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PIPELINE AND RISERS

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May 2021 Semester

These content are the extracts of the lecture notes:

1. The Pipe: Carbon-Manganese Steel Pipe
2. Pipeline Construction
3. Pipeline Installation
4. Pipeline Route Selection
5. Problems Associated with Pipelines
6. New Technology in Pipeline

How to transport hydrocarbon?

Pipeline, rail, truck or tanker ship?

Pipeline, rail, truck or tanker ship?

For human death and property destruction:

truck worse than train worse than pipeline worse than tanker

(Oilprice.com)

For amount of oil spilled:

truck worse than pipeline worse than rail worse than tanker

(Congressional Research Service)

For environmental impact (dominated by impact to aquatic habitat):

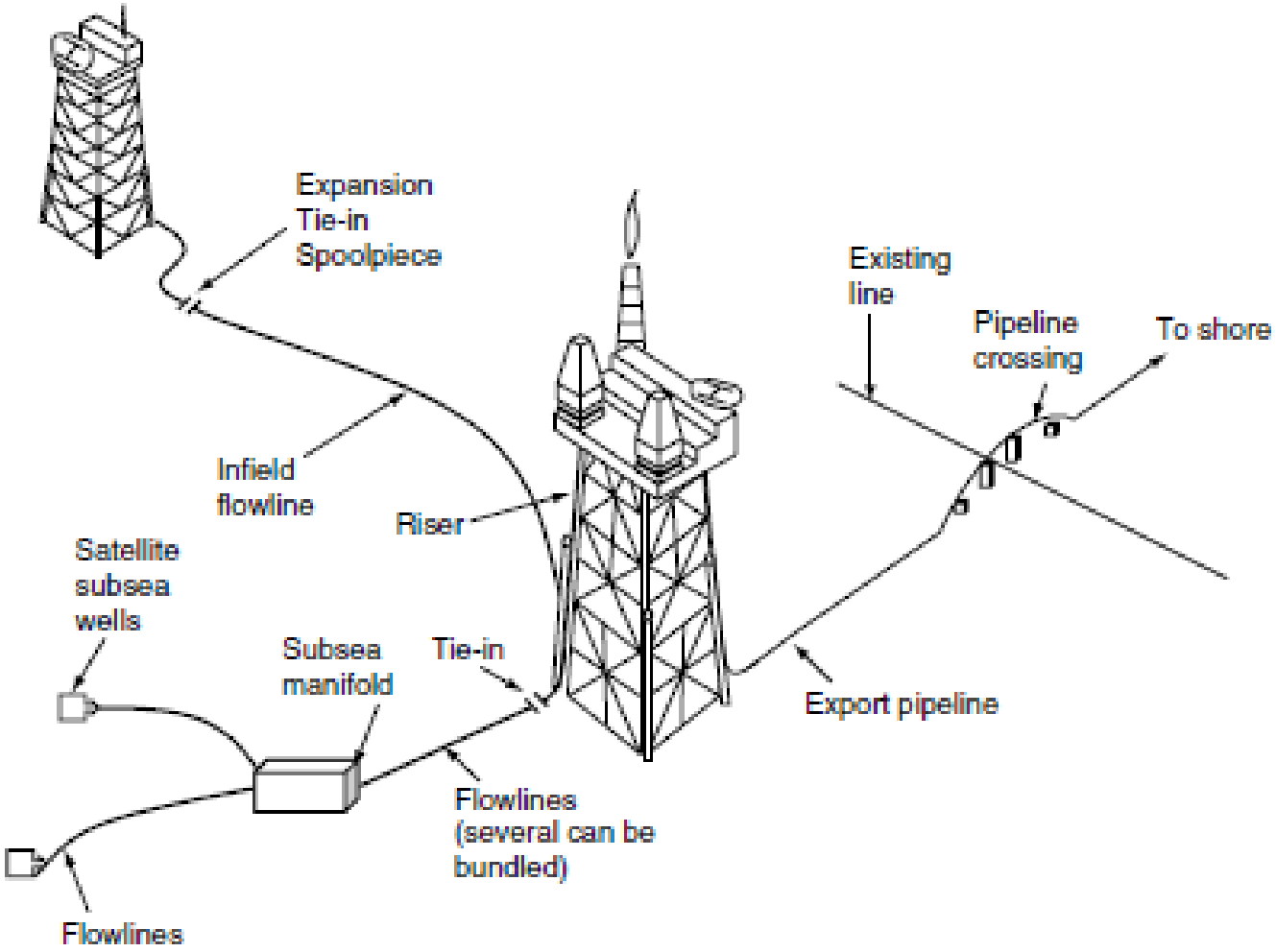
tanker worse than pipeline worse than truck worse than rail

! So it depends upon what your definition is for *worse*.

What is Pipeline?

- Function to transports hydrocarbon, chemicals, injection water & gas from one point to another point
- Infield flowlines: To transport hydrocarbon/water/gas between components of a field (e.g. manifold and riser base)
- Export pipelines: To transport hydrocarbon to the other platforms or onshore
- Trunk pipeline: To transport oil and petroleum products over long distances

Classifications of Offshore Pipelines



Source: Guo et al. (2005)

Reservoir Production Profiles

Production profiles **define how the oil, water, and gas flowrates will change with time for the whole filed life.**

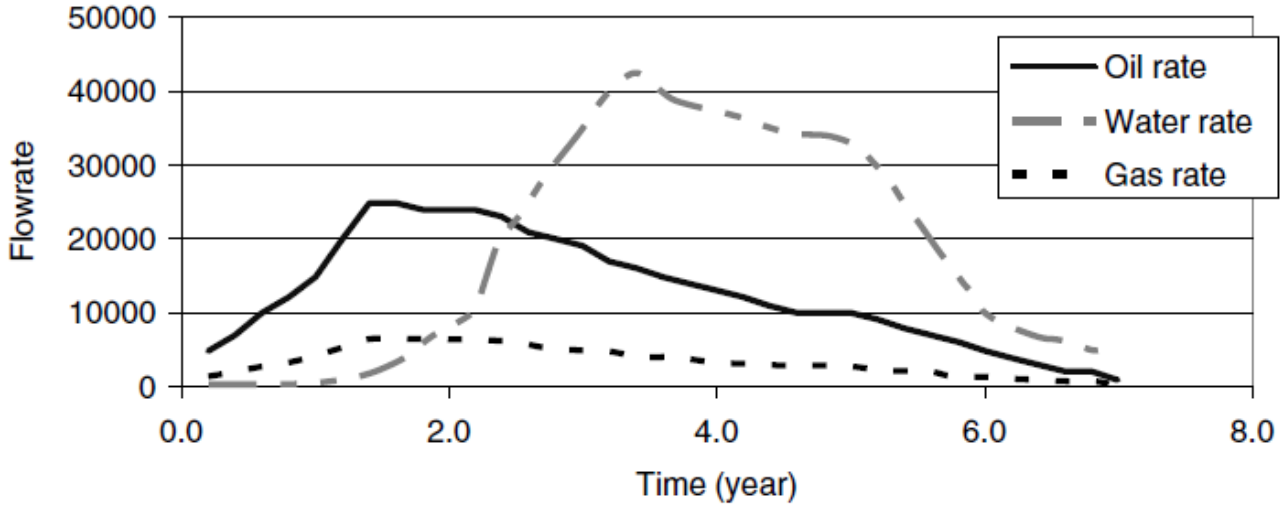
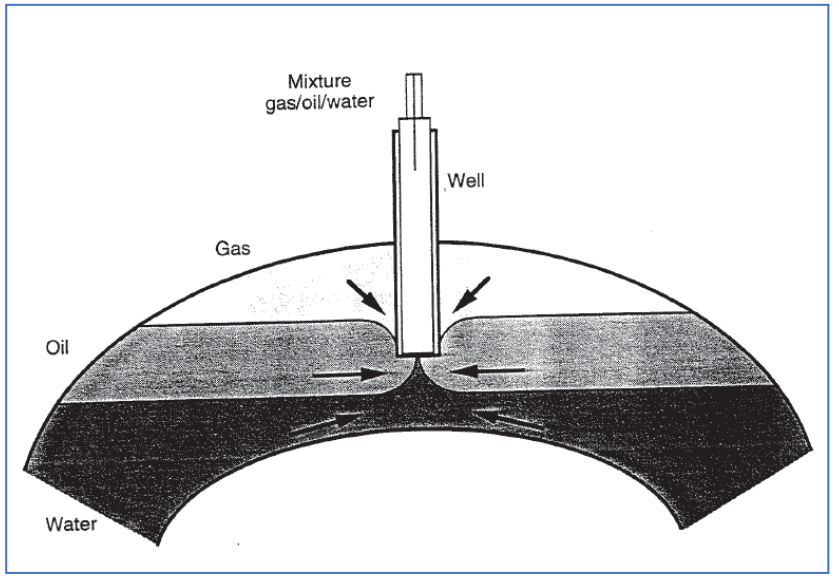


FIGURE 2.1 Typical oil, water, and gas production profiles.



Source: Guo et al. (2005)

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The Pipe

Carbon-manganese Steel Pipe

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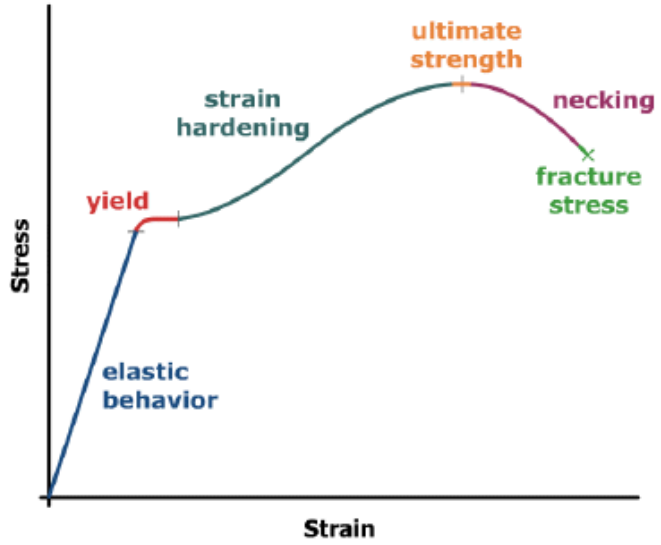
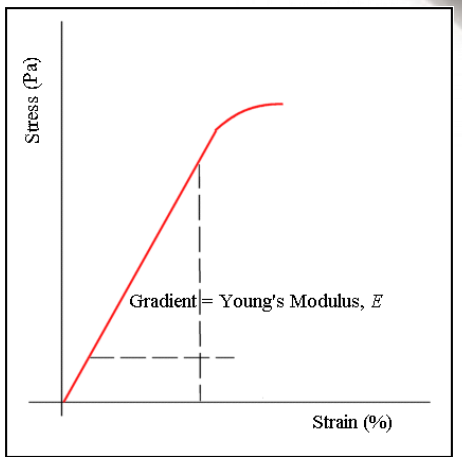
Carbon-manganese steel pipe is widely used for oil and gas pipelines due to its high strength.

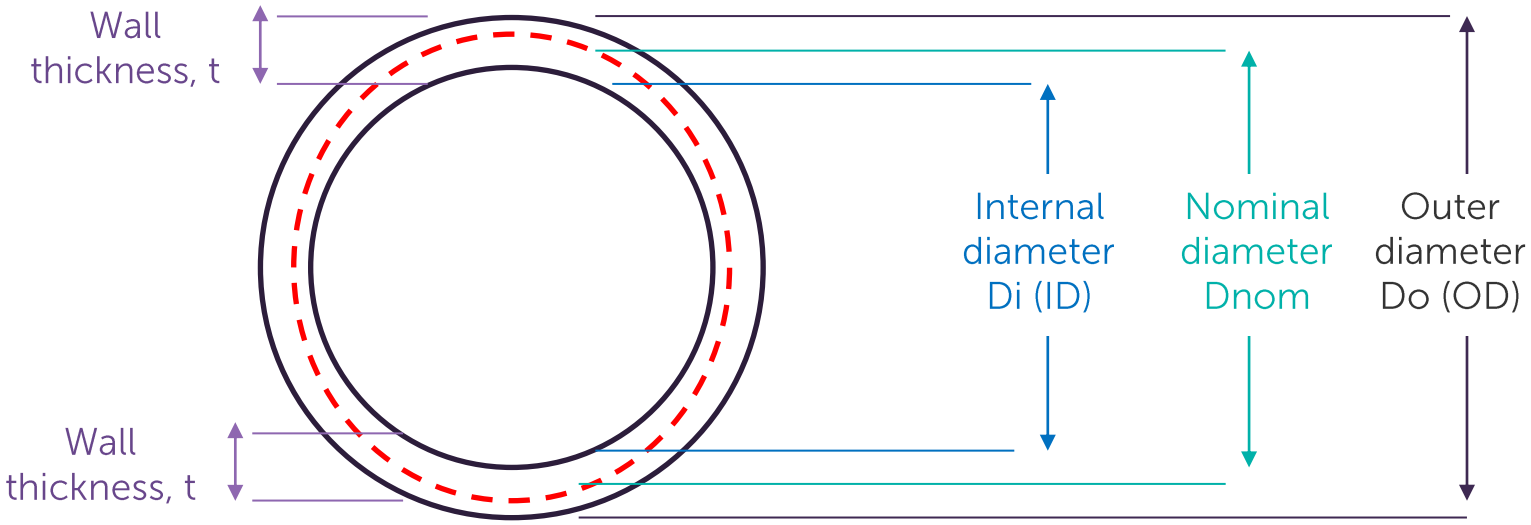
Recall strength of materials!





- Generally, the pipes are manufactured in approximately 40-foot (12 m) lengths.

- The pipe diameter must be large enough to transport the maximum volume of hydrocarbon.



- The pipes are usually made of high-quality carbon steel that is produced to specific standards e.g. API 5L specifications.

Pipe Material Specifications

Standard strength grades and yield to tensile rations:

***Table 3–1** Standard Strength Grades and Yield to Tensile Ratios*

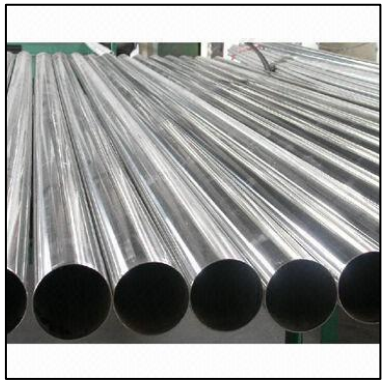
Grade	Minimum Yield Strength		Minimum Tensile Strength		YS/TS ratio
	lb/in^2	*MPa*	lb/in^2	*MPa*	
A25	25,000	172	45,000	310	0.556
A	30,000	207	48,000	331	0.625
B	35,000	241	60,000	413	0.583
X42	42,000	289	60,000	413	0.700
X46	46,000	317	63,000	434	0.730
X52	52,000	358	66,000	455	0.788
X56	56,000	386	71,000	489	0.789
X60	60,000	413	75,000	517	0.800
X65	65,000	448	77,000	530	0.844
X70	70,000	482	82,000	565	0.854
X80	80,000	551	90,000	620	0.889

Source: Palmer and King (2004)

Advantages and disadvantages of a carbon steel pipe:

ADVANTAGES	DISADVANTAGES
High tensile strength	Prone to external corrosion
High compressive strength	Electrolysis prone
Range of corrosion protection system	Jointing requires skilled welders
Wide range of diameters and wall thickness	Internal/external corrosion protection system add to price
Welded joints give continuity	Coatings and lining can get damaged during installation by third parties

Different wall thicknesses of wall have their own complications.



	ADVANTAGES	DISADVANTAGES
Thick Diameter	Higher strength.	Higher operating costs.
Thin Diameter	Reduce material, transportation, loading and welding costs.	Cannot operate at high pressures.

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Pipeline Construction

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The pipeline is made by one of four fabrication methods:

1. **Seamless method** has no longitudinal weld seam. One solid piece of steel. A *billet* is cut from slab and heated and formed by rollers to produce a length of pipe.

2. **Electrical resistance welded (ERW) pipe** is formed from plate of steel flattened and pass through a sequence of rolls to form the pipe. The longitudinal seam weld is made by ERW.

3. **Submerged Arc Welded (SAW)** or sometimes called U-O-E pipe is formed from individual plate of steel by forming a plate into a U, then into a tube (O).

4. **Spiral Weld** is manufactured by steel strips and welded spirally.

Seamless Pipe

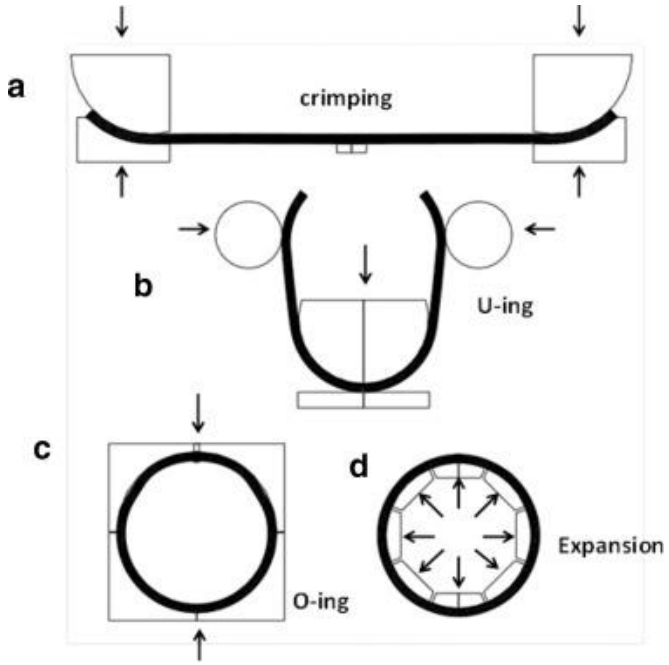
- Seamless tubing is fabricated by drawing a billet of metal through a die.
- No welding.
- Potential problems of variance in wall thickness.

Welded Pipe

- Welded tubing is made from sheet stock that has been cut, rolled into a tube, and welded.
- The weld is thicker than the rest of the tube wall, which is extremely consistent in thickness.
- Welded tubing has the risk of being slightly out of round, due to its manufacturing process.
- Without further interior finishing, the weld leaves ridges the length of the tube.
- Welded tubing is 20% weaker than seamless as far as burst strength is concerned.

Welded Pipes: ERW, SAW, Spiral

ERW



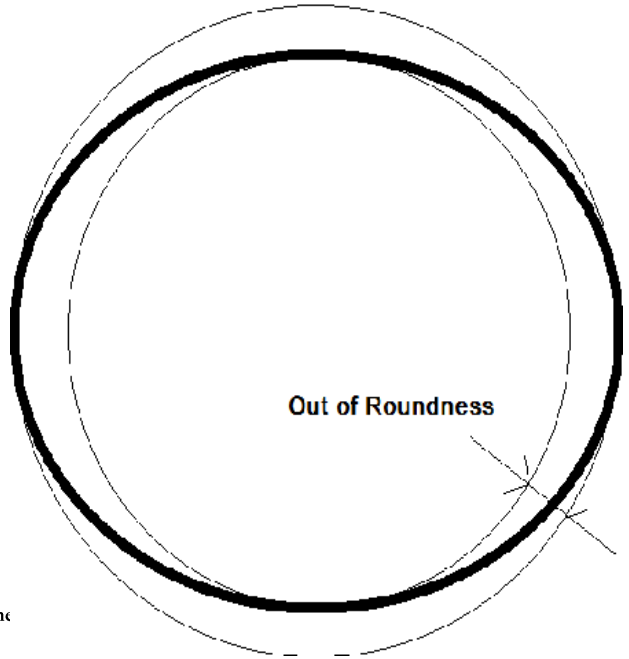
SAW (UOE)

Spiral

Choose your Pipe

Factors to be considered are:

- Burst strength – seamless provides the strongest burst strength!
- Roundness/Consistence of wall thickness – welded pipes are more prone to out-of-roundness problem.
- Cost – seamless is the most expensive option and welded is the least expensive.
- Least corrosion – welded may trigger more corrosion at the welding area due to imperfections.



