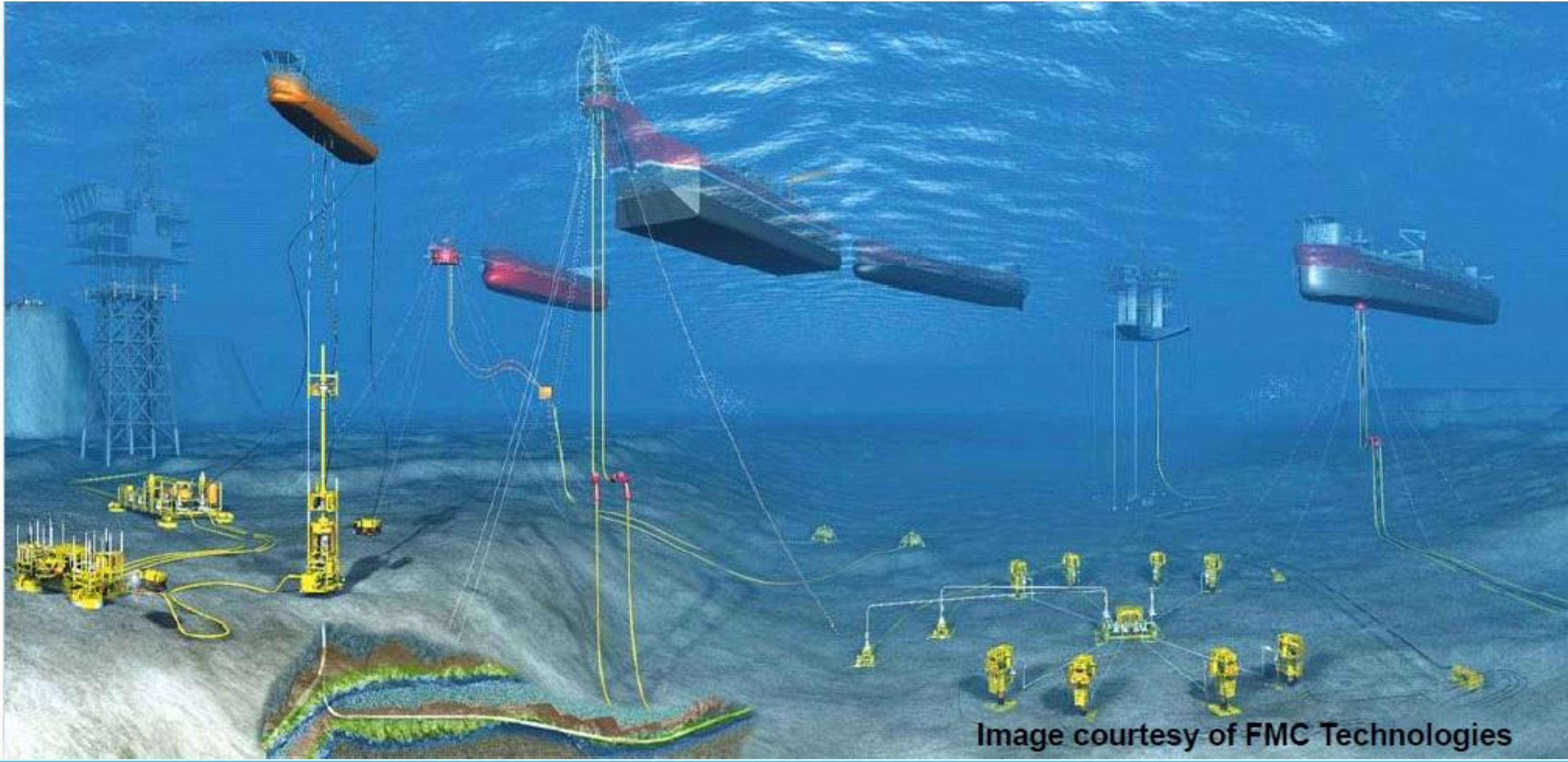


Introduction to Offshore Platform Engineering

Yutaek Seo

HW 3-1. Beggs and Brill correlation

Two Phase Flow - Beggs & Brill Method

CheGuide.com
Chemical Engineer's Guide

Number	*HW 3*
Description	*Flow Assurance*
Date	*16-04-20*
By	*Professor*

User Input

Pipe Data	Metric		English	
Inner Diameter	50.67	mm	1.995	inch
Pipe Roughness	0.00180	mm	0.000071	inch
Pipe Length	100.00	m	328.084	foot
Flow Direction	uphill			
Pipe Inclination angle	30	° with horizontal		
Gas				
Flowing Temperature	32.2	Deg C	90.00	Deg F
Inlet Pressure	119	bar	1719.7	psi
Volumetric flowrate	5.0	m^3/h	2.94	ft^3/min
@ Standard Conditions	523.4	Nm^3/h @ 1 atm, 0°C	325.5	SCFM @ 14.7 PSI, 60°F
Density	141.3	Kg/m^3	8.823	lb/ft^3
Viscosity	0.020	cP	1.34E-05	lb/ft.s
Liquid				
Volumetric flowrate	5.00	m^3/h	22.014	US gpm
Density	613.8	Kg/m^3	38.320	lb/ft^3
Viscosity	0.500	cP	3.36E-04	lb/ft.s
gas/liquid Surface tension	28.0	dyne/cm		

Results				
Flow pattern map	Intermittent			
Pressure drop due to head				
Holdup volume fraction, $E_L(0)$	0.570		0.570	
Inclination correction factor, β	1.098		1.098	
Inclined holdup v.f, $E_L(\theta)$	0.625		0.625	
Mixture density	436.87	Kg/m^3	27.27	lb/ft^3
DP due to Head	2.14	bar	31.07	psi
Pressure drop due to friction				
Friction factor ratio	1.438		1.438	
No Slip Reynold's Number	101366		101366	
No Slip friction factor, f_{NS}	0.0045	*Fanning*	0.0045	*Fanning*
Two phase firction factor, f_{TP}	0.0065	*Fanning*	0.0065	*Fanning*
DP due to friction	0.18	bar	2.67	psi
Total pressure drop	2.33	bar	33.74	psi
Correction due to acceleration	0.995		0.995	
Corrected Total Pressure drop	**2.34**	bar	**33.91**	psi
Pressure drop / Length	2.34	bar / 100 mt	10.34	psi / 100 ft

Effect of changing flowrates and length, angle

1) 초기 input data에서 가스 volumetric flow rate을 50 m3/hr로 증가시키시오. 어떤 변화가 나타나는가?

Flow pattern map	Intermittent	
Pressure drop due to head	1.23	bar
Pressure drop due to friction	1.87	bar
Inclined liquid holdup	0.2310	

2) 초기 input data에서 Inner diameter = 100.67 mm, pipe length = 5000 m, 가스 volumetric flow rate = 50 m3/hr로 증가시키시고, 얻어지는 결과를 정리하시오. 마찰과 수두압에 의한 압력 강하를 더하고, 초기 입구 압력과 Corrected total pressure drop (Cell:F46)을 비교하시오.

