A Report of Contemporary Rammed Earth Construction and Research in North America

ISISS 2011 & US Workshop on Earth Based Materials and Sustainable Structures

Oct 28-30, 2011, Xiamen, China

Bly Windstorm

“Historic” Rammed Earth - Nepal

“Modern” Rammed Earth - North America

Yuchanglou
Yongding, Fujian

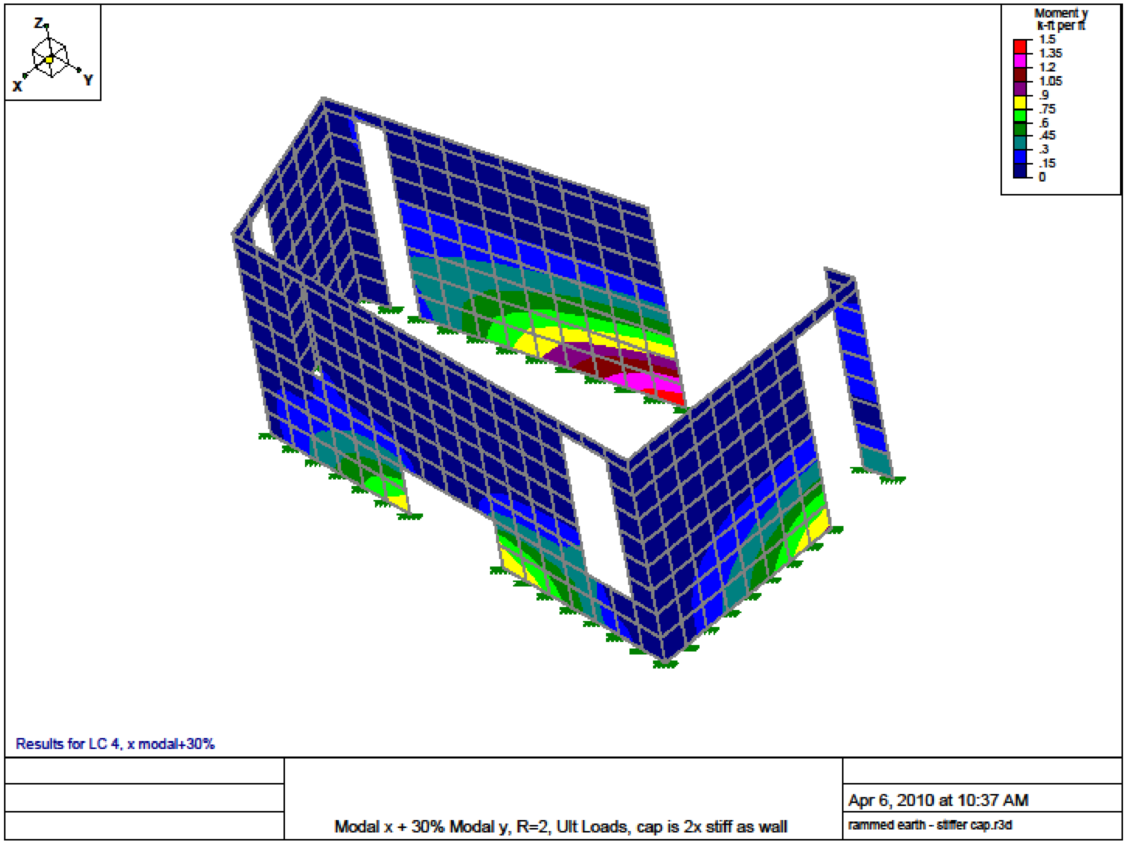
Plum Creek Pumping Station
British Columbia, Canada

