IPLOCA excellence in project execution award 2022

# DRY GULCH CROSSING DESIGN

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# 1 BUSINESS PROFILE

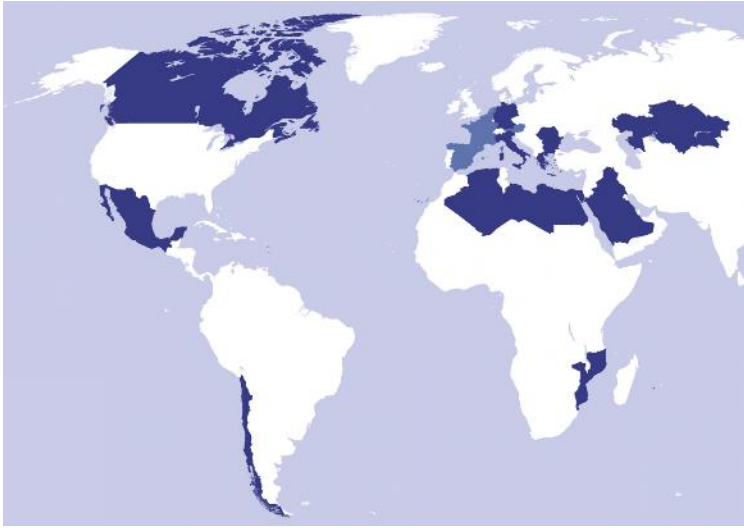
## 1.1 Bonatti Company Profile

Bonatti Group is an International Contractor providing services to the energy industry. Our main activities are EPC & construction of plants and pipelines, operation & maintenance and well production enhancement.

Our project's total approach is the key-factor in our Clients' satisfaction. Construction-focused engineering and fit-to-purpose constructability at every step guarantee to our Clients the best quality and cost-effective execution.

This model consists in managing the entire project lifecycle in direct execution throughout all phases: starting from engineering, procurement and logistics, to civil construction, mechanic and piping erection, E&I installations, up to commissioning and start-up activities.

Our goal is to be country-embedded, to comply with HSEQ and to adopt a sustainable approach in delivering either turn-key EPC projects or stand-alone construction projects.



The Bonatti Group is currently present in 4 continents and 24 countries, relying on the skills of 6,500 people.

Management system certificates:
ISO 9001
ISO 14001
ISO 45001
ISO 3834-2
SA 8000

## 1.2 Trans Mountain Expansion Project (TMEP)

The existing Trans Mountain Pipeline (TMPL) system is approximately 1,176 km long commencing at a storage terminal in Edmonton, AB and ending at the Westridge Marine Terminal in Burnaby, BC. The original pipeline, built in 1953, is an NPS 24 and since that time three segments of the original pipeline have been looped: Edson, AB to Hinton, AB (89 km) with an NPS 30; Hinton, AB to Hargreaves, BC (151 km) with an NPS 36 and Darfield, BC to Kamloops, BC (81 km) with an NPS 30. Owner is developing the Trans Mountain Expansion Project (TMEP) and proposes to undertake the looping of the existing TMPL system with the exception of the Hinton, AB to Hargreaves, BC and Darfield, BC to Black Pines, BC pipeline segments. The expanded pipeline system will consist of a Line 1 pipeline of NPS 24 and NPS 30 pipeline segments with a maximum sustainable capacity of 55,640 $m^3$/d (350,000 bpd) and a Line 2 pipeline of NPS 30, NPS 36 and NPS 42 pipeline segments with a maximum sustainable capacity of 85,850 $m^3$/d (540,000 bpd). Spread 5B of the TMEP Project covers the construction of approximately 51000 m (KP 990+273 to KP 1041+6) of 914 mm (NPS 36) OD pipeline. The route for Spread 5B is represented in the figure below.

*Figure 1: TMEP Project Spread 5B*

Bonatti (in joint venture with Kiewit Corporation) scope of work covers pipeline construction activities for the pipeline segment from KP 990+273 to KP 1041+660.

# 2 FINDINGS: DRY GULCH CROSSING DESIGN

The TMEP Pipeline Project – Spread 5B interests a challenging area of British Columbia, characterized by extreme geomorphological conditions proper of the mountainous regions. In particular the pipeline route intersects at KP 993 the Dry Gulch channel, which consist in a deep canyon originated as a glacial meltwater channel. Bonatti developed and designed the field strategy for the crossing execution.

## 2.1 Dry Gulch Description

*Figure 2: Dry Gulch looking northwest; pipeline route crosses about 200 m northwest of bridge*

Dry Gulch is a steep v-shaped canyon near the Coquihalla Summit about 39 km northeast of Hope, BC. Pipeline route alignment crosses the canyon near KP 993+000 approximately 200 m northwest of Dry Gulch bridge on Coquihalla Highway 5 (Figure 1).

Figure 2 is a cross section through Dry Gulch along the pipeline alignment based on LiDAR. The span between the top of the northeast wall (KP 992+856) and the top of southwest wall (KP 993+086) is about 225 m. The invert of the gulch (KP 992+958) is at elevation 1101.3 masl on the pipeline alignment.

The northeast wall of Dry Gulch is about 94 m in height, ranging from elevation 1195.7 masl at its highest point to the invert elevation along the pipeline alignment. The upper portion of the northeast wall comprises a rock outcrop with a slope angle of about 57° (locally as steep as 78°) and a slope length of about 45 m. Below this outcrop is a blocky rock colluvium lower slope with a slope angle of about 37° and a slope length of about 94 m terminating at the invert of the gulch. The southwest wall of the gulch is 97 m in height, ranging from elevation 1197.9 masl at its highest point to the invert elevation along the pipeline alignment. The majority of the southwest wall comprises a rock outcrop with a slope angle of about 42° (locally as steep as 58°) and a slope length of about 121 m. Below this outcrop is a rock block colluvium lower slope with a slope angle of about 29° and a slope length of about 32 m terminating at the invert of the gulch.

