EMAS AMC (Singapore)

Engineering ‘Lunch & Learn’ Series

“Free Span Rectification Methodology – Project Example (Gendalo Gehem Export Pipelines)”

18th June 2013

WIN – EXECUTE – SAFE DELIVERY

Together We Deliver

AMC Energy Marine Production

Content of talk

- Brief introduction on ‘allowable span’ and how it is derived
- Brief explanation of ‘bottom roughness analysis’ and its purpose
- Brief introduction on various methods for span correction
- Use of project example to illustrate how span correction methodology is chosen
- Finally, based on chosen project, show how much seabed intervention is expected to cost

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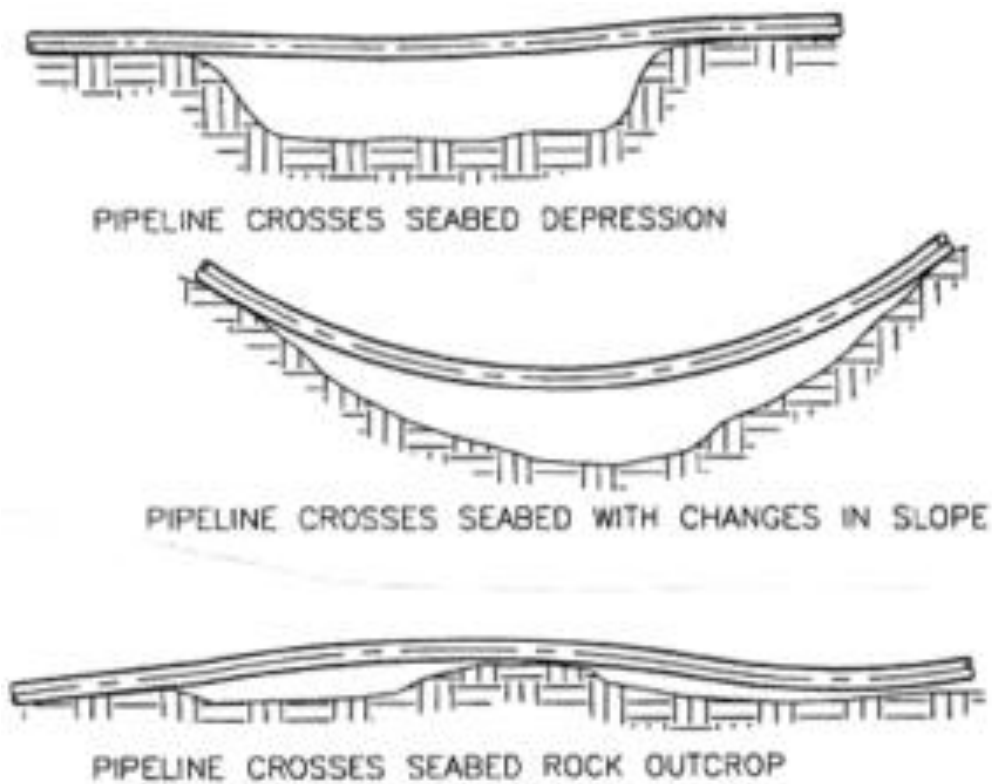
Free Span Analysis (Traditional – DNV 1981)

What is meant by: pipeline allowable span?

Allowable span = maximum length of pipeline that can be allowed to stay on seabed unsupported.



Introduction

- The pipeline span analysis is performed to determine allowable pipeline free spans in installation, hydrotest and operation conditions.
- The allowable pipeline span is established from static load and dynamic (vortex shedding) considerations.
- Static span design criteria are based on the allowable bending stress for the pipeline. The static span calculations take into account the pipeline weight, design pressure, design temperature and additional forces due to current and significant waves associated with the relevant return period. The hydrodynamic loading is computed based on the design water depth.
- The vortex shedding calculations are based on the design currents and significant waves associated with the relevant return period.

Static Span

- The maximum allowable span length based on static stress considerations are dependent on self-weight of the pipe and coatings and the uniformly distributed load from the environment.
- The allowable static span length for a pipeline is calculated by limiting the equivalent stress in the span to σ_{ab} where σ_{ab} is the allowable bending stress based on the Von Mises equation after deducting the axial stress.

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Static Span (Cont'd)

- The allowable bending stress is computed based on a fully restrained pipeline, which gives the most critical span requirement.
- The allowable bending stress due to span effect is determined by using the Von Mises equation. The allowable bending stress is computed by setting the allowable equivalent stresses and deducting the stress due to internal pressure, curvature and temperature effect.
- The pipe stresses must not exceed the allowable combined stresses in all conditions. These allowable stresses are used in the static span calculation to determine the allowable span length with self-weight and 1 year and 100 year environmental loading.

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Static Span (Cont'd)

- Allowable combined stresses are presented below:

TABLE 4.2 – ALLOWABLE STRESS CRITERIA (DNV 1981)	
Description	**Allowable Combined Stress (%SMYS)**
Installation	72
Hydrotest	90
Operation	90

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Dynamic Span

- The dynamic span is calculated by considering the vortex induced vibration (VIV) from the flow velocity acting on the pipeline.
- The excitation due to vortex shedding is analysed in accordance with Appendix A of 1981 DNV “Rules of Submarine Pipeline System” . In this guideline, the pipeline is designed for no vortex shedding vibration.
- Under the guidelines of DNV 81, to avoid the occurrence of vortex shedding excitation, the maximum permissible free-span length will be determined based on a comparison of the frequency of vortex shedding and the natural frequency of the pipe span.

Types of Oscillations

Two types of oscillations may occur:

- oscillations in-line with the velocity vector (in-line motion), and
- oscillations perpendicular to the velocity vector (cross-flow motion).

Free Span Analysis – using latest DNV Code

- Latest DNV Code, DNV RP-F105, provides preliminary fatigue screening of observed submarine pipeline span and calculates the allowable spans due to Vortex Induced Vibration (VIV), Fatigue, and Ultimate Limit State (ULS).
- Supposedly, it is intended to allow “maximization” of allowable span so that span corrections can be minimised.
- The maximum free span lengths are determined based on the following criteria:
  - Inline Fatigue Screening criterion
  - Cross Flow Fatigue Screening criterion
  - Inline ULS criterion
  - Cross Flow ULS criterion
- Based on my personal (but limited) experience with this latest code, instead of getting ‘longer’ allowable spans, we obtain less – what an irony!
- The latest code is complicated, difficult to use, and in my opinion, disappointing *(but I am an old dog & have difficulty learning new tricks).*

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Outcome of Free Span Analysis (whether by old fashion method or new)

Based on the free span analyses, the maximum allowable span for following conditions will be obtained:

1. Pipeline on seabed (empty & unpressurised)
2. Pipeline on seabed (flooded & unpressurised)
3. Pipeline on seabed (flooded & hydrotested)
4. Pipeline on seabed (in operation & uncorroded)
5. Pipeline on seabed (in operation & corroded)

Based on the above data & outcome of on-bottom roughness analysis, the installation contractor can determine the strategy for span correction, i.e. to perform pre-lay intervention or post-lay intervention or combination

On-bottom roughness analysis is an analysis whereby the seabed profile is simulated and the pipeline is laid on this simulated seabed to predict number of spans and locations of these spans

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Bottom Roughness Analysis

General

- Bottom Roughness analysis is performed to assess the requirements for seabed preparation and span correction.
- The study is accomplished by performing following tasks:
  - Review of seabed profile using the pipeline alignment drawings and identify the segments of the pipeline route that require detailed investigations;
  - Perform bottom roughness using specialist software, such as OFFPIPE, and determine locations of significant free spans and number of free spans that require span correction;
  - Determine areas that may require pre-lay correction;
  - Determine areas that may require post-lay correction;
  - Review alternative methods of remedial corrections, and propose remedial actions that are cost effective.

Bottom Roughness Analysis

- Specialist finite element or finite difference software is normally used for this analysis.
- The bottom roughness analysis is performed for empty, hydrotest and operational conditions.
- The computer model for the bottom roughness analysis incorporates following information:
  - Properties of the pipeline, including weight of concrete weight coating and content.
  - Seabed profile is simulated using x-y co-ordinates along the pipeline route under investigation.
  - Surface soil is simulated in the analysis to determine level of settlement for different design conditions, i.e. empty and flooded with seawater.

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Bottom Roughness Analysis (Cont'd)

- Hydrotest pressure is included for the pipe in hydrotest condition for bottom roughness analysis to determine if the pipe stresses and predicated spans are within design allowable. This determines if the pipeline can be hydrostatically tested before span correction.
- For analysis in operation condition, design pressure and temperature, as well as reduction in wall thickness due to corrosion, are included in the analysis.

- The predicted free spans are then compared with recommended allowable free spans for each design condition.
- Also stresses in the pipeline are checked to ensure they are within the design allowable for all design conditions.

Interpretations of Findings

- As the input for seabed profile co-ordinates are of certain intervals, span can be predicted to an accuracy of plus or minus the spacing of the pipe nodes. The number of the spans reported in the above is therefore subjected to that accuracy.
- The estimated number of spans reduces when the pipeline is flooded. This is due to increase in weight which results in (1) further settlement/collapse of soil due to increased external load and (2) increase in pipe sag which will reduces pipe span.
- After hydrotesting and dewatering of the pipeline, the collapsed soil will remain in the collapsed state. However, as the pipeline is now lighter, the pipe span will increase. The actual span length cannot be predicted but would be somewhere between that for an empty condition and for a flooded condition.

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Interpretations of Findings (Cont'd)

- If the span corrections is carried out only after pipeline has been hydrotested and dewatered, then the expected number of span correction corresponding to operation condition can be expected to be less, but this is also depend on the soil condition.
- Estimation of spans is based on the assumption that the pipeline is laid exactly on the route. However, as pipe cannot be laid exactly on the planned route, and seabed varies due to route deviation, the number of spans and span length predicted are merely indicative. Actual post-lay survey is required to determine the actual span lengths and numbers of spans requiring correction.

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OVERVIEW OF EXISTING SPAN RECTIFICATION METHODS

Span Rectification Methods

Free span correction methods may be categorised into those suitable for pre-lay intervention and those which are installed after the pipeline is in place.

The factors which are considered when he selecting the preferred correction method are:

- Long term integrity of the pipeline
- Safety during construction
- Environmental impact
- Capital cost
- Operational IMR costs

Span Rectification Methods (Cont'd)

The span correction design considers:

- Whether the pipeline is hydrodynamically stable
- Geotechnical conditions
- Potential for scour
- Potential for hooking and snagging

Span correction 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.

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Support Type Span Correction Methods (mostly post-lay)

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

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Pre-lay Span Correction methods

Type	Limits	Advantages	Disadvantages	Diverless installation feasible
Grout bags	3 m height	Tolerant to uneven seabed Low risk to pipeline –no heavy lift	Intolerant to scour Unsuitable for steep slopes	y
Sand bags			Require competent seabed soil Unsuitable for steep slopes	N
Spot rock berm		Tolerant to uneven seabed and scour	Requires mobilisation of specialised vessel	Y
Strakes	Suitable when VIV is limiting		Increase drag load	Y
Massflow excavation	Non-cohesive soil	No structures to maintain		Y
Dredging- CSD	20m	Efficient, effective	Requires mobilisation of specialised vessel	Y
Dredging- THSD	20m	Efficient, effective	Requires mobilisation of specialised vessel	Y
Dredging- backhoe	20m	Efficient, effective	Requires mobilisation of specialised vessel	Y

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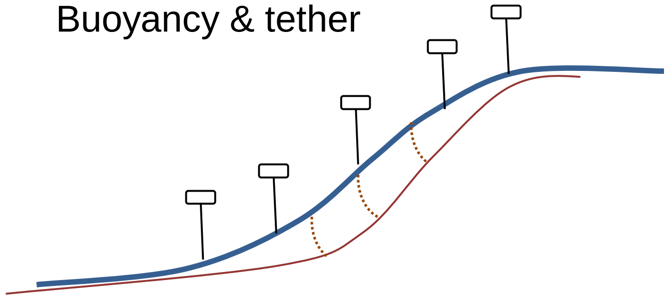
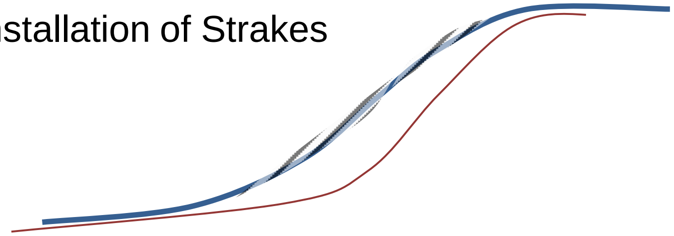
Unorthodox method illustrated