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PIPELINE INSTALLATION

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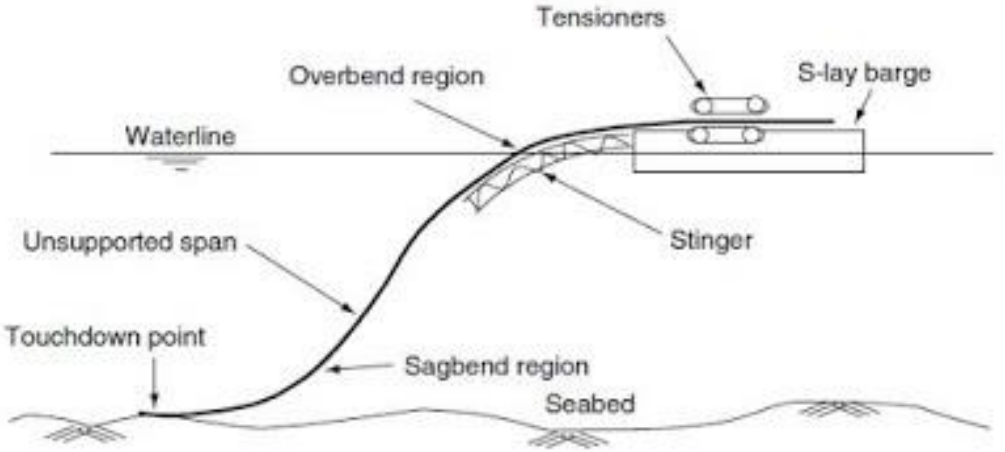
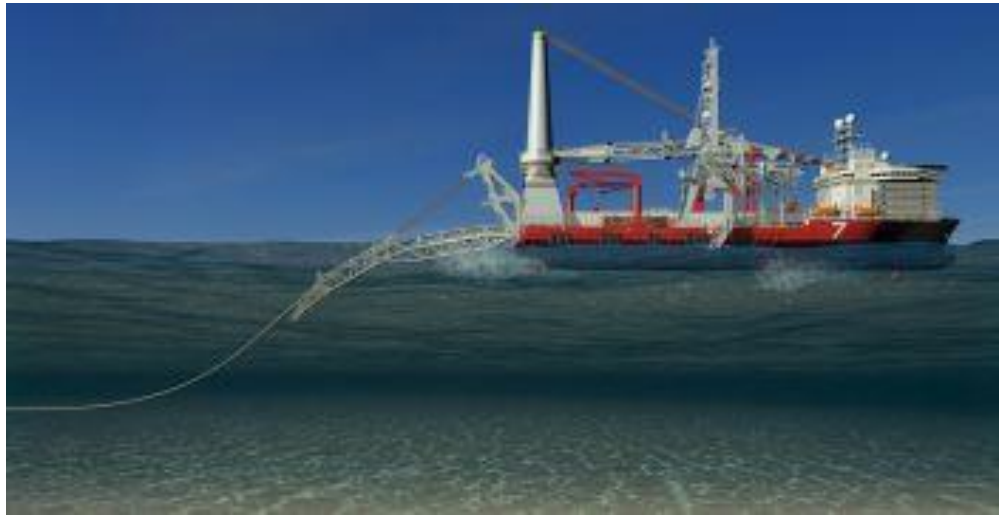
There are four methods to install offshore pipelines:

1. S-lay
2. J-lay
3. Reel barge
4. Tow-in methods
   - Surface tow method
   - Off-bottom tow method
   - Mid-depth tow method
   - Bottom tow method

S-Lay Method





The S-lay method is used in a range of water depths from shallow to deep. Requires a laying barge equipped with several welding stations.

As the barge moves forwards, the pipe is eased off the stern, curving downward through the water as it leaves until it reaches the touchdown point *i.e.* 'S' shape!

A stinger is used to support the pipe as it leaves the barge, by reducing the bending stress.

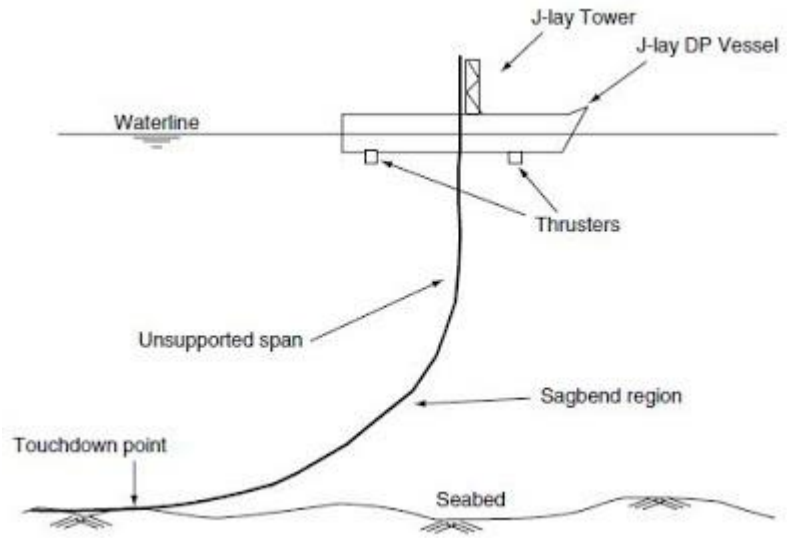
Advantages:

- Pipeline with a diameter up to 60” can be installed
- Cost effective for remote locations
- Can install concrete coated pipelines

Disadvantages:

- Suitable for shallow water installation only (about 300 m)
- Slow installation rate
- Large construction team required
- High lay tension applied to barge due to shallow lay angle
- Line pipe to be supplied by other vessels

J-Lay Method



The J-lay method avoid difficulties of S-laying approach.

Can be used in deeper water than the S-lay method.

The barge has a tall tower on the stern to weld and slip pre-welded pipe sections.

Its barge drops the pipe down almost vertically until it reaches downtown *i.e.* 'J' shape!

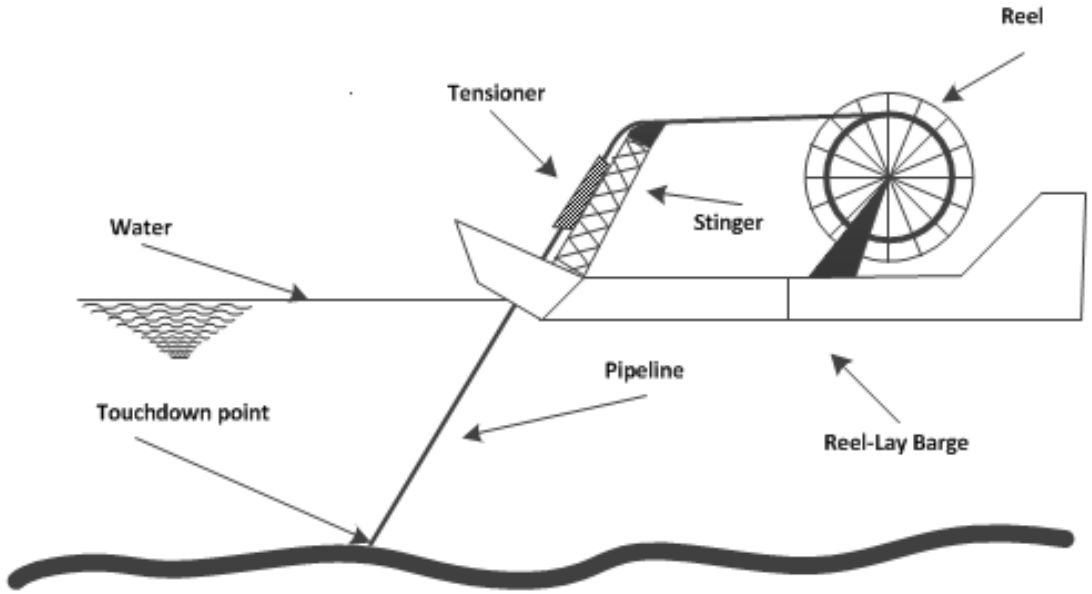
Advantages

- Suitable for deep water installation
- Pipelines with large diameter can be installed
- Can install concrete coated pipelines
- Only option for installing large diameter pipelines in ultra deep water

Disadvantages

- Slow installation rate as there is not working/welding station only
- Pipe quads need to be supplied by other vessels

Reel barge Method



Advantages

- Smaller pipe lay barge and construction team
- Faster installation rate as joints pre-welded

Disadvantages

- Pipeline undergoes some cycles of plastic deformation
- All type of coating system can not be used
- Limitation in pipeline diameter
- Pipeline thickness may increases due to the buckling resistance required during reeling
- Require more than one reel, thus reel barge needs to go back to the spool.

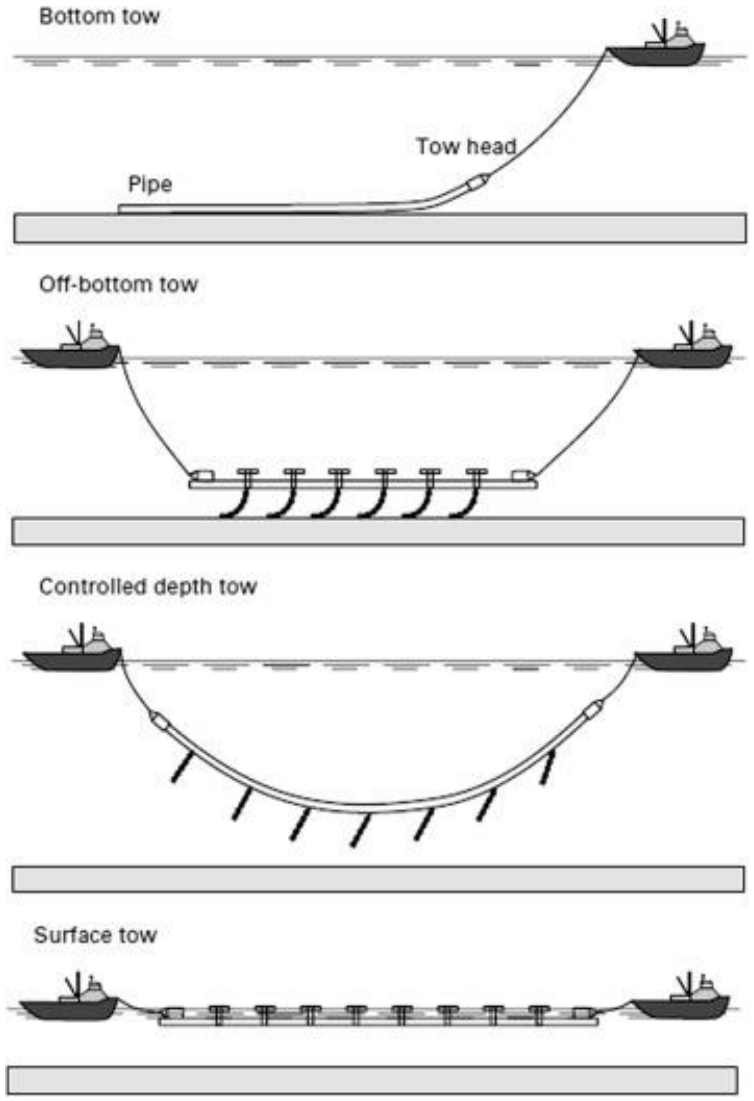
Technip's Evanton Spoolbase (UK)

Reel Barge-Technip's Apache II

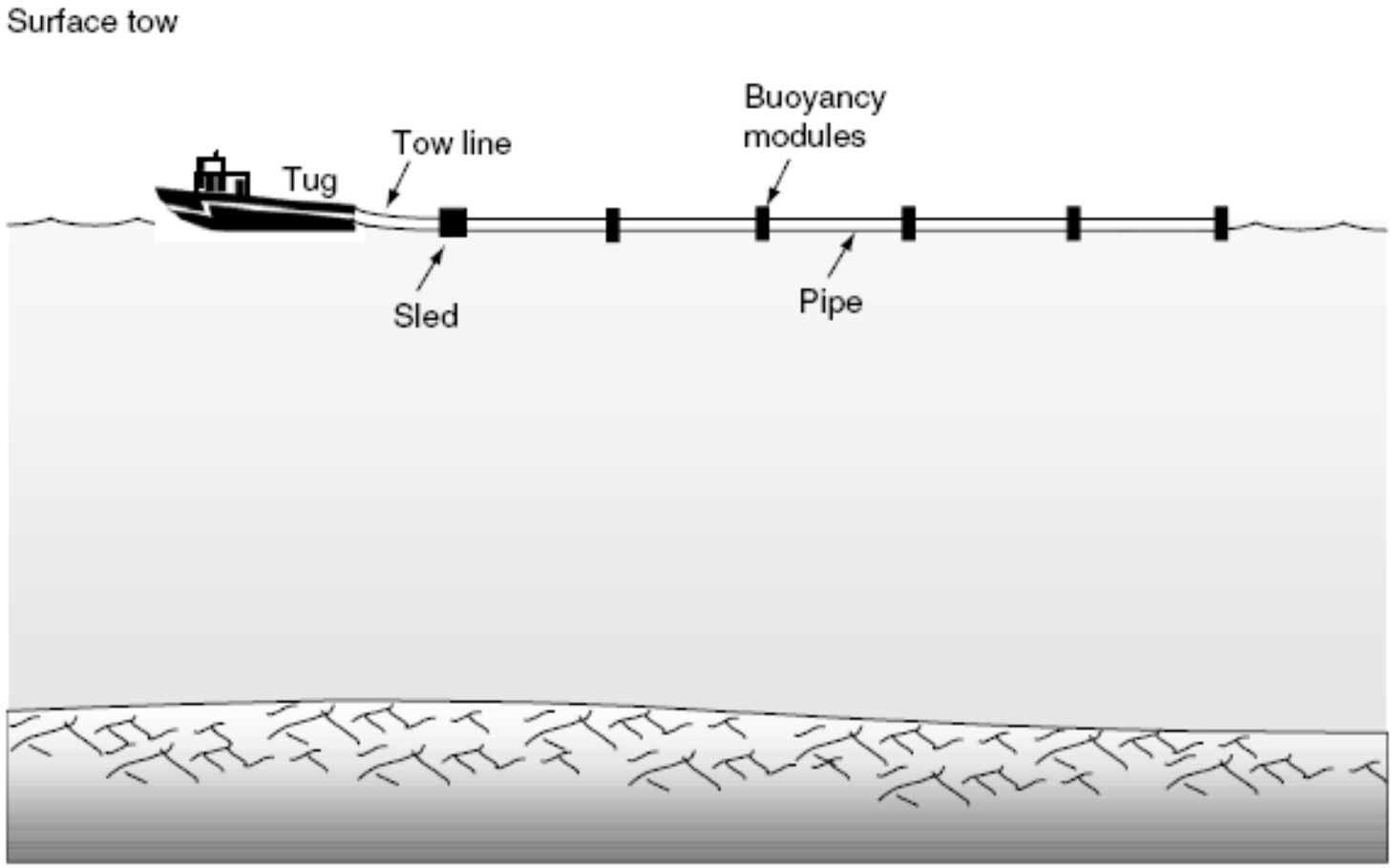
Tow-in-Methods

For all tow-in methods, the pipe has to have a uniform low weight during the tow.

Must have an abrasion-resistant coating that can stand up to being dragged across the seabed.

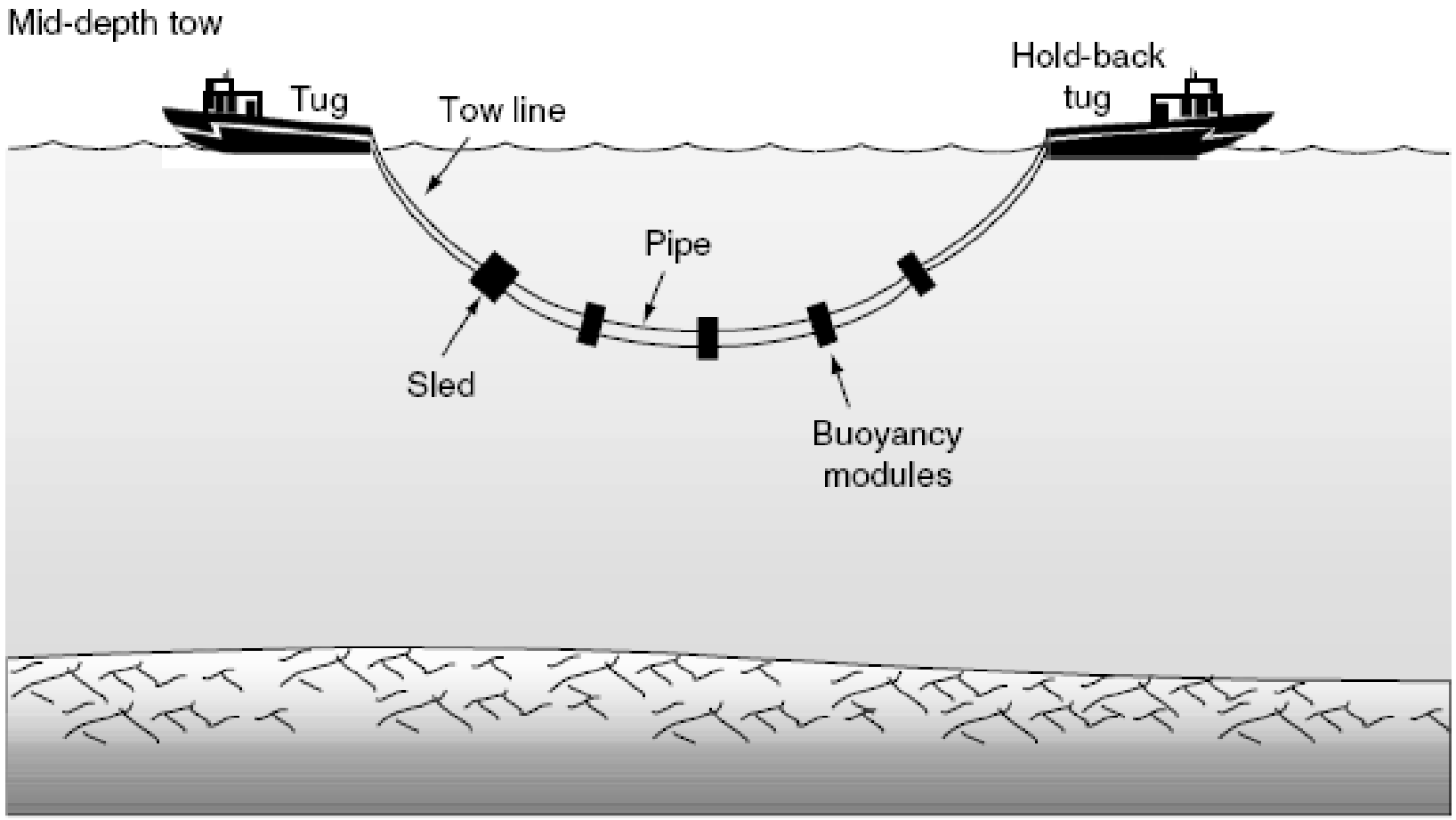


Surface Tow Method



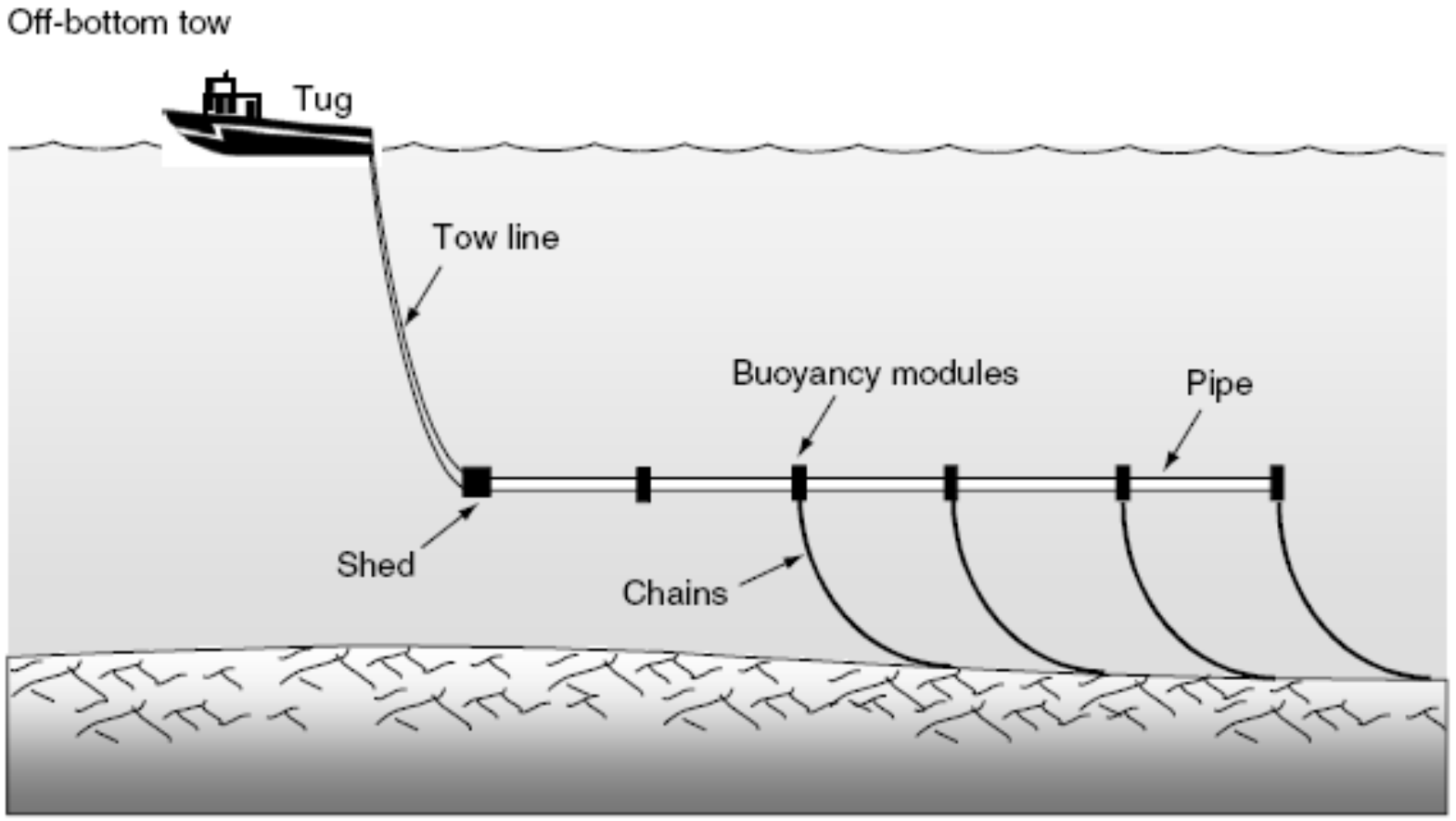
Buoyancy are added to the pipeline so that it floats at the surface. Once the pipeline is towed on site by the two towboats, the buoyancy modules are removed or flooded, and the pipeline settles to the sea floor.

