Comparison of Damaged Borosilicate Constitutive Constants Obtained with Confined-Compression and Constant-Pressure-Compression Devices

(Comparison of "sleeve" and "bomb" tests)

Sidney Chocron
Kathryn Dannemann
Arthur Nicholls
James D. Walker
Charles E. Anderson
Southwest Research Institute
San Antonio, Texas 78238

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
27 JAN 2008	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Comparison of Damaged Borosilicate Constitutive Constants Obtained with Confined-Compression and Constant-Pressure-Compression Devices	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Sidney Chocron; Kathryn Dannemann; Arthur Nicholls; James D. Walker; Charles E. Anderson	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Southwest Research Institute San Antonio, Texas 78238**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000**	10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM/TARDEC**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **18599**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**29**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

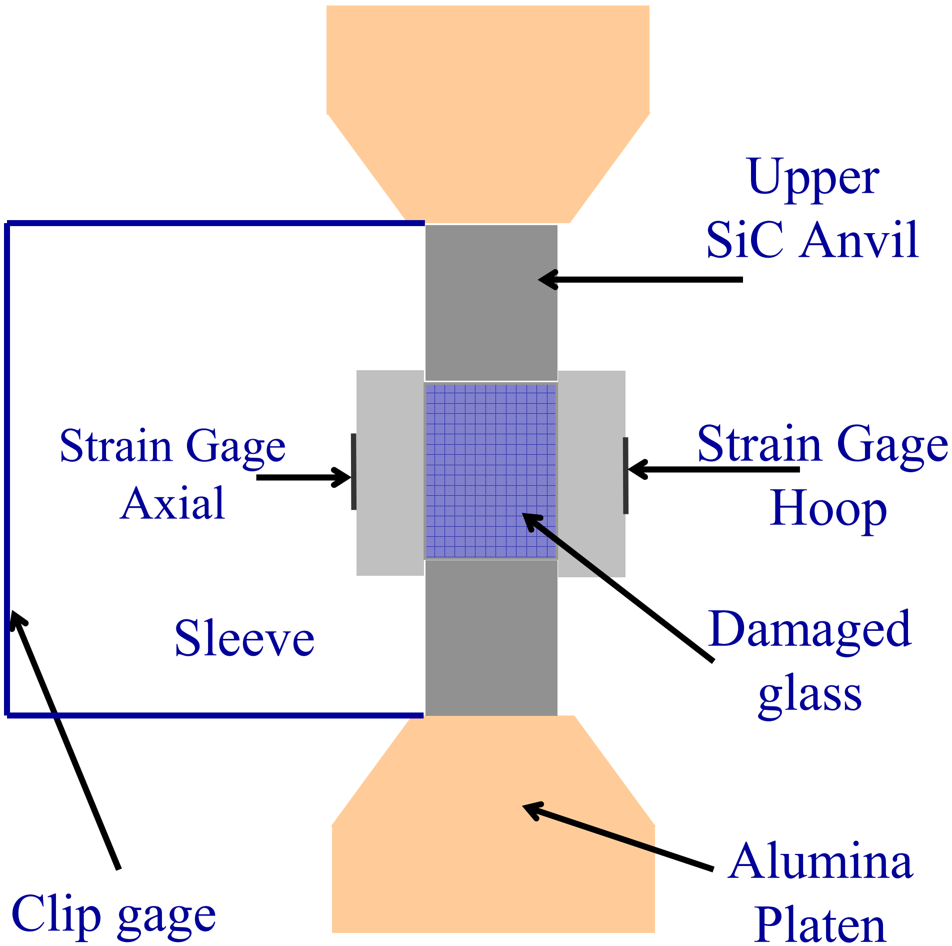
Objectives

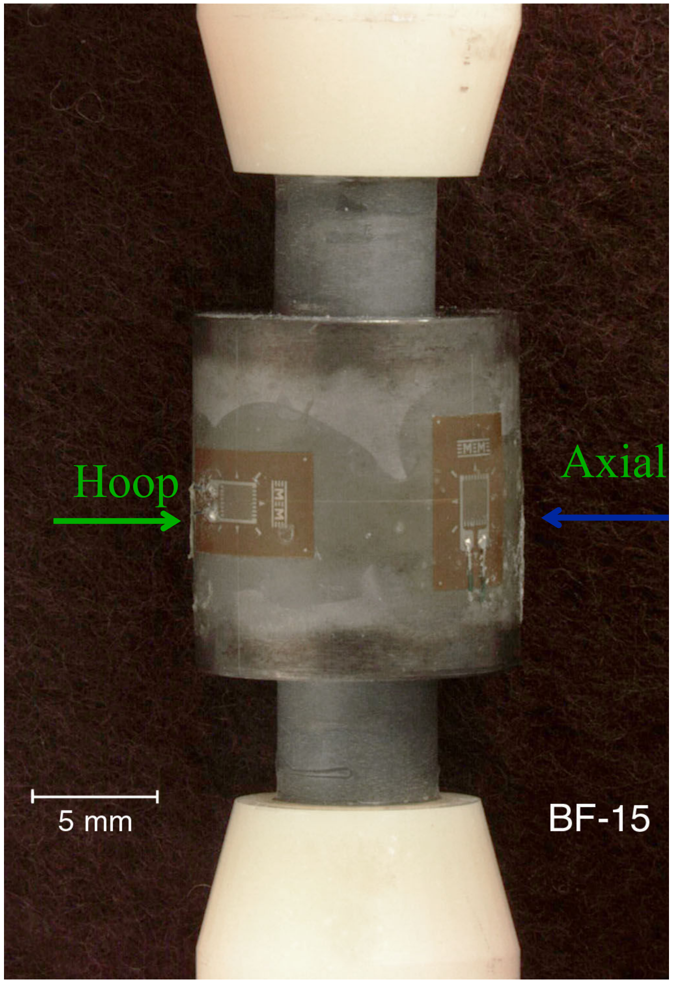
- Ultimate objective: Transfer properties measured in the lab to ballistic simulations that can predict ballistic tests results
- Milestones:
  - Determine with laboratory experiments the strength of damaged borosilicate and soda-lime at low and high confining pressures
  - Find the Drucker-Prager constants, β and Y0, in an independent way and compare them with the sleeve tests.
  - Validate sleeve tests

Damaged Borosilicate Glass

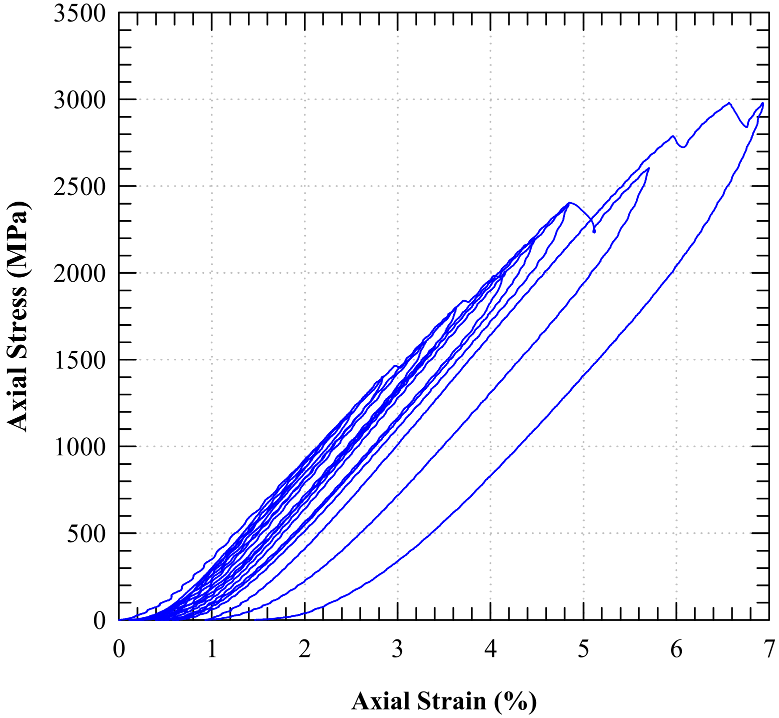
- Two cycles in oven at 500 C and iced water.
- Structural integrity
- Why damaged borosilicate?
  - During ballistic penetration the projectile is in direct contact with damaged material.

