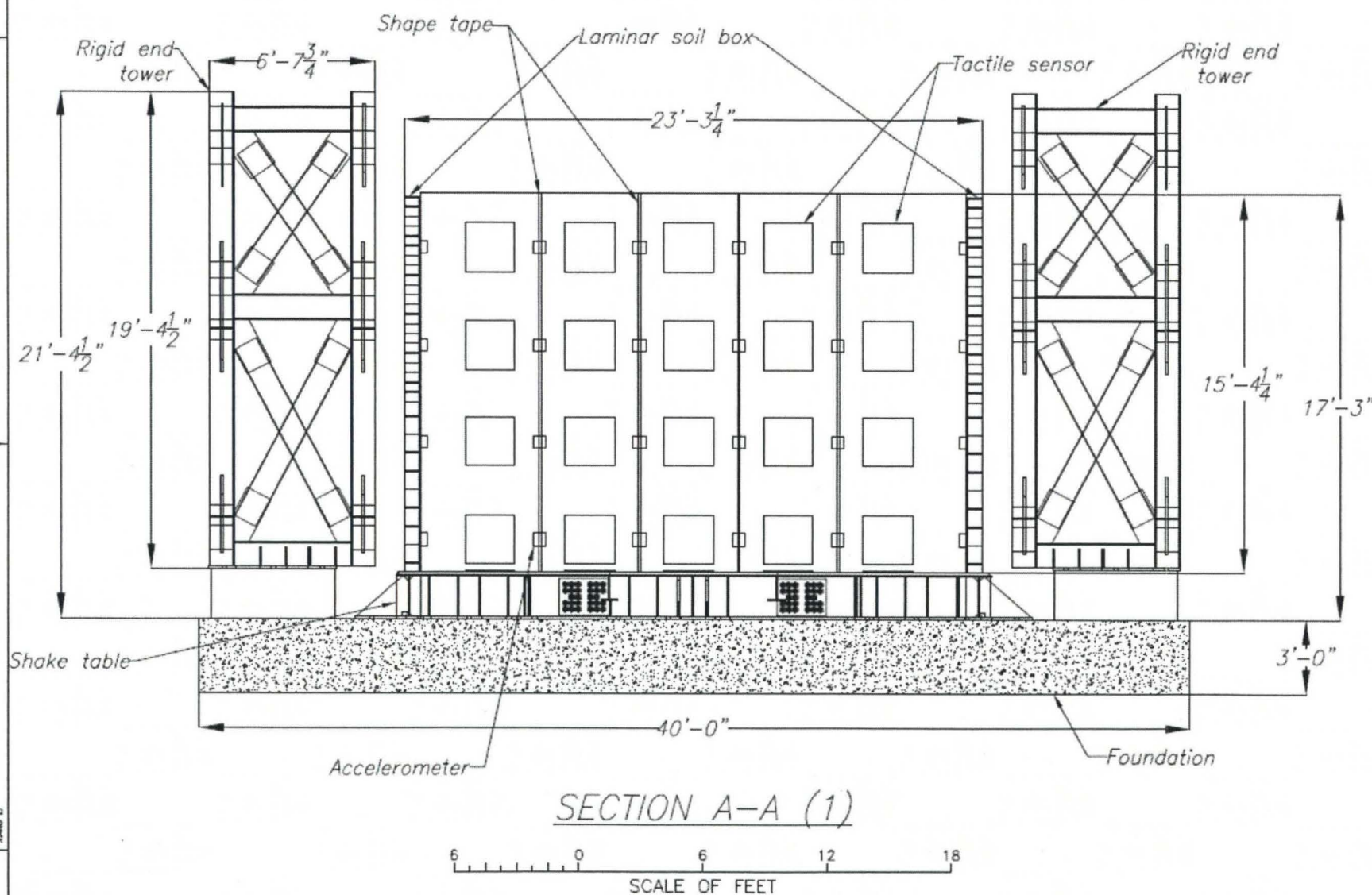
TYPICAL SECTION ELEVATION (GEOMETRY)

SHEET 1 OF 2

2013-06-08

DATE AND TIME PLOTTED
PLAN AND
PLOTTED BY
JANUARY 11

DATE PLOTTED
AND PLOTTED BY
JANUARY 11



NOTES:

1. The retaining wall, backfill, and sensors are not shown
2. The laminar soil box container was fabricated for previous shake table experiments. The rigid soil box would need to be reassembled on the shake table to complete this experiment.

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SSI RESEARCH PROJECT

FEASIBILITY LEVEL DESIGN
FULL SCALE RETAINING WALL
LARGE LAMINAR SOIL BOX OPTION

TYPICAL SECTION ELEVATION (GEOMETRY)

SHEET 2 OF 2

2013-08-08

DATE AND TIME PLOTTED
TYPICAL SECTION ELEVATION (GEOMETRY)
PLOTTED BY
JANG, J.