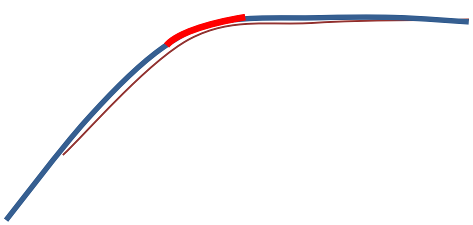
Buoyancy & tether



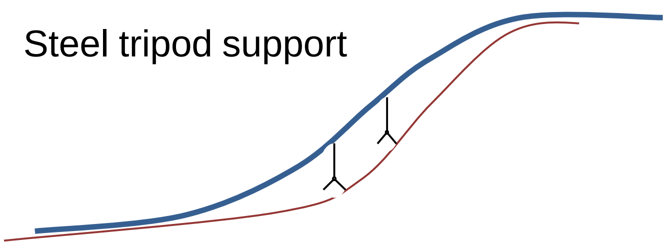
Installation of Strakes



Controlled deformation



Steel tripod support



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Seabed Modification Type Span Correction Methods

Type	Limits	Advantages	Disadvantages	Suitability		
				Pre-lay	Post-lay	Diver-less
Spot rock berm		Tolerant to uneven seabed and scour	Requires mobilisation of specialised vessels			Y
Trenching- ploughing	Soil strength	No structures to maintain	Not suitable for large span gaps		Y	Y
Trenching- jetting	Soil strength/type	No structures to maintain	Not suitable for large span gaps		Y	Y
Trenching- cutting	Soil strength/type	No structures to maintain	Not suitable for large span gaps		Y	Y
Massflow excavation	Non-cohesive soil	No structures to maintain		Y	Y	Y
Jet AGR type				Y		Y
Massflow excavation	Non-cohesive soil	No structures to maintain		Y	Y	Y
Dredging- CSD	Cemented soil, rock, calcarenite 1-30 MPa			Y		Y
Dredging- THSD	Unconsolidated sediments			Y		
Dredging- backhoe	Unconsolidated sediments			Y		

Modification of Pipe Behaviour Span Correction methods

Type	Limits	Advantages	Disadvantages	Diverless installation feasible
Strakes	Suitable when VIV is limiting		Increase drag load	Y
Plastic formation			Pipeline in plastic mode after span correction – used only as last resort	

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Free Span Correction – Project Example

Project Example as Basis for Talk

- Results of study for an existing project - Gendalo Gehem (GG) Export Pipelines - are used for this session
- The GG project is the deepest deep-water project in Indonesia (1,800m)
- The export pipelines comprise:
  - 20” Gendalo Gas Export Pipeline x 148 km;
  - 16” Gehem Gas Export Pipeline x 82 km;
  - 8” Gendalo Condensate Export Pipeline x 148 km; and
  - 8” Gehem Condensate Export pipeline x 82 km.
- This study was carried out during FEED
- It is in the process of being awarded
- Hundreds of spans are expected, and hence, seabed intervention as well as other interventions are expected to correct all unacceptable spans
- Based on the problems encountered along the GG export pipelines, almost all the ‘tricks’ available for span corrections were investigated

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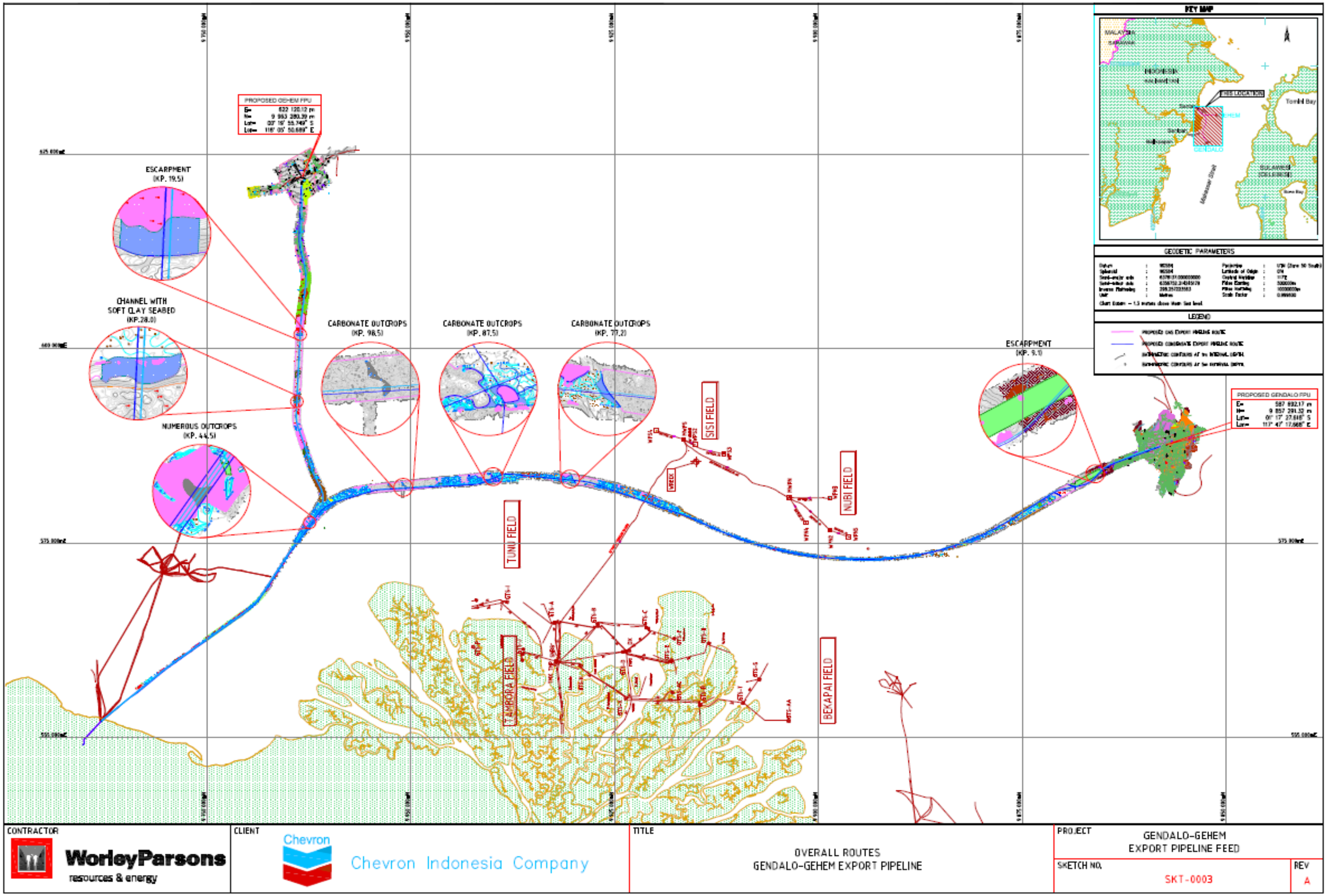
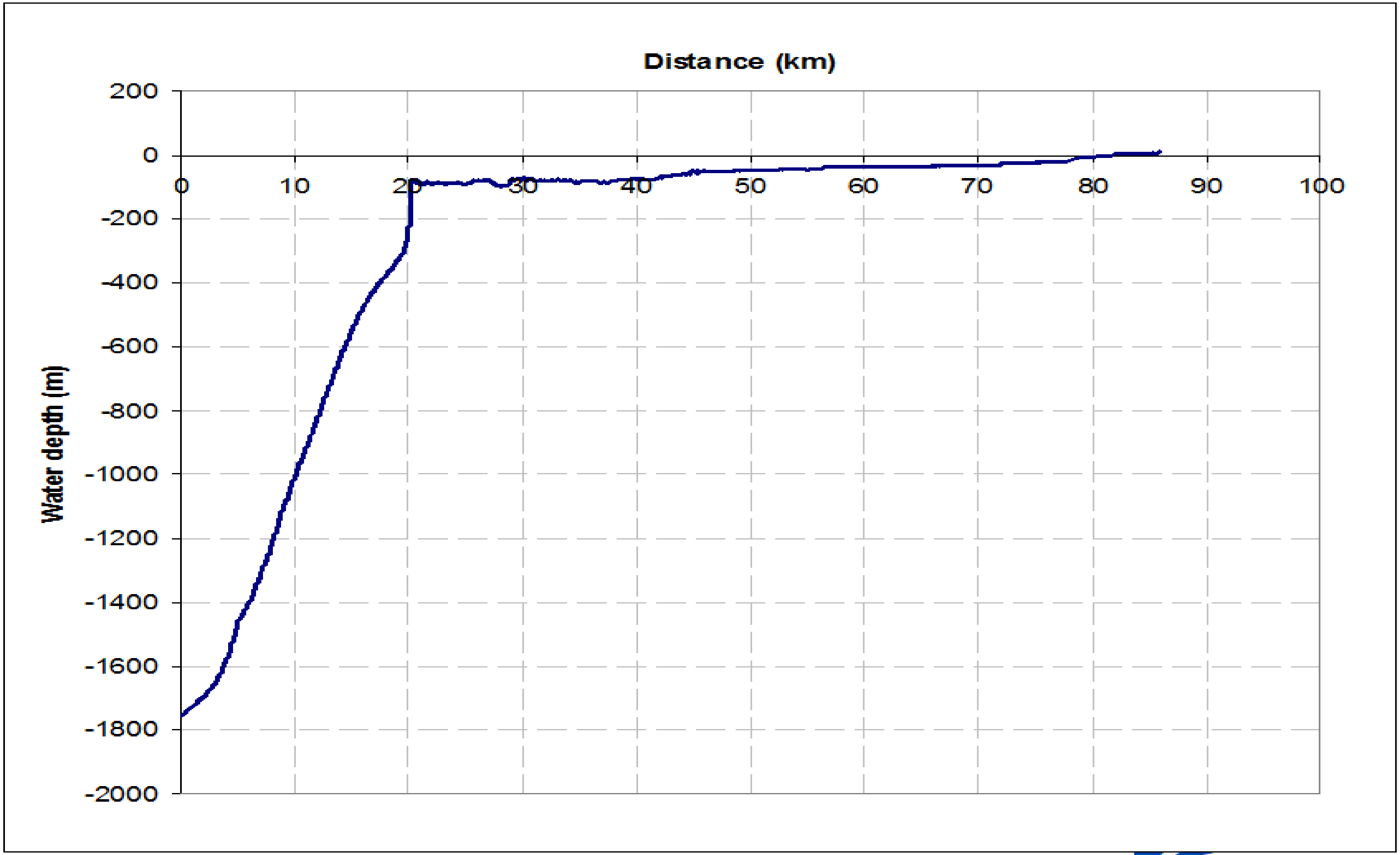
Overall Route Layout