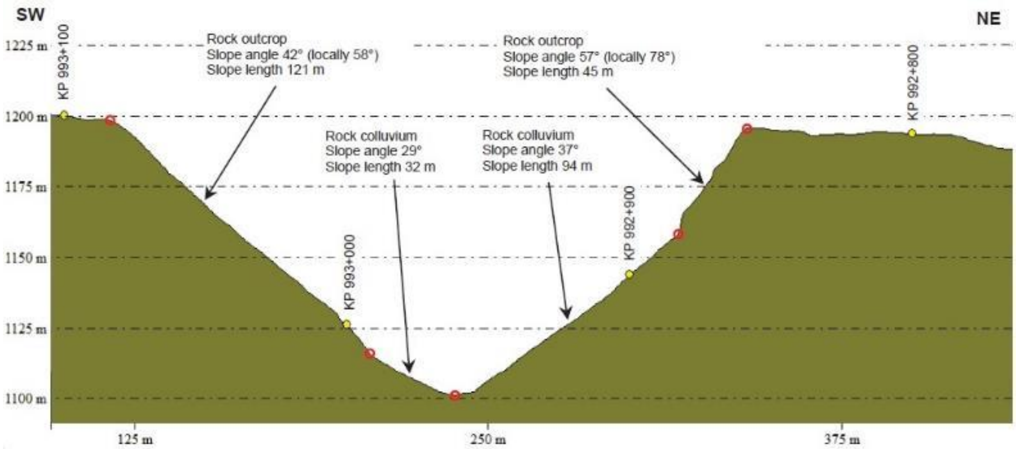


*Figure 3: SW-NE cross section through Dry Gulch along centreline based on LiDAR*

## 2.2 Dry Gulch Geological assessment

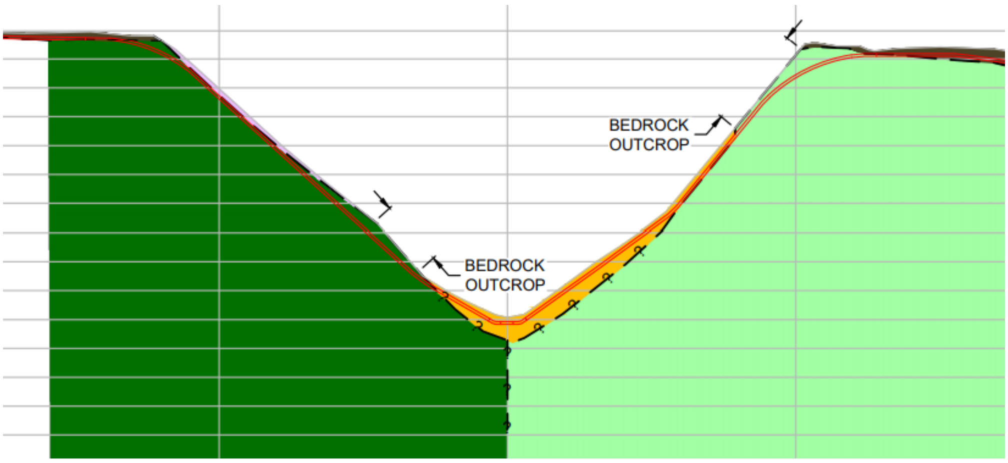


*Figure 4: Dry Gulch Geological section*

In summary, according to geotechnical investigations (by others), key design and construction considerations for crossing Dry Gulch are as follows:

- Lithologic contact and faulting – the contact between the two stratigraphic units in the Dry Gulch area (Eagle Gneiss to the northeast and Fallslake Suite granitic rocks to the

southwest) is complex based on the intrusive nature of lithologies involved; brittle faulting and fracturing of the rock mass at Dry Gulch should be anticipated.
- Rock mass characteristics – there are differences in rock mass characteristics between the northeast and southwest sides of Dry Gulch (BGC, 2015a). As a result, there are different kinematic failure modes and rockfall hazards to consider.
- Talus thickness - the thickness of accumulated talus, and depth to groundwater table, in the bottom of the gulch are unknown.
- ML/ARD potential - there is unconfirmed moderate (uMod) ML/ARD potential associated with the stratigraphic unit to the southwest of Dry Gulch;
- Rockfall hazard – depending on the crossing option, management of rockfall hazard prior to and during construction could require extensive temporary and/or permanent rockfall mitigation.
- Unexpected geological conditions – the Dry Gulch bridge excavation (Rawlings and Wyllie, 1986) identified previously undetected faults, open joints (disturbed zones), and a deep buried channel on the northeast bank that affected the near-surface geotechnical design and construction for the bridge abutments.

Due to the great complexity of the bedrock geology, the absence of a precise characterization of surficial deposit and the lack of direct investigations, in August 2011 TMEP commissioned an exploratory geotechnical borehole for a total measured distance of 1705.1 m (approximately 1663.43 m horizontal distance, from the southwest of Dry Gulch near KP 993+830 to KP 992+167).

Based on the information available from the exploratory geotechnical borehole, the following conclusions were drawn:
- Lithology - the lithology encountered in the borehole generally matches the previous studies conclusions
- Fracture zones and hydrothermal alteration – there is evidence of hydrothermal alteration and potential fracture zones within the approximate footprint of Dry Gulch. However, the identified zones did not preclude successful drilling, and showed no evidence of borehole instability or drilling mud loss.
- Caveat – As per the drilling plan, the exploratory borehole was terminated within the rock mass without daylighting to avoid over-pressure and potential drilling mud loss. Consequently, fractured bedrock conditions between the termination point and the ground surface along the drilling trajectory are possible; however, based on the shallow depth, such conditions (if present) would be unlikely to affect a drilling activity.

## 2.3 Dry Gulch - crossing options

The initially selected strategy for Dry-Gulch crossing execution is open-cut method with the following characteristics.

