SEISMIC PERFORMANCE OF INNOVATIVE STRAW BALE WALL SYSTEMS

Pakistan Straw Bale and Appropriate Building (PAKSBAB)
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www.paksbab.org

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Sponsored by:
Earthquake Engineering Research Institute (EERI)

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ABSTRACT

Introduction

On October 8, 2005, the northern mountainous region of Pakistan was struck by a magnitude Mw = 7.6 earthquake which killed an estimated 100,000 people, destroyed over 780,000 buildings and rendered more than 3.5 million homeless due to poor building construction. Structurally safe building methods are largely unaffordable for the poor in developing countries such as Pakistan. In response, Pakistan Straw Bale and Appropriate Building (PAKSBAB) is developing simple, unique, earthquake-resistant straw bale building methods that are affordable, energy efficient, and utilize local labor and indigenous renewable materials.

Objective

The objective of this research project was to determine the capacity of clay plastered, load bearing, straw bale wall assemblies under in-plane cyclic loading, and the performance of a small full-scale straw bale house using shake table simulation. The system was unique in that the site-fabricated bales were not as wide as those used in a typical straw bale building, and the fishing net reinforcement and gravel bag foundation were non-conventional. Designated as a shared-use project, the experimental work was conducted using the NEES facilities at the University of Nevada, Reno (NEES@UNR). EERI's Special Projects and Initiatives Committee provided a research grant from its Endowment Fund for the specimen building materials and other related expenses.

The overall research plan consisted of 4 parts:

1. Component field tests and material tests (December, 2009)
2. Wall assembly tests of varying configurations (completed June, 2008)
3. Bi-axial shake table tests of a 14' x 14' x 10' full-scale house (completed March, 2009)
4. Report of findings and seismic design and construction recommendations (January, 2010)

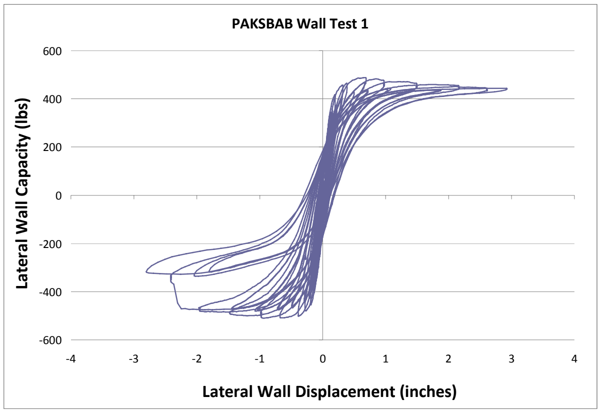
Wall Assembly Tests

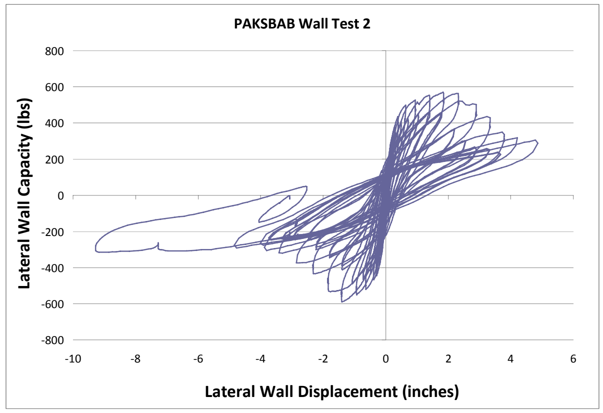
The wall assemblies were tested individually on a shake table which was slowly displaced in-plane for 16 load steps consisting of increasing cyclic peak displacements (5% max. drift) with subsequent trailing cycles (3.8% max. drift). Walls 2 and 3 were subjected to a final displacement of 9.7% drift. The top of the wall was attached to a frame mounted to the laboratory floor and instrumented to measure tension and compression. 16 displacement transducers were used to measure horizontal and vertical displacements, including the overall wall displacement measured at the top of wall from a table-mounted reference frame.

WALL CONSTRUCTION MATRIX	Wall 1	Wall 2	Wall 3	Wall 4
4' wall length	X	X	X	
8' wall length				X
Light detailing [a)]	X			
Medium detailing [b)]		X		
Heavy detailing [c)]			X	X

[a)] Light detailing: control specimen without fishing net plaster reinforcement
[b)] Medium detailing: #9 fishing net plaster reinforcement
[c)] Heavy detailing: #12 fishing net reinforcement with additional detailing at foundation

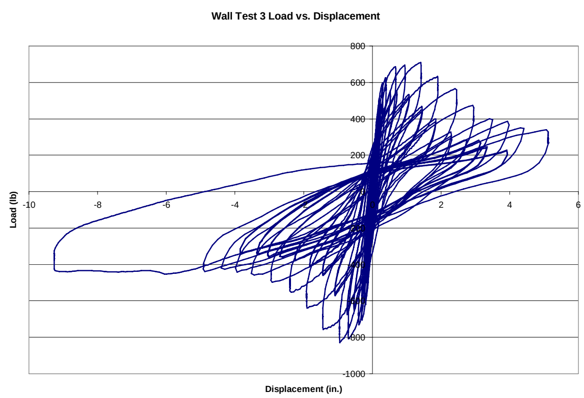
Wall 1 was constructed as a control specimen without fishing net plaster reinforcement. Its post peak behavior was dominated by rocking. Its maximum capacity of 500# occurred at a drift of 0.8% (0.8").

