Engineering ‘Lunch & Learn’ Series

“An overview of Typical and Non-typical Seabed Intervention Methodologies”

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Purpose for Seabed Intervention

Seabed intervention refers to physical intervention of the seabed through seabed modification or placement of objects, etc.

Seabed intervention is carried out for several purposes, including but not limited to:
- Preventing excessive spans during pipelaying
- Correcting excessive spans after pipelaying
- Allowing for crossing of new pipeline/cable over existing infrastructure (i.e. pipeline, cable, etc.)
- Protection of infrastructure (e.g. burial of pipelines & cables)
- Levelling of seabed (e.g. prior to subsea structure installation), and so on

Seabed intervention for pipeline span correction is most common & may take place by prevention (pre- lay) or by correction (post-lay). Span correction methods may be categorized as those which:
- Provide support to the pipe
- Modify the seabed
- Modify the behavior of the pipe.

The first two methods are the most frequently adopted ones.
Challenges along pipeline routes

Even after route optimization, the lay corridor may still contain bathymetric features which result in unavoidable spans that need seabed intervention for mitigation. These include:

- Reef and carbonate complexes/outcrops
- Growth faults
- Steep terrain at shelf break
- Irregular or undulating seabed
- Pinnacles
- Landslide complexes
- Channels
- Gullies
- Sand waves/ripples
- Pockmarks (seabed craters)
Pre-lay Seabed Intervention
Pre-lay Seabed Intervention by dredging

- Pre-lay seabed intervention by dredging is relatively common.
- For shallow water up to 30m depth, it is generally felt that cutter suction dredger, backhoe dredger and Trailing Suction Hopper Dredger (TSHD) are most appropriate for soil of varying conditions (soft to hard).
- For seabed intervention in deep water beyond the reach of TSHD, bucket dredger could still be used.

<table>
<thead>
<tr>
<th>Dredging Equipment</th>
<th>Suitable Soil Condition</th>
<th>Depth Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutter Suction Dredger</td>
<td>Soft to hard soil</td>
<td>35m</td>
</tr>
<tr>
<td>Backhoe Dredger</td>
<td>Soft to hard soil</td>
<td>30m</td>
</tr>
<tr>
<td>Bucket Dredger</td>
<td>Soft soil</td>
<td>1000m</td>
</tr>
<tr>
<td>Trailing Suction Hopper Dredger</td>
<td>Soft soil (without draghead)</td>
<td>100m (Tideway/ Dredging International) – 250m (1) (Boskalis)</td>
</tr>
<tr>
<td></td>
<td>Hard soil up to 1MPa (Tideway) or 30 MPa (Boskalis) with Draghead c/w teeth</td>
<td></td>
</tr>
</tbody>
</table>

(1) Boskalis’ brochure shows 90m but they claim 250m during face to face discussion
Near shore dredging

Geocean’s Marine Autonomous Excavator

Shore approach / mangrove swamp dredging using ‘march buggy’

Shallow water cutter suction dredger
Cutter Suction Dredger

Tideway Cutter Suction Dredger “d’Artagnan”
(dredging up to 30m depth)
Dredging of Channel along Pipeline Route to obtain Required Seabed Design Profile

Van Oord’s Backhoe Dredger “Ave Caesar” dredging rocky seabed in Singapore & 2 no. hopper barges for disposal of spoils
Seabed Intervention by Excavation (Bucket Dredger)

Schematic Showing a typical Boskalis Bucket Dredger at Work
Pre-Pipelay Dredging: Trailing Suction Hopper Dredger (TSHD)

Boskalis’ Trailing Suction Hopper Dredger Prins der Nederlanden
Peak Shaving with TSHD

Typical presweep longitudinal profile

Distance (m)  200  400  600  800

Proposed dredgeline
Original seabed
Final pipeline level
Mass Flow Excavator (MFE)

SeaVator Mass Flow Excavator with V-jet system (left)

SeaVator MFE coupled with ClayCutter X

- For trenching of pipelines & cables from 4” to 50” OD
- No contact with pipeline/cable
- Trench depth up to 5m
- Water depth from 5m onwards (max depth limited by hose handling)

ClayCutterX can cut 5m wide trench in soils up to 500kPa

- Can be used for deburial and rock dump removal
- Seabed levelling
- Sandwave clearance
- Span rectification even on live pipelines

Dredgers (e.g. TSHD) can be adapted to perform MFE functions
Pre-Lay Seabed Preparation by Rock Dumping

Dredging itself may not be sufficient, and rock dumping may be required as supplementary means of span mitigation.

