Vertical Tendon Design for Deepwater Application

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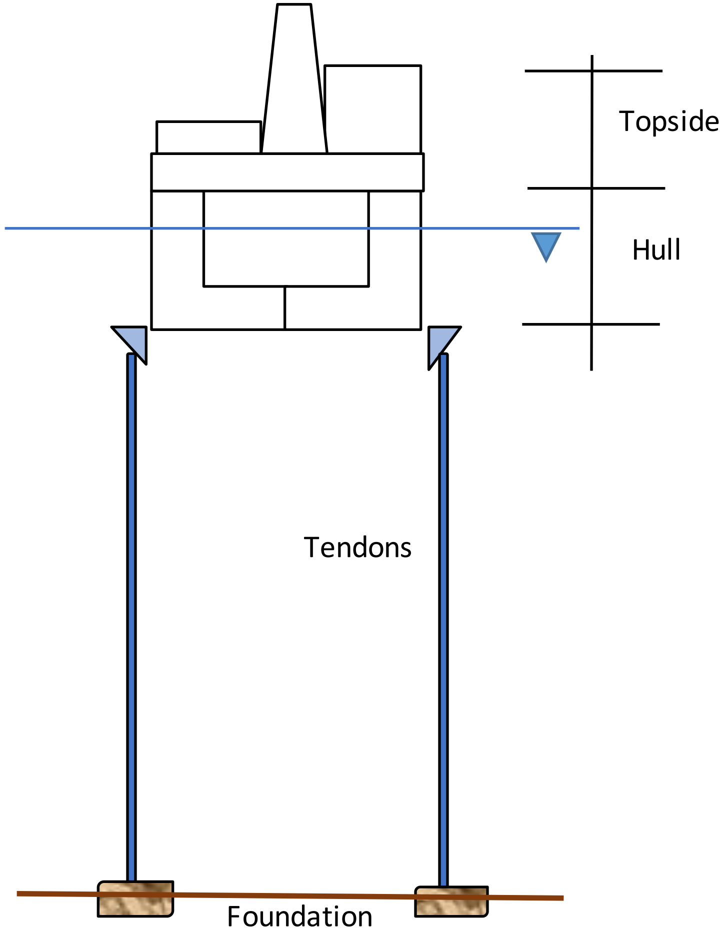
MCEDD
DEEPWATER DEVELOPMENT

Tension Leg Platform (TLP) – Overall Concept

- TLP is a buoyant unit connected to fixed piles by pre-tensioned vertical tendons.
- TLP is designed such that the tendons are are always in tension for most loading conditions.
- The axial stiffness of tendons provide favourable response in heave, roll and pitch directions with natural periods of below the wave energy range of around 5 seconds.
- The lateral restraint is similar to the classical semi-submersible platforms.



