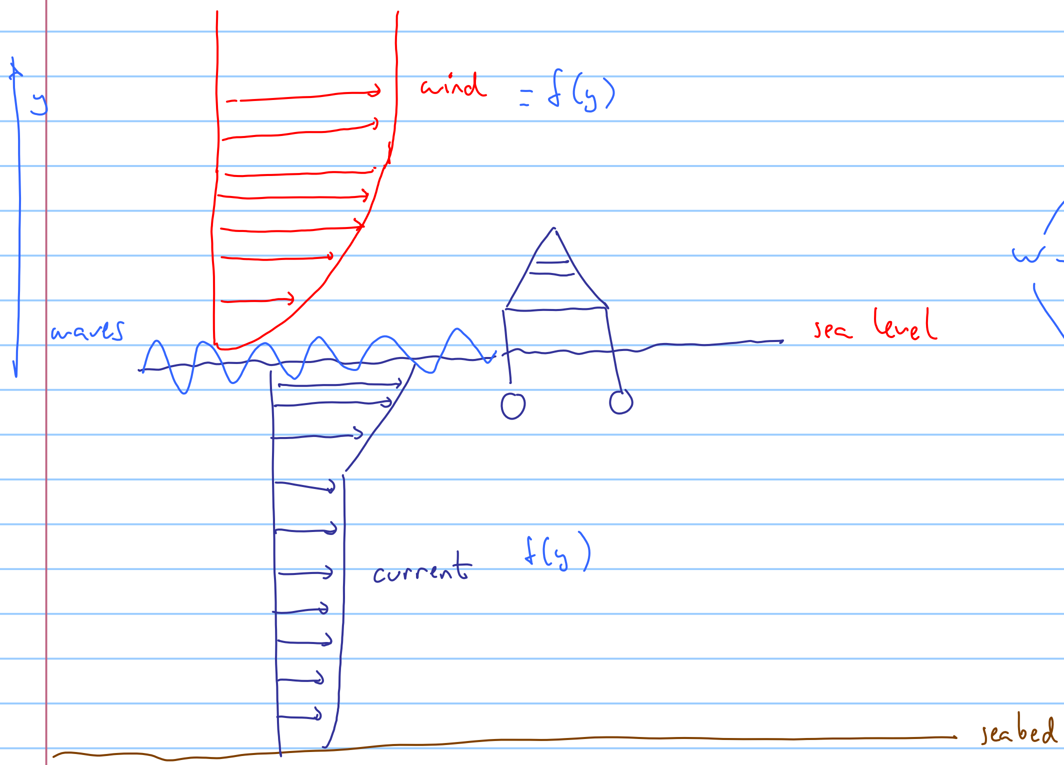
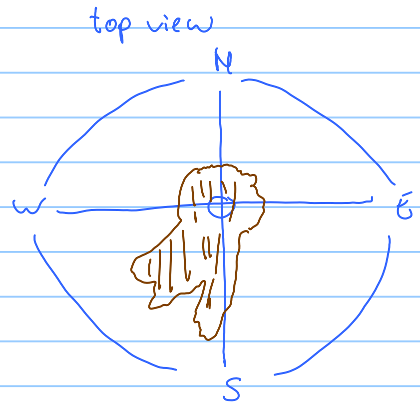
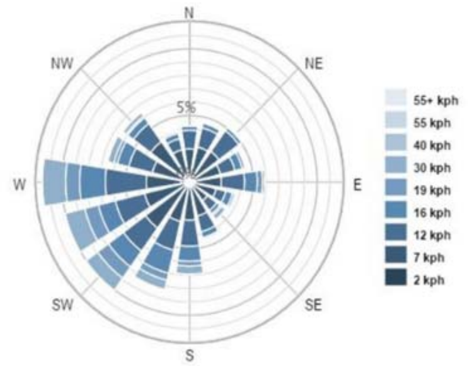
Marine loads in offshore structures





marine loads usually have a preferential direction



- for practical purposes:
  - wind is considered with a uniform constant value (exception some floating structures)

    values vary with minutes

  - current: the spatial variation is considered. Considered constant with time (a high value is usually used (100 years current)

    values usually change within hours

- waves:

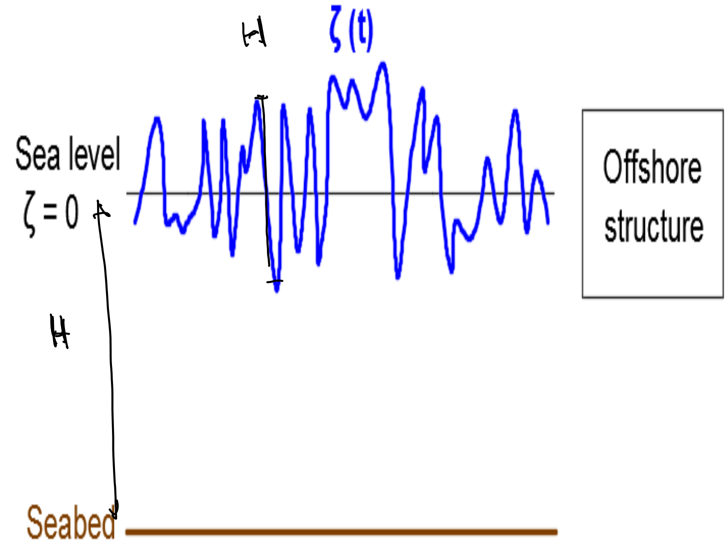
height difference between two consequtive waves
periodocity