The recommended equipment are:
• Buckets for shallow water and deep water but is slow.
• Side stone dumping vessels are efficient for shallow water rock dumping.
• Fall pipe rock dumping vessels can operate to 1000m and new builds can operate up to 2000m

(L&C) : Van Oord’s Rock dumping using Side Stone Dumping Vessel, Jan Steen
Drilling & Blasting Works along Pipeline Route to Shatter the Rocks where dredger was unable to dredge
Drilling & Blasting Works along Pipeline Route (2nd vessel – same project; very slow process)

View of drilling machine in operation (from another project)

Note cables hanging from drilling m/cs to sea. Those are detonation control cables to initiate the detonation.
Dredger and D&B Vessel Working Side by Side – D&B vessel shatters rock & dredger removes shattered rock
Seabed intervention through Placement of ‘structures’ on seafloor
Concrete mattresses are used to provide separation between existing infrastructure and newbuilds.
Picking up of Mattress from material barge & subsea deployment via Lifting Frame
Mattresses can be installed single, dual or triple layers

Single

All ROV Releasable

Dual

Triple
Right angle crossing

Existing 10” Pipe

Existing Umbilical

Pipelay Route

6 mats

9 mats

9 mats

Assume ½ mat to 1 mat sinking into seabed
Shallow angle crossing

Existing 10" Pipe

Existing Umbilical

10 mats

15 mats

10 mats

15 mats

10 mats

 +/- 7m
Typical Crossing Supports (ULO Products)

- Prelay Crossing Support
- Standard and Large Base Pipeline Supports
- Wedge Cable / Umbilical / Flexible Pipeline Crossing Support
- Jacking Supports
- Mono Crossing Support
- Pillar Supports
- Cable Crossing Supports
- Dome Support
- J-Tube Support
- Pipeline Stabilisation
SPS Crossing Bridges are an ideal solution for crossing an existing pipeline with a pipeline or cable in a single unit installation. These can be manufactured to:

- Standard Design
- Client Design
- Client/Manufacturer Joint Design

As for all products, due consideration is given to all issues around handling, installation and certification.
Steel sleepers for pipeline crossing
Post-<i>lay</i> Seabed Intervention
Where Rock Dumping by Specialised Rock-dumping Vessel is not possible (e.g. depth too shallow for vessel draft), Conventional Grab Dredger may be Used.
Rock Dumping by Specialised Fall Pipe Vessel (e.g. for pipeline/cable/structure stabilization, scour protection, seabed preparation, span correction, impact protection, etc.)
Where post-lay seabed intervention is required to correct unacceptable spans due to the undulating nature of the seabed, possible seabed intervention would include:

➢ Free span correction using grout bags
➢ Free span correction by rock dumping
➢ Jetting to correct spans by removing high spots

Typical Grout Bags for Span Corrections
Span Correction by Rock Dumping

(L) Side Stone Dumping Vessel; (R) Fall Pipe Stone Dumping Vessel
Span Correction by Removing High Spots

Mass Flow Excavators can be used to jet away high spots so that the pipeline settles down and excessive spans are rectified.

Typical Mass Flow Excavators
Typical Jetsled Deployed on Pipeline
Schematic Showing Typical Deployment of Jet Sled

- The lifting slings from the jet-sled are attached to the crane hook.
- The crane picks up the jet-sled from its saddle and lifts it over the side of the barge directly above the platform.

**PLAN VIEW**

- When the jet-sled is properly deployed over the pipeline, the self-activating jet nozzles are stowed away in the designated area on the top frame of the sled.
- Normal jetting mode can now commence.