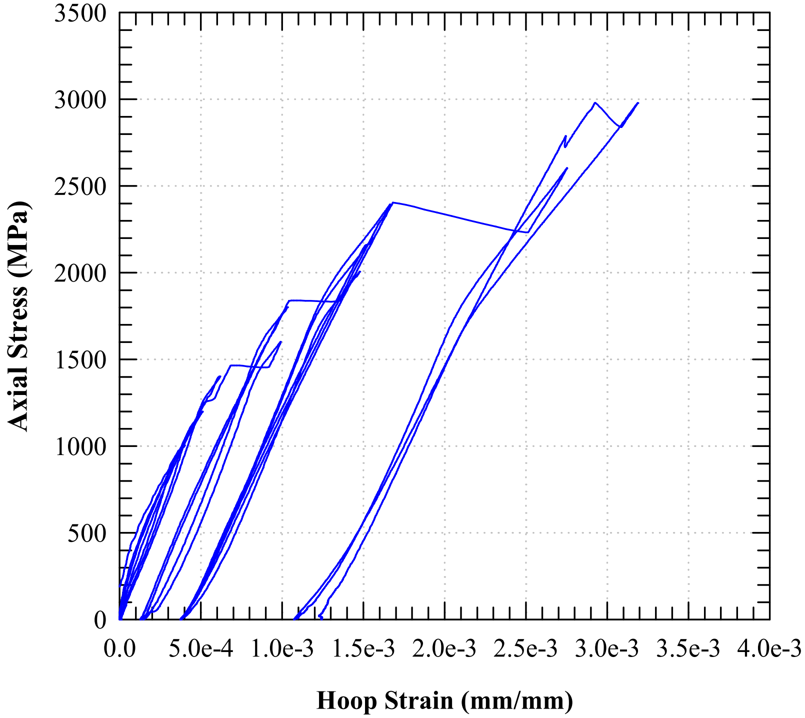
Review: "Sleeve" test set-up



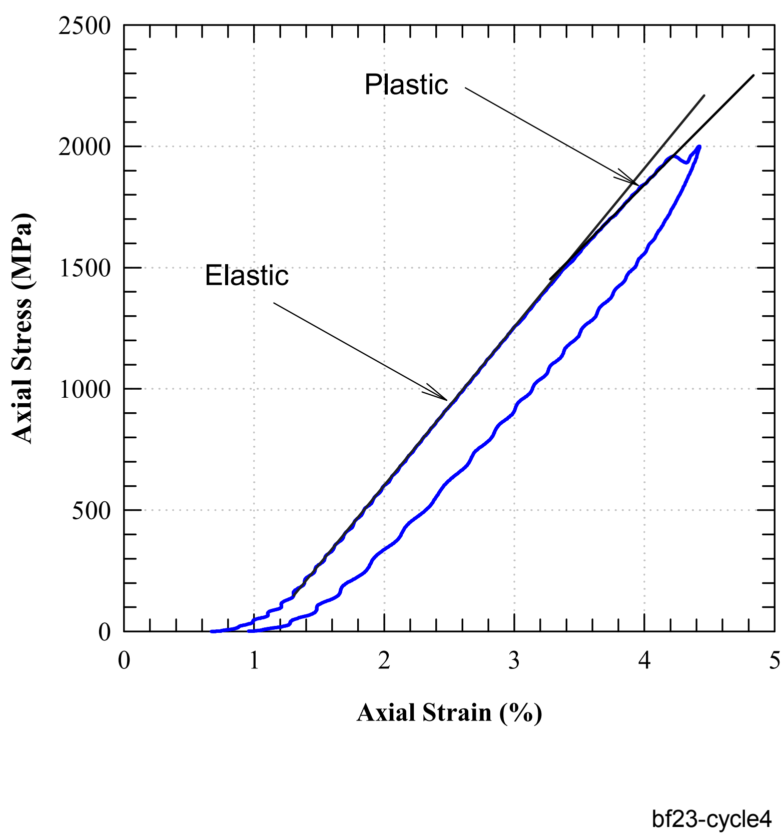


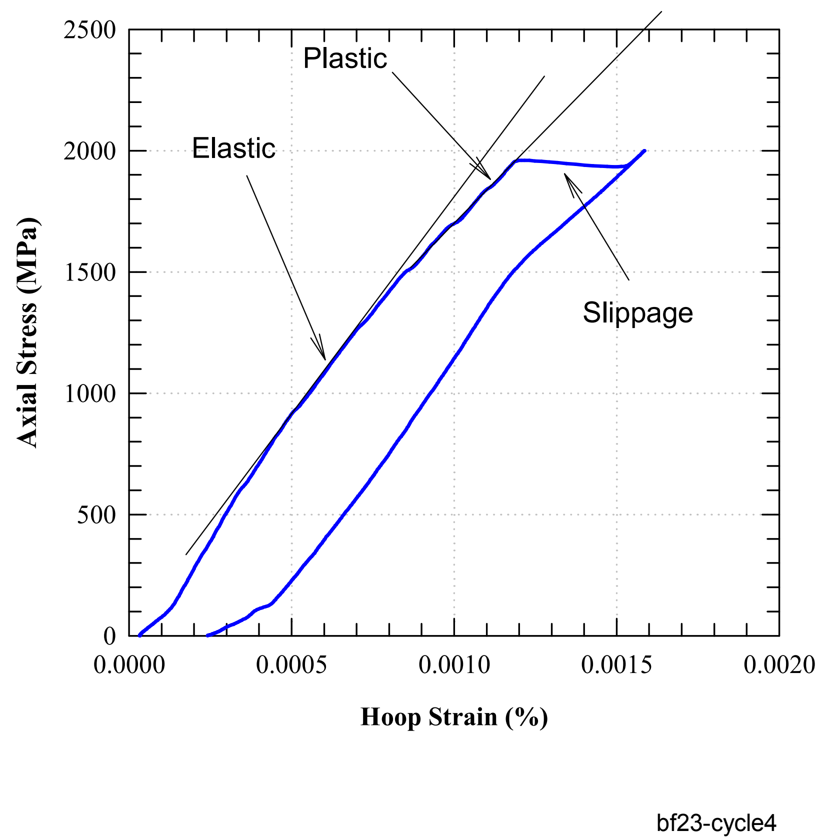
Review: “Sleeve” test results





Review: "Sleeve" test results





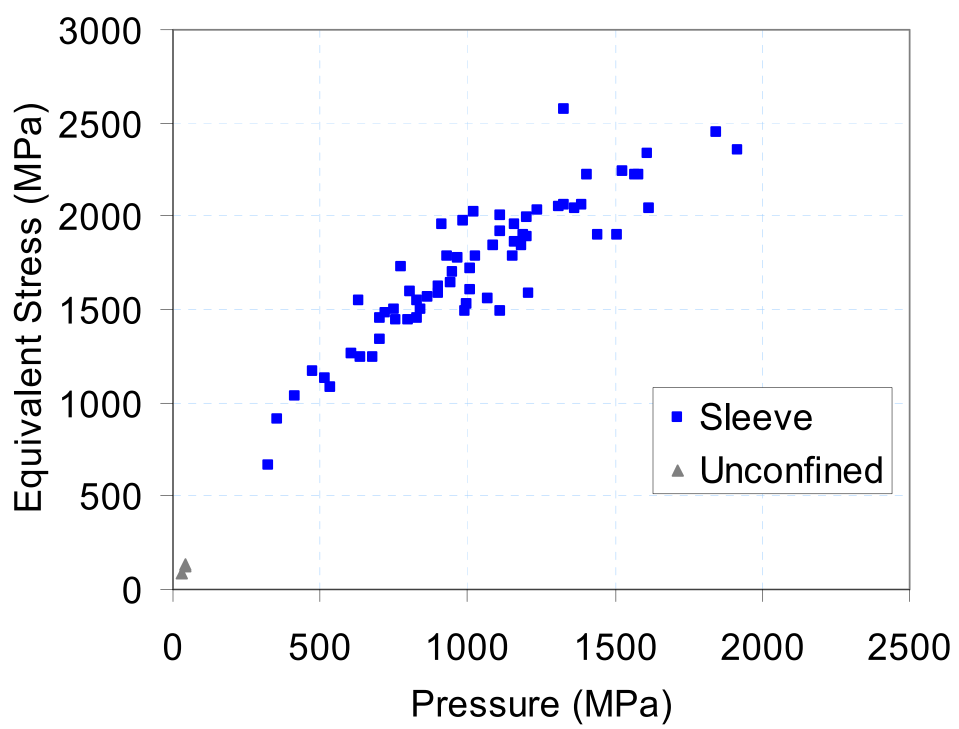
Review: “Sleeve” test results

- Assumed Drucker-Prager

  $Y = Y_0 + \beta P$
- Analysis of sleeve data

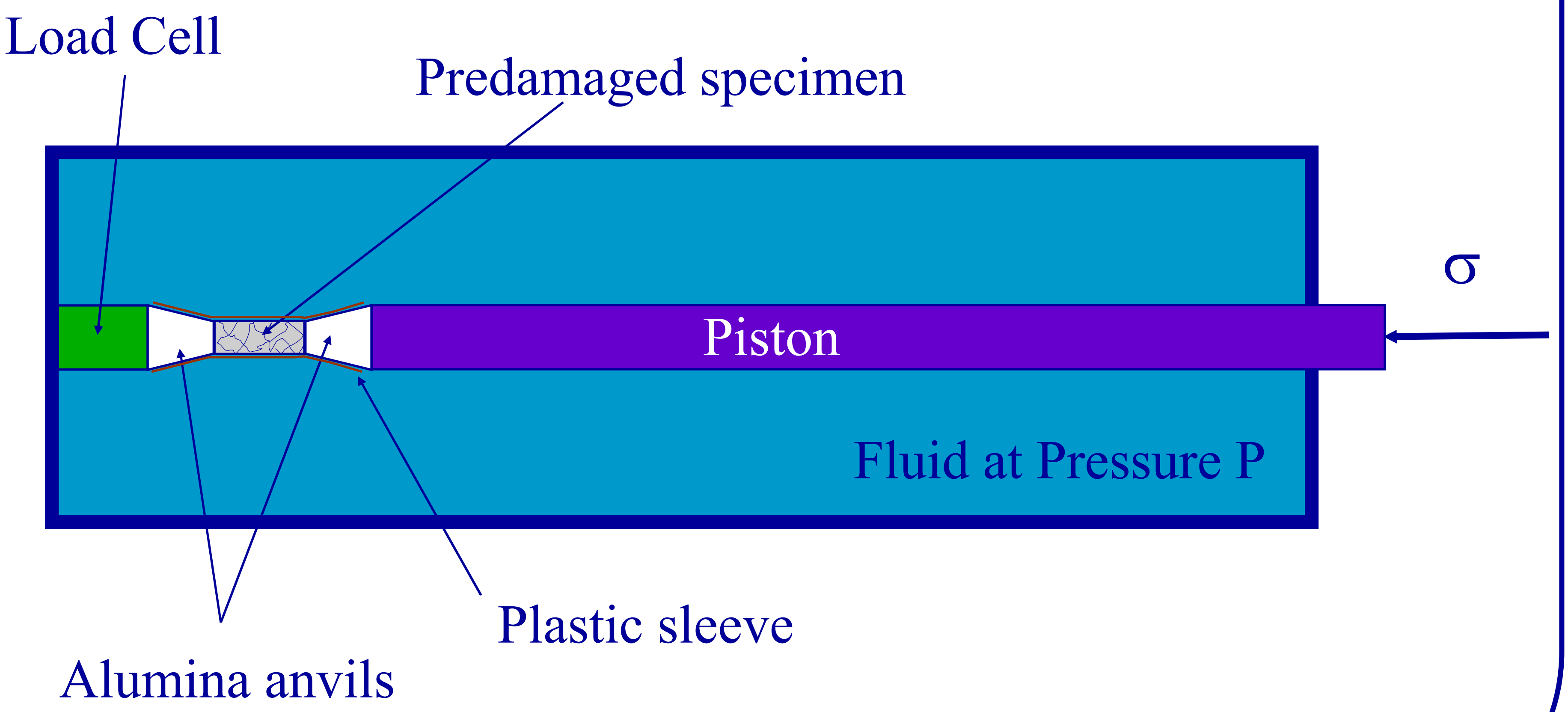
  $\beta = 1.8$
- Analysis of unconfined data