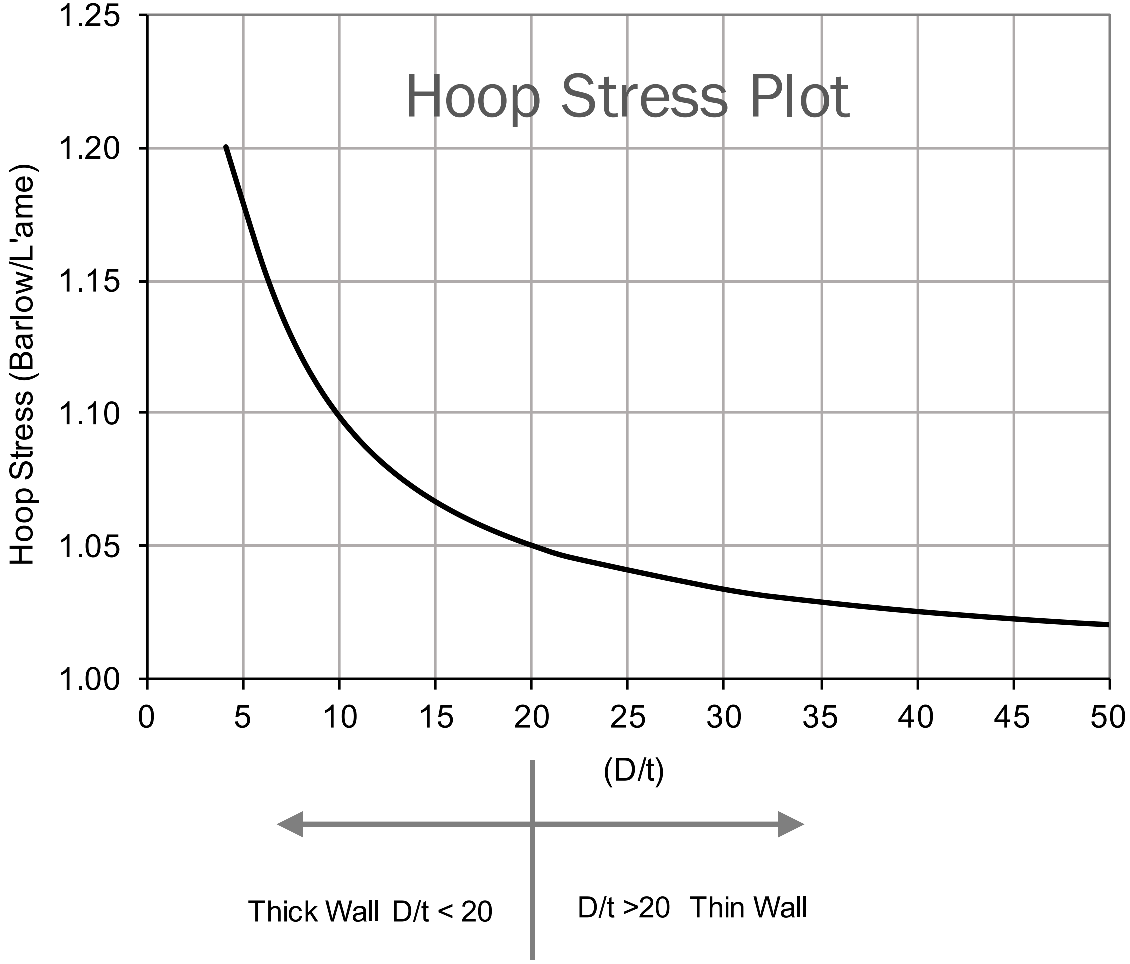
Objective of the Present Study

- In deepwater, the relatively low axial stiffness, due to increased overall length of tendons leads to higher unfavourable natural periods.
- To offset the impact of tendon’s increased length, cross-sectional properties of each tendon must be improved to provide an adequate stiffness into the tendon system.
- The objective of present study is to develop design charts that can effectively be used in minimizing the overall submerged weight of the tendon system whilst maintaining adequate axial stiffness.