Insulation & Steel

XPS Foam Insulation

Rock Wool Insulation

Masonry & Concrete Analogy



Unusually Challenging Site

Rammed Earth Compressive Strength

Steel Specifications & Concrete Code

Steel Placement Protocol

Typical Steel Placement at Wall Cap

Balance


LEHIGH
HEIDELBERGCEMENT Group
TYPE GU
TYPE 10
GENERAL USE
PORTLAND CEMENT

Embodied Energy Comparison

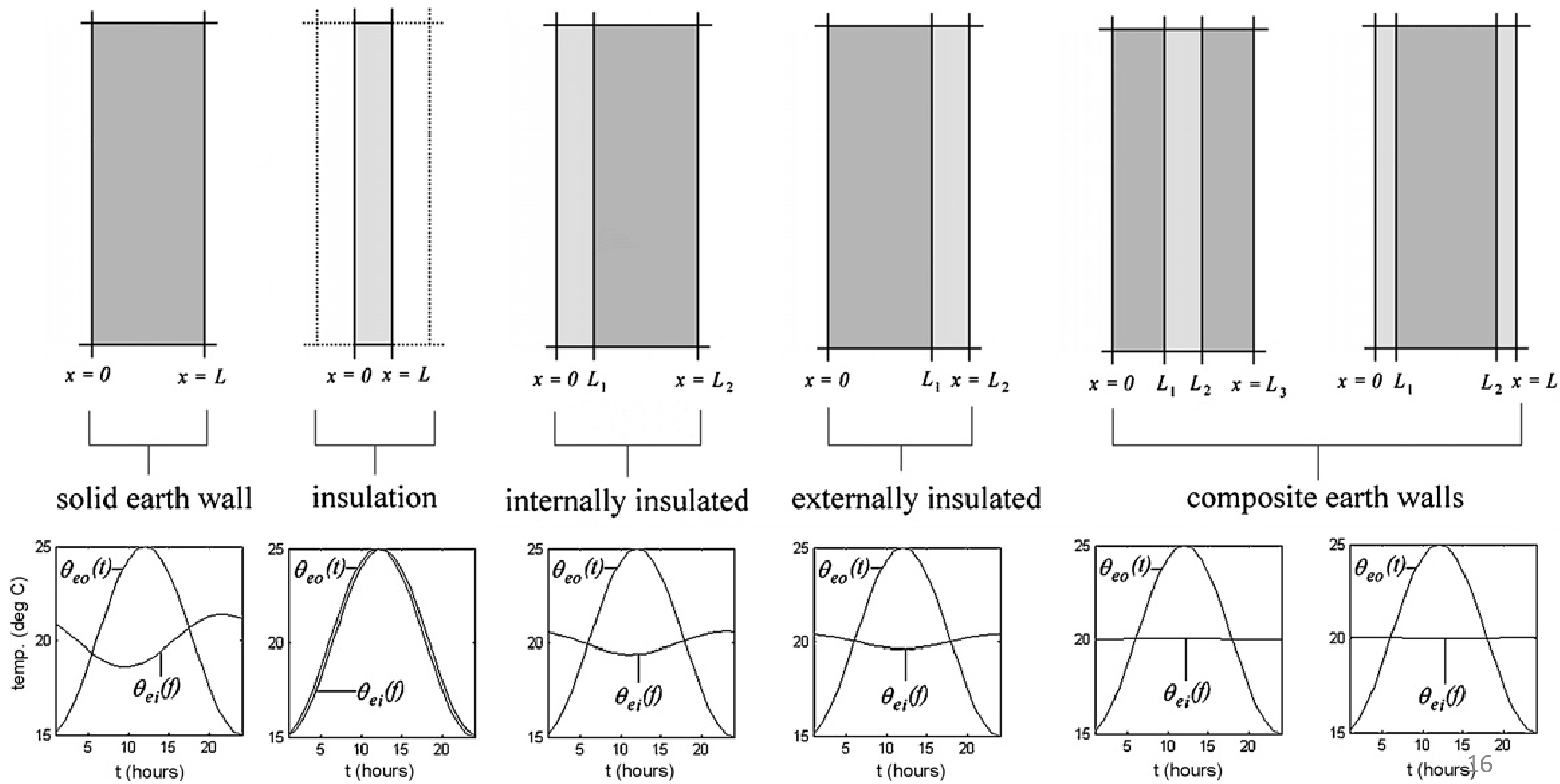
- B.V. Venkatarama Reddy, P. Prasanna Kumar from the Department of Civil Engineering, Indian Institute of Science
- Embodied energy in CSRE walls (with 8% cement) is only about 15–25% of the embodied energy in burnt clay brick masonry
- CSRE with 8% cement gives 17% higher compressive strength when compared to brick masonry strength
- Compressive Strength of 3.38 MPa with hand rammers (20% of what is typical with pneumatics)

Embodied Energy in Structures

Thermal Performance (R=26)

M. A. Hall

Assessing the moisture-content-dependent parameters of stabilized earth materials using the cyclic-response admittance method, 2008



Stuart Fix & Russell Richman

Viability of Rammed Earth Building Construction in Cold Climates, 2009

- "Insulated rammed earth walls achieve high levels of thermal resistance [and] can actually improve the thermal mass performance over solid rammed earth construction"
- "a composite rammed earth envelope is highly applicable in all climate zones…"

Insulation and Through Ties

Compaction Forces

NAREBA

North American Rammed Earth Builders Association

Stabilized-Rammed Earth Research 2009-2010

- The North American Rammed Earth Builders Association (NAREBA)
- Thor A. Tandy, P. Eng, C. Eng, Struct. Eng, MIStructE, of Unisol Engineering
- British Columbia Institute of Technology (BCIT)
- Funding from the Cement Assoc. of Canada

