Risk-based Fatigue Estimate of Deep Water Risers

-Course Project of EM388F: Fracture Mechanics

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Oil Platforms

Fixed platform: since the 1950s

Floating production system: since 1970s

Fixed Platform
(suited for water depth up to 1,700 ft)

Floating Production Storage and Offloading (FPSO)Vessels
(Effective for deepwater)

Risers

The risers are the interface system between structure on the ocean floor and the FPSO structure at the ocean's surface

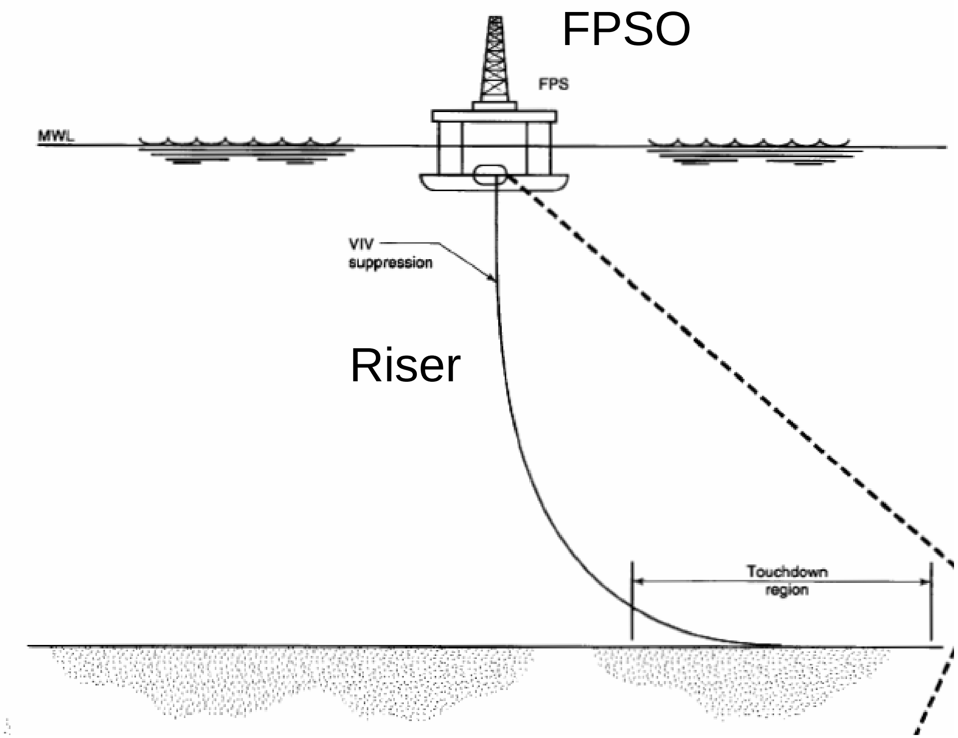
The main function of the riser: convey fluids between ocean wells and the FPSO

Fatigue Damage:

- Cessation of production
- Spillage and pollutions

Fatigue Loading:

- Wave response
- Low frequency response
- Vortex-induced vibration
- Installation, thermal, etc.



Fatigue Analysis of Risers-General

Two phases of fatigue life: crack initiation, crack propagation.

Two types of components:

- un-welded components: crack initiation period takes over 95% of the total fatigue life.
- welded joints: The crack propagation period represents the bulk of the total fatigue life.

Fatigue Criterion:

$$D_{fat} \times DFF \leq 1$$

D_{fat} :Accumulated fatigue damage

DFF :Design fatigue factor, 3, 6 or 10 depends on the safety classes low, normal or high

Long-term Fatigue Damage

Procedure:

- Divide all sea current state data into a number of representative blocks
- Use a single sea state to represent all the sea-state within one block. The probabilities of occurrence for all sea-states within the block are lumped to the selected sea-state.

Note: The selected sea-state should give equal or greater damage than all the original sea-state with the block.