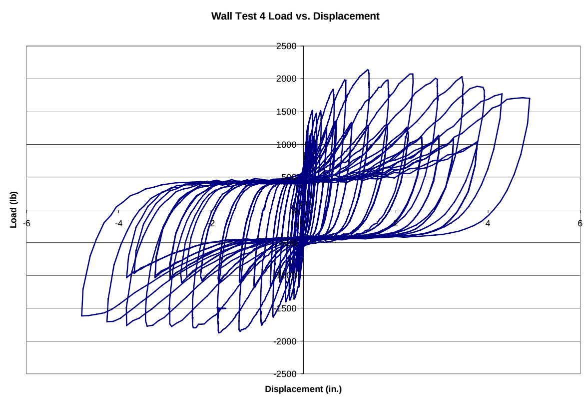




The capacity of wall 2 increased due to the addition of fishing net plaster reinforcement which provided shear and overturning resistance as well as increased ductility. Its maximum capacity of 580# occurred at a drift of 1.7% (1.6") with 290# capacity at a maximum drift of 9.7% (9.3").

Wall 3 had heavier weight fishing net and an extra double strip spanning from the foundation soil cement plaster to the straw bale wall clay plaster above, resulting in a further increase in capacity and ductility. Its maximum capacity of 770# occurred at a drift of 1.2% (1.2") with 340# capacity at a maximum drift of 9.7% (9.3").





Wall 4 was not tested to its full capacity due to the method of restraint at the top of the wall which did not accurately represent the building's earthquake load path and resulted in top plate attachment failure. Its maximum value of 1160# occurred at a drift of 1.7% (1.6"). We plan to repair and retest the wall in the future.

House Construction Method

The construction method was a load bearing design consisting of site fabricated straw bales resting on a soil cement encased gravel bag foundation. Exterior opposing bamboo pins were used to keep the walls plumb during construction and to provide out-of-plane support. Fishing net was installed under the gravel bags, stretched up both sides of the walls and nailed to the top plates. The roof consisted of wooden I-joists insulated with light straw clay (straw tossed in a mixture of clay and water) and covered with corrugated metal roofing. Gravel bags were placed at the top of walls to simulate a light snow load. The walls were finished with clay plasters and lime wash.