Flow pattern map	Intermittent	
Pressure drop due to head	67.29	bar
Pressure drop due to friction	2.93	bar
Inclined liquid holdup	0.282	

3) 초기 input data에서 Inner diameter = 100.67 mm, pipe length = 5000 m, pipe inclination angle = 0 °, 액체 volumetric flow rate = 50 m3/hr로 증가시키고, 결과를 정리하시오. (가스 volumetric flow rate = 5 m3/hr)

Flow pattern map	Distributed	
Pressure drop due to head	0.0	bar
Pressure drop due to friction	8.86	bar
Inclined liquid holdup	0.93	

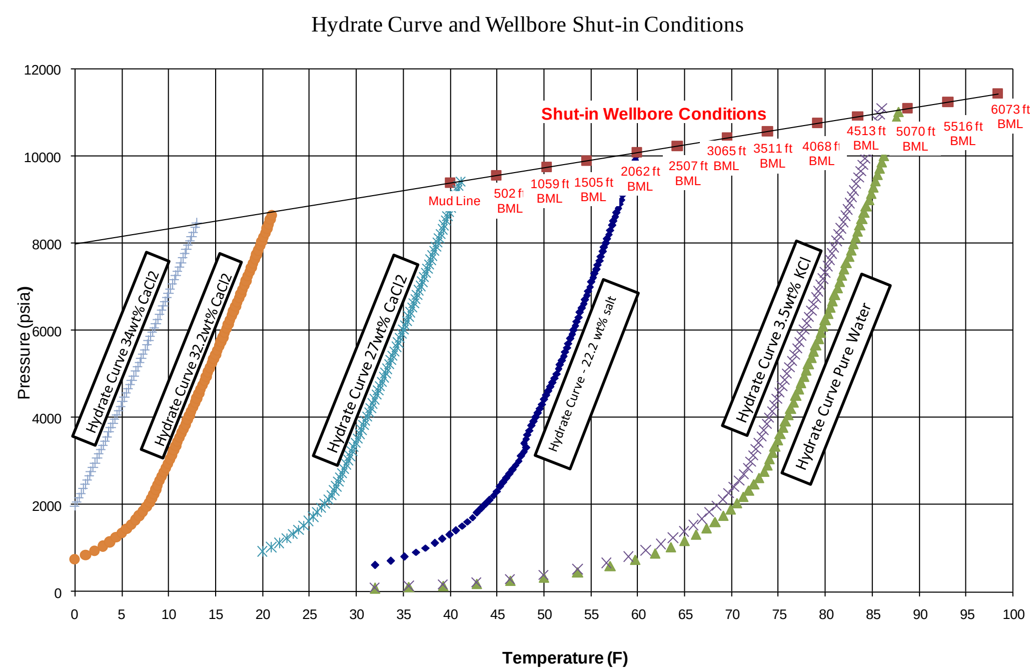
HW 3-2. Hydrate inhibition with MEG

i) Shut-in Wellbore condition에 따라 온도는 Mudline 온도까지 떨어짐. 최종 압력이 3000 psi라고 할 때, 하이드레이트 생성을 피하기위한 ΔT는 몇 oF인가? 단, 3000 psi일 때 순수 물의 하이드레이트 생성 온도는 75oF. Answer: 35 oF

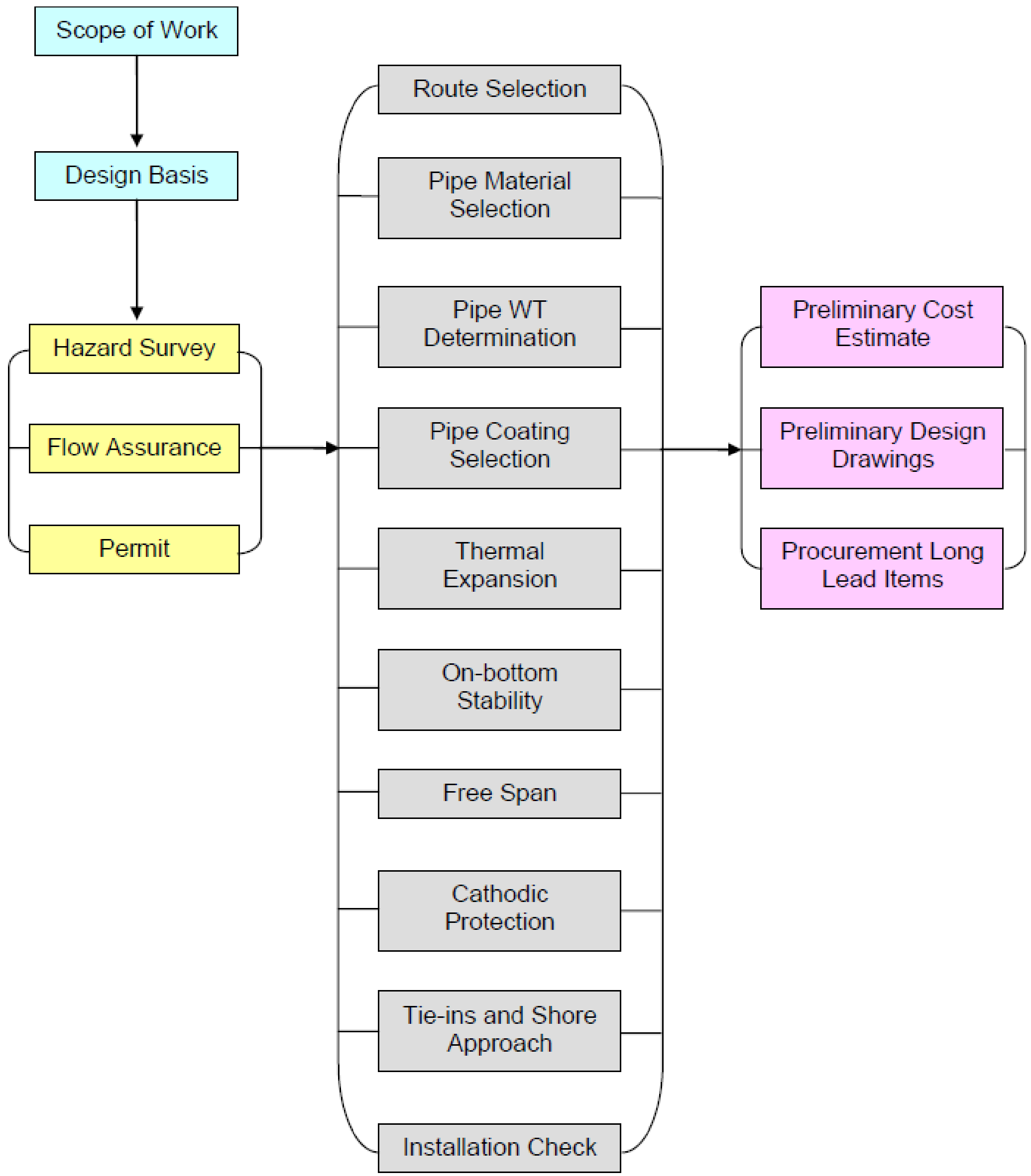
ii) MEG를 주입하기로 결정하였다. 하이드레이트 생성을 피하기위해 필요한 MEG 주입량을 gallon/min 으로 계산하시오. 현재 물 생산량은 2500 bbl/day. 먼저, Hammerschmide eq을 이용해 요구되는 MEG 농도를 wt%로 계산하시오.

Answer: X = 52.15 wt% → 49.57 vol%, MEG 주입량 = 2457.37 bbl/day = 71.7 gallon/min

$$\Delta T = \left(\frac{2000}{MW} * \frac{X}{1-X}\right)$$



Subsea pipeline design procedures



Pipeline Route Selection

- When layout the field architecture, several considerations should be accounted for:

: Compliance with regulation authorities and design codes
: Future field development plan
: Environment, marine activities, and installation method (vessel availability)
: Overall project cost
: Seafloor topography
: Interface with existing subsea structures