- The long-term fatigue damage is equal to the weighted summation of all short-term fatigue damage

$$D_{fat} = \sum_{i=1}^{N_s} D_i P_i$$

D_{fat} : Long-term fatigue damage

N_S : Number of single sea-state, number of blocks of sea-state

D_i : Short-term fatigue damage

P_i : Sea-state probability

Example of Lumped Sea-State

H_s (m)	T_p (s) 6–8	8–10	10–12	12–14	14–16	16–18
0.00–0.25	0.00	0.00	0.00	0.00	0.00	0.00
0.25–0.50	0.00	0.00	0.00	0.00	0.00	0.00
0.50–0.75	0.08	0.14	0.07	0.15	0.00	0.01
0.75–1.00	0.63	1.36	1.86	1.89	0.26	0.11
1.00–1.25	2.03	4.74	3.79	4.15	1.05	0.40
1.25–1.50	0.67	7.77	9.35	7.62	2.29	0.75
1.50–1.75	0.67	4.67	9.88	6.73	2.63	0.71
1.75–2.00	0.26	1.00	5.56	3.94	1.51	0.63
2.00–2.25	0.03	0.25	1.62	1.78	1.20	0.37
2.25–2.50	0.00	0.14	1.03	0.78	0.68	0.23
2.50–2.75	0.00	0.00	0.32	0.40	0.32	0.10
2.75–3.00	0.00	0.00	0.01	0.18	0.19	0.07
3.00–3.25	0.00	0.00	0.01	0.16	0.06	0.04
3.25–3.50	0.00	0.00	0.00	0.01	0.06	0.01
3.50–3.75	0.00	0.00	0.00	0.03	0.01	0.06
3.75+	0.00	0.00	0.00	0.00	0.01	0.00
Probability (%)	4.37	20.05	32.49	27.82	10.26	3.49

Bin	1	2	3	4	5	6	7
Pr (%)	0.8	4.37	20.05	32.5	27.82	10.26	3.49
H_{se}	1.34	1.34	1.51	1.67	1.71	1.90	1.98
T_p	5	7	9	11	13	15	17

Short-term Fatigue: S-N Curve Approach

Linear S-N curve: $N = a \times S^{-m} \Leftrightarrow \log(N) = \log(a) - m \times \log(S)$

N : Number of stress cycles to failure
S : Constant stress range
a, m: Empirical constants estimated by experiments

Palmgren-Miner rule $D = \sum_i \frac{n(S_i)}{N(S_i)}$

$n(S_i)$ The number of stress cycles with stress range S_i
$N(S_i)$: The number of stress cycles to failure with stress range S_i

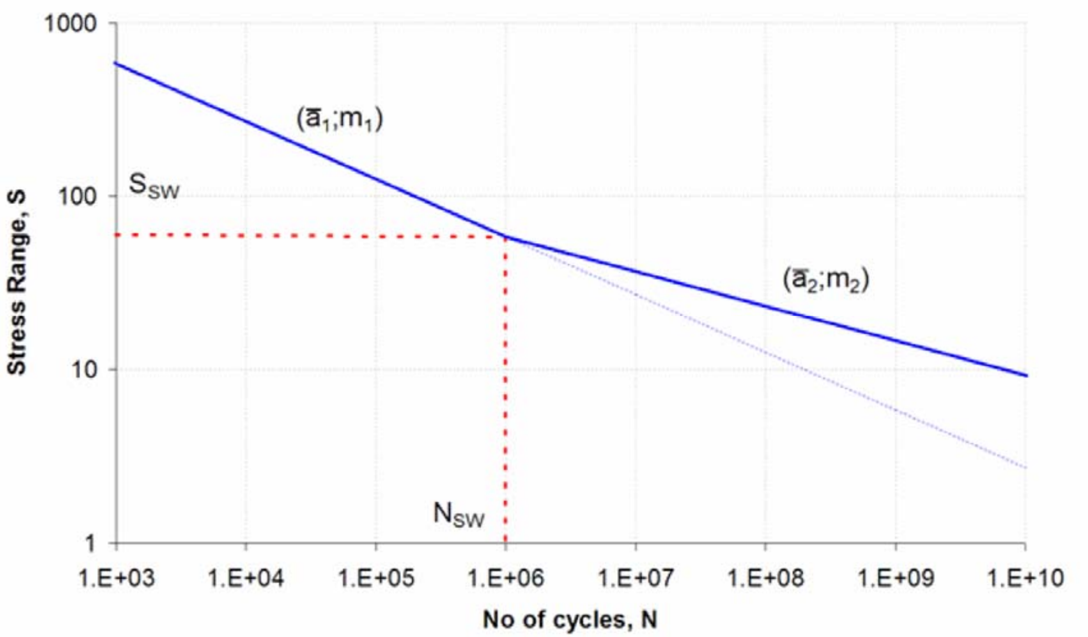
$$D = \frac{Tf_V}{a} \int_0^\infty S^m \times f_s(s)\, ds = \frac{Tf_V}{a} E\left[S^m\right]$$

