Typical Pipeline Installation Methodologies, Potential Failure Modes and Considerations for Installation

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WIN – EXECUTE – SAFE DELIVERY

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Agenda

- **Overview of Submarine Pipeline Installation Methodologies**
- **Conventional Pipeline Installation Methods**
- **Unconventional Pipeline Installation Methods**
- **Potential Failure Modes and Design Considerations/ Lessons Learnt**

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Agenda

Overview of Submarine Pipeline Installation Methodologies

Conventional Pipeline Installation Methods

Unconventional Pipeline Installation Methods

Potential Failure Modes and Design Considerations/ Lessons Learnt

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Installation Techniques for Submarine Pipelines

Conventional Pipeline Installation Tehcniques

- S-Lay *
- J-Lay *
- Reel Lay *

Unconventional Pipeline Installation Techniques
(Examples)

- Surface Tow *
- Below Surface Tow
- Bottom Tow
- Bottom Pull *
- Push Pull Method (for Shorepull) *
- Control Depth Tow Method
- Horizontal Directional Drilling *

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Agenda

Overview of Submarine Pipeline Installation Methodologies

Conventional Pipeline Installation Methods

Unconventional Pipeline Installation Methods

Potential Failure Modes and Design Considerations

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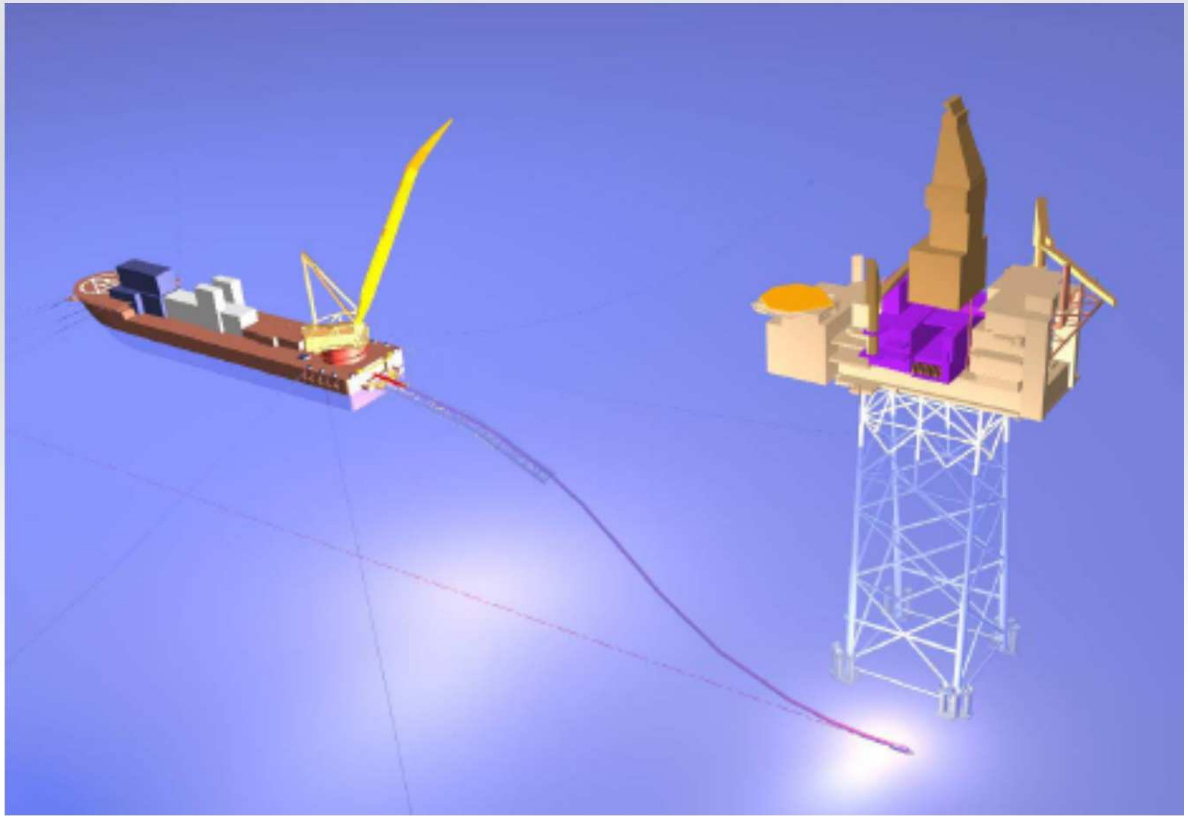
Conventional Pipeline Installation Methods

S-Lay

S-LAY INSTALLATION



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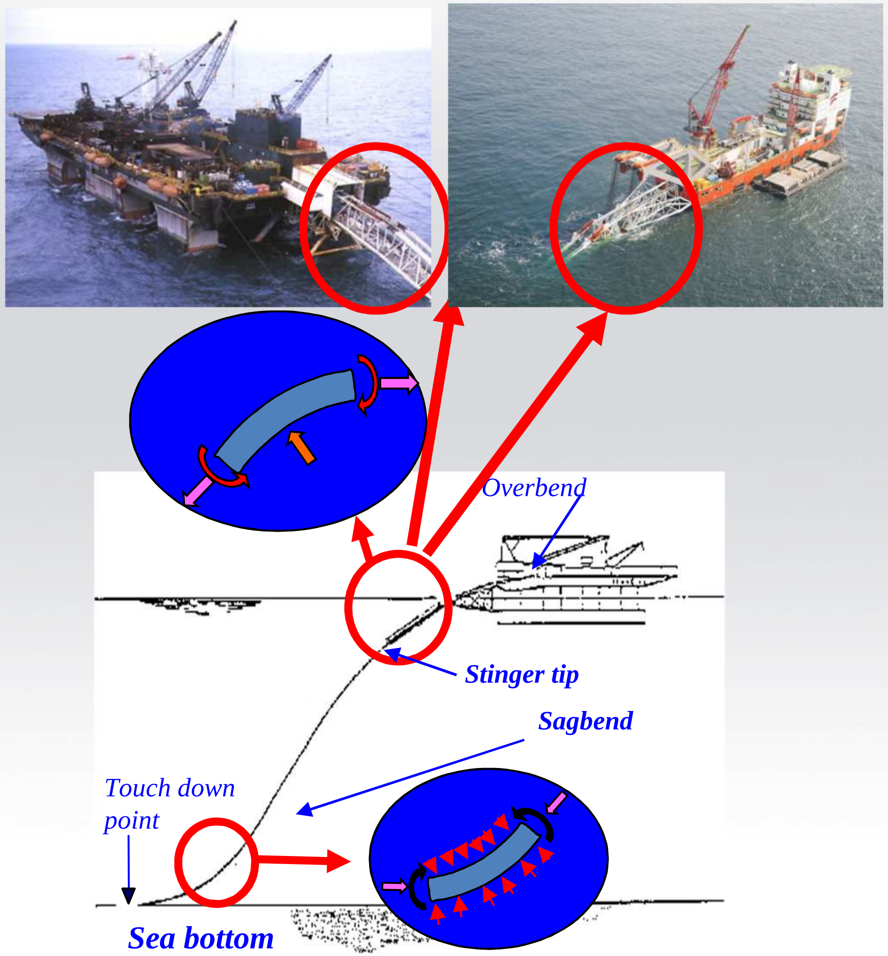
S-Lay

What is S-Lay?



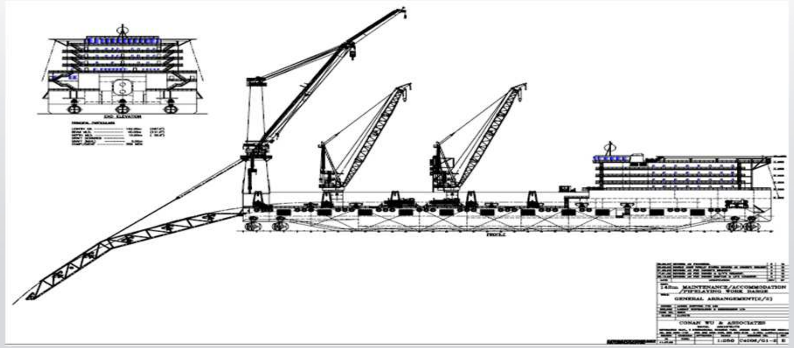
- S-lay relates to the shape of the pipe curvature during the laying process.
- This is maintained by the stinger and tension that must be applied throughout the operation.
- It is a continuous process, with near-horizontal welding carried out over several stations in the firing line.
- Method can be applied to pipe diameter up to 60" (typically)
- Stresses/ strains are controlled by applied tension and stinger configuration
- S-lay technique may result in high residual tensions, which has disadvantage of increase span lengths and larger horizontal radii for routing.

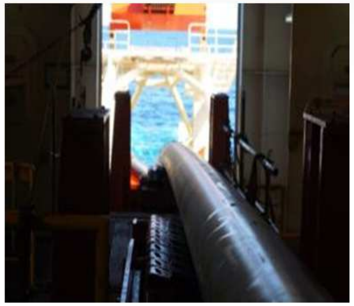
S-Lay

EMAS AMC's LEWEK CHAMPION

DP 2 HEAVYLIFT & PIPELAY VESSEL

Shallow to Medium Depths Pipelaying





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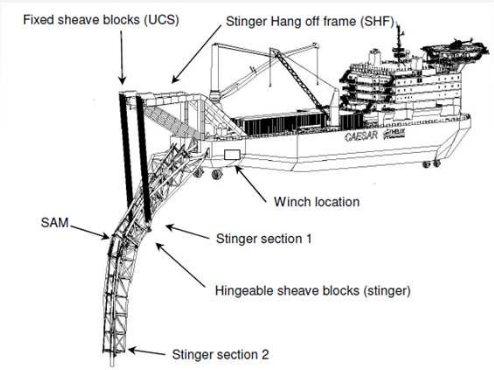
S-Lay

EMAS AMC's <u>LEWEK CENTURION</u>
(previously known as CAESAR)

<u>DP PIPELAY VESSEL</u>

Medium to Deepwater Pipelaying



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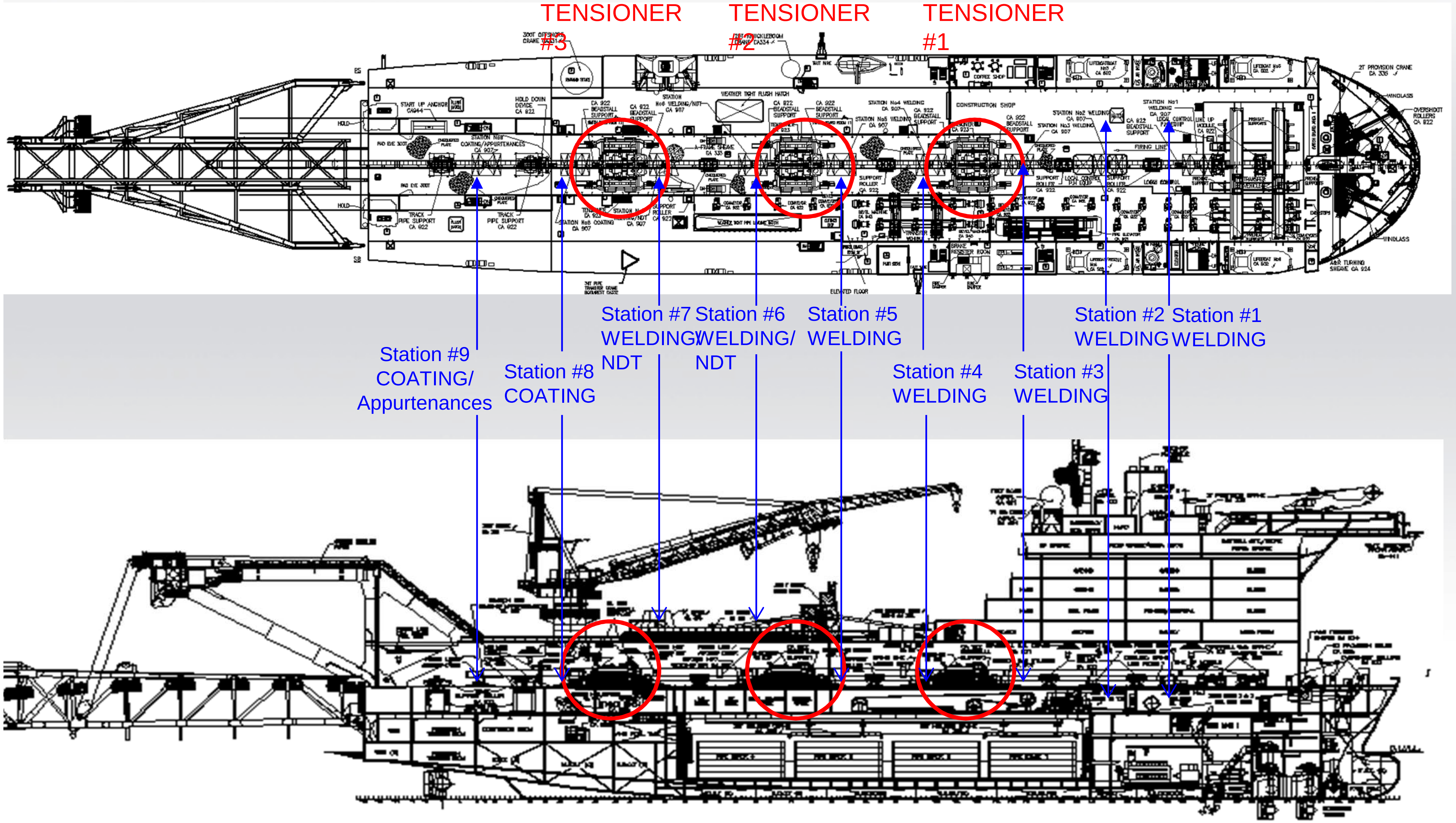
S-Lay

EMAS AMC's <u>LEWEK CENTURION</u> Equipment Layout

Pipe assembly on horizontal ramp on lay vessel



Conventional Pipeline Installation Methods

S-Lay

TYPICAL S-LAY
OPERATION ON EMAS
AMC's VESSEL

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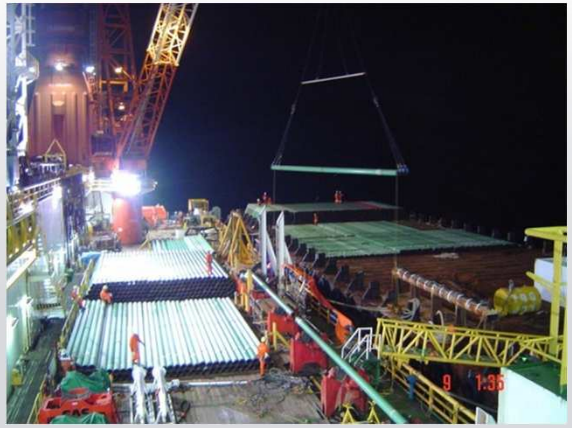
S-Lay

Offloading of Line Pipes and Commencement of Pipelay (Start-Up)







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S-Lay

Welding of Line Pipes to Form Pipeline

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S-Lay

Perform NDT (Phased Array UT) and Complete Field Joint Coating

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S-Lay

Connect Laydown Head and Abandon Pipeline

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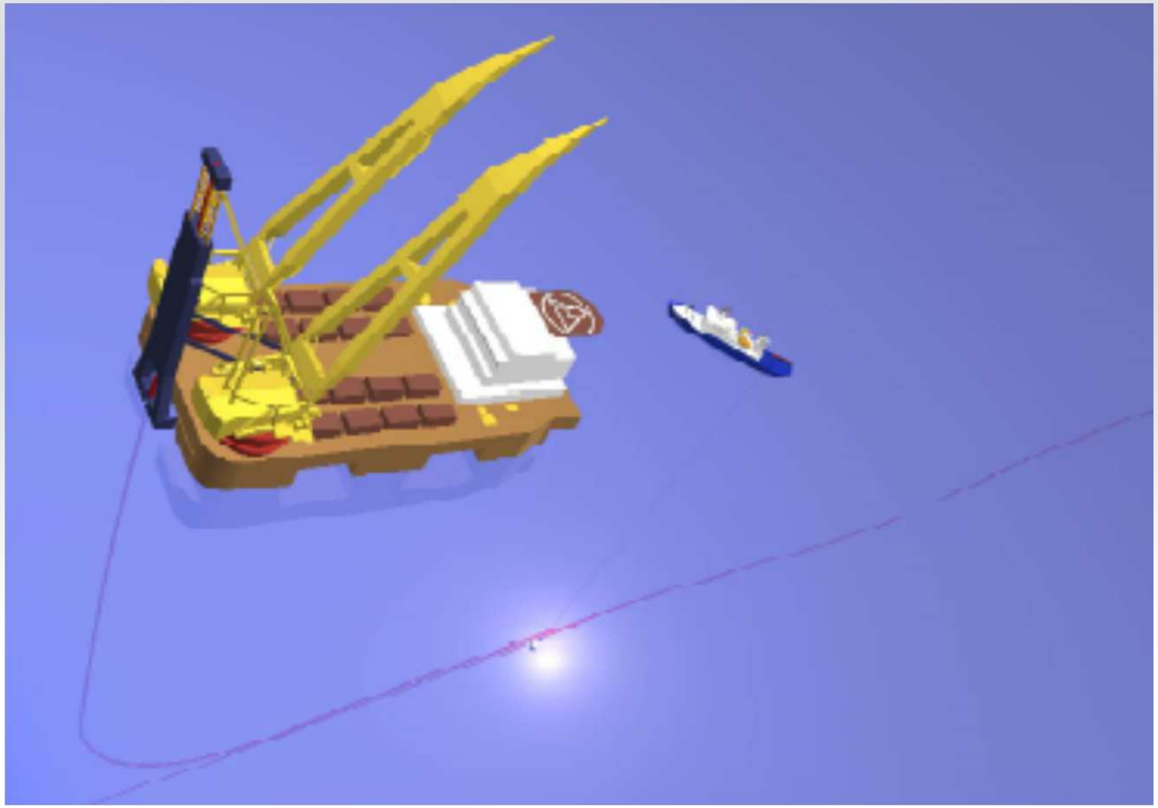
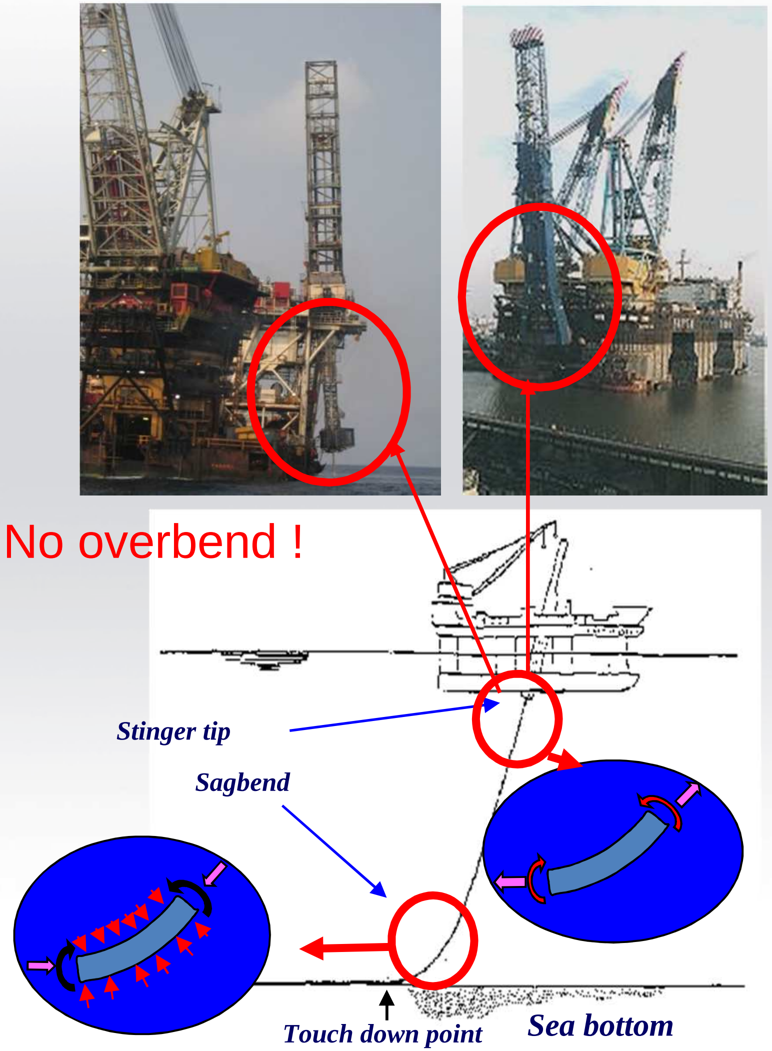
Conventional Pipeline Installation Methods
J-Lay

J-LAY INSTALLATION



J-Lay

What is J-Lay?