QAD SYSTEM
AUTOCAD
QAD PLENAIRE
UNIVERSITY

APPENDIX B: PILOT 6.7 FT (2 M) WALL TESTING TASK AND EXPENSE BREAKDOWN

First Test

Work Element 1 - Soil Procurement

Description	Quantity	Unit	Hours	Rate	Total	Note
Soil Purchase	19	yd ³	-	LS	\$3,000.00	1
Delivery	1	LS	-	-	\$500.00	-
Short-term Storage/Stockpile	-	-	-	-	\$500.00	-
Overhead (55%)					\$2,200.00	-
Total - Work Element 1					\$6,200.00	-

Work Element 2 - Soil Preparation

Item	Quantity	Unit	Hours	Rate	Total	Note
Lab Testing of Soil	1	Engineer	40	\$67.00	\$2,680.00	2
Lab Testing of Soil	1	Student	80	\$32.00	\$2,560.00	2
Moisture Conditioning	1	Engineer	8	\$67.00	\$536.00	3
Moisture Conditioning	1	Student	16	\$32.00	\$512.00	3
Soil Preparation	1	Student	8	\$32.00	\$256.00	4
Overhead (55%)					\$3,599.20	-
Total - Work Element 2					\$10,143.20	-

Work Element 3 - Computational Framework Setup/Calibration/Predictive Estimates

Item	Quantity	Unit	Hours	Rate	Total	Note
Numerical / Predictive Modeling	1	LS	-	\$20,000.00	\$20,000.00	5
Overhead (55%)					\$11,000.00	-
Total - Work Element 3					\$31,000.00	-

Work Element 4 - Container Preparation, Setup and CIP Retaining Wall Construction

Item	Quantity	Unit	Hours	Rate	Total	Note
Soil Box Preparation/Cleaning	1	Student	16	\$32.00	\$512.00	-
Soil Box Assembly	2	Dev. Tech	40	\$55.00	\$4,400.00	-
Liner (purchase and installation)	1	ea	-	-	\$3,000.00	-
Retaining Wall Design	1	Student	24	\$32.00	\$768.00	-
Retaining Wall Construction	4	yd ³	-	\$2,000.00	\$8,000.00	-
Overhead (55%) *Liner Excluded					\$7,524.00	-
Total - Work Element 4					\$24,204.00	-

Work Element 5 - Instrumentation (install and test)

Item	Quantity	Unit	Hours	Rate	Total	Note
Strain Gages	24	ea	-	\$100.00	\$2,400.00	6
Displacement Transducers	12	ea	-	\$50.00	\$600.00	6
Accelerometers	16	ea	-	\$50.00	\$800.00	6
Pressure Transducers	12	ea	-	\$600.00	\$7,200.00	7
Shape Tape	14	ft	-	\$280.00	\$3,920.00	7
Tactile Sensors (12"x18")	1	ea	-	\$24,000.00	\$24,000.00	7
Cameras	2	ea	-	\$200.00	\$400.00	6
Overhead (55%) *Tactile Sensor Excluded					\$8,426.00	-
Total - Work Element 5					\$47,746.00	-

Work Element 6 - Soil Placement

Item	Quantity	Unit	Hours	Rate	Total	Note
Soil Placement & Compaction	2	Dev. Tech	40	\$55.00	\$4,400.00	8
Soil Placement & Compaction	2	Student	40	\$32.00	\$2,560.00	8
Bobcat	1	ea	40	\$40.00	\$1,600.00	9
Conveyor	1	ea	40	\$25.00	\$1,000.00	10
Compactor	1	ea	40	\$30.00	\$1,200.00	11
Density Testing - Sand Cone	24	ea	-	\$25.00	\$600.00	12
Density Testing - Nuke Gage	4	ea	-	\$40.00	\$160.00	12
CPT	1	day	-	\$1,500.00	\$1,500.00	13
Overhead (55%)					\$7,161.00	-
Total - Work Element 6					\$20,181.00	-

Work Element 7 - Shake Table Testing

Item	Quantity	Unit	Hours	Rate	Total	Note
Shake Table Usage	1	Dev. Tech	40	\$55.00	\$2,200.00	-
Overhead (55%)					\$1,210.00	-
Total - Work Element 7					\$3,410.00	-

Work Element 8 - Soil Removal

Item	Quantity	Unit	Hours	Rate	Total	Note
Lab Testing of Soil	1	Student	24	\$32.00	\$768.00	14
Excavate/Remove Backfill	1	Dev. Tech	24	\$55.00	\$1,320.00	-
Stockpile used soil	1	ea	-	LS	\$500.00	-
Overhead (55%)					\$1,423.40	-
Total - Work Element 8					\$4,011.40	-