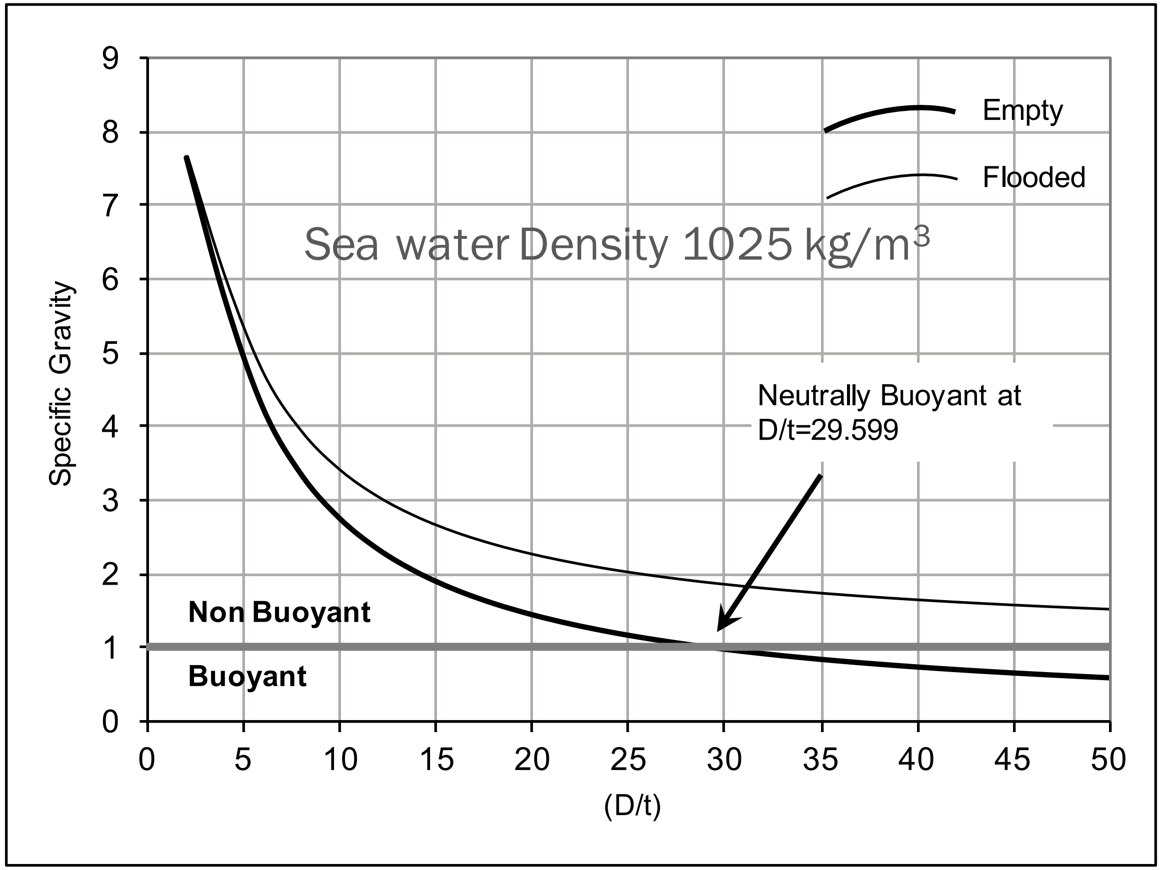
Pipe Dimension Ratio - D/t

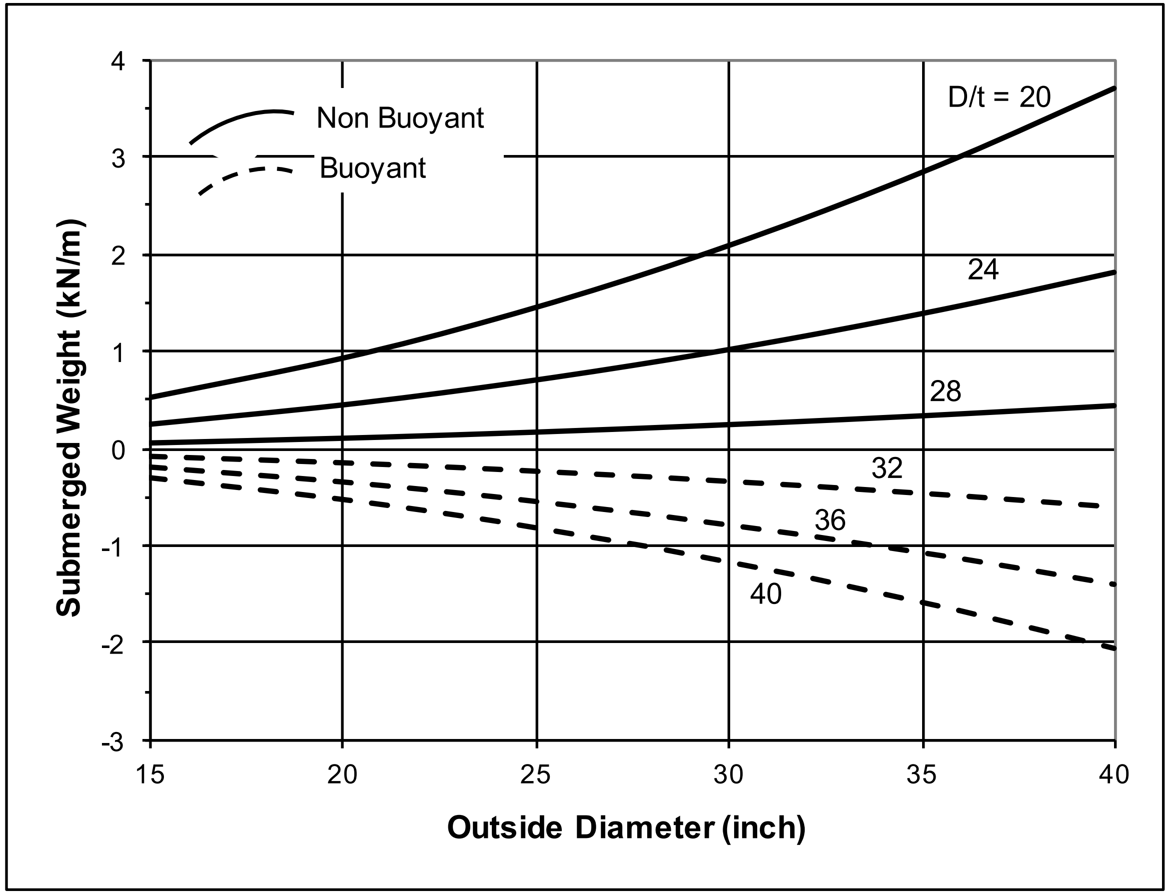
D/t dimension is the ratio of the nominal outside diameter to the nominal wall thickness.

