CHALLENGES IN DEEPWATER STRUCTURES

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OUTLINE

- Introduction
- Station Keeping Systems
- Mooring System Configurations
- Spar-Yoke-Semisubmersible system
- Experimental Study
- Salient results

FLOATING SYSTEMS FOR OIL AND GAS EXPLORATION

- Floating Production Storage and Offloading System (FPSO)
- Single Point mooring And Reservoir (SPAR)
- Tension Leg Platforms (TLP)
- Semi-submersible

Purpose of Mooring

- To keep on station floatable units
- To allow relocation of the units
- To check clearance with other units or pipelines during drilling campaigns or installation procedures

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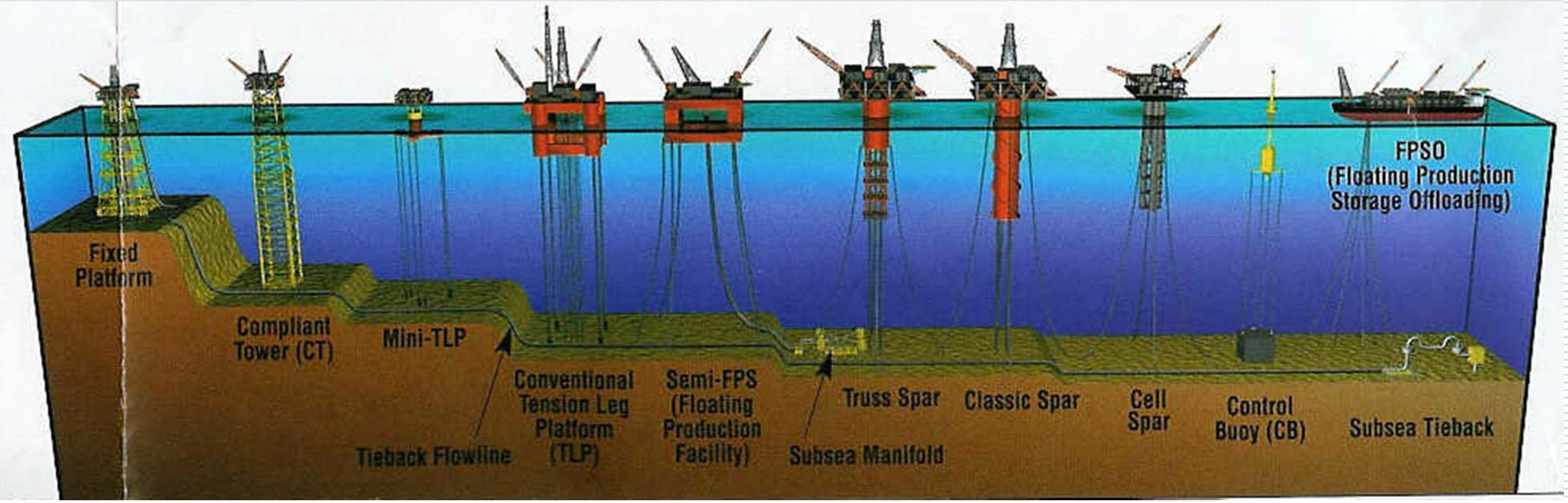
Mooring System Design

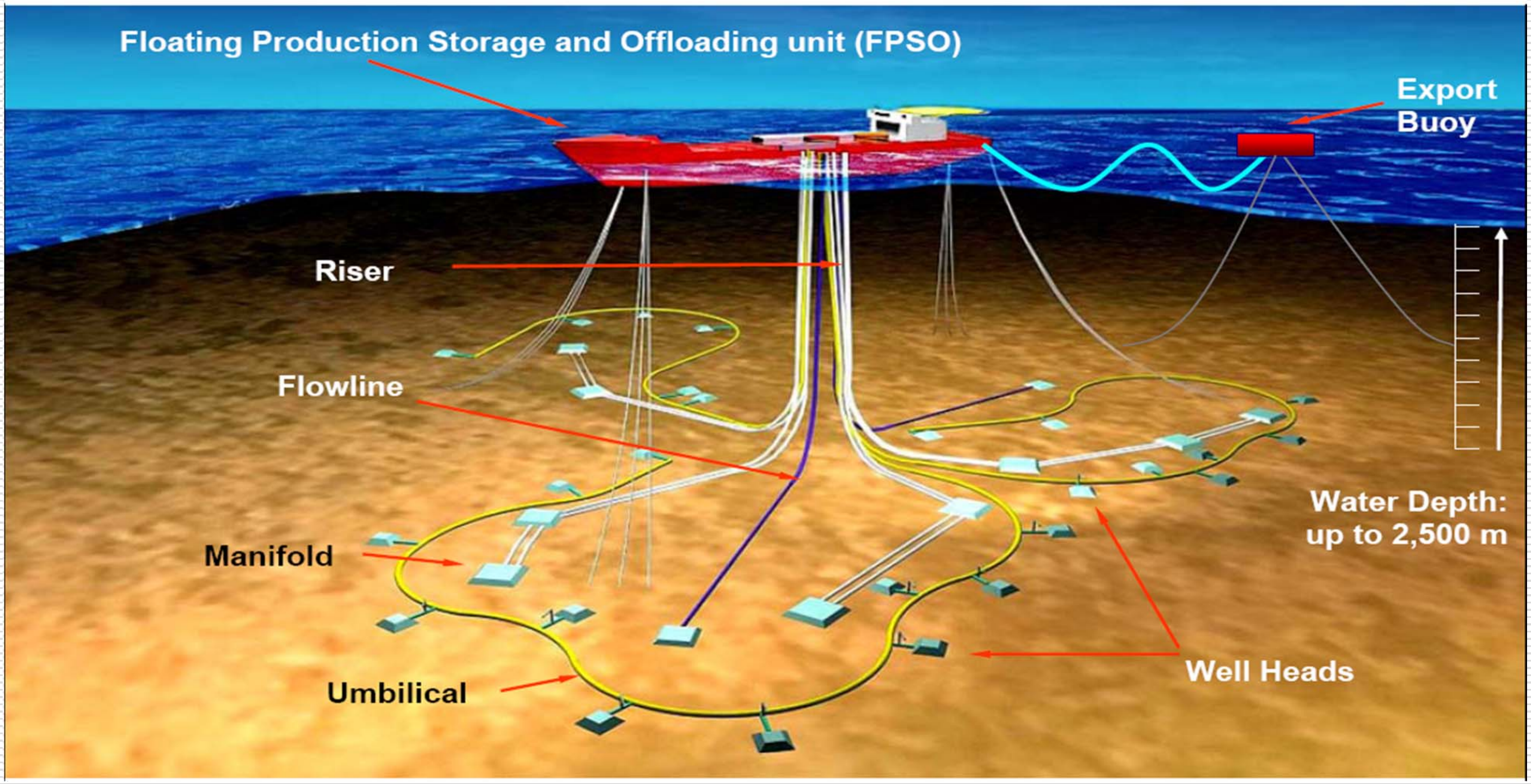
- Mooring systems
  - Single point mooring
  - Multi point mooring
  - Turret mooring
- Mooring Line
  - Materials
  - Static Analysis
  - Quasi-static Analysis
  - Dynamic Analysis
- Combined mooring line / system analysis
  - Statics & Dynamics
  - Fatigue analysis
- Model testing
- Rules, Regulations & safety factors
- Reliability of mooring systems

Station keeping system

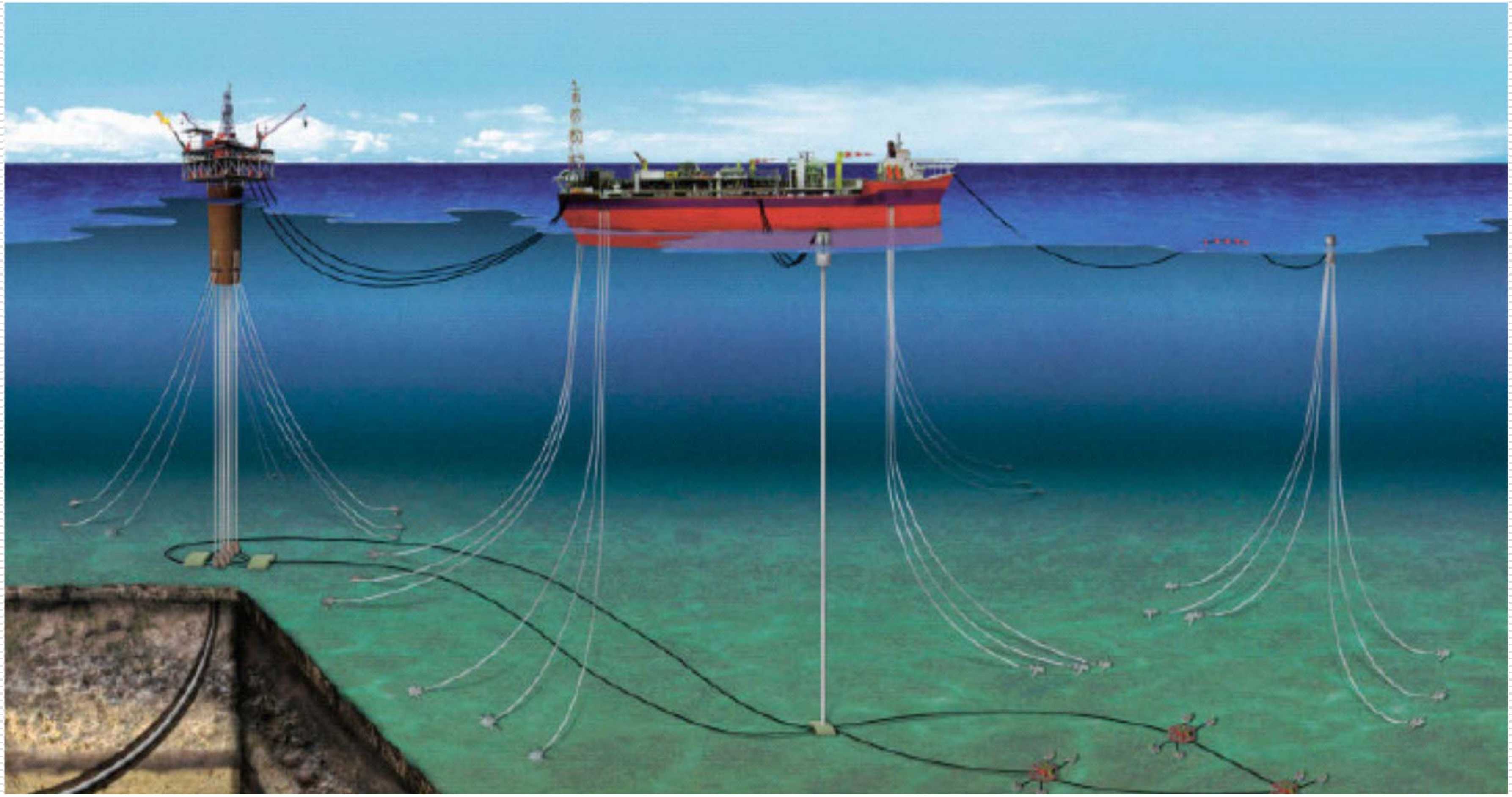
- Most floating facilities are designed to stay at a single location secured to the sea floor by a purpose built mooring system
- Some systems are designed to be disconnectable to allow escape from bad weather such as cyclones
- Dynamic positioning and Thruster Assisted station keeping is also used, though much less frequently



FLOATING, PRODUCTION, STORAGE AND OFFLOADING (FPSO)

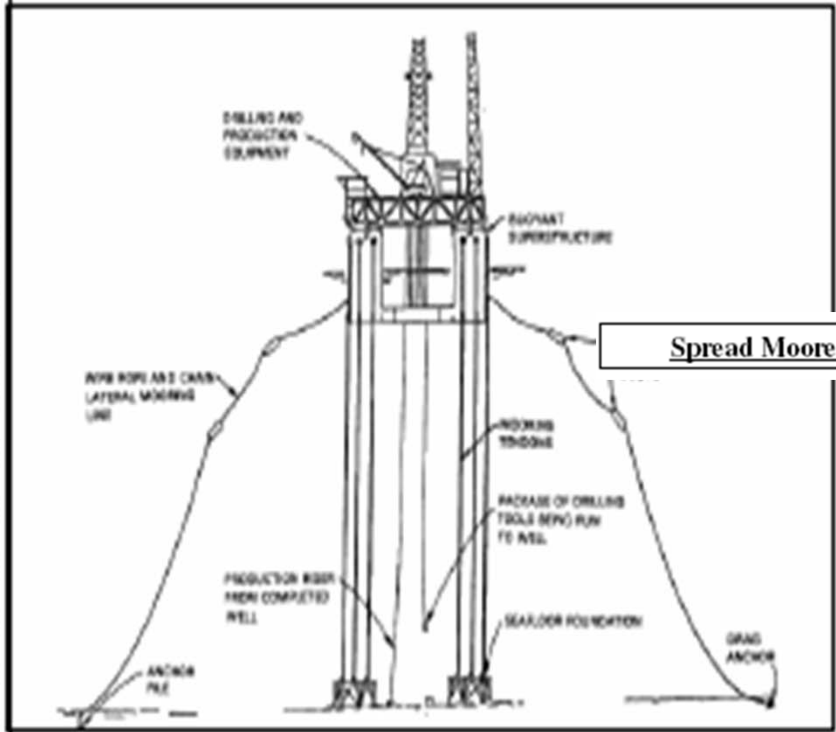


FPSO AND SPAR

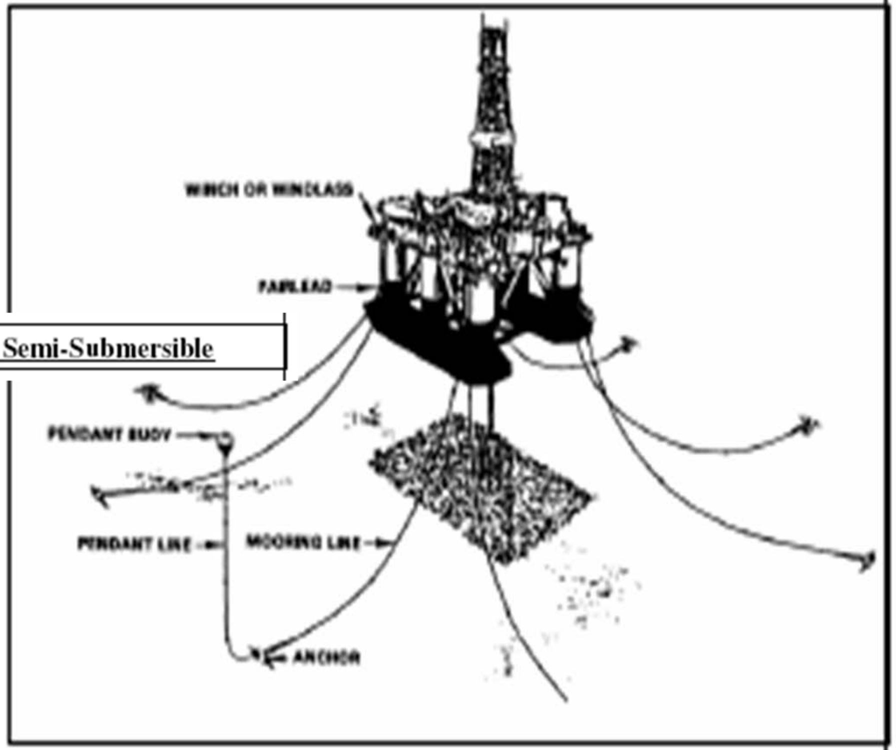


TLP AND SEMI-SUBMERSIBLE

TLP with lateral mooring



Spread Moored Semi-Submersible



Spread Moored Semi-Submersible

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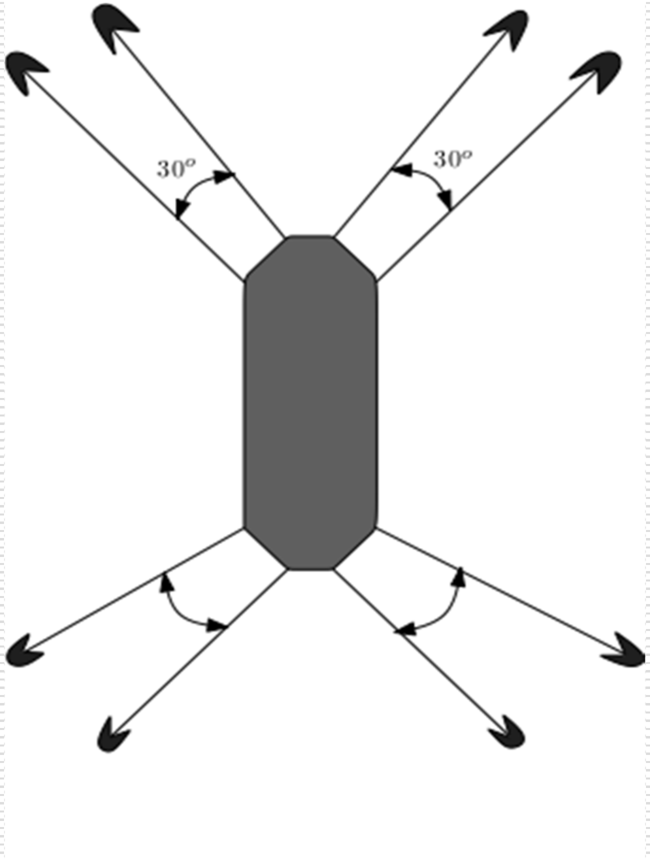
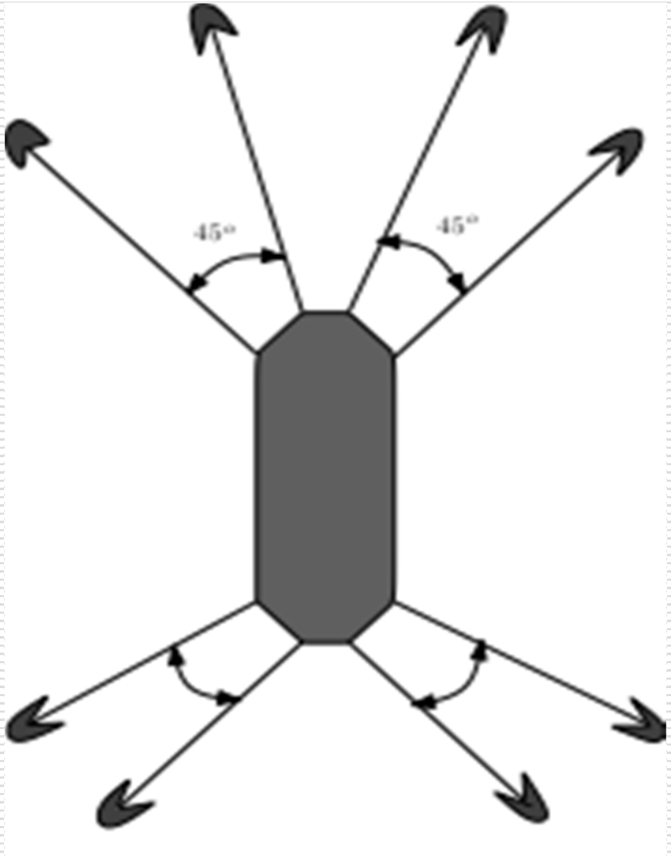
Mooring Configurations

