AASHTO COBS Meeting, Burlington, Vermont, 2018
T-2: AASHTO Technical Committee for Bearings and Expansion Devices
Diamond 1, June 25, 1:00 – 5:00 PM

Disc Bearing Specification Review and Potential Revision

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Specifications for Disc Bearings

- High Load Multi Rotational (HLMR) Bearings
- Provisions of Disc Bearings are not adequately developed
- Relevant Specifications
  - AASHTO LRFD Bridge Design Specifications (BDS)
  - AASHTO LRFD Construction Specifications (BCS)
  - AASHTO Material Specifications
  - ASTM Specifications

Objective

- Develop/Elaborate the design, construction and material specification for Disc Bearings
- Review all relevant specifications and propose modifications to rectify any inconsistencies and other shortcomings

Tasks

- Review specifications
- Literature search
- Review industry documents/proposal
- Identify areas requiring change
- Develop proposals for change
- Discuss with T-2
- Discuss with industry
- Incorporate changes

Goal: Potential ballot items at the COBS Meeting, 2019

Progress

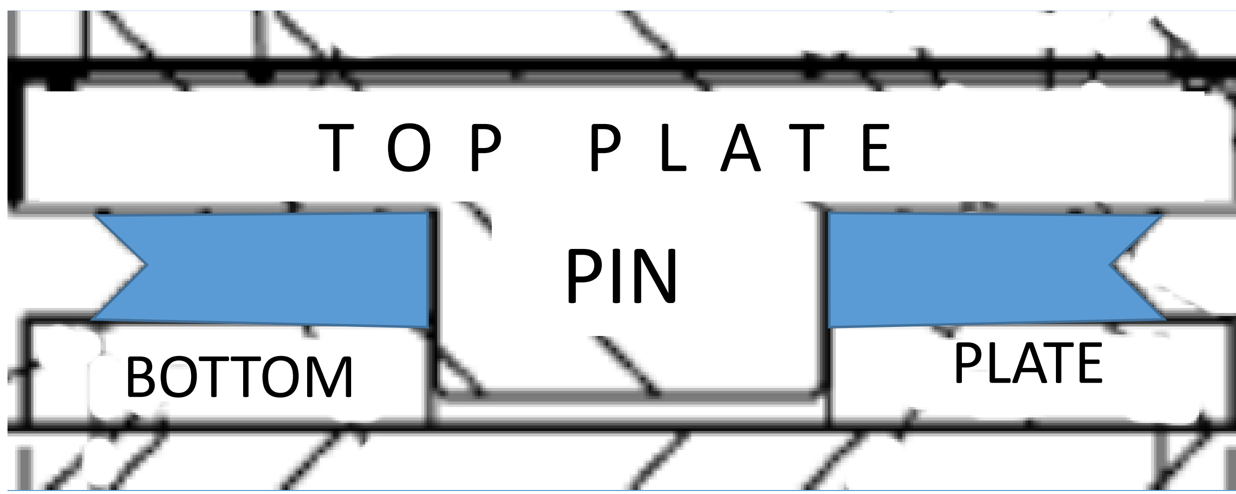
- Reviewed AASHTO LRFD BDS
- Reviewed AASHTO LRFD BCS
- Reviewed/Reviewing othe relevant specifications
- Reviewed/Reviewing published literature
- Reviewing comments/proposals received from industry

Specifications

- AASHTO LRFD BDS Article 14.7.8
- AASHTO LRFD BCS Section 18, Relevant Articles
- AASHTO M251-06 – Elastomeric Bearings
- ASTM D4014 – Elastomeric Bearings
- ASTM D395 –Compression Set
- ASTM D412 –Tension
- ASTM D429 –Adhesion to Substrate
- ASTM D746 –Brittleness Temperature
- ASTM D2240 –Durometer Hardness
- ASTM D2990 – Creep
- Others…

Material (Elastomeric Disc)

- Polyehter urethane
  - Stiff for vertical deflection
  - Flexible for rotation without *liftoff*
  - Creep should be taken into account
- Virgin material
  - Hardness 45-65 Shore D



AASHTO LRFD BDS - Elastomeric Disc

- Service Limit State
  - $\Delta_i \leq 0.1h$
  - $\Delta_{cr} \leq 0.08h$
  - No lift off
  - $\sigma_{c,avg} \leq 5.0\ ksi$
- Strength Limit State
  - Design for δ_u, θ_u

AASHTO LRFD BCS

18.3.2.8—Polyether Urethane Structural Element for Disc Bearings

The polyether urethane structural element used in the construction of disc bearings shall be molded from a monolithic polyether urethane compound. The physical properties of the polyether urethane shall conform to the minimum requirements listed in Table 18.3.2.8-1.

C18.3.2.8

Polyether urethane is a hard tough plastic material. However, its tensile strength varies significantly depending on the quality-control exercised during processing. The properties required here are intended to ensure a good quality material.

Required minimums for tensile stress at specific elongations, tensile strength, ultimate elongation, and compression set may be interpolated for durometer hardness values between 45 and 55, and 55 and 65.

Table 18.3.2.8-1—Physical Properties of Polyether Urethane

Physical Properties	ASTM Test Method	Requirements		
Hardness, Type D Durometer	D2240	45	55	65
Minimum Tensile Stress, ksi At 100% elongation At 200% elongation	D412	 1.5 2.8	 1.9 3.4	 2.3 4.0
Minimum Tensile Strength, ksi	D412	4.0	5.0	6.0
Minimum Ultimate Elongation, %	D412	350	285	220
Maximum Compression Set, 22 h at 158°F Method B, %	D395	40	40	40

AASHTO LRFD BCS

18.3.3—Fabrication Details

18.3.3.1—General

The Contractor shall provide the Engineer with written notification 30 days prior to the start of bearing fabrication.

The finish of the mold used to produce the elastomeric rotational element for pot bearings or the polyether urethane structural element for disc bearings shall conform to good machine shop practice.

After fabrication, steel surfaces exposed to the atmosphere, except stainless steel surfaces, shall be shop painted or coated to protect against corrosion as specified in the contract documents. Prior to coating, the exposed steel surfaces shall be cleaned in accordance with the recommendations of the coating Manufacturer. Metal surfaces to be field-welded shall be given a coat of clear lacquer or other protective coating approved by the Engineer, if the time of exposure before welding takes place is to exceed three months. The lacquer coating shall be removed at the time of welding. The final painting or coating of these surfaces shall be done after the completion of welding.

Except as noted, all bearing surfaces of steel plates shall be finished or machined flat within 0.0008 in./in. Out-of-flatness greater than 0.0008 in./in. on any plate shall be cause for rejection. The bottom surfaces of lower bearing plates (masonry plates) designed to rest on bearing pads shall not exceed an out-of-flatness value of 0.005 in./in. Oxygen-cut surfaces shall not exceed a surface roughness value of 1000 μin., as defined by ANSI B46.1.

