

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

## **Key words:**

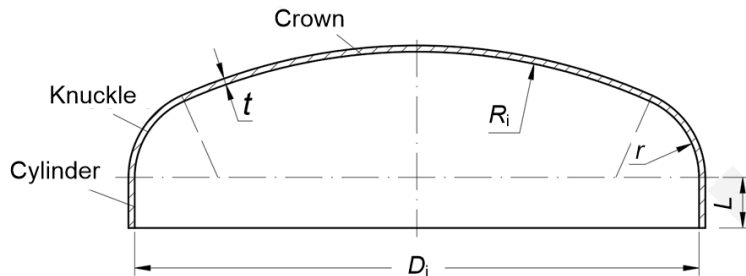
Torispherical head; Plastic buckling; Elastic-plastic analysis; Prediction formula; Finite element method

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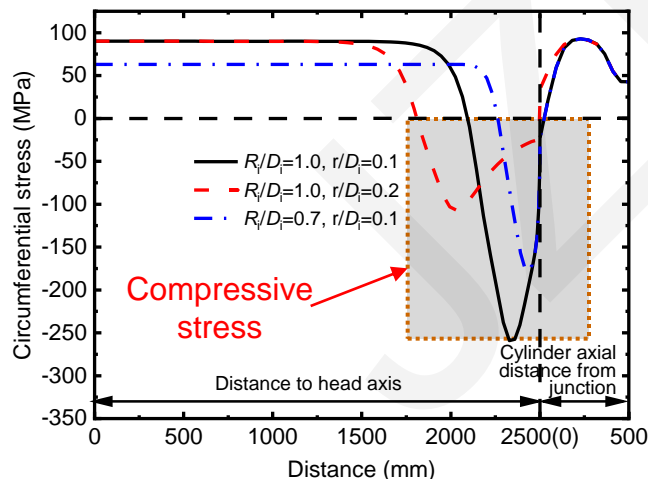
<https://doi.org/10.1631/jzus.A2300432>

# Introduction

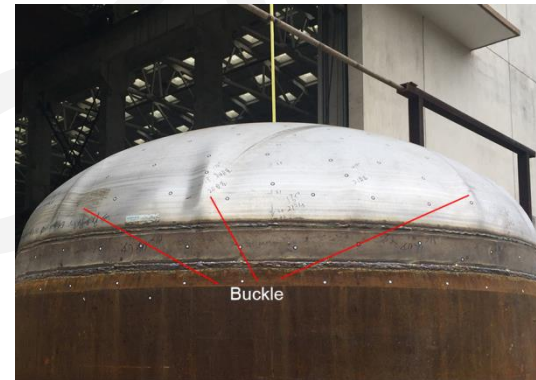
- Torispherical heads are widely used as end closures of pressure vessels in petrochemical, aerospace, and nuclear industries, etc.
- Buckling is a critical failure mode of torispherical heads, due to compressive stresses in the head knuckle under internal pressure.



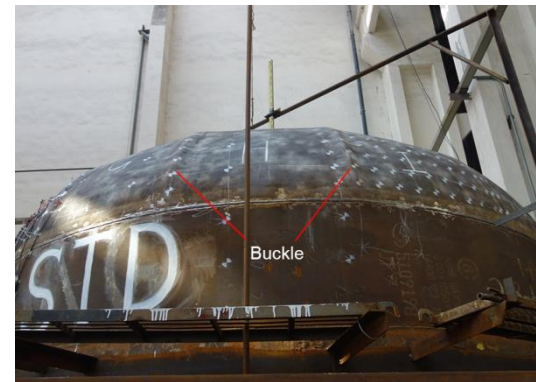
Geometry of a torispherical head



Compressive circumferential stresses under internal pressure



(a)

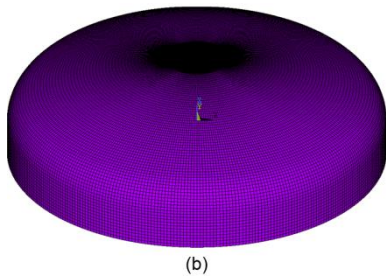
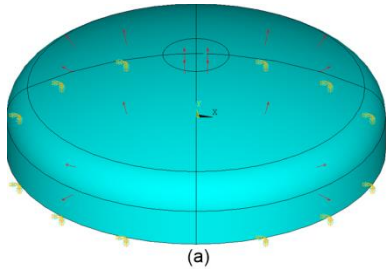


(b)