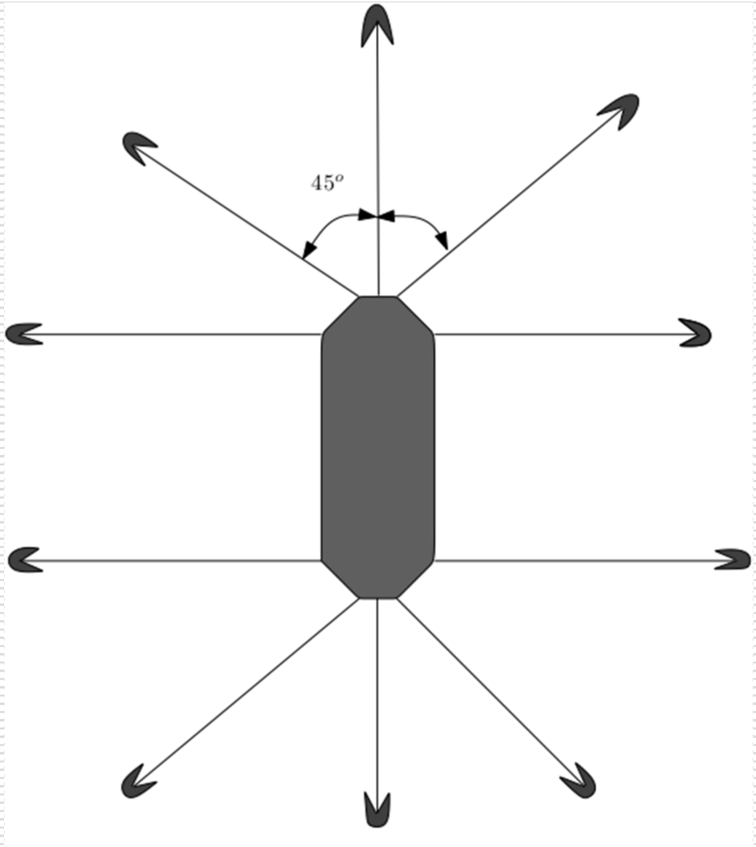


30^{0} – 8 LINE MOORING SYSTEM

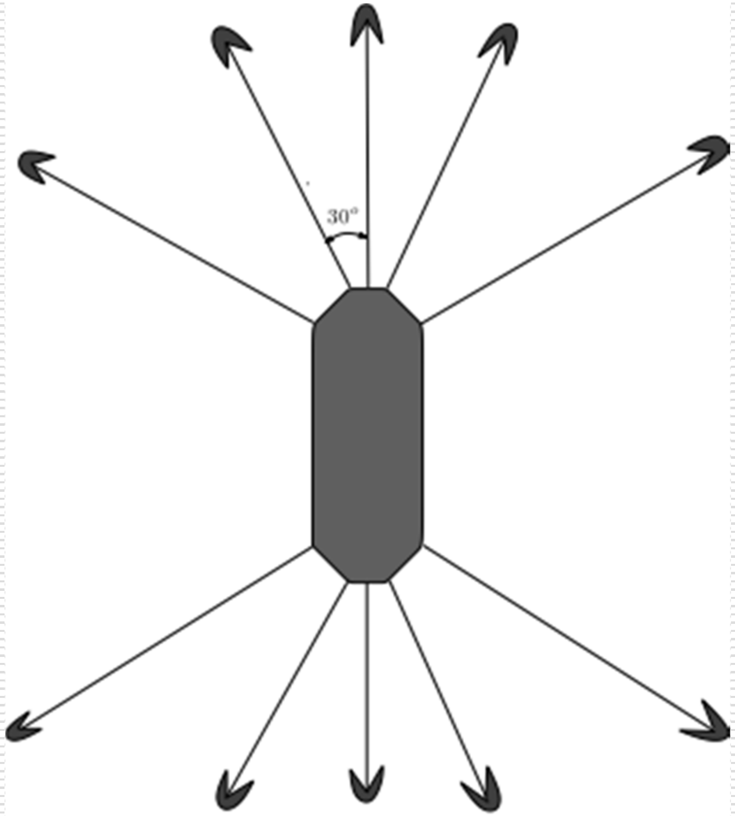


SYMMATRIC – EIGHT LINE

Mooring Configurations



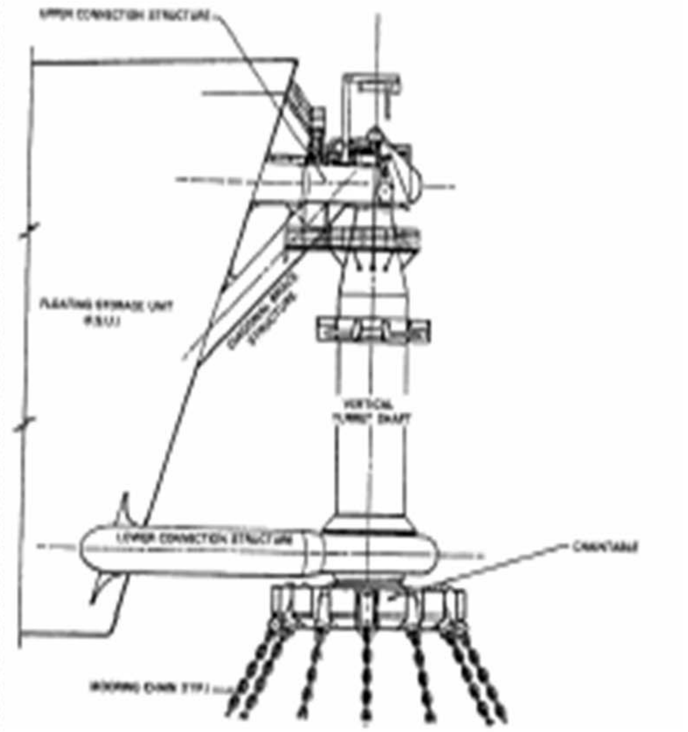
45° – TEN LINE

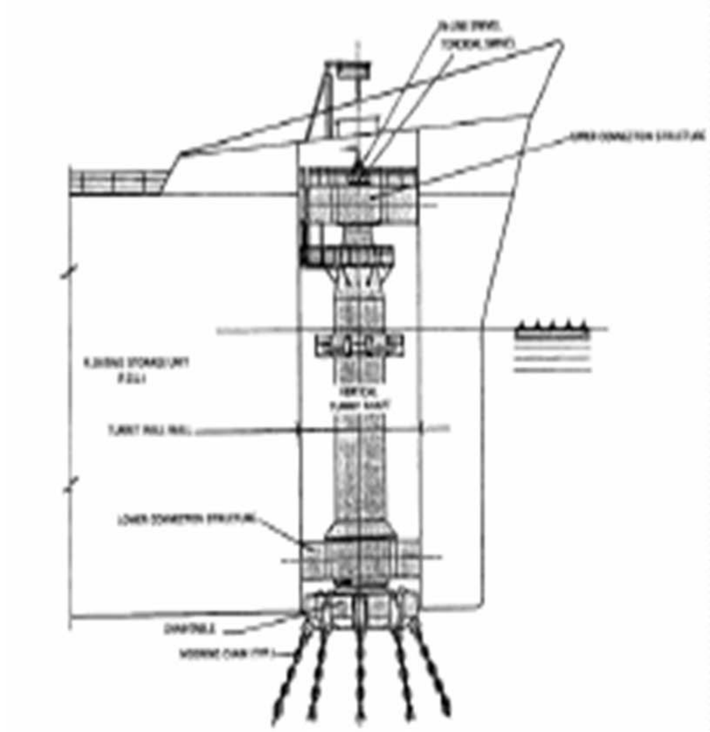


30° – TEN LINE

FPSO Turret Configurations

Bow Mounted External Turret **Bow Mounted Internal Turret**





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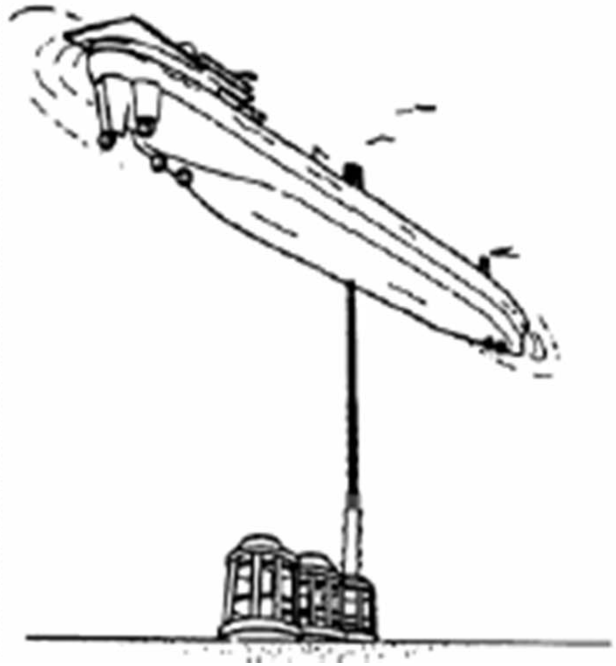
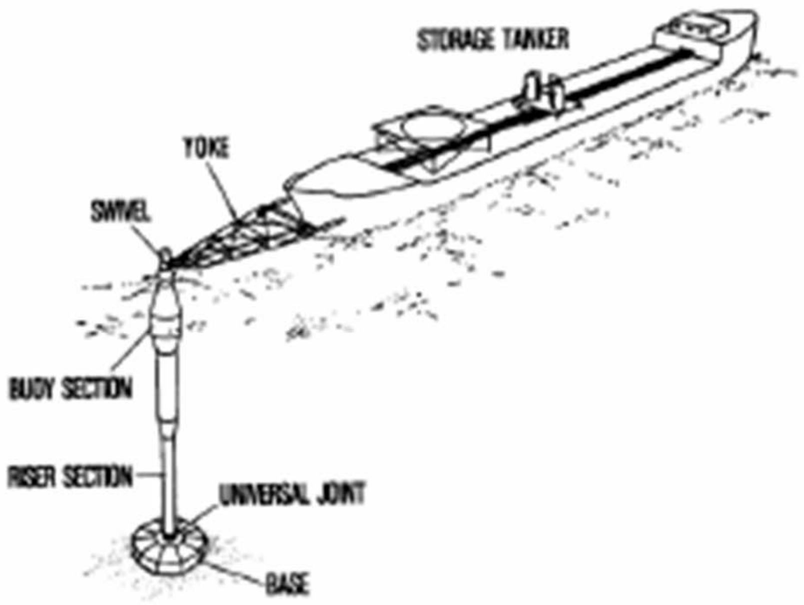
Other Station Keeping Methods

Dynamic Positioning



Single Anchor Leg Mooring (SALM)



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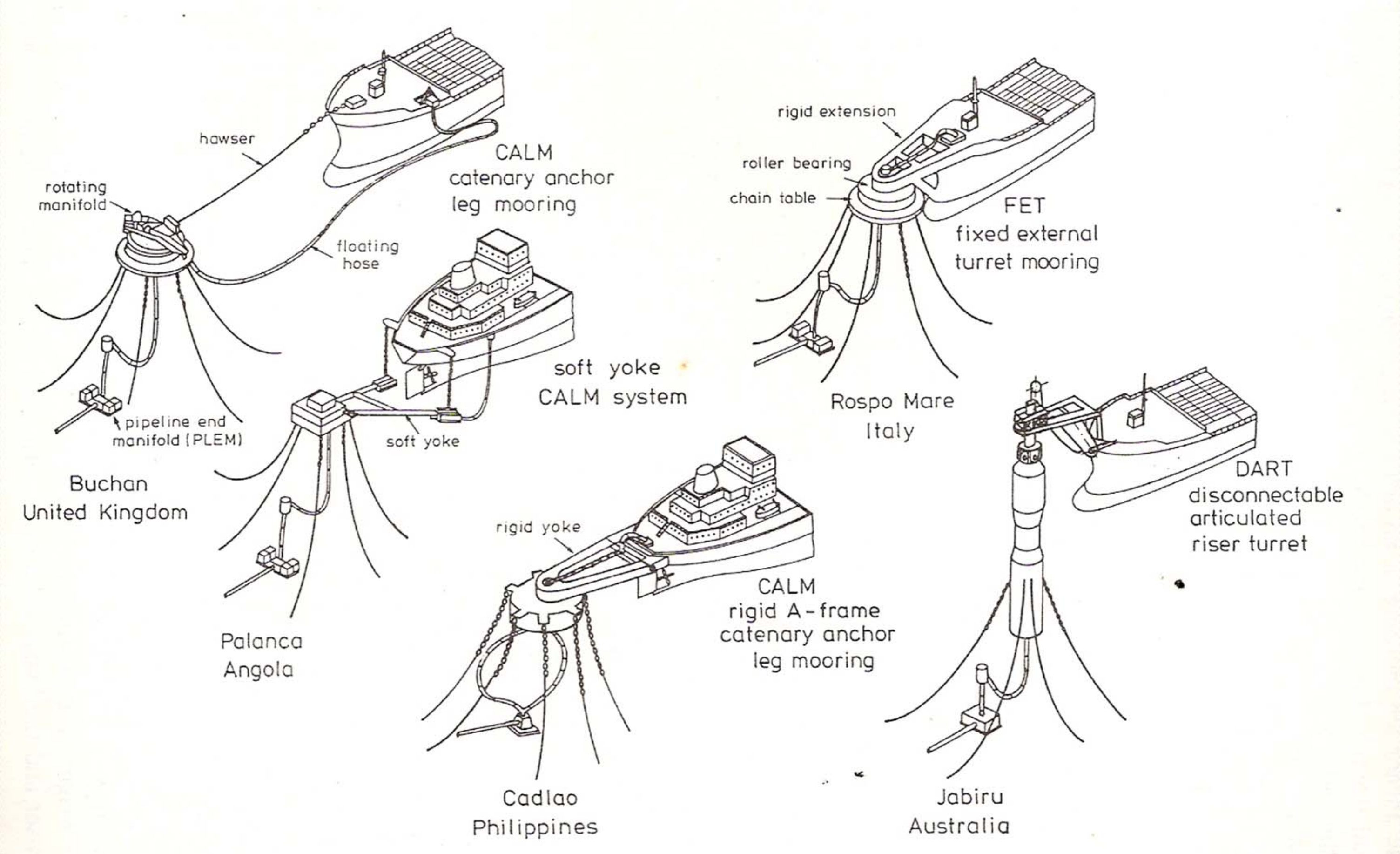
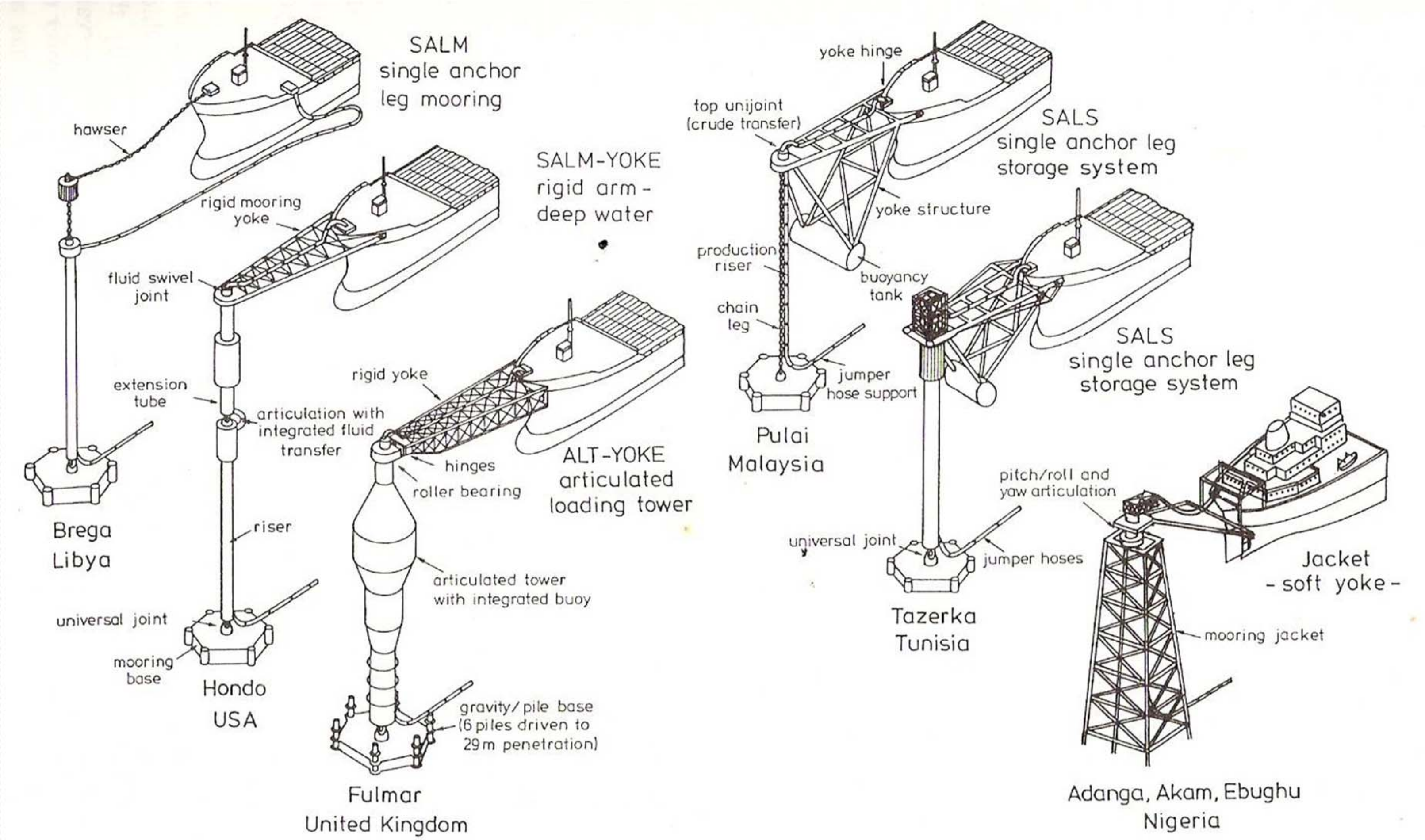
Turret Mooring Configurations



Source: Offshore Structures, G.Clause, E. Lehmann, C.Ostergaard

Turret Mooring Configurations



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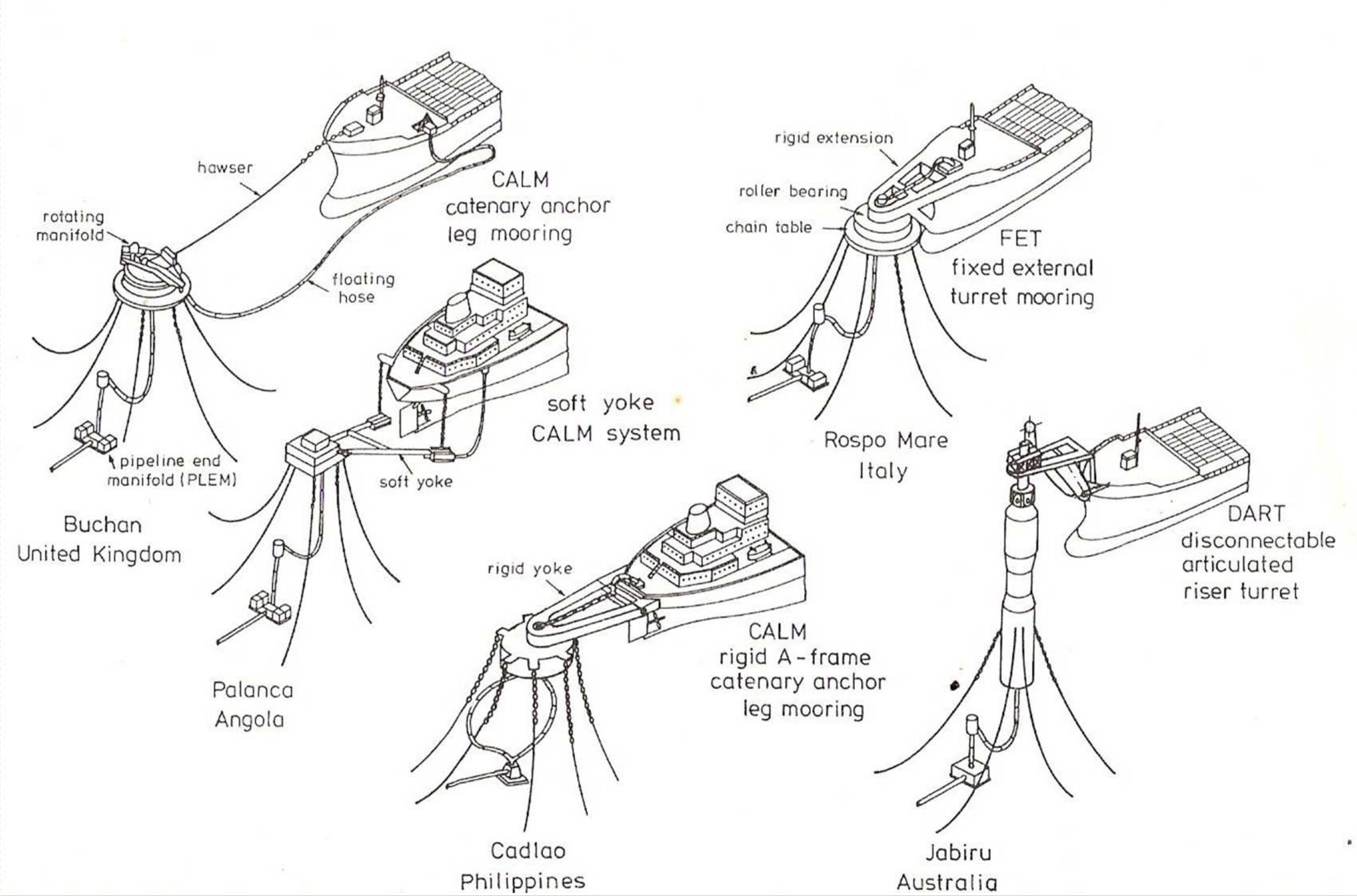
Turret Mooring Configurations