- J-lay methodology is a proven technique for laying pipelines in very deep waters (not shallow water)
- The pipe is laid through an almost vertical ramp positioned on board the vessel.
- Typically there is only one welding station (slower lay rate) but J-lay pipes are normally pre-assembled in 2 (double joints), 4 (quad joints) or 6.
- J-lay offers the following advantages:
  - Allows the pipe to be laid in a more natural configuration
  - Pipe stresses are maintained well within the elastic limit
  - Lower tension required, resulting in reduced on-bottom tension – hence, reduced free spans
  - Less susceptible to weather conditions
  - Vessel is free to choose an optimal heading to minimise environmental forces
- Method can be applied to pipe diameter up to 32" (typically)

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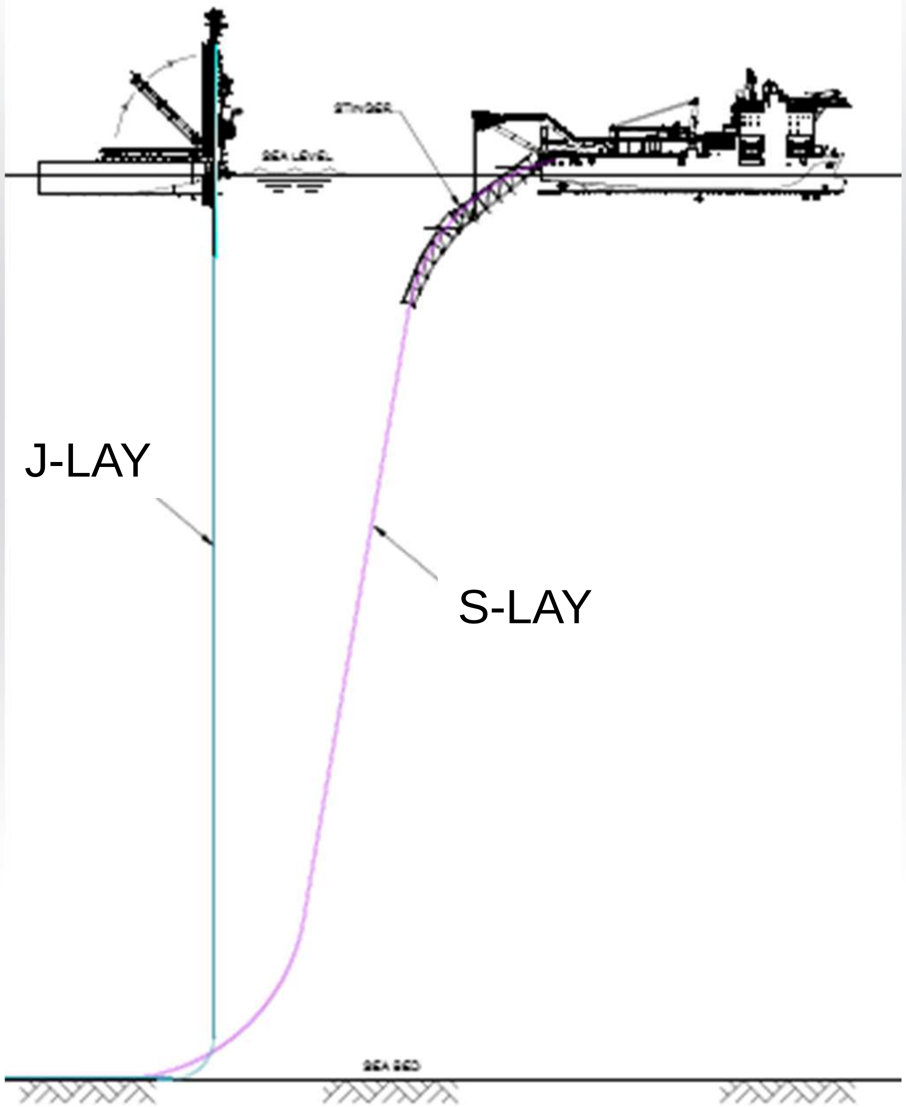
J-Lay vs S-Lay

Schematic



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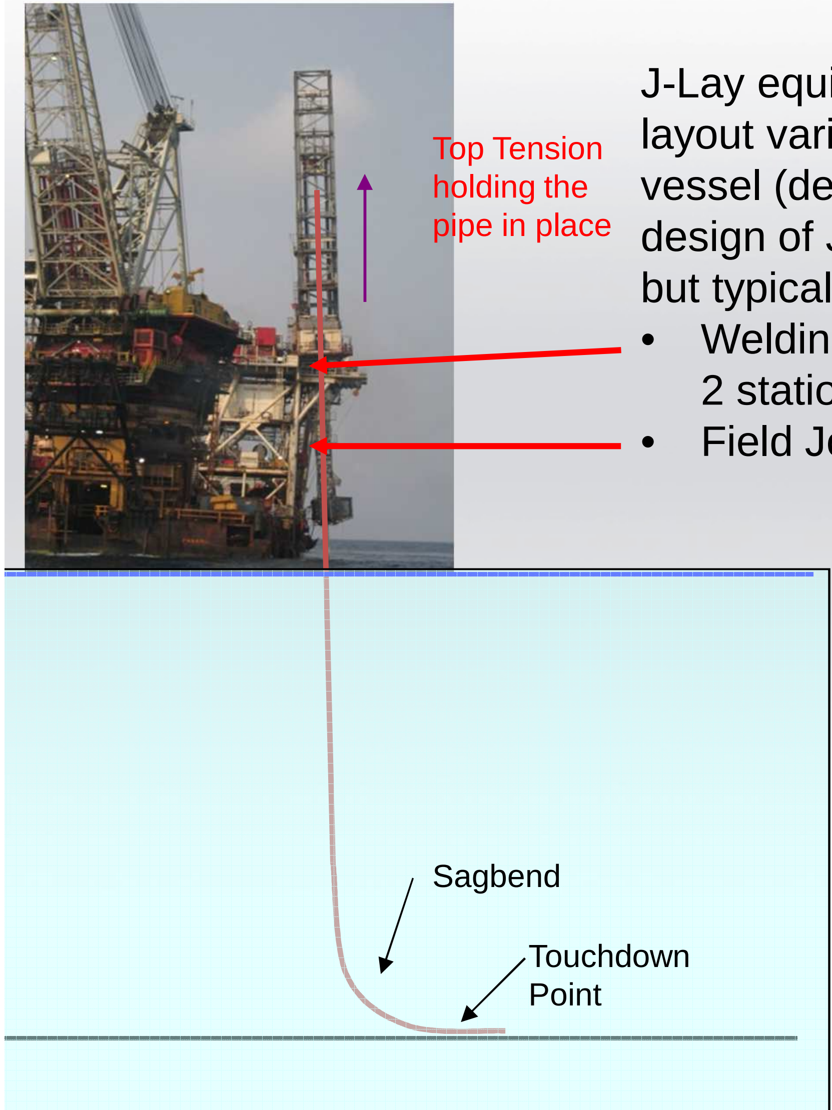
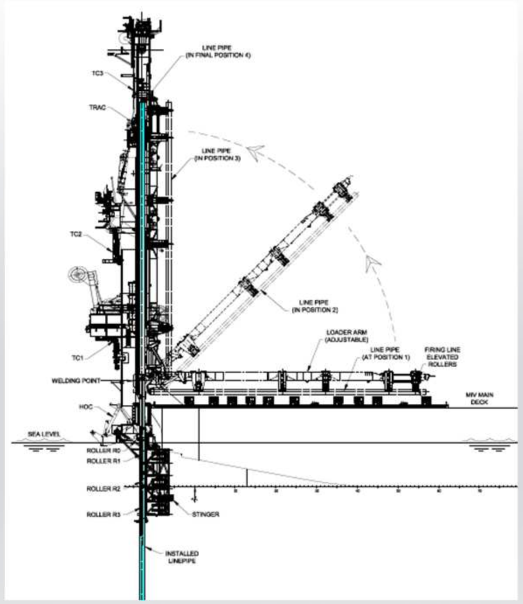
J-Lay

Typical Equipment Layout



J-Lay equipment layout varies with each vessel (depending on design of J-Lay tower) but typically consist of:

- Welding & NDT (1-2 stations)
- Field Joint Coating



- A complex handling system lift the stalks from horizontal position into J-lay tower
- Once in the tower, pipe stalk is aligned with preceding pipe string
- Weld connection & NDT
- Apply field joint coating
- Move vessel forward
- Pay out tensioner

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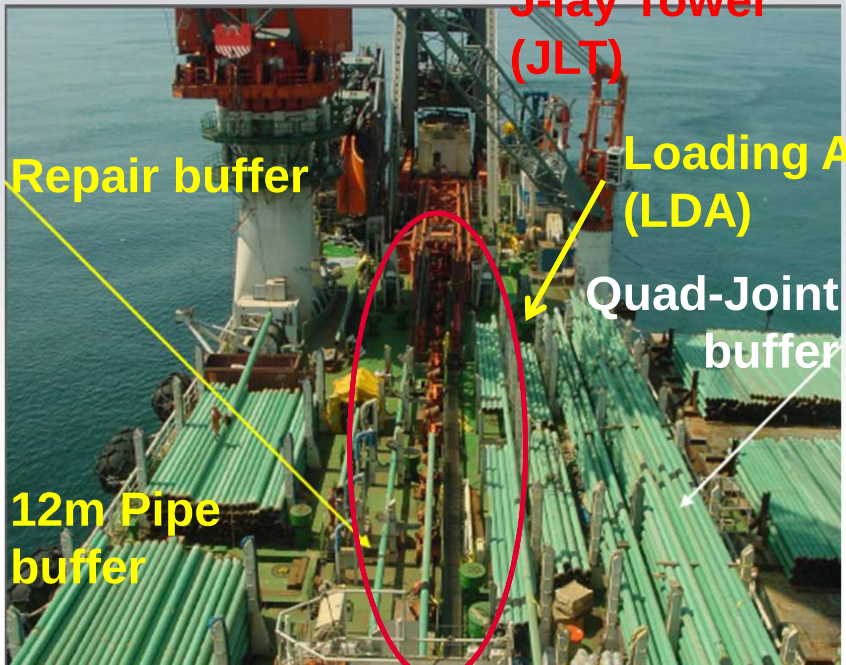
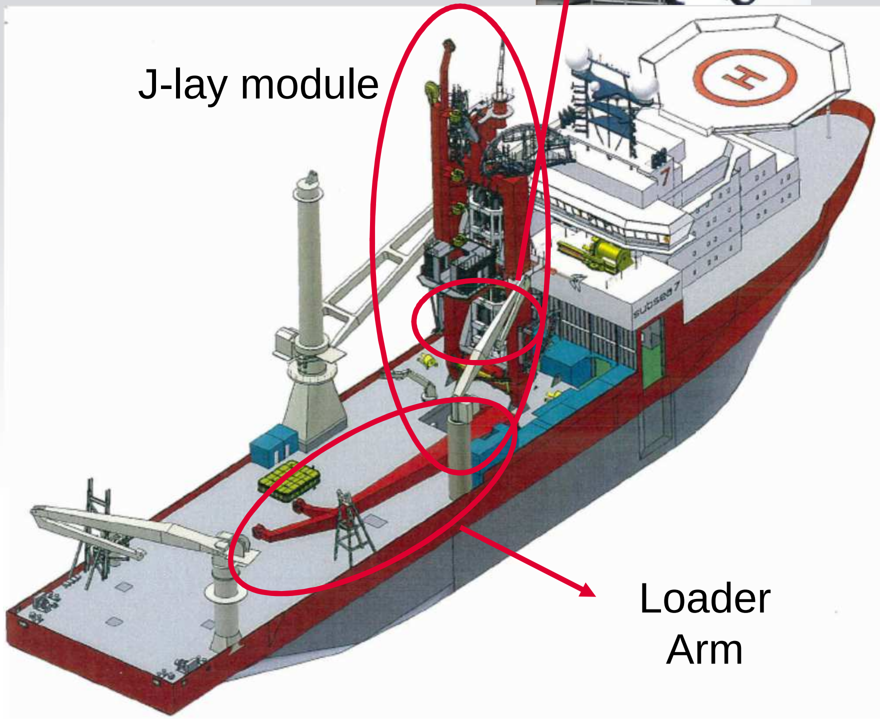
J-Lay

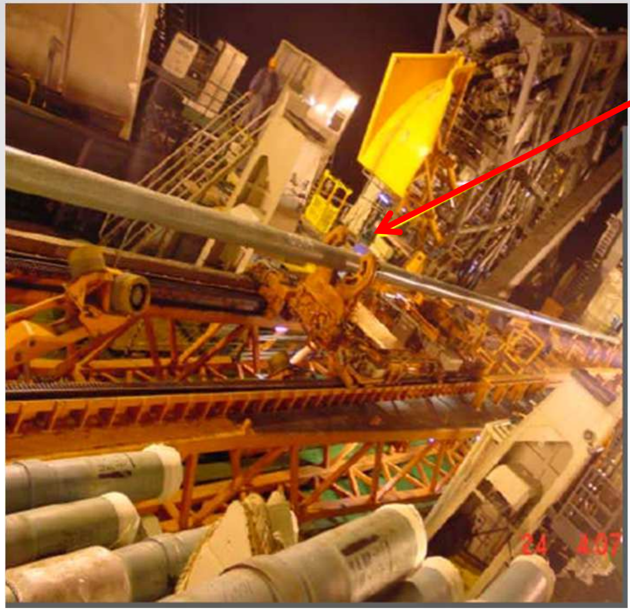
Typical Equipment Layout (Saipem's FDS 1 and Subsea7's Seven Seas)





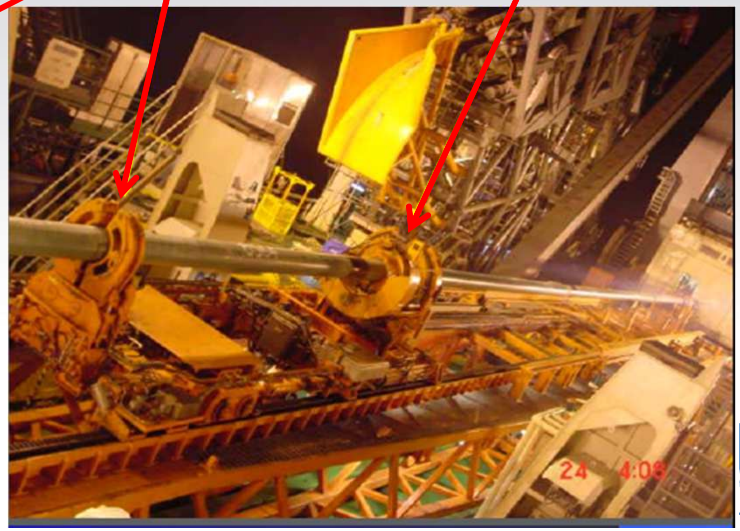
J-Lay

Welding of Single Joints to Form Double/ Quad Joints



Loading Arm Secures Quad-Joint

Clamp Trolley of Loading Arm



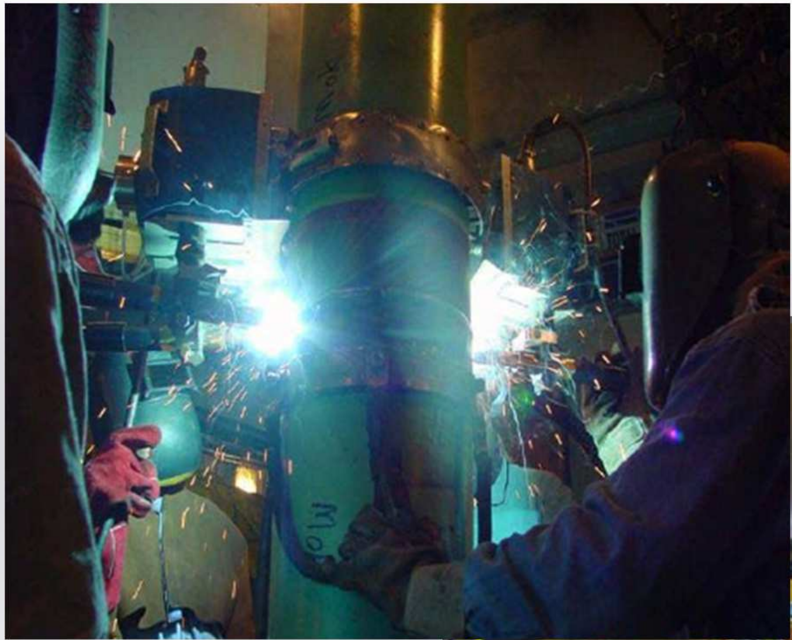
J-Lay

Transfer of Quad-Joints for Alignment with Preceding String and Subsequent Welding

