Shallow water FPSO design

mooring systems and risers

FPSO FORUM October 3, 2001-LISBON

1) A review of the developments on mooring systems of FPSOs in shallow water

2) What is the difference between shallow and deep water? The current, waves and mooring system?

by

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1) A review of the developments on mooring systems of FPSOs in shallow water

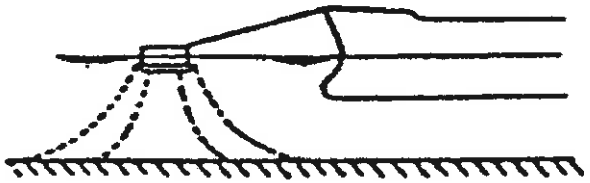
Start of mooring in the open sea

Shell (John Flory)
1959: Malaysia
WD= 48 ft

Esso (John Flory)
1969: Brega, Lybia
WD= 140 ft

CALM

old Shell patent



pipe line with PLEM

underwater hoses-Lazy S or Chinese lantern configuration (2-3 hoses)

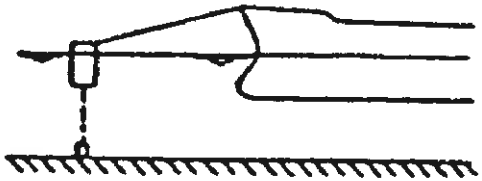
buoy swivel-turntable

floating hose (2-3 hoses)