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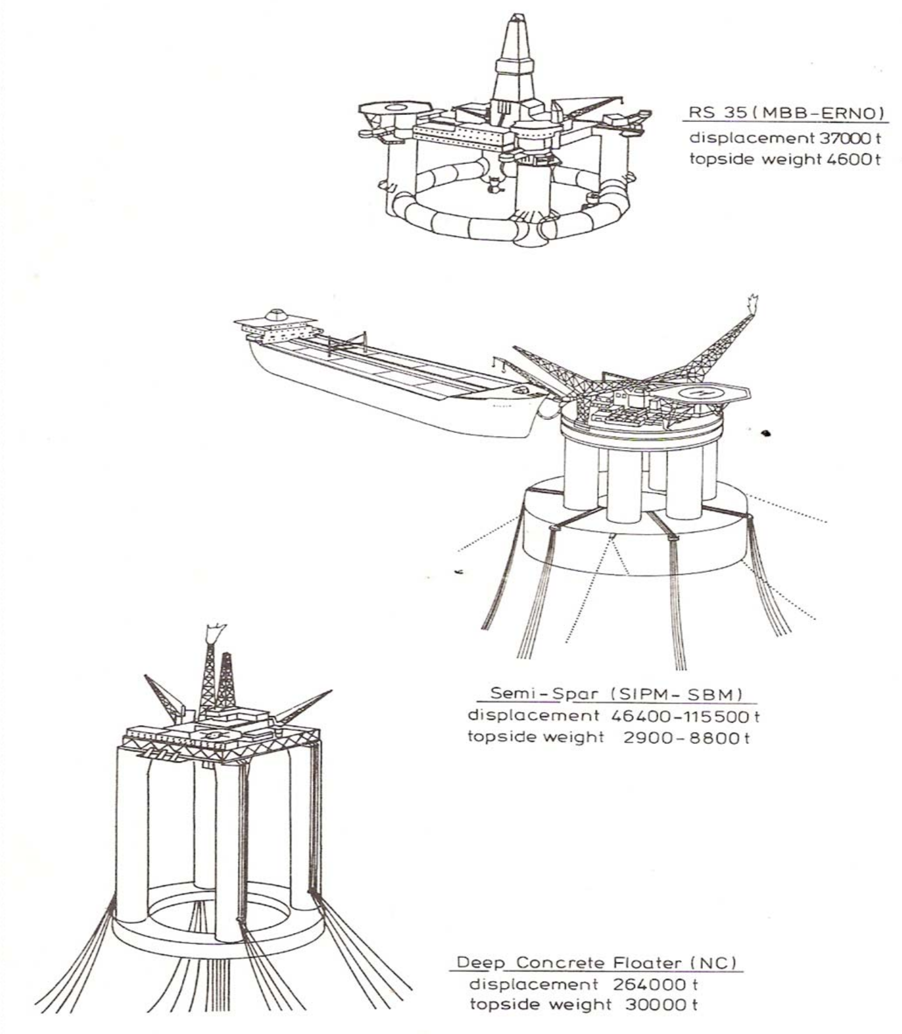

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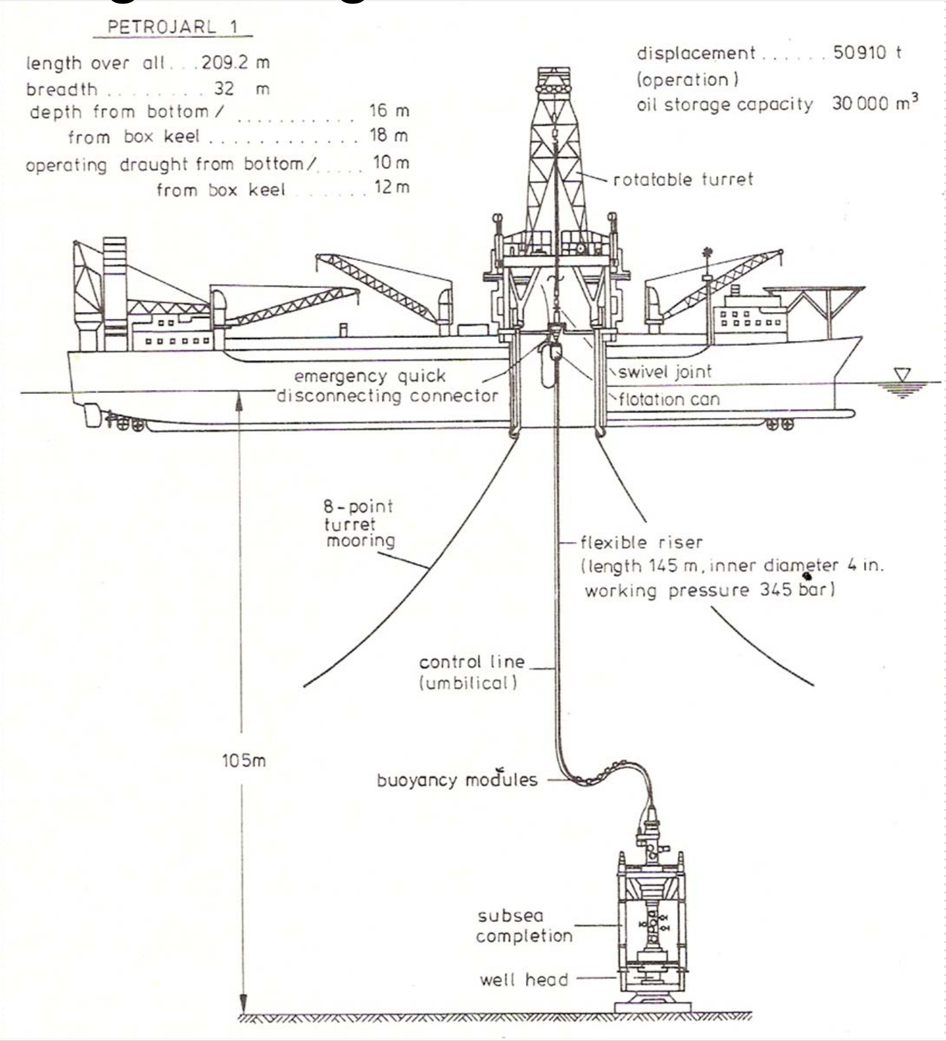

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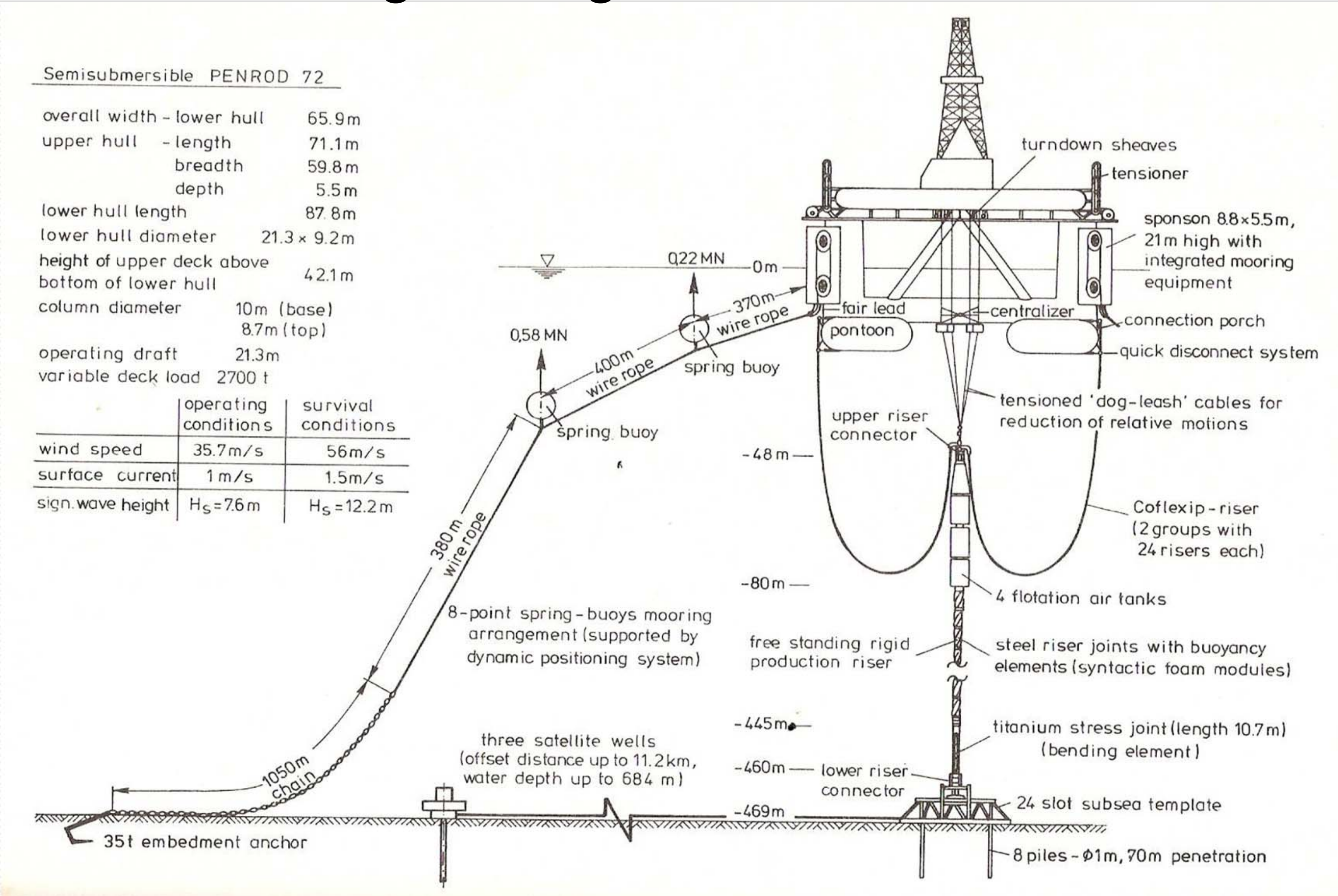
Turret Mooring Configurations



Source: Offshore Structures, G.Clause, E. Lehmann, C.Ostergaard

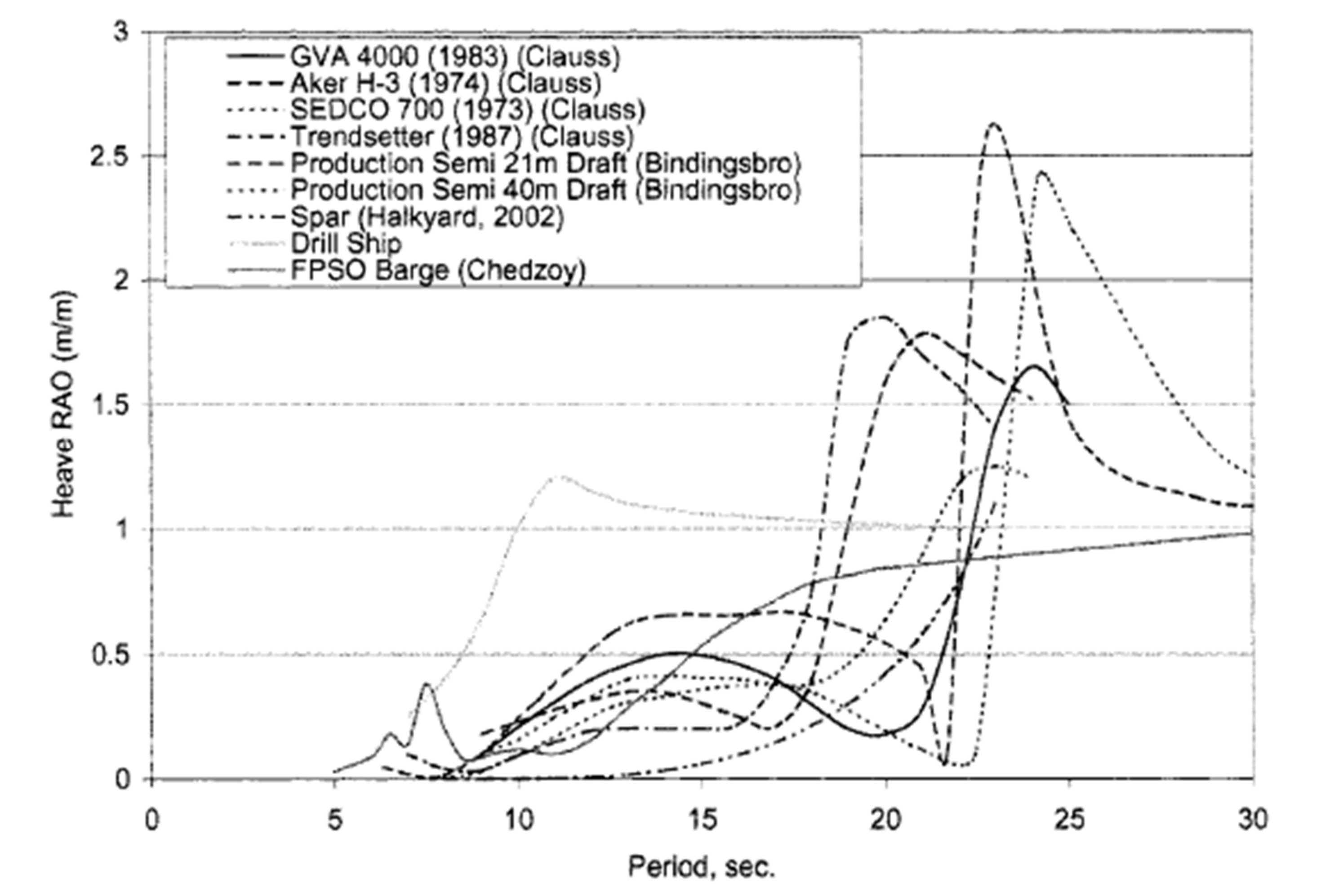
Mooring System Classification

Mooring systems can be broadly classifieds in to following two categories.

- **Taut Mooring System**
  - Mooring lines are under pre-tension all the time
  - Used for deep water structures specially for TLP's
  - Generally used in situation where heave response is to be limited
- **Slack Mooring System (Catenary Mooring System)**
  - Mooring lines will be slack and may or may not have pre-tension
  - Generally used for mooring vessels, deep water floating bodies etc.
  - Mooring line angle at seabed may be zero or higher

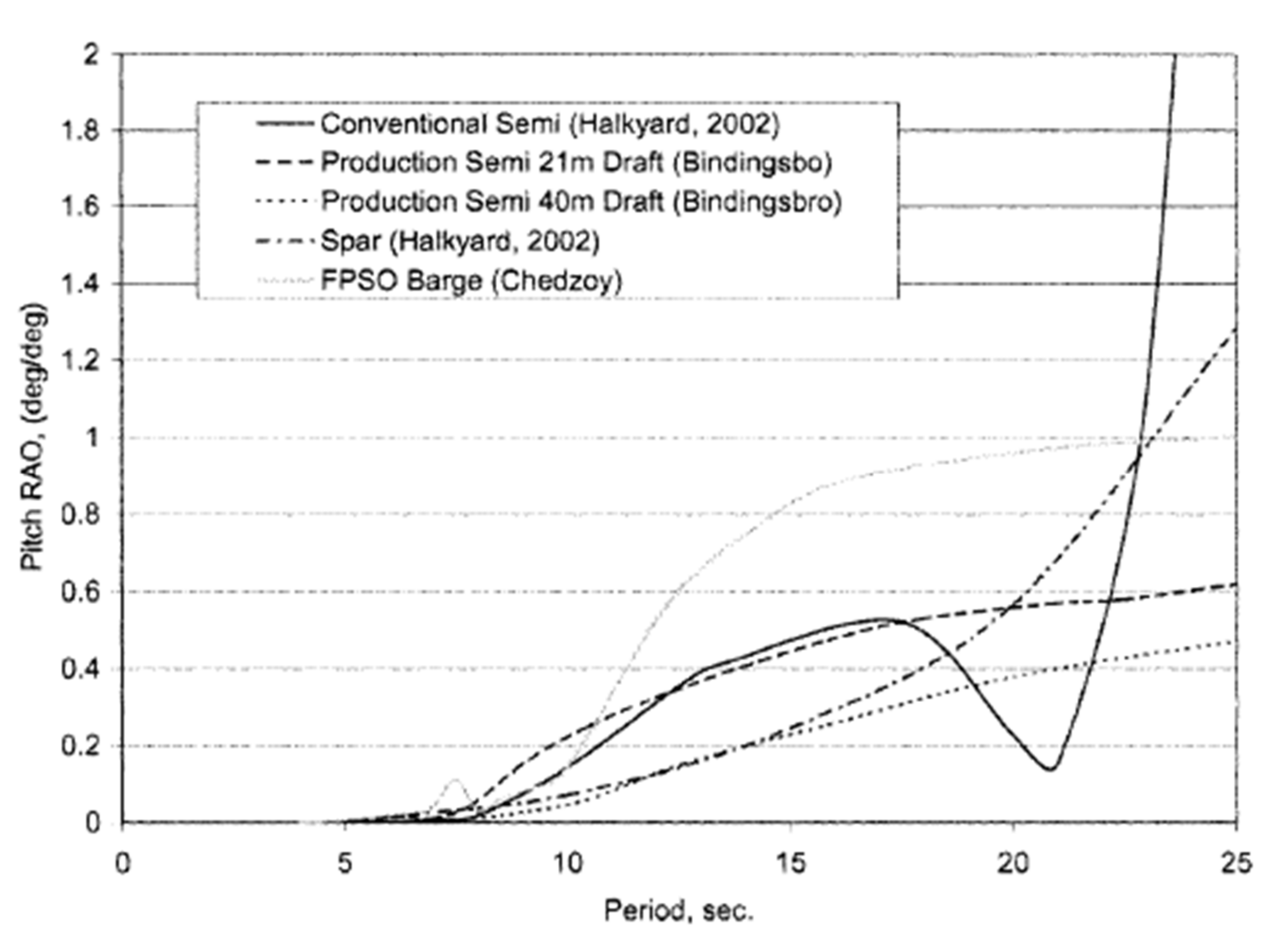
TYPICAL RAO'S

WEATHER VANING OF FLOATING STRUCTURES



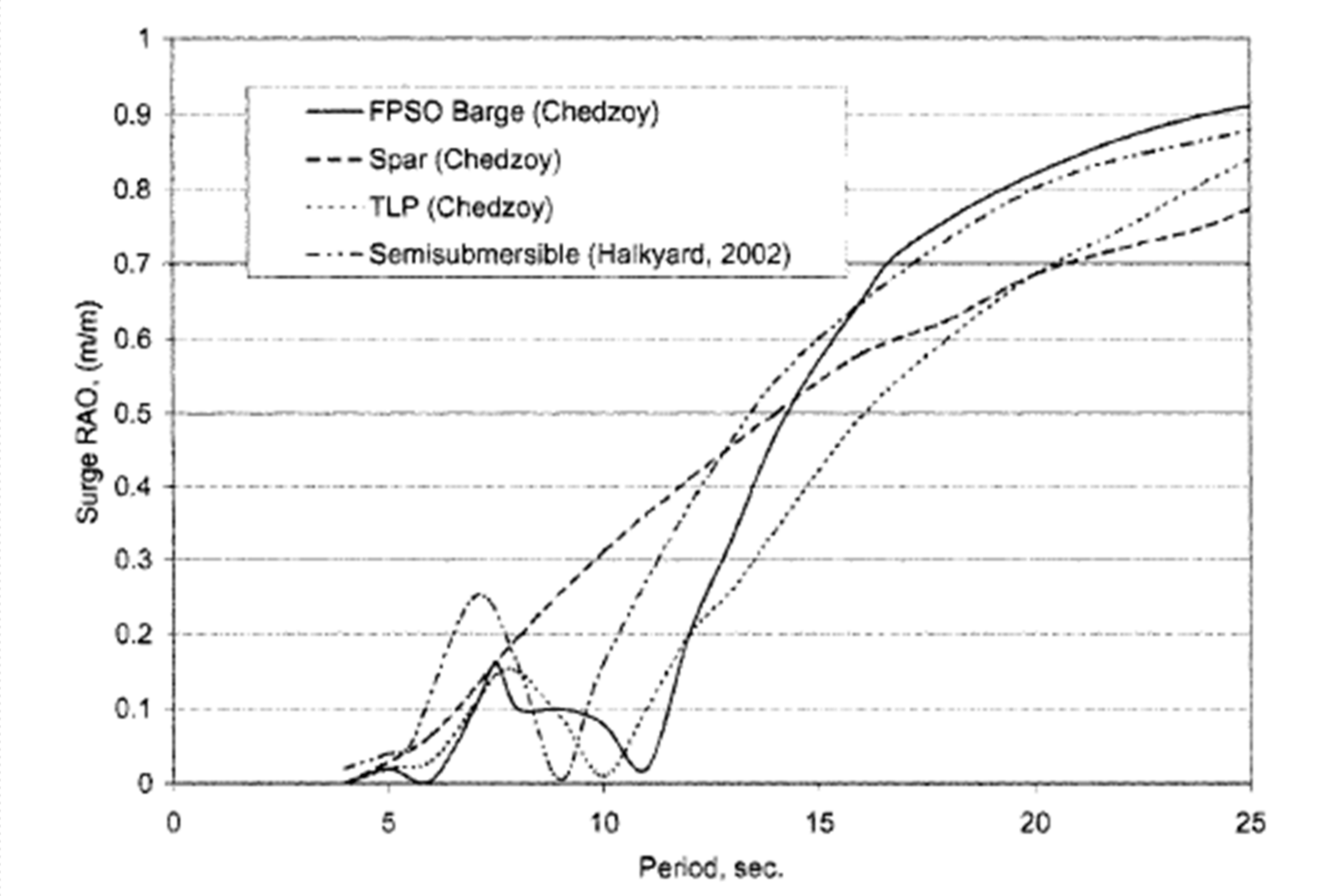
Typical Heave RAO's for floaters (Off. Engg by S. Chakrabrthi)