Mid-Depth Tow Method



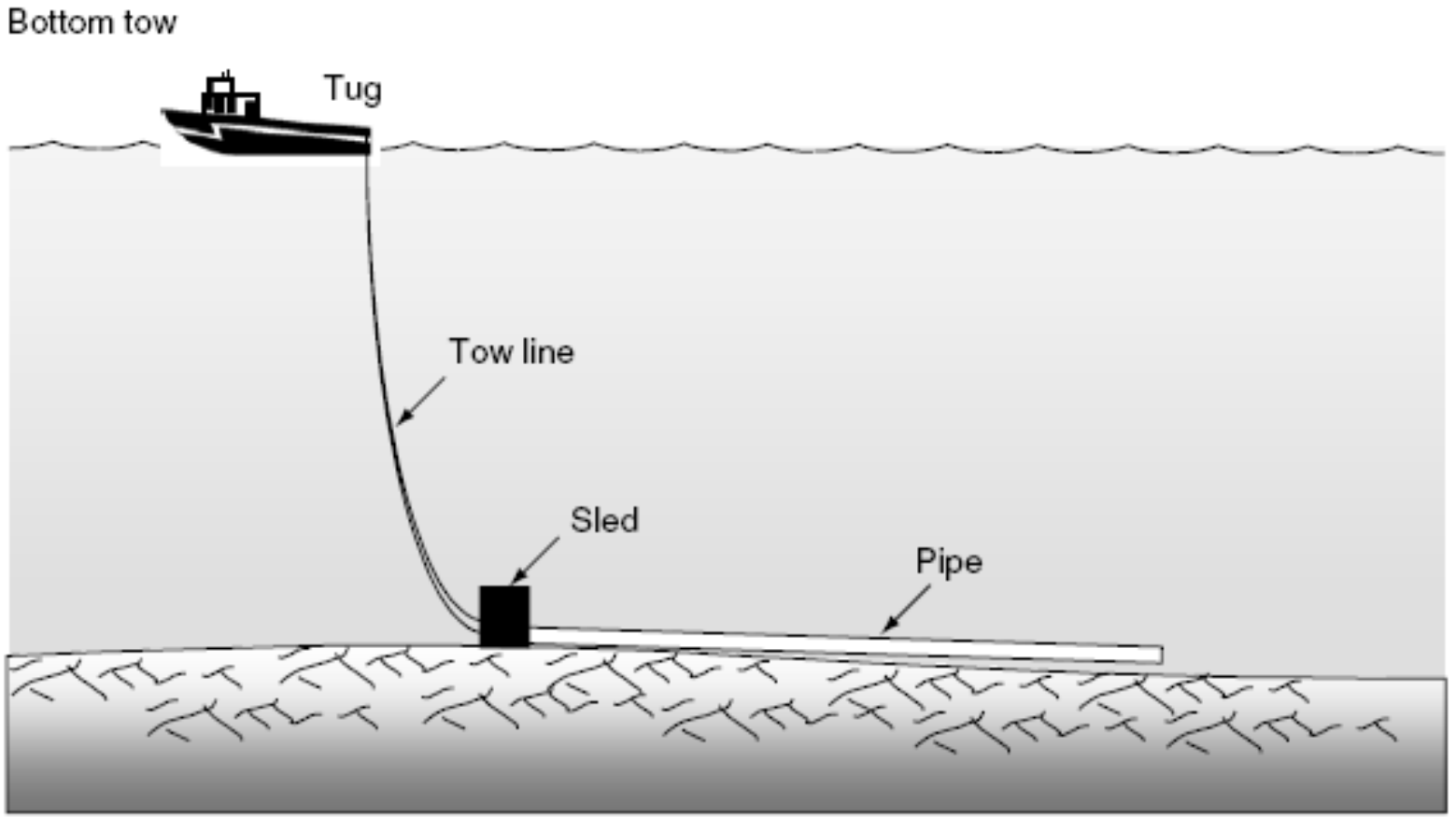
Requires fewer buoyancy modules. The pipeline settles to the bottom on its own when the forward progression ceases.

Off-Bottom Tow Method



Involves both buoyancy modules and added weight in the form of chains. Once on location, the buoyancy is removed and pipeline settles to the sea floor.

Bottom Tow Method



The route has to be surveyed carefully. Pipeline is allowed to sink to the bottom and then towed along the sea floor.

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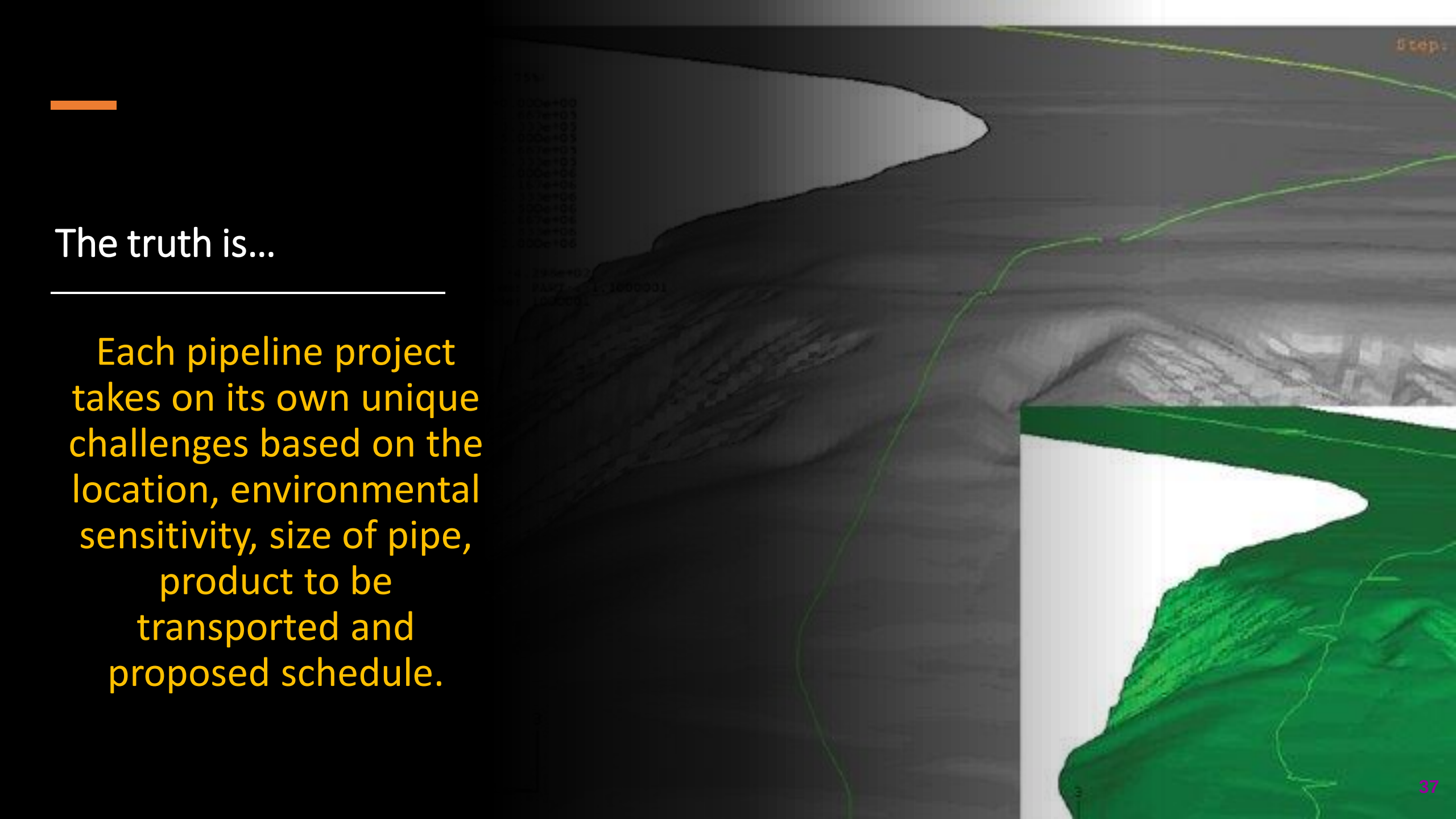
Pipeline Route Selection

The truth is…

Each pipeline project takes on its own unique challenges based on the location, environmental sensitivity, size of pipe, product to be transported and proposed schedule.



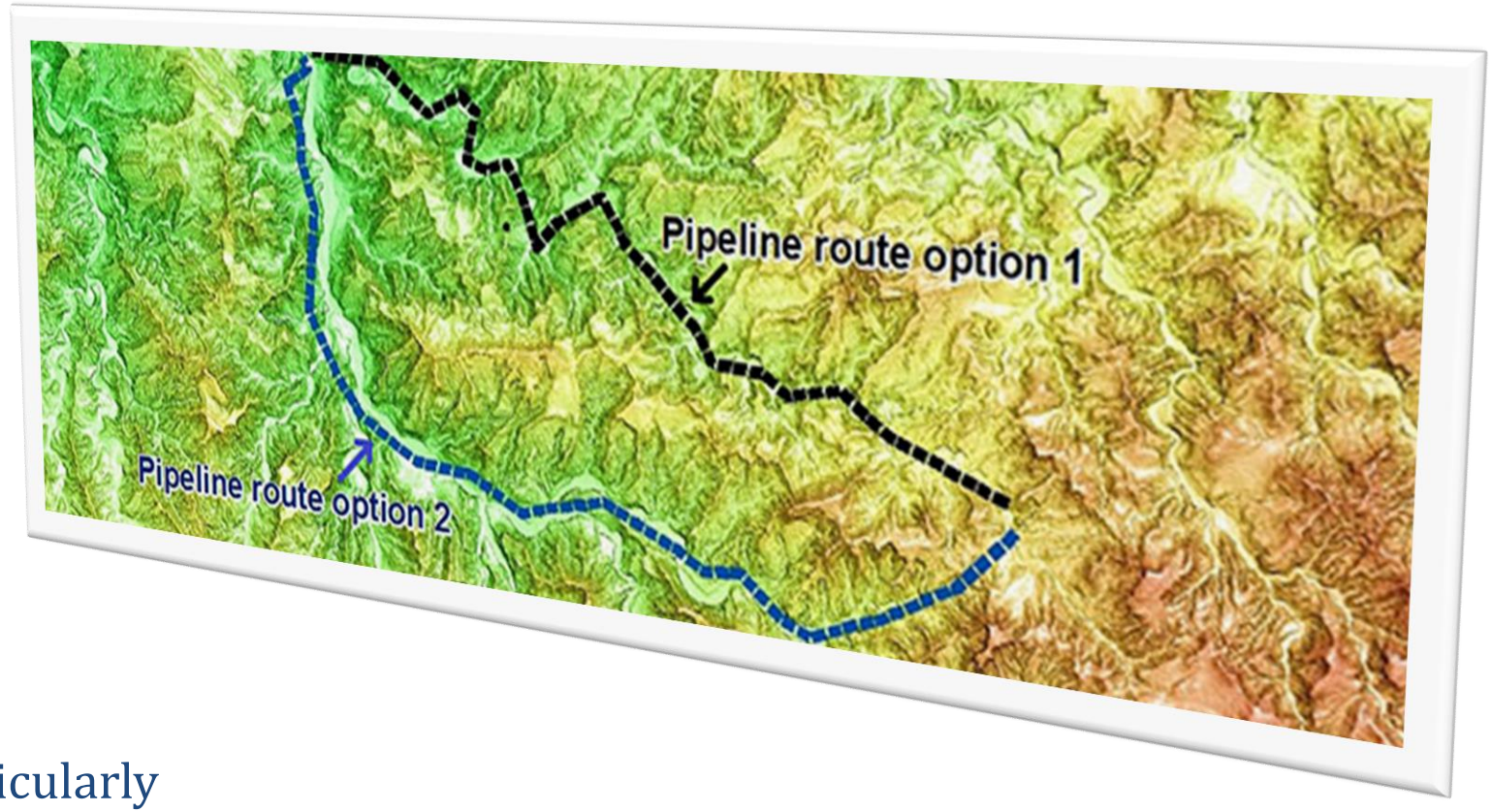
Basic Questions to Consider...

- What is the best route between two points?
  - Straight line

- Why can't have straight line?
  - Seabed obstructions
  - Existing infrastructures

- What to do:
  - Avoid them as much as possible

- What if can't?
  - Bend the pipeline around them
  - Cross existing pipeline perpendicularly

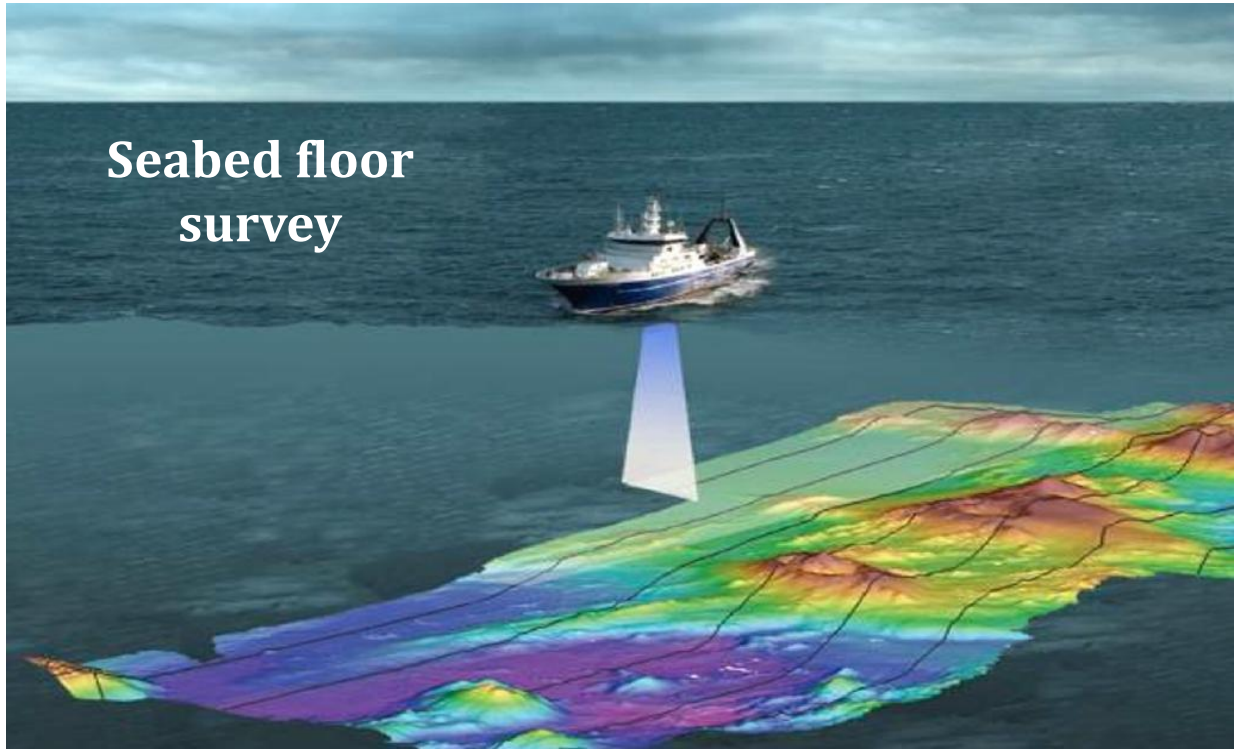


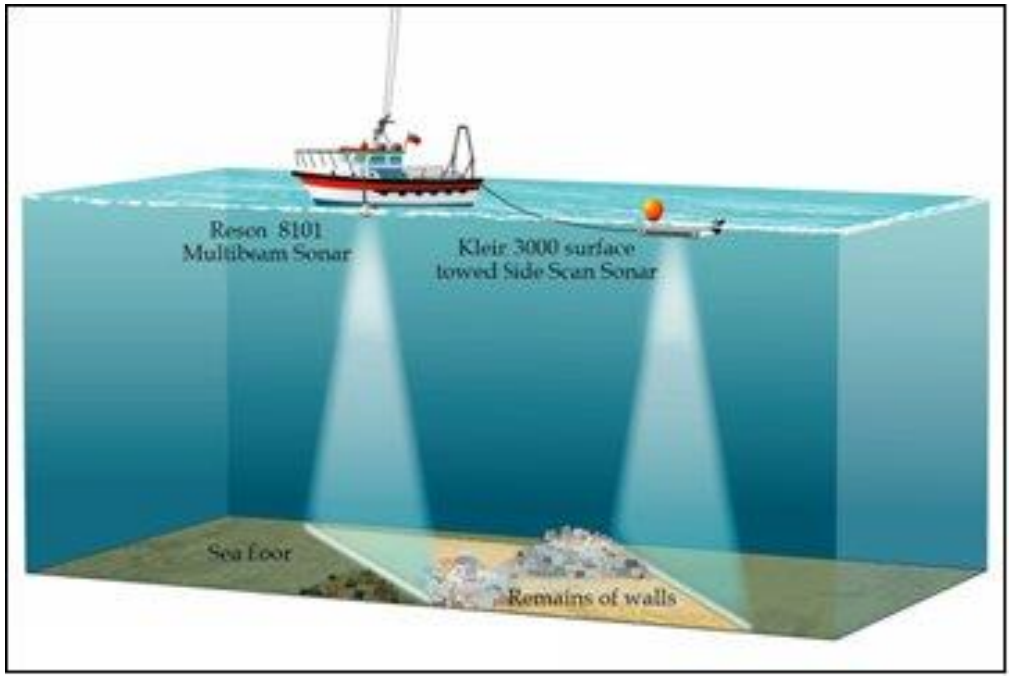
Pipelines may need to be buried to protect them from near-shore wave forces, ship anchors and commercial fishing activities.