LDA in the tower, tower clamps in position & QJ lowered for line-up

J-Lay

Welding of New Quad-Joints to Preceding String



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J-Lay

Welding of New Quad-Joints to Preceding String

Travelling Clamp

Tower Clamp

Travelling Clamp

Hang-off Clamp

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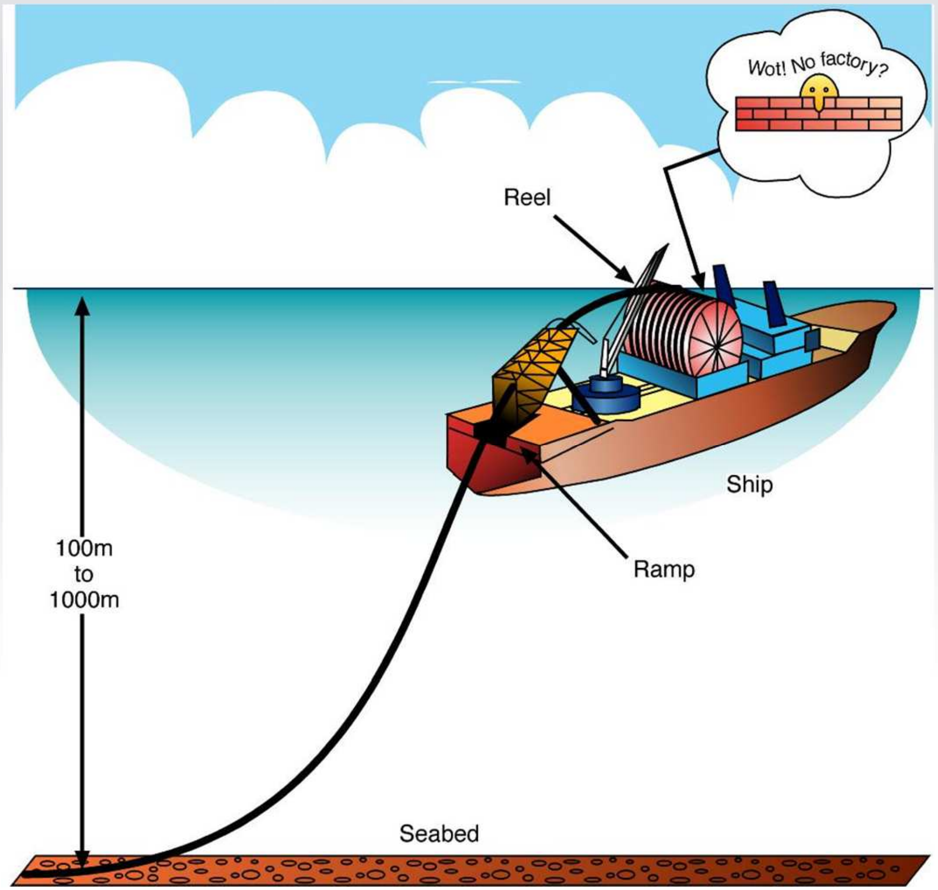
Conventional Pipeline Installation Methods

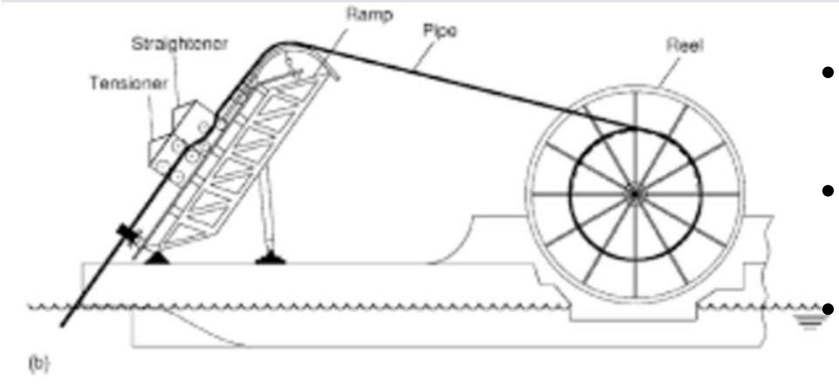
Reel Lay

REEL LAY INSTALLATION



Reel Lay

What is Reel Lay?



- Reel-lay is the process where rigid (or flexible) pipe is un-spooled from a drum, straightened, tension applied, and then laid over a ramp to the seabed.
- Essentially, the pipe is fabricated onshore and reeled onto a large drum (on the laybarge).
- The pipe is unreeled, straightened, then passed through a tensioner prior to leaving the vessel.
- Majority of vessels have the reel positioned such that the pipeline unwinds in the vertical plane.
- Benefits of reeling as installation method:
  - ➢ Onshore welding and fabrication
  - ➢ Enables greater assurance of welds as they can be tested onshore
  - ➢ Minimize offshore welding and, hence, installation time, resulting in overall increase of lay rate in comparison with S-lay and J-lay techniques
- Often most economical method for pipeline up to 16” OD

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Reel Lay

What is Reel Lay (Cont'd) ?

- Pipe joints are welded to form stalks at onshore spool base
- Stalks are welded together as they are reeled onto spool on the reel barge
- Reel vessel travels to site

EMAS's Ingleside Spool base

<u>Disadvantages:</u>

- Higher steel wall thickness for allowable curvature during onshore spooling and offshore installation
- Limited max outside diameter (typically 16")
- Limitation of coating options
- Need for a spool base

S-Lay
EMAS AMC's "LEWEK EXPRESS"

Express - Multi-service Vessel

Express is reel pipeline construction vessel having 2 reels capable of holding 3,000 tons of pipe up to 14 inches in diameter.

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Reel Lay

EMAS's Ingleside Spool Base – Texas, USA

Reel Lay

EMAS's Planned Spool Base – Halsvik, Norway

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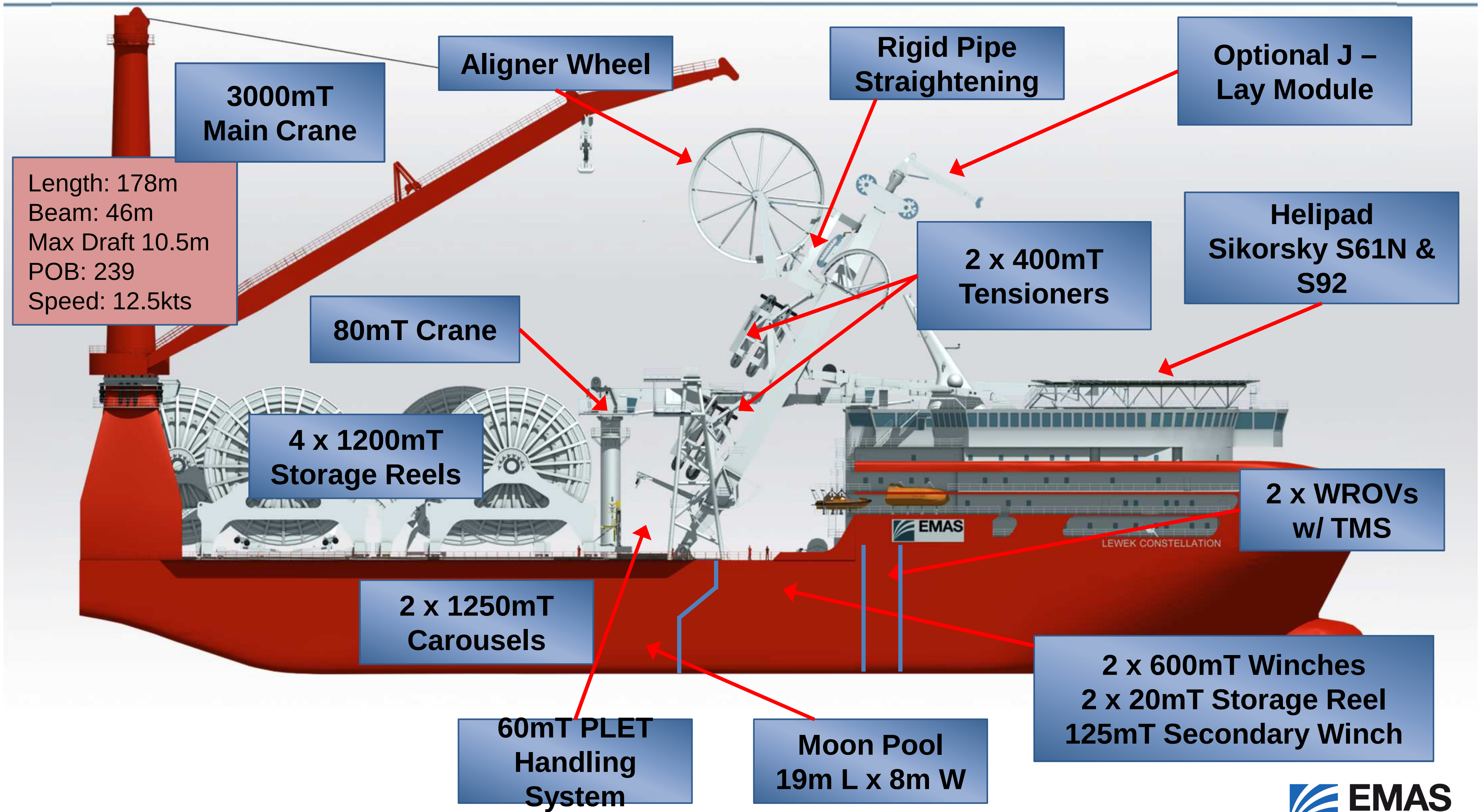
Reel Lay

EMAS's State-of-the-art Multi Lay Vessel "LEWEK CONSTELLATION"

OPERATIONAL
2014



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Reel Lay

EMAS's State-of-the-art Multi Lay Vessel "LEWEK CONSTELLATION"

OPERATIONAL
2014

- Rigid pipelines and SCR's up to 16" (by reel lay)
- Umbilicals and flexibles
- Flexible and Rigid Jumpers
- Heavy Lift / Subsea Construction
  - Topsides, Manifolds, Piles

Traditional vs Modern
Reel Lay Vessel

Traditional: Pipe Spool fixed on the reel barge

- Limited pipe length

Modern:

- Pipe spools can be reeled on dedicated spools and transported offshore to be loaded onto the vessel to replenish pipe supply
- More pipes can be laid

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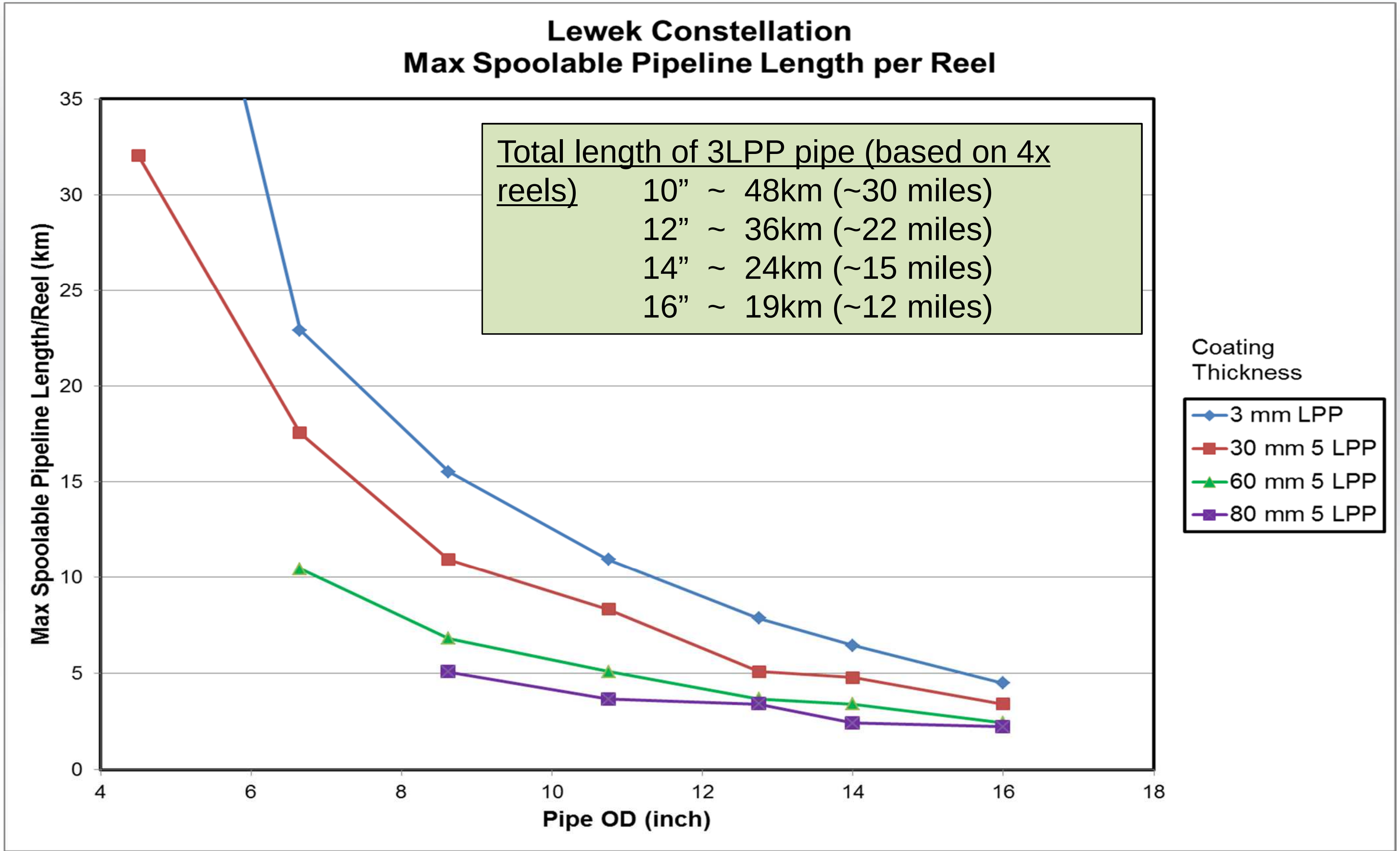
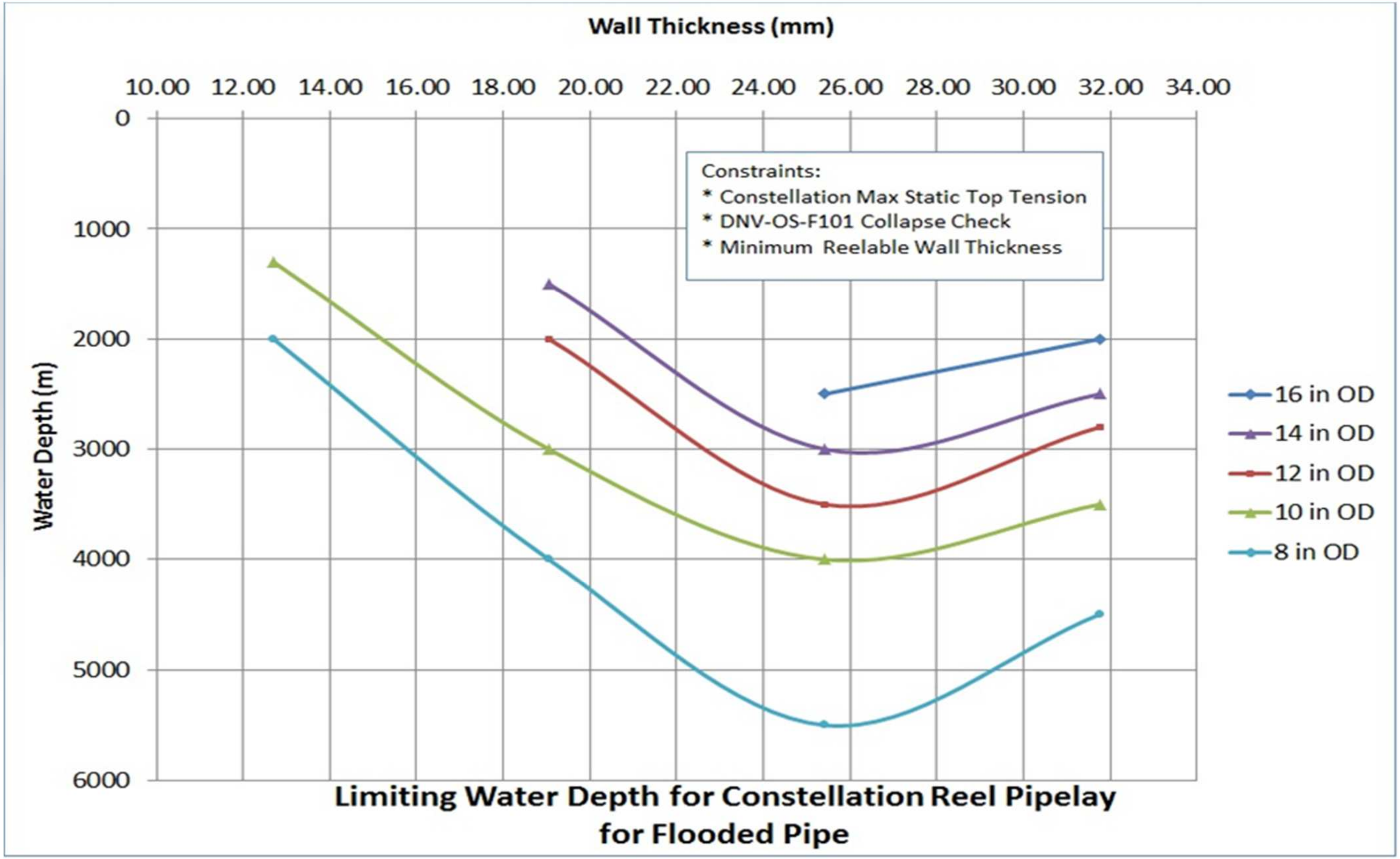
Reel Lay

Lewek Constellation's Reeling Capacity



Reel Lay

Lewek Constellation's Water Depth Capability



Agenda

- Overview of Submarine Pipeline Installation Methodologies
- Conventional Pipeline Installation Methods
- **Unconventional Pipeline Installation Methods**
- Rectifying Problems Starts at Engineering Phases
- Potential Failure Modes and Design Considerations

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Unconventional Pipeline Installation Methods

Push-Pull Method

PUSH-PULL METHOD

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Push-Pull Method

Project Example – Ref. Geocean

Dredging for Pipeline Installation from Shore Approach to Landfall

Buoyancy Drums to Provide Positive Buoyancy

Completion of PUSH-PULL Installation & Reinstatement

Unconventional Pipeline Installation Methods

Surface Tow Method

SURFACE TOW METHOD

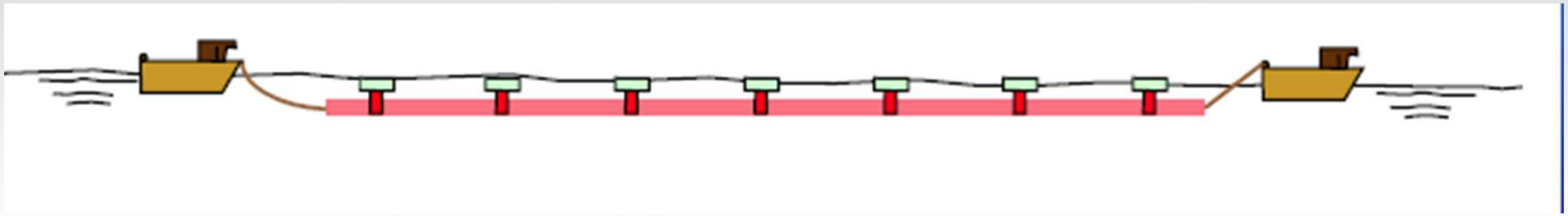
Surface Tow Method (Rentis)

Installation Methodology for Short Pipelines

- In this method, the required pipe string length is fabricated onshore and fitted with buoyancy devices at a given spacing, then it is launched and finally towed to the desired offshore location.

- One end of the pipeline is connected to a pre-installed line on the platform.

- After positioning and aligning of the pipe string, the buoyancy devices are stripped by one of the tugs in a control manner so that the pipeline settles to seabed due to its own weight in a controlled manner.