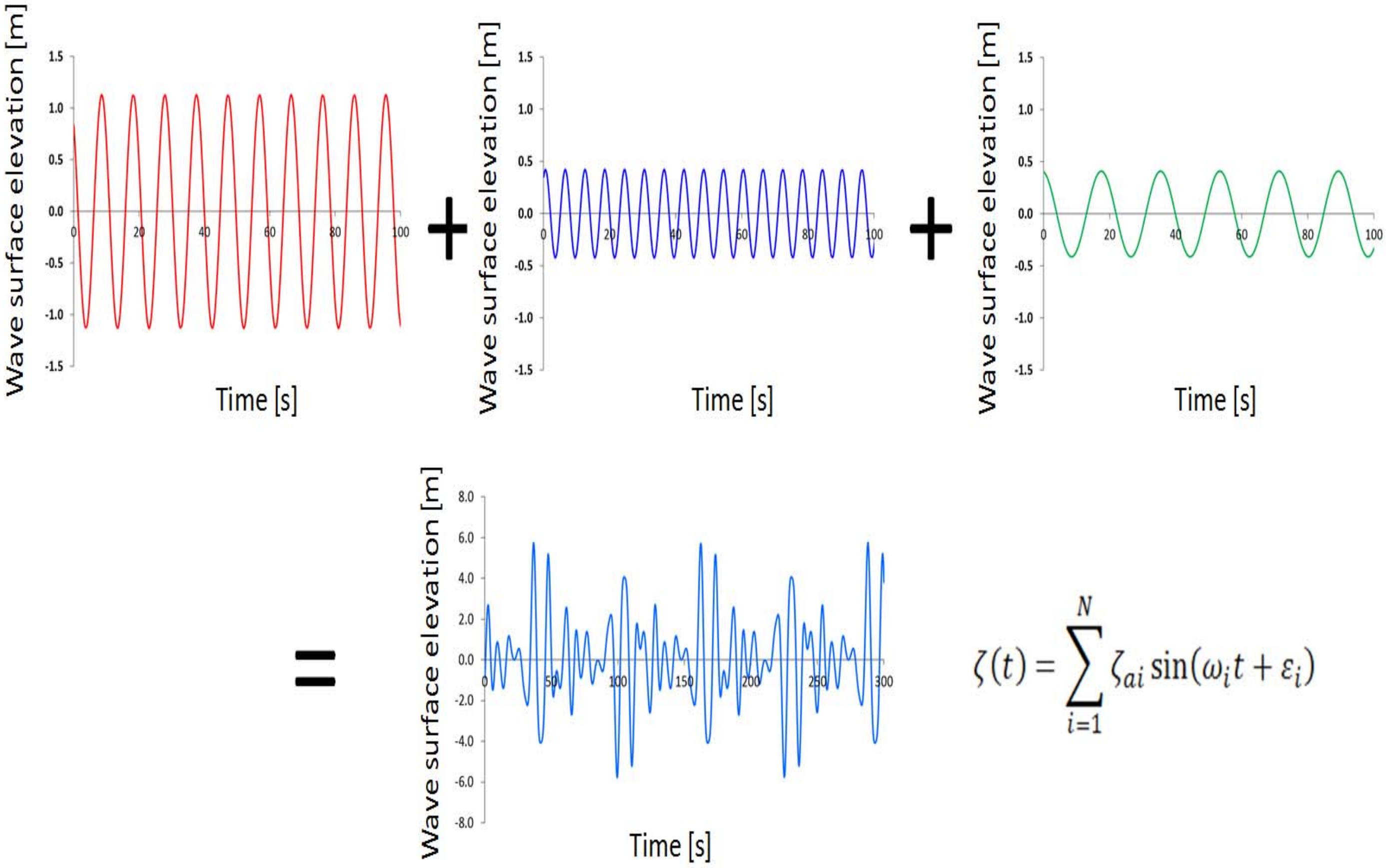
• waves

wave elevation

ζ

fourier theorem

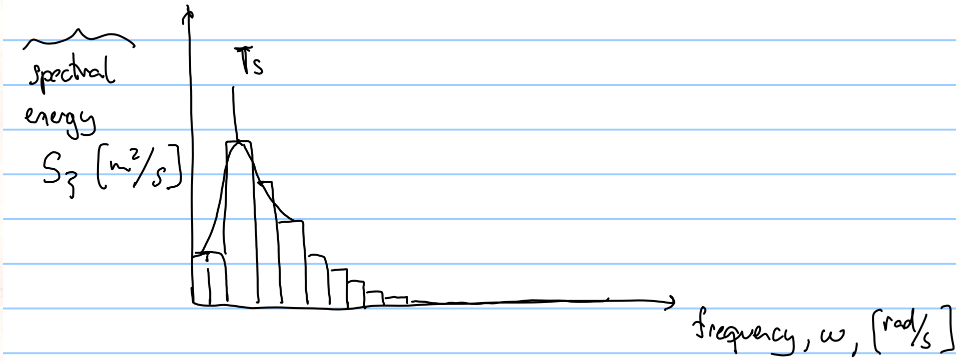




$$\zeta(t) = \sum_{i=1}^{N} \zeta_{ai} \sin(\omega_i t + \varepsilon_i)$$

measurements of wave statistics buoys attached to mecchant ships
measurement ships
existing offshore structures.

