Lloyd's Register Educational Trust

UNIVERSITY OF Southampton

Installation Engineering and Execution of Offshore Projects

by

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The LRET Research Collegium
Southampton, 11 July – 2 September 2011

Guest Lectures at The LRET Research Collegium

University of Southampton

Installation Engineering and Execution of Offshore Projects

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CORE Centre for Offshore Research and Engineering

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Characteristics and Requirements for Offshore Structures

- **The particular characteristic of offshore structures is that, unlike onshore or near-shore structures, they cannot be constructed in their final location**
- **An offshore structure must be built in a yard, loaded out, transported to their actual site, launched or lifted off, and finally installed**
- **These requirements have major influences on the design, which requires close integration with the methods of construction, both onshore and offshore, and their particular environmental and geographical conditions**

General View of a Fabrication Yard

Jacket load-out (in the fore-ground), cranes and flat-top barges

Conoco's Platforms in V Fields in Southern North Sea

Notes:

Three existing shallow water platforms, one new jacket (awaiting topside installation)

Bridge links to the central complex

Maureen Gravity Based Platform

Shell/Esso Eider Platform

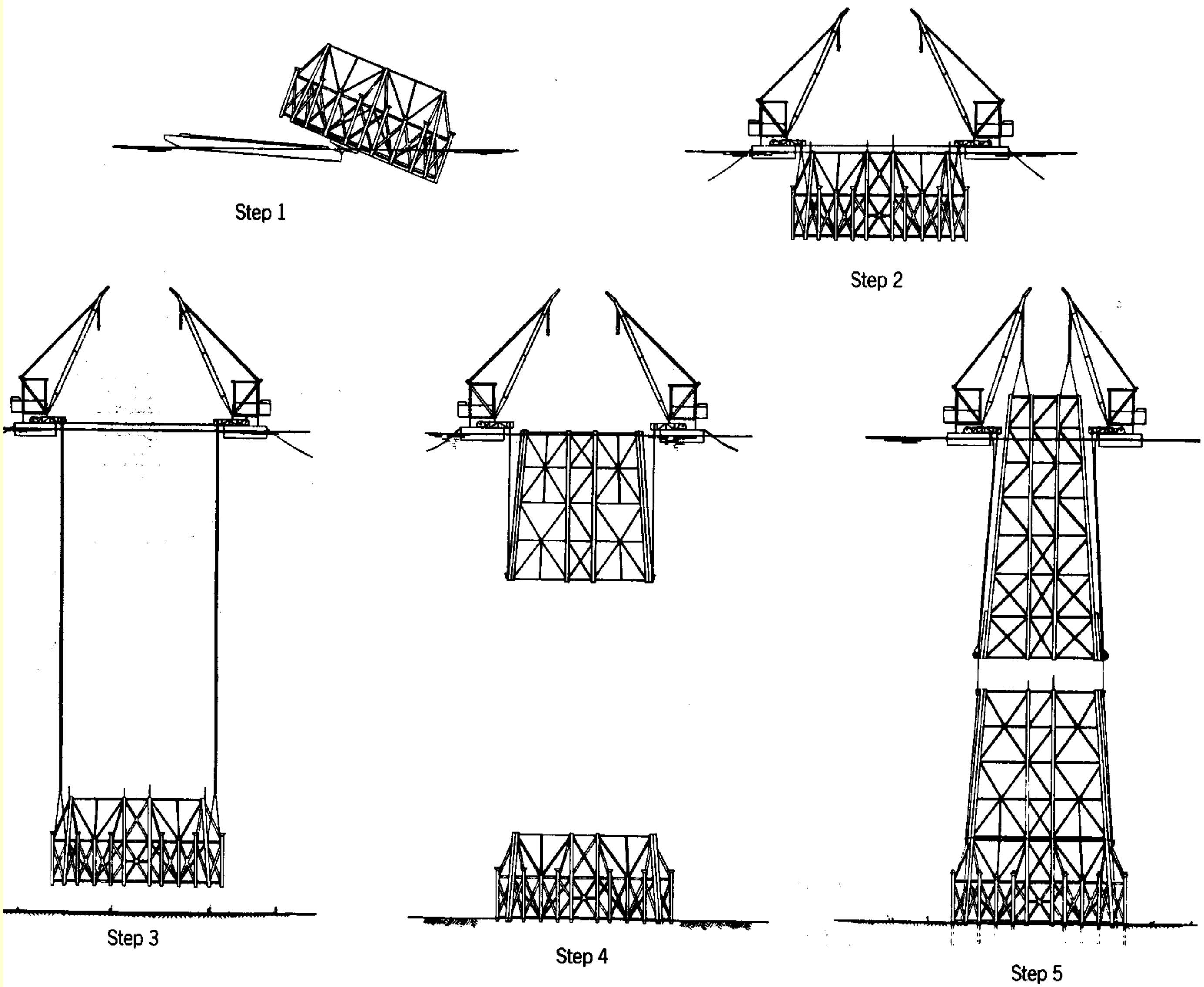
Sections of Cognac Platform (Prior to Field Installation)

Mid section

Top section

Bottom section

Offshore Assembly Sequence of Cognac Platform

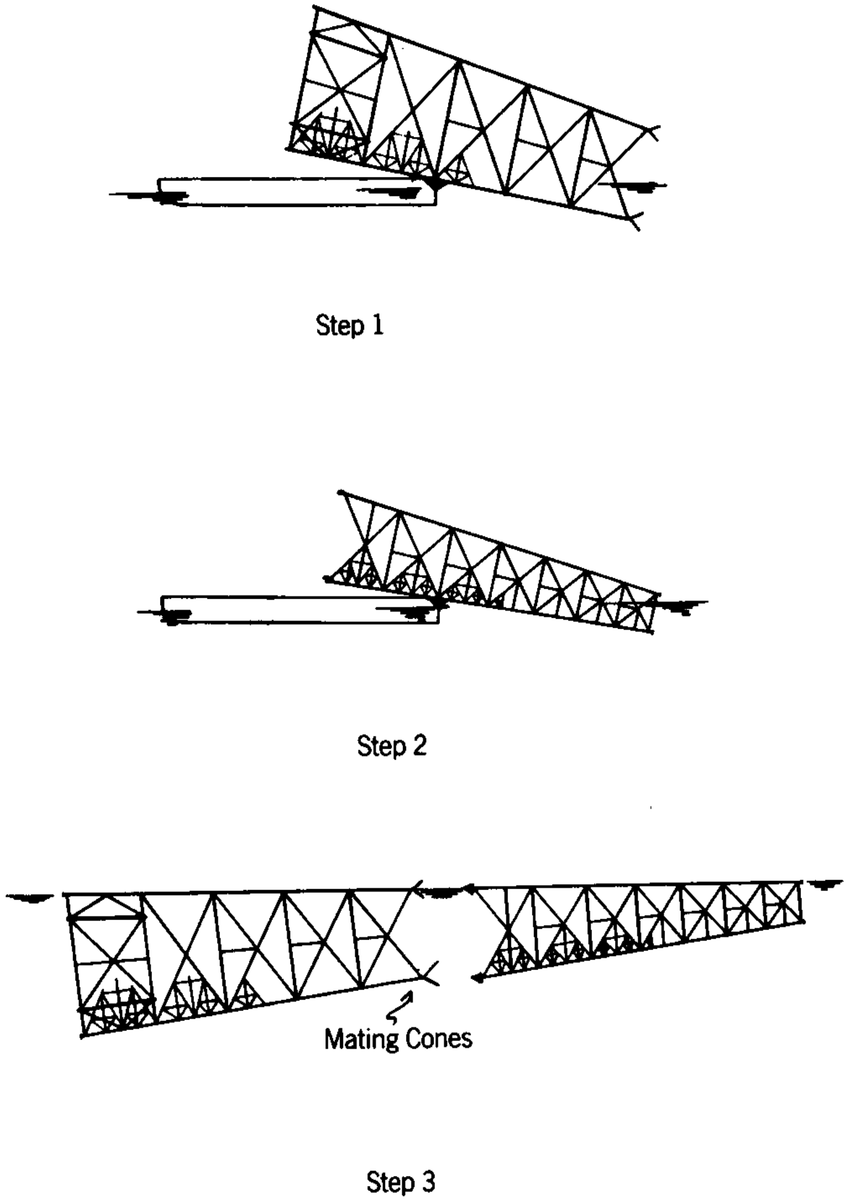


Assembly of jacket for Cognac platform.

Marine Spread for Cognac Mid-Section Installation

Two crane barges and tugs around mid-section (on transport barge)

Assembly of Jacket for Hondo Platform



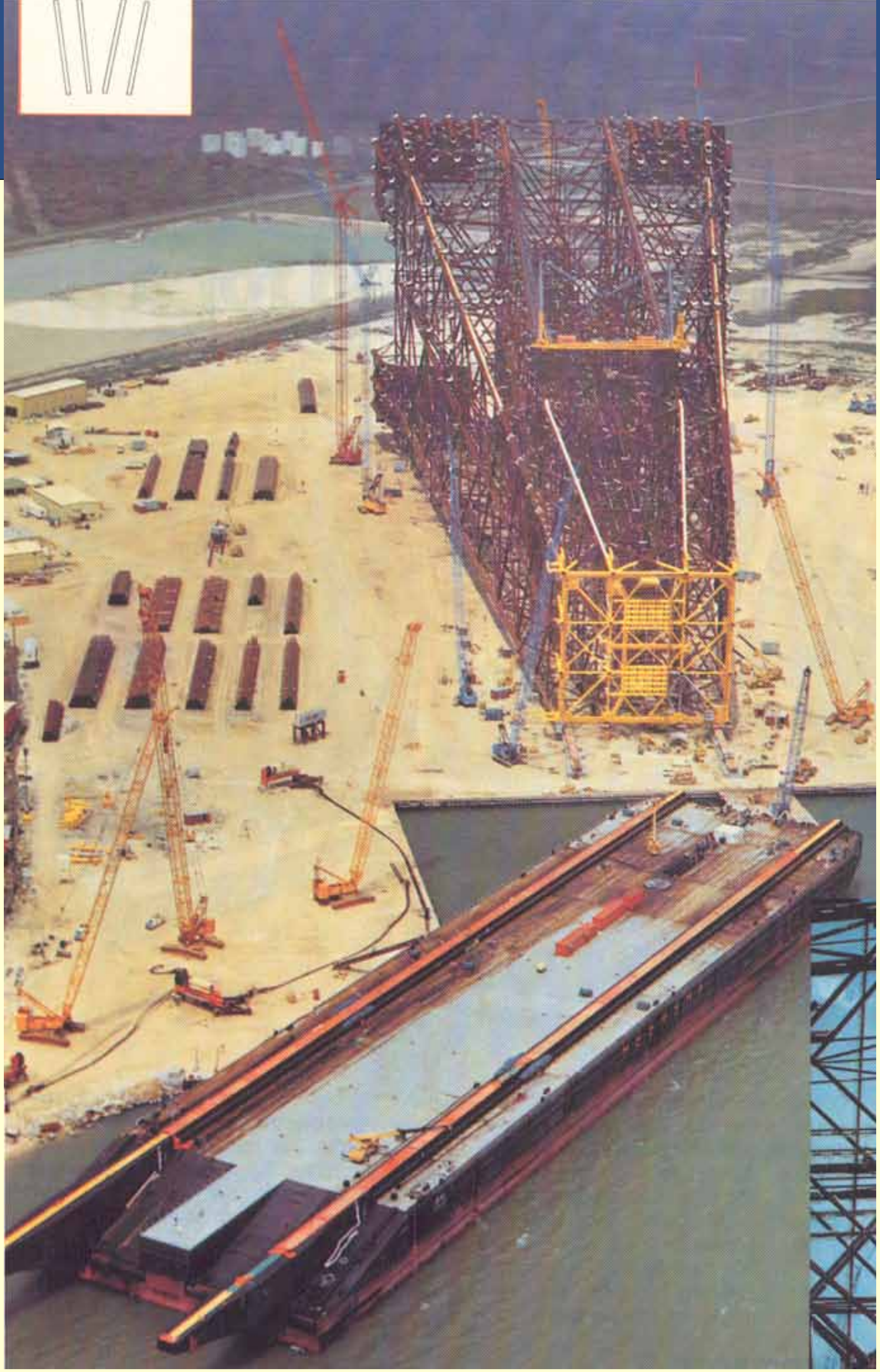
Assembly of jacket for Hondo platform.

Cerveza Platform (nearing completion in 1981)

Height (to top of rigs): 327m; Weight (at launch): 26,000 tonne

Base dimensions: 107m x 79m; top dimensions: 45m x 25m

Bullwinkle Jacket & H851 Barge

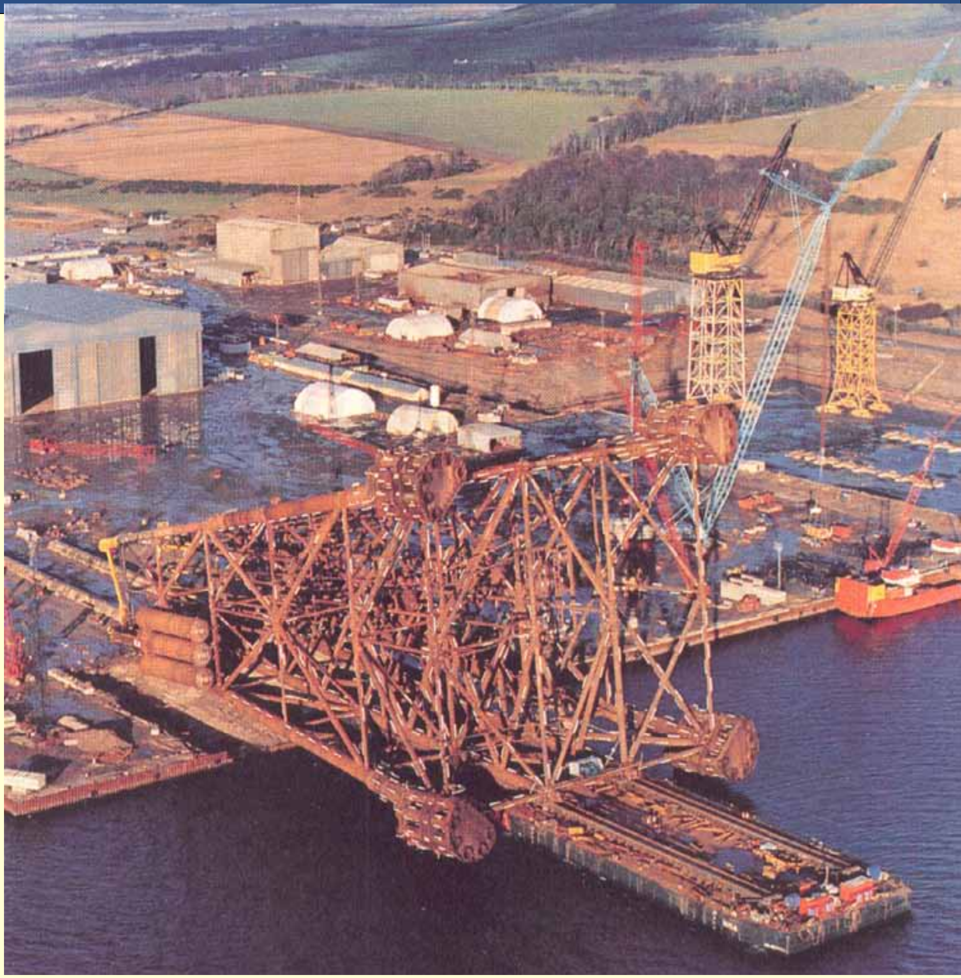


- World's tallest jacket structure
- Height: 416 m
- Base dimensions: 148 m x 124 m
- Launch weight: 44,800 tonne
- 3000+ members
- 1000+ joints
- Top of jacket cantilevered 120m beyond one end of H851 barge, with un-supported weight of 12,000 tonne

