# *Engineering 'Lunch & Learn' Series*

# *Repair Methodologies for In-service Pipelines in both Shallow & Deep Waters*

***By: Ng Eng Bin***
***Principal Consultant***
***Submarine Pipelines Consulting Engineers***

# Introduction

- This presentation addresses available repair methods for in-service pipelines, i.e. after the pipelines have been installed and commissioned.
- It addresses viable repair methods for the pipelines repairs in shallow waters as well as in deep waters.
- The repair methods covered pertain only to the structural repairs of the main pipeline, and exclude repairs to the concrete coating, corrosion coating or sacrificial anodes.

# Failure Types

Generally, the repair methods and equipment selected for pipeline repair depends on the cause of failure, type of failure and extent of failure.

The most probable failures associated with most typical pipelines are:

- Anchor snag;
- Dropped object;
- Weld or material defect or seam weld failure;
- Local mechanical damage or material defect;
- Operational damage, e.g. internal corrosion, contamination, or fatigue;
- Previously undetected installation damage: or
- Fatigue failure caused by excessive span, seabed movement or other some environmental events, such as earthquake, etc.

# Repair Objectives

The key objective of any pipeline repair is to return the affected pipeline system to operational status in the shortest possible time, while at the same time ensuring that the following conditions are met:

- Safety of all personnel and equipment at all times;
- Prevention of environmental damage;
- Minimization of lost production;
- Optimization of repair duration; and
- Minimization of repair costs.

# General Repair Methods

Pipeline repairs are generally carried out by one or a combination of the following methods:

1. Lift to surface
2. On-bottom repair clamps
3. On-bottom replacement
    a. using horizontal spool
    b. using vertical spool

# Limits for Diver Intervention

Pipeline repair is problematic beyond the upper limit for diver intervention as all activities have to be performed using ROV equipment.

The common understanding for diver intervention is:

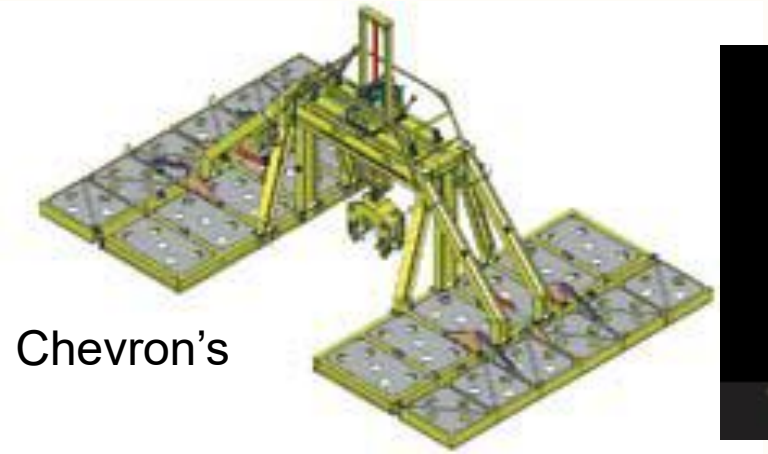
- Air diving is generally limited to 50m water depth, though some operations, e.g. Chevron limits this to 30m.
- Saturation diving can practically be performed up to 250m water depth.
- It is not economically viable to use diver intervention in water depths deeper than 250m.
- ROV intervention can be used generally in both shallow and deep waters.
- May need to work more closely with ROV operators to come up with viable solutions for pipeline repair beyond 1000m.

# General Classification for Repairs

| Type of Failure | Viable Repair Method | |
|---|---|---|
| | **Shallow Water** | **Deep Water** |
| **Pin hole** | On-bottom repair using Repair Clamp (Diver/ ROV support) | On-bottom repair using Repair Clamp (ROV support) |
| **Dent** | On-bottom repair using Repair Clamp; or Cut & lift to surface; or on-bottom repair using horizontal or vertical spools (Diver/ ROV support) | On-bottom repair using Repair Clamp; or Cut & lift to surface; or on-bottom repair using horizontal or vertical spools (ROV support) |
| **Wet buckle** | Cut & lift to surface, or on-bottom repair using horizontal or vertical spools (Diver/ ROV support) | Cut & lift to surface, or on-bottom repair using horizontal or vertical spools (ROV support) |
| **Rupture** | Cut & lift to surface, or on-bottom repair using horizontal or vertical spools (Diver/ ROV support) | Cut & lift to surface, or on-bottom repair using horizontal or vertical spools (ROV support) |
| **Multiple damage/ long section** | Cut & lift to surface, or on-bottom repair using horizontal or vertical spools, or long replacement spool via pipelaying & hot-tapping (Diver/ ROV support) | Cut & lift to surface, or on-bottom repair using horizontal or vertical spools (ROV support) |

## Components and Support Equipment of Pipeline Repair System

Pipeline lifting frames are required to raise the pipeline from the seafloor so that repair works can be carried out. They are typically installed over the pipelines by divers or ROV assisted. Typical examples:



Chevron’s


Oil State’s


STATOIL’s

# Pipe Cutting Tools

There are four primary types of subsea pipeline cutters. These are:

1. Guillotine Saw: The saw clamps to the pipe and hydraulically moves a blade through the pipe.
2. Rotary Cutter: A band is installed around the pipe, which provides the track for the cutter to follow. The cutter tracks around the pipe to complete the cut.
3. Diamond Wire Saw: The saw uses a diamond-coated wire formed into a closed loop.
4. Grinder: A rotating grinder can be an effective means to cut small diameter pipelines.
5. Abrasive water jet cutter: A high pressure jet using combination of water and abrasive ingredients.

# Coating Removal Tools

Coating removal tools are used for removal of concrete coating and corrosion coating on the pipeline before further repair work can be carried out.

- Concrete removal tool utilizes high pressure water jet to cut through the concrete coating and wire reinforcement.
- Corrosion coating removal tools generally consist of a set of rotating wire brushes installed onto a guide frame.

**Typical Concrete Coating Removal Tools: (L) STATOIL and (R) CAPE**

# Pipe End Preparation & Acoustic Measurement Tools

## Pipe End Preparation Tools

End preparation tools can be indexed on either the pipe internal using a mandrel or by clamping onto the external of the pipe.

## Acoustic Measurement Tools

Once the pipeline has been cut and the damaged section removed, significant springing between the cut ends may be expected, and misalignment would occur. Accurate measurement of the pipe ends (using acoustic measurement tools) in terms of the following need to be taken in order to fabricate an accurate spool piece:

- Pitch (for horizontal and vertical spool)
- Roll (for vertical spool)
- Yaw (for horizontal spool)
- Height (for horizontal and vertical spool)
- Heading (for vertical spool)

Figure 3.3.2-3: Oil States Diverless Pipe Recovery Tool (Ref 5)

# Pipe RecoveryTools

Recovery of pipeline to the surface can be carried out by a number of methods, including:

- Ball grab
- Drop-on clamps
- Mechanical clamps

The purpose of these recovery tools is to bring the severed pipe end to surface for connection to components of the pipeline repair system, e.g. PLET, flange, etc.

Oil states Diverless Pipe Recovery Tool

# Repair Clamps

- If pipeline damage is limited to small area and the line is not severed, a permanent repair can be made by installing a repair clamp.
- These are typically split sleeve type clamp that are joined by studs and nuts to form a high integrity pressure vessel around the pipe.
- For shallow water, the clamps can be either diver or ROV installed, but for deep water, these are ROV installed.

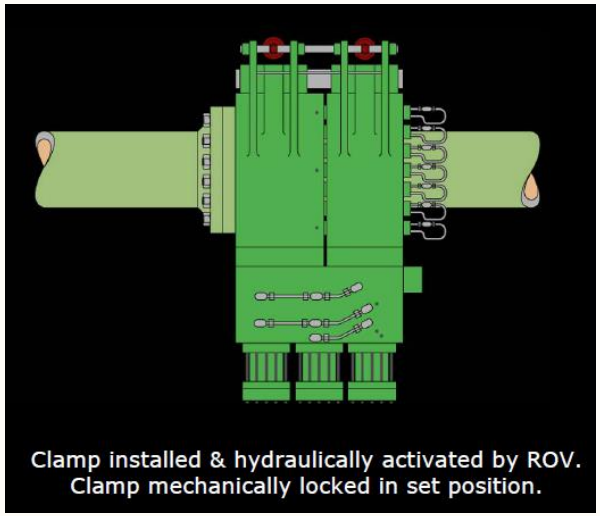
**Typical Dual Seal Repair Clamp from STATS Group**

**ROV-operated Repair Clamp by Oceaneering**

# Repair Clamps (Cont'd)



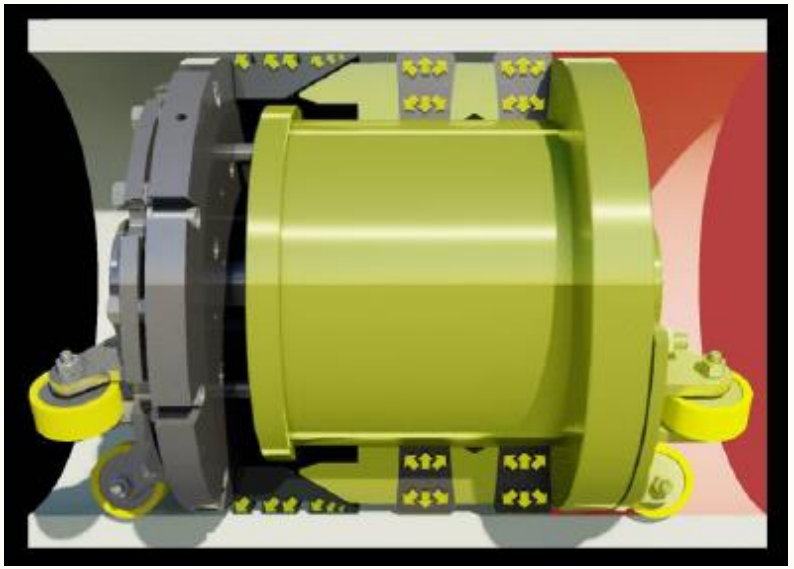
Oil States' (L) Diver-Assisted and (R) ROV-Operated Clamp




ROV Operated Clamps from CAPE

# Isolation Plugs

- Isolation plugs are used to provide a barrier to contain fluid/gas under pressure or to prevent migration of vapour.
- Useful tool for isolating the damaged section of a pipeline so that repair can be carried out with minimal risk to divers or/and without risk of pollution.
- Isolation plugs can be delivered to the problem location by pigging or by tether or by remote operation.



Isolation Plug from STATS Group with double block and bleed capability.

# Lift to Surface Method of Repair - Shallow Water

A construction barge or laybarge with davits may be used to pick up the pipeline and perform the repair:

**Possible Option 1 (flange connection)**

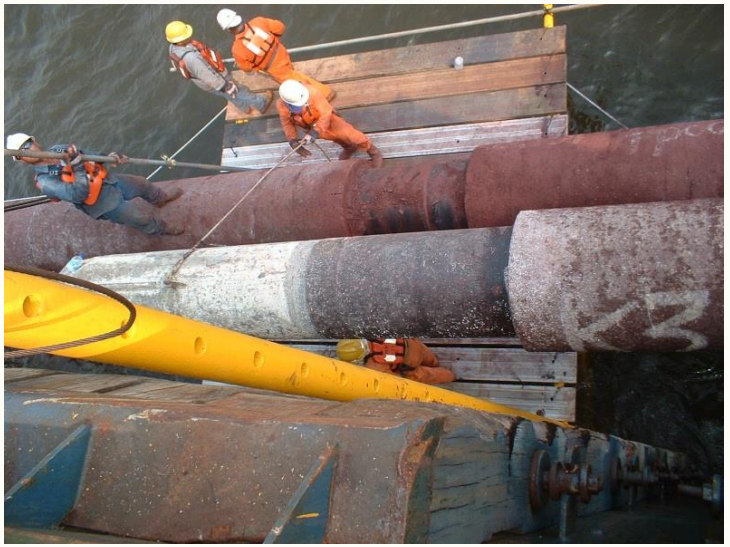
- Remove or isolate production
- Remove coating and cut pipe
- Attach davit lines to one segment of the pipeline
- Davit lift one segment of pipeline up so that the pipe end is at work level on the barge
- Secure pipe to barge and remove excess pipe as required
- Bevel pipe end and install flange
- Lower pipe to seabed and remove davit lines
- Repeat for the other cut segment of pipe
- Take measurements, fabricate horizontal rigid jumper spool, then connect both ends with horizontal spool.
- Test for integrity

# Typical Davit Lift method to recover pipeline to surface (not for repair – but concept is similar)

# Lift to Surface Method of Repair - Shallow Water (Cont'd)

**Possible Option 2 (welded connection):**
Remove or isolate production
Remove coating and cut pipe
Attach davit lines to both segments of the pipeline and add buoyancy tanks to control pipeline stresses (see note 1)
Davit lift both segments of pipeline up so that the pipe end is at work level on the barge and both pipe ends are horizontal
Secure pipe to barge and bevel pipe ends
Take measurements, fabricate pup piece and weld pup piece to both ends of pipeline
Lower to seabed
Test for integrity
(Note 1: If davits do not have the capacity to pick up the wet pipeline, then the pipeline segments would need to be dewatered first. To do this, a PRT is attached to the ends of both pipe segments, and a dewater pig is run from each end of the pipeline to remove the water. The PRTs will the act as the pig receivers. )

# Typical method of lifting pipeline to surface for tie-in (example shown is not for of repair, but concept is similar)



# Lift to Surface Method of Repair – Deep Water

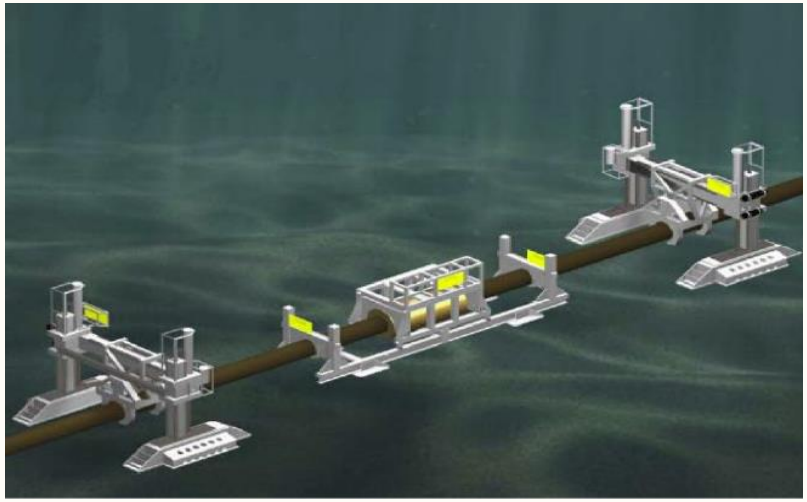
A construction vessel is used to recover damaged pipeline ends to surface where a PLET is welded to each end, lowered to seabed, measurement taken, rigid jumper spool made, then connected to the upward looking hubs on the PLET, where ROV actuates the collet connectors on each end of the jumper. The following sequence is typically followed:

- Remove or isolate production
- Cut pipeline
- Remove coating
- Install recovery clamp on one section
- Recover and secure pipeline to vessel
- Install PLET and abandon
- Repeat above steps for other pipeline end
- Measure, fabricate and install jumper
- Verify integrity

# On-bottom Repair using Clamps

- For localised repair on pipe that is not deformed, such as pin hole leak, clamping devices in either structural or non-structural form provide the most cost effective and efficient repair method.
- Traditional diver installed clamps have been modified for ‘deeper’ waters for ROV applications using same proven technology.
- On-bottom clamping methods require the following sequence of operation:
  - Coating removal
  - Seal area preparation
  - Clamp installation
  - Integrity verification
- Pipeline repair using specialized clamps, e.g. Morgrip Repair Couplings, is relatively straight-forward:
  - Concrete coating is removed by underwater concrete removal tool, cleaned, and the repair coupling fitted over the repair area.

# Underwater repair using repair couplings



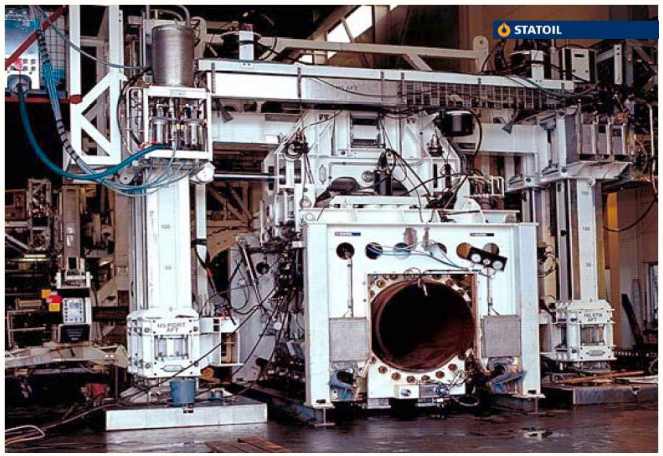
Schematic Showing Equipment Deployed Underwater for Pipe Clamp Installation

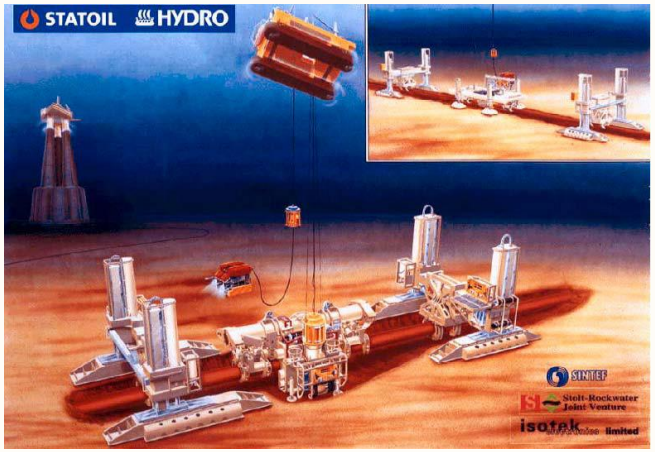
Handling Frame for Repair Couplings

Morgrip Repair Couplings in Storage


# On-bottom Horizontal Spool Repair System

- The conventional approach to deep water pipeline repair has been to develop large ROV tools that are capable of raising the pipeline and removing the damaged section followed by manipulation of the severed ends before insertion of an expandable horizontal spool.
- The process is often supplemented by the inclusion of swivel joints to allow for misalignment.
- This approach had been adopted by Saipem (Sonsub) for the Bluestream Project and by Statoil for their North Sea infrastructure.




