ภาคผนวก ค

ตัวอย่างการใช้สมการแคทีนารีในการวิเคราะห์แรงจากการวางท่อตามมาตรฐาน

DNV-OS-F101

ค.1 บทนำ

ภาคผนวก ค ถูกจัดทำขึ้นเพื่อแสดงตัวอย่างการใช้สมการแคทีนารีในการวิเคราะห์แรงที่เกิดจากการวางท่อ เงื่อนไขของการยอมรับ (Acceptance criteria) ได้นำมาจากมาตรฐาน DNV-OS-F101 ตัวอย่างการคำนวณเป็นวิเคราะห์แรงจากการวางท่อ 8 นิ้ว API Spec 5L เกรด X52 ซึ่งมีค่า yield strength 358 MPa ในน้ำลึก 60 เมตร

ค.2 รายการคำนวณ

Input Data

Pipe nominal outside diameter	D	=	$0.229m$
		=	$8.626\ in$
Wall thickness during installation	t_2	=	$12.7\ mm$
		=	$0.5in$
Water depth	d	=	$1000\ mm$
Seawater density	p_w	=	$1025\,\frac{kg}{m^3}$
Steel density	P_{steel}	=	$7850\,\frac{kg}{m^3}$
Young's modulus for steel	E	=	$207 \cdot 10^3 M\ Pa$
		=	$3.002x10^4.\,ksi$
Poisson's ratio	v	=	0.3
SMYS of X52 steel	σ_{smys}	=	$52ksi$
		=	$358.527M\ Pa$
Specified minimum ultimate stress	σ_{ult}	=	$530M\ Pa$

		=	$76.87 \cdot ksi$
Installed ovalityin Sagbend	f_0	=	15%

When $f_0$cannot be more than 3% nor less than 0.5%

Applied tension in catenary	T	=	$150kN$

DNV partial safety factors

Material strength factor	α_u	=	0.96
Fabrication factor	α_{fab}	=	0.93
Safety class resistance	Y_{sc}	=	1.14
Functional load factor	Y_{sc}	=	1.14
Pressure load factor	Y_p	=	1.05
Conditional load factor	Y_c	=	1.0
Material resistance factor	Y_m	=	1.15

ค.3 วิธีคำนวณ

Pipeline parameters

Material resistance factor	Y_m	=	1.15
Inside diameter of pipe	D_i	=	$D - 2t_2$
		=	$193.7 \cdot mm$
Second moment of area	I	=	$\frac{\pi}{64}(D^4 - D_i^4)$

= $4.402\ x\ 10^{-3} m^2$

Pipe submerged weight

Cross sectional area of steel A_{steel} = $\frac{\pi}{4}(D^2 - D_i^2)$

= $8.235\ x\ 10^{-3} m^2$

Area of displaced water A_{water} = $\frac{\pi}{4} \cdot D^2$

= $0.038\ m^2$

Submerged weight of pipe

W = $(A_{steel} \cdot P_{steel} - A_{water} \cdot P_w) \cdot g$

= $254.965 \cdot \frac{N}{m}$

Catenary parameters at touchdown

Area of displaced water A_{water} = $\frac{\pi}{4} \cdot D^2$

Horizontal component of tension H = $T - w \cdot d$

= $134.702 \cdot kN$

Radius of bending at touchdown r_{bend} = $\frac{H}{w}$

= $528.315\ m$

Bending moment at touchdown Mb M_b = $\frac{E \cdot I}{r_{bend}}$

= $17.247 \cdot kN \cdot m$

Design bending moment M_d = $M_b \cdot Y_F \cdot Y_c$

= $20.696 \cdot kN \cdot m$

Seawater pressure at touchdown P_e = $P_w \cdot g \cdot d$

		=	$603.109 \cdot kPa$
End cap force	F_{ec}	=	$P_e \cdot \frac{\pi}{4} \cdot D^2$
		=	$22.739 \cdot kN$
Design net axial force	S_a	=	$(H - F_{ec}) \cdot Y_F \cdot Y_c$
		=	$134.356 \cdot kN$

DNV Local buckling

The system collapse is based on the pipe body material and shall fulfill the following criteria:

$$P_e \leq \frac{Pc}{1.1 \cdot Y_m \cdot Y_c}$$

$$(P_c - P_{el}) \cdot (P_c^2 - P_p^2) = P_c \cdot P_{el} \cdot P_p \cdot f_0 \cdot \frac{D}{t}$$

