Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

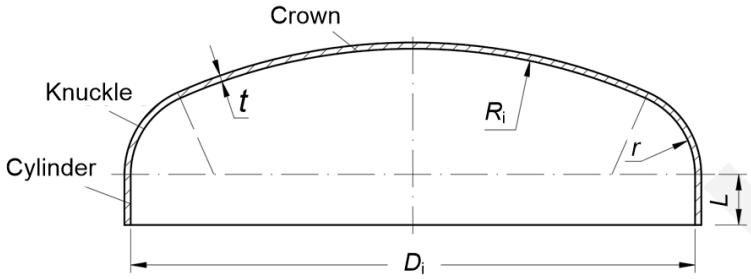
New formula for predicting the plastic buckling pressure of steel torispherical heads under internal pressure

Key words:
Torispherical head; Plastic buckling; Elastic-plastic analysis; Prediction formula; Finite element method

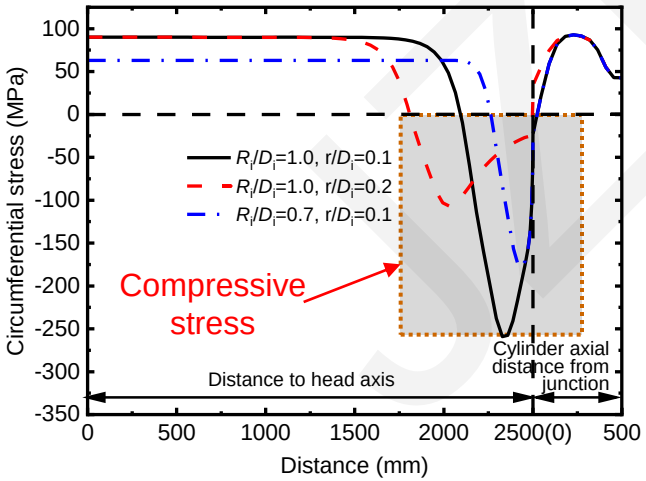
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Introduction

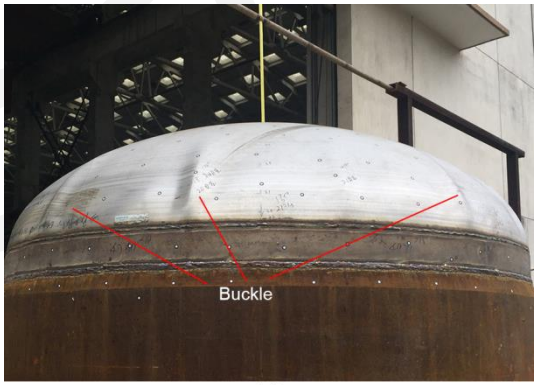
- Torispherical heads are widely used as end closures of pressure vessels in petrochemical, aerospace, and nuclear industries, etc.
- Buckling is a critical failure mode of torispherical heads, due to compressive stresses in the head knuckle under internal pressure.



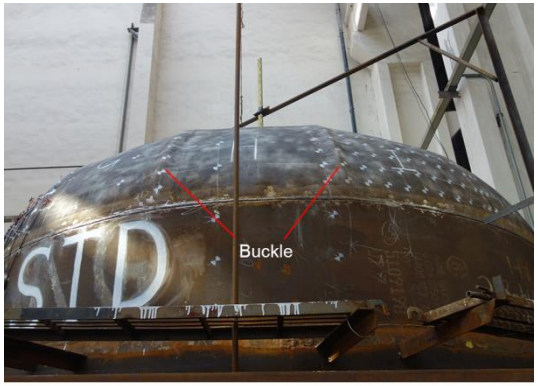
Geometry of a torispherical head



Compressive circumferential stresses under internal pressure



(a)

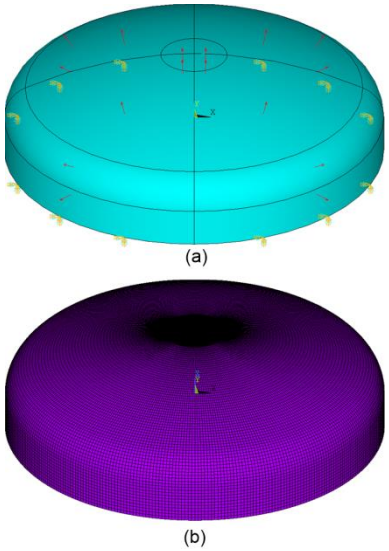


(b)