Play Bullwinkle Movie

Construction Yard Facilities

Vertically fabricated jackets; decks on dollies



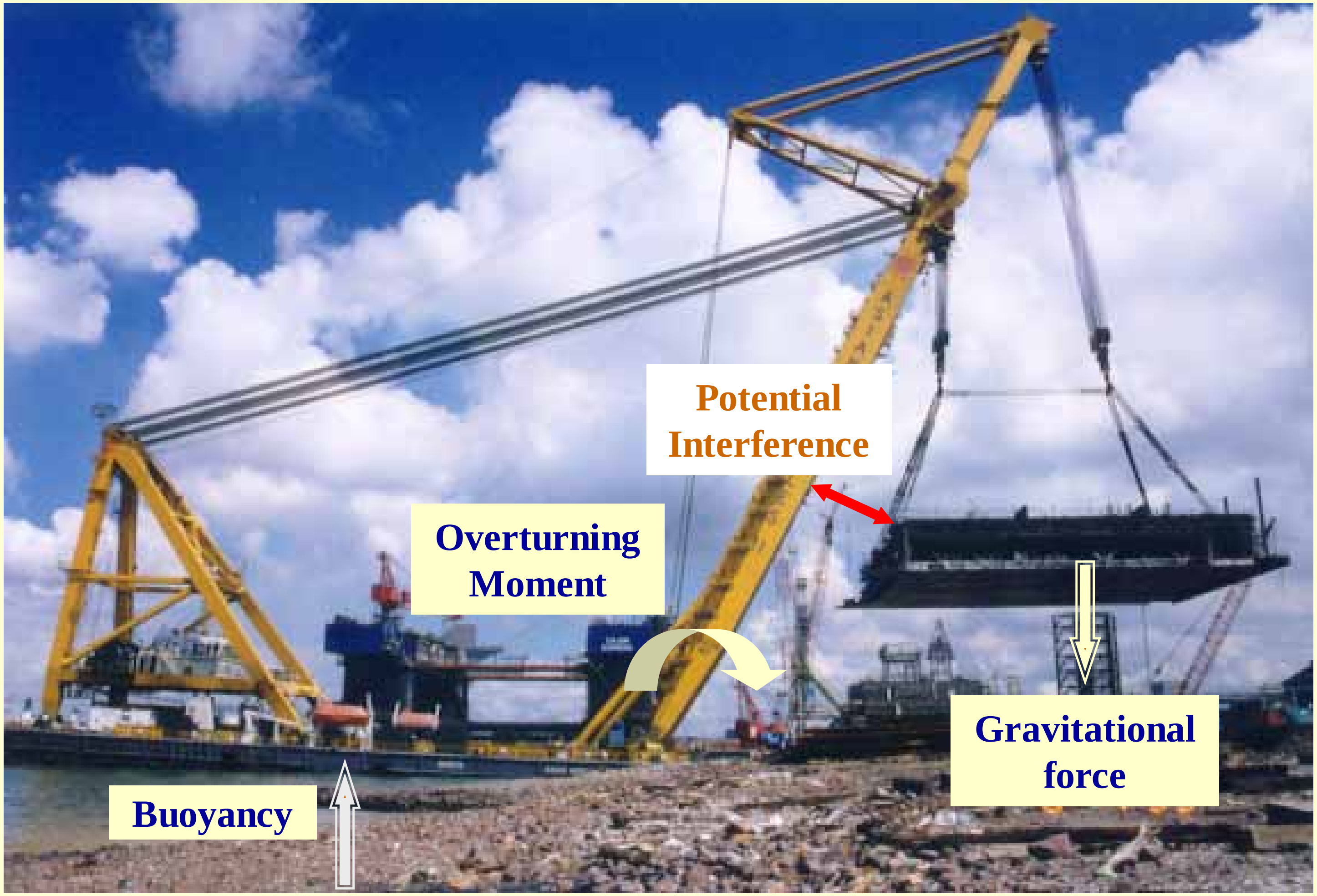
Load-out of horizontally fabricated jacket to barge. Note cranes at the background

Different Fabrication Methods Due to Constraints of Available Construction Equipment

Reach and capacity of crawler cranes sufficient for roll-up of bent

Bullwinkle "core-block" method due to larger dimensions of base structure. At required height, crawler cranes provide in-adequate lift capacity

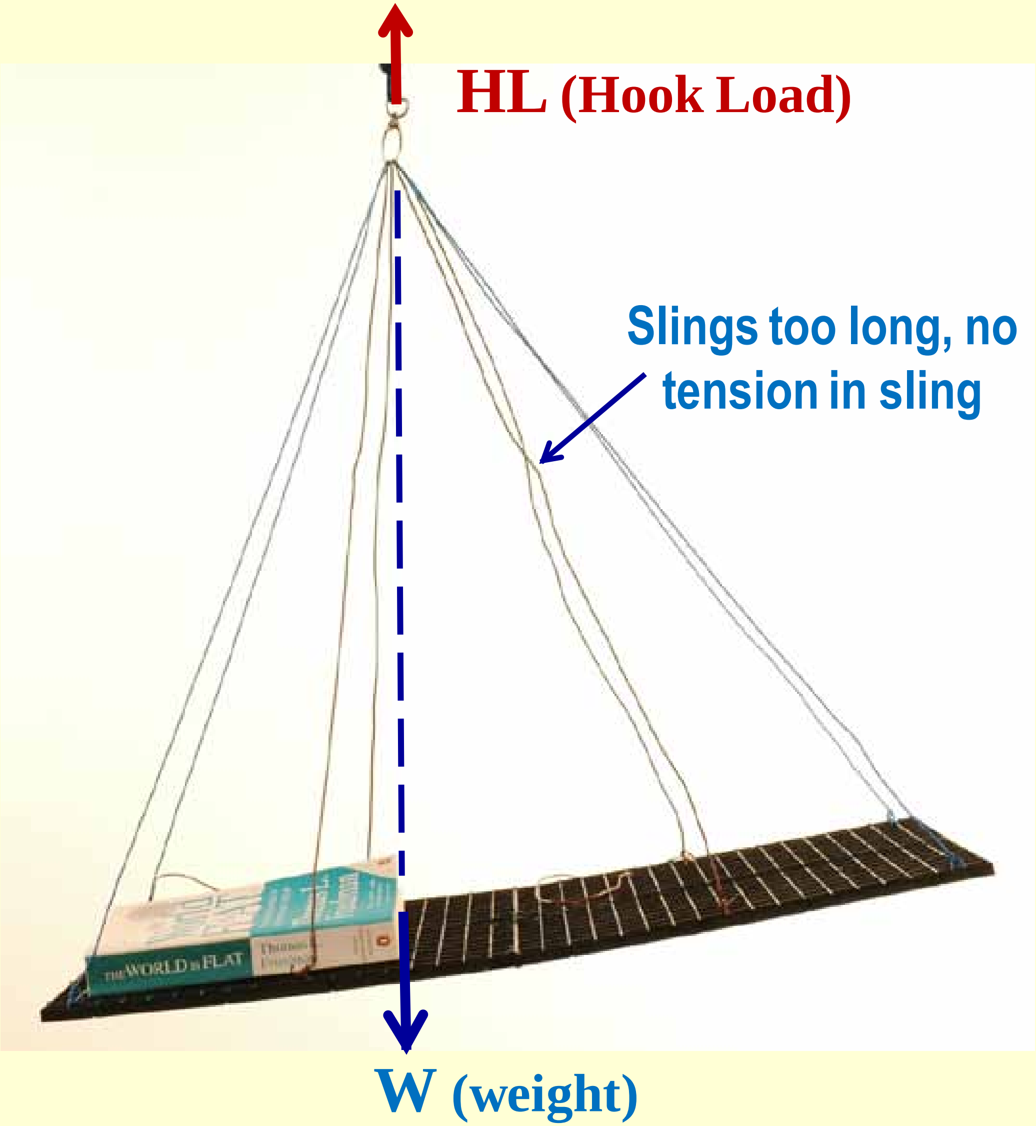
Engineering and Geometric Considerations for Lifting Using Crane Vessel



Equilibrium – Buoyancy, gravitational force and overturning moment

Compatibility – Geometrically, check potential interference or hook height

Equilibrium (Newton's Law) and Compatibility Considerations for Lifting



Static Equilibrium:

$$\sum F = 0 \quad \sum M = 0$$

For Lift System shown,
HL = W (along line of action), with associated tilt

Dynamic Equilibrium:

$$\sum F = m\frac{dv}{dt}$$

Lift Dynamics to be prevented or minimised

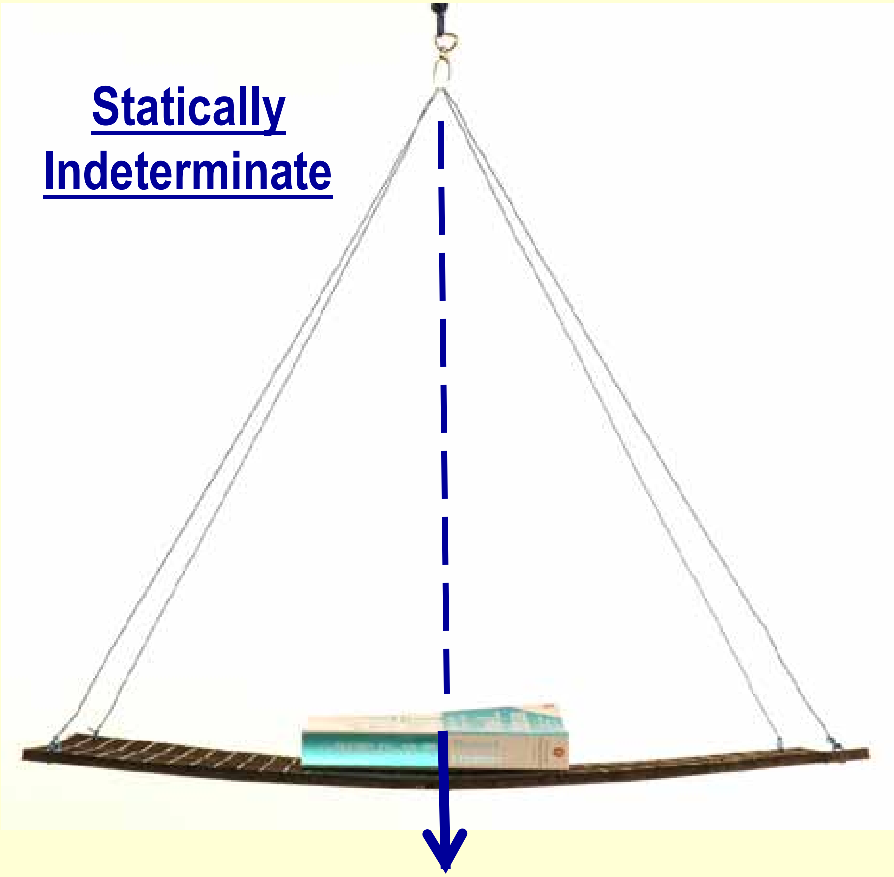
Compatibility:

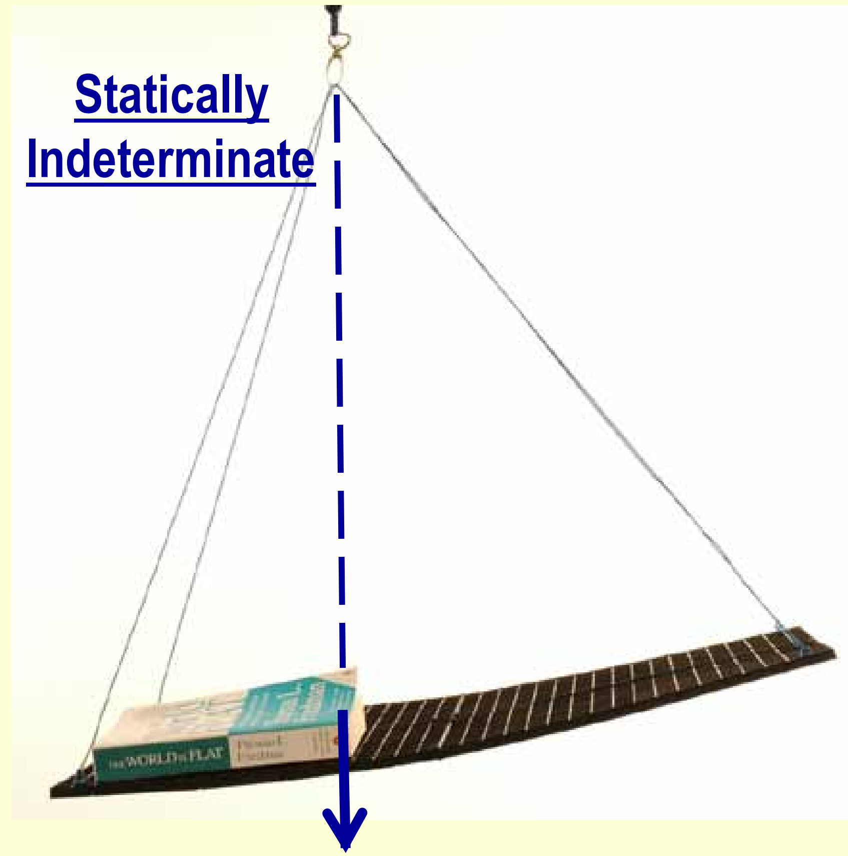
Continuity conditions on strains and deflections. Imposes considerations on sling length misfit.

Constitutive Law:

Structural material used. Does it obey Hooke's Law?

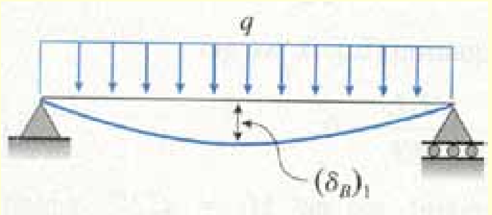
Single Hook – 4 Sling Arrangement
Effect of Indeterminacy on Sling Tension & C.G. Shift



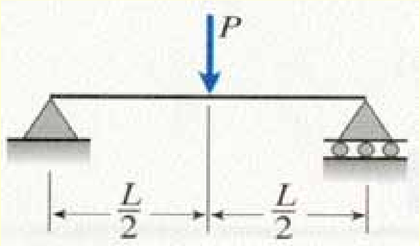


1 hook-4 sling arrangement is statically indeterminate and requires considerations of compatibility (in sling lengths and deflections) and equilibrium. System will rotate with combined C.G. position below hook. Tilt is important in installation engineering, and results in localised contact during placement

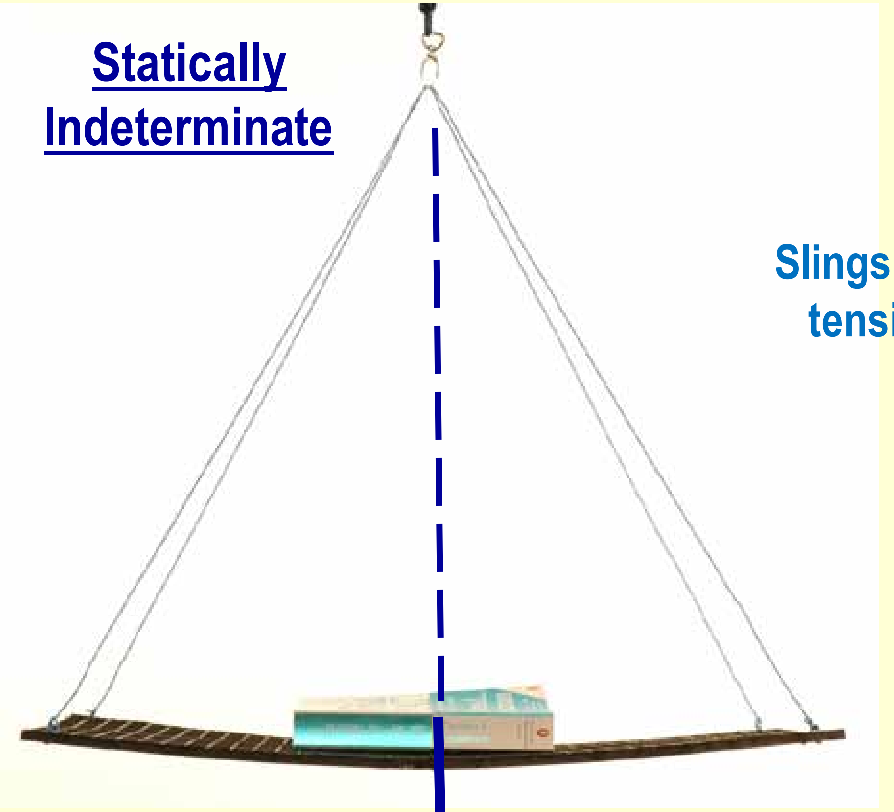
Single or Dual Hook – 4 Sling Arrangement
Effect of Lift Point Spacing & Location on Deflection