FFT fast fourier transform



wave energy spectrum

To convert from energy to elevation:

$$\varsigma_i = \sqrt{2 \cdot S_{\varsigma i} \cdot \Delta\omega_i}$$

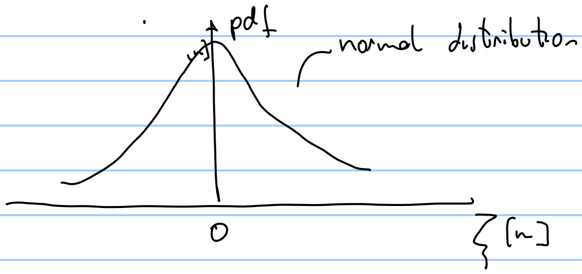
Some formulas that are typically used for spectrum

Pierson moskowitz (P-M)

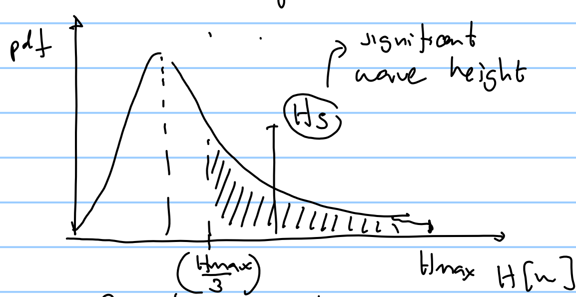
JONSWAP

for shorts periods of time (sea state) → 3hrs : there is a significant period mean period which is dominant and is usually considered constant.

the wave elevation



the wave height



Rayleigh distribution

T_s, H_s characterize a sea state

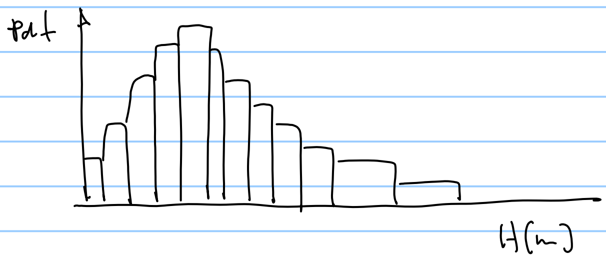
Scatter diagram of long term wave statistics Aasta Hansteen for 15 years

	Spectral Peak period (T_p) [s]																						
Hs [m]	0-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	Sum
0-1	15	290	1367	2876	3716	3527	2734	1849	1138	656	362	192	101	52	26	13	7	3	2	1	0	0	0	18927
1-2	1	81	1153	5308	12083	17323	18143	15262	10980	7053	4169	2316	1229	631	315	155	75	36	17	8	4	5	1	96348
2-3	0	2	94	1050	4532	10304	15020	15953	13457	9752	5991	3403	1795	894	426	197	88	39	17	7	3	1	1	83026
3-4	0	0	2	72	686	2782	6171	8847	9189	7493	5082	2991	1577	762	345	148	61	24	9	4	1	0	0	46246
4-5	0	0	0	2	51	433	1645	3495	4807	4750	3638	2286	1229	584	251	100	37	13	5	1	0	0	0	23327
5-6	0	0	0	0	2	39	294	1037	2069	2664	2440	1709	968	463	193	72	25	8	2	1	0	0	0	11986
6-7	0	0	0	0	0	2	32	215	692	1264	1485	1228	767	382	159	57	18	5	1	0	0	0	0	6307
7-8	0	0	0	0	0	0	2	27	157	447	730	762	555	302	130	46	14	4	1	0	0	0	0	3177
8-9	0	0	0	0	0	0	0	2	23	112	276	392	355	223	104	38	11	3	1	0	0	0	0	1540
9-10	0	0	0	0	0	0	0	0	2	19	77	160	192	148	79	31	9	2	0	0	0	0	0	719
10-11	0	0	0	0	0	0	0	0	0	2	16	50	85	85	55	24	8	2	0	0	0	0	0	327
11-12	0	0	0	0	0	0	0	0	0	0	2	12	29	40	33	18	7	2	0	0	0	0	0	143
12-13	0	0	0	0	0	0	0	0	0	0	0	2	8	15	17	12	5	2	0	0	0	0	0	61
13-14	0	0	0	0	0	0	0	0	0	0	0	0	2	5	7	6	4	1	0	0	0	0	0	25
14-15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	2	1	0	0	0	0	0	9
15-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	4
16-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	16	373	2616	9308	21070	34410	44041	46687	42514	34212	24268	15503	8892	4587	2143	921	372	146	55	22	8	6	2	292172

Design is usually made using values for longer periods. thus an extrapolation is required.

Looking at T_p ~ spectral peak period

T_{p_1}



$H_{s[15year]}$ =

15 years ~> 292000 states of (3h)

it has an associated propability of $\left(\frac{1}{292000} = 7.6E-6\right)$

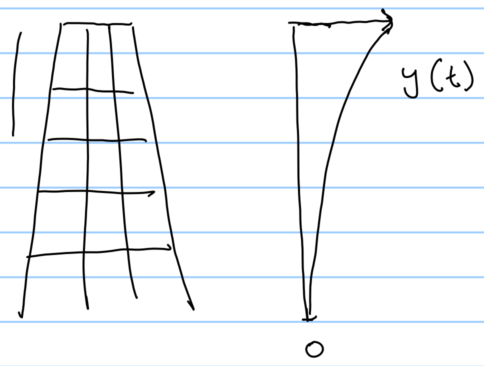
we assume that significant wave heights in different time periods follow a logarithmic equation