  $Y_0 = 43$ MPa



Data from 13 different tests.
Each test can provide more than one point because of load/reload cycles

Setup of bomb test

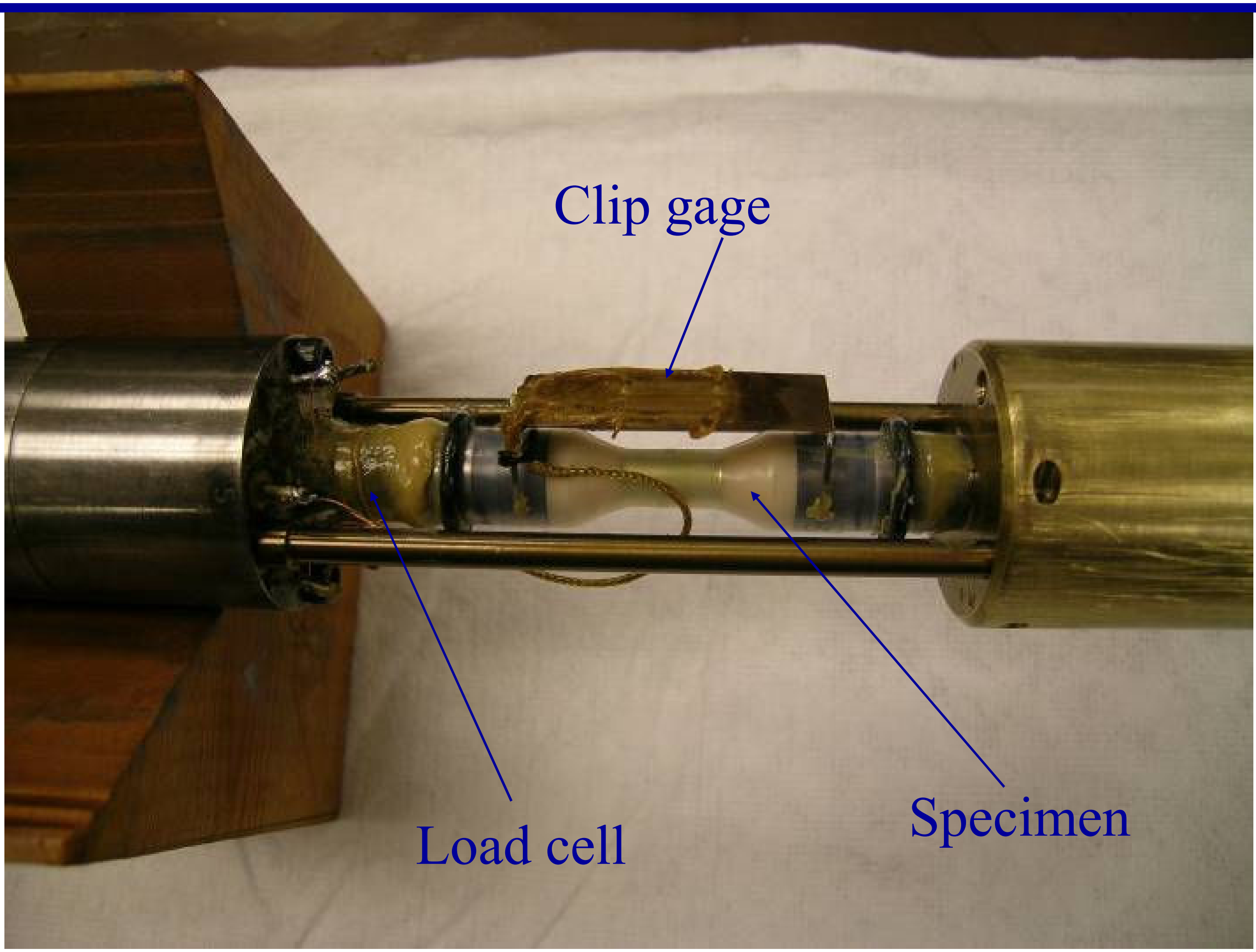


OD = 7.5 in

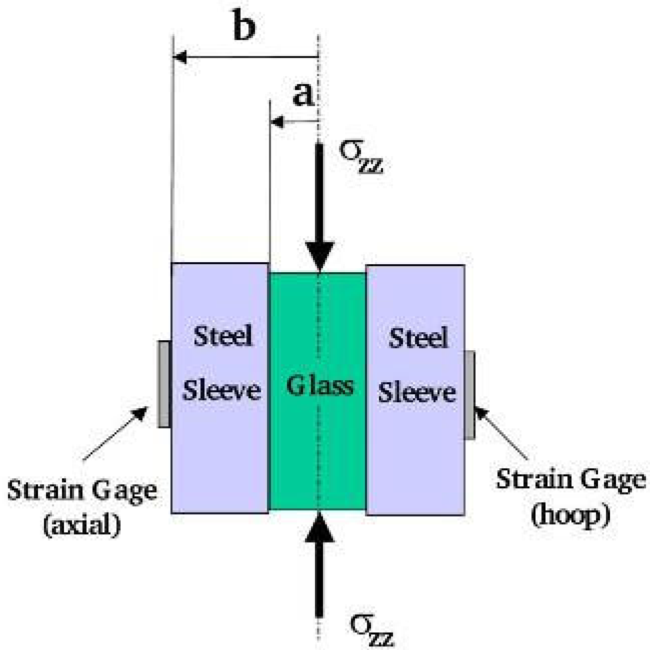
ID = 1.5 in

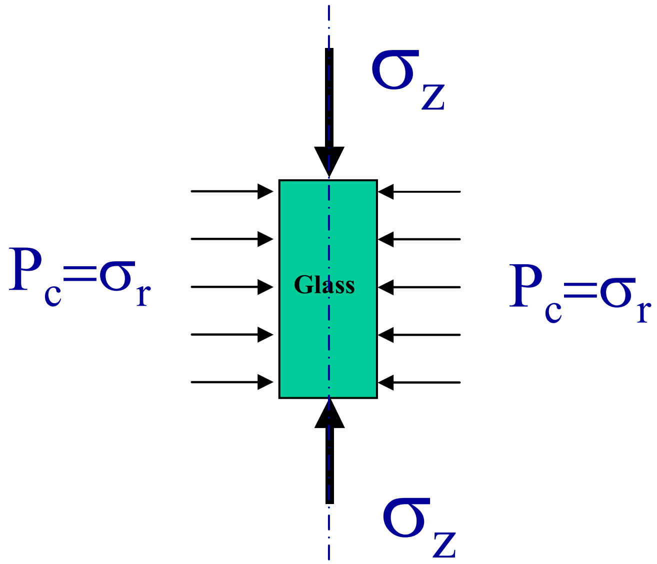
Thick = 2.5 in

Length = 23 in


Clip gage
Load cell
Specimen

Comparison of test methods





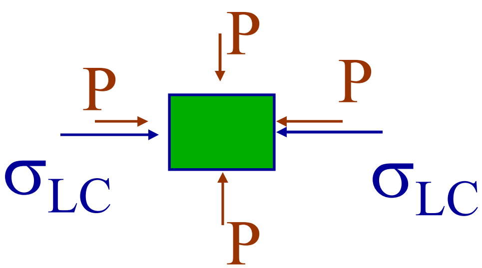
Sleeve Test

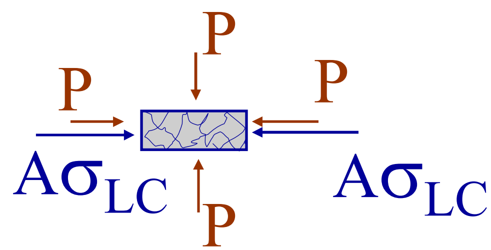
- Confinement pressure changes during the test
- The analysis is involved
- An analytical model is needed to infer constants
- Conceptually more involved but test relatively straightforward in practice.

Bomb Test

- The confinement pressure is kept constant during the test
- Conceptually easy test, difficult in practice

Bomb test technique





σ_{LC} is the output given by the load cell. Strain gages on load cell are mounted to directly give the equivalent stress.