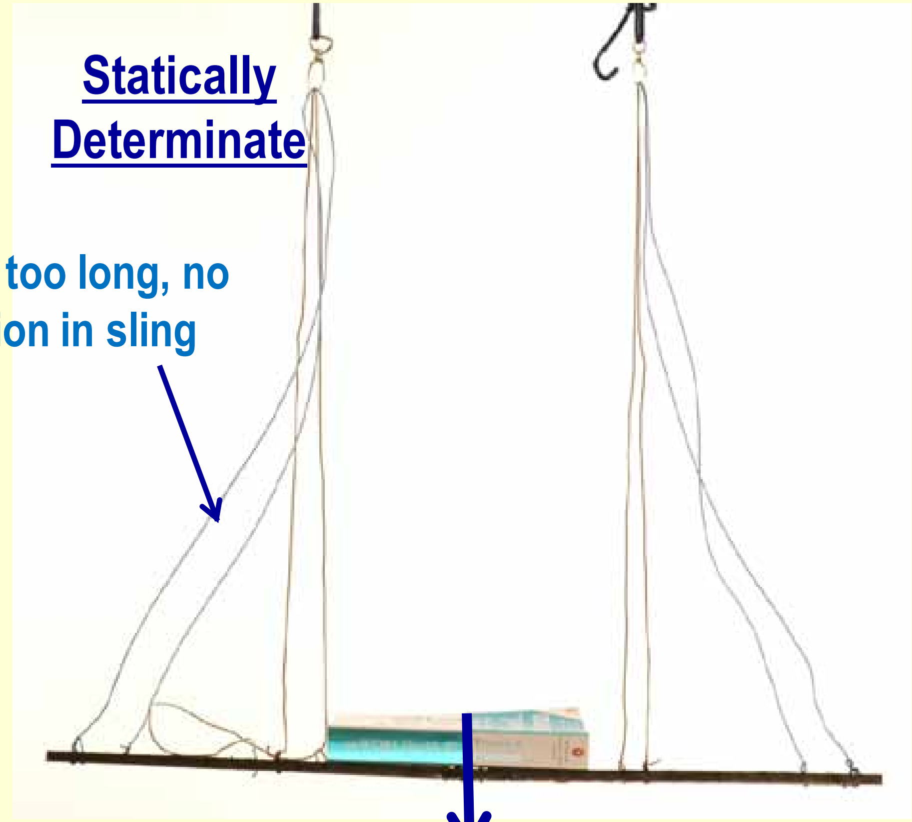
$$\delta_C = \frac{5qL^4}{384EI}$$



$$\delta_C = \frac{PL^3}{48EI}$$



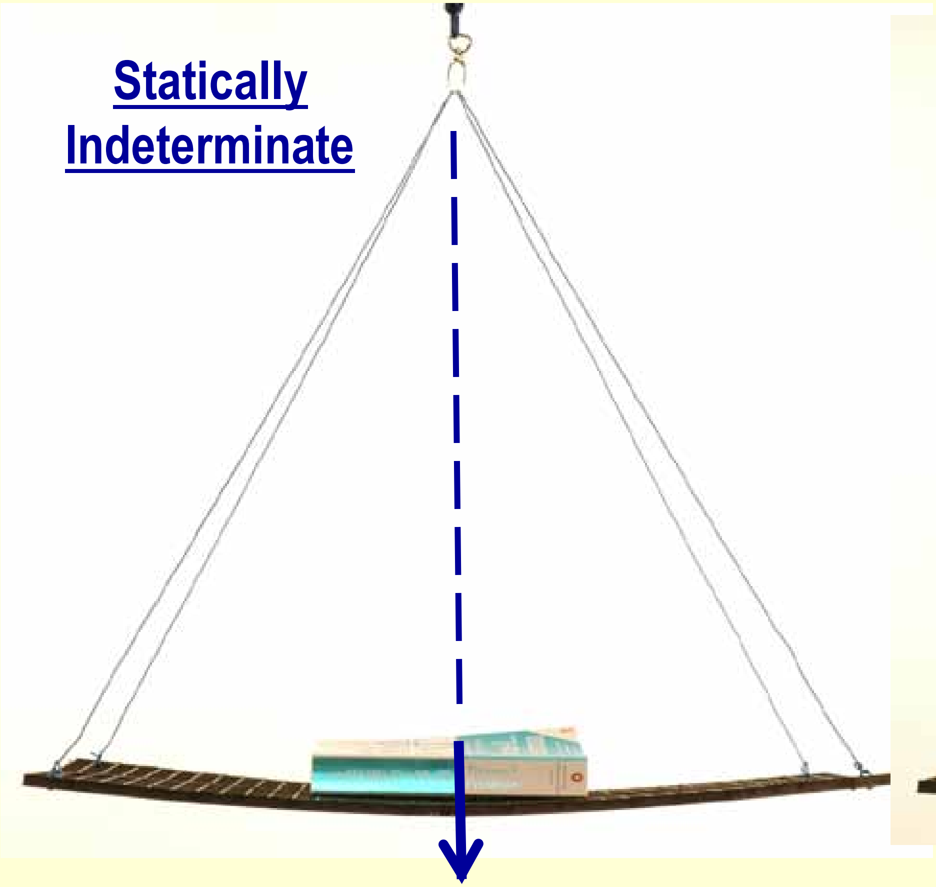
Significant deflection; Resolved compression from sling tension

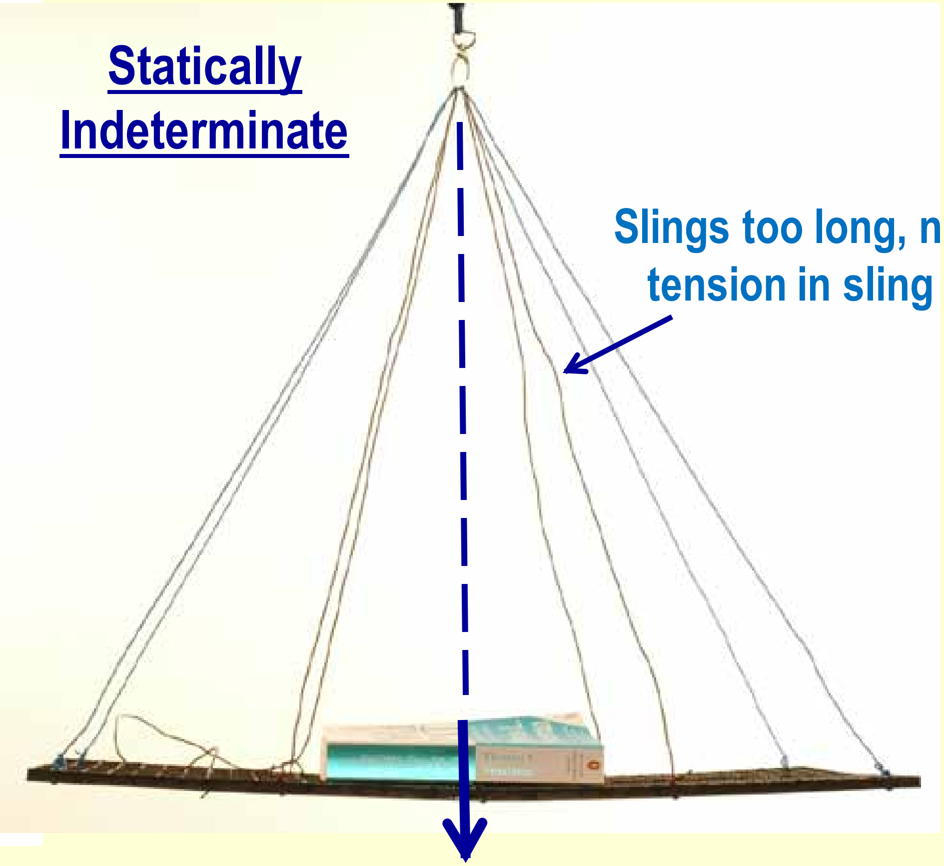


Slings too long, no tension in sling

Reduced deflection (shorter mid-span); Tilt adjustment

Single Hook – 4 or 8 Sling Arrangement
Effect on Sling Tension & Module Deflection





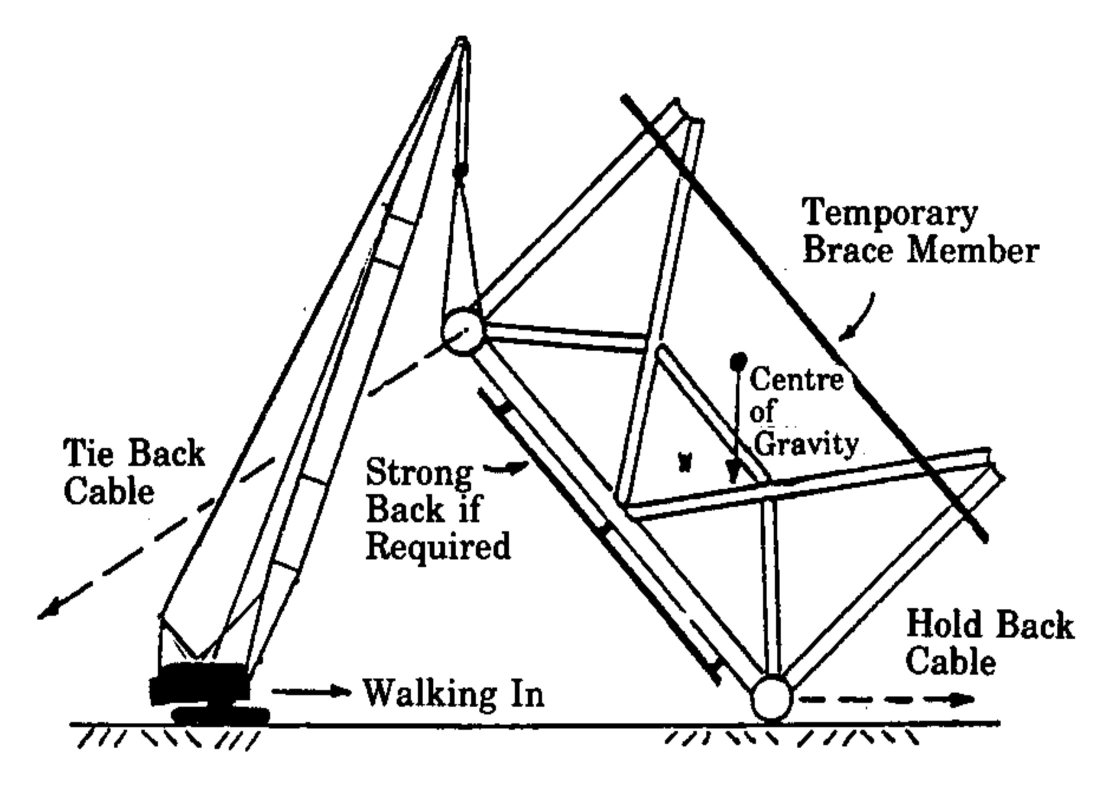
Both rigging schemes are statically indeterminate, need to consider compatibility and equilibrium. Note some slings are not in tension due to sling length misfit in this example.

Reduction in module deflection with additional lift points

General View of Roll-Up of Jacket "Bent"

Note the **synchronized** movement of cranes in the roll-up operation

Considerations in Roll-Up Operations



If members during fabrication stage do not have adequate strength, strong back may be needed.

Temporary brace members may be required to keep structure stable during roll-up

During roll-up, structure will be **unstable** after the C.G. passes over the support point, tie back cables at top and hold back cables at bottom are required.

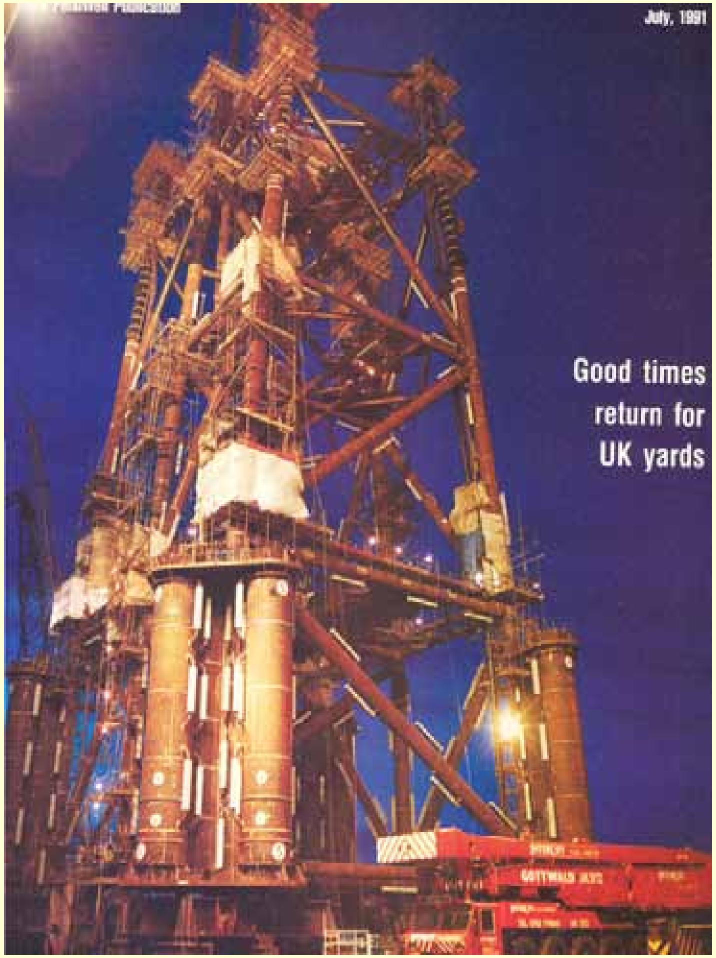
As roll-up operation progresses, the crawler crane needs to walk towards the jacket to keep the main **cables vertical**. This is a difficult operation as movement of all the cranes need to be **in-phase**.

Stages of Roll-Up Operations

Bent being lifted from horizontal position

Bent lifted towards vertical plane

Other Methods of Fabrication of Sub-Structures



Vertical jacket fabrication

Fabrication of hull structure for Nepture Spar platform

Heavy Lift Analysis and Design

Considerations:

- Outreach
- Capacity
- Interference
- Rigging
- Lift Points
- Verticality

2 stages of lifting lower turret – off quayside & clearing side of Northern Endeavour (Laminaria FPSO)

Example of FPSO (from Converted Tanker)

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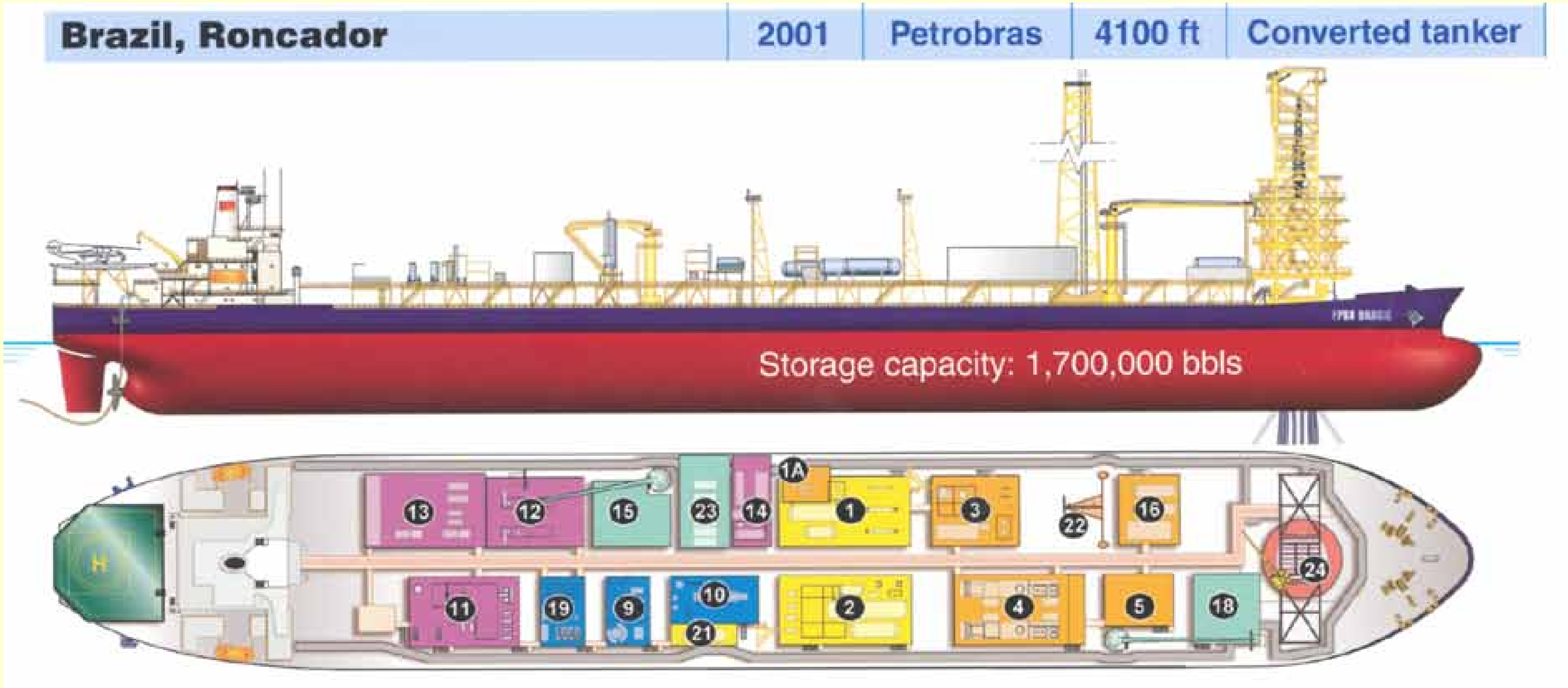


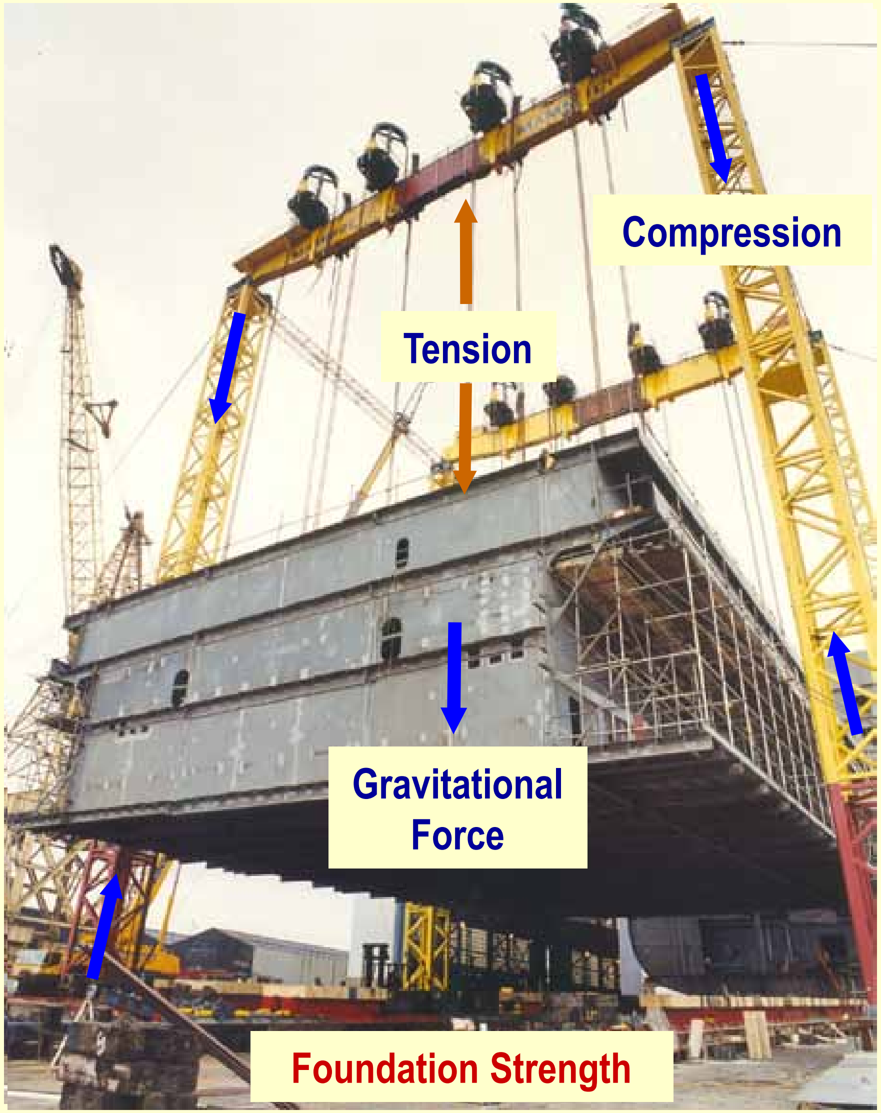
Barge lift capacity and reach

FPSO dimensions and module locations and weights

Module strength, lift points, rigging arrangement

Floating Production Storage and Offloading (FPSO) vessel completed by Keppel

Engineering and Geometric Considerations for Lifting Using Towers & Transfer Beams