Pipeline Route Curve Radius

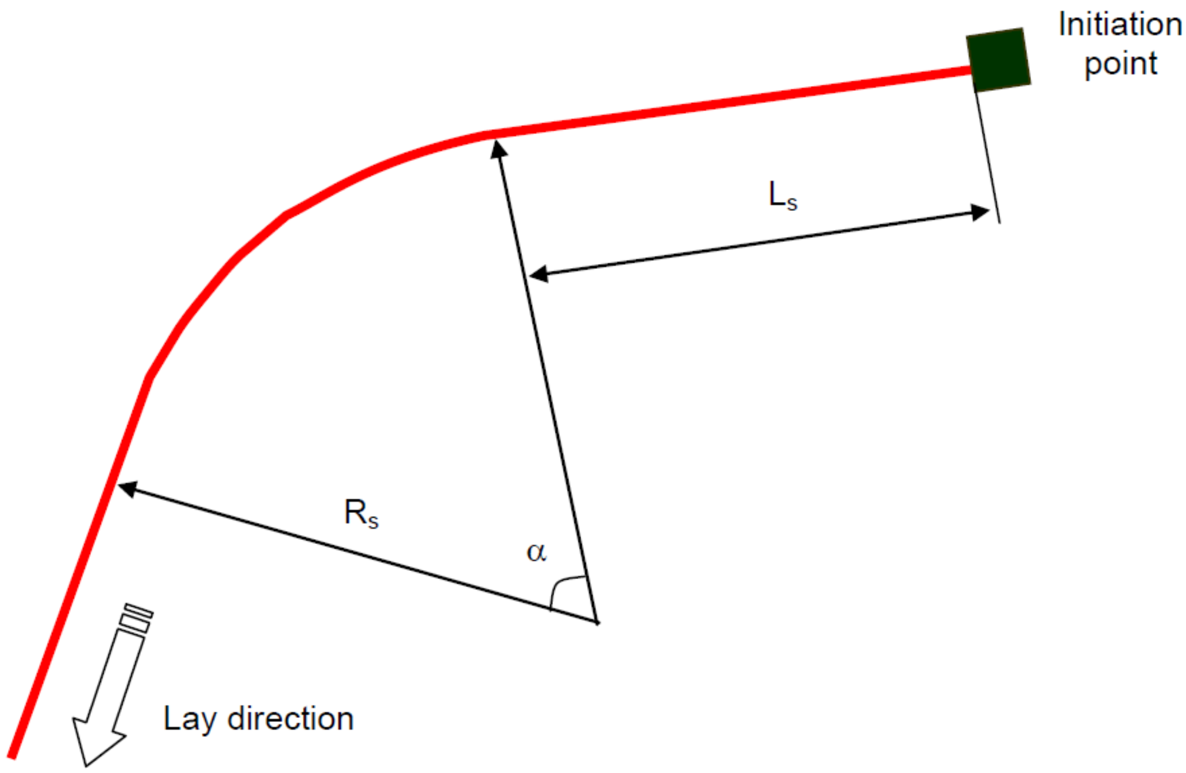
- The required minimum pipeline route curve radius (R_s) should be determined to prevent slippage of the curved pipeline on the sea floor while making a curve in accordance with the formula.

$$R_s = L_s = \frac{F\, T_H}{W_s\, \mu}$$

R_s =	Min. non-slippage pipeline route curve radius
L_s =	Min. non-slippage straight pipeline length
F =	Safety factor (~2.0)
T_H =	Horizontal bottom tension (residual tension)
W_s =	Pipe submerged weight
μ =	lateral pipeline-soil friction factor (~0.5)

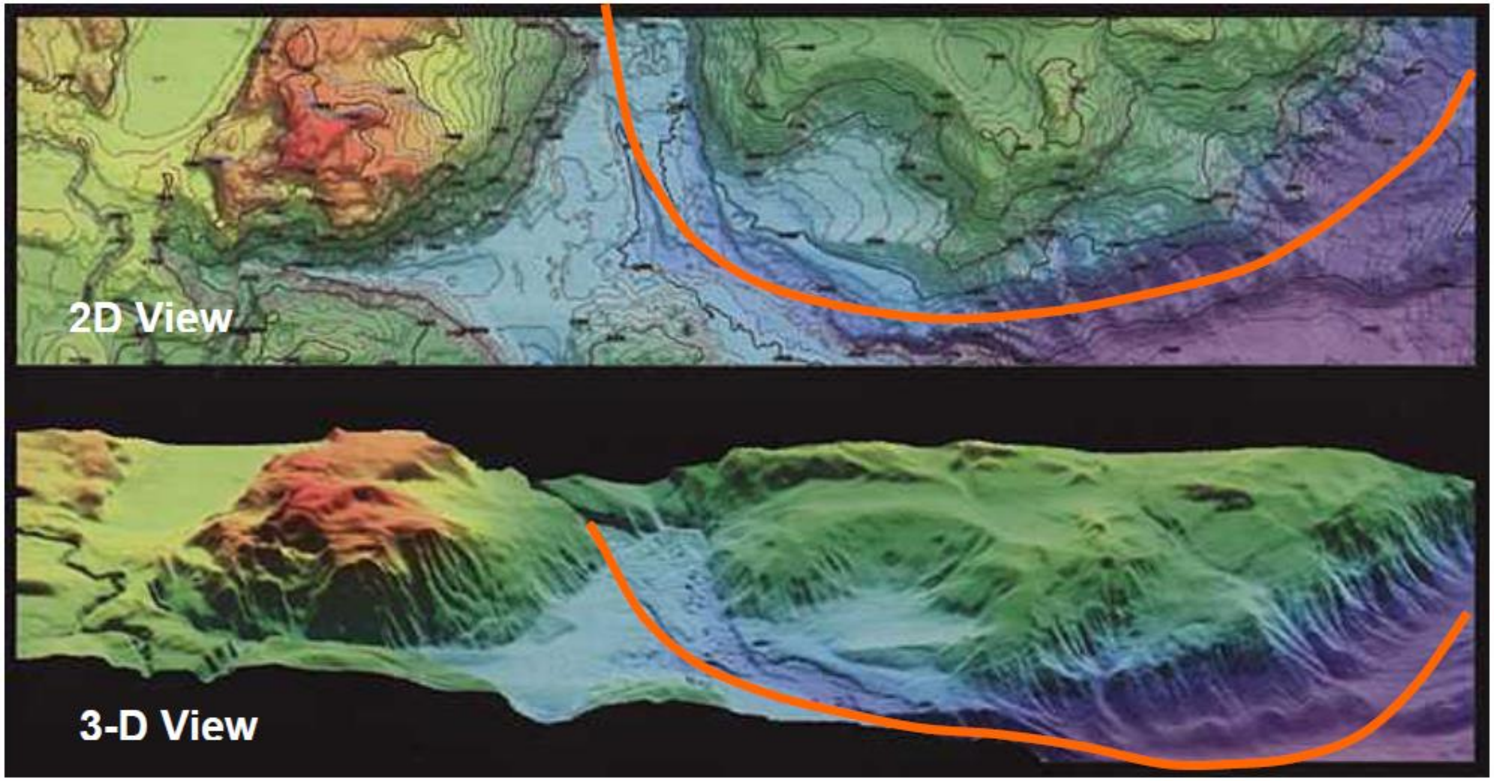
- If the pipeline-soil friction resistance is too small, the pipeline will spring-back to straight line.

- The formula also can be used to estimate the required minimum straight pipeline length (L_s), before making a curve, to prevent slippage at initiation.
- If L_s is too short, the pipeline will slip while the curve is being made.



Pipeline Route Survey

- Once the field layout and pipeline route is determined by desktop study using an existing field map, the pipeline route needs to be surveyed
- The survey company is contracted to obtain site-specific information including bathymetry, seabed characteristics, soil properties, stratigraphy, geohazards, and environmental data.
- Bathymetry (hydrographic) survey using echo sounders provides water depths (sea bottom profile) over the pipeline route.
- The new technology of 3-D bathymetry map shows the sea bottom configuration more clearly than the 2-D bathymetry map.


2D View
3-D View

On-bottom stability analysis

- Subsea pipelines resting on the seabed are subject to fluid loading from both waves and steady currents.
- For regions of the seabed where damage may result from vertical or lateral movement of the pipeline, it is a design requirement for the pipe weight to be sufficient to ensure stability under the worst possible environmental conditions.
- In most cases this weight is provided by a concrete coating on the pipeline. In some circumstances the pipeline may be allowed to move laterally if provided stress limits are not exceeded.
- The wave and current data must be based on extreme conditions. For example, the wave with a probability of occurring only once in 100 years is often used for the operational lifetime of a pipeline.

Pipeline on-bottom stability design

- Waves and steady currents subject the pipeline on the seabed to drag, lift, and inertia forces.
- To keep the pipeline stable, the soil resistance should be greater than the hydrodynamic force induced on the pipeline.