To define generic design charts applicable to any wall thickness, the D/t ratio is used through out the present study.



Specific Gravity and Submerged Weight Plots





Further reading: Properties of cylindrical shells submerged in seawater, Marine Structures 18(4): May 2005

API RP 2A (WSD)– Combined Axial Tension, Bending and Pressure

$$A^2 + B^2 + 2\nu |A| B \leq 1.0$$

where:

$$A = (f_b + f_{tw})(\frac{SF_x}{F_y})$$

$$B = \frac{f_h}{f_{hc}} \times (SF_h)$$

f_{tw} , f_b and f_h are axial, bending and hoop stress respectively.

F_{hc} is the critical hoop stress.

F_y is the material yield strength and,

SF_x and SF_h are factors of safety for axial tension and hoop stress respectively.

True wall stress is:

$$f_{tw} = (f_a + f_p)$$

where:

$f_a =$ effective axial stress

$f_p = -\frac{1}{2} f_h$ end cap or end effect stress

and,

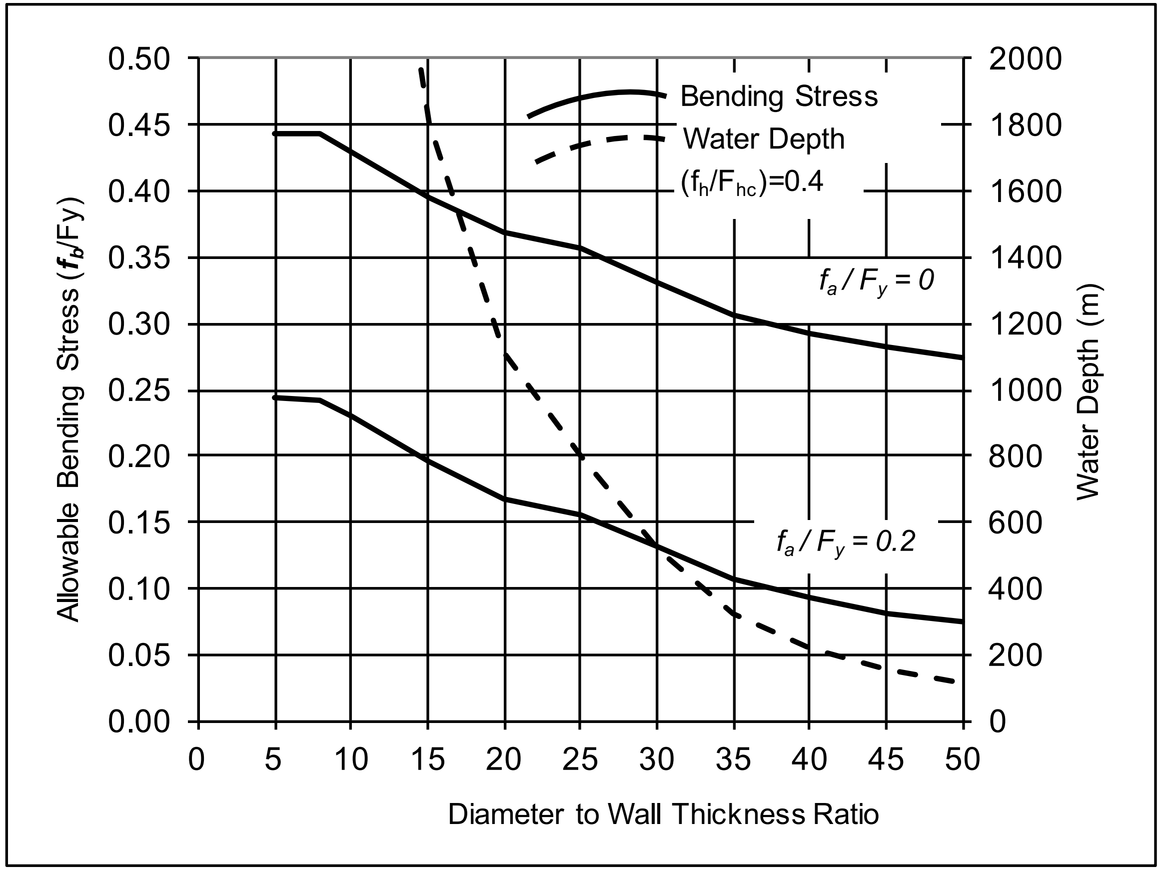
$f_h = P_0 \frac{D}{2t}$ Hoop stress

Combined Axial Tension, Bending and Pressure – API RP 2A