T : Design life time in year
f_V : Mean frequency of stress cycles
$f_s(s)$: Probability density function for stress cycles

Bilinear S-N Curve Approach

Bilinear S-N curve:

$$N = \begin{cases} a_1 \times S^{-m1} & S > S_{sw} \\ a_2 \times S^{-m2} & S \leq S_{sw} \end{cases}$$



Palmgren-Miner rule

$$D = \frac{Tf_V}{a_2}\int_0^{S_{sw}} S^{m_2} \times f_s(s)\,ds + \frac{Tf_V}{a_1}\int_{S_{sw}}^{\infty} S^{m_1} \times f_s(s)\,ds$$

Fatigue Stresses

The stress considered for riser fatigue damage is the cyclic principal stress.

Cyclic nominal stress: $$\sigma(t) = \sigma_a(t) + \sigma_M(\theta, t)$$

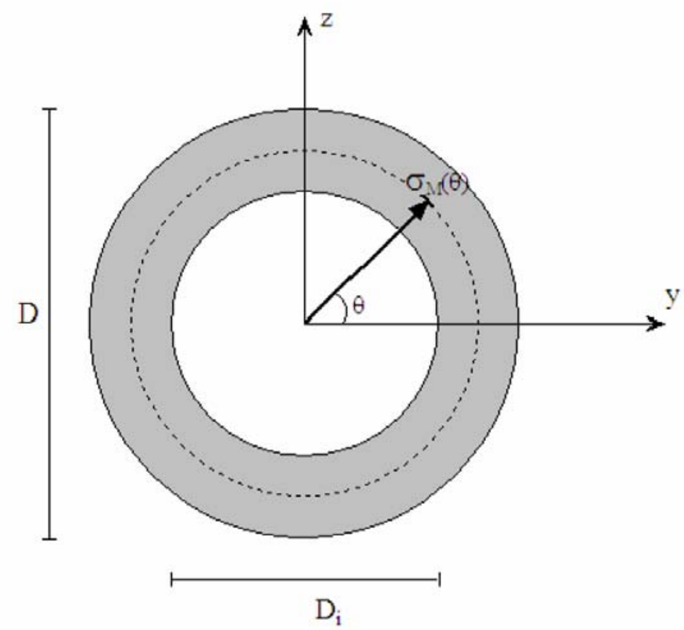
Axial Stress: $$\sigma_a(t) = \frac{T_e(t)}{\pi(D - t_{fat})t_{fat}}$$

Bending stress: $$\sigma_M(\theta, t) = \left(M_y(t)\sin(\theta) + M_Z(t)\cos(\theta)\right) \times \left(\frac{D - t_{fat}}{2I}\right)$$

- M_y , M_Z : bending moments about the local y and z axes
- At least 8 points along the circumference needs to be analyzed.
- Pipe wall thickness:

$t_{fat} = t_{norm}$ Before installation

$t_{fat} = t_{norm} - 0.5 \times t_{corr}$ After installation



Uncertainties of Fatigue Estimate

Many factors associate with riser fatigue analysis, including the input variables (drag coefficient, pipe wall thickness, etc.), are stochastic in nature

Table 6-4 Stochastic variables

Variable	*Probabilistic distribution*	$COV = \frac{\sigma_{Xi}}{\mu_{X_i}}$
Drag coefficient	Lognormal	0.15 - 0.20
Floater RAO amplitude	Lognormal	0.05 - 0.10
Static Floater Offset	Normal	1% of water depth
Soil Stiffness	Lognormal	0.20 - 0.50
Soil riser interaction model uncertainty (trenching/suction effects)	Lognormal	0.10 - 0.30
Riser weight	Normal	0.05 - 0.10
Environmental modelling	Lognormal	0.05 - 0.10
Additional stochastic variables may also be relevant and need to be identified for each specific project.		