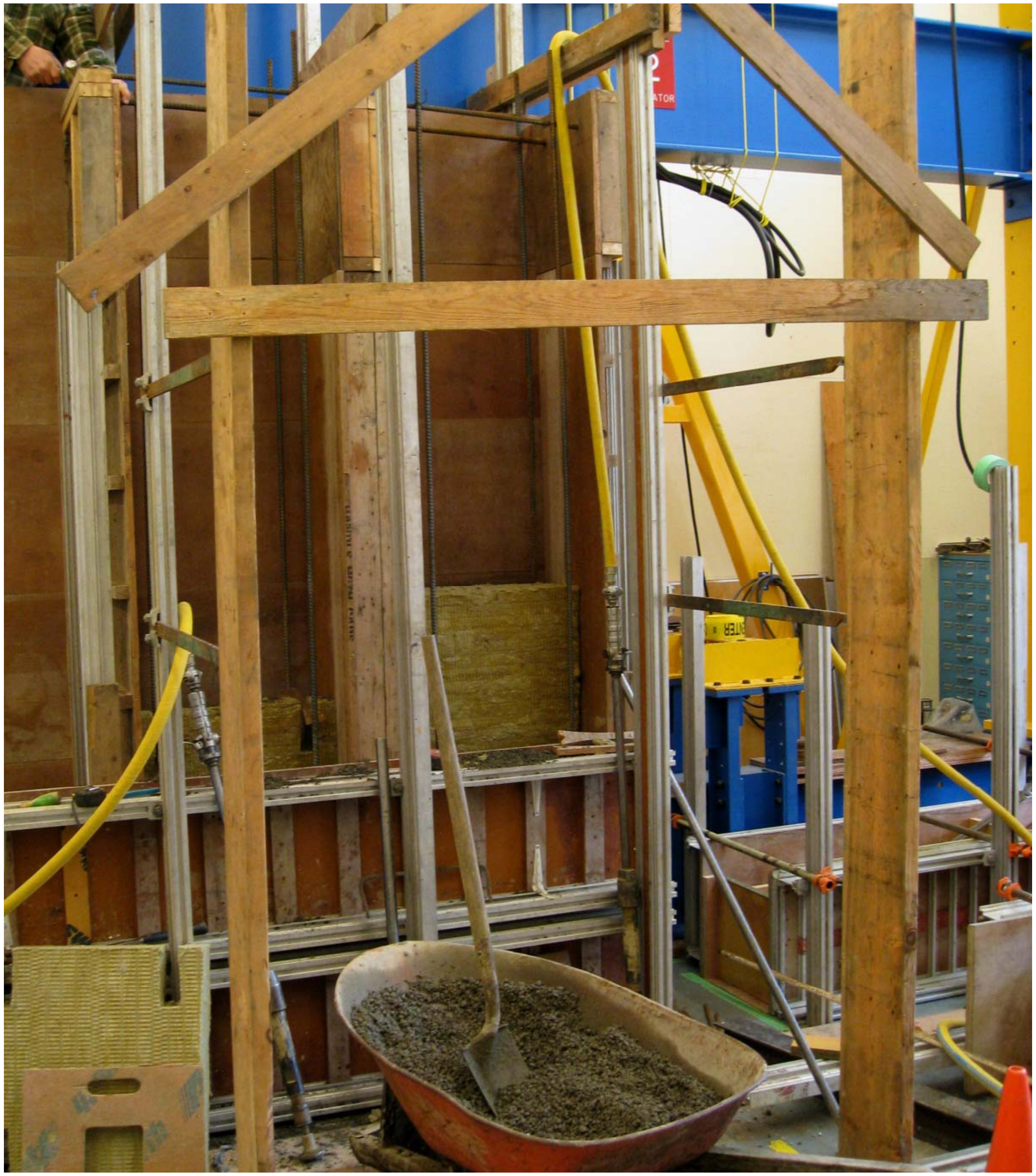
Compression Testing of The Soil

Vertical Rebar Pull Out

Horizontal Rebar Pullout

Flexural Beam Tests

Out Of Plane Bending of Composite Columns



- Tests were designed to simulate the methods of construction typical to stabilized-rammed earth structures
- Sample size is small and results must be viewed in that context