Equilibrium

- Tension cables overcoming gravitational pull;
- Towers in compression – Stability through cables and connecting beams; Foundation strength requirement;
- Bending of transfer beam

Strand Jacks, Braced Columns and Beams for Placing Fabricated Module above Hull Structure

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Lifting using synchronised strand jacks

C.G. of module;
Column stability;
Foundation strength;
Geometric constraints

Note skid beams prepared for skidding of lower hull

Sufficient height of towers for skidding of lower hull while upper module is held stationary

Example: Shell Malampaya Integrated Deck

- Multi-level Rigging Arrangement for Deck Panels

- Float-over Operations at Offshore Location

Fabrication of Shell Malampaya Deck

Concurrent fabrication of three deck levels: cellar, main and weather decks

- Compatible deflections
- Overall tilt and Support reactions

Placement of weather deck onto lower decks through multi-tier rigging system

Rigging Arrangement for Shell Malampaya Deck

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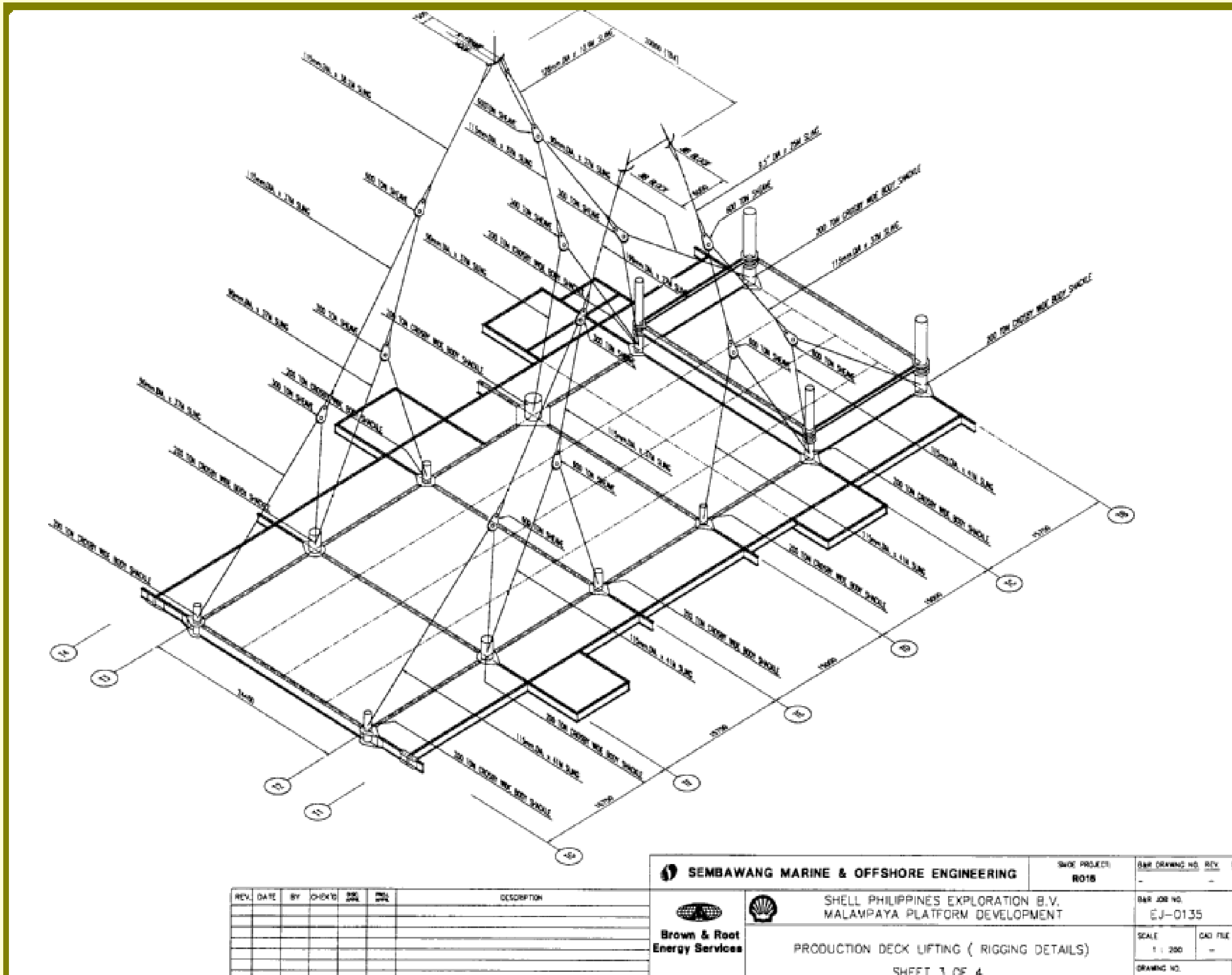
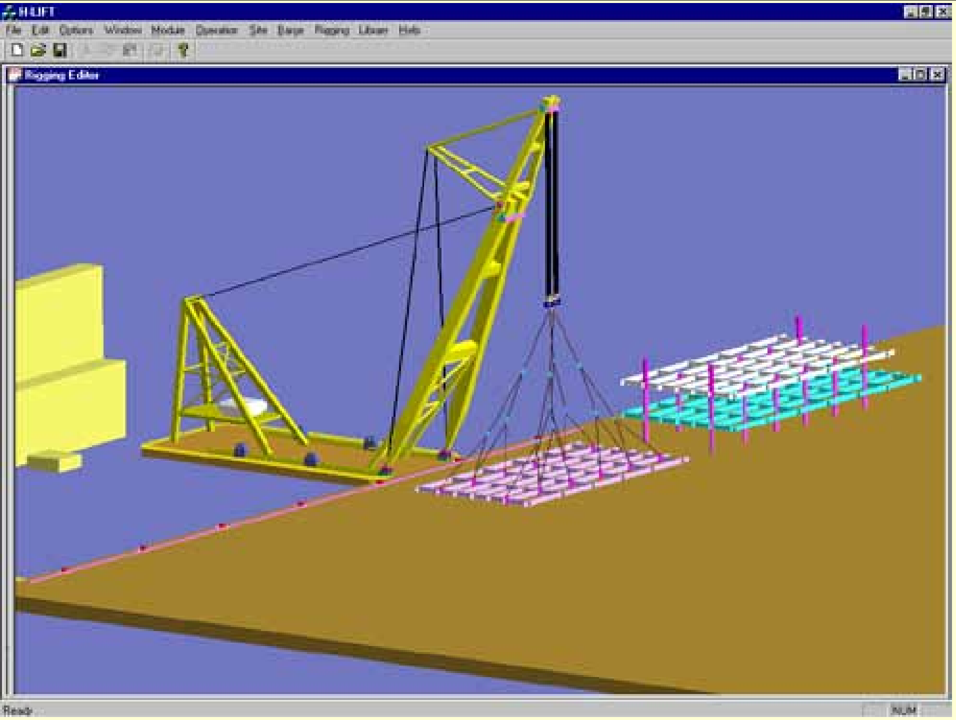
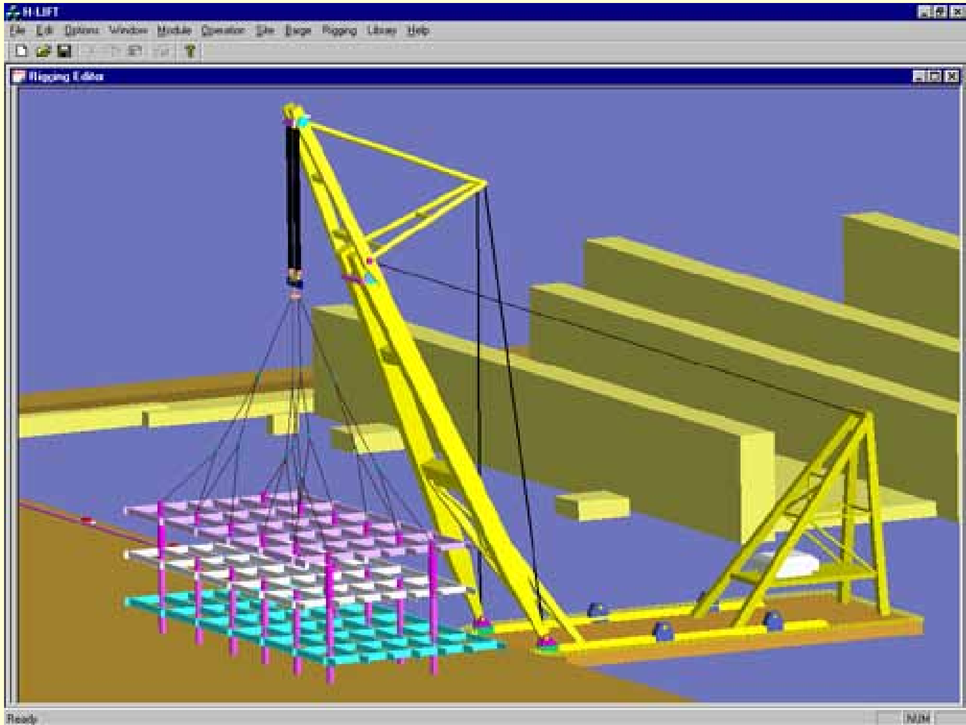


Shell Malampaya Deck Fabrication – Lifting Simulation using H-LIFT



Lifting of upper deck panel from fabricated position

Placement of upper deck panel to lower deck structure



Stanley Gray Award 2001 – IMarEST

IES Prestigious Engineering Achievement Award 2003

Shell Malampaya Deck Panel Lifting and Integrated Deck Lift

Lifting of top deck panel using crane barge using multi-tier rigging system

Lifting of deck using strand jacks on columns for placement of loadout truss

Shell Malampaya Deck – Strand Jack Details

Views of vertical columns and strand jacks prior to lifting

Shell Malampaya Deck – Lifted prior to Loadout Truss Placement

Total deck weight (12,000 tonne) supported on 4 columns

Shell Malampaya Deck –Transport Truss Placement and Deck Load-out onto Transport Barge

Positioning transport truss below jacked-up integrated deck

- Differential elevations & Uneven reactions; Foundation strength

Loading out integrated deck onto transport barge

Shell Malampaya Deck – Towing and Placement onto Pre-installed Sub-structure

Towing of Malampaya deck from Singapore

- High CG – Roll during tow
- Impact forces during mating

Float-over mating of Malampaya deck and substructure

Example: Sedco Forex Semi-submersible

- 3 lifts for deck structure using sheerleg vessel;

- Use of fabricated pipe trunnions

Lifting Arrangement for Deck Components of Cajun Express Semi-submersible

Installation of side block 2

- Potential physical interference
- Overall stability of vessel + module

Lifting of centre block from yard

Lift Installation of Centre Block of Cajun Express - 1

Asian Hercules II sheerleg crane vessel, with centre block, approaching Cajun Express

Zoomed-in view (note the temporary truss on side of block, and lift point)

Lift Installation of Centre Block of Cajun Express - 2

Lowering of centre block in-between the two side blocks

Final adjustment for fitting up; note the fabricated trunnion in the fore-ground

Lift Installation of Centre Block of Cajun Express - 3

Final adjustment for fitting up; note fabricated trunnion in the fore-ground

Lowering of centre block in-between the two side blocks

- **Compatible deflections**
- **Minimal environmental effects due to protected & calm waters**

Cajun Express Semi-submersible Drilling Rig – Views of Rig being Completed in Singapore

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Side view of semi-submersible vessel

View of drilling rig of semi-submersible vessel

<u>Example</u>: Sedco Forex Semi-submersible

- Fabrication in Brest (France)

- Towers to lift deck

- Positioning of Lower Hull through flooding in dry dock

Towers and Strand Jacks for Elevating Deck Structure - 1

Elevating deck structure using towers and strand jacks

- Stability of towers
- Foundation strength

Towers and Strand Jacks for Elevating Deck Structure - 2

Elevating deck structure using towers and strand jacks

Flooding of dry dock for controlled mating of deck & lower hull

- Stability of towers
- Height of towers vs constructional constraints
- Foundation strength

Jacking System by Mammoet

- Tower Lifting System
- Push-up System

Mammoet Jacking Systems and Trusses – ATP MinDOC Project - 1

Mammoet Jacking Systems and Trusses – ATP MinDOC project - 2

Preparations for Jack-up operations

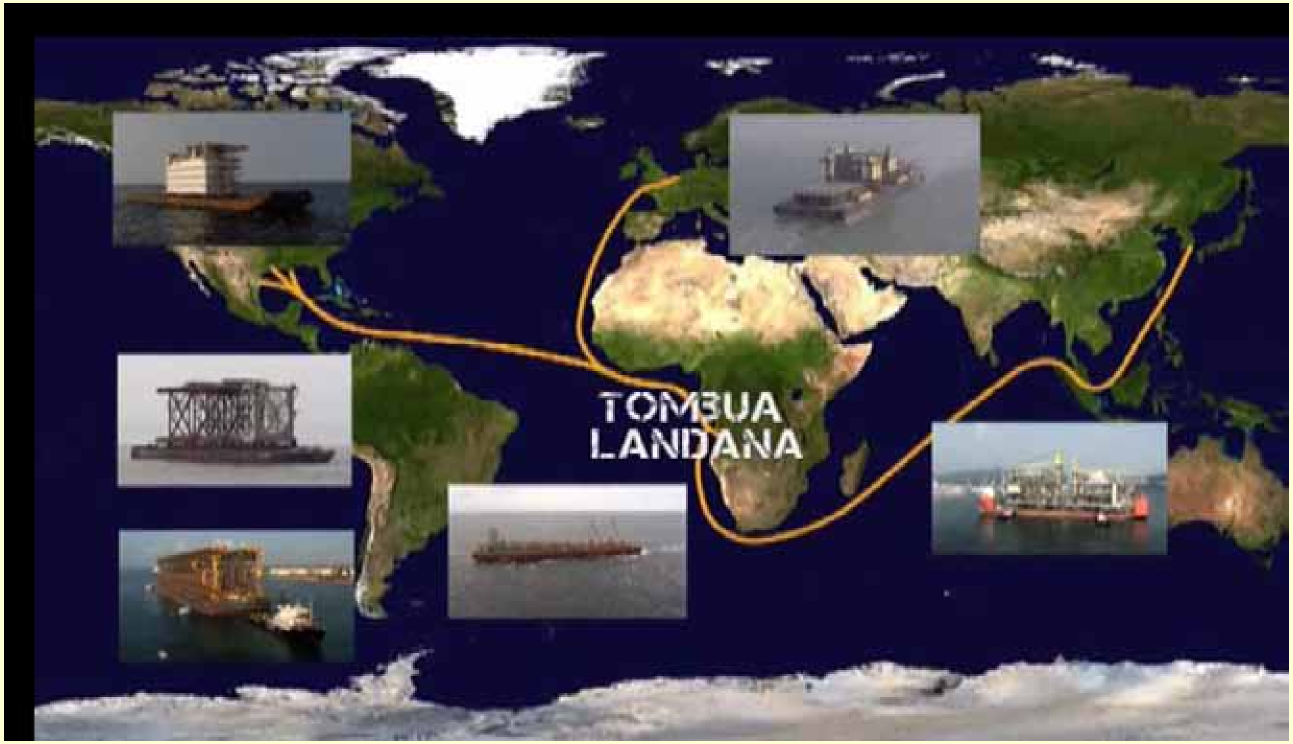
Preparing the jacking towers for lifting the ATP MinDoc

Jacking of ACG East Azeri Integrated Deck Using Mammoet's Push-up System

Related to static indeterminacy – Limiting load variation through shimming plates

Chevron Tombua Landana Compliant Tower – Global Involvement in Offshore Industry

Chevron Tombua Landana Compliant Tower – Global Involvement in Offshore Industry



Tombua Landana Project for DSME/Chevron comprises of installation of compliant tower and topsides in 370m offshore Cabinda, Africa.

- 500 t leveling pile template, 4 leveling piles (84" dia, 450 ft length, 315 t each)
- 3000 t Tower Base Template and 12 foundation piles (108" dia, 625 ft length, 850 t each)
- 30,000 t Tower Bottom Section, Tower Top Section and 4 deck modules: Module Support Frame, Central Module, West Module, East Module.
- Various parts of tower and platform built in 6 yards spread all over the globe.

Chevron Tombua Landana MSF Lift Installation – 6300 tonne

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Dual crane-4 lift point lift

Statically determinate and sling tensions can be assessed by equilibrium considerations.