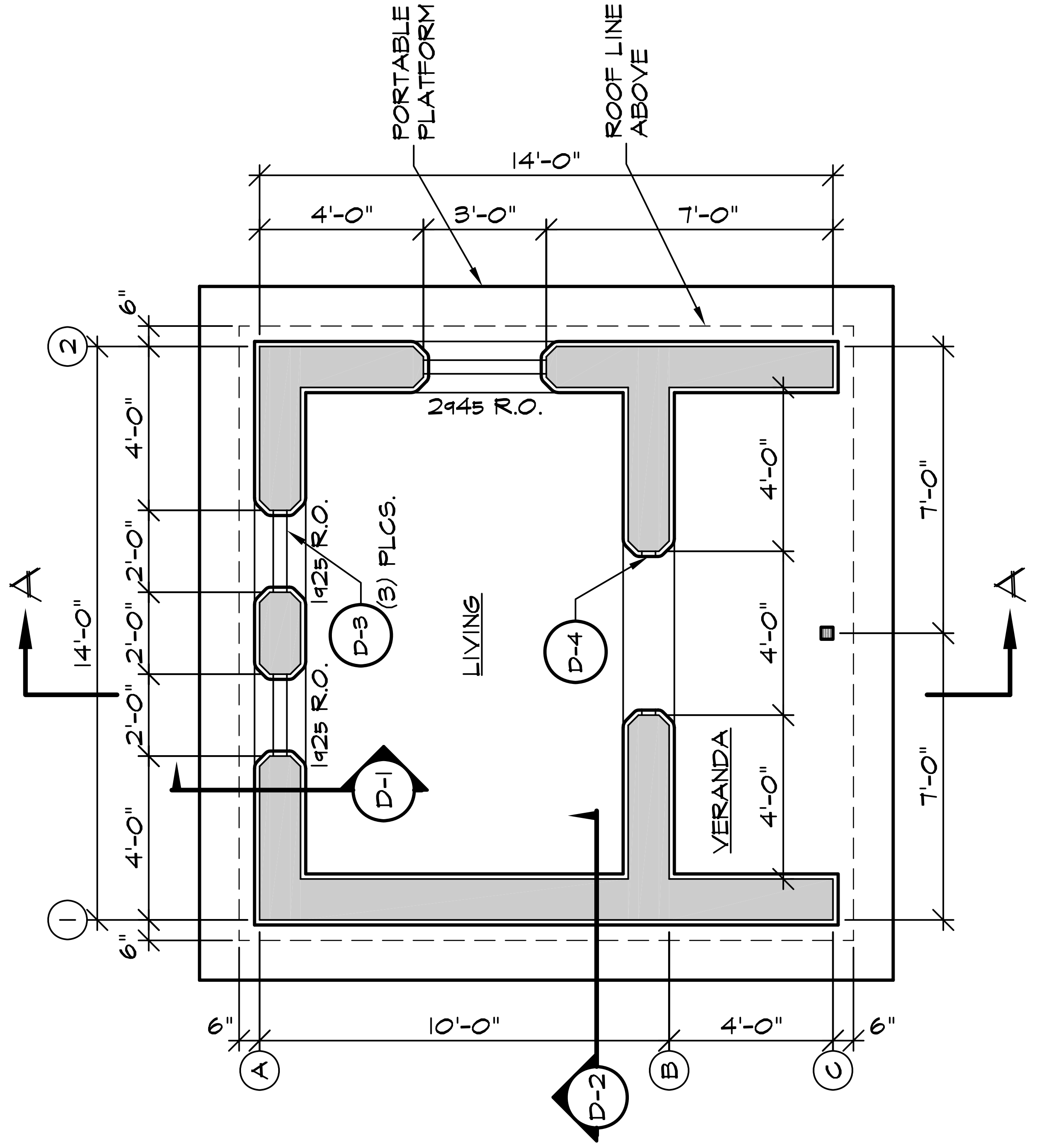
Shake Table Tests
The objective of the shake table tests was to assess the seismic response of a 14’ x 14’ x 10’ full-scale house constructed with heavy detailing. The input motion was the Canoga Park Topanga Canyon record of the 1994 Northridge, California earthquake, Mw 6.7. The house was subjected to eight levels of seismic shaking, beginning at 25% of the recorded ground acceleration and increasing at 25% increments. The house survived 0.82g, twice the acceleration of the Canoga Park record. Although severely damaged, the building did not appear in danger of collapse, even at the end of the test sequence.

Preliminary Assessment of System Performance
The straw bales, plaster skins and fishing net reinforcement worked together as a low tech composite sandwich panel, with overall system properties superior to the sum of the individual constituent materials. The plaster skins were the stiffest elements, providing compressive strength and transmitting the loads to the foundation. The plaster skins were bonded to the straw bale core, which helped to restrain them from buckling. As the plaster cracked and spalled, it provided damping and energy dissipation. Once the plaster was significantly damaged, with a corresponding decrease in stiffness, the ductile straw bale core acted as a backup mechanism and helped to resist the vertical and lateral loads. The fishing net provided tensile strength and ductility. At the foundation interface it provided shear and overturning resistance, allowing the building to displace to a certain extent, then pulling it back to its original position.

Advisory Committee
Mark Aschheim, Ph.D., Santa Clara University Associate Professor of Civil Engineering
Ian Buckle, Ph.D., UNR Professor of Civil Engineering, UNR NEES Project Director
Craig Comartin, S.E., EERI Board of Directors and past President, Project Liaison
Darcey Donovan, P.E., PAKSBAB C.E.O., Principal Investigator / Committee Chair
Martin Hammer, Architect
David Mar, S.E., Tipping Mar & Associates, Principal
Dan Smith, Daniel Smith & Associates Architects, Principal
Mark Smith, G.E., S.E., Vector Engineering, Inc., Managing Director

About PAKSBAB
Pakistan Straw Bale and Appropriate Building is a nonprofit organization created in response to the Kashmir earthquake that devastated Northern Pakistan in October 2005. Our mission is to adapt, apply and transfer straw bale and other appropriate building methods to protect and improve the lives of the poor, especially in earthquake and extreme weather regions of the developing world. Through our Community Participation Program we build houses for those in need, and engage the beneficiaries in the construction process. The building material cost for our typical 24’ x 24’ house is approximately $3000, with a 5 men / 3 months construction duration. To date we have built 11 straw bale buildings in Pakistan’s North West Frontier Province.

For More Information
Please visit our website www.paksbab.org for more information about PAKSBAB and http://nees.unr.edu/projects/straw_bale_house.html for more information about our seismic research project.