Work Element 9 - Demobilization and Model Dismantling

Item	Quantity	Unit	Hours	Rate	Total	Note
Remove Soil Box	1	Student	16	\$32.00	\$512.00	-
Remove Soil Box	1	Dev. Tech	8	\$55.00	\$440.00	-
Soil Disposal	1	LS	-	-	\$1,500.00	-
Retaining Wall Disposal	1	ea	-	-	\$1,000.00	-
Bobcat	1	ea	8	\$40.00	\$320.00	-
Overhead (55%)					\$2,074.60	-
Total - Work Element 9					\$5,846.60	-

Work Element 10 - Data Analysis & Report Preparation

Item	Quantity	Unit	Hours	Rate	Total	Note
Post-processing and Analysis	1	Student	480	\$32.00	\$15,360.00	-
Post-processing and Analysis	1	Engineer	10	\$67.00	\$670.00	-
Post-processing and Analysis	1	P.I.	-	-	\$9,000.00	-
Overhead (55%)					\$13,766.50	-
Total - Work Element 10					\$38,796.50	-

Subtotal - Pilot Shake Table Test	\$191,538.70
Design Contingencies (10%)	\$19,153.87
Contract Cost	\$210,692.57
Construction Contingencies (15%)	\$31,603.89
Field Cost	\$242,296.46

Subsequent Pilot Tests

Work Element 1 - Soil Procurement

Description	Quantity	Unit	Hours	Rate	Total	Note
Soil Purchase	19	yd ³	-	LS	\$3,000.00	-
Delivery	1	LS	-	-	\$500.00	-
Short-term Storage/Stockpile	-	-	-	-	\$500.00	-
Overhead (55%)					\$2,200.00	-
Total - Work Element 1					\$6,200.00	-

Work Element 2 - Soil Preparation

Item	Quantity	Unit	Hours	Rate	Total	Note
Lab Testing of Soil	1	Engineer	0	\$67.00	\$0.00	-
Lab Testing of Soil	1	Student	40	\$32.00	\$1,280.00	-
Moisture Conditioning	1	Engineer	16	\$67.00	\$1,072.00	-
Moisture Conditioning	1	Student	8	\$32.00	\$256.00	-
Soil Preparation	1	Student	8	\$32.00	\$256.00	-
Overhead (55%)					\$1,575.20	-
Total - Work Element 2					\$4,439.20	-

Work Element 3 - Computational Framework Setup/Calibration/Predictive Estimates

Item	Quantity	Unit	Hours	Rate	Total	Note
Numerical / Predictive Modeling	1	LS	-	\$0.00	\$0.00	-
Overhead (55%)					\$0.00	-
Total - Work Element 3					\$0.00	-

Work Element 4 - Container Preparation and Setup

Item	Quantity	Unit	Hours	Rate	Total	Note
Soil Box Preparation/Cleaning	1	Student	0	\$32.00	\$0.00	-
Soil Box Assembly	2	Dev. Tech	0	\$55.00	\$0.00	-
Liner (purchase and installation)	1	ea	-	-	-	-
Overhead (55%)					\$0.00	-
Total - Work Element 4					\$0.00	-

Work Element 5 - Instrumentation (install and test)

Item	Quantity	Unit	Hours	Rate	Total	Note
Strain Gages	3	ea	-	\$100.00	\$300.00	-
Displacement Transducers	0	ea	-	\$50.00	\$0.00	-
Accelerometers	32	ea	-	\$50.00	\$1,600.00	-
Pressure Transducers	0	ea	-	\$600.00	\$0.00	-
Shape Tape	0	ft	-	\$280.00	\$0.00	-
Tactile Sensors (12"x18")	0	ea	-	\$2,000.00	\$0.00	-
Cameras	2	ea	-	\$200.00	\$400.00	-
Overhead (55%) * Excludes Pressure Transducers, Shape Tape & Tactile Sensors					\$1,265.00	-
Total - Work Element 5					\$3,565.00	-

Work Element 6 - Soil Placement

Item	Quantity	Unit	Hours	Rate	Total	Note
Soil Placement & Compaction	2	Dev. Tech	40	\$55.00	\$4,400.00	-
Soil Placement & Compaction	1	Student	40	\$32.00	\$1,280.00	-
Bobcat	1	ea	0	\$40.00	\$0.00	-
Conveyor	1	ea	40	\$25.00	\$1,000.00	-
Compactor	1	ea	40	\$30.00	\$1,200.00	-
Density Testing - Sand Cone	24	ea	-	\$25.00	\$600.00	-
Density Testing - Nuke Gage	4	ea	-	\$40.00	\$160.00	-
CPT	1	day	-	\$1,500.00	\$1,500.00	-
Overhead (55%)					\$5,577.00	-
Total - Work Element 6					\$15,717.00	-

