U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Strain-Based Acceptance Criteria for Section III of the ASME B&PV Code

Gordon Bjorkman
U.S. Nuclear Regulatory Commission

Doug Ammerman
Sandia National Laboratories

INTRODUCTION

- The U.S. NRC has a long history of assuring the safety of the public from the potential hazards associated with the transportation of radioactive material.
- For most of this history, the design of the packages used to transport this material has been based upon the ASME Boiler and Pressure Vessel Code and guidance has been provided by U.S. NRC Regulatory Guide 7.6.
- Currently, the relevant section of the Code is Section III, Division 3 (NUPACK).

STRESS INTENSITY

- The ASME Code relies on the concept of stress intensity to establish allowable stresses.
- Stress intensity is the maximum difference between principle stresses.
- This is equal to twice the maximum shear stress.
- Allowable stress intensities vary with loading case (normal vs. accident) and type of stress (primary, secondary, membrane, bending, local, etc.).
- Some allowable stresses are above the yield stress.

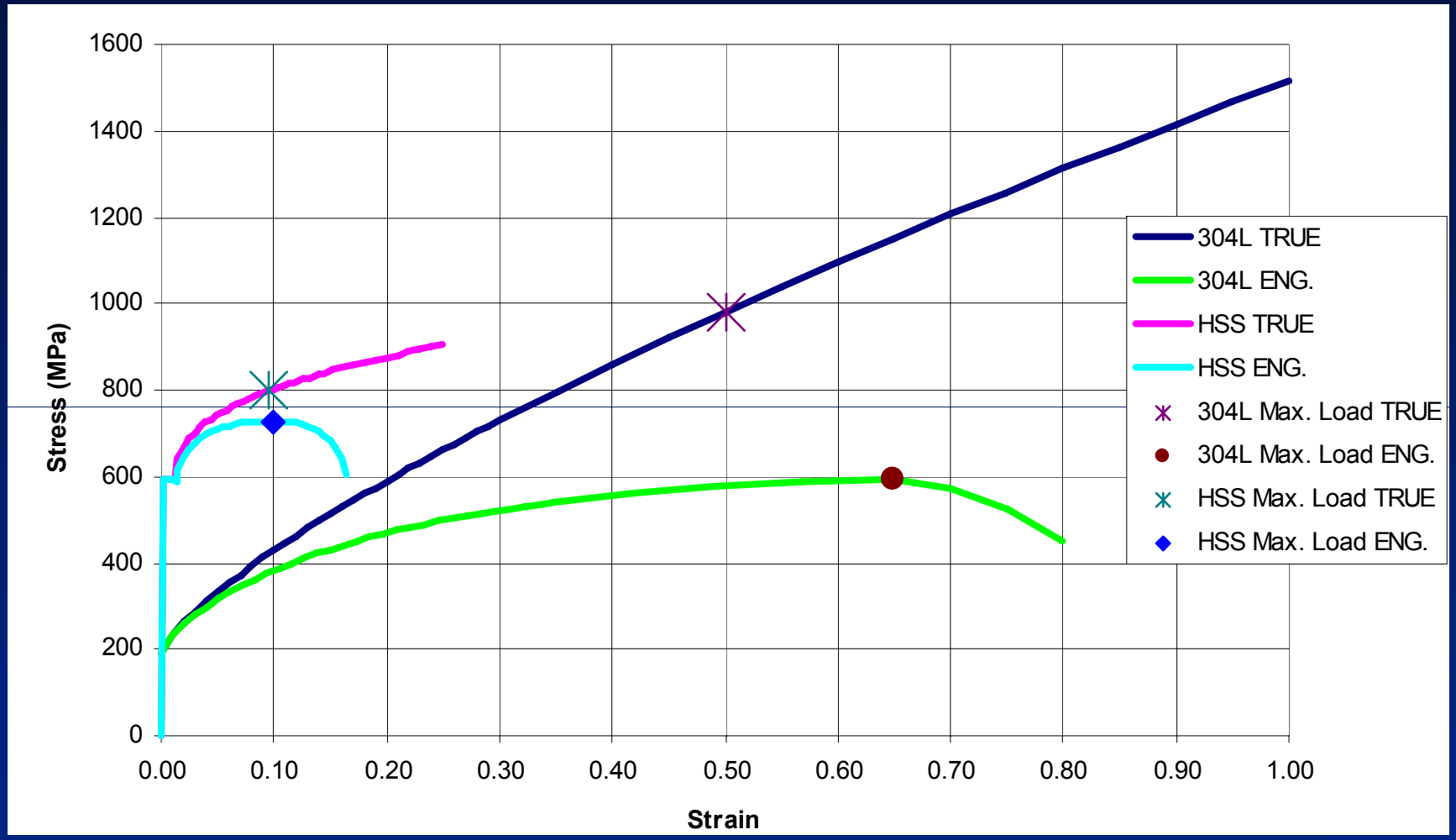
INELASTIC ANALYSIS

- Elastic analyses and stress intensity were very useful methods when doing hand calculations.
- If ASME and the regulators can revise their current analysis criteria, package designers would like to use inelastic analyses to determine the stresses.
- Modern finite element codes can readily compute the stress/strain state at any point in the package.

STRESS BASED vs. STRAIN BASED

- Current Code philosophy for inelastic analysis is an extension of the stress-based criteria used for elastic analysis.