Seabed Profile along Gehem Pipelines' Routes



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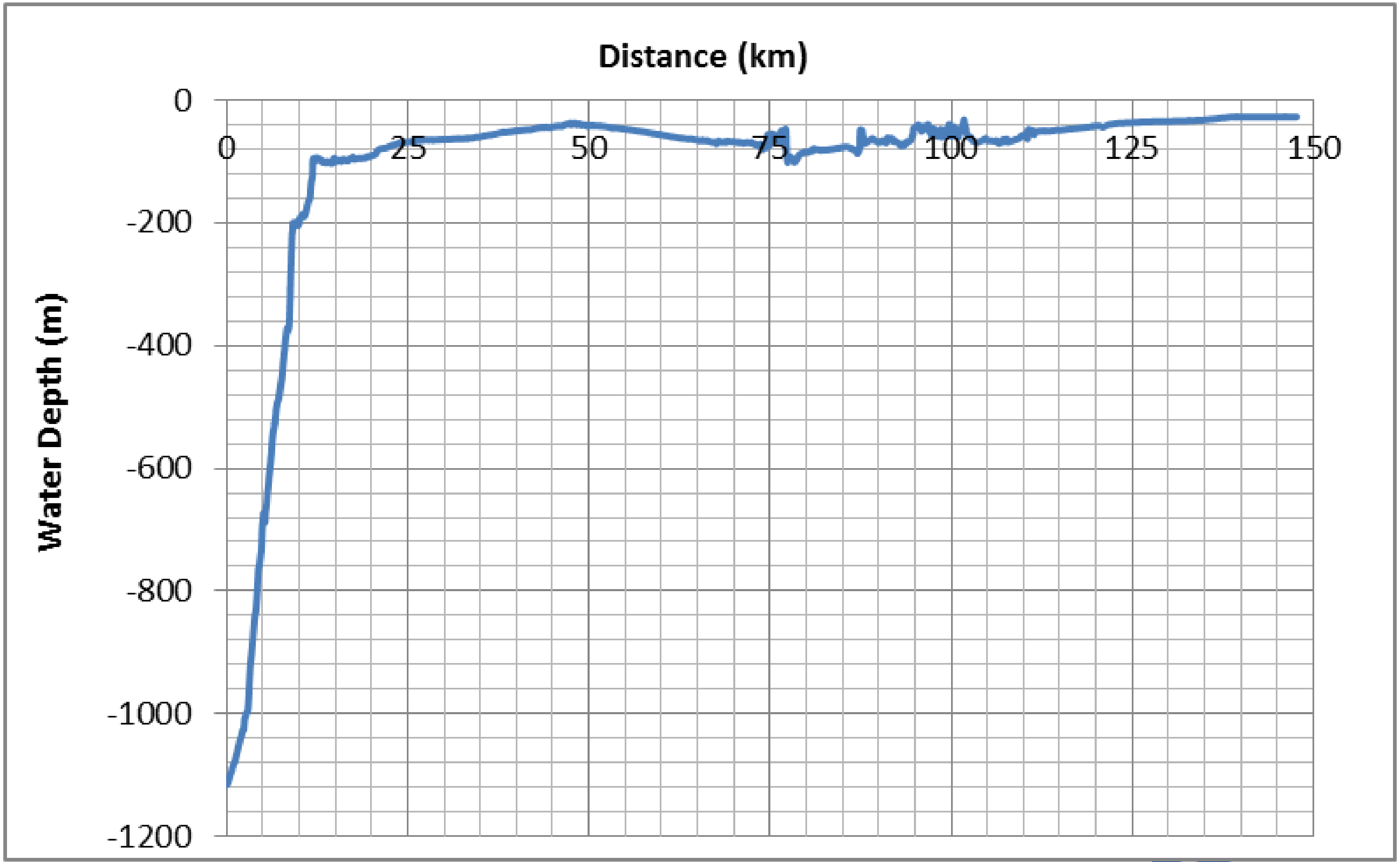
Seabed Profile along Gendalo Pipelines' Routes



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Challenges along pipeline routes

The route corridors contain several geological and bathymetric features which present considerable challenges for pipeline installation, resulting in unavoidable spans. These include:

- Reef and carbonate complexes
- Growth faults
- Steep terrain at shelf break
- Irregular reef / carbonate surface & pockmarks
- Pinnacles
- Landslide complexes
- Channels
- Gullies

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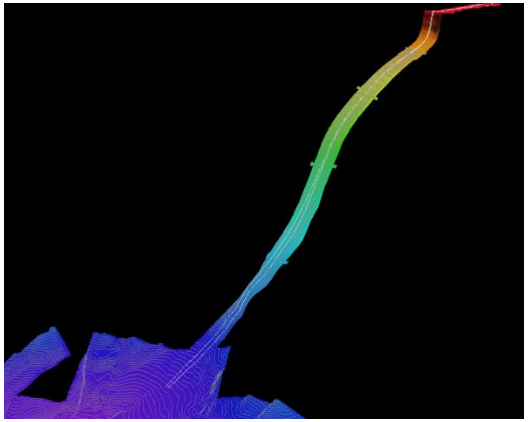
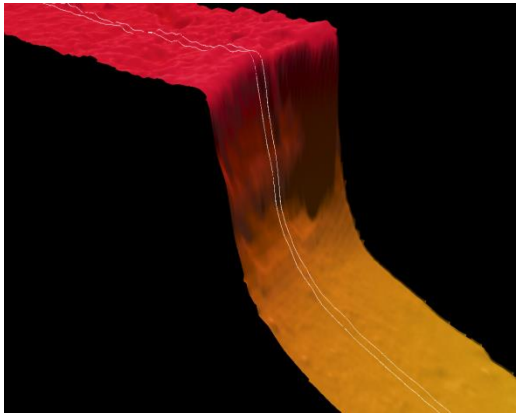
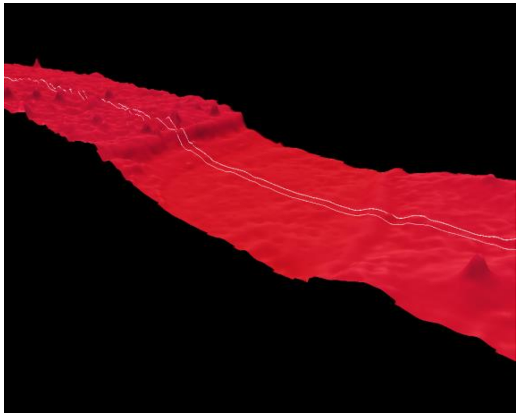
Sample Seabed Features Along Gehem Route

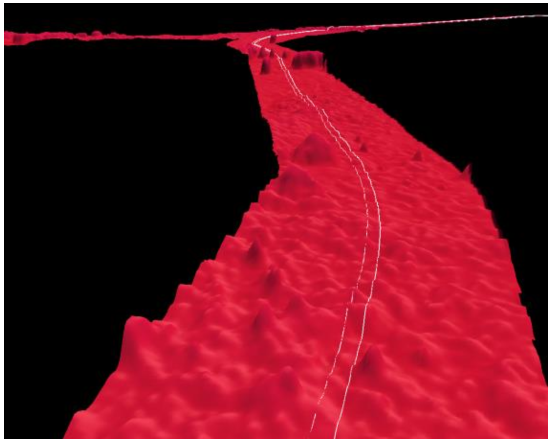


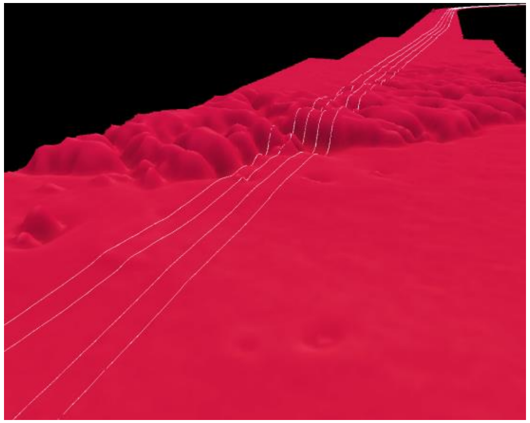




At Vicinity of Gehem FPU

Kp 28

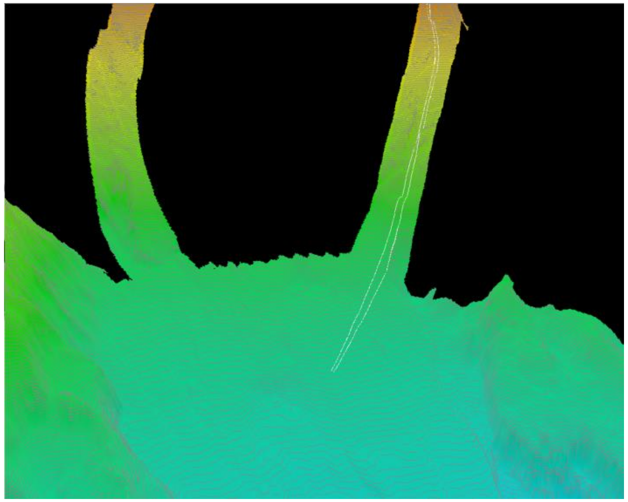




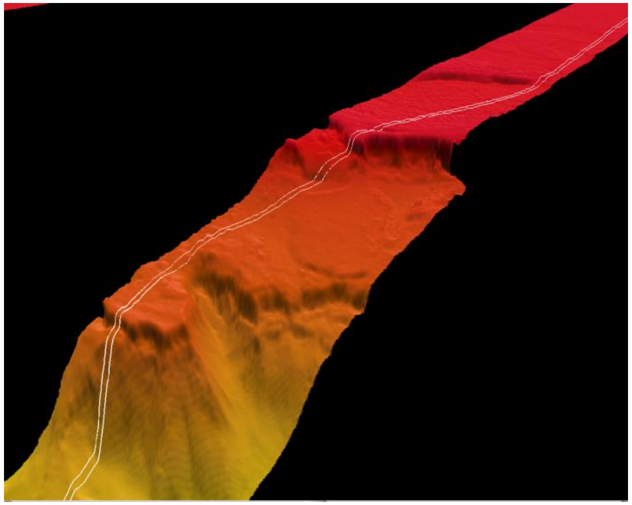
Kp 32.5

Kp 44.5

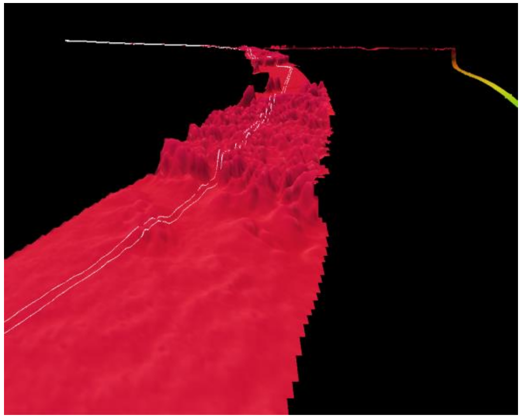
Sample Seabed Features Along Gendalo Route



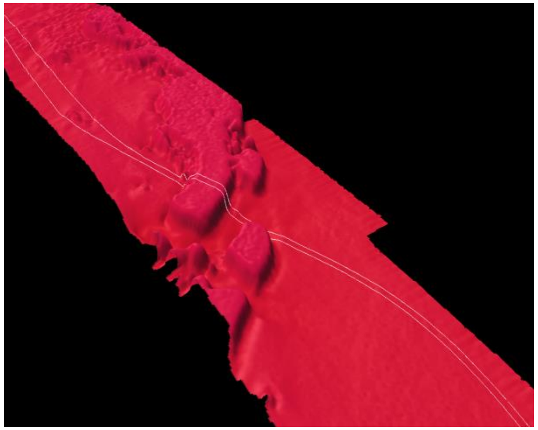
At FPU



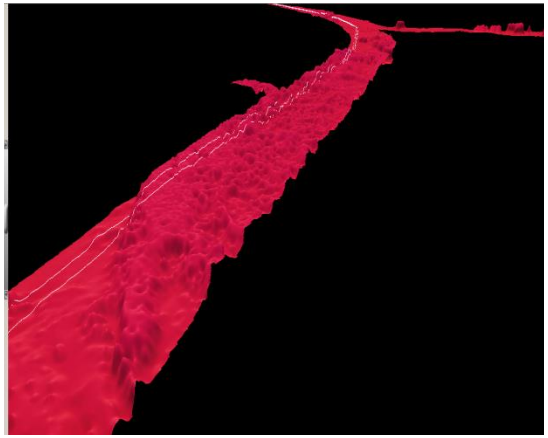
Kp 9.1



Kp 77.2



Kp 87.5



Kp 98.5

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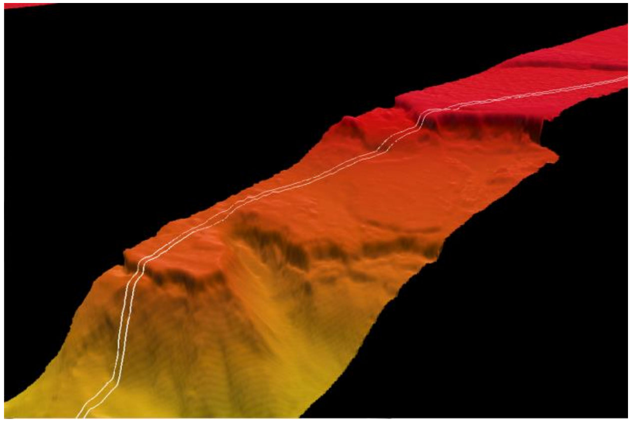
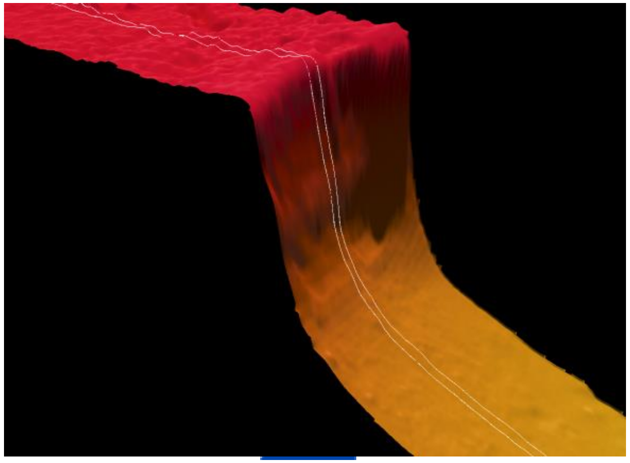
Notable challenges for project