Statoil Emergency Pipeline Repair System

# On-bottom Horizontal Spool Repair System (Cont'd)

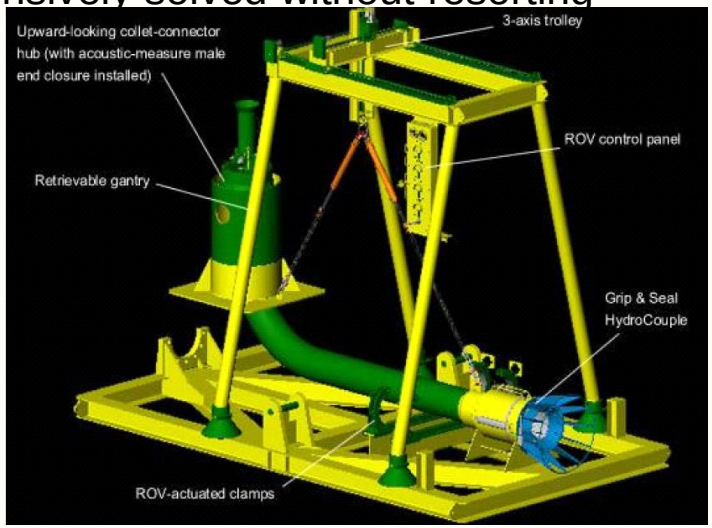
Left: Sonsub Brutus System & Right: Morgrip Diverless Connector

- The principal weakness of the horizontal spool approach is that it is not very effective at dealing with misalignment between the cut ends. It is likely that when the damaged section of the pipeline is removed, significant springing would exist between the two cut ends.
- Misalignment in various degrees of freedom would need to be accounted for before a replacement spool could be installed.

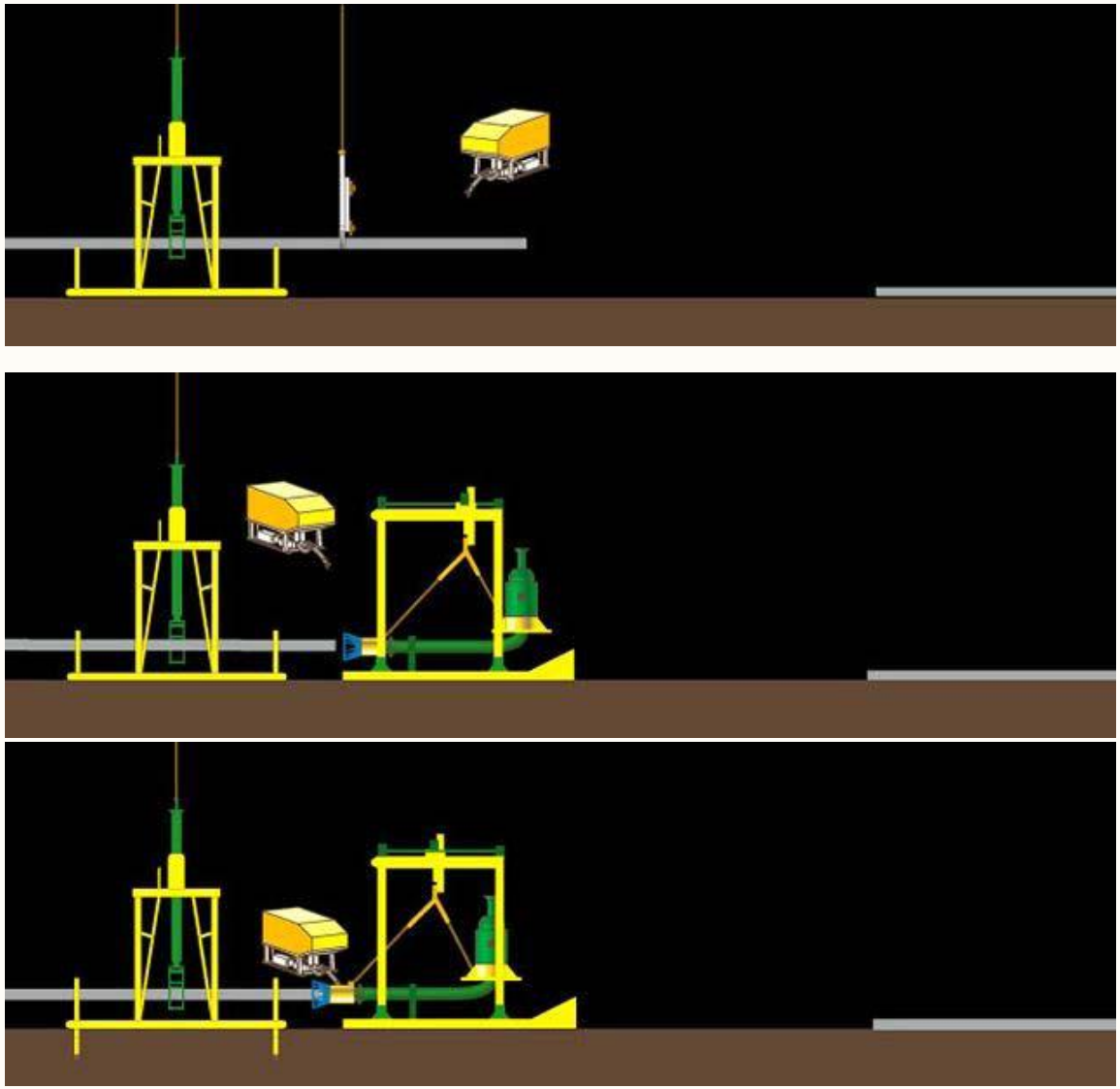
# On-bottom Repair by Vertical Spool

- In the vertical spool repair system, the replacement spool is orientated in the vertical direction.
- This repair system is used mainly for pipeline repair where use of divers is not preferred.
- The connection of the vertical spool is achieved with vertical collet connectors consisting of a female collect attached to the spool and a male hub attached to the pipeline under repair.
- The upward facing hub is attached to the severed ends of the pipeline using grip and seal connectors inter-connected via 90$^{o}$ elbows.
- In this arrangement, the modular assembly of the repair lends itself to ROV assembly and the issue of misalignment is comprehensively solved without resorting to swivel joints.
- Some specialised equipment is required such as a gantry frame to attach the connector-elbow-hub assembly to the severed end.

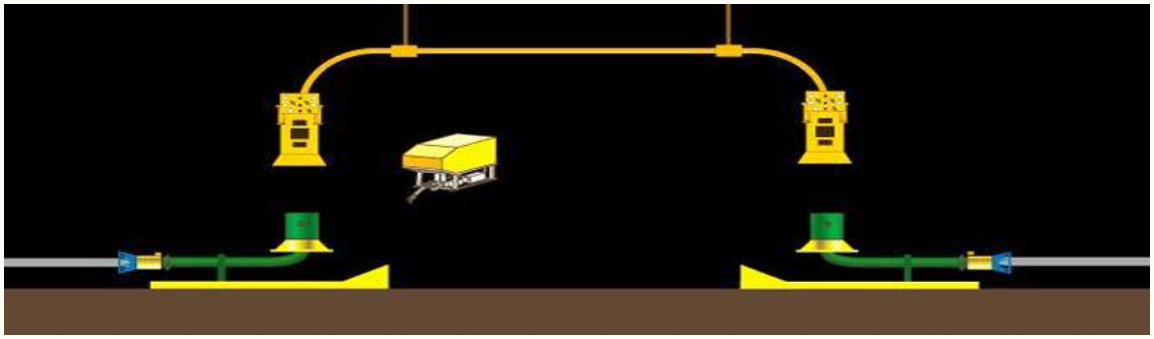
An example of a typical gantry frame



# Diverless sequence of events associated with a typical vertical spool pipeline



# Diverless sequence of events associated with a typical vertical spool pipeline (Cont'd)



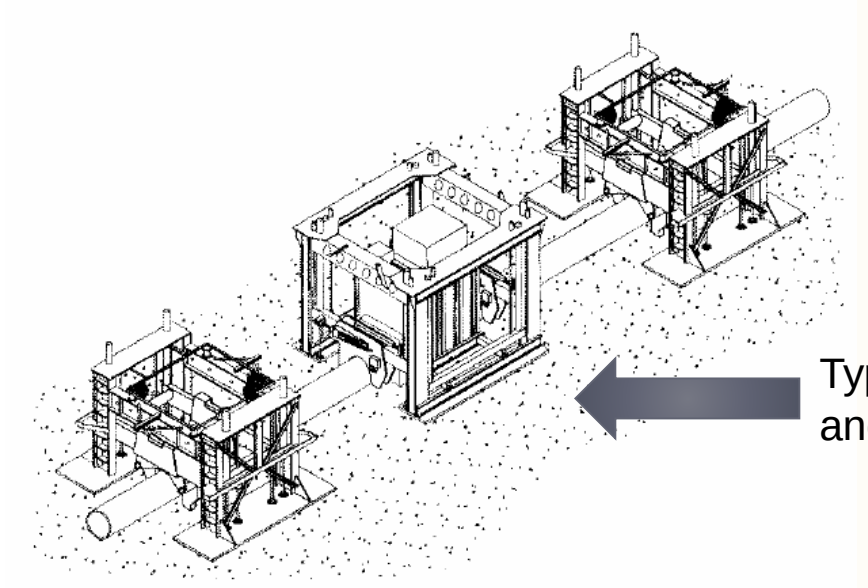
# On-bottom Repairs by Hyperbaric Welding

- Hyperbaric welding refers to welding works carried out under water but in a dry habitat by a specialised subsea contractor using highly skilled diver welders.
- This process is used for underwater repair of pipeline where a permanent repair is required. This method is also classified as horizontal spool repair.
- Hyperbaric welding is carried out under water and in a dry atmosphere created by the welding habitat. The habitat atmosphere is a breathable mix of helium and oxygen gases.
- Diver welders are deployed from the pressurised chamber on board the vessel and then swim from the diving bell to the welding habitat, remove their diving equipment and dress in fireproof coveralls for welding and related activities.
- The welding habitat is set up inside as a welding station allowing two diver welders to work at the same time in a dry environment.
- Manual hyperbaric welding is most commonly used as it can comply with most national specifications and is cost effective in the depth range of zero to 200m water depth.
- Hyperbaric welding equipment is normally modular and transportable as freight for mobilisation to anywhere in the world.

# Typical hyperbaric system

A typical hyperbaric system comprises the following components:

- One unit of Combined Habitat & Alignment System (CHAS)
- Two units of Pipe Handling Frames (PHFs)
- One unit of Welding & Diving Station (WADS)
- A series of umbilicals and winches to servise the CHAS.



Typical Seabed Arrangement for PHFs and CHAS for Hyperbaric Operation

# Typical hyperbaric system (Cont'd)

**Combined Habitat & Alignment System (CHAS)**

- The CHAS is a fabricated steel structure which is sealed to provide a dry environment within which the welding process can be undertaken.
- The position of the habitat within the frame can be adjusted for alignment with the pipeline.
- The pipeline itself can be manipulated by holding clamps located under each portal frame end.
- The habitat is equipped with all functions required for welder-diver life support and the welding process itself.

**Pipe Handling Frames (PHFs)**

- The PHFs are fabricated steel box shaped frames housing a lift platform containing a pipe clamp.
- The PHFs are utilised to manipulate the pipeline to provide the basic alignment prior to welding.

# Typical hyperbaric system (Cont'd)

**Welding & Diving Station (WADS)**

- The WADS is a containerised module from which the control and monitoring of all aspects of the habitat welding activity is carried out.
- The unit is normally stationed on deck of the support vessel.

**Umbilicals & Winches**

The CHAS system utilises service umbilicals to provide power and instrumentation to the habitat and PHFs.

# Hyperbaric Welding Facility

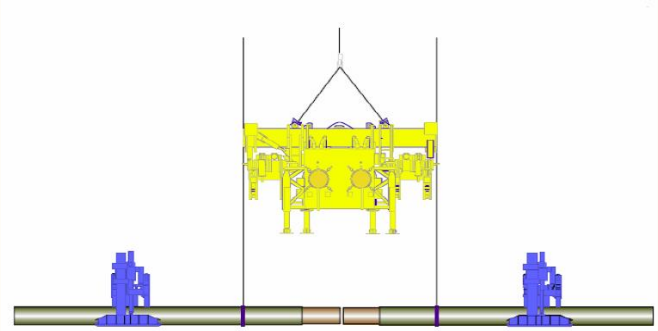
Prior to actual hyperbaric operation, the weld procedures and welders will need to be qualified. This is normally carried out at a land based hyperbaric welding facility.

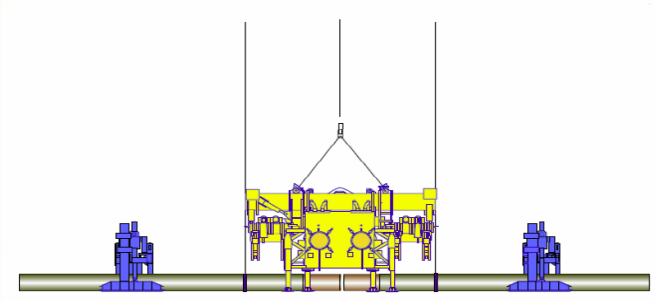
Welding trials ongoing in the work chamber of a Hyperbaric centre (L) and Saturation Control (R)

# Typical Hyperbaric Operation

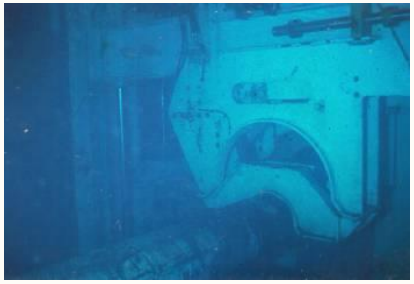
Typical hyperbaric operation comprises the following activities:

- The diver or ROV carries out a visual or video survey of the seabed area where the equipment is to be positioned.
- Pipe handling frames (PHFs) are utilised to manipulate the lengths of pipe to be welded in order to provide alignment.
- The divers measure and mark out the locations of the PHFs. The distance of each PHF from the weld is determined by analysis during the engineering phase to provide the optimum alignment of the pipe ends for welding.
- PHFs are deployed subsea by the vessel crane until the divers have visual contact.
- Divers guide the PHFs into position over the pipeline, typically one PHF each side of the weld.
- The habitat within the CHAS is then lowered onto the pipes and final alignment is achieved using a combination of the PHFs and the CHAS clamps.
- Final fit-up is achieved by a combination of the PHFs and the clamps on the CHAS itself.



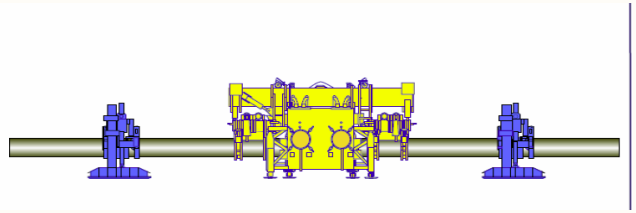


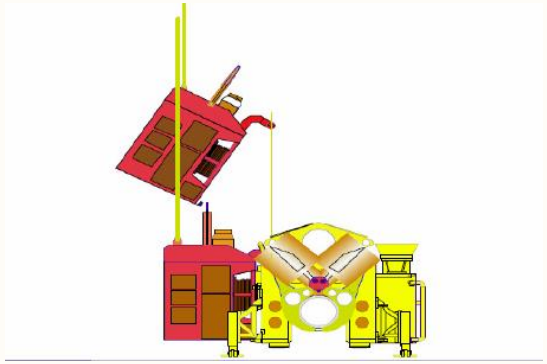
Deployment of CHAS over Pipeline after PHFs are Deployed



Deployment of CHAS over the side of vessel and onto the pipeline repair location

After the pipeline has been aligned in the CHAS, the doors are fitted to seal the habitat around the pipes and the habitat is blown-down utilising the appropriate gas mix for the divers to breath at the relevant depth.





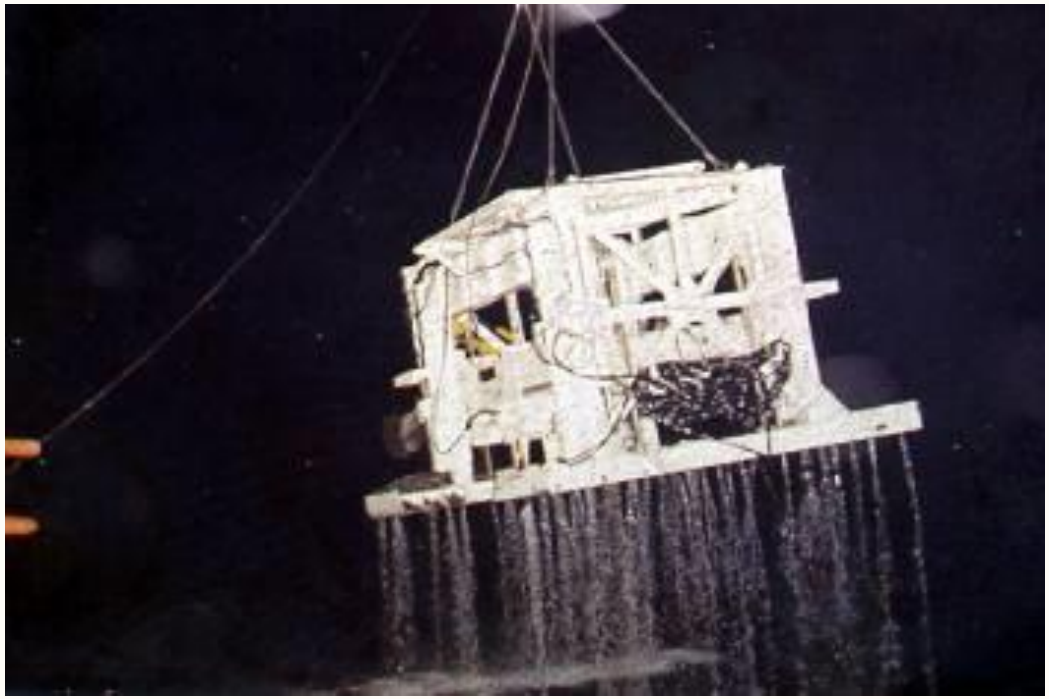
With the habitat now dry, the divers can dress out of their diving equipment and commence preparations for welding.
When ready, the pre-heat and welding umbilicals are deployed from surface and connected to the habitat.
After pre-heating, welding begins.

