



SIDANG P3



JUDUL TUGAS AKHIR:

**ANALISIS ON-BOTTOM STABILITY DAN LOCAL
BUCKLING: STUDI KASUS PIPA BAWAH LAUT DARI
PLATFORM ULA KE MENUJU PLATFORM UW**

DOSEN PEMBIMBING:

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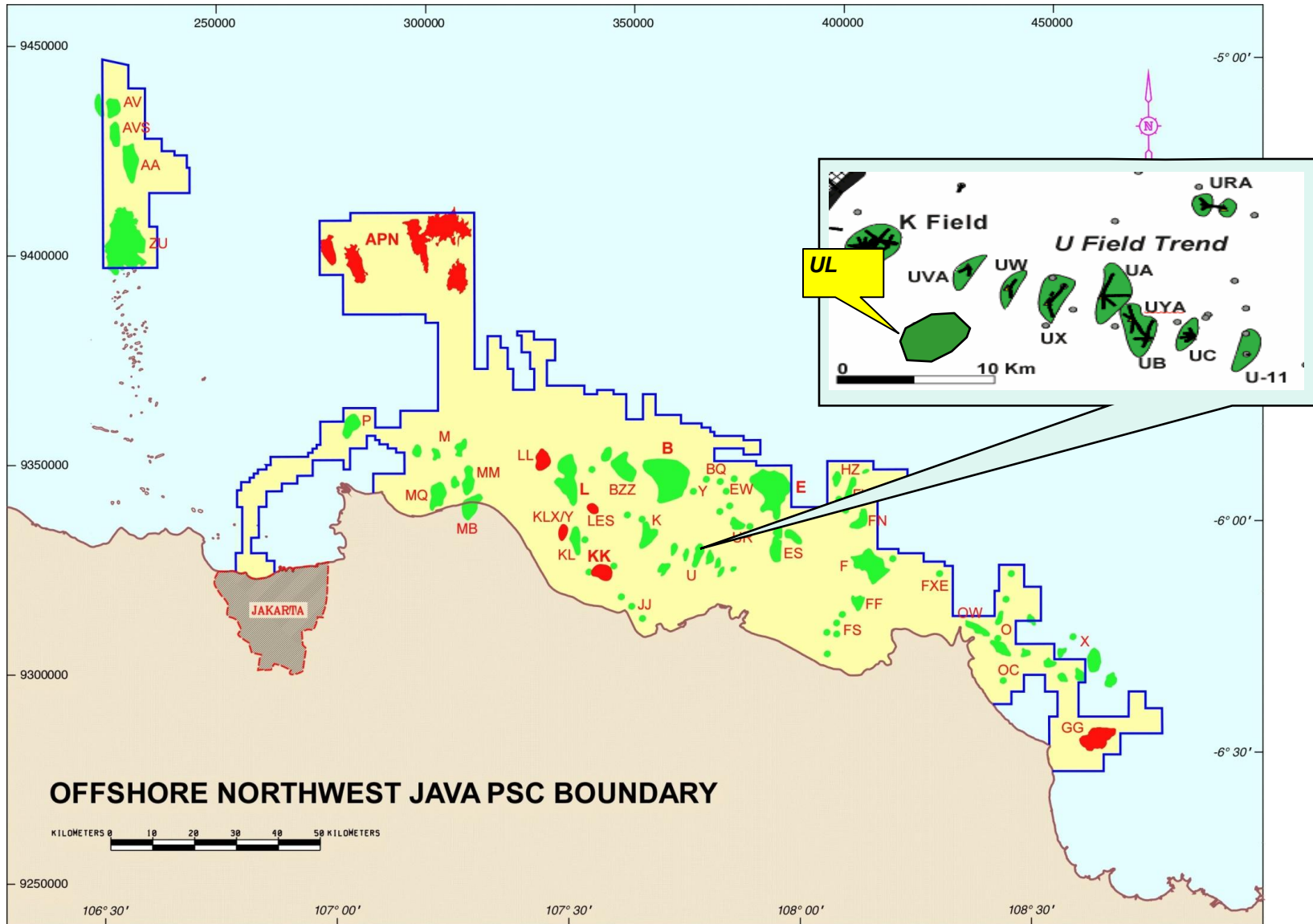
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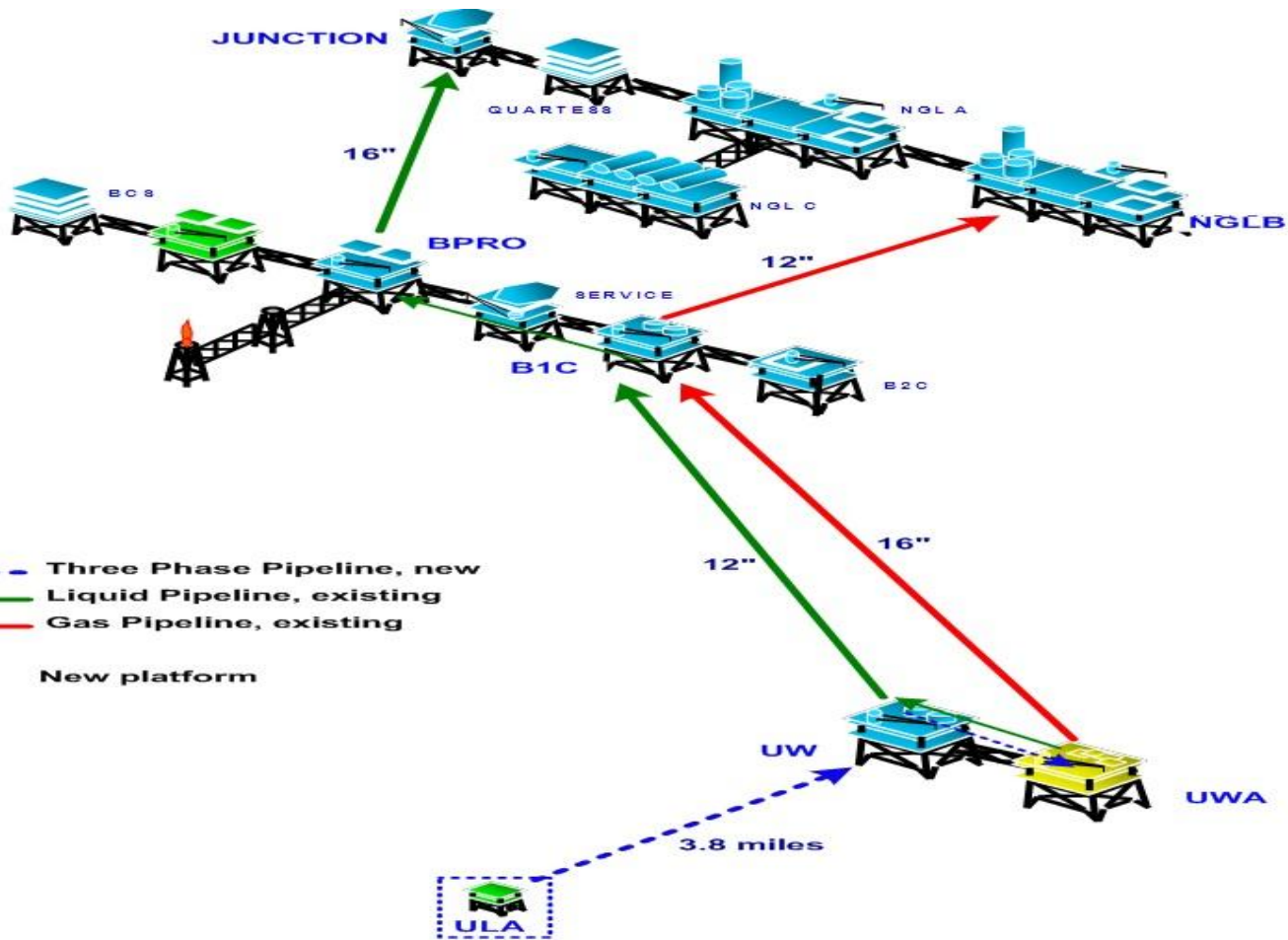
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LATAR BELAKANG

- PT. Pertamina Hulu Energi ONWJ memiliki jaringan pipa sepanjang 1900 km.
- Apabila pipa bawah laut mengalami kegagalan, akan berdampak besar pada kerugian ekonomi dan lingkungan.
- On-bottom stability dan local buckling pipa bawah laut merupakan aspek penting yang perlu dianalisis pada pipa bawah laut untuk menghindari kegagalan.

Peta Lokasi





RUMUSAN MASALAH

1. Berapa besar gaya eksternal yang bekerja pada pipa di dasar laut berdasarkan DnV?
2. Apakah pipa bawah laut memenuhi kriteria on-bottom stability berdasarkan DnV?
3. Berapa panjang maksimum free span agar tidak terjadi local buckling pada pipa bawah laut berdasarkan DnV?

TUJUAN PENELITIAN

1. Mengetahui besarnya gaya eksternal yang bekerja pada pipa bawah laut berdasarkan DnV.
2. Mengetahui apakah pipa bawah laut memenuhi kriteria on-bottom stability berdasarkan DnV.
3. Mengetahui panjang maksimum free span agar tidak terjadi local buckling berdasarkan DnV.

MANFAAT

Acuan dalam menghitung berat minimum pipa agar dapat stabil di dasar laut dan menghitung panjang maksimum free span .

BATASAN MASALAH

- Pipa bawah laut yang analisis adalah pada kondisi setelah instalasi (kosong) dan operasi (berisi fluida).
- Kondisi arus dalam keadaan *steady flow*.
- Pipa bawah laut dalam keadaan meletak bebas (tanpa anchor, matras, dll).
- Tidak ada *trenching*.
- Tidak ada absorpsi air pada *concrete*.