18.3.3.3—Fabrication Requirements for Disc Bearings

18.3.3.3.1—Steel Housing

The steel housing shall be manufactured by welding or machining from a single piece of plate. The shear restriction mechanism shall be connected to the bearing plate by mechanically fastening, welding, or other means approved by the Engineer.

18.3.3.3.2—Polyether Urethane Rotational Element

The polyether urethane rotational element for disc bearings shall be molded as a single piece. The finish of the mold shall be free of burrs and shall conform to good shop practice.

- Elaborate on PU disc Fabrication?
- Surface finish of PU disc?
- Clarification on surface coating?

Fabrication Tolerance

Table 18.1.4.2-1—Fabrication Tolerances

Item		Thickness Tolerance, in.	Dimension Tolerance, in.	Flatness or Out-of-Round Tolerance, in.	Surface Finish, μin.(rms)
Disc Bearings					
	Overall Dimensions	–0.000, +0.250	–0.000, +0.125	—	—
	Shear-Restricting Element	—	–0.000, +0.005	Class A	32
	Other Machined Parts	–0.000, +0.063	–0.000, +0.063	Class B	63
	Urethane Disc	–0.000, +0.063	–0.000, +0.125	Class B	63

QC and QA

- 18.3.4.2 Material Certification and Performance Testing by Manufacturer
  - Minimum 2 bearings
  - Minimum 2 individual bearing components
- 18.3.4.3 Quality Assurance Testing by the Engineer
  - Only if required by the contract (random sampling)
  - At least one set of material property tests per lot

Table 18.3.4.3-1—Sampling

Test	Samples Required
Proof Load	One production bearing per lot
Coefficient of Friction	One production bearing per lot
Physical Properties of Elastomeric Rotational Element	One elastomeric element per lot
Physical Properties of PTFE Sheet	One 10.0-in. × 15.0-in. sheet of PTFE material per project
Physical Properties of Polyether Urethane Structural Element (except compression set)	One 10.0-in. × 15.0-in. sheet of polyether urethane material (thickness of 0.0625 in. to 0.125 in. per lot
Compression Set of Polyether Urethane Structural Element	One 4.0-in. × 4.0-in. sheet of polyether urethane per lot, molded or cut to the thickness requirements of ASTM D395, Method B

18.3.4.4.1 Material Certification Testing

18.3.4.4.1—Material Certification Testing

Material certification tests shall be conducted in accordance with Article 18.1.5.2.2.

Certification shall be provided for all elastomeric and polyether urethane elements. Their material properties shall satisfy the requirements specified in the contract documents and the tests described in Article 18.3.2.4 for pot bearings and Article 18.3.2.8 for disc bearings. Additional tests may be required by the Engineer.

18.1.5.2.2—Material Certification Tests

Material certification tests to determine the physical and chemical properties of all materials shall be conducted in accordance with the appropriate specification governing the material. The test certificates shall be provided to the Engineer.

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Dimension Check and Clearance Test

18.3.4.4.2—Dimension Check and Clearance Test

Dimensions and clearances shall be checked for all bearings according to Articles 18.1.5.2.4 and 18.1.5.2.5.

18.1.5.2.4—Dimension Check

The dimensions of all bearings shall be checked by the Manufacturer and shall be recorded and provided to the Engineer. Failure of a bearing dimension to satisfy any dimensional tolerance shall be cause, at the discretion of the Engineer, for rejection of the bearing or a lot. Flatness shall be checked by placing a precision straightedge on the surface to be checked and by inserting feeler gages between the two. The straightedge shall be placed at different orientations and the worst condition shall be established. No more than three feeler gages may be stacked on top of one another. The straightedge shall be as long as the largest dimension of the flat surface.

All dimension checks shall satisfy the tolerances of Article 18.1.4.2.

18.1.5.2.5—Clearance Test

The components of the bearing shall be moved through their design displacements or rotations to verify that the required clearances exist. If the test is conducted on a rotational component which is not under simultaneous full vertical load, allowance shall be made for the displacements which would be caused by that load.

- Gap between disc and retaining pin?
- Gap between pin and plate?

Long Term Deterioration Test

18.3.4.4.3—Long-Term Deterioration Test

The long-term deterioration test shall satisfy the requirements of Article 18.1.5.2.7. When testing is specified by the Owner to be on a per lot basis, the long-term deterioration test shall be performed on one (1) sampled disc bearing of each lot and one (1) sampled pot bearing of each lot.

The following shall be cause for rejection of the bearing:

- Damage visible to the naked eye on disassembly of the bearing, such as excessive wear, cracks, or splits in the material.
- A coefficient of friction which exceeds the value used in design.

18.1.5.2.7—Long-Term Deterioration Test

At the discretion of the Owner, the contract documents shall specify if the long-term deterioration test is to be conducted on a per lot basis or if the test is satisfied by pre-qualification. The Owner's pre-qualification criteria or contract documents, as applicable, shall specify whether the test is to be conducted on full size bearings, scaled down versions of the bearings, components of bearings, samples of the materials used in the bearings, or a combination of these. Other pre-qualification criteria associated with the long-term deterioration test shall be as specified by the Owner.

The samples shall have an area not less than 7.0 in.^{2}. The test piece shall first be loaded in compression to a stress corresponding to the service limit state design capacity of the bearings. Flat sliding systems shall then be displaced through at least 1000 cycles with an amplitude of at least ±1.0 in. (2.0 in. peak to peak). Curved sliding systems and rotational systems that depend on deformation of an elastomeric element shall be subjected to 5000 cycles or displacements corresponding to a rotation of plus or minus the design amplitude. The sliding may take place at up to 10.0 in. per min, except when readings of the coefficient of friction are taken, at which time the sliding speed shall be 2.5 in. per min.

- Elaborate acceptance criteria?