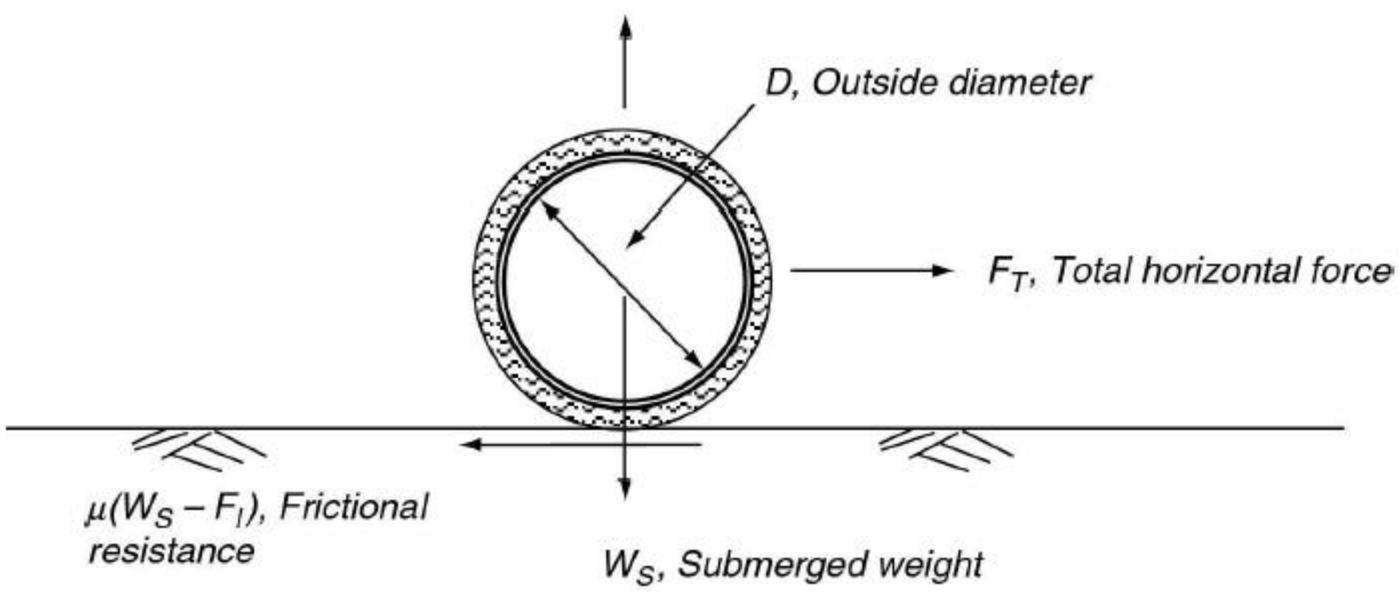


FIGURE 13.1 Forces acting on the pipeline resting on the seabed.

- The traditional method of pipeline stability is given by the following:

$$\mu(W_s - F_L) \geq (F_D + F_I)$$

$$\frac{\mu(W_S - F_l)}{F_T} > 1$$

where

μ = soil-pipe friction
W_S = submerged weight
F_l = lift force
F_T = total horizontal force from waves and currents

- In general, the larger the submerged weight, the higher the frictional resistance.
- However, later methods for determining the stability include the depth of embedment of the pipeline. Additional resistance is provided by the soil and reduces the required submerged weight of the pipeline.

Drag force

- Drag and Inertia forces act together laterally on the pipeline.
- The drag force due to water particle velocities is given by

$$F_d = \frac{1}{2}\rho C_D D(U + V)^2$$

where

F_d = drag force/unit length
ρ = mass density of seawater
C_D = drag coefficient
D = outside diameter of pipeline (including the coatings)
U = water particle velocity due to waves
V = steady current

(C_D is 0.7 from DNV 1981 Pipeline Design Guidelines)

Lift force

- Lift force, F_l, acting vertically tends to reduce the submerged weight of the pipeline.

$$F_L = \frac{1}{2} \rho_w D C_L V^2 \qquad \text{Lift Force}$$

Where, ρ_w is the water mass density (64 lb/ft^3)

V is the near-bottom wave & current velocity (=U+V)

D is the outside diameter of pipeline (including coating)

C_L is the lift coefficient

(= 0.9 from DNV 1981 Pipeline Design Guidelines)

Inertia force

- The inertia force due to water particle acceleration is given by

$$F_i = \rho C_M \frac{\pi D^2}{4} \left(\frac{du}{dt}\right)$$

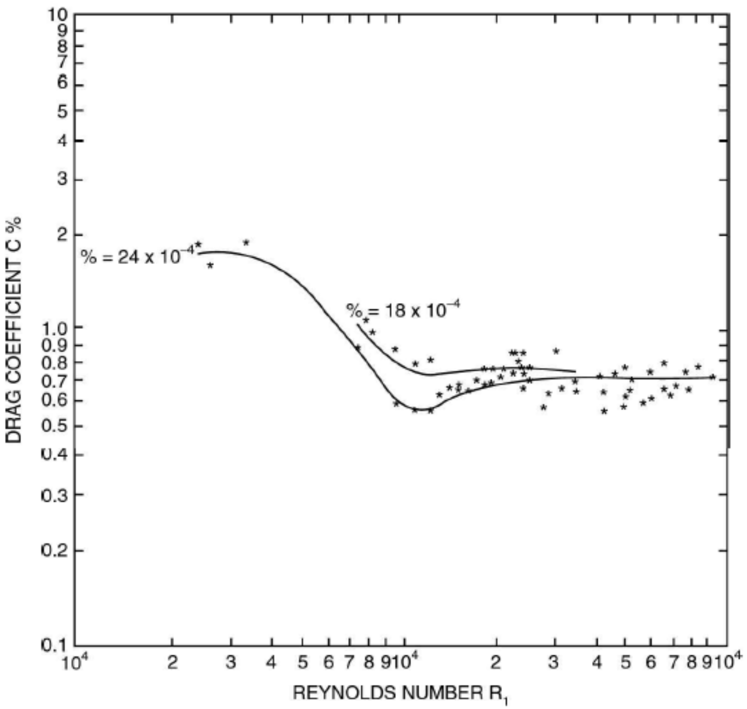
where

F_i = inertia force/unit length
ρ = mass density of seawater
C_M = drag coefficient
D = outside diameter of pipeline (including the coatings)
$\frac{du}{dt}$ = water particle acceleration due to waves

(C_M is 3.29 from DNV 1981 Pipeline Design Guidelines)

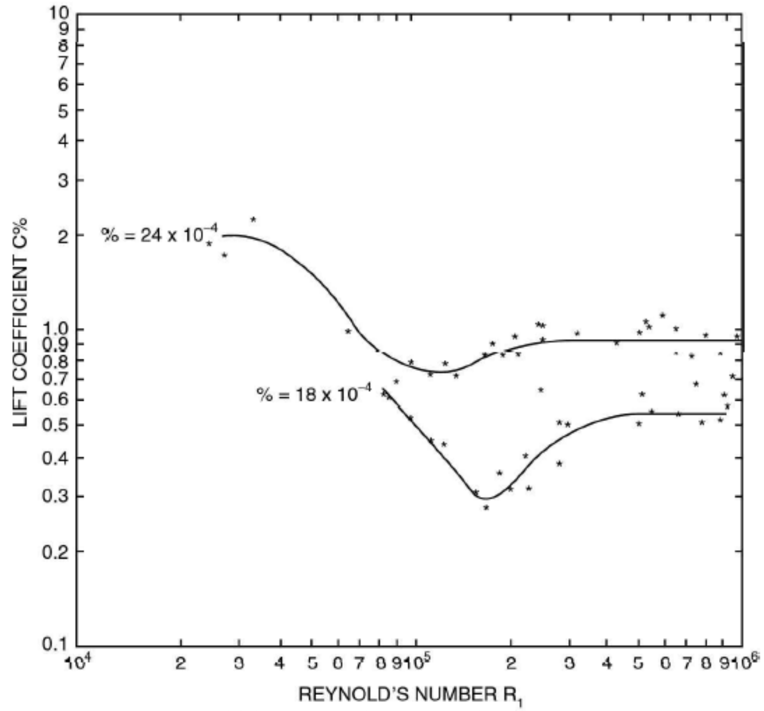
Determining hydrodynamic coefficients

- The hydrodynamic coefficients C_D, C_L, and C_M given in DNV 1981 Pipeline Design Guidelines are 0.7, 0.9, and 3.29, respectively.
- However, it is possible to use to determine the values of these coefficients with respect to *Re* for steady current and Keulegan-Carpenter number for steady currents combined with wave-induced currents.