mid ship manifold

SALM

old EXXON patent



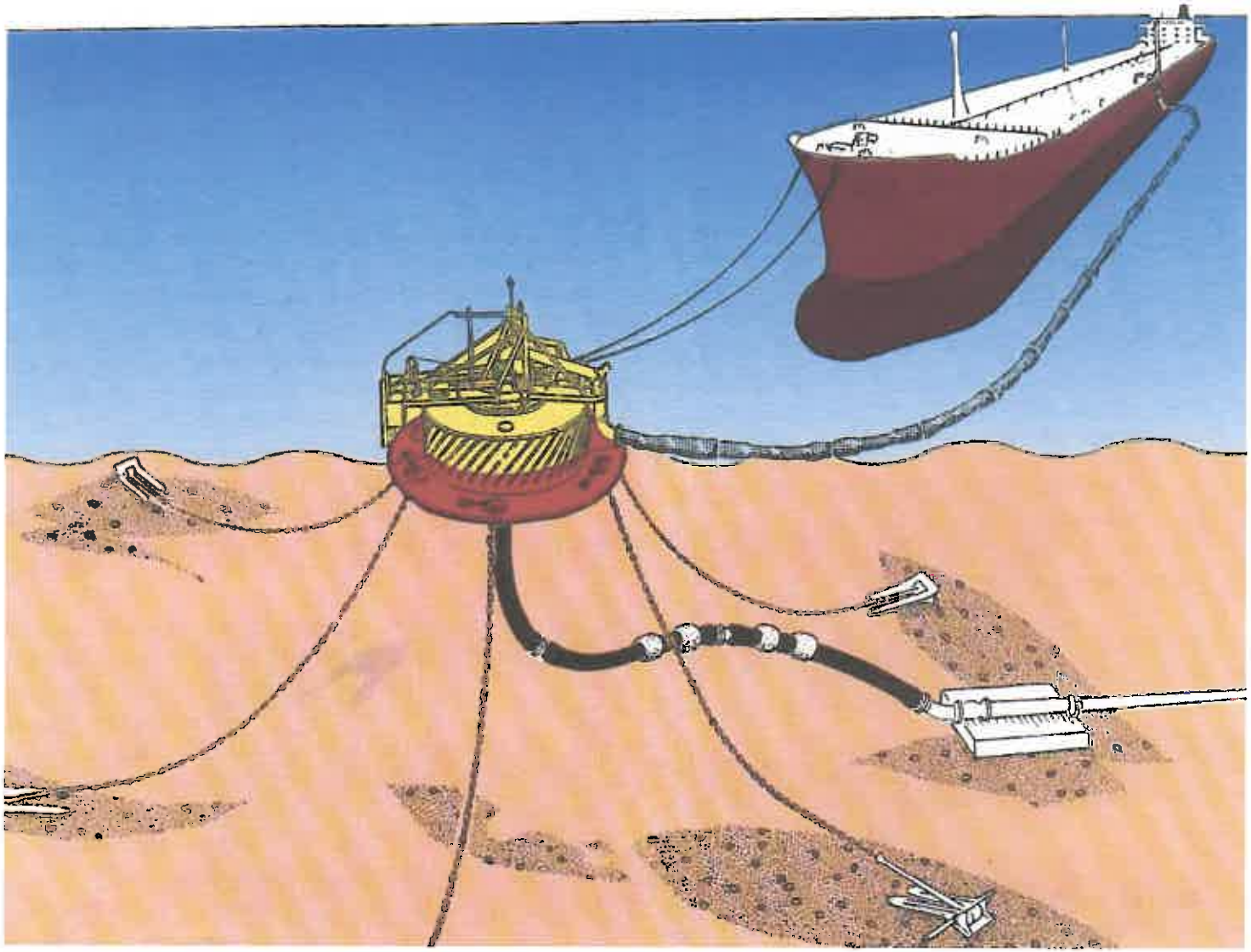
pipe line with PLEM

fluid swivel above piled bottom frame

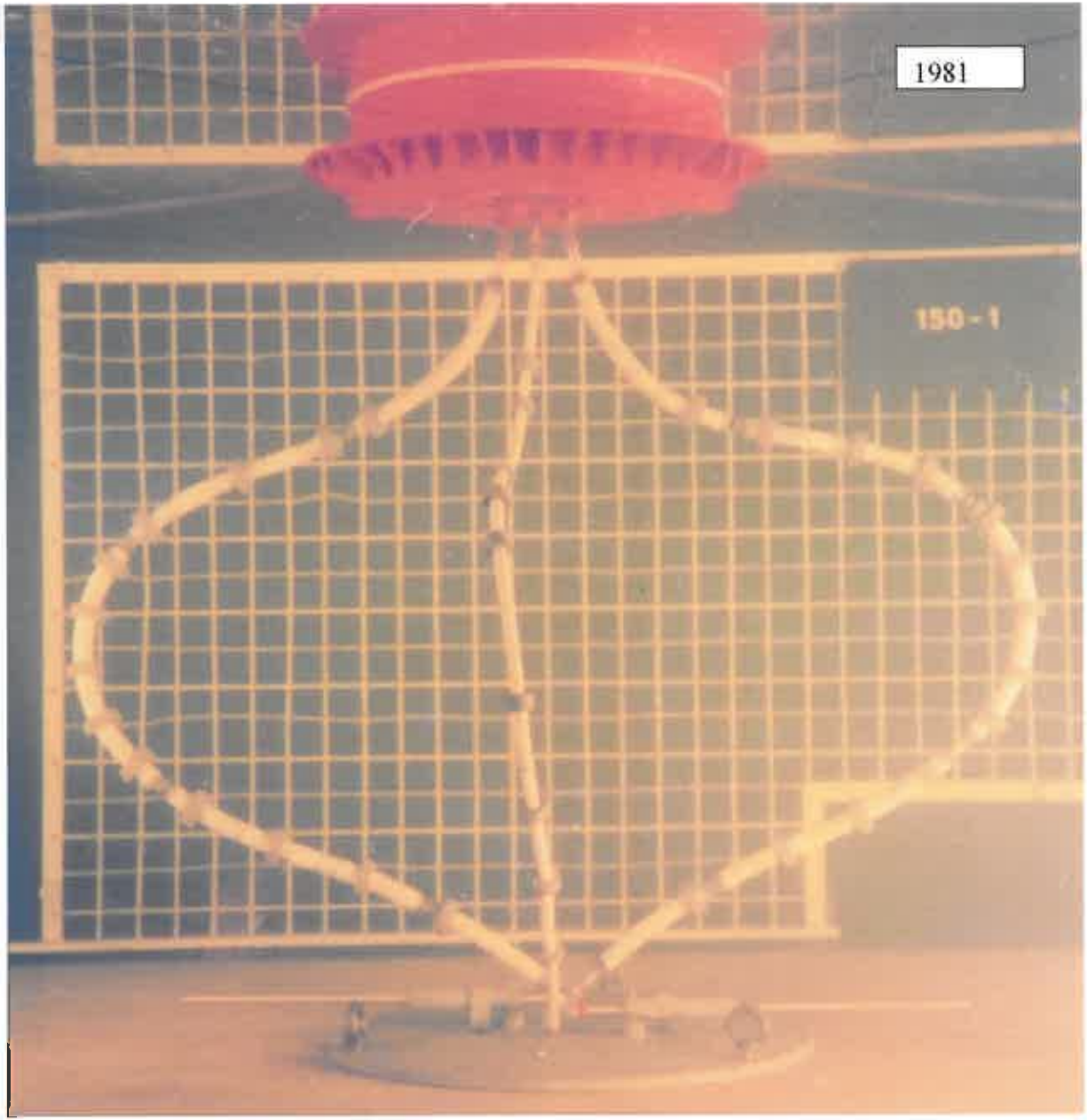
underwater/floating hoses from swivel

to surface and to mid ship manifold

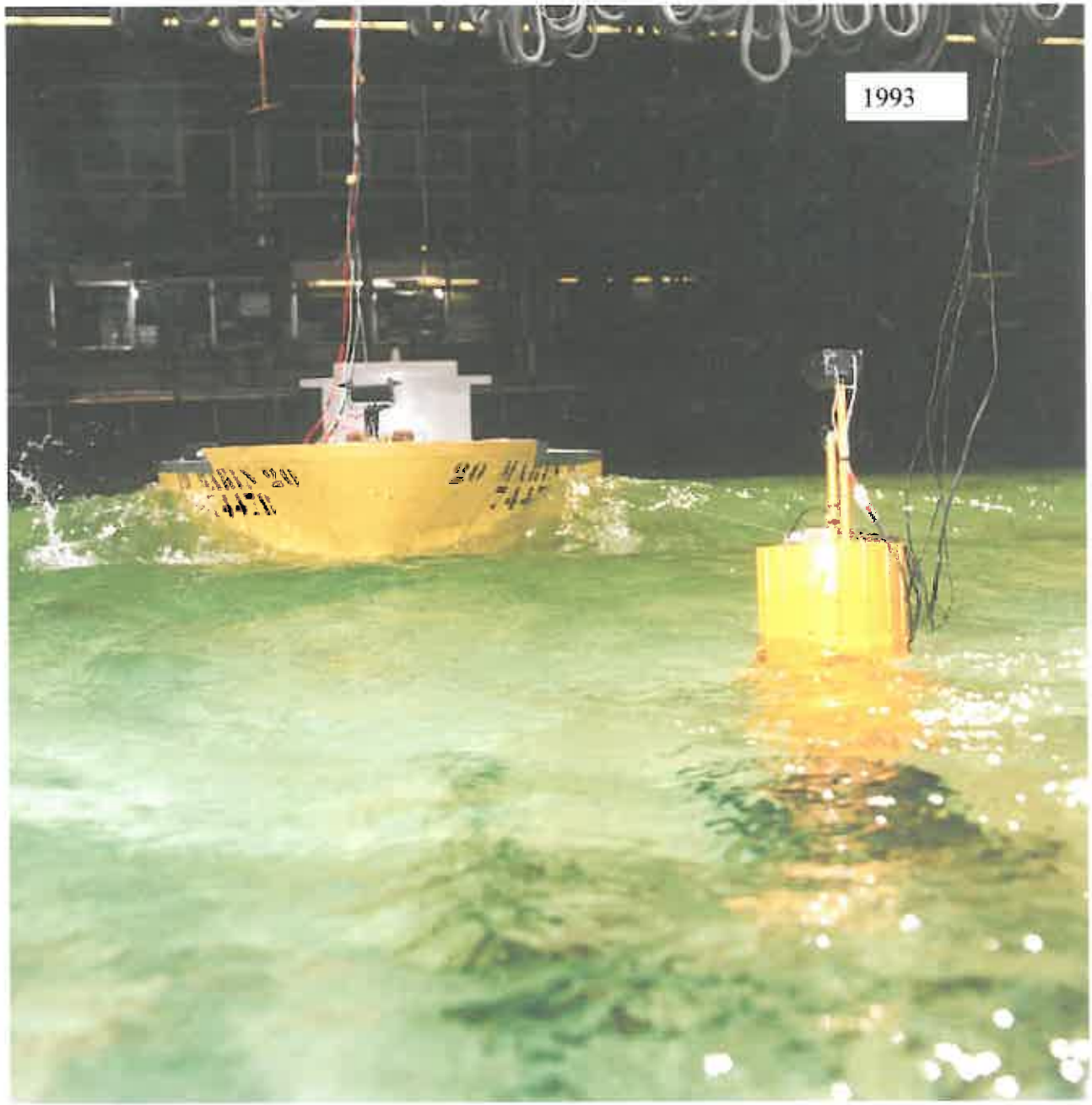
underwater hoses CALM buoy



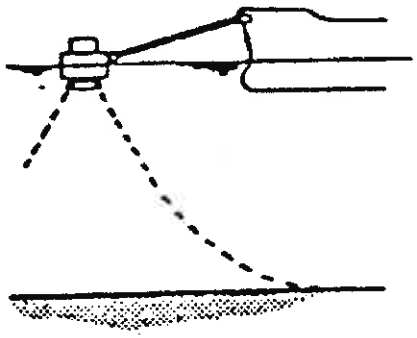
underwater hoses CALM buoy



The SALM buoy F812410



Underwater hoses of SALM buoy-hose behavior during storm

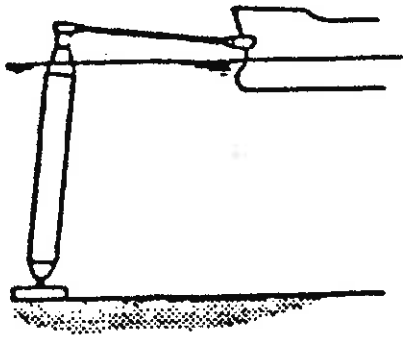


Permanently moored tankers Mooring system derived from the CALM buoy:

SBS-system:

Cadlao 1981-97 m

Kakap 1986-87 m



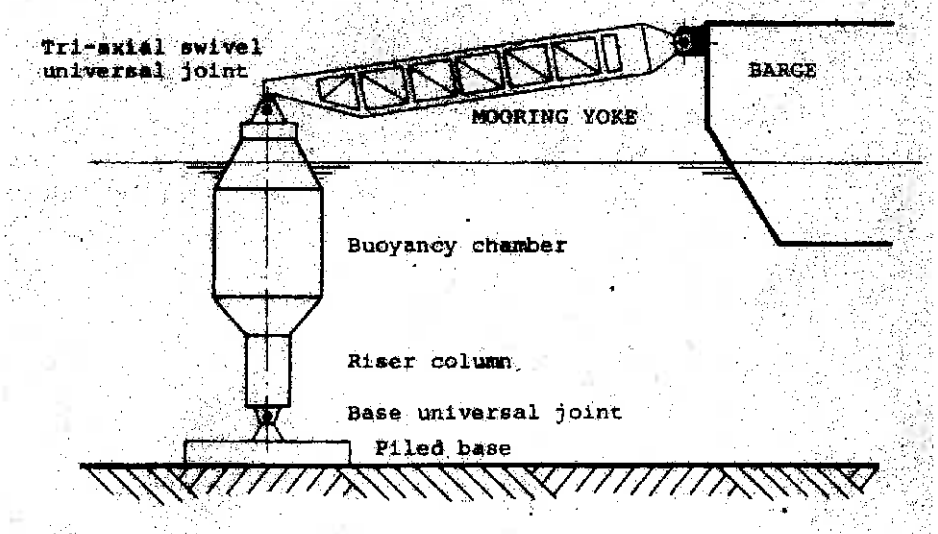
Permanently moored tankers Mooring system derived from the SALM buoy:

Yoke Tower or SALMRA system

a number are built-see next slide

Motivation at that time no risers

Only jumper hoses and fluid swivels

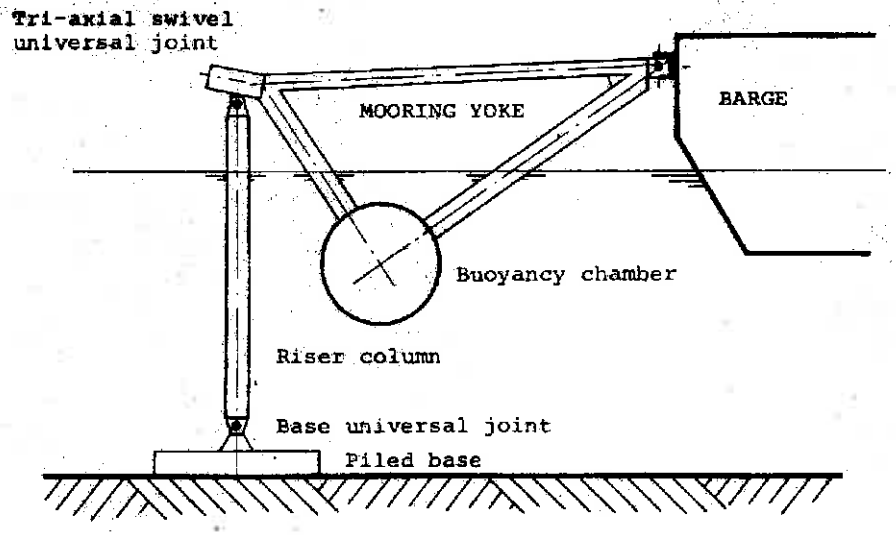


Hondo (1981)- 150 m

Fulmar (1982)-90 m

Challis (1989)-100 m

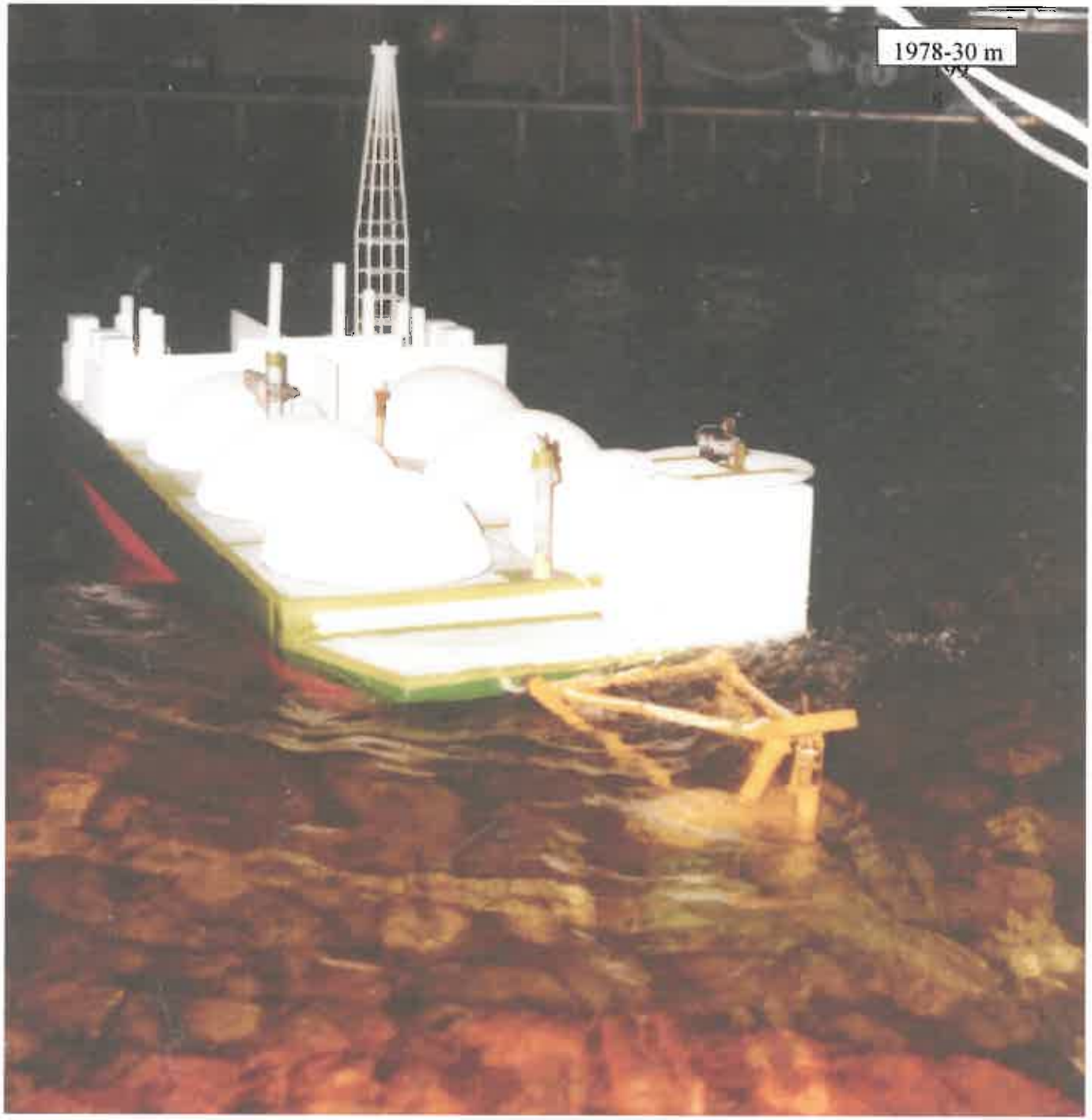
To reduce the wave frequency wave loading on top-uni-joint: SALS system