σ_z is negative in compression (P is positive in compression)

A is the area reduction factor between anvil and specimen: $A=A_{anvil}/A_{specimen}$

Axial stress on specimen:

$$\sigma_z = A\sigma_{LC} - P$$

Hydrostatic Pressure in specimen:

$$P_H = -\frac{1}{3}(\sigma_z + 2\sigma_r) = -\frac{1}{3}(\sigma_z - 2P)$$

Equivalent stress of specimen:

$$\sigma_{eq} = |\sigma_z - \sigma_r| = |\sigma_z| - P = A|\sigma_{LC}|$$

Expected "theoretical" results

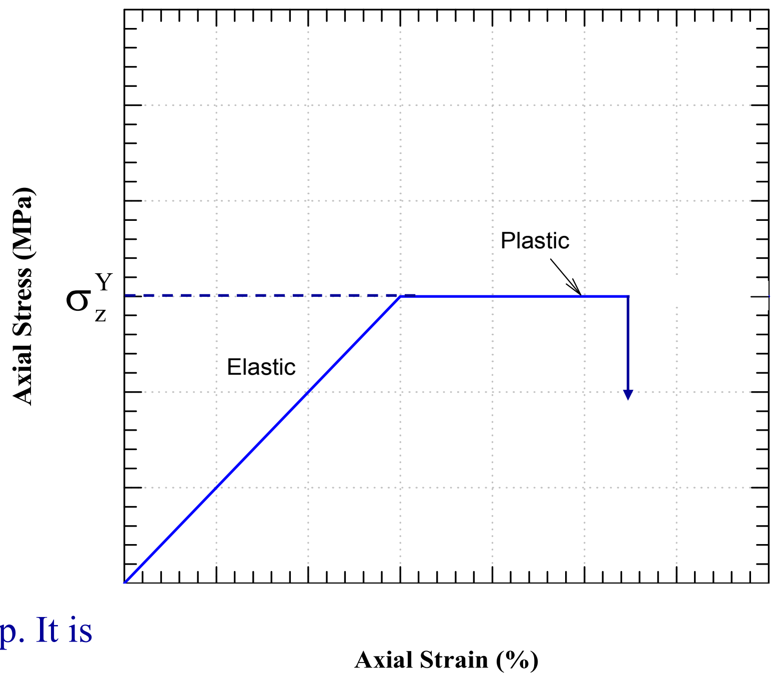
$\sigma_{eq} = |\sigma_r - \sigma_z|$

Drucker-Prager: $Y = Y_0 + P_H$

When yielding: $\sigma_{eq} = Y \Rightarrow \sigma_r - \sigma_z = Y_0 + \beta P = Y_0 + \frac{\beta}{3}(\sigma_r + \sigma_\theta + \sigma_z)$

$$\sigma_z\Big|_{yield} = \frac{Y_0}{\frac{\beta}{3} - 1} + \frac{2\beta + 3}{\beta - 3} P_C^0$$

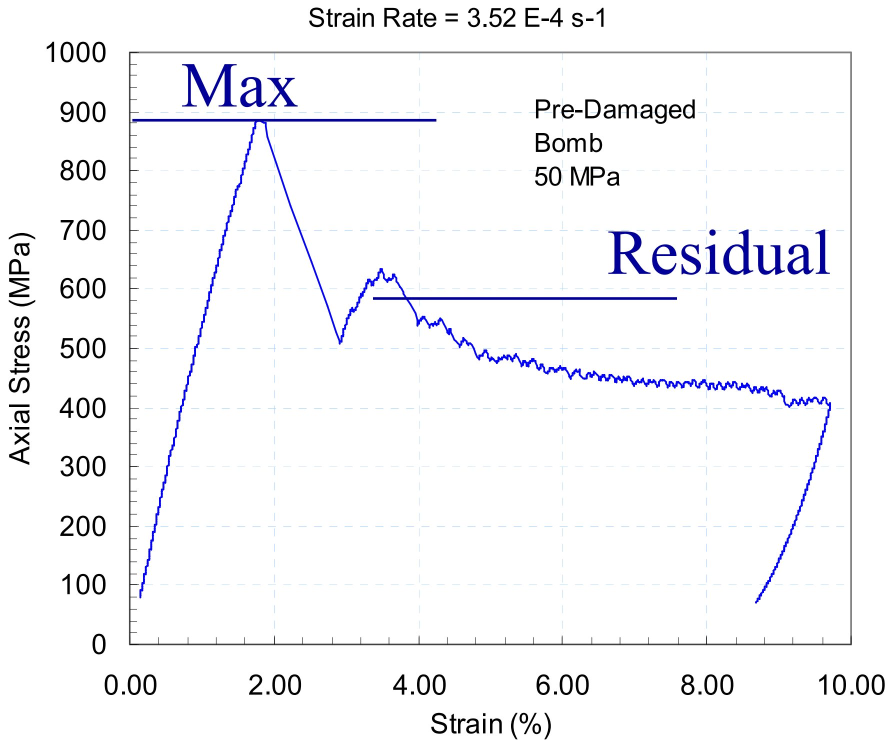
Where P^0_C is the confinement pressure (or fluid pressure)



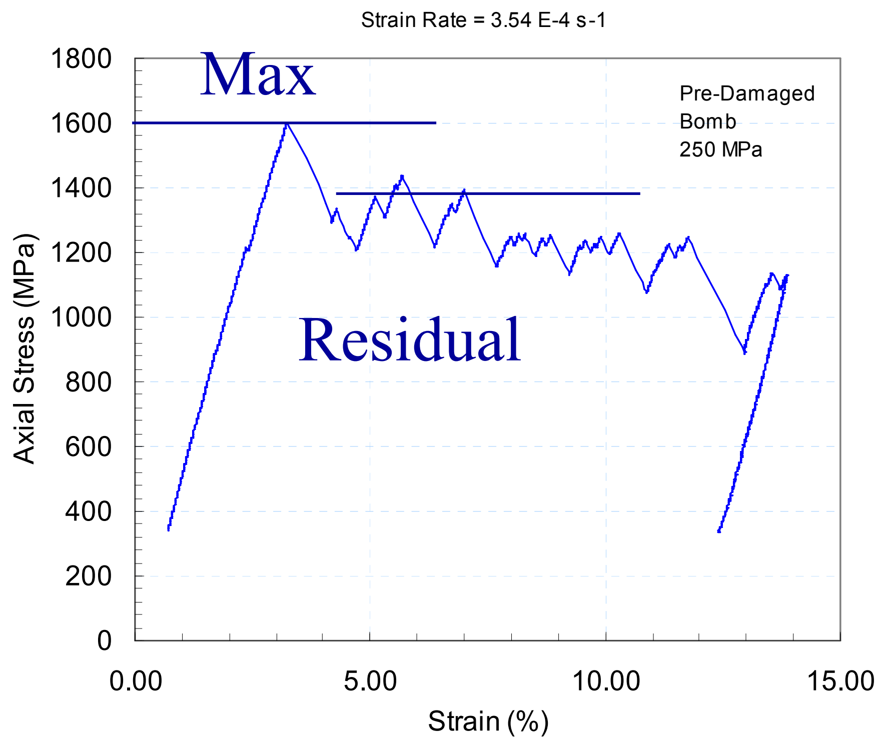
Note: The plateau is NOT a cap. It is "plastic" flow of the sample

Example of results (Borosilicate glass)

BF-52



BF-49



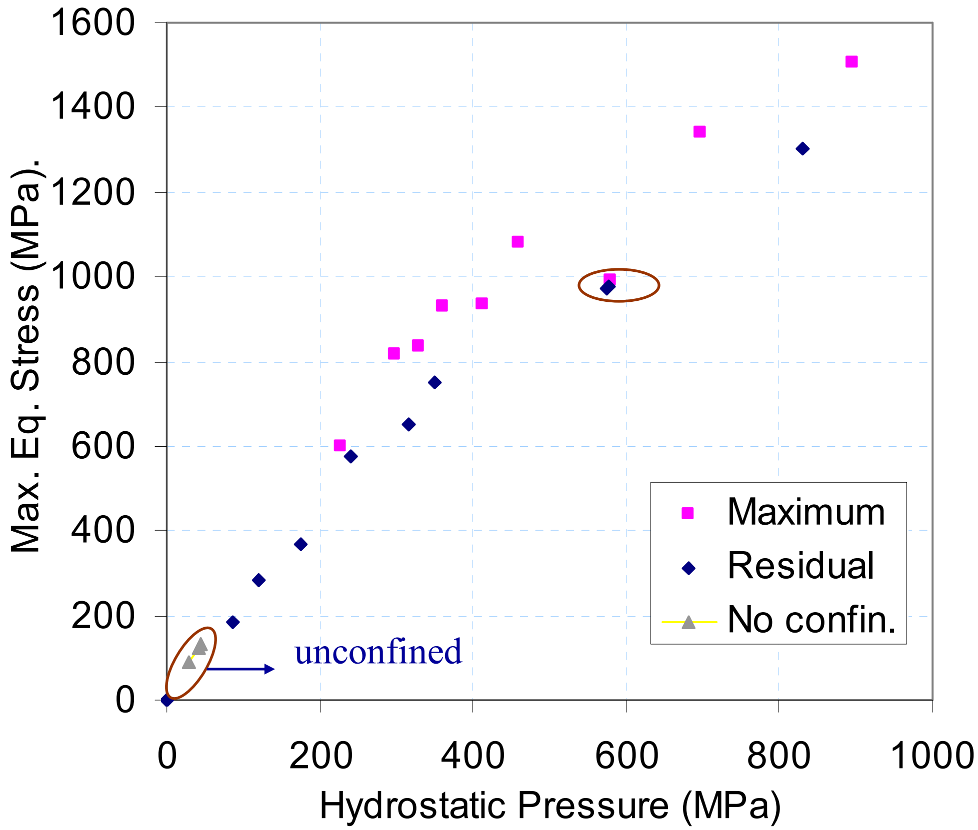
The residual strength is created by sliding two faces with friction between them