**VIEW A-A (INITIAL)**

**VIEW A-A (FINAL)**
Schematic Showing Normal Jetting Mode During Post-Trenching Operation

- To commence jetting, divers activate the water jets, air jet, and air lifts.
- The air tugger tension, water jets, air jets, and air lifts are adjusted to obtain optimum excavating efficiency.
Jet-Sled used for post-lay trenching of pipeline

Closer View of Jetting Claw, Showing Nozzles and Eductors
Typical Post-trenching Plough

ROCKWATER F.A.S.T. PLOUGH
ELEVATION
View of 2nd Generation Plough in Action during Dry Run

View of Trench made by Plough
Typical Arrangement for Post-trenching using Plough (2nd Generation)
Pipeline burial by Post-trenching Plough

McDermott’s 2\textsuperscript{nd} Generation Plough – Successfully used on 2 projects in Malaysia (already scrapped)
- Requires vessel to pull plough
- Max. trench depth = 1.8m
- Suitable for sand and clay
New generation post-lay trenching machines (samples)

CTC Marine’s Rockplough2:
- Cable burial up to 3m depth
- Suitable for various soil types ranging from sand to soft – hard clay and fractured rocks.
- Fitted with echo sounders, sonar, cameras, u/w lamps & enhanced jetting system

CTC Marine’s Trencher T1:
- Burial of flexibles (e.g. umbilicals and cable)
- Can operate in jetting or wheel cutting mode
- Can simultaneously lay and trench flexible products
- Up to 1.2m trench depth (cutting mode) and 2m (jetting mode)
- Suitable for sands and soft – very hard clays
New generation trenchers (Cont’d)

CTC Marine’s Trencher T3:
- Burial of pipelines, umbilicals and cables
- Can operate in jetting or wheel cutting mode
- Can simultaneously lay and trench flexible products
- Up to 1.2m trench depth
- Suitable for sands and soft – very hard clays

CTC Marine’s Trencher T2:
- Burial of pipelines, umbilicals and cables
- Can operate in jetting or chain cutting mode
- Up to 1.6m trench depth
- Suitable for sands and soft – very hard clays
Correcting Spans which are too high or/and too deep

Where conventional methods (e.g. pre-trenching, rock dumping, grout bags, etc) is deemed not viable for span correction, unconventional means may be required.

Below is one example: Using External Clamps
When to choose pre-lay intervention and when to choose post-lay intervention?
Pre-lay intervention vs Post-lay Intervention

• Pre-lay intervention needs to be carried out if resulting spans during pipeline installation will result in pipeline overstress/yield or unacceptable vortex-induced vibration; otherwise, Contractor has option to intervene after pipeline installation

• Due to pipelaying tolerance (typically, +/- 10m), pre-lay intervention requires intervening a relatively large area (hence, costly)

• Advantage of post-lay intervention is that pipeline location is already identified, so Contractor only needs to intervene at specific points
Case Study –
Seabed Intervention at Escarpment
Challenges of laying pipeline through escarpment – Project Example

• On the Gendalo-Gehem pipeline project, the ascent to the shelf break contains channel, growth faults and steep ascent, with highly irregular seabed.

Shelf break & growth faults (Gendalo Pipelines)

Steep ascent to shelf break (Gehem Pipelines)
### Summary of Preferred Methodologies from Various Contractors