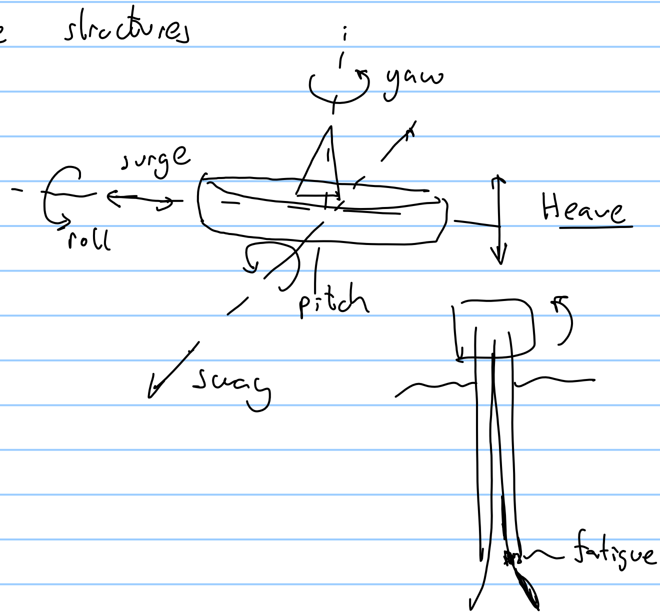
$$\log(P(H)) = \frac{1}{a} H$$

$$\log(7.6E-6) = \frac{1}{a} H_{15}$$

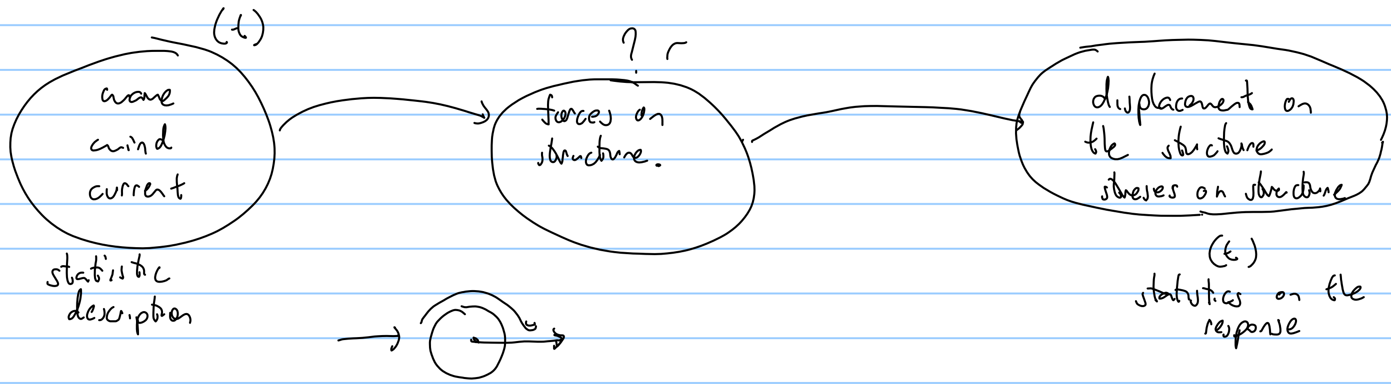
- Calculation of displacements of offshore structures

bottom supported structures





- H_{s} (100 years) is used to desig deck height



three types of analysis are usually made

- Design wave $H_{s,100}$ → with a range of periods. NORSOK N-003 suggests using

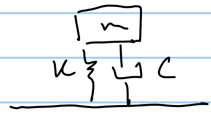
$$\sqrt{6.5\, H_{s,100}} \leq T \leq \sqrt{11 \cdot H_{s,100}}$$

$$\boxed{H_{s,100} = 1.9 \cdot H_s}$$

- short term design H_s, T_s → usually to calculate maximum loads and stresses on components. storm

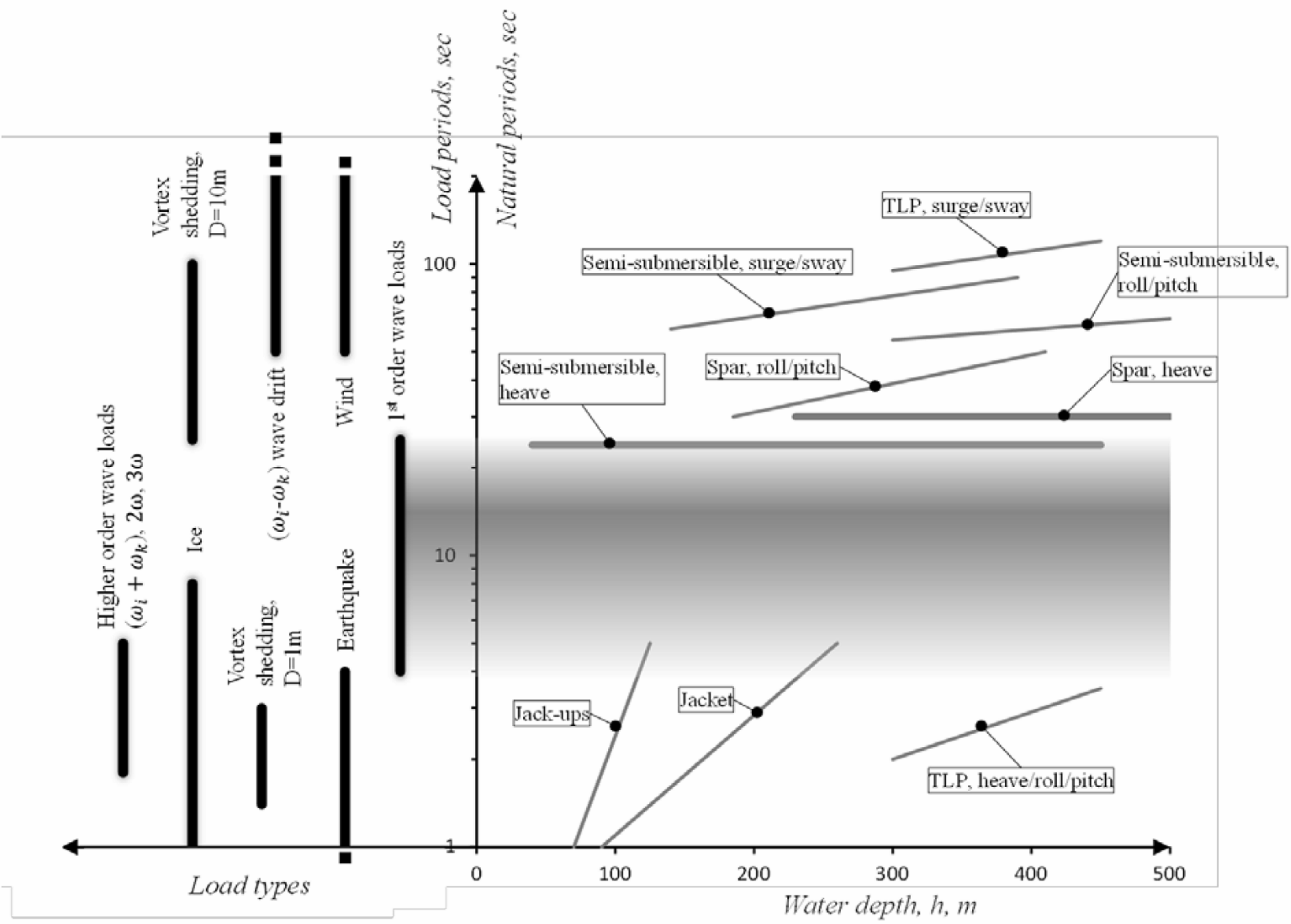
- long term desingn: varying H_s, T_s, is usually used to calculate fatigue.