The Mix

Drum Style Mixer

Stabilized Earth Mix

Compression Strength Comparison

6" PVC Rammed Cylinder

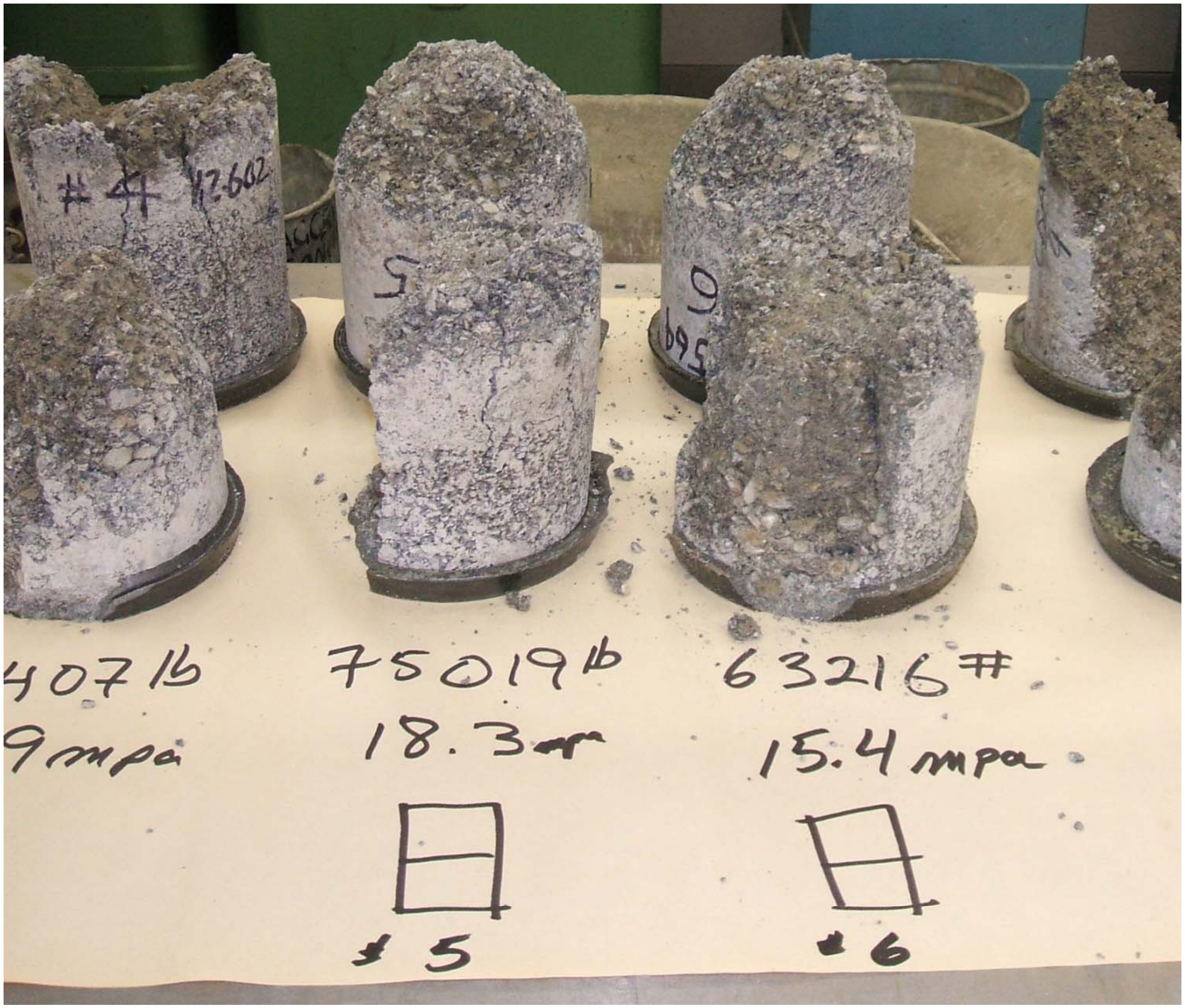
Composite Wall Simulation for Cores

Compression Strength Comparison

PVC Cast Cylinders

Cored Cylinders

Shear Profiles



Compression Test Results

PVC Cast Cylinders

- Average strength at 6 days- 12 MPa (1741 psi)
- Average strength at 12 days- 16 MPa (2221 psi)

Cored Cylinders

- Average strength at 16 days- 15 MPa (2176 psi)

Vertical Rebar Pull Out Tests (VPO)

Marked Specimen

Specimen in Baldwin Machine

Vertical Rebar Pull Out Tests (VPO)

Specimen Fracture

Bar Yield

VPO Results 10M (#3) Phase 1

10M (#3) VPO

- Two specimens tested
- Specimens had a high degree of variability
- Specimen A – Yield in excess of 3 MPa
- Specimen B – Pull out in excess of 1.5 Mpa

15M (#4) Results Phase 1 & Phase 2

15M (#4) VPO – Phase 1

- Two specimens tested
- Specimens in Phase 1 damaged in handling
- Unable to provide useful data

15M (#4) VPO- Phase 2

- Two Specimens tested
- Specimens provided consistent results
- Yield reached with a bond strength 2.9MPa (420 psi)