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>COMPANY</th>
<th>METHOD</th>
</tr>
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</table>
| Suggestion for Escarpment & superspan | Global Industries | • Activity at escarpment should be curtailed unless detailed soil investigation has carried out due to concern over slope failure.  
• If soil data not available, suggest to lay in 2 segments, one from FPU and other from shore, then both abandoned before the escarpment.  
• Spool (flexible or rigid) to connect both segments subsequently, thereby ensuring minimal intervention at escarpment.  
• If soil investigation shows that seabed features are stable, then cutting and profiling is the easiest and preferred solution, supplemented by span correction by prefabricated grout bags and mechanical supports. |
| SapuraCergny | | • Excavation by Mass Flow Excavator (MHE) at tip of escarpment to remove ‘protrusion’ this will reduce super span substantially  
• Dump rocks in between to correct excessive spans, **OR**  
• Change properties of pipe (increase grade, wall thickness, weight) to reduce span and increase allowable span  
• Increase allowable strain criteria for superspan  
• Reduce residual lay tension |
<p>| Saipem | | • Not studied. Insufficient soil information to provide assessment. |</p>
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<tr>
<td></td>
<td>McDermott</td>
<td>One or combination of following:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dredging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Backfilling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Steel frames</td>
</tr>
<tr>
<td></td>
<td>Nippon Steel</td>
<td>• Pre-dredging or post-trenching (jetting down)</td>
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<tr>
<td></td>
<td></td>
<td>• Consider strain-based displacement control design</td>
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<td></td>
<td>COOEC</td>
<td>• Trenching and post-jetting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Installation of grout bridge</td>
</tr>
<tr>
<td></td>
<td>Boskalis</td>
<td>• Trim the top of escarpment using TSHD and install pipe clamps to achieve allowable spans</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rock dumping can replace the pipe clamps if soil is stable</td>
</tr>
<tr>
<td></td>
<td>Tideway</td>
<td>• Trim off top of escarpment using TSHD and dump rocks to eliminate excessive spans</td>
</tr>
<tr>
<td></td>
<td>AGR</td>
<td>• AGR’s clay cutter X can cut clay up to 500kPa at rate between 20m³/hr to 600m³/hr and is suitable for cutting the escarpment to get a suitable profile which will reduce pipe stresses and spans.</td>
</tr>
<tr>
<td></td>
<td>Jan de Nul</td>
<td>• Trimming of the ‘top’ and rock dumping to correct remedial span</td>
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</tbody>
</table>
Eventual Recommended Solution for Escarpment (FEED costing purpose)

Based on assumption that the soil along escarpment is suitable for excavation, the most cost effective and proven method of span rectification (and pipeline stress mitigation) was deemed to comprise:

1) Excavation of ‘undesirable’ areas causing unacceptable pipeline stresses and resultant spans by TSHD or MFE before commencement of pipelaying.

2) Plus, post-lay span correction using either rock dumping (fall pipe vessel for accurate deposition of rocks) or grout bag supports (ROV installed) or other means preferred by EPCI contractor.
General Findings
(from Past Studies)
## Summary of Preferred Methodologies from Various Contractors

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<tbody>
<tr>
<td>Pre-lay Seabed</td>
<td>Global Industries</td>
<td>• Pre-trenching to cut and profile is preferred if soil is stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rock dumping is an option</td>
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<tr>
<td></td>
<td></td>
<td>• Support frame, concrete slab may be used for expected low height spans</td>
</tr>
<tr>
<td></td>
<td>SapuraAcergy</td>
<td>• CSD will be used within depth limitation to do pre-sweeping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For remainder – not investigated yet; will subcontract to dredging company</td>
</tr>
<tr>
<td></td>
<td>Saipem</td>
<td>• Depending on site conditions and could be one or more of:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mass flow excavation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Clay cutting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rock bedding</td>
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<tr>
<td></td>
<td></td>
<td>• Pre-sweeping by cutting pinnacles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Steel sleeper structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Concrete mattresses</td>
</tr>
<tr>
<td></td>
<td>McDermott</td>
<td>• Concrete mattresses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Steel frames</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dredging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Backfill</td>
</tr>
<tr>
<td></td>
<td>Nippon Steel</td>
<td>• Pre-sweeping for shallow water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pre-sweeping up to 155m, rock dumping above 155m</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>COMPANY</td>
<td>METHOD</td>
</tr>
<tr>
<td>-------------</td>
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</tr>
</tbody>
</table>
|             | COOEC   | • Primarily by dredging to smoothen seabed profile  
|             |         | • Soil replacement to improve foundation properties  
|             |         | • Clearing of obstacles along route  
| Boskalis    | • Typical method is by ‘trimming’ and backfilling, i.e. cutting off protruding sections and backfilling trenches  
|             |         | • Dredging can be by backhoe (up to 30m) or TSHD or dredging bucket  
|             |         | • Backfilling using side stone dumping vessel, fall pipe vessel or by buckets  
| Tideway     | • Suggests trimming and backfilling, i.e. cutting off protruding sections and backfilling trenches  
|             |         | • For depth up to 30m, use cutter suction dredger  
|             |         | • From 30m to 100m, use TSHD if soil is soft  
|             |         | • Rock dumping using fall pipe vessel can be carried out to 1000m  
| AGR         | • AGR’s clay cutter X can cut clay up to 500kPa at rate between 20m³/hr to 600m³/hr and is suitable for pre-trenching works  
| Jan de Nul  | • For depth up to 32m, cutter suction dredger and backhoe dredger are suitable  
|             |         | • TSHD can be used for soft to 3-4 MPa soil from 5m to 160m  
|             |         | • Rock dumping using fall pipe vessel can be carried out to 2000m  
|             |         | • Fall pipe dredger with grab excavation system can be used to dredge in water depth up to 2000m  