Max. Equivalent Stress - Borosilicate glass

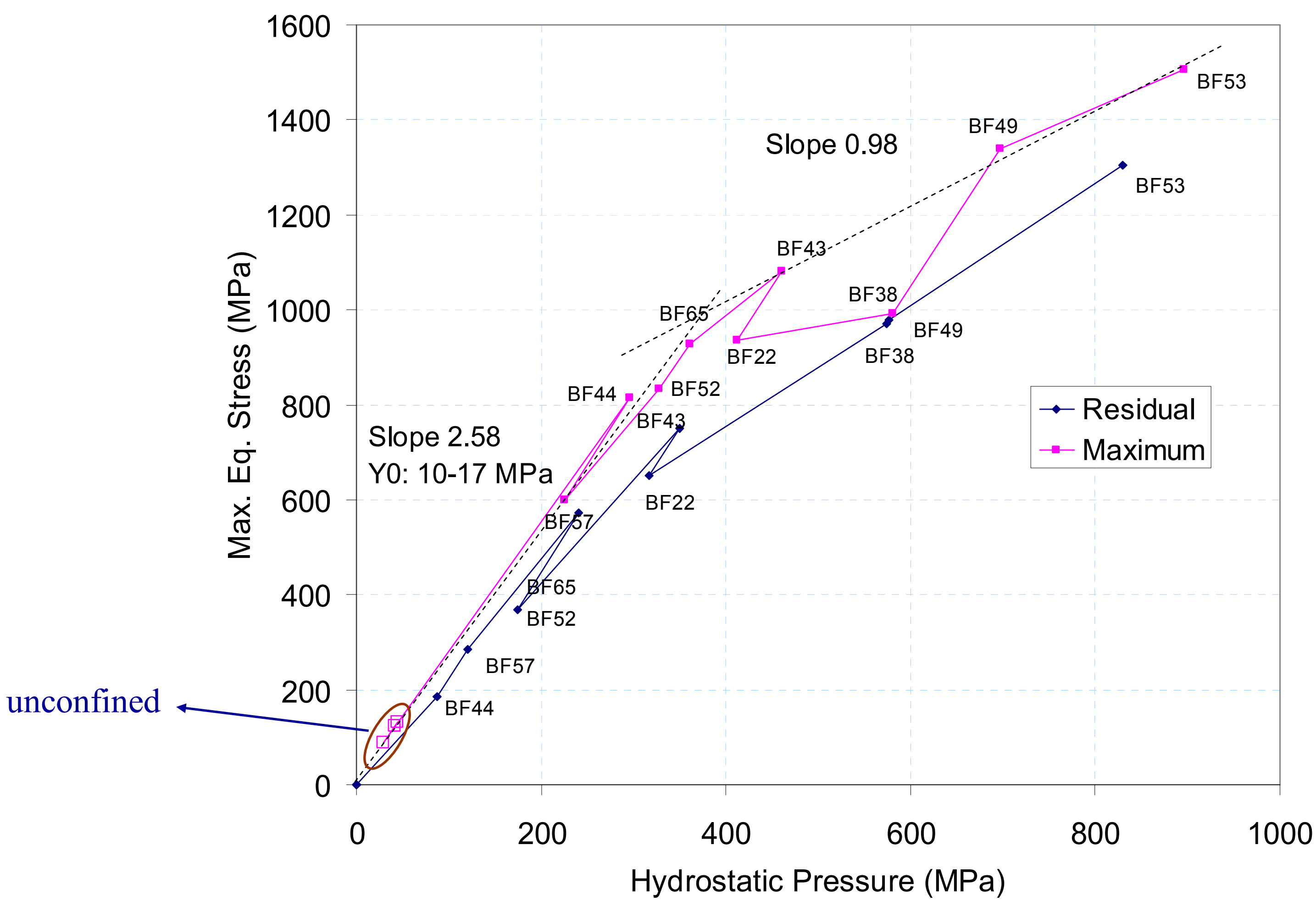
Each point is a test.
The triangles are P=0
(unconfined tests)

Y0 is around 10 – 20 MPa.

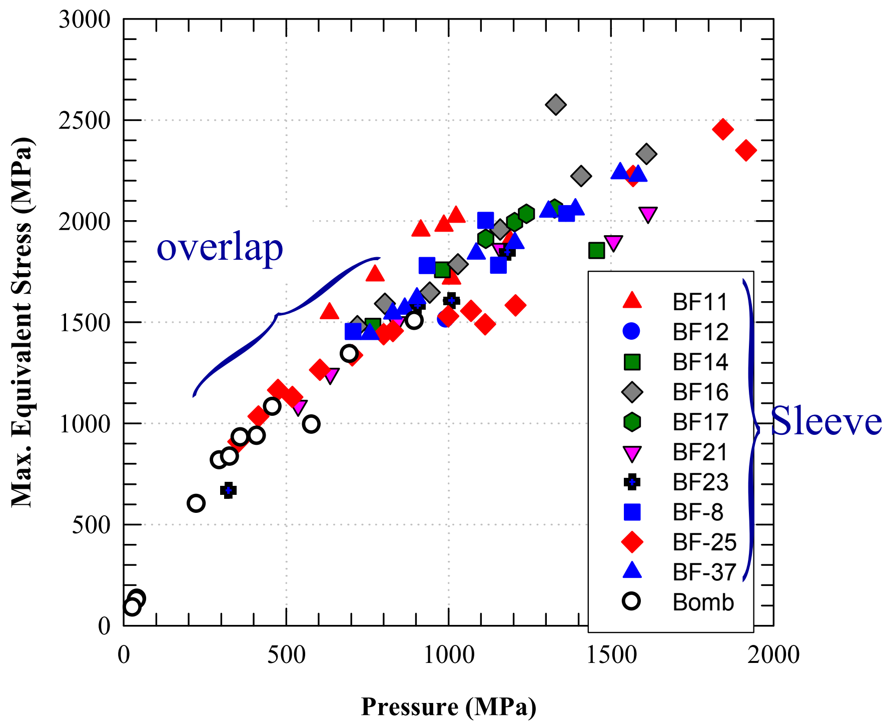
The outlier might have been
more damaged and directly
went to the residual curve.



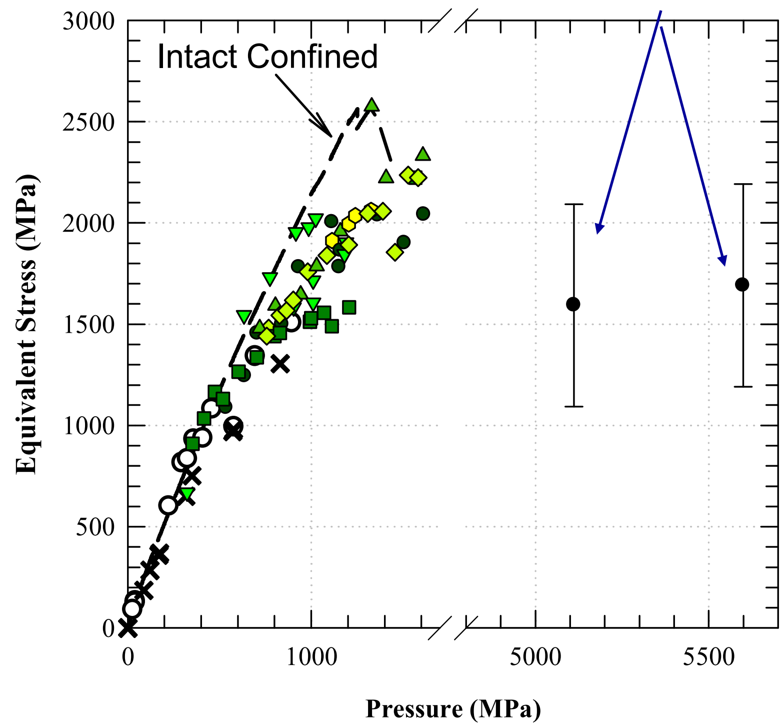
Max. Equivalent Stress - Borosilicate glass



Comparison with sleeve data - Borosilicate glass



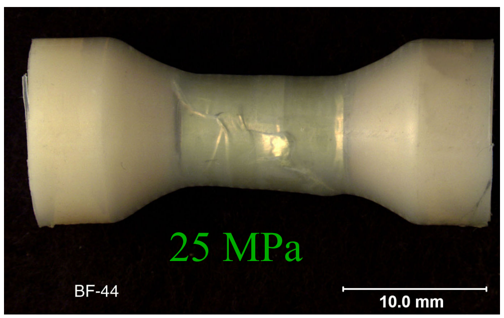
Partom

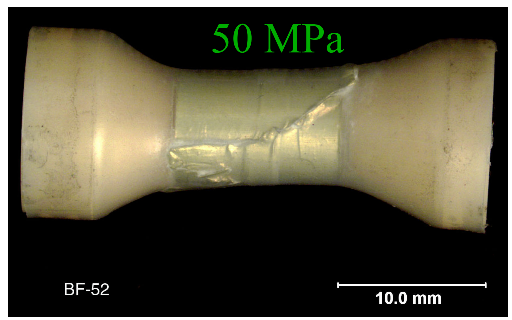


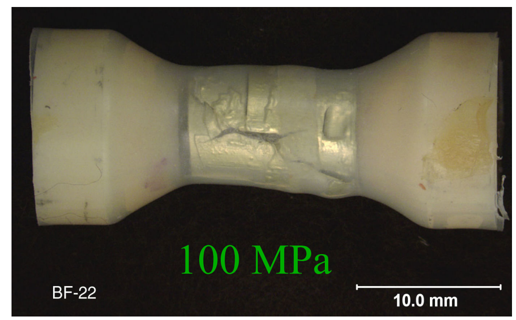
The overlap between sleeve tests and bomb tests gives increased confidence on the sleeve tests results