Work Element 7 - Shake Table Testing

Item	Quantity	Unit	Hours	Rate	Total	Note
Shake Table Usage	1	Dev. Tech	8	\$55.00	\$440.00	-
Overhead (55%)					\$242.00	-
Total - Work Element 7					\$682.00	-

Work Element 8 - Soil Removal

Item	Quantity	Unit	Hours	Rate	Total	Note
Lab Testing of Soil	1	Student	0	\$32.00	\$0.00	-
Excavate/Remove Backfill	2	Student	40	\$32.00	\$2,560.00	-
Stockpile used soil	1	ea	-	LS	\$500.00	-
Overhead (55%)					\$1,683.00	-
Total - Work Element 8					\$4,743.00	-

Work Element 9 - Demobilization and Model Dismantling

Item	Quantity	Unit	Hours	Rate	Total	Note
Remove Soil Box	0	Student	16	\$32.00	\$0.00	-
Remove Soil Box	0	Dev. Tech	8	\$55.00	\$0.00	-
Soil Disposal	0	LS	-	-	\$1,500.00	-
Bobcat	0	ea	8	\$40.00	\$0.00	-
Overhead (55%)					\$0.00	-
Total - Work Element 9					\$1,500.00	-

Work Element 10 - Data Analysis & Report Preparation

Item	Quantity	Unit	Hours	Rate	Total	Note
Post-processing and Analysis	1	Student	200	\$32.00	\$6,400.00	-
Post-processing and Analysis	1	Engineer	20	\$67.00	\$1,340.00	-
Post-processing and Analysis	1	P.I.	-	-	\$2,000.00	-
Overhead (55%)					\$5,357.00	-
Total - Work Element 10					\$15,097.00	-

Subtotal – Additional Pilot Shake Table Test	\$51,943.20
Design Contingencies (10%)	\$5,194.32
Contract Cost	\$57,137.52
Construction Contingencies (15%)	\$8,570.63
Field Cost	\$65,708.15

Note	Description
1	Suitable soils have been identified and preliminary laboratory tests completed on samples from Vulcan Soils and Scott Sales.
2	Laboratory testing to include sieve analysis (ASTM D4829), moisture content and maximum dry density determination (ASTM D1557), moisture content and dry density determination (ASTM D2216), gradation analysis with hydrometer (ASTM D422), etc.
3	Based on laboratory testing (ASTM D2216 and ASTM D1557), soils will be moisture conditioned prior to placement and compaction.
4	As necessary, soils will be screened or blended to get desired mechanical properties.
5	Computational framework set-up/calibration/predictive estimates.
6	Sensors from current UCSD inventory will be utilized for testing. Costs are associated with installation and verification testing.
7	New sensors will have to be procured (and are included within costs herein). These sensors may be re-used on large-scale tests.
8	Soils shall be placed in 8 to 12 inch lifts and compacted to 90-95% of the maximum dry density (ASTM D1557).
9	It will be necessary to rent a Bobcat to move the soils from the stockpile to the conveyor.
10	A conveyor will be utilized to place soils in the soil box.
11	A walk behind vibrating compactor shall be utilized to compact soils to 95% of the maximum dry density (ASTM D1557).
12	Density of compacted soils to be verified via sand cones (ASTM D1556) and nuclear gage testing (ASTM D6938).
13	Cone Penetration Testing (CPT) to be performed as necessary for characterizing compacted soil profiles.
14	Upon completion of shake table testing, soils will be excavated and samples retrieved for moisture content determination.

FEATURE: Pilot Scale Retaining Wall Dynamic Shake Table Test		PROJECT: Soil-Structure Interaction Phase 3 Feasibility Level Design					
		WOID: SSINT		ESTIMATE LEVEL: Feasibility			
		REGION: DO		UNIT PRICE LEVEL: Aug - 13			
Dam Safety Technology Development Program		FILE: U:\SSI Research Project - Phase 3 Year 2\UCSD Deliverables\Draft Reports\Cost Estimate Pilot Test 09-26-13 for final review.xlsx\Pilot Shake Table Test - 1 of 2					
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
Labor During Testing							
	17	Student		744	hours	\$49.60	\$36,902.40
	18	Engineer		58	hours	\$103.85	\$6,023.30
	19	Development Technician		232	hours	\$85.25	\$19,778.00
	20	P.I.		1	ls	\$13,950.00	\$13,950.00
	21	Numerical/Predictive Modeling		1	ls	\$31,000.00	\$31,000.00
SUBTOTAL LABOR ITEMS							\$107,653.70
Summary							
		Subtotals:-					
		- Civil Items					\$26,250.00
		- Equipment Rental Items					\$6,386.00
		- Instrumentation Items					\$51,249.00
		- Labor					\$107,653.70
		Subtotal 1					\$191,538.70
		Design Contingencies		10%	+/-		\$19,153.87
		Subtotal 2 = Subtotal 1 + Design Contingencies					\$210,692.57
		CONTRACT COST					\$210,692.57
		Construction Contingencies		15%	+/-		\$31,603.89
		FIELD COST					\$242,296.46
Ref.: For appropriate use and terminology, see Reclamation Manual, Directives and Standards FAC; 09-01, 09-02 and 09-03.							
QUANTITIES				PRICES			
BY Ahmed Elgamal		CHECKED Stephen Dominic		BY Ahmed Elgamal		CHECKED Stephen Dominic	
DATE PREPARED September 26, 2013		PEER REVIEW / DATE Patrick Fox		DATE PREPARED September 26, 2013		PEER REVIEW / DATE Patrick Fox	