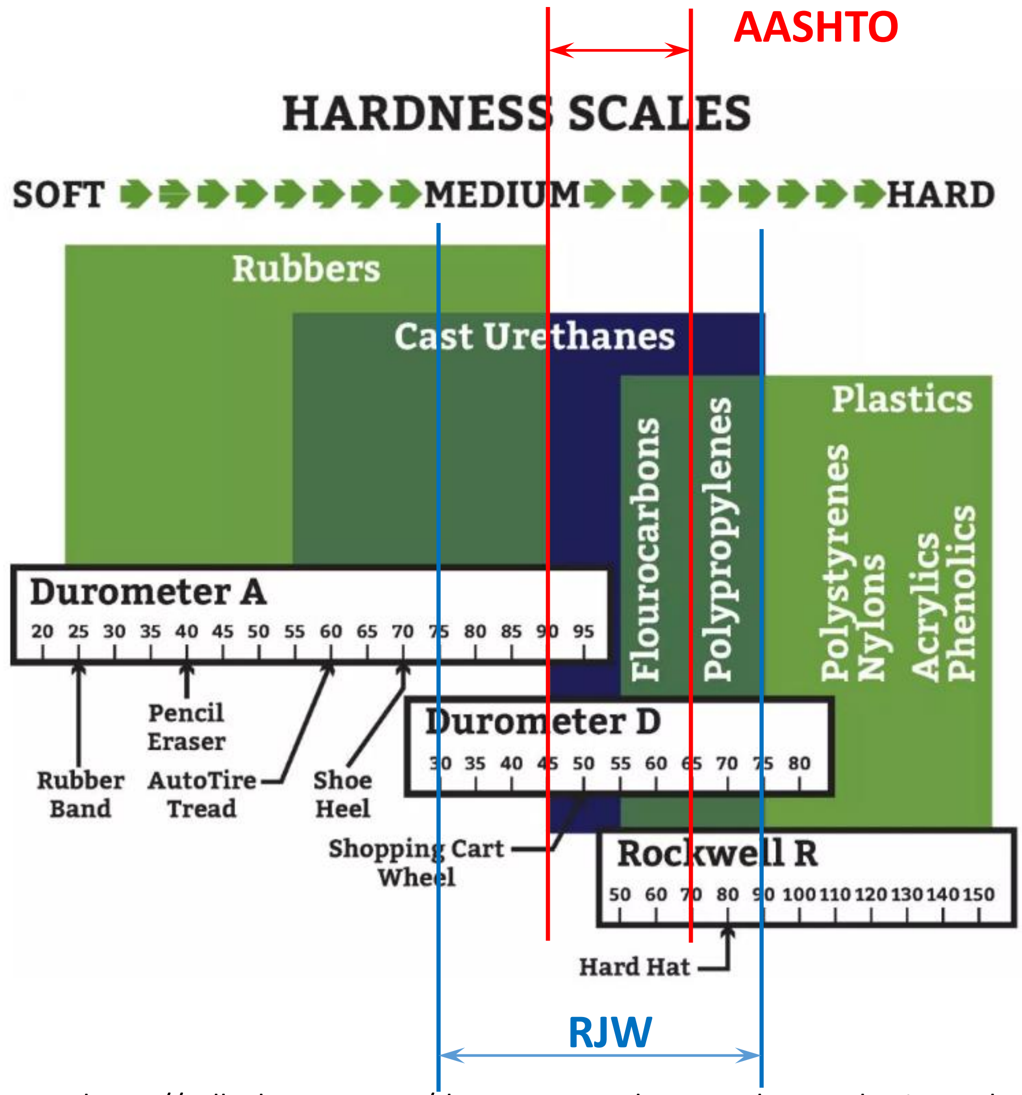
Example

Review Comments of RJW Proposal – Stress Limits

- First develop specifications for $\sigma_c \leq 5\ ksi$
  - Concern about uniformity of material production and performance
  - Concern about long term performance and creep deformation

Hardness (Durometer)

- Too relaxed hardness limits
- Retain AASHTO limits



https://gallaghercorp.com/thermoset-urethane-vs-thermoplastic-urethane/

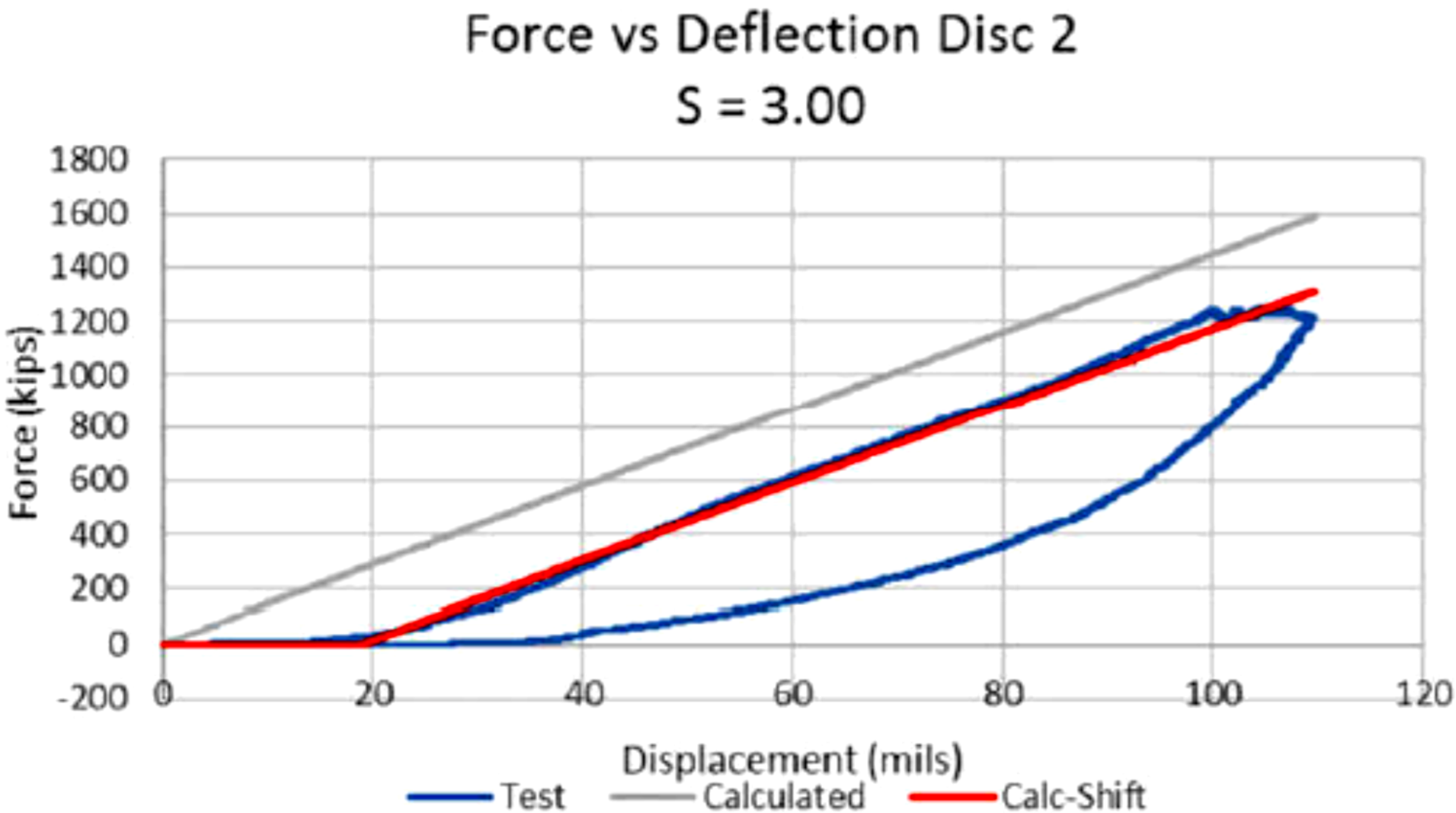
Modulus of Elasticity – E and E_c

- E: Actual modulus of elasticity
  - can be obtained from stress-strain response of material
- E_c: Apparent modulus of elasticity
  - Including the effect of shape factor, S, and boundary conditions of the loaded surface
- $E_c = E(a + bS^2)$
  - a, b to be determined from experiments and depends on boundary conditions (friction) of the loaded surface