- The ascent to the break in the continental shelf and the break itself are the most demanding.
- For the Gendalo pipelines, the ascent to the shelf break contains a channel and growth faults
- The seabed beyond the shelf break (i.e. approaching landfall) is highly irregular
- The section of route where 4 pipelines merged towards landfall contains highly irregular area of steep sided carbonate outcrops, with large number of large outcrops



Shelf break & growth faults (Gendalo Pipelines)

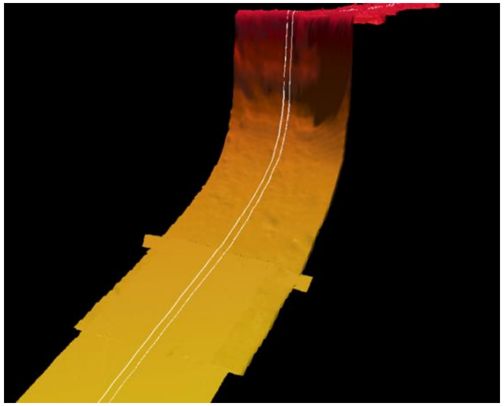
Steep ascent to shelf break (Gehem Pipelines)

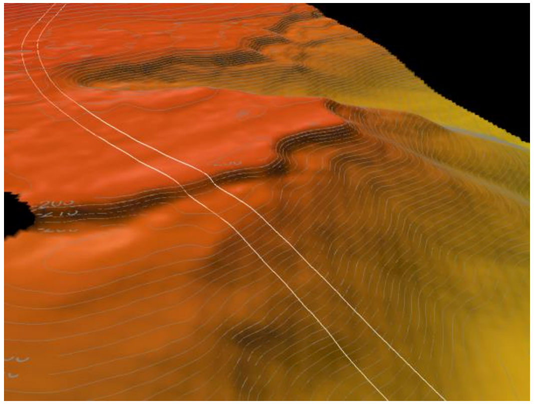


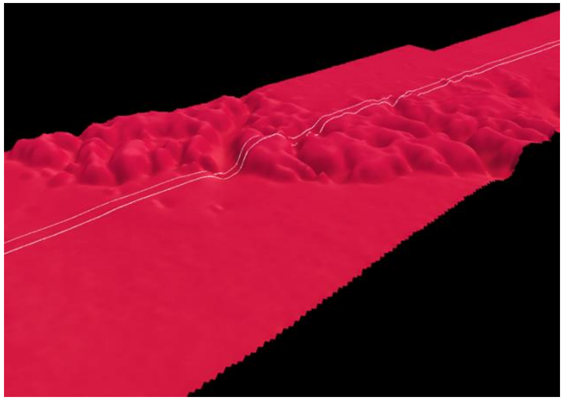
Span Minimization at Design Phase

Best way to avoid unacceptable spans – through design

- The most efficient & least costly way to avoid span is through optimization of pipeline route design
- Unfortunately, very often we have limited survey corridor to work with – hence, there is only so much we can do
- However, in many cases, e.g. fault lines, escarpment, etc. no matter how much big the survey corridor is, you just can't avoid them, e.g.:







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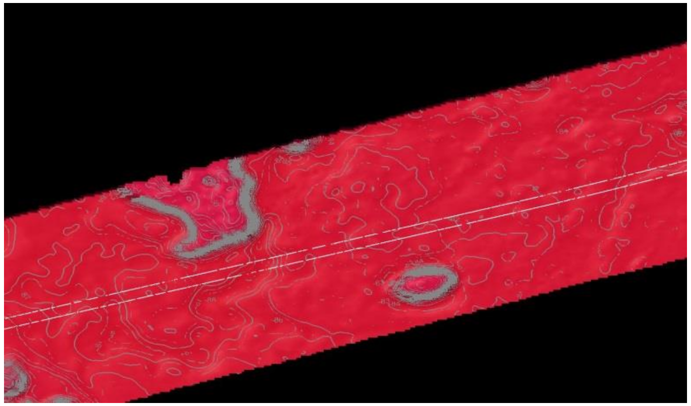
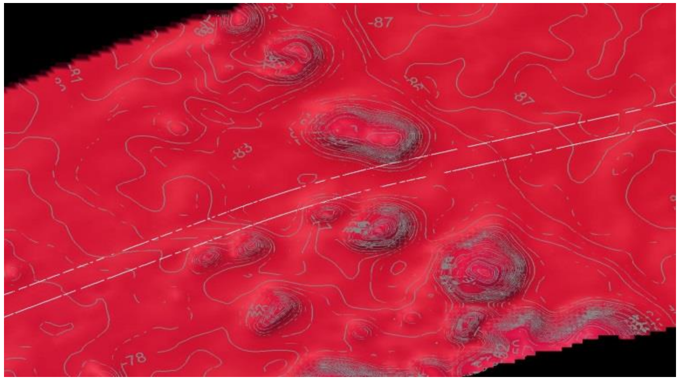
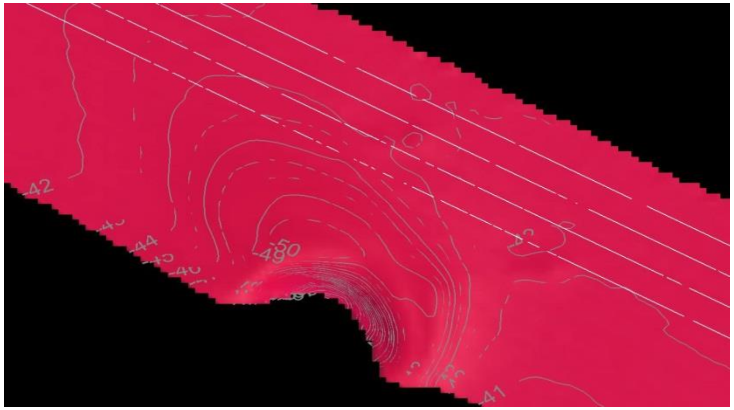
Routing to minimize spans (examples)



Routed to between large outcrops

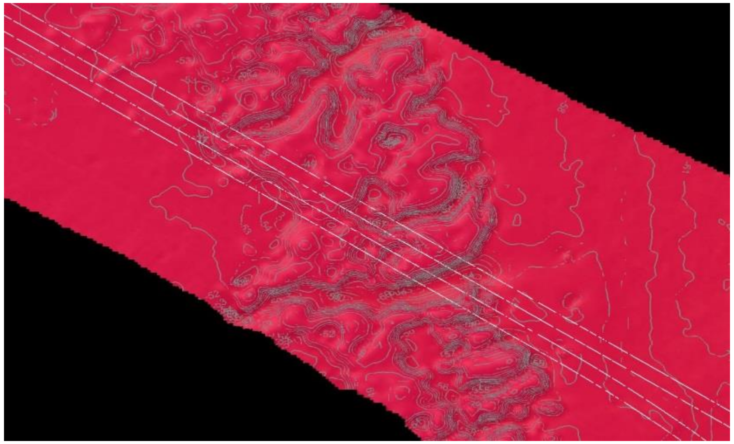
Routed through gap between outcrops



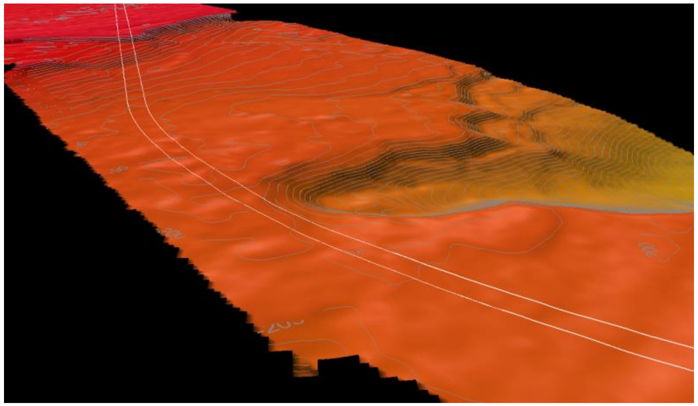


Routed north to avoid scour hole adjacent large mound

Routed to reduce traverse length of outcrops

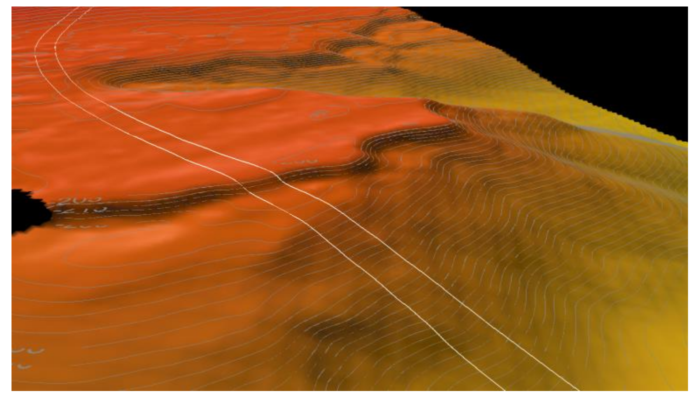


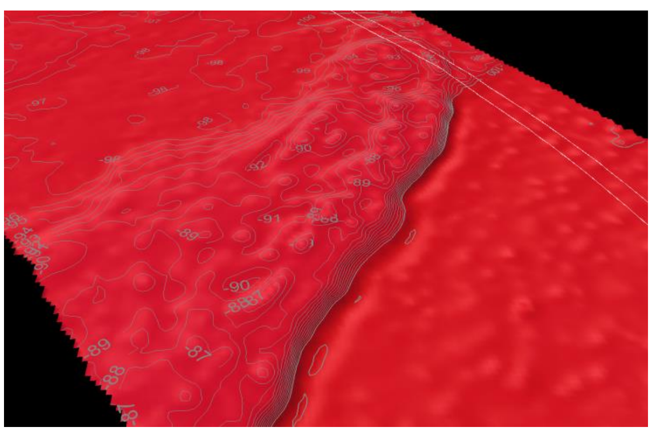
Routing to minimize spans (Cont'd)



Routed to west of corridor to avoid canyon, then aligned to cross growth fault at 'steps'.

Aligned 90° to contours, crosses scarp at point of lower step height & gradient



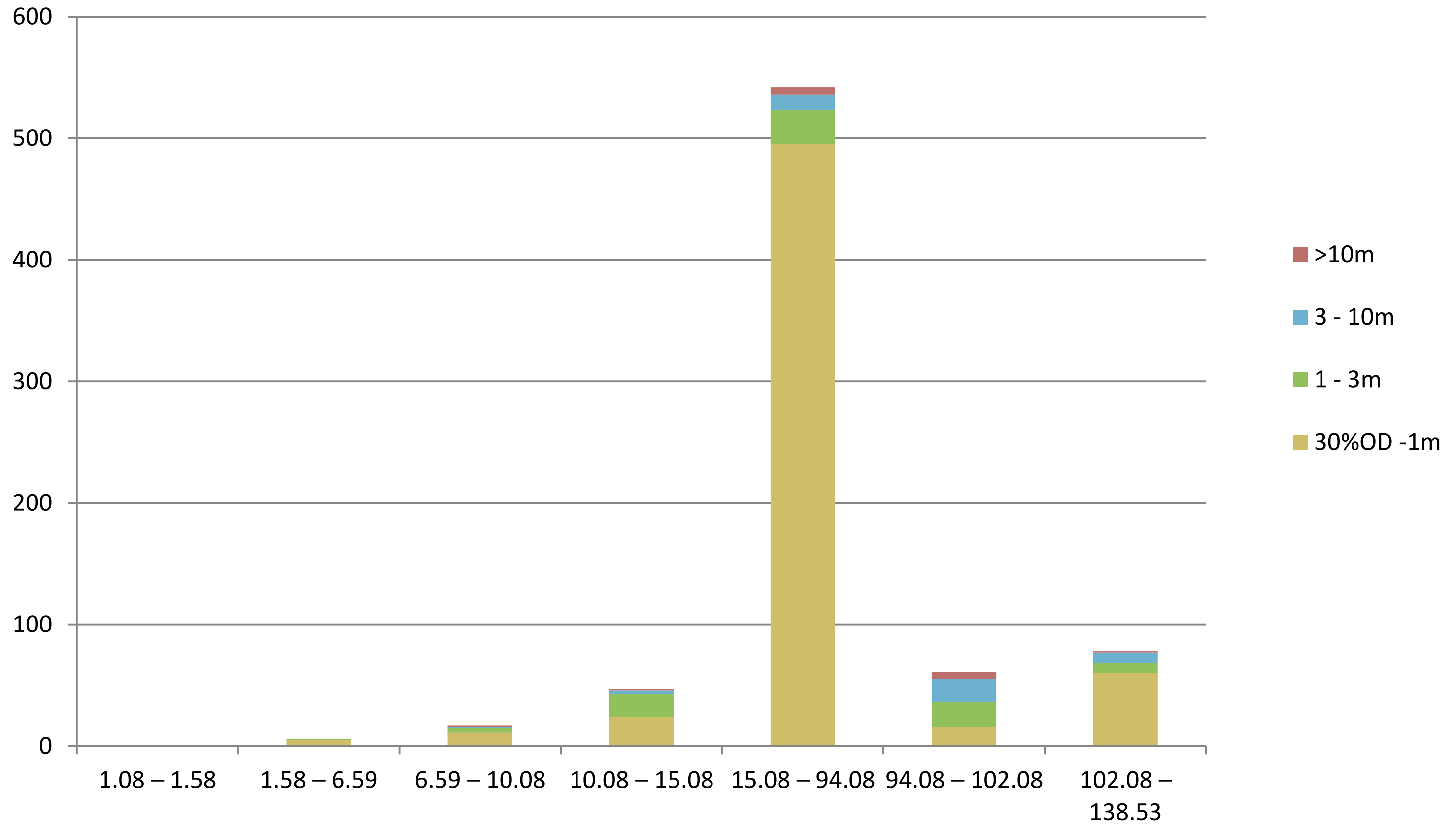


Routed east of corridor to area of low step height, where growth fault has collapsed