Castellon (1977)-141 m

Nilde (1980)-96 m

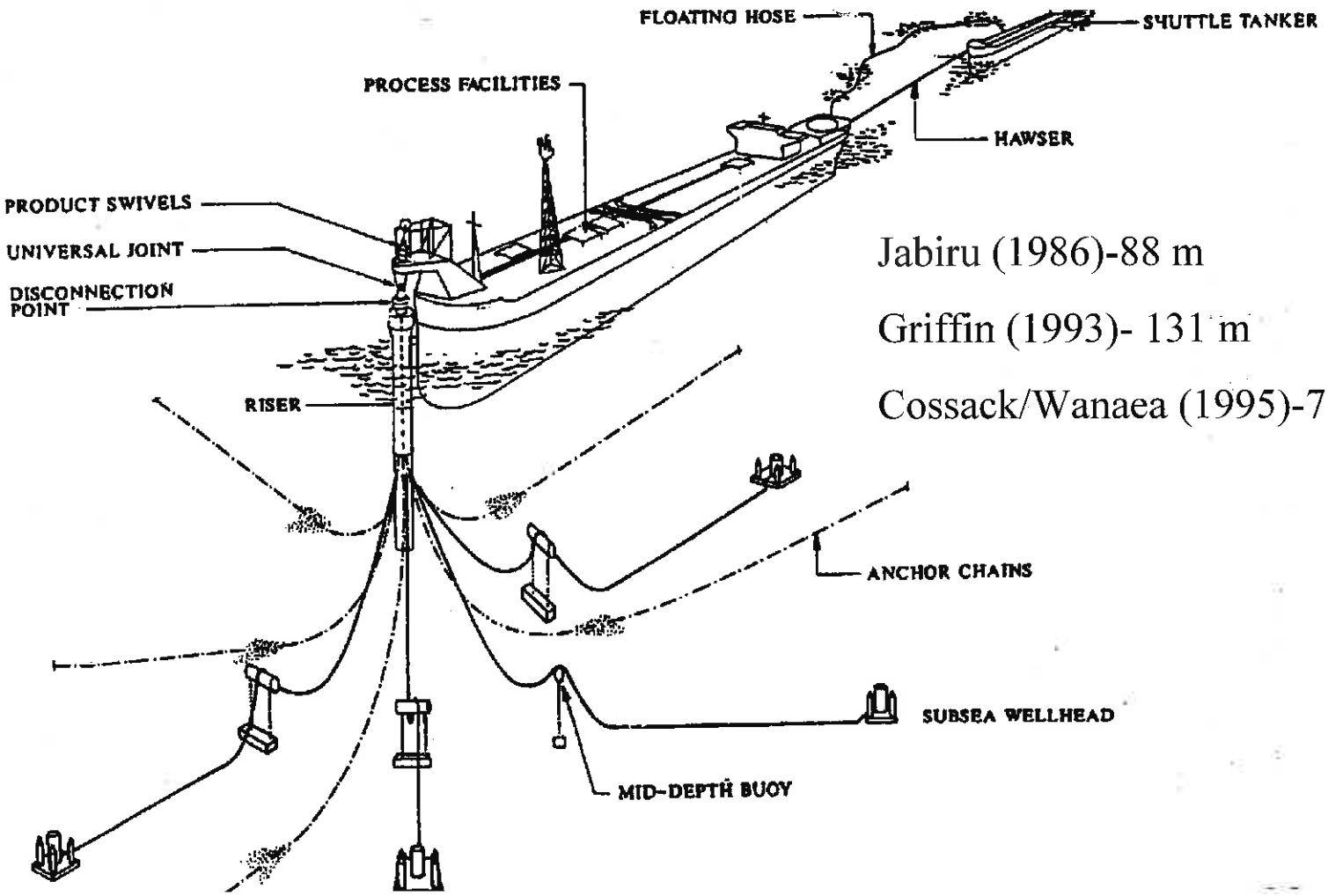
Tazerka (1982)-143 m


1978-30 m

RTM: Riser Turret Mooring

BTM: Buoy Turret Mooring

motivation disconnectable system in typhoon area



Jabiru (1986)-88 m

Griffin (1993)- 131 m

Cossack/Wanaea (1995)-76 m

Jabiru Venture - RTM

In very shallow water (<50 m):

Change in thinking not buoyancy but weight

(reversed yoke tower system)