APPENDIX C: LHPOST TESTING TASK AND EXPENSE BREAKDOWN

First Test

Work Element 1 - Soil Procurement

Description	Quantity	Unit	Hours	Rate	Total	Note
Soil Purchase	400	yd ³	-	\$40.00	\$16,000.00	1
Delivery and Bobcat	1	LS	-	-	\$3,000.00	-
Bobcat Operators	2	ea	16	\$67.00	\$2,144.00	-
Short-term Storage/Stockpile	-	-	-	-	\$500.00	-
Overhead (55%)					\$11,904.20	-
Total - Work Element 1					\$33,548.20	-

Work Element 2 - Soil Preparation

Item	Quantity	Unit	Hours	Rate	Total	Note
Lab Testing of Soil	1	Engineer	40	\$67.00	\$2,680.00	2
Lab Testing of Soil	1	Student	80	\$35.00	\$2,800.00	2
Moisture Conditioning	1	Engineer	24	\$67.00	\$1,608.00	3
Moisture Conditioning	1	Student	40	\$35.00	\$1,400.00	3
Soil Preparation	1	Student	24	\$35.00	\$840.00	4
Overhead (55%)					\$5,130.40	-
Total - Work Element 2					\$14,458.40	-

Work Element 3 - Computational Framework Setup/Calibration/Predictive Estimates

Item	Quantity	Unit	Hours	Rate	Total	Note
Numerical / Predictive Modeling	1	LS	-	\$30,000.00	\$30,000.00	5
Overhead (55%)					\$16,500.00	-
Total - Work Element 3					\$46,500.00	-

Work Element 4 - Container Preparation, Setup and CIP Retaining Wall Construction

Item	Quantity	Unit	Hours	Rate	Total	Note
Soil Box Preparation/Cleaning	1	Student	24	\$35.00	\$840.00	-
Soil Box Assembly	1	Sub-cont			\$50,000.00	-
Liner (purchase and installation)	1	ea	-	-	\$20,000.00	-
Retaining Wall Design	1	Student	40	\$35.00	\$1,400.00	-
Retaining Wall Construction	10	yd ³	-	\$2,000.00	\$20,000.00	-
Overhead (55%) *Excludes Liner					\$39,732.00	-
Total - Work Element 4					\$131,972.00	-

Work Element 5 - Instrumentation (install and test)

Item	Quantity	Unit	Hours	Rate	Total	Note
Strain Gages	48	ea	-	\$100.00	\$4,800.00	6
Displacement Transducers	48	ea	-	\$67.00	\$3,216.00	6
Accelerometers	32	ea	-	\$67.00	\$2,144.00	6
Pressure Transducers	36	ea	-	\$850.00	\$30,600.00	7
Shape Tape (6.5 m long)	8	ea	-	\$5,000.00	\$40,000.00	7
Tactile Sensors (12"x18")	12	ea	-	\$5,000.00	\$60,000.00	7
Cameras	2	ea	-	\$200.00	\$400.00	6
Overhead (55%) *Excludes Tactile Sensors					\$44,638.00	-
Total - Work Element 5					\$185,798.00	-

Work Element 6 - Wall and Soil Placement and Testing

Item	Quantity	Unit	Hours	Rate	Total	Note
Soil Placement & Compaction	3	Dev. Tech	120	\$67.00	\$24,120.00	8
Soil Placement & Compaction	2	Student	120	\$35.00	\$8,400.00	8
Bobcat	1	ea	120	\$110.00	\$13,200.00	9
Compactor (hand held)	1	ea	120	\$40.00	\$4,800.00	10
Crane & Front-end Loader	1	ea	120	\$360.00	\$43,200.00	11
Density Testing - Sand Cone	50	ea	-	\$25.00	\$1,250.00	12
Density Testing - Nuke Gage	6	ea	-	\$40.00	\$240.00	12
CPT	2	day	-	\$1,500.00	\$3,000.00	13
Overhead (55%)					\$54,015.50	-
Total - Work Element 6					\$152,225.50	-