Tinjauan Pustaka

- Sampai tahun 1970-an, teori *Coulomb friction* merupakan satu-satunya cara untuk memperkirakan tahanan tanah terhadap perpindahan pipa bawah laut akibat beban hidrodinamis (Jeng *et al.*, 2013)
- Wagner *et al.* (1987) mengembangkan teori *Coulomb friction*.
- Verley *et al.* (1987) studi perbandingan pemodelan hidrodinamis di laboratorium dan di lapangan.

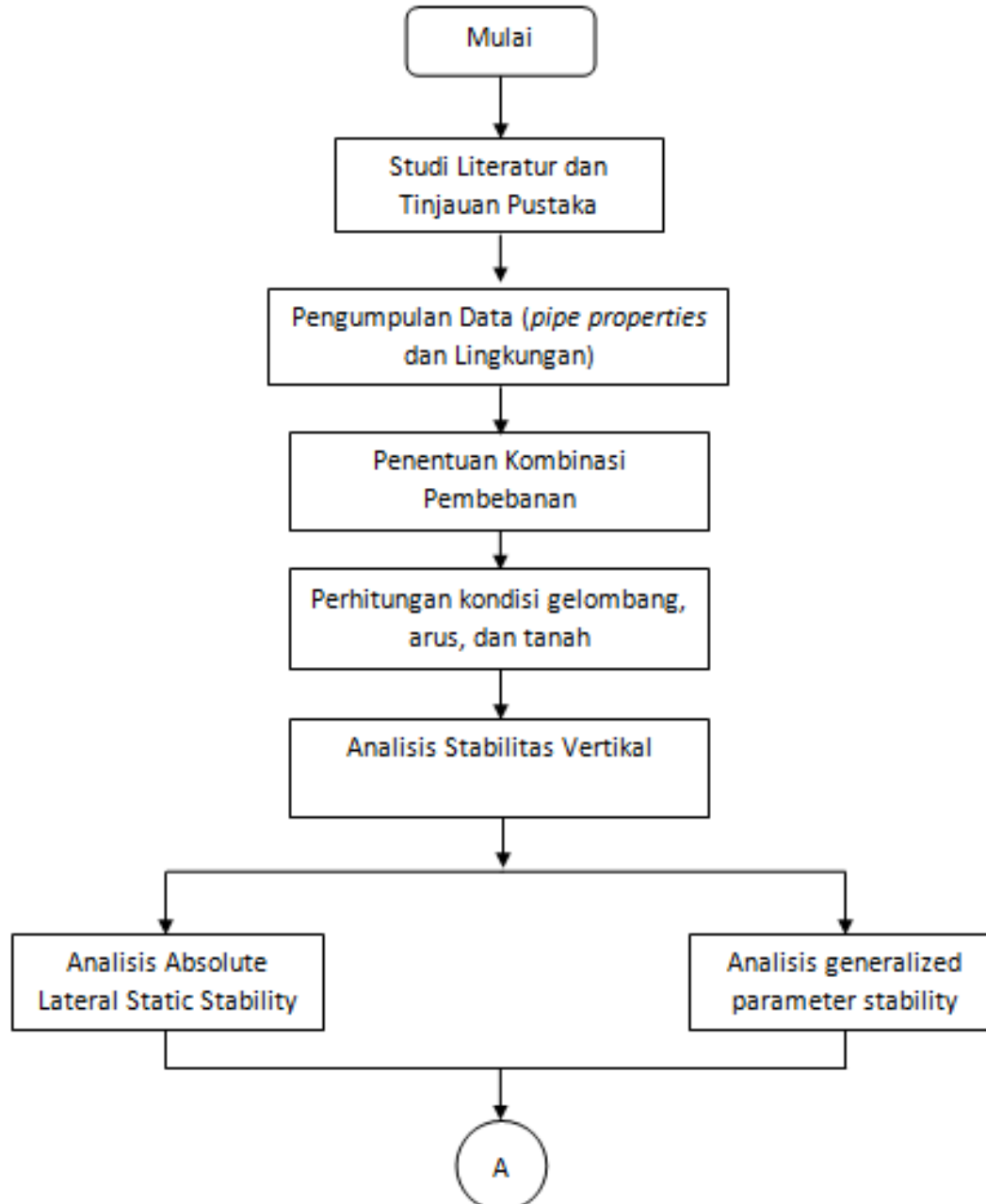
Lanjutan...

- Verley dan Sotberg (1992) menemukan formula *passive resistance*.
- DNV RP E305 (1988) diterbitkan untuk analisis *on-bottom stability*. *code* ini tidak memperhitungkan efek penetrasi pipa bawah laut ke dalam tanah
- DNV RP F109 (2007) diterbitkan untuk menggantikan DNV RP E305.

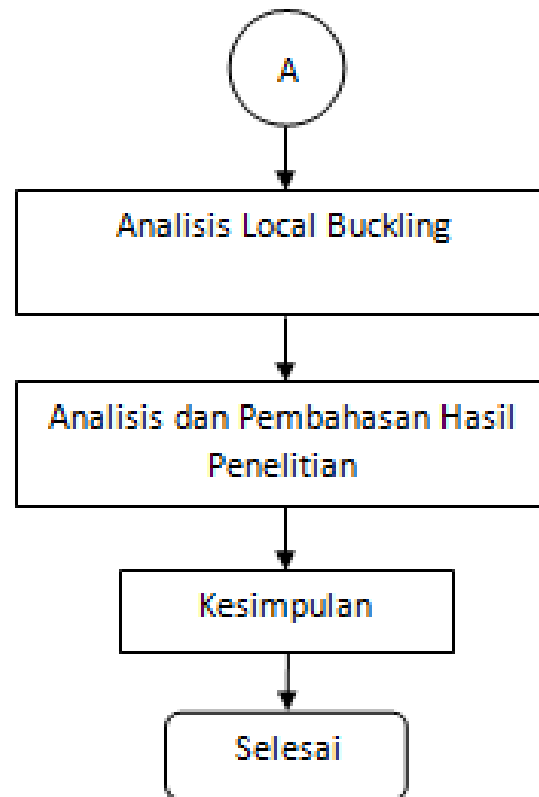
Lanjutan...

- Dong *et al* (2015) mengatakan *local buckling* adalah kegagalan yang sering terjadi pada free span.

METODE PENELITIAN



Lanjutan....



Data Pipa

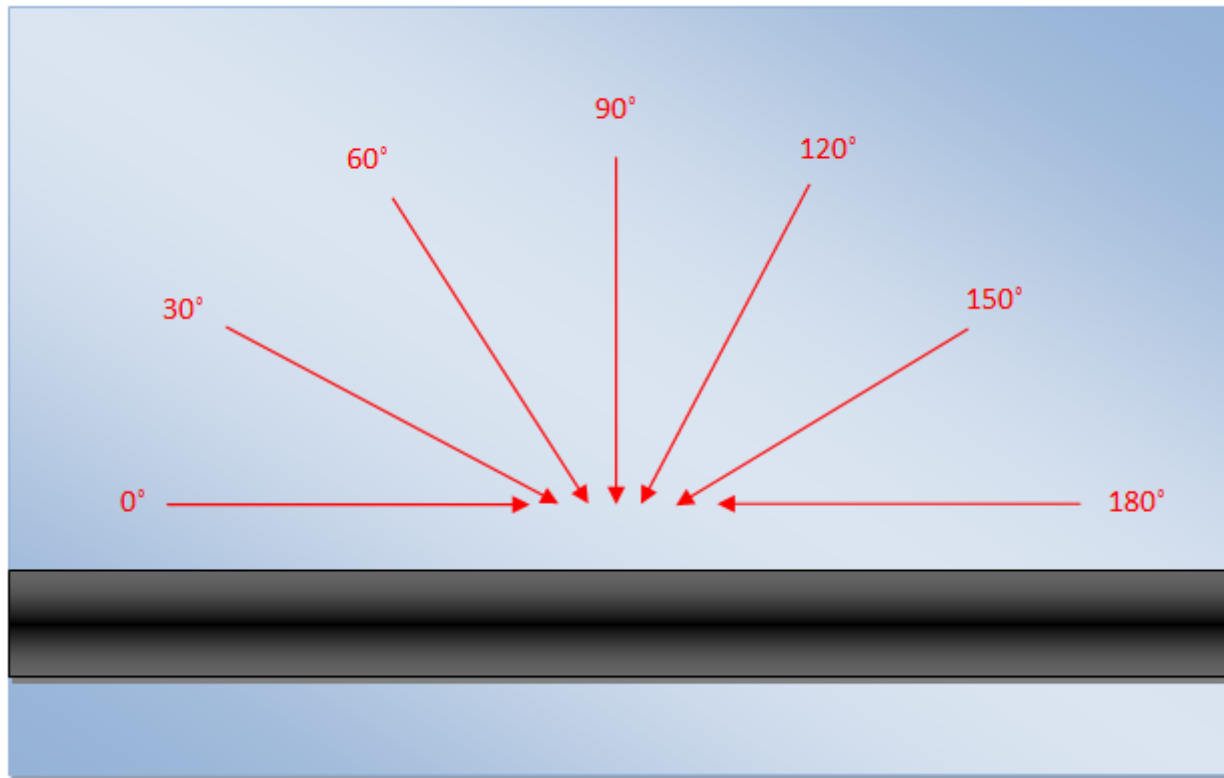
Deskripsi	Nilai	Satuan
Material	API 5L Grade X52MO PSL2 CS	
<i>Nominal Outer Diameter</i>	323	mm
<i>Wallthickness</i>	14,27	mm
<i>Corrosion Allowance</i>	3	mm
<i>Steel Density</i>	7850	Kg/m ³
<i>Content Density</i>	134	Kg/m ³
<i>External Corrosion Coating Thickness</i>	4	mm
<i>External Corrosion Coating Density</i>	1281	Kg/m ³
<i>Concrete Thickness</i>	38	mm
<i>Concrete Density</i>	3044	Kg/m ³
<i>Elastic Module of Steel</i>	2x10 ⁵	MPa
<i>Yield Strength</i>	360	MPa
<i>Tensile Strength</i>	440	MPa
<i>Operating Temperature</i>	44,4	°C
<i>Design Pressure</i>	1,01	MPa
<i>Effective Layer Tension</i>	230	MPa
<i>Thermal Expansion Coefficient</i>	11x10 ⁻⁶	-
<i>Poison Ratio</i>	0,3	-