VPO Results 20M (#5) Phase 1 & Phase 2

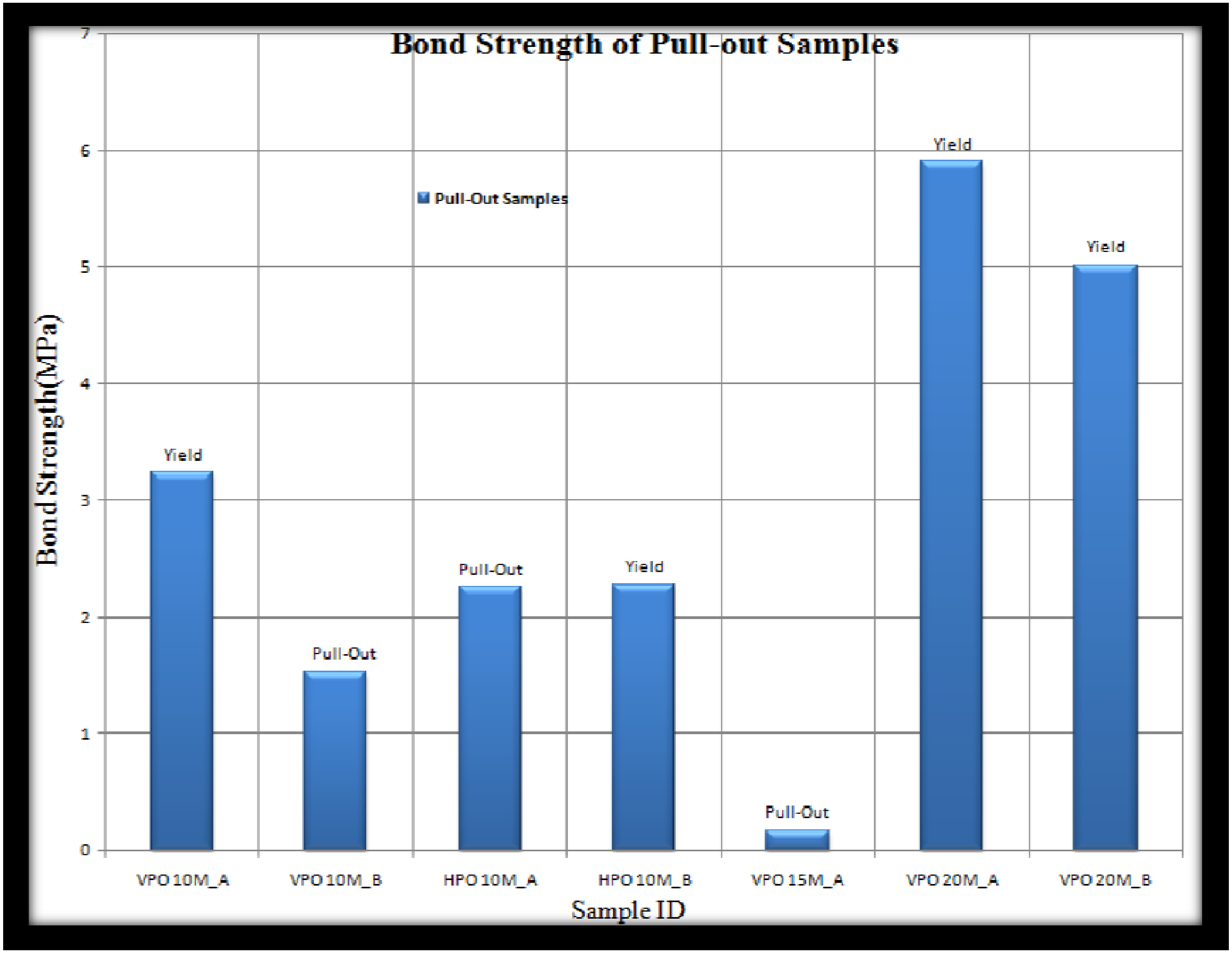
20M (#5) VPO – Phase 1

- Two specimens tested
- Yield reached on both with a bond strength in excess of 5 MPa (725 psi)

20M (#5) VPO – Phase 2

- Two Specimens tested
- Pull out achieved in excess of 4 MPa (600psi)

VPO & HPO Results (Phase 1)



Horizontal Bar Pull Out (HPO)

Typical Specimen

Specimen In Baldwin Machine

Horizontal Bar Pull Out (HPO)
Bar Yield

Horizontal Bar Pull Out Results

- 10M (#3) rebars
- Two specimens tested
- Results were consistent with one specimen reaching yield and one pulling out after reaching a bond strength of slightly less than 2.5 MPa (363 psi)

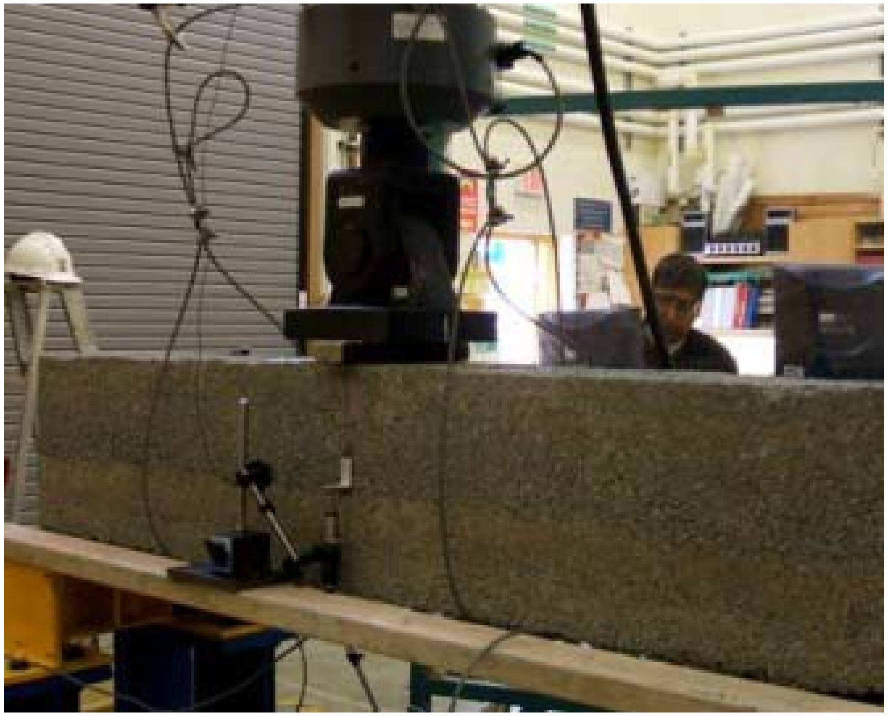
Thor Tandy (Unisol Engineering)

Engineering Conclusions, R&D #1, BCIT. 2010

- Results suggest the ramming procedure has a direct effect on the bond stress.
- There may be a mechanical connection between the steel and SRE that is unlike the cement bond that occurs in concrete or masonry models, and this would likely be affected by the thoroughness of the compaction.
- The test results outperformed the equivalent in concrete or masonry by a significant factor
- There was no significant difference of bond stress with the various bar diameters.
- The use of the concrete analogy in steel design is supported but may result in overestimating the development length required