Each offshore structure has a natural frequency
- flexibility of structure
- weight of structure
- damping of structure

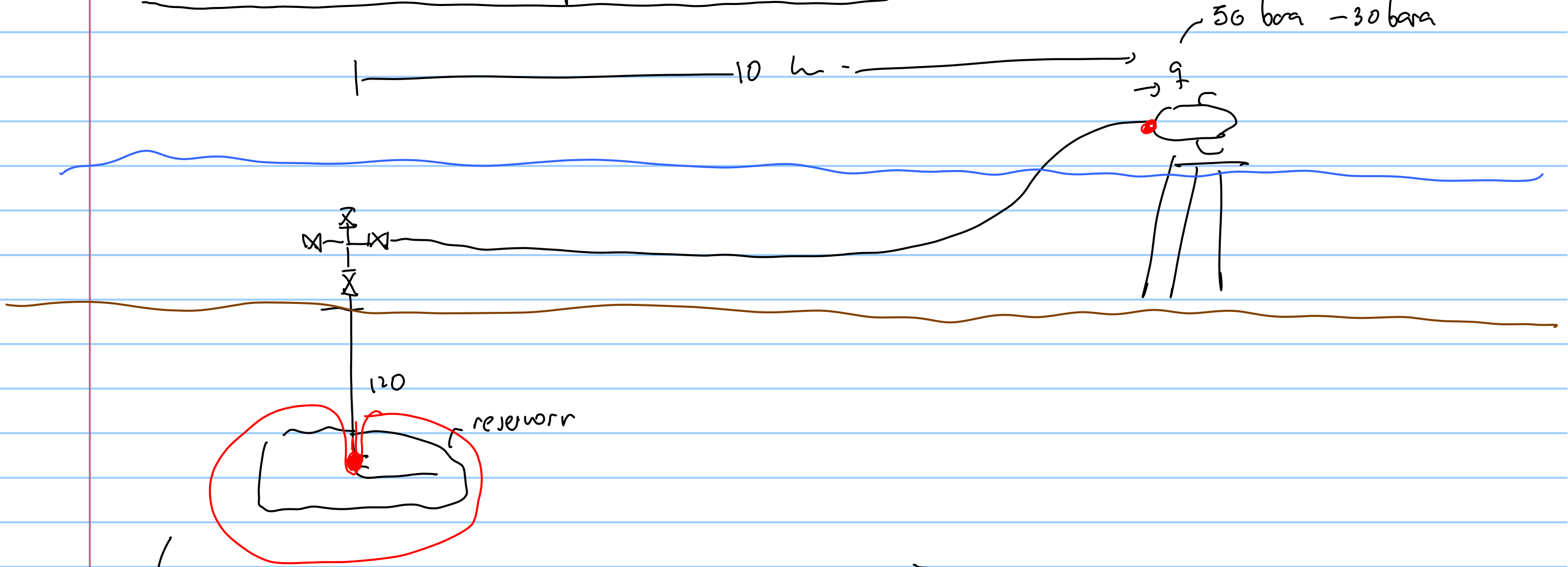


Resonance excite the structure with natural frequency and amplitudes will be big

→ stresses and loads are usually big

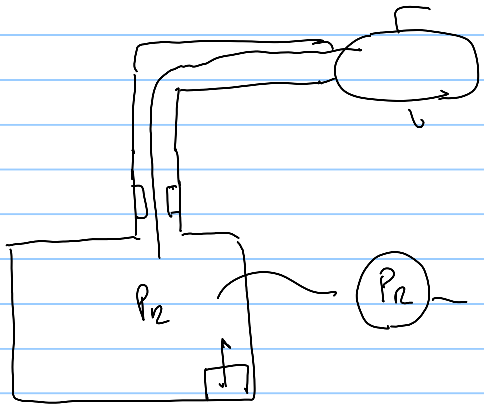


Flow performance of production system.