Characteristic elastic collapse pressure	P_{el}	=	$\frac{2 \cdot E \cdot \left(\frac{t_2}{D}\right)^3}{1-v^2}$
		=	$88.602 \cdot MPa$
Characteristic yield strength	f_y	=	$\sigma_{smys} \cdot \sigma_u$
		=	$344.186 \cdot MPa$
Plastic collapse pressure	P_p	=	$2 \cdot f_y \cdot \alpha_{fab} \cdot \frac{t_2}{D}$
		=	$37.108 \cdot MPa$
Tensile stress used in design	f_u	=	σ_{ult}
Local design pressure (ambient internal)	P_{ld}	=	$0 MPa$

Intermediate values for flow stress parameter

$$q_h = \left| \frac{\frac{P_{ld}-P_e}{2P_p} x \frac{2}{\sqrt{3}} if\ P_{ld} < P_{Pe}}{0\ otherwise} \right.$$

$$\beta = \left| \begin{array}{c} (0.4 + q_h) if \frac{D}{t_2} < 15 \\ \left[(0.4 + q_h) \left(60 - \frac{D}{t_2} \right) \right] if\ 15 \leq \frac{D}{t_2} \leq 60 \\ 0 otherwise \end{array} \right.$$

Flow stress parameter accounting for strain hardening.

$$\alpha_c = min \left| \begin{array}{c} (1-\beta) + \beta x \frac{f_u}{f_y} \\ 1.2 \end{array} \right| \begin{array}{c} q_h = -0.125 \\ \beta = 11.773 \\ \alpha_c = 1.2 \end{array}$$

Solution for pc is in the cubic equation above is as follow

$$b = -P_{el} c$$

$$= -\left(P_p^2 + P_p \cdot P_{el} \cdot f_0 \cdot \frac{D}{t_2} \right) d$$

$$= P_{el} \cdot P_P^2$$

$$u = \frac{1}{3} \left(\frac{-1}{3} \cdot b^2 + c \right) v$$

$$= \frac{1}{2} \left(\frac{2}{27} \cdot b^3 - \frac{1}{3} \cdot b \cdot c + d \right)$$

$$\emptyset = acos \left[\frac{-v}{\sqrt{(-u)}^3} \right] q$$

$$= -2\sqrt{-u} \cdot cos \left(\frac{\emptyset}{3} + \frac{60 \cdot \pi}{180} \right)$$

Characteristic resistance for collapse

$$P_c = q - \frac{b}{3}$$

$$= \quad 37.314 \ \cdot MPa$$

Characteristic plastic axial compression force resistance

$$S_p \quad = \quad -f_y \cdot \pi \cdot (D - t_2) \cdot t_2$$

$$= \quad 3.558x10^3 \ \cdot kN$$

Plastic moment resistance

$$M_p \quad = \quad f_y \cdot (D - t_2)^2 \cdot t_2$$

$$= \quad 233.726 \cdot kN \cdot m$$

Load controlled criteria

$$Check1 \quad = \quad p_e \leq \frac{P_c}{1.1 \cdot Y_m \cdot Y_c}$$

$$= \quad 1$$

$$Check2 \quad = \quad \left[Y_{sc} \cdot Y_m \left(\frac{M_d}{a_c \cdot M_p}\right) + Y_{sc} \cdot Y_m \ \cdot \left(\frac{S_a}{a_c \cdot S_p}\right)^2\right] + \left[Y_{sc} \cdot Y_m \cdot \left(\frac{P_e}{P_c}\right)\right] \leq 1$$

$$= \quad 1$$

$$P_e \quad = \quad 10.052 \cdot MP_a \frac{P_c}{1.1 \cdot y_m \cdot \ y_c}$$

$$= \quad 29.497 \cdot Mp_a$$

$$\left[Y_{sc} \ \cdot Y_m \left(\frac{M_d}{a_c \cdot M_p}\right) + \ Y_{sc} \cdot Y_m \left(\frac{S_a}{a_c \cdot S_p}\right)^2\right] + Y_{sc} \ \cdot Y_m \cdot \left[\frac{P_e}{P_c}\right]$$

$$= \quad 0.409$$

$Check_{overall}$ = $\left| \begin{matrix} "OK"\ Check1 = 1 \Delta Check2 = 1 \\ "Fail"\ otherwise \end{matrix} \right. Check_{overall}$

= $“OK”$

Propagation and arrestors

Propagation buckling pressure P_{pr} = $35 \cdot \frac{f_y \cdot \alpha_{fab}}{Y_m \cdot Y_{sc}} \cdot \left(\frac{t_2}{D}\right)^{2.5}$

= $8.676 \ \cdot MPa$

Propagation depth d_{pr} = $\frac{P_{pr}}{P_w \cdot g}$

= $8.63.159\ m$

Thickness of wall at arrestors t_{arr}: = $\left(\frac{P_e \cdot Y_m \cdot Y_{sc}}{35 \cdot f_y \cdot \alpha_{fab}}\right)^{0.4} \cdot D$

= $13.47\ m$