STRAW BALE HOUSE FLOOR PLAN

1/4" = 1'

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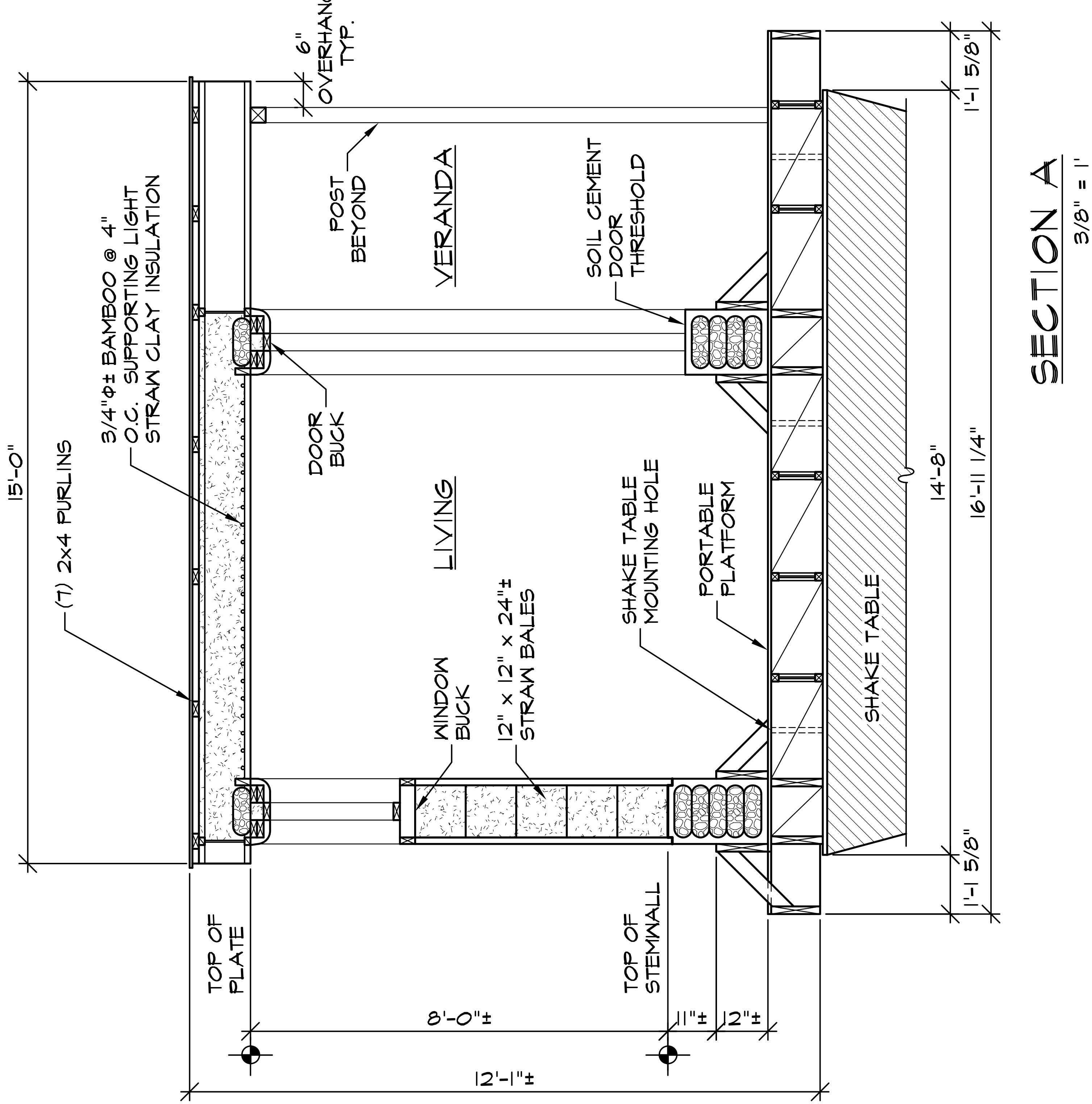

