Experimental and Numerical Techniques to Characterize Structural Properties of Fresh Concrete

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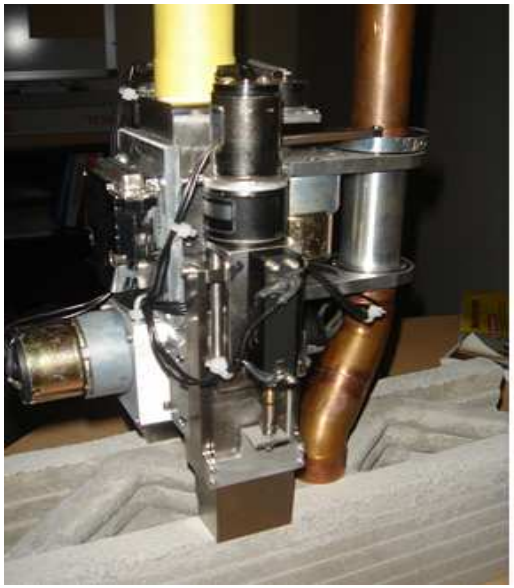
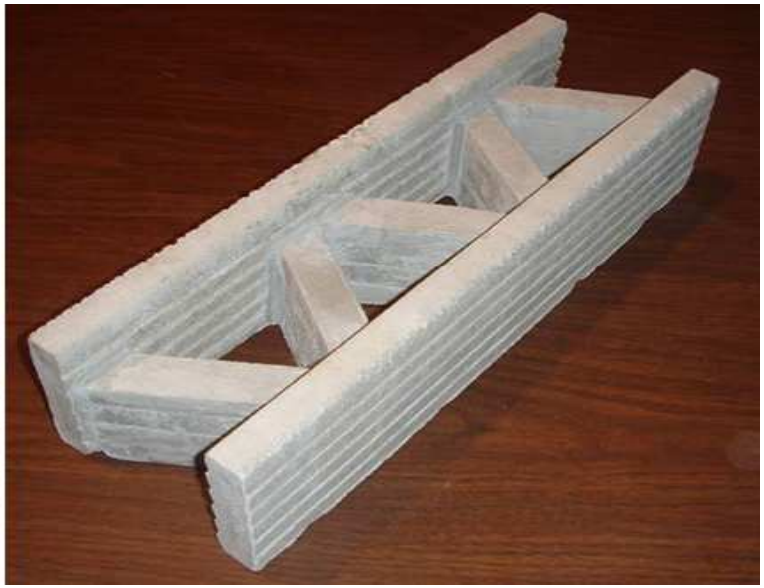
Overview

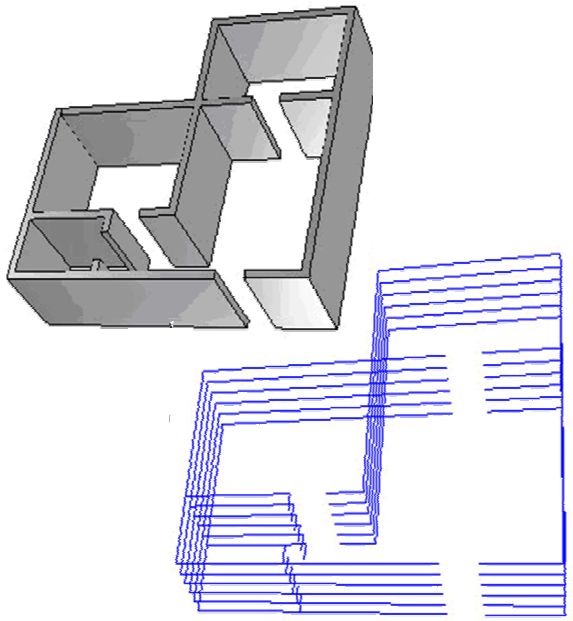
- Contour Crafting
- Properties of Fresh Concrete
- Experimental Techniques
- Numerical Techniques
- Fresh Concrete Stacking Regimens
- Fresh Concrete Stacking Test
- Opportunities for Research

Contour Crafting - Intro

- **Computer-controlled layering** of cementitious materials
- **A special mixture of extrudable mortar**
- **Successive layers accrete from the bottom up**
- **Process is formless; fresh mortar is shape stable**
- **Green strength to match** substantial and unprecedented **fabrication loads**







A prototypical structure and its fabrication tool path (Zhang 2009)

