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A finite element analysis comparison study of the proposed new CEN method for the design of conical shells under combined loadings

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Conical Vessel Design

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- EN13445 provides rules for the design of pressurised conical shells based on former East German TGL rules
- These have also been adopted into the UK PD5500 code
- The main shell thickness, e_{con}, is evaluated on the basis of a pressure calculation satisfying simple equilibrium

$$e_{con} = \frac{P \cdot D_e}{2f \cdot z + P} \cdot \frac{1}{\cos(\alpha)}$$

Where P is the internal pressure, D, the diameter, f, the design stress, z, the joint efficiency and α the cone semi-apex angle

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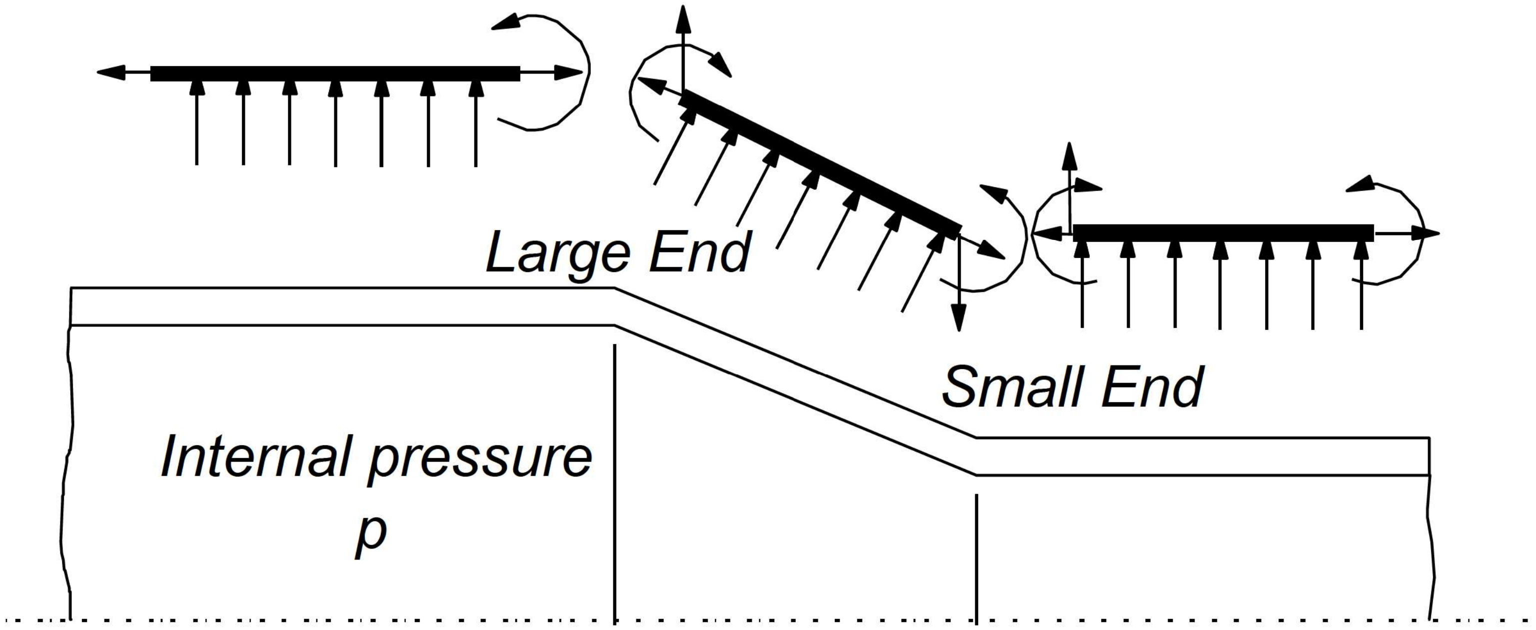
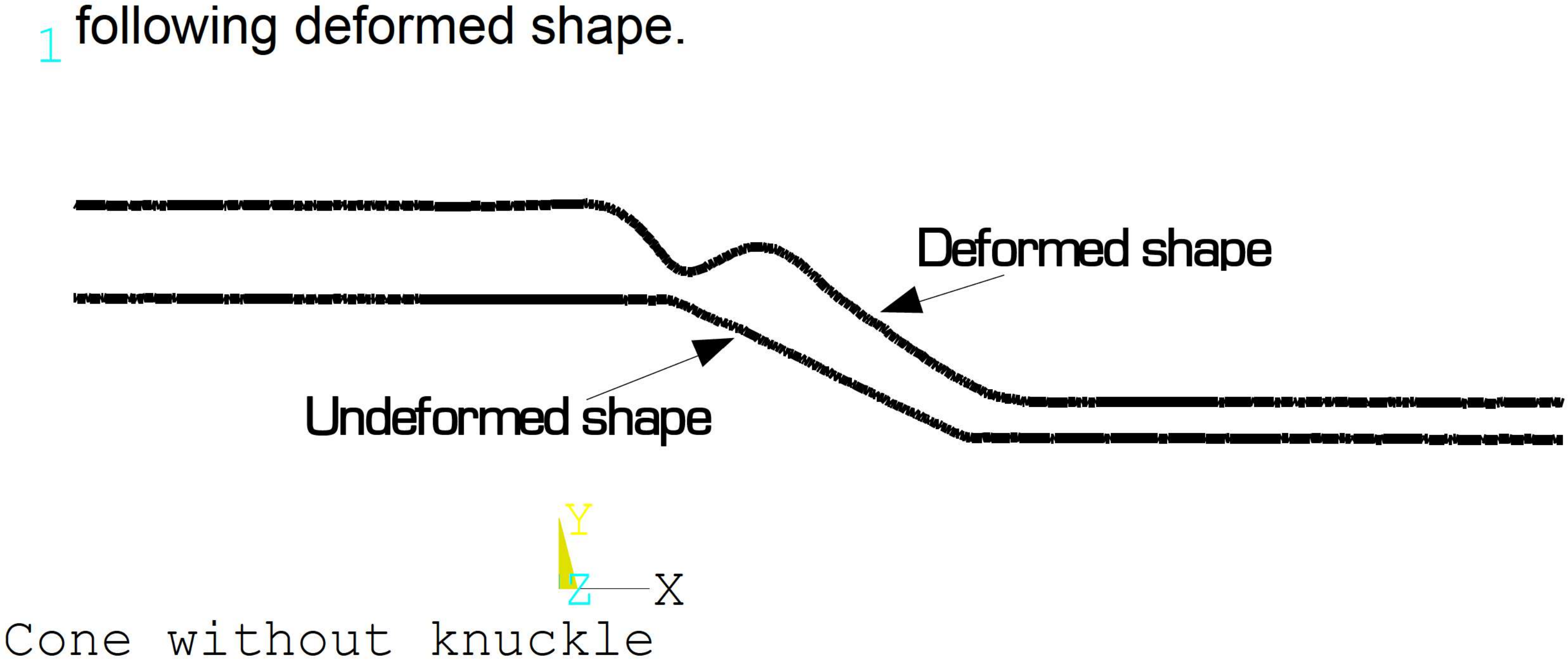
Discontinuity Analysis