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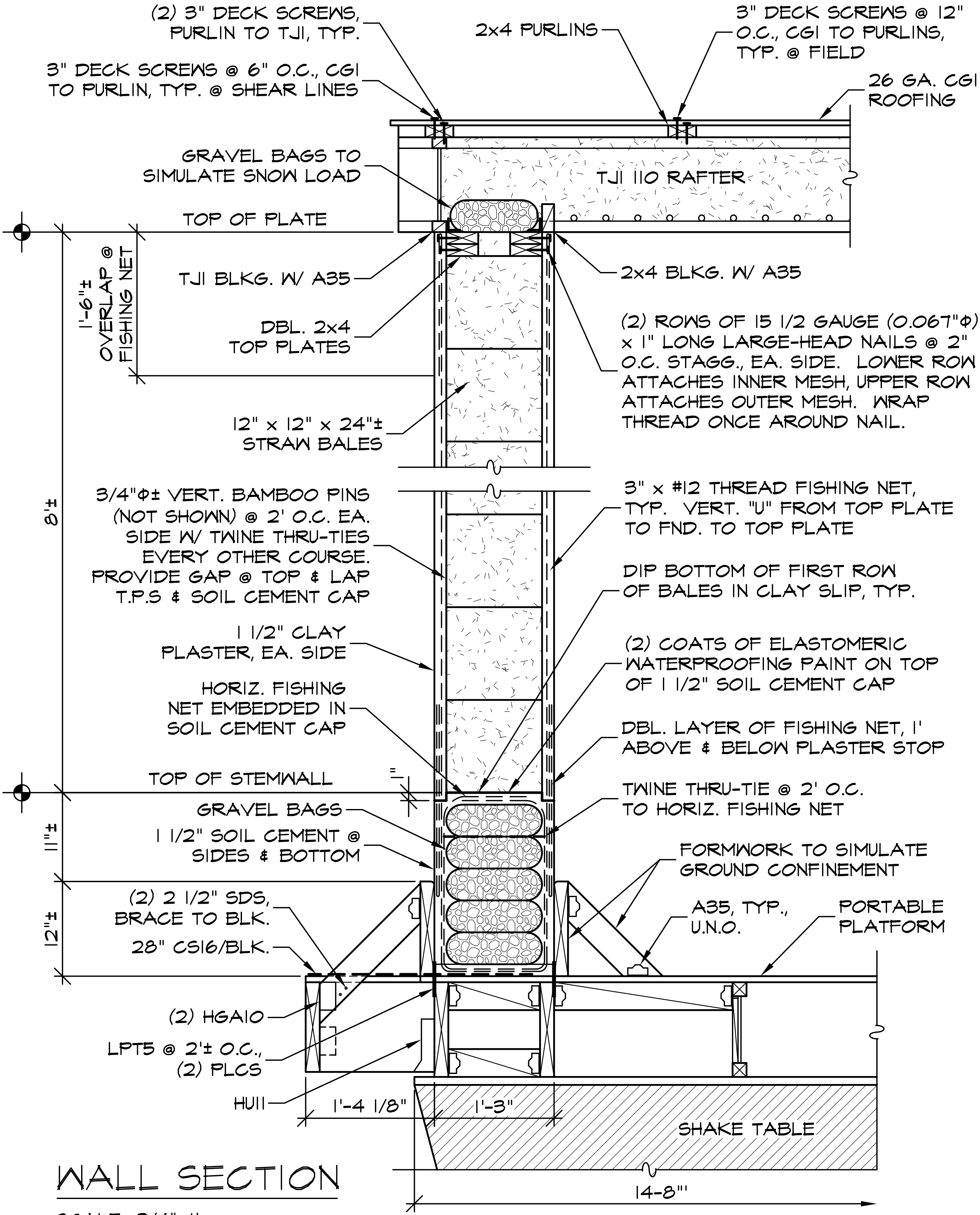

WALL SECTION

SCALE: 3/4"=1'

D-1

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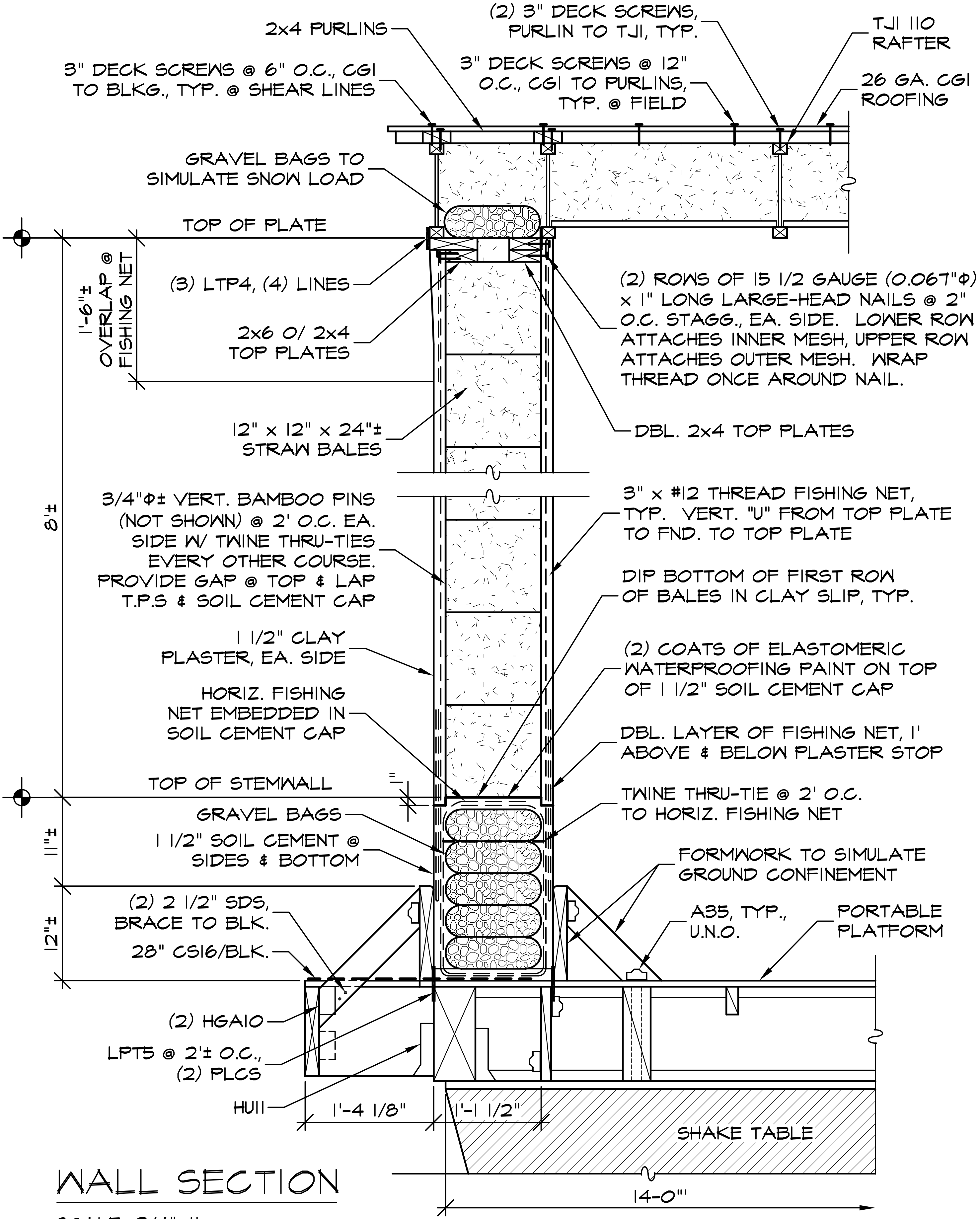