Surface Tow Method

Project Example – Location: Brunei

Pipe Strings at BSP's Telisai Yard

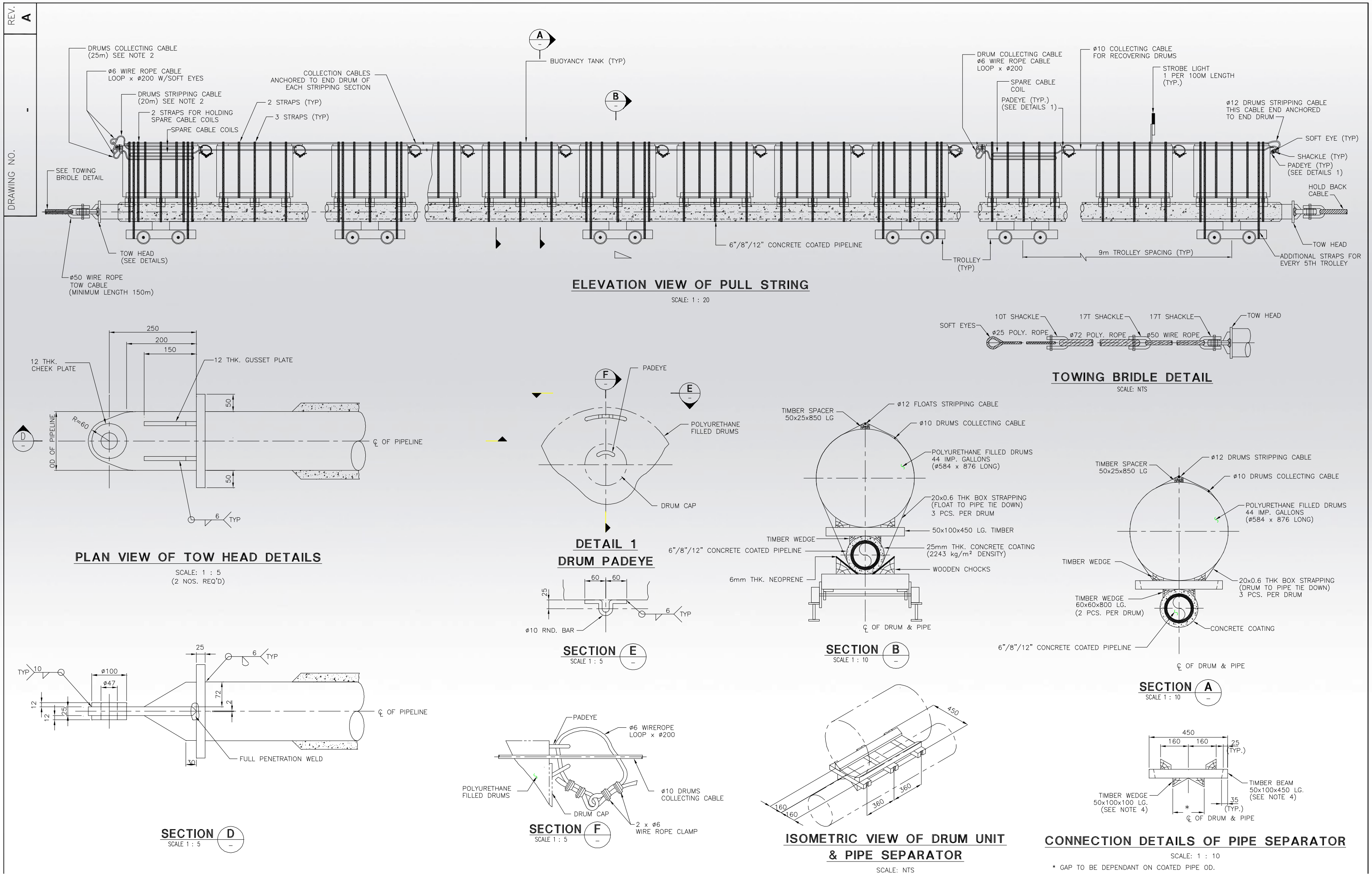
- Typical fabrication yard : BSP at Telisai.
- Pipes are welded together to form pipe strings.
- Strings x-rayed, flushed, scraped, gauged and hydrotested.
- Then strings will be purged dry, field joint coated, capped at both ends and stored in the storage area.
- When required, pipe strings are rolled over on to the trolleys on the launching track.
- Finally, the floatation drums and a stripping wire are strapped onto the pipeline.

Surface Tow Method

Attaching Oil Drums and Stripping Wire to Pipe String

Surface Tow Method

Typical Strapping Details for Rentis Installation



Surface Tow Method

Launchway Arrangement at BSP's Telisai Yard

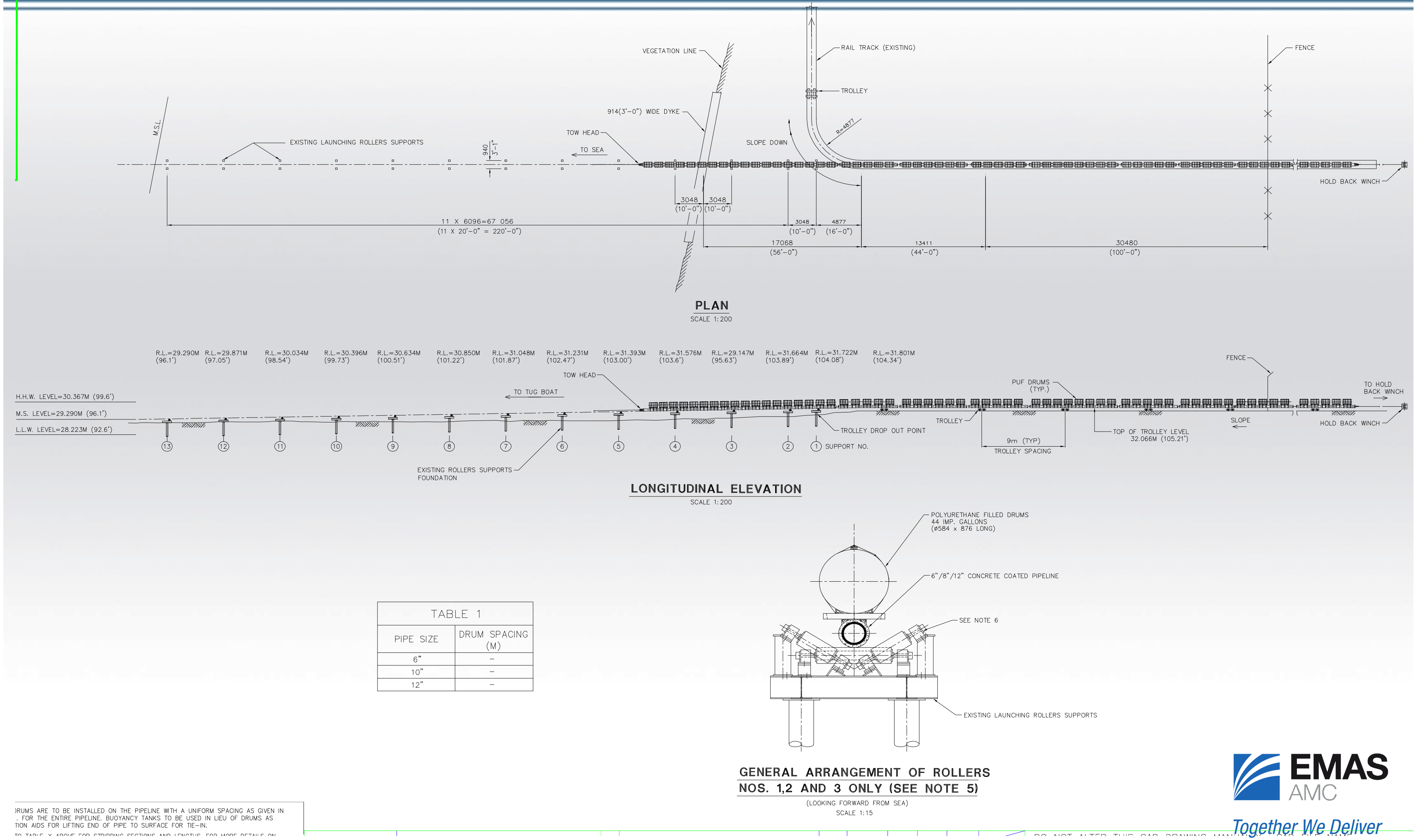


TABLE 1

PIPE SIZE	DRUM SPACING (M)
6"	–
10"	–
12"	–

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Surface Tow Method

Project Example (Miri, Sarawak) – Bundle Pipe Pull to Beach

Commencement of Bundle Pipe Pull to Beach (Fabrication site was few kms from shoreline

Pipe Bundle Approaching Beach

Two bull-dozers were used as land towing vehicle

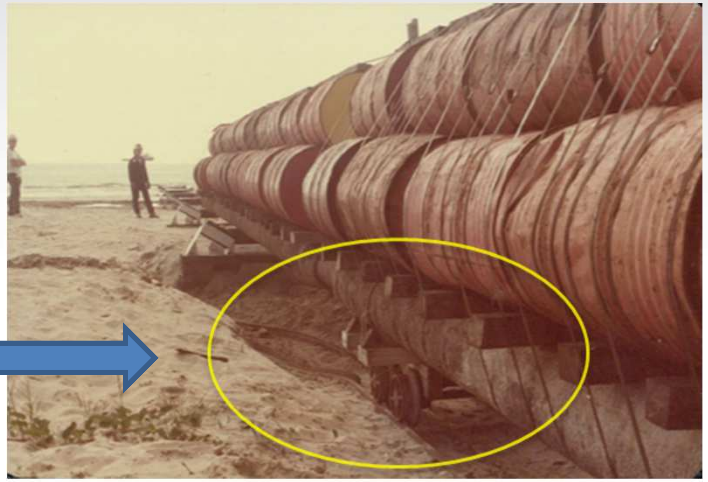
Surface Tow Method

Project Example – Bundle Pipe Pull to Beach
Note: Diverter used to allow pulling vehicles to turn 90º to avoid entering water

Pull wire diverter at 'landfall' is required to allow bull dozers to pull the pipe string bundle into the sea

On reaching the diverter, pull wire needs to be disconnected from the tow bridle and attached to the intermediate pull clamp

Straps on trolleys are cut and trolleys drop into a collection station



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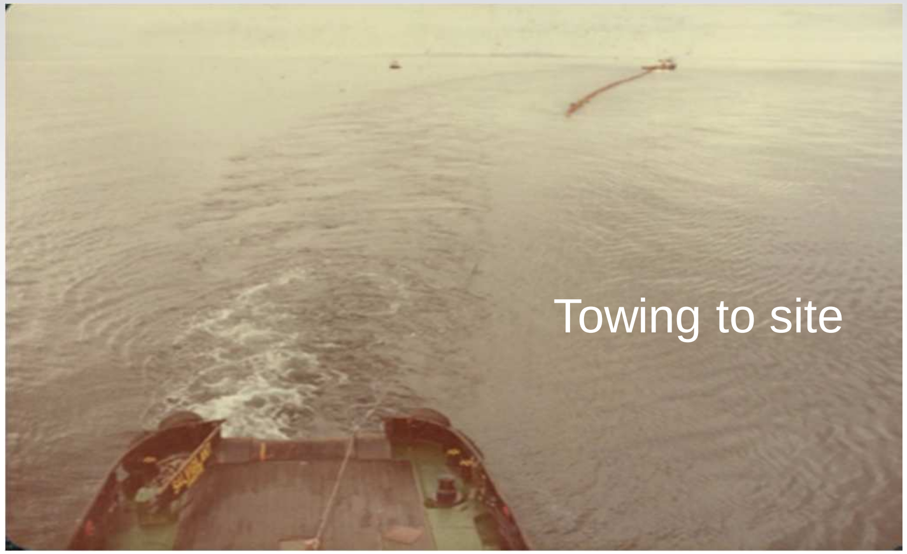
Surface Tow Method

Project Example – Connecting tow wire from tow tug to bundle pulling bridle, and launching pipeline into the sea (via onshore equipment)

Surface Tow Method

Project Example – Most Critical Moment of Operation is when Trailing Wire is released and before 2nd tug takes over this wire



Towing to site

Surface Tow Method

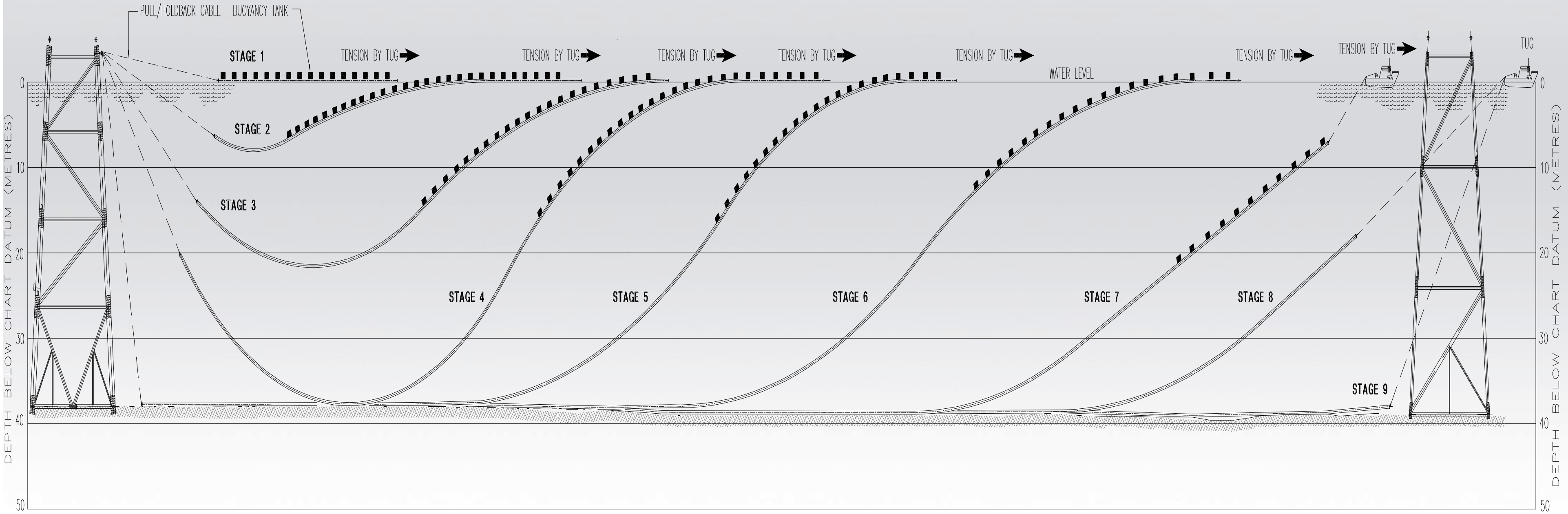
Project Example – Connecting Pull head to Pre-Installed Line on Platform & Retrieval of Stripping wire for Commencement of Pipelaying

Surface Tow Method

Project Example – Stripping of Buoyancy Drums

Surface Tow Method

Schematic: Stripping of Buoyancy Drums and Laying of Pipeline



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Unconventional Pipeline Installation Methods

Bottom Pull Method (Landfall to Landfall)

BOTTOM PULL METHOD
Landfall to Landfall

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Bottom Pull Method (Landfall to Landfall)

Project Example

Project Requirement:
- 8 Pipelines
- 2 Fiber Optic Cables

Installation Concept:
- Build Pipeline & Cable Bundle at Bukom
- Bottom Pull across Shipping Channel
- Protect with Rock Berm

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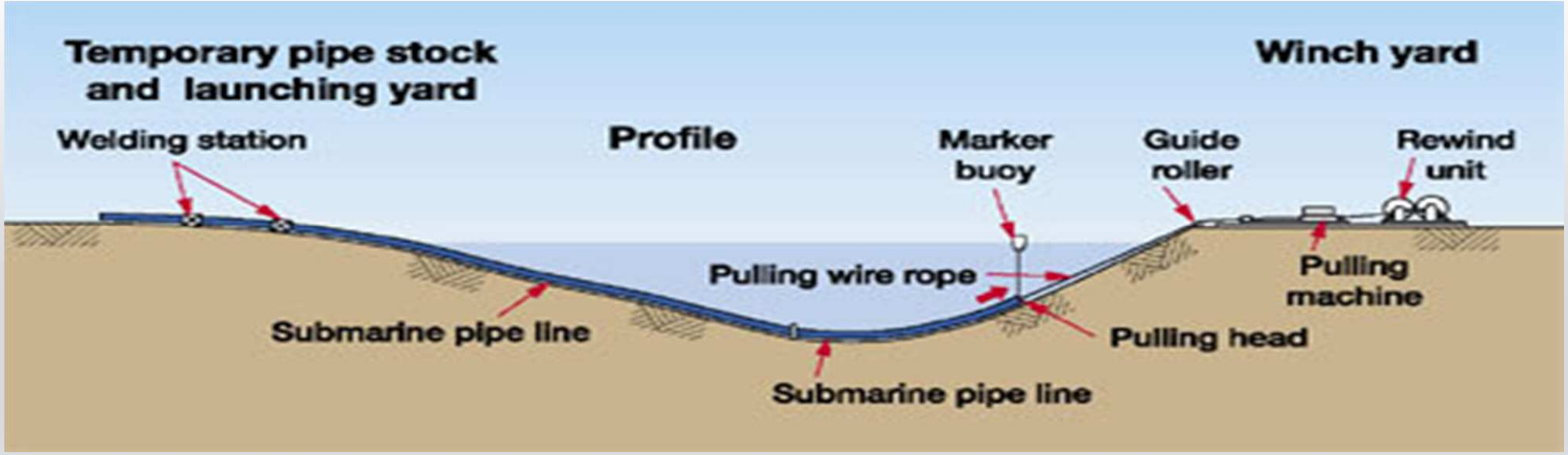
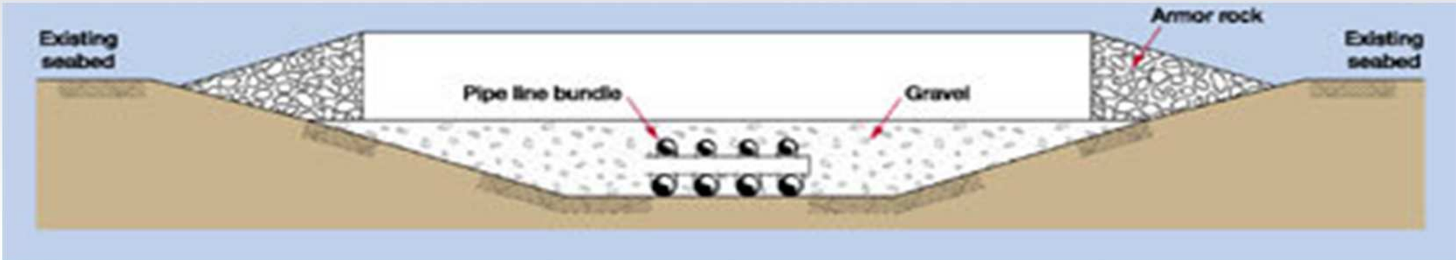
Bottom Pull Method (Landfall to Landfall)

Schematic





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Bottom Pull Method (Landfall to Landfall)

Preparatory Works: Pipe Bundling

Pullhead for Pipe Bundle

Bottom Pull Method (Landfall to Landfall)

Preparatory Works: Cofferdam Construction

Bukom End

Penjuru End (Singapore)

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Bottom Pull Method (Landfall to Landfall)