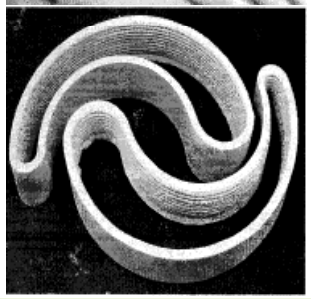
Contour Crafting - Motivation

- **Reduce the time and cost of fabrication**
- **Automation → affordable high quality dwellings**
- **Material savings (less waste and formwork)**
- **Less labor, fewer construction-related injuries**
- **More design freedom**

Contour Crafting - Evolution

Melted Polystyrene (Russell 1999)

Plaster and Clay

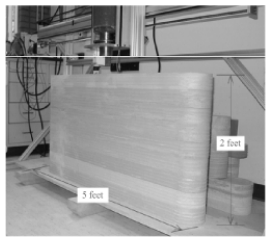


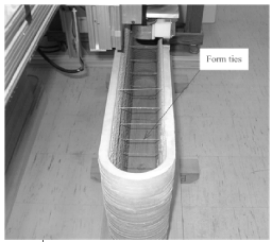
Uncured Ceramic Materials (Kwon 2002)

RapidSet Cement All Ultimax

Concrete with Clay VMA (Hwang 2005)

Cement 35.3%
Sand 40.6%
Bentonite 2.5%
Water 21.6%
(% by weight)