WALL SECTION

SCALE: 3/4"=1'

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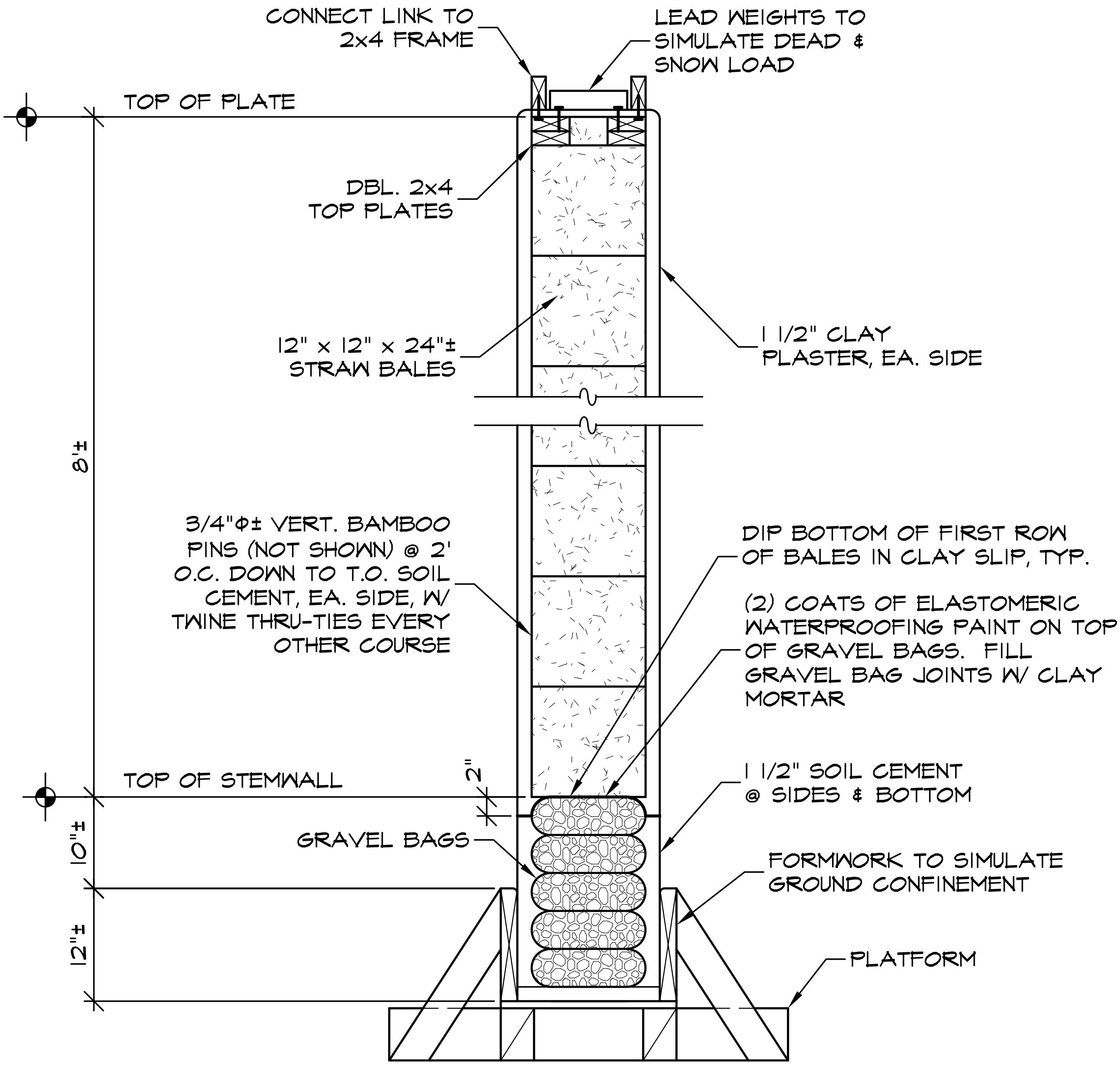