Preparatory Works: Construction of Holdback Anchor

Construction of Holdback Anchor for Linear Winch



Linear Winch Base Construction and Arrangement for Pipe Pull



Bottom Pull Method (Landfall to Landfall)

Preparatory Works: Dredging and Blasting Works

Dredging of Channel along Pipeline Route to Required Seabed Profile

Drilling and Blasting Works along Pipeline Route to shatter rocks to enable Dredging

Bottom Pull Method (Landfall to Landfall)

Commencement of Pulling of Bundled Pipe

Pipeline Bundles ready for Pull

Launch of Pipe Pull

Pipe Bundle (with BT) on Launch way

Linear Winch

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Bottom Pull Method (Landfall to Landfall)

Pipeline Installation : Alignment and Tie-In of new String to Preceding String

Bottom Pull Method (Landfall to Landfall)

Pipeline Installation: Arrival of Pulling Head at Destination Point & Installation of Risers

Arrival of Pulling Head

Installation of Risers on Pipe Bundle

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Unconventional Pipeline Installation Methods

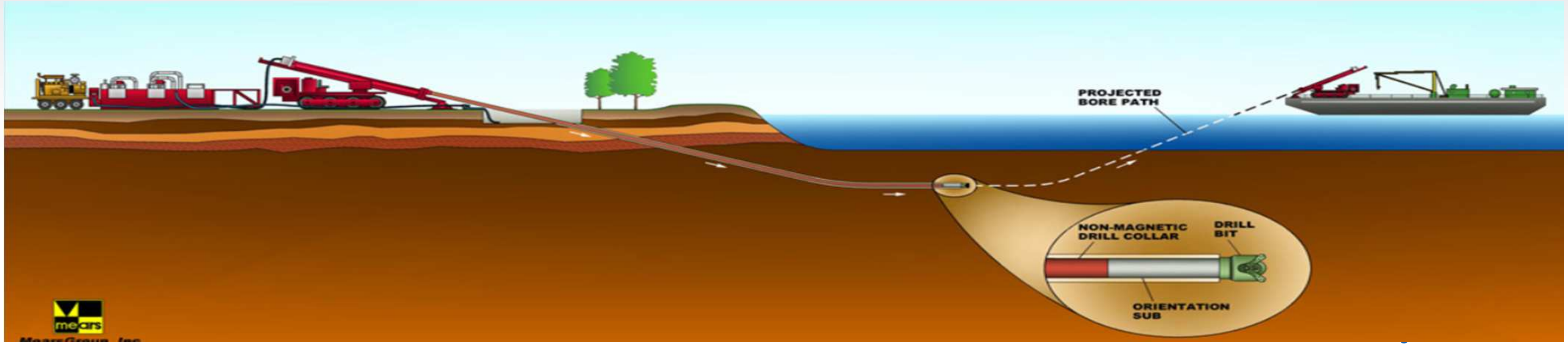
Shore Approach by HDD

SHORE APPROACH BY HDD

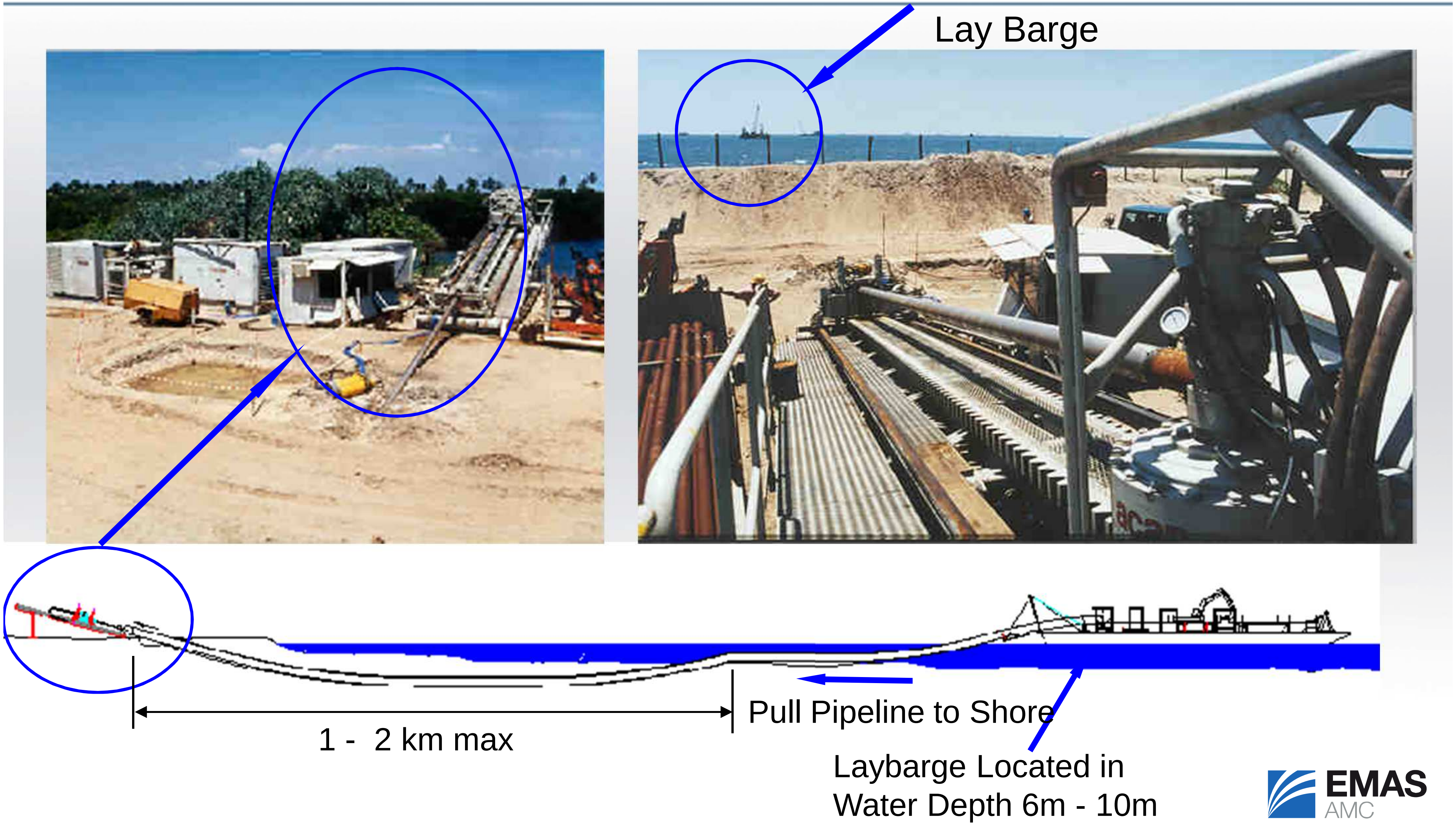
Shore Approach by HDD

What is HDD?

- HDD is a trenchless construction method utilizing equipment and techniques from horizontal well drilling technology & conventional road boring
- 3 stages of HDD:
  - ➢ Drilling an initial pilot hole with a down-hole navigation package, relaying the position & depth of the drilling device
  - ➢ Increasing the hole diameter by using different types of reamers depending upon ground conditions
  - ➢ When the hole is opened to a suitable diameter, pulling the pipeline into position
- It has been used for offshore pipeline construction mainly for shore approach pipeline installation, typically, for following reasons:
  - ➢ To avoid damaging and disturbing environmentally sensitive areas (mangrove swamp, home to protected species, etc)
  - ➢ To avoid difficult terrain, and minimize construction cost, where applicable, etc.



Shore Approach Installation by HDD: Typical Concept



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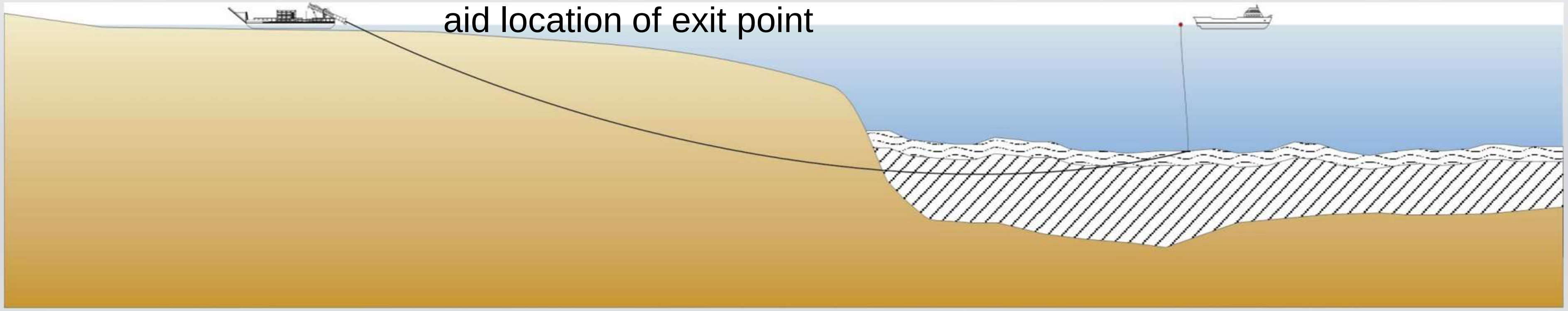
Shore Approach by HDD

Operation Sequence (typical)

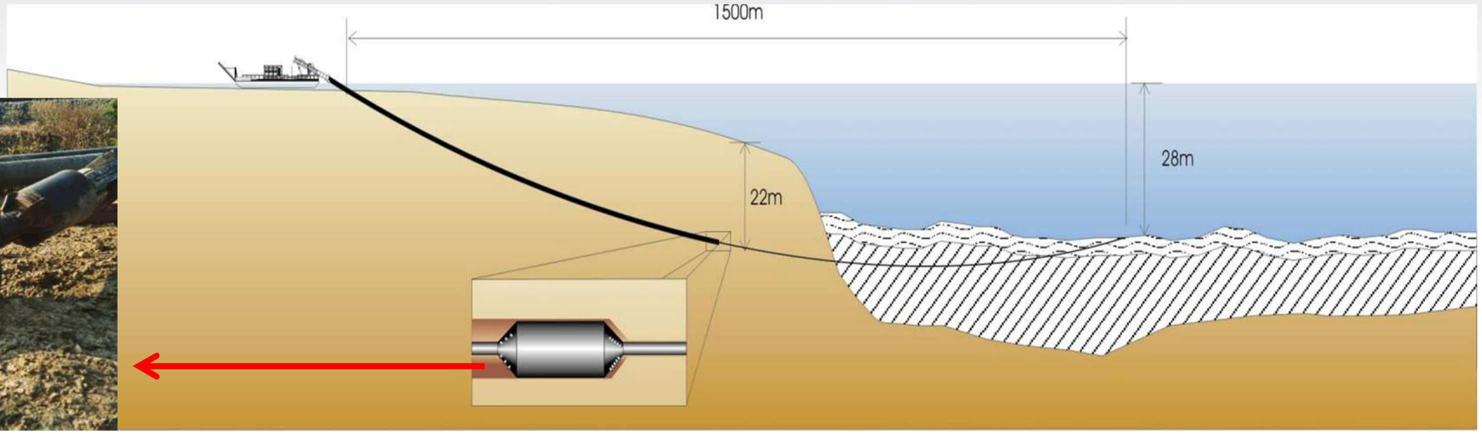
Drilling of Pilot Hole

- Pilot hole is drilled from shore based HDD equipment to a designated “exit” point offshore
- A jet-head assembly is used at the “front” of the drill pipe
- On exiting the seafloor, compressed air is blown through the drill bit to aid location of exit point



Reaming of Pilot Hole

- Pilot hole is forward reamed using barrel reamers
- Hole diameter will be 50% larger than size of product pipe

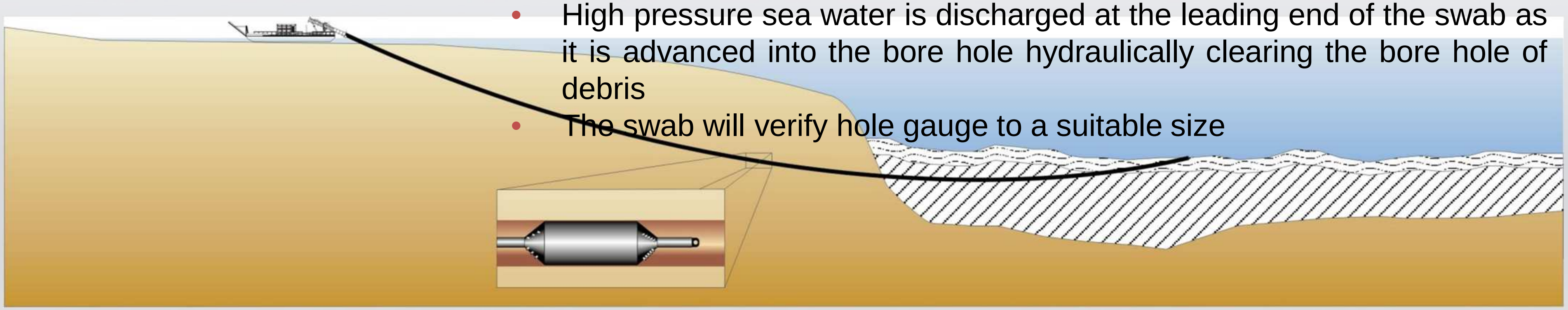


Shore Approach by HDD

Operation Sequence

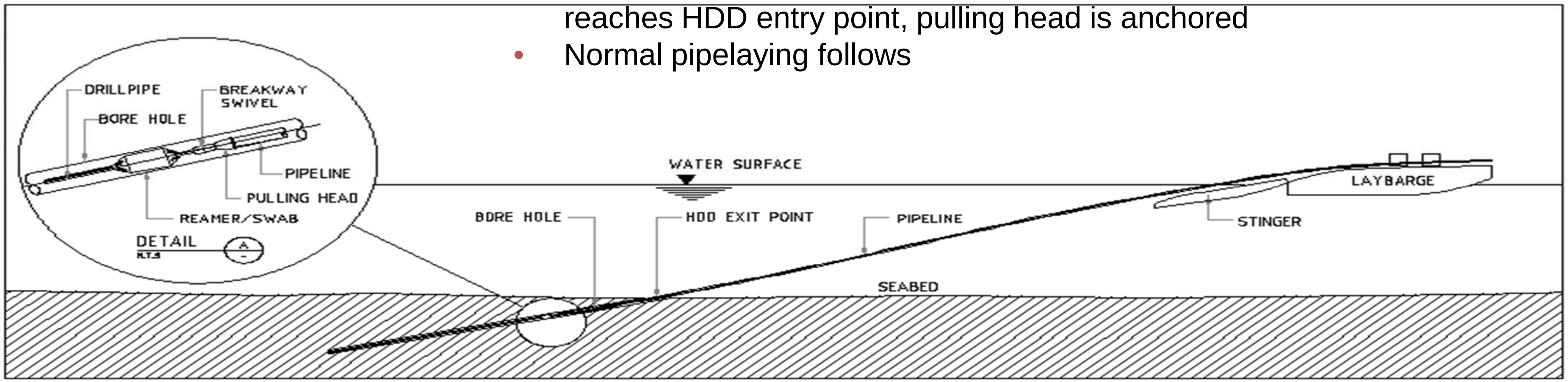
Hole Swabbing/ Cleaning

- On completion of the reaming the bore hole will be swabbed with a suitable size barrel swab
- The swab is advanced from the entry surface to the sub-sea exit location and then back to the entry surface location
- High pressure sea water is discharged at the leading end of the swab as it is advanced into the bore hole hydraulically clearing the bore hole of debris
- The swab will verify hole gauge to a suitable size



Pull-in of Product Pipeline

- Retrieve reamer on laybarge & connect to pullhead
- Pipeline is pulled into the HDD bore hole – when pipeline pullhead reaches HDD entry point, pulling head is anchored
- Normal pipelaying follows



Shore Approach by HDD

Operation Sequence

Swabber/ reamer on laybarge and connected to pullhead

Swabber and pipeline pulled back to shore

Shore Approach by HDD

Advantages & Disadvantages

Advantages:

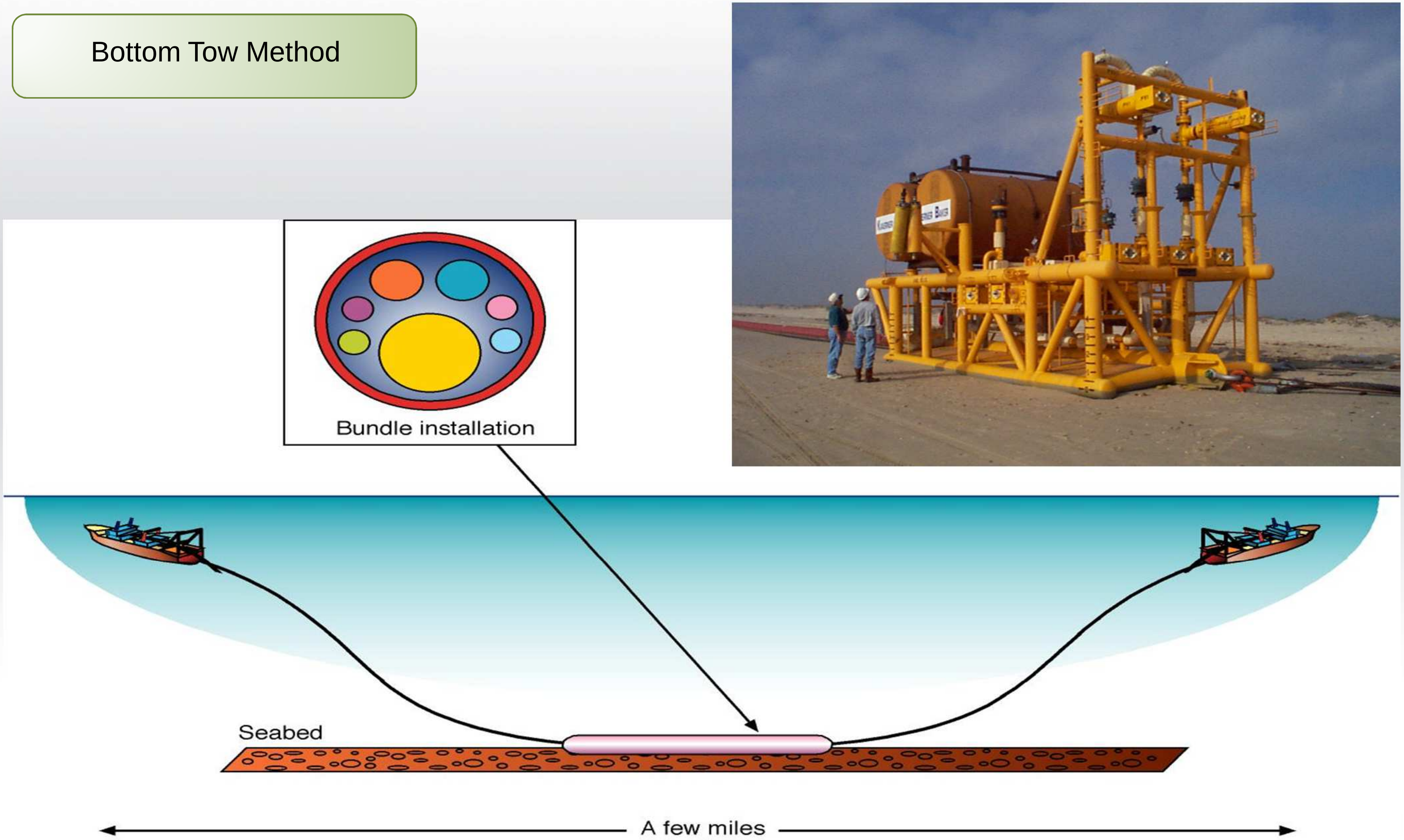
- Minimal environmental damage
- Minimal 3rd party interference and disruption
- Can be undertaken from land or using sea-based construction units