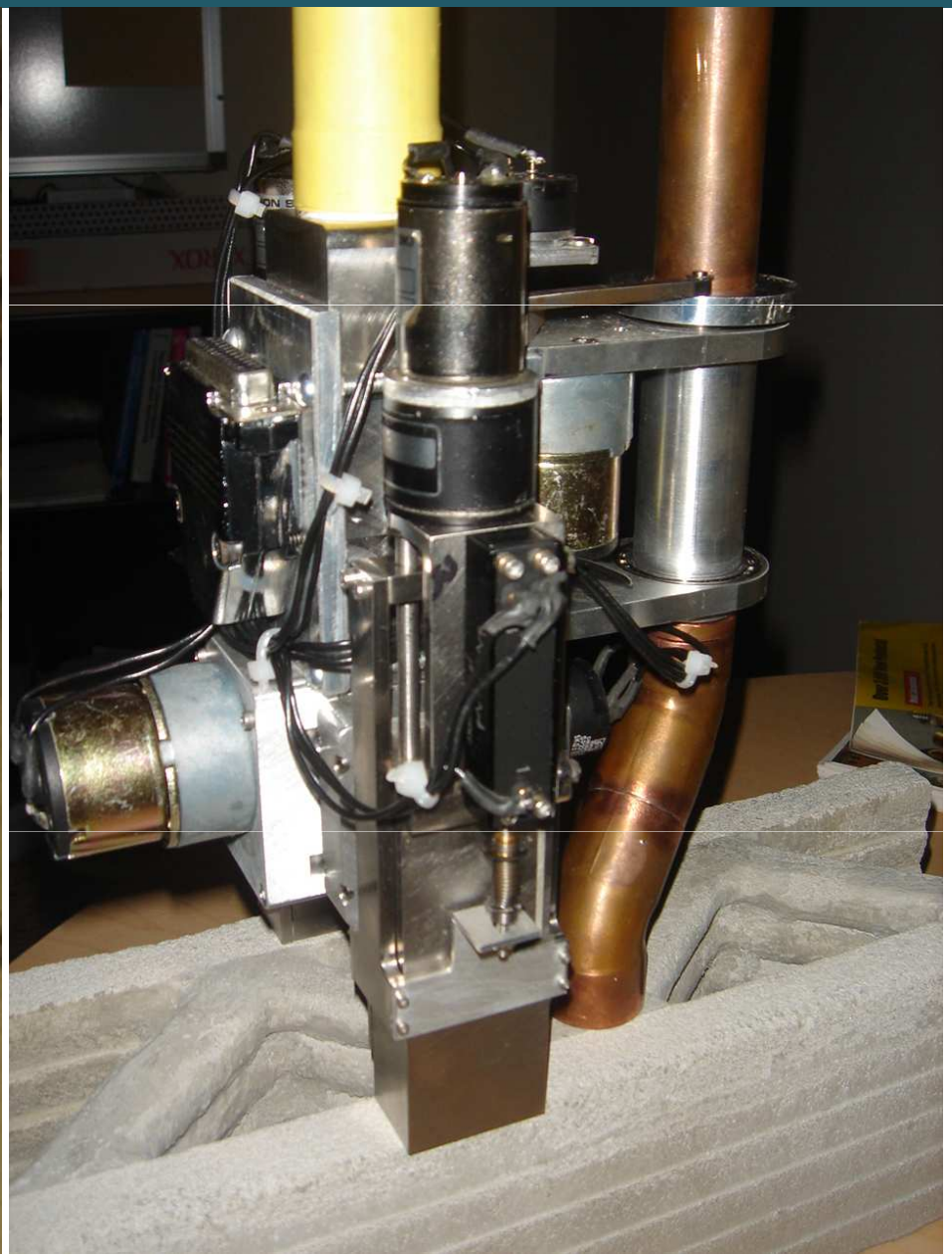




SikaRepair

'98 '99 '00 '01 '02 '03 '04 '05 '06 '07 '08 '09 '10

Contour Crafting in Action



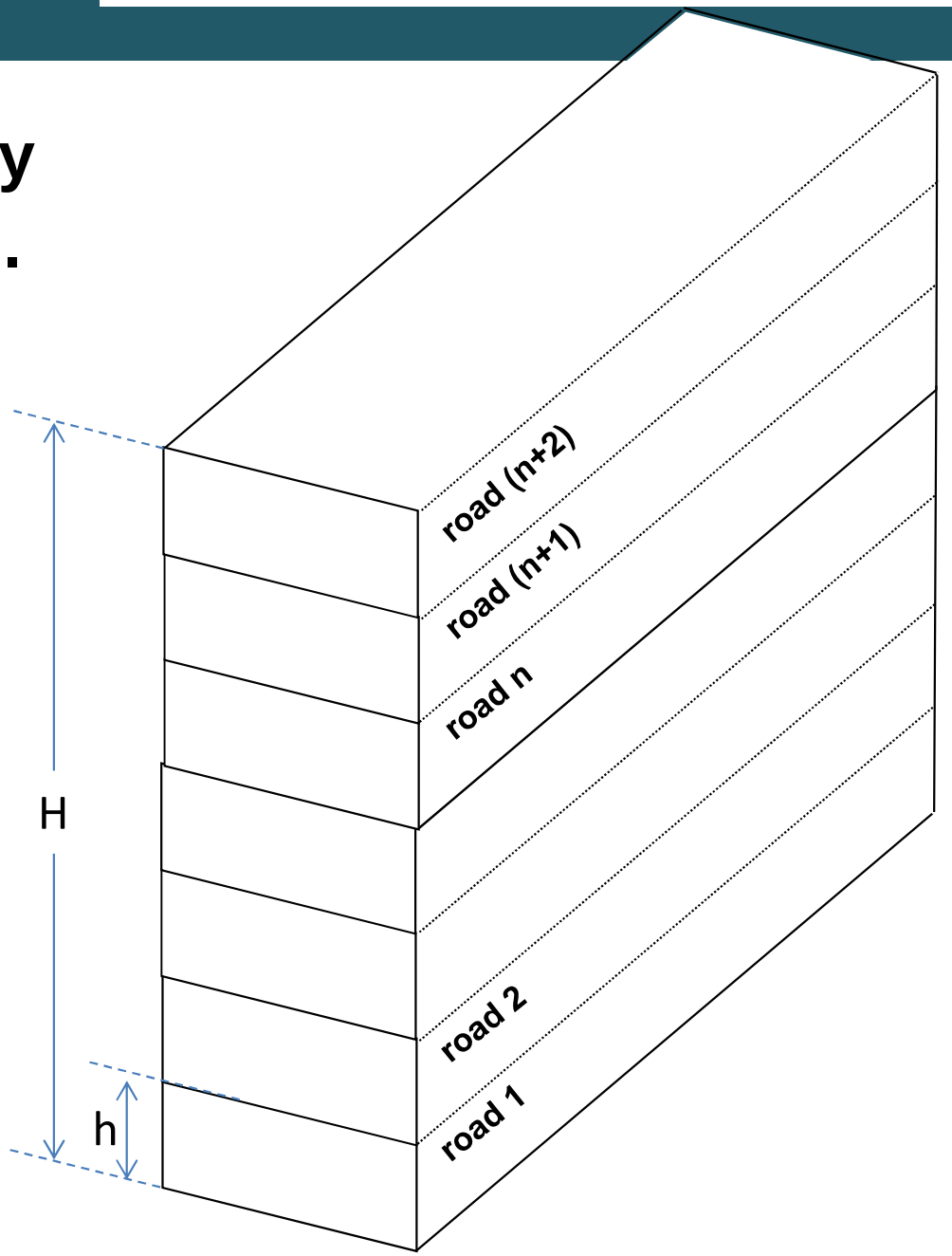