NOTES:
1) TRIM BALES AND FILL VOIDS WITH LIGHT STRAW CLAY BEFORE PLASTERING.
2) LIGHTLY MOISTEN THE SURFACE WITH WATER BEFORE EACH COAT OF PLASTER.
3) WORK THE FIRST COAT OF PLASTER DEEPLY INTO THE STRAW.

WALL SECTION W/ LIGHT DETAILING

SCALE: 3/4"=1'

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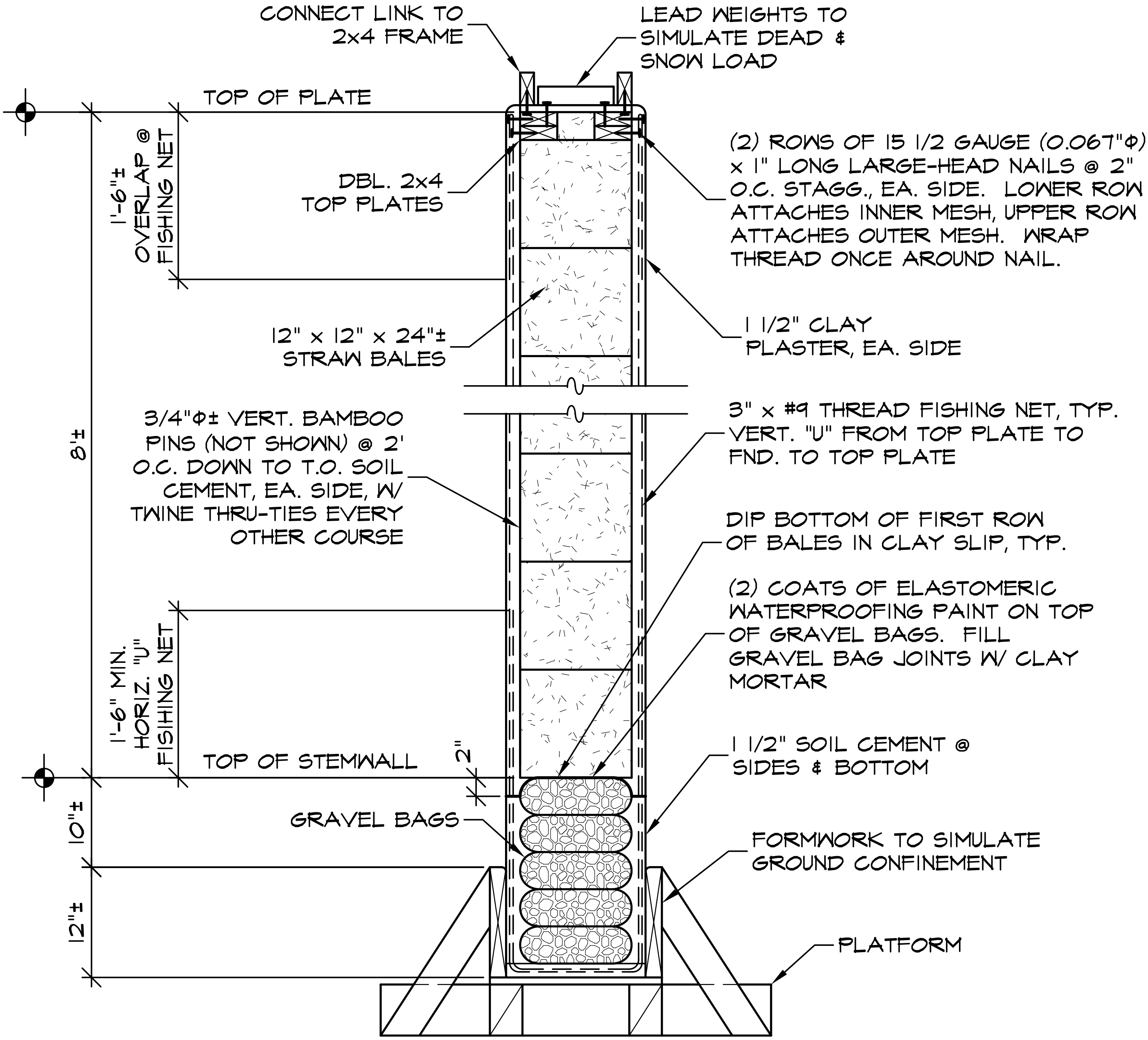

