Structural Testing of Straw Bales in Axial Compression

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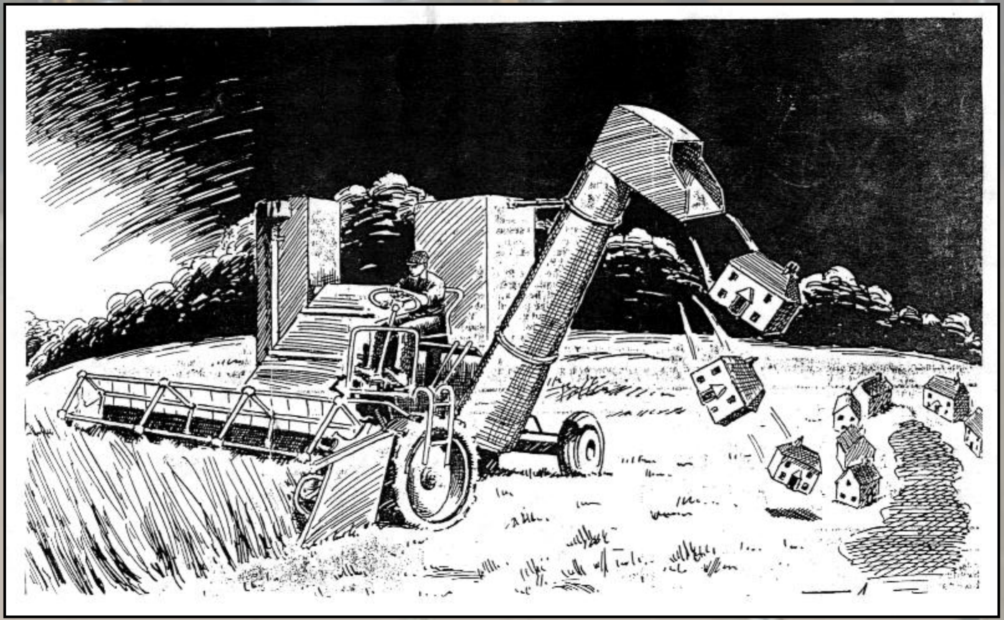
Straw Bale Construction

- Began ~ 100 years ago in western Nebraska
- Utilizes a waste material to construct well insulated walls ~ relatively high R-value
- Constructed from large blocks and then rendered or plastered with a finish to weather proof the building
- Natural material, no industrial/polluting processes

Modern Rediscovery



Resurgence of straw bale building in recent years derives largely from our concerns for the **degradation of the environment and sustainability of human activities on earth**, in particular the impact of the **unsustainable nature of current building practices**.

Straw as a Building Material

- Waste products from food consumption
- Timber has a regeneration cycle of at least 20 years
- Straw is regenerated once or twice a year

- Sustainable: as long as humans produce grains for food, straw will be a by product

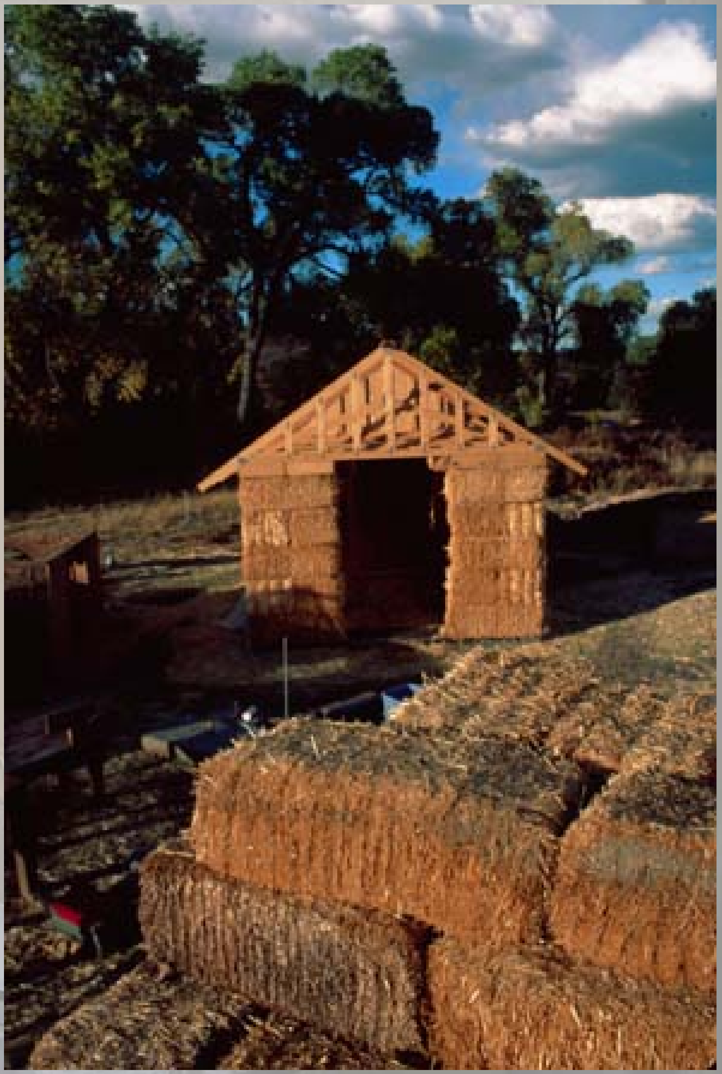
- Logging of native forests for building products has had a devastating effect on the natural environment