Work Element 7 - Shake Table Testing

Item	Quantity	Unit	Hours	Rate	Total	Note
Preparation / Calibration	1	Dev. Tech	24	\$67.00	\$1,608.00	14
Low-level Dynamic Excitation	1	Dev. Tech	40	\$67.00	\$2,680.00	15
Dynamic / Earthquake Excitation	1	Dev. Tech	40	\$67.00	\$2,680.00	16
Data Reduction / Storage	1	Dev. Tech	24	\$67.00	\$1,608.00	17
Facility Usage Expense					\$200,000.00	18
Overhead (55%) * Excludes Facility Usage					\$4,716.80	-
Total - Work Element 7					\$213,292.80	-

Work Element 8 - Soil Removal

Item	Quantity	Unit	Hours	Rate	Total	Note
Lab Testing of Soil	1	Student	40	\$35.00	\$1,400.00	19
Excavate/Remove Backfill	2	Student	40	\$35.00	\$2,800.00	-
Crane Operator	1	Dev. Tech	40	\$67.00	\$2,680.00	
Crane	1	ea	40	\$210.00	\$8,400.00	-
Front end Loader	1	ea	40	\$150.00	\$6,000.00	-
Stockpile used soil	1	ea	-	LS	\$500.00	-
Overhead (55%)					\$11,979.00	-
Total - Work Element 8					\$33,759.00	-

Work Element 9 - Demobilization and Model Dismantling

Item	Quantity	Unit	Hours	Rate	Total	Note
Remove Soil Box	2	Student	40	\$35.00	\$2,800.00	-
Remove Soil Box	1	Dev. Tech	40	\$67.00	\$2,680.00	-
Soil Disposal	1	LS	-	-	\$10,000.00	-
Dismantling/storage	1	Sub- contr	40		\$50,000.00	-
Overhead (55%)					\$36,014.00	-
Total - Work Element 9					\$101,494.00	-

Work Element 10 - Testing, Data Analysis & Report Preparation

Item	Quantity	Unit	Hours	Rate	Total	Note
Post-processing & Prelim-Analysis	1	Student	960	\$35.00	\$33,600.00	-
Testing & Prelim Analysis	2	P.I.		\$20,000.00	\$40,000.00	-
Overhead (55%)					\$40,480.00	-
Total - Work Element 10					\$114,080.00	-

Total - LHPOST Test	\$1,027,127.90
Graduate Student Funding and PI Support	\$200,000.00
Design Contingencies (10%)	\$102,712.79
Contract Cost	\$1,329,840.69
Construction Contingencies (15%)	\$199,476.10
Field Cost	\$1,529,316.79

Note	Description
1	Suitable soils have been identified and preliminary laboratory tests completed on samples from Vulcan Soils and Scott Sales.
2	Laboratory testing to include sieve analysis (ASTM D4829), moisture content and maximum dry density determination (ASTM D1557), moisture content and dry density determination (ASTM D2216), gradation analysis with hydrometer (ASTM D422), etc.
3	Based on laboratory testing (ASTM D2216 and ASTM D1557), soils will be moisture conditioned prior to placement and compaction.
4	As needed, soils will be screened or blended to get desired mechanical properties.
5	Computational framework set-up/calibration/predictive estimates.
6	Sensors from current UCSD inventory will be utilized when available. Costs are associated with installation and verification testing.
7	New sensors will have to be procured (and are included within costs herein). Estimates here are for overall anticipated cost per sensor category. Sensors from current UCSD inventory will be utilized when available.
8	Soils shall be placed in 8 to 12 inch lifts and compacted to 90-95% of the maximum dry density (ASTM D1557).
9	It will be necessary to rent a Bobcat to move the soils from the stockpile to the conveyor.
10	A conveyor will be utilized to place soils in the soil box.
11	A walk behind vibrating compactor shall be utilized to compact soils to 95% of the maximum dry density (ASTM D1557).

12	Density of compacted soils to be verified via sand cones (ASTM D1556) and nuclear gage testing (ASTM D6938).
13	Cone Penetration Testing (CPT) to be performed as necessary for characterizing compacted soil profiles.
14	Preparation of input motion and shake table training and Cost of verification that all instrumentation equipment is operational
15	Low shaking level testing
16	Dynamic and earthquake testing
17	Data storage and reduction and preparation for analysis
18	Facility usage fees.
19	Upon completion of shake table testing, soils will be excavated and samples retrieved for moisture content determination.

Appendix D: LHPOST Experimental Equipment

LHPOST (UCSD Outdoor Shake Table Facility)

The material below is extracted from <http://nees.ucsd.edu/facilities/shake-table.shtml>.