WEATHER VANING OF FLOATING STRUCTURES



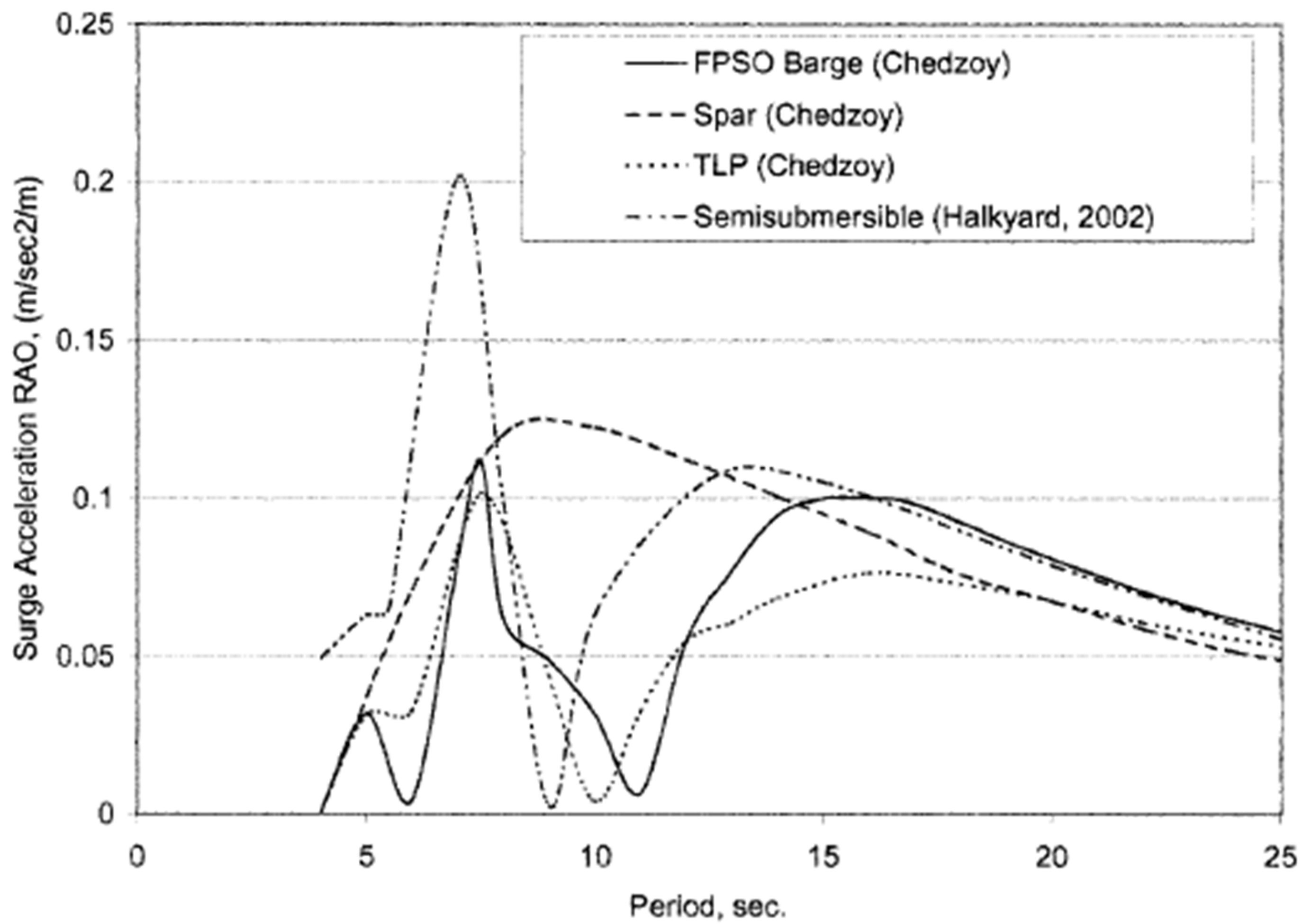
Typical Pitch RAO's for floaters (Off. Engg by S. Chakrabrthi)

WEATHER VANING OF FLOATING STRUCTURES



Typical Surge RAO's for floaters (Off. Engg by S. Chakrabrthi)

WEATHER VANING OF FLOATING STRUCTURES



Typical Surge Acceleration for floaters (Off. Engg by S. Chakrabrthi)

PROPOSED SPAR-SEMISUBMERSIBLE SYSTEM

PROPOSED DESALINATION SYSTEM

- This desalination project is initiated by NIOT off the coast of Chennai to generate fresh water of 10 MLD from sea.
- Proposed system consists of cold water in-take pipes and floating system to mount desalination plant for the production of 10MLD.
- Advantage of spar semi-submersible system.
  - Conventional deepwater system not possible for the present system.
  - Mooring a flat bottom barge with buoy or spar are possible, but the response is unacceptable to the operation of desalination plant.
  - In order to reduce response as well as to increase weather window to operation, semi- submersible connected to spar is adopted.

PROPOSED FLOATING SYSTEM

- Weather vaning : When a vessel / floating structure is connected to a turret, through a swivel joint, it allows the vessel to rotate and adopt the optimum orientation in response to weather and current conditions. This rotation of the vessel about the turret is known as weather vaning.

- Desalination using low temperature thermal desalination (LTTD) method requires water to be drawn from a depth of 1000m.

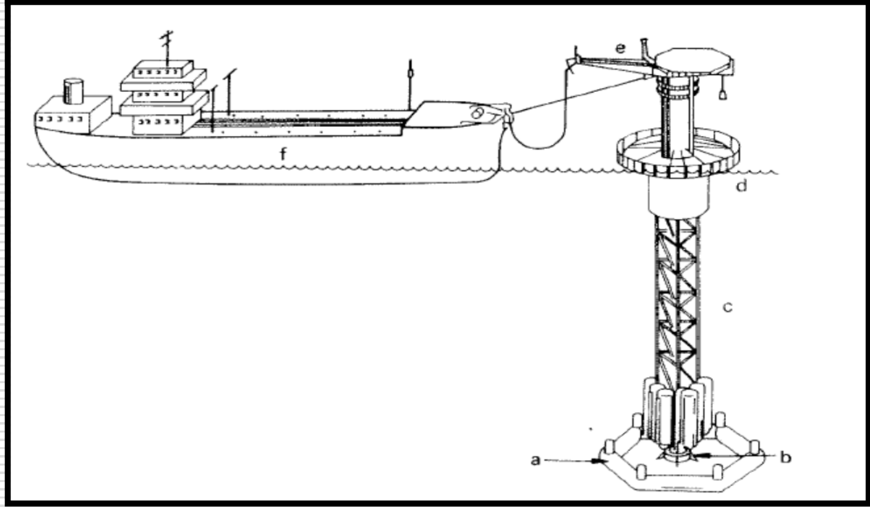
- The possible configurations for mounting desalination plant are:

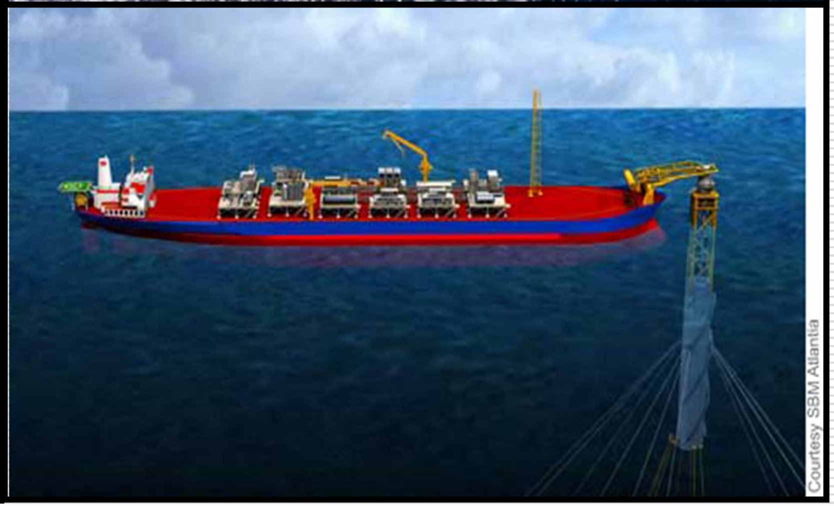
  Barge, FPSO, Spar, Semi-submersible and
  spar combined with semi-submersible.

Spar – Semisubmersible connected by rigid yoke

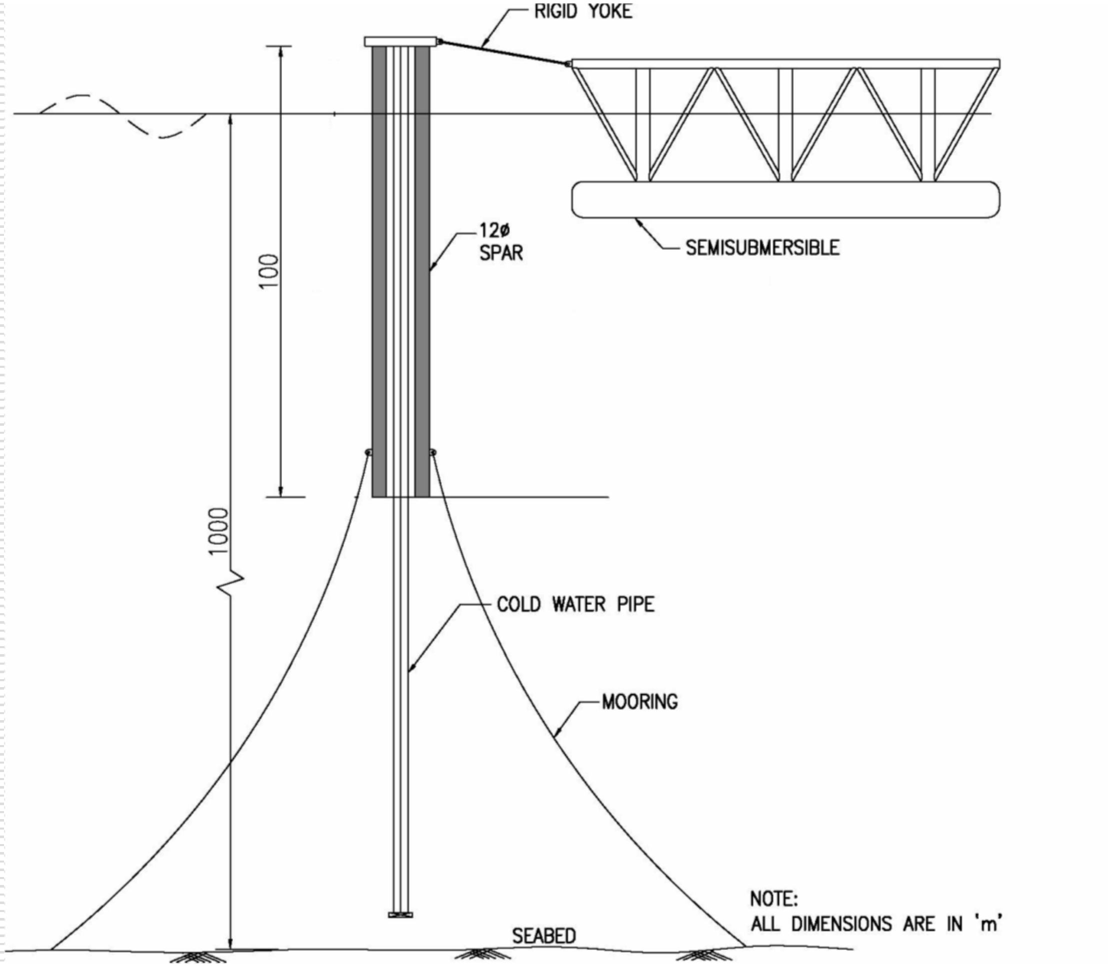
- Cold water pipes are mounted on spar
- Desalination plant is mounted on semi-submersible
- Spar designed for 100 year survival conditions
- Semi-submersible designed for 1 year operating environment
- During extreme weather conditions at offshore, semi-submersible is disconnected from spar and towed to the shoreline.

Examples of System connected by yoke





Proposed Configuration of spar linked with semi-submersible



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Proposed Study

To study the motion response of spar-semi-submersible system interlinked with rigid yoke suitable for an offshore desalination plant.

- Spar alone
  - To conduct tests on spar model in wave basin for regular and random waves to find motions and mooring line forces.
  - Compare experimental results with analytical results for validation using Ocraflex and WAMIT.
- Spar connected with semi-submersible by a rigid yoke
  - To conduct model tests in wave basin regular and random waves to find motions and mooring line forces.
  - Compare xperimental results with analytical results for validation using Ocraflex and WAMIT.

WEATHER VANING OF FLOATING STRUCTURES

Desalination plant system particulars

Capacity 4 units of 2.5MLD	10 MLD
Temperature difference (minimum) Between surface water to cold water at 1000m below	20 deg C
Water depth	1000 m
Cold water flow rate (4 units *2057 Kg/s)	8228 Kg/s
HDPE cold water pipes-No. & size	7no., 1m Φ
Velocity of flow in cold water pipes	1.28 m/s

Estimated loads on spar

Description	**Load (Tonnes)**
Sea water pumps (cold water)	100
Deck plate	100
Supporting frame for HDPE pipes	200
Ballast tank at end of HDPE pipes	100
Total	500

Estimated loads on semi-submersible

Description	**Load (Tonnes)**
Flash chamber including duct	300
Condenser	600
Water pumps	100
D.G.set	70
Vacuum system	30
Water pipes and bends	1300
Fresh water	1200
Diesel	700
Steel for erection of components and accommodation	500
Material handling equipment and accessories	200
Total	5000

WEATHER VANING OF FLOATING STRUCTURES

Spar details

C	Description	Prototype	Scaled model
1.	Scale ratio	1:100	
2.	Material	Steel	Acrylic
3.	Mass density	7.85T/m^3	1.2T/m^3
4.	Length	120m	1200mm
5.	Outer cylinder	ϕ12m x 0.06m	ϕ120m x 5mm
6.	Inner cylinder	ϕ6m x 0.06m	ϕ60mm x 3mm
7.	Draft	100m	1000mm
8.	Free board	20m	200mm
9.	Weight of spar	3062Tonnes	3.44kg
10.	Deck pay load	500Tonnes	0.5 kg
11.	Steel ballast at keel	4000Tonnes	4.24 kg
12.	Total download force	7762 Tonnes	8.18kg
13.	Bouyancy force	7762 Tonnes	8.18kg
14.	VCG	36m	368mm
15.	VCB	44m	440mm
16.	GM	7.6m	75mm
17.	Water depth	1000m	3m(mooring line truncation)
18.	Heave Natural Period	28 sec	2.8 Sec
19.	Number of mooring lines	4	4

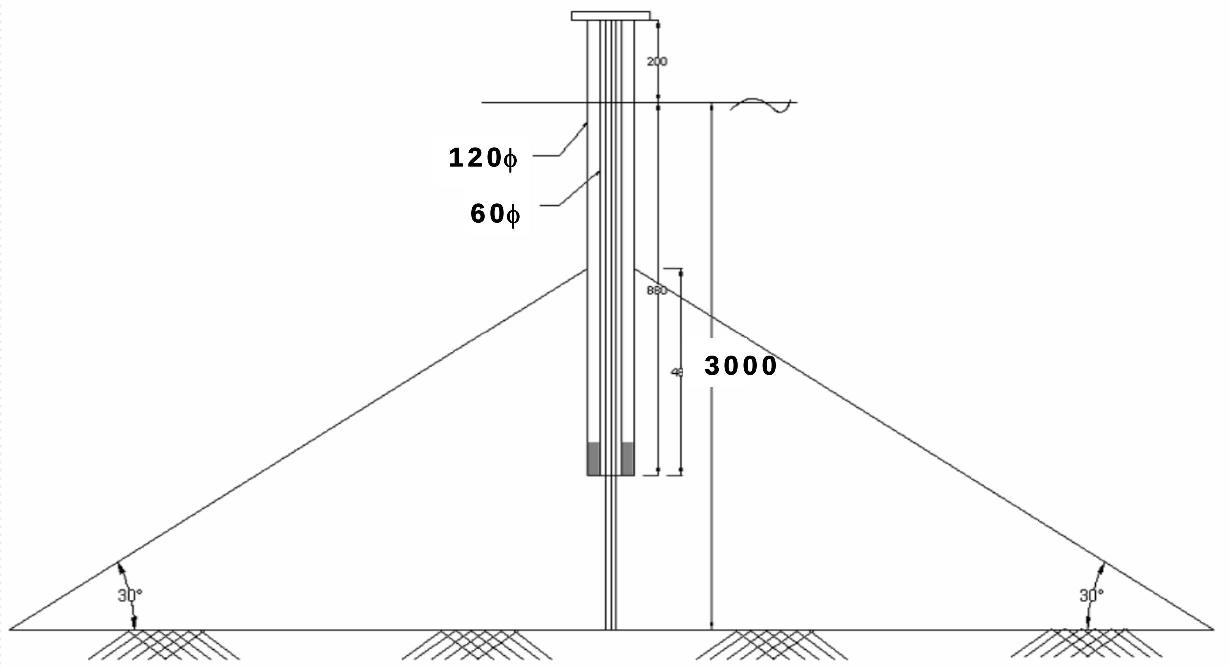
Semi-submersible details

C	Description	Prototype	Scaled model
1.	Scale ratio	1:100	
2.	Material	Steel	Acrylic
3.	Mass density	7.85T/m^3	1.2T/m^3
4.	L x B x H	100m x 70m x 33.2m	1000mm x 700mm x 332mm
5.	Draft	25.2m	252mm
6.	Free board	8m	80mm
7.	Main pontoons L x B x H x t	100m x 19.2m x8.2m x 0.06m	1000mm x192mmx 82mm x 5mm
8.	Cross pontoons c/s	ϕ5m x 0.06m	ϕ50mm x 5mm
9.	Columns c/s	ϕ10m x 0.06m	ϕ100mm x 5mm
10.	Weight of semisubmersible	15470 Tonnes	15.65 kg
11.	Deck pay load	5000Tonnes	5kg
12.	Water ballast	18000 Tonnes (75% of pontoons volume)	18kg(75% of pontoons volume)
13.	Total download force	38470 Tonnes	38.65kg
14.	Buoyancy force	38470 Tonnes	38.65kg
15.	VCG	12m	131mm
16.	VCB	5.3m	65mm
17.	GM	7.7m	67mm
18.	Heave Natural Period	23 sec	2.3 sec