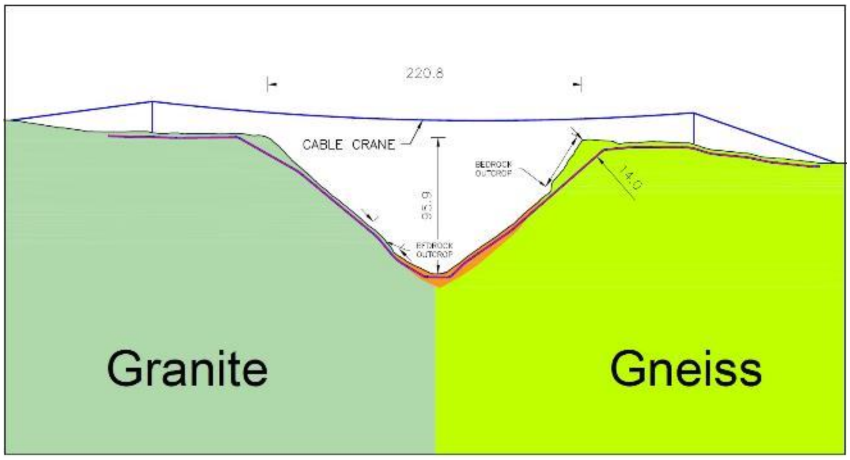



*Figure 5: Open-cut crossing of Dry-Gulch*

The maximum cut height has been assumed to be approximately 15 m (13 m at the pipe centreline) and the maximum longitudinal gradient approximately 47°. A cut slope angle of 0.25H:1V has been assumed. It has to be noted that the grading will imply a great amount of earthworks (especially rock excavation) to be disposed, which will imply a permanent landscape impact on the canyon.
Induction bends or fittings have been assumed for top and bottom of slope transition and field bends assumed for areas along the slopes.
Use of cable crane (for pipe lowering and welding) and spider hoe (for earthworks), even roped, has been considered necessary for performing the work since the graded slopes cannot be run across by standard equipment and there is no access road to the bottom of the channel.

*Figure 6: Special Excavation on slope and cable crane operations*

The main concerns and critical aspects of this construction method are the following:

- No accessibility to the slopes and Dry Gulch bottom from the top, which require a cable crane for moving material, equipment and personnel, resulting as a major safety issue;
- Significant works for grading to perform with controlled blasting
- Complex works for excavated soil movement (from top to downslope) and requirement for evacuating significant volumes of excavated material;
- ROW in steep longitudinal slopes (47 deg)
- Limited working space (ROW)
- Pipe installation in the trench to be performed under special morphological condition with significant rock fall hazard during construction: in fact, portions of the pipe alignment are

exposed to rock fall from rocks dislodged from colluvium or talus on the moderately steep gulch slopes, or from rock bluffs adjacent to the pipe alignment. Measures will be required to reduce the risk to site safety during construction from rock fall, either by preventing rock fall from occurring, controlling rock fall to prevent impacts to the pipe trench, or minimizing unprotected personnel exposure to rock fall through site access protocols.

- Need of extensive works for stabilization of bedding and padding (sand bags trench breakers). Final grading design should consider surface water management and management of water infiltration into the pipe trench to preserve the depth of cover on the gulch slopes over the long-term by avoiding surface or sub-surface water erosion.
- Complex reinstatement works and significant residual impact on the Environment (original morphology nearly impossible to reinstate with backfilling materials after completion of construction activities).
- Reduced time window, for the completion of pipeline installation and mandatory restoration measures, to less than 5 months (From June to the middle of October) due to adverse weather conditions (snow events and snow avalanche hazard).This method requires a longer construction time than the main line.

Advantages and disadvantages of the strategy can be identified as follow:

| **BENEFITS** | **RISK/CRITICALITIES** |
|---|---|
| Limited additional work space required | Significant concerns for safety during construction (Rock fall hazard, limited accessibility, challenging construction activities) |
| | Significant earth works for grading (max excavation 14 m) by controlled blasting |
| Crews may work in parallel on both slopes | Need of cable crane and special equipment |
| | Pipe installation in trench to be performed in special morphological condition; ROW in high longitudinal slopes (47 deg) |
| | Restricted Time window availability and schedule for whether conditions |
| Certainty of the feasibility | Complex reinstatement and stabilization works |
| | Stability of restauration measures and long term maintenance |
| | Significant residual Environmental and visive impact |

# 3 SOLUTIONS

Considering the issues highlighted in the previous chapter the realization of the crossing by open cut method has not been deemed the best option in terms of safety, environmental impact, durability and schedule. Therefore, the feasibility of other trenchless crossing options was assessed , such as HDD, Direct Pipe, Microtunnel, Tunnelling and Raise Boring, identifying the below two options as the preferred crossing methodologies for safety, environmental impact, pipeline durability and impact on cost and schedule. Bonatti developed and designed the field strategy for the crossing execution.

**SELECTED SOLUTION: *Horizontal directional drilling***
The Challenge for this solution is mainly represented by the Complex String design and management due to geometrical configuration and terrain morphology of area available for string preparation.

**BACK-UP SOLUTION: *Double Raise Boring***
The main Challenge is represented by the lack of accessibility to the bottom, requiring that all the transportation of Equipment, materials and personnel shall be realized by a High Load Capacity Cable Crane.

## 3.1 SELECTED SOLUTION: Horizontal directional drilling

The Dry-Gulch crossing execution with the HDD has the following characteristics.

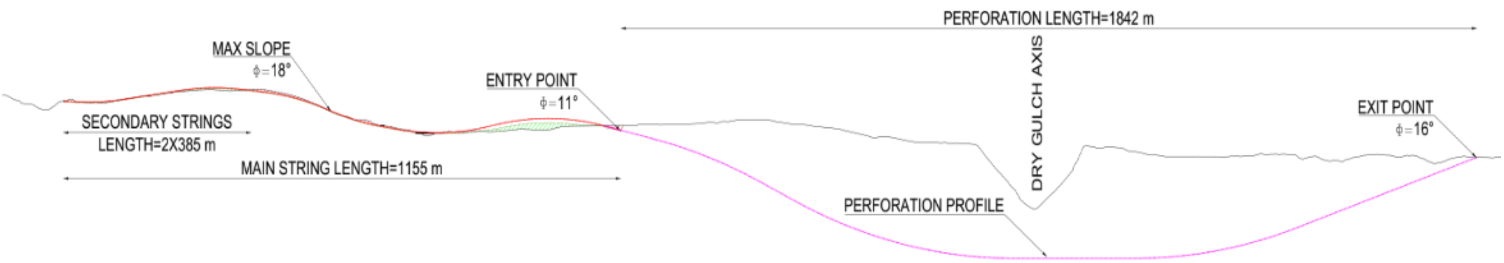



*Figure 7: Schematic representation of HDD string preparation and perforation profile*