Simple Beam Flexural Test 2-15M Bar

Beam 1 Set Up



Flexural Capacity Achieved

Simple Beam Flexural Test 2-10M Bar

Beam 2 Set Up

Flexural Capacity Achieved

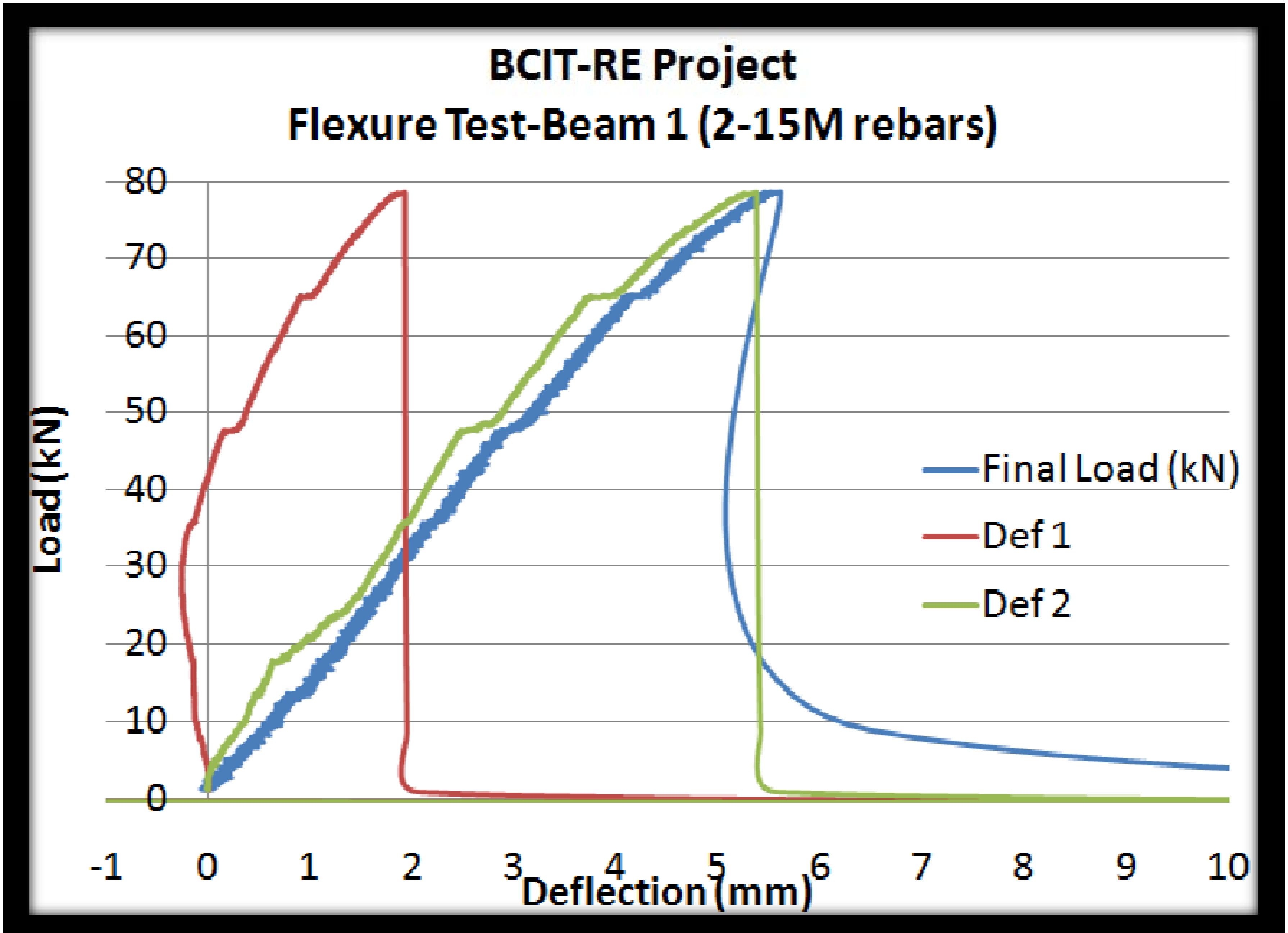
Simple Beam Test Results

Beam 1

- 200mm X 300mm X 1500mm
- 8”X10”X60”
- **2- 15M (#5)** deformed rebars
- Three point loading system
- Failed at peak shear load of **78 kN**
- Deflection at peak approximately **5.5mm (.22”)**
- Shear failure

Beam 2

- 200mm X 300mm X 1500mm
- 8”X10”X60”
- **2- 10M (#3)** deformed rebars
- Three point loading system
- Failed at peak shear load of **60 kN**
- Deflection at peak approximately **4.5mm (.17”)**
- Shear failure


BCIT-RE Project
Flexure Test-Beam 1 (2-15M rebars)
Load (kN)
80
70
60
50
40
30
20
10
0
-1
0
1
2
3
4
5
6
7
8
9
10
Deflection (mm)
Final Load (kN)
Def 1
Def 2

Composite Wall Column Out of Plane Bending

Wall Columns – Forms Removed

Composite Section View

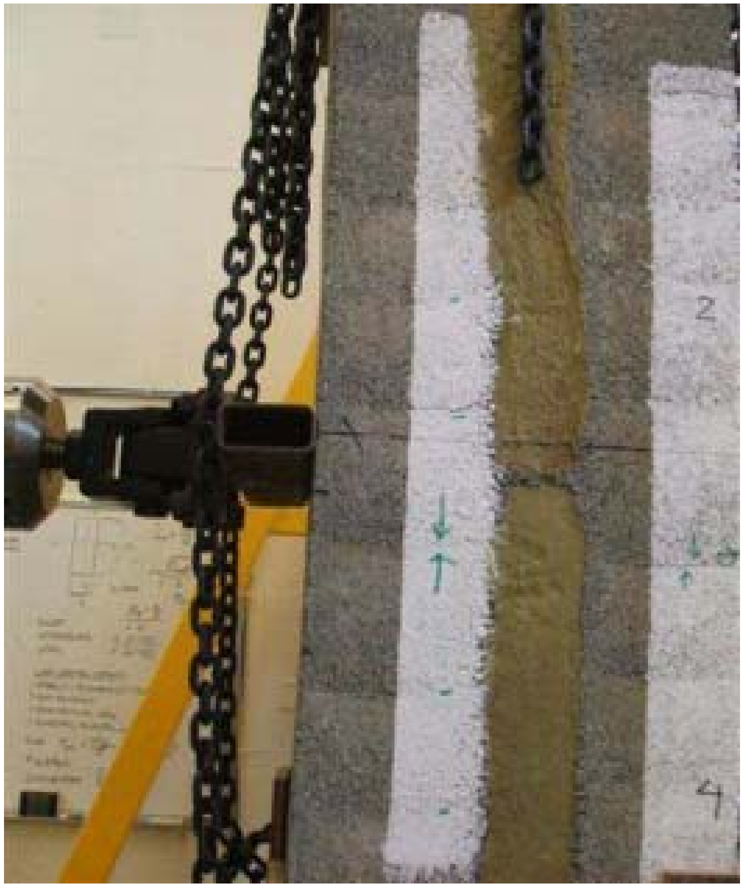
Composite Wall Column Out of Plane Bending