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>COMPANY</th>
<th>METHOD</th>
</tr>
</thead>
</table>
| Post-lay Seabed  | Global Industries | • Span corrections using grout bags  
|                  |              | • For deepwater, suggested sand/cement bags, pre-fabricated grout bags and mechanical supports  
|                  |              | • Post-lay jetting  
|                  |              | • For deepwater, post-lay jetting by ROV for small seabed humps  
| SapuraAcery      |              | • Span corrections using grout bags and mattresses  
|                  |              | • Pre-sweep using water jetting or mass flow excavator  
|                  |              | • Rock dumping (if required)  
| Saipem           |              | • Span rectification by standard fabric grout support  
|                  |              | • Rock dumping  
|                  |              | • Mechanical supports  
| McDermott        |              | • ROV operated grout bags  
|                  |              | • Flexible concrete mattresses  
|                  |              | • Steel frames with adjustable heights  
|                  |              | • Rock dumping  

## Summary of Preferred Methodologies from Various Contractors (Cont’d)

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
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<th>METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nippon Steel</td>
<td>• Grout bags, sand bags, mechanical supports, post-trenching, depending on circumstances and soil conditions</td>
<td></td>
</tr>
</tbody>
</table>
| COOEC | • Use mass flow excavator to remove high spots  
• Rock dumping |
| Boskalis | • Backfilling by side stone dumping vessel (up to 30m), fall pipe vessel or by buckets  
• For shallow water, side stone dumping is efficient  
• Fall pipe dumping is good for both shallow and deep water and is used for accurate placement of rock |
| Tideway | • Rock dumping using fall pipe vessel can be carried out to 1000m |
| AGR | • AGR’s mass flow excavator, SeaVator, is suitable for removing high spots, which subsequently reduces pipe spans |
## Support Type Span Correction Methods (mostly post-lay)

<table>
<thead>
<tr>
<th>Type</th>
<th>Limits</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Diverless installation feasible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grout bags</td>
<td>3 m height</td>
<td>Tolerant to uneven seabed</td>
<td>Intolerant to scour</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low risk to pipeline – no heavy lift</td>
<td>Unsuitable for steep slopes</td>
<td></td>
</tr>
<tr>
<td>Flexible formwork – grout filled</td>
<td></td>
<td>Tolerant to uneven seabed</td>
<td>Intolerant to scour</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low risk to pipeline – no heavy lift</td>
<td>Unsuitable for steep slopes</td>
<td></td>
</tr>
<tr>
<td>Sand bags</td>
<td>2 – 3 m height</td>
<td>Do not need specialised equipment or vessel</td>
<td>Require competent seabed soil</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unsuitable for steep slopes</td>
<td></td>
</tr>
<tr>
<td>Concrete flexible mattresses</td>
<td>2m height</td>
<td>Suitable if few spans are anticipated</td>
<td>Becomes very expensive if there are a lot of spans to correct</td>
<td>Y</td>
</tr>
<tr>
<td>Steel structures</td>
<td>5m or so</td>
<td>Suitable for steep slopes</td>
<td>Engineered solution required for each span</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Positive experience West Seno</td>
<td>May induce slope failure</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Sensitive to lateral hydrodynamic loads</td>
<td></td>
</tr>
<tr>
<td>Spot rock berm</td>
<td></td>
<td>Tolerant to uneven seabed and scour</td>
<td>Requires mobilisation of specialised vessels</td>
<td>Y</td>
</tr>
<tr>
<td>Buoy &amp; tether</td>
<td></td>
<td>May maintain pipeline above height of mass flows</td>
<td>Dynamic, requires fatigue analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sensitive to submerged weight</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Unproven</td>
<td></td>
</tr>
<tr>
<td>Buoy &amp; drag chain</td>
<td></td>
<td>May maintain pipeline above height of mass flows</td>
<td>Dynamic, requires fatigue analysis</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Unproven</td>
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# Pre-lay Span Correction methods