- The requirements are given in non-mandatory Appendix F to Section III, Division 1.
- These requirements were mostly developed for load-limited events that are the major concern for most of the ASME code.
- For energy-limited events that are the major concern of package designers a strain-based philosophy is more appropriate.

MATERIAL BEHAVIOR



- The ability of the material to absorb energy is related to the area under the stress-strain curve.

MATERIAL BEHAVIOR (cont.)

- The high-strength steel has a higher allowable stress but lower energy absorption capacity.
- Stress-based acceptance criteria drive designers towards higher-strength materials.
- These materials may not actually provide additional safety for energy-limited events.

FAILURE STRAIN

- The true strain at fracture (including necking) can be calculated from the reduction in area.

$$\varepsilon_f = ln\left(\frac{1}{1-\mathrm{RA}}\right)$$

- The strain at maximum load (the point of onset of necking), also known as the uniform elongation strain, is considerably less than the true strain at fracture and could be the basis for any strain-based criteria.

- The strain to failure is a function of the stress state.

ASME PROPOSED STRAIN LIMITS

- Applicable only to "Quality Models"
- Away (>$3t_n$) from discontinuities
  - Average through thickness < (0.67 x $\varepsilon_{uniform}$)/ TF
  - Max. <[$\varepsilon_{uniform}$ + 0.25 x ($\varepsilon_{fracture}$ - $\varepsilon_{uniform}$)]/ TF
- At discontinuities
  - Average < (0.85 x $\varepsilon_{uniform}$)/ TF

$$TF = \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{\sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}} \geq 1$$