Edge forces resulting in discontinuity stresses

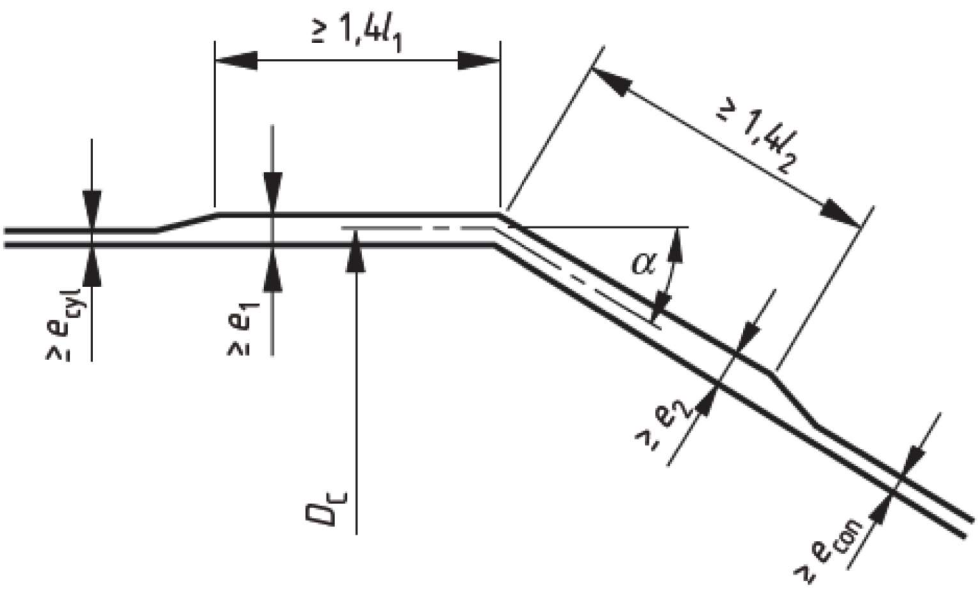


Axi-symmetric FEA

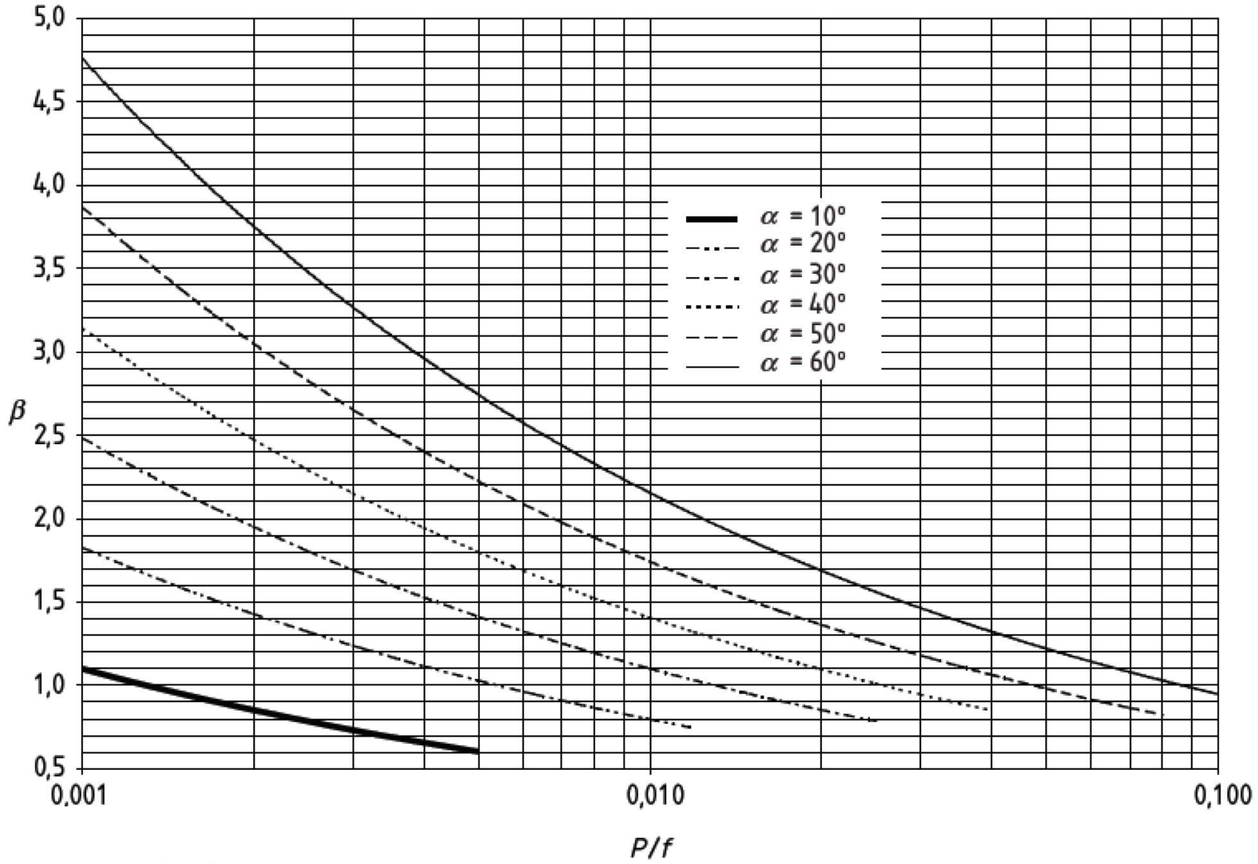
An axi-symmetric finite element analysis of the cone/cylinder junctures made using conical shell elements results in the following deformed shape.



Junction Reinforcement (1)



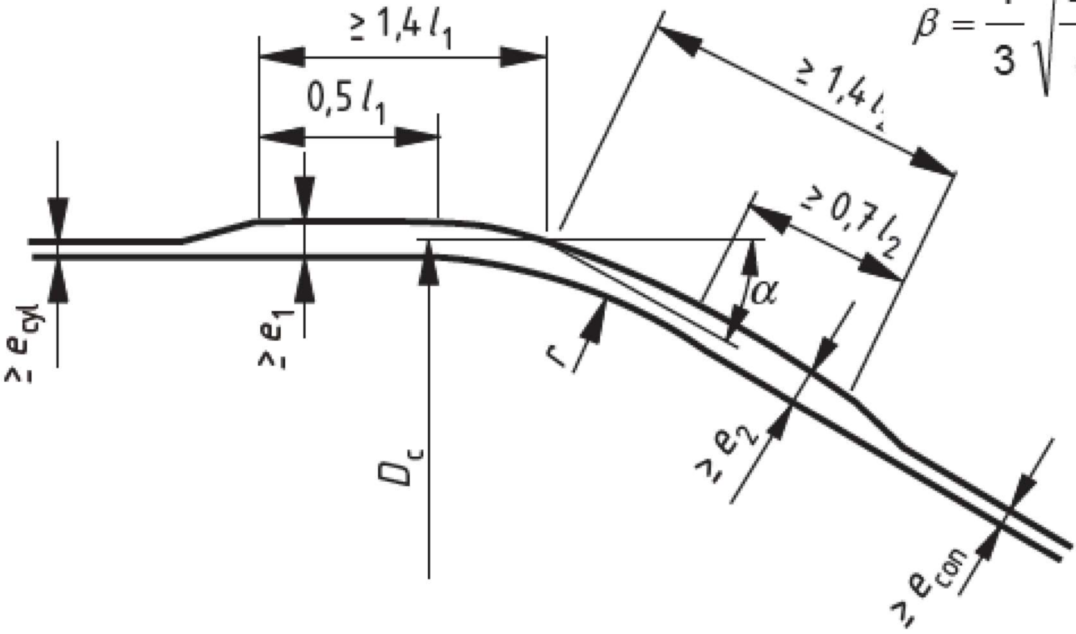
Geometry of cone/cylinder intersection without knuckle – Large end – EN13445 Figure 7.6-1