$q_{field}(t) = ?$ → Revenue → NPV

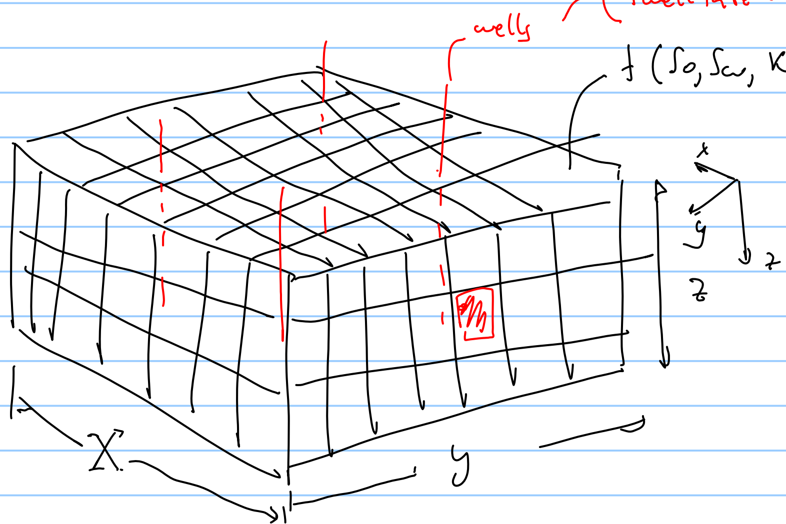
to compute the performance of production system we use numerical models



$q \propto P_R - P_{sep}$ ~ (rate effect)

P_R ~ with production (time effect)

In early phases of field development reservoir simulator is often used and the surface production system is ignored



($q_{well\ rate}$ (target), $P_{wf\ min}$)

$f(S_o, S_w, K_y, K_x, K_z, \phi, P_c)$

P_{Ri} initial reservoir pressure

fluid properties

$\mu - f(P,T)$

$\rho - f(P,T)$

$q = \frac{K}{\mu} \frac{\partial P}{\partial r}$

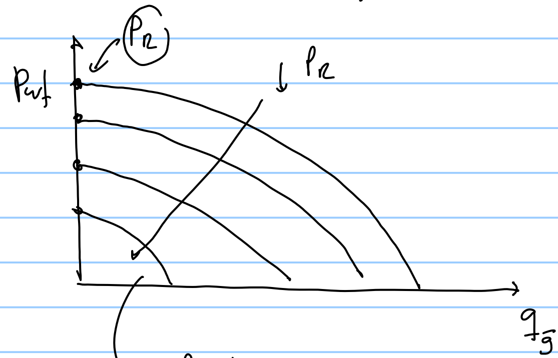
Result of reservoir simulator is $p_{wf}^{i}(t)$

$q_{w}^{i}(t)$

Snowhite. dry gas example. Proxy → surrogate of a reservoir model

∘ material balance →

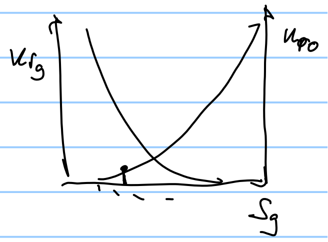
∘ productivity of well IPR
inflow performance relationship



Backpressure equation

$$q_g = C_R \left(P_R^2 - P_{wf}^2\right)^n$$

↳ K, μ, S



material balance

$$P_R = \frac{z_R}{z_i} P_i \left(1 - \frac{G_p}{G}\right) \qquad G_p = \int_0^t q_g \, dt$$

R_F

initial gas in place

initial reservoir pressure

initial deviation factor

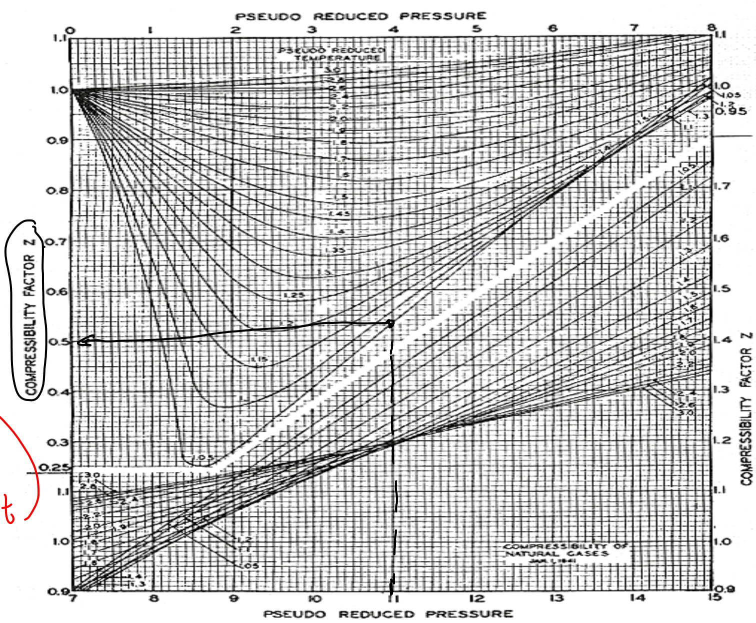
deviation factor @ current P_R

https://www.youtube.com/watch?v=ssmJrENliwg&list=PLgktb39S1tGcix-up7-23QyYhNeUuhMX0&index=1

provide $P_i, z_i, \overbrace{G_p, G}^{R_F}$

$$z = f\left(\frac{P}{P_c}, \frac{T}{T_c}\right) ?$$

$$P_c, T_c = f(\gamma_g)$$



implicit equation

- assume P_R, calculate z
- calculate P_R from MB
- check if $P_{R\,calc} = P_{R\,assum}$. if not

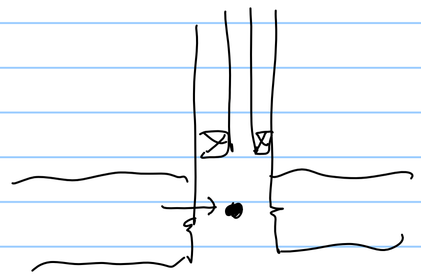
http://folk.ntnu.no/stanko/Courses/TPG4230/2017/Class_files/20170214/