Contour Crafting – Fabrication Scenario

- **Goal: a house in a day**
- **Mortar stacking rate...**

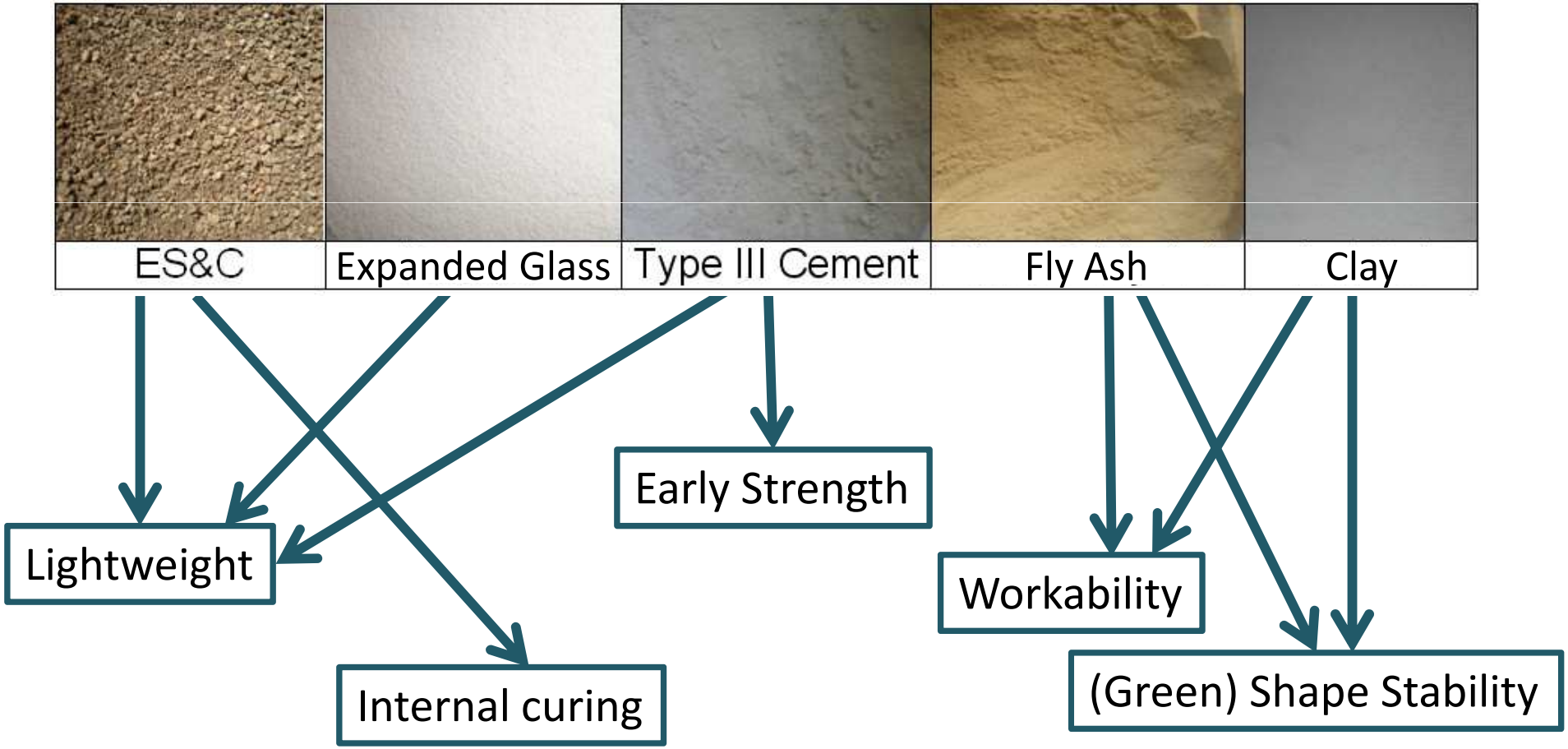
H=96” (8 feet)
h=3”