$$\beta = \frac{1}{3}\sqrt{\frac{D_c}{e_j}} \cdot \frac{\tan(\alpha)}{1 + 1/\sqrt{\cos(\alpha)}} - 0{,}15$$

$$e_j = \frac{P \cdot D_c \cdot \beta}{2f}$$

Junction Reinforcement (2)



$$\beta = \frac{1}{3}\sqrt{\frac{D_c}{e_j}} \cdot \frac{\tan(\alpha)}{1 + 1/\sqrt{\cos(\alpha)}} - 0{,}15$$

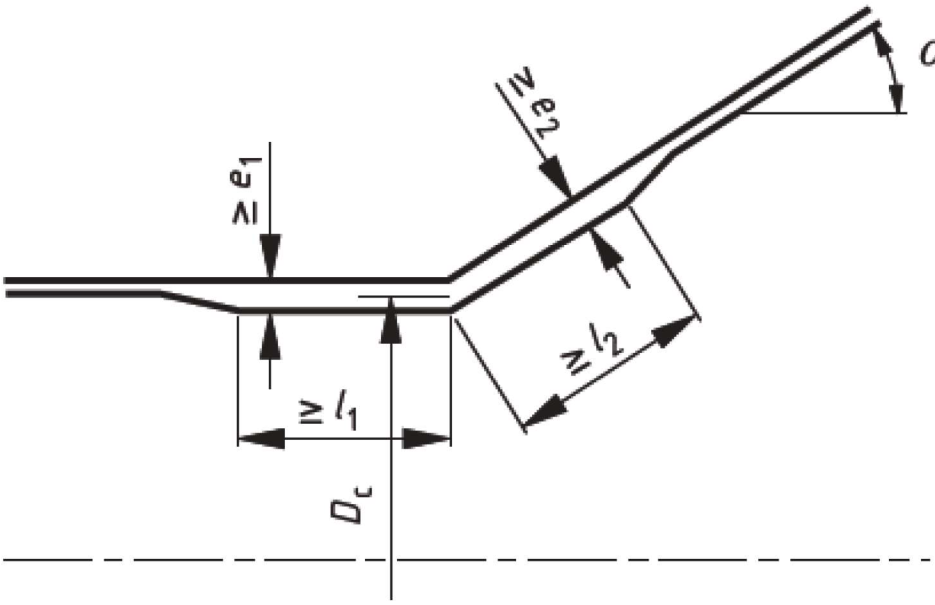
$$\rho = \frac{0{,}028r}{\sqrt{D_c \cdot e_j}} \frac{\alpha}{1 + 1/\sqrt{\cos(\alpha)}}$$

$$\gamma = 1 + \frac{\rho}{1{,}2\left(1 + \frac{0{,}2}{\rho}\right)}$$

$$e_j = \frac{P \cdot D_c \cdot \beta}{2f\gamma}$$

Geometry of cone/cylinder intersection with knuckle – Large end – EN13445 Figure 7.6-2

Junction Reinforcement (3)



Geometry of cone/cylinder intersection – Small end – EN13445 Figure 7.6-3

$$s = \frac{e_2}{e_1}$$

when $s < 1$

$$\tau = s\sqrt{\frac{s}{\cos(\alpha)}} + \sqrt{\frac{1+s^2}{2}}$$

when $s \geq 1$

$$\tau = 1 + \sqrt{s\left\{\frac{1+s^2}{2\cos(\alpha)}\right\}}$$

$$\beta_H = 0{,}4\sqrt{\frac{D_c}{e_1}} \cdot \frac{\tan(\alpha)}{\tau} + 0{,}5$$

If

$$P \leq \frac{2f \cdot z \cdot e_1}{D_c \cdot \beta_H}$$

Limitations

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- Semi-apex angle greater than 75degrees
- Cones for which

$$\frac{e_a \cdot \cos(\alpha)}{D_c} \leq 0{,}001;$$

- Short cones joining to a jacket
- Limitations on each case for die-out distances
- NO method for global loads –
  - thrust force
  - overturning moment
  - Interaction with pressure loading

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Global Loads – EN13445 Clause 16.14

- Rules are given for determining the minimum thickness of a cylindrical shell subject to a combination of loads in addition to pressure, at sections remote from the area of application of local loads and from structural discontinuities.

- Simple equilibrium calculations
- Simple interaction relationships
- Checks for maximum compressive stress
- Permissible compressive stress check
- Tolerance checks – out-of-roundness
- Caution over wind and earthquake regions

Kiesewetter Method – new 16.15

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- Proposed new method – KM Method
- Limit analysis based on the formation of plastic hinges
- Postulated deformation modes
- Two calculation routes –
  - Can be considered as a ‘conical transition
  - Otherwise large and small ends considered seperately
- Loads applicable for FEA study