Recommended E_c (RJW)

- $E_c = E(1 + S^2)$
  - Assumes $a = 1, b = 1$
- Only valid for high friction and practically no slip at the loaded surface
  - Not always the case
- Test data did not correlate well due to significant nonlinear stiffening response
- Slip reduces apparent stiffness, results increased deflection
- Concerns with retainer pin touching the base plate and affecting bearing performance

Test Result



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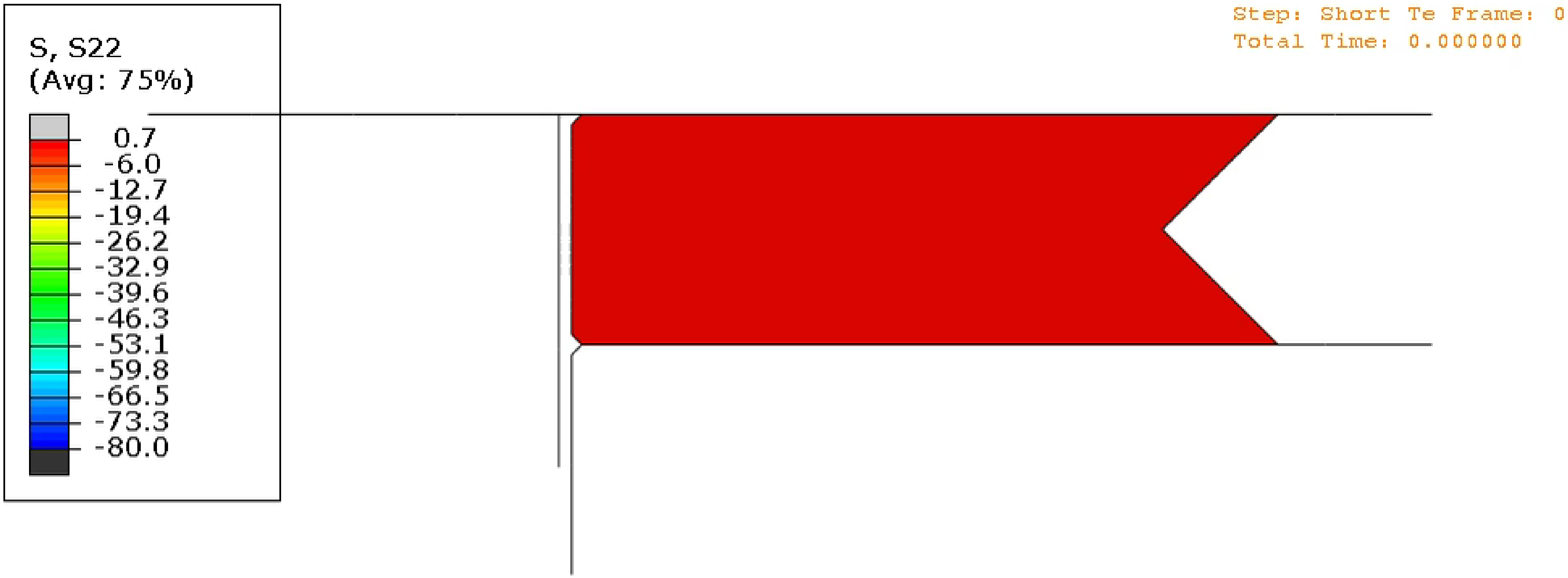
Friction

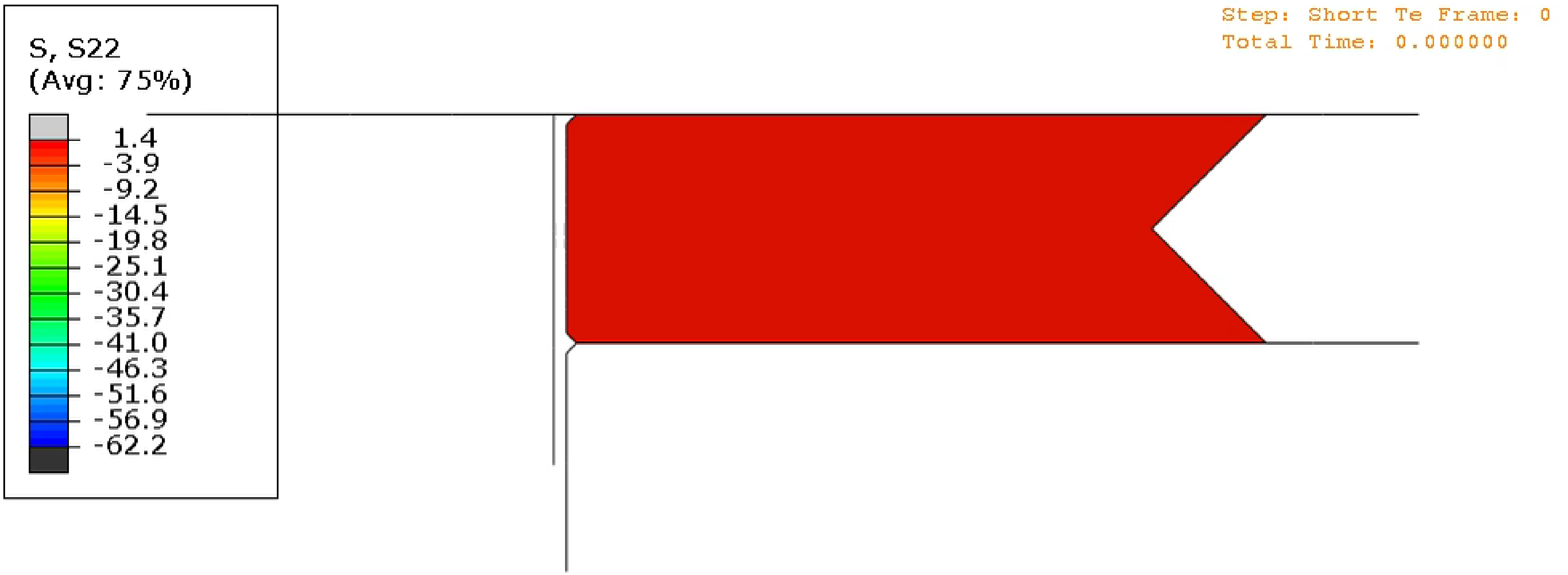
- Not measured in RJW tests
- Important for performance
- Needs to be verified for conformance with design by proof testing