n=94/3=32
t= 8 hrs = 480 min

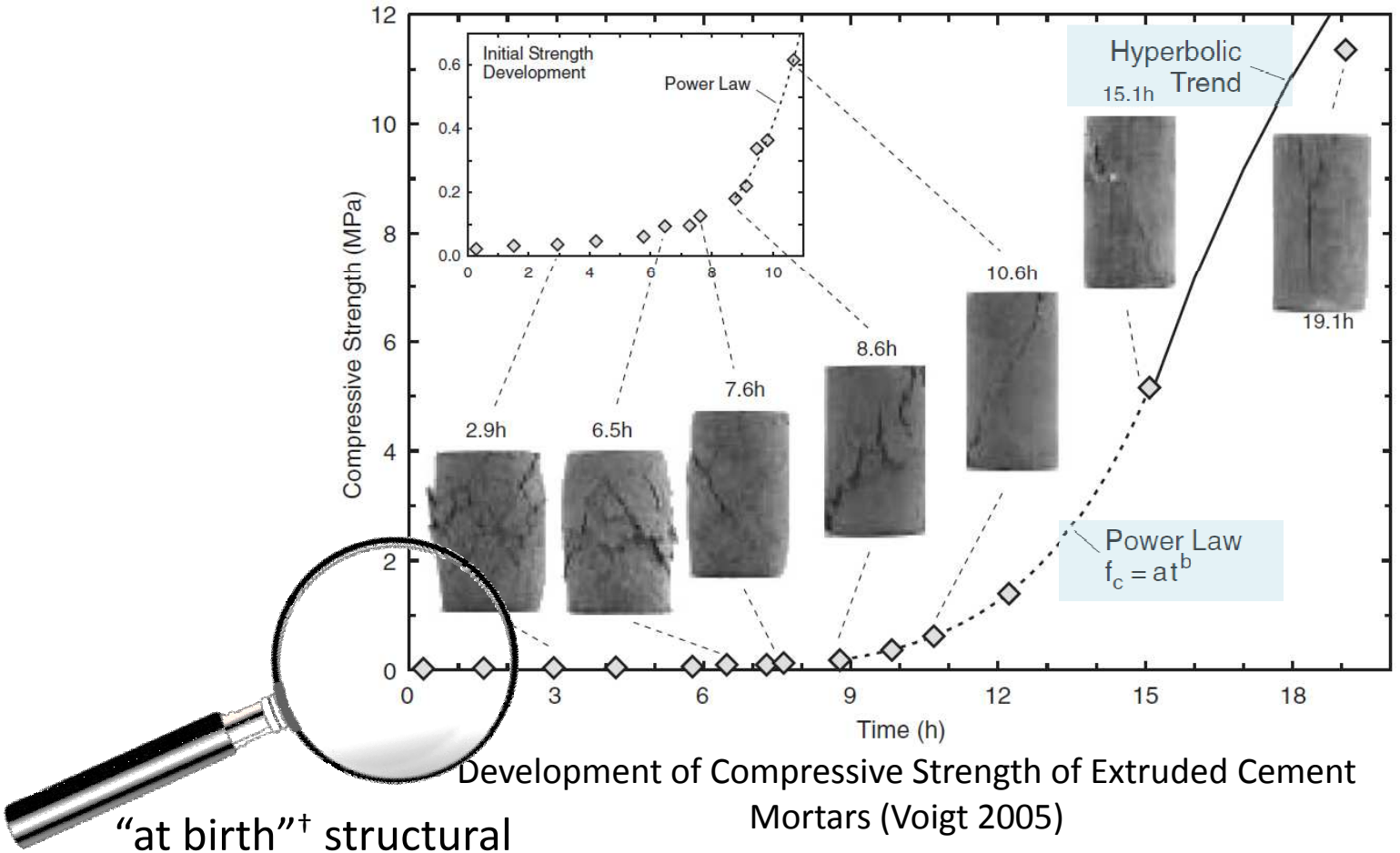
n/t = 32/480
n/t = 1 road / 15 min



Mix Design ↔ Stacking Regimen



Properties of Fresh Concrete



Development of Compressive Strength of Extruded Cement Mortars (Voigt 2005)

"<u>at birth</u>"† structural properties of concrete

After Carino (2001) and Freiesleben (1985) the gradual strength development during setting can be modeled with an exponential function:

$$y = Ce^{mt}$$

† credit: Mario Ucci

Experiments with Fresh Concrete

Bin to hold sand used to charge the loading device.

6 in.x12 in. cylinder guided laterally and suspended by springs. The cylinder collects sand flowing in at a constant rate from above. This charge stretches the suspension system, and is considerably larger than the resistance exerted by the compressed fresh mortar specimen - this disparity assures nearly constant axial strain rate.

Dummy specimen used to zero extensometer.

Ram used to extrude test specimens.