DRAG COEFFICIENT FOR A CYLINDER RESTING ON THE BED

k roughness height
d diameter



LIFT COEFFICIENT FOR A CYLINDER RESTING ON THE BED

k roughness height
d diameter

Free span analysis

- Over a rough seabed or on a seabed subject to scour, pipeline spanning can occur when contact between the pipeline and seabed is lost over an appreciable distance.
- It needs to evaluate an allowable free-span length

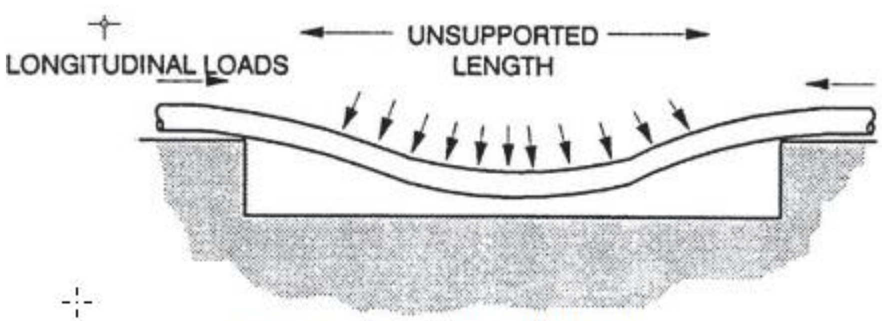


Figure 27-8 Pipeline Span Analysis

Global buckling analysis

- Global buckling of a pipeline occurs when the effective compressible force within the line becomes so great that the line has to deflect and, hence, reduces these axial loads.
- Analysis will be performed to identify whether the global buckling is likely to occur

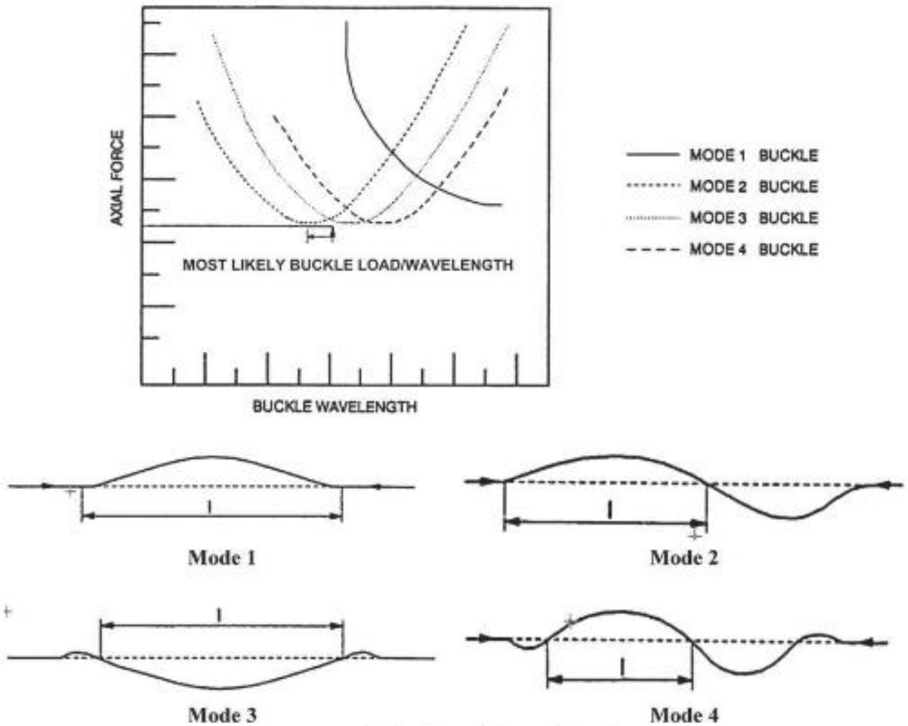
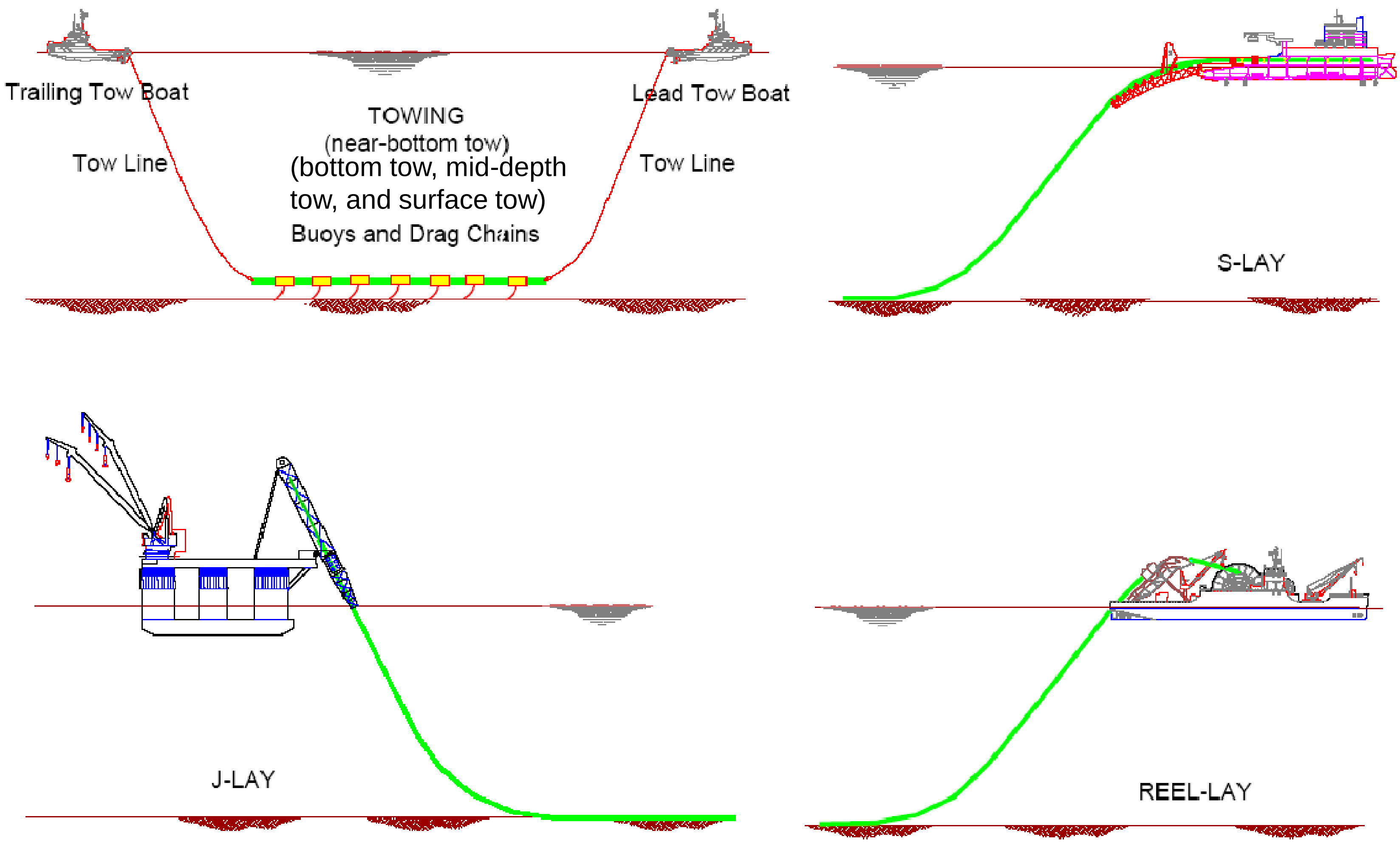


Figure 27-10 Global Buckling of Pipeline [11]

Pipeline installation

- In early days, the pipeline was fabricated at beach and towed to the project field by a tug boat.
- Most widely used installation method is using a pipeline installation vessel which can weld pipe joints on the deck and lower the pipes by releasing the pipes from the tensioners while moving the vessel.
- Depending on the pipeline’s profile from the vessel to the sea floor, it is called S-lay or J-lay.
- Another installation method is to fabricate the pipeline at spool base near beach and reel the pipe onto the reel ship. Then the reel ship carry the reeled pipe to the project field and lay by un-spooling the pipes.