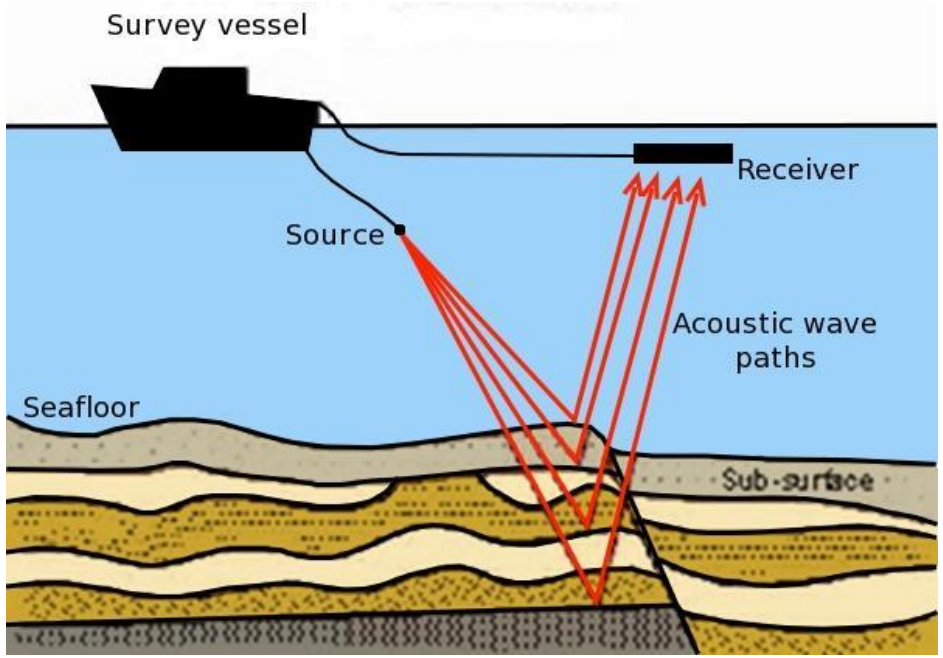
Buried Pipeline

Geophysical Survey

- Geophysical survey is to obtain:
  - Seafloor terrain
  - Seabed bathymetry
  - Natural seabed features
  - Existing infrastructures
  - Man -made obstructions
  - Shallow subsea profile







- Sub-bottom profiler is used to investigate under seabed soil layers
- Layers and thicknesses are shown by colour coding

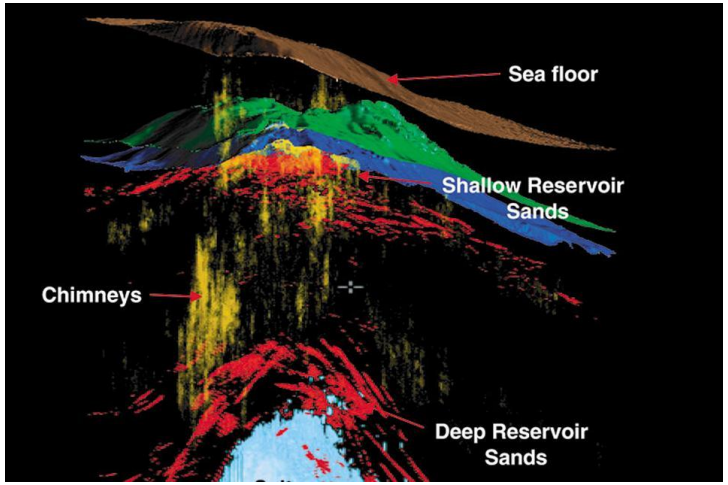
Geotechnical Survey

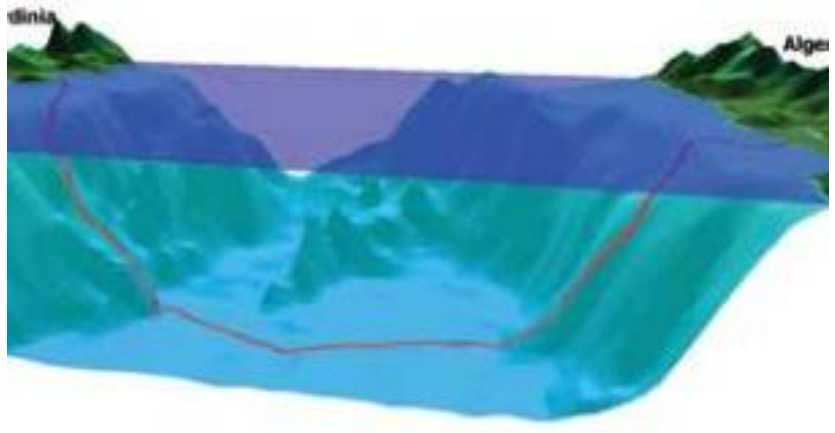
- To obtain soil design parameters to:
  - Assess soil downwards resistance (soil as foundation, penetration and etc.)
  - Assess lateral resistance (on-bottom stability, lateral buckling and etc.)
  - Assess soil upwards resistance (upheaval buckling)

- Tests/Survey Types:
  - In situ testing
  - Sampling

Seabed Obstructions

- **Natural seabed features**
  - Boulders
  - Iceberg groves
  - Gas chimneys
  - Sensitive seabed
  - Seabed slopes
- **Existing infrastructures**
  - Pipelines and umbilicals and cables
  - Anchoring zones and anchor chains
  - Manifolds and wellheads
- **Man-made obstructions**
  - Debris
  - Wrecks
  - Scaffolds (close to existing platforms)
  - Mattresses (close to existing platforms)





What to Avoid?

FACTOR	TO AVOID
Depth, waves, currents	• Very deep water • Very shallow water • High currents • High waves • Refraction
Seabed	• Very soft bottom • Very hard bottom • Rough bottom • Steep slopes • Sand waves and megaripples • Boulder fields
Other users	• Other pipelines/platforms/mooring systems/cables • Fishing • Military • Mining for sand and gravel • Navigation (anchorages, port approaches)
Environmental	• Deepwater: seabed disturbance, sediment from trenching, marine mammals • Shallow water: birds, fish, mammals, coral reefs
Politics	• Other operator's blocks • Other jurisdictions • Other countries

PIPELINE DESIGN

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Problems Associated with Pipelines

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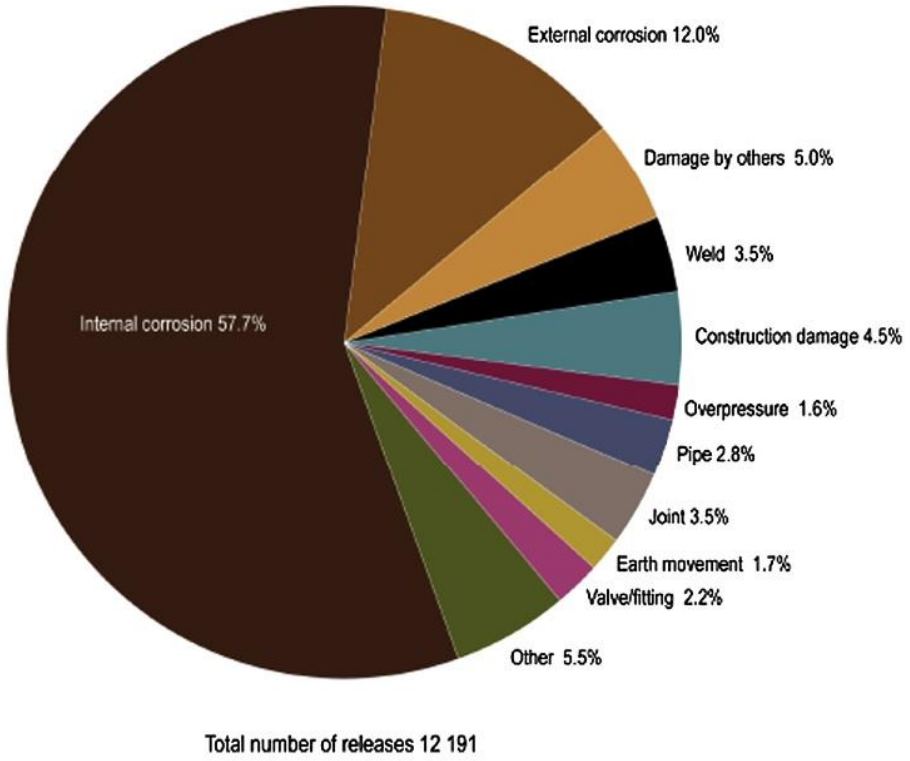
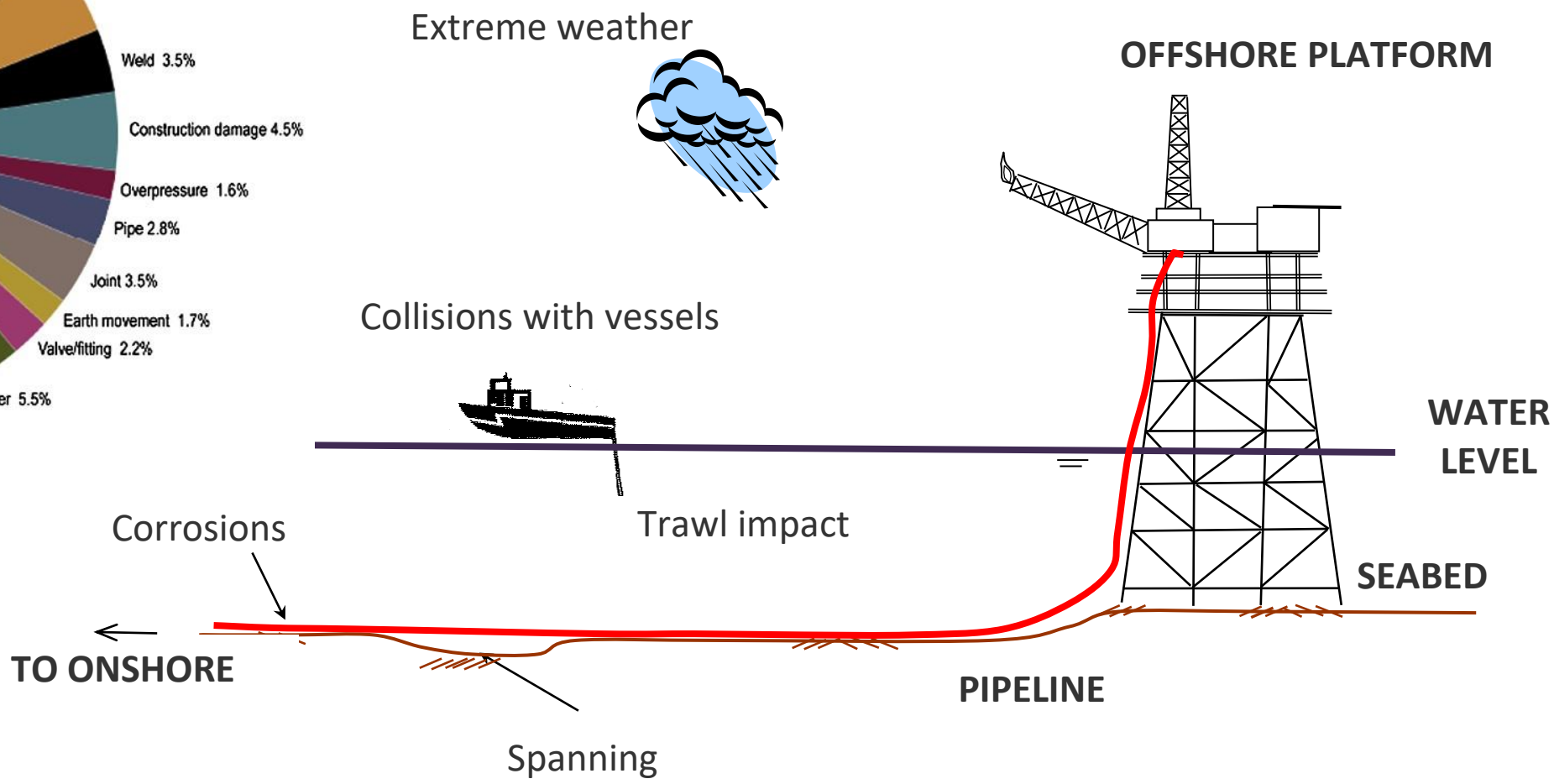
Hazards in Offshore Pipelines

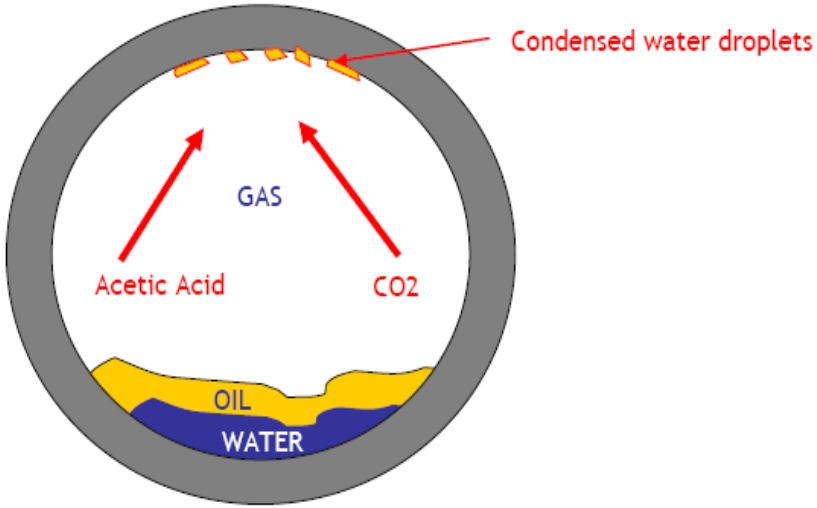




What is corrosion?

Corrosion is defined as the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces deterioration of the material of the material and its properties.

Corrosions can be observed either at the **internal** or **external** side of the pipeline wall.



(a)

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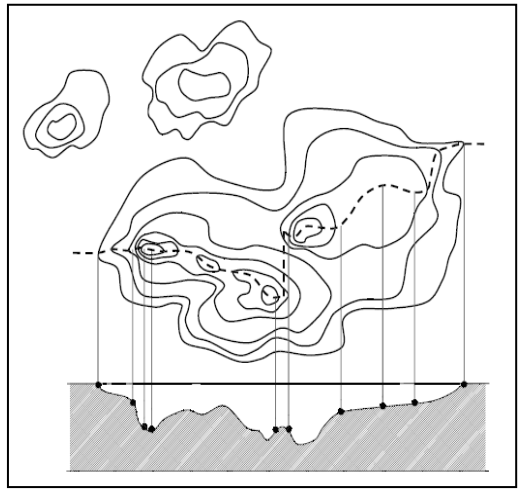
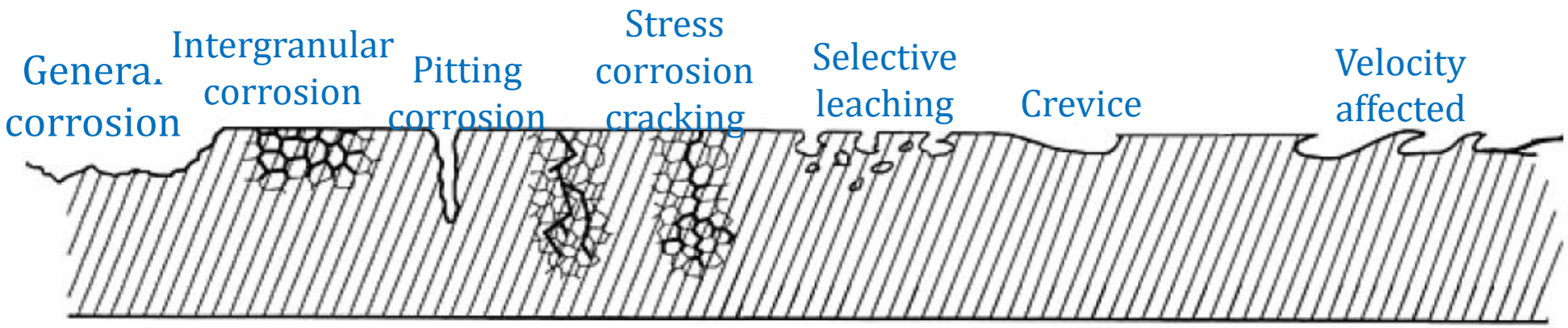


(c)

Forms of Corrosion



Different forms of corrosion developed on a particular metal surface (Freeman, 2002)

Corrosion	Characteristics
General (Uniform) corrosion	• Defined as corrosion with a length and width greater than three times the uncorroded wall thickness. • Uniform thinning of metal surface that proceeds without appreciable localized attack. • Corrosion rate is assumed constant over the period of time.
Localized (Pitting) corrosion	• Defined as corrosion with a length and width less than or equal to three times the uncorroded wall thickness. • A form of extremely localized corrosion that leads to the creation of small holes in the metal. • Thickness is reduced locally.
Crevice corrosion	• Occurs in spaces to which the access of the working fluid from the environment is limited, e.g. slots and in gaps at metal-to-metal and metal-to-nonmetal interfaces, especially at critical joining surfaces.
Galvanic corrosion	• Occurs when two dissimilar conducting materials (metallic or nonmetallic) are in electrical contact. • One metal corrodes preferentially to another when both metals are in electrical contact and immersed in an electrolyte.
Intergranular corrosion	• A form of corrosion where the boundaries of crystallites (grains) of the material are more susceptible to corrosion than their insides. • Caused by environmental interactions or metallurgical changes in the grain-boundary regions during manufacturing or service exposure.

Corrosion	Characteristics
Stress corrosion cracking (SCC)	• An unexpected sudden failure of normally ductile metals subjected to a tensile stress in a corrosive environment, especially at elevated temperature in the case of metals.
Selective leaching	• Removal of one element or phase from a solid alloy which results in an altered matrix usually consisting of a porous mass. • Also known as dealloying, and when referring to the noble metals, it is also called parting.
Velocity affected corrosion	• Depends on the relative velocity between the water and the metal surface. • Water corrosivity can be dramatically increased by dissolved gases, acids, salts, strong bases, entrained abrasives, high temperature, fluctuating pressure, cavitation, or impingement.
Microbially-induced corrosion (MIC)	• Caused or promoted by microorganisms or living organisms, e.g. sulphate-reduced bacteria (SRB), algae or fungi. • Often associated with the presence of tubercles or slimy organic substances.

Corrosion Mitigation

There are two kinds of corrosion mitigation strategies:

1. INTERNAL CORROSION

- Corrosion inhibitor is the chemical injection used to control corrosion development inside the pipeline.
- It is released into the pipeline at certain time intervals.

Corrosion inhibitors

2. EXTERNAL CORROSION

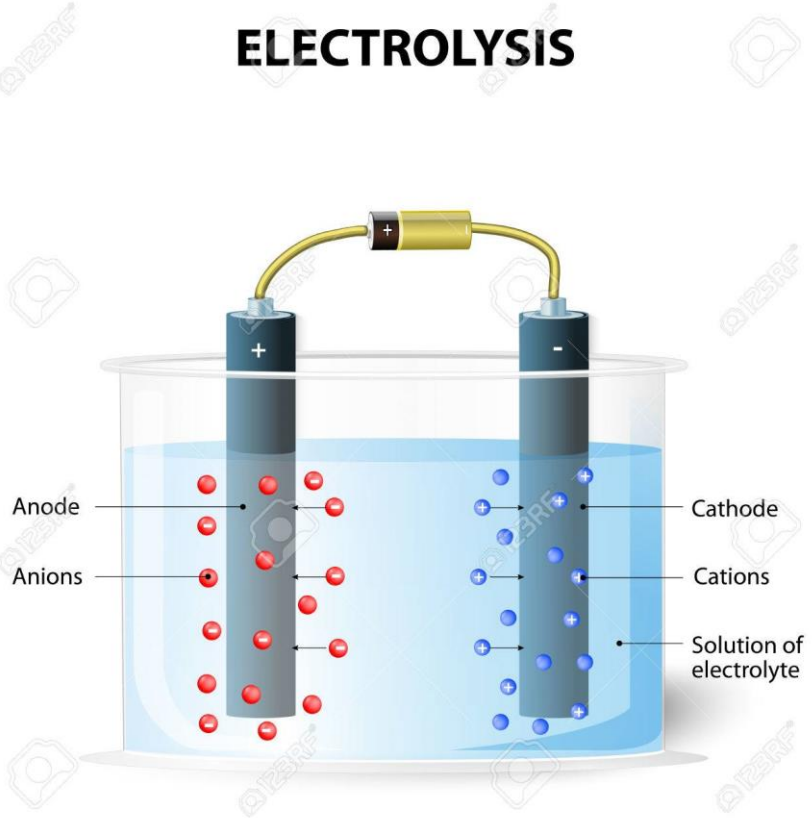
- Sacrificial anode is used to control corrosion development outside the pipeline.