Anual oftake for gas $\underbrace{(2-3\%)(G)}_{20E6\ Sm^3/d}$

Atila East gas Field (Base Case Data)									
G=IGIP	270E+09	Sm3							
T_R	92	oC							
Pi, initial Res pressure	276	bara							
C, inflow Back pressure coefficient	1000	Sm3/bar^2n							
n, backpressure, exponent	1								
Gas molecular weight (Methane)	16	kg/kmole							
Gas specific gravity	0.55	Gas specific gravity							
Number of wells	4								
pwfmin	120	[bara]							
qfield_target	2.00E+07	[Sm^3/d]							
	time	qwell_pot	qfield_pot	qfield	ΔGp	Gp	Z	RF	PR
	[years]	[Sm^3/d]	[Sm^3/d]	[Sm^3/d]	[Sm^3]	[Sm^3]	[-]	[-]	[bara]
	0				0.00E+00		0.9672446		276
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								

the end of the year

Calculating well potential by applying the provided $P_{wf\,min}$ in the sand phase



$$q_g = C_R\left(P_R(t)^2 - P_{wf\,min}^2\right)^n$$

$q_{g\,pot}$ = maximum rate that the well can produce

$q_{g\,pot} > q_{g\,target}$ the target rate provided is feasible

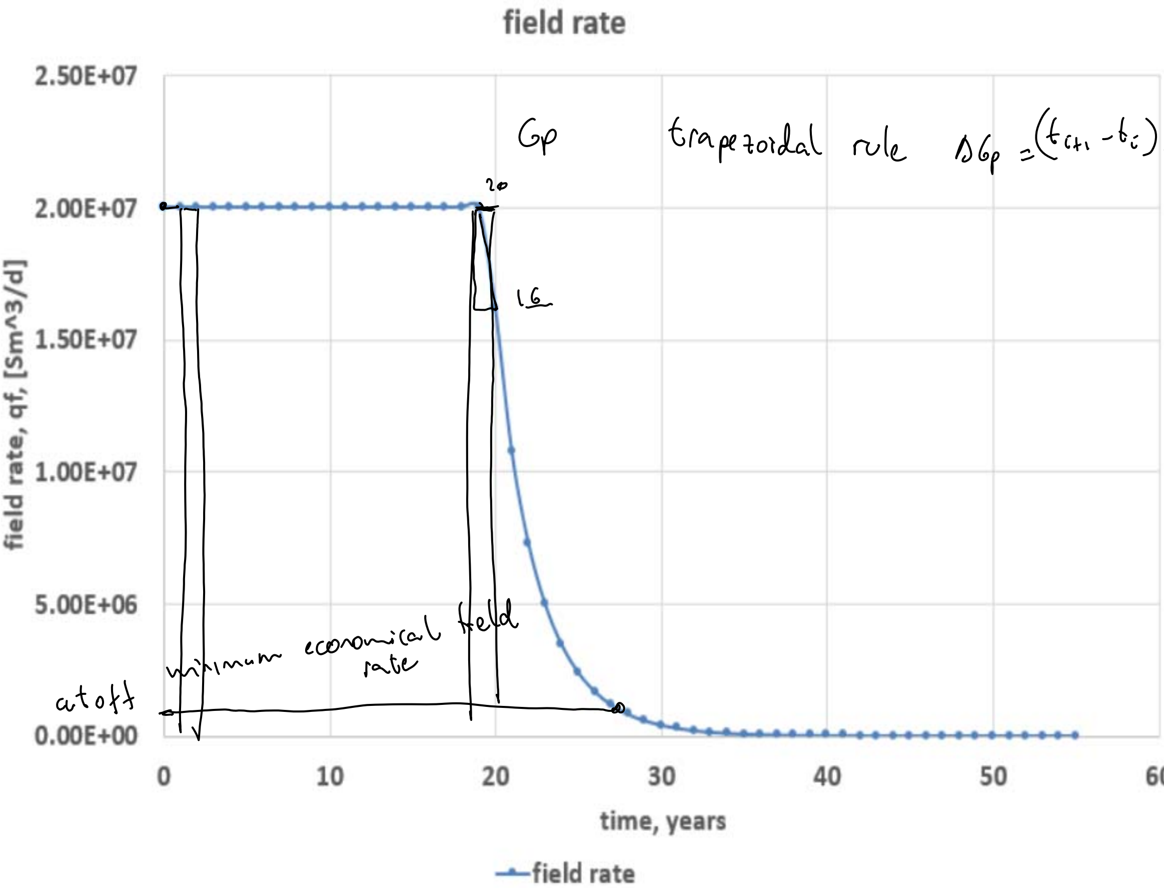
$q_{g\,pot} < q_{g\,target}$ i canot produce the target rate provided