All supplies to the habitat are monitored and controlled on deck from the Welding and Diving Station (WADS).

From the WADS, supervisory personnel maintain communication with the divers, monitor and control weld parameters including gas and power for the welding process, record weld data and monitor and control life support parameters within the habitat.

Supervisor in WADS Controlling the Hyperbaric Welding Operation

- Following completion of the welding process, NDT is performed to approve the weld.
- After the weld is approved and field joint coating applied, the habitat is de-rigged and the equipment recovered to deck.



PHF Recovered to Surface after Completion of a Weld

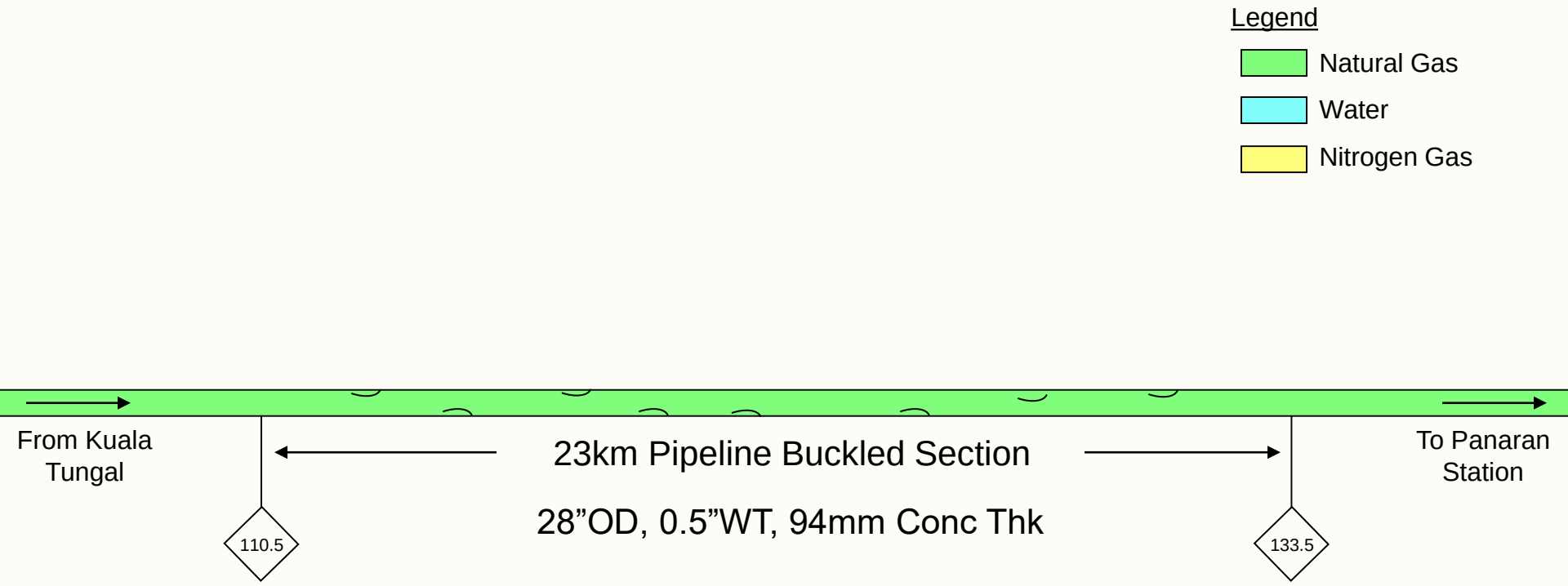
# Repair by Hot-tapping

- Repair by ‘hot tapping’ has been used for pipelines that have not ruptured and where the Operator requires the pipeline to be repaired in ‘live’ condition.
- The operating pressure of the pipeline may need to be reduced during the hot-tap operation.
- Typically, the hot tapping solution package includes hot taps, plugs (e.g. TDWilliamson’s STOPPLE plugs) and associated accessories.

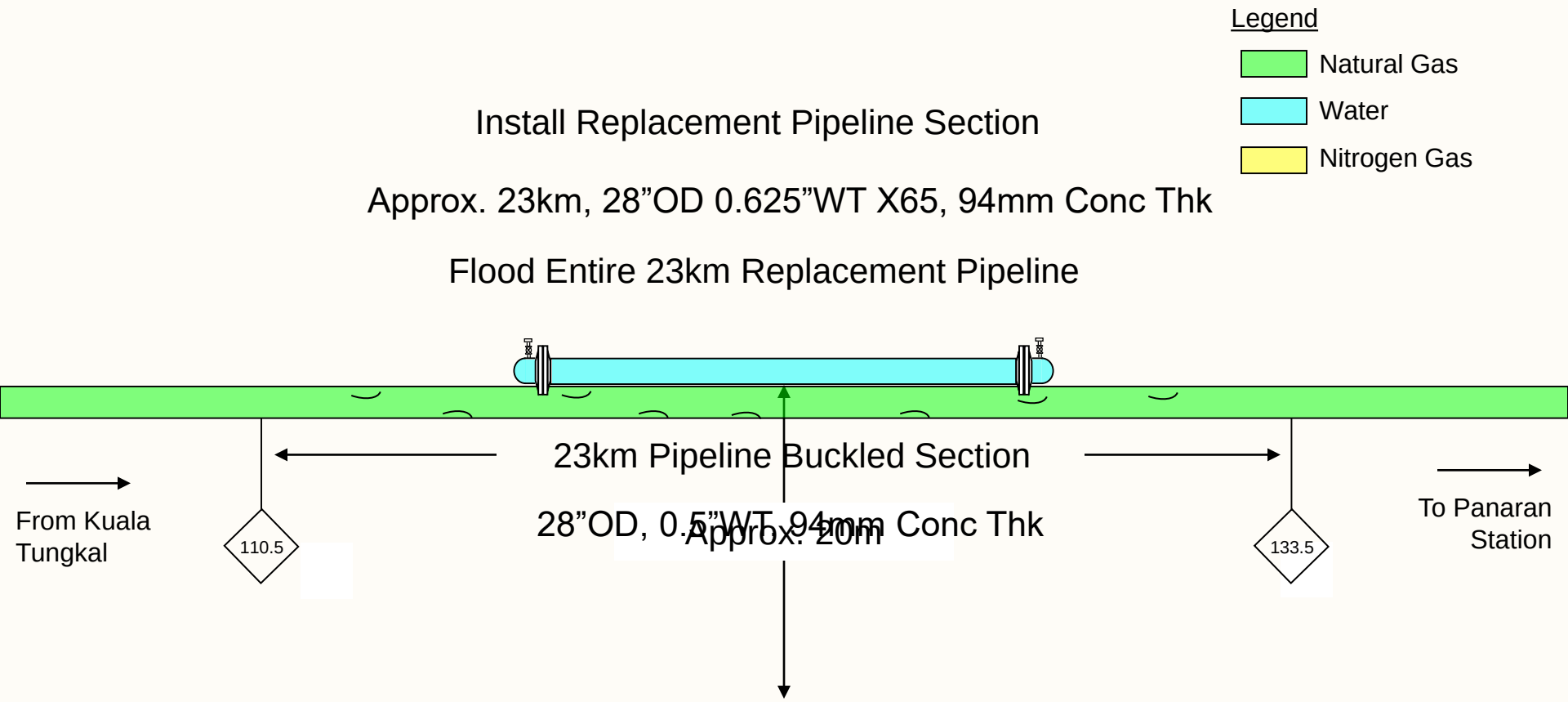
# Key Component for  Hot-tapping – Hot Tapping Machine


# Key Component for  Hot-tapping – Stopple Plugs


# Hot-tap Repair Method – Zero Downtime



# Hot-tap Repair Method – Zero Downtime (Cont'd)

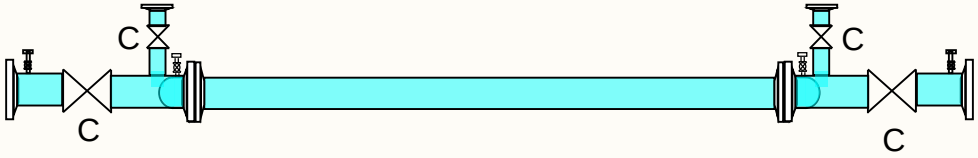


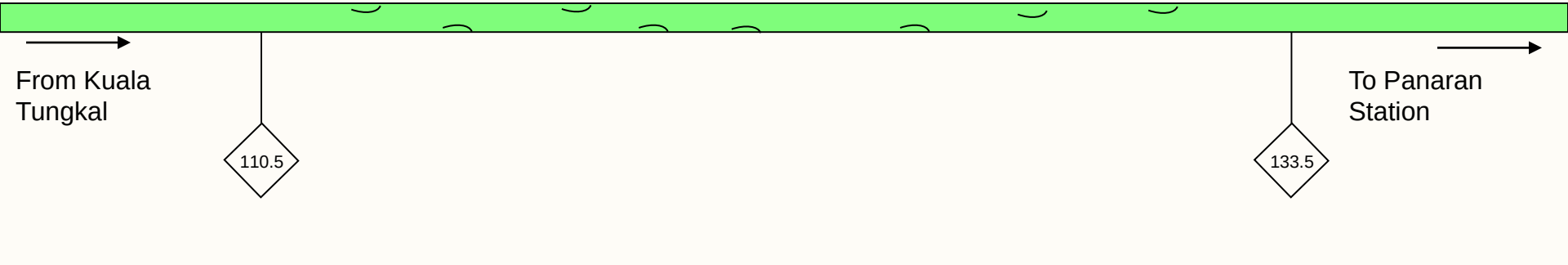
# Hot-tap Repair Method – Zero Downtime (Cont'd)

Legend

- Natural Gas
- Water
- Nitrogen Gas

Install Valve Skids at Both Ends after Cleaning



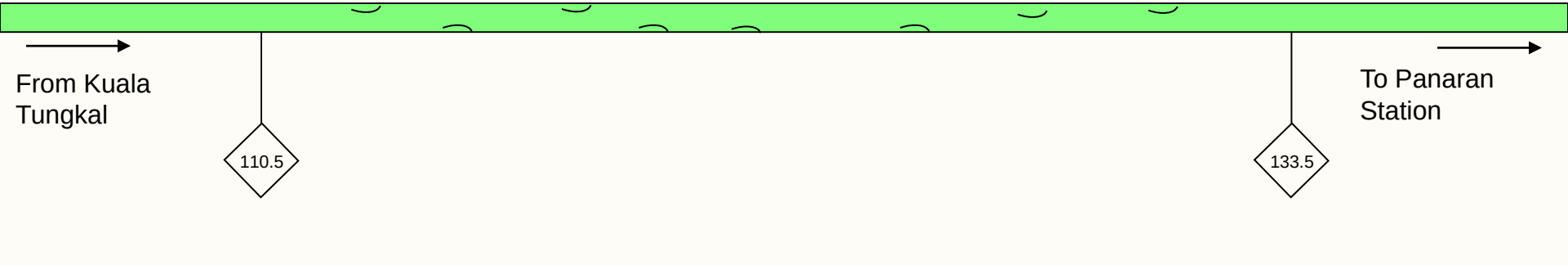
# Hot-tap Repair Method – Zero Downtime (Cont'd)

Legend

- Natural Gas
- Water
- Nitrogen Gas

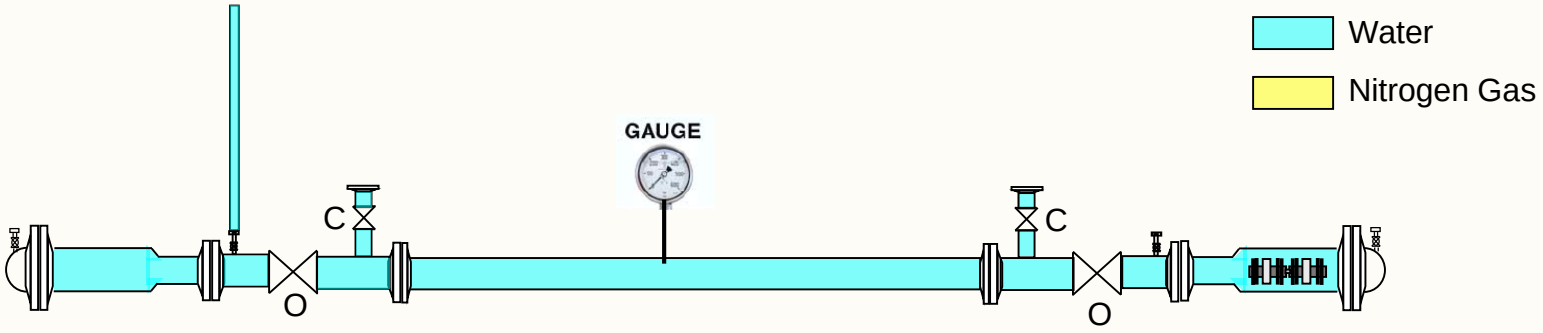
Install Temporary Pig Receiver & Launcher

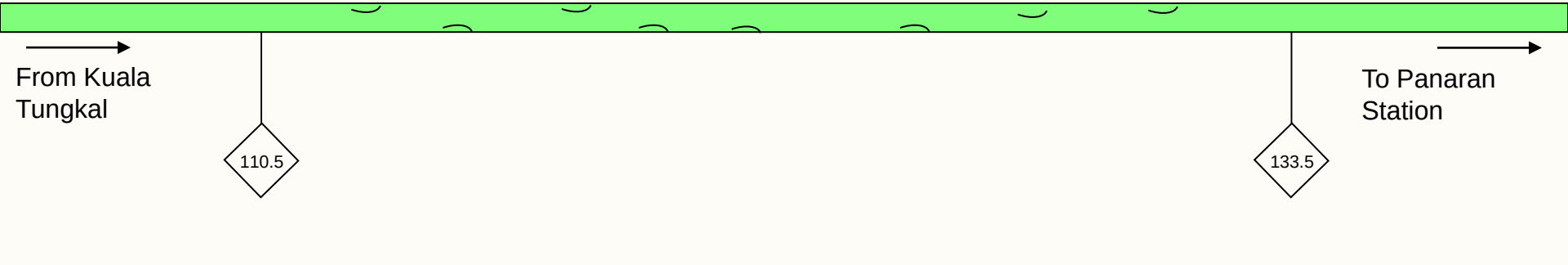
Perform Gauging on Replacement Pipeline

# Hot-tap Repair Method – Zero Downtime (Cont'd)

Dewater Replacement Pipeline After Hydrotest
Perform Hydrotest on Replacement Pipeline



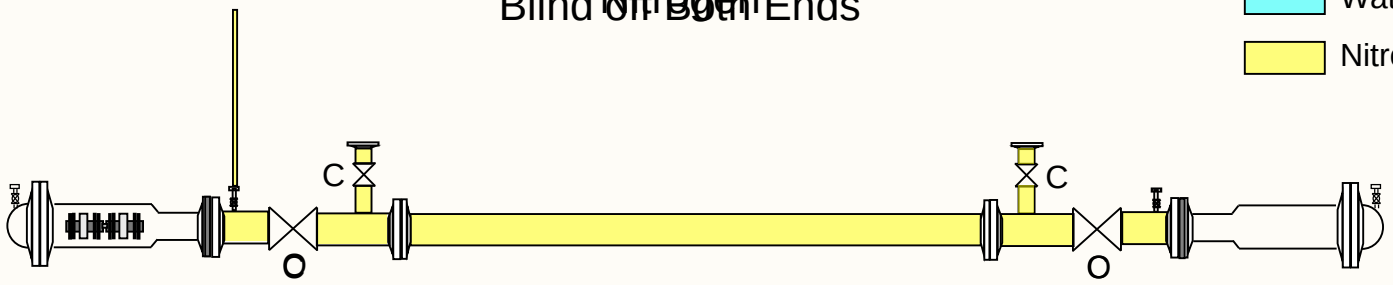
# Repair Method – Zero Downtime

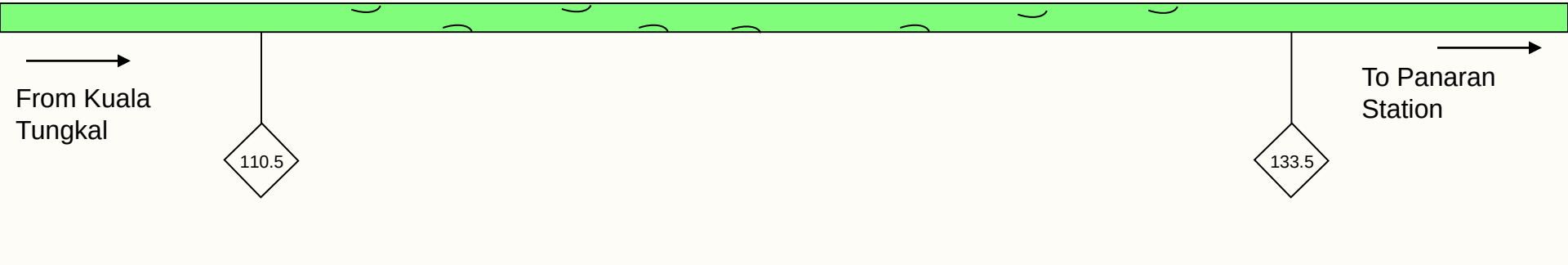
Remove Temporary Pig Receiver & Launcher