Play video of Tombua Landala from Heerema

Marine Studies

- **Primary concern during marine operations is security of the cargo (structure).**
- **The following are to be avoided:**
  - **Total Loss** **(capsize and loss of barge and cargo)**
  - **Cargo Loss** **(failure of tie-down devices and subsequent loss of cargo)**
  - **Damage** **(structural failure of any of cargo's components due to excessive accelerations or due to direct wave impact)**
  - **Reduction in Fatigue Life** **(During tow, portions of the structure may have suffered sufficient number of stress cycles at levels which may reduce the safe life of the structure under service conditions, after delivery and installation)**

Loadout of Cerveza Jacket

Loadout of Brae B Jacket

Loadout Conditions to be Considered - 1

- **Stresses induced by the loadout operation must be checked**
- **The loading conditions for checking include:**
  - **Prior to loadout (representative of cargo immediately after fabrication, with all unnecessary supports removed and ready for loadout)**
  - **<u>Level barge loadout</u> (representative of loadout from a level quay onto a grounded level barge, or a barge complete with pumps for ballast transfer ensures that cargo is level at all times)**
  - **<u>Quay and barge out of level</u> (representative of loadout from quay to barge where a vertical step occurs between level of quay slipways and barge launch ways)**

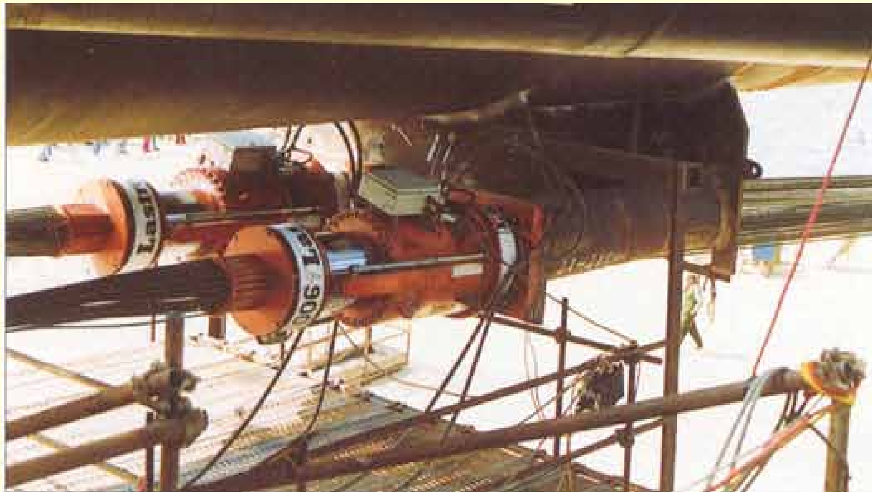
Loadout Conditions to be Considered - 2

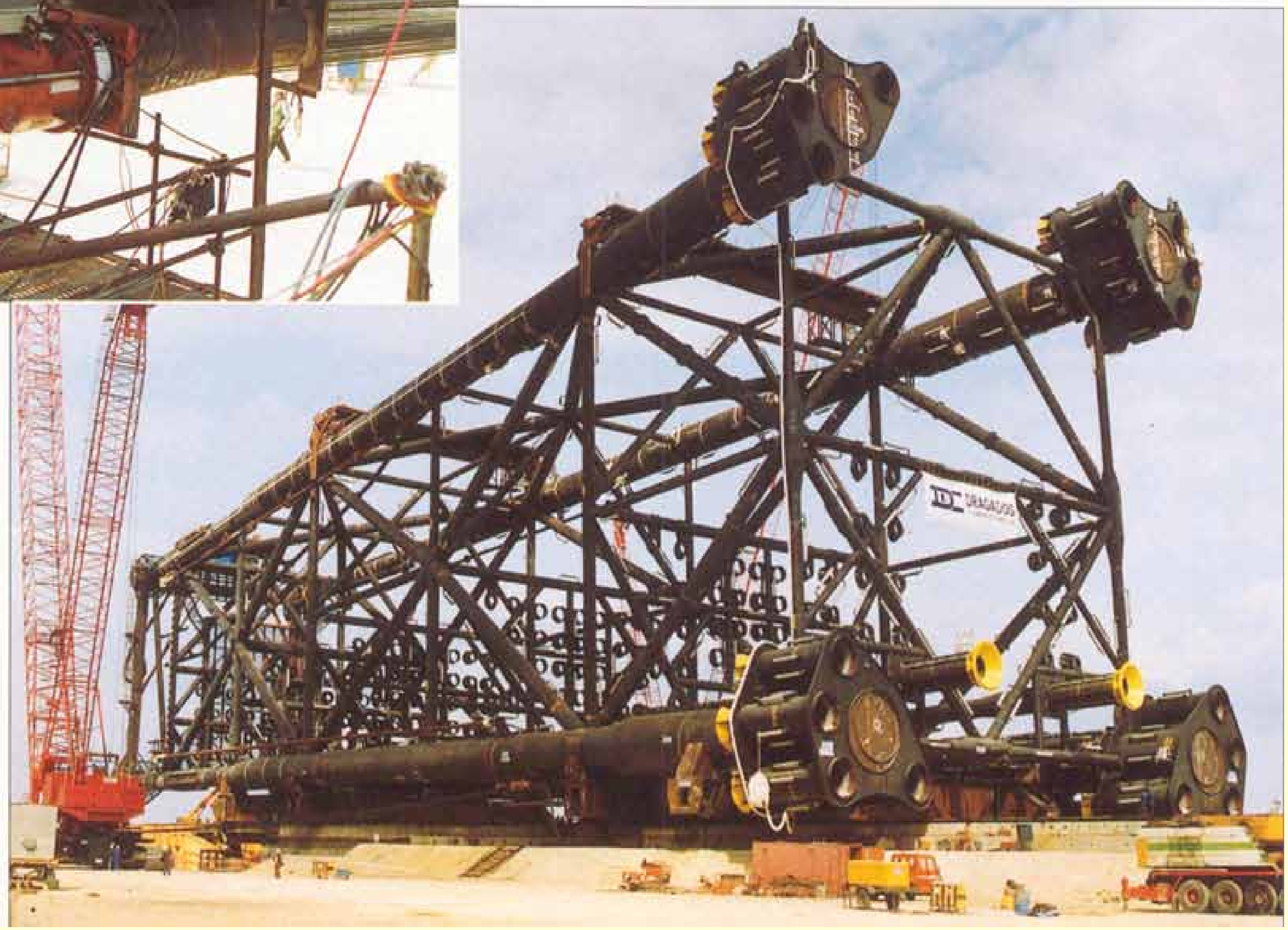
- **Load condition for <u>Quay and barge out of level</u>**
  - **This may occur due to improper grounding of the launch barge, or an incorrect ballasting sequence.**
  - **<u>Critical</u> for cargoes with continuous loadout trusses, typical of jacket launchings**
  - **The distance between the end of the slipways on the quay, and the launch ways on the barge (i.e. the maximum <u>unsupported length</u> traversed by the jacket at loadout is required to determine the number of loadout truss nodes which will be unsupported at any one time)**
  - **Variations in slope of the slipways and barge will result in selected truss nodes unsupported, and cases with barge lift off need to be considered**

Skidding Loadout

- **Large launch jackets are normally erected on a pair of ground skidways which support the jacket weight during fabrication stage**
- **The ground and barge skidways (including the link bridge arrangement) need to be checked for alignment, with tolerance in two planes, where the vertical alignment is dictated by deflection tolerance in the structure**
- **Alignment checks are essential to prevent excessive bending and racking loads in the structure, as well as concentrated loads on the barge**

Loadout of Jacket through Strand Jacks





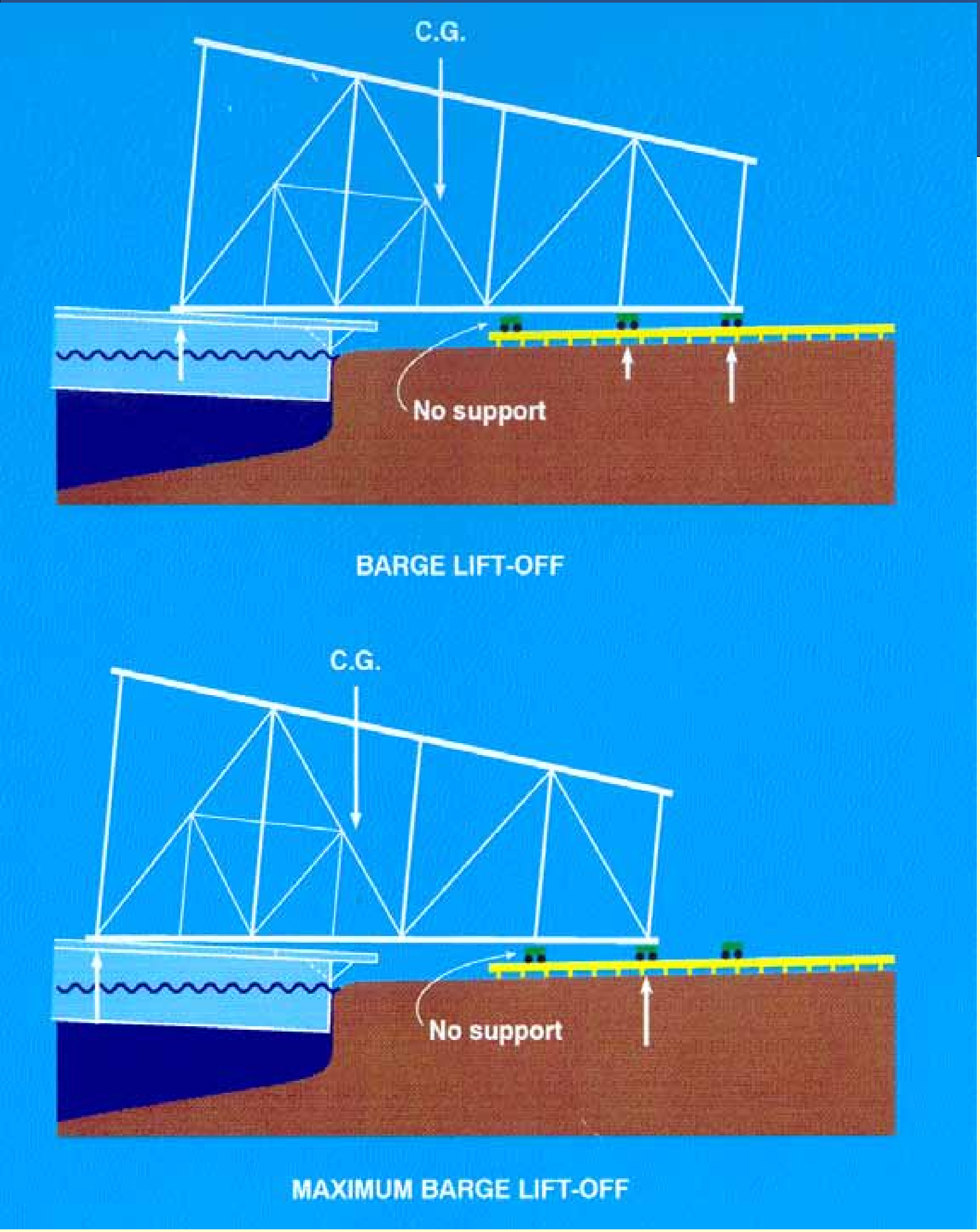
SPAIN: Pulling load-out of Jacket, weight 9.500 tonnes.

Deck Loadout on Skidways – pulling through strand jacks

Loadout with Barge Afloat

- The barge afloat operation is very time-dependent
- The ballast/deballast system must be able to cope with the maximum tidal rate to ensure that the barge is at the desired level
- There should be reserve capacity in the event of pump failures.
- There is need for constant monitoring of tide level, ballasting, barge level, and good communication among key personnel involved
- The weather, sea state, current and tidal behaviour in the loadout area need to be monitored, and an appropriate mooring arrangement must be provided

Jacket Loadout – Reaction Forces



As jacket is progressively loaded-out to the transport barge, different reaction forces may be imposed on the jacket due to **deferential elevation** of the barge and other supports.

The correct **sequence** of ballasting and de-ballasting of the barge as the jacket is progressively transferred to the barge is required.

Wheeled Loadout

- **Dollies are wheeled vehicles for loadout**
- **The dolly may be a very simple platform with wheels in fixed axles, or complex arrangement fitted with suspensions, a hydraulically operated elevating system, brakes, and steering control**
- **More complex systems may have independent suspensions for tires than can equalise tire loads in uneven terrain, can maintain platform horizontality when tires are on uneven slopes, or added together to form a larger platform to take heavier payload**

Wheeled Loadout of Arco Zu LQ Module

Crane-Lift Loadout

- The use of cranes to lift a structure from shore onto the barge deck is one simple method for loadout which may be performed relatively quickly – provided the lifting equipment (barge) may be available
- The **accurate weight & centre of gravity** of the structure needs to be verified to select the rigging arrangement and design the lift points (padeye or trunnion)
- The **lifting procedure & sequence** should be worked out, based on crane lift capacity, reach, clearances, position of transport barge, and mooring arrangement (for crane vessel) while minimising the maneuvers required to effect the loadout

Crane Lift Loadout of Deck

Crane barge movement after lifting deck from yard

Crane-Lift Loadout of Jacket - 1

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Note the small gap between jacket and crane barge

Crane-Lift Loadout of Jacket - 2

Placement of jacket onto transport barge

Preparing to connect seafastening to jacket leg

<u>Example</u> : GlobalSantaFe Semi-submersile vessel

- Provision of support structure for deck modules

- Innovative use of different elevations in yard

- Skidding of deck structure and control mating in dry dock

Lifting of Deck Modules and Integration using Fabricated Trusses

Lifting of module ; support towers; and support truss for integration of deck modules

Skidding of Upper Deck with Support Frame for Mating with Hull - 1

Start of skidding operations

- Consistent elevations of deck and lower hull for mating operations

Provision of support trusses for skidding operations

Skidding of Upper Deck with Support Frame for Mating with Hull - 2

Horizontal movement through skidding operations

Group photograph after skidding operations

Development Driller Semi-Submersible - Completed

Transport/Launch Barge Used for Cerveza Jacket

Note the 2 skid beams on barge, used for loadout and launch operations

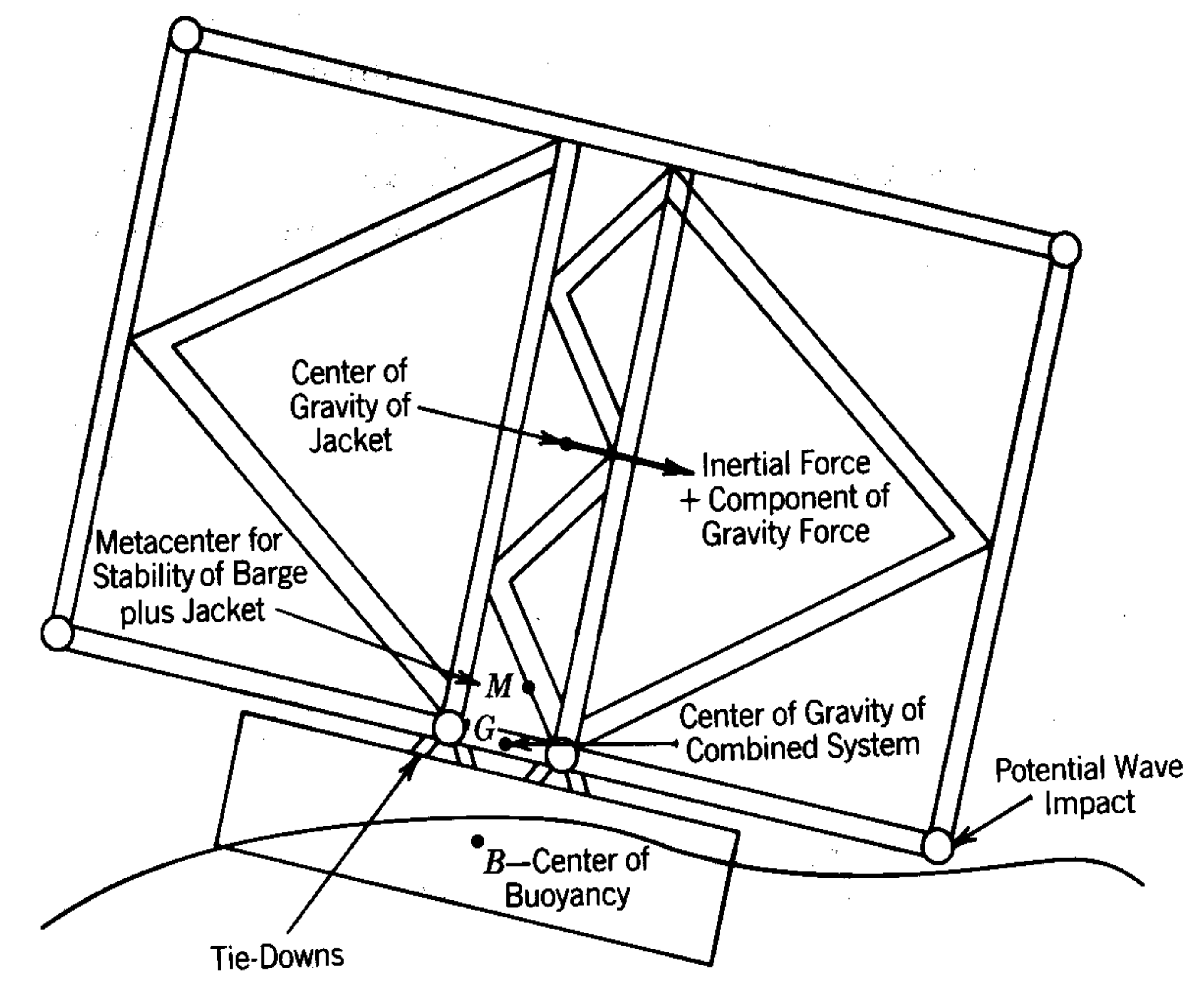
Hutton TLP Deck on Transport Barge

Note complex transfer truss supporting deck and large overhang on both sides of barge