Straw as a Building Material

- Understanding of straw bale properties is limited
- Straw bales offer excellent thermal insulation
- Straw bale buildings promote energy efficiency

Straw as a Building Material

- **Drawbacks for straw:**
  - **Peoples' perception**
  - **Conventional "wisdom"**
  - **Lack of understanding of the material often scares the so-called building professional**
  - **The bewildered reaction of layman when straw bale building is mentioned**



Straw as a Building Material

The dramatization of the big bad wolf and the three little pigs has planted deeply into peoples' minds that one cannot build houses with straw.

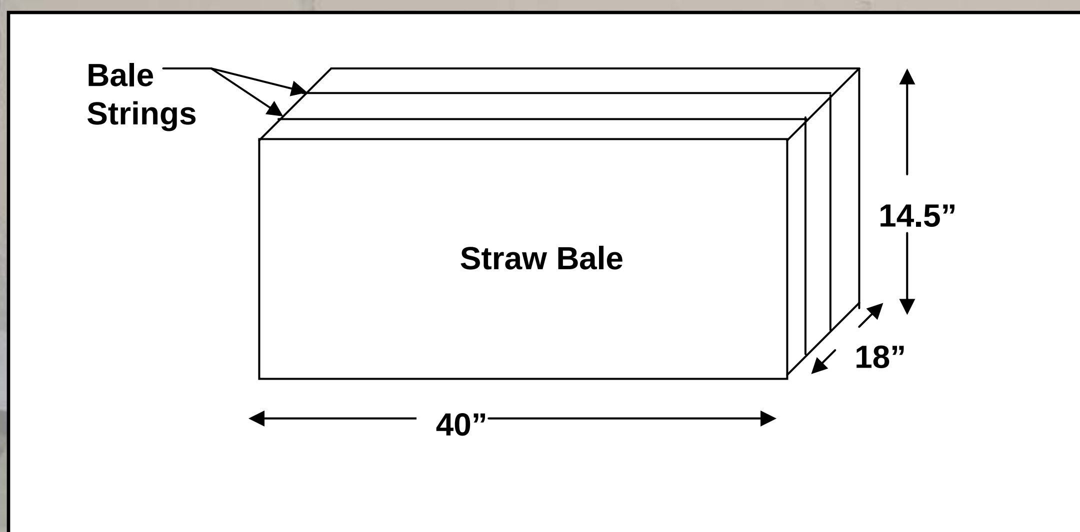
Straw as a Building Material

The lack of understanding on how straw bales behave in a built environment when exposed to various natural effects deters its wider application.

- Our Project: axial compression tests of straw bales, both plastered and unplastered
- This information can prove to local building officials that straw bales can meet and exceed the safety requirements for buildings