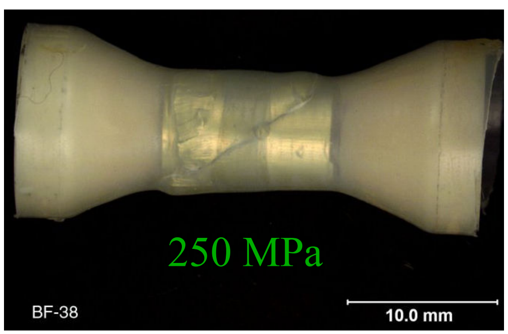
Drucker-Prager misses failure pattern

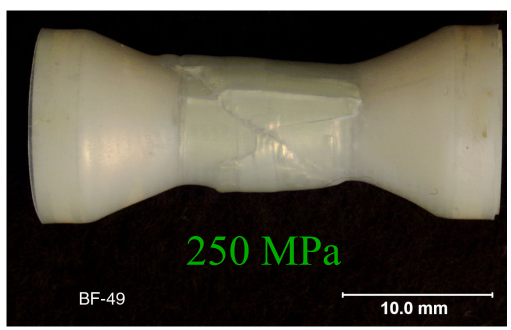
- A Drucker-Prager model is unable to predict a preferred failure angle, something systematically seen in the bomb tests.
- The failure angle does not depend on the fluid pressure (55-65 degs)

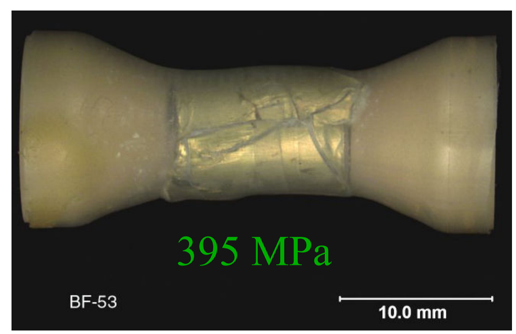












Mohr-Coulomb theory

- Based on maximum shear stress
- Yielding if:

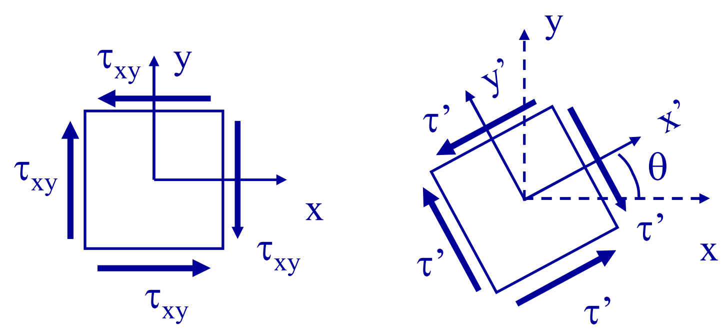
  $\tau = c + \mu \, \sigma_n$

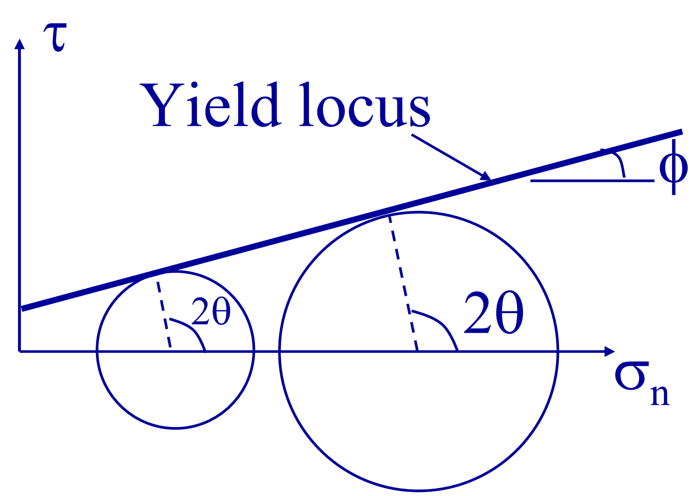
  μ is internal friction coeff.

  c is cohesion
- For a given stress state the radius and center of the MC circle are:

  $R = (\sigma_1 - \sigma_3)/2$

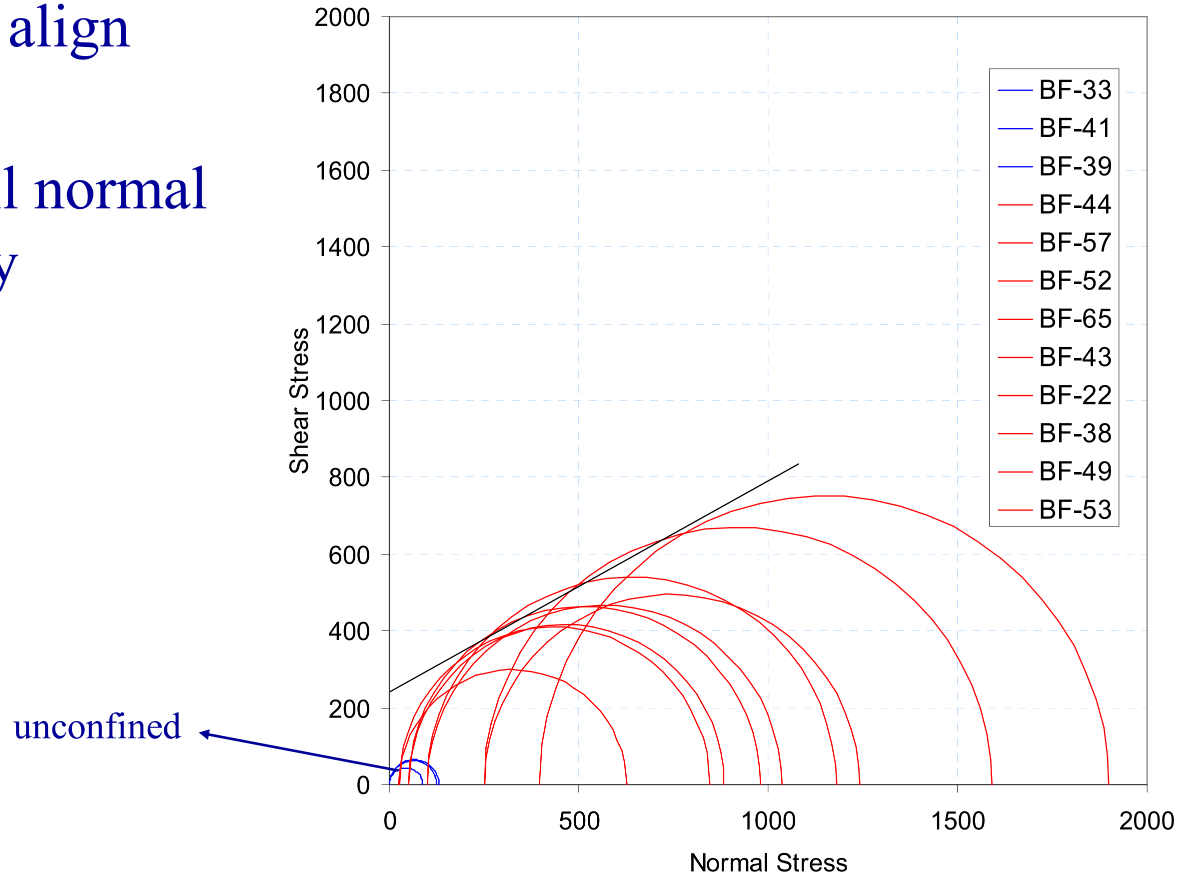
  $C = (\sigma_1 + \sigma_3)/2$
- Only two tests needed to find the constants



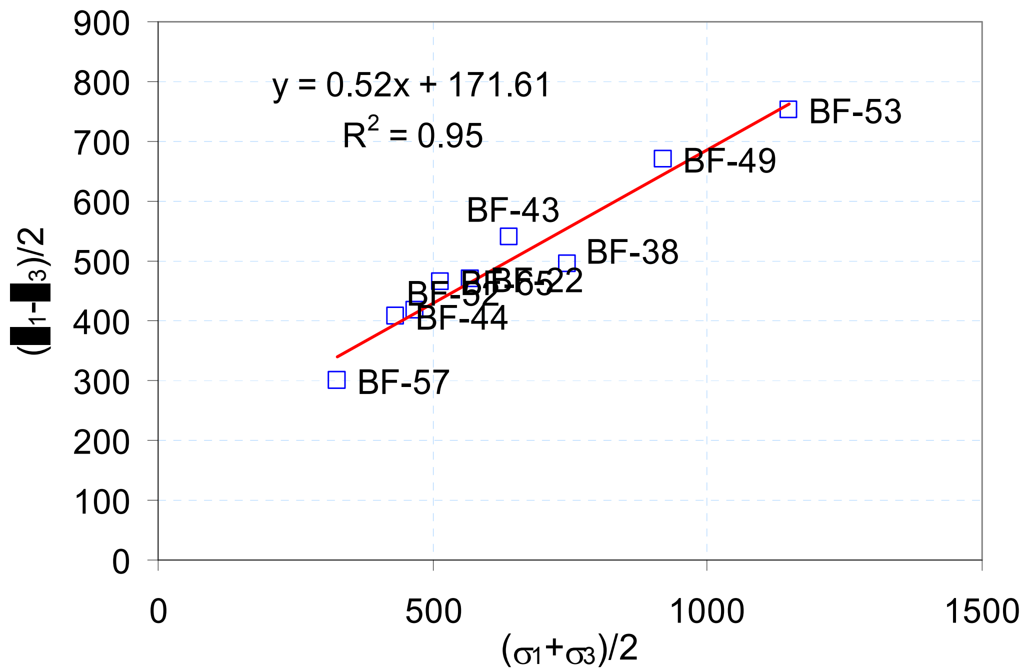


Bomb tests – MC perspective

- Bomb tests seem to align reasonably well
- Sharp drop for small normal stresses indicated by unconfined tests.