Risk based fatigue analysis by using Monte Carlo simulation

Monte Carlo Simulation

(1) Establish the probabilistic model (mode type, mean and standard deviation) for each independent basic input variables, such as the pipe wall thickness

(2) Sampling probability distribution to obtain point estimate for each independent input variable

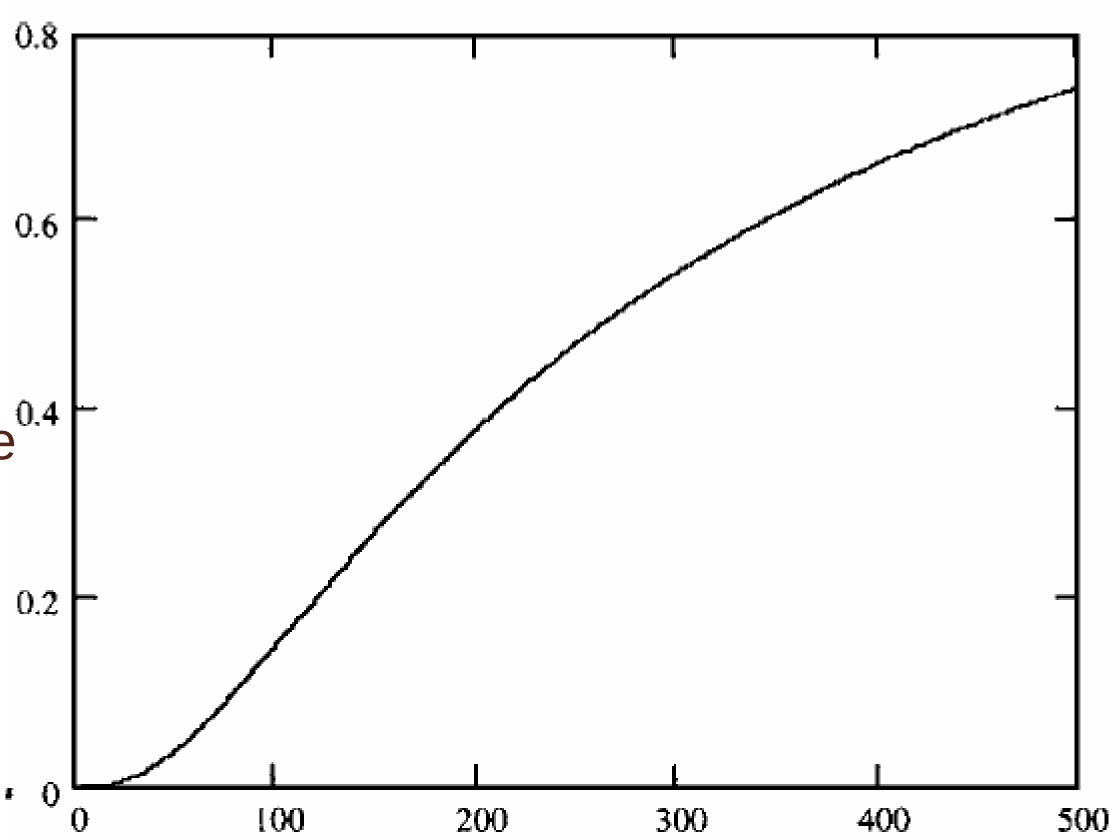
(3) Calculate dependent and then output variables

(4) Do loop for sets 2-3 (typically more than 100,000 times for satisfied accuracy)

(5) Post-process results to obtain probabilistic distribution of the output.

Example-probability curve

Fatigue failure probability (time some scale)



Years

Summary

❑ Fatigue damage estimation is critical important for riser design and analysis

❑ The procedures and considerations are very complex

❑ Bilinear S-N curve and Miner rule are the typical approach

❑ Fatigue damage and fatigue life can be estimated by using the mean value of the input variables

❑ Probability of fatigue failure can be estimated by the stochastic model of the input variables and Monte Carlo simulation

References

- DNV, 2005, Riser fatigue, DNV-RP-F204
- Sen, T.K., Probability of fatigue failure in steel catenary risers in Deep Water, Journal of Engineering Mechanics, Sep. 2006