Open Stirrup

Diagonal Stirrup

Composite Wall Column Out of Plane Bending

Column 1 Deflection



LVDTs and Cracks

Composite Wall Column Out of Plane Bending

Column 2 Deflection

Column Removed Via Forklift

Composite Wall Column Out of Plane Bending Results

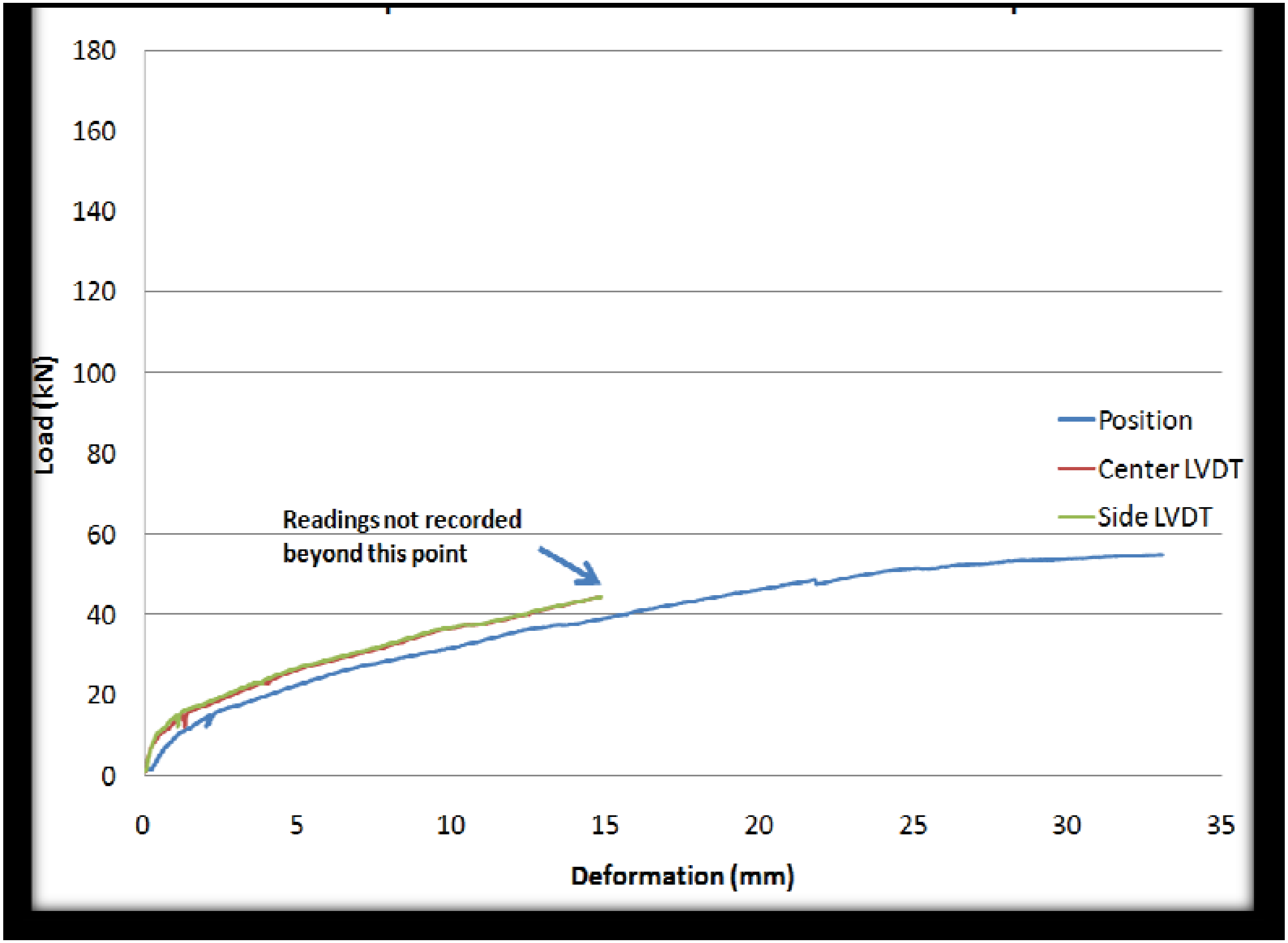
Column 1

- **Open horizontal stirrup**
- Tested in displacement control
- Load applied along entire face
- Maximum deflection exceeded **30mm (1.2”)**
- Maximum load just under **60 kN**