And

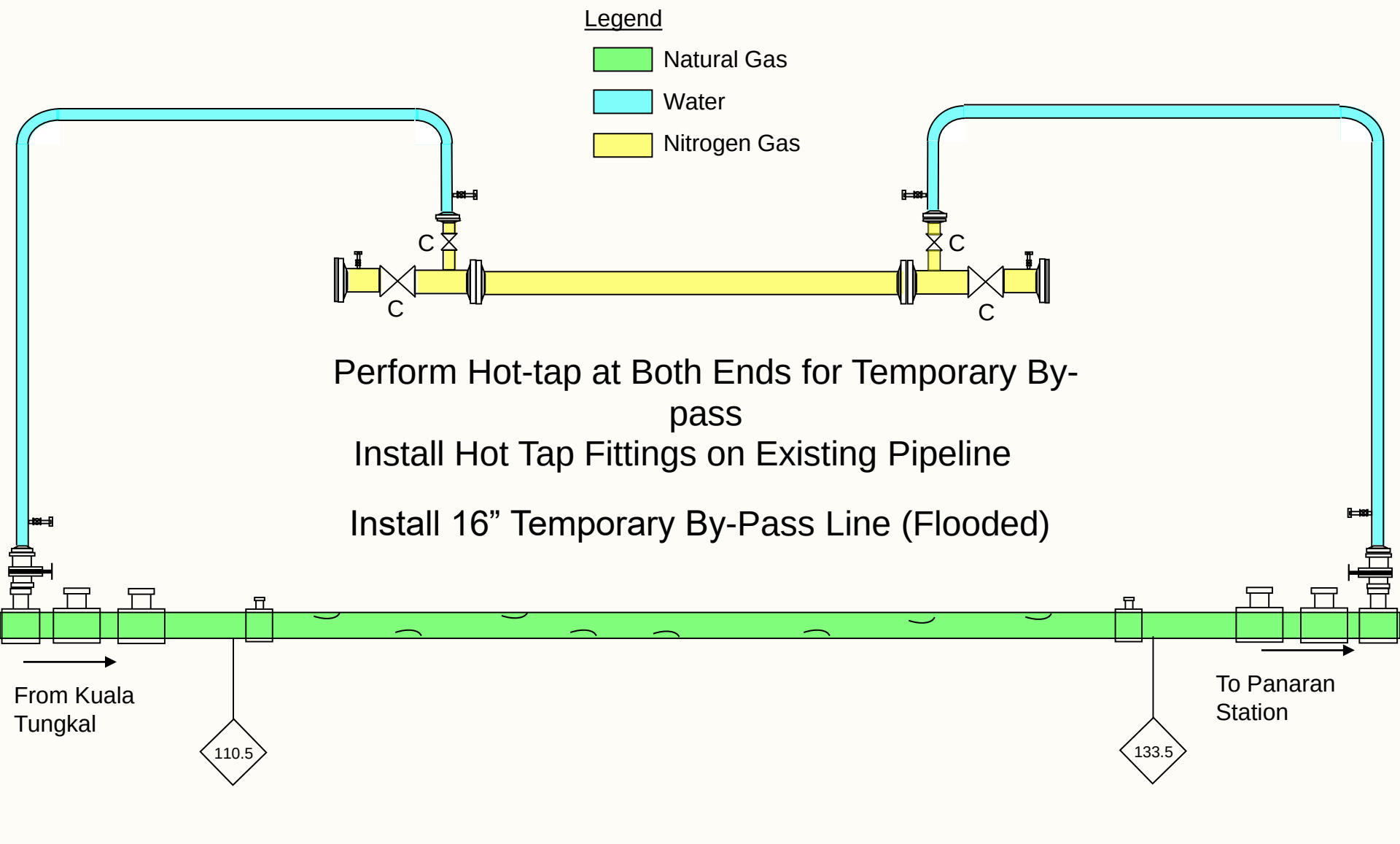
Vacuum Dry Pipeline and Fill Pipeline With Nitrogen

Blind off Both Ends

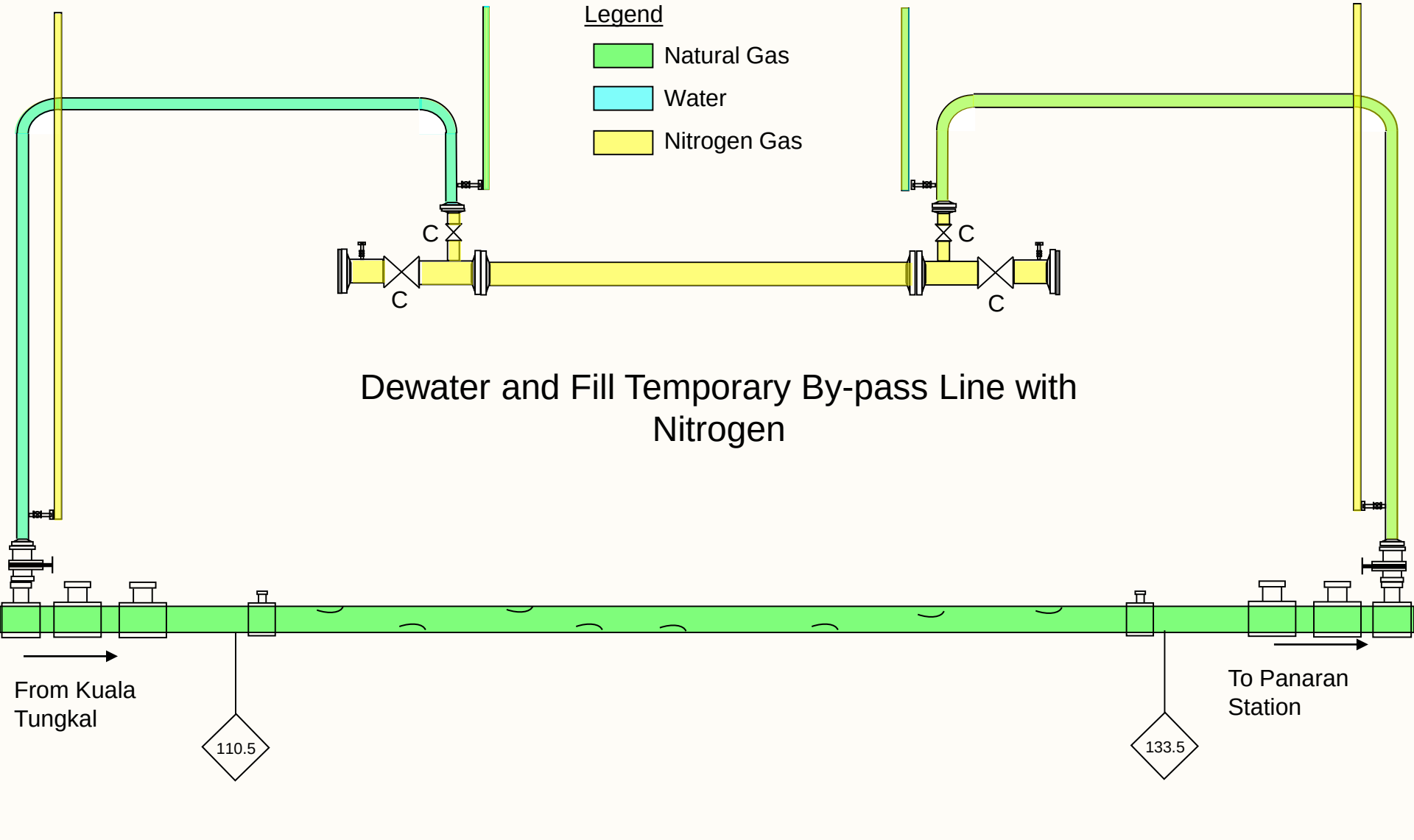


# Hot-tap Repair Method – Zero Downtime (Cont'd)

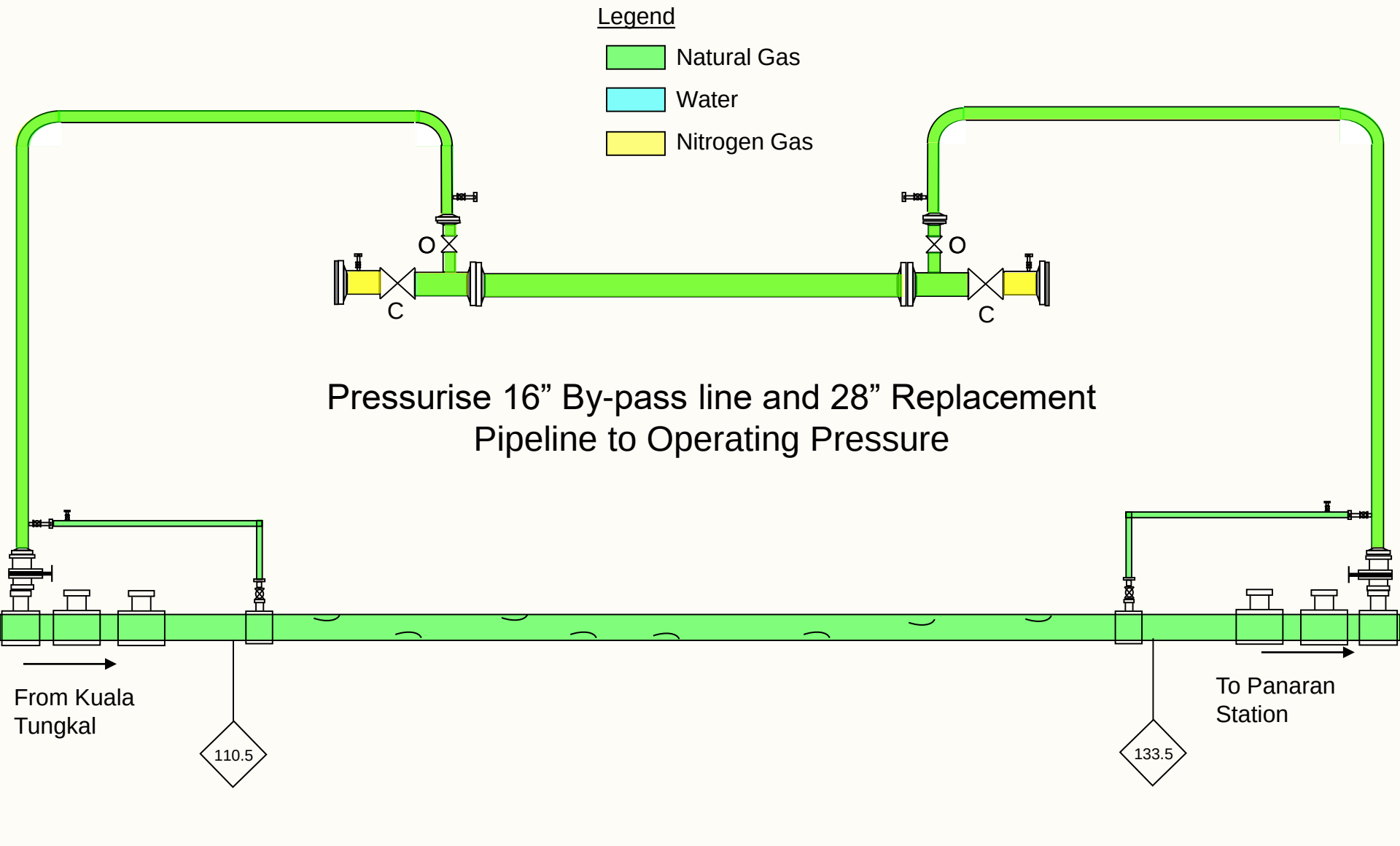


# Hot-tap Repair Method – Zero Downtime (Cont'd)

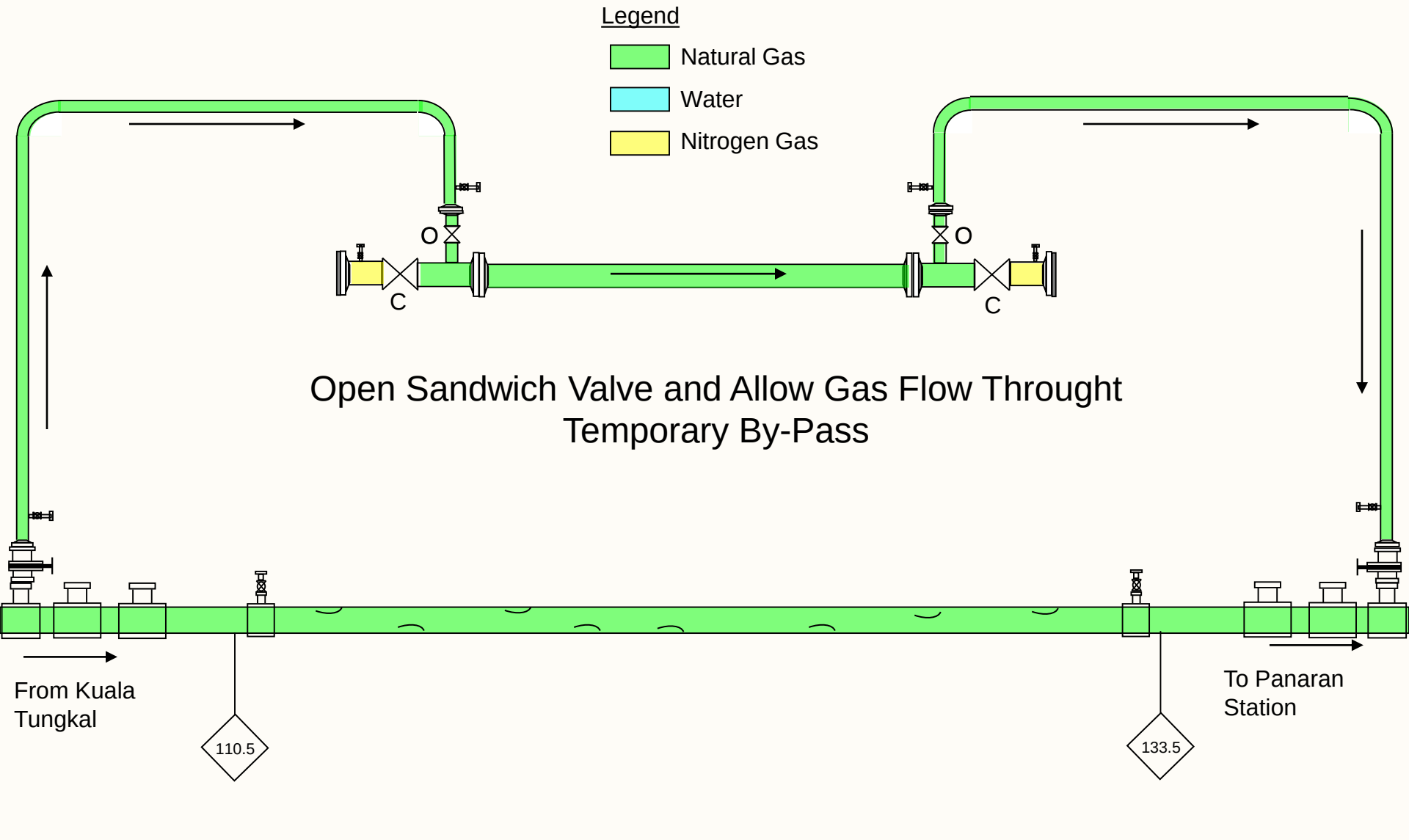



Dewater and Fill Temporary By-pass Line with Nitrogen

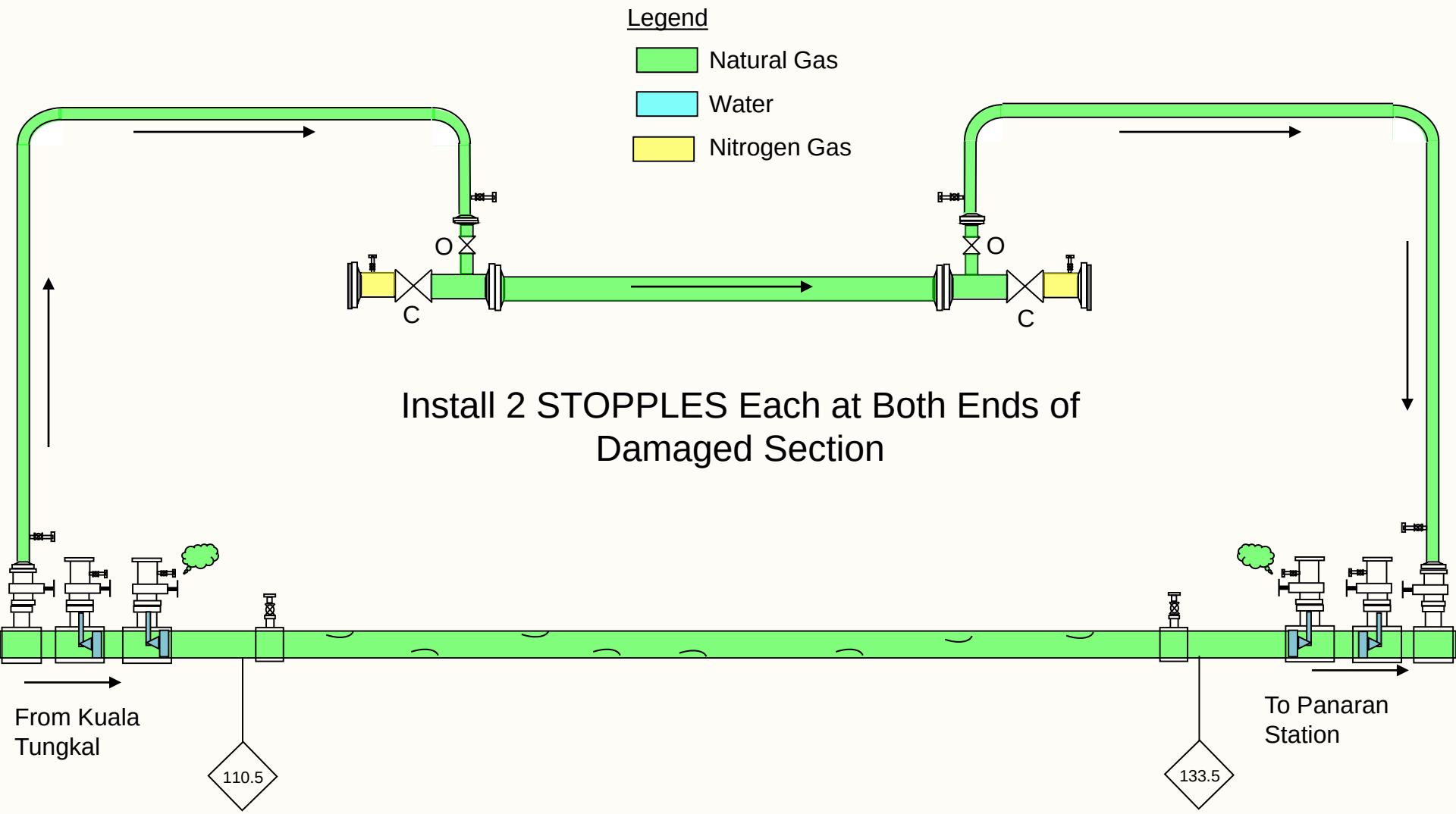
# Hot-tap Repair Method – Zero Downtime (Cont'd)