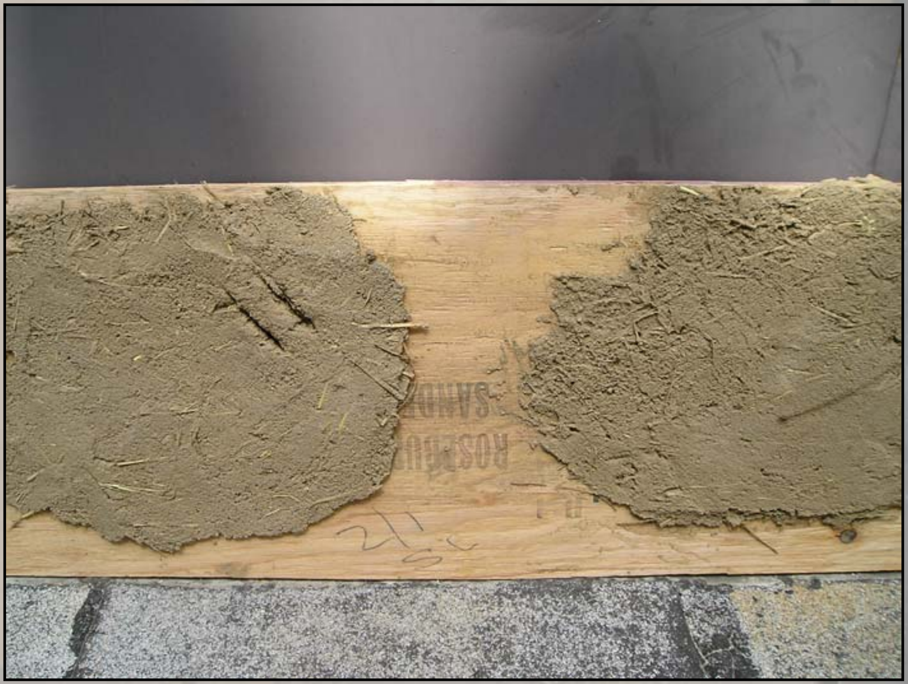
Straw Bale Samples

- Six identical bales, the same as used in the class workshop
- Two string bales
- Avg. density = 8.3 pcf



Plaster

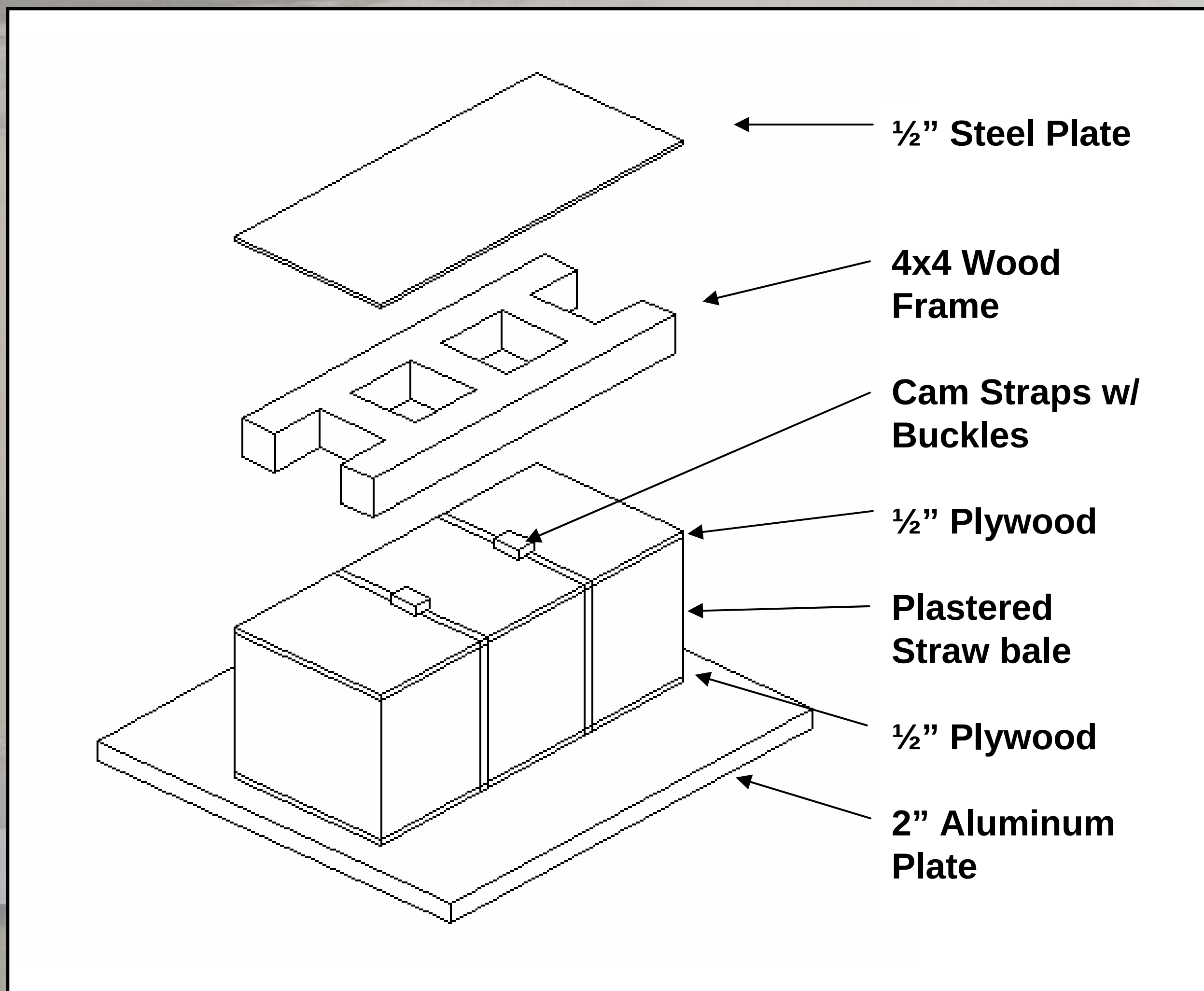
- 3 bales
- Clay slip: clay, water
- Plaster: 1 sand, 1 subsoil, straw, water
    - Two formulas tested
- Finish coat: 9 crushed refine, 1 clay, small straw, water