Safety during Tow

- **Two primary damage or loss modes for the tow: stability loss and structural failure need to be assessed**
- **Barge stability to be assessed to ensure that barge will not capsize in the anticipated wind and waves**
- **The action of the waves on the barge and jacket needs to be determined to define the slamming and inertia loads for tie-down design and checks on the jacket members**

Forces to be Considered for Transportation



Motions during Tow

- **Wave forces are the single most important environmental factor causing a vessel's dynamic motions**
- **Stresses of the structure induced by the combined structure-barge system should be analysed early in the design process**
- **The following empirical motions may be used**
  - **(which include the effect of wind)**

Type of barge/tow	Roll*	Pitch*	Heave
Small cargo barge (76m LOA or 23m beam)	25^o	15^o	0.2g
Larger barges	20^o	12.5^o	0.2g
Inland tows	5^o	5^o	0.1g

Note: * single amplitude (in 10 sec period)

Tie-downs for Jacket on Barge

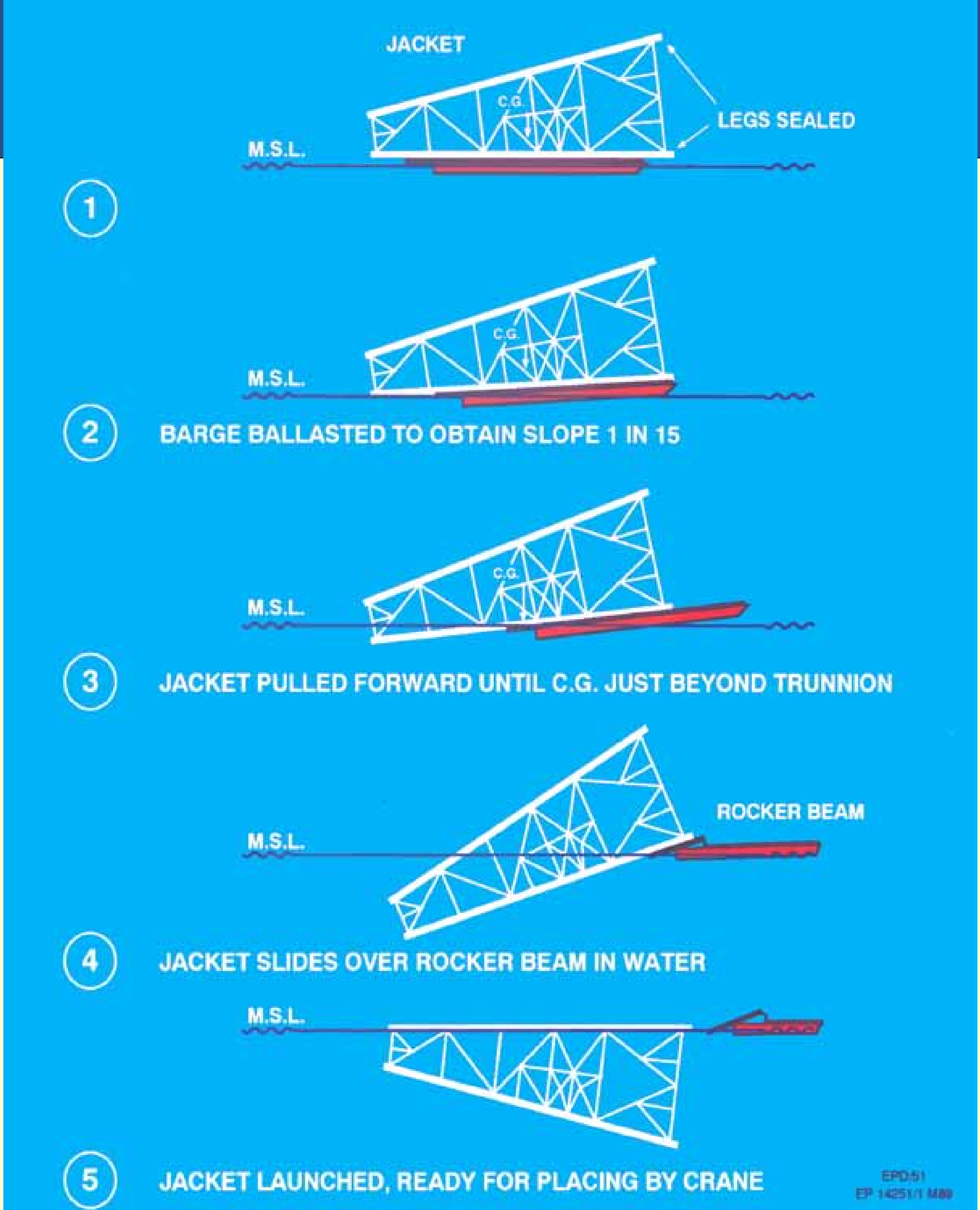
Tie-downs located at jacket and barge strong points
(with spreader beam when necessary)

Large Overhang of Jacket During Transportation

Note the need to check for tow fatigue resulting from large stress ranges imposed on the connections for long and stormy voyage

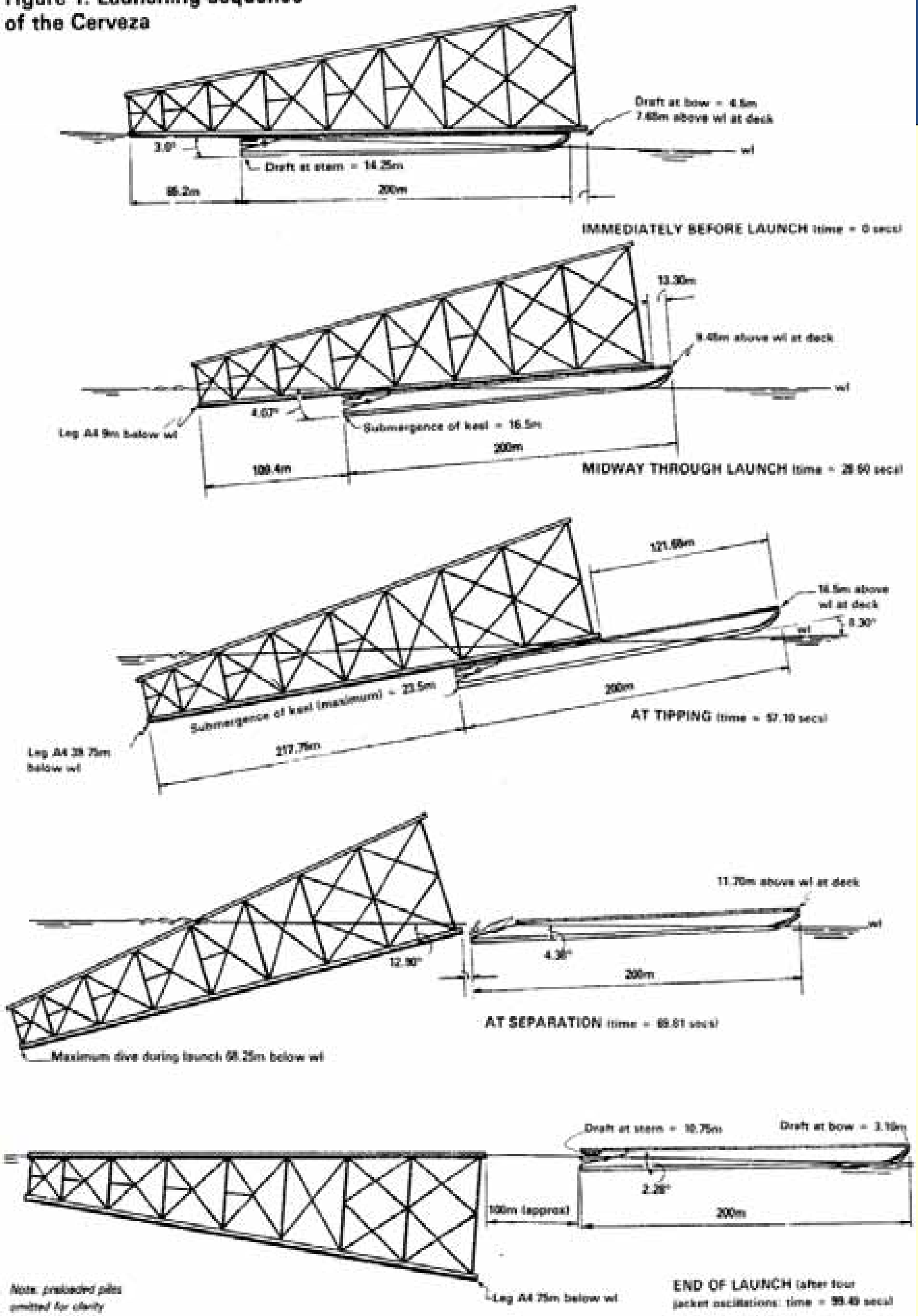
Bullwinkle Jacket under Tow

Jacket Launching Sequence from Barge



Launching Sequence of Cerveza Jacket

Figure 1: Launching sequence of the Cerveza



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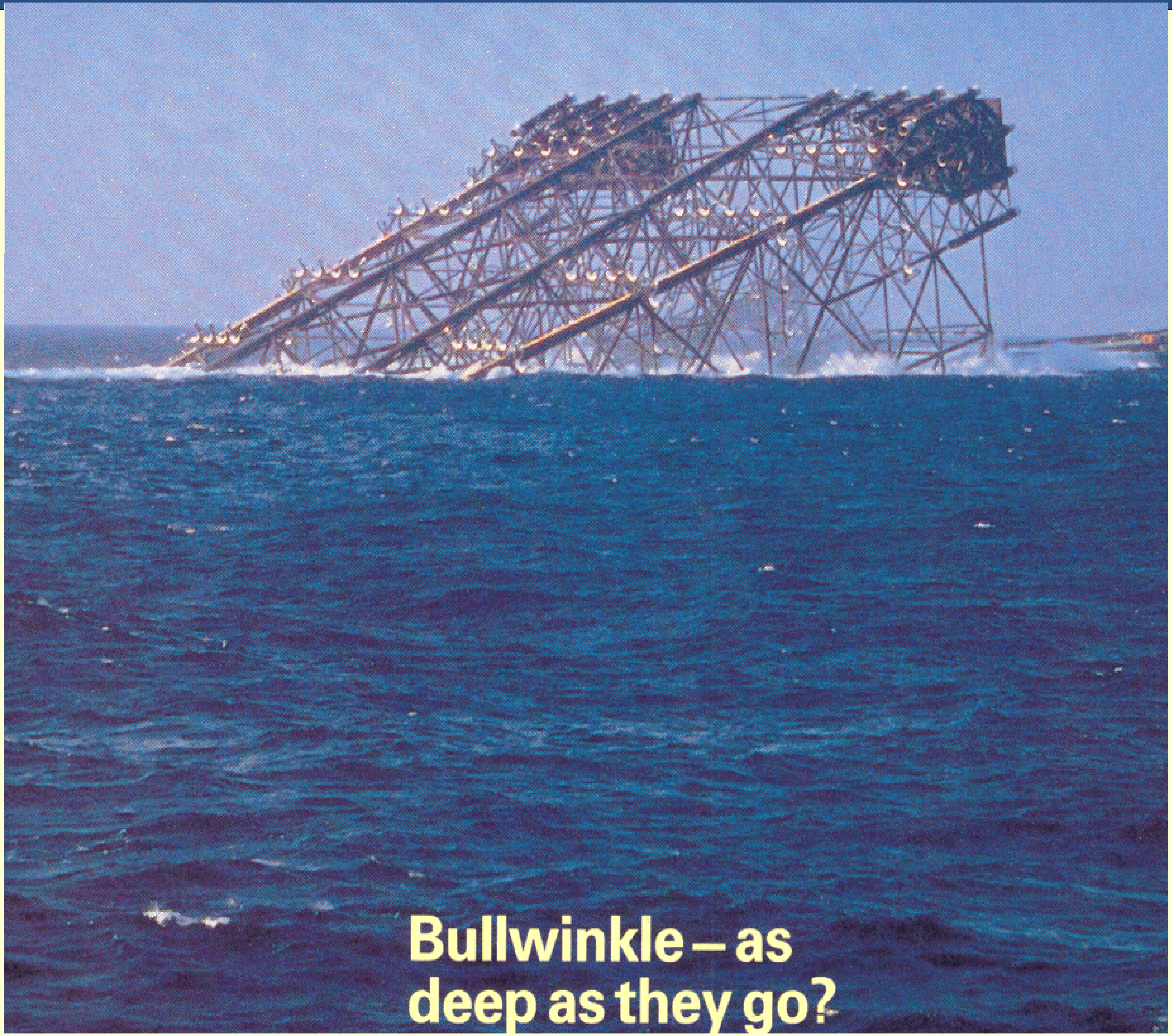
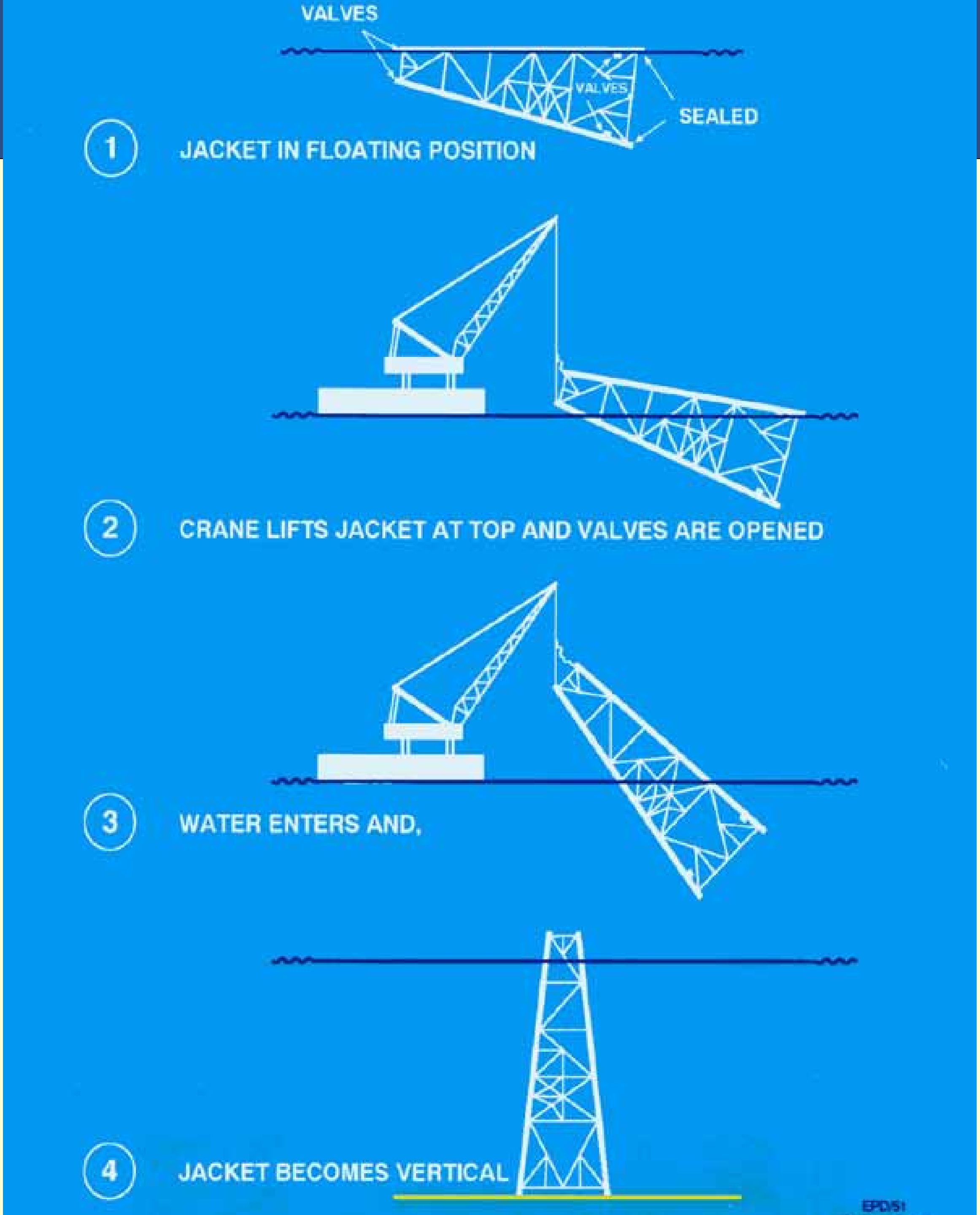
5 stages indicated:

- Immediately before launch (0 sec)
- Midway through launch (t=29 sec)
- At tipping (t=57 sec)
- At separation (t=70 sec)
- End of launch (t=100 sec)