In moderate wave conditions

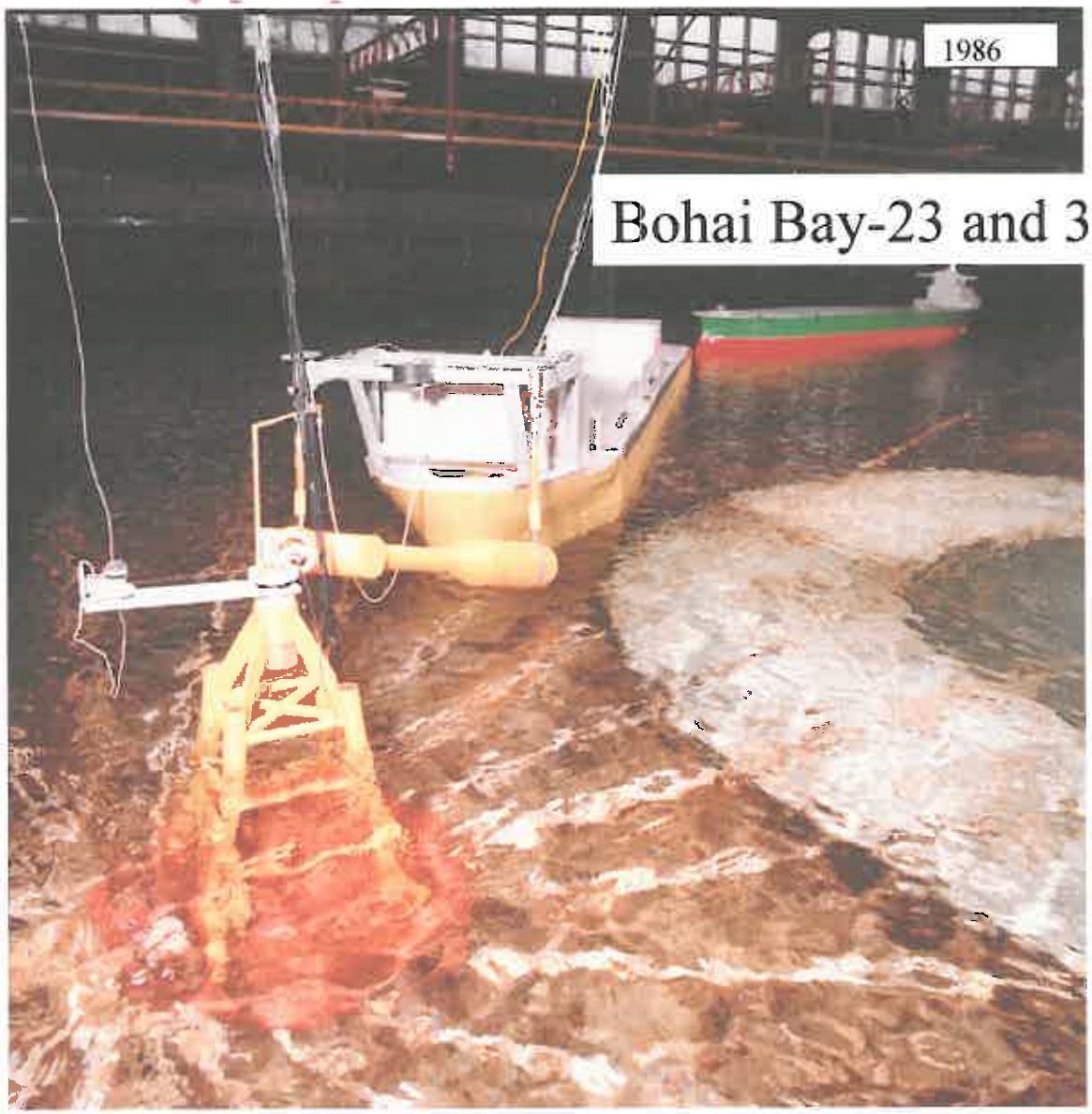
Motivation: no risers

Only jumper hoses and fluid swivels

In moderate wave conditions

Motivation: no risers

Only jumper hoses and fluid swivels



In moderate wave conditions

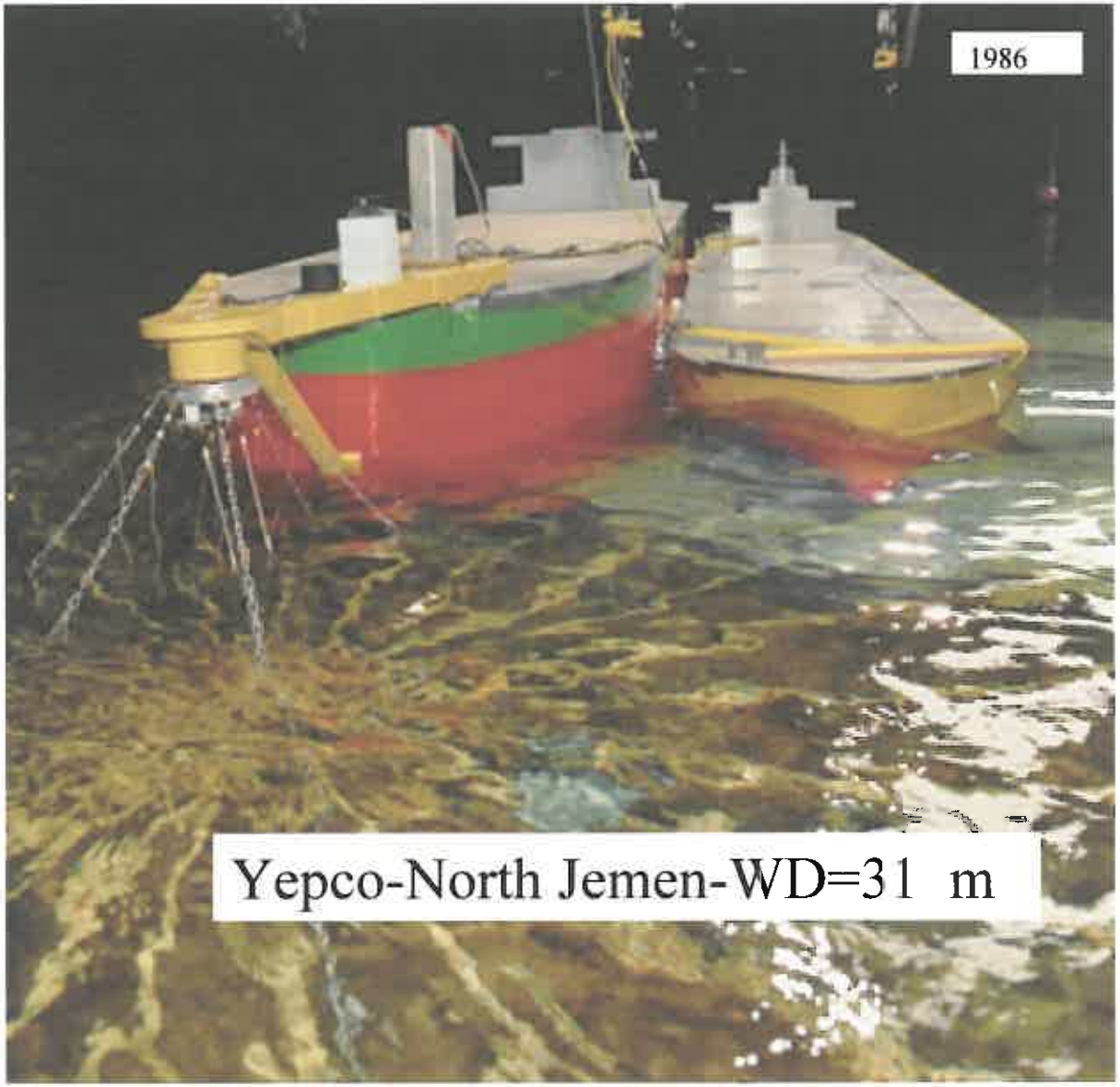
Motivation: no risers

Only jumper hoses and fluid swivels

Turret-external and internal

motivation: no structural joints

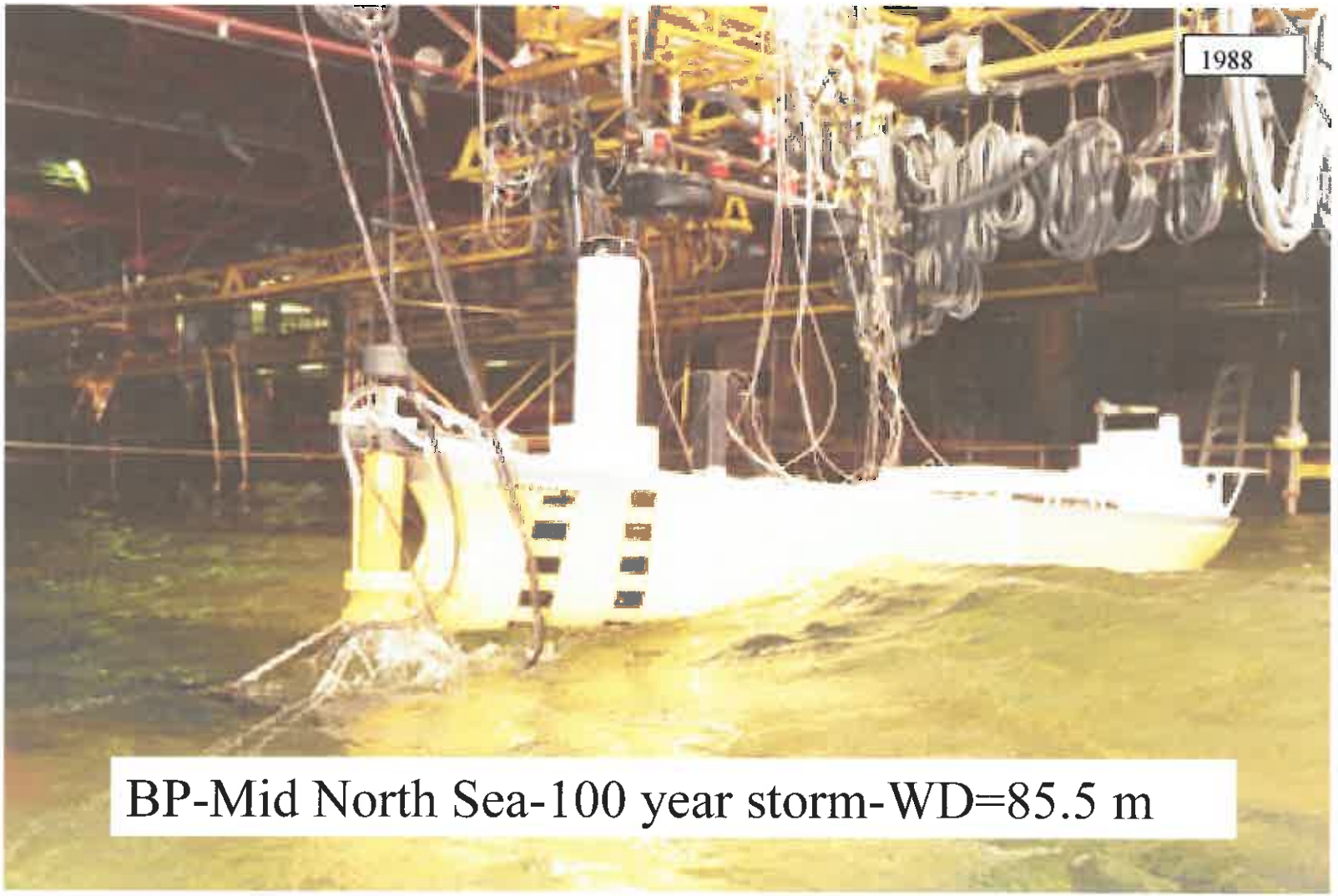
Use of risers 960275



Turret-external and internal

motivation: no structural joints

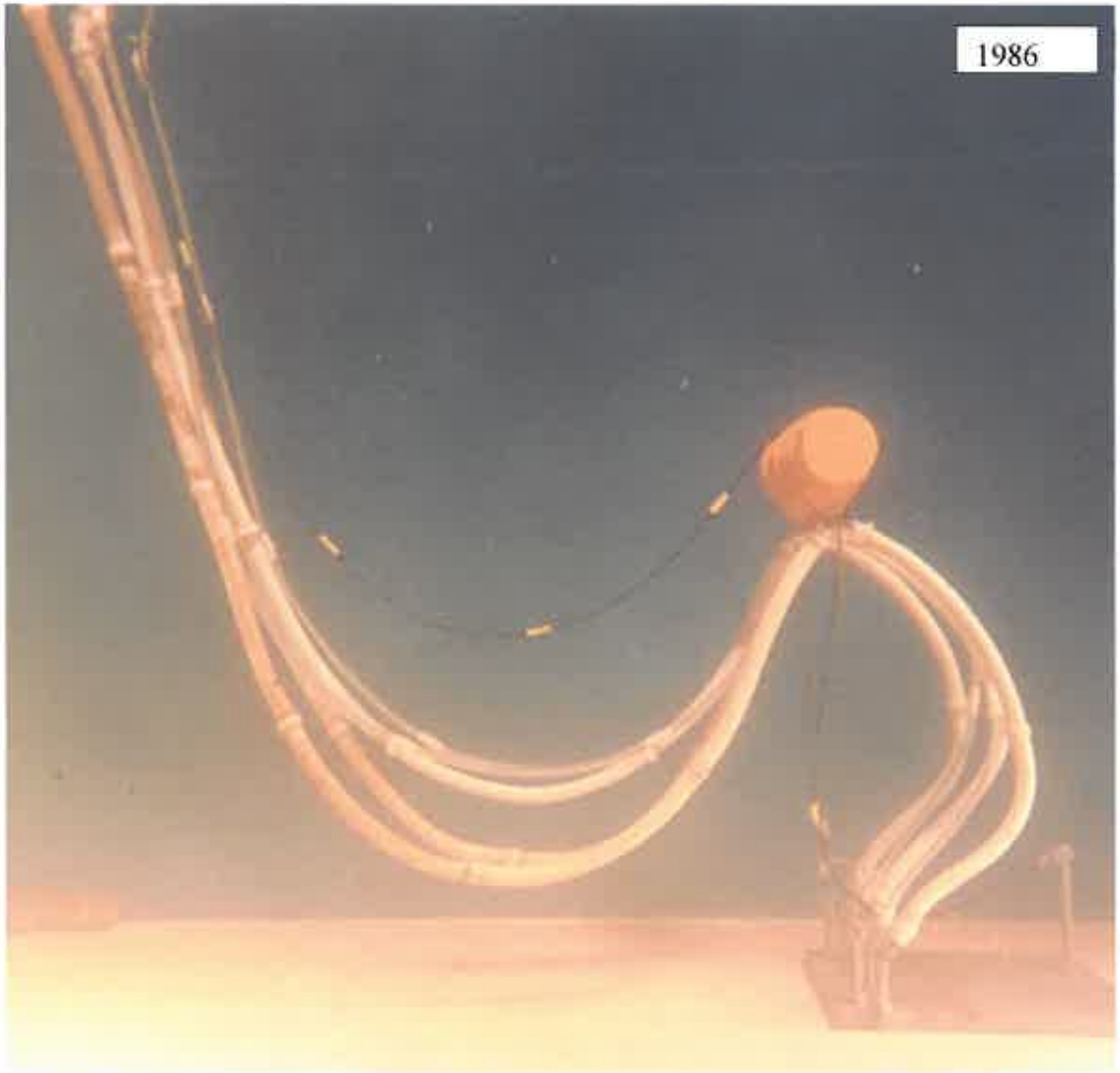
Use of risers



Turret-external and internal

careful design of risers –not touching seafloor-not taught

No high out-of-plane bending moments due to cross-current



Historical development in shallow water: 1959-2001

CALM → SBS → TURRET

(hawser replaced by yoke)

(CALM buoy fixed to vessel)

RTM/BTM

(RTM: CALM buoy with UJ connected to vessel-disconnectable)

(BTM: CALM buoy locked into vessel-disconnectable)

fluid swivel and underbuoy hoses-low pressure/risers-high pressure-turret can be disconnectable

SALM → YOKE TOWER → SALS → SOFT YOKE

(buoyancy in tower)

(buoyancy in yoke)

(reversed system)

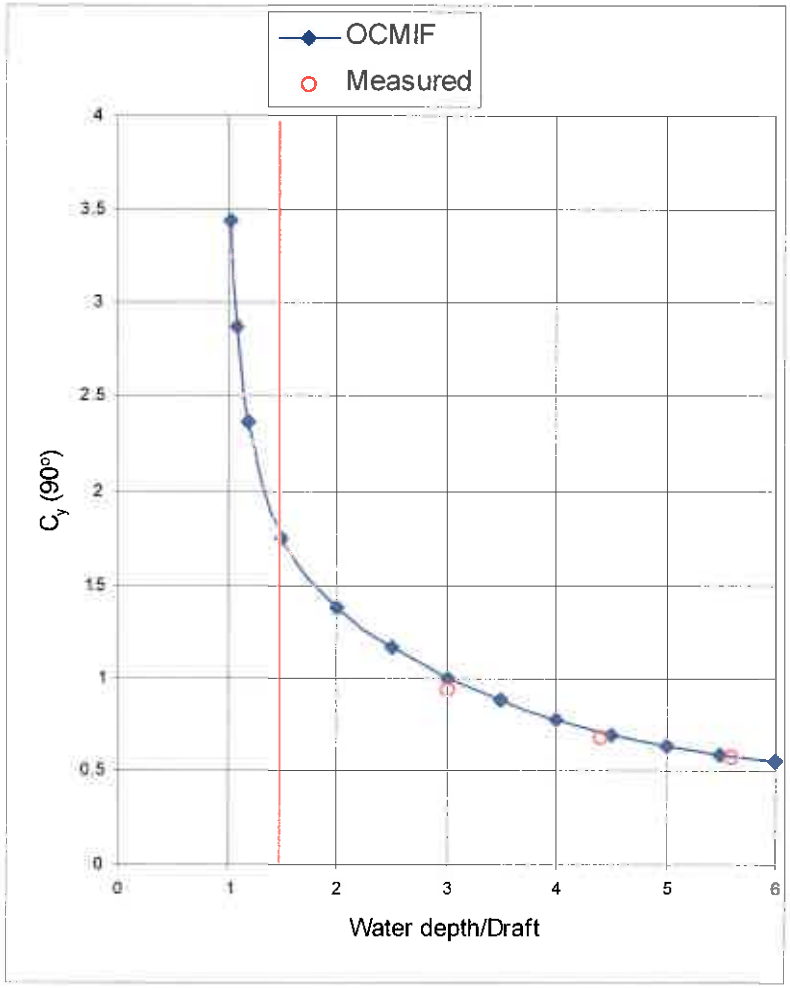
fluid swivel and jumper hoses-low or high pressure-soft yoke can be disconnectable

2) What is the difference between shallow and deep water?
Mooring system, current and waves?