Sacrificial Anodes

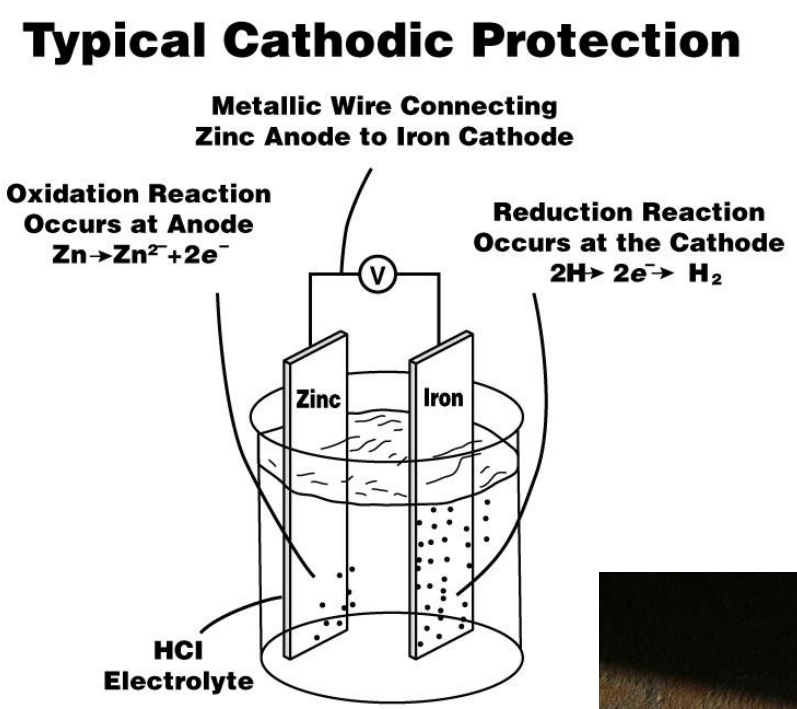
External Corrosion - Electrolysis

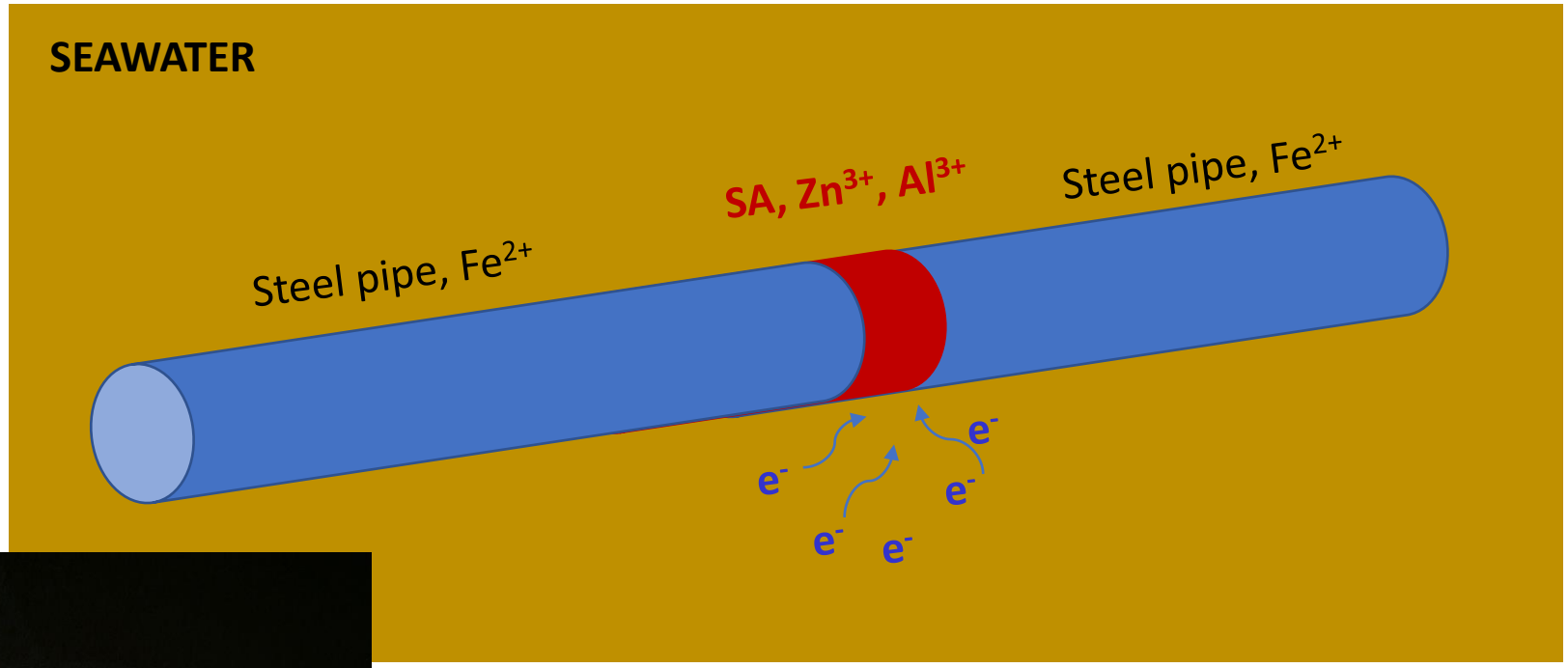
Electrolysis is chemical decomposition produced by passing an electric current through a liquid or solution containing ions.

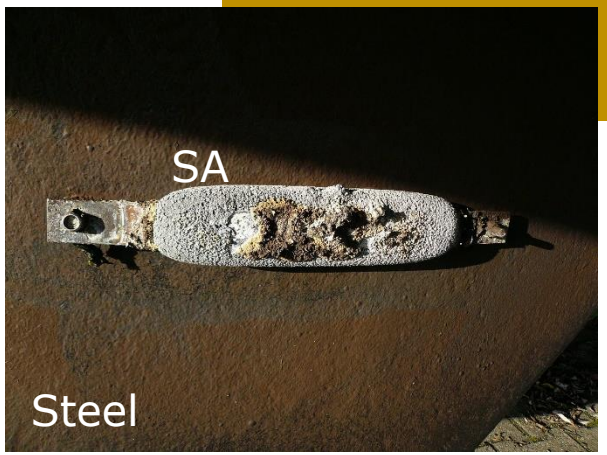
Electrolysis is commercially important as a stage in the separation of elements from naturally occurring sources such as ores using an **electrolytic** cell.



External Corrosion – Sacrificial Anode







Ring type sacrificial anode

Corrosion Inspection - Pigging

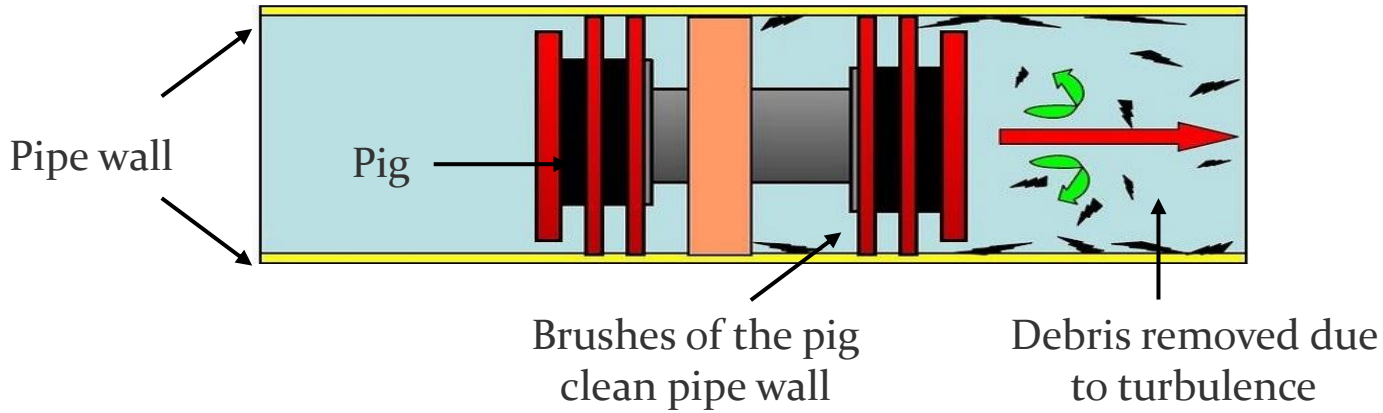
- *Pigging* in the maintenance of pipelines refers to the practice of using pipeline inspection gauges or *pigs* to perform various operations without stopping the flow of the product in the pipeline.

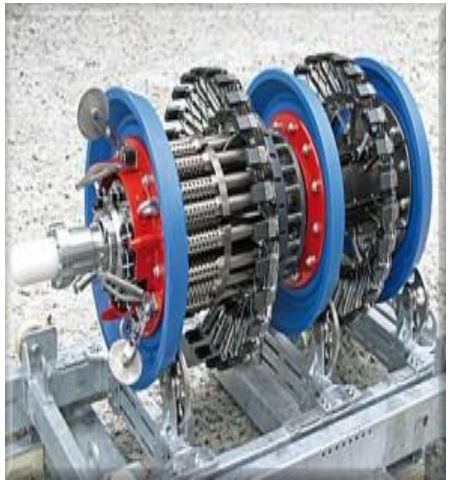
- The name pig was originally applied to scrapers which were devices driven through the pipeline by the flowing fluid trailing spring-loaded rakes to scrape wax off the internal walls. The rakes made a characteristic loud squealing noise.

Intelligent Pigging

An intelligent pigging (IP) is an important tool used to:

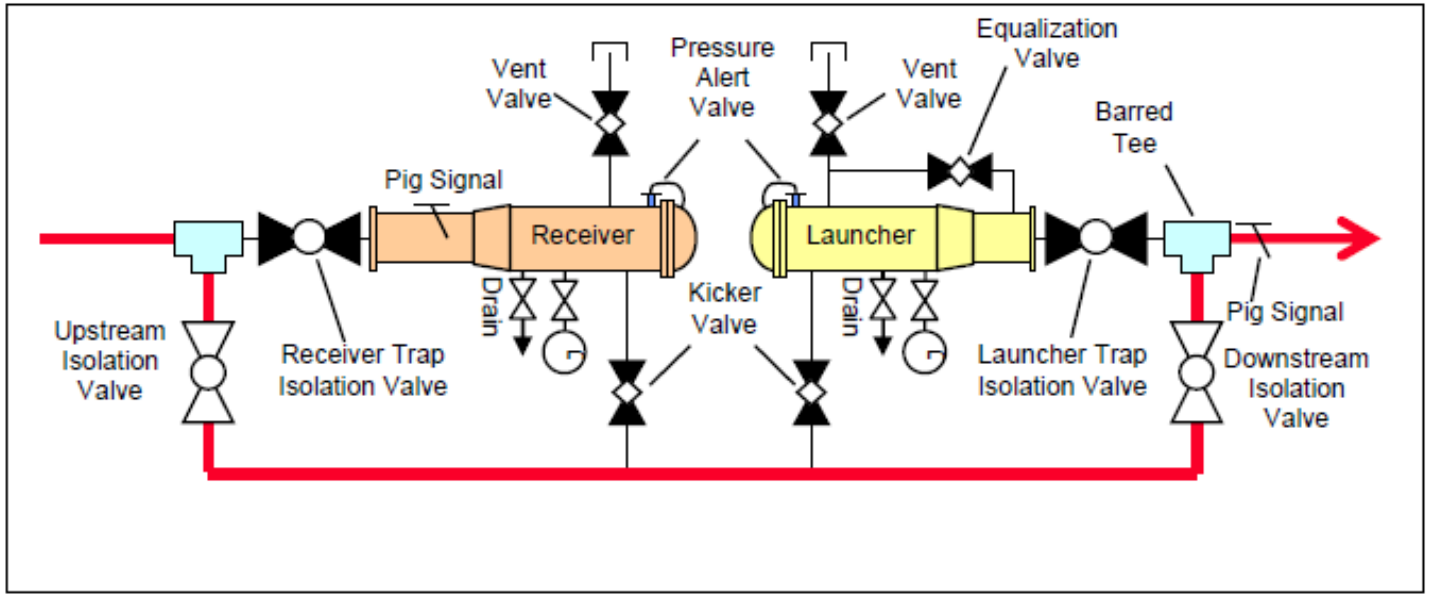
- remove deposits which could obstruct or retard flow through a pipeline.
- report conditions of the pipeline wall.
- control corrosion development.





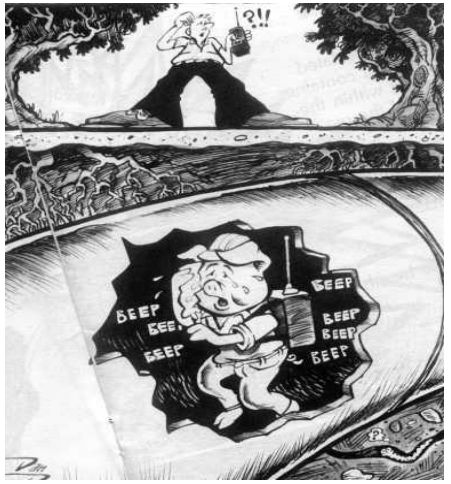
Pig Trap System

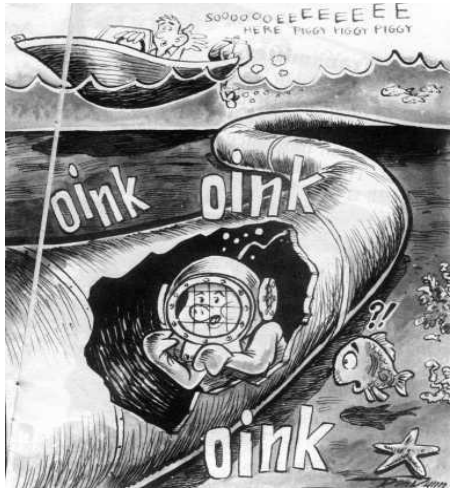
Pipeline pigs are inserted into the pig launcher and travel throughout the length of a pipeline driven by a product flow, and collected at the pig receiver.



Lost Pig in Pipeline

- A pig sometimes experiences difficult time to find its way ‘home’ and consequently lost in the pipelines.





- One of the reported incidents involving pig lost can be referred to Lino et al. (2006). The incident happened when a *mandrill pig* was unable to be detected at the pig receiver.

“In Search of the Lost Pig”

Pipeline & Gas Journal, August 1, 2006

Lino, Antonio Carlos Ferreira; Filho, Durval Florencio; Pereira, Fernando Borja; da Silva, Jose Silverio; Amado, Ulisses Dias

“A mandril pig was lost and then found in an operating oil pipeline in Brazil's Amazon forest in a project that involved six field operations involving 48 days of work over a nine-month period.

The adventure began when a 14-inch mandril pig was launched from the Urucu Unit to run through the ORSOL I oil pipeline in the Amazon and did not arrive at the Coari Terminal, located 280 km from the launch site. The crew at Coari was surprised, to say the least, when the pig did not turn up on time. In cleaning operations, low-density foam pigs normally were used in ORSOL I. This mandril pig was used for the first time in ORSOL I to improve the cleaning process. In the past, other types of mandril pigs were used without problems.

Once the pig was determined to be lost, considering the possibility of a lack of sealing, the crew decided to launch a low-density foam pig with an abrasive coating. When the original mandril pig and the foam pig didn't arrive, the crew sent two more foam pigs without success. Pieces of the foam pigs were recovered in the receiver but most pieces remained lost somewhere inside the pipeline, along with the mandril pig.”

- The search for the lost pig by Lino et al. (2006) reached to an end when the pig was located 20 km farther away from the launcher.

- The pig that was broken into parts was then investigated to identify the causes of failures.

- Based on the examination and analysis of all pig components, the pig could be dismantled:
  - ✓ due to a valve misalignment,
  - ✓ caused by a dent in the sector of pipeline between the launcher and valve station,

Dent in Pipe

  - ✓ as a result of inadequate construction whereby, the pig was unable to support the operational loads, or
  - ✓ from an operational failure during the launching.

When a **pig got stuck in a pipeline**, the pipeline operations are exposed to production dangers like:

- Wax accumulation — in regular pigging routines, wax accumulation is controllable. However, disruption to a cleaning routine could create a significant wax accumulation.

- Water accumulation — in addition to wax removal, pigging removes water. A disruption to the cleaning routine could create a significant accumulation of water which could, in turn, create a pipeline blockage.

- Pipeline erosion — an increase in flow velocity in the specific location of the lost pig could amplify the erosion factor and cause further damage to the pipeline.

#2. Buckling

Types of global buckling:

- Upheaval buckling
- Lateral buckling

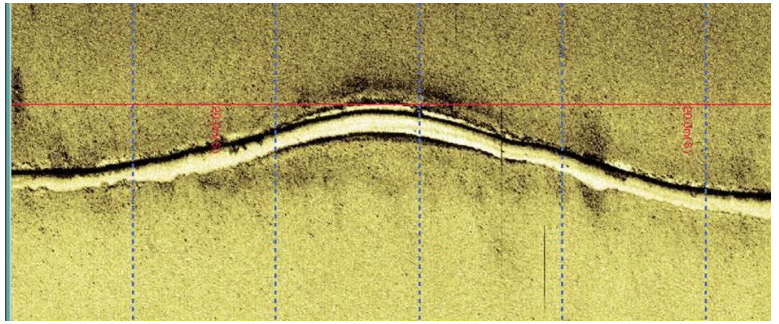
Some key factors are:

- Pipeline dimensions and mechanical properties
- Content pressure & temperature
- Soil properties
- Seabed features and vertical and lateral imperfections
- Boundary conditions
- Fishing gear interaction
- Residual lay tension

- Key factor is effective axial force.

Lateral Buckling

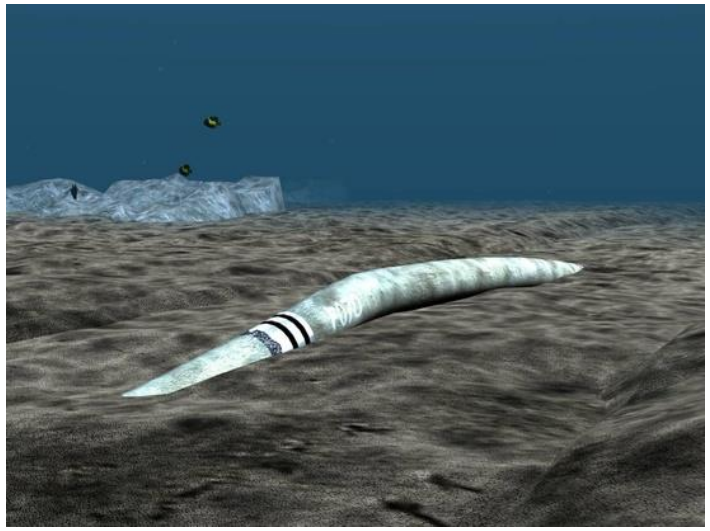
- Is a type of global buckling where the pipeline buckles sideways from the location where it has been laid. In this case, due to the pressure and temperature in the pipeline, effective compressive axial force increases to the level above the resistance of the soil frictional and embedment resistance.