The perforation profile has a total length of 1842 m, with an horizontal distance of 1794.4 m. The target depth in the lowest point of the channel, to be reached by the perforation profile, is of 74.2 m. The entry point is located on the southwest side of the channel, and foreseen an entry angle of 11°. The exit point is located on the northeast side of the channel, and foreseen an exit angle of 16°. After the realization of a pilot borehole, due to the exceptional length of the perforation and the type of crossed layers (mainly rocks), the reaming phase of the HDD will be realized by the use of two rigs, which will alternatively transfer torque and pulling/pushing forces to maintain the perforation pipes aligned: this will avoid excessive strain on perforation pipes. As mentioned before TMEP in August 2011 commissioned an exploratory geotechnical borehole that confirmed, at first instance, the feasibility of the HDD highlighting a moderate risk of frack out phenomena.
This construction method is featured by the following critical:

- Significant works for grading of necessary ROW to prepare the HDD string (including 2 temporary bridges);
- Coordination for the preparation of drilling pad and HDD string ready for pullback;
- Preparation of various foundations for pipe rollers and thruster;
- Perform of pre-hydrotest for the three string (main string laid on to the rollers and along the steep slope);

- Complex works for soil movement and for embankment preparation (almost 60000 mc of earthworks required), requiring additional works space and land usage;
- Concerns for safety during the pipeline string management (especially for the over bend at the entry point and along the steep slope);
- Complex operation for the realization of pilot hole and for perform the reaming phase;
- Complex operations for drilling fluid management (even considering a moderate frack-out risk and mud loss);
- Use a combination of sidebooms, roller cradlers and rollers for simultaneous operations during pullback phase;
- Use of particular sideboom (Safe-T-Rex model designed and fabricated By Bonatti) for string management at high altitude;
- Realization of two (2) tie-in during pullback phase;
- Reduced time window, for the completion of crossing;

Advantages and disadvantages of the strategy can be identified as follow:

| BENEFITS | RISK/CRITICALITIES |
|---|---|
| Exploration borehole successfully completed and feasibility confirmed, with minimal residual risk of frack-out and bore collapsing | Additional temporary work space and permitting procedures required |
| Beneficial cost impact | Environmental impact on the pullback areas |
| Improved schedule, as some activities may be performed within the winter window | HDD string to be laid in complex area with important grading |
| Minimal environmental and visive impact on the Dry Gulch geological feature | Complex pullback string management |
| Highest worker safety | Concerns for safety during the pipeline string management (over bend at the entry point at 20 m high and along a steep slope) |
| Stability and integrity of the crossing during the years | Difficult slurry management due to the geometry |
| No stabilization measures required | Two tie-in to be realized during pull-back phase |

Particular relevance for this strategy assumes the preparation of pipeline string. According to the permitting and land acquisition the suitable area for the preparation of pipeline string is located on the southwest side of Dry Gulch. Due to the complex morphology of the area and material properties (minimum elastic radius for the pipeline string assumed of 600 m) is not possible to locate the pipeline string on a flat area, but it will be laid on a slope area. The string will be divided in three part (1 main string of 1155 m and 2 secondary string of 385 m): tie-in welds will be performed during the pullback phase at suitable moments. At the entry point a pipe thruster will be installed in order to help during the string pullback phase. Moreover at entry point, due to the selected great entry angle (11°), it will be necessary to raise the string at high altitude (20 m) from the original ground. The pipeline string will be laid on rollers, where applicable, and sustained by sidebooms, where the over bend is necessary for the pullback phase (entry point) and considerable lateral reactions are expected.

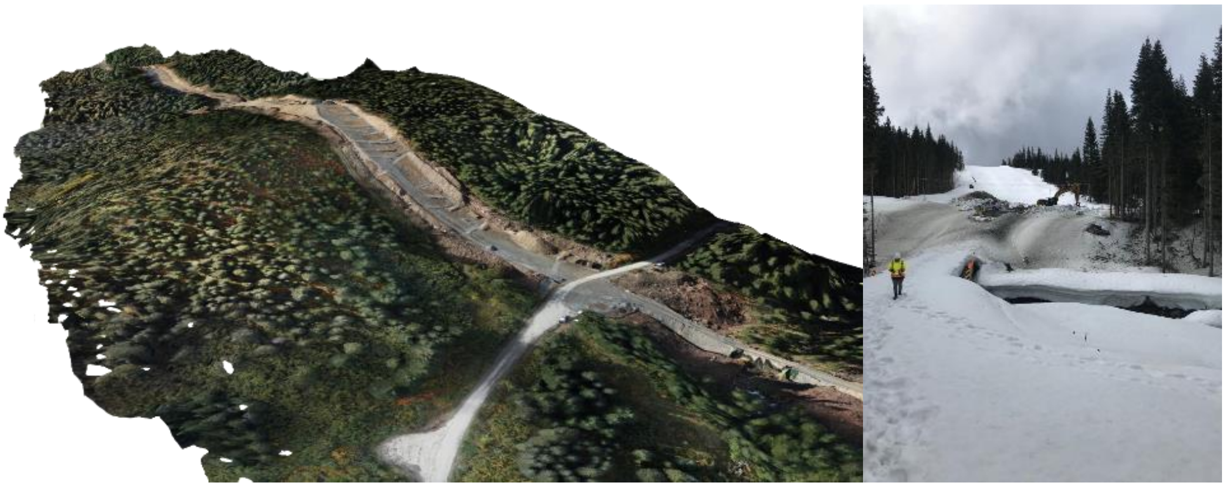


*Figure 8: Available area for preparation of Pipeline String*

In these sense a complex study for the string preparation has been carried out: in particular a detailed 3D model has been prepared in order to define the optimal grading (minimize earthworks and optimize mass movement balance), define the arrangements for the installation of temporary bridges, to verify the actual dimensions of the equipment to be used and define the final profile of the pipeline.