NOTES:

1) 1' MIN. FISHING NET LAP, TYP. SPREAD & PIN FISHING NET TO BALES WITH STEEL LANDSCAPE PINS OR SIM.
2) TRIM BALES AND FILL VOIDS WITH LIGHT STRAW CLAY BEFORE PLASTERING.
3) LIGHTLY MOISTEN THE SURFACE WITH WATER BEFORE EACH COAT OF PLASTER.
4) WORK THE FIRST COAT OF PLASTER DEEPLY INTO THE STRAW.

WALL SECTION W/ MEDIUM DETAILING

SCALE: 3/4"=1'

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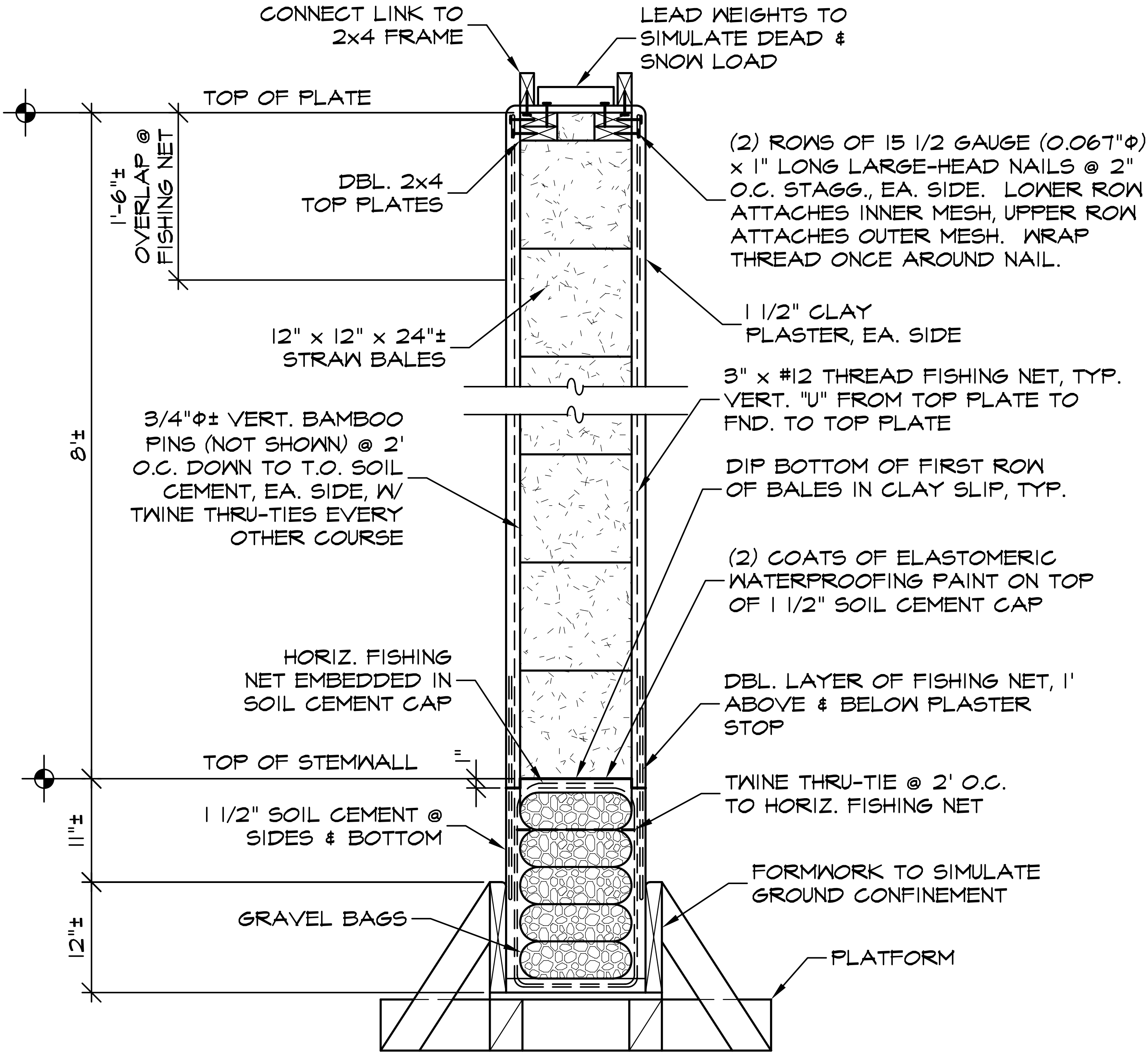

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WALL SECTION W/ HEAVY DETAILING

SCALE: 3/4"=1'

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