$$P = 0.3 \times \frac{2e_C f_C \cos\alpha}{D_L}$$

$$M_{BS} = 0.3 \times \frac{\pi D_S^2 e_S f_S}{4}$$

$$F = -0.3 \times \pi D_S e_S f_S$$

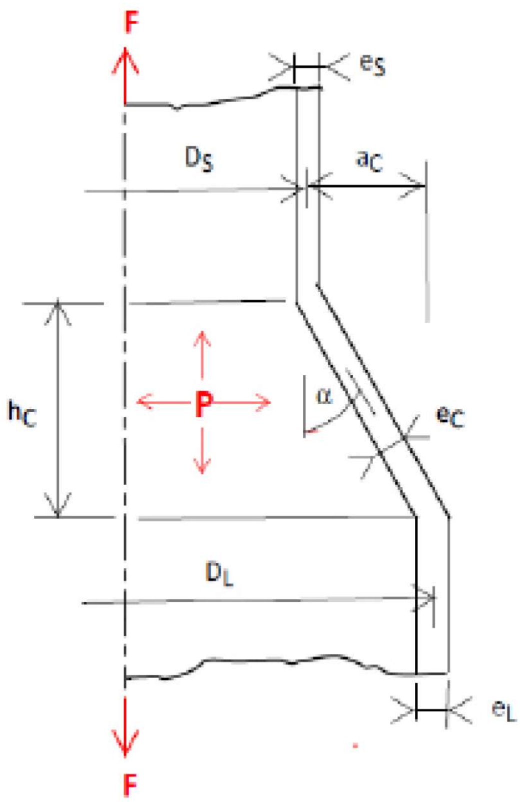


Figure 2a: Sketch of conical transition loaded by int. pressure and axial force

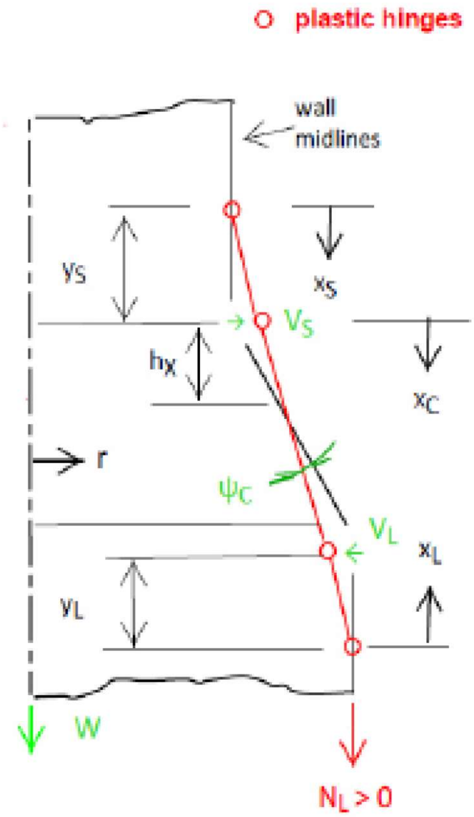


Figure 2b: Deformed model for resulting axial **tension** force

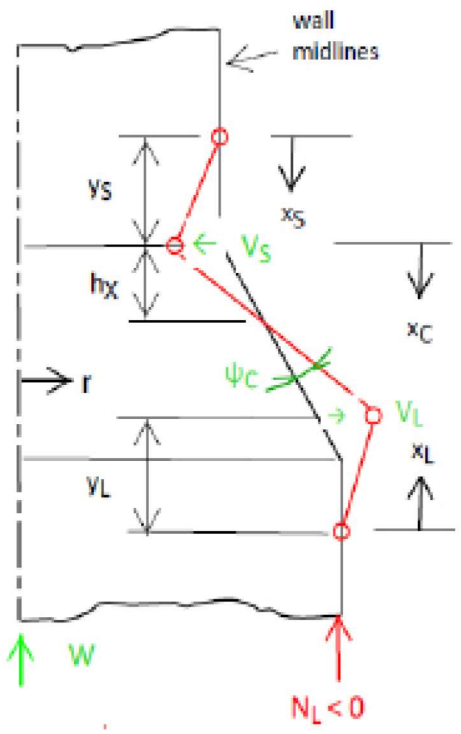
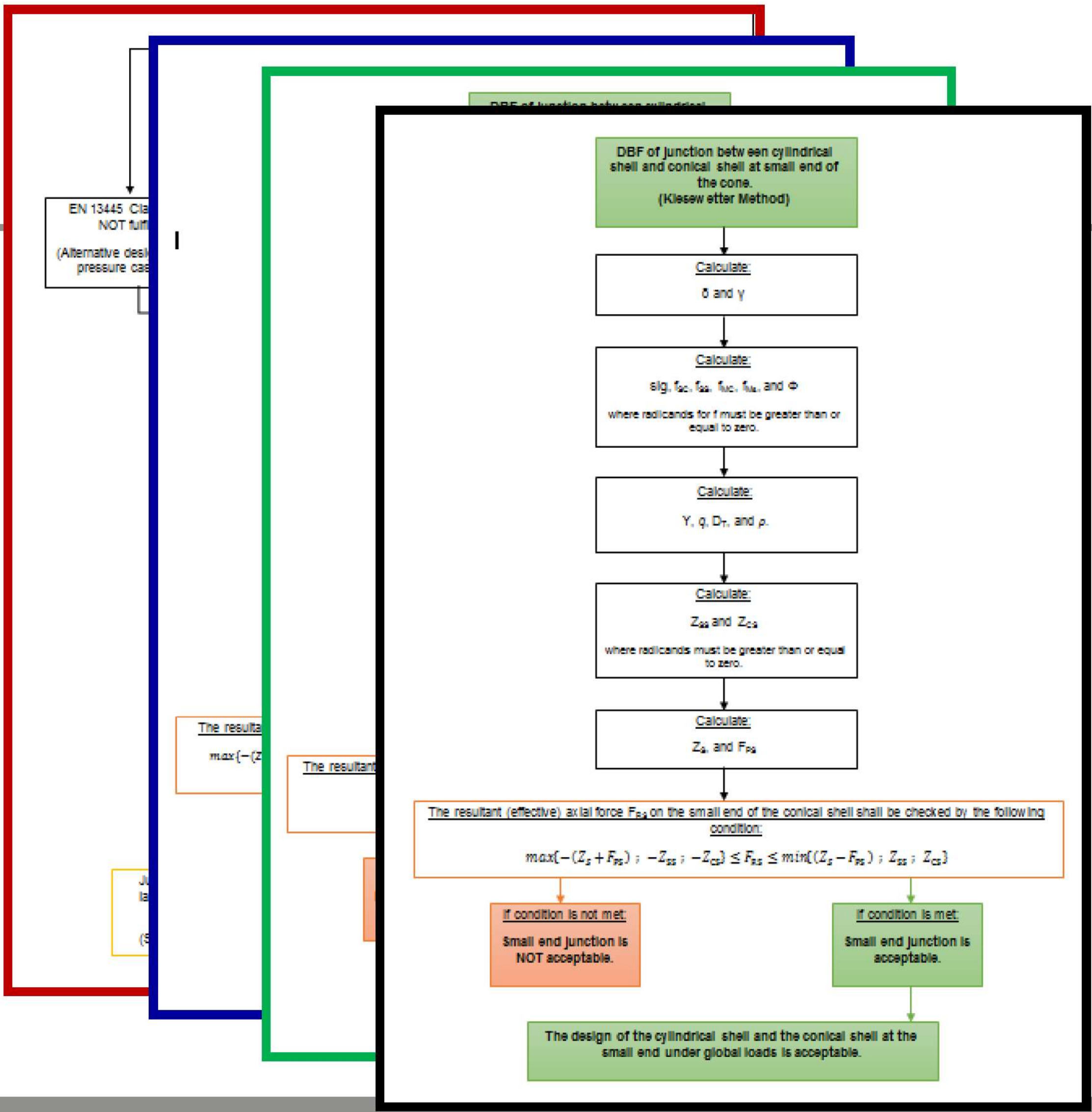


