My Calculation

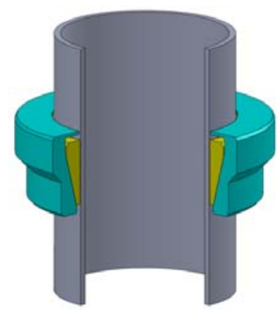
Engineering Calculation Sheet

Calculation No 006

Subject: Reinhold-Spiri formula derivation based on axisymmetric radial load on pipe lateral surface

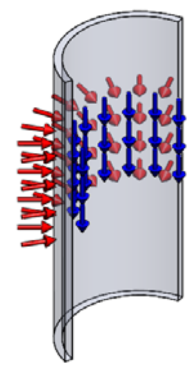
Prepared By: YUDHI   Date: 9-Oct-15

This calculation was conducted in order to verify Reinhold-Spiri formula as a slip crushing load (F_Z) based on axisymmetric wedge that generates axisymmetric radial load on pipe lateral surface. As the wedge slip bite on pipe, pipe shall be exposed to radial load. By using Lame equation for a thick wall cylinders, the axial and hoop stress on pipe ID can be estimated from radial stress acting on pipe OD. since radial stress as a function of axial load, the axial load at which VME stress at pipe ID reaches stress to cause pipe yielding can be determined.



Nomenclature

OD	Pipe outer diameter
ID	Pipe inner diameter
A_1	Pipe cross section area
A_L	Pipe lateral surface area around slip bite
Sy	Pipe yield material based on grade
F_A	Pipe axial load
F_R	Pipe radial load
L	Slip length
α	Slip angle
μ	Friction coefficient
S_a	Axial stress
$S_{r\,(o/i)}$	Radial stress (outer / inner)
S_h	Hoop stress
K	Tranverse factor from axial stress (S_a) to radial stress (S_r)
F_Z	Slip crushing load



Let

$S_{ro} = (K A_1 / A_L) S_a$ ___ see page 2 for transverse factor derivation

From Lame equation for thick wall cylinder (S_{ri} = 0 as radial stress on pipe ID vanish)

$$S_h = [(OD^2 + ID^2) / (OD^2 - ID^2)]S_{ri} - [2OD^2 / (OD^2 - ID^2)]S_{ro} \quad \text{\_\_\_ [1]}$$
$$= - [2OD^2 / (OD^2 - ID^2)]S_{ro}$$
$$= - [2OD^2 / (OD^2 - ID^2)][(K A_1 / A_L)S_a]$$

Apply VME stress equivalent on pipe ID.

$$S_y = \{[(S_a-S_{ri})^2 + (S_{ri} - S_h)^2 + (S_h - S_a)^2] / 2\}^{0.5}$$
$$= \{[(S_a)^2 + (S_h)^2 + (S_h - S_a)^2] / 2\}^{0.5}$$
$$= \{[(S_a)^2 + (- [2OD^2 / (OD^2 - ID^2)]S_{ro})^2 + (- [2OD^2 / (OD^2 - ID^2)]S_{ro} - S_a)^2] / 2\}^{0.5}$$
$$= \{[(S_a)^2 + [- [2OD^2 / (OD^2 - ID^2)](K A_1 / A_L) S_a]^2 + (- [2OD^2 / (OD^2 - ID^2)](K A_1 / A_L) S_a - S_a)^2] / 2\}^{0.5}$$
$$= \{[(S_a)^2 + [- [2OD^2 / (OD^2 - ID^2)](K A_1 / A_L) S_a]^2 + (- [2OD^2 / (OD^2 - ID^2)](K A_1 / A_L) S_a - S_a)^2] / 2\}^{0.5}$$
$$= \{S_a^2 [1 + [[2OD^2 / (OD^2 - ID^2)](K A_1 / A_L)]^2 + ([2OD^2 / (OD^2 - ID^2)][(K A_1 / A_L) + 1)^2] / 2\}^{0.5}$$
$$= S_a \{[1 + [[2OD^2 / (OD^2 - ID^2)](K A_1 / A_L)]^2 + ([1 + 2OD^2 / (OD^2 - ID^2)][(K A_1 / A_L))^2] / 2\}^{0.5}$$
$$= (F_z / A_1) \{[1 + [[2OD^2 / (OD^2 - ID^2)](K A_1 / A_L)]^2 + ([1 + 2OD^2 / (OD^2 - ID^2)][(K A_1 / A_L))^2] / 2\}^{0.5}$$

$$F_z = (S_y \,.\, A_1) \{2 / [1 + [[2OD^2 / (OD^2 - ID^2)](K A_1 / A_L)]^2 + ([1 + 2OD^2 / (OD^2 - ID^2)][(K A_1 / A_L))^2]\}^{0.5}$$

since

$$A_1 = \pi/4\,(OD^2 - ID^2)$$
$$A_L = \pi\, OD\, L$$

$$F_z = (S_y \,.\, A_1) \{2 / [1 + [[2OD^2 / (OD^2 - ID^2)](K A_1 / A_L)]^2 + ([1 + 2OD^2 / (OD^2 - ID^2)][(K A_1 / A_L))^2]\}^{0.5}$$
$$= (S_y \,.\, A_1) \{2 / [1 + [K\, OD / 2L)]^2 + ([1 + (K\, OD / 2L))^2]\}^{0.5} \quad \text{\_\_\_ [2]}$$

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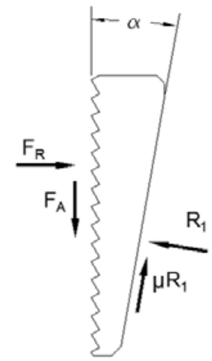
Transverse factor derivation



Free body diagram determination

$F_R + R_1 + \mu R_1 + F_A = 0$

$F_A = R_1.\sin\alpha + \mu R_1.\cos\alpha$ _ _ _ for $\Sigma F_Y = 0$

$R_1.\cos\alpha = F_R + \mu R_1.\sin\alpha$ _ _ _ for $\Sigma F_X = 0$

$F_R = R_1.\cos\alpha - \mu.R_1.\sin\alpha$

$= R_1.(\cos\alpha - \mu.\sin\alpha)$

$R_1 = F_R / (\cos\alpha - \mu.\sin\alpha)$

$F_A = R_1.\sin\alpha + (\mu.R_1).\cos\alpha$

$= R_1.(\sin\alpha + \mu.\cos\alpha)$

$= [F_R / (\cos\alpha - \mu.\sin\alpha)] (\sin\alpha + \mu.\cos\alpha)$

$= F_R [(\sin\alpha + \mu.\cos\alpha) / (\cos\alpha - \mu.\sin\alpha)]$

$= F_R / \cot(\alpha+\theta)$ _ _ _ [4] page 157

$F_R = F_A . \cot(\alpha+\theta)$ _ _ _ cot (α+θ) known as transverse factor

$F_R = F_A . K$ from pipe axial load to radial load [2]

Then

$S_{ro} . A_L = K. S_a . A_1$

$S_{ro} = (K A_1 / A_L) S_a$

Reference:

[1] SPE 13434 - Triaxial Load Capacity Diagrams Provide a New Approach to Casing and Tubing Design Analysis
[2] SPE 99074 - A Re-examination fo Drillpipe/Slip Mechanism
[3] SPE 80169 - Advanced Slip Crushing Consideration for Deepwater Drilling
[4] Machinery Handbook, 27TH Edition