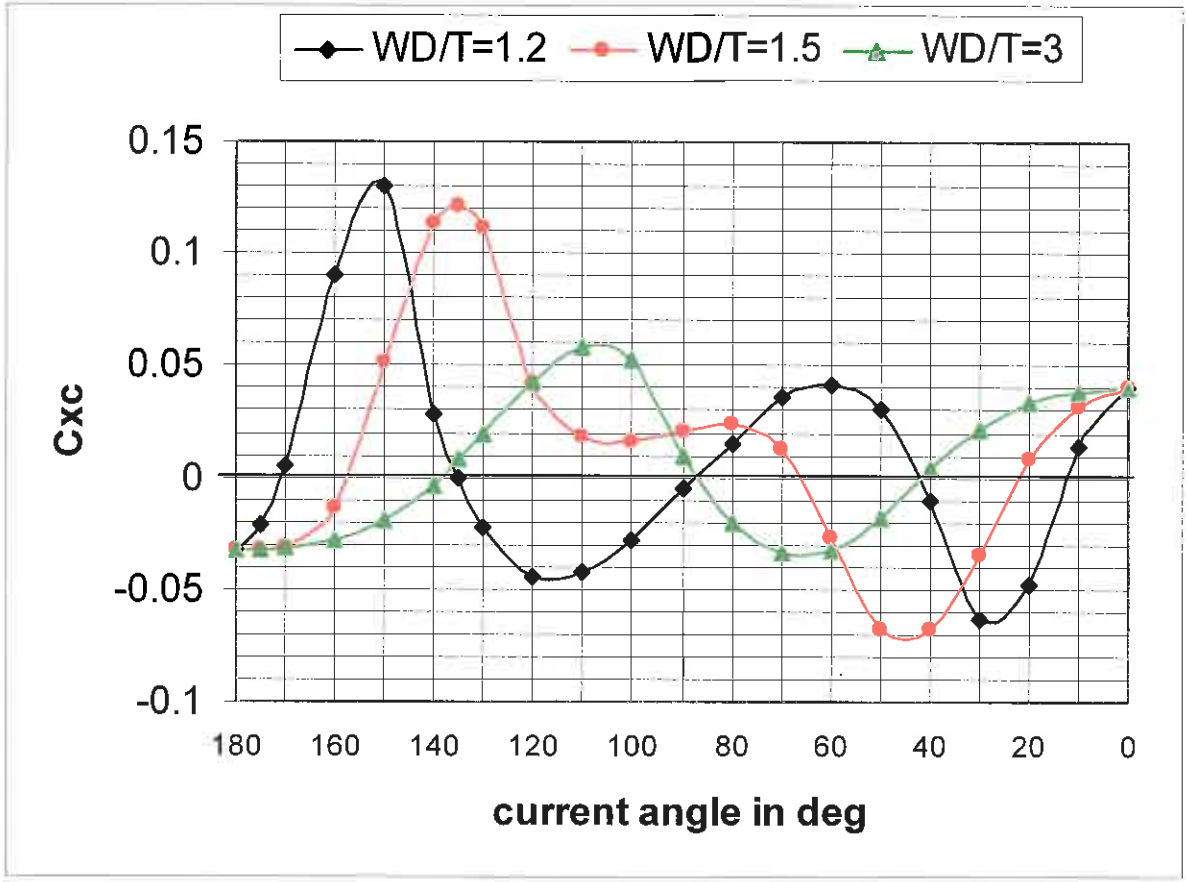
Current?

Current loads on VLCC's

$$X_{current} = 0.5\,\rho_w\,V_{cr}^2\,C_{cx}(\alpha_{cr})\,T\,L_{PP}$$
$$Y_{current} = 0.5\,\rho_w\,V_{cr}^2\,C_{cy}(\alpha_{cr})\,T\,L_{PP}$$
$$N_{current} = 0.5\,\rho_w\,V_{cr}^2\,C_{cn}(\alpha_{cr})\,T\,L_{PP}^2$$

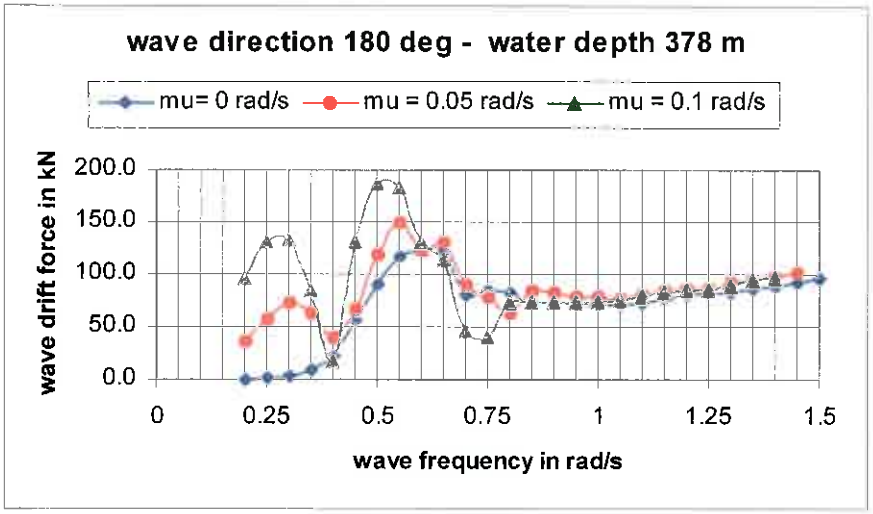


High current loads in sway and yaw direction in shallow water

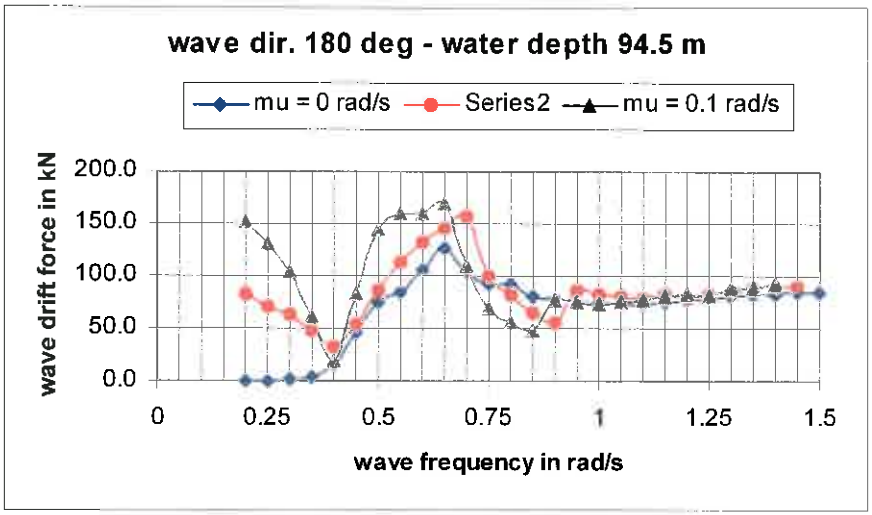


In surge direction due to large lift force in shallow water : positive surge force (driven force fishtailing hawser moored SPM VLCCs)

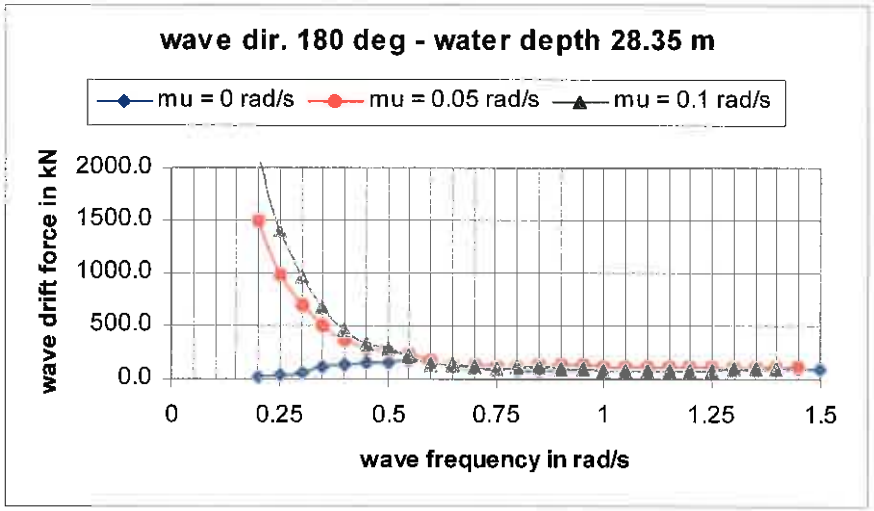
waves?