For hoop stress of 40% of critical hoop (f_h/F_{hc}=0.4), this plot shows allowable bending stress when axial stress (f_a/F_y) is zero and when it is 20% of material yield (f_a/F_y = 0.2).

Note that the curves are identical in shape, but with a knockdown factor to describe the allowable bending stress when f_a/F_y = 0.2.

Limiting water depth for both solution curves is identical since hoop stress (f_h/F_{hc}) is fixed to a value of 0.4.



Tendon Diameter Selection Charts – Numerical Examples

- Tendon is assumed to consist of three segments
- Top Segment with bending stress of 5% SMYS
- Main body segment with bending stress of 1% SMYS
- Bottom segment with bending stress of 10% SMYS

Description	Value	Unit
Modulus of Elasticity	200,000	MPa
Steel Yield Stress	448	MPa
Steeil Tensile Strength	531	MPa
Steel Density	7,850	Kg/m^3
Sea Water Density	1,025	Kg/m^3

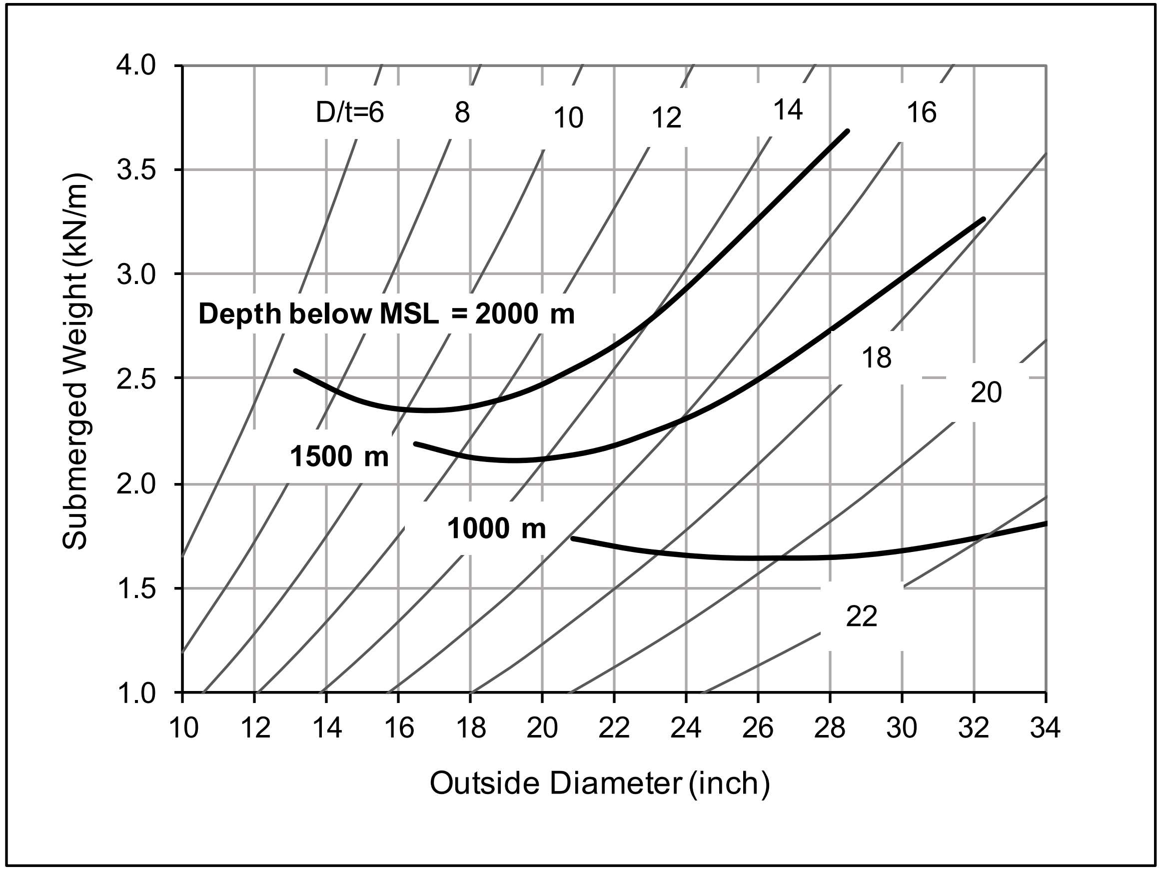
- Maximum tendon pipe size of 44 inch and maximum wall thickness of 1.7 inch are assumed. The diameter limit is based on maximum tendon connector diameter and wall thickness limit is based on what presently can be fabricated.