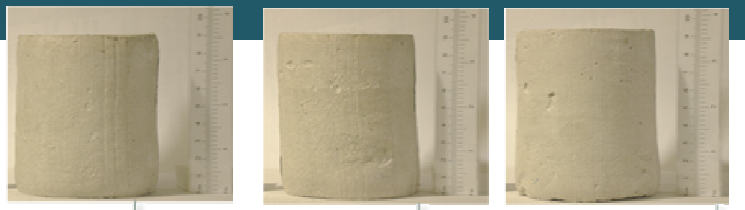
Extensometer to measure slump and axial deflection.

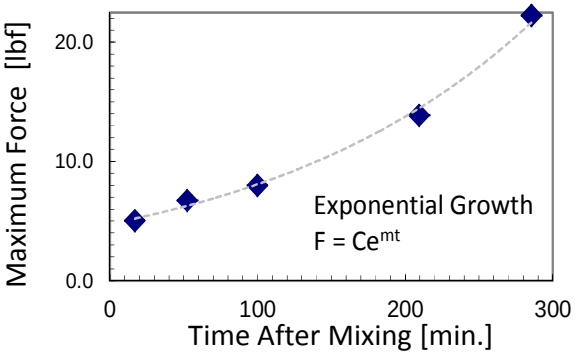
Vibration table used to consolidate test specimens inside extrudable cylindrical mold.

Digital weighing platform to measure applied force.

Stacking Strength

Stacking Regimen





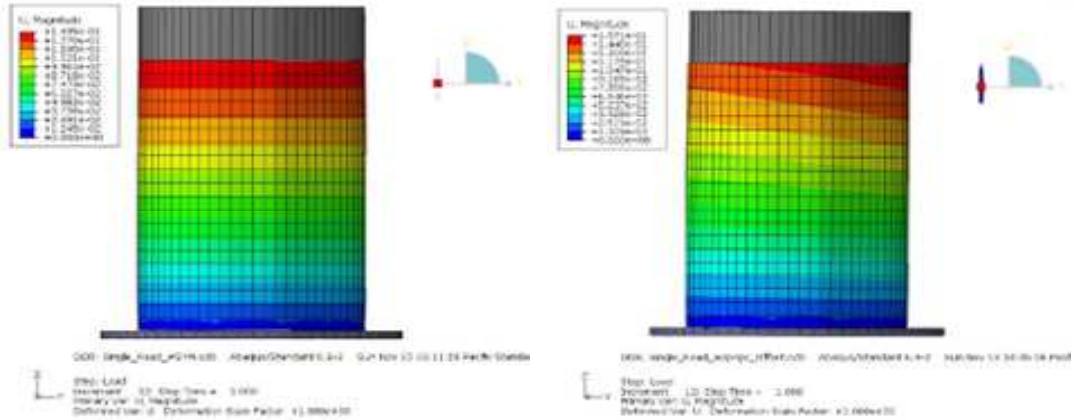
o = no failure during road stacking test; x = road-stacking test failure