Data Lingkungan

Parameter	Nilai			Satuan
	1 year	10 year	100 year	
<i>Significant wave height, Hs</i>	1,9	3,1	3,9	m
<i>Peak period, Ts</i>	6,5	7,6	8,8	s
<i>Current Velocity</i>	0,366	0,421	0,518	m/s
<i>Water depth</i>	22,6-26,8			m
<i>Storm Surge</i>	0,244			m
<i>Highest Astronomical Tide (HAT)</i>	1,158			m
<i>Highest Temperature of Sea Water</i>	30			°C
<i>Lowest Temperature of Sea Water</i>	22,2			°C

Deskripsi	Nilai	Satuan
Jenis tanah	<i>soft clay</i>	-
<i>Friction factor</i>	0,2	-
<i>Submerged weight</i>	18000	N/m ³
<i>Undrained Shear Strength</i>	6000	N/m ²

Model Pipa dan Arah Pembebanan



Penentuan Kombinasi Pembebanan

- Kondisi setelah instalasi (kosong)
Periode ulang 1 tahun gelombang dikombinasikan dengan periode ulang 10 tahun arus.
- Kondisi operasi (berisi fluida)
Periode ulang 10 tahun gelombang dikombinasikan dengan periode ulang 100 tahun arus.

Menghitung Kecepatan Arus Dasar Laut

- Menggunakan Spektrum JONSWAP yang ditransfer dengan transfer function G.

$$S_{\eta\eta}(\omega) = \alpha \cdot g^2 \cdot \omega^{-5} \cdot \exp\left[-\frac{5}{4}\left(\frac{\omega}{\omega_0}\right)^{-4}\right] \gamma \exp\left[-0,5\left(\frac{\omega - \omega_p}{\sigma \cdot \omega_p}\right)^2\right]$$

Peak enhancement factor (γ)

$$\phi = \frac{T_p}{\sqrt{H_s}} = \frac{6,5}{\sqrt{1,9}} = 4,7$$

$$\gamma = \exp(5,75 - 1,15\phi) = \exp(5,75 - 1,15 \cdot 4,7)$$

$$\gamma = 1,4$$

Konstanta Generalized Philips (α)

$$\alpha = \frac{5}{16} \cdot \frac{H_s^2 \cdot \omega_p^4}{g^2} \cdot (1 - 0,287 \cdot \ln \gamma); \omega_p = \frac{2\pi}{T_p} = \frac{2.3,14}{6,5} = 0,966 \text{ rad/s}$$

$$\alpha = \frac{5}{16} \cdot \frac{1,9^2 \cdot 0,966^4}{9,81^2} \cdot (1 - 0,287 \cdot 1,4)$$

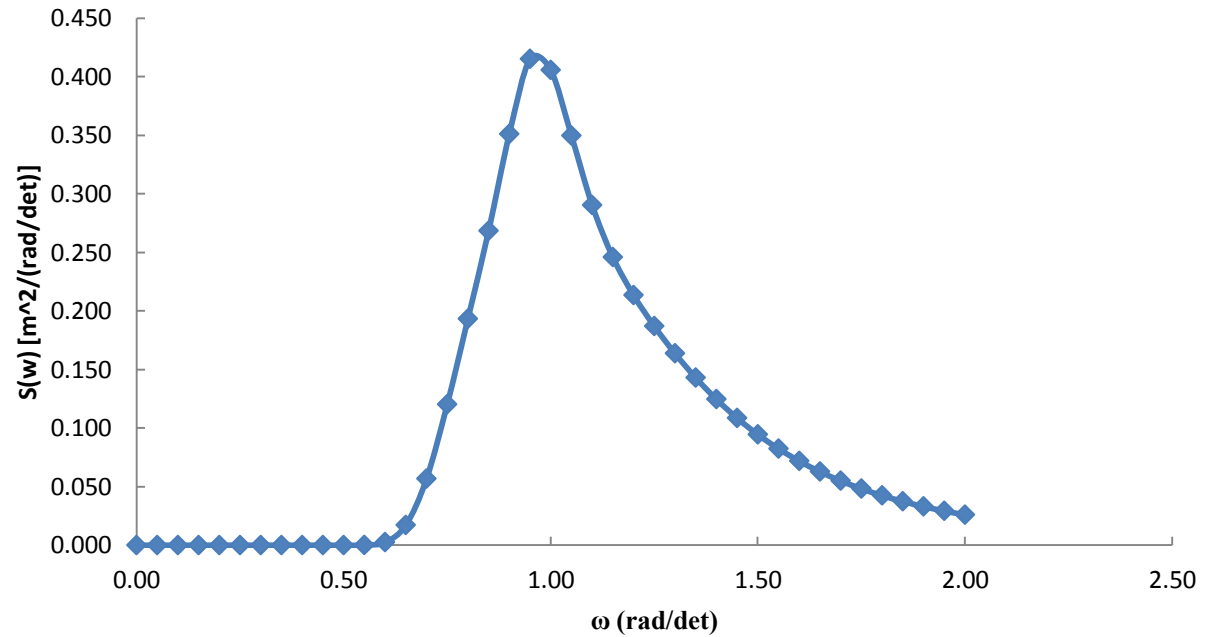
$$\alpha = 0,01$$

Spectral Parameter (σ)

$$\sigma = \begin{cases} 0,07 & \text{jika } \omega \leq \omega_p \\ 0,09 & \text{jika } \omega > \omega_p \end{cases}$$

ω	σ	$S(\omega)$
		$\gamma=2.2$
0.00	0.07	0.000
0.05	0.07	0.000
0.10	0.07	0.000
0.15	0.07	0.000
0.20	0.07	0.000
0.25	0.07	0.000
0.30	0.07	0.000
0.35	0.07	0.000
0.40	0.07	0.000
0.45	0.07	0.000
0.50	0.07	0.000
0.55	0.07	0.000
0.60	0.07	0.003
0.65	0.07	0.017
0.70	0.07	0.057
0.75	0.07	0.120
0.80	0.07	0.193
0.85	0.07	0.269
0.90	0.07	0.351
0.95	0.07	0.415
1.00	0.09	0.406
1.05	0.09	0.350
1.10	0.09	0.290
1.15	0.09	0.246
1.20	0.09	0.214
1.25	0.09	0.187
1.30	0.09	0.164
1.35	0.09	0.143
1.40	0.09	0.125
1.45	0.09	0.109
1.50	0.09	0.095
1.55	0.09	0.082
1.60	0.09	0.072
1.65	0.09	0.063
1.70	0.09	0.055
1.75	0.09	0.048
1.80	0.09	0.042
1.85	0.09	0.037
1.90	0.09	0.033
1.95	0.09	0.029
2.00	0.09	0.026

Spektrum Energi JONSWAP



Transfer Function (G)

$$G(\omega) = \frac{\omega}{\sinh(k \cdot d)}$$

K diperoleh dengan iterasi

$$\frac{\omega^2}{g} = k \cdot \tanh(k \cdot d)$$

Nilai $\tanh(k \cdot d)$ diasumsikan bernilai 1 untuk menentukan k awal yang akan digunakan pada iterasi, sehingga:

$$k_{awal} = \frac{0,966^2}{9,81}$$

$$k_{awal} = \frac{0,966^2}{9,81}$$

$$k_{awal} = 0,095$$

Iterasi k

No	k (asumsi)	kh	$\tanh(kh)$	k
1	0.0952	2.1505	0.9733	0.097768
2	0.0978	2.2096	0.9762	0.097473
3	0.0975	2.2029	0.9759	0.097505
4	0.0975	2.2036	0.9759	0.097502
5	0.0975	2.2035	0.9759	0.097502
6	0.0975	2.2035	0.9759	0.097502
7	0.0975	2.2035	0.9759	0.097502
8	0.0975	2.2035	0.9759	0.097502
9	0.0975	2.2035	0.9759	0.097502
10	0.0975	2.2035	0.9759	0.097502
11	0.0975	2.2035	0.9759	0.097502
12	0.0975	2.2035	0.9759	0.097502
13	0.0975	2.2035	0.9759	0.097502
14	0.0975	2.2035	0.9759	0.097502
15	0.0975	2.2035	0.9759	0.097502
16	0.0975	2.2035	0.9759	0.097502
17	0.0975	2.2035	0.9759	0.097502
18	0.0975	2.2035	0.9759	0.097502
19	0.0975	2.2035	0.9759	0.097502
20	0.0975	2.2035	0.9759	0.097502

Setelah iterasi maka diperoleh nilai k, yaitu 0,0975.
Selanjutnya nilai k dimasukkan ke transfer function G.