Offshore environment data for east coast of India

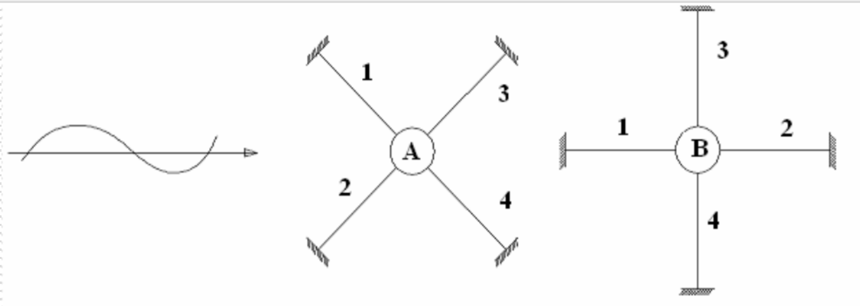
Environment	Parameter	Return Period	
Sea state	Max. wave height	100 year	1year
		21.3m	10.5m
	Wave period	14.0s	10.4s
Wind	Wave period hourly mean speed at 10m above water surface	59.0m/s	33.5m/s
Current	Surface current	3.3m/s	2.0m/s
	Current 1m above seabed	2.0m/s	1.4m/s

Spar model

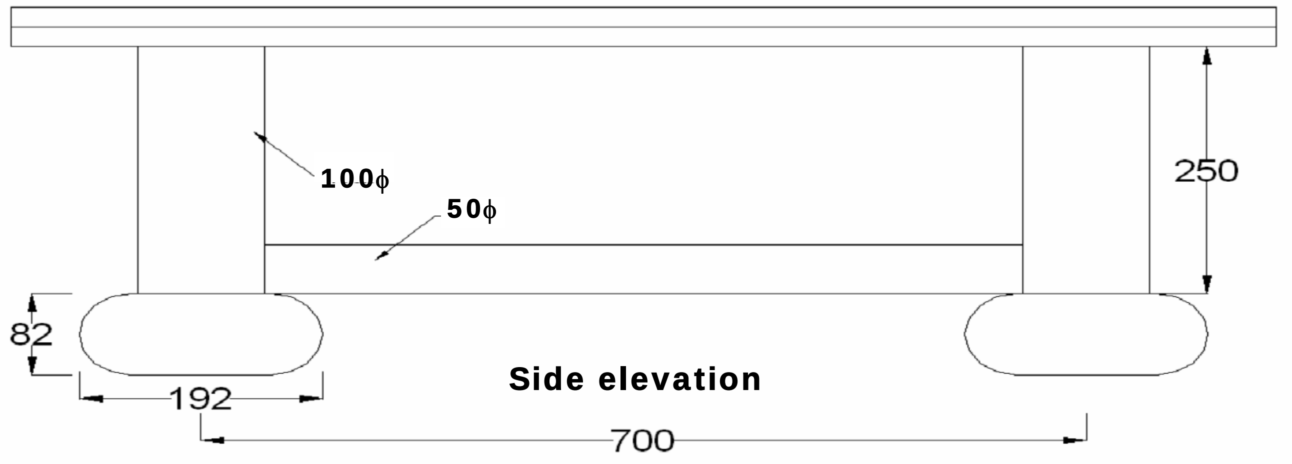


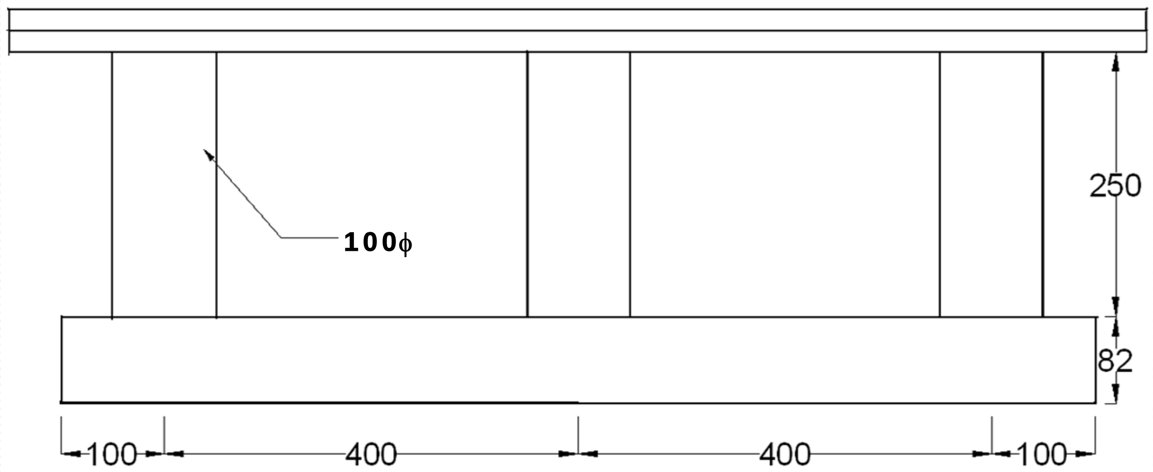
All dimensions in mm

Mooring orientation



Semi-submersible model

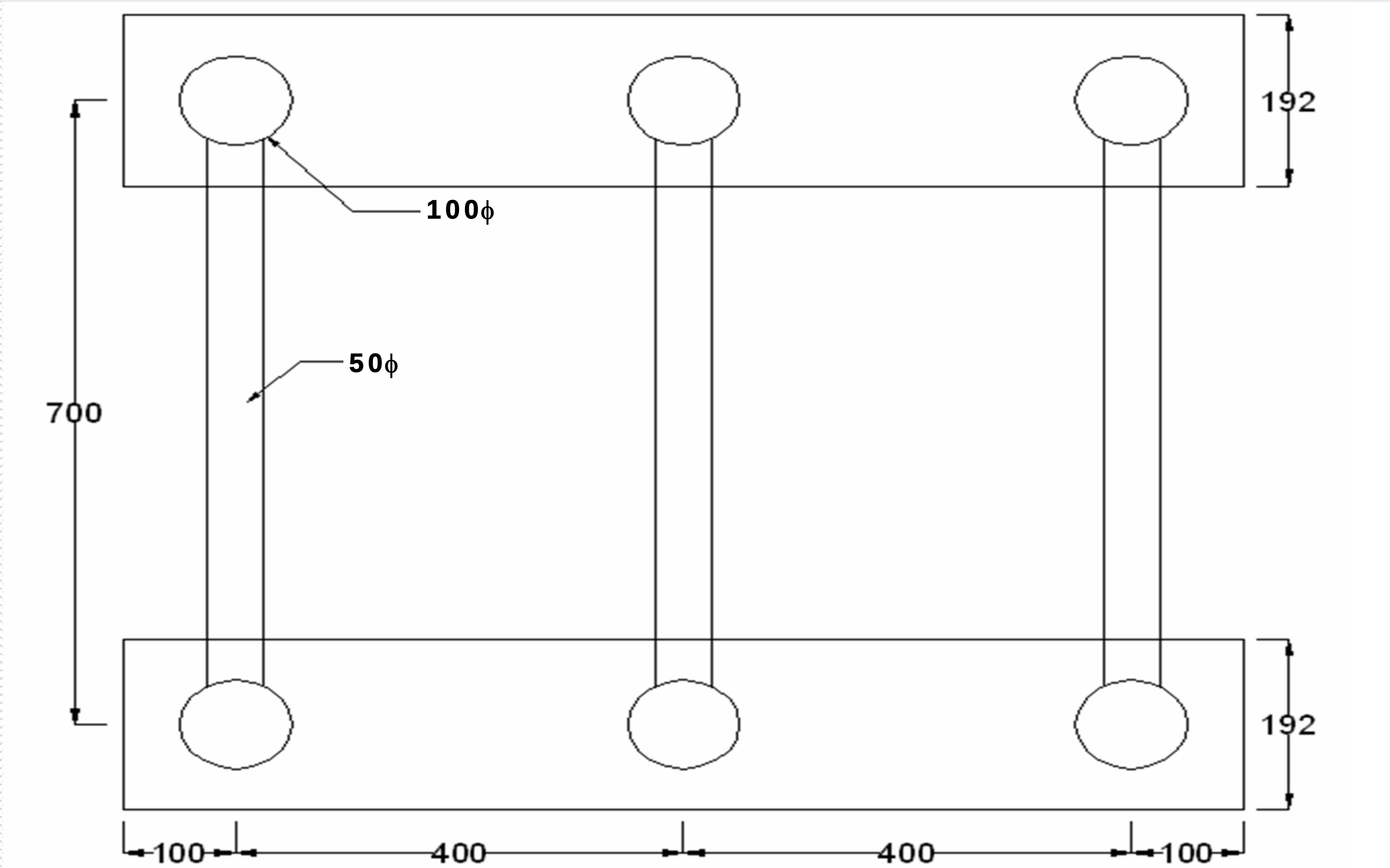




elevation

All dimensions in mm

Semi-submersible model (contd.)