Stacking Simulation





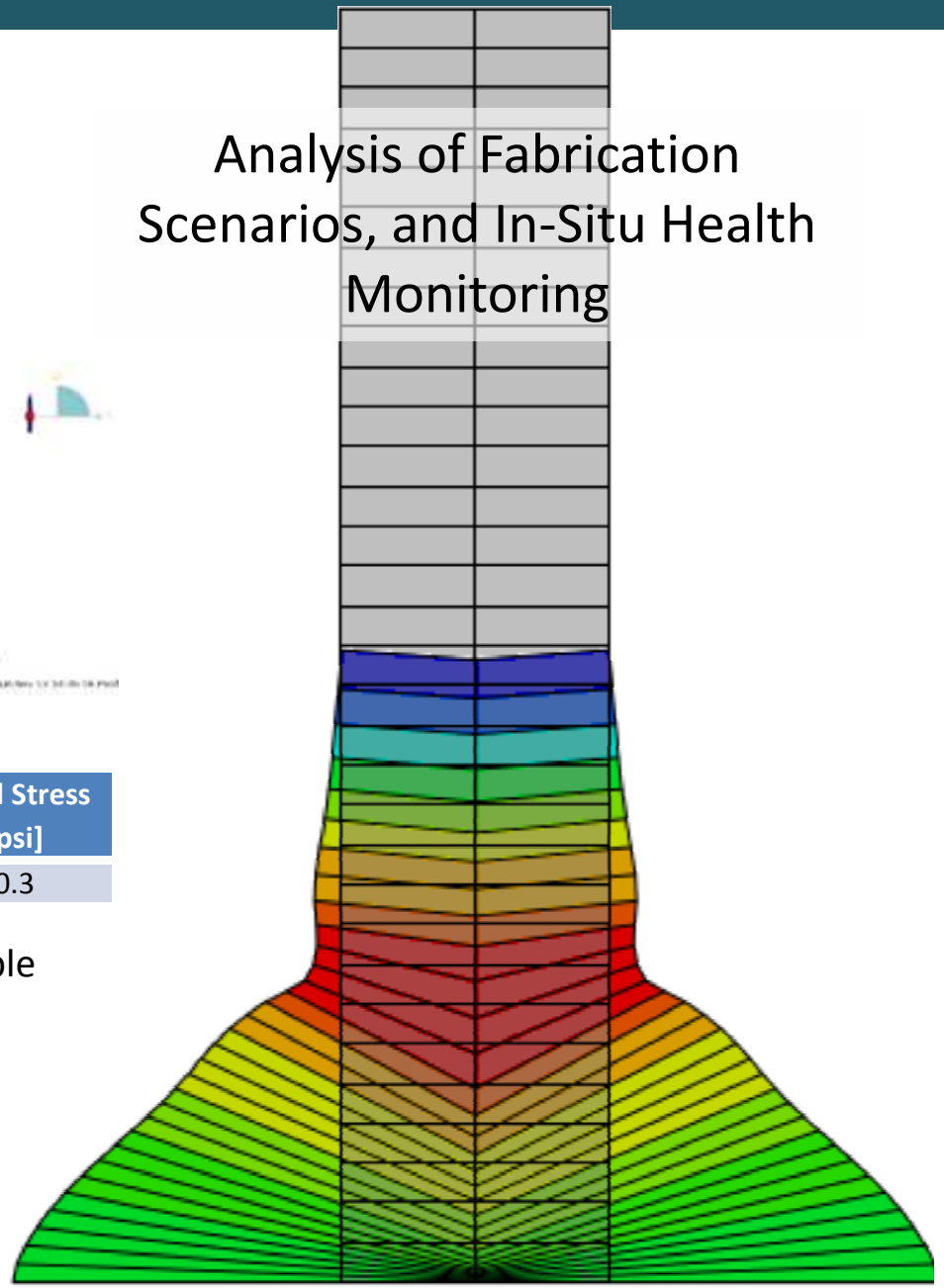

Numerical Methods for Fresh Concrete



Modulus [psi]	Poisson's ratio, v	Angle of Friction	Initial Hydrostatic Tension Strength	Dilation Angle	Yield Stress [psi]
5	0.2	45	0.2	45	0.3

Typical Drucker-Prager parameters for a Contour-Craftable mortar 30 minutes after mixing

Analysis of Fabrication Scenarios, and In-Situ Health Monitoring



Research Opportunities

- **Varying temperatures**
- **Varying moisture contents**

- **Analysis of creep**
- **Analysis of autgeneous shrinkage cracking of the monolithic structure**
- **Optimize grading (including large aggregate) improve shape stability and green strength**
- **…**