- It would be desirable also to check Poisson Ratio
  - Probably close to 0.48

Low Friction – Axial Compression



High Friction – Axial Compression



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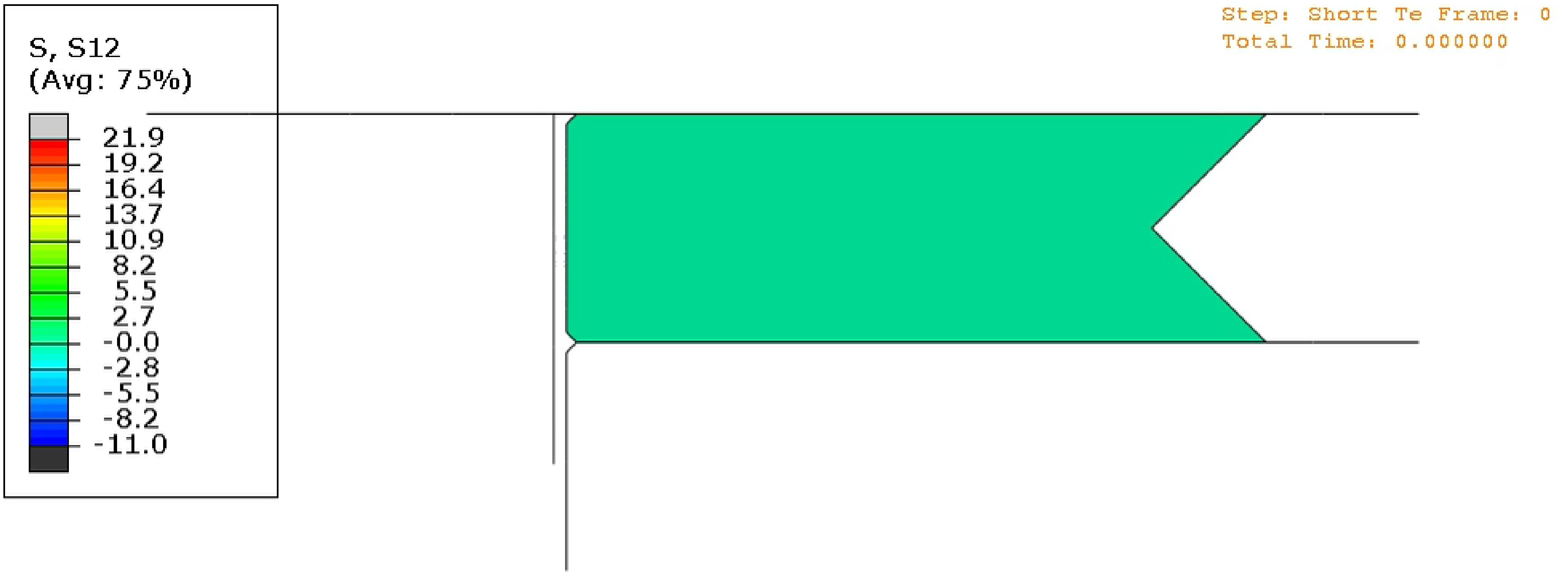
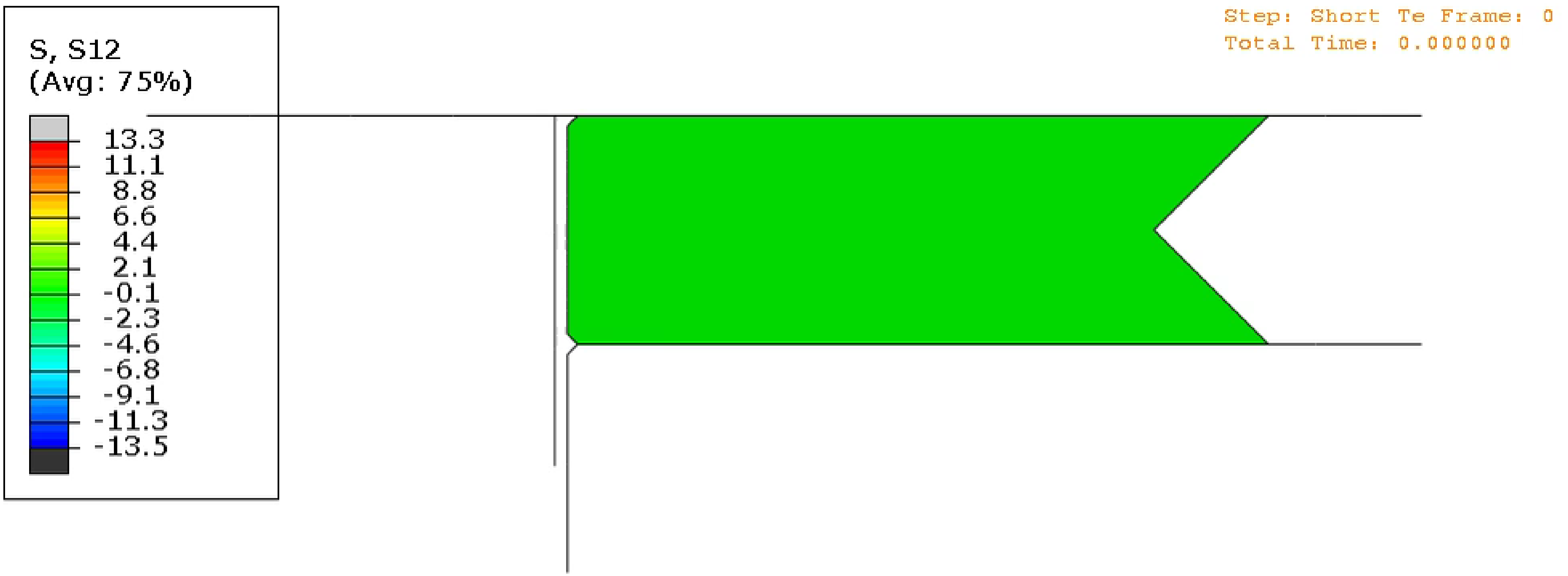
Low Friction - Shear