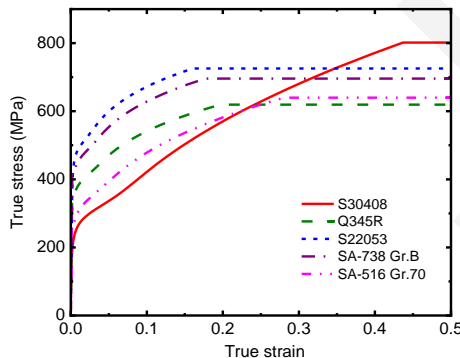
Buckling of torispherical heads under internal pressure

# Numerical simulation of buckling

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

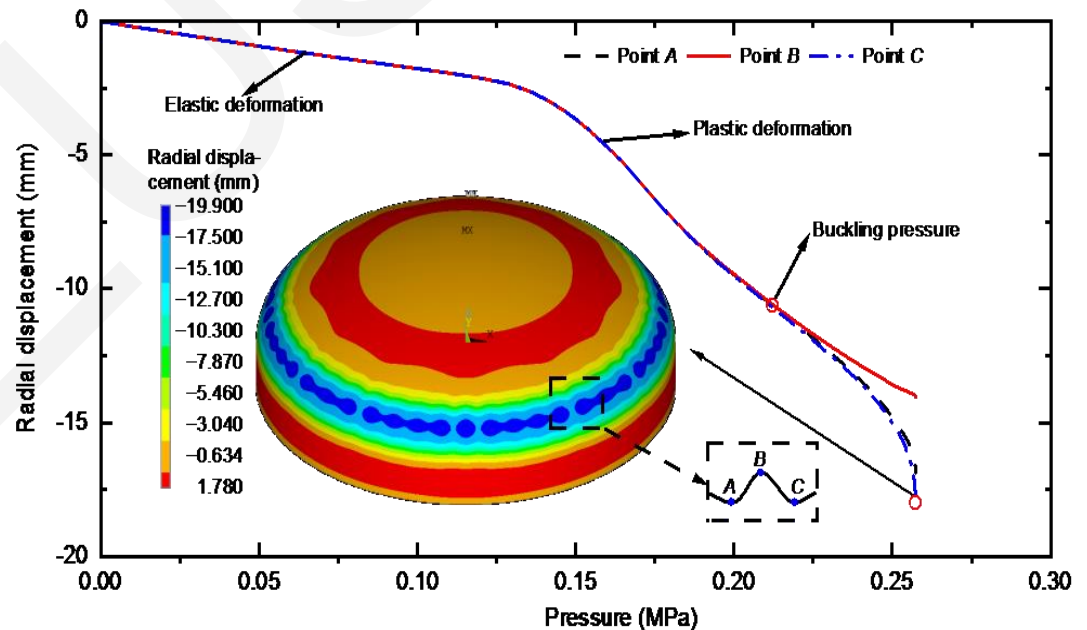


## Geometry and mesh models



Material models

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

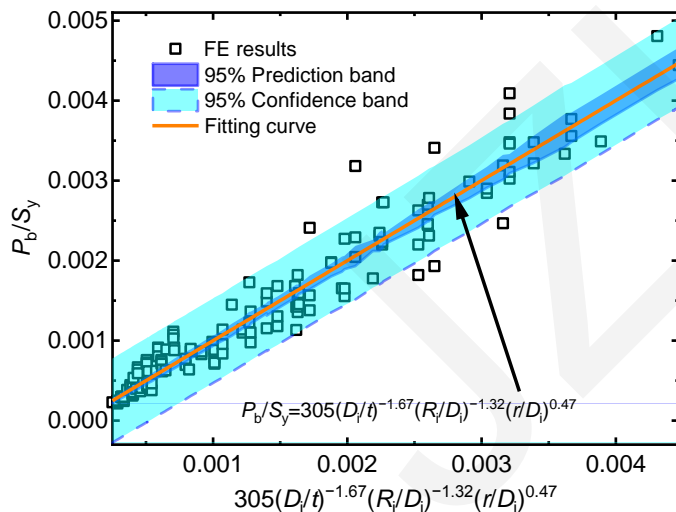


FE results on buckling of torispherical heads

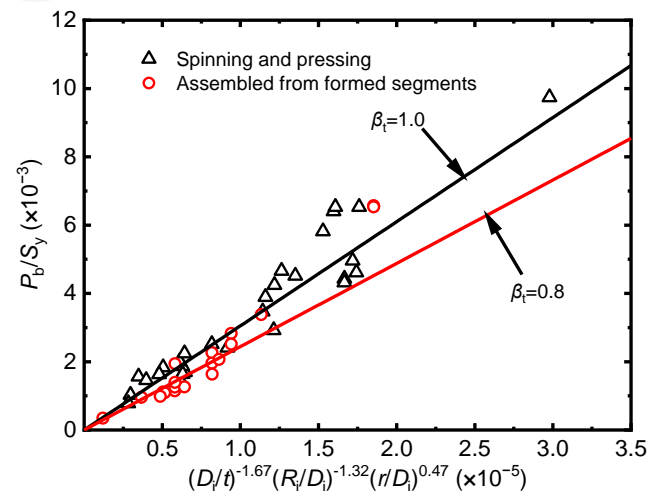
# Development of new formula

■ 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

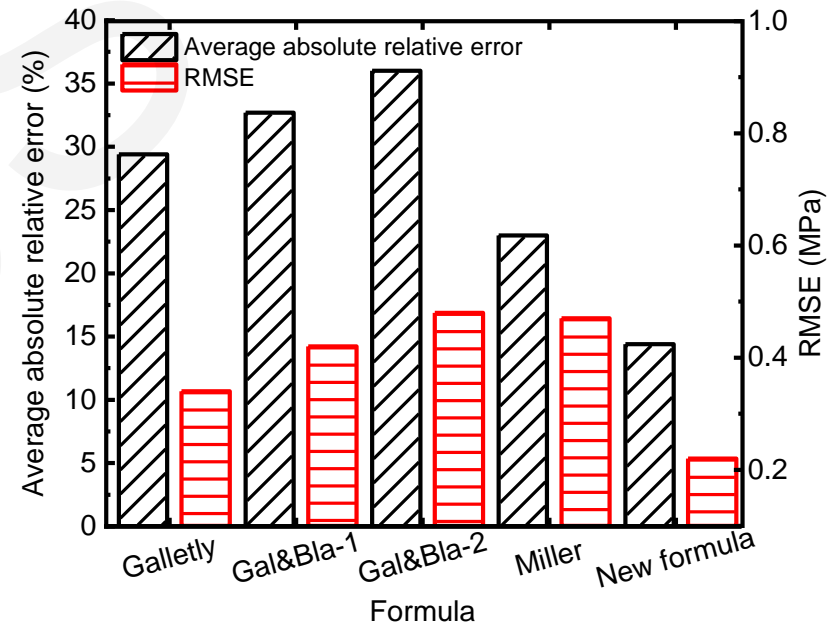


Formula modified by experimental data

# 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
<b>Galletly</b>	$P_b = \frac{230S_y (r/D_i)^{0.84}}{(D_i/t)^{1.53} (R_i/D_i)^{1.11}}$	$500 \leq D_i/t \leq 1500,$ $0.75 \leq R_i/D_i \leq 1.5,$ $0.06 \leq r/D_i \leq 0.18$