Thank You for you Kind Attention

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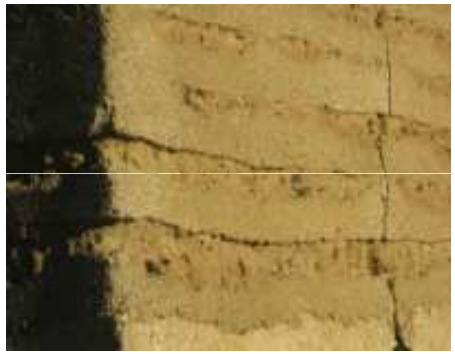
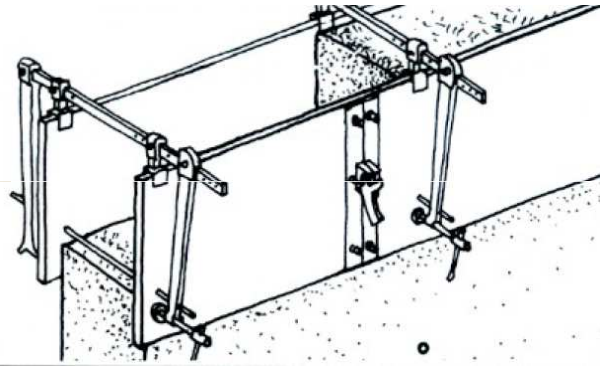
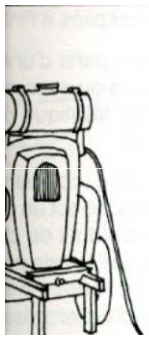
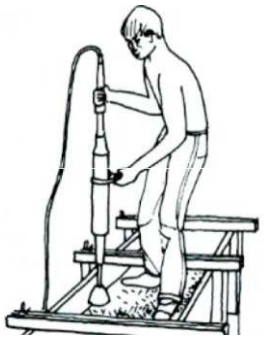
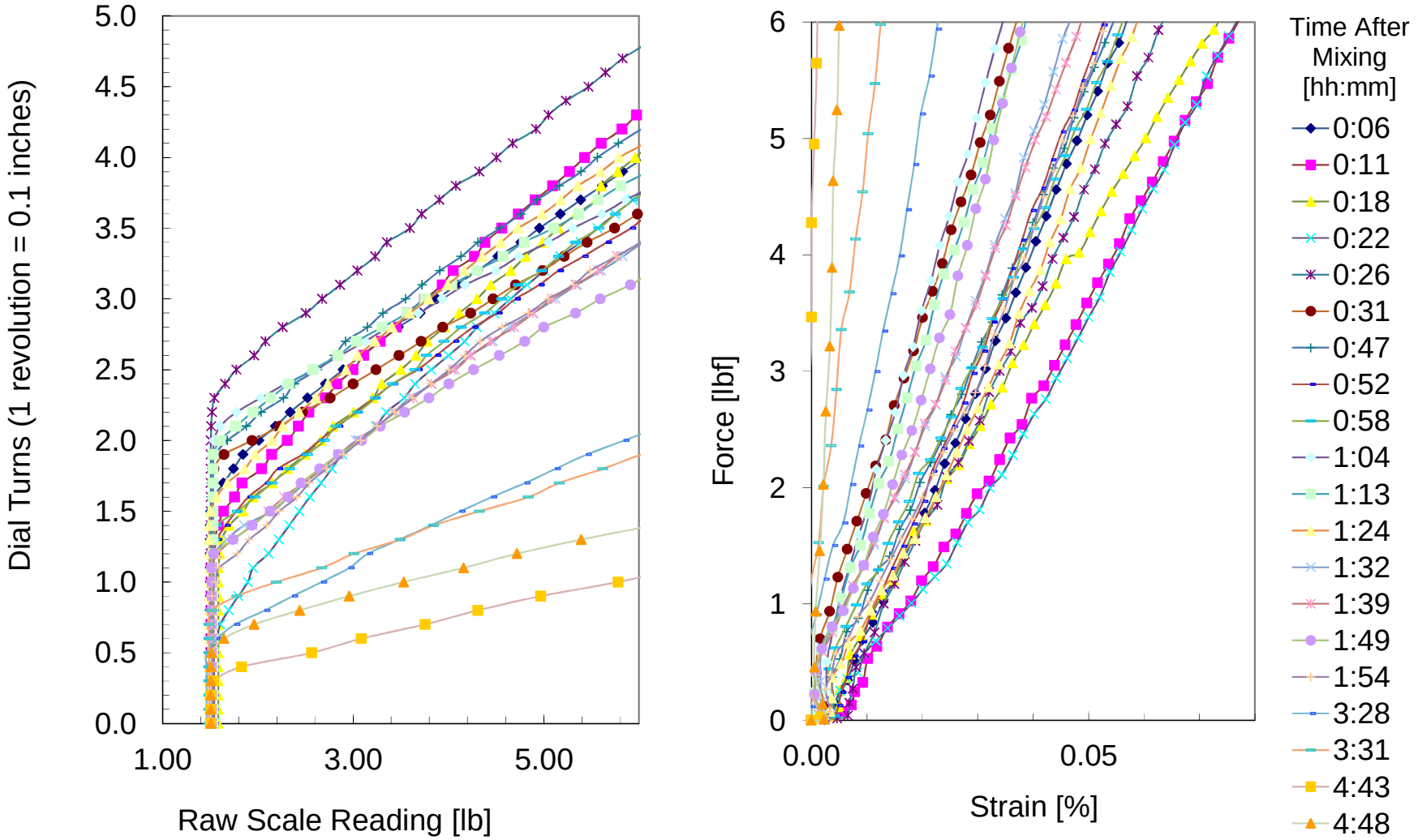
Maison en Pise’ (Rammed Earth)

Ref. 1: « traité de construction en terre » CRATerre ed parenthèses, 1995, p. 207)

Ref. 2: « Architecture et Terre en SYRIE , une tradition de onze Millénaires » par Mahmoud BENDAKIR ed CRAterre. 2008.

Green Strength Test - Results



Unconfined Compressive Strength of a Contour-Craftable Mortar