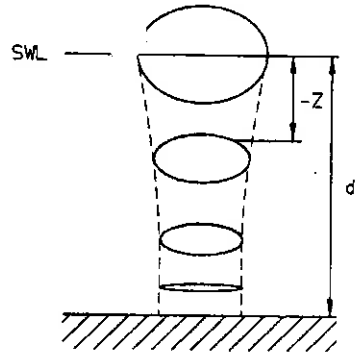
WD/T= 20



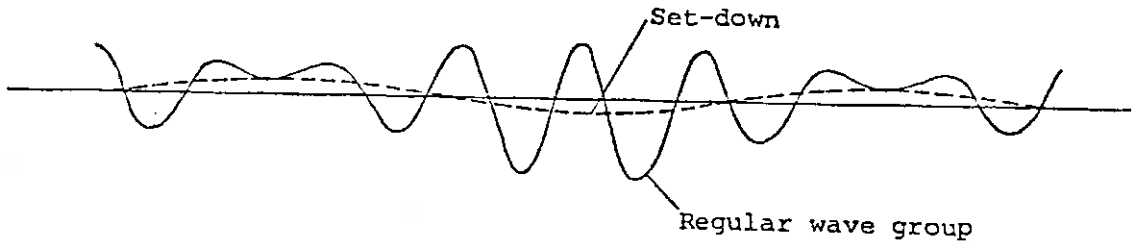
WD/T=5



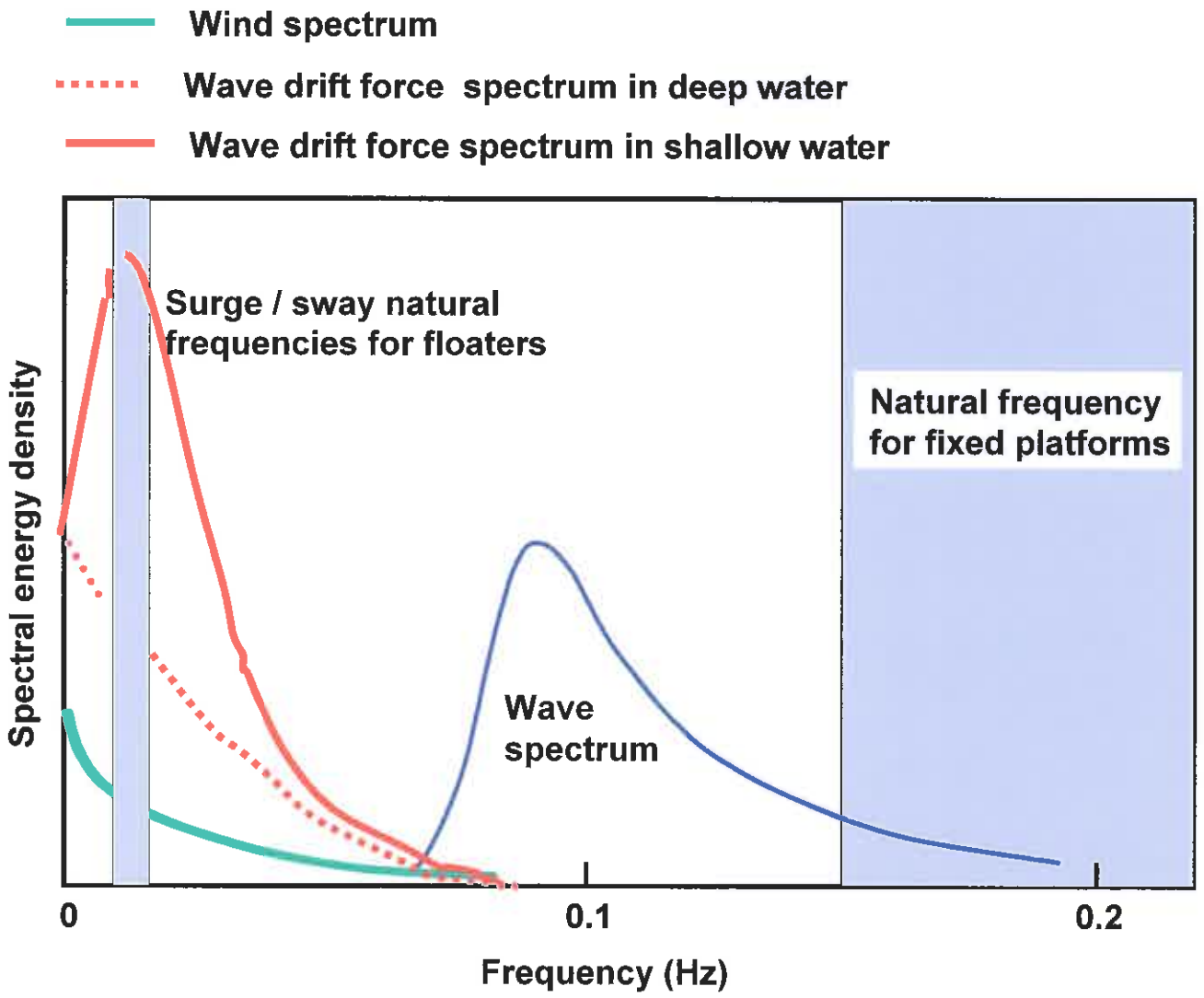
WD/T= 1.5



Particle orbits according to linear wave theory.

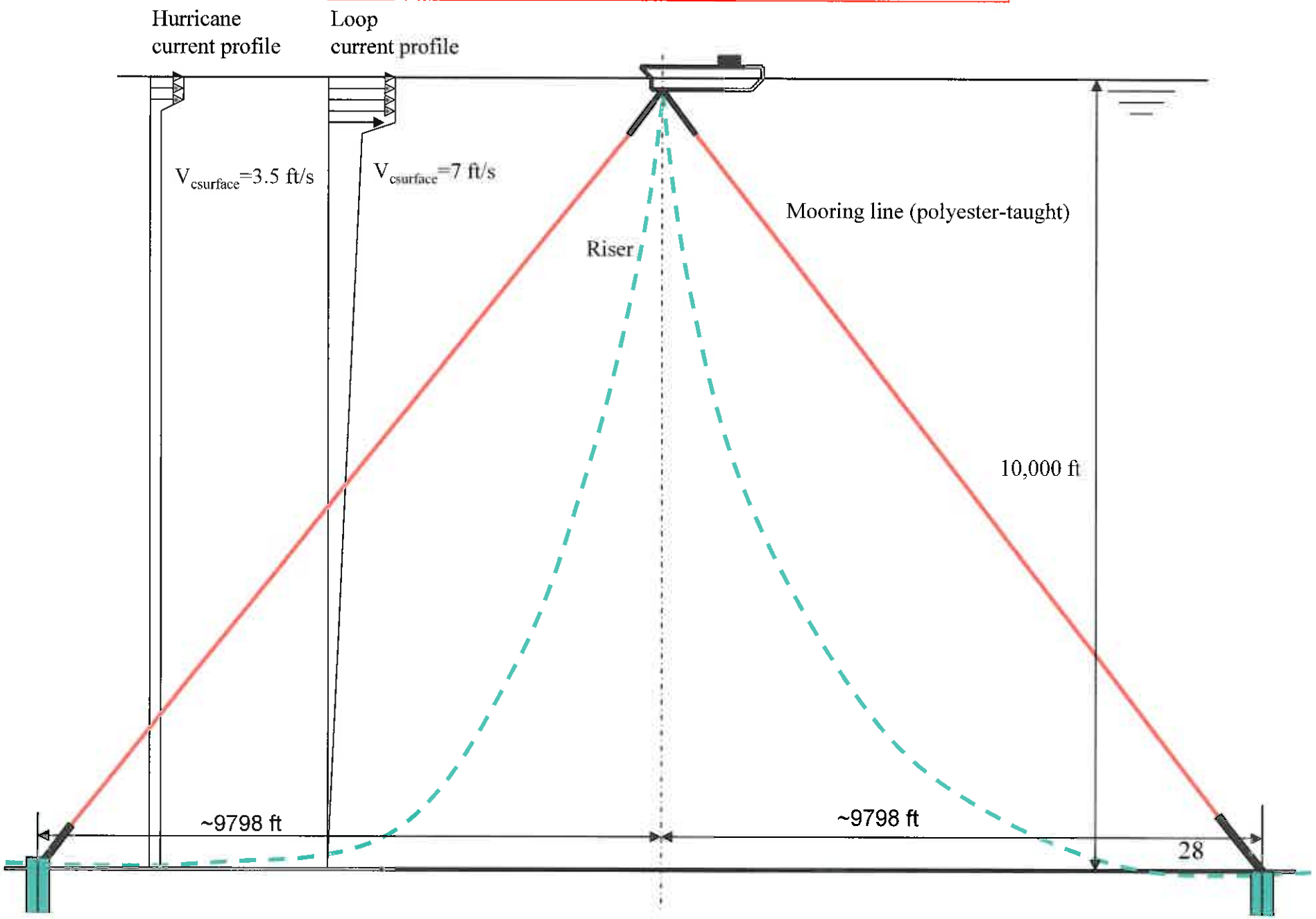


Shallow water causes wave group set down: direct long wave excitation force.

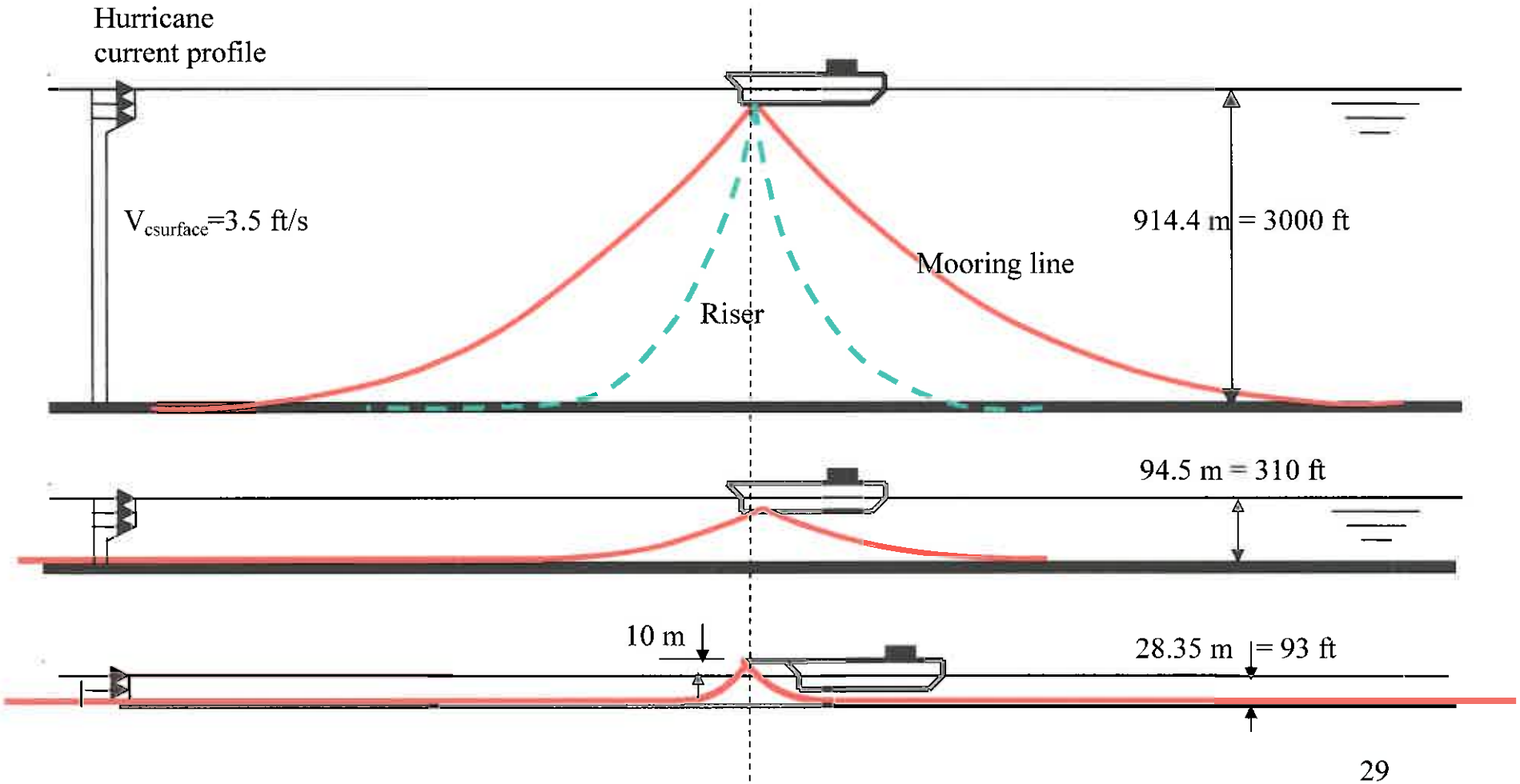

Wind spectrum
Wave drift force spectrum in deep water
Wave drift force spectrum in shallow water
Surge / sway natural frequencies for floaters
Natural frequency for fixed platforms
Wave spectrum
Spectral energy density
0
0.1
0.2
Frequency (Hz)

Mooring system?