Bottom Segment – Wall Thickness Selection Chart

Bending Stress = 10% material yield
Effective tension at considered depth = 1000 mT
Interaction ratio (Unity Check) =1.0

Tendon Properties that Yield Min. Sub. Weight

Depth below MSL (m)	OD (inch)	Wall Thickness (inch)	D/t (-)	Steel CSA (m^2)	Sub. Weight (kN/m)
2000	16.5	1.605	10.28	0.048	2.344
1500	18.3	1.455	12.55	0.050	2.117
1000	26.1	1.322	19.71	0.066	1,644



Bottom Segment – Impact of Effective Tension on Wall Thickness

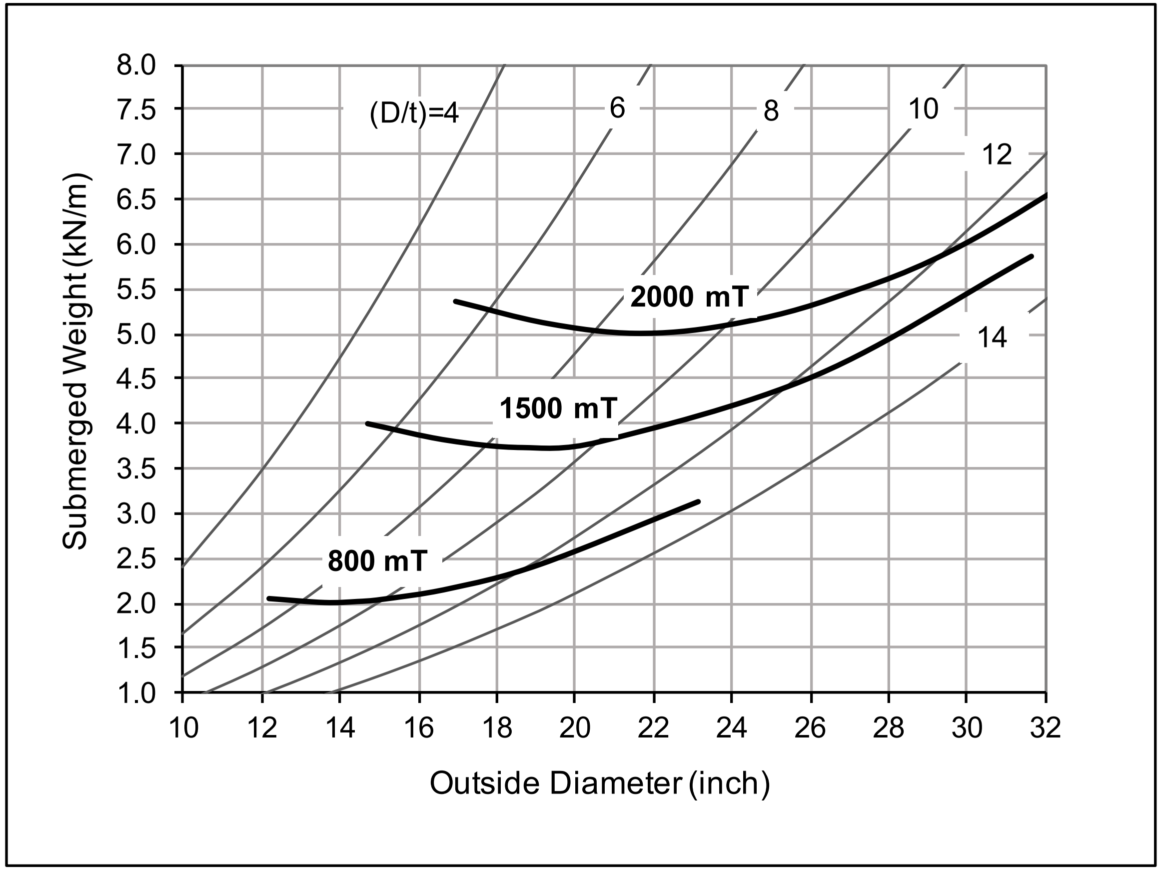
Depth Below MSL = 2500 m

Bending Stress = 10% Yield

Interaction ratio (Unity Check) =1.0

Tendon Properties that Yield min. sub. Weight