Predicting production profile of Snohvit field - Reservoir simulator proxy - Milan Stanko, 20170214										
Snohvit gas Field										
G=IGIP	270E+09	Sm3								
T_R	92	oC								
Pi, initial Res pressure	276	bara								
C, inflow Back pressure coefficient	1000	Sm3/bar^2n								
n, backpressure, exponent	1									
Gas molecular weight (Methane)	16	kg/kmole								
Gas specific gravity	0.55	Gas specific gravity								
Number of wells	4									
pwfmin	120	**[bara]**								
qfield_target	2.00E+07	**[Sm^3/d]**								
	time	**qwell_pot**	**qfield_pot**	**qfield**	**pwf**	**ΔGp**	**Gp**	**Z**	**RF**	**PR**
	[years]	**[Sm^3/d]**	**[Sm^3/d]**	**[Sm^3/d]**	**[bara]**	**[Sm^3]**	**[Sm^3]**	**[-]**	**[-]**	**[bara]**
	0	61776000	2.47E+08	2.00E+07	267	0.00E+00	0.00E+00	0.9672446	000.0E+0	276
	1	58113872.7	2.32E+08	2.00E+07	260	6.57E+09	6.57E+09	0.9672446	24.3E-3	269
	2	53941551.6	2.16E+08	2.00E+07	252	6.57E+09	1.31E+10	0.9630236	48.7E-3	261
	3	49857914.9	1.99E+08	2.00E+07	243	6.57E+09	1.97E+10	0.9583206	73.0E-3	253
	4	45961532.4	1.84E+08	2.00E+07	235	6.57E+09	2.63E+10	0.9538497	97.3E-3	246
	5	42258575.5	1.69E+08	2.00E+07	227	6.57E+09	3.29E+10	0.9497312	121.7E-3	238
	6	38740056.4	1.55E+08	2.00E+07	219	6.57E+09	3.94E+10	0.9459766	146.0E-3	231
	7	35395346.7	1.42E+08	2.00E+07	212	6.57E+09	4.60E+10	0.9425795	170.3E-3	223
	8	32214305.9	1.29E+08	2.00E+07	204	6.57E+09	5.26E+10	0.9395311	194.7E-3	216
	9	29187545.5	1.17E+08	2.00E+07	196	6.57E+09	5.91E+10	0.9368227	219.0E-3	209
	10	26306418.5	1.05E+08	2.00E+07	189	6.57E+09	6.57E+10	0.9344457	243.3E-3	202
	11	23562975	9.43E+07	2.00E+07	182	6.57E+09	7.23E+10	0.932392	267.7E-3	195
	12	20949917.2	8.38E+07	2.00E+07	174	6.57E+09	7.88E+10	0.9306539	292.0E-3	188
	13	18460558.4	7.38E+07	2.00E+07	167	6.57E+09	8.54E+10	0.9292238	316.3E-3	181
	14	16088783.8	6.44E+07	2.00E+07	160	6.57E+09	9.20E+10	0.9280946	340.7E-3	175
	15	13829016.2	5.53E+07	2.00E+07	152	6.57E+09	9.86E+10	0.9272597	365.0E-3	168
	16	11676183.7	4.67E+07	2.00E+07	145	6.57E+09	1.05E+11	0.9267125	389.3E-3	161
	17	9625689.72	3.85E+07	2.00E+07	138	6.57E+09	1.12E+11	0.926447	413.7E-3	155
	18	7673386.72	3.07E+07	2.00E+07	131	6.57E+09	1.18E+11	0.9264573	438.0E-3	149
	19	5815551.3	2.33E+07	2.00E+07	123	6.57E+09	1.25E+11	0.9267379	462.3E-3	142
	20	4048861.89	1.62E+07	1.62E+07	120	6.57E+09	1.31E+11	0.9272836	486.7E-3	136
	21	2689377.84	1.08E+07	1.08E+07	120	5.32E+09	1.37E+11	0.9280894	506.4E-3	131
	22	1824335.63	7.30E+06	7.30E+06	120	3.53E+09	1.40E+11	0.928925	519.5E-3	127
	23	1251902.59	5.01E+06	5.01E+06	120	2.40E+09	1.43E+11	0.9295651	528.3E-3	125
	24	865700.421	3.46E+06	3.46E+06	120	1.65E+09	1.44E+11	0.9300388	534.4E-3	124
	25	601733.801	2.41E+06	2.41E+06	120	1.14E+09	1.45E+11	0.9303821	538.6E-3	122

In this time, potential rate is smaller than the target rate. The mode changes to constant bottomhole pressure

MIN f_x =IF(D16>=B12,B12,D16)

	A	B	C	D	E	F	G	H	I	J	K
1	Predicting production profile of Snohvit field - Reservoir simulator proxy - Milan Stanko, 20170214										
2	**Snohvit gas Field**										
3	G=IGIP	270E+09	Sm3								
4	T_R	92	oC								
5	Pi, initial Res pressure	276	bara								
6	C, inflow Back pressure coefficient	1000	Sm3/bar^2n								
7	n, backpressure, exponent	1									
8	Gas molecular weight (Methane)	16	kg/kmole								
9	Gas specific gravity	0.55	Gas specific gravity								
10	Number of wells	4									
11	**pwfmin**	120	**[bara]**								
12	**qfield_target**	2.00E+07	**[Sm^3/d]**								
13											
14		**time**	**qwell_pot**	**qfield_pot**	**qfield**	**pwf**	**ΔGp**	**Gp**	**Z**	**RF**	**PR**
15		**[years]**	**[Sm^3/d]**	**[Sm^3/d]**	**[Sm^3/d]**	**[bara]**	**[Sm^3]**	**[Sm^3]**	**[-]**	**[-]**	**[bara]**
16		0	61776000	2.47E+08	=IF(D16>=$	267	0.00E+00	0.00E+00	0.9672446	000.0E+0	276
17		1	58113872.7	2.32E+08	2.00E+07	260	6.57E+09	6.57E+09	0.9672446	24.3E-3	269
18		2	53941551.6	2.16E+08	2.00E+07	252	6.57E+09	1.31E+10	0.9630236	48.7E-3	261
19		3	49857914.9	1.99E+08	2.00E+07	243	6.57E+09	1.97E+10	0.9583206	73.0E-3	253
20		4	45961532.4	1.84E+08	2.00E+07	235	6.57E+09	2.63E+10	0.9538497	97.3E-3	246



trapezoidal rule $\Delta G_p = (t_{i+1} - t_i) \cdot \frac{(q_{i+1} + q_i)}{2}$