Water depth 3048 m (10,000 ft)



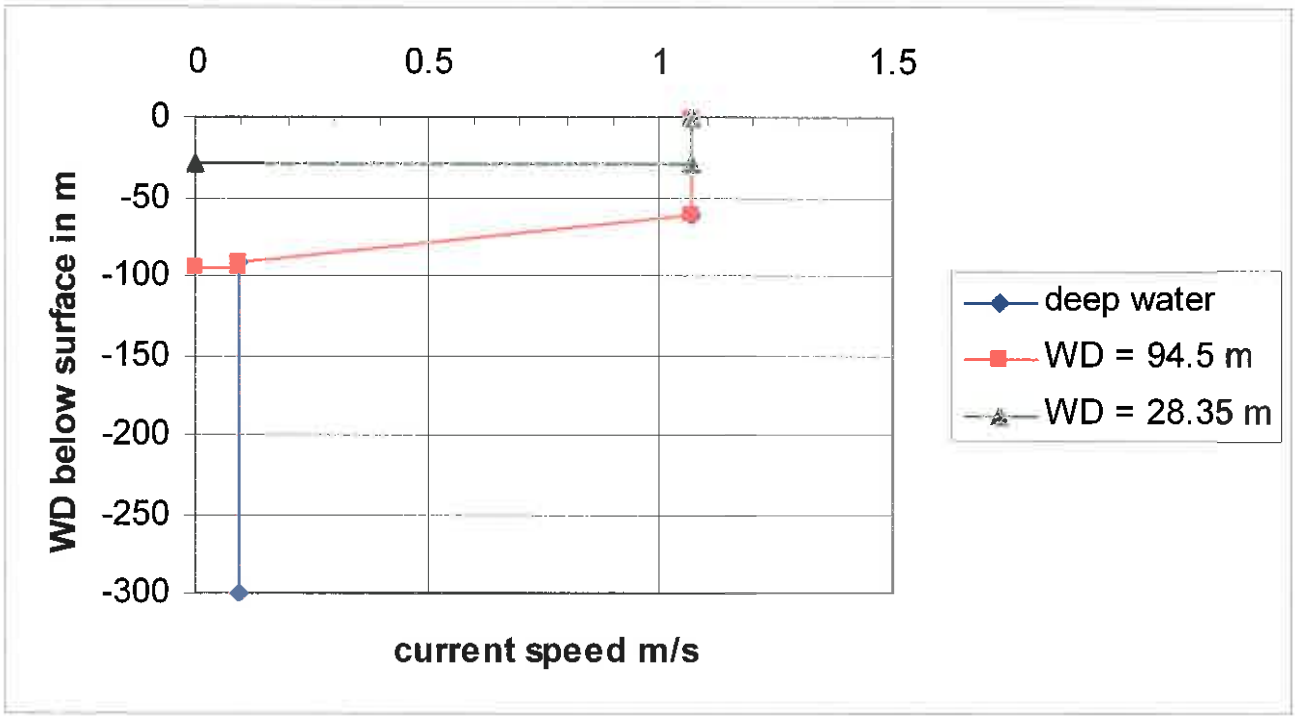
Water depth 914.4 m, 94.5 m and 28.35 m



Description	Hurricane
Waves:	
Hs in m	12.19
Tp in sec	14
Wave spectrum type	Jonswap(γ=2.5)
Wave direction	180°
Wind:	
Wind speed	
1 hour mean speed	41.12 m/sec@10 m
Wind spectrum type	API
Wind direction	210°
Current:	
Current direction:	150°
0 m-surface	1.07 m/sec
61 m	1.07 m/sec
91 m	0.09 m/sec
Seabed	0.09 m/sec

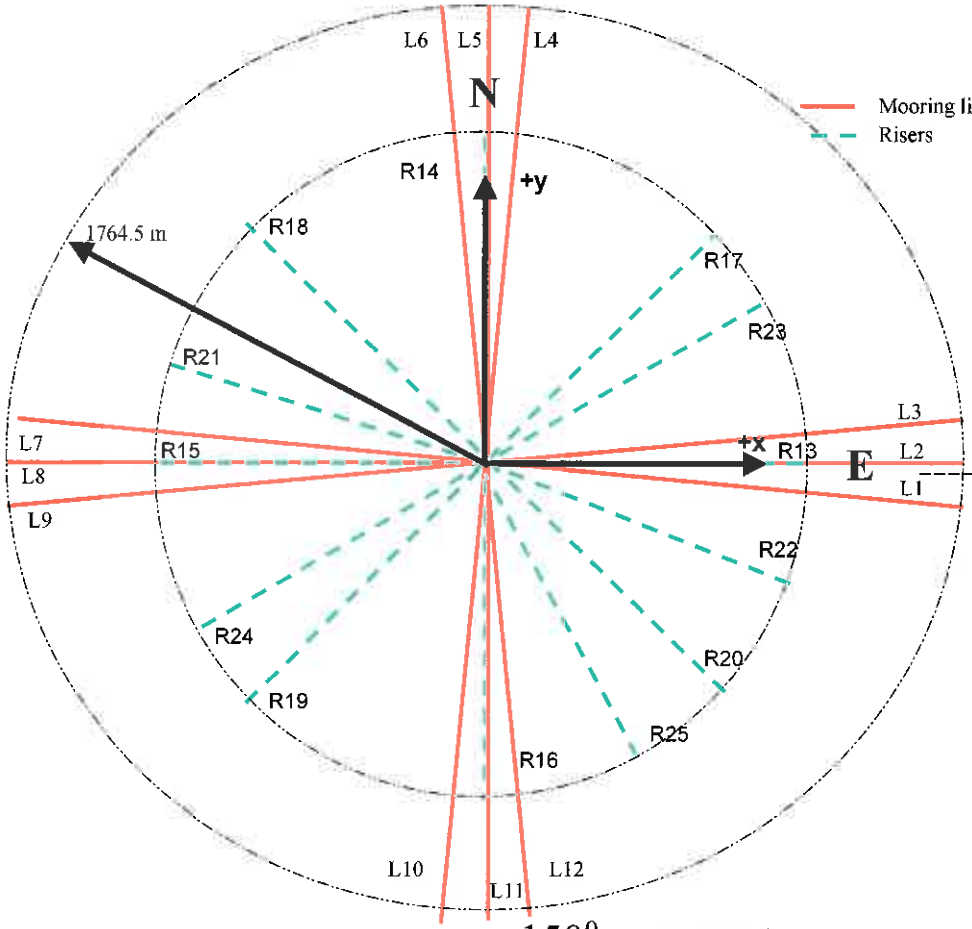
FPSO:
production level 120,000 bpd
storage 1,440,000 bbls
Tanker size 200 kDWT

3,048 m-polyester- 4"
914.4 m-spiral wire- 3.5"
94.5 m-spiral wire- 4.5"
28.35 m- spiral wire - 6-3/8"

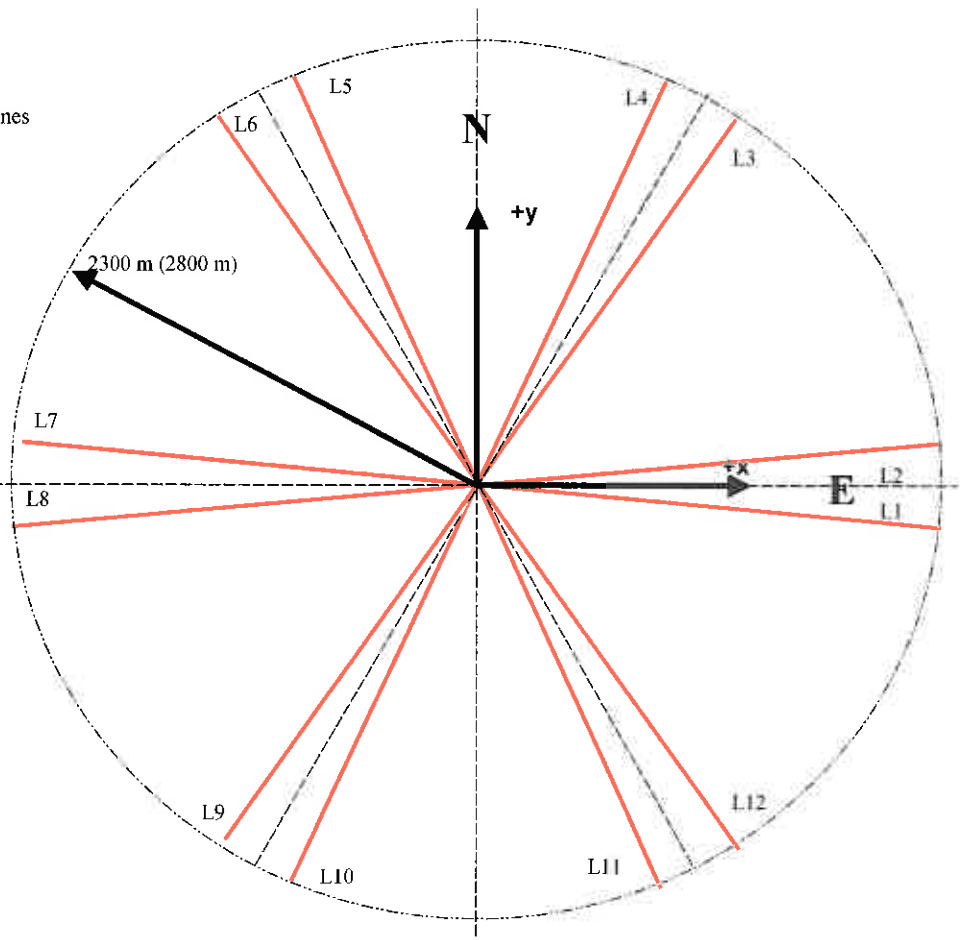

0
0.5
1
1.5
0
-50
-100
-150
-200
-250
-300
WD below surface in m
current speed m/s
deep water
WD = 94.5 m
WD = 28.35 m