Disadvantages:

- Requires good geophysical and geotechnical surveys to ensure soil condition is suitable
- No post-installation maintenance of pipe

Other Unconventional Pipelay Techniques

Bottom Tow Method



Other Unconventional Pipelay Techniques

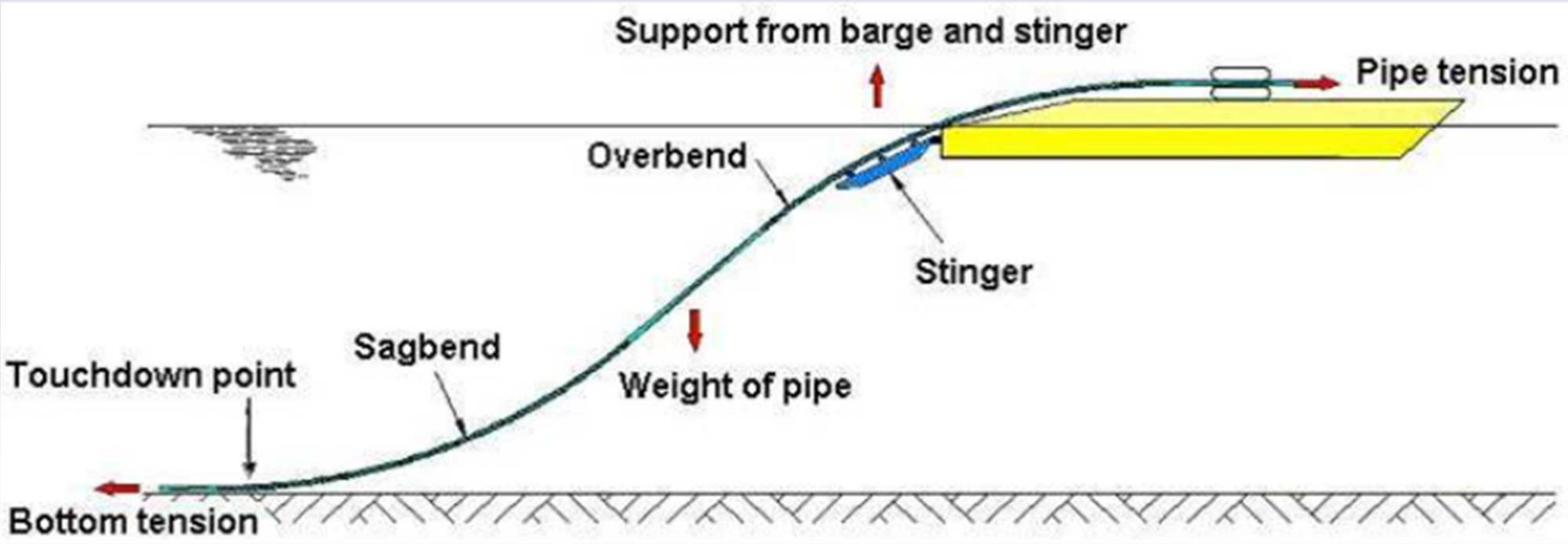
Control Depth Tow Method

Agenda

- Overview of Submarine Pipeline Installation Methodologies
- Conventional Pipeline Installation Methods
- Unconventional Pipeline Installation Methods
- **Potential Failure Modes and Design Considerations**

Potential Failure Modes and Design Considerations
S-Lay

S-LAY INSTALLATION
Forces on Pipeline



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S-Lay

Potential Failure Modes during Pipelay

Pipelines are subject to large local forces during installation:

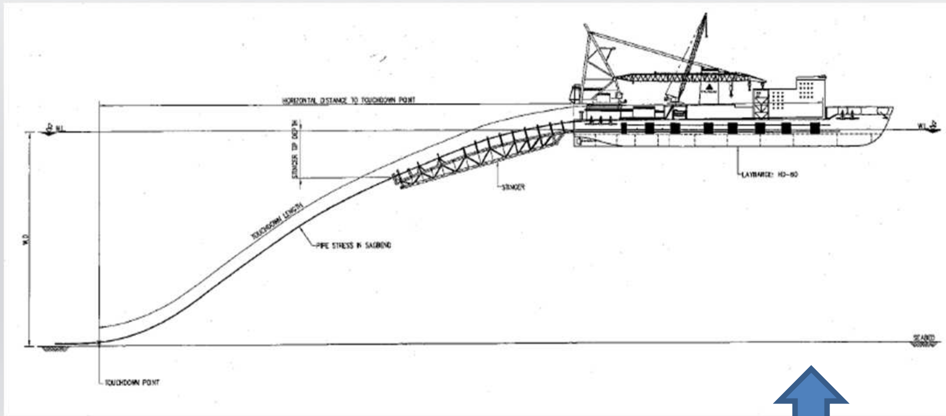
- Overbend - on barge
  - Typically, on the last few rollers of S-lay barge launching ramp, where the pipe can plastically bend
  - Offshore pipelines subjected to point-load forces may lead to local deformation (dent) and global deformation. In such circumstances, the ultimate capacity of the pipe section to sustain bending moment is significantly reduced.
- Overbend - on stinger
  - Typically, on the last few stinger rollers
  - Pipe subject to dynamic excitation from severe environmental conditions
- Sagbend - just before touchdown point – where tension capacity plays the important role

S-Lay

Design Considerations

<u>Installation Engineering at construction phase</u>: Identify Pipelay Configuration to ensure safe and economical installation

- The design process can normally be divided into:
  - ➢ Definition of static setting, i.e. stinger geometry and required lay tension
  - ➢ Definition of safety margin for dynamic load effect, e.g. lay barge ability to sustain expected sea states
  - ➢ Definition of maximum allowable sea state, i.e. applicable operational window
- Avoid damage due to unacceptable seastate resulting in unacceptable vessel motion by having appropriate abandonment & recovery procedure in place
- Abandon before storm arrives : typically, rely on weather forecast and barge superintendent's / OCM's experience, and can be subjective.



- Required Tension and Barge Setting
- Expected Roller Loads and Clearance
- Water Depth and S-Lay Suspended Span Length
- Distance of TDP to Barge (for ROV Touch Down Monitoring)

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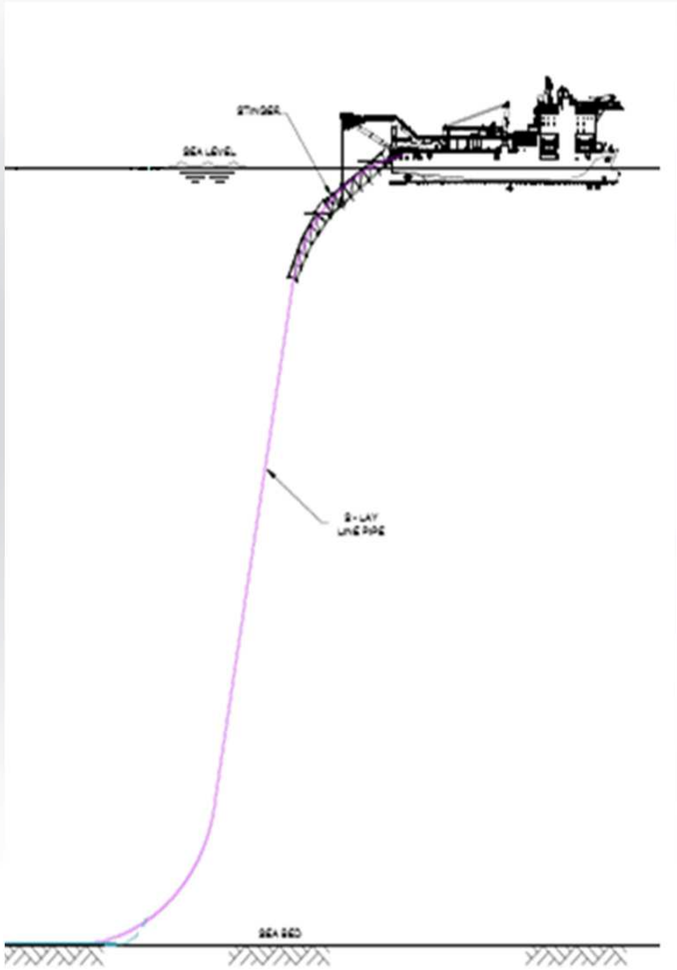
S-Lay

Design Considerations DEEPWATER



Challenges:

- Longer & Heavier Catenary
- Higher bending
- Higher Tension requirement to hold Catenary
- Pipe manufacturing and buckle arrestor design
  (preference of seamless pipe which has lower fabrication tolerance; supplementary requirement, etc)
- Other deepwater specific aspects: flooding, tension variations, pipeline rotation, etc

Need very large lay vessel with high tension requirement

Design:

- Remove (where possible) or reduce conservatism level
- Consider increased strain level in overbend

Table 13-5 Simplified criteria, overbend

Criterion	*X70*	*X65*	*X60*	*X52*
I	0.270%	0.250%	0.230%	0.205%
II	0.325%	0.305%	0.290%	0.260%

0.35%? some consider 0.5%

- Stinger design – geometry and length, achievable radius, number of roller supports for load distribution

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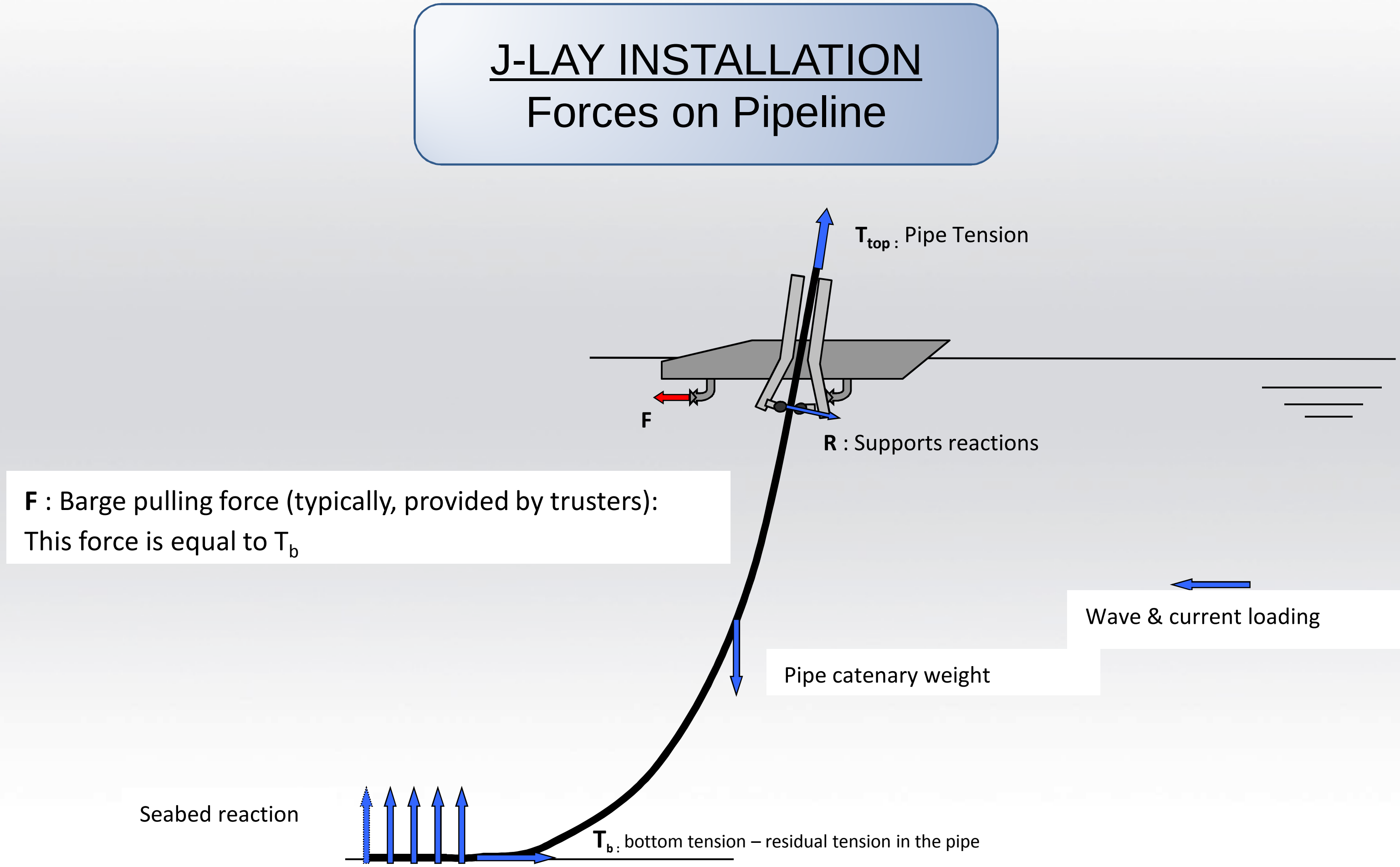
Potential Failure Modes and Design Considerations

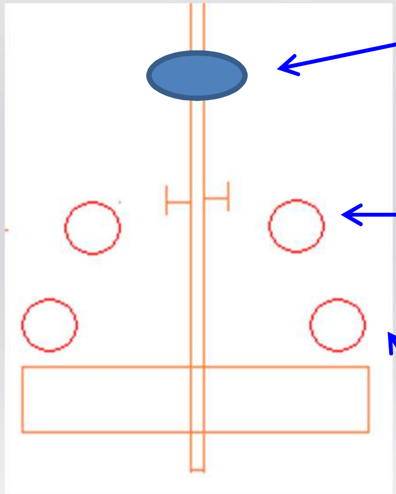
J-Lay



J-Lay

Potential Failure Modes and Design Considerations during Pipelay

No Overbend → Remove one potential failure mode during pipelay



Typical J-Lay Arrangement

Tower Bushing/ Clamp/ Tensioner to hold PIpe

Upper rollers to “guide” pipeline

Lower rollers to “guide” pipeline but allowing anticipated movement due to dynamic loads

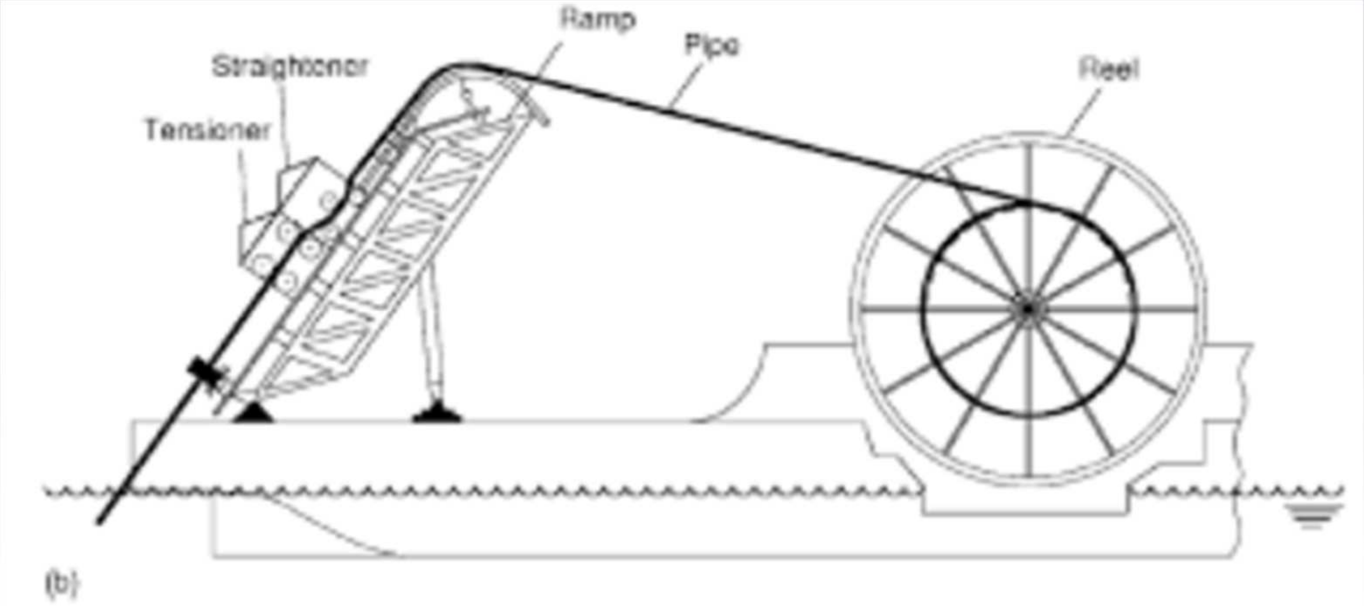
Design Considerations:

- Setting of J-Lay Tower Angle and Roller Clearances
- Define maximum allowable sea state i.e applicable operational window
- Define maximum allowable vessel excursion

Potential Failure Modes and Design Considerations

Reel Lay

REEL LAY INSTALLATION



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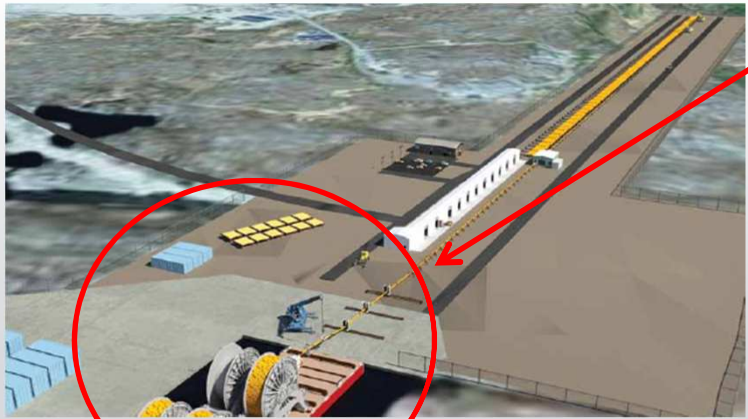
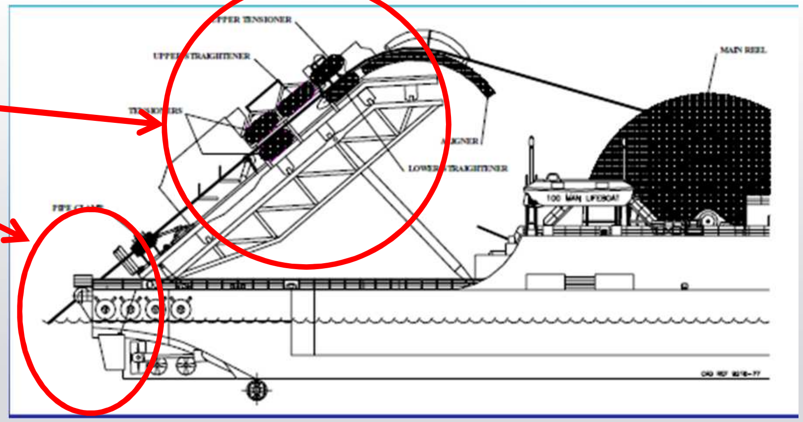
Reel Lay