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<td></td>
<td></td>
<td>Low risk to pipeline –no heavy lift</td>
<td>Unsuitable for steep slopes</td>
<td></td>
</tr>
<tr>
<td>Sand bags</td>
<td></td>
<td></td>
<td>Require competent seabed soil</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unsuitable for steep slopes</td>
<td></td>
</tr>
<tr>
<td>Spot rock berm</td>
<td></td>
<td>Tolerant to uneven seabed and scour</td>
<td>Requires mobilisation of specialised vessel</td>
<td>Y</td>
</tr>
<tr>
<td>Strakes</td>
<td>Suitable when VIV is limiting</td>
<td></td>
<td>Increase drag load</td>
<td>Y</td>
</tr>
<tr>
<td>Massflow excavation</td>
<td>Non-cohesive soil</td>
<td>No structures to maintain</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Dredging- CSD</td>
<td>20m</td>
<td>Efficient, effective</td>
<td>Requires mobilisation of specialised vessel</td>
<td>Y</td>
</tr>
<tr>
<td>Dredging- THSD</td>
<td>20m</td>
<td>Efficient, effective</td>
<td>Requires mobilisation of specialised vessel</td>
<td>Y</td>
</tr>
<tr>
<td>Dredging- backhoe</td>
<td>20m</td>
<td>Efficient, effective</td>
<td>Requires mobilisation of specialised vessel</td>
<td>Y</td>
</tr>
</tbody>
</table>
## Seabed Modification Type Span Correction Methods

<table>
<thead>
<tr>
<th>Type</th>
<th>Limits</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Pre-lay</th>
<th>Post-lay</th>
<th>Diver-less</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot rock berm</td>
<td>Tolerant to uneven seabed and scour</td>
<td>Requires mobilisation of specialised vessels</td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trenching-ploughing</td>
<td>Soil strength</td>
<td>No structures to maintain</td>
<td>Not suitable for large span gaps</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Trenching-jetting</td>
<td>Soil strength/type</td>
<td>No structures to maintain</td>
<td>Not suitable for large span gaps</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Trenching-cutting</td>
<td>Soil strength/type</td>
<td>No structures to maintain</td>
<td>Not suitable for large span gaps</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Massflow excavation</td>
<td>Non-cohesive soil</td>
<td>No structures to maintain</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Jet AGR type</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Massflow excavation</td>
<td>Non-cohesive soil</td>
<td>No structures to maintain</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Dredging- CSD</td>
<td>Cemented soil, rock, calcarenite 1-30 MPa</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Dredging- THSD</td>
<td>Unconsolidated sediments</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dredging- backhoe</td>
<td>Unconsolidated sediments</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Modification of Pipe Behaviour Span Correction methods

<table>
<thead>
<tr>
<th>Type</th>
<th>Limits</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Diverless installation feasible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strakes</td>
<td>Suitable when VIV is limiting</td>
<td></td>
<td>Increase drag load</td>
<td>Y</td>
</tr>
<tr>
<td>Plastic formation</td>
<td></td>
<td></td>
<td>Pipeline in plastic mode after span correction – used only as last resort</td>
<td></td>
</tr>
</tbody>
</table>
# Summary Of Methodologies For Seabed Intervention (for span correction)