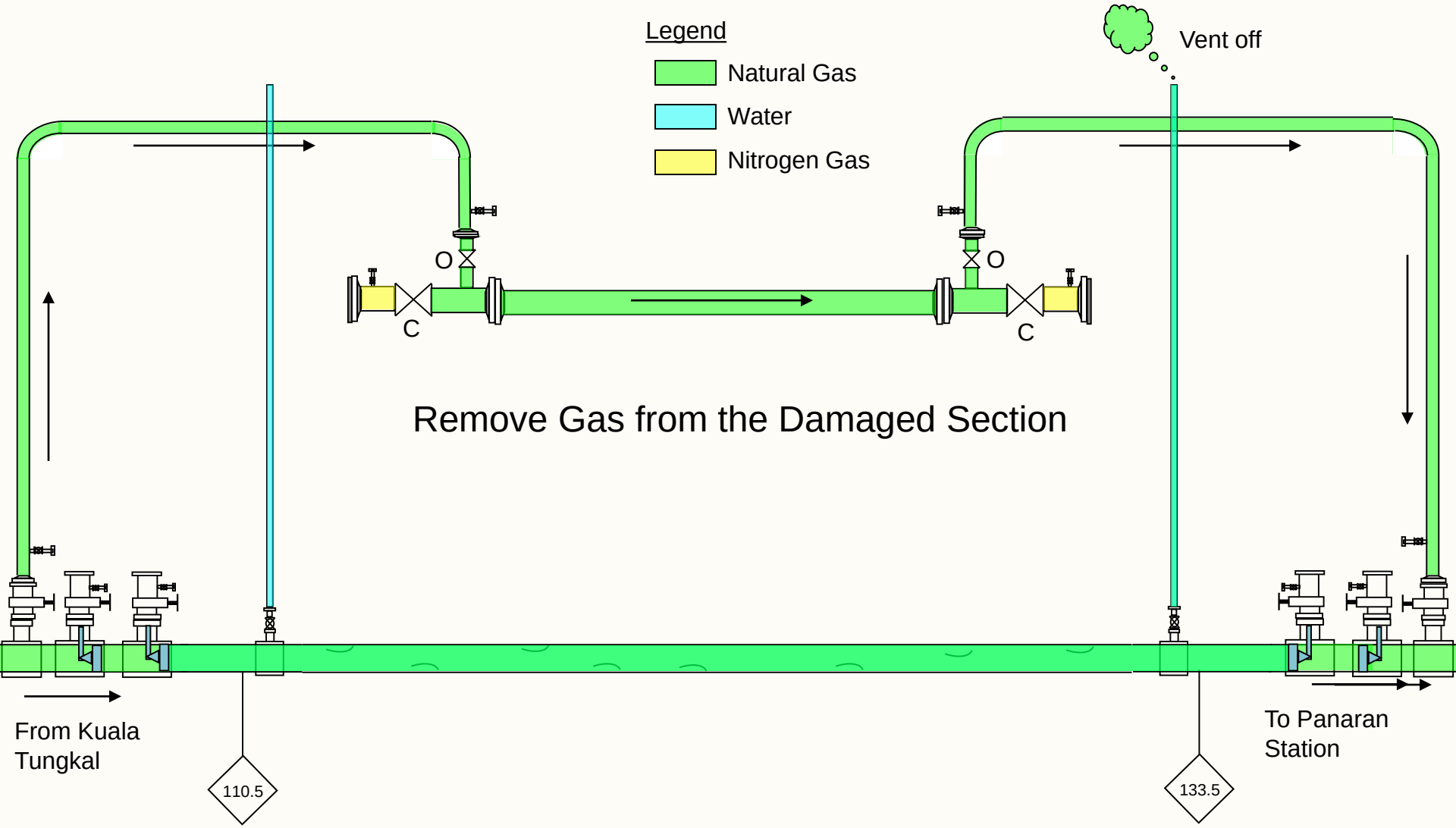
# Hot-tap Repair Method – Zero Downtime (Cont'd)



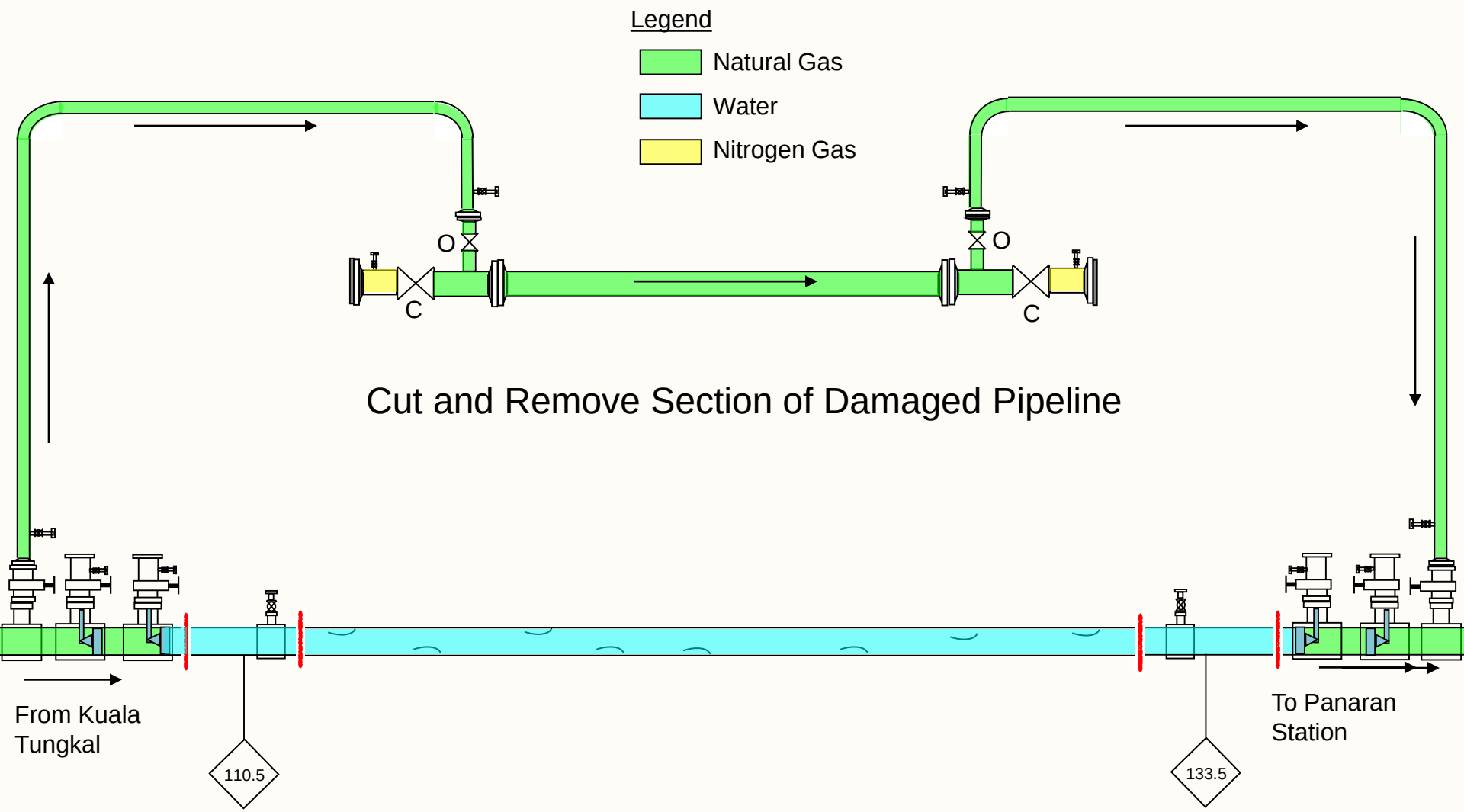
# Hot-tap Repair Method – Zero Downtime (Cont'd)



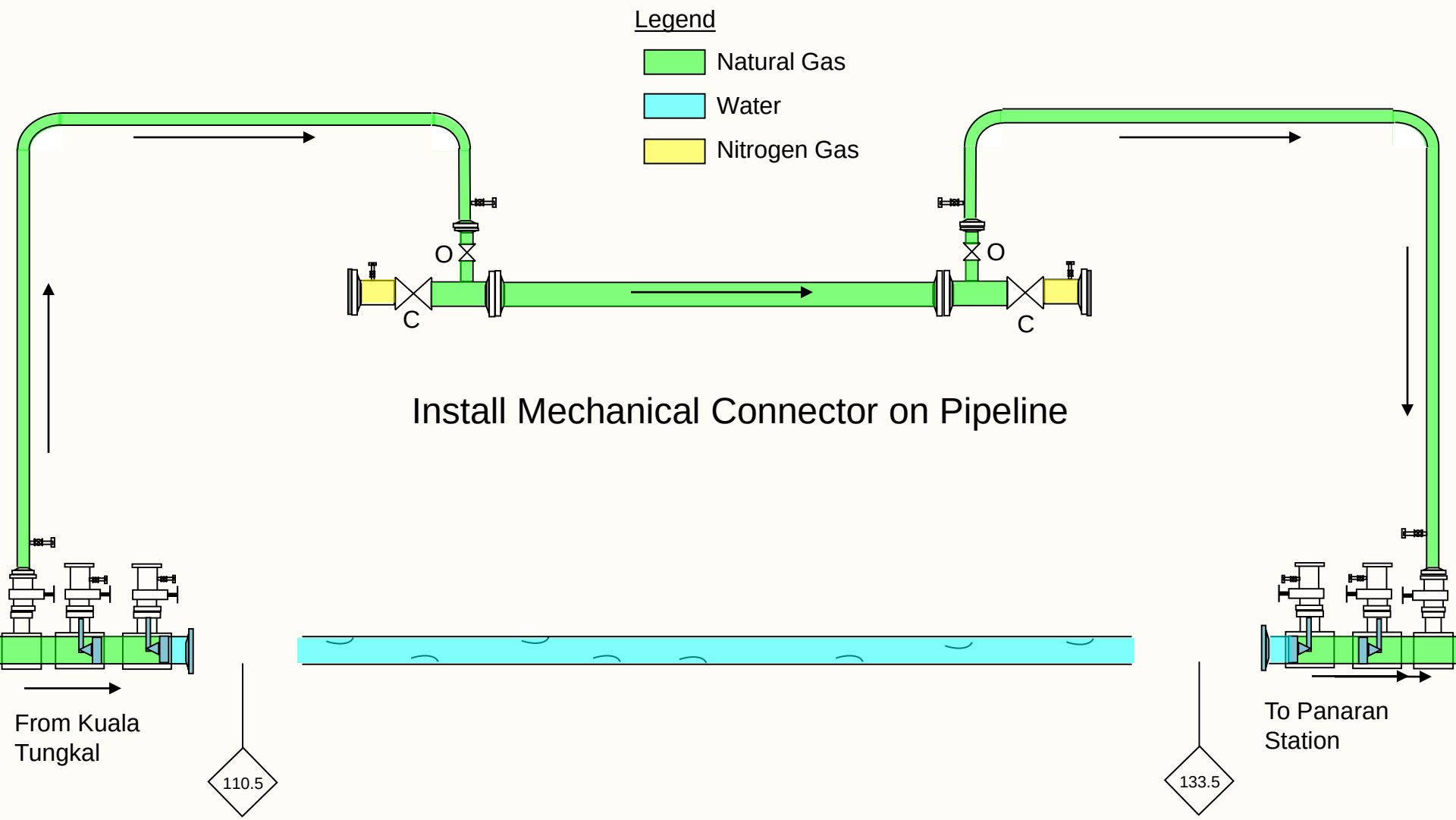
# Hot-tap Repair Method – Zero Downtime (Cont'd)



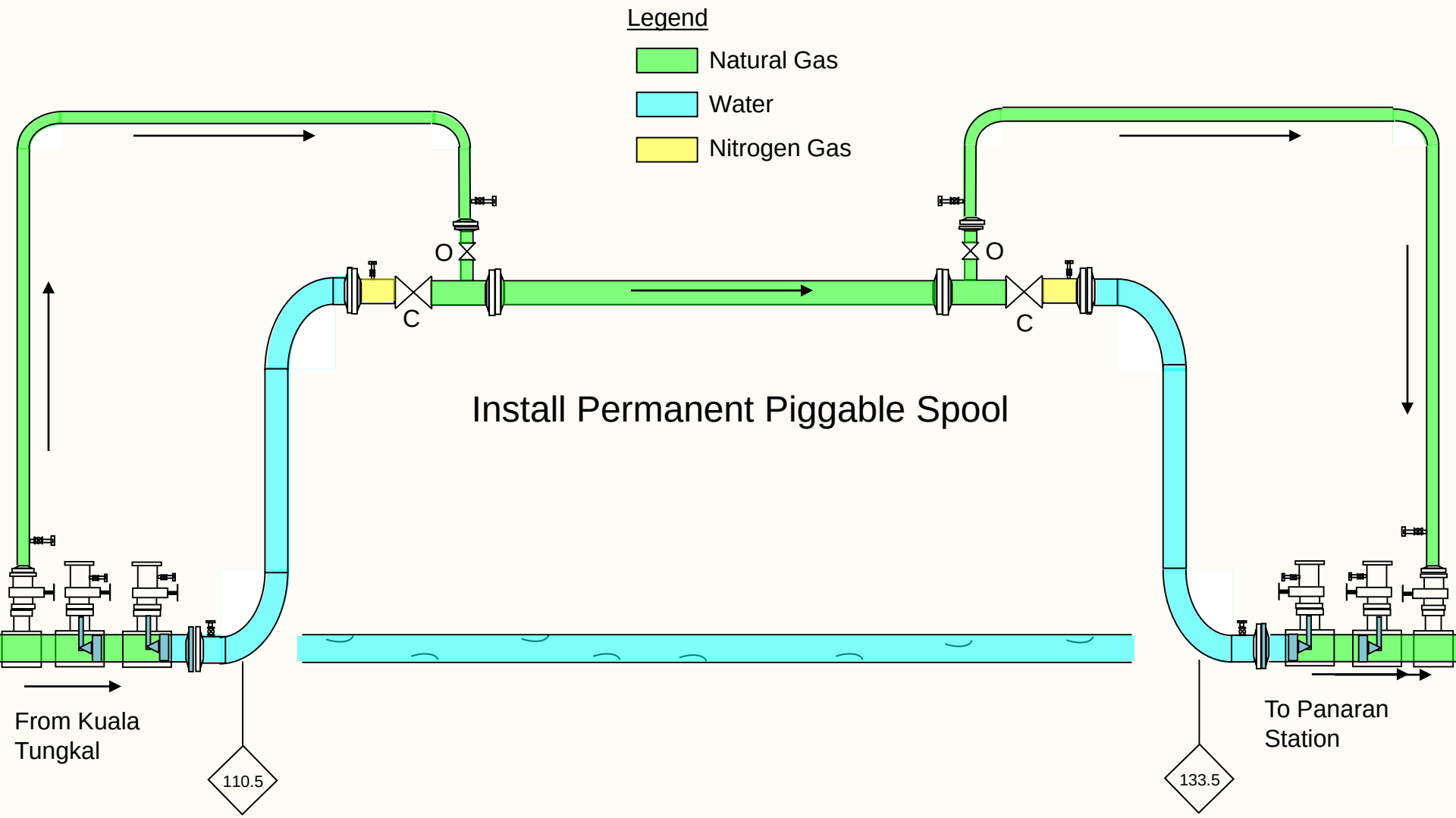
# Hot-tap Repair Method – Zero Downtime (Cont'd)