Play Cerveza Movie

Bullwinkle Jacket Launch





Upending Sequence of Jacket – Crane Assisted

DB102: Tandem Lift of Jacket

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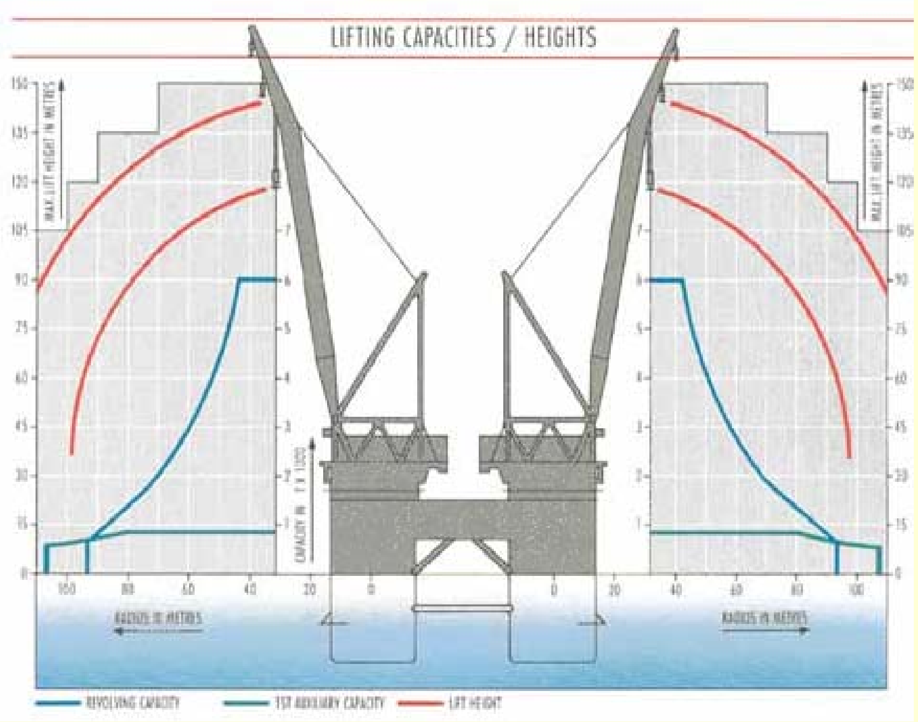
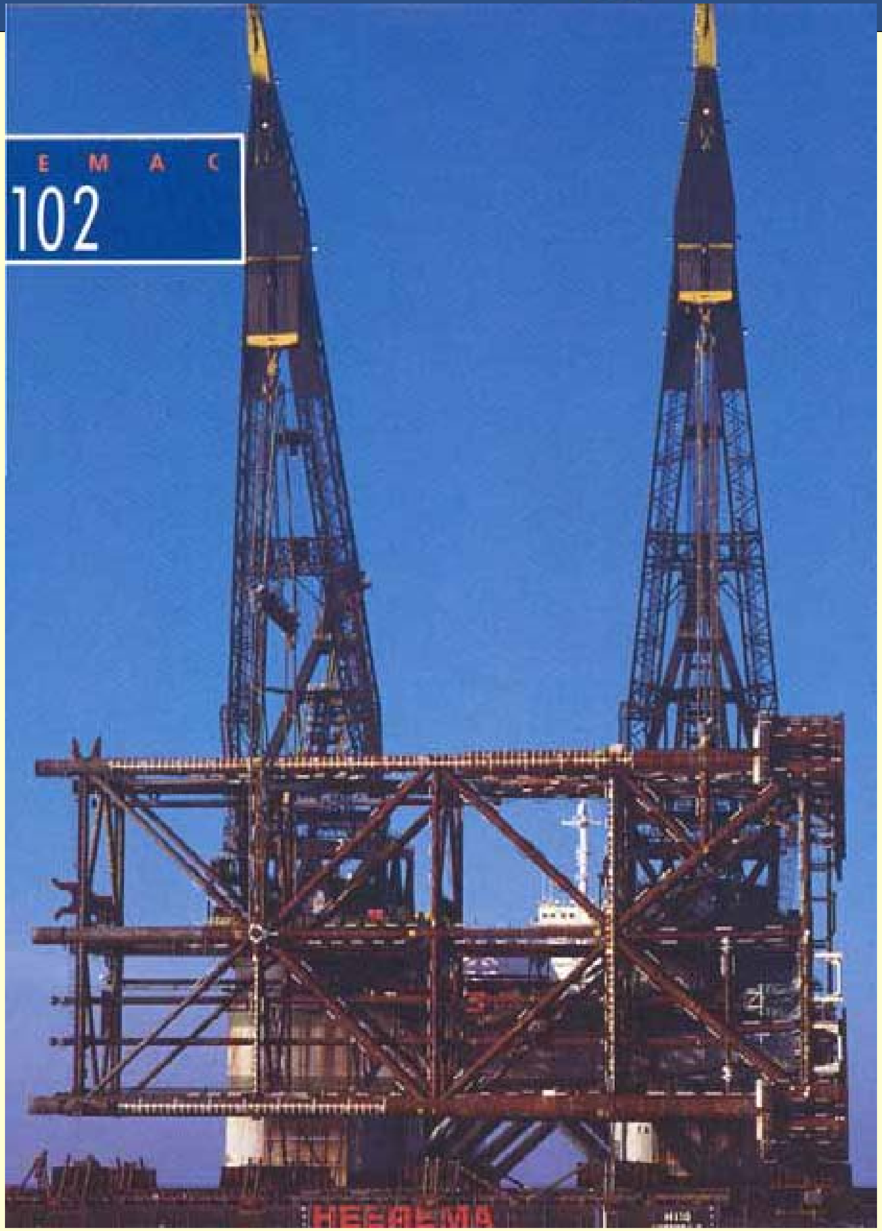
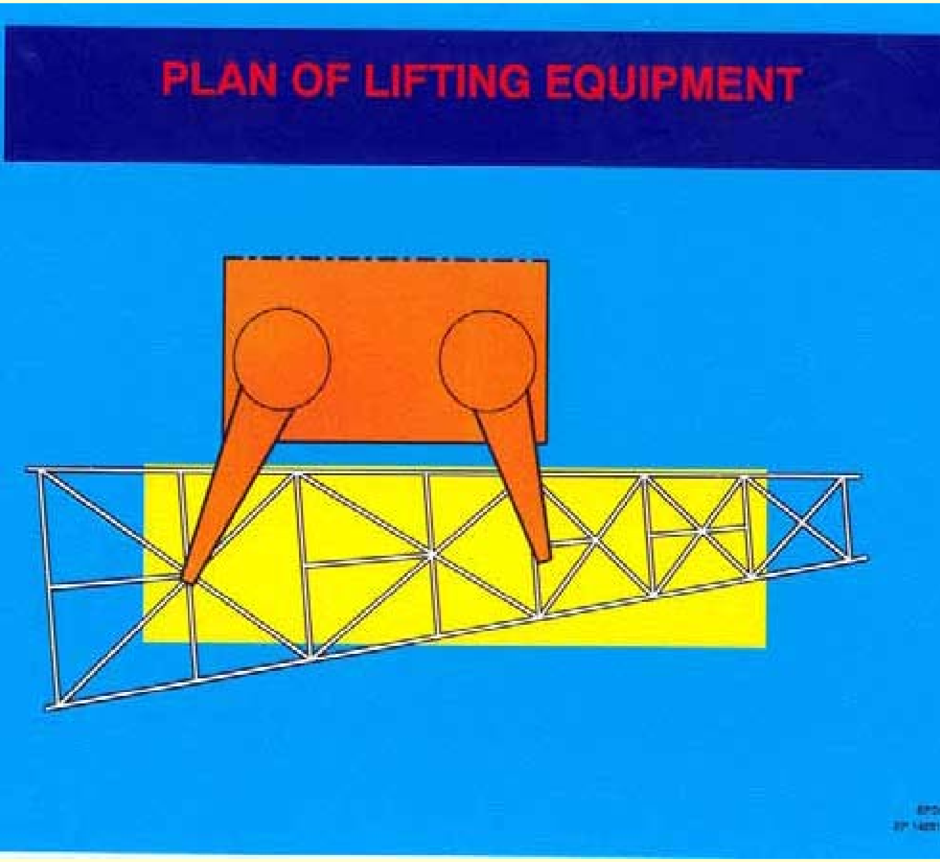


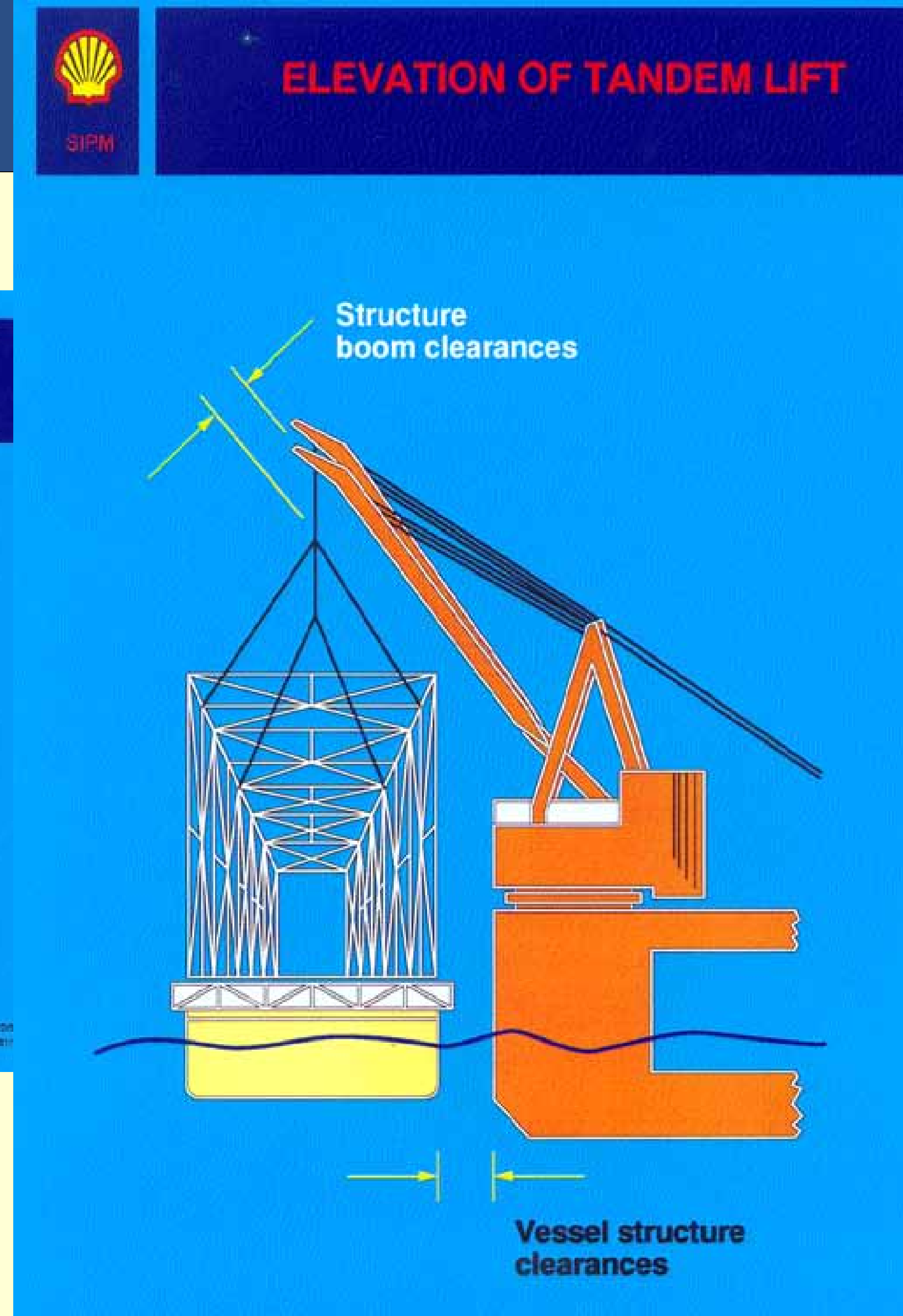
Crane reach-lift capacity curves

Jacket lifted off transport barge, ready for crane-assisted upending

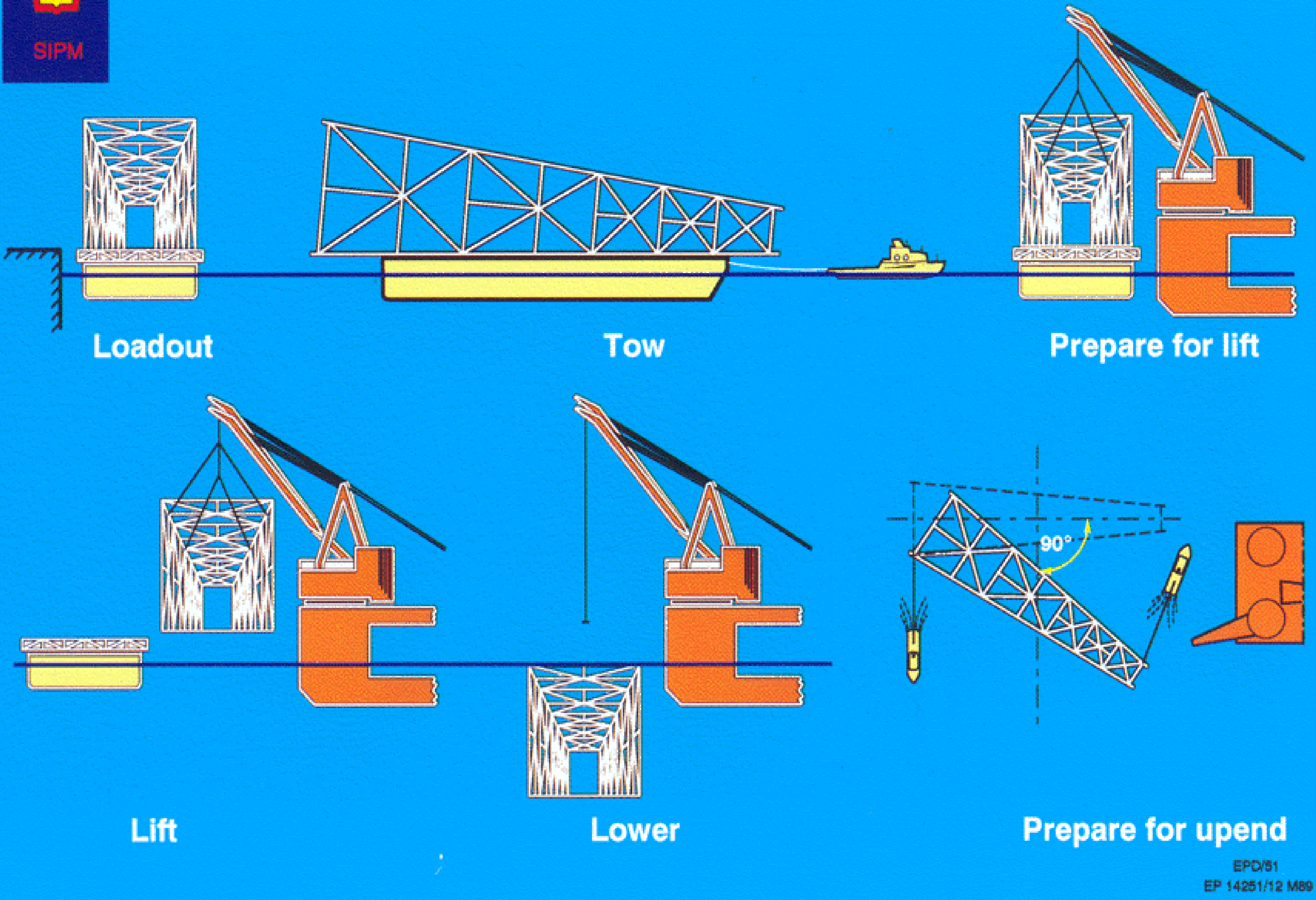


Tandem Lift – Design Considerations





Sequence of Installation Stages for Jacket



Lift Installation of Brae A module

Notes:

- Single hook – 4 lift point rigging arrangement
- Multi-module topsides due to lift capacity constraints
- Effect of multi-module arrangement on jacket-deck connection

Lift Installation of Deck with Spreader Frame (above deck)

Esmond Deck – Tandem Lift

Notes:

- Eight-leg trussed deck
- Four lift points, each pair attached to spreader bar
- Doubled sling at each lift point