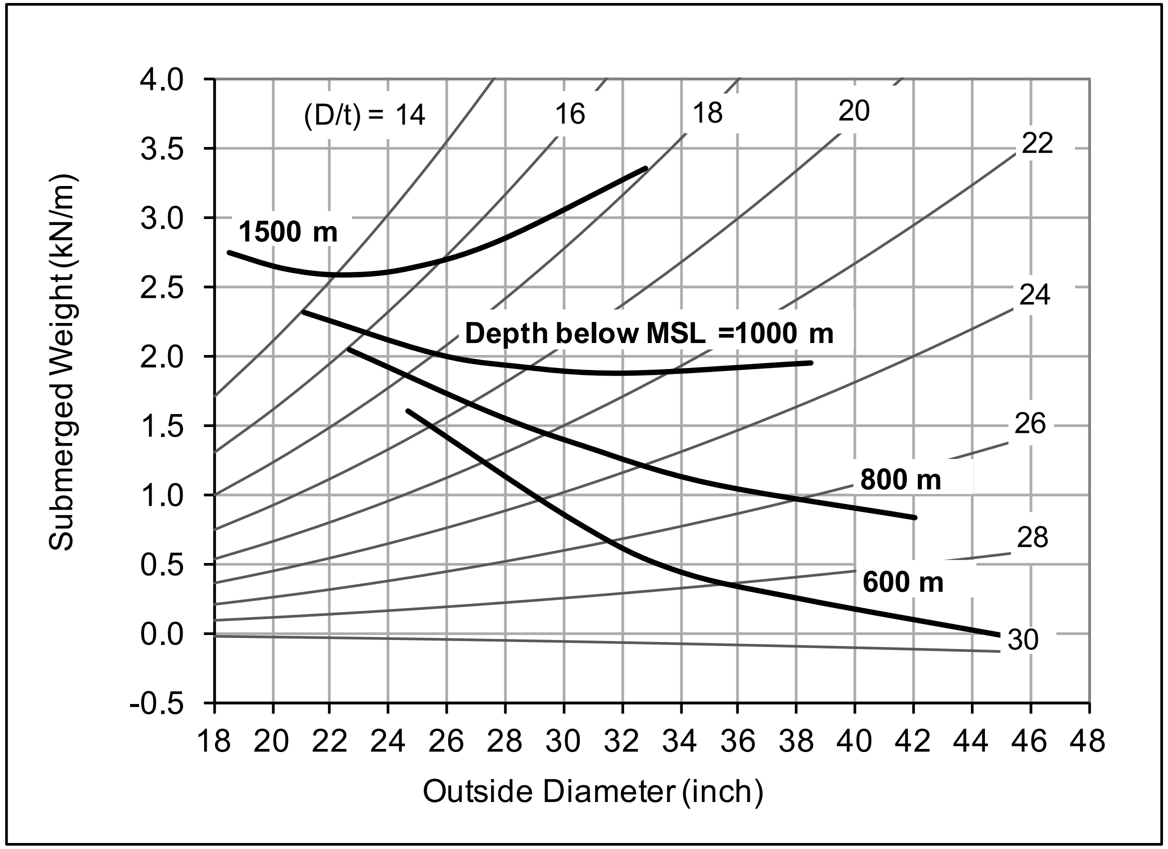
Effective Tension (mT)	OD (inch)	Wall Thickness (inch)	Steel CSA (m^2)	Sub. Weight (kN/m)
2000	21.5	2.475	0.096	4.997
1500	18.6	2.144	0.072	3.750
800	13.6	1.565	0.038	1.999



Main Body Segment – Wall Thickness Selection Chart

Bending Stress = 1.0% material yield
Effective tension at considered depth = 1500 mT
Interaction ratio (Unity Check) =1.0

At shallower depths (depths less than 1000m below MSL), wall thickness solution curve does not exhibit a distinctive minimum value but provide solutions for larger buoyant tendon diameters with potential of providing adequate stiffness into the tendon system for deepwater application.