Buckling of torispherical heads under internal pressure

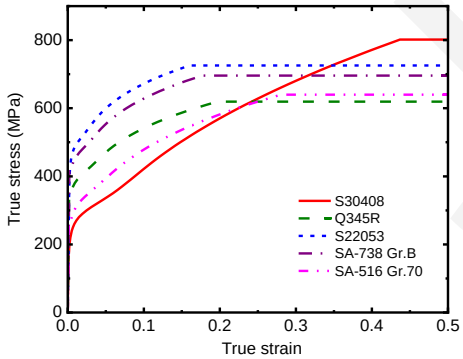
Numerical simulation of buckling

■ **FE model for buckling pressure of torispherical heads is established.**

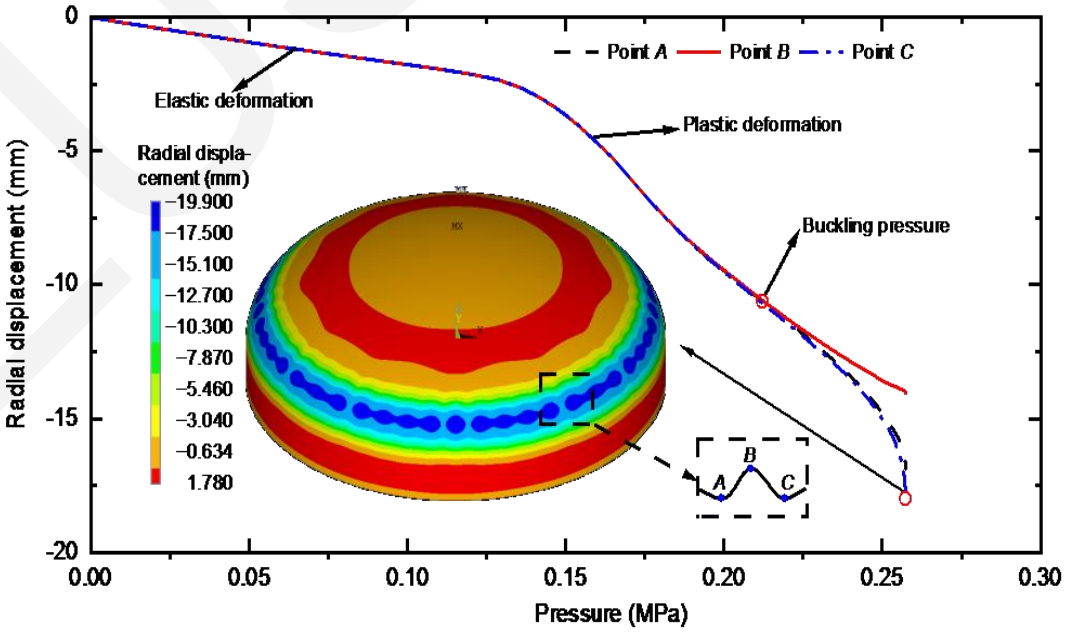


Geometry and mesh models

- **Arc-length method**
- **Material strain hardening**
- **Geometrical nonlinearity**



Material models

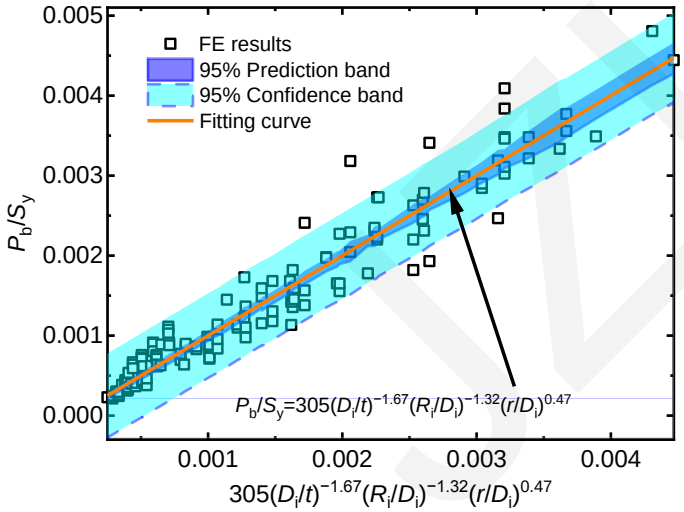


FE results on buckling of torispherical heads

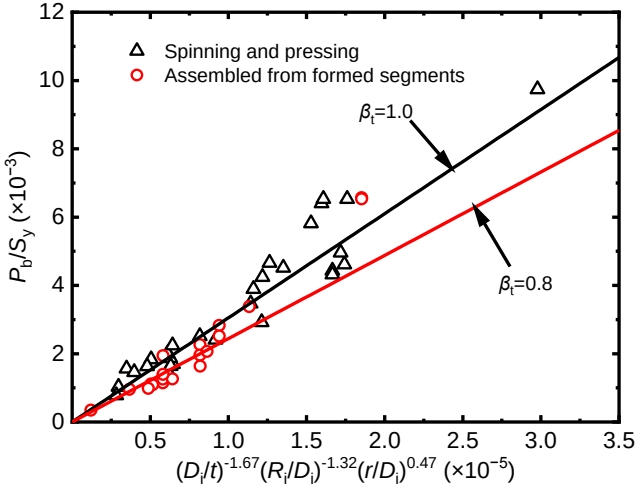
Development of new formula

- **A new formula to predict buckling pressure of torispherical heads is proposed by fitting FE results from parametric study, and introducing a reduction factor determined by experiment data to account for the effect of shape imperfections caused by manufacturing.**

$$P_b = 305\beta_t S_y \left(\frac{D_i}{t}\right)^{-1.67} \left(\frac{R_i}{D_i}\right)^{-1.32} \left(\frac{r}{D_i}\right)^{0.47}$$