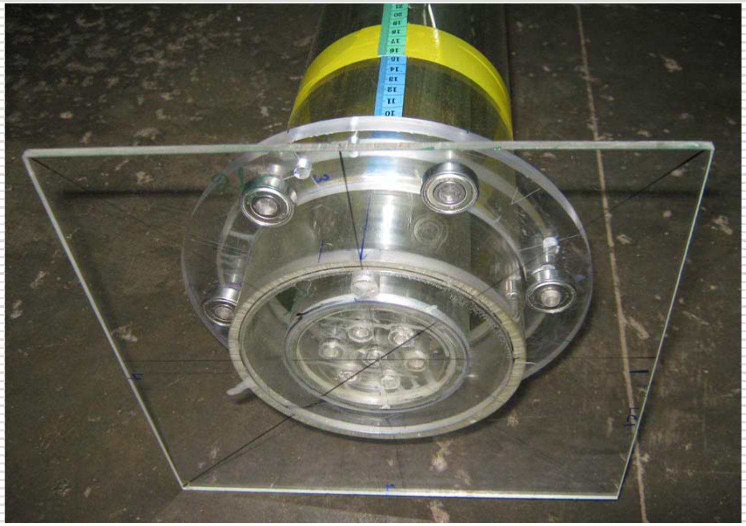


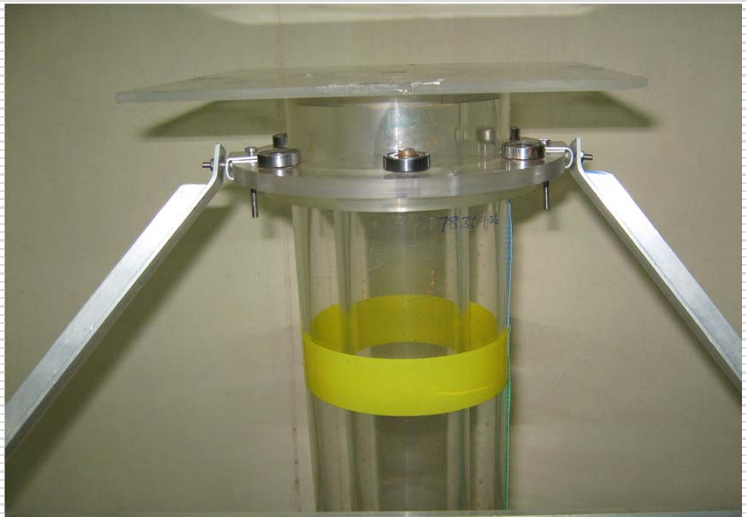
All dimensions in mm

Plan

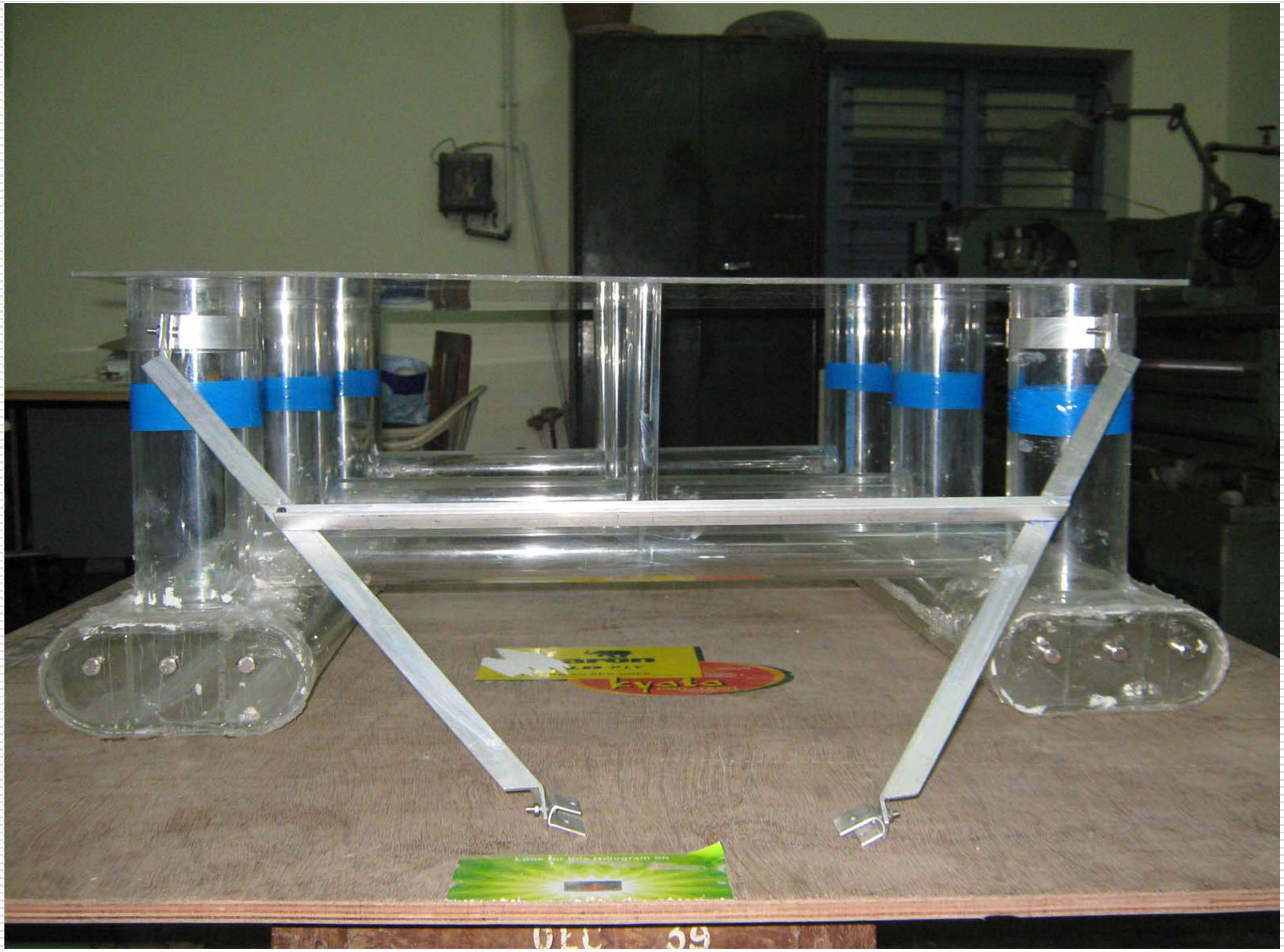
WEATHER VANING OF FLOATING STRUCTURES

Spar Model





Semi- submersible model

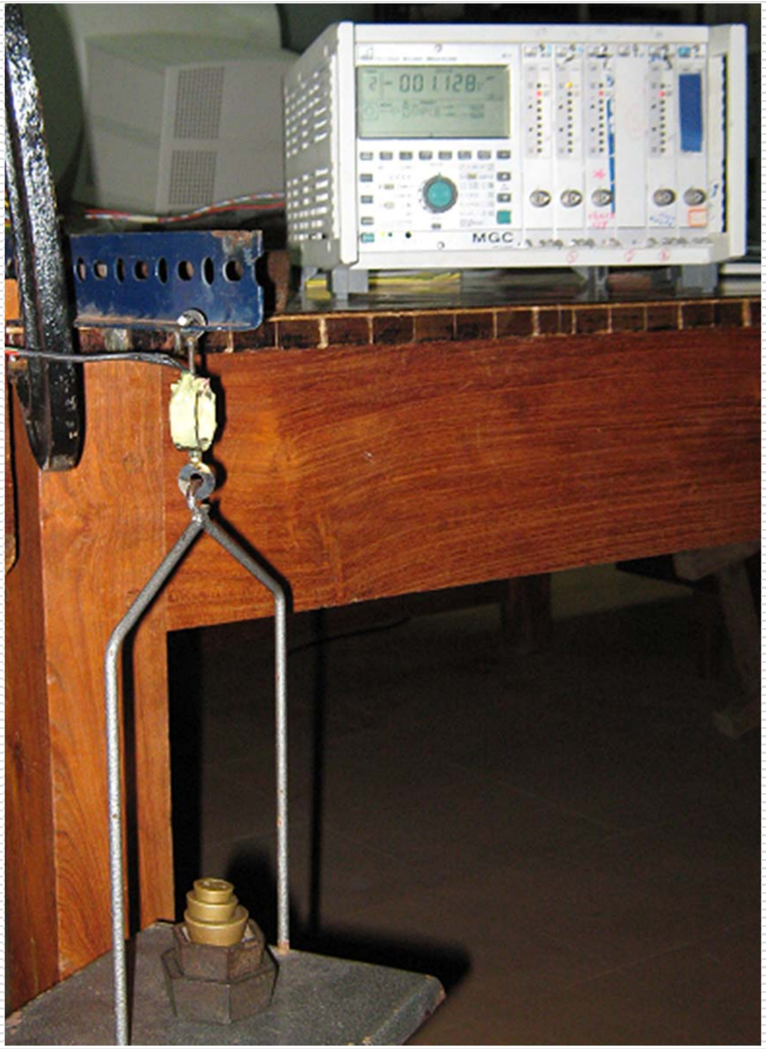


Experimental programme

Loadcell calibration

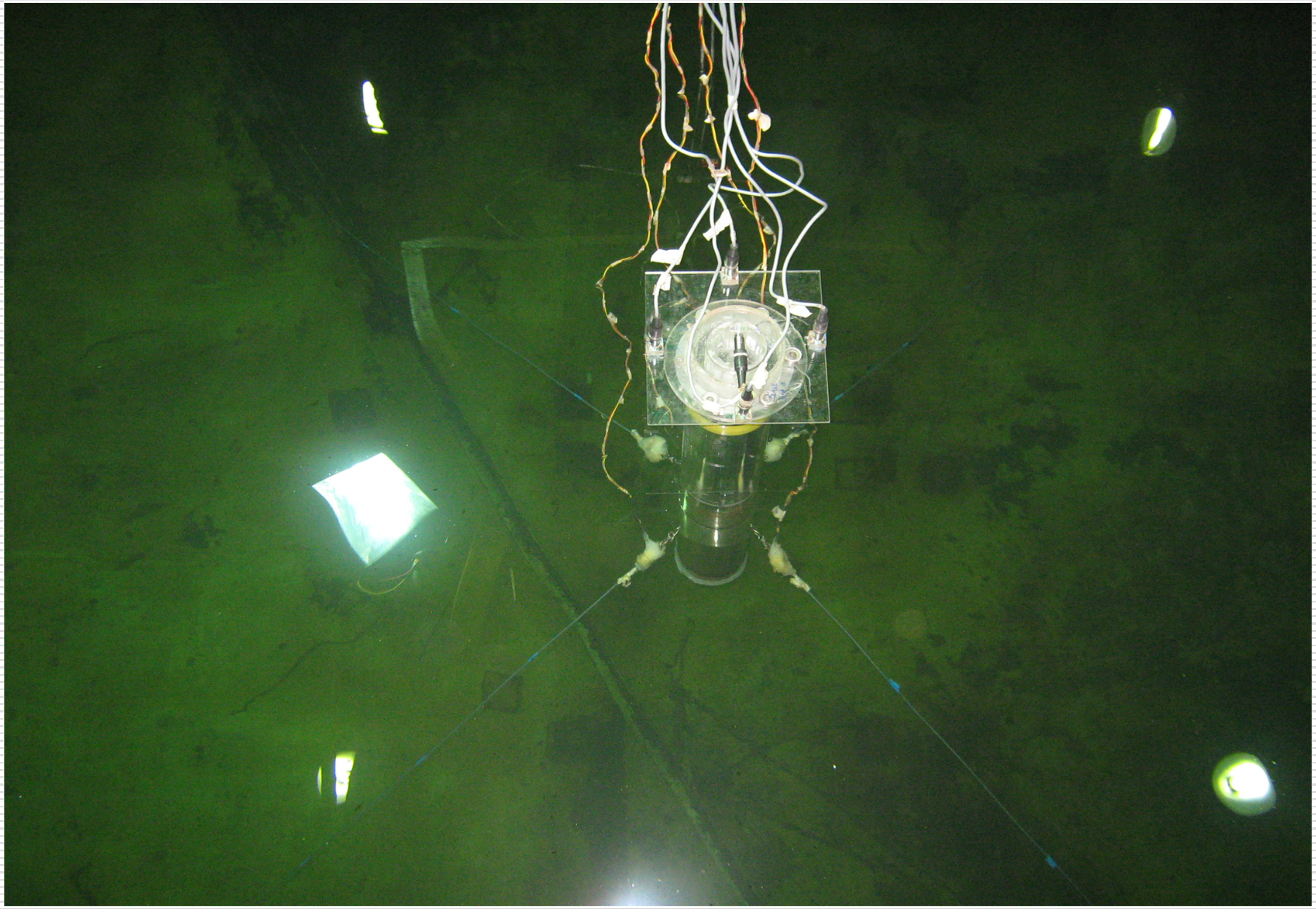
Ring type Load cell

Accelerometer calibration

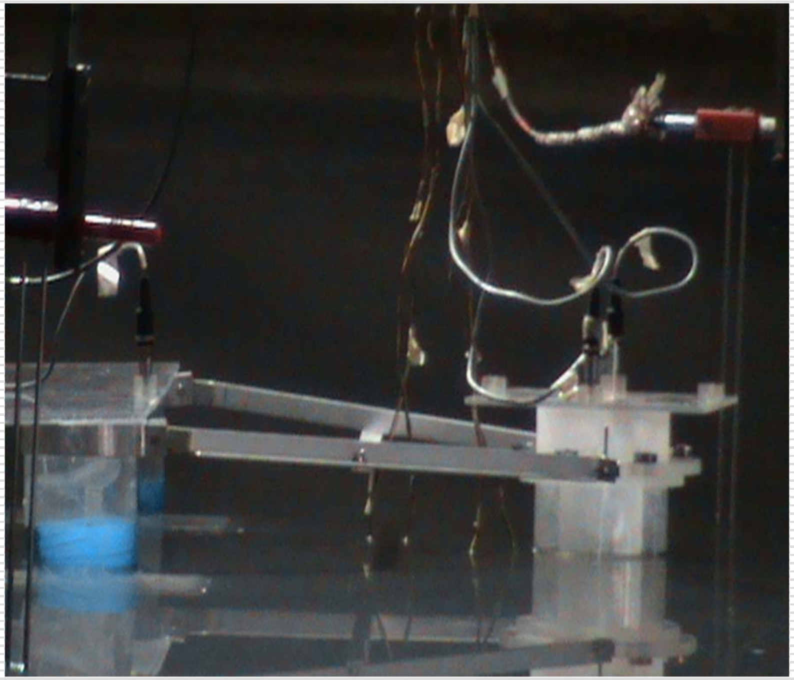


WEATHER VANING OF FLOATING STRUCTURES

Spar with four mooring lines in wave basin



Semi-submersible connected to spar by a rigid yoke in wave basin



Video: Regular wave Hs=100mm,T=1sec

Video: Random wave H_s=100mm,T=1s

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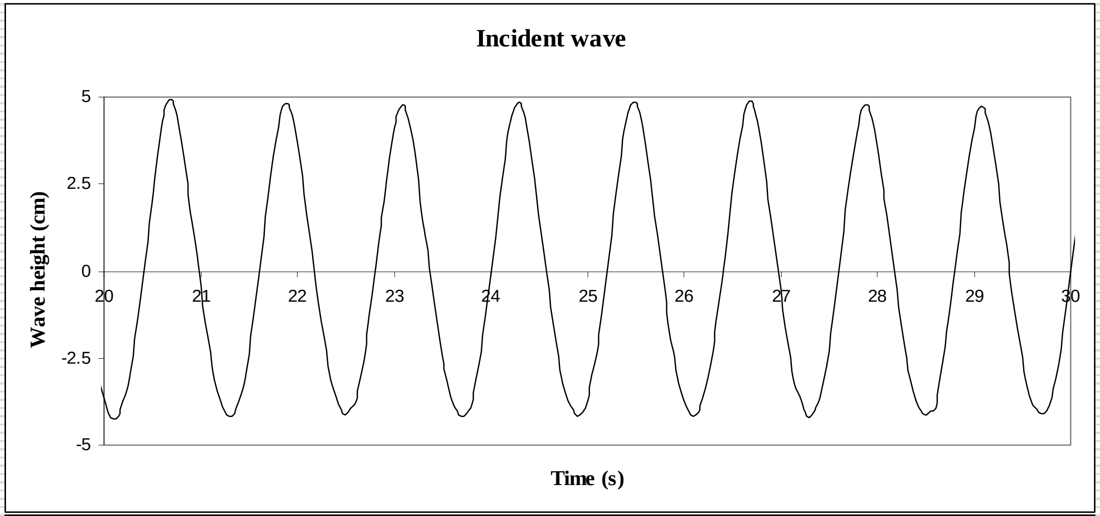
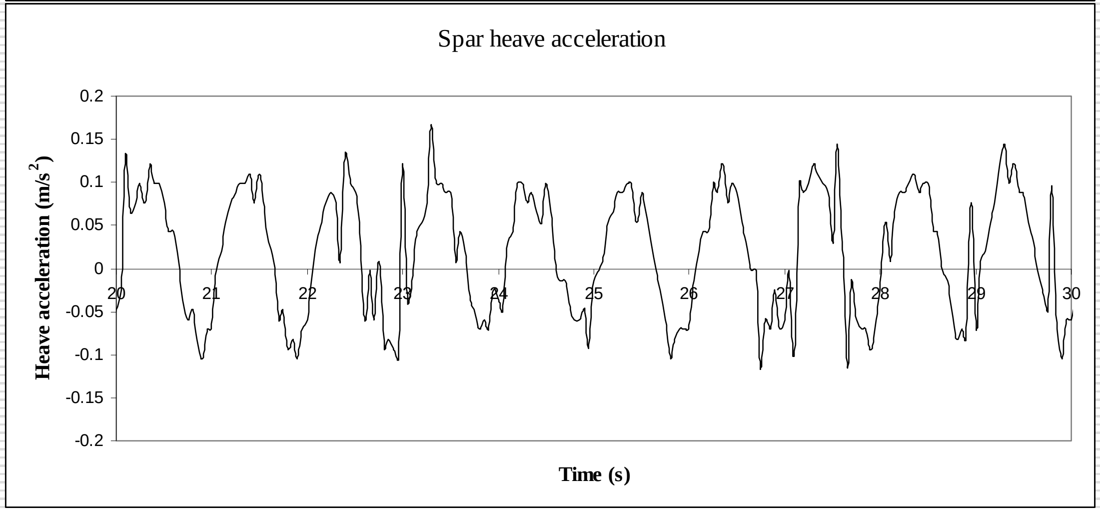
WEATHER VANING OF FLOATING STRUCTURES

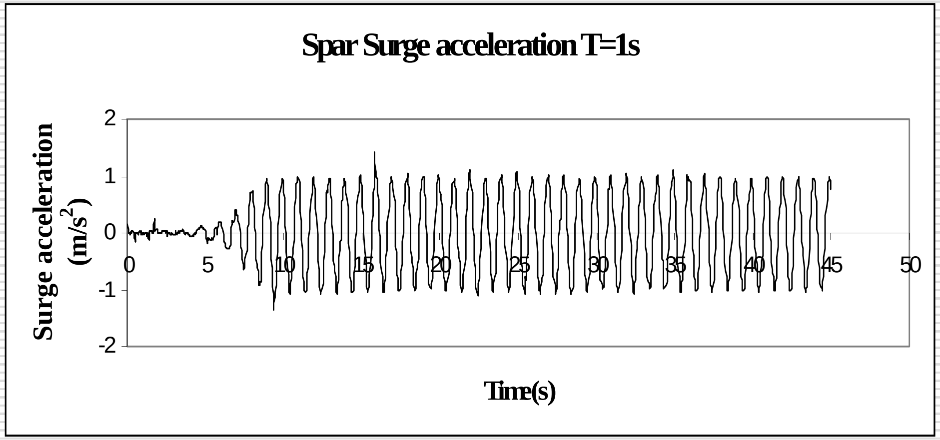
Time series for measured wave and acceleration

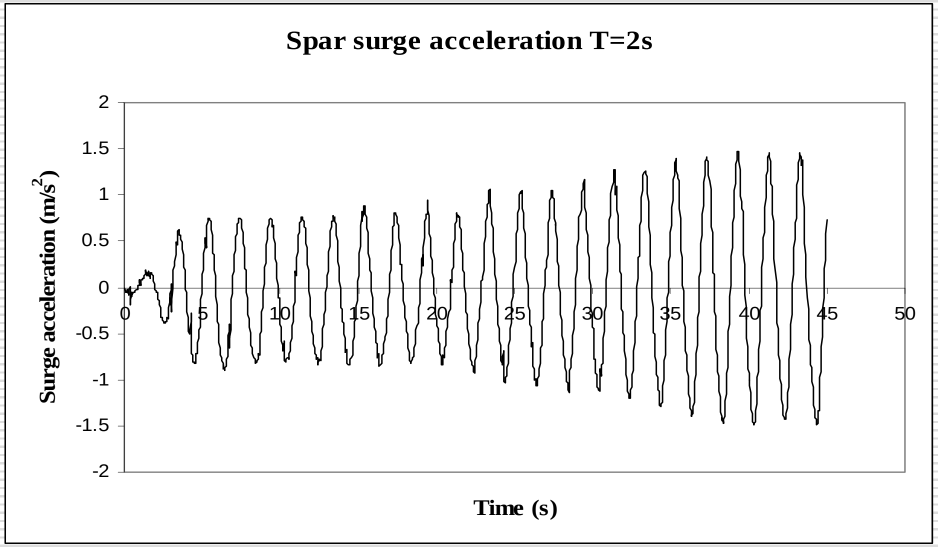




WEATHER VANING OF FLOATING STRUCTURES

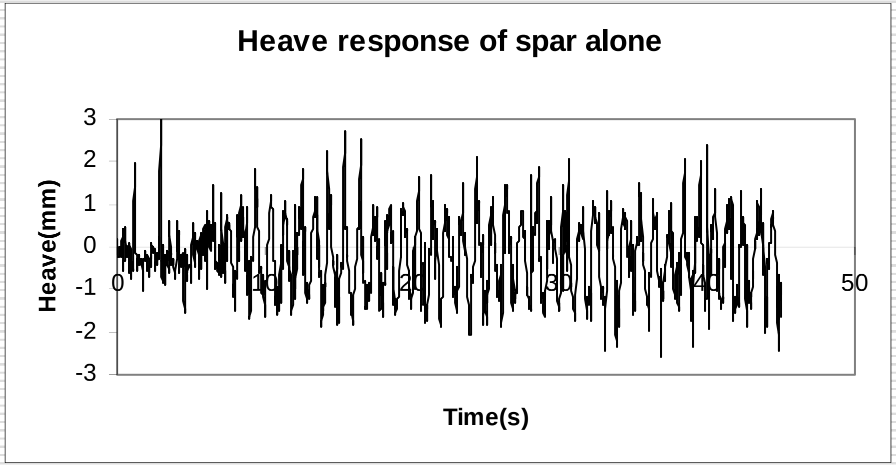
Times series for surge acceleration (spar alone)



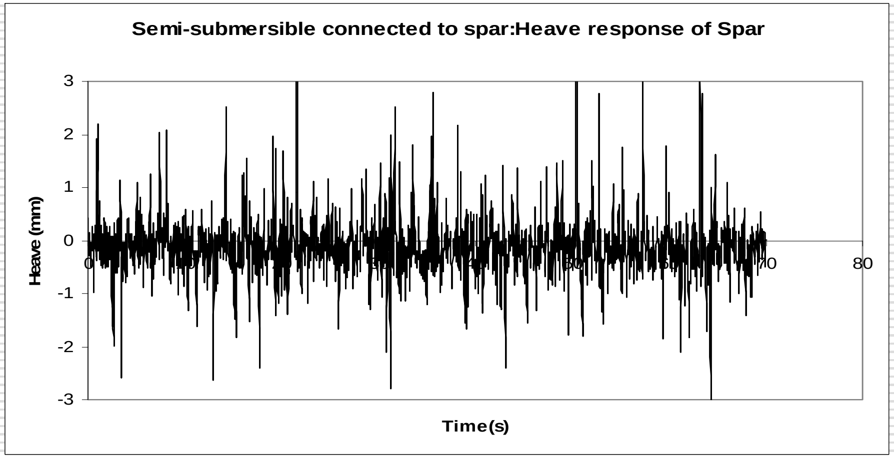


WEATHER VANING OF FLOATING STRUCTURES

Heave response of Spar

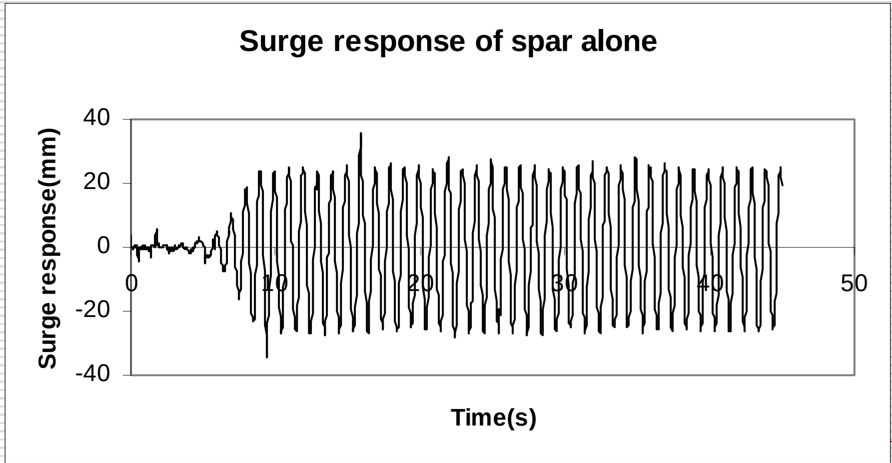


Heave response of spar alone

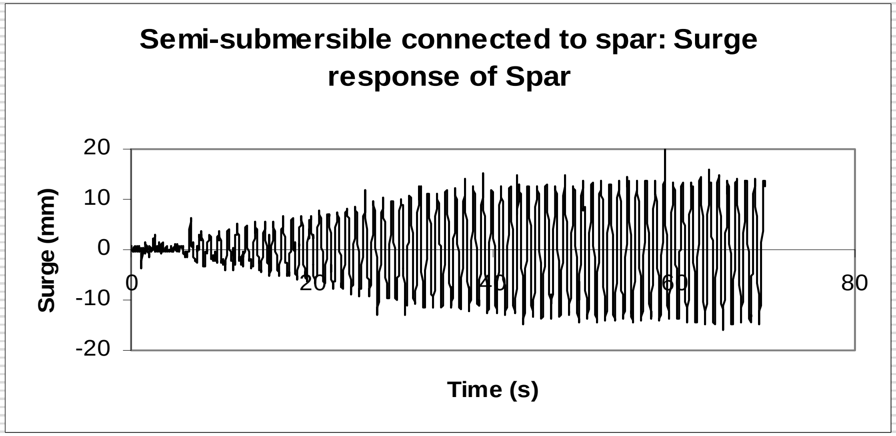


Semi-submersible connected to spar:Heave response of Spar

Surge response of Spar

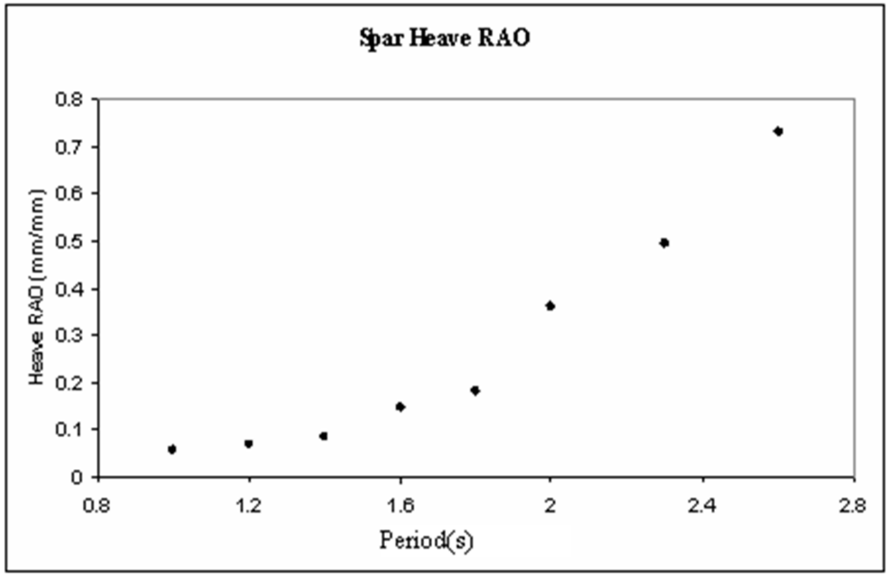


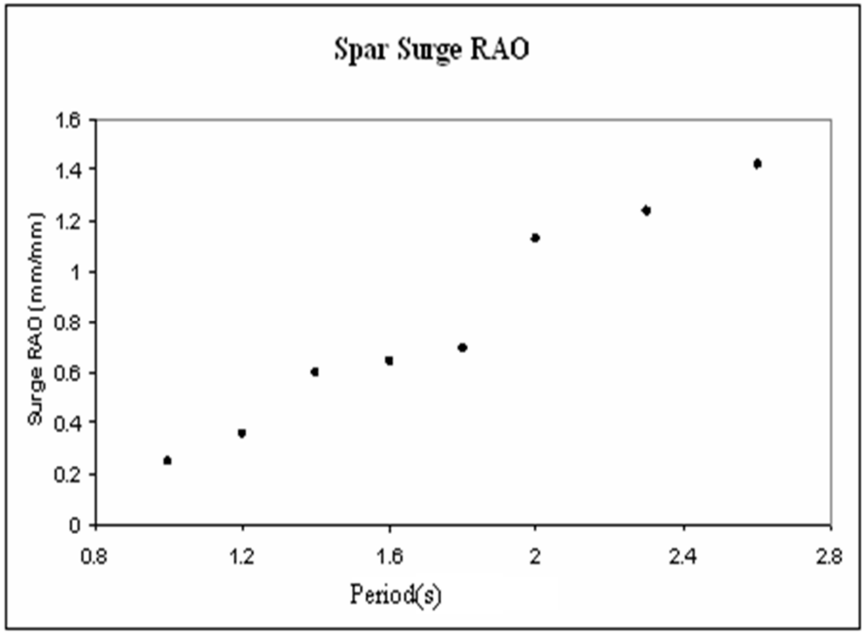
Surge response of spar alone



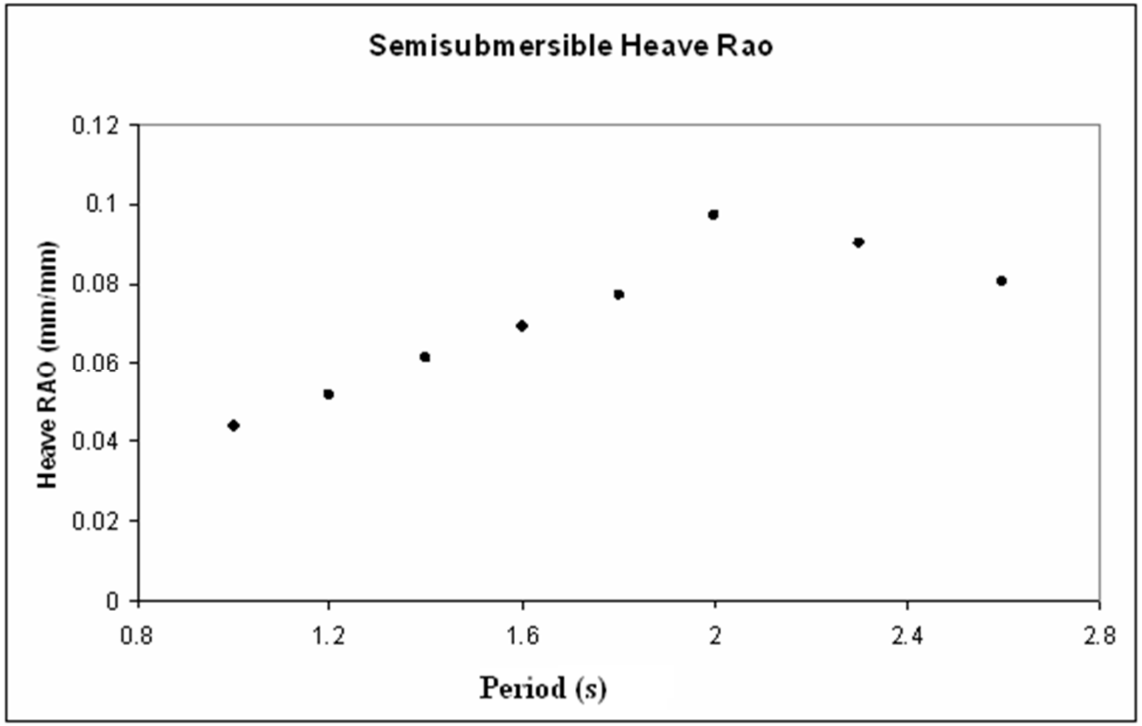
Semi-submersible connected to spar: Surge response of Spar