Span Rectification – For Spans that cannot be avoided

Expected Spans along Pipeline Route (after route optimization) - Typical

Numberous excessive spans, e.g. Gendalo Gas Pipeline:



Summary of Preferred Methodologies from Various Contractors

DESCRIPTION	COMPANY	METHOD
Pre-lay Seabed	Global Industries	• Pre-trenching to cut and profile is preferred if soil is stable • Rock dumping is an option • Support frame, concrete slab may be used for expected low height spans
	SapuraAcergy	• CSD will be used within depth limitation to do pre-sweeping • For remainder – not investigated yet; will subcontract to dredging company
	Saipem	Depending on site conditions and could be one or more of : • Mass flow excavation • Clay cutting • Rock bedding • Pre-sweeping by cutting pinnacles • Steel sleeper structures • Concrete mattresses
	McDermott	• Concrete mattresses • Steel frames • Dredging • Backfill
	Nippon Steel	• Pre-sweeping for shallow water • Pre-sweeping up to 155m, rock dumping above 155m

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Summary of Preferred Methodologies from Various Contractors (Cont'd)

DESCRIPTION	COMPANY	METHOD
	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 $20m^3/hr$ to $600m^3/hr$ 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

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Summary of Preferred Methodologies from Various Contractors (Cont'd)

DESCRIPTION	COMPANY	METHOD
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.
	SapuraAcergy	• 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
	Saipem	• Not studied. Insufficient soil information to provide assessment.

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Summary of Preferred Methodologies from Various Contractors (Cont'd)

DESCRIPTION	COMPANY	METHOD
	McDermott	One or combination of following: • Dredging • Backfilling • Steel frames
	Nippon Steel	• Pre-dredging or post-trenching (jetting down) • Consider strain-based displacement control design
	COOEC	• Trenching and post-jetting • Installation of grout bridge
	Boskalis	• Trim the top of escarpment using TSHD and install pipe clamps to achieve allowable spans • Rock dumping can replace the pipe clamps if soil is stable
	Tideway	• Trim off top of escarpment using TSHD and dump rocks to eliminate excessive spans
	AGR	• AGR's clay cutter X can cut clay up to 500kPa at rate between $20m^3/hr$ to $600m^3/hr$ and is suitable for cutting the escarpment to get a suitable profile which will reduce pipe stresses and spans.
	Jan de Nul	• Trimming of the 'top' and rock dumping to correct remedial span

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Summary of Preferred Methodologies from Various Contractors (Cont'd)

DESCRIPTION	COMPANY	METHOD
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
	SapuraAcergy	• 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

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Summary of Preferred Methodologies from Various Contractors (Cont'd)

DESCRIPTION	COMPANY	METHOD
	Nippon Steel	• Grout bags, sand bags, mechanical supports, post-trenching, depending on circumstances and soil conditions
	COOEC	• Use mass flow excavator to remove high spots • Rock dumping
	Boskalis Tideway	• 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 • 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

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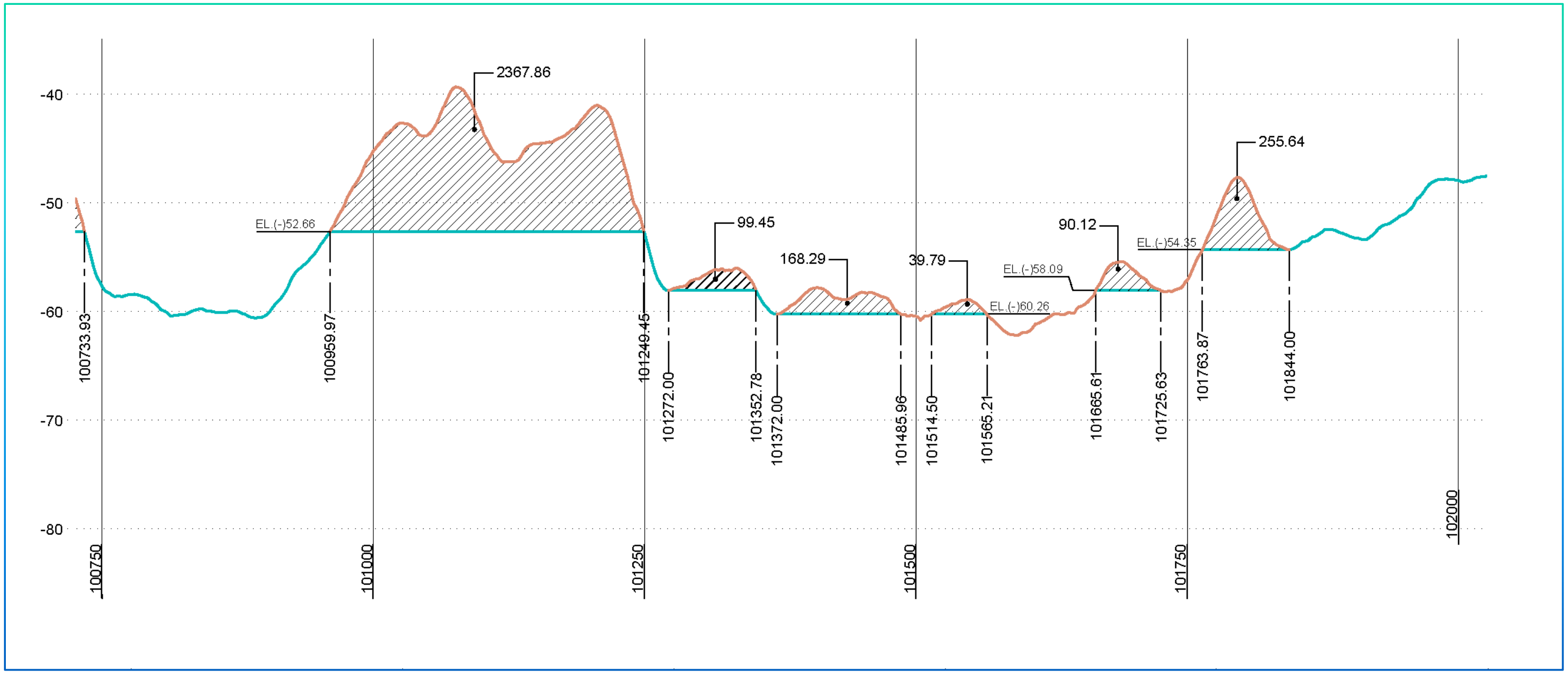
Pre-lay Seabed Intervention Proposed

- Shelf area – Spans numerous
- Pre-lay seabed preparation proposed *(this is in general agreement with most contractors)*
- Example:



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Pre-lay Seabed Intervention

Dredging Equipment for Pre-lay Seabed Intervention

- For shallow water up to 30m depth, it is generally felt that cutter suction dredger and backhoe dredger 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.
- However, seabed intervention is required mostly from shore till the escarpment and a TSHD would be most appropriate, especially if a draghead is used.

Dredging Equipment	Suitable Soil Condition	Depth Limitation
• Cutter Suction Dredger	Soft to hard soil	35m
• Backhoe Dredger	Soft to hard soil	30m
• Bucket Dredger	Soft soil	1000m
• Trailing Suction Hopper Dredger	Soft soft (without draghead) Hard soil up to 1MPa (Tideway) or 30 MPa (Boskalis) with Draghead	100m (Tideway/ Dredging International) – 250m (Boskalis)

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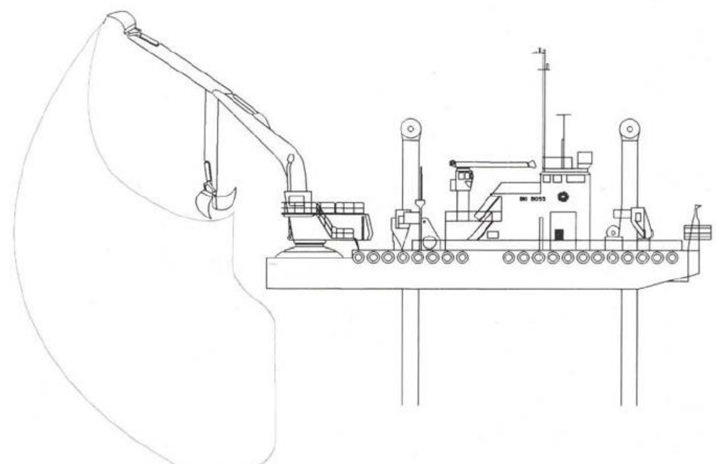
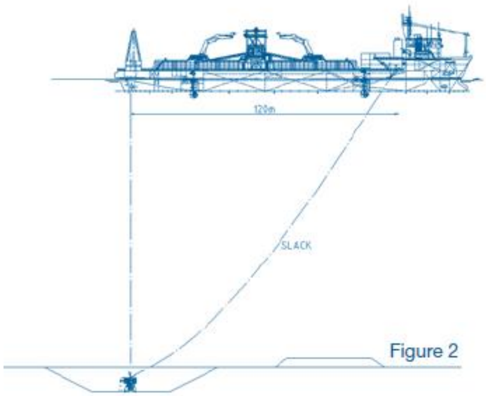
Pre-Lay Seabed Preparation by Excavation

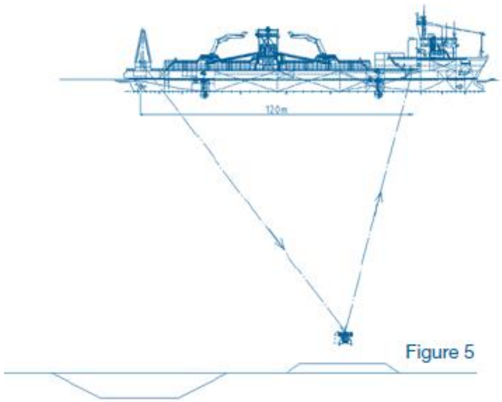
Tideway Cutter Suction Dredger “d’Artagnan”



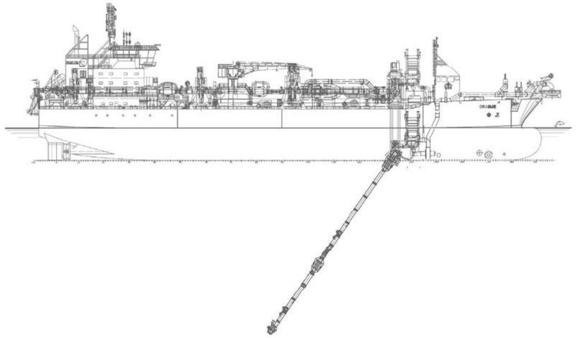
Tideway Backhoe Excavator ‘Big Boss’

Pre-Lay Seabed Preparation by Excavation (Cont'd)