Figure 2c: Deformed model for resulting axial **compression** force



DBF of junction between cylindrical shell and conical shell at small end of the cone. (Kiesewetter Method)
Calculate: δ and γ
Calculate: sig, f_{ac}, f_{as}, f_{Mc}, f_{Ms}, and Φ where radicands for f must be greater than or equal to zero.
Calculate: Y, q, D_T, and ρ.
Calculate: Z_{SS} and Z_{CS} where radicands must be greater than or equal to zero.
Calculate: Z_S, and F_{PS}
The resultant (effective) axial force F_{RS} on the small end of the conical shell shall be checked by the following condition:
$max\{-(Z_S+F_{PS})\ ;\ -Z_{SS}\ ;\ -Z_{CS}\} \le F_{RS} \le min\{(Z_S-F_{PS})\ ;\ Z_{SS}\ ;\ Z_{CS}\}$
If condition is not met: Small end junction is NOT acceptable.
If condition is met: Small end junction is acceptable.
The design of the cylindrical shell and the conical shell at the small end under global loads is acceptable.
EN 13445 Cla
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pressure cas
The resulta
The resultant

Parametric Range

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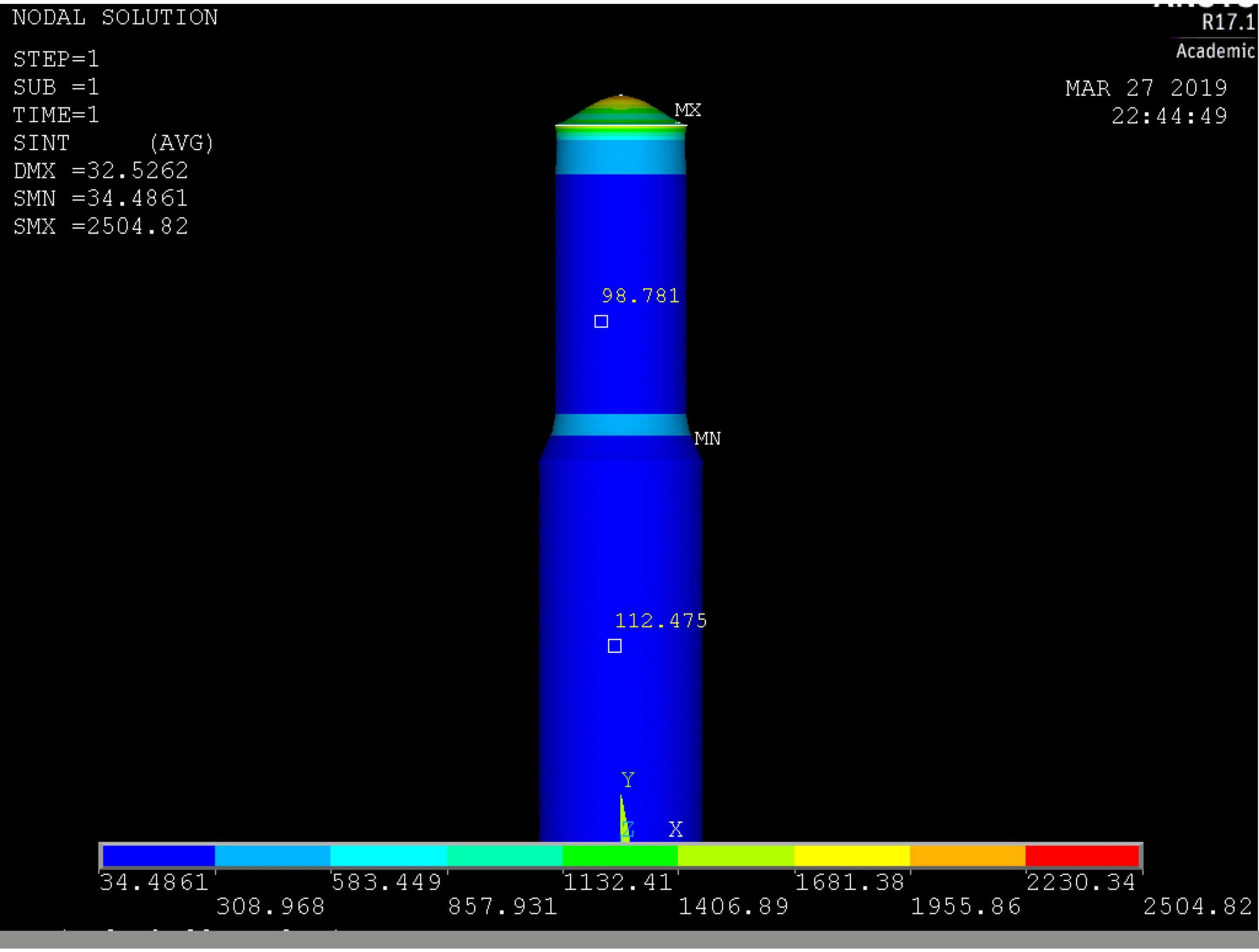
Cone Angle (°)	e/D	D_S/D_L
15	0.002	0.2
30	0.005	0.3
45	0.01	0.45
60	0.02	0.65
75	0.05	0.8