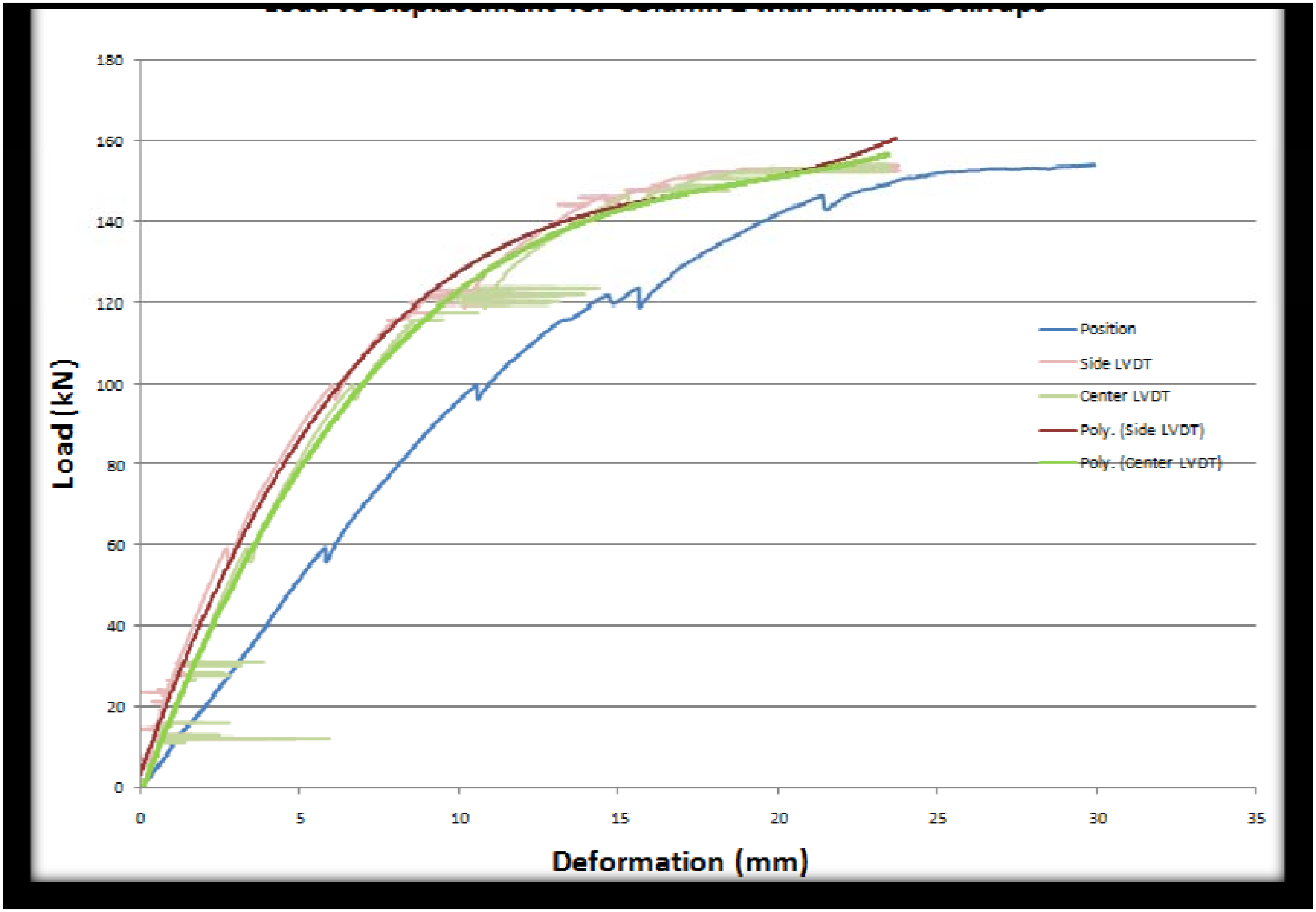
Column 2

- **Diagonal Tie**
- Tested in displacement control
- Load applied along entire face
- Maximum deflection of **25mm (1.0”)**
- Maximum load of **155 kN**

Load vs Displacement for Column 1 with Horizontal Stirrups



Load vs. Displacement for Column 2 with Diagonal Stirrups



Conclusions:

Thor Tandy (Unisol Engineering)

- Both columns met or exceeded the expectations of the researchers based upon the masonry analogy and the concrete analogy
- The data supports the use of either of these steel reinforcing approaches on single story SRE walls
- The diagonal stirrup in Column 2 resulted in a load capacity approx. 250% of the horizontal stirrup
- This approach could be used where shear loading is of greater concern

Future Research

- Exploration of the cement bond or mechanical bond on deformed steel reinforcing
- The effects of shear reinforcing on beam tests
- The effects of rigid foam on the shear capacities of composite SRE walls
- The bond strength of steel reinforcing in lower strength SRE
- A comprehensive analysis of the different types of insulations used in rammed earth walls
- The strength capacities of SRE mixes that utilize environmentally beneficial pozzolans with a reduced cement content

Acknowledgments

- Hall, M. A. – *Assessing the moisture-content-dependent parameters of stabilized earth materials using the cyclic-response admittance method, 2008*
- Fix, Stuart & Richman, Russell – *Viability of Rammed Earth Building Construction in Cold Climates, 2009*
- Jaquin, Paul - Website Photo – www.historicrammedearth.co.uk
- Tandy, Thor - *Engineering Conclusions, R&D #1, BCIT. 2010*
- NAREBA –For test design and construction of the test specimens. www.nareba.org ,
- The Cement Association of Canada for funding contributions
- Dr. Rishi Gupta (BCIT Instructor and Head of Dept.) who coordinated the testing protocol.
- Significant assistance was provided on the laboratory floor by Ken Zeleschuk and Iraj Manshadi.