Test Preparation

- Pre-compress plastered bales
- Give bales time to dry
- Build wood frame
- Obtain metal plates

Test Configuration

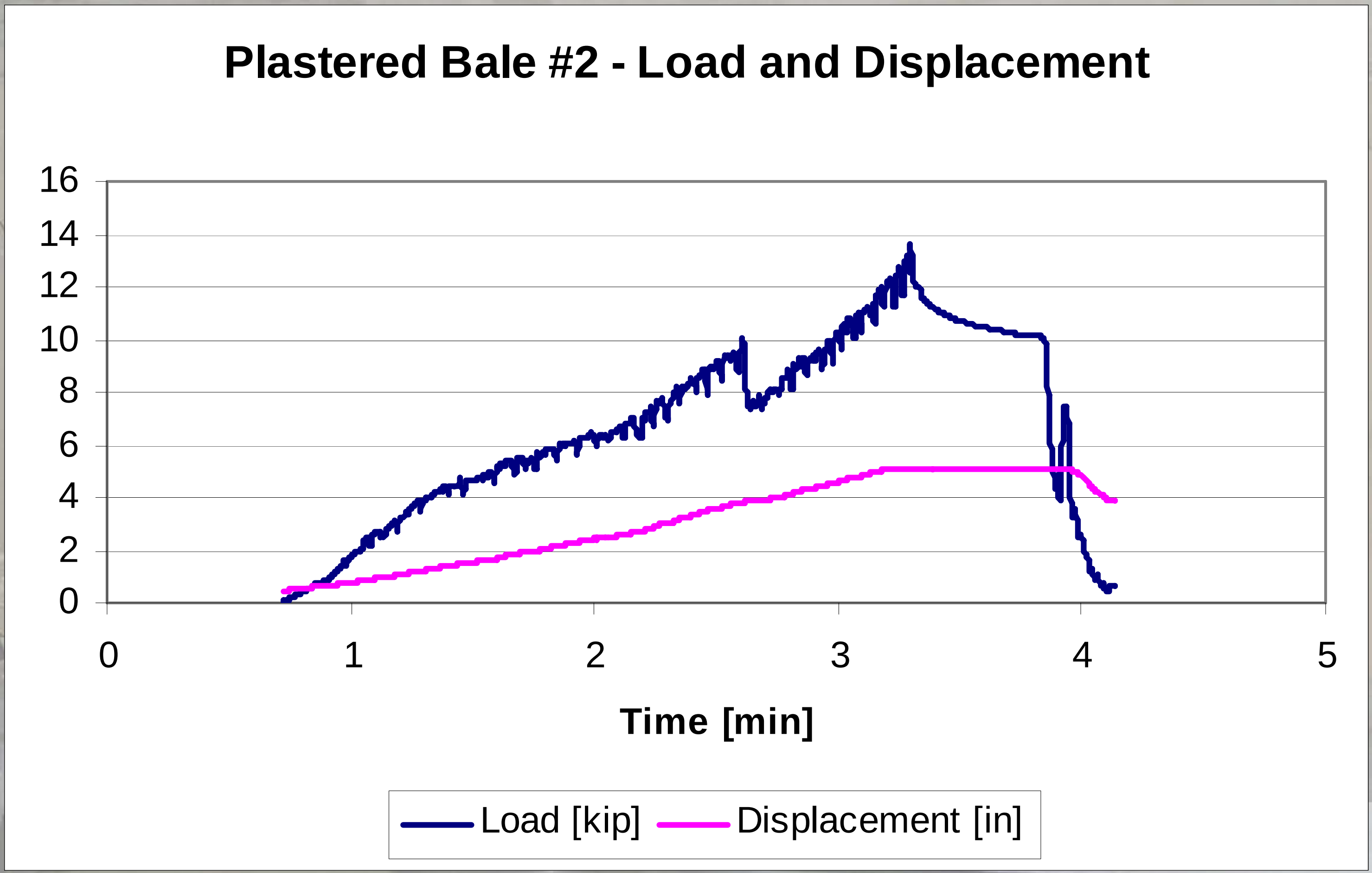


Plastered Axial Compression Test

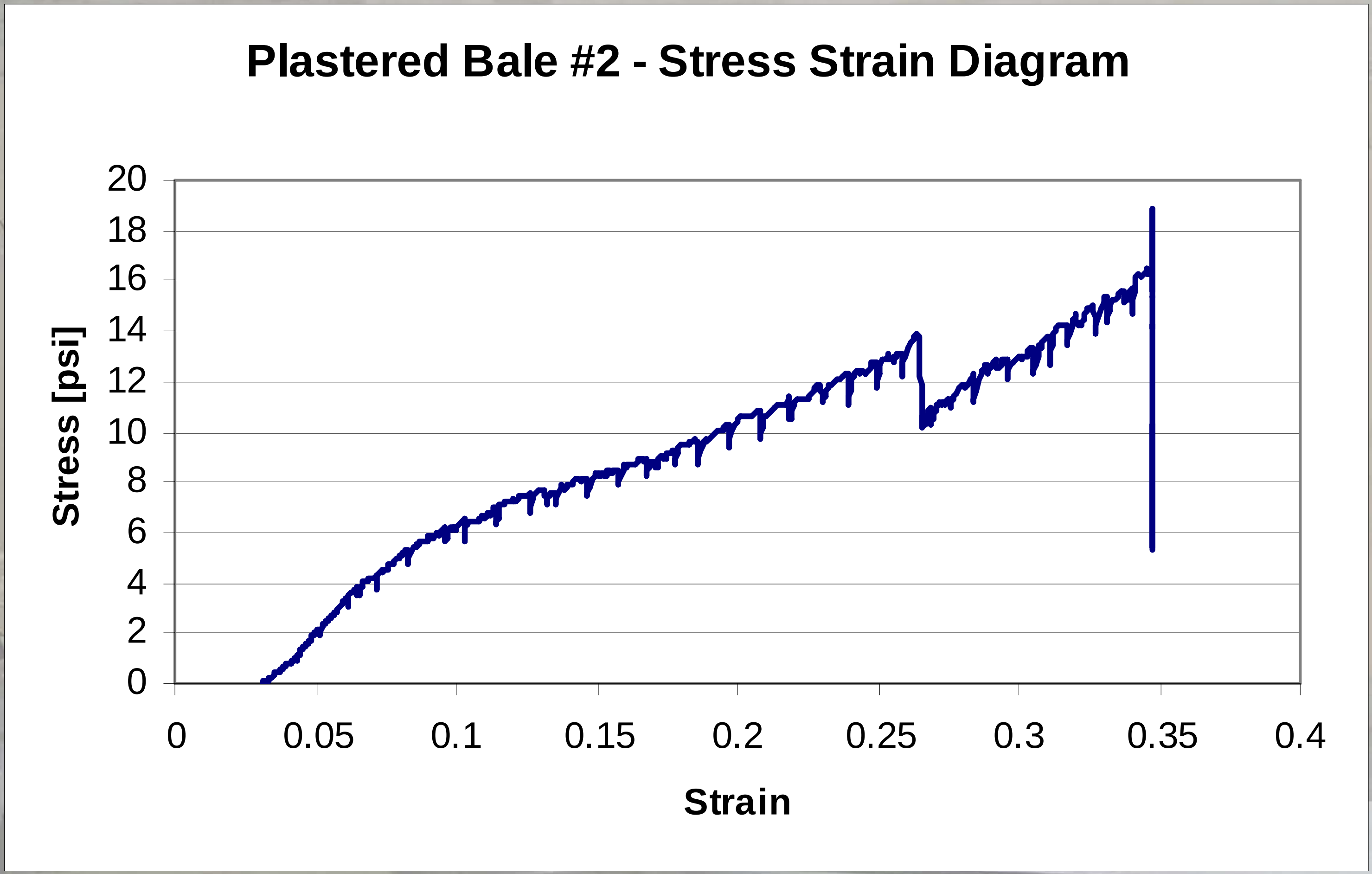



Unplastered Axial Compression Test

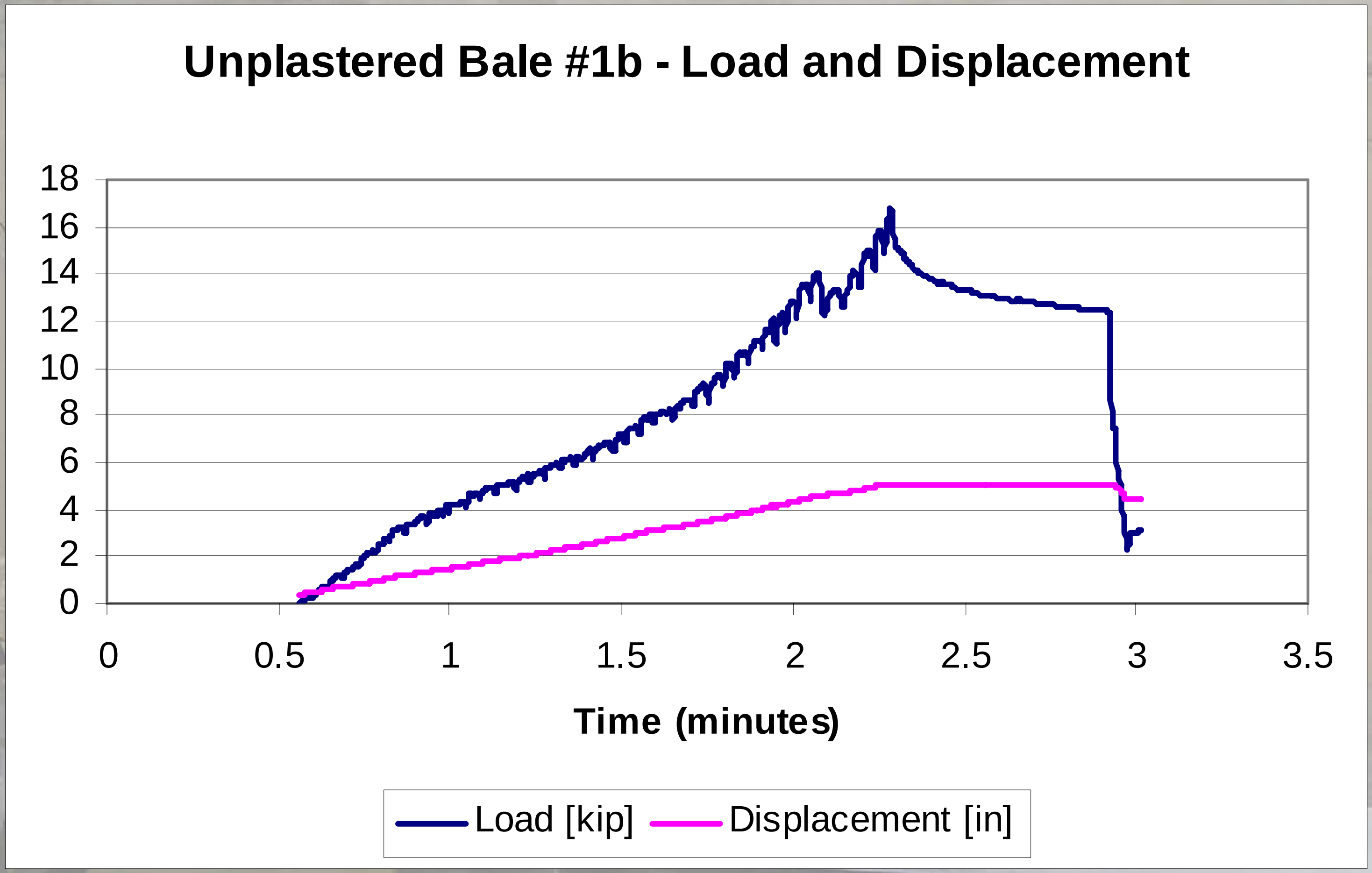
Plastered Bale Results



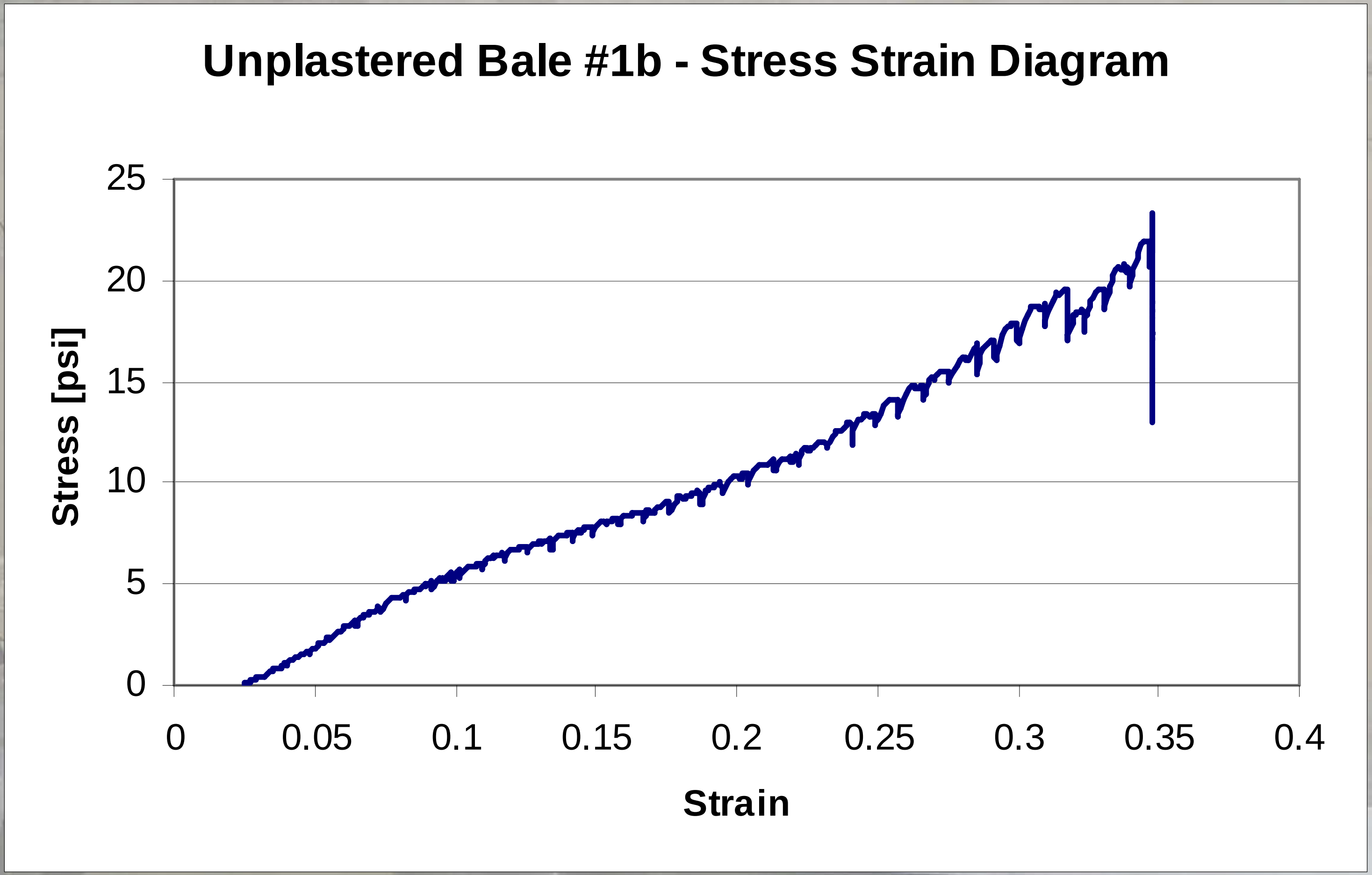
Plastered Bale Results



Unplastered Bale Results



Unplastered Bale Results



Analysis of Test Results

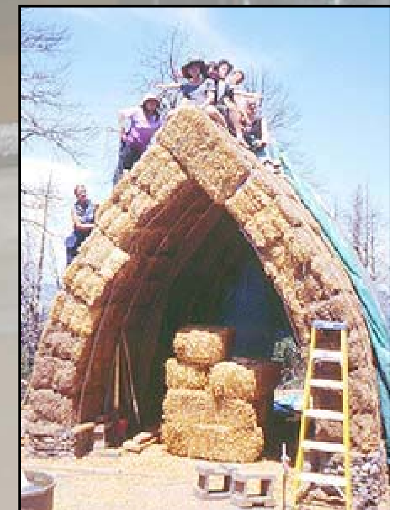
$$\sigma = \frac{Load}{Area}$$

$$\varepsilon = \frac{\Delta L}{L_o}$$

$$E = \frac{\sigma}{\varepsilon}$$