Note: D_s/D_L is the ratio of small end to large end and e/D is 0.002 to 0.16.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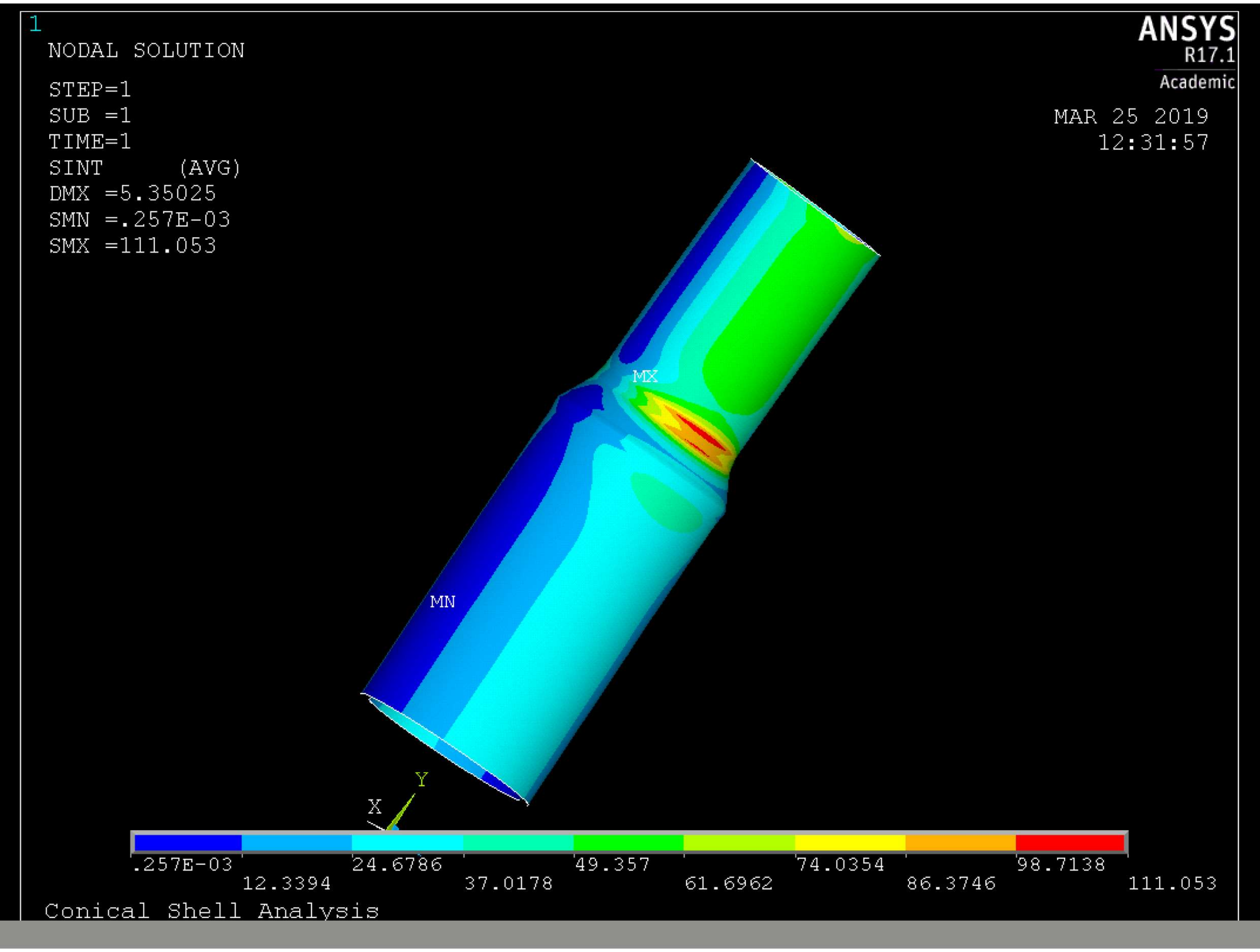
SUB =1
TIME=1
SINT (AVG)
DMX =32.5262
SMN =34.4861
SMX =2504.82
R17.1
Academic
MAR 27 2019
22:44:49
MX
MN
98.781
112.475
Y
Z
X
34.4861
308.968
583.449
857.931
1132.41
1406.89
1681.38
1955.86
2230.34
2504.82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SMN =.257E-03
SMX =111.053
ANSYS
R17.1
Academic
MAR 25 2019
12:31:57
MX
MN
Y
X
.257E-03
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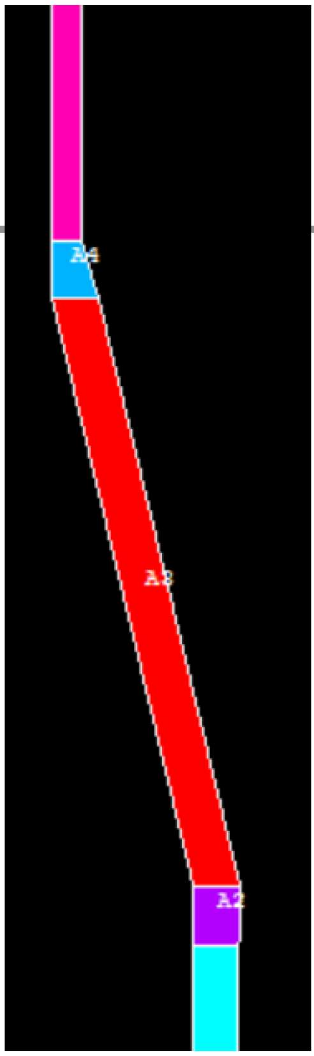
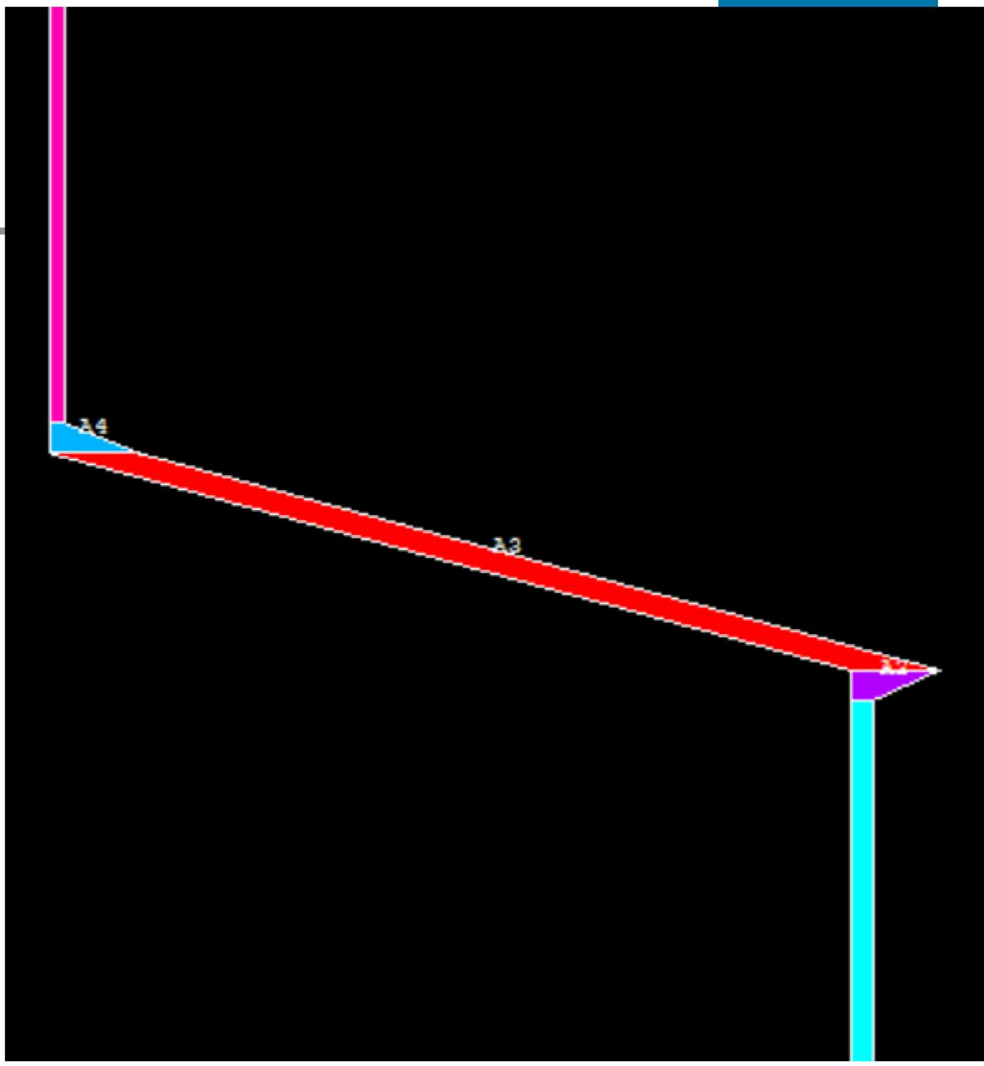
24.6786
37.0178
49.357
61.6962
74.0354
86.3746
98.7138
111.053
Conical Shell Analysis