The large outdoor shake table is the only such facility in the United States and worldwide, with unparalleled specifications that allow for conducting the proposed near full-scale testing. The main such characteristics include: i) the large geometric foot-print and load carrying capacity, ii) the outdoor ease of access and construction of large soil-structure systems, iii) availability of first rate instrumentation, technical support and expertise, and iv) prior track record. Technical details of this facility are included below.

UCSD Outdoor Shake Table Specifications



The design criteria and main specifications of the shake table system were dictated by consideration of a number of potential research applications involving large or full-scale shake table experiments and a variety of earthquake ground motions. The resulting performance parameters including specifications for actuator stroke, velocity and force capacities, and frequency bandwidth of the earthquake simulator are summarized in the table below.

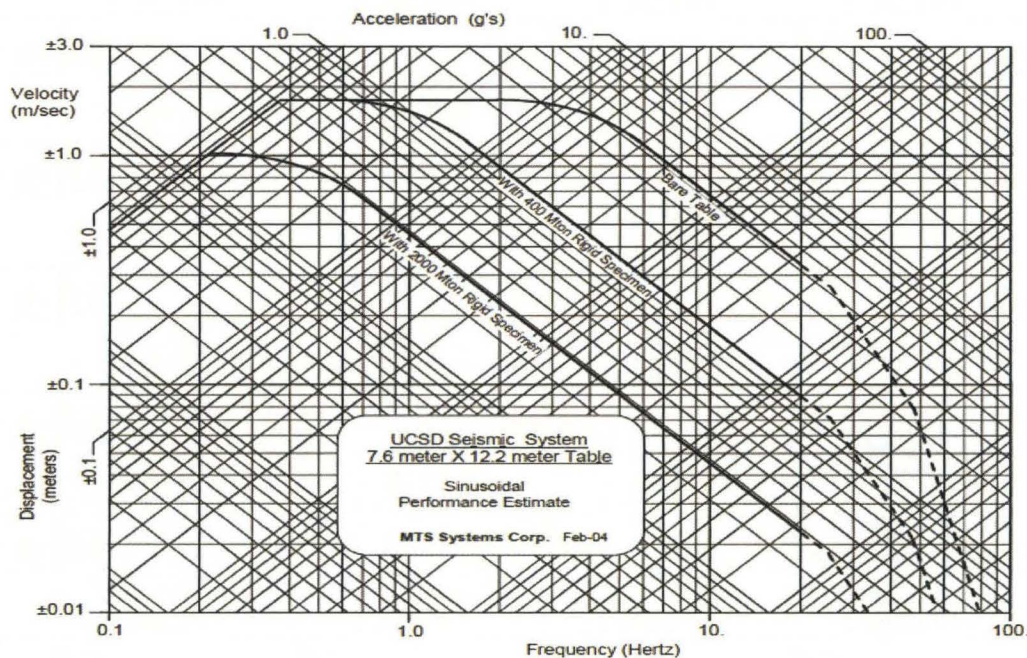
In deciding on these parameters, far-source (or "ordinary") and near-source earthquake ground motions to be reproduced by the shake table were considered. A maximum horizontal peak ground and peak table acceleration of just over 1g was selected based on the upper bound for the vast majority of recorded ground motion records. To determine the maximum force of 1.5 million pounds (6.8 MN) to be imparted by the shake table actuators and a maximum overturning moment

of 36.9 Mlb-ft (50 MN-m) to be accommodated by the platen and its support mechanism, many factors were considered. A suite of desired large or full-scale specimens for the shake table experiments was taken into account, as well as the assumed mass of the platen including elastic and inelastic dynamic amplification effects 15,760 slugs (230 metric tons), the assumed effective height of the specimen 32.8 ft (10 m), as well as dynamic similitude requirements.

It was essential that the LHPOST be able to accurately reproduce near-fault ground motion effects. The reproduction capability of near-source ground motions by the shake table is controlled by the peak table velocity parameter. A peak table velocity of 5.9 ft/s (1.8 m/s) was selected by considering a set of representative near-source records used extensively in numerical earthquake engineering research. When the laminar shear box is mounted on the table, additional amplification takes place within the soil box and the peak velocity on the soil surface can exceed 5.9 ft/s (1.8 m/s).