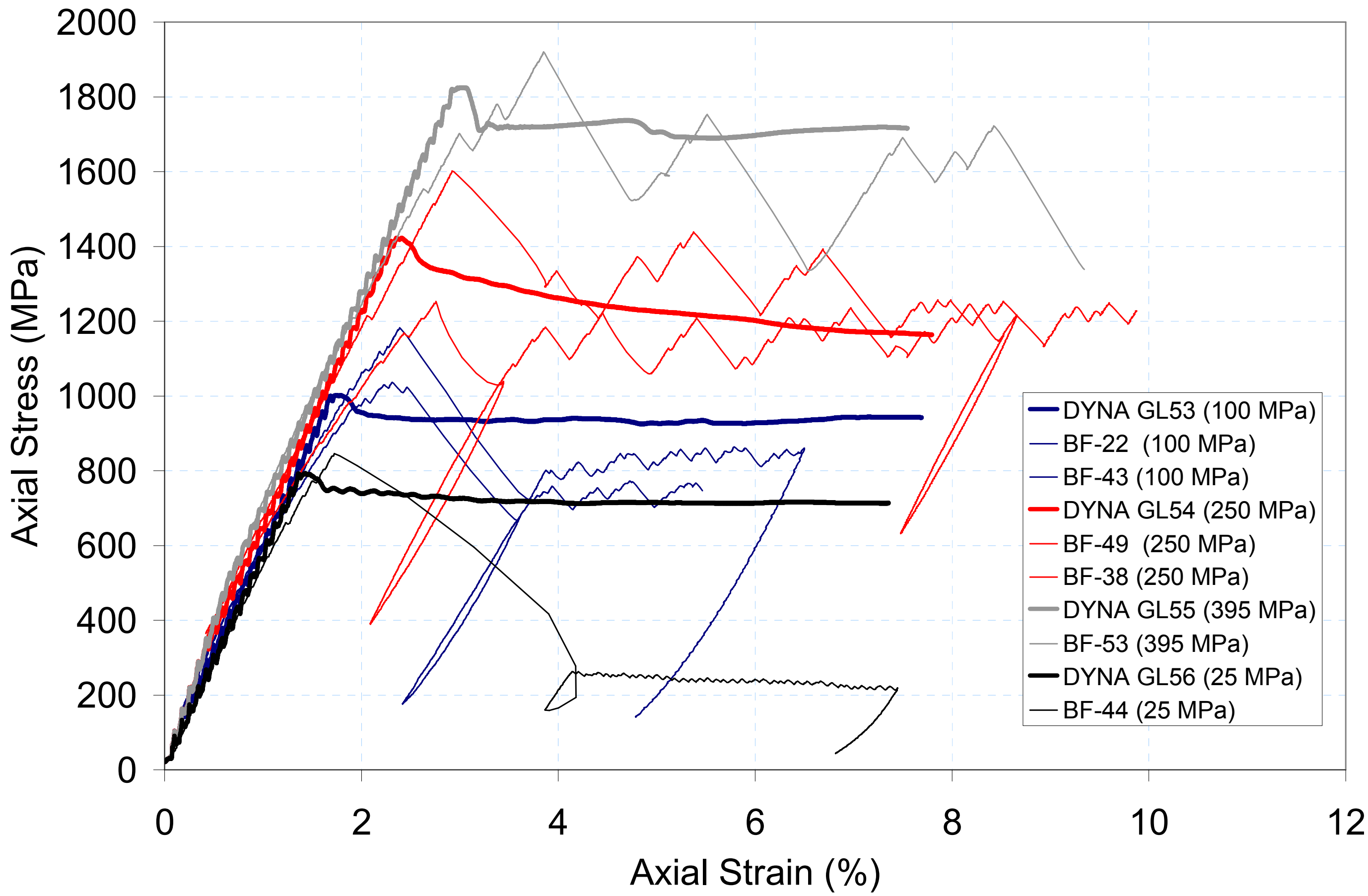


Bomb – MC parameters



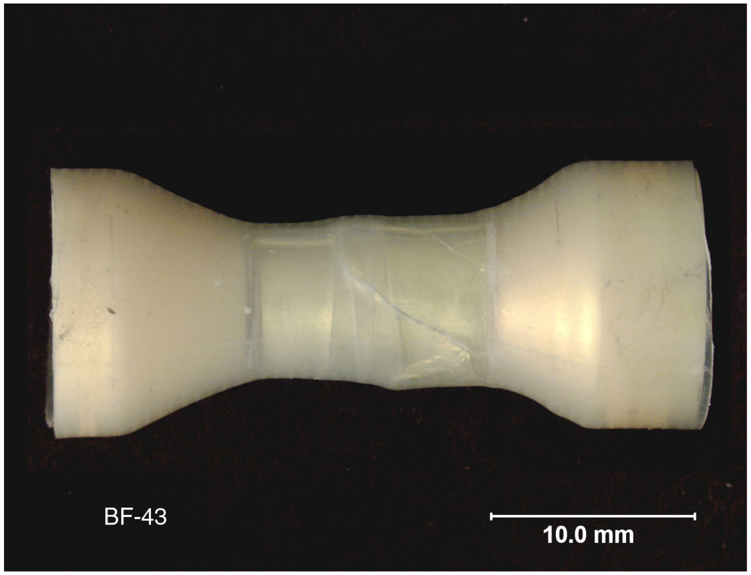
slope	intercept	Angle of friction (deg/rad)	μ	Cohesion (MPa)
0.52	171.61	31.04/0.54	0.60	200.30

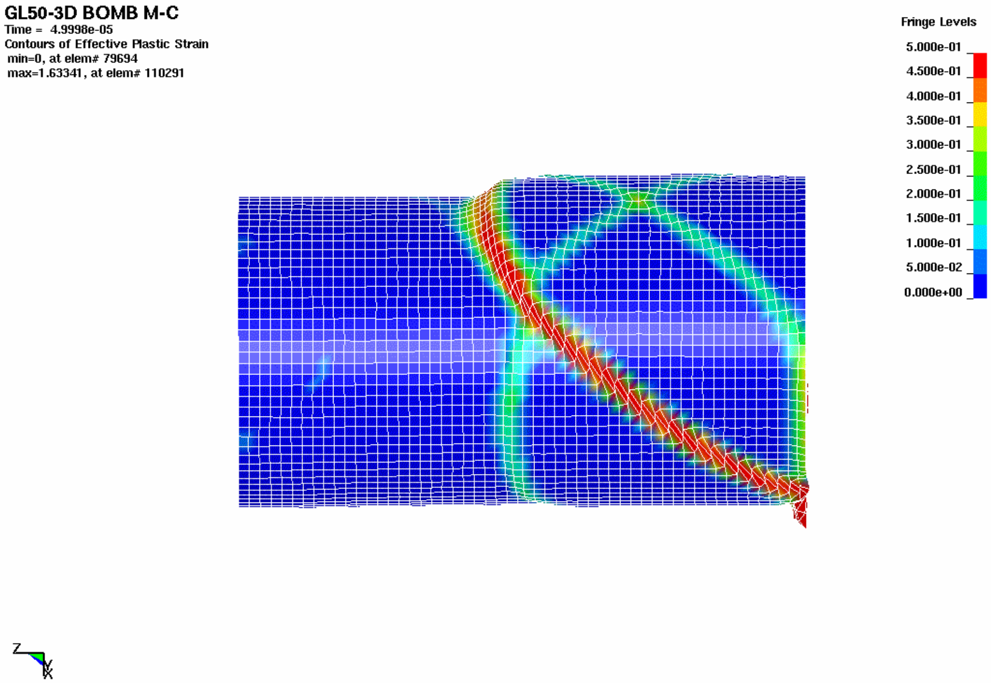
Bomb Tests – LSDYNA simulations with Mohr-Coulomb