Design Considerations



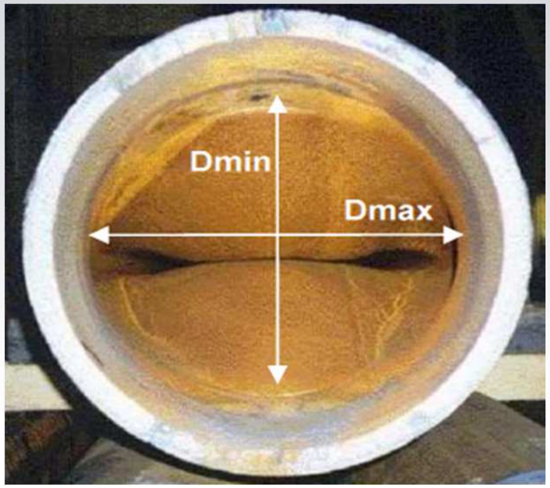
- Reeling
- Straightening
- Laying



Gives cumulative large plastic strains up to 2% which degrade material fracture resistance

Challenges:

- Reeling (at yard) and un-reeling (offshore) increases pipe ovality causing:
  - Hydrostatic pressure greater on flatter sides of pipe, leading to:
  - Hydrostatic collapse in deepwater



Reel Lay
Design Considerations

Design specification

- Low thickness fabrication tolerance (D/t ratio)
- Low variation in yield stress
- Low Yield Strength /Ultimate Tensile Strength ratio
- Apply high and steady back tension during reeling

Similar problem for girth welds

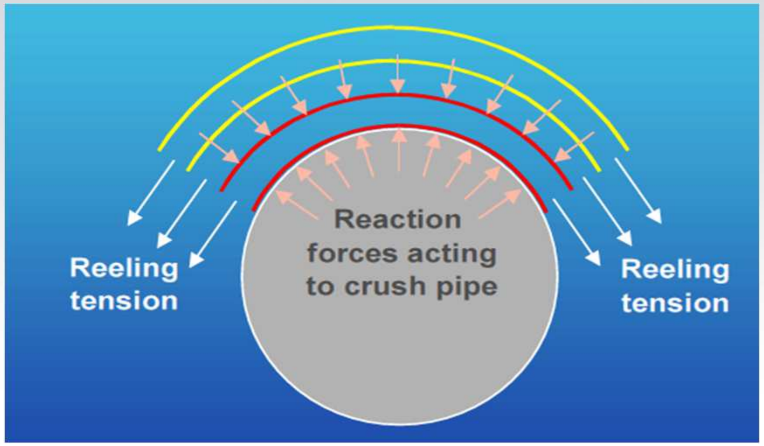
- Over match weld properties to avoid excessive strain in weld

For successful reeling operation, Contractor needs to accurately estimate the following:

- Cumulative strain build-up
- Potential for local buckling
- Resultant ovality
- Crushing

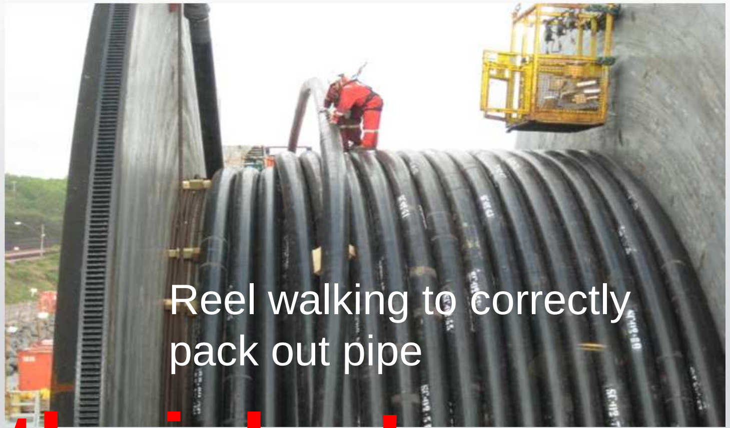
Handling Care

- Care should be taken to ensure that back tension is applied to the pipe when being reeled is not sufficiently high as to crush the pipe layers beneath
- Another problem is that the reel must be held under tension throughout the reeling-on, transport to site and reeling-off process.
- The amount of stored energy in the larger reels can be massive and failure of a section that maintains this tension can result in uncontrolled release of this energy.
- When this occurs, the pipe will uncontrollably spool itself off the wheel.



Reel Lay

Potential Risks (associated with “traditional” reel-lay operation)



Critical path risks !

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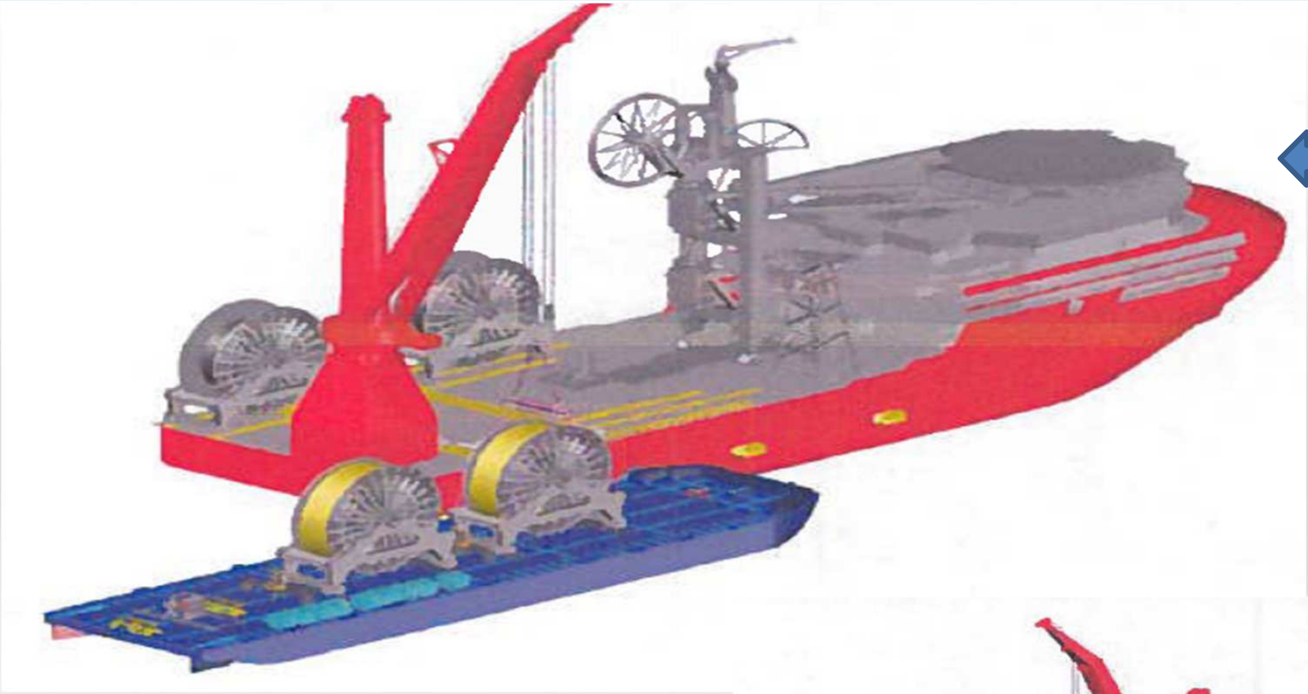
Reel Lay

Potential Risks (associated with "traditional" reel-lay operation)

- Weld repairs into storage - when spooling on critical path, contractor sometimes have to accept a weld repair as it would be quicker than chopping it out completely. With Constellation, spooling will all be off critical path, so if there is a weld repair it will just be chopped rather than repaired.
- Stalk handling coating damage – causes delay in spooling time
- Damaged FJC – causes delay in spooling time
- Risk of critical path welding failures
- Coating failures during spooling – again, these need to be repaired on critical path
- Reel walking: see earlier picture. Worker(s) walk on top of the reel as the pipe is being spooled - highly questionable activity but sometimes manual intervention is required to pack out the pipe.
- Conventional reel vessel typically reel at 2m per minute – restricted to spooling pipe onto the reel on critical path as the reel is built into the vessel.
- With EMAS's Constellation, above critical path risks are eliminated because spooling is done independently (while vessel is busy installing pipe) and any delay caused by above typically will not affect critical path activities

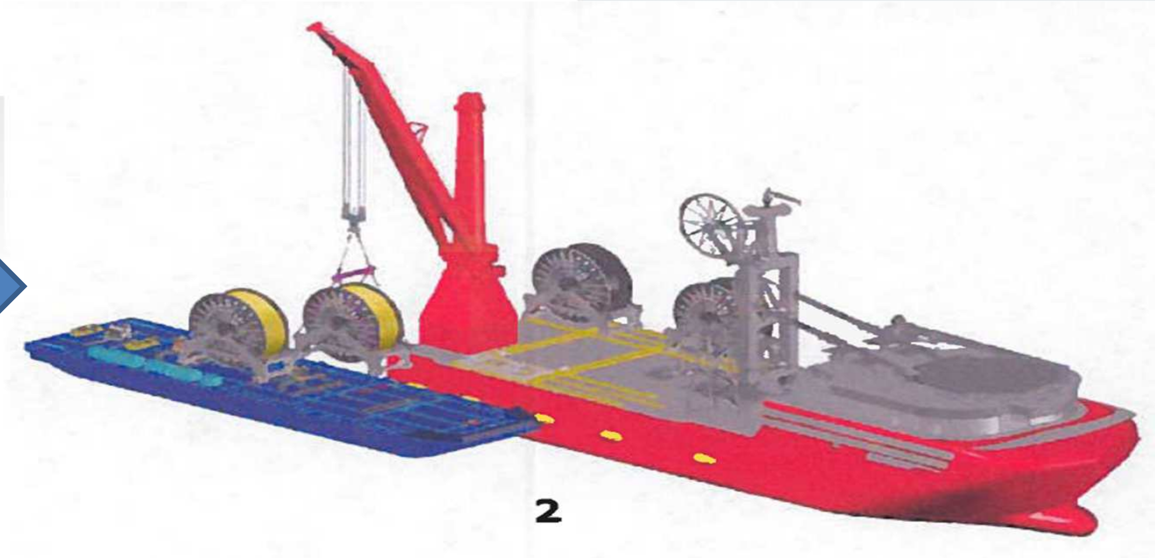
Reel Lay

Potential Risks (associated with "traditional" reel-lay operation)



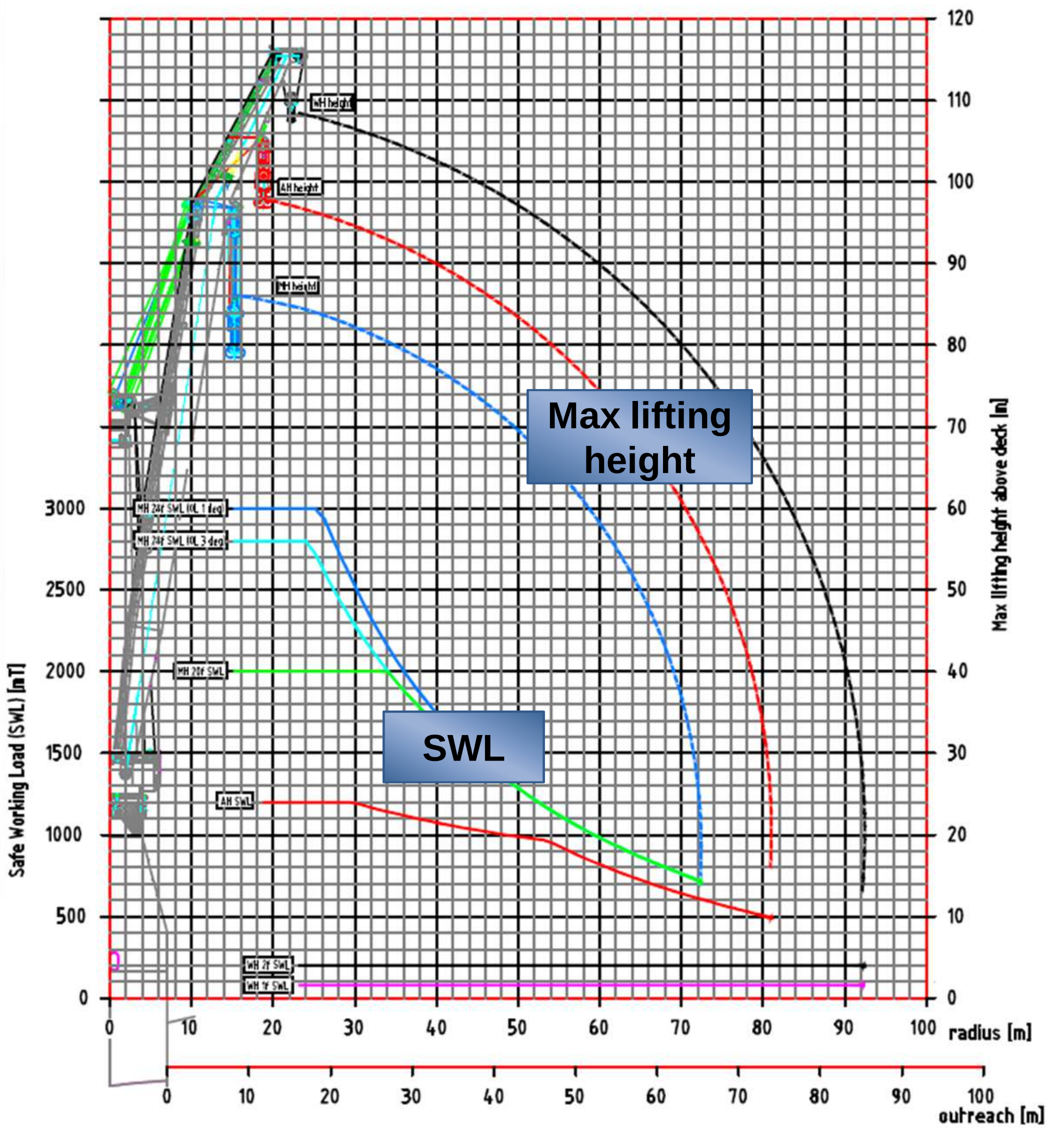
Critical path risks removed by separating "spooling" from reel lay

Pipeline spooled separately and transported offshore to be loaded to reel vessel



Reel Lay

Heavy Lift System on EMAS's Constellation allows for Spool Replacement Offshore



- **Main** 3000mT @25m radius
  - 80m travel w/ 28 falls
- **Auxiliary** 1200mT @ 30m radius
  - 330m travel for 2 winch
  - 165m travel for single winch
- **Whip @ 1 fall,** 80mT @ all radii,
  - approx. 2000m travel
- **Whip @ 2 fall,** 200mT @ all radii,
  - approx. 1000m travel

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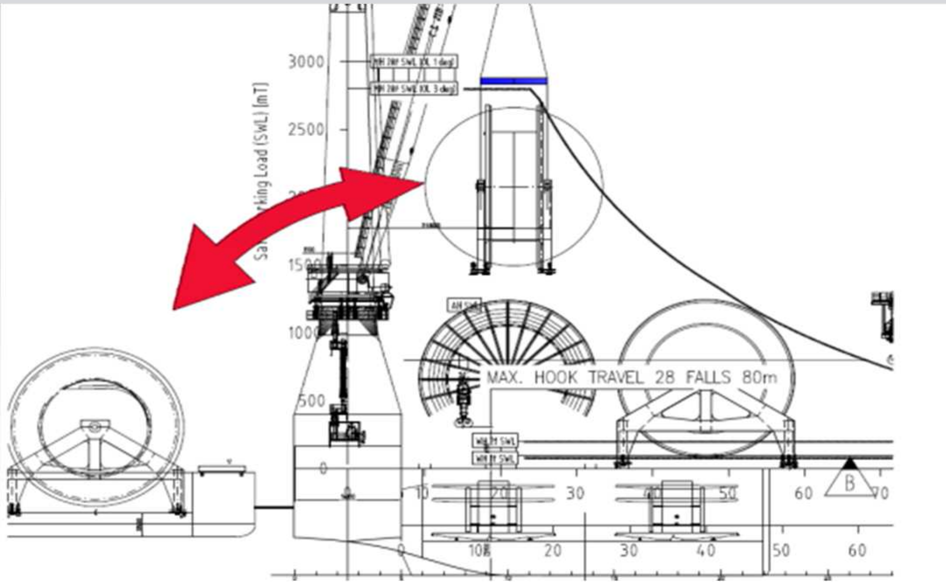
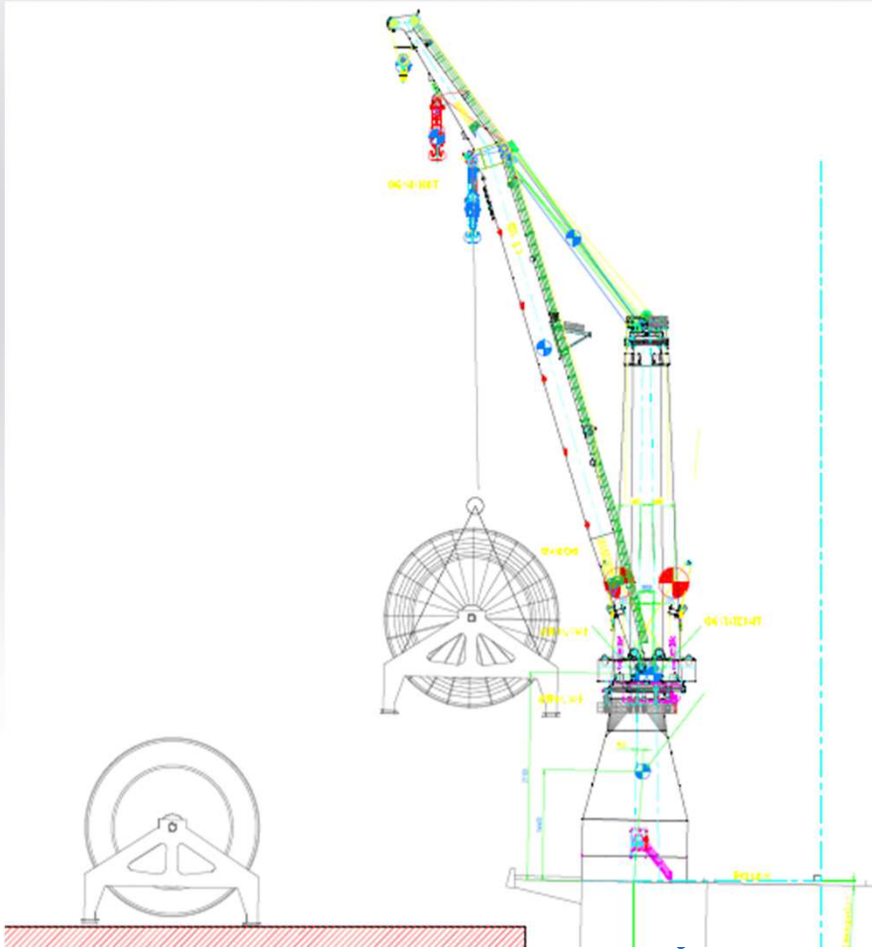
Reel Lay