After that a FEM analysis has been conducted to analyse both the static and cinematic behaviour of the pipe string during the pullback phase. In particular the FEM simulation produced the following results:

- Verified the acceptable stress induced in the string during lifting and pulling operations;
- Assessed the optimal distribution of rollers and equipment for assisting the string during the pullback phase;
- Defined the reactions on the pipe rollers (used to design the foundations) and on the sidebooms (verified the loading capacity of the equipment);
- Defined the maximum displacement during the pullback phase;
- Verified the resulting stresses in correspondence of the tie-in point (very low stress allowed to perform the tie-in welds);
- Define the resulting pulling forces needed and the necessity of any anchoring devices along the steep slope;

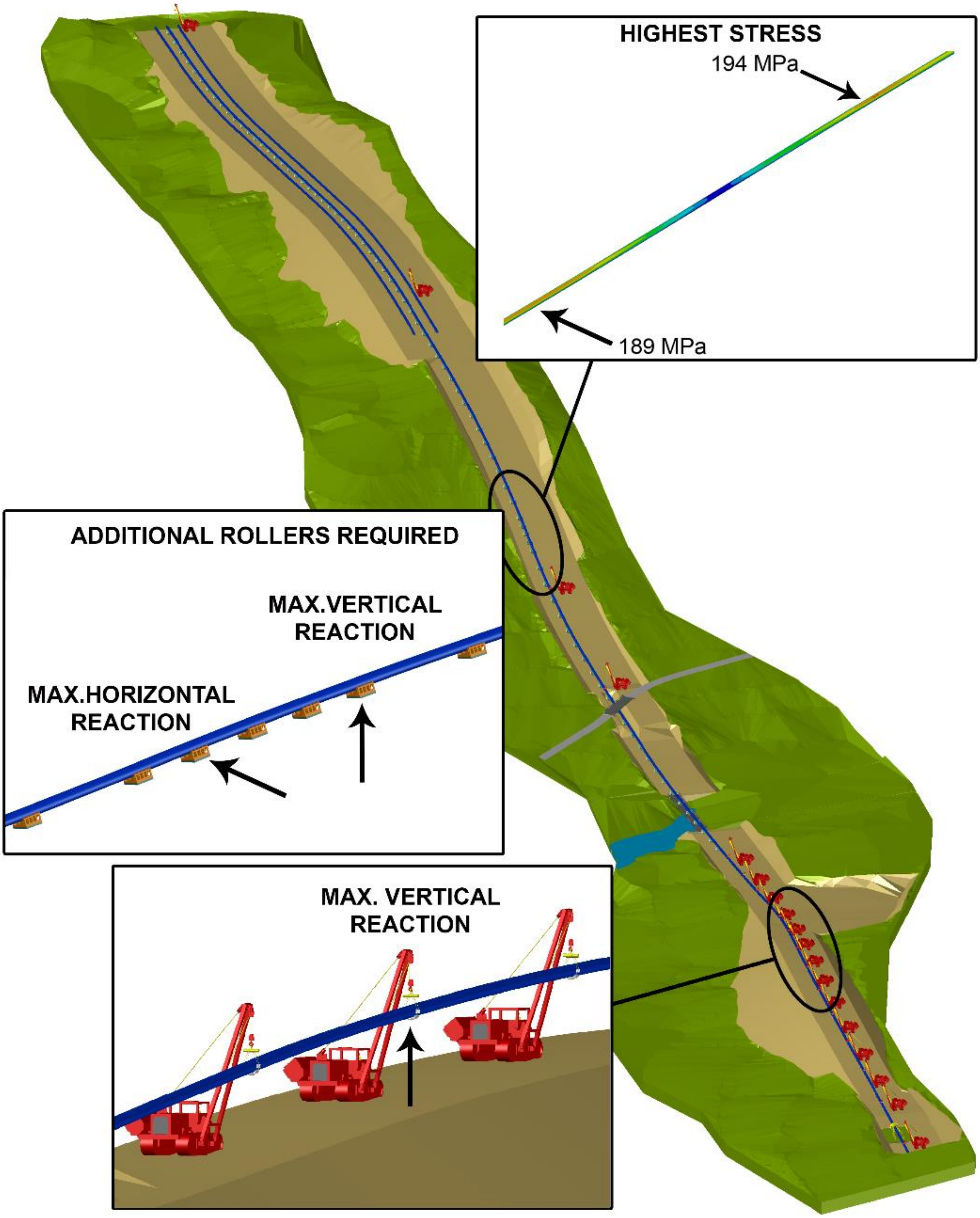



*Figure 9: 3D Model & FEM Simulation – Grading and general HDD string preparation*