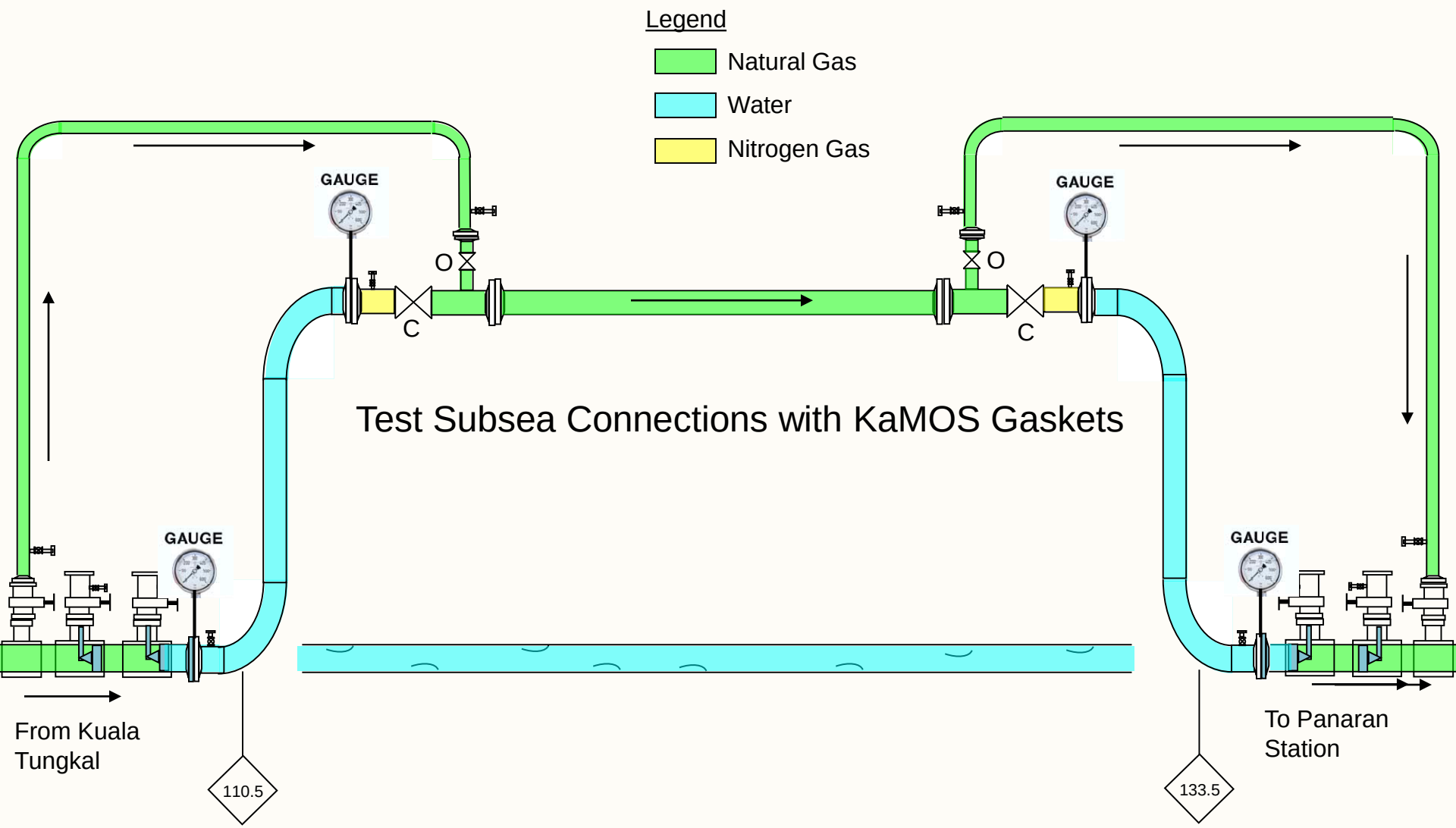
# Hot-tap Repair Method – Zero Downtime (Cont'd)



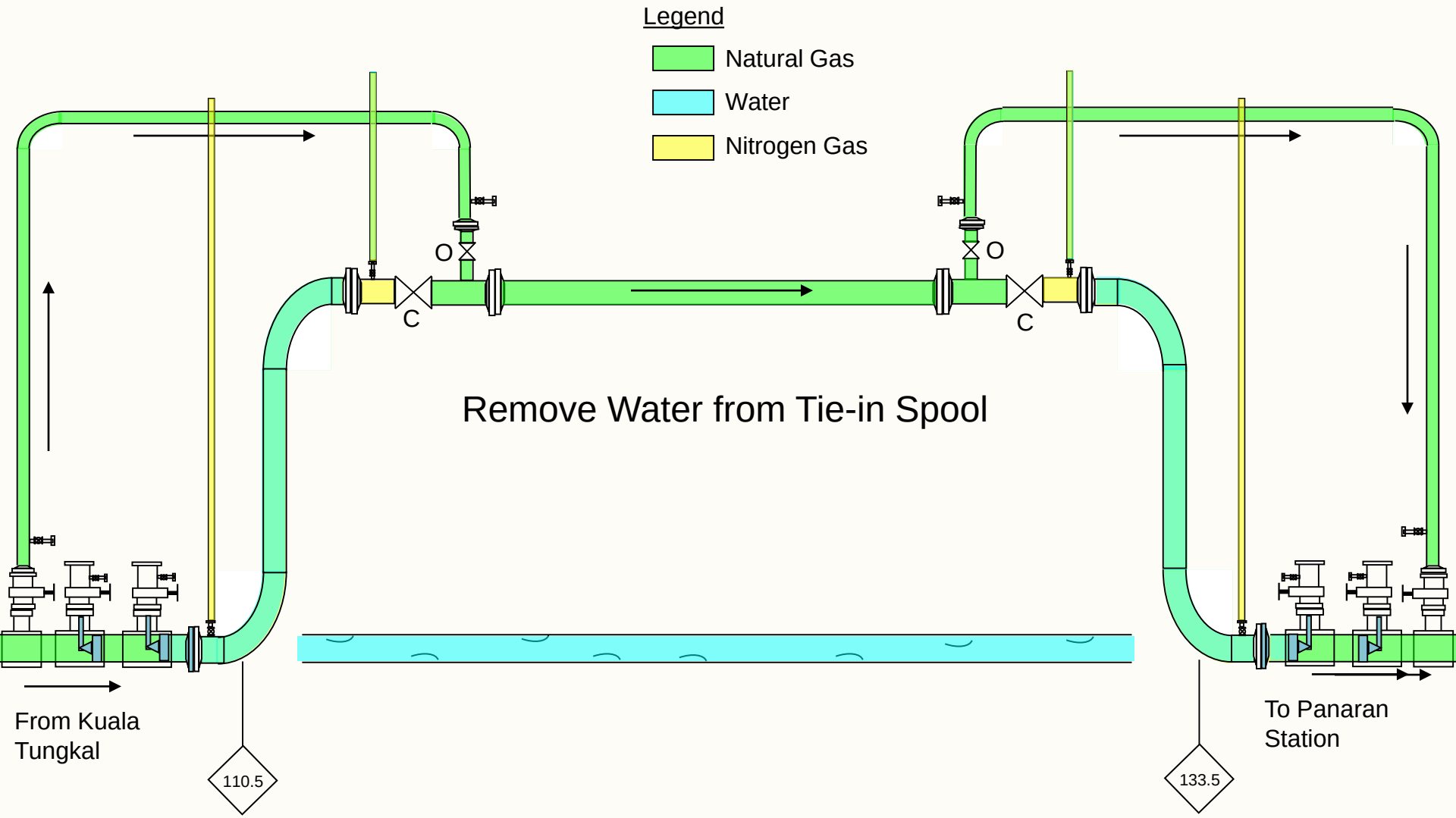
# Hot-tap Repair Method – Zero Downtime (Cont'd)



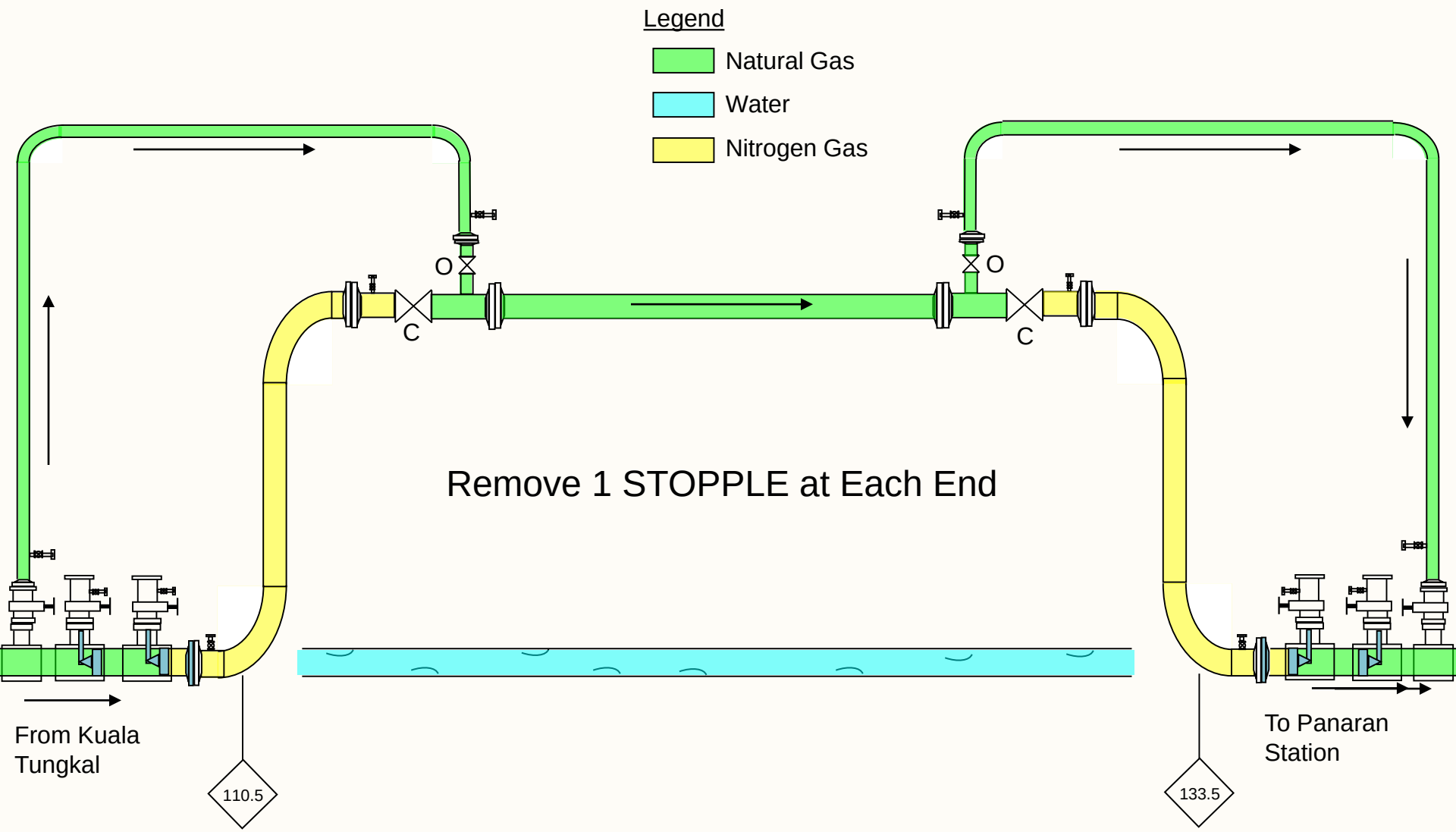
# Repair Method – Zero Downtime



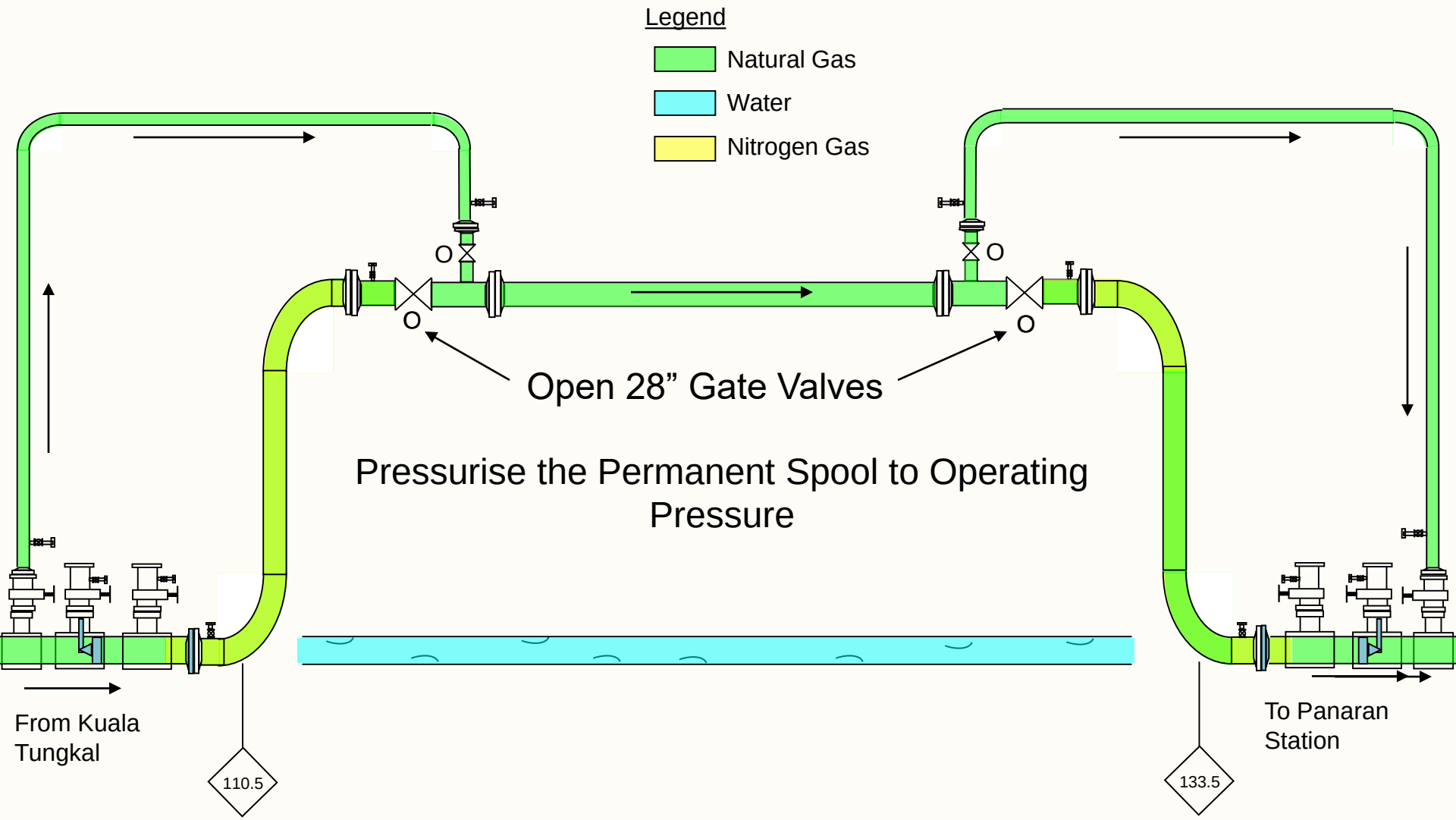
# Repair Method – Zero Downtime



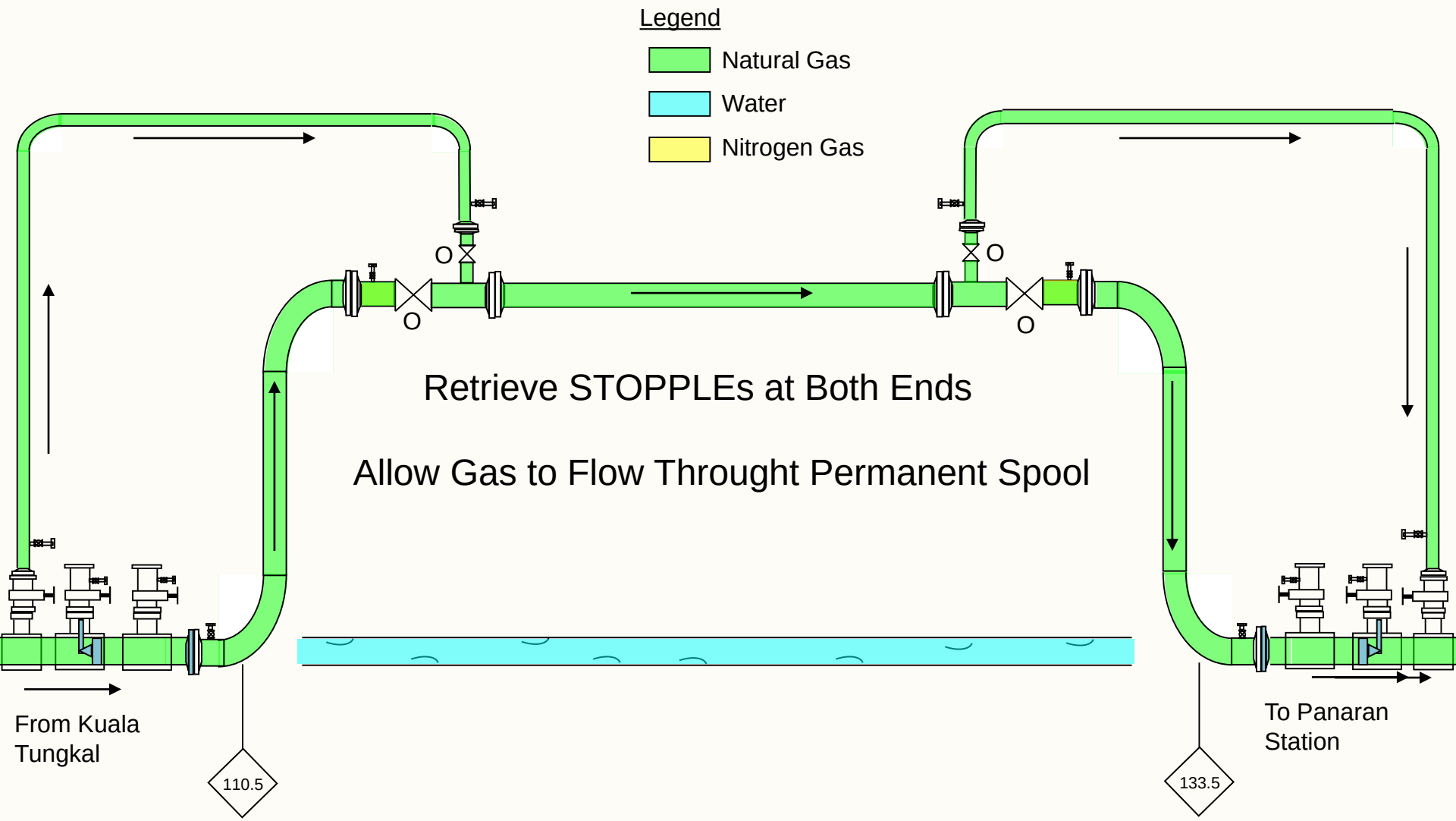
# Hot-tap Repair Method – Zero Downtime (Cont'd)