A4
A3
A2


A4
A3

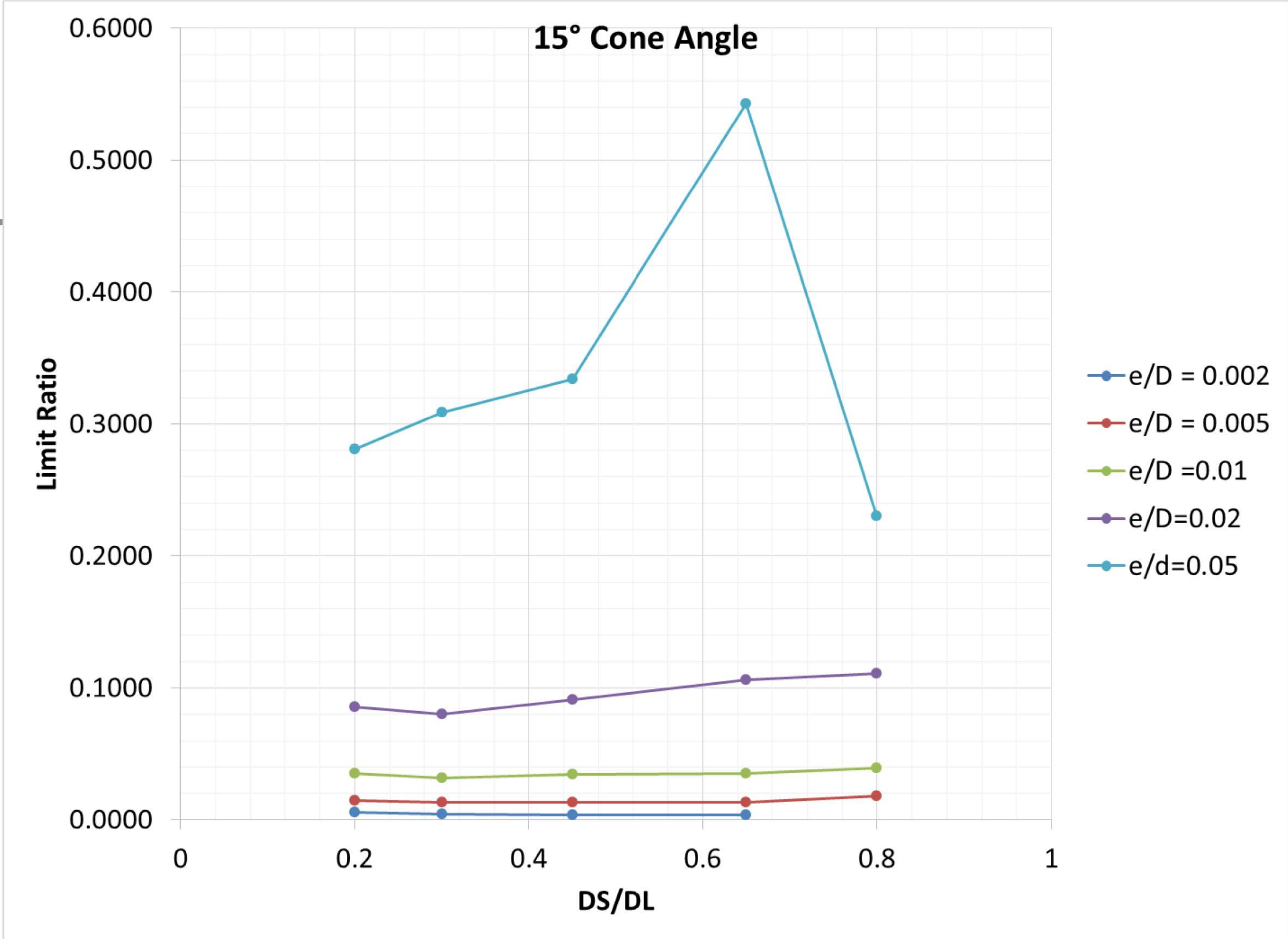
Pass/Fail Criterion

$$Proportion\ of\ Allowable\ Stress = \frac{FEA\ Result}{f}$$

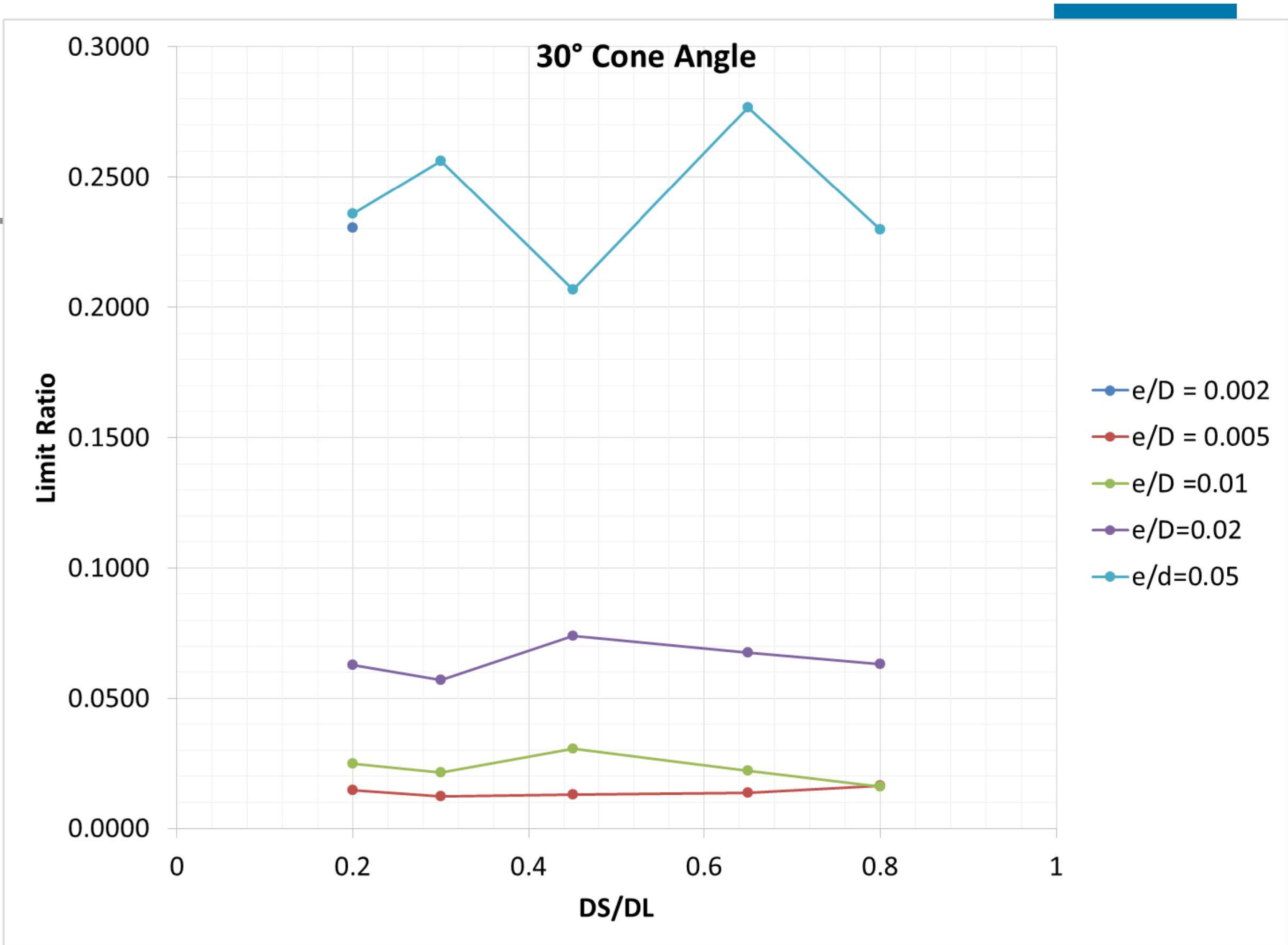
$$max\{-(Z_T + F_{\mathrm{PC}})\ ;\ -Z_{\mathrm{SS}}\ ;\ -Z_{\mathrm{LL}}\ ;\ -Z_{\mathrm{CS}}\ ;\ -Z_{\mathrm{CL}}\} \leq F_{\mathrm{RC}} \leq min\{(Z_T - F_{\mathrm{PC}})\ ;\ Z_{\mathrm{SS}}\ ;\ Z_{\mathrm{LL}}\ ;\ Z_{\mathrm{CS}}\ ;\ Z_{\mathrm{CL}}\}$$