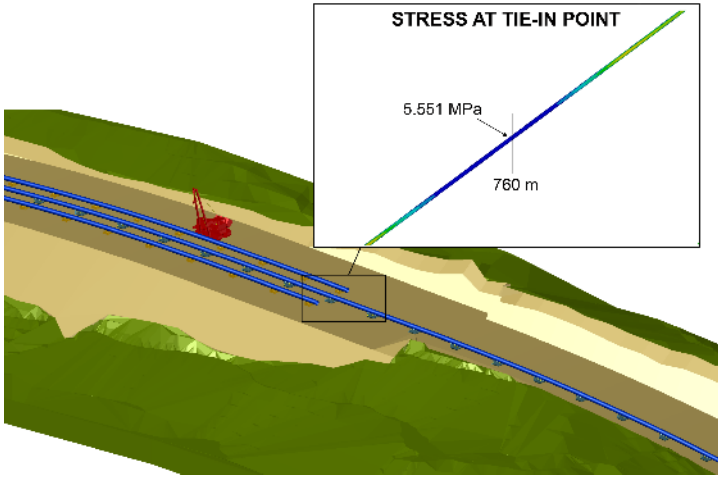



*Figure 10: 3D Model & FEM Simulation - Tie-in point*

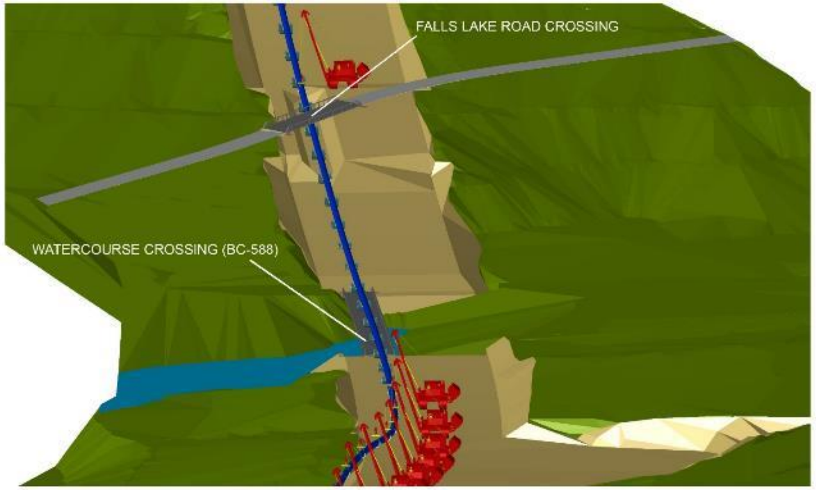



*Figure 11: 3D Model - Temporary Bridges arrangements*

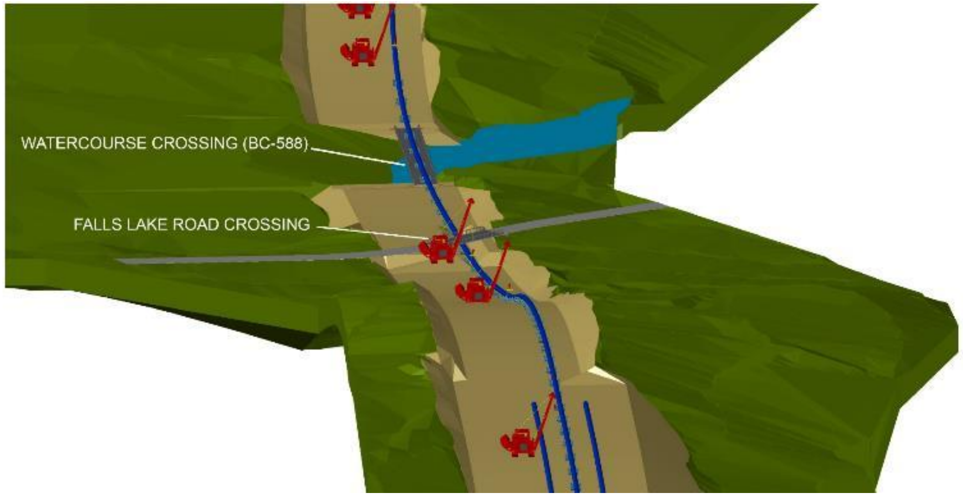



*Figure 12: 3D Model - Steep Slope configuration*

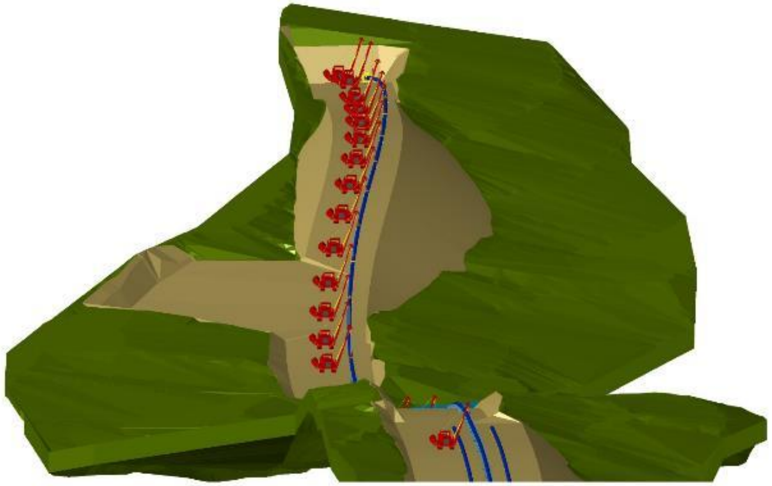


*Figure 13: 3D Model - Overbend configuration*

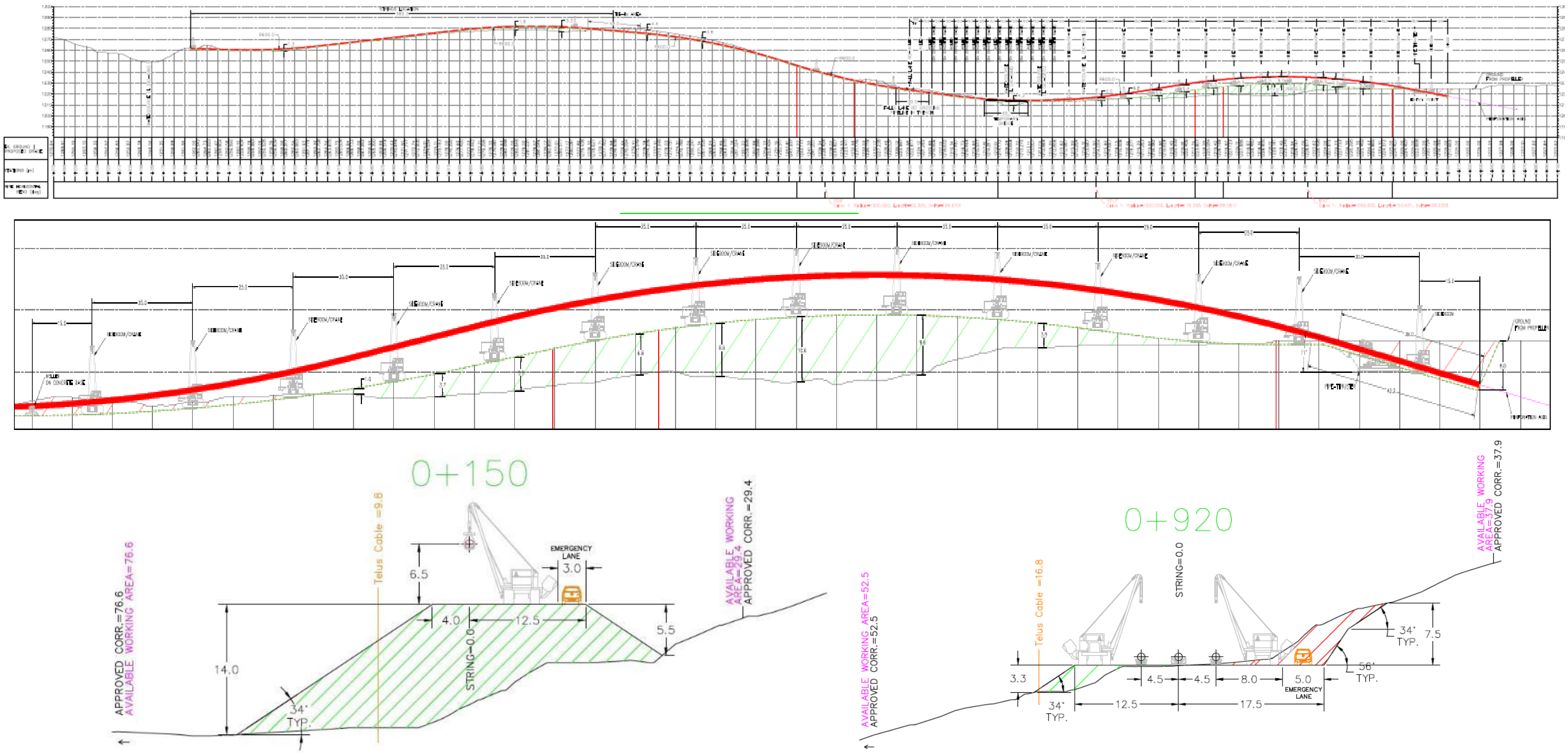



*Figure 14: HDD String preparation design*

### 3.2 BACK-UP SOLUTION: Double raise boring

The Dry-Gulch crossing execution with the Double raise boring has the following characteristics.

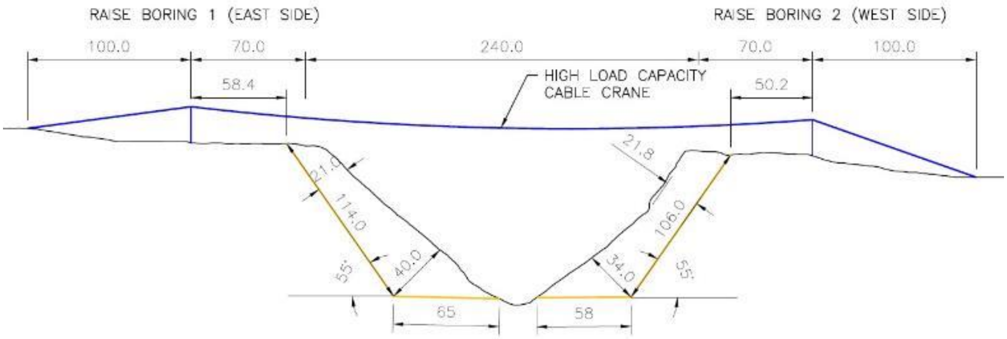



*Figure 15: Double Raise Boring Crossing Design*

*Raise Borer 1 (East Side)*
Inclined Distance: 114 m
Slope of the Inclined Distance (°):55°
Tunnel Length (m): 65 m
Difference in Height (m): 96 m approx.

*Raise Borer 2 (West Side)*
Inclined Distance: 106 m
Slope of the Inclined Distance (°): 55°
Tunnel Length (m): 61 m
Difference in Height (m): 91 m approx.

The solution has been precisely designed taking into account the actual conditions of the site and the relevant constrains in term of schedule, availability of equipment and pipeline final configuration.
Due to the absence of direct access to the bottom of the channel any transportation of equipment and personnel, necessary for the excavation of the tunnels (drill and blast operations), stringing, welding and lowering of the pipeline, shall be performed by a dedicated high capacity cable-crane (22 tons max): in this scenario a special equipment has been selected and optioned, ready to be installed.
Only necessaries and appropriate Light weight equipment have been selected and took in account for execution planning. Personnel number and shift have been exactly defined taking into account the reduced mobility due to the necessity of being transported only by cable crane.