Pile Installation – Concerns and Incidents

Stability during pile installation – example of tripod jacket toppling

Play Jacket Installation Movie

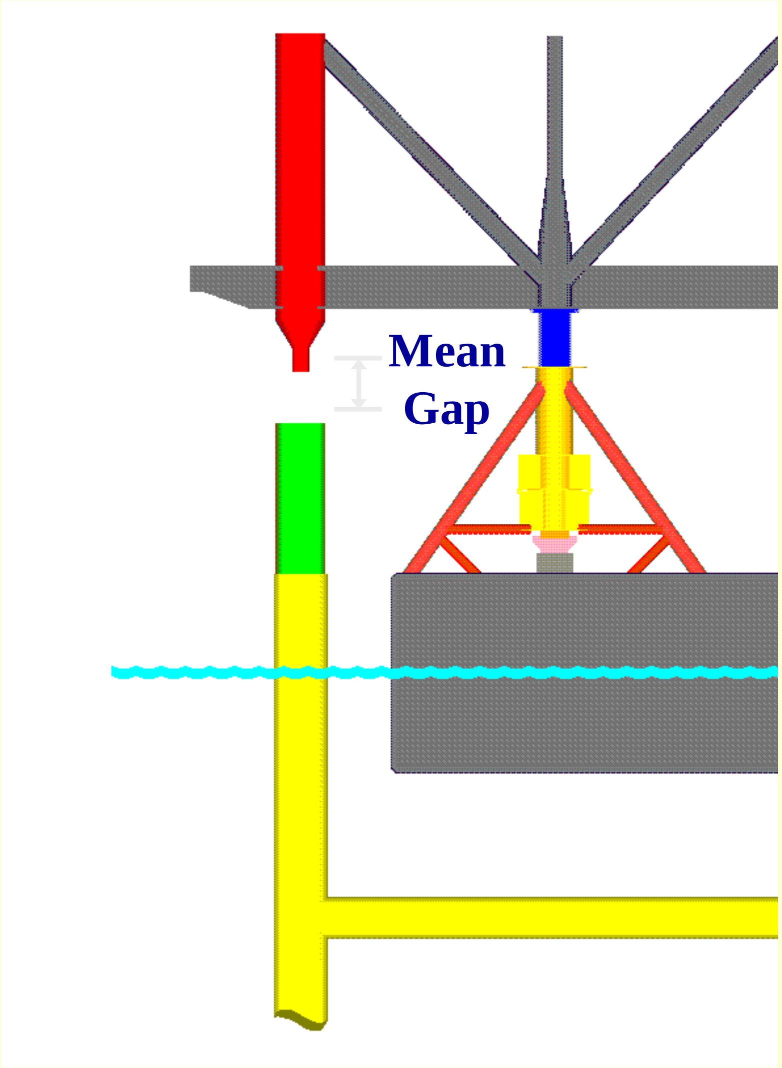
Pile installation – example of sudden loss of soil resistance

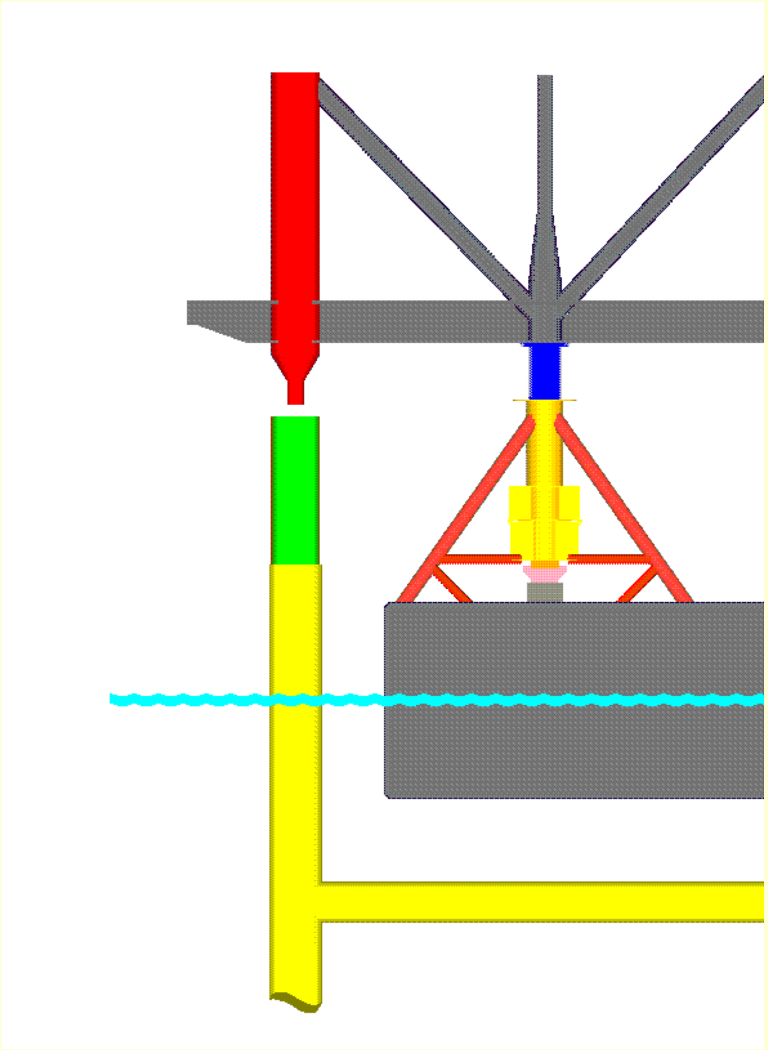
Play Piling Movie

Floatover of TLP Topsides on Barge

From Alp Kocaman (MOSS 2008)

Basics of Float Over Concept - 1

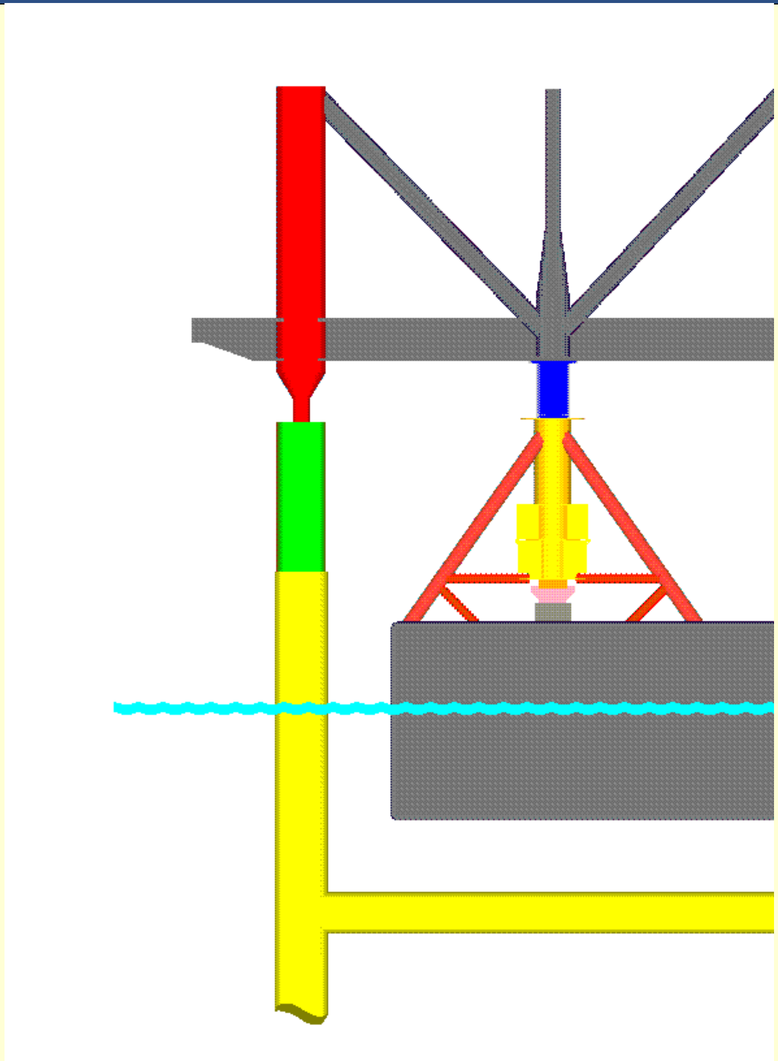




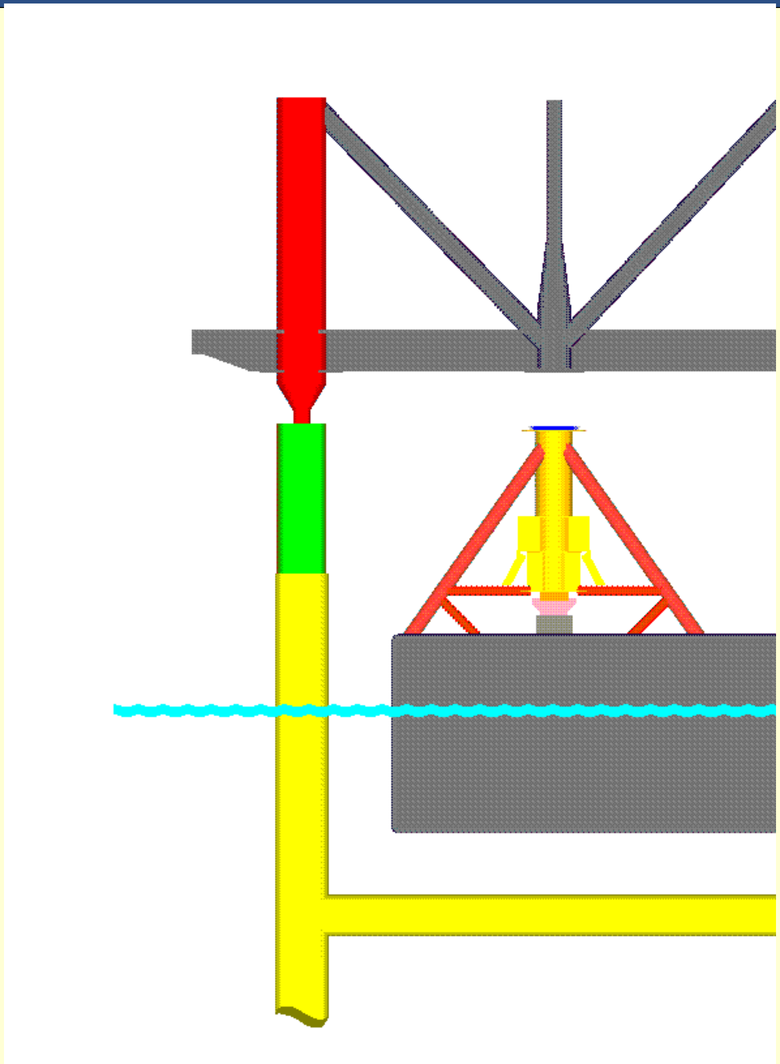
Entry into the Slot **Ready to Weight Transfer**

From Alp Kocaman (MOSS 2008)

Basics of Float Over Concept - 2



Weight Transfer



Barge is Disengaged

From Alp Kocaman (MOSS 2008)

Su Tu Vag Project – Jacket Loadout and Launch


Loadout and Launch of Su Tu Vag Jacket


Launch of Su Tu Vag Jacket and observed rocker arm rotations

Su Tu Vag Project – Deck Loadout and Floatover Installation

Two views of Su Tu Vag integrated deck during loadout operations in Batam yard

Towing and Installation of Su Tu Vag integrated deck in offshore location

Play Su Tu Vag Video from J Ray McDermott

Concepts from Companies for Float-over Installations onto Floating Systems

Float-over Installation of Floating Sub-structure

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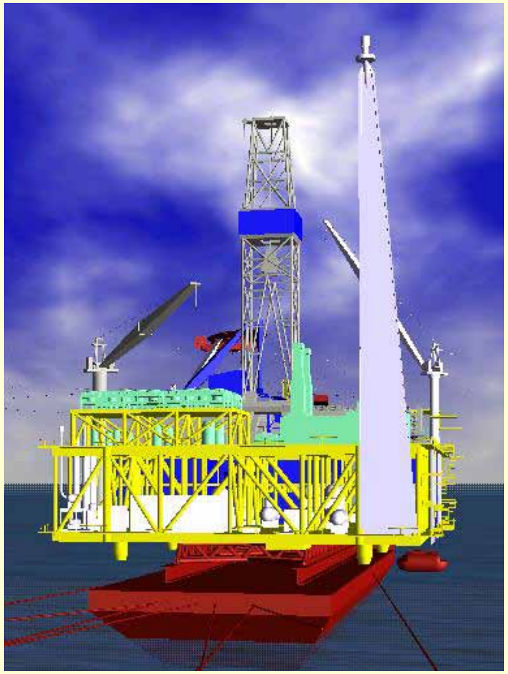
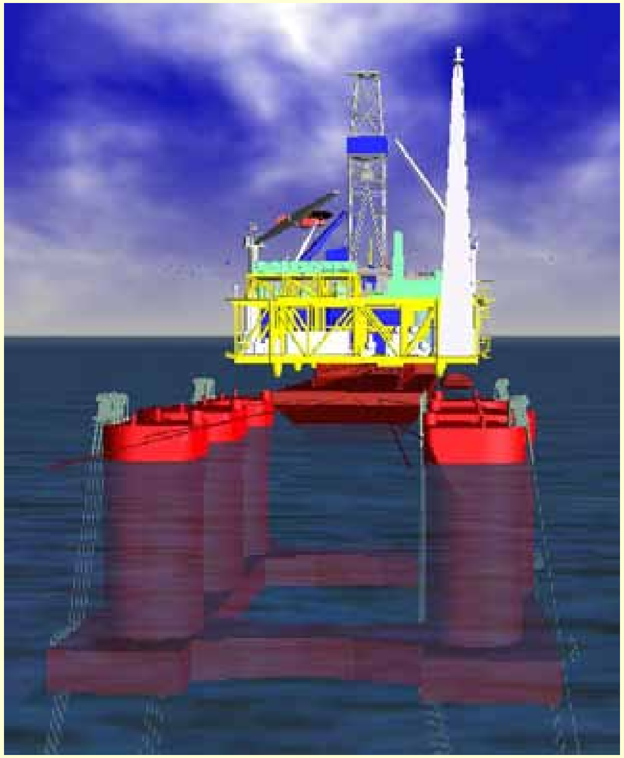
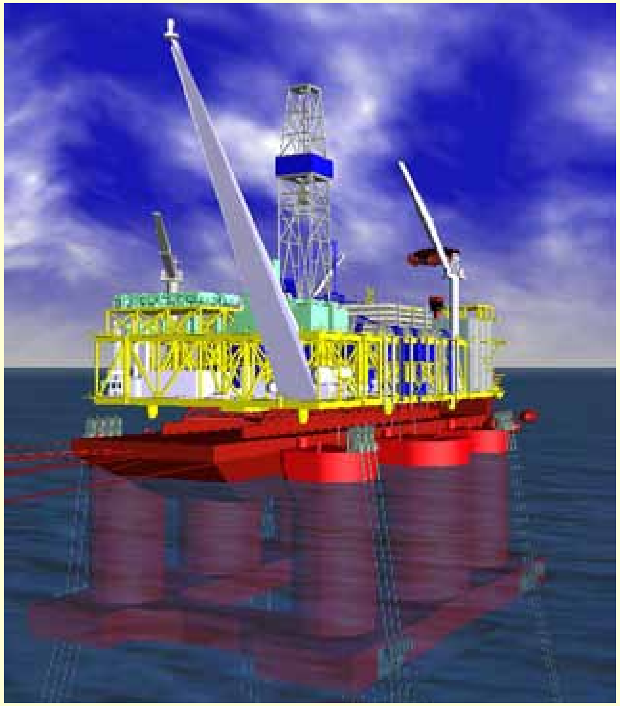




Challenges in Open Sea

Positioning - **Required mooring system for floating sub-structure.**

Relative motions - **Synchronizing deck and substructure motion**

Impact loads

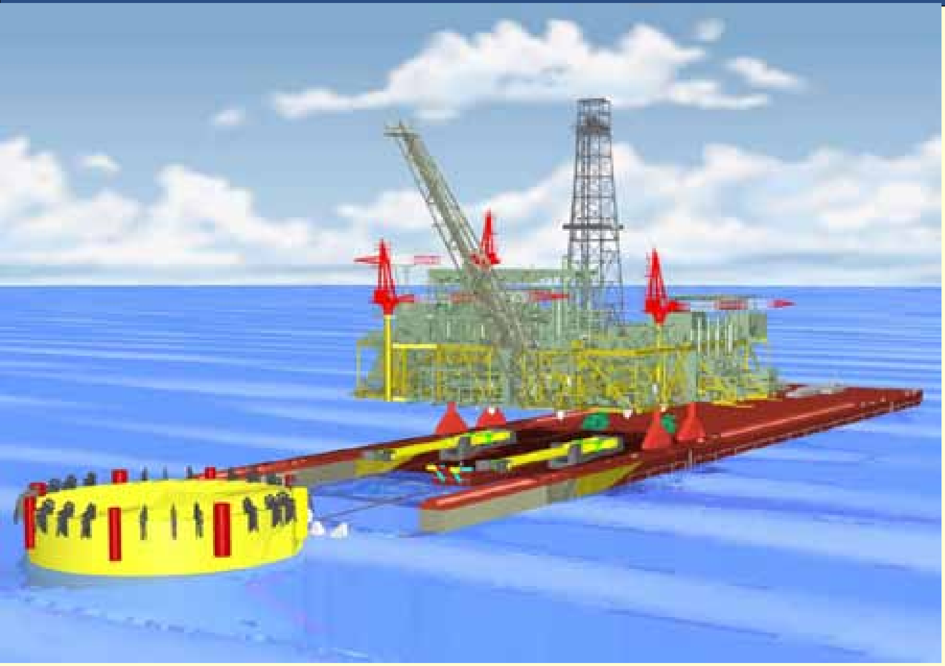
Catamaran – Twin Barge Concept

Challenges in Open Sea

- **Relative motions (displacements & rotations) ↔ Possible Impact**

Figures from Netherlands Maritime Agencies – Study on Kvaerner Deep Draft Floater concept

Fork-Lift Concept - Heerema



Positioning vessel to floating structure

Challenges in Open Sea

- Barge strength (high shear forces)
- Relative motions (displacements & rotations) ↔ Possible Impact

Transferring deck to floating structure

Kikeh Floatover Installation


Transfer from One Barge to Catamaran


Leaving Labuan Harbor

Play Kikeh Movie

Concluding Remarks

- Engineering considerations (Equilibrium, Compatibility and Contact) and Geometric considerations (interference) for Construction and Installation are presented through example projects
- Use of crane vessels and towers for yard-based operations highlight the unique, and sometimes constraining, features of selected designs.
- Float-over concepts for large and heavy decks over fixed, or floating, sub-structures offer viable options for installation.
- Successful solutions for installation projects can be found through expert knowledge and sound engineering principles.