- The four pipeline installation methods

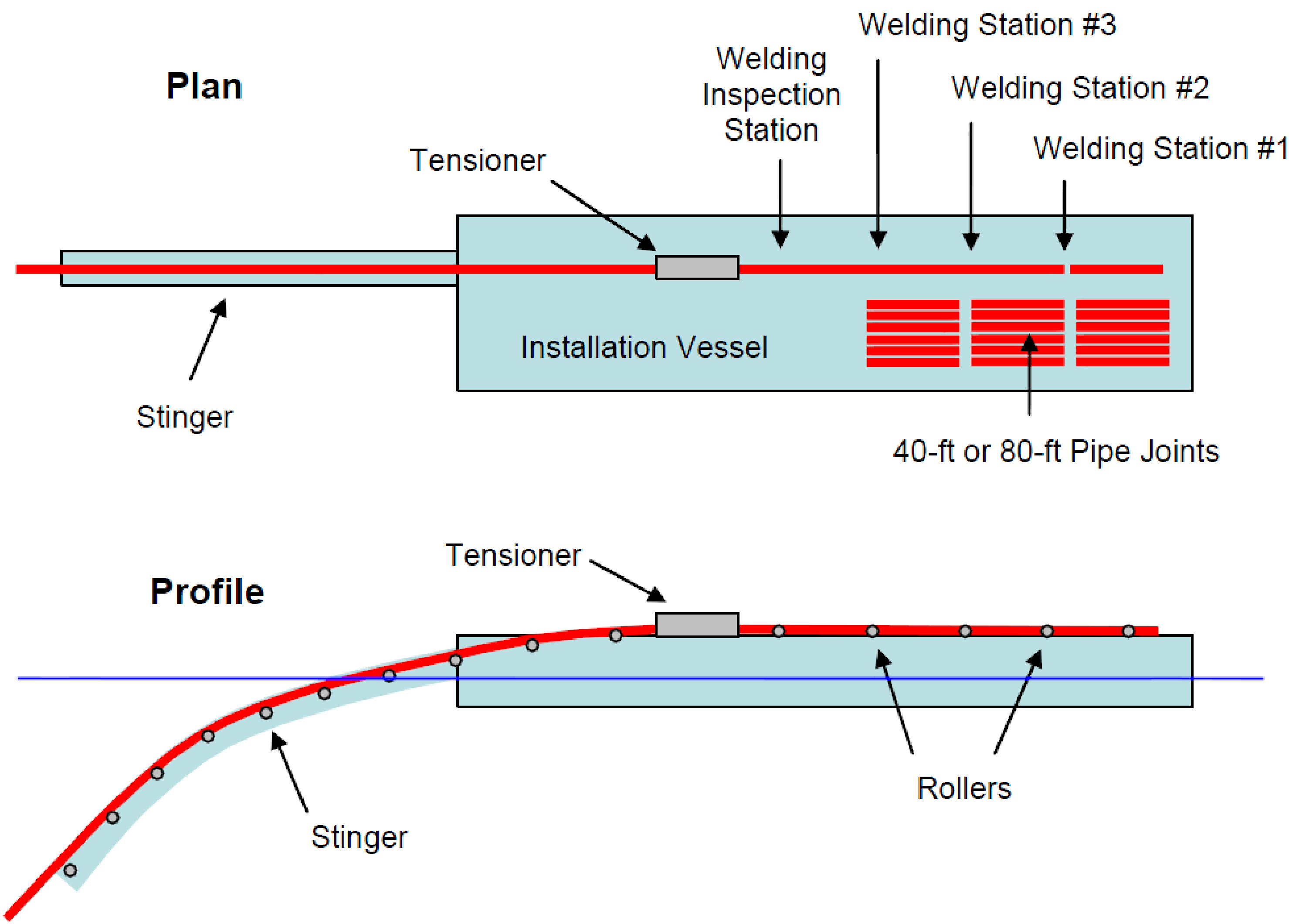


Pipeline installation

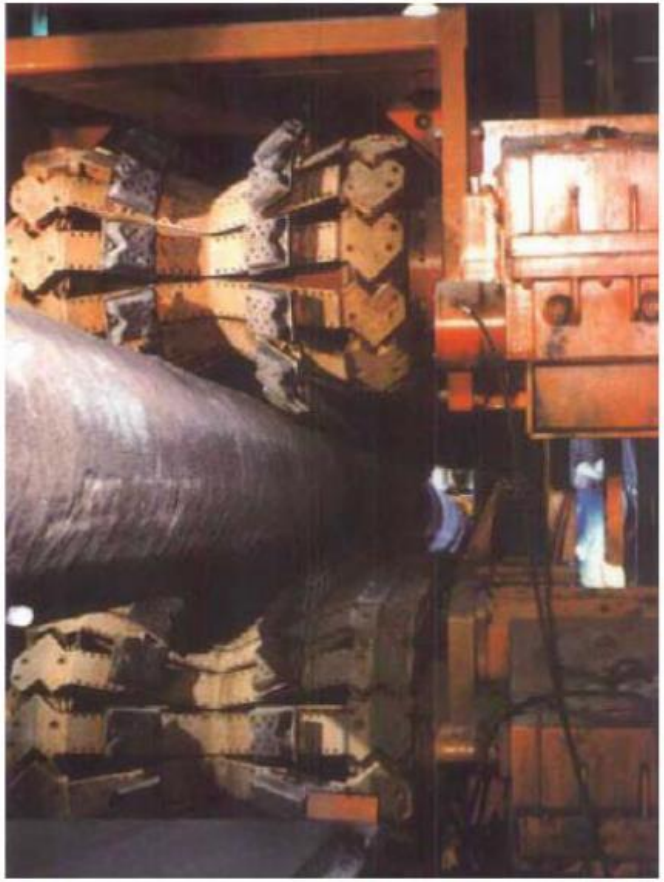
S-Lay

- Pipeline is fabricated on the vessel using single, double, or triple joints
- Requires a “stinger” up to 100m long, either single section or two/three articulated sections
- Deeper water requires longer stinger and higher tension resulting in more risk
- Typical lay rate is approximately 3.5km per day
- Maximum installable pipe size is 60”OD by AllSeas Solitaire