$$G(\omega) = \frac{\omega}{\sinh(k \cdot d)} \quad , \text{ dengan } \omega = 0 \text{ sampai dengan } 2$$

w	G(w)
0.00	0.0000
0.05	0.0112
0.10	0.0224
0.15	0.0335
0.20	0.0447
0.25	0.0559
0.30	0.0671
0.35	0.0782
0.40	0.0894
0.45	0.1006
0.50	0.1118
0.55	0.1230
0.60	0.1341
0.65	0.1453
0.70	0.1565
0.75	0.1677
0.80	0.1788
0.85	0.1900
0.90	0.2012
0.95	0.2124
1.00	0.2235
1.05	0.2347
1.10	0.2459
1.15	0.2571
1.20	0.2683
1.25	0.2794
1.30	0.2906
1.35	0.3018
1.40	0.3130
1.45	0.3241
1.50	0.3353
1.55	0.3465
1.60	0.3577
1.65	0.3689
1.70	0.3800
1.75	0.3912
1.80	0.4024
1.85	0.4136
1.90	0.4247
1.95	0.4359
2.00	0.4471

Setelah spektrum energi dan transfer function G diperoleh, nilainya akan digunakan untuk mencari spektrum energi partikel air di dasar laut akibat gelombang di permukaan laut menggunakan persamaan:

$$S_{UU}(\omega) = G^2(\omega) \cdot S_{\eta\eta}(\omega)$$

w	S(w)	G(w)	G^2(w)	Suu
0.00	0.000	0.0000	0.0000	0.0000
0.05	0.000	0.0112	0.0001	0.0000
0.10	0.000	0.0224	0.0005	0.0000
0.15	0.000	0.0335	0.0011	0.0000
0.20	0.000	0.0447	0.0020	0.0000
0.25	0.000	0.0559	0.0031	0.0000
0.30	0.000	0.0671	0.0045	0.0000
0.35	0.000	0.0782	0.0061	0.0000
0.40	0.000	0.0894	0.0080	0.0000
0.45	0.000	0.1006	0.0101	0.0000
0.50	0.000	0.1118	0.0125	0.0000
0.55	0.000	0.1230	0.0151	0.0000
0.60	0.003	0.1341	0.0180	0.0000
0.65	0.017	0.1453	0.0211	0.0004
0.70	0.057	0.1565	0.0245	0.0014
0.75	0.120	0.1677	0.0281	0.0034
0.80	0.193	0.1788	0.0320	0.0062
0.85	0.269	0.1900	0.0361	0.0097
0.90	0.351	0.2012	0.0405	0.0142
0.95	0.415	0.2124	0.0451	0.0187
1.00	0.406	0.2235	0.0500	0.0203
1.05	0.350	0.2347	0.0551	0.0193
1.10	0.290	0.2459	0.0605	0.0176
1.15	0.246	0.2571	0.0661	0.0163
1.20	0.214	0.2683	0.0720	0.0154
1.25	0.187	0.2794	0.0781	0.0146
1.30	0.164	0.2906	0.0845	0.0138
1.35	0.143	0.3018	0.0911	0.0130
1.40	0.125	0.3130	0.0979	0.0122
1.45	0.109	0.3241	0.1051	0.0114

w	S(w)	G(w)	G ² (w)	Suu	FS	m ₀	m ₁	m ₂	m ₄
0.00	0.000	0.0000	0.0000	0.0000	1	0.000	0.000	0.000	0.000
0.05	0.000	0.0112	0.0001	0.0000	4	0.000	0.000	0.000	0.000
0.10	0.000	0.0224	0.0005	0.0000	2	0.000	0.000	0.000	0.000
0.15	0.000	0.0335	0.0011	0.0000	4	0.000	0.000	0.000	0.000
0.20	0.000	0.0447	0.0020	0.0000	2	0.000	0.000	0.000	0.000
0.25	0.000	0.0559	0.0031	0.0000	4	0.000	0.000	0.000	0.000
0.30	0.000	0.0671	0.0045	0.0000	2	0.000	0.000	0.000	0.000
0.35	0.000	0.0782	0.0061	0.0000	4	0.000	0.000	0.000	0.000
0.40	0.000	0.0894	0.0080	0.0000	2	0.000	0.000	0.000	0.000
0.45	0.000	0.1006	0.0101	0.0000	4	0.000	0.000	0.000	0.000
0.50	0.000	0.1118	0.0125	0.0000	2	0.000	0.000	0.000	0.000
0.55	0.000	0.1230	0.0151	0.0000	4	0.000	0.000	0.000	0.000
0.60	0.003	0.1341	0.0180	0.0000	2	0.000	0.000	0.000	0.000
0.65	0.017	0.1453	0.0211	0.0004	4	0.001	0.001	0.001	0.000
0.70	0.057	0.1565	0.0245	0.0014	2	0.003	0.002	0.001	0.001
0.75	0.120	0.1677	0.0281	0.0034	4	0.014	0.010	0.008	0.004
0.80	0.193	0.1788	0.0320	0.0062	2	0.012	0.010	0.008	0.005
0.85	0.269	0.1900	0.0361	0.0097	4	0.039	0.033	0.028	0.020
0.90	0.351	0.2012	0.0405	0.0142	2	0.028	0.026	0.023	0.019
0.95	0.415	0.2124	0.0451	0.0187	4	0.075	0.071	0.068	0.061
1.00	0.406	0.2235	0.0500	0.0203	2	0.041	0.041	0.041	0.041
1.05	0.350	0.2347	0.0551	0.0193	4	0.077	0.081	0.085	0.094
1.10	0.290	0.2459	0.0605	0.0176	2	0.035	0.039	0.043	0.051
1.15	0.246	0.2571	0.0661	0.0163	4	0.065	0.075	0.086	0.114
1.20	0.214	0.2683	0.0720	0.0154	2	0.031	0.037	0.044	0.064
1.25	0.187	0.2794	0.0781	0.0146	4	0.058	0.073	0.091	0.143
1.30	0.164	0.2906	0.0845	0.0138	2	0.028	0.036	0.047	0.079
1.35	0.143	0.3018	0.0911	0.0130	4	0.052	0.070	0.095	0.173
1.40	0.125	0.3130	0.0979	0.0122	2	0.024	0.034	0.048	0.094
1.45	0.109	0.3241	0.1051	0.0114	4	0.046	0.066	0.096	0.202
1.50	0.095	0.3353	0.1124	0.0106	2	0.021	0.032	0.048	0.108
1.55	0.082	0.3465	0.1201	0.0099	4	0.040	0.061	0.095	0.229
1.60	0.072	0.3577	0.1279	0.0092	2	0.018	0.029	0.047	0.121

$$M_0 = \frac{1}{3} \cdot \Delta\omega \cdot \Sigma m_0$$

$$M_0 = \frac{1}{3} \cdot 0,05 \cdot 0,867$$

$$M_0 = 0,0145$$

$$M_1 = \frac{1}{3} \cdot \Delta\omega \cdot \Sigma m_1$$

$$M_1 = \frac{1}{3} \cdot 0,05 \cdot 1,111$$

$$M_1 = 0,0185$$

$$M_2 = \frac{1}{3} \cdot \Delta\omega \cdot \Sigma m_2$$

$$M_2 = \frac{1}{3} \cdot 0,05 \cdot 1,512$$

$$M_2 = 0,0252$$

$$M_4 = \frac{1}{3} \cdot \Delta\omega \cdot \Sigma m_4$$

$$M_4 = \frac{1}{3} \cdot 0,05 \cdot 3,29$$

$$M_4 = 0,0548$$

Kecepatan rata-rata di dasar laut adalah:

$$U_s = 2\sqrt{M_0}$$

$$U_s = 2\sqrt{0,0145}$$

$$U_s = 0,240 \text{ m/s}$$

Periode gelombang yang bekerja pada pipa adalah:

$$T_u = 2\pi \sqrt{\frac{M_0}{M_2}}$$

$$T_u = 2\pi \sqrt{\frac{0,0145}{0,0252}}$$

$$T_u = 4,755 \text{ detik}$$

Single oscillation velocity (kecepatan ekstrim) di dasar laut didapatkan menggunakan persamaan:

$$k_U = \frac{U^*}{U_s} = \frac{1}{2} \cdot \left(\sqrt{2 \cdot \ln \tau} + \frac{0,5772}{\sqrt{2 \cdot \ln \tau}} \right)$$

dengan, $\tau = T/T_u$

$$\tau = 3 \cdot 3600 / 4,755$$

$$\tau = 2271$$

$$k_U = \frac{U^*}{0,473} = \frac{1}{2} \cdot \left(\sqrt{2 \cdot \ln (2271)} + \frac{0,5772}{\sqrt{2 \cdot \ln (2271)}} \right) = 2,039$$

$$U^* = 0,490 \text{ m/s}$$

Periode gelombang pada kondisi ekstrim dihitung dengan persamaan:

$$k_T = \frac{T^*}{T_u} = \begin{cases} k_t - 5 \cdot (k_t - 1) \cdot T_n/T_u & \text{untuk } T_n/T_u \leq 0,2 \\ 1 & \text{untuk } T_n/T_u > 0,2 \end{cases}$$