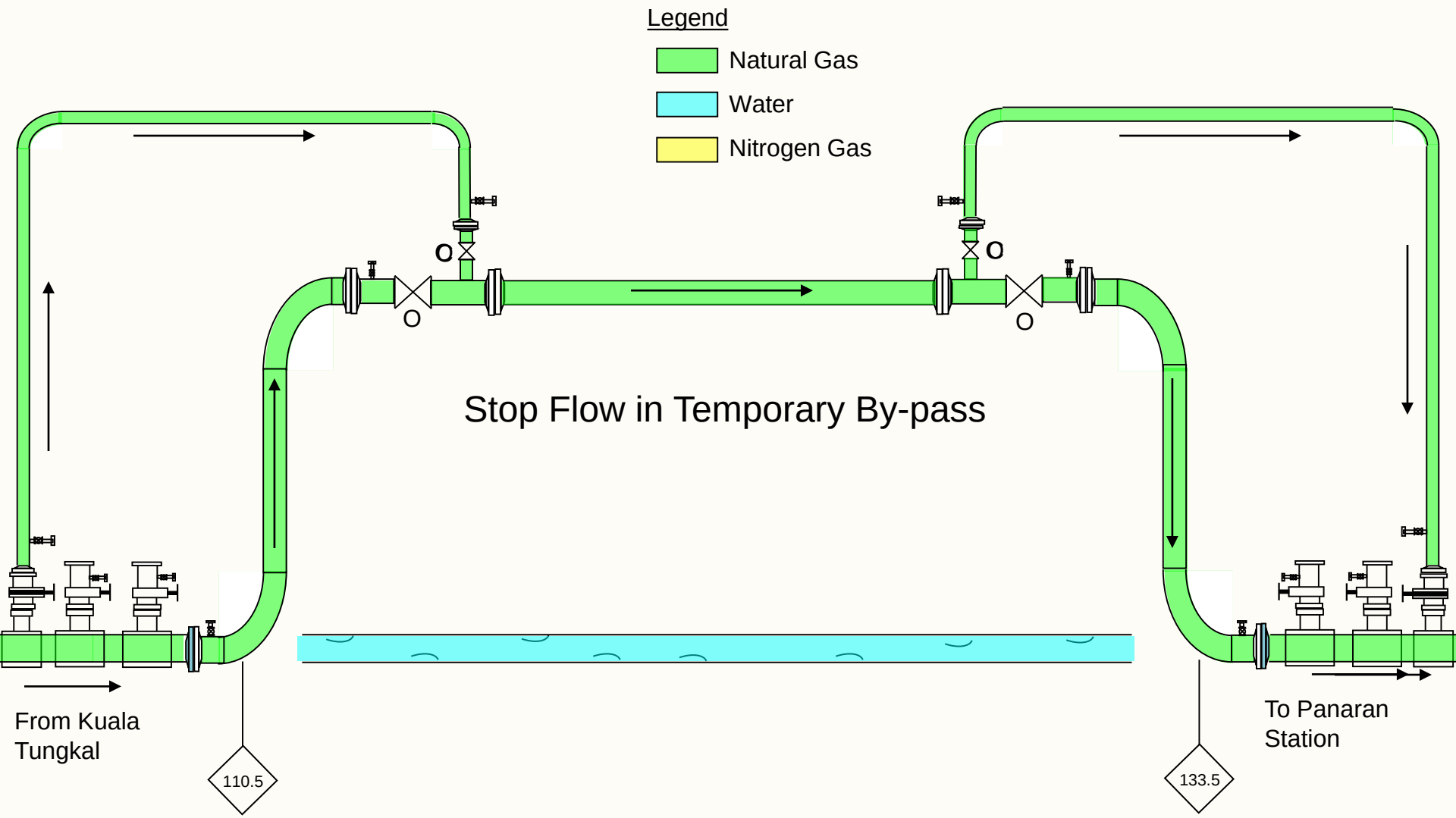
# Hot-tap Repair Method – Zero Downtime (Cont'd)



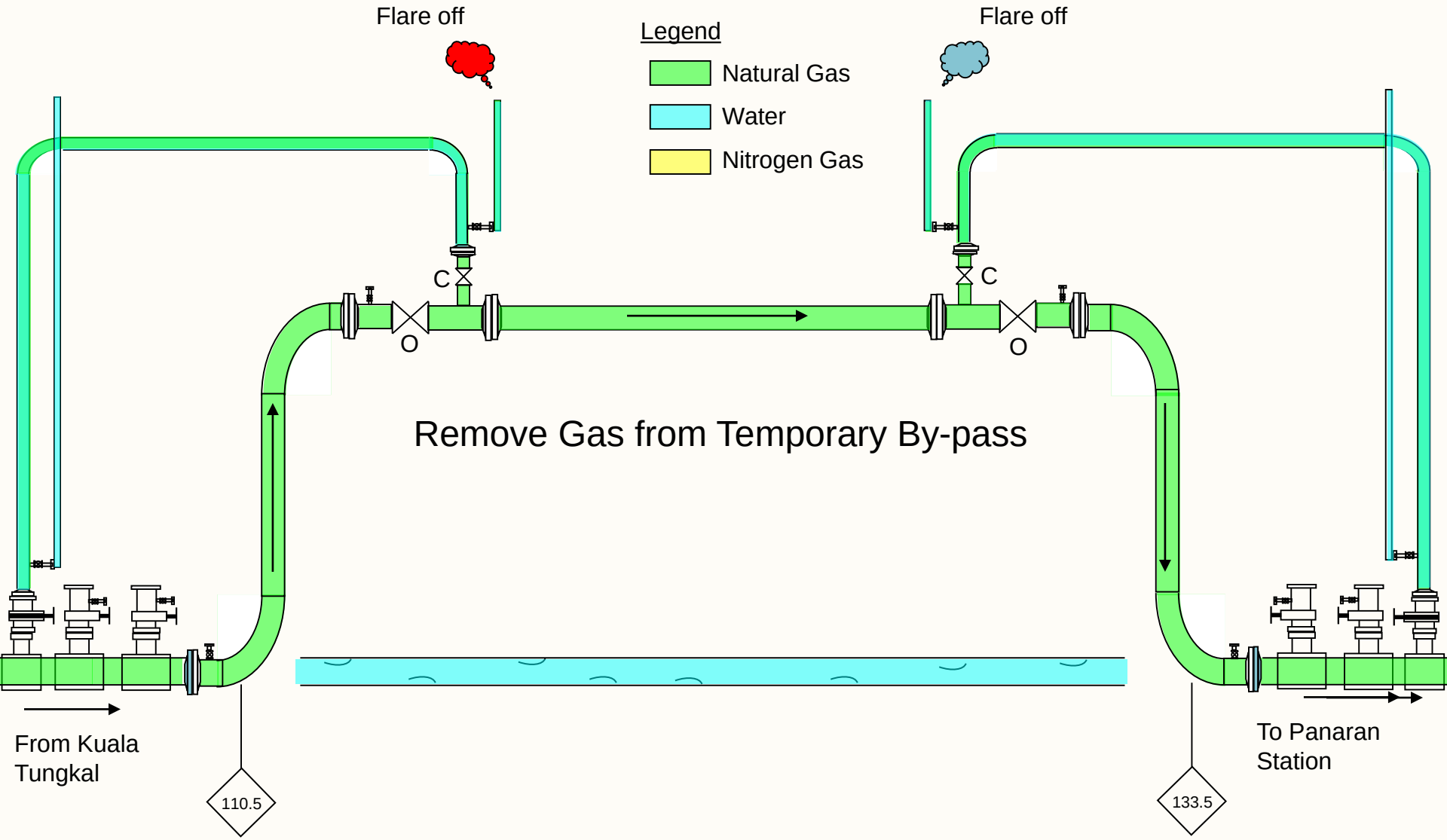
# Hot-tap Repair Method – Zero Downtime (Cont'd)



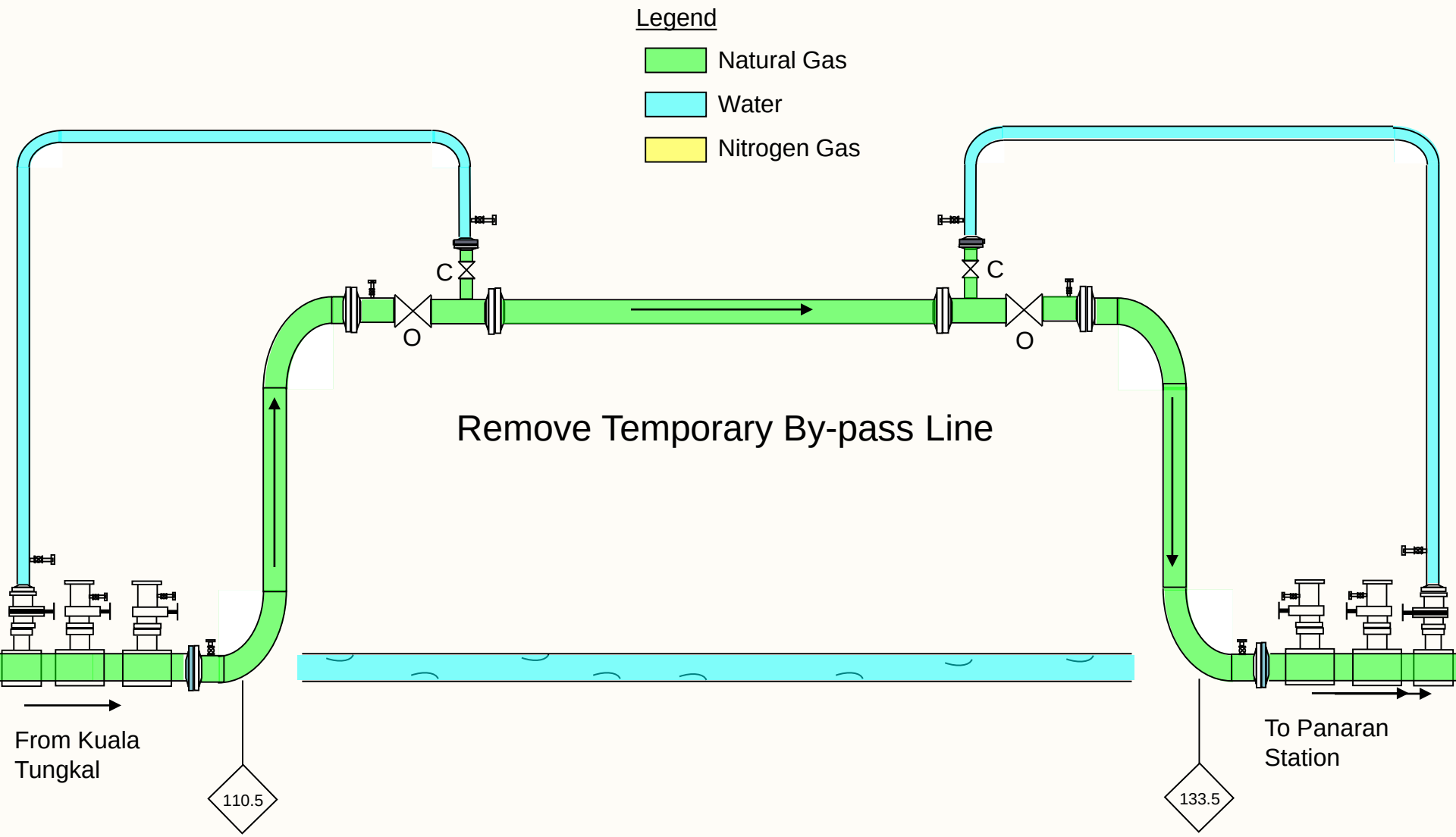
# Hot-tap Repair Method – Zero Downtime (Cont'd)



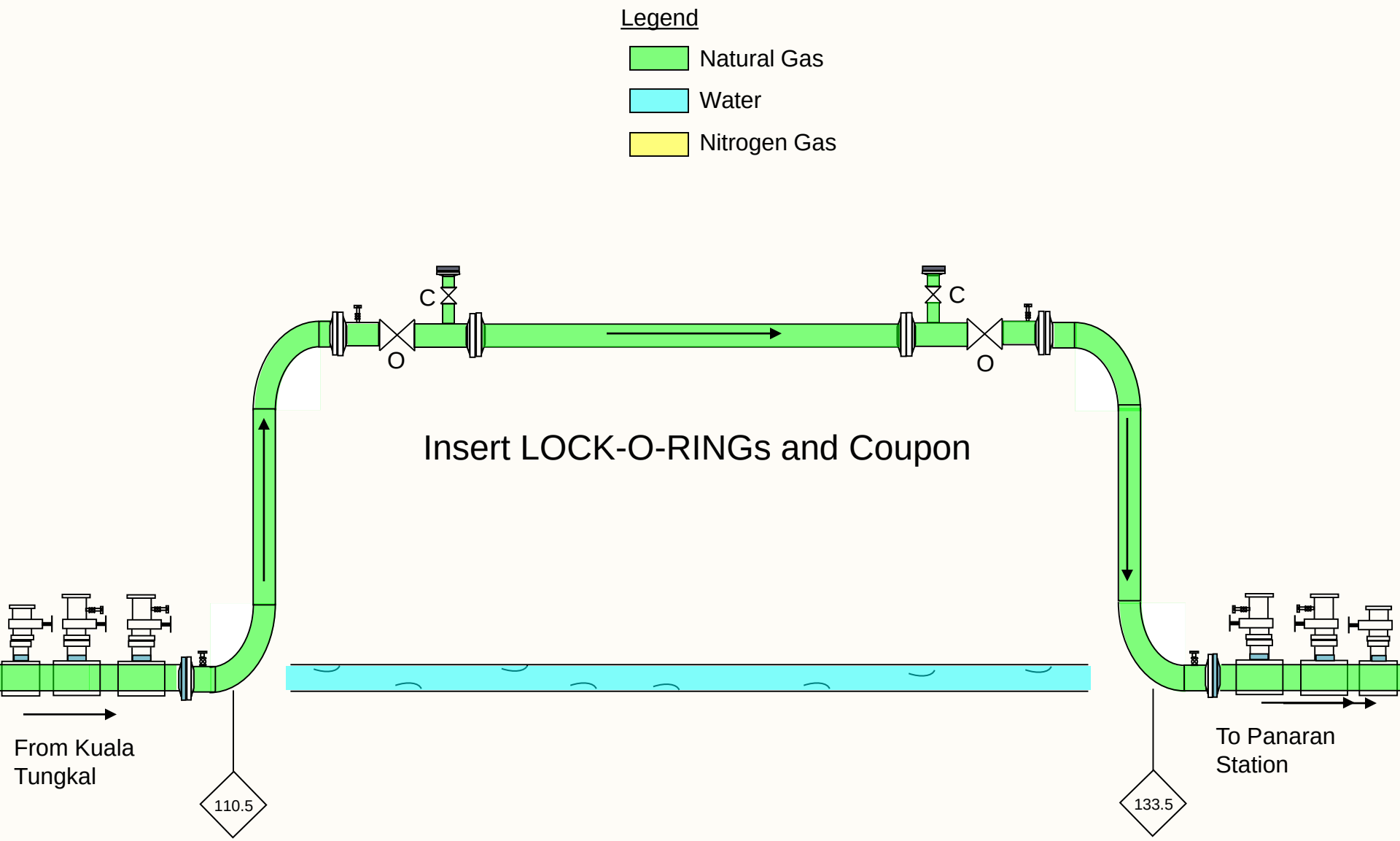
# Hot-tap Repair Method – Zero Downtime (Cont'd)



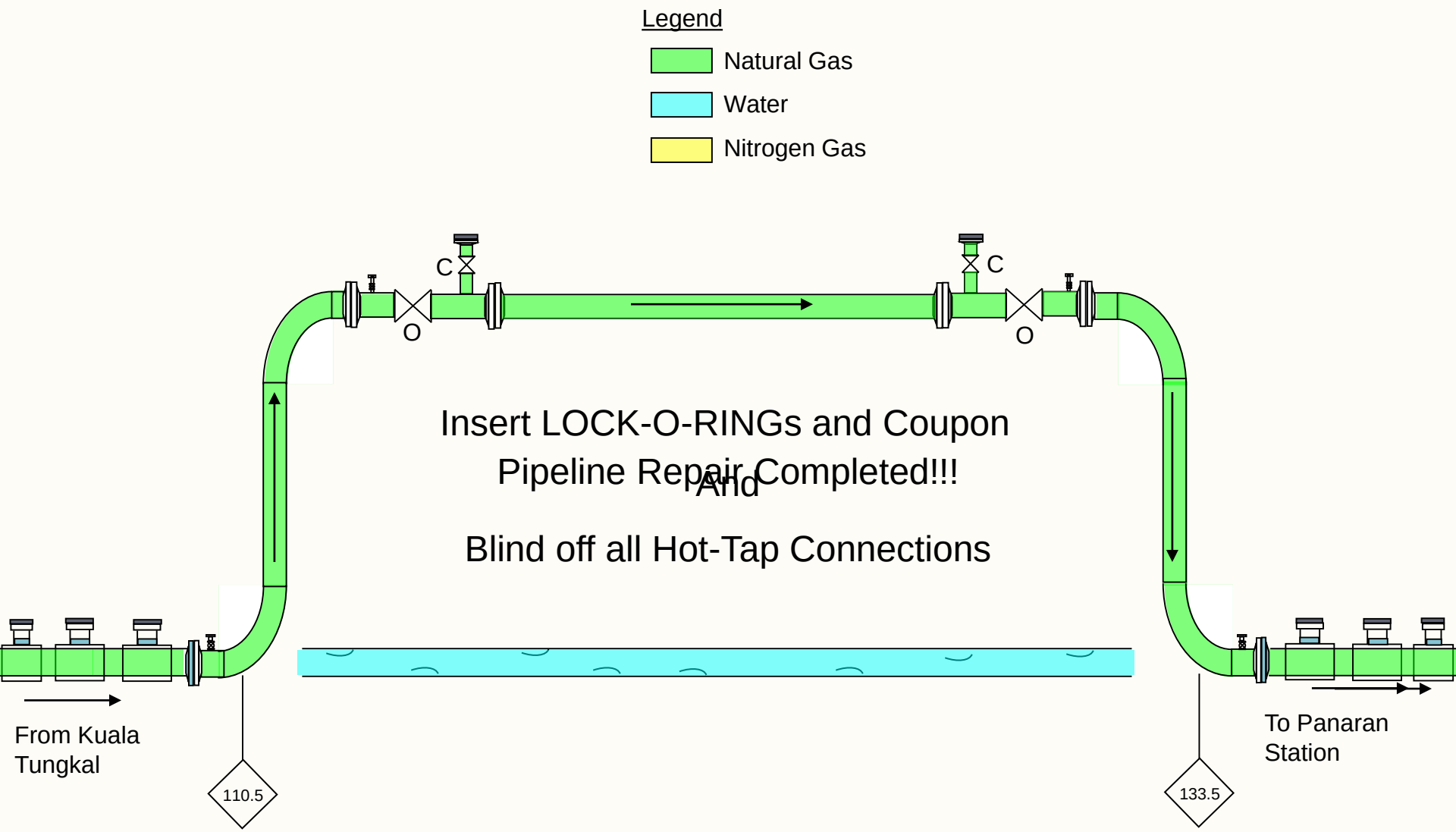
# Hot-tap Repair Method – Zero Downtime (Cont'd)