- S-Lay configuration



- S-Lay tensioner and stinger

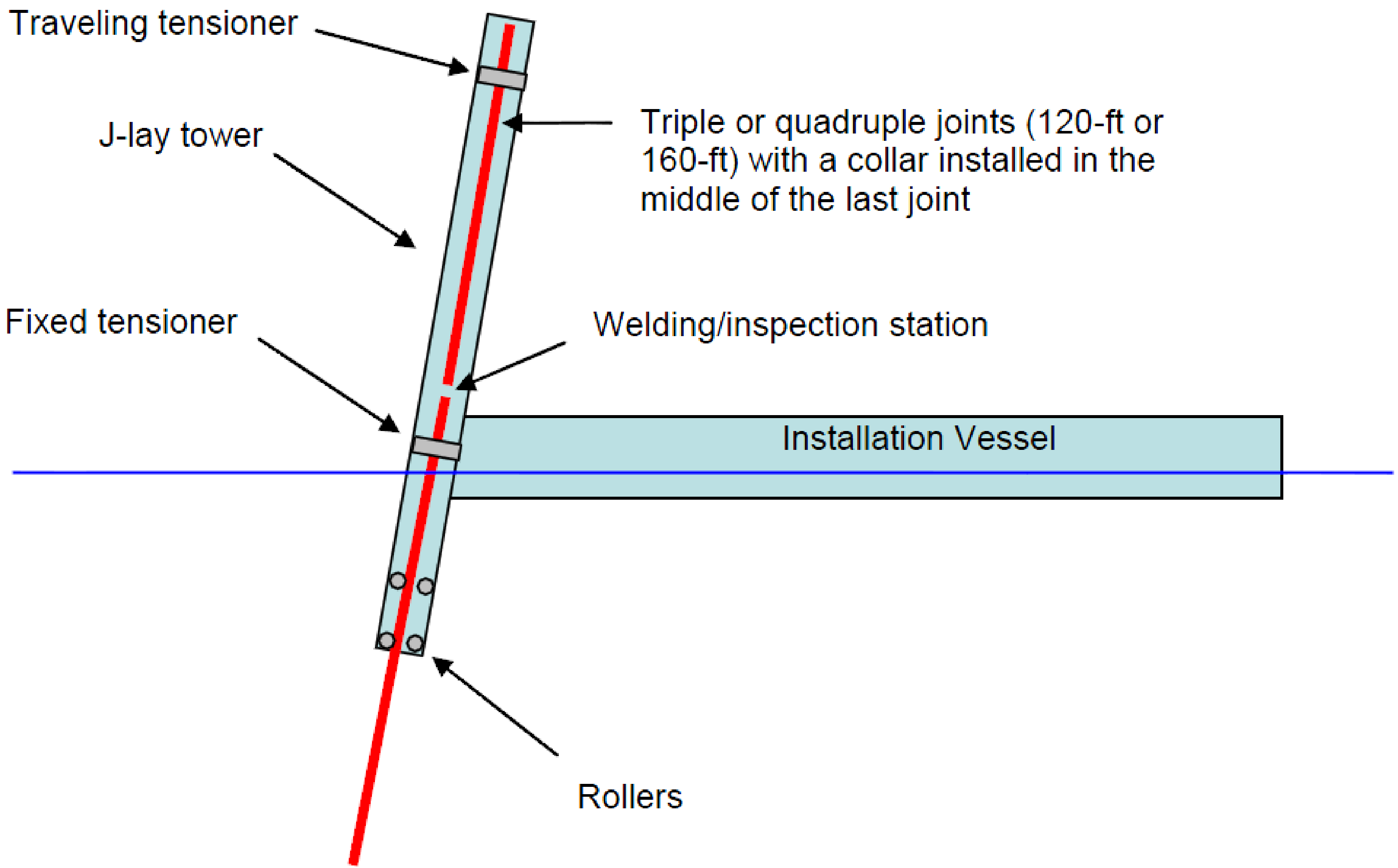


Pipeline installation

J-Lay

- Welding is done on vessel, but at one station, so is slower
- Pipe has a departure angle very close to vertical, so less tension is required
- Principal application is for deep water
- Stinger is not required
- Typical lay rate is approximately 1 - 1.5 km per day
- Maximum installable pipe size is 32”OD by Saipem S-7000

- J-Lay configuration



- Welding station and tensioner

- There are multiple welding stations in S-lay, depending on pipe size and pipe WT. Therefore, it is important to control the time spending at each station.
- If one station spends 10 minutes while the others spend 5 minutes, the pipe lay rate is reduced by 50%.
- For example, if each station takes 7 minutes to connect one pipe joint (40 ft), the lay rate would be 1.6 miles per day as below:

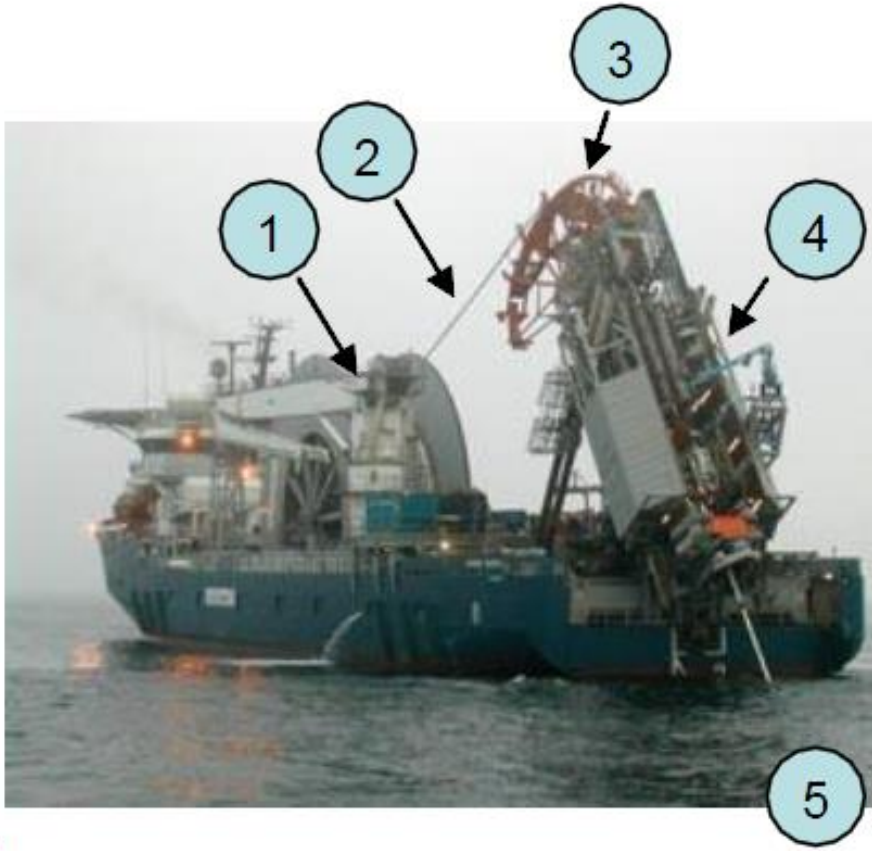
  (24 x 60 min/day) / (7 min/40 ft) = 8,230 ft/day = 1.6 miles/day

- The J-lay has only one welding station but can weld multiple pipe joints such as triple to hex joints (120 ft to 240 ft).

Pipeline installation

Reel-Lay

- Pipe welded onshore in a controlled environment and spooled onto vessel in continuous length until complete or maximum capacity is reached.
- Much lower tension and therefore more control than S lay.
- Limited on coating types – no concrete coating or stiff insulation coating.
- Limitations on reeling capacity by volume or weight.
- Typical lay rate is 14 km per day.


1
2
3
4
5

- Pipeline Installation Vessel (S-Lay)

- Pipeline Installation Vessel (J-Lay)

- Pipeline Installation Vessel (Reel-Lay)

Contractor	Vessel	Tension capacity (kips)	Max. pipe OD (inch)	Max. water depth* (ft)	Lay method
Allseas	Lorelay	360	30	10000+	S
	Solitaire	1200	60 (S) / 18 (Reel)	10000+	S
	Audacia	1155	44	10000+	S (2007)
Helix (Cal Dive)	Intrepid	268	12	8000	S / Reel
	Express	352	14	?	J / Reel
	Caesar	891	36	6560	S / J
Global	Hercules	1200	60 (S) / 18 (Reel)	8000+	S / Reel
	Chickasaw	180	12	6000	S/Reel
Heerema	Balder	1250	32	10000	J
J. Ray McDermott	DB50	775 (J) 100 (Reel)	20	10000	J / Reel
	DB16	300 (S/J) 100 (Reel)	48 (S/J)/10 (Reel)	10000	S / J / Reel
Saipem	S-7000	1160	32	10000	J
	FDS	881 (J) 551 (Reel)	20	10000	J / Reel
Acergy (Stolt)	Falcon	300	14	9840	J
	Kestrel	265	12	5000	J / Reel
	Polaris	529	60 (S/J)/18 (Reel)	7000	S / J / Reel
	Sapura 3000	528	60	6560	S / J (2007)
Technip	Deep Blue	1697	28 (J)/18 (Reel)	10000	J / Reel
	Apache	440	16	5000	Reel
	Constructor	440	14	5000	J / Reel
Torch	Midnight Express	160	12	10000	S / J / Reel
Subsea 7	Skandi Navica	500	19	9500+	Reel
	Fennica	500	19	6500	Reel
	Seven Oceans	880	16	?	Reel

Subsea Systems Cost Estimation

- URF

Description	Cost (US$)	Basis
CRA Material Cost – 316L	5,100-6,300	Per tonne, 4” to 26”
CRA Material Cost – 825	7,600-10,080	Per tonne, 4” to 32”
Carbon Steel Material Cost	1,300	Per tonne, all sizes
Insulation Coating	333,000-794,000	Per km, for 12” to 32”
Manifolds	2.8-5.2 Million	4 slot to 10 slot
Infield Gathering Manifold (18”)	8.8 Million	6 x 18” tie-ins.
Umbilical	$170-$310 per m	2-10 well cluster sizes
12” Flexible Riser	2.4 Million	Complete with ancillaries
Riser Bases	1.0-3.2 Million	4” to 26”
PLETs	0.2-4.7 Million	4” to 34”
Main Jumpers	532,000	18”
Well Jumpers – Solid Duplex	810,000 -889,000	6”-8”, included Multiphase Meter