Bale	E [psi]	Failure Load [kips]
1	44	10.8
2	41	9.9
3	41	9.6
1b	60	14.1
2b	68	18.5
3b	65	7.8

Discussion of Results



- The load at which the first bale string ruptured is the failure load
- Mostly linear stress strain curves ~ Elastic
- All six bales continued to exhibit elastic behavior even after rupture of a bale string
- Plastered bales performed well below expectations
  - Plastered bales basically expand in two dimensions under compression
  - Increased stress on the bale strings
  - Testing bales vs. a wall
  - Moisture content of the bales

Comparison to Previous Test Results

Study Info.	Density (pcf)	Ultimate Compressive Load (psi)	E (psi)	Assembly	Notes
Bou-Ali, 1993, AZ	8.5	84	78-211	Indiv. Bale, flat	Wheat, 3-string, all elastic, unplastered
Thompson, 1995,Canada		6-10	18-26	Indiv. Bale, flat	Wheat, oat, barley
Stephens, 2000, WA	18		992	Indiv. Bale, on edge	“Supercompressed” bales, 6 strings
Mar, 2003, EBNet		3.9		Two half-bales, stacked vertically	High straw fiber earthen plaster with coconut fiber mesh
Mar, 2003, EBNet		2.6		Two half-bales, stacked vertically	Low straw fiber earthen plaster with coconut fiber mesh

Comparison to Previous Test Results

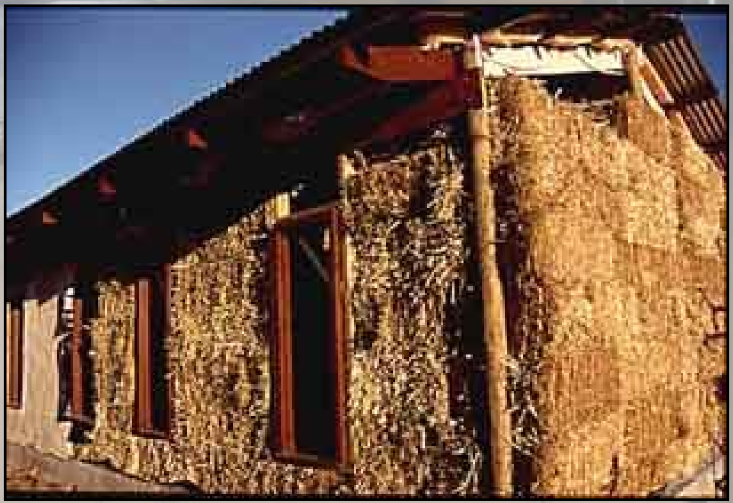
- Bou-Ali’s E = 78-211 psi
  - Our modulus of elasticity = 60-68 psi
- Bou-Ali ultimate load = 84 psi
  - Our “failure” load = 10.8-25.7 psi
- Bou-Ali used three string bales
  - We used two string bales
- Bou-Ali bale density = 8.5 pcf
  - Our bale density = 8.3 pcf

Comparison to Previous Test Results

- **Thompson ultimate load = 6-10 psi**
  - **Our "failure" load = 10.8-25.7 psi**
- **Thompson E = 18-26 psi**
  - **Our modulus of elasticity = 60-68 psi**

- **Major differences reflect the potential for variation between different bale sources**

Lessons Learned



- More common in the United States in recent years
- Hard to get permits to build load bearing straw bale structures
- Keep moisture out of the straw bales
- Three string bales or higher density bales recommended for large loads

Lessons Learned

- Studied structures must support between 636 and 800 plf
- Our bales can support approximately 3000 plf
- With good test data officials can plainly see how safe a straw bale structure can be
- Promote straw bale as an alternative to conventional building materials

Conclusion

- Due to the compressive strength of straw bales and thus their ability to support typical roof loads and their exceptional thermal characteristics, straw bale technology is very well suited for residential and small commercial construction.

Any Questions?