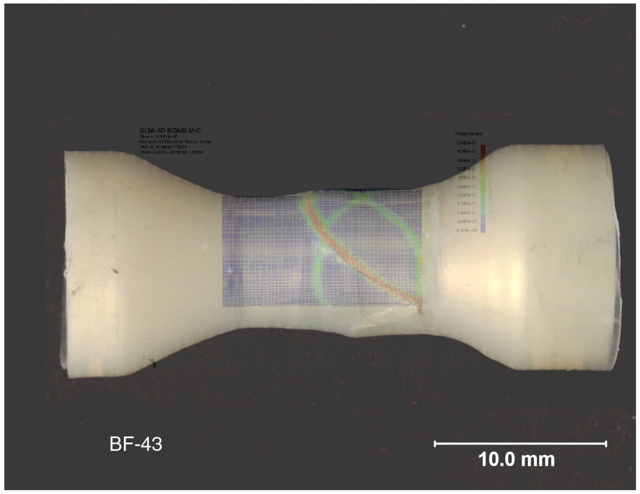
ϕ=0.51 rad (μ=tan(ϕ)=0.56), c=219 MPa

LS-DYNA Failure Patterns

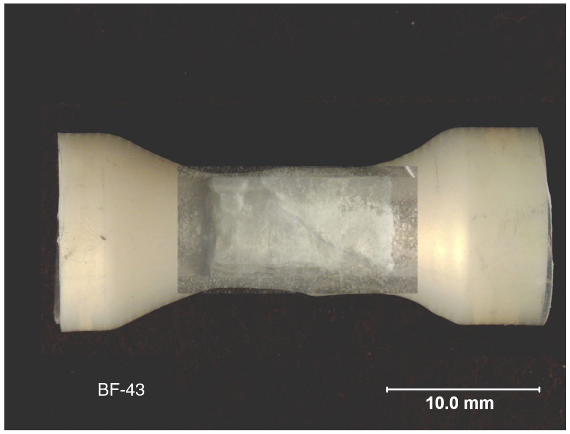




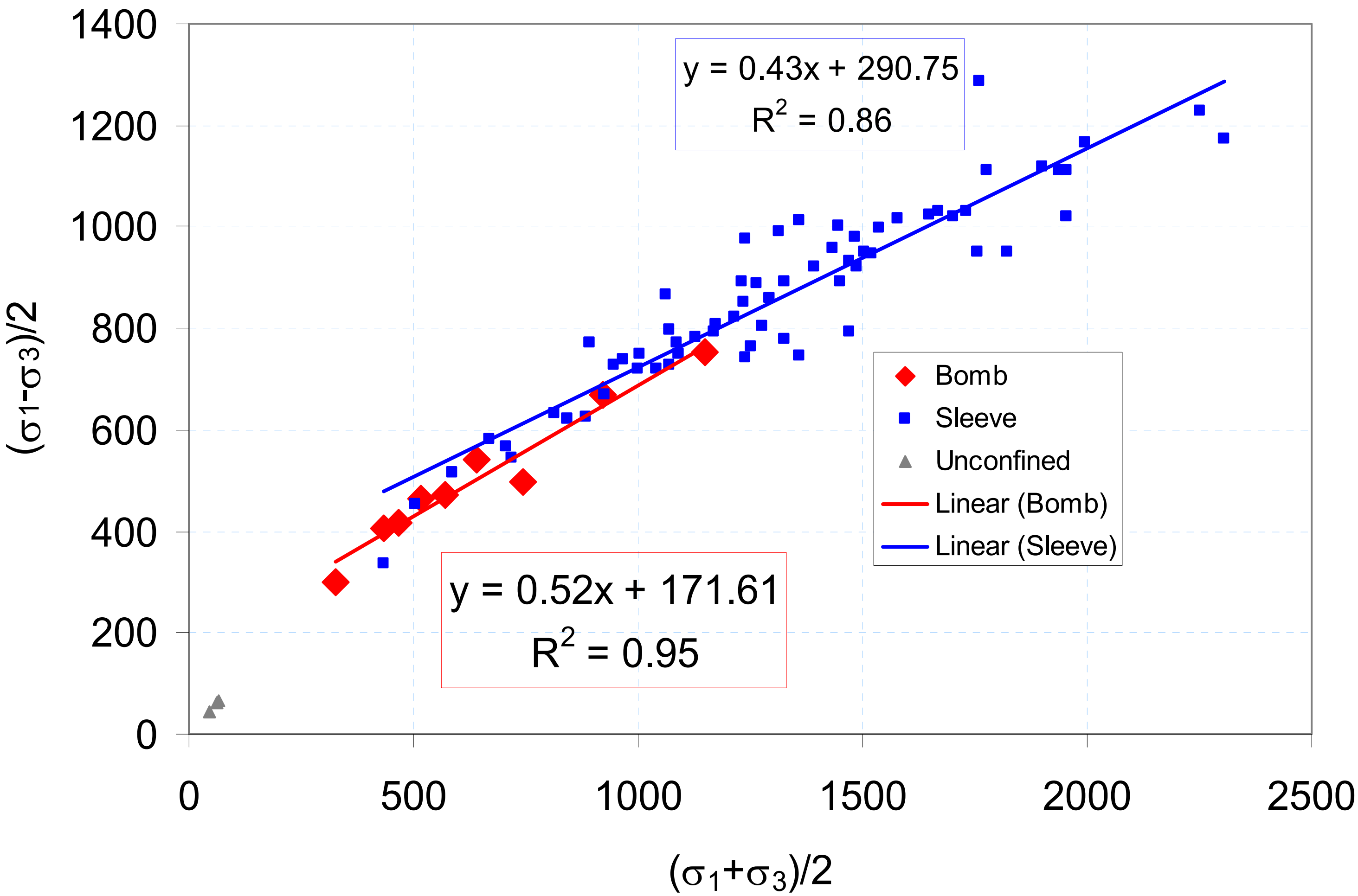
LS-DYNA Failure Patterns



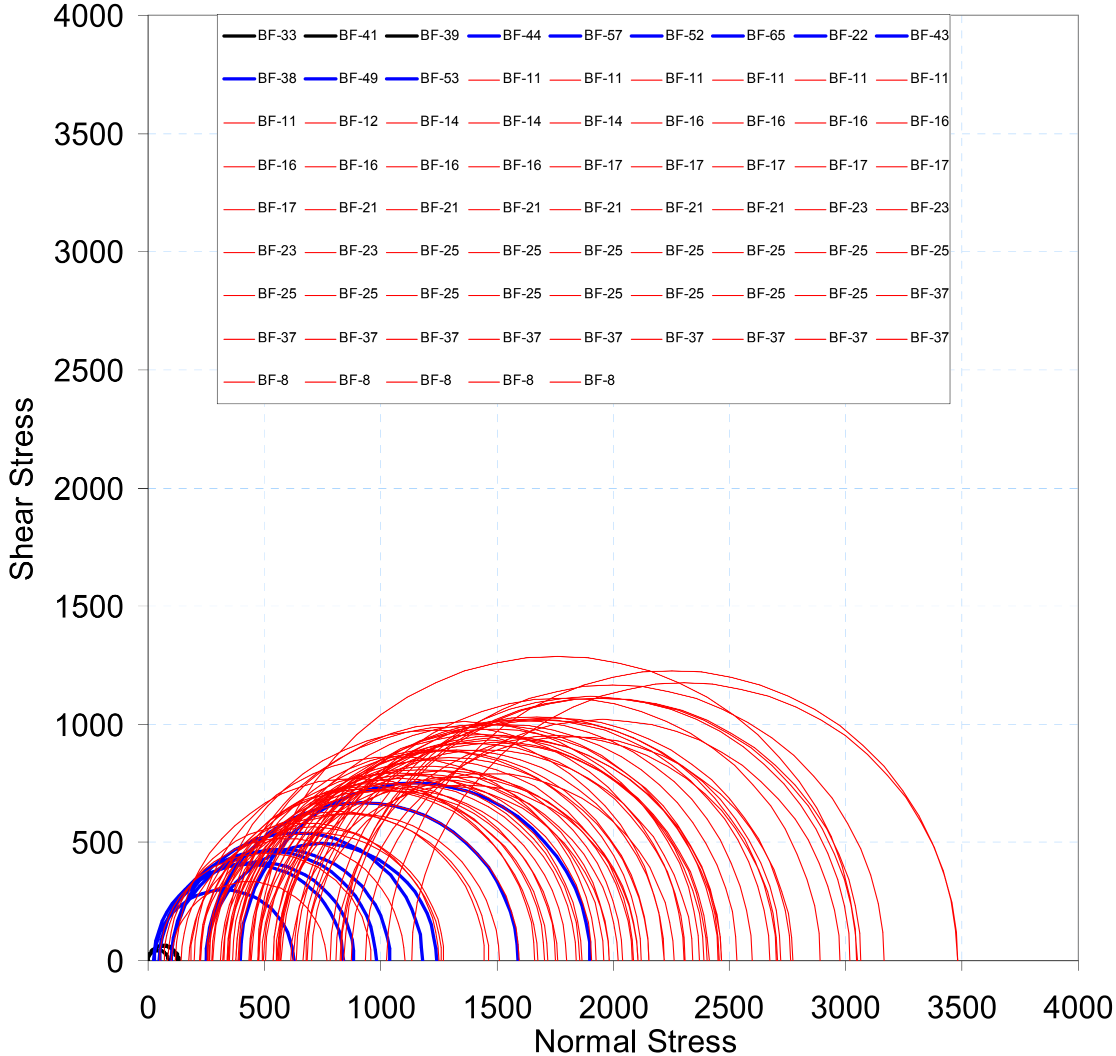
BF-



Sleeve tests from MC perspective



All the tests



Conclusions

- Mohr-Coulomb captures very nicely both strength and failure phenomenon for bomb tests.
- MC also captures failure angle and strength in the sleeve tests.
- The overlap between bomb and sleeve tests support the results of the sleeve tests
- MC is being implemented in CTH to reproduce penetration experiments.

Acknowledgments

- To Doug Templeton from TARDEC/RDECOM