High Friction - Shear



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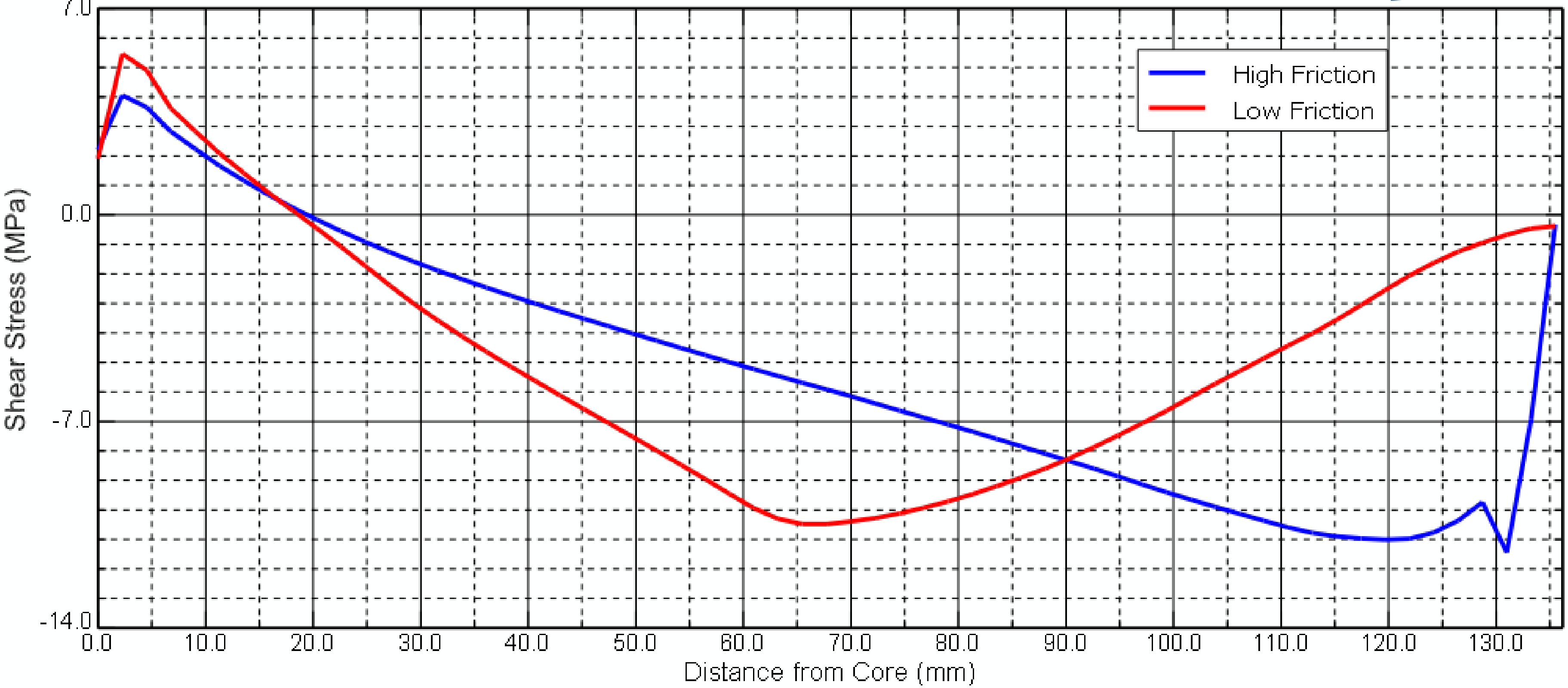
Shear Stress at Top Plate Interface



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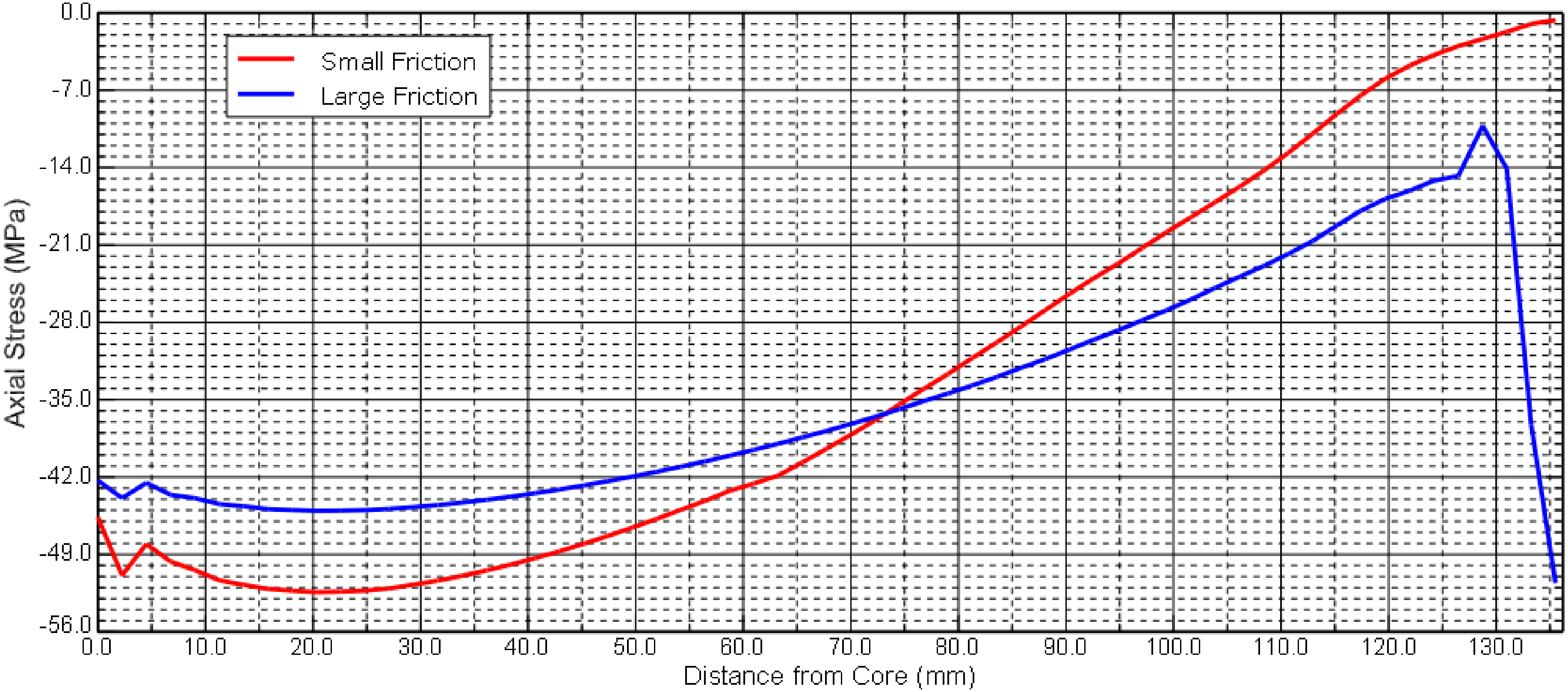
Axial Stress at Top Plate Interface



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Surface Finish and Friction

After fabrication, steel surfaces exposed to the atmosphere, except stainless steel surfaces, shall be shop painted or coated to protect against corrosion as specified in the contract documents. Prior to coating, the exposed steel surfaces shall be cleaned in accordance with the recommendations of the coating Manufacturer. Metal surfaces to be field-welded shall be given a coat of clear lacquer or other protective coating approved by the Engineer, if the time of exposure before welding takes place is to exceed three months. The lacquer coating shall be removed at the time of welding. The final painting or coating of these surfaces shall be done after the completion of welding.