APPLICATION OF ASME STRAIN LIMITS

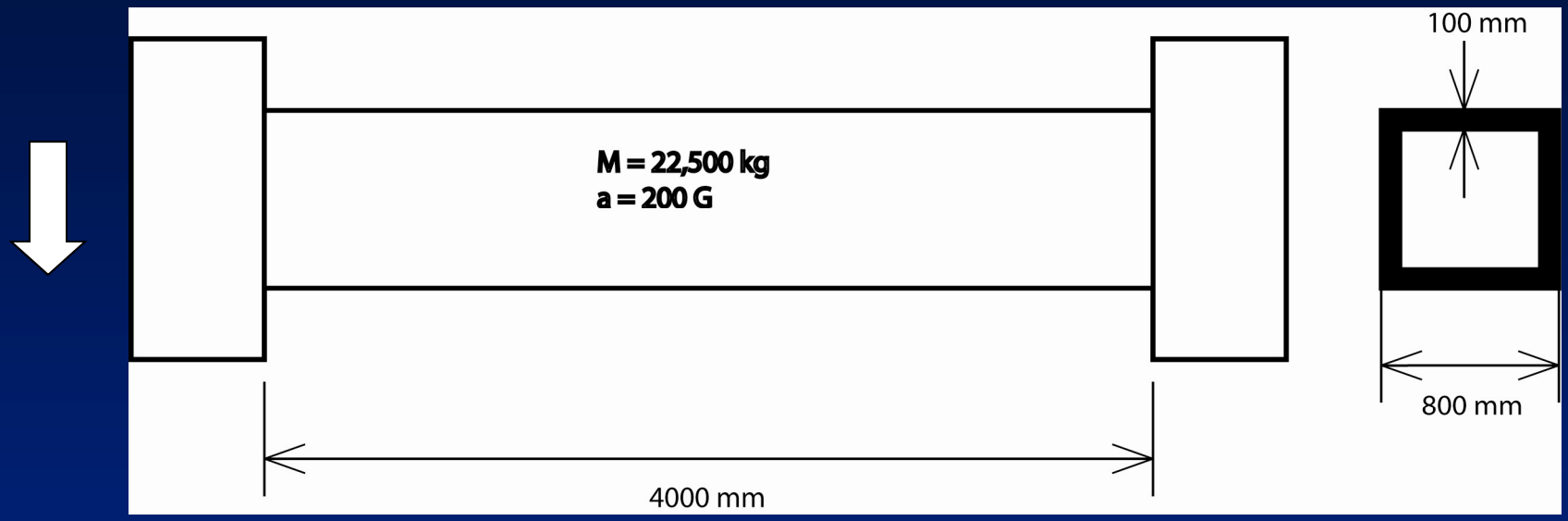
- The proposed strain limits do not supersede the requirement that the closure region should remain essentially elastic.
- The common practice of limiting package accelerations by the addition of impact limiters/impact limiting material should reduce the allowable strain in the containment vessel.
- The criteria is only valid for energy limited events.

COMPARISON OF ACCEPTANCE CRITERIA

- The goal of the Code for the design of radioactive material transportation packages is the same whatever acceptance criteria are used – to assure the package can perform its intended function of containing the radioactive contents.

- It is expected that the design of packages will not change significantly with any change of acceptance criteria, but rather that the acceptance criteria will make it easier to demonstrate compliance with the intent of the regulations.

EXAMPLE PACKAGE



- Stresses and strains for this example package subjected to a side impact will be compared.
- Material: Type 304 stainless steel (S_m = 20 ksi)

ELASTIC ANALYSIS

	Maximum from Analysis	Code Allowable
Membrane Stress	331 MPa [48 ksi]	331 MPa [48 ksi]
Membrane Plus Bending Stress	378 MPa [55 ksi]	496 MPa [72 ksi]

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

INELASTIC ANALYSIS

	Maximum from Analysis	Code Allowable (Appendix F)
Membrane Stress	306 MPa [44.4 ksi]	361 MPa [52.5 ksi]
Membrane Plus Bending Stress	318 MPa [46.1 ksi]	464 MPa [67.5 ksi]
Strain	5.3%	20%? proposed
Strain/% elongation	13%	–

REVISION TO DESIGN

- Case 1: What acceleration leads to inelastic stress equal to the design allowable?

  234 G

- Case 2: What wall thickness for a 200 G acceleration leads to inelastic stress equal to the design allowable?

  81 mm

- The maximum strain in both of these cases is about 9.5%, significantly less than 0.67 x $\varepsilon_{uniform}$

WHAT WE LEARN FROM THIS PROBLEM

- Designs based on the inelastic stress allowables of Appendix F differ only slightly from those based on Section III, Div. 3.
- The proposed ASME allowable strain-based acceptance criteria is intended for strains that are confined to a small area, so they should not be applied for gross strains in casks with impact limiters.
- It may be necessary to more precisely define when and where the proposed acceptance criteria are applicable.

QUALITY MODELS

- Currently, there is not a definition of what constitutes a “quality model”.
- ASME Task Group on Computational Modeling for Explicit Dynamics is addressing this.
- Topics for the Task Group include benchmarking, convergence studies, and qualification of analysts.

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

CONCLUSION

- Energy limited events should be analyzed using strain-based acceptance criteria.
- The ASME recognizes this and is developing standards for these analyses.
- The analysis sophistication of the design community has progressed sufficiently to allow inelastic analyses.