$$T_n/T_u = \frac{\sqrt{d/g}}{T_u} = \frac{\sqrt{22.6/9,81}}{4,755} = 0,319$$

Maka,

$$1 = \frac{T^*}{T_u}$$

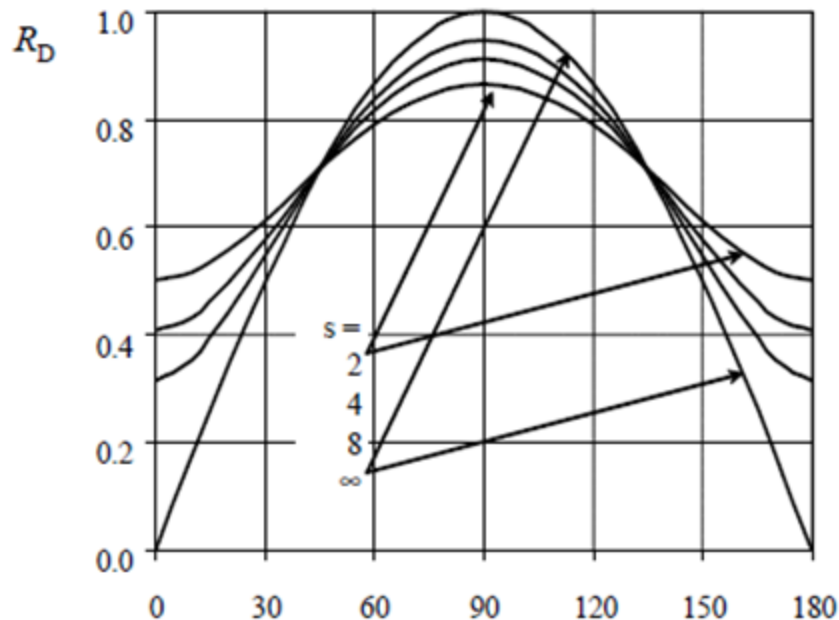
$$T^* = T_u = 4,755 \text{ detik}$$

Kecepatan Akibat Gelombang

Kecepatan partikel gelombang pada berbagai arah.

$$U_w = R_D \cdot U_{w\theta}$$

Nilai R_D didapatkan dari grafik faktor reduksi.



θ	R_D	U_w^*
0	0.41	0.201
30	0.58	0.284
60	0.81	0.397
90	1	0.490
120	0.81	0.397
150	0.58	0.284
180	0.41	0.201

Kecepatan arus:

$$V(z) = V(z_r) \cdot \left(\frac{\ln(z+z_0)}{\ln(z_r+z_0)} \right) \cdot \sin \theta_c$$

θ	v
0	0.000
30	0.220
60	0.382
90	0.441
120	0.382
150	0.220
180	0.000

Berat Terendam Pipa

a)	Steel Weight			
	$W_{st} =$	1065,298	N/m	
b)	Coating 1 weight			
	$W_{cs1} =$	37,470	N/m	
c)	Concrete weight			
	$W_{conc} =$	1313,053	N/m	
	Pipe Weight on Air =	2416	N/m	
	Pipe Bouyancy =	1497	N/m	
	Pipe Submerged Weight =	918	N/m	

1. Stabilitas Vertikal

Berdasarkan DnV RP F109 kriteria stabilitas vertikal pipa bawah laut adalah:

$$\gamma_m \frac{b}{w_s + b} \leq 1$$

Dengan $\gamma_m = 1,1$ dan $b = 1497 \text{ N/m}$, maka

$$1,1 \frac{1497}{w_s + 1497} \leq 1$$

$$w_{s, \min} = 150 \text{ N/m}$$

- Kondisi Instalasi
 $w_s > w_{s, \min}$
 $918 \text{ N/m} > 150 \text{ N/m}$ **Memenuhi**
- Kondisi Operasi
 $w_s > w_{s, \min}$
 $1008 \text{ N/m} > 150 \text{ N/m}$ **Memenuhi**

2. Stabilitas Lateral

- *Absolute Lateral Static*

Desain kriteria metode *absolute stability* adalah:

$$\gamma_{SC} \cdot \frac{F_Y^* + \mu \cdot F_Z^*}{\mu \cdot W_s + F_R} \leq 1,0$$

$$F_Y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Y^* (U^* + V^*)^2$$

$$F_Z^* = r_{tot,z} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Z^* (U^* + V^*)^2$$

Mencari Koefisien Reduksi

$$F_Y^* = r_{tot,y} \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Y^* (U^* + V^*)^2$$

$$F_Z^* = r_{tot,z} \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Z^* (U^* + V^*)^2$$

- Reduksi beban karena permeable seabed
 $R_{perm,z}=0,7$
- Reduksi beban karena penetrasi pipa ke tanah

$$r_{pen,y} = 1,0 - 1,4 \cdot \frac{z_p}{D} \geq 0,3$$

$$r_{pen,z} = 1,0 - 1,3 \cdot \left(\frac{z_p}{D} - 0,1 \right)$$

dengan,

$$\frac{z_{pi}}{D} = 0,0071 \cdot \left(\frac{G_c^{0,3}}{\kappa_c} \right)^{3,2} + 0,062 \cdot \left(\frac{G_c^{0,3}}{\kappa_c} \right)^{0,7}$$

dengan,

$$\kappa_c = \frac{s_u \cdot D}{w_s - F_z} = \frac{6000 \cdot 0,407}{1008} = 2,422$$

dan

$$G_c = \frac{6000}{0,407 \cdot 18000} = 0,81$$

Maka,

Z_{pi} = 0,01 meter

Maka,

$$r_{pen,y} = 1,0 - 1,4 \cdot \frac{0,01}{0,407}$$

$$r_{pen,y} = 0,96$$

$$r_{pen,z} = 1,0 - 1,3 \cdot \left(\frac{0,011}{0,407} - 0,1 \right)$$

$$r_{pen,z} = 1,09$$

r total:

$$r_{total,y} = 0,96$$

$$\begin{aligned} r_{total,z} &= r_{pen,z} \cdot r_{perm,z} \\ &= 1,09 \cdot 0,7 \\ &= 0,76 \end{aligned}$$

$$F_Y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Y^* (U^* + V^*)^2$$

$$F_Z^* = r_{tot,z} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Z^* (U^* + V^*)^2$$

Mencari koefisien CY^* dan CZ^*

Keulegan-Carpenter Number adalah:

$$K^* = \frac{U_s^* \cdot T_U^*}{D}$$

Dengan $T_U^* = 5.329$ dan $D = 0.407$ m, maka K^* :

θ	U_w^*	K^*
0	0.490	6.42
30	0.693	9.08
60	0.968	12.68
90	1.195	15.65
120	0.968	12.68
150	0.693	9.08
180	0.490	6.42

Mencari koefisien CY^* dan CZ^*

Rasio kecepatan arus dan gelombang adalah:

$$M^* = \frac{V^*}{U^*}$$

θ	U_w^*	V	M^*
0	0.490	0.000	0.0
30	0.693	0.220	0.3
60	0.968	0.382	0.4
90	1.195	0.441	0.4
120	0.968	0.382	0.4
150	0.693	0.220	0.3
180	0.490	0.000	0.0

Mencari koefisien CY^* dan CZ^*

θ	M^*	K^*
0	0.0	6.42
30	0.3	9.08
60	0.4	12.68
90	0.4	15.65
120	0.4	12.68
150	0.3	9.08
180	0.0	6.42

Tabel 3.3: Koefisien beban puncak horizontal

C_T^*		K^*										
		2.5	5	10	20	30	40	50	60	70	100	≥ 140
M^*	0.0	13.0	6.80	4.55	3.33	2.72	2.40	2.15	1.95	1.80	1.52	1.30
	0.1	10.7	5.76	3.72	2.72	2.20	1.90	1.71	1.58	1.49	1.33	1.22
	0.2	9.02	5.00	3.15	2.30	1.85	1.58	1.42	1.33	1.27	1.18	1.14
	0.3	7.64	4.32	2.79	2.01	1.63	1.44	1.33	1.26	1.21	1.14	1.09
	0.4	6.63	3.80	2.51	1.78	1.46	1.32	1.25	1.19	1.16	1.10	1.05
	0.6	5.07	3.30	2.27	1.71	1.43	1.34	1.29	1.24	1.18	1.08	1.00
	0.8	4.01	2.70	2.01	1.57	1.44	1.37	1.31	1.24	1.17	1.05	1.00
	1.0	3.25	2.30	1.75	1.49	1.40	1.34	1.27	1.20	1.13	1.01	1.00
	2.0	1.52	1.50	1.45	1.39	1.34	1.20	1.08	1.03	1.00	1.00	1.00
	5.0	1.11	1.10	1.07	1.06	1.04	1.01	1.00	1.00	1.00	1.00	1.00
	10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Tabel 3.4: Koefisien beban puncak vertikal

C_Z^*		K^*										
		≤ 2.5	5	10	20	30	40	50	60	70	100	≥ 140
M^*	0.0	5.00	5.00	4.85	3.21	2.55	2.26	2.01	1.81	1.63	1.26	1.05
	0.1	3.87	4.08	4.23	2.87	2.15	1.77	1.55	1.41	1.31	1.11	0.97
	0.2	3.16	3.45	3.74	2.60	1.86	1.45	1.26	1.16	1.09	1.00	0.90
	0.3	3.01	3.25	3.53	2.14	1.52	1.26	1.10	1.01	0.99	0.95	0.90
	0.4	2.87	3.08	3.35	1.82	1.29	1.11	0.98	0.90	0.90	0.90	0.90
	0.6	2.21	2.36	2.59	1.59	1.20	1.03	0.92	0.90	0.90	0.90	0.90
	0.8	1.53	1.61	1.80	1.18	1.05	0.97	0.92	0.90	0.90	0.90	0.90
	1.0	1.05	1.13	1.28	1.12	0.99	0.91	0.90	0.90	0.90	0.90	0.90
	2.0	0.96	1.03	1.05	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	5.0	0.91	0.92	0.93	0.91	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	10	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