<table>
<thead>
<tr>
<th>No.</th>
<th>Method</th>
<th>Application</th>
<th>Practical Span Height Limitation</th>
<th>Depth Limitation</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Backhoe dredger</td>
<td>Pre-lay</td>
<td>20m</td>
<td>32m</td>
<td>Soft to 10MPa</td>
</tr>
<tr>
<td>2</td>
<td>Cutter suction dredger</td>
<td>Pre-lay</td>
<td>20m</td>
<td>30m</td>
<td>Soft to 10MPa</td>
</tr>
<tr>
<td>3</td>
<td>Grab dredger</td>
<td>Pre-lay</td>
<td>10m</td>
<td>2000m</td>
<td>Soft to 500 KPa</td>
</tr>
<tr>
<td>4</td>
<td>TSHD</td>
<td>Pre-lay</td>
<td>50m</td>
<td>250m</td>
<td>Soft to 3MPa</td>
</tr>
<tr>
<td>5</td>
<td>MFE</td>
<td>Pre- and post-lay</td>
<td>50m</td>
<td>850m</td>
<td>Soft to 500 KPa</td>
</tr>
<tr>
<td>6</td>
<td>Rock dumping vessel (side stone dumping)</td>
<td>Pre-lay</td>
<td>5m</td>
<td>35m</td>
<td>All</td>
</tr>
<tr>
<td>7</td>
<td>Rock dumping vessel (fall pipe)</td>
<td>Pre- and post-lay</td>
<td>5m</td>
<td>2000m</td>
<td>All</td>
</tr>
<tr>
<td>8</td>
<td>Fall pipe vessel with grab excavation system</td>
<td>Pre-lay</td>
<td>5m</td>
<td>2000m</td>
<td>Soft to 500 KPa</td>
</tr>
<tr>
<td>9</td>
<td>Steel support structures</td>
<td>Post-lay</td>
<td>20m</td>
<td>2000m</td>
<td>All</td>
</tr>
<tr>
<td>10</td>
<td>Insertion of flexible spool</td>
<td>Post-lay</td>
<td>N.A.</td>
<td>2000m</td>
<td>All</td>
</tr>
<tr>
<td>11</td>
<td>Insertion of rigid spool</td>
<td>Post-lay</td>
<td>N.A.</td>
<td>2000m</td>
<td>All</td>
</tr>
</tbody>
</table>
Potential Methodologies For Seabed Intervention at varying Water Depths & Span Heights

SPAN ABOVE 10m NOT EXPECTED EXCEPT AT ESCARPMENT IF HIGH LAY TENSION IS USED

Depth Range

- 0m - 2.5m
  - Grout bags (Post-Lay)
  - Rock dumping (Post or Pre-Lay)
  - Backhoe dredger, etc.
  - Pre-sweeping by TSHD, cutter suction dredger,
  - Mass flow excavator (Post or Pre-Lay)

- 2.5m - 5m
  - Pre-sweeping by TSHD or mass flow excavator
  - Post-Lay rectification by mass flow excavator

- 5m - 7.5m
  - Post-Lay structural support

- 7.5m - 10m
  - Post-Lay structural support

- 10m - 20m
  - Post-Lay structural support

- > 20m
  - Post-Lay structural support

Depth Range

- 13m - 100m
- 100m - 250m
- > 250m
Innovative Solution to avoid seabed intervention –
Use of Spoilers
(subject to seabed condition)
Introduction

- A non-conventional method of pipeline burial is by implementation of spoilers on the pipeline.

- Where conventional method is not practical or cost effective, e.g. where pipeline is subject to scouring, a self-burial device known as “Spoilers” could be used. This could effectively ensure that the pipeline will self-bury after becoming exposed due to scouring.
Spoiler Mechanics

The effect of spoiler is based on scouring and fluid mechanical process. The spoiler, which is fitted on the top of pipeline, changes flow pattern around the pipeline compared with a plain pipeline, as shown in Figure 1.

![Flow pattern comparison](image)

<table>
<thead>
<tr>
<th>Plain Pipeline</th>
<th>Pipeline with Spoiler</th>
</tr>
</thead>
</table>

Figure 1 – Flow pattern of plain pipeline and spoiler-fitted pipeline
The spoiler causes an increased flow velocity underneath the pipeline. This results in tunnel erosion taking place at lower ambient velocities than with a plain pipe and more aggressively not only in the vertical direction but also along the pipeline length.

The spoiler brings about significant changes in the flow pattern and results in:

- Smaller upward lift forces when the pipeline is in contact with the seabed;
- Increased downward (negative) lift forces when the pipeline lifts off from the seabed;
- Increased hydrodynamic drag and inertia coefficients;
- Suppressed vortex shedding;
- Increased stability of the hydrodynamic process - less scatter in drag and lift coefficients.
The following schematic illustrates the phases and manner in which a spoiler-fitted pipeline achieves self-burial.