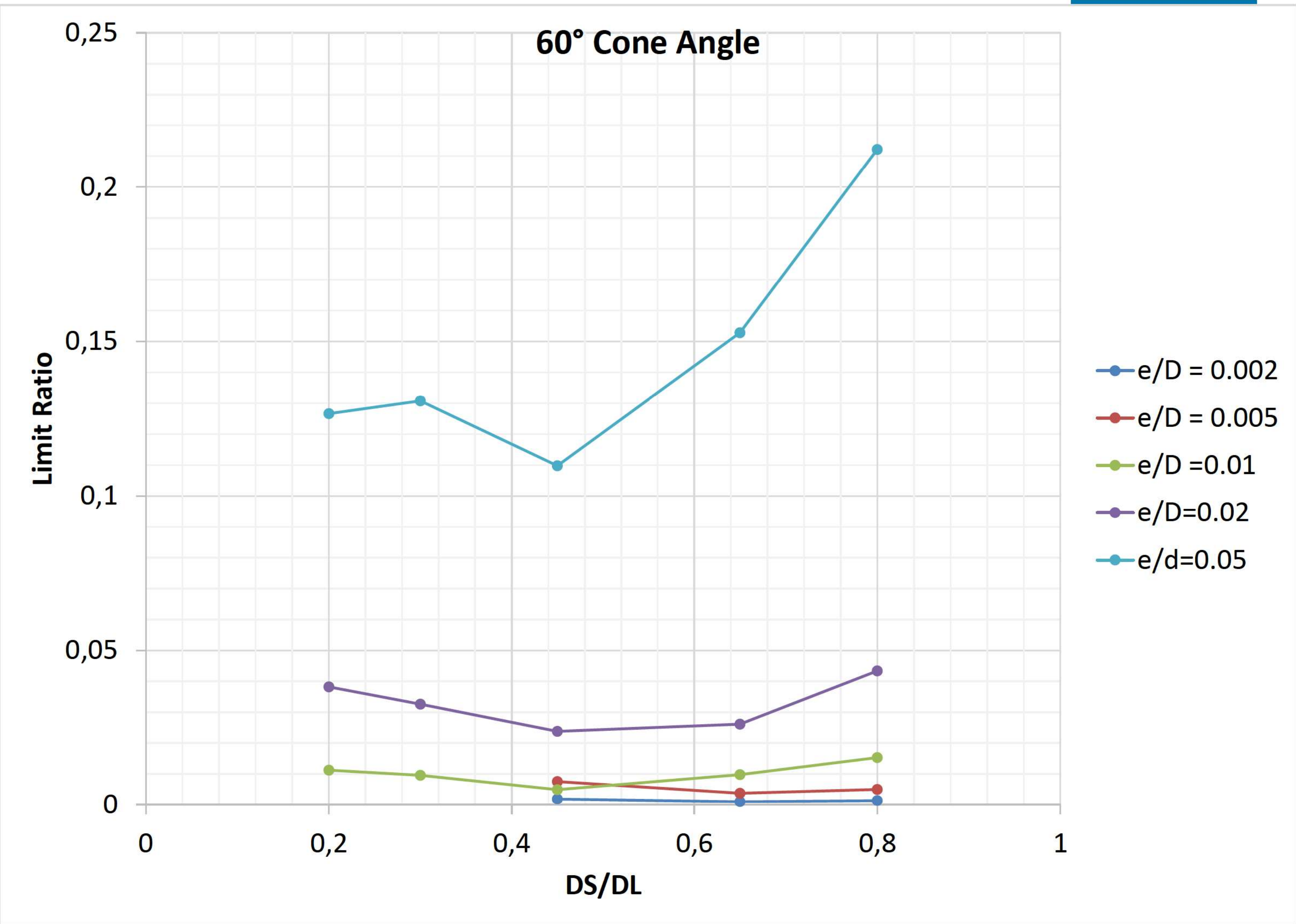
$$Proportion\ of\ Limit\ Load = \frac{F_{RC}}{Limit\ Load}$$

$$Limit\ Ratio = \frac{Proportion\ of\ Limit\ Load}{Proportion\ of\ Allowable\ Stress}$$



15° Cone Angle
Limit Ratio
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
0
0.2
0.4
0.6
0.8
1
DS/DL
e/D = 0.002
e/D = 0.005
e/D =0.01
e/D=0.02
e/d=0.05


30° Cone Angle
Limit Ratio
DS/DL
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
0
0.2
0.4
0.6
0.8
1
e/D = 0.002
e/D = 0.005
e/D =0.01
e/D=0.02
e/d=0.05



60° Cone Angle
0,25
0,2
0,15
0,1
0,05
0
Limit Ratio
0
0,2
0,4
0,6
0,8
1
DS/DL
e/D = 0.002
e/D = 0.005
e/D =0.01
e/D=0.02
e/d=0.05

Discussion & Conclusions

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- KM method has been implemented in Excel and FEA analysed
- There are modelling issues around the junctions cf. KM however for ‘regular vessels’ benchmark case is validated
- KM/FEA do not represent the junctions well – and excessively high stresses result (can be fixed – but not with KM)
- Some parameter ratios should be withdrawn as they represent extreme cases (e.g. 75^{o} case)
- Some thickness to diameter ratios also produce unrealistic relationships – excessively thick and thin configurations
- More work needed on representative parametric range
- Future limit analysis to be undertaken

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Thank You!

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