Size	24.9 ft x 40.0 ft 7.6 m x 12.2 m
Peak acceleration: bare table, 400 ton payload	4.2 g, 1.2 g
Peak velocity	5.9 ft/s 1.8 m/s
Stroke	±2.46 ft ±0.75 m
Maximum gravity (vertical) payload	4.99 Mlb 20 MN
Force capacity of actuators	1.5 Mlb 6.8 MN
Maximum overturning moment: bare table, 400 ton specimen	25.8 Mlb-ft, 36.9Mlb-ft 35 MN-m, 50 MN-m
Frequency bandwidth	0 — 33 Hz
Performance envelope (please see below)	 view [pdf]
Shake Table 3D	 view [dwg]
EFS Building	 view [dwg]
Safety Tower Footprint	 view [dwg]

Performance Envelope



Laminar Soil Shear Box

MATERIAL BELOW IS TAKEN FROM THE WEBSITE

[HTTP://NEES.UCSD.EDU/FACILITIES/SOIL-SHEAR-BOX.SHTML](http://NEES.UCSD.EDU/FACILITIES/SOIL-SHEAR-BOX.SHTML)

A full-scale laminar soil shear box was designed and fabricated for full-scale testing of soil-structure interaction under static or dynamic test loading conditions. This soil box, funded by the California Department of Transportation (Caltrans), has a length of 22 ft (6.7 m), a width of 9.6 ft (3 m) and a height of 4.7 m 15.2 ft (4.7 m). The laminar soil box consists of 31 steel laminar frames, each separated by a steel roller system on stainless steel lined webs, to allow for uni-directional movement. Movement of the laminar frames, when subject to uni-directional dynamic loading, provides a mechanism by which energy propagating through the soil can be absorbed. This energy absorption simulates in-situ soil conditions, in which energy can propagate through a uniform soil deposit over great distances with minimal energy reflection.

The laminar frames consist of: nine frames of W8x35 steel section in the lower region of the box, sixteen frames of W8x15 steel section in the mid height region and six frames of W8x10 steel section in the uppermost region. This variation in steel frame section sizes minimizes weight, so that the ratio of laminar frame weight to soil is in the range of 8 to 10%; a range common in similar full-scale laminar soil boxes in Japan. Displacement of the frames in the direction

perpendicular to motion (or shaking) due to high soil pressures and potential hydrodynamic forces (if water is present) will be restrained by a steel tower reaction system. The tower system was designed to have a natural frequency 2.5 times the soil box natural frequency.

This soil box will allow full-scale testing of reinforced concrete piles, such as a cast-in-drilled-hole (CIDH) pile, with a diameter up to 2 ft (0.60 m). The effects of liquefaction (loss of soil strength in a saturated soil deposit) can be studied as well, with the aid of a watering system in the steel framed base. Water and soil can be kept inside the laminar soil box with a waterproof polypropylene liner. When filled with a soil of unit weight 120 lb/ft^3 (1922 kg/m^3), the container will hold approximately 380,000 lb (172,000 kg) of soil.



Laminar Weight to Soil Weight Ratio (target)	8 — 15%
Length to Height Ratio	$L/H < 2.0$
Width to Height Ratio	$W/H < 1.0$
Deflection Due to Soil-Water 125 lb/ft^3 (2000 kg/m^3)	$L/1000$
Ratio of Frequency of Lateral Support (f_{lat}) to Interested Maximum Frequency (f_{max})	$f_{\text{lat}}/f_{\text{max}} > 2.5$
Ratio of Out-of-Plan Acceleration to Maximum Horizontal Acceleration	0.1 — 0.25

Ratio of Maximum Vertical Acceleration to Maximum Horizontal Acceleration	0.5 — 0.67
Laminar Frame to Soil Weight Ratio	< 0.1
Lateral Support to Soil Weight Ratio	< 0.1

Rigid Soil Container

A rigid-wall container is also available as shown in the Figure below. The height is 25 ft, length is 33 ft and width can be configured at either 15 ft-2 inches or 19 ft-2 inches.

As shown in the figure below, this rigid container consists of a system of reinforced concrete essentially rigid walls, connected side-by-side using a series of steel columns. A steel bracing system surrounds the container at six different levels along the height. The entire system is tied down and connected to the shake table platen by Dywidag post-tensioned bars threaded through the reinforced concrete wall segments along the entire container perimeter.



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DSO-2013-13

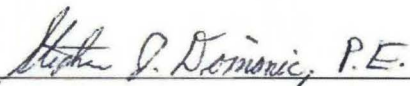
Soil-Structure Interaction
Phase 3 Feasibility Level Design
Full-Scale Retaining Wall Shake Table Testing



Prepared: Ahmed Elgamal
Professor, University of California, San Diego

9-27-2013

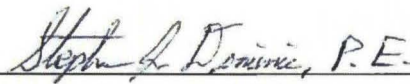
Date



Checked by: Stephen J. Dominic, P.E.
Civil Engineer, Waterways and Concrete Dams Group, 86-68130

9/27/2013

Date



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9/27/2013

Date



Peer review: Patrick J. Fox, P.E.
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9-27-2013

Date

REVISIONS					
Date	Description	Prepared	Checked	Technical approval	Peer review