- Subsea tree CAPEX

Subsea Tree System	4,099,702
Tubing Hanger System	603,979
Choke Module	3,332,604
Flowline Support Base	401,833
Wellhead System	261,882
Total	**8,700,000**

- Subsea tree Intervention

Type of Intervention	**Intervention Costs (AU$M) Based on Rig Spread of AU$890k/day**	
	Vertical System	**Horizontal System**
Through Tubing Intervention	3.375	6.267
Tree Replacement	5.563	11.793
Tubing Replacement	11.348	8.233
Sidetrack	20.025	23.407

Subsea Installation Cost Estimation

Description	Cost (US$)	Basis
Lay Barge	450,000	Per Day
Lay Barge Mob/demob	15 million	Per Campaign
MSV	200,000	Per Day
MSV Mob/demob	4 Million	Per Campaign
Survey	1,000,000	Per Campaign
CRA Pipelay rates	0.8-1.8	km/day, 36” – 4”
Carbon Steel Pipelay Rates	2.3-4.5	km/day, 36” – 4”

Pipeline Protection

Trenching and Burial

- The offshore pipelines are trenched for such conditions and requirements as:
  - Physical protection from anchor dropping or trawl dragging
  - On-bottom stability
  - Approval authorities
- The open trench could be covered by natural sedimentation depending on soil conditions and currents near sea bottom.
- However, backfilling after the trenching or burial is required for additional protection and thermal insulation purposes.

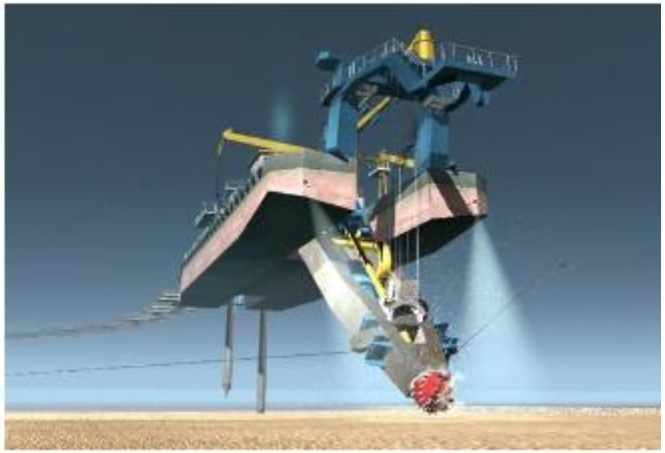
- Trenching equipment should be selected based on sea floor soil conditions. Followings are available trenching equipment in the industry :
  - Ploughing – all types of soil
  - Jetting –sand and soft clay
  - Mechanical digging & cutting – stiff clay and rock
  - Dredging – all types of soil

- Trenching Equipment

(a) Plough

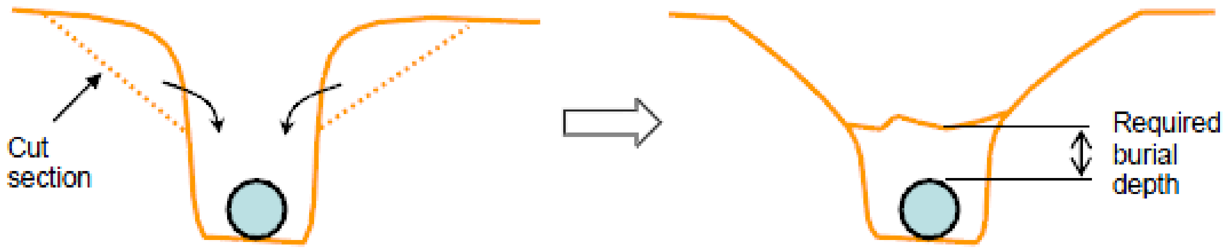
(b) Water Jet Trencher

(c) Mechanical Trencher

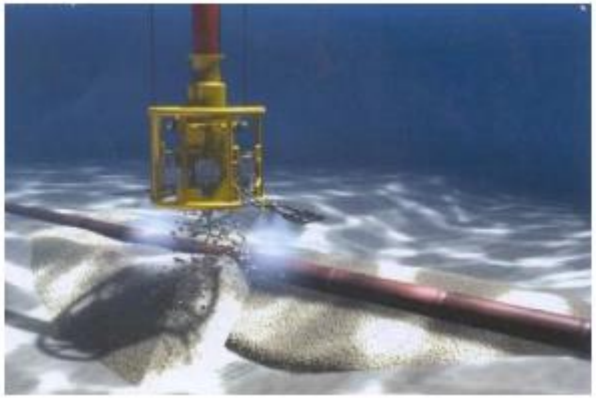


(d) Dredger

- Burial could be done by backfill the soil by cutting each top side of the open trench using the same jet trencher used for trenching.



- Without burial, pipelines can be covered with rocks or concrete mattress. This method is good for a pipeline laid on a hard rock sea bottom which is difficult to be buried.

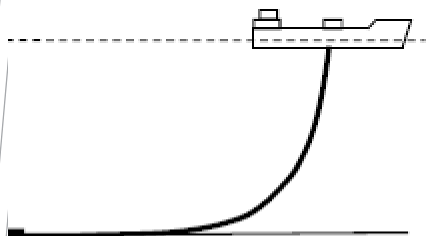


Flexible Riser configurations

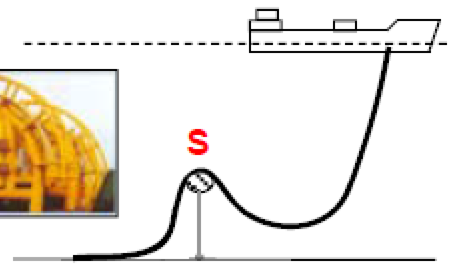
Free-Hanging Configuration

S Configuration

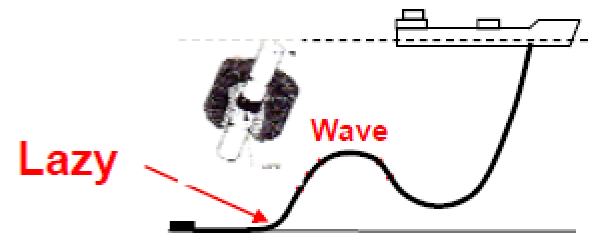
Wave Configuration



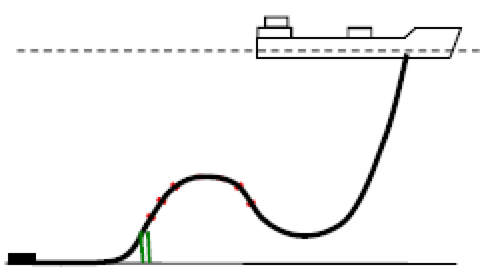
Free Hanging Catenary



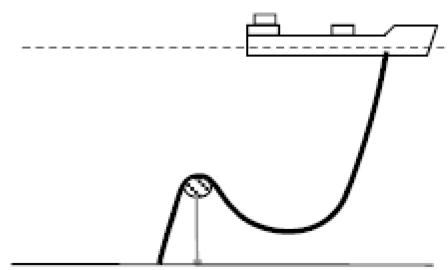
Lazy-S



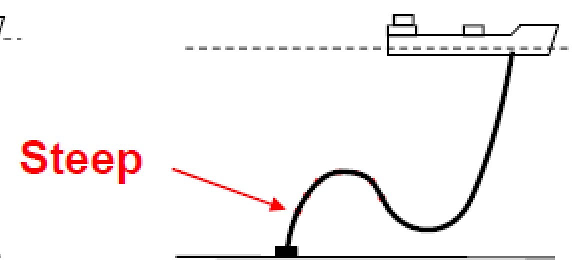
Lazy Wave



Pliant Wave® (Tethered)



Steep-S



Steep Wave

- Subsea Arch

Thank you!