θ	CY^*	CZ^*
0	6.16	4.96
30	3.07	3.48
60	2.31	2.94
90	2.1	2.49
120	2.31	2.94
150	3.07	3.48
180	6.16	4.96

Beban Hidrodinamis

Beban maksimum arah horizontal dan vertikal adalah:

$$F_Y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Y^* (U^* + V^*)^2$$

$$F_Z^* = r_{tot,z} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Z^* (U^* + V^*)^2$$

θ	FY*	FZ*
0	295	189
30	510	461
60	838	851
90	1119	1058
120	838	851
150	510	461
180	295	189

Soil Passive Resistance

Tahanan pasif untuk tanah lempung adalah:

$$\frac{F_R}{F_C} = \frac{4,1 \cdot \kappa_c}{G_c^{0,39}} \cdot \left(\frac{z_p}{D}\right)^{1,31}$$

$$\frac{F_R}{918} = \frac{4,1 \cdot 2,65}{0,81^{0,39}} \cdot \left(\frac{0,011}{0,407}\right)^{1,31}$$

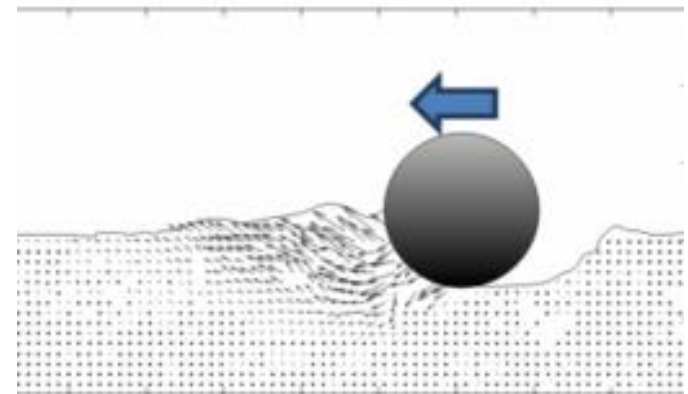
$$F_R = 110,64 \text{ N/m}$$

Coulomb Friction

$$CF = \mu \cdot W_s$$

$$= 0,2 \cdot 918$$

$$= 184 \text{ N/m}$$



Hasil Analisis Absolute Lateral Stability

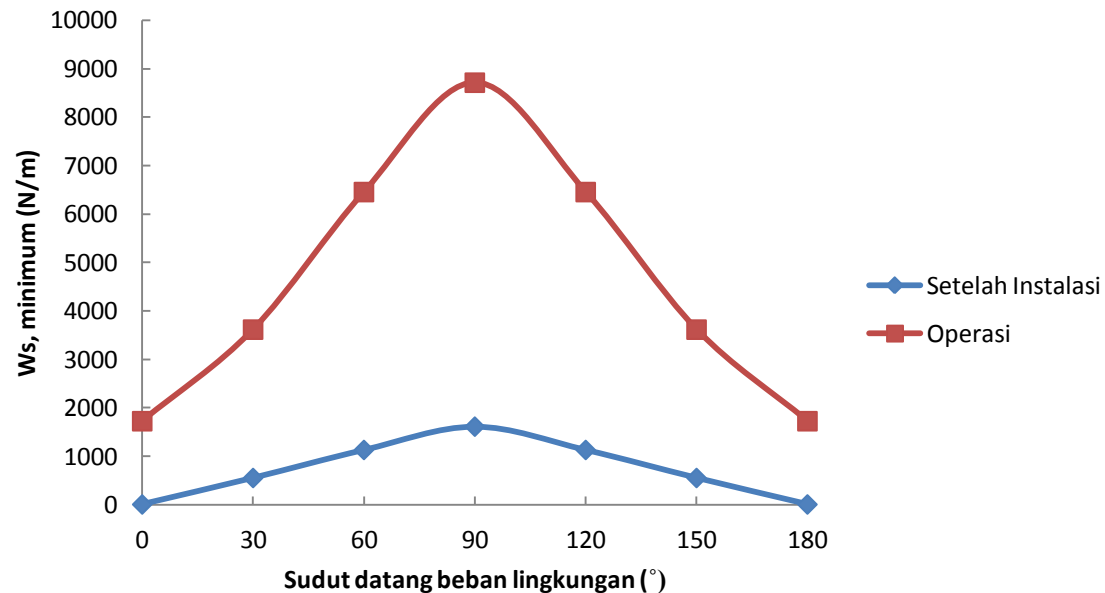
Desain kriteria metode *absolute stability* adalah:

$$\gamma_{SC} \cdot \frac{F_Y^* + \mu \cdot F_Z^*}{\mu \cdot W_s + F_R} \leq 1,0$$

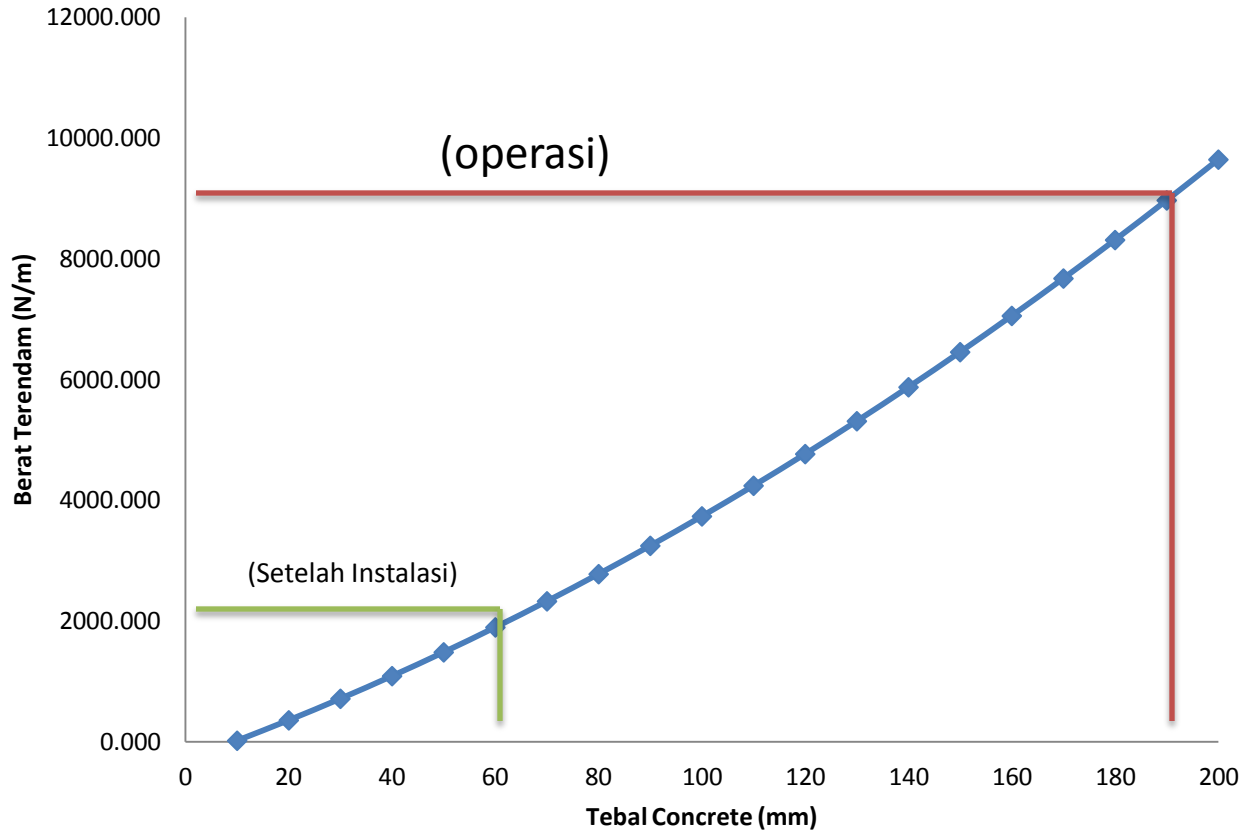
θ	$W_{s,min}$ (N/m) (Setelah Instalasi)	$W_{s,min}$ (N/m) (Operasi)
0	4	1722
30	550	3612
60	1129	6452
90	1610	8710
120	1129	6452
150	550	3612
180	4	1722

Berat Terendam Aktual= 918 N/m

Berat Terendam Minimum (W_s , min)



Berat Terendam VS Tebal Concrete



- Generalized Parameter Stability

1. Kondisi Setelah Instalasi

θ	Uw	V	M
0	0.241953	0	0.0
30	0.342274	0.220313	1.6
60	0.478004	0.381594	2.0
90	0.590128	0.440626	1.8
120	0.478004	0.381594	2.0
150	0.342274	0.220313	1.6
180	0.241953	0	0.0

$$\frac{L_{10}}{(2+M)^2} = \begin{cases} C_1 + \frac{C_2}{K^{C_3}} & \text{for } K \geq K_b \\ C_1 + \frac{C_2}{K_b^{C_3}} & \text{for } K < K_b \end{cases}$$

Table A-4 Parameters for calculating minimum weight, $L_{10}/(2+M)^2$, for pipe on clay, $G_c = 0.556$