Curve fitting of FE results from parametric study

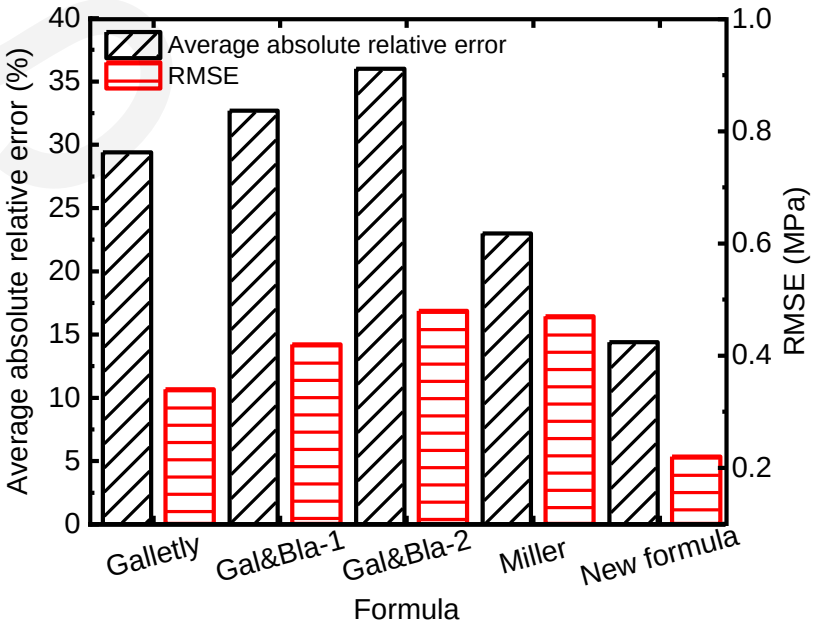


Formula modified by experimental data

Comparison with other formulas

- The new formula and existing formulas were compared with experimental data from a total of 49 full-scale torispherical heads.
- Compared with existing formulas, the new formula has a comprehensive advantage in terms of its accuracy and applicability.

	Formula	Limitation
Galletly	$P_b = \frac{230 S_y (r/D_i)^{0.84}}{(D_i/t)^{1.53}(R_i/D_i)^{1.1}}$	$500 \le D_i/t \le 1500$, $0.75 \le R_i/D_i \le 1.5$, $0.06 \le r/D_i \le 0.18$
Galletly & Błachut	$P_b = \frac{120 S_y (r/D_i)^{0.81}}{(D_i/t)^{1.46}(R_i/D_i)^{1.18}}$ and $P_b = \frac{200 S_y (r/D_i)^{1.5}}{(D_i/t)^{1.42}(R_i/D_i)^{1.17}}[1+0.05(r/D_i)^{-1.315}]$	$300 \le D_i/t \le 1500$, $0.8 \le R_i/D_i \le 1.0$, $0.05 \le r/D_i \le 0.2$
Miller	$P_b = \begin{cases} 0.6P_e, & P_e/P_y \le 1.0, \\ 0.408P_y + 0.192P_e, & 1.0 < P_e/P_y \le 8.29, \\ 2.0P_y, & P_e/P_y > 8.29. \end{cases}$ and $P_b = \begin{cases} 0.6P_e, P_e/P_y \le 1.667, \\ 0.748P_y + 0.151P_e, 1.667 < P_e/P_y \le 8.29, \\ 2.0P_y, P_e/P_y > 8.29. \end{cases}$	$20 \le D_i/t \le 2806$, $0.72 \le R_i/D_i \le 1.82$, $0.04 \le r/D_i \le 0.35$
New Formula	$P_b = 305\beta_t S_y \left(\frac{D_i}{t}\right)^{-1.67}\left(\frac{R_i}{D_i}\right)^{-1.32}\left(\frac{r}{D_i}\right)^{0.47}$	$200 \le D_i/t \le 2000$, $0.7 \le R_i/D_i \le 1.0$, $0.06 \le r/D_i \le 0.2$



The new formula has a higher accuracy than existing formulas

Conclusions

- Nonlinear FE Model is established to calculate buckling pressure of torispherical heads, considering strain hardening and geometrical nonlinearity.
- A new formula to predict buckling pressure of torispherical heads is proposed by fitting FE results and introducing a reduction factor determined from experimental results.
- Compared with existing formulas, the new formula has a comprehensive advantage in terms of its accuracy and applicability.
- The development of new formula is important for preventing buckling failure of torispherical heads under internal pressure.