Pipeline Span Assessment

Content

- Introduction
- Seabed Irregularity
  - Stresses due to low depression
  - Stresses due to elevated obstruction
  - Analysis Methodology
- Vortex Shedding
  - No vibration allowed
  - Onset of vibration allowed
- Scouring and erosion