Schematic Showing a typical Boskalis Bucket Dredger at Work



Boskalis' Trailer Suction Hopper Dredger Prins der Nederlanden

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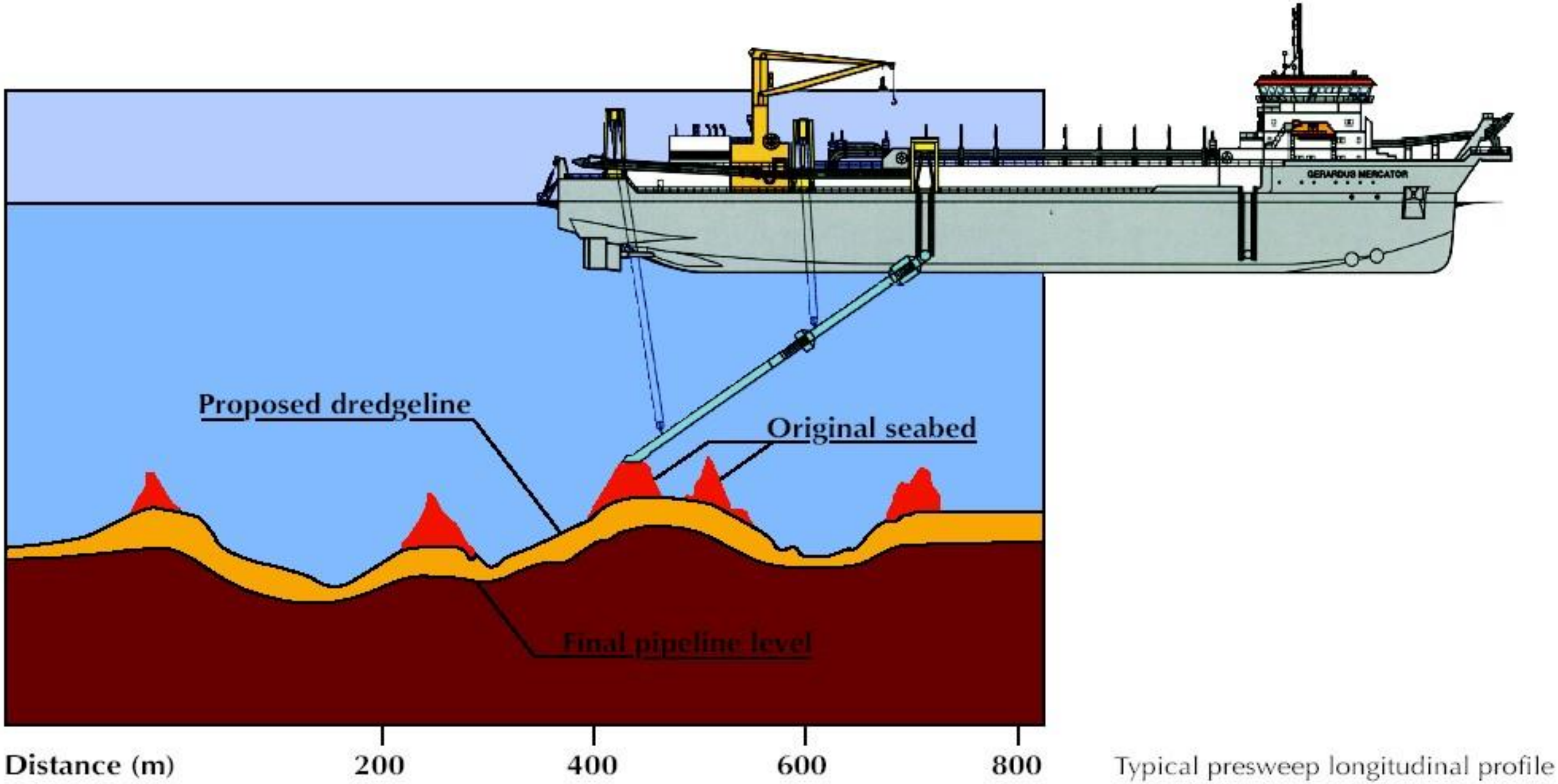
Peak Shaving with TSHD



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

Van Oord's Rock dumping using Side Stone Dumping Vessel, Jan Steen

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Post-lay Seabed Intervention

Post -Lay Seabed Intervation

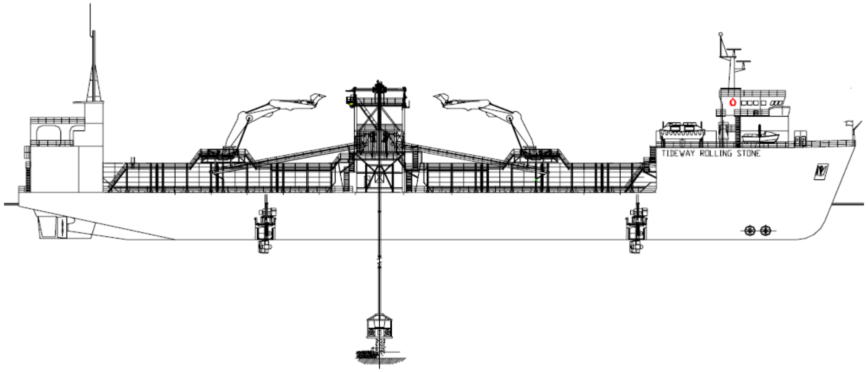
Substantial post-lay seabed intervention is envisaged for this project due to the undulating nature of the seabed, which would result in substantial amount of unacceptable spans.

The types of seabed intervention expected 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

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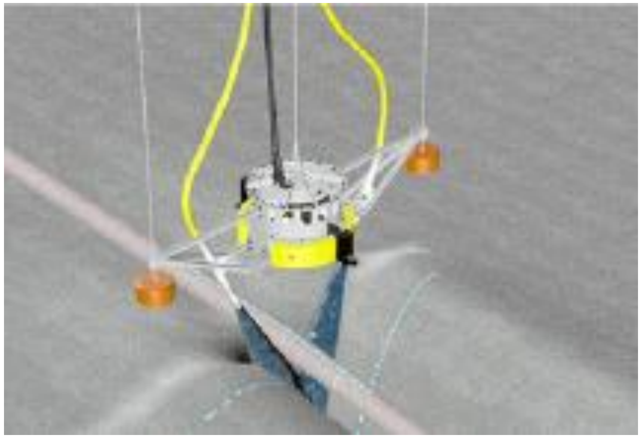
Span Correction by Removing High Spots

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



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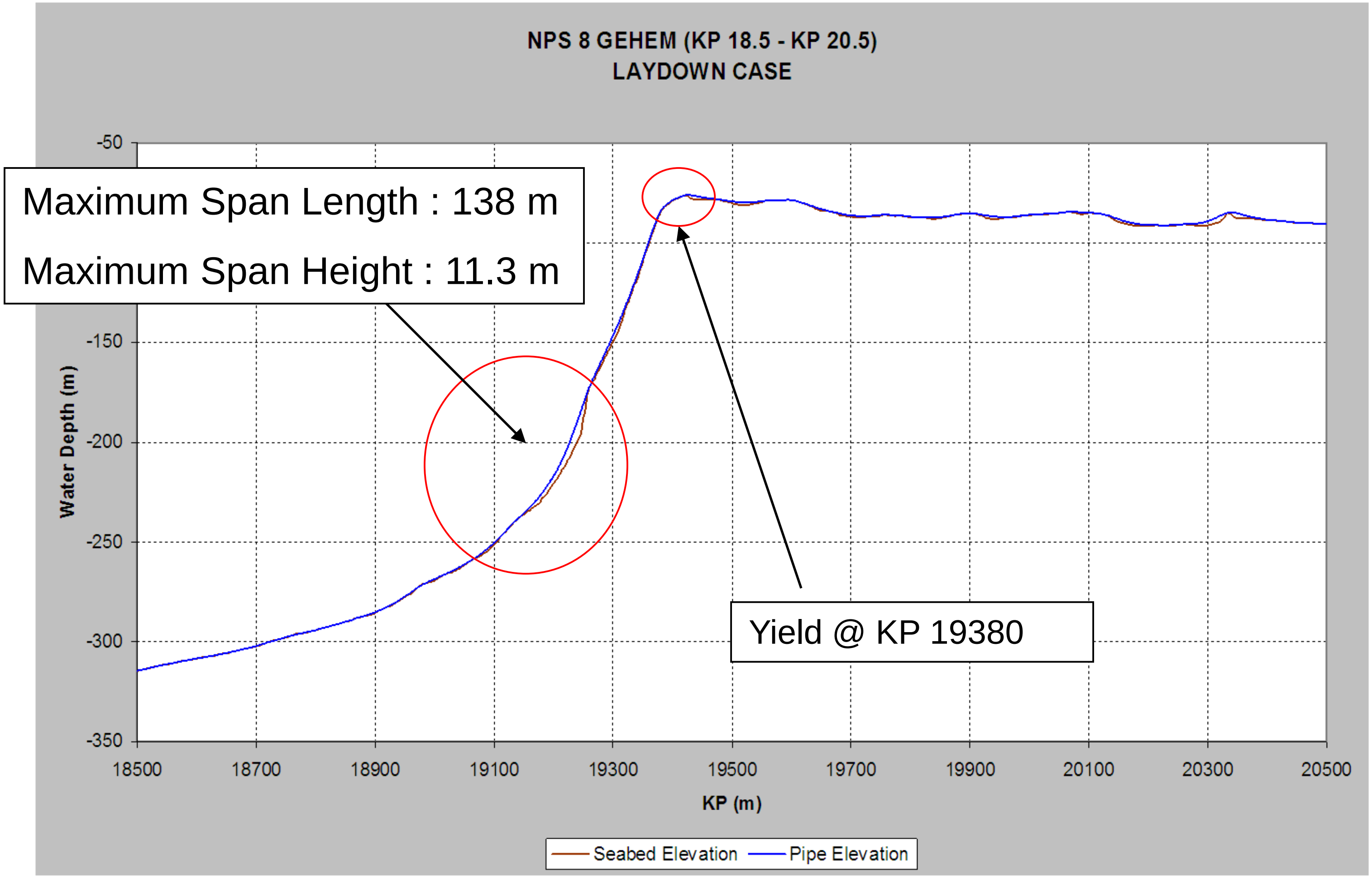
Case Study - Escarpment