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Shape Factor, S

- $S = \frac{Loaded\ Area}{Area\ Free\ to\ Bulge}$
- For a circular disc

$$S = \frac{\frac{\pi D^2}{4}}{\pi D h} = \frac{D}{4h}$$

- Thinner disc, i.e., larger $\frac{D}{h}$ => larger stiffness and larger stress carrying capacity (smaller strain)
- Thicker disc, i.e., smaller $\frac{D}{h}$ => smaller stiffness and larger strain (smaller stress)

Annular Disc (Donut Shape)

- If inside free to bulge

$$S = \frac{\frac{\pi}{4}(D_o^2 - D_i^2)}{\pi(D_o + D_i)h} = \frac{D_o}{4h}\left(1 - \frac{D_i}{D_o}\right) = S_o(1 - \beta)$$

- If inside is constrained

$$S = \frac{\frac{\pi}{4}(D_o^2 - D_i^2)}{\pi D_o h} = \frac{D_o}{4h}\left(1 - \frac{D_i^2}{D_o^2}\right) = S_o(1 - \beta^2)$$

- For Disc Bearings, $0.2 \le \beta \le 0.5$
  - If inside free to bulge: $0.5S_o \le S \le 0.8S_o$
  - If inside constrained : $0.75S_o \le S \le 0.96S_o$

- For Disc Bearings, S≈2

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Suggested Design Specification

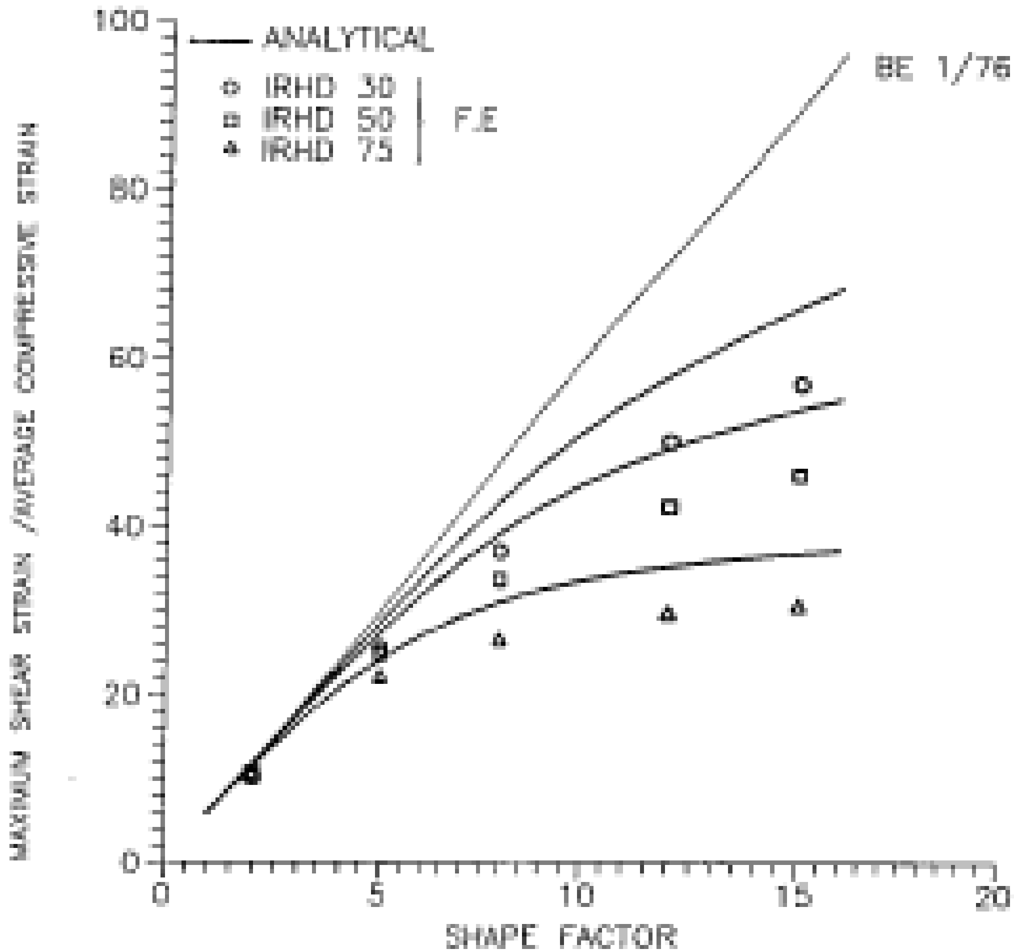
- Based on existing design practice (RJW)
  - $\sigma_c \leq 5.0\ ksi$
  - $\epsilon_c \leq 0.1$
  - $\alpha_{min} \geq 0.013\ rad$ (scaled from 0.02 radians at 150% of the specified rated capacity for proof load test)
- Limit on $\sigma_c \epsilon_c$?
- Shear strain limit?

Shear Strain – Circular Disc

$$\gamma_c \sim 6S\epsilon_c - 36S^3\left(\frac{G}{K}\right)\epsilon_c$$

For small S (<4)

$$\gamma_c \sim 6S\epsilon_c$$



Constantinou et al. (1992)

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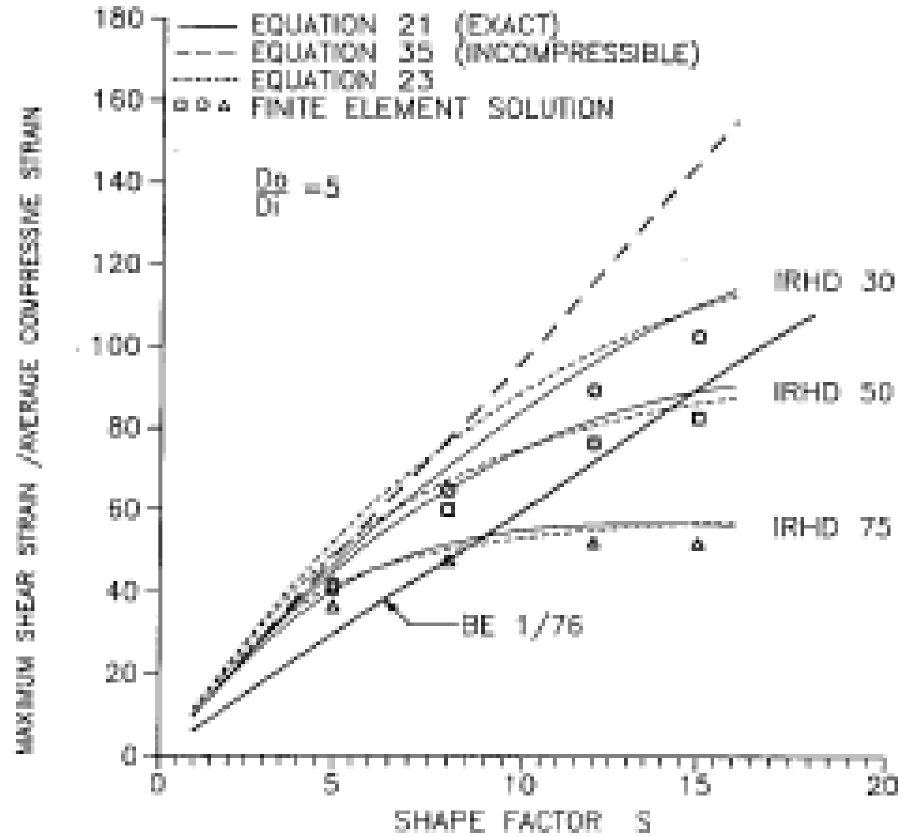
Shear Strain – Annular Disc