Top Segment – Wall Thickness Selection Chart

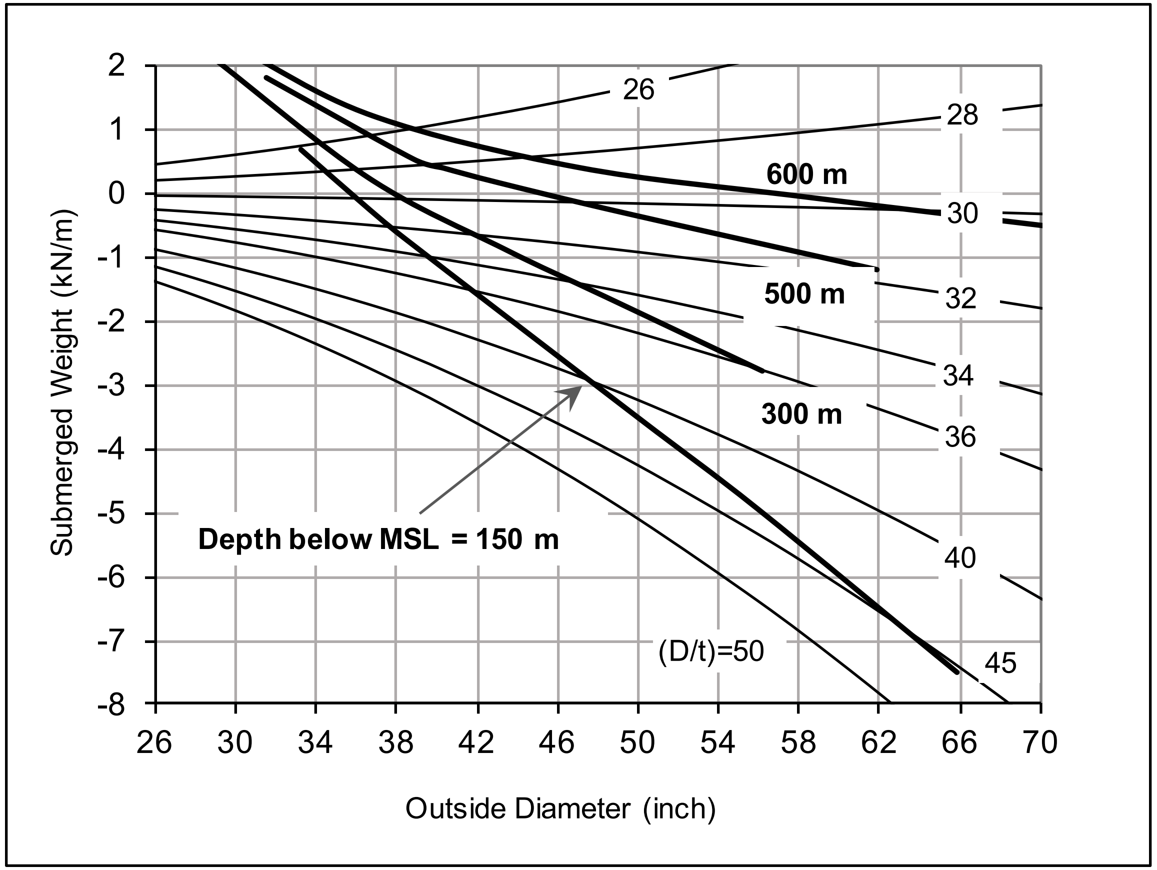
Bending Stress = 5.0% material yield

Effective tension at considered depth = 2000 mT

Interaction ratio (Unity Check) =1.0

Wall THK Requirement for 42-in Tendon Pipe

OD (inch)	Depth Below MSL (m)	Wall Thickness (inch)	Sub. Weight (kN/m)
42.0	150	1.15	-1.651
	300	1.17	-1.512
	500	1.35	-0.393
	600	1.45	0.210



Conclusion

- The methodology presented in this study is only to highlight the design approach rather than addressing all requirements by the permitting bodies. Upon further validation, the approach can accommodate all codes and standards parameters and requirements.
- For deepwater application tendon weight penalty and reduction in overall axial stiffness is often seen as the limiting factor.
- The step diameter concept together with wall thickness selection charts are shown to offer a reliable and a practical method with potential for material cost savings.
- At deepwater segment, results have shown that tendon submerged weight is sensitive to effective tension, pipe OD and wall thickness selection.
- It is recommended that formulation applicable to deepwater be developed and used for accurate estimate of effective tension, hoop stress and their interactions with bending.

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