$G_c = 0.556$								
M	$N \leq 0.003$				$0.006 \leq N \leq 0.024$			
	C_1	C_2	C_3	K_b	C_1	C_2	C_3	K_b
≤ 0.2	1.4	3	0.5	15	0.0	8	0.5	10
0.4	0.5	6	0.5	5	0.3	6	0.5	5
0.5	0.5	6	0.5	5	0.3	6	0.5	5
0.6	0.5	6	0.5	5	0.3	6	0.5	5
0.8	1.1	4	0.5	5	0.4	7	0.5	5
1.0	1.3	4	0.5	10	0.4	7	0.5	5
1.5	1.2	7	0.5	10	0.8	6	0.5	10
2.0	1.2	7	0.5	10	0.8	6	0.5	10
4.0	1.2	7	0.5	10	0.8	6	0.5	10
≥ 10	1.4	6	0.5	10	0.8	6	0.5	10

θ	M	N	K_b	c_1	c_2	c_3	L
0	0.0	0.005187	5	0	8	0.5	3.577709
30	1.6	0.007337	10	0.8	6	0.5	3.483282
60	2.0	0.010247	10	0.8	6	0.5	3.483282
90	1.8	0.01265	10	0.8	6	0.5	3.483282
120	2.0	0.010247	10	0.8	6	0.5	3.483282
150	1.6	0.007337	10	0.8	6	0.5	3.483282
180	0.0	0.005187	5	0	8	0.5	3.577709

Kondisi setelah instalasi

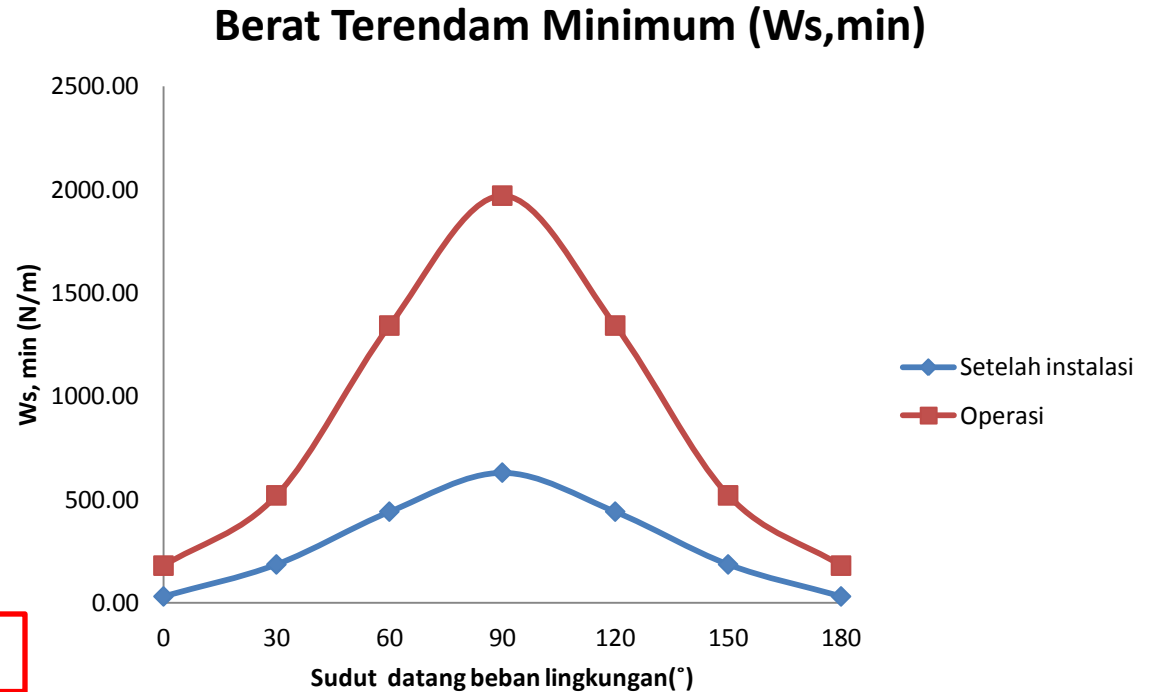
$$L \quad \text{Significant weight parameter} = \frac{W_s}{0.5 \cdot \rho_w \cdot D \cdot U_s^2}$$

θ	L	Ws,min (N/m)
0	3.577709	30.15
30	3.483282	185.04
60	3.483282	440.57
90	3.483282	629.60
120	3.483282	440.57
150	3.483282	185.04
180	3.577709	30.15

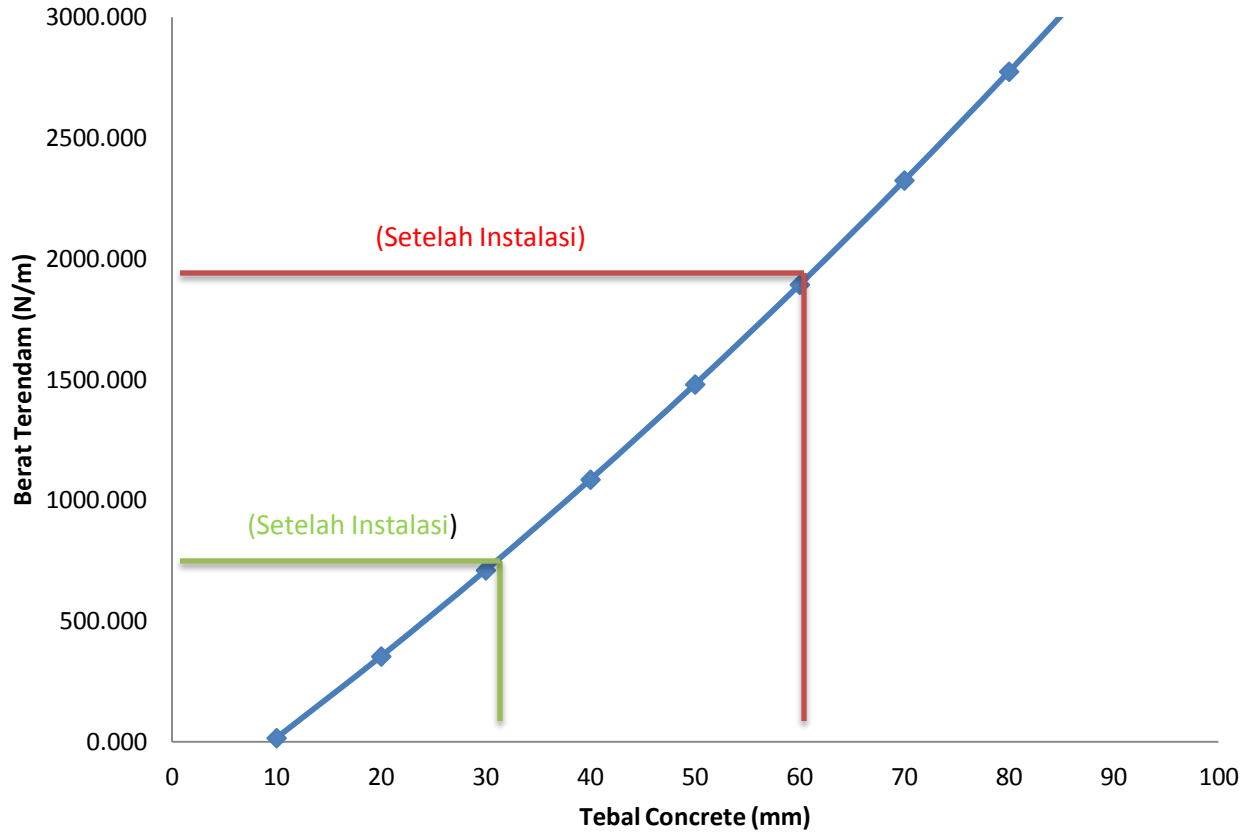
Hasil Analisis Generalized Parameter

θ (°)	$W_{s,min}$ (N/m) Setelah instalasi	$W_{s,min}$ (N/m) Operasi
0	30.15	179.17
30	185.04	519.23
60	440.57	1341.34
90	629.60	1970.31
120	440.57	1341.34
150	185.04	519.23
180	30.15	179.17

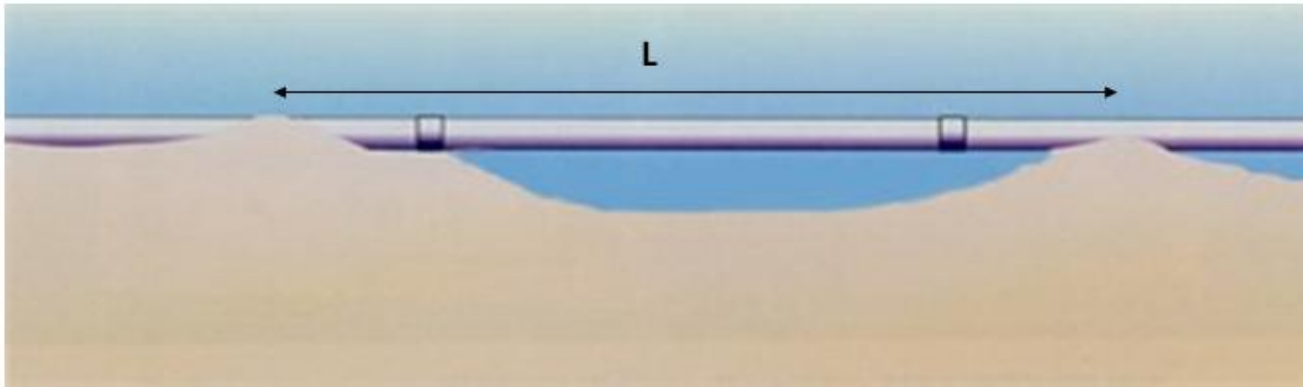
Berat Terendam Aktual= 918 N/m



Berat Terendam VS Tebal Concrete



Analisis Local Buckling



Kriteria kegagalan local buckling pipa bawah laut akibat kombinasi beban tekanan eksternal, tekanan internal, momen bending dan effective axial force pada DnV OS F101 adalah:

$$\left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right) \right\}^2 \leq 1$$

$$\left\{ Y_m \cdot Y_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{Y_m \cdot Y_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

➤ Location= 1

Location	Definition
1	The area where no frequent human activity is anticipated along the pipeline route.
2	The part of the pipeline/riser in the near platform (manned) area or in areas with frequent human activity. The extent of location class 2 should be based on appropriate risk analyses. If no such analyses are performed a minimum horizontal distance of 500 m shall be adopted.