The Portable Reel and Drive System allows for Loading/ Off-loading of reels at Quayside or Offshore

- 1200mT Reels – 22m outer flange, 16m hub, 6m wide
- 4 x Reels lifted by vessel crane
  - Reels lifted to/from quayside
  - Reels lifted to/from vessel / barge
- Drive motor on separate trolley
  - Back Tension capacity 100mT

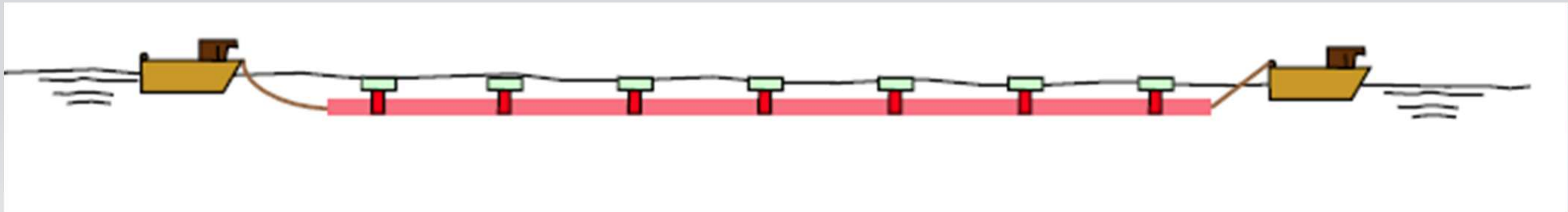




Potential Failure Modes and Design Considerations

Surface Tow (Rentis)

SURFACE TOW



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Surface Tow (Rentis) Method

Potential Failure Modes

- Loss of control during launching – see pictures in next slide
- Loss of control during tow when encounter bad storm – need to apply sufficient pull to ensure pipeline is not badly curved
  - ➢ May lead to pipe damage if profile is not properly controlled
  - ➢ Loss of buoyancy will make control difficult
  - ➢ May need to 'follow the storm' until storm subsides, then resume path to final location – fighting the storm may result in loss of control for pipeline string
- Uncontrolled sinking during removal of supplementary buoyancy
  - ➢ When insufficient buoyancy is used, pipeline will sink uncontrollably after initial stripping of the buoyancy => high chance of damage to pipeline
- Insufficient pull during buoyancy removal, which leads overstress at overbend => may lead to buckle

Surface Tow (Rentis) Method

Potential Failure Modes: Lack of Control after Launching

- Holdback cable was released after launch to await pick-up by 2nd tug
- This resulted in a period where there was no tension in the pipeline to straighten the line.
- This could have resulted in an undesirable situation if the current had been very strong

Note curvature in pipe string due to current

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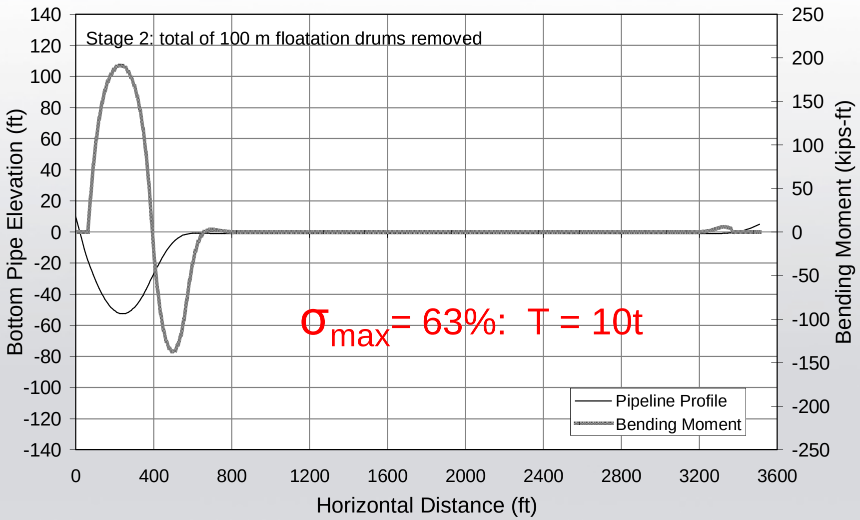
Surface Tow (Rentis) Method

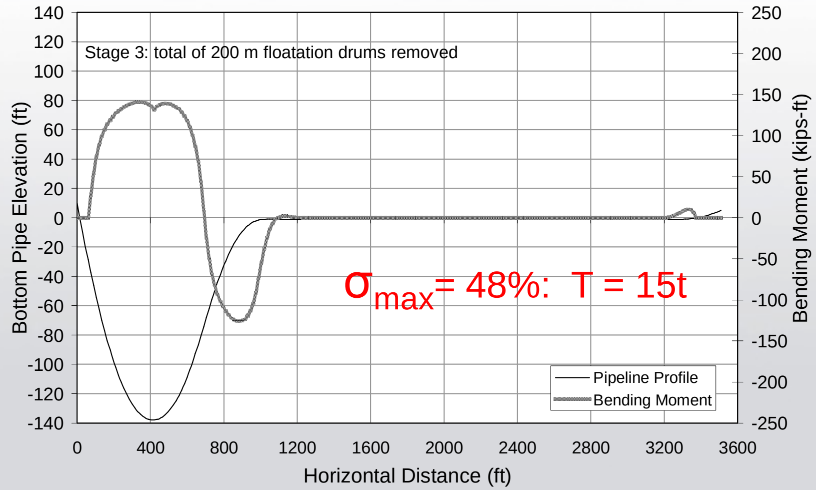
Design Considerations

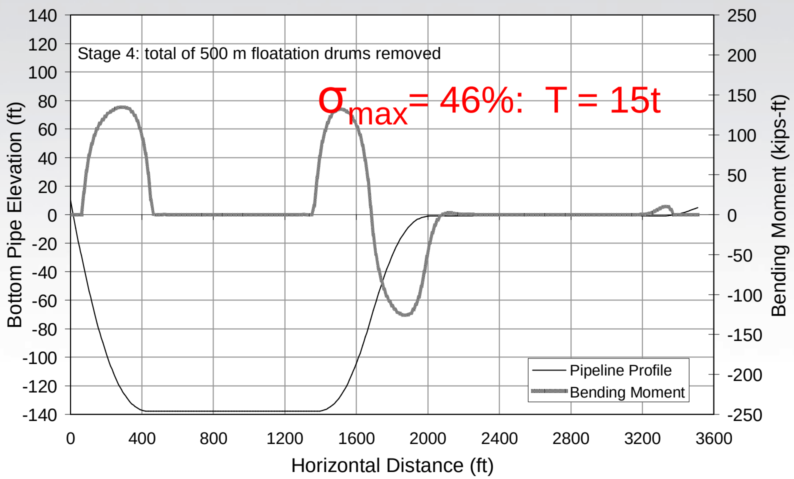
- Perform detailed installation engineering to determine appropriate buoyancy requirement
  - Need to ensure pipeline stresses within allowable
  - Need to ensure sufficient buoyancy to prevent uncontrolled sinking
  - Need to ensure that buoyancy drums do not fall below ‘collapse’ depth
    - collapsed or partially collapsed oil drums result in ‘domino’ effect, causing more drums to drop below ‘collapse’ depth, therefore resulting in uncontrolled sinking
- Ensure sufficient lay tension during laying (i.e. stripping of drums)
  - This will ensure that, if pipeline sinks uncontrollable, pipeline will not buckle
  - This will help ensure that buoyancy drums do not ‘drop’ below their ‘collapse’ depth before being removed
- Allow for excess buoyancy drums, as some of these may ‘drop off’ during tow, especially when caught in a storm
- Lay the pipeline in a curve to allow some ‘slack’ for subsequent riser installation

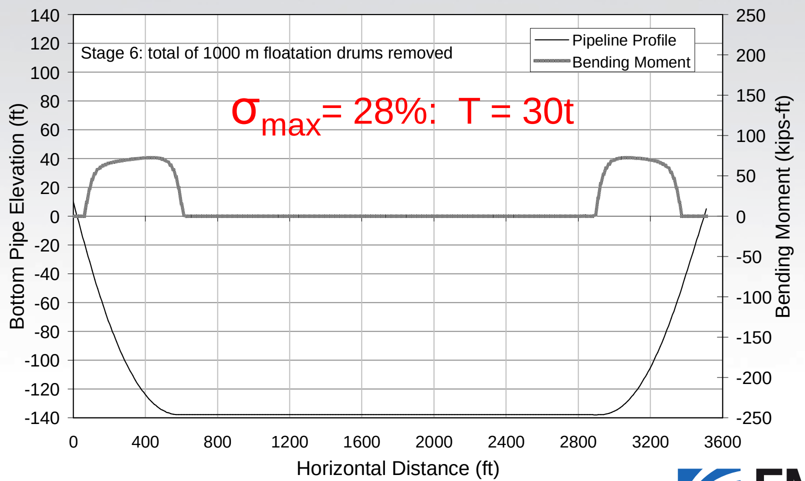
Surface Tow (Rentis) Method

Sample Lay Analysis for Rentis Installation – Stresses, Depth of Drums ensuring Controlled Sinking









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Surface Tow (Rentis) Method

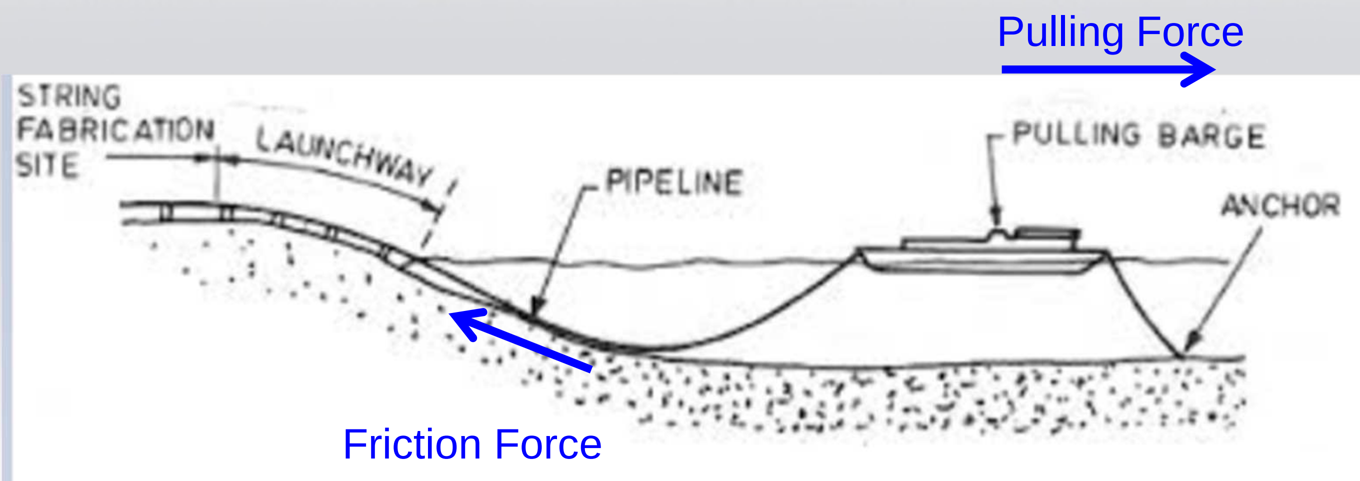
Lessons Learnt

- Calm weather is very important for “Rentis” tow – do not launch the pipeline until good weather window is certain
- Don’t always trust the weather forecast – we launched the pipeline bundle based on a 3-day good weather window, but ‘hit’ the storm within 3 hours
- Allow for excess buoyancy drums as some may get dislodge during tow, especially if hit by storm
- Do the pipelaying in the morning so that you have sufficient time to collect the oil drums before sunset

Potential Failure Modes and Design Considerations

Bottom Pull Installation

BOTTOM PULL INSTALLATION
Forces on Pipeline



Bottom Pull

Potential Failures

Challenges:

- Insufficient pull capacity of pulling winch:
  - Undersized winch
  - Embedded pull wire (especially when laid in liquefiable soils and non-straight)
  - Pullhead embedded into soil
  - Obstacles along corridor of pipeline
- Damage to pipeline coating and/ or itself
- Almost not possible to retrieve pipeline once pipeline is pulled partially to its final location

Design:

- In event of liquefiable soils, attach buoyancy devices along pull wire at engineered spacing for wire to self-dislodge during high tide
- Oversize the linear winch
- Reduce number of buoyancy tanks for pipeline

Just enough buoyancy, not too many!

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Bottom Pull – Lesson Learnt

Excessive Buoyancy caused undesirable pipeline deflection in strong current during night pull

Bottom Pull – Lesson Learnt

Uprooting buried cable and straightening cable before next pull

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Bottom Pull – Lesson Learnt

Dislodging and straightening of cable was a continuous process in between pulls

Bottom Pull – Lesson Learnt

Installing oil drums along the entire pull cable along inter-tidal zone to self-dislodge cable during rising tide

Bottom Pull – Lesson Learnt

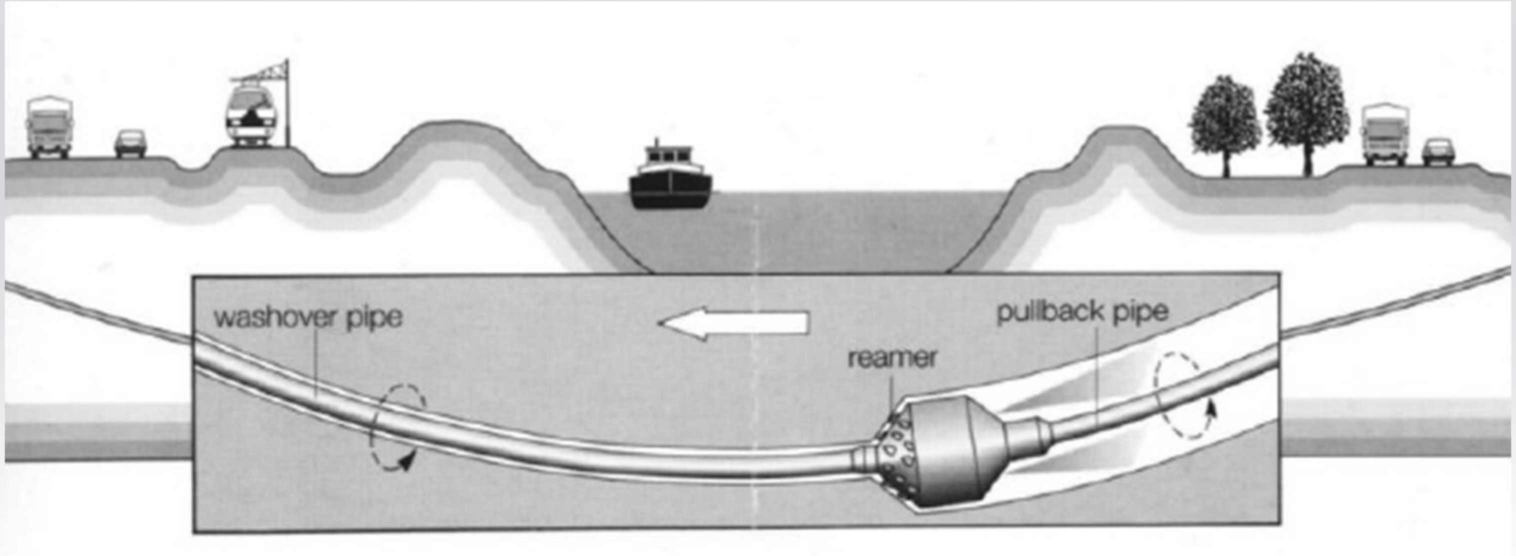
Observation from a successful bottom pull project:

- The contractor spent tremendous amount of time (4 days over 4.5km) to lay the pull wire, ensuring that wires were straight before commencement of pull
- Seabed was painstakingly 'smoothen' and all debris removed before the pull
- Linear winch was carefully chosen and adequate contingency allowed within the winch capacity
- The contractor had a lot of experience with similar projects and implemented all the lessons learnt from past projects
- Spares were present and machines maintained while subsequent pipe strings were being welded – the discipline paid off

Potential Failure Modes and Design Considerations

HDD

HORIZONTAL DIRECTIONAL DRILLING (HDD)



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HDD

Potential Failure Modes

HDD Failures	Cause
Loss of Drilling Fluid/ Loss of Circulation	• Permeable deposits or jointed and/ or fractured bedrock along drill path • Excessive annular pressures for the bedrock formation or soils encountered
Drilling mud seepage directly into watercourse	• Permeable deposits or jointed and/ or fractured bedrock along drill path • Excessive annular pressures for the bedrock formation or soils encountered
Drilling mud seepage onto land and then into watercourse	• Permeable deposits or jointed and/ or fractured bedrock along drill path • Excessive annular pressures for the bedrock formation or soils encountered • Suggests inadequate monitoring along drill path
Collapsed hole ☆	• Erosion or settling of the bore hole
Stuck drill stem or pipe string ☆	• Collapse of hole along the drill along the drill path, due to swelling of highly plastic clays, boulders, bentonic shales, coal seams • Inadequate reaming to obtain optimal bore diameter for pull back
Lost tools and/ or drill stands ☆	• Twisting off of drill stem or metal failure of down hole tools
Damaged pipe or coating ☆	• Inadequate reaming to obtain optimal bore diameter for pull back • Excessive entry or exit angle for bend radius of the pipe string • Sharp objects or casing present in bore • Collapse of hole along the drill path

Ref: Canadian Association of Petroleum Producers, Guideline for Planning HDD for Pipeline Construction, Sept 2004

HDD
Design Considerations

Geotechnical

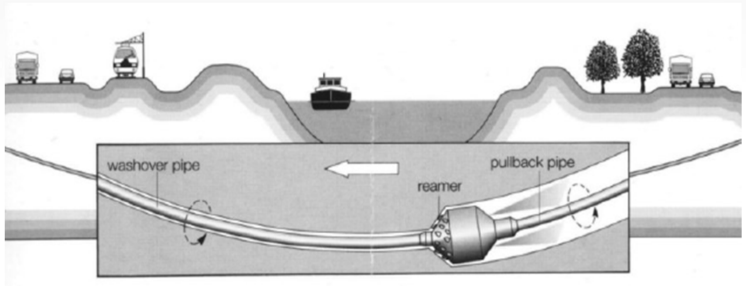
- Consider distribution and characteristics of the surficial overburden deposits
- Consider presence of high plastic clay and bentonitic shale bedrock materials
- Consider occurrence of structurally complex, hard and/ or abrasive bedrock
- <u>Competent bedrock is one of the preferred materials for HDD</u>

Pipeline

- Pipeline tensile & bending stresses within acceptable limit during HDD
- Pipe Coating carefully selected to avoid damage during HDD
- Pipe Weight *(Pipe weight near neutral when submerged on bentonite to avoid excessive pull back force and damage to pipe and/ or coating)*

Drill Path

- Length of borehole to be drilled
  (As of early 2000's, longest drill path is 1.8km, largest pipe is 1.2m OD)
- Radius of curvature allowing installation and minimization of bending stress *(Minimum radius = 1200 x OD in meters)*
- Reaming Diameter (1.5 x OD)
- Entry and Exit Angle



Thank You!

Questions?

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