<b>Galletly &amp; Blachut</b>	$P_b = \frac{120S_y (r/D_i)^{0.81}}{(D_i/t)^{1.46} (R_i/D_i)^{1.18}}$ $P_b = \frac{200S_y (r/D_i)^{1.5}}{(D_i/t)^{1.42} (R_i/D_i)^{1.17}} [1 + 0.05(r/D_i)^{-1.315}]$	$300 \leq D_i/t \leq 1500,$ $0.8 \leq R_i/D_i \leq 1.0,$ $0.05 \leq r/D_i \leq 0.2$
<b>Miller</b>	$P_b = \begin{cases} 0.6P_e, & P_e/P_y \leq 1.0, \\ 0.408P_y + 0.192P_e, & 1.0 < P_e/P_y \leq 8.29, \\ 2.0P_y, & P_e/P_y > 8.29. \end{cases}$ $P_b = \begin{cases} 0.6P_e, & P_e/P_y \leq 1.667, \\ 0.748P_y + 0.151P_e, & 1.667 < P_e/P_y \leq 8.29, \\ 2.0P_y, & P_e/P_y > 8.29. \end{cases}$	$20 \leq D_i/t \leq 2806,$ $0.72 \leq R_i/D_i \leq 1.82,$ $0.04 \leq r/D_i \leq 0.35$
<b>New Formula</b>	$P_b = 305\beta_1 S_y \left(\frac{D_i}{t}\right)^{-1.67} \left(\frac{R_i}{D_i}\right)^{-1.32} \left(\frac{r}{D_i}\right)^{0.47}$	$200 \leq D_i/t \leq 2000,$ $0.7 \leq R_i/D_i \leq 1.0,$ $0.06 \leq r/D_i \leq 0.2$



**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.**