Together We Deliver
AMC Energy Marine Production

Scarp crossing NPS8 GHM - Laydown Case



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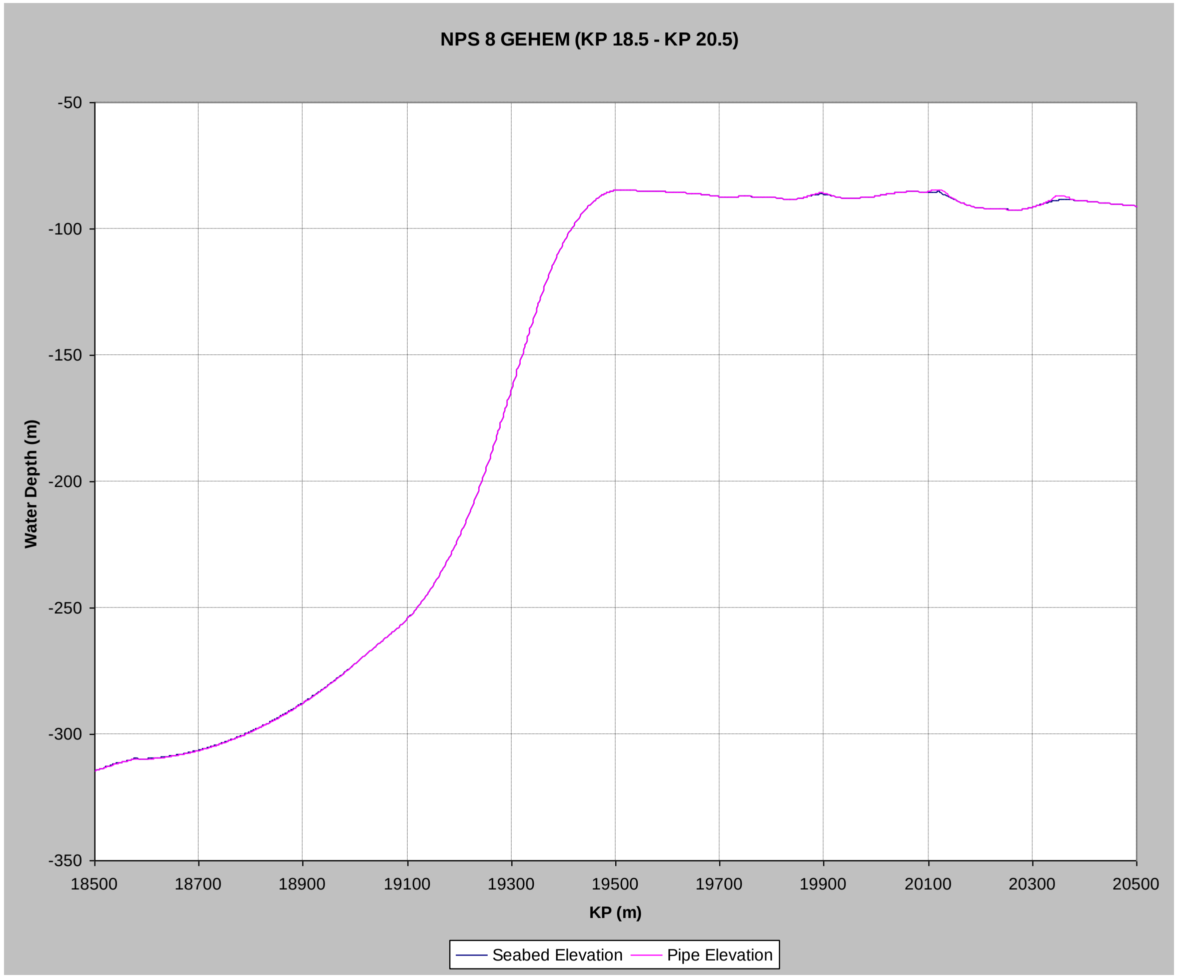
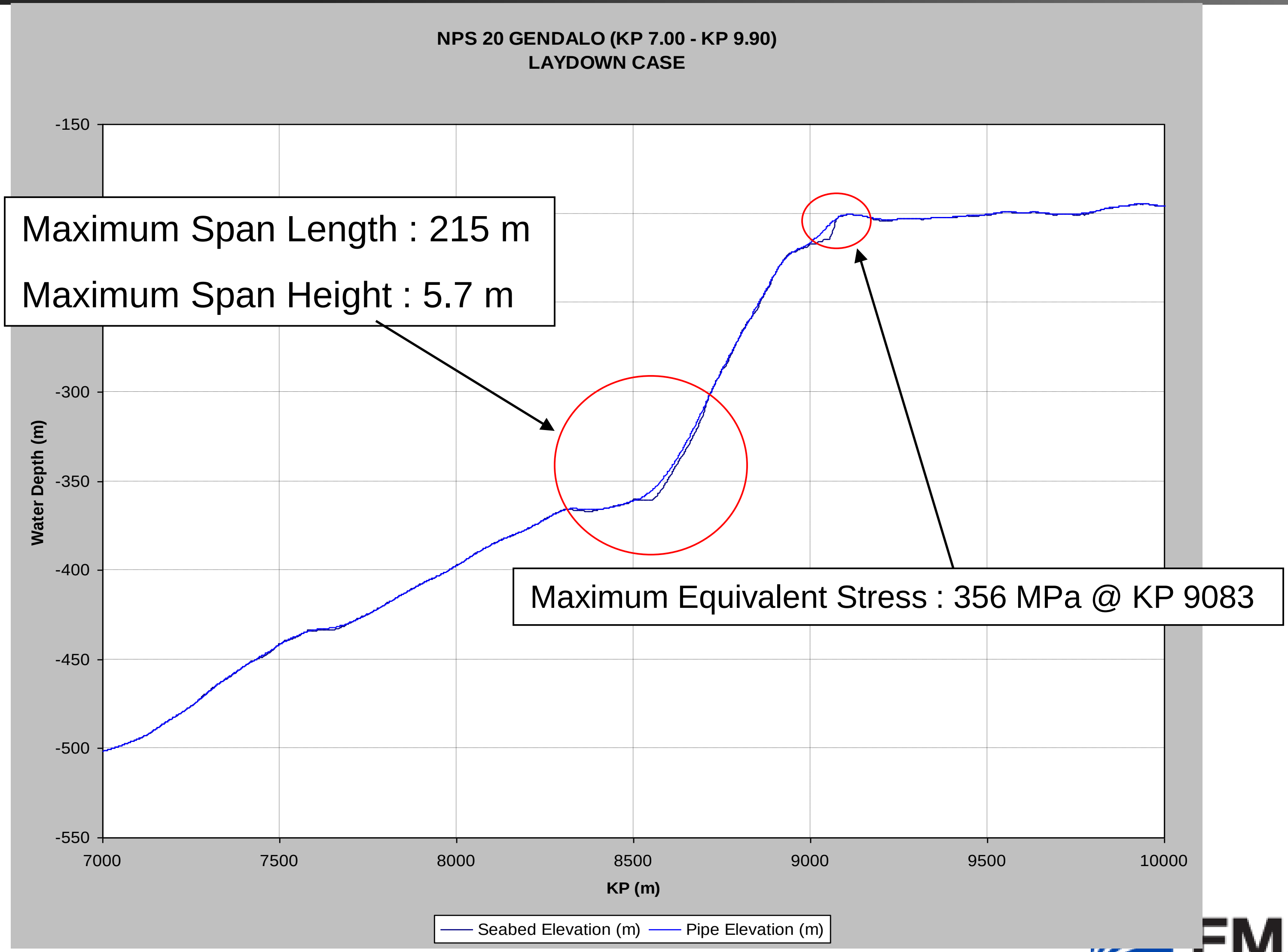
Scarp crossing NPS8 GHM
– Operation Case After Excavation



Scarp crossing NPS20 GLO – Laydown Case



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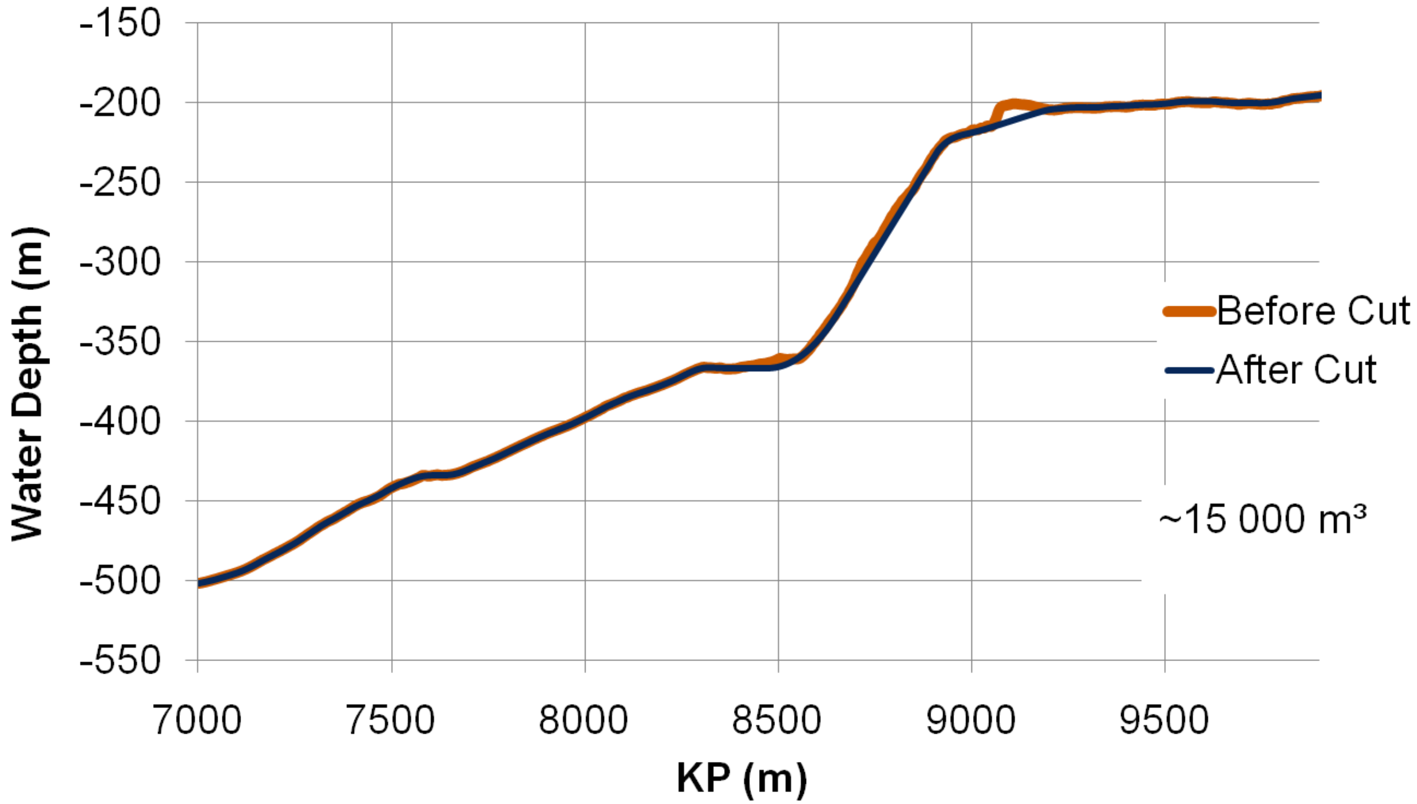
NPS 20 Proposed Excavation



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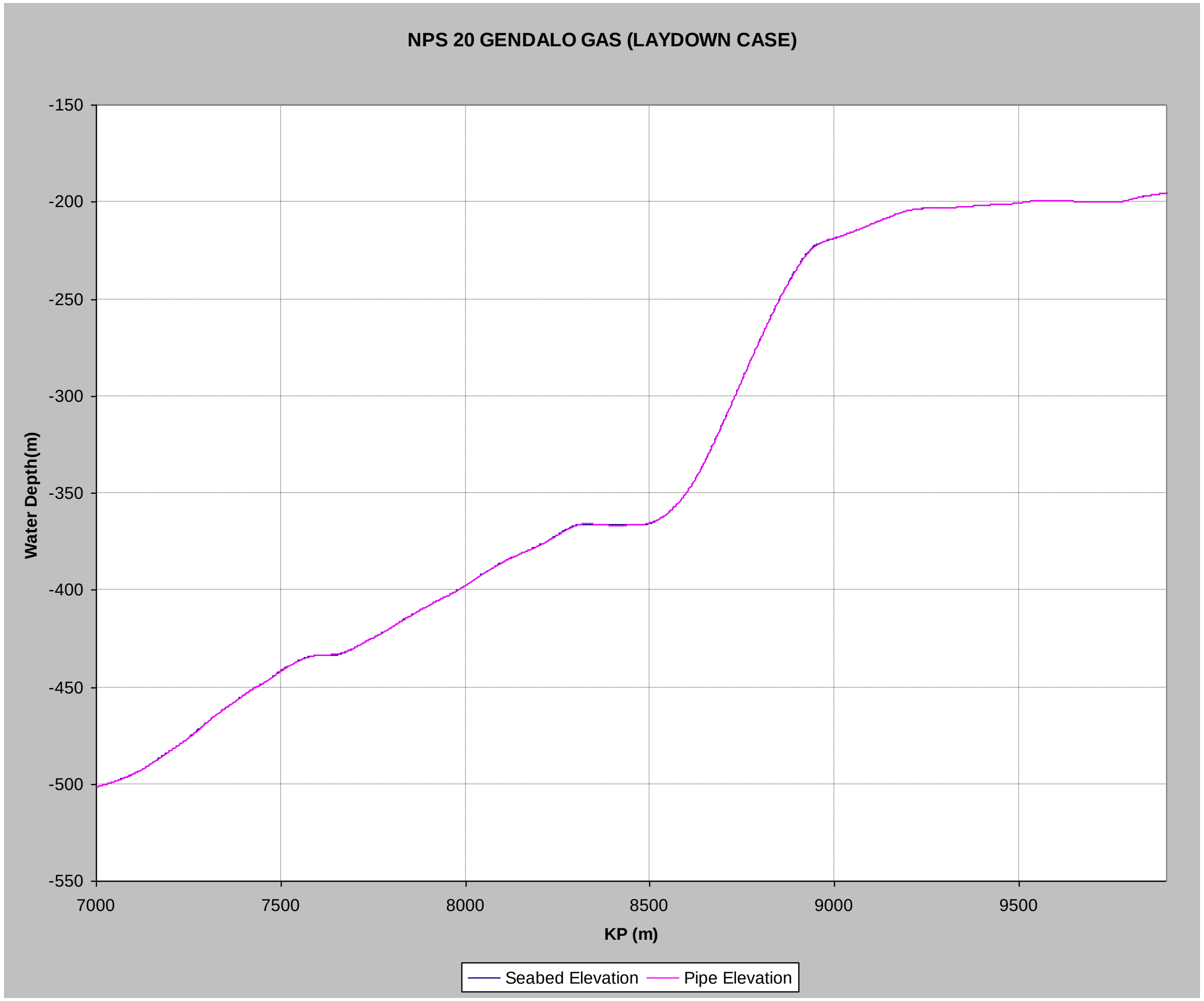
Scarp crossing NPS20 GLO – Laydown Case After Excavation