*Figure 16: Transportation of Equipment by High Load Capacity Cable Crane*

*Figure 17: Transportation of personnel by High Capacity Cable Crane and Specific Gondola*

This construction method is characterized by the following issues:

- Geotechnical investigation (seismic and geo/electric surveys) required to confirm the nature and the thickness of the coarse sediments and of the colluvium and optimize the shaft position and its cover, avoiding as much as possible areas presenting deteriorated rock;
- Limited accessibility to the canyon's bottom to be mitigated trough installation of an high capacity cable-crane (22 tons max), equipped with a suitable gondola, for personnel transportation.
- Basal Tunnels to be realized (drill and blast method) by means of light equipment: transportation to the bottom of the Gulch shall be performed only by the use of cable crane
- Realization of pilot bore hole; pilot bore collapsing is not expected, as compact rock is envisaged; in case, the issue might be easily resolved by drilling fluid selection and/or in-hole grouting

- Realization of shaft; Shaft bore collapsing is unlikely due to the rock nature
- Limited working area on top of the Gulch: pipeline installation is performed from the top shaft and from the bottom tunnel.
- Great amount of earth movement at the bottom of Dry Gulch (Additional area is required) to install the middle pipeline spool.
- No personnel working along the slopes.
- Restoration works localized at the shafts top holes and at the base tunnel entries.
- No risks for backfilling erosion or trench breaker collapsing. No concern for long time maintenance. Stabilization measures required at the bottom of the channel, in correspondence of the axis of the Gulch.
- Higher control on construction schedule: once tunnels are excavated, raise boring operation and pipeline installation works are expected to proceed smoothly (no disruption due to unexpected conditions on the ROW)