<table>
<thead>
<tr>
<th>Phase Description</th>
<th>Schematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch down</td>
<td>![touch down]</td>
</tr>
<tr>
<td>First tunnel erosion, pipe is sagging</td>
<td>![first tunnel erosion]</td>
</tr>
<tr>
<td>Partial Burial</td>
<td>![partial burial]</td>
</tr>
<tr>
<td>Start leeside erosion</td>
<td>![leeside erosion]</td>
</tr>
<tr>
<td>Pipe on ridge</td>
<td>![pipe on ridge]</td>
</tr>
<tr>
<td>Second tunnel erosion, pipe is sagging</td>
<td>![second tunnel erosion]</td>
</tr>
<tr>
<td>Second partial burial</td>
<td>![second partial burial]</td>
</tr>
<tr>
<td>Natural backfilling to original seabed</td>
<td>![natural backfilling]</td>
</tr>
</tbody>
</table>

Figure 2: Self-burial illustration
Spoiler Mechanics

First Stage – Touch Down

Second Stage – Tunneling

Final Stage - Burial

Figure 3: Self-burial Stages
**Spoiler Mechanics**

- Optimal performance of spoiler for pipeline self-burial is best achieved under certain environmental conditions as shown in Table 1 below.
- Based on the results of tests conducted by SPS at Delft Hydraulics Institute in Holland, sufficient tidal current velocity as well as a highly erodible seabed condition should be available to invoke the tunneling erosion effect, which is the mechanism of the self-burial process of pipeline.

<table>
<thead>
<tr>
<th>Table 1 – Environmental Conditions for Optimal Spoiler Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seabed Material (Top Layer)</strong></td>
</tr>
<tr>
<td>Sand + Maximum of 10 % Silt</td>
</tr>
<tr>
<td><strong>Current</strong></td>
</tr>
</tbody>
</table>
Spoiler installation at stern of laybarge during pipelaying

Spoilers are strapped on pipeline at stern of laybarge, just before entrance to stinger
Photo from site (shore approach to landfall)

View of pipeline at shore approach during low tide. Note that minor rotation had occurred during pulling operation, partially due to flooding and receding tides.

Note scour on both sides of pipeline due to spoiler effects.
Evidence of spoiler effect on another project

- On a onshore to offshore pipe pull at Dahej (India) across an inter-tidal zone, the spoiler effect was seen when pipe pull was stopped when the tide receded.
- The buoyancy tanks acted like ‘spoilers’, causing soil of both sides of the pipeline to scour.
- The soil was very fine and highly liquefiable.
- Current was very strong and changes direction four times a day (2 tides a day)
Risks and Challenges of Utilising Spoilers

• The main risk associated with utilizing the spoiler is the effect of additional hydrodynamic forces caused by the presence of the spoilers if self-burial did not occur immediately upon touchdown.

• Ideally, a contingency plan should be in place of the “worst case” scenario, i.e. spoiler fails to initiate self-burial fast enough. A feasible contingency plan is to have a jetting spread on standby. The jetting equipment should be modified such that the spoiler fin will not be damaged during jetting.
Field Verification of Spoiler Performances

• For Hangzhou Bay project, subsea survey was carried out regularly during pipelaying to determine the burial condition of the pipeline.

• Generally, it was found that the pipeline underwent burial almost upon touchdown and the tunneling effect continued until almost all the pipeline was below the natural seabed.

• In areas where there were greater concentrations of fine particles, the burial rate proceeded at a slower rate and portions of the pipeline continued the tunneling at a slower rate until the top of pipeline was below the natural seabed.

• As-built survey of the pipelines showed that prior to hydrotesting, the entire pipeline route achieved at least 50% burial and considerable portions achieved complete burial to over one meter of cover.
Conclusions (on use of Spoilers)

• The spoiler is particularly suited for areas which experience strong bi-directional currents and have erodable seabed.

• The spoiler is also suitable in areas where dynamic movement of seabed profile is experienced, e.g. Hangzhou Bay. When the pipeline is exposed to the environment due to scouring, the spoiler is expected to re-initiate burial.

• Based on the successful use of spoilers in the Hangzhou Bay Pipeline Crossing project, as well as other applications in the North Sea, it is envisaged that the spoiler would find many more uses for similar projects under similar conditions worldwide.
For more details on seabed intervention, refer to my new book: “Subsea Rigid Pipelines – Methods of Installation”
QUESTIONS ????