➤ Fluid Type = B

Category	Description
A	Typical non-flammable water-based fluids.
B	Flammable and/or toxic fluids which are liquids at ambient temperature and atmospheric pressure conditions. <u>Typical examples are oil and petroleum products.</u> Methanol is an example of a flammable and toxic fluid.
C	Non-flammable fluids which are non-toxic gases at ambient temperature and atmospheric pressure conditions. Typical examples are nitrogen, carbon dioxide, argon and air.
D	Non-toxic, single-phase natural gas.
E	Flammable and/or toxic fluids which are gases at ambient temperature and atmospheric pressure conditions and which are conveyed as gases and/or liquids. Typical examples would be hydrogen, natural gas (not otherwise covered under category D), ethane, ethylene, liquefied petroleum gas (such as propane and butane), natural gas liquids, ammonia, and chlorine.

$$\left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

➤ Safety Class= Medium

Table 2-4 Normal classification of safety classes¹⁾

Phase	Fluid Category A, C		Fluid Category B D and E	
	Location Class		Location Class	
	1	2	<u>1</u>	2
Temporary ^{2,3}	Low	Low	-	-
<u>Operational</u>	Low	Medium ⁴	<u>Medium</u>	High

1) Other classifications may exist depending on the conditions and criticality of failure the pipeline. For pipelines where some consequences are more severe than normal, i.e. when the table above does not apply, the selection of a higher safety class shall also consider the implication, on the total gained safety. If the total safety increase is marginal, the selection of a higher safety class may not be justified.

2) Installation until pre-commissioning (temporary phase) will normally be classified as safety class Low.

3) For safety classification of temporary phases after commissioning, special consideration shall be made to the consequences of failure, i.e. giving a higher safety class than Low.

4) Risers during normal operation will normally be classified as safety class High.

$$\left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

➤ Safety Class Resistance Factor = 1,138

	γ_{SC}		
Safety class	Low	Medium	High
Pressure containment ¹⁾	1.046 ^{2),3)}	1.138	1.308 ⁴⁾
Other	1.04	1.14	1.26

➤ Material Resistance Factor = 1,15

Limit state category ¹⁾	SLS/ <u>ULS</u> /ALS	FLS
γ_m	<u>1.15</u>	1.00

1) The limit states (SLS, ULS, ALS and FLS) are defined in D.

$$\left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

$$f_y = (SMYS - f_{y,temp}) \cdot \alpha_U$$

$$f_u = (SMTS - f_{u,temp}) \cdot \alpha_U$$

$\alpha_U = 0.96$
 $f_{y,temp} = 0$ Mpa
 $f_{u,temp} = 0$ Mpa
 $f_y = 345.6$ MPa
 $f_u = 441.6$ MPa

$$f_{cb} = \min\left[f_y, \frac{f_u}{1.15}\right]$$

$f_u/1.15 = 384$
 $f_{cb} = 345.6$ MPa

$$P_b(t_2) = \frac{2t_2}{D_s - t_2} \cdot f_{cb} \cdot \frac{2}{\sqrt{3}}$$

$t_2 = 11.27$
 $P_b(t_2) = 28.8548$ MPa

$$\left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

$$\beta = \begin{cases} 0.5 & D_s/t_2 < 15 \\ \frac{60 - D_s/t_2}{90} & 15 \leq D_s/t_2 \leq 60 \\ 0 & D_s/t_2 > 60 \end{cases}$$

$D_s/t_2 = 28.6602$
sehingga,
 $\beta = 0.34822$

$$\alpha_c = (1 - \beta) + \beta \cdot \frac{f_u}{f_y}$$

$\alpha_c = 1.09673$

$$\left\{ \gamma_m \cdot \gamma_{sc} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{sc} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

$$P_{inc} = p_d \cdot \gamma_{inc}$$

$\gamma_{inc} = 1.1$
 $P_{inc} = 1.111 \text{ Mpa}$

$p_e = 314476.19 \text{ Pa}$
 0.31447619 Mpa

$$\left\{ \gamma_m \cdot \gamma_{sc} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{sc} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right) \right\}^2 \leq 1$$

$$p_{inc} = p_d \cdot \gamma_{inc}$$

$$\begin{aligned} \gamma_{inc} &= 1.1 \\ p_{inc} &= 1.111 \text{ Mpa} \end{aligned}$$

$$\begin{aligned} p_e &= 314476.19 \text{ Pa} \\ &= 0.31447619 \text{ Mpa} \\ p_i - p_e / p_b &= 0.03 \\ \alpha_p &= 0.65177955 \end{aligned}$$

$$\alpha_p = \begin{cases} 1 - \beta & \frac{p_i - p_e}{p_b} < \frac{2}{3} \\ 1 - 3\beta \left(1 - \frac{p_i - p_e}{p_b}\right) & \frac{p_i - p_e}{p_b} \geq \frac{2}{3} \end{cases}$$

$$\left\{ \gamma_m \cdot \gamma_{sc} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{sc} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right) \right\}^2 \leq 1$$

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

$$S_p(t_2) = f_y \cdot \pi \cdot (D_s - t_2) \cdot t_2$$

$$M_p(t_2) = 470062.248 \text{ N}$$

$$S_p(t_2) = 3812465.28 \text{ N}$$

$$\left\{ \gamma_m \cdot \gamma_{sc} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{sc} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

$$S_{sd} = H - \Delta p_i A_1 (1 - 2\nu) - A_1 E \Delta T \alpha_c$$

$$S_{sd} = -136683.38 \text{ N}$$

$$\left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{SC} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

$$M_{sd} = \frac{(F_G - F_F) \times \gamma_F \gamma_C \times L^2}{8}$$

FG=	2505	N			
FF=	1497	N			
γ_F =	1.1				
γ_C =	1				
L1=	40	m	Msd1=	221760	N.m
L2=	45	m	Msd2=	280665	N.m
L3=	50	m	Msd3=	346500	N.m
L4=	55	m	Msd4=	419265	N.m
L5=	60	m	Msd5=	498960	N.m

$$\left\{ \gamma_m \cdot \gamma_{sc} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p(t_2)} + \left\{ \frac{\gamma_m \cdot \gamma_{sc} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p(t_2)} \right\}^2 + \left(\alpha_p \cdot \frac{p_i - p_e}{\alpha_c \cdot P_b(t_2)} \right)^2 \right\} \leq 1$$

L(m)	Msd (N.m)	Mp(t2) (N.m)	Ssd (N)	Sp(t2) (N)	pi (MPa)	pe (MPa)	Pb(t2) (MPa)	Hasil
40	221760	470062	-136683	3812465.3	1.111	0.3144762	28.85482298	0.319
45	280665	470062	-136683	3812465.3	1.111	0.3144762	28.85482298	0.511
50	346500	470062	-136683	3812465.3	1.111	0.3144762	28.85482298	0.777
55	419265	470062	-136683	3812465.3	1.111	0.3144762	28.85482298	1.137
60	498960	470062	-136683	3812465.3	1.111	0.3144762	28.85482298	1.609

KESIMPULAN

1. Besar gaya hidrodinamis **horizontal** pada kondisi setelah instalasi (kosong) dan operasi (berisi fluida) masing-masing adalah **405 N/m** dan **1119 N/m**.

Besar gaya hidrodinamis **vertikal** pada kondisi setelah instalasi (kosong) dan operasi (berisi fluida) masing-masing adalah **138 N/m** dan **1058 N/m**.

Besar ***Coulomb friction*** pada kondisi setelah instalasi (kosong) dan operasi (berisi fluida) masing-masing adalah **184 N/m** dan **202 N/m**.

Besar **tahanan pasif** pada kondisi setelah instalasi (kosong) dan operasi (berisi fluida) masing-masing adalah **111 N/m** dan **121 N/m**

KESIMPULAN

2. Berdasarkan kriteria *on-bottom stability* DnV, pipa bawah laut **stabil secara vertikal** pada kondisi setelah **instalasi** (kosong) dan **operasi** (berisi fluida).

Pada metode *absolute lateral static* pipa bawah laut **tidak stabil secara lateral** pada kondisi setelah instalasi (kosong) dan operasi (berisi fluida). Sehingga, tebal *concrete* perlu ditambah menjadi **60 mm** dan **190 mm** agar stabil pada kondisi setelah instalasi dan operasi.

Pada metode *generalized parameter* pipa bawah laut **tidak stabil secara lateral** pada kondisi **operasi** (berisi fluida), namun **stabil secara lateral** pada kondisi **instalasi** (kosong). Sehingga, tebal *concrete* perlu ditambah menjadi **70 mm** agar stabil pada kondisi operasi.

KESIMPULAN

3. Panjang *free span* pipa bawah laut maksimum yang **dijinkan** agar tidak terjadi *local buckling* adalah **50 m**. Hasil analisis *local buckling* dapat digunakan untuk melakukan mitigasi pada *free span* pipa bawah laut.

**TERIMA KASIH
(MOHON BIMBINGANNYA)**