# Hot-tap Repair Method – Zero Downtime (Cont'd)



# Hot-tap Repair Method – Zero Downtime (Cont'd)



# EMERGENCY PIPELINE REPAIR SYSTEM

- A few major operators (e.g. Statoil and Chevron) have some form of Emergency Pipeline Repair System (EPRS) scheme.
- The components of an EPRS typically comprise some or all of the following components:
  - Combined Habitat and Alignment System (CHAS)
  - Pipe Handling Frames (PHF, 2 nos.)
  - Welding and Diving Station (WADS)
  - Repair Couplings
  - Repair Coupling Installation Frame (CIF)
  - Concrete Removal Machine (CRM)
  - Pipeline Retrieval Tool (PRT)
  - Pipeline Isolation Plugs (2 nos.)
  - Launching Frame
  - Appurtenances and Spares

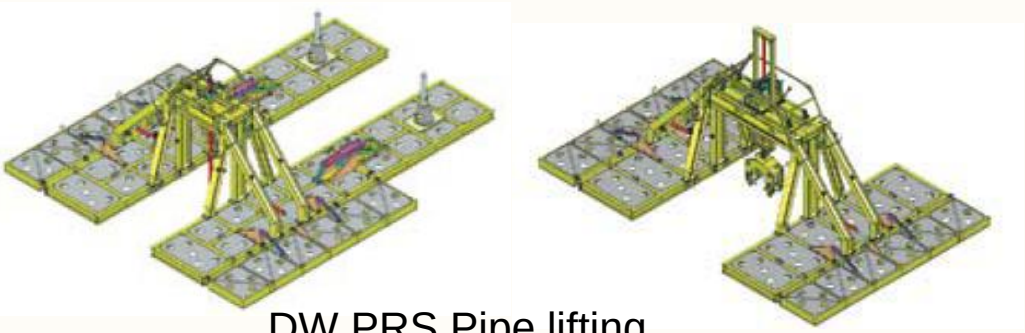
# Typical EPRS Contract

- Typically, an EPRS can be maintained by the Operator or sub-contracted to specialist subsea contractors.
- Under this scheme, specialist contractor provides, maintains and operates the emergency pipeline repair system.
- The purpose of having an EPRS contract is to ensure that the emergency repair system is properly maintained and in relatively good condition for mobilization.
- If such a system is not in place, significant lead time would be required to go out to invite and evaluate proposals and quotations for the repair at a time where response time is of the essence, plus significant time for mobilization.
- Under the terms of this contract, the scope of work normally calls for the provision of a nominated project manager to be the focal point for contact between Operator and Contractor.
- The Contractor is obligated to maintain the repair system in working conditions at all times, and to keep track of the hyperbaric diver welders, who are free agents in the market and whose services need to be secured in advance.
- During an emergency, the Contractor’s project manager will be notified and the Contractor will swing into action, mobilizing the spread and personnel.

# CHEVRON DEEP WATER REPAIR SOLUTION

- Chevron, in partnership with Energy Technology Company (ETC) operates a system for deepwater pipeline repair known as Deepwater Pipeline Repair Solution (DW PRS).
- The DW PRS is based on a pipeline cut-and-lift methodology.
- The system is manufactured to be modular by Oil States Hydrotech to facilitate assembly, disassembly and shipment to anywhere in the world.
- Chevron's DW PRS is designed with the following concept:
  - For use with any vessel of opportunity
  - Standard ROV tools for installation and support
  - Transportation via standard trucking or shipping via air freight in modular form
  - Diverless technology
  - Adaptable to deepwater hyperbaric welding
  - Interchangeable parts
  - 12-inch to 24-inch pipeline repair capability

# Key components of the DW PRS



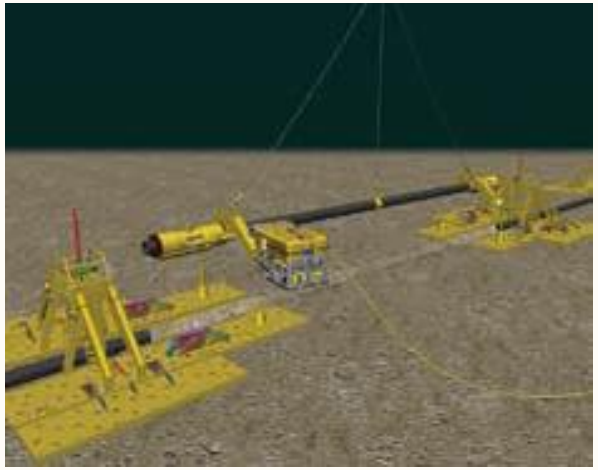
DW PRS Pipe lifting
and alignment frames

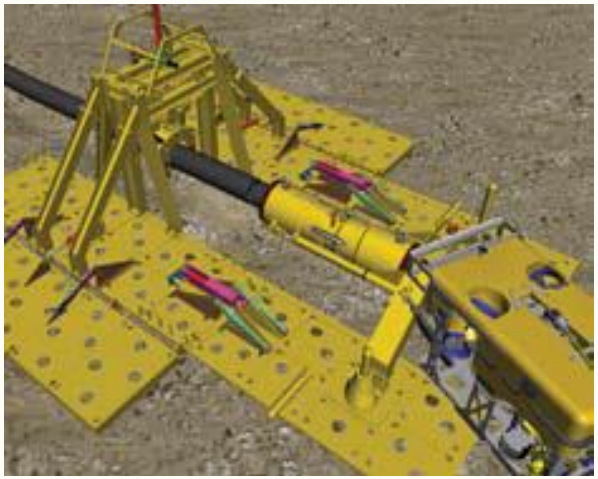
Dual Grip &
Seal Hyraulic
Connector

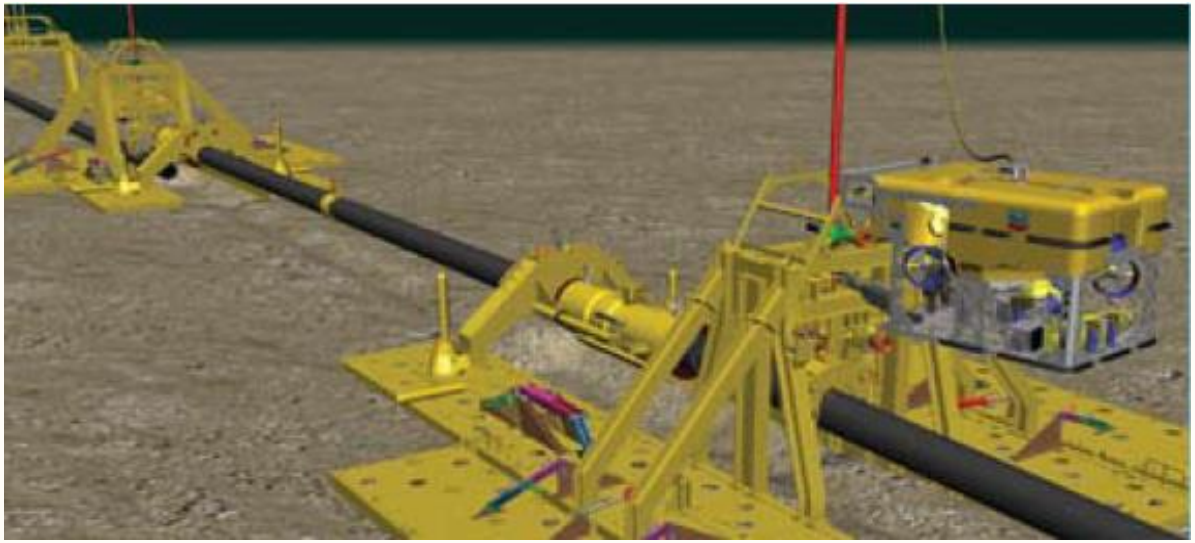
Combination
Preparation Tool

Pipeline Preparation
Tool on Damaged
Pipe and Operated
by ROV

# Chevron DW PRS in Operation Replacing Damaged Pipe with Spool

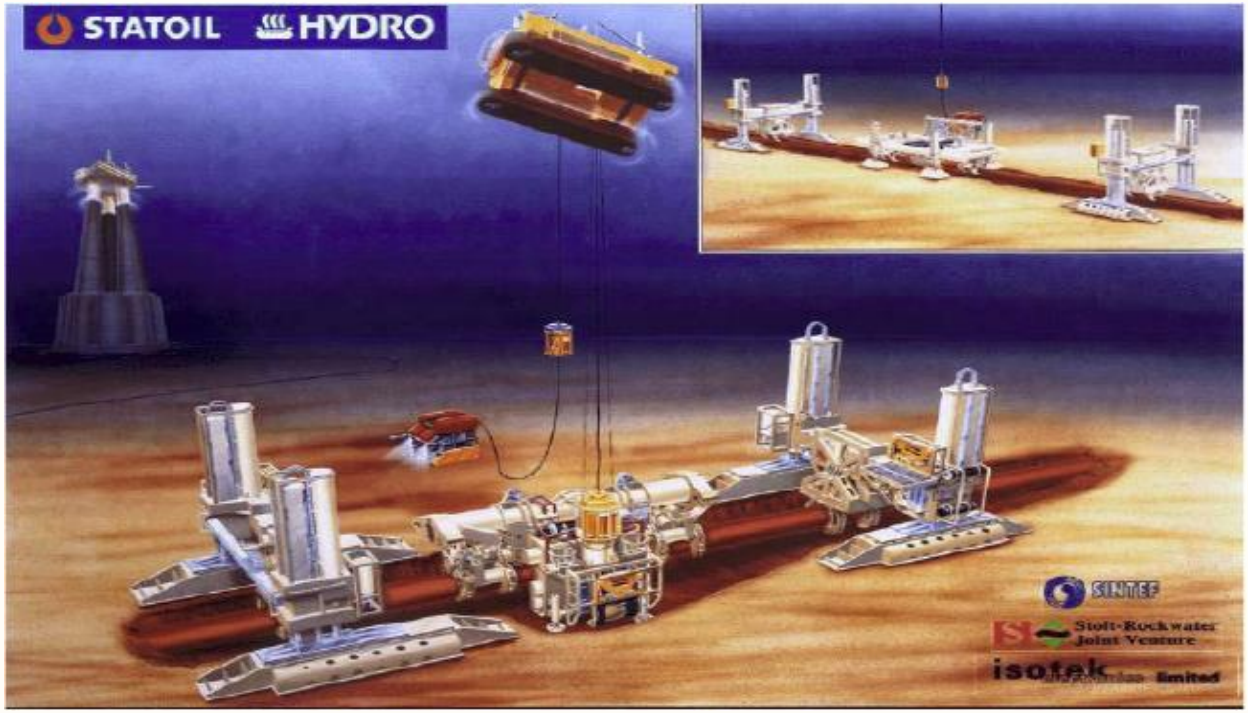






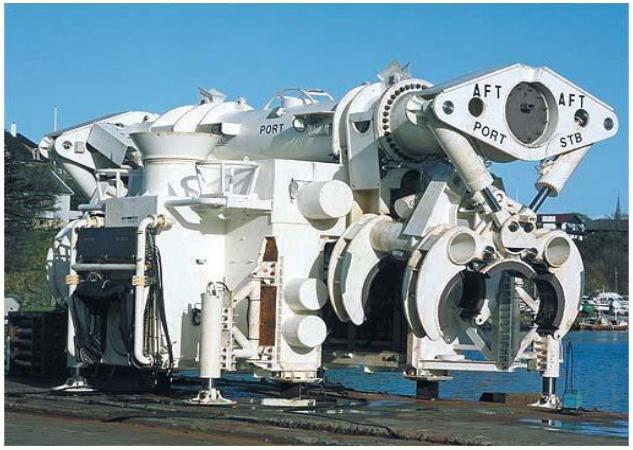
# STATOIL EPRS SYSTEM FOR NORTH SEA

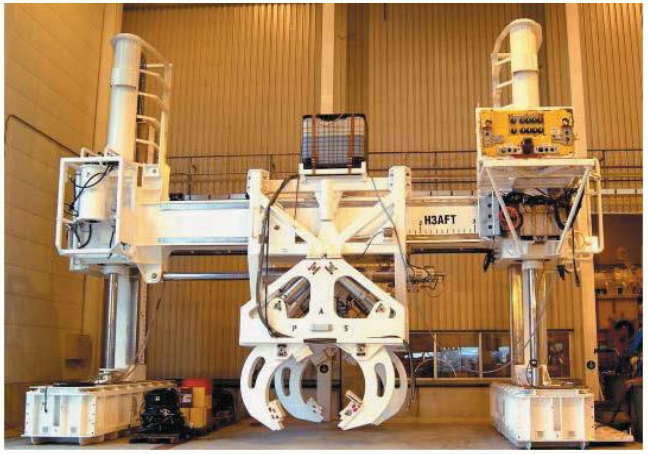
- The STATOIL system had been designed to cater for a large infrastructure of pipeline within the Norwegian sector of the North Sea, and significant investment had been put in to make it a comprehensive system.
- This repair system is based on the longitudinal spool repair concept.



# Major components of the STATOIL EPRS system

CHAS




PHF


Launching Frame with
Heave Compensator

Concrete Cutting Machine

# Major components of the STATOIL EPRS system (Cont'd)

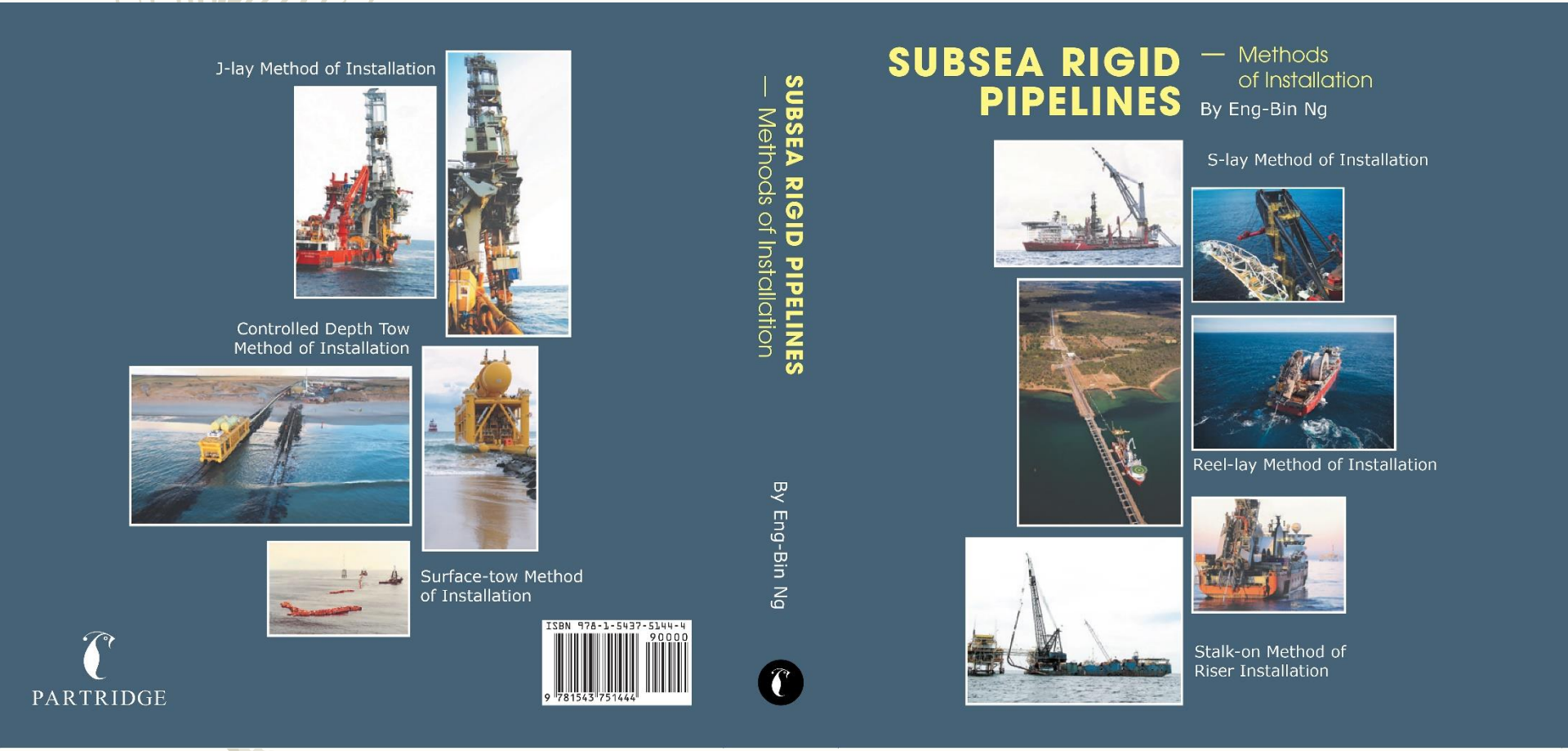
Morgrip Repair Coupling

Handling Frame for Repair Coupling

Pipe Retrieval Tool

Pipeline Isolation Plug

**For more details on repairs of rigid pipelines during installation & during operation, refer to my new book:**
**"Subsea Rigid Pipelines – Methods of Installation"**



***QUESTIONS ????***