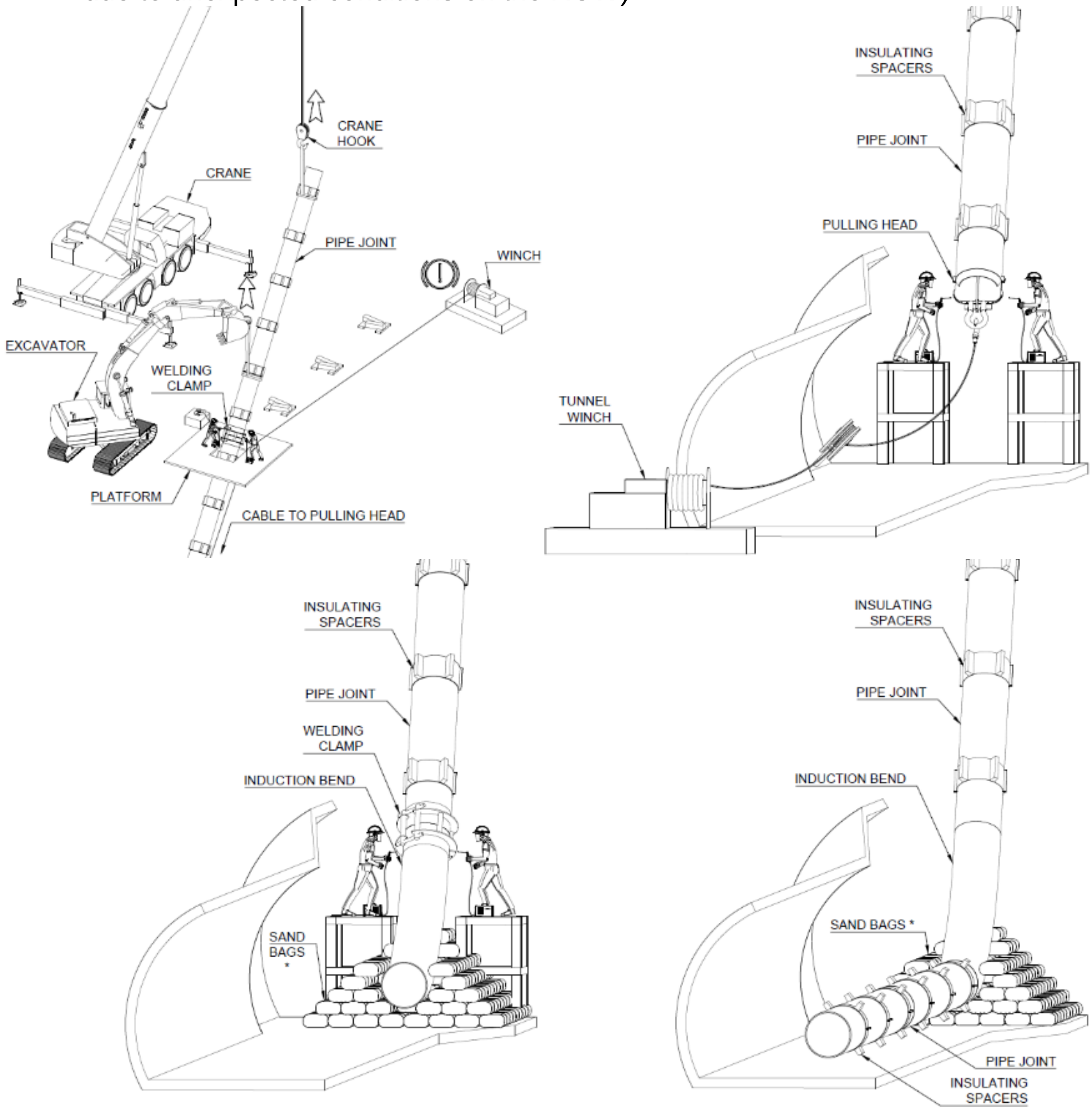



*Figure 18: Double raise-boring pipeline installation phases*

| BENEFITS | RISK/CRITICALITIES |
|---|---|
| Very High Feasibility level | Installation of high load capacity Cable Crane required for operations and equipment/personnel transportation |
| Limited and expedite geotechnical investigation required | Moderate Risk of shaft collapses due to unknown subsoil conditions |
| Reduced construction risk compared to open cut | Higher costs respect to HDD |
| Stability and integrity of the crossing during the years along the slope | Safety concern due to limited accessibility to Dry Gulch (via cable crane only) and for operations inside the tunnels (confined spaces) |
| Minimal environmental and visive impact, due to limited working areas | Considerable earthworks at the bottom of the Gulch (removal of debris): additional area required. |
| No significant additional working areas required | More complex schedule management respect to HDD, as works at Dry Gulch bottom are higly impacted by the weather window |

# 4 ACHIEVEMENTS

The Dry Gulch Crossing design required a wide and extensive study of various trenchless technologies due to the fact that the open cut solution has been considered not the best solution in terms of Safety, Environmental Impact, pipeline integrity and schedule.
Both the presented solutions, HDD and Double Raise Boring, have significant challenges for which Bonatti presented relevant solutions and elaborate detailed planning and studies.
Furthermore in this specific scenario trenchless proposed solutions highlight improvements in terms of:

- **SAFETY:** the risks connected with the operation along the steep slope for open cut solution have not considered acceptable. Residual risks have been identified for both the solutions (even if the risks associated with HDD operation are considered way lower), but these have been considered acceptable and could be considerably reduced by applying a correct and constant policy of HSE.
- **ENVIRONMENTAL IMPACT:** the open cut solution foreseen a deep impact on the area with no possibility to implement a comprehensive reinstatement plan (especially in terms of landscape). Both the solutions guaranteed almost no residual impact at the end of operations; however some crucial aspects (frack out risk for HDD – impact on the bottom channel for Double Raise Boring) shall be carefully monitored during the execution of the Project.
- **PIPELINE INTEGRITY:** long term maintenance and durability of reinstatement has been considered critical for open cut solution. In this term both the trenchless solution offer a considerable improvement for this aspect.
- **SCHEDULE:** due to the severe climatic condition and the extreme events that could affect the Project Area, the time window available for the realization (limited to the summer period) of open cut solution has been recognize critical, since stabilization and reinstatement measures, to be realized soon after the installation of pipeline, are considered mandatory before the winter season. In this scenario both the solutions designed offer a considerable improvements: in fact after the preliminary preparation works both the strategies could be completed in different phases, not related to a unique time window.

According to the solutions designed, TMEP decided to consider **HDD** as the preferred technical solution. However **Double Raise Boring** may be considered a viable “Contingency Plan”, to be implemented in case of any unexpected failure of HDD, in order to be able to achieve the completion of the Project within the fixed deadline.

In conclusion, an attentive and detailed planning and design of the pipeline installation methodologies allowed to not only identify the most reliable and sustainable solution for the Dry Gulch crossing execution, but also to define a robust contingency plan, which allows to mitigate the impact of cost and schedule of an unlikely failure.