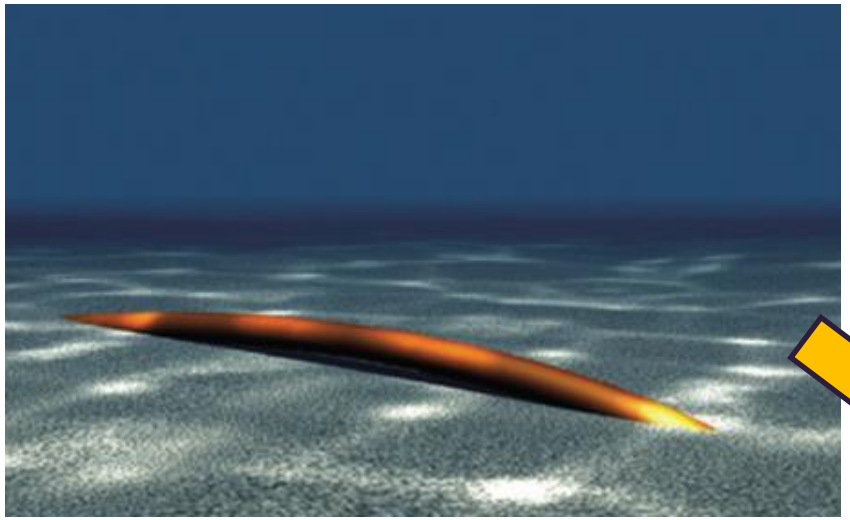
Plan view

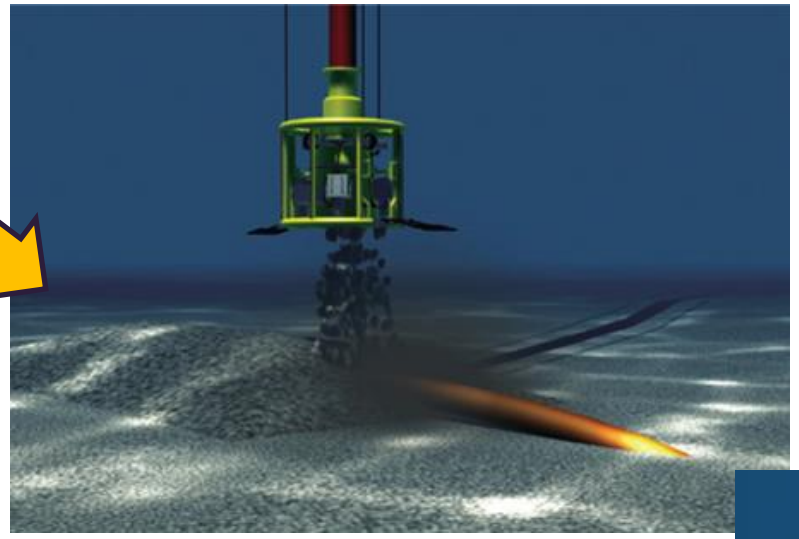
Upheaval Buckling

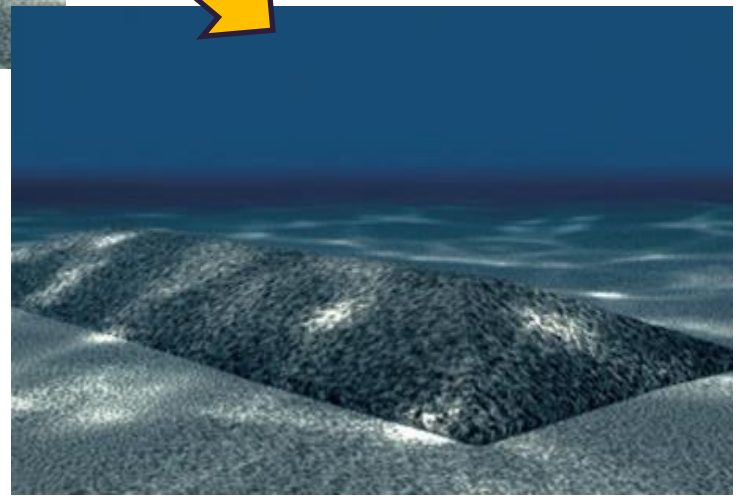
- Is a type of global buckling where the pipeline buckles upward from the location where it has been laid. In this case, due to the pressure and temperature in the pipeline, effective compressive axial force increases to the level above the resistance of the soil and rockdump cover.



Rock Dumping on Upheaval Buckling







#3. Other Products

Wax – Paraffin precipitation and deposition in crude oil transport flowlines and pipelines is called wax.

Hydrate – Gas hydrates are ice-like crystals that forma around water molecules when the water us subjected to low temperatures and high pressure like those found in deep-sea drilling.

Scale – Scale is the formation of inorganic, sparingly soluble salts from aqueous brines during oil and gas production. Scale forms and deposits under supersaturated conditions, wherever the mixing of the incompatible types of water; formation water from the bottom hole and the injected seawater, takes place.

WAX

HYDRATES

SCALES

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New Technology in Pipelines

- Composite Pipeline
- Smart Pipe

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COMPOSITE PIPELINE

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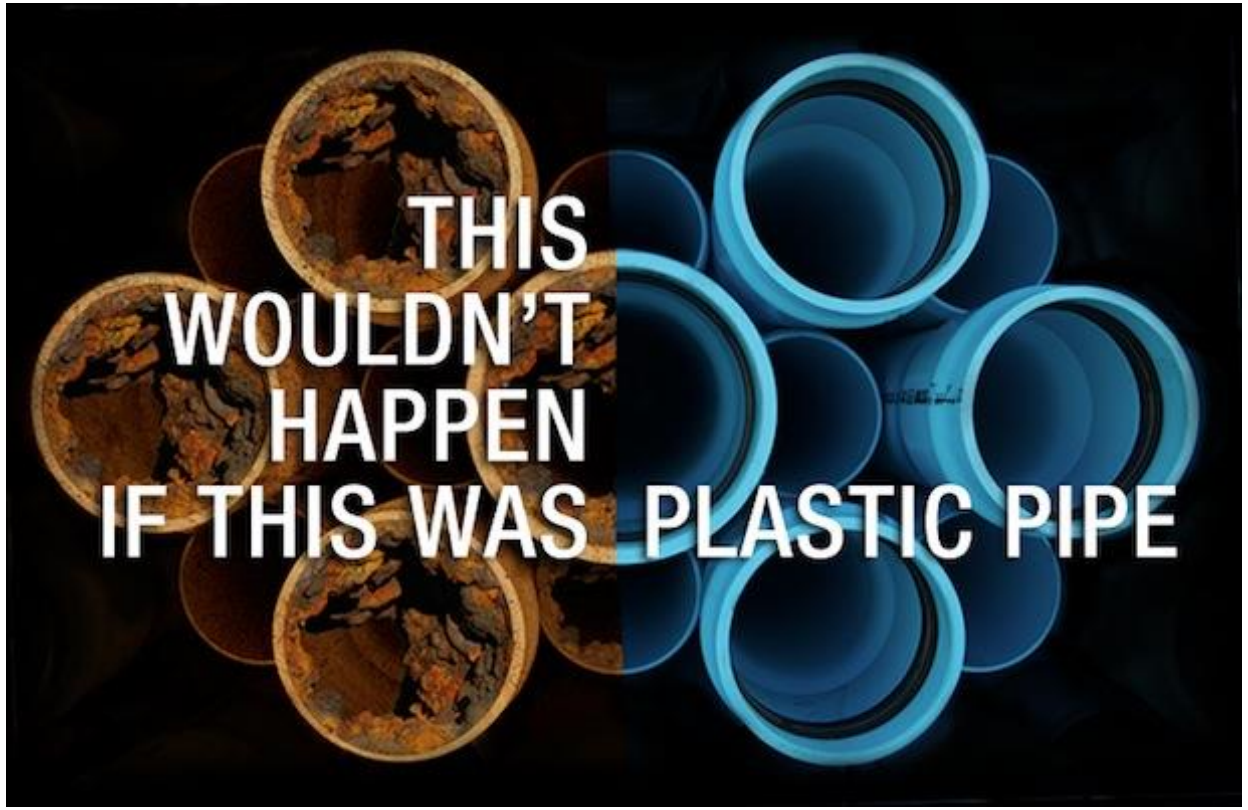
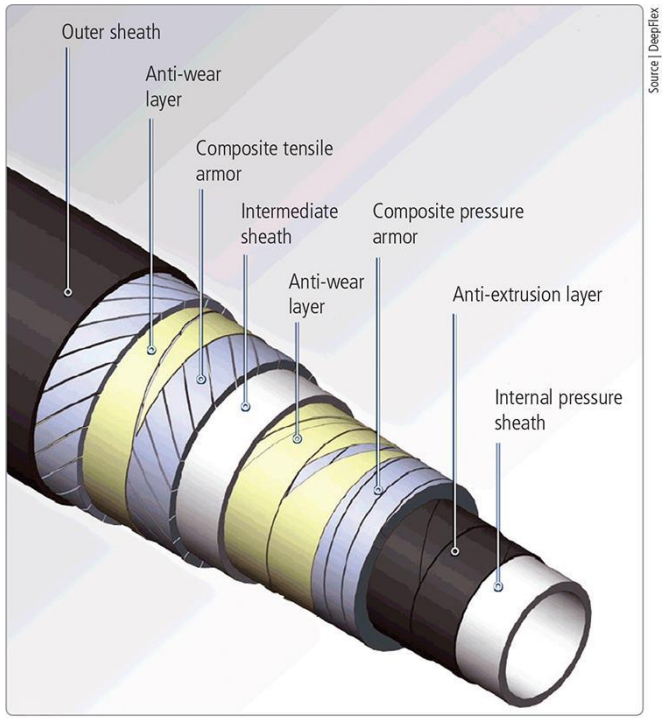
Why Non-Metallic Pipe?



Ordinary Carbon Steel Pipe

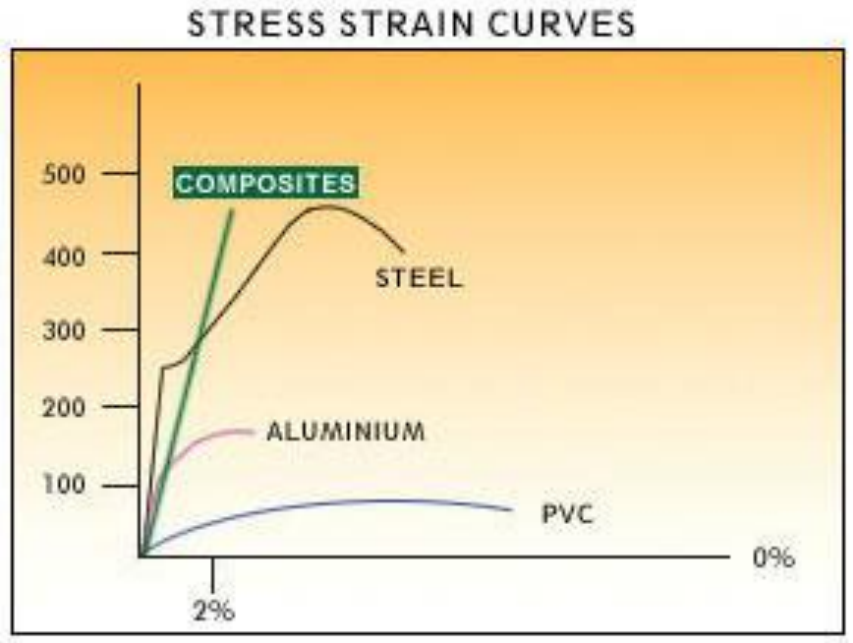
Corroded Carbon Steel Pipe!



Non-Metallic (Composite) Pipe

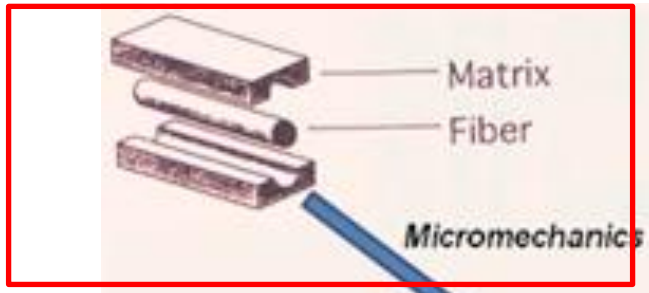
VS.

Carbon Steel Pipe



Material properties

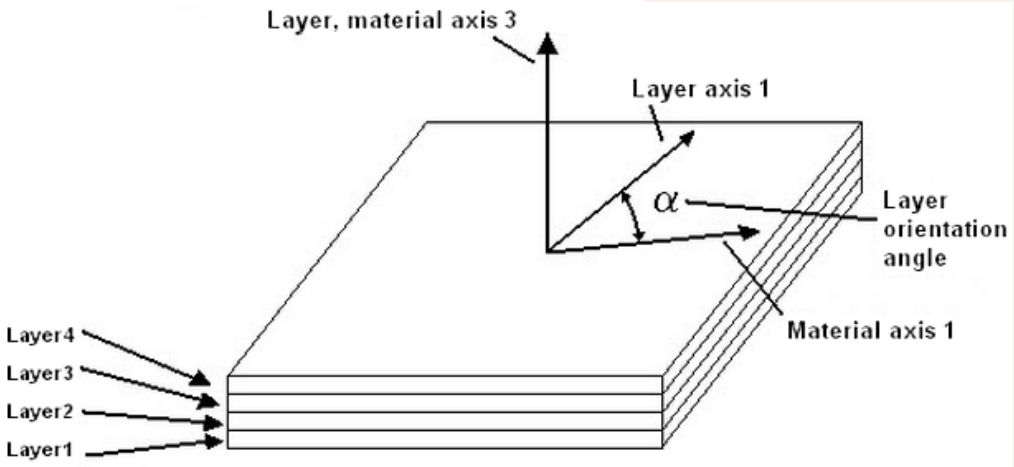
What is Composite?



Micromechanics

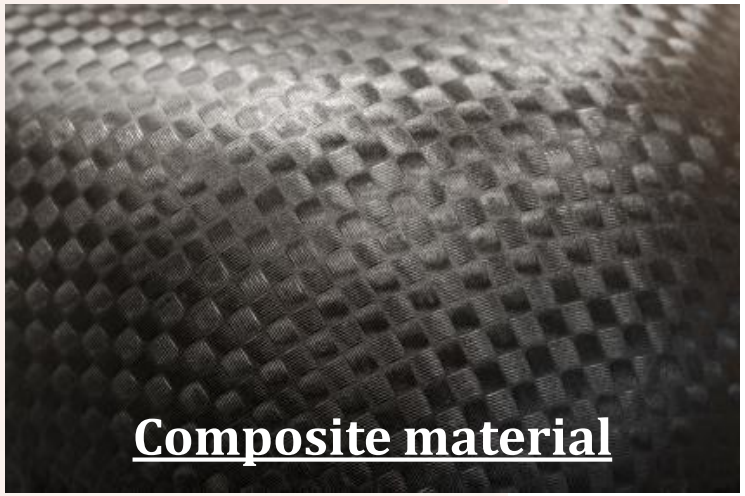
Lamina / Ply

Macromechanics

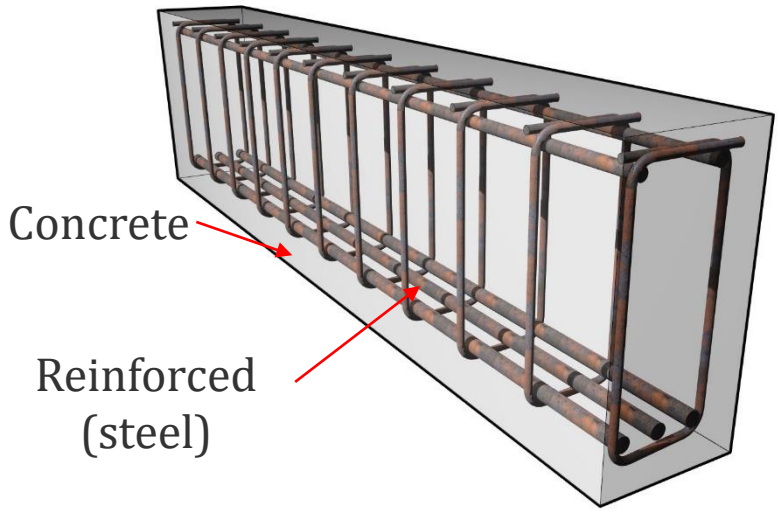


Laminate

Finite Element Analysis

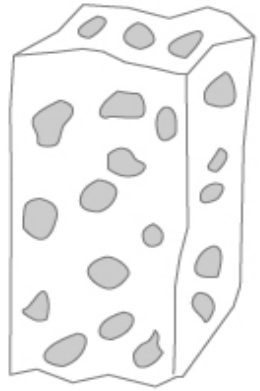


Origin…

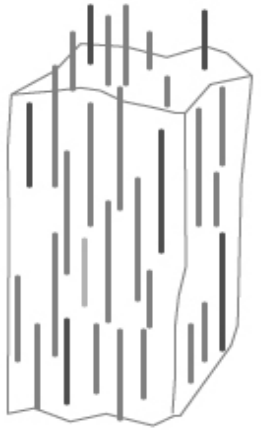


Modified to…

A. Particle Reinforced Composites
B. Fiber Reinforced Composites
   - Short Fiber Reinforced
   - Long Fiber Reinforced

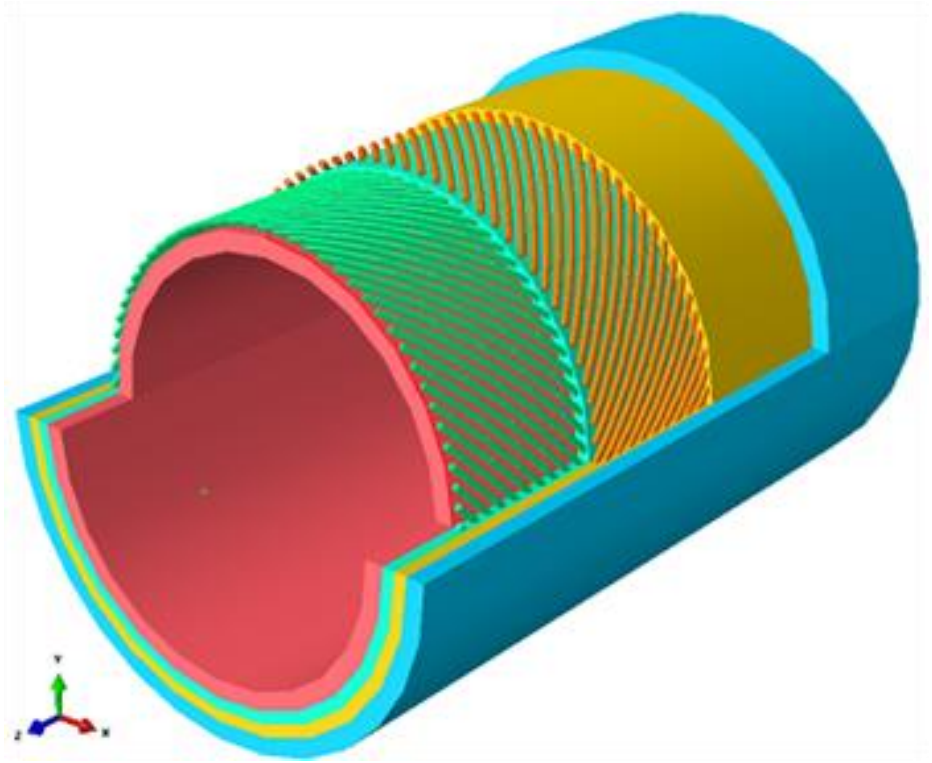


Particle reinforced composite

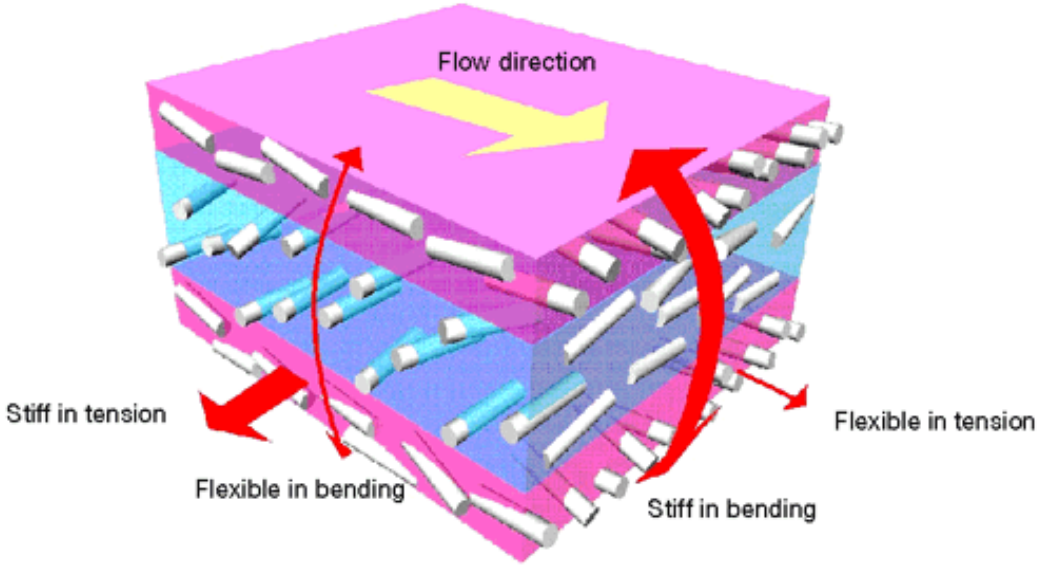


Fiber reinforced composite

Composite materials are made of multiple layers of different materials.