$$\gamma_{cH} = 6S\varepsilon_c \left\{ \frac{\left(\frac{D_0}{D_i}\right)^2 - \ln\left(\frac{D_0}{D_i}\right)^2 - 1}{\left(\frac{D_0}{D_i} - 1\right)\ln\left(\frac{D_0}{D_i}\right)^2} \right\} \qquad (35)$$



Constantinou et al. (1992)

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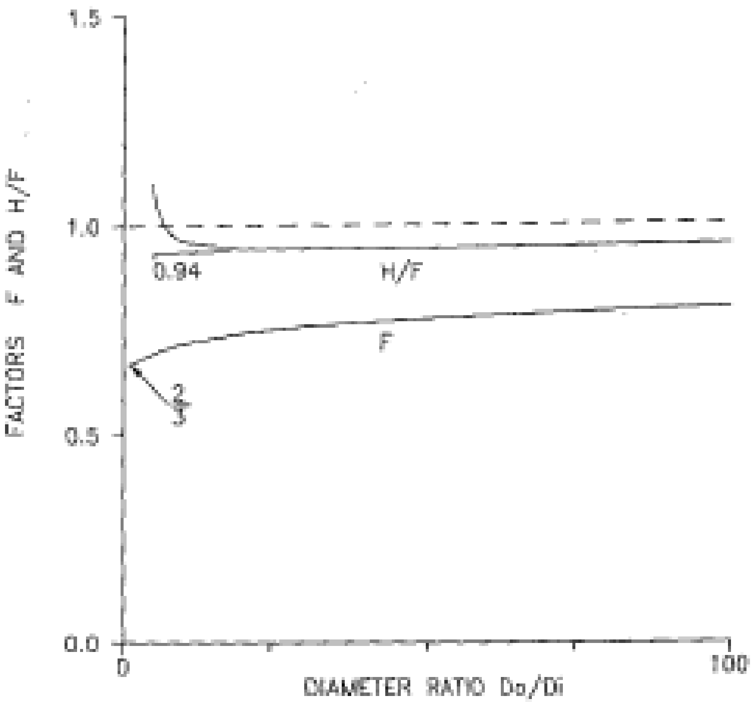
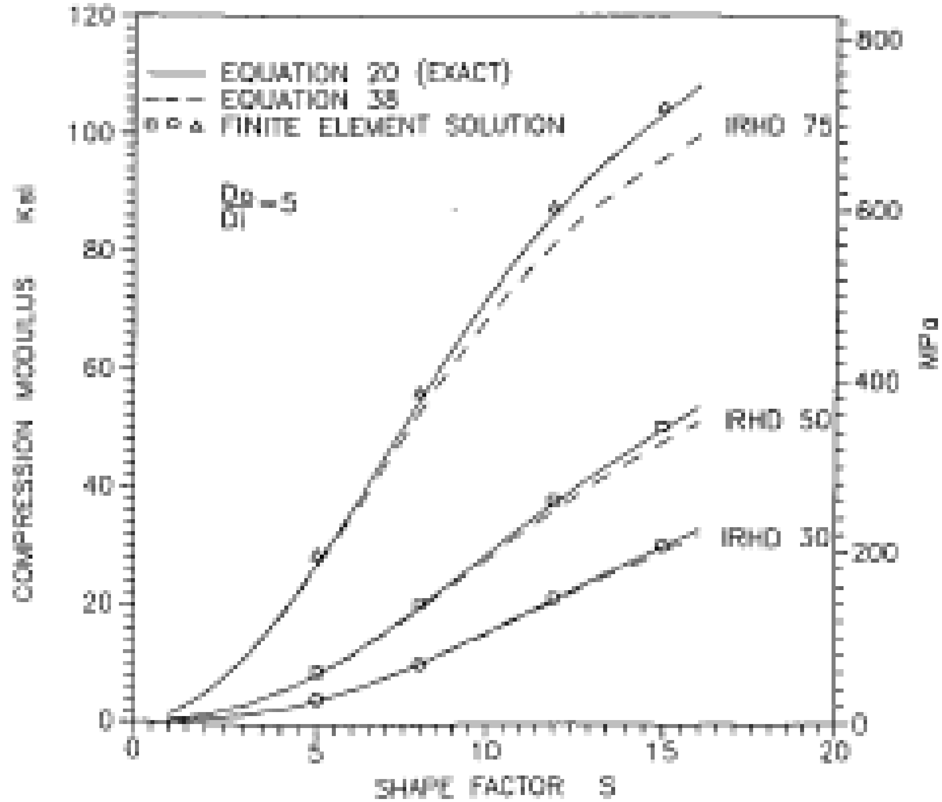
Compression Modulus

$$\frac{1}{E_c} = \frac{1}{6GS^2F} + \frac{4}{3K}\left(\frac{H}{F}\right) \qquad (38)$$





Constantinou et al. (1992)

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Clearances

- Between PU disc and retaining pin
- Between plate and retaining pin

Required Specification Changes

- Material properties of Polyether Urethane
  - Clarification of PU (elastomer?)
  - Specification of Polyether Urethane – ASTM?
    - Shear strength and modulus
    - Creep
    - Low temperature performance
- Fabrication
  - Casting (what about extrusion?)
    - Any special requirements or QC?
- Surface Finish for PU
- Clarification on surface coating for Steel Plates
- Clarification on acceptance criteria after surface deterioration test
- Testing for
  - Shear strength and modulus
  - Creep
  - Friction between PU and Steel Plate

Groove Shape

- Angular – 45, 60 degrees?

- Parabolic?

Additional Suggestions, Comments, Questions, Criticisms?

Input from all stake holders are welcome

Thank You