RAO's for Spar alone

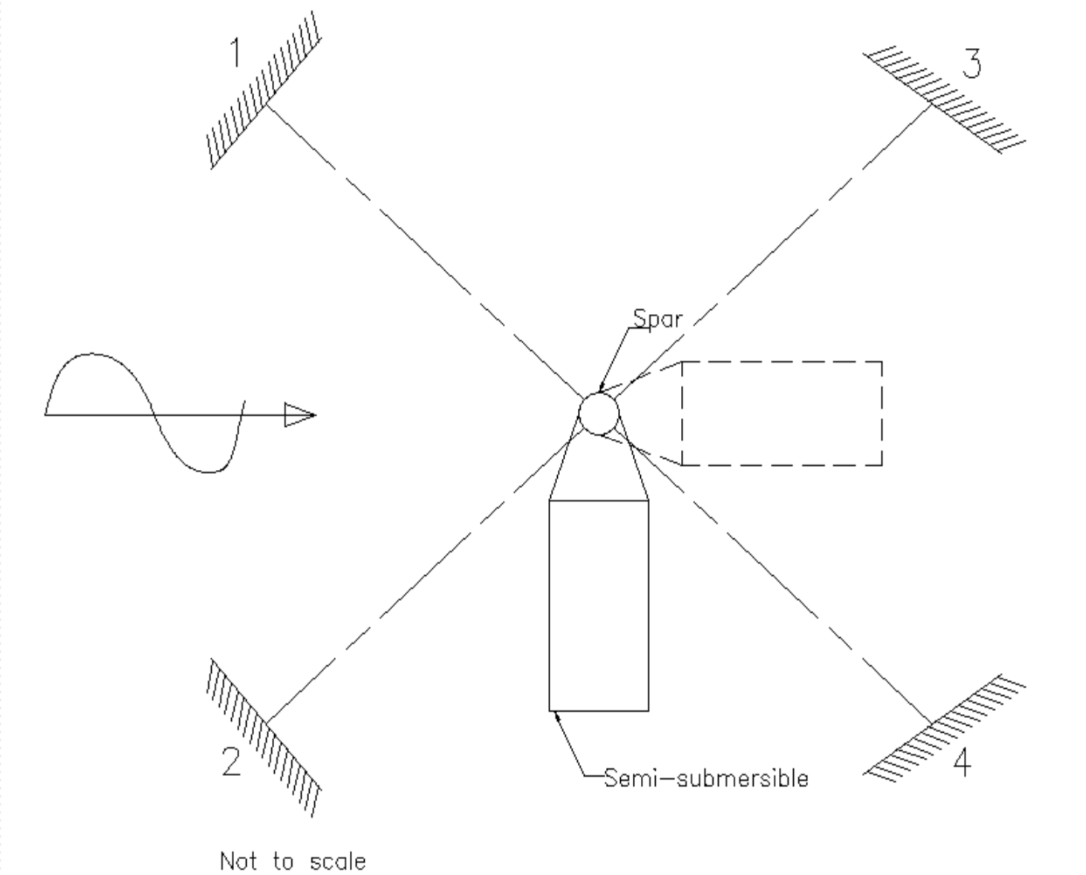




RAO for semi-submersible connected to spar



Measured mooring line forces on scale model



Mooring line orientation:

LC1,LC2 : Wave maker side

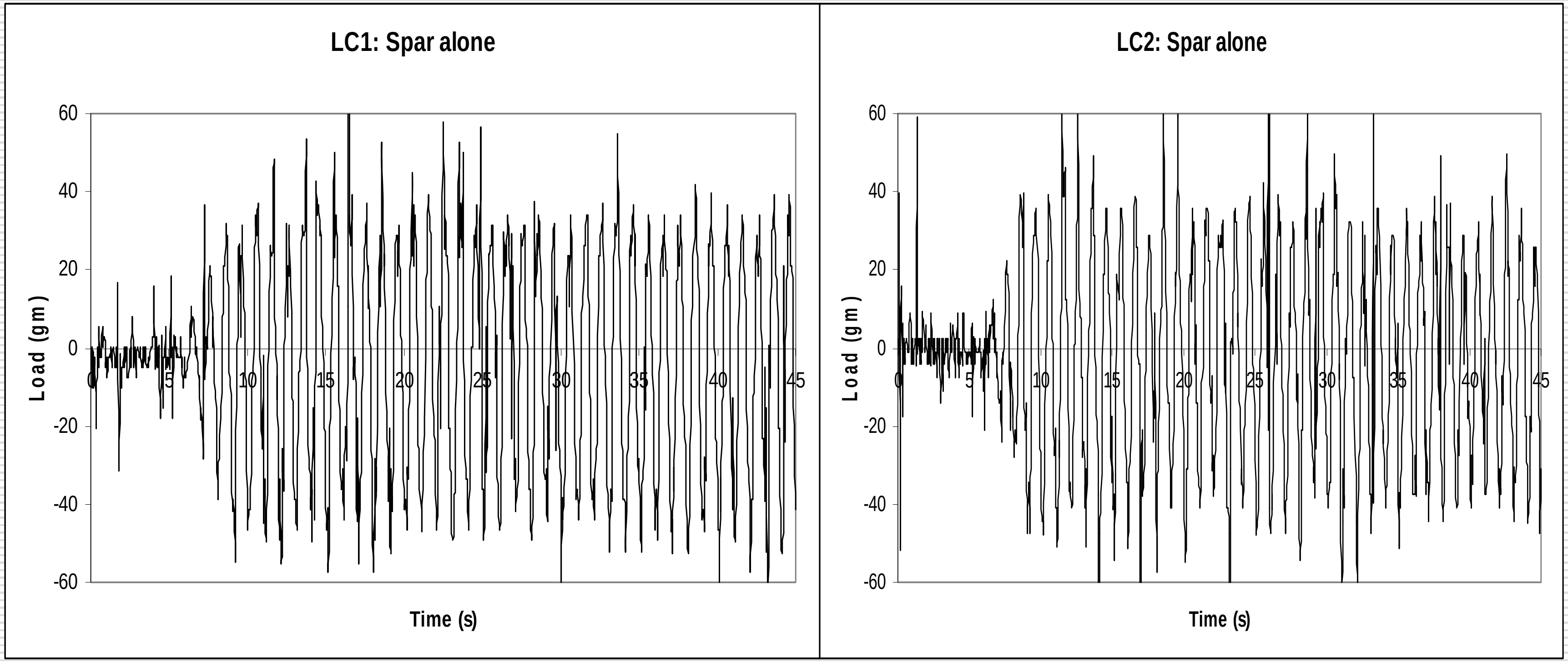
LC3,LC4 : Lee side

Model Scale=1:100

Load of 1 gm in model equivalent to 1 Tonne for prototype

Measured mooring line forces: Spar alone

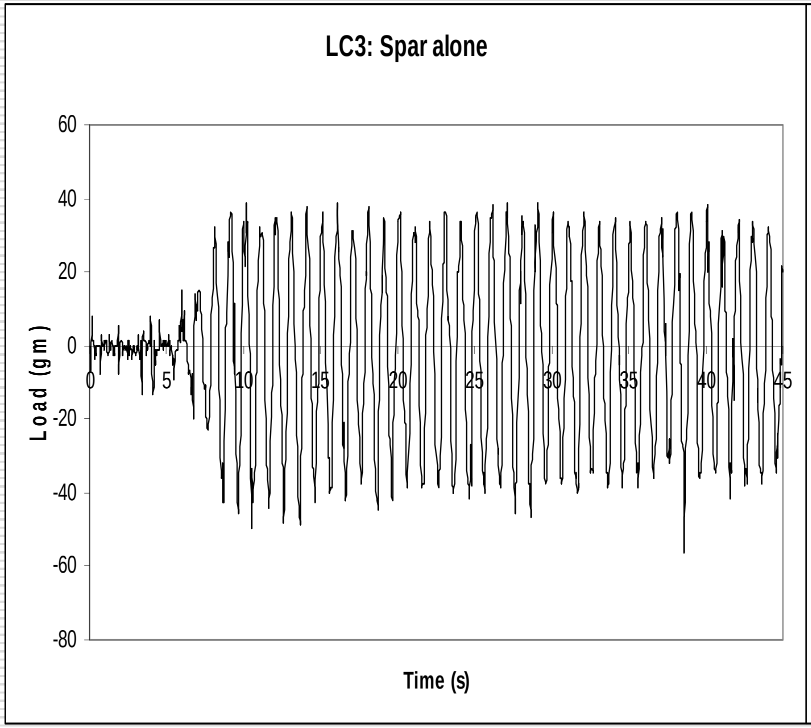
Regular wave H=10cm, T=1s

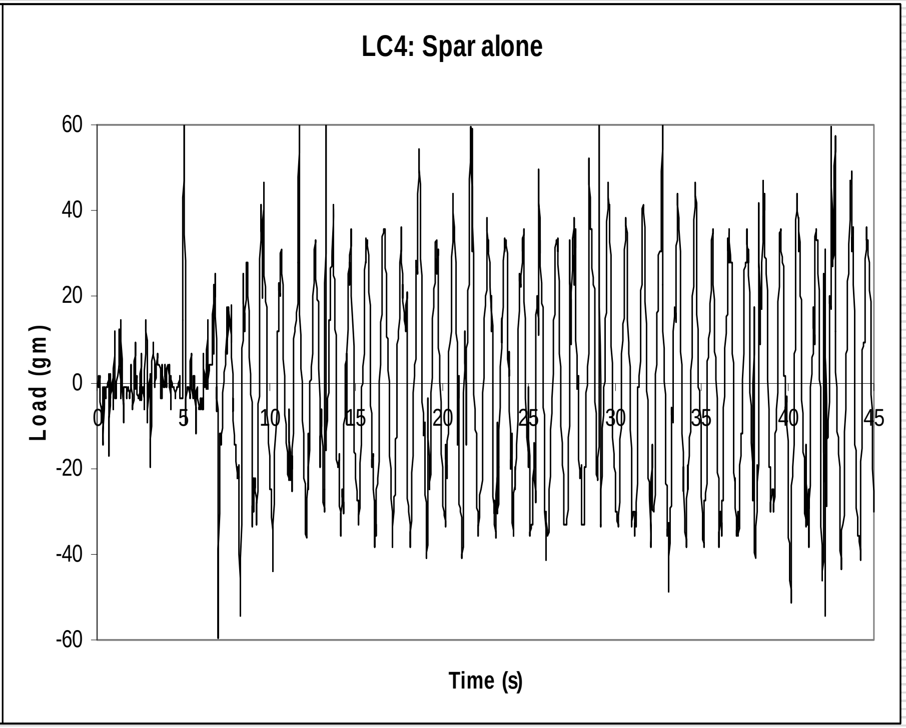


LC1,LC2 :wave maker side

Measured mooring line forces: Spar alone

Regular wave H=10cm, T=1s

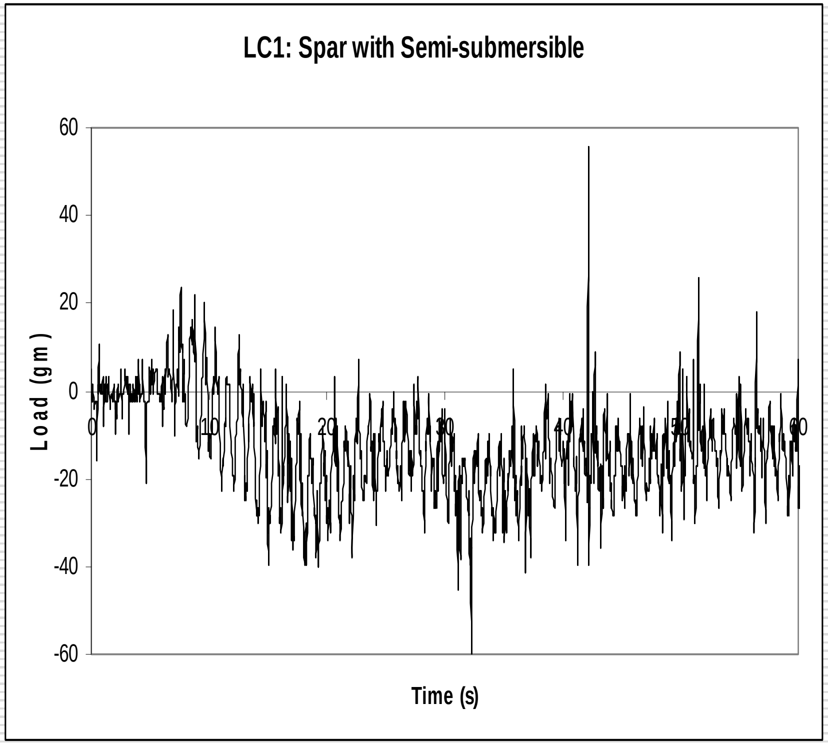


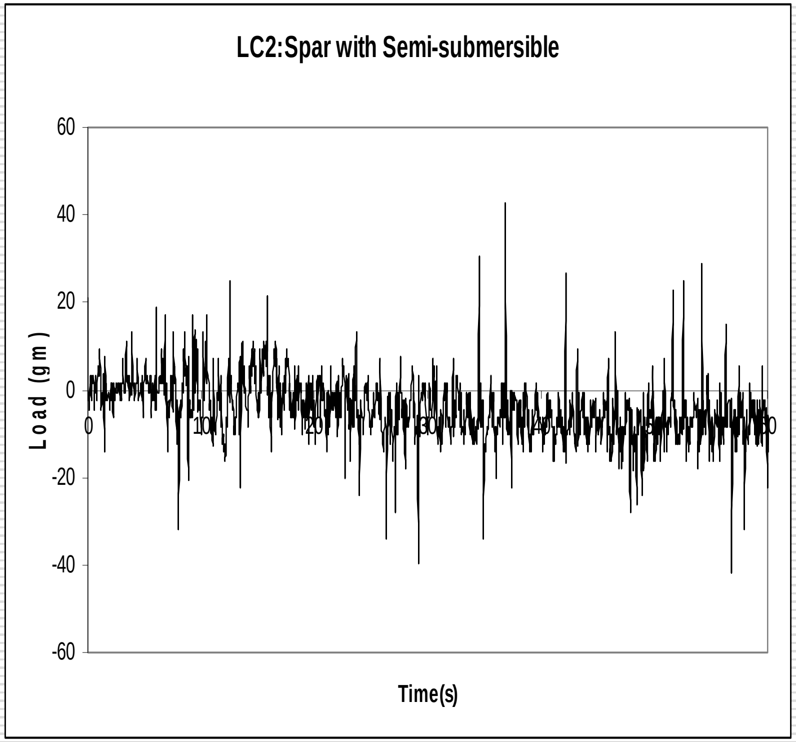


LC3,LC4 : Lee side

Measured mooring line forces: Spar with Semi-submersible

Regular wave H=10cm, T=1s

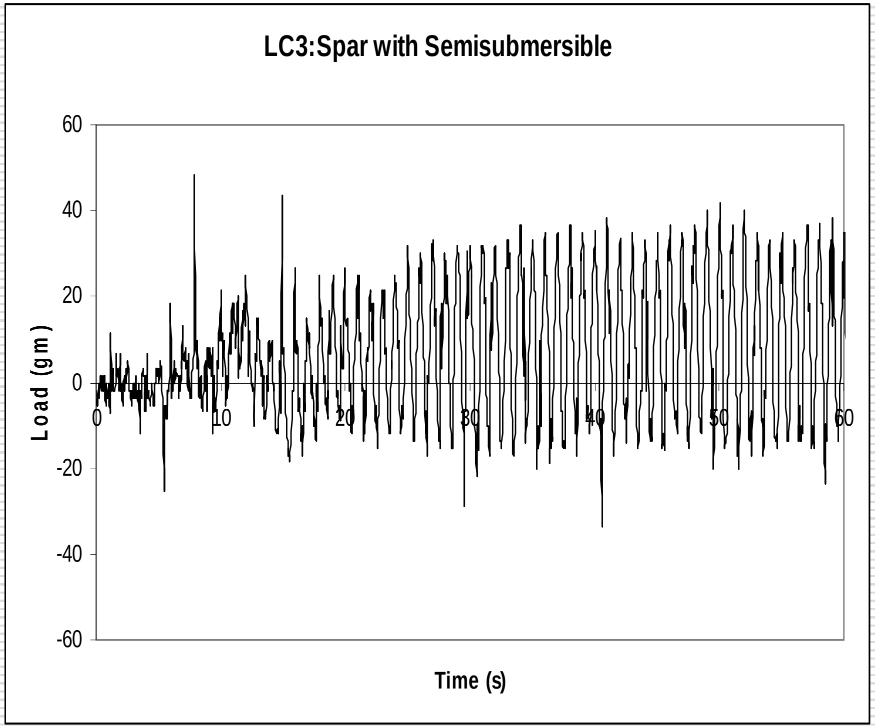


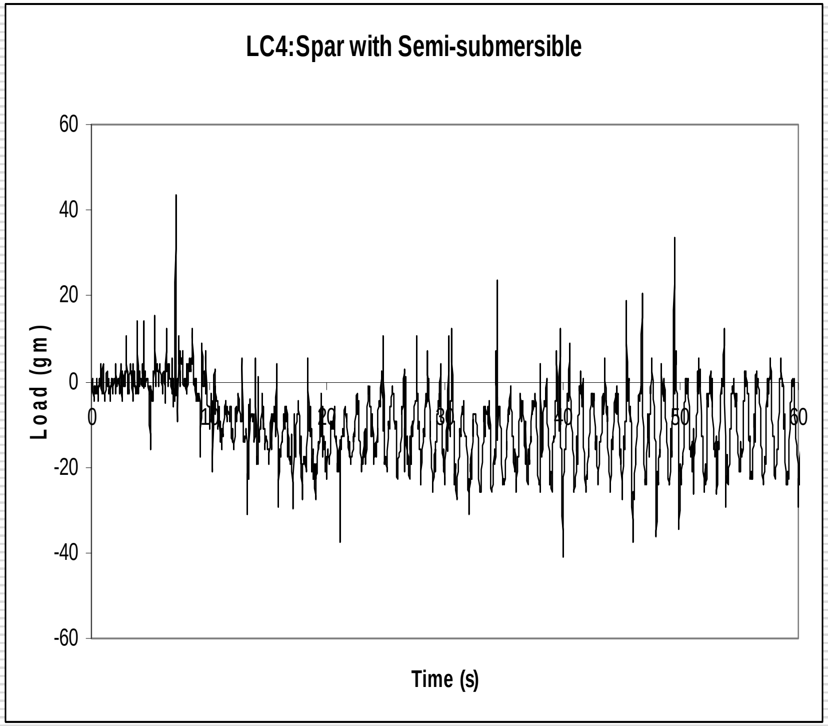


LC1,LC2 :wave maker side

Measured mooring line forces: Spar with Semi-submersible

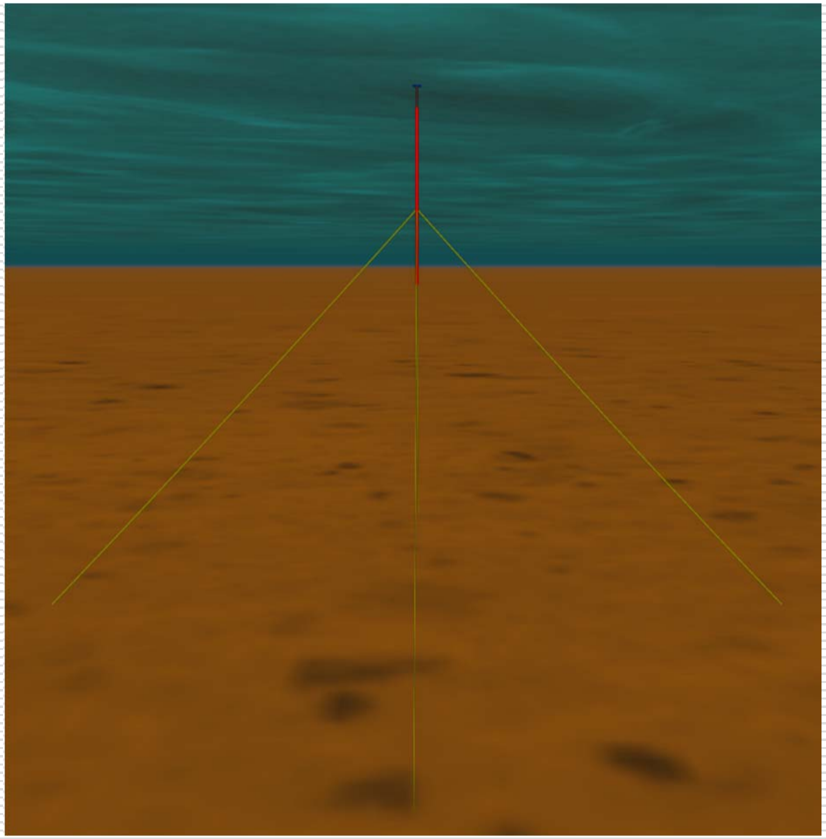
Regular wave H=10cm, T=1s





LC1,LC2 : Lee side

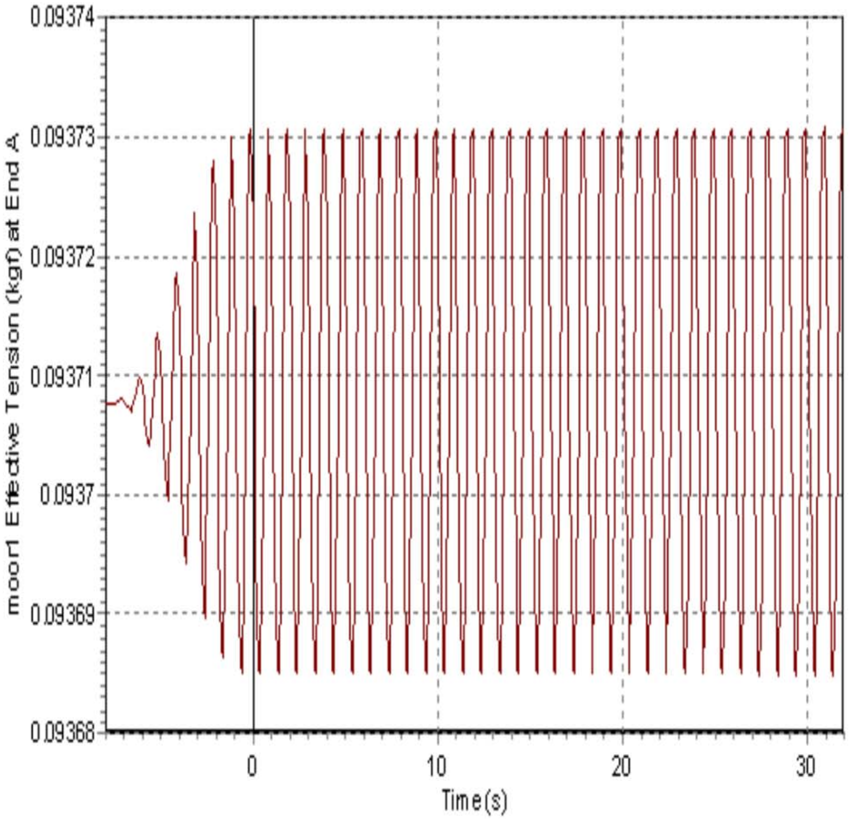
Mooring analysis: Spar alone



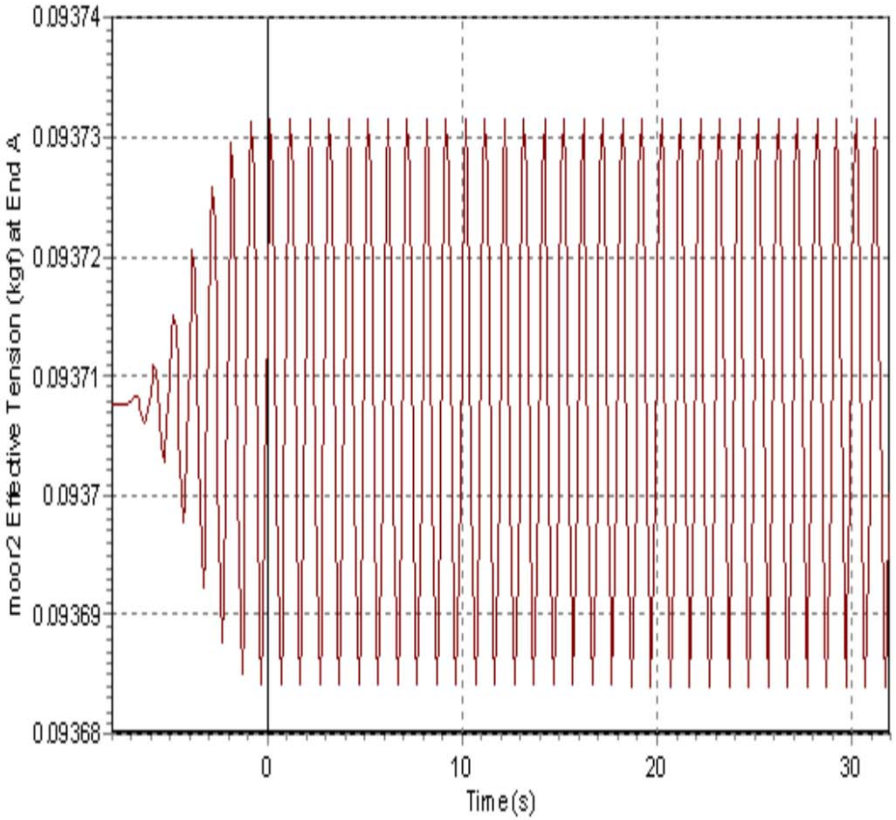
	Measured	Analytical
Wavemaker side	84.8 gm	93.73 gm
Lee side	84.5 gm	93.69 gm

Mooring line forces-wavemaker side: Spar alone

Mooring line 1

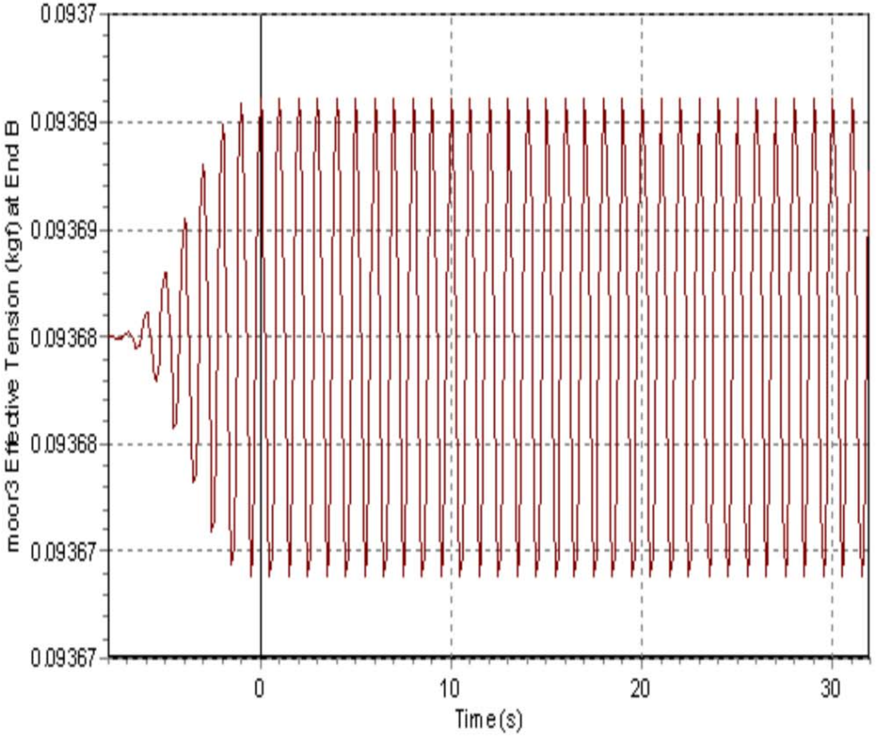


Mooring line 2

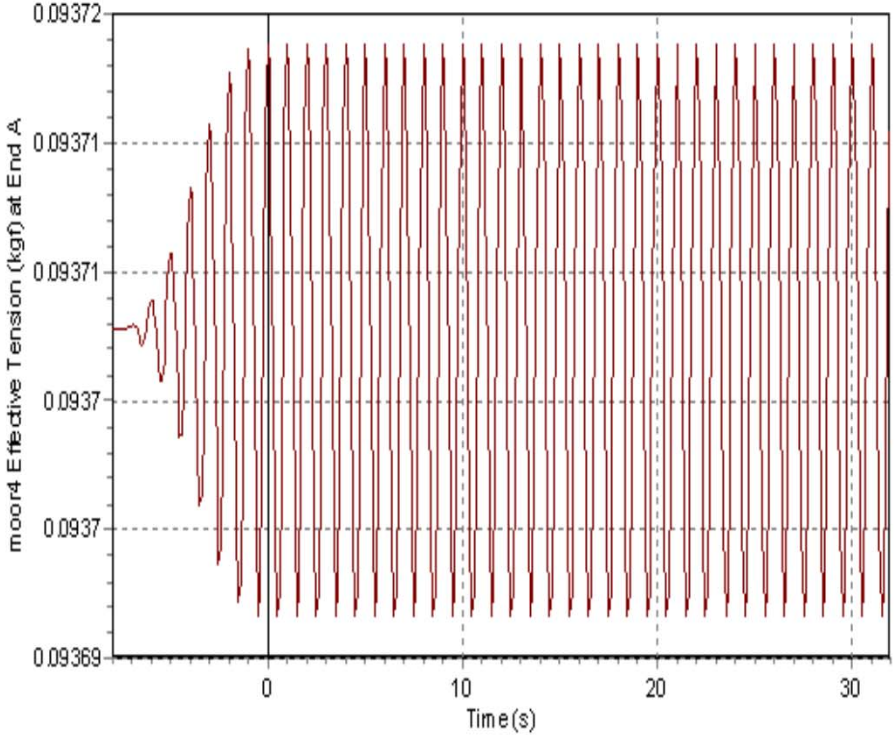


Mooring line forces-Lee side: Spar alone

Mooring line 3



Mooring line 4



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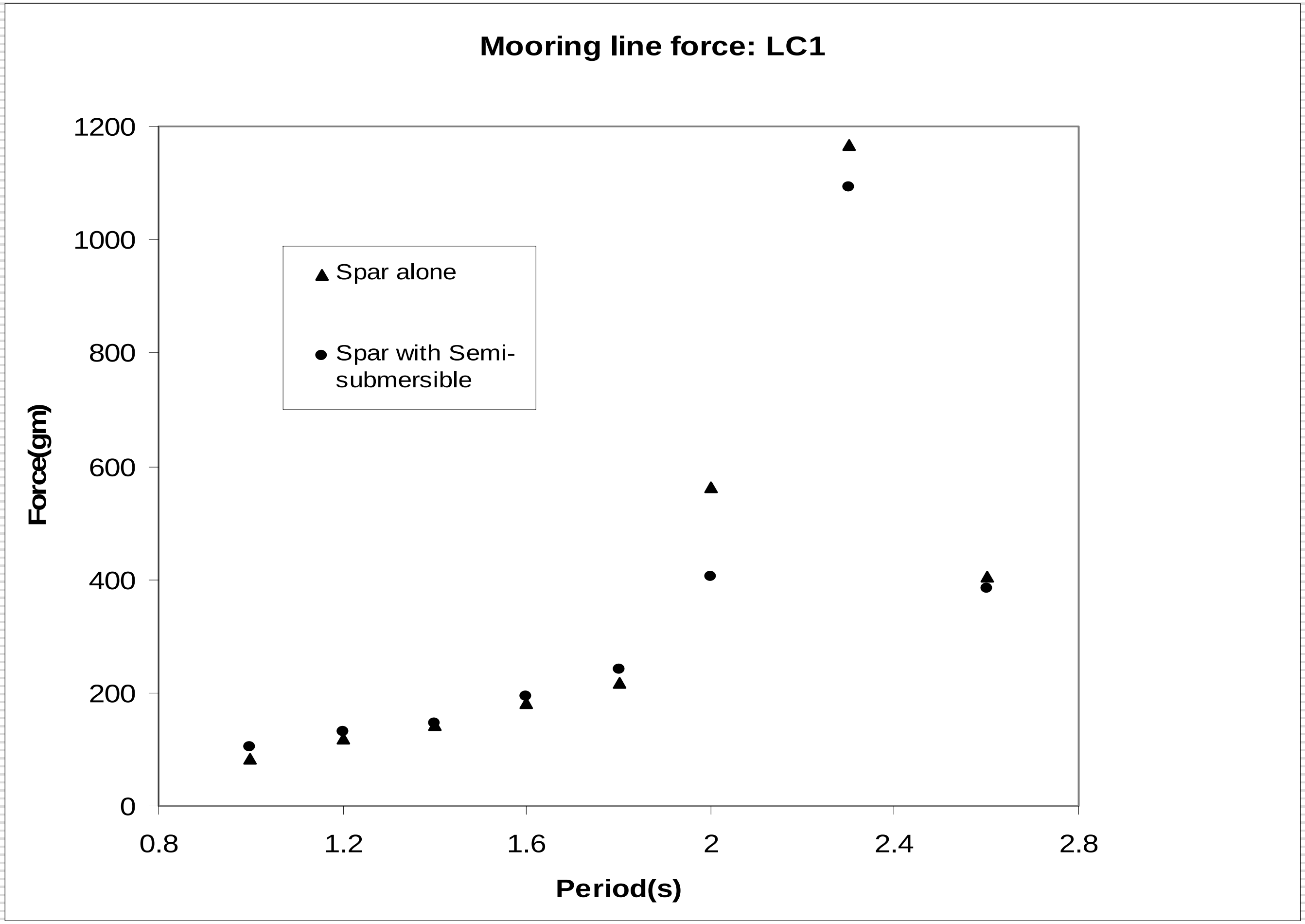
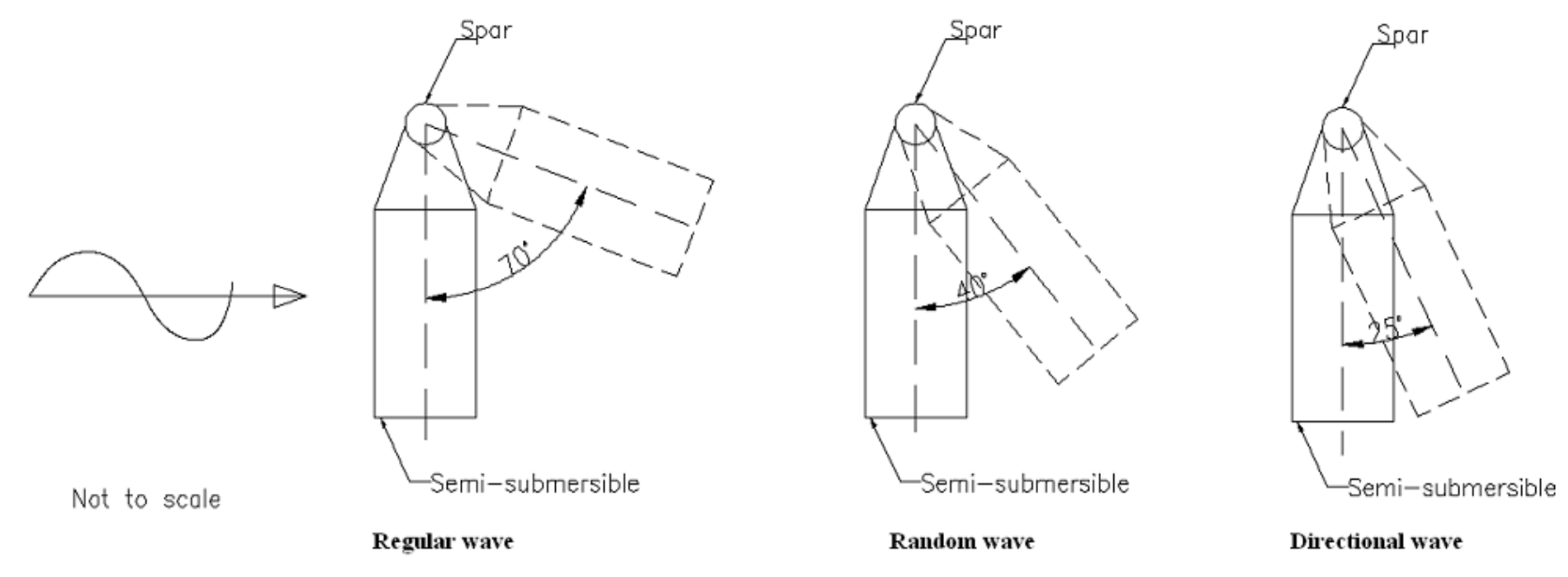
Measured mooring line force for wave height =10cm



Observed weather vaning for H=10cm, T=1s



Response of the Spar in operating environment

(1 year return period wave)

Response	Scale Model	Prototype
Heave response of spar	4mm	0.4m
Surge response of spar	35mm	3.5m
Mooring line force	85 gm	85 Tonnes

Response of the Spar in operating environment (100 year return period wave)

Response	Scale Model	Prototype
Heave response of spar	10mm	1m
Surge response of spar	40mm	4.0m
Mooring line force	190gm	190 Tonnes

Calculated from measured RAO's

Response of the Semisubmersible in operating environment

(1 year return period wave)

Response	Scale Model	Prototype
Heave response	8mm	0.8m

Conclusions

- Proposed Spar – Semi-submersible system is able to operate in the 1 year operating conditions and the Spar is able survive in the 100 year environmental condition
- Heave, surge displacements of spar when connected with semi-submersible are less when compared to spar alone.
- Heave, surge displacements of spar connected with semi-submersible by a rigid yoke are small and the system is stable in weather vaning.
- Mooring line forces are more for long period waves compared to short period waves.
- The difference in mooring line forces for spar alone and for the combined system is about 5-20% only. This is due to the restraint in surge direction when semi-submersible is connected to spar by a rigid yoke.

Thank you