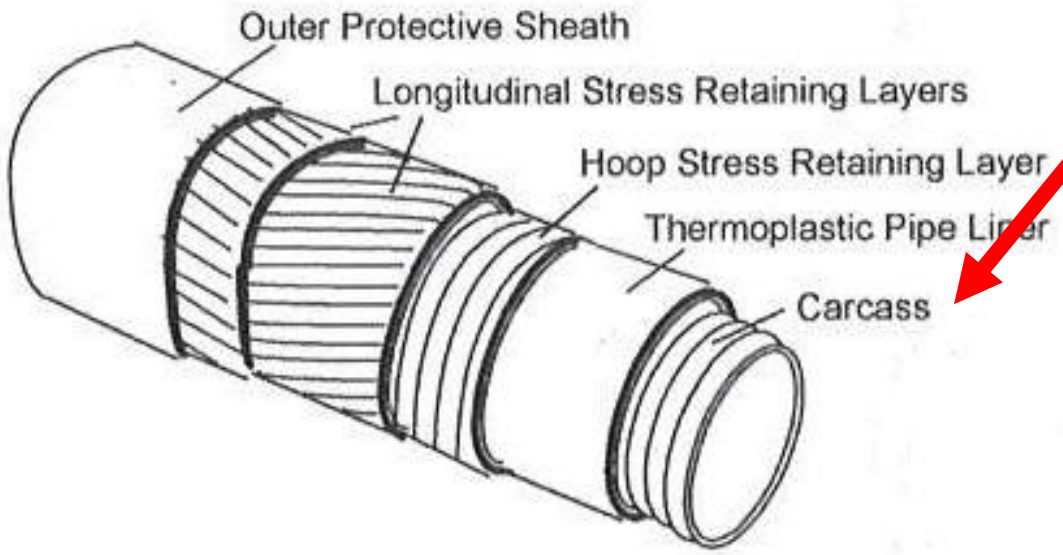


Composite Pipe



Composite fibre directions

Composite Pipe – Function of Layers

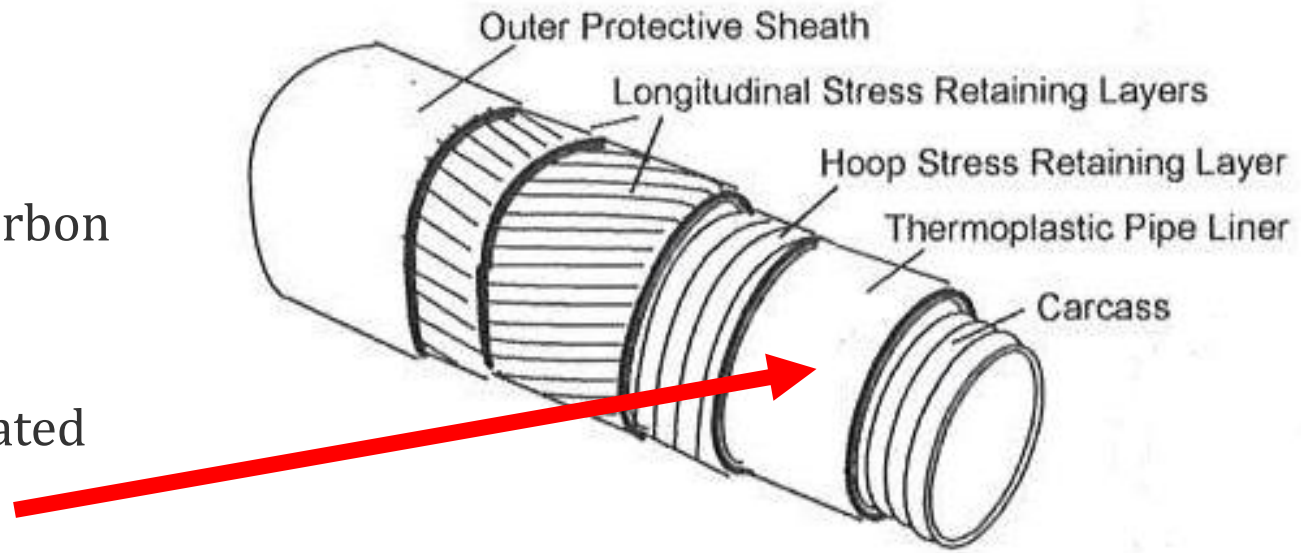


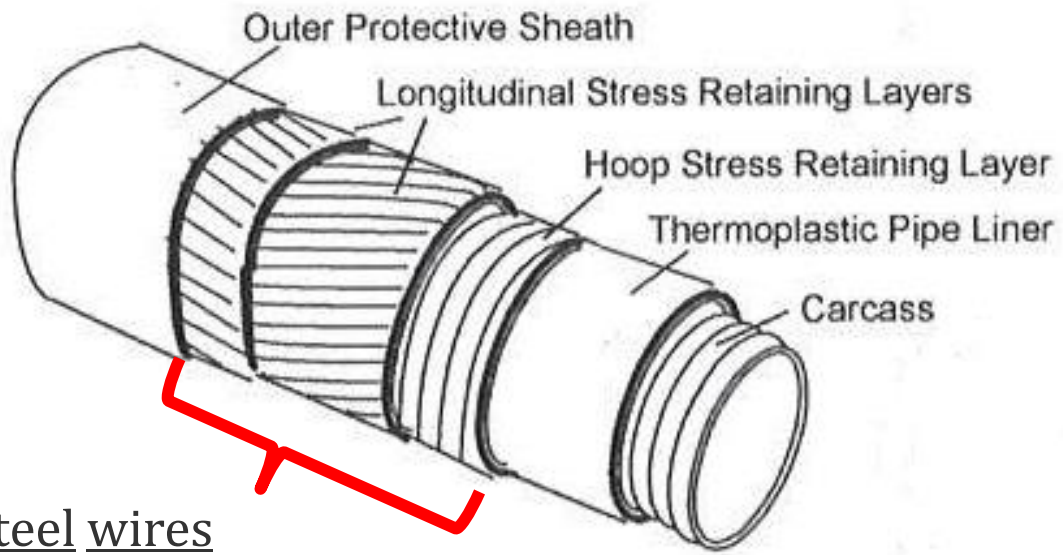
Carcass:

- Function to prevent collapse of the thermoplastic pipe liner as a result of gas expansion or hydrostatic pressure.
- Helically wound interlocking metal strip that is permeable to the transported fluid.
- Not gas/fluid tight, liner will swells and seals the carcass when exposed to hydrocarbon.

Liner:

- Function to contain the hydrocarbon fluid.
- Fabricated from high-density polyethelene, nylon and fluorinated polymers.
- Choice of liners depends on the operating temperature:





Pressure Containment layers:

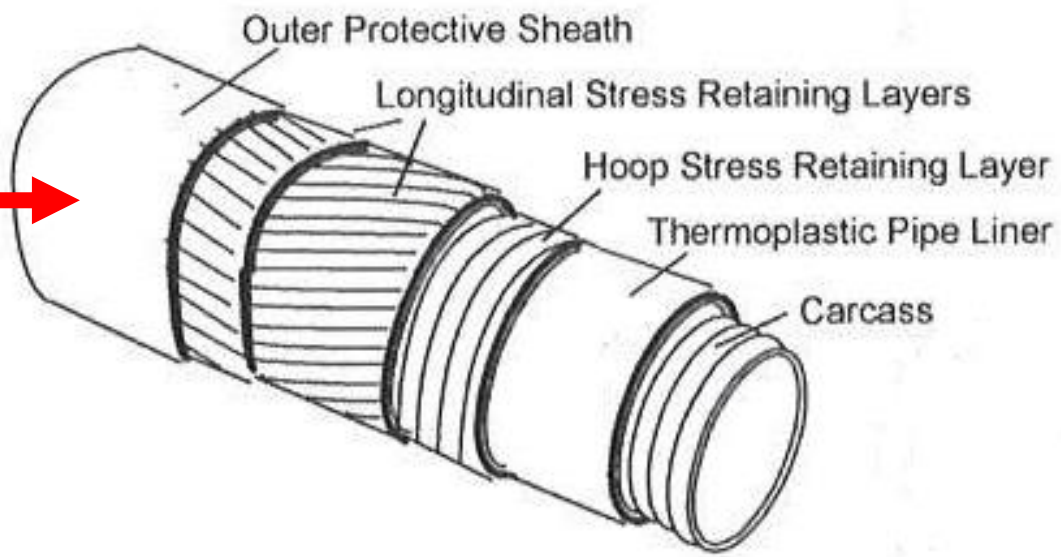
- **Internal pressure:** Contained by steel wires wrapped around the thermoplastic pipe liner. *e.g.* hoop stress retaining layer.

- **External pressure:** Hoop stress retaining layer is overlaid with two layers of armoring. Circular or flat steel strips layers. Opposing helical wounding to balance the extension forces.

Outer Sheath:

- Hot-melt extruded plastic sheath. *e.g.* HDPE
- Function to protect steel armoring from external corrosion.
- Additional layers of insulating foam may be applied.
- Cathodic protection is also provided.

  e.g. sacrificial anode



Advantages and disavantages of a composite pipe:

ADVANTAGES	DISADVANTAGES
Stronger than steel pipe Flexible, reducing stress Cheaper compared to steel	Slow to be recognized due to lack of standards and testing procedures Lack of material production.

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'SMART PIPE'

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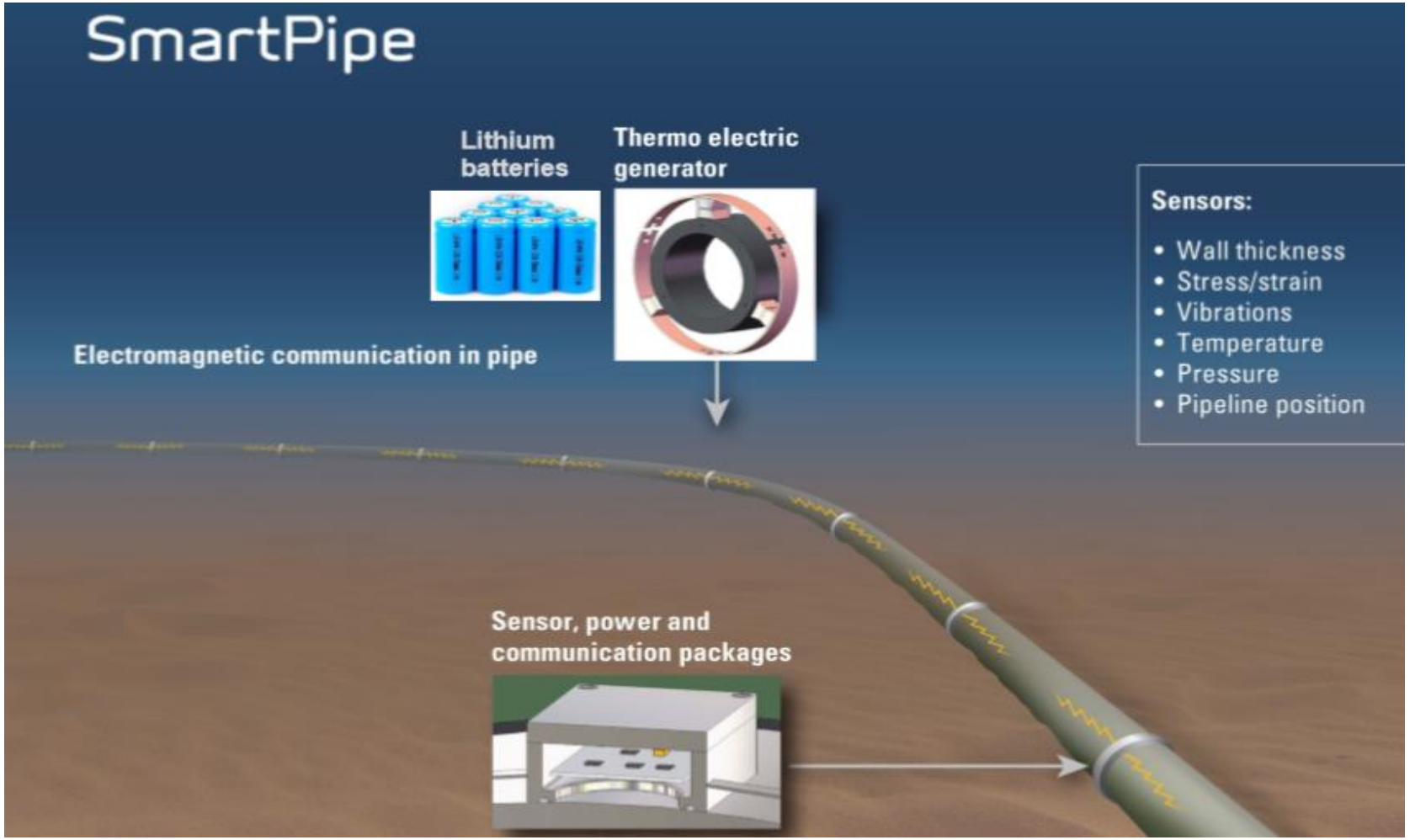
WHY SMART PIPELINE?

Industries' ***wish list*** of the next Pipe Technology:

- Real-time monitoring system
- Real-time health condition of the pipe
- Hazards free pipe
- Optimized assessment approach (e.g. probabilistic approach etc.)
- Zero maintenance
- Zero inspection
- Self-healing pipe *etc*.

SmartPipe - SINTEF

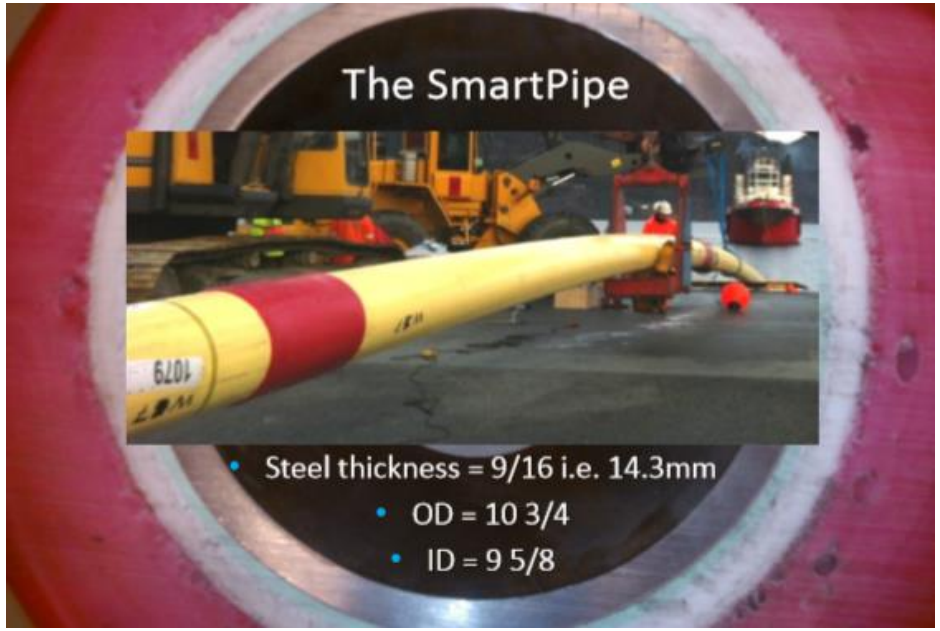


SINTEF was a 6 yr project (2006-2013), research funding of USD 25 mil. with collaboration by many partners.

Test was conducted on a 200 meter pipe, which was a part of a 100 km pipeline.

The sensors are placed as a belt, at 24 meters interval.

Aim to see whether the electronics and communication system will work underwater for a long period of time.



How Smart?

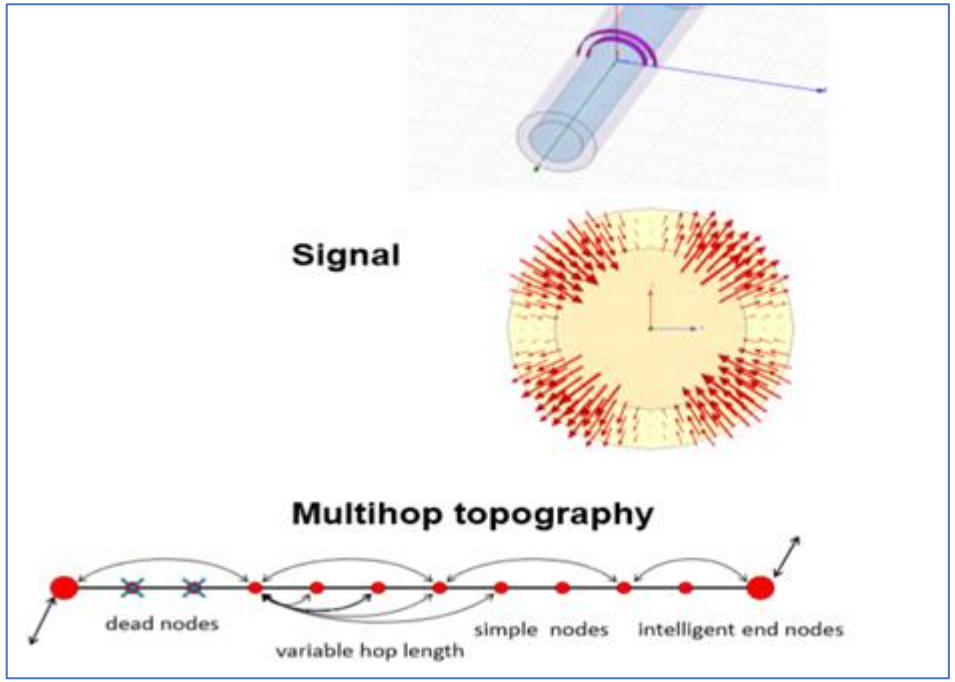
Intention:

- To gather real time information and constructing a database from the collected information to assist in future decision making, to respond to problems at early stages.
- To maintain the condition of a pipeline in an entirely different way.

Information collected:

Design, fabrication, installation, and operation of pipeline.

Temperature Pressure Flow composition Vibration	Tension Movement Pipeline wall thickness Corrosion Fatigue



Challenges:

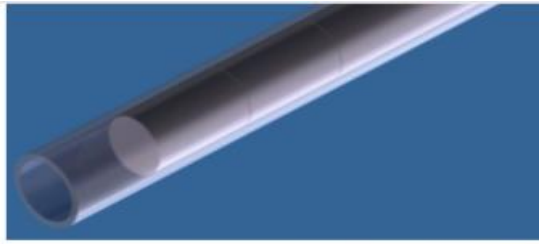
To devise a feasible concept for powering up the sensors and the communication system between the sensors and the operator.