Global motions and mooring forces in shallow an deepwater

Mooring pattern in 3045 m and 913.5 m water depth



Mooring pattern in 94.5 m and 28.5 m water depth

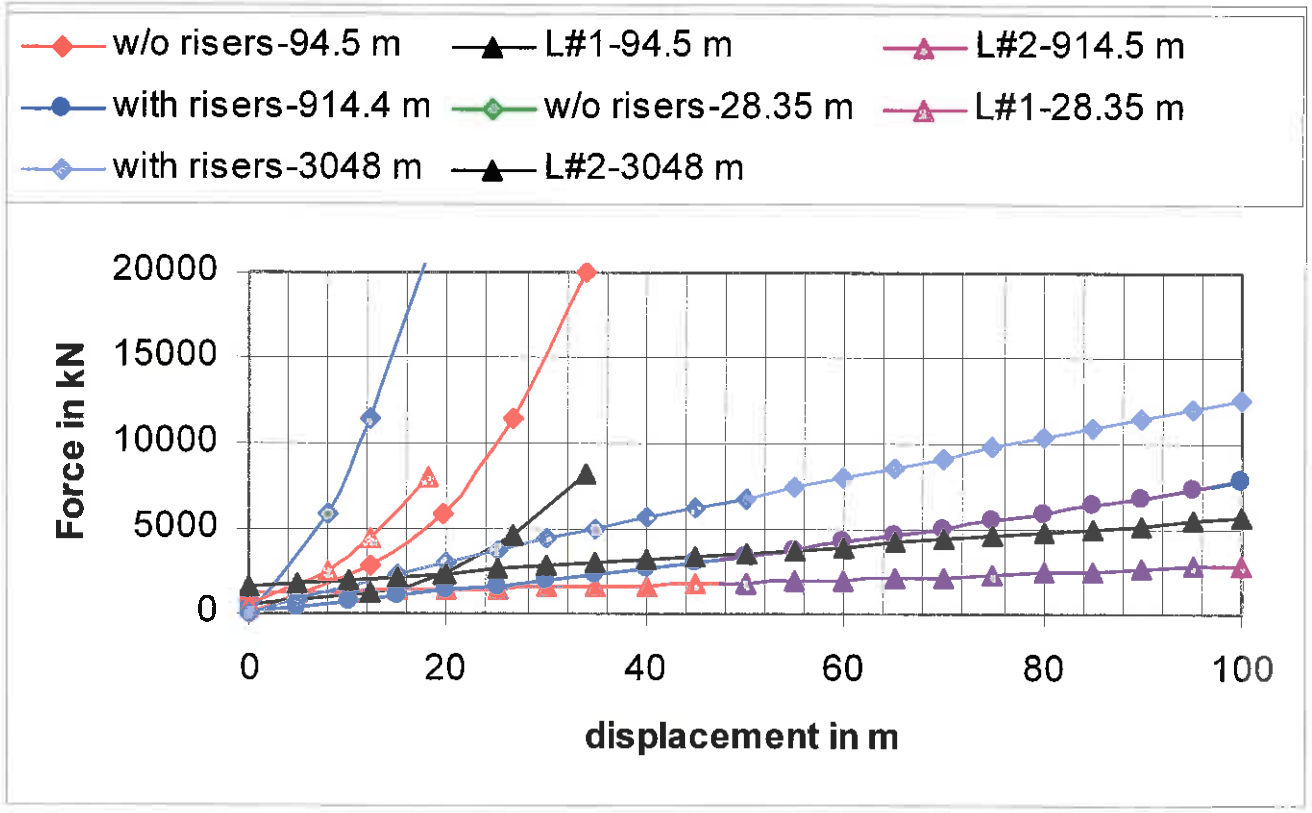


150^0 - current

180^0 - waves

210^0 - wind

Designation	Unit	Internal	Internal	Internal	External
Water depth	m	**3,048**	**914.4**	**94.5**	**28.35**
Pre-tension	kN	1,691	1,201	503.7	472
Number of lines		4*3	4*3	6*2	6*2
Angle between lines	degr.	5	5	2*5	2*5
Length of mooring line	m	4,267	2,088	1,900	2,800
WD/Length ratio		1.4	2.28	20.1	84.8
Radius chain stoppers	m	7	7	7	7
Segment 1 (ground): Chain		K4 studless			
Length at anchor point	m	122	914.4	50	50
Diameter	inch	4	3.5	4.5	6--3/8
Diameter	mm	101.6	88.9	114	162
Mass	kg/m	215	164.80	284.6	575
Weight in water	N/m	1,838	1,406.90	2,429.1	4,905
Stiffness AE	kN	1,037,720	794,484	1,121,000	2,266,000
Mean breaking load (MBL)	kN	8,669	6,512	12,420.5	22,320
Segment 2: wire		polyester	spiral strand*)		
Length	m	4,054	1,127.80	1,600	2300
Diameter	inch	7.09	3.5	4.5	6
Diameter	mm	180	107.95	137	174
Dry weight	kg/m	21.7	42	70	120
Weight in water	N/m	56	350	539.6	941.8
Stiffness AE	kN	240,192	689,858	1,200,000	2,100,000
Mean breaking load (MBL)	kN	9,576	6,418	12,263	21,582
Segment 3 (top): Chain		K4 studless			
Length	m	91	45.7	250	450
Diameter	inch	4	3.5	4.5	6--3/8
Diameter	mm	101.6	88.9	114	162
Dry weight	kg/m	215	164.80	284.60	575
Weight in water	N/m	1,838	1,406.89	2,429.10	4,905
Stiffness AE-average	kN	1,037,720	794,484	1,121,000	2,266,000
Mean breaking load (MBL)	kN	8,669	6,512	12,420.50	22,320
*)Sheathing thickness included					


w/o risers-94.5 m
L#1-94.5 m
L#2-914.5 m
with risers-914.4 m
w/o risers-28.35 m
L#1-28.35 m
with risers-3048 m
L#2-3048 m
20000
15000
10000
5000
0
Force in kN
0
20
40
60
80
100
displacement in m

		Hs=12.19 m-Hurricane-3048 m-pol.-4"					Hs=12.19 m-Hurri.-914.4 m-spiral-3.5"				
	unit	Fpre-t	mean	st.dev.	min	max	Fpre-t	Mean	st.dev.	min	Max
x_1-motion turret	m		-21.1	9.5	-60			-43.7	15.5	-97	-8.3
X_2-motion turret	m		5.4	1.7		13.1		15.4	2.8	7.5	25
Heave turret	m		0	2.5		10		0	2.5	-9.4	10
Roll	deg		0	0.6		2.5		0	0.6	-2.9	3.1
Pitch	deg		0	1.2		4.4		0	1.2	-4.3	4.4
Yaw	deg		8.98	1.89		14.9		8.96	2.2	2.3	15.97
Force in L#2	kN	1691	2464	377		4071	1,201	1767	355	493	3508
Force in L# 8	kN	1691	1150	251		1943	1,201	864	208	0	1968
X-force turret	kN		2697	2148		12954		2688	1358	-1438	9135
Y-force turret	kN		-1460	874	-7618			-1455	570	-5438	-60
Z-force turret	kN	62209	-62793	11339	-154390		25149	-25589	5158	-66537	-1332
Liquid production R#13	kN	3714	3762	876		11513	1113	1185	282	0	3841
Gas production R#20	kN	2033	2086	840		9307	610	668	258	0	3374
Gas export R#25	kN	1530	1564	643		7212	454	484	196	0	2433
		Hs-12.19 m-Hurricane-94.5 m-spiral-4.5"					Hs=12.19 m-Hurricane-28.35 m-spiral-6"				
	unit	Fpre-t	Mean	st.dev.	min	Max	Fpre-t	Mean	st.dev.	min	Max
x_1-motion turret	m		-9.5	7.9	-33.6	15.5		-3.2	9.8	-40.1	32
X_2-motion turret	m		4.9	3.6	-8.5	16		1.2	1.4	-7.0	7.2
Heave turret	m		0	2.09	-7.52	8.29		0	2.3	-7.7	8.7
Roll	deg		0	0.42	-0.6	13.1		0	0.6	-4.5	4.5
Pitch	deg		0	1.02	-3.6	3.5		0	0.53	-1.9	1.7
Yaw	deg		7.6	1.9	-0.6	13.1		-4.1	1.0	-9.0	-1.4
Force in L#1	kN	503.7	1298	746	246	7741	472	2474	3178	0	24522
Force in L#2	kN	503.7	1211	685	243	7164	472	2408	3098	0	24020
Force in L#3	kN	503.7	614	203	147	1644	472	1157	1061	0	10327
Force in L#12	kN	503.7	1141	420	278	40170	472	1638	1683	0	14745
Force in L#7	kN	503.7	334	115	0	1571	472	1166	1889	0	17823
X-force turret	kN		2351	2168	-4150	17876		3358	11616	-50749	70573
Y-force turret	kN		-1498	991	-7843	895		-761	1671	-10419	80852
Z-force turret	kN	-4726	-5163	587	-10155	-1962	-5449	-7041	1670	-16786	-2200

Hs=12.19 m not allowed

		Hs=12.14 m-Hurricane-3048 m-pol.-4"					Hs=12.14 m-Hurri.-914.4 m-spiral-3.5"				
	unit	Fpre-t	mean	st.dev.	min	max	Fpre-t	Mean	st.dev.	min	Max
x_1-motion turret	m		-21.1	9.5	-60			-43.7	15.5	-97	-8.3
X_2-motion turret	m		5.4	1.7		13.1		15.4	2.8	7.5	25
Heave turret	m		0	2.5		10		0	2.5	-9.4	10
Roll	deg		0	0.6		2.5		0	0.6	-2.9	3.1
Pitch	deg		0	1.2		4.4		0	1.2	-4.3	4.4
Yaw	deg		8.98	1.89		14.9		8.96	2.2	2.3	15.97
Force in L#2	kN	1691	2464	377		4071	1,201	1767	355	493	3508
Force in L# 8	kN	1691	1150	251		1943	1,201	864	208	0	1968
X-force turret	kN		2697	2148		12954		2688	1358	-1438	9135
Y-force turret	kN		-1460	874	-7618			-1455	570	-5438	-60
Z-force turret	kN	62209	-62793	11339	-154390		25149	-25589	5158	-66537	-1332
Liquid production R#13	kN	3714	3762	876		11513	1113	1185	282	0	3841
Gas production R#20	kN	2033	2086	840		9307	610	668	258	0	3374
Gas export R#25	kN	1530	1564	643		7212	454	484	196	0	2433
		Hs-12.14 m-Hurricane-94.5 m-spiral-4.5"					Hs=7.1 m-Hurricane-28.35 m-spiral-6"				
	unit	Fpre-t	Mean	st.dev.	min	Max	Fpre-t	Mean	st.dev.	min	Max
x_1-motion turret	m		-9.5	7.9	-33.6	15.5		-1.8	7.2	-27.3	21.3
X_2-motion turret	m		4.9	3.6	-8.5	16		1.4	1.3	-3.4	4.3
Heave turret	m		0	2.09	-7.52	8.29		0	1.4	-4.9	6
Roll	deg		0	0.42	-0.6	13.1		0	0.5	-1.7	1.7
Pitch	deg		0	1.02	-3.6	3.5		0	0.33	-1.1	1
Yaw	deg		7.6	1.9	-0.6	13.1		-6	0.7	-7.9	-4.6
Force in L#1	kN	503.7	1298	746	246	7741	472	1568	2093	0	14883
Force in L#2	kN	503.7	1211	685	243	7164	472	1508	2014	0	1439
Force in L#3	kN	503.7	614	203	147	1644	472	822	621	0	4973
Force in L#12	kN	503.7	1141	420	278	40170	472	1264	1155	0	9092
Force in L#7	kN	503.7	334	115	0	1571	472	990	1547	0	10313
X-force turret	kN		2351	2168	-4150	17876		1554	8085	-27765	41555
Y-force turret	kN		-1498	991	-7843	895		-831	959	-4518	2834
Z-force turret	kN		-5163	587	-10155	-1962		-6424	1224	-12132	-4113

	mooring line in kN			surge motion in		
Condition	Max	Fbr	SF	mean	s.d.	max
Hs=12.14 m-3048 m-polyester	4,071	8,669	2.13	-21.1	9.5	-60
Hs=12.14 m-914.4 m-spiral 3.5"	3,508	6,512	1.86	-43.7	16	-97
Hs=12.14 m-94.5 m- spiral 4.5 "	7,741	12,263	1.58	-9.5	7.9	-33.6
Hs=7.1 m -33 m-spiral 6"	14,883	21,582	1.45	-1.8	7.2	-34.3

Guidelines On Global Performance Verification of Deepwater Floating Structures (DeepStar)

Factors Involved in Model Testing

Factors	Shallow Water	Deep & Ultra-Deep Water
Viscosity (risers)	Not important	Important
Basin depth	Adequate	Inadequate
Modeling testing approach	Completely scaled model	Model not completely scalable. Must truncate mooring and riser systems.
Analysis tools	Not important	Necessary – must "model-the-model" to adjust model test results from truncated model to full depth system

Conclusions:

-From CALM buoy to a turret system and from SALM buoy to soft yoke: a long way

-Deepwater has another problem than shallow water:

•Deepwater: VIV, prototype values and damping more important

•Shallow water: heavier mooring system and careful design of riser system

-In shallow water: the wave drift forces and current forces are much larger than in deepwater

JEWW/09-24-01