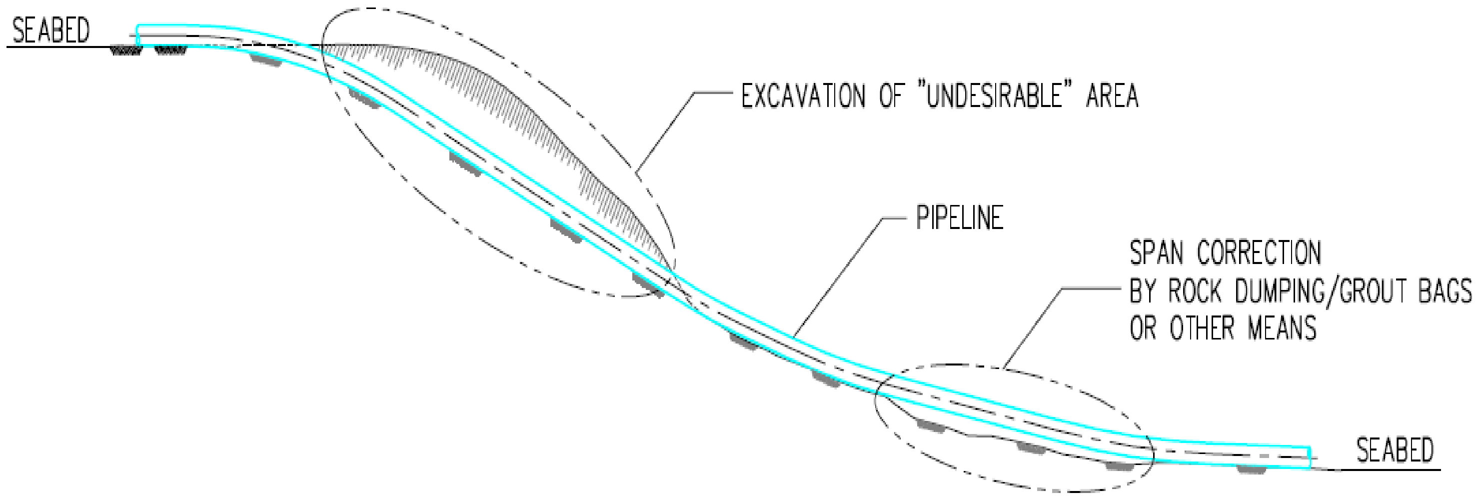


Recommended Solution for Escarpment

Should the soil along escarpment be deemed as suitable for excavation, then the most cost effective and proven method of span rectification (and pipeline stress mitigation) is:

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.



Recommended Solution for Escarpment (Cont'd)

In the event of uncertainty over soil stability during dredging, then the following mitigation plans could be utilized for the escarpment area:

1) Perform minimal amount of dredging using MFE to remove extremely high spots; then

2) Use non-intrusive methods for span corrections, such as:

    a. Mechanical supports (with strakes, as required to suppress VIV)

    b. Rigid or flexible spools along the problem area

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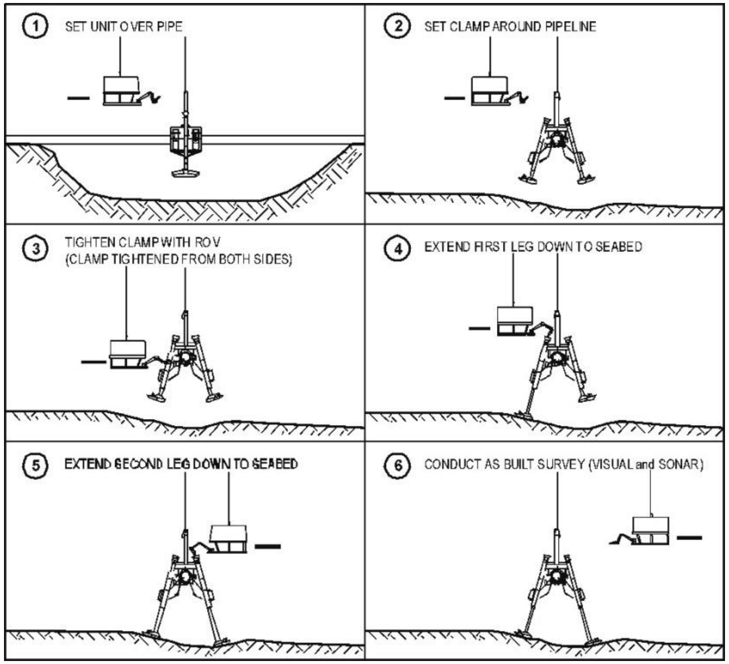
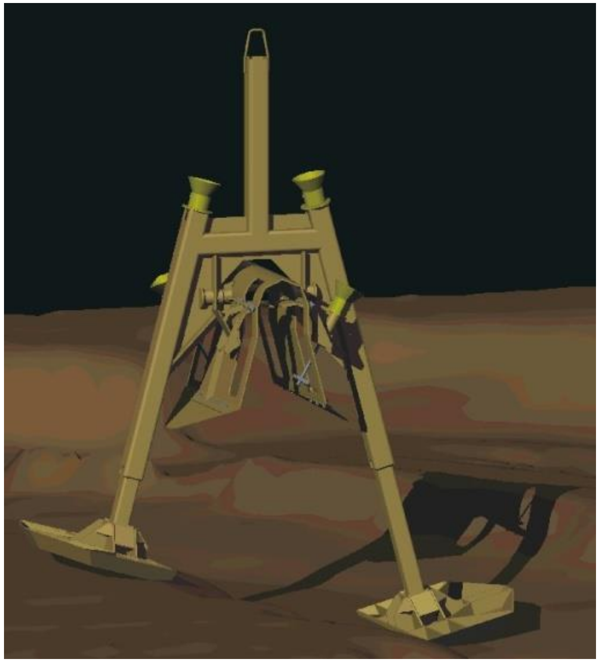
Less Conventional but Viable Method Proposed

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





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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

General Conclusion

Summary Of Equipment For Seabed Intervention

No.	Method	Application	Practical Span Height Limitation	Depth Limitation	Soil Type
1	Backhoe dredger	Pre-lay	20m	32m	Soft to 10MPa
2	Cutter suction dredger	Pre-lay	20m	30m	Soft to 10Mpa
3	Grab dredger	Pre-lay	10m	2000m	Soft to 500 KPa
4	TSHD	Pre-lay	50m	250m	Soft to 3MPa
5	MFE	Pre- and post-lay	50m	850m	Soft to 500 KPa
6	Rock dumping vessel (side stone dumping)	Pre-lay	5m	35m	All
7	Rock dumping vessel (fall pipe)	Pre- and post-lay	5m	2000m	All
8	Fall pipe vessel with grab excavation system	Pre-lay	5m	2000m	Soft to 500 KPa
9	Steel support structures	Post-lay	20m	2000m	All
10	Insertion of flexible spool	Post-lay	N.A.	2000m	All
11	Insertion of rigid spool	Post-lay	N.A.	2000m	All

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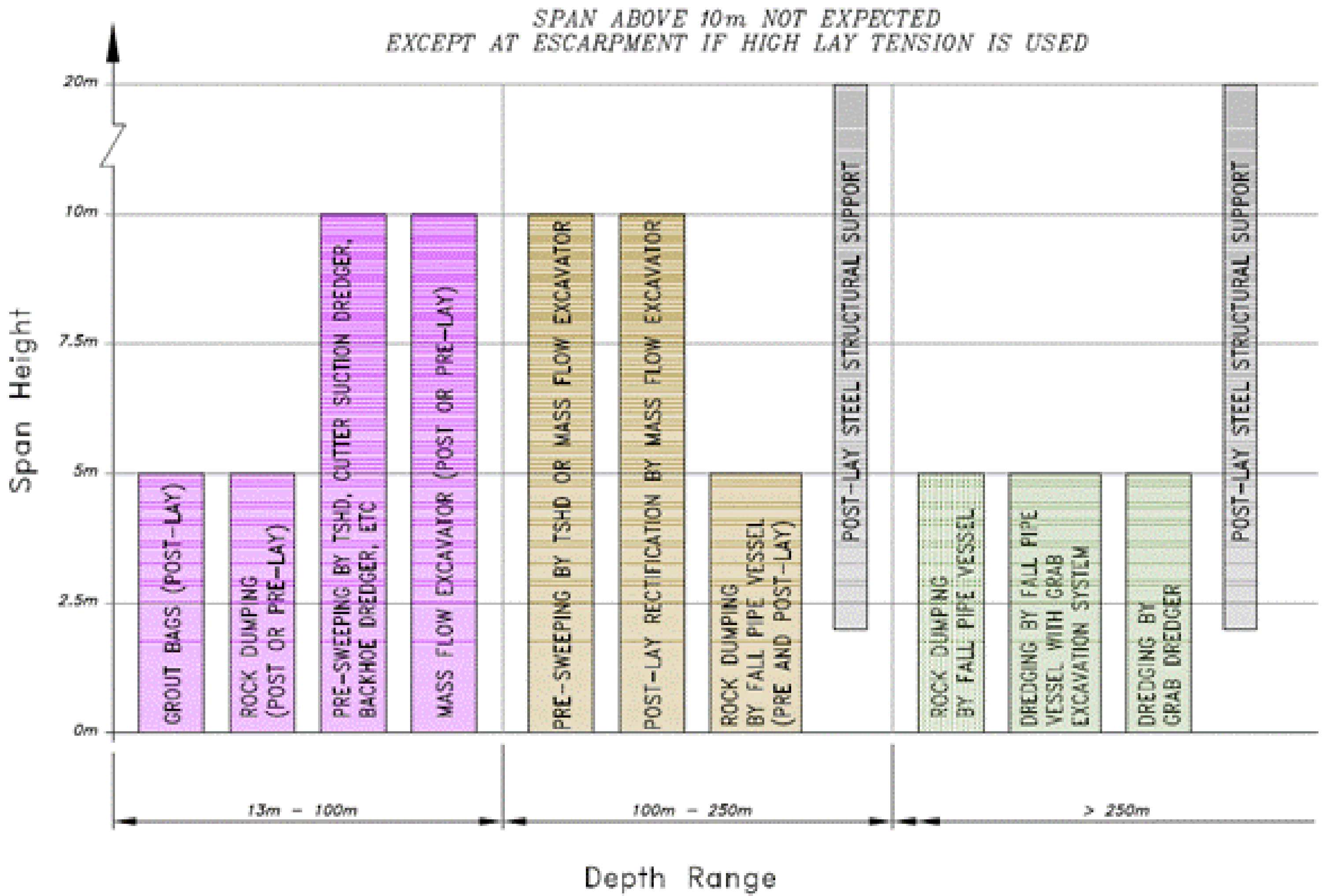
Summary of Recommendation for Span Correction



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Rough idea of how expensive seabed intervention can be – based on FEED Cost Estimate

	Budget	Estimated	Total	% Total
Material	**207,967,730**	**36,699,031**	**244,666,761**	**26.8%**
Line Pipe	160,970,828	3,464,298	164,435,126	
Coating	40,297,055	1,234,733	41,531,788	
Other	6,699,847	32,000,000	38,699,847	
Construction	**524,408,979**	**3,041,600**	**527,450,579**	**57.8%**
Survey	9,829,493	1,000,000	10,829,493	
Seabed Intervention	256,552,815	1,584,000	258,136,815	
Pipeline Installation	190,021,623	220,000	190,241,623	
Linepipe Transpotation	29,522,126		29,522,126	
15% handling of seabed int.	38,482,922	237,600	38,720,522	
Precom	**24,144,981**		**24,144,981**	**2.6%**
Intermediate Precomm	6,034,906		6,034,906	
Final Pre-comm	14,960,730		14,960,730	
15% handling of precomm	3,149,345		3,149,345	
SUB TOTAL A	**756,521,691**	**39,740,631**	**796,262,322**	
EPCM		**29,834,663**	**29,834,663**	**3.3%**
Detailed		7,769,923	7,769,923	
Project Management		9,825,090	9,825,090	
Construction Management		8,323,651	8,323,651	
Other PMT		2,860,000	2,860,000	
Marine Warranty		1,056,000	1,056,000	
SUB TOTAL A + EPCM	**756,521,691**	**69,575,295**	**826,096,985**	
Project Contingency	75,652,169	6,957,529	82,609,699	**9.1%**
Total - All	**832,173,860**	**76,532,824**	**908,706,684**	
Inflation	2,794,705	257,022	3,051,727	**0.3%**
Total - All with inflation	**834,968,565**	**76,789,846**	**911,758,411**	**100.0%**
%	**91.6%**	**8.4%**	**100.0%**	

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Questions ??