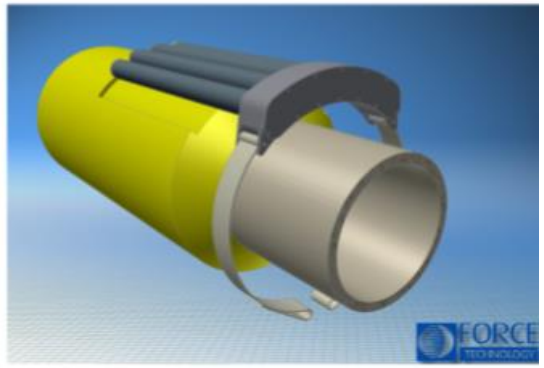
Power supply cables are not feasible especially for long distance pipelines due to cost of material.

The SINTEF SmartPipe developed was equipped with locally produced power (thermoelectric generator) and lithium batteries.

Battery packing

- Four cells in series inserted in steel tubes
  - 600 mm length
  - Space available for charge balancing electronics
  - Hermetically sealed to prevent water intrusion
- Ten 14.4 V battery packs encased in exterior bracelet
  - 40 cells in total (120% capacity)
  - Close contact to cold sea water beneficial for battery lifetime
- Exterior bracelet can be partially embedded in PP-insulation.





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What is Next?

'Digital Transformation in the Pipeline Industry'

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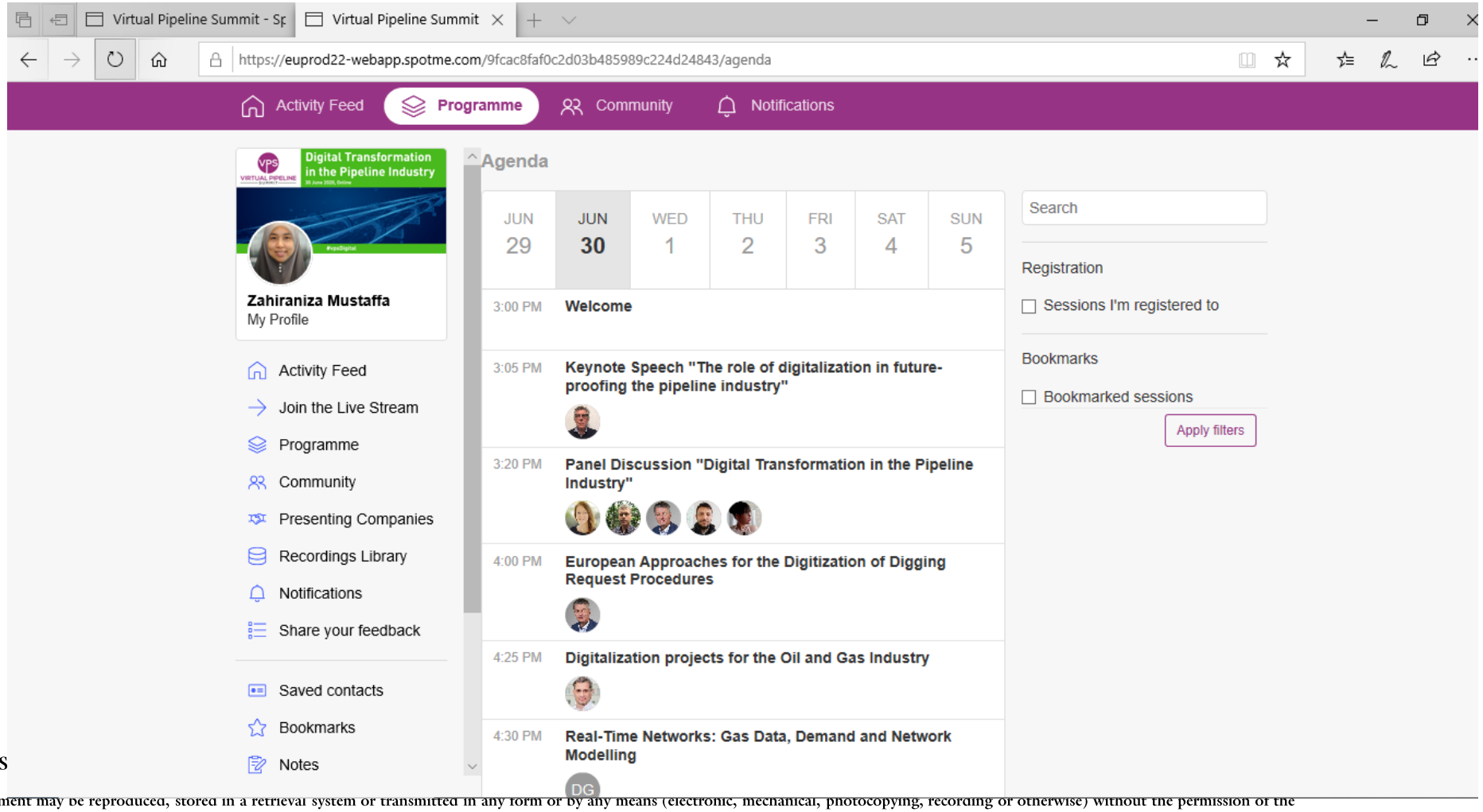
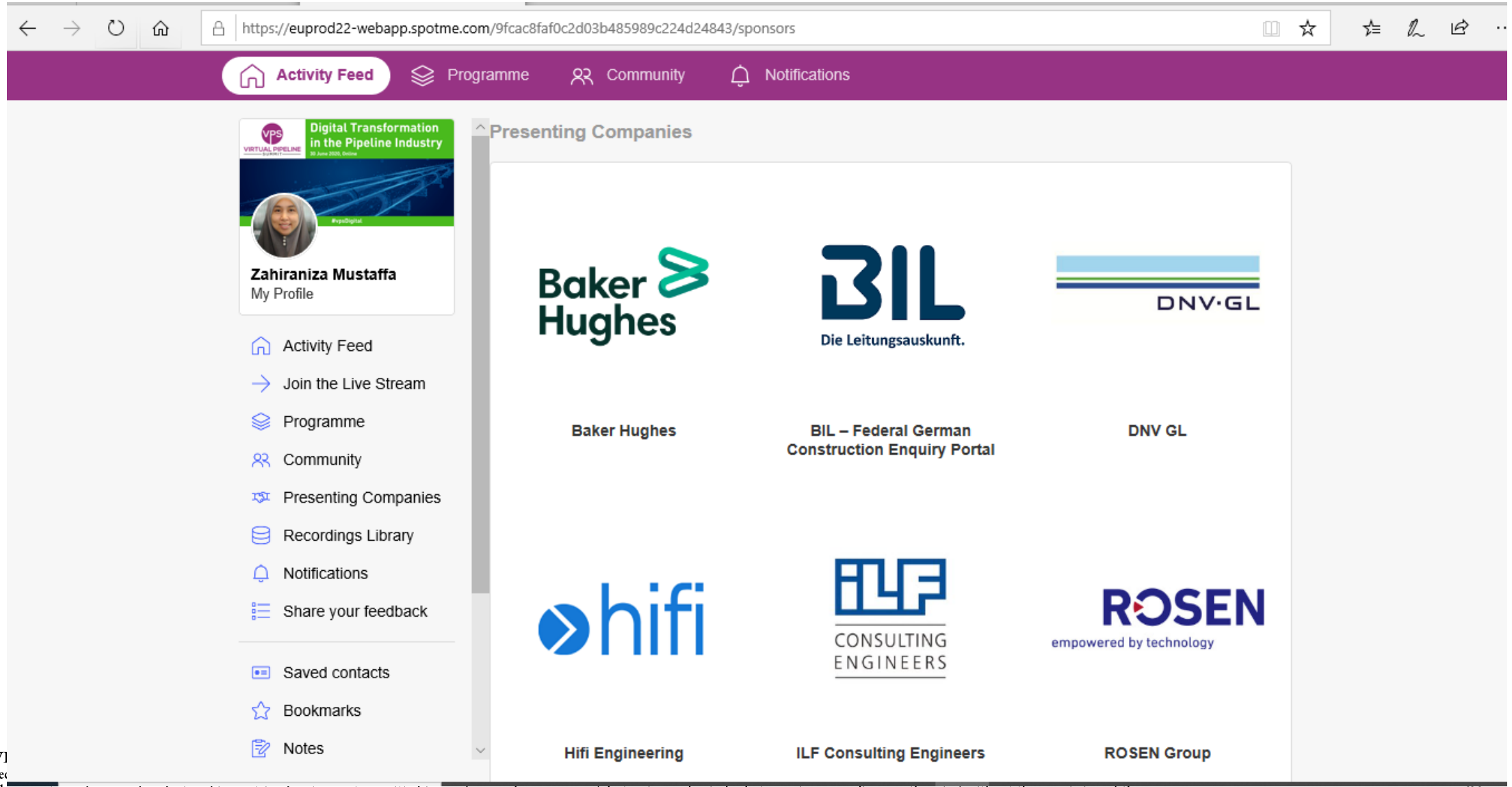
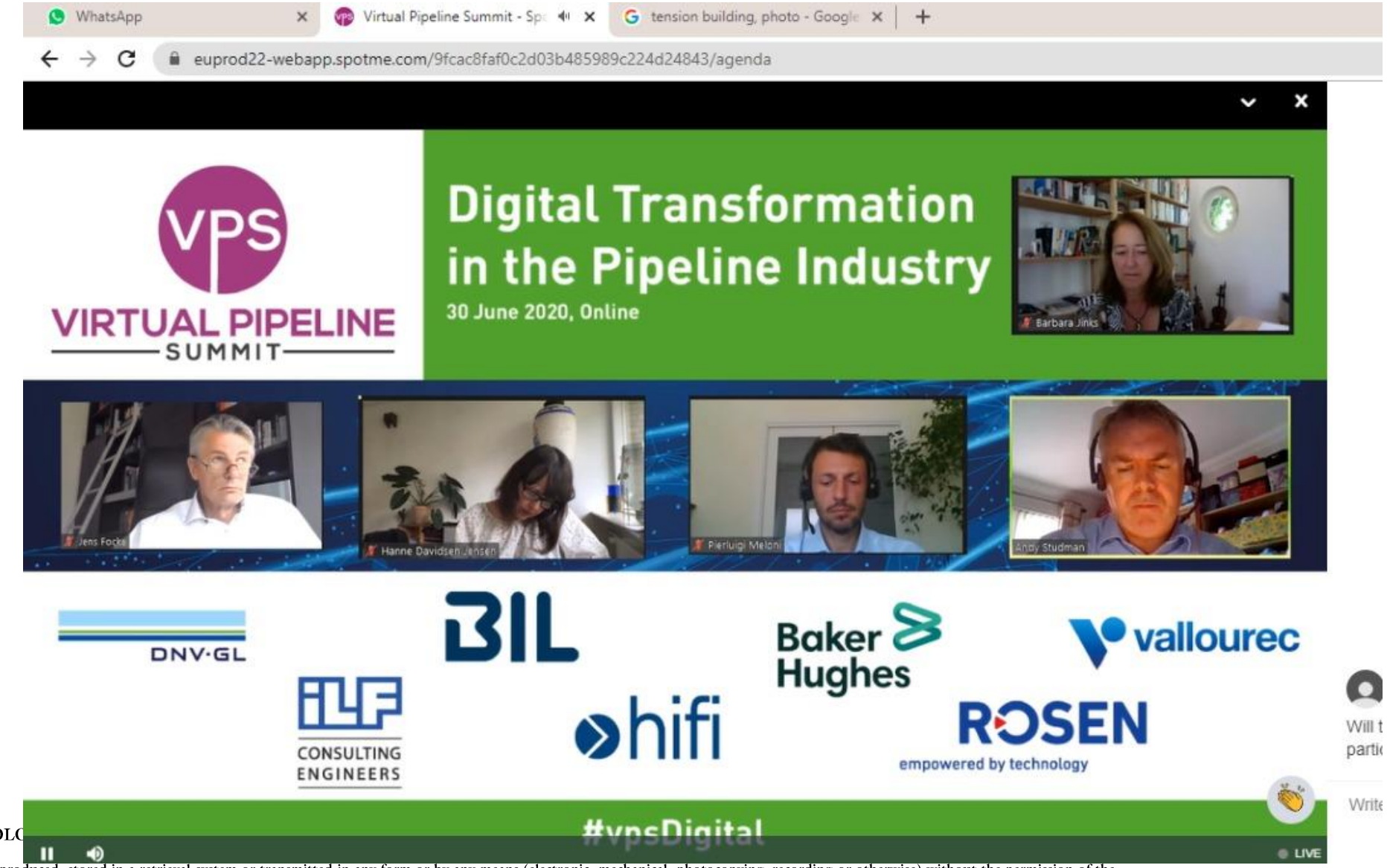
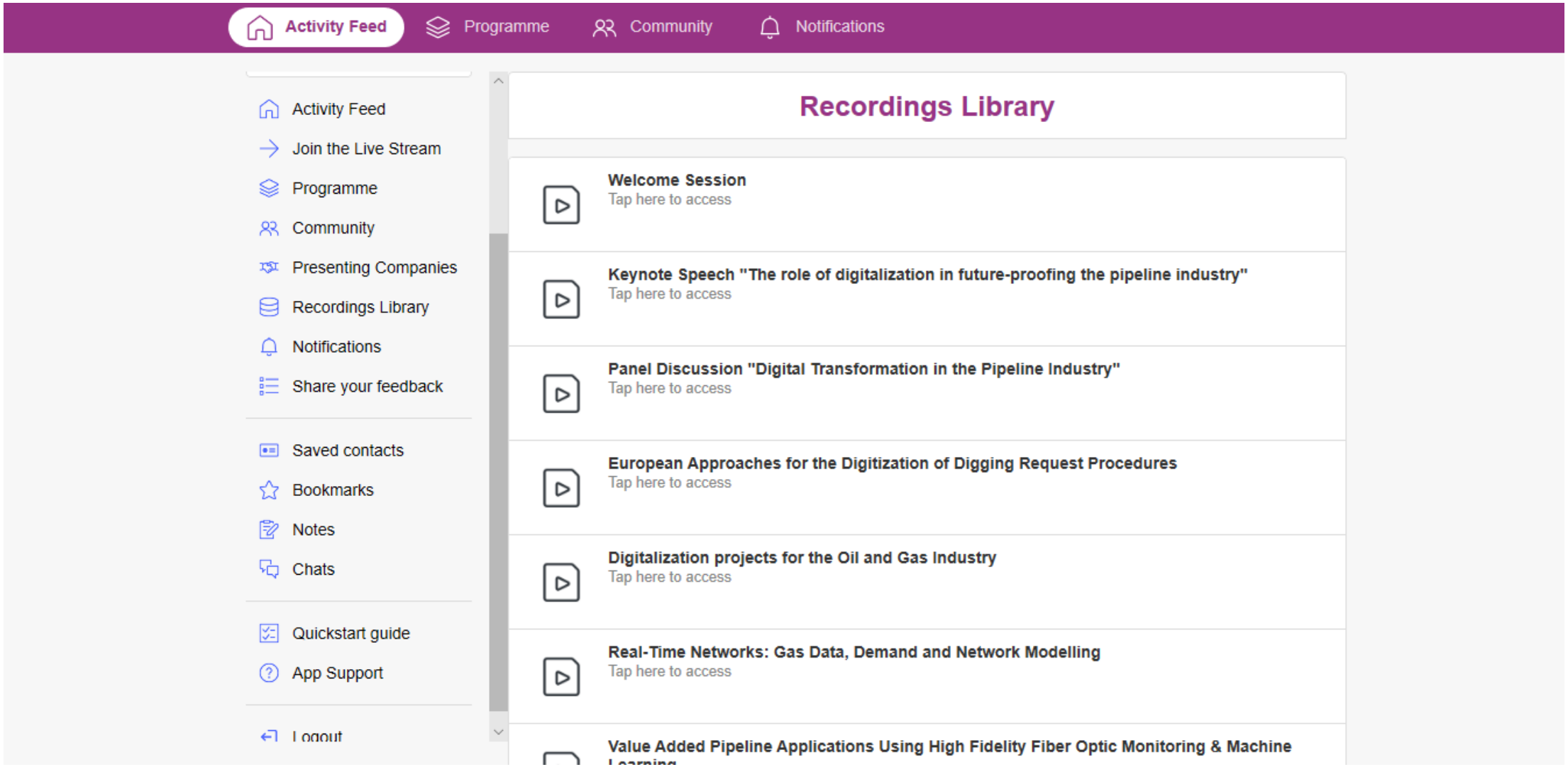
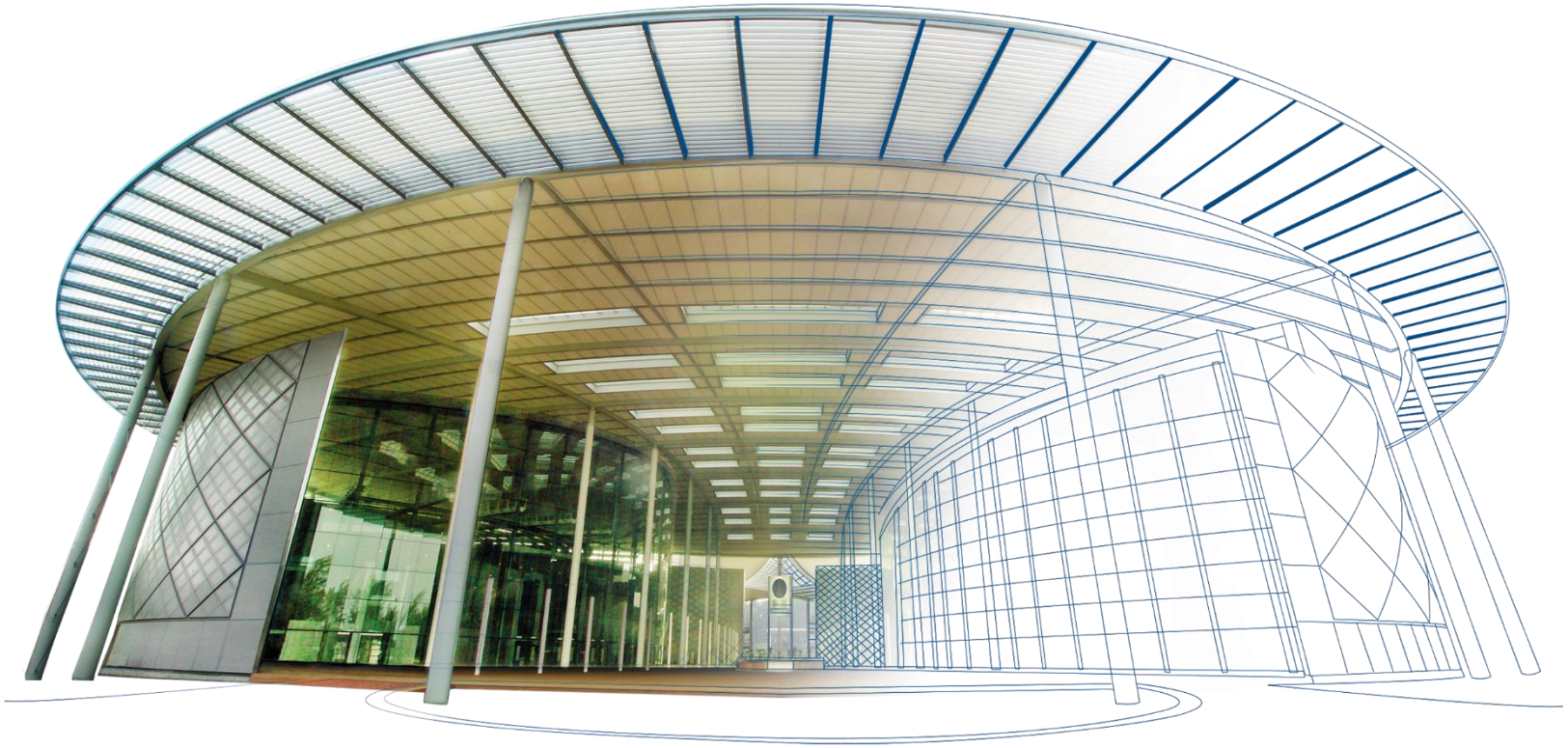
Virtual Pipeline Summit, 30th June 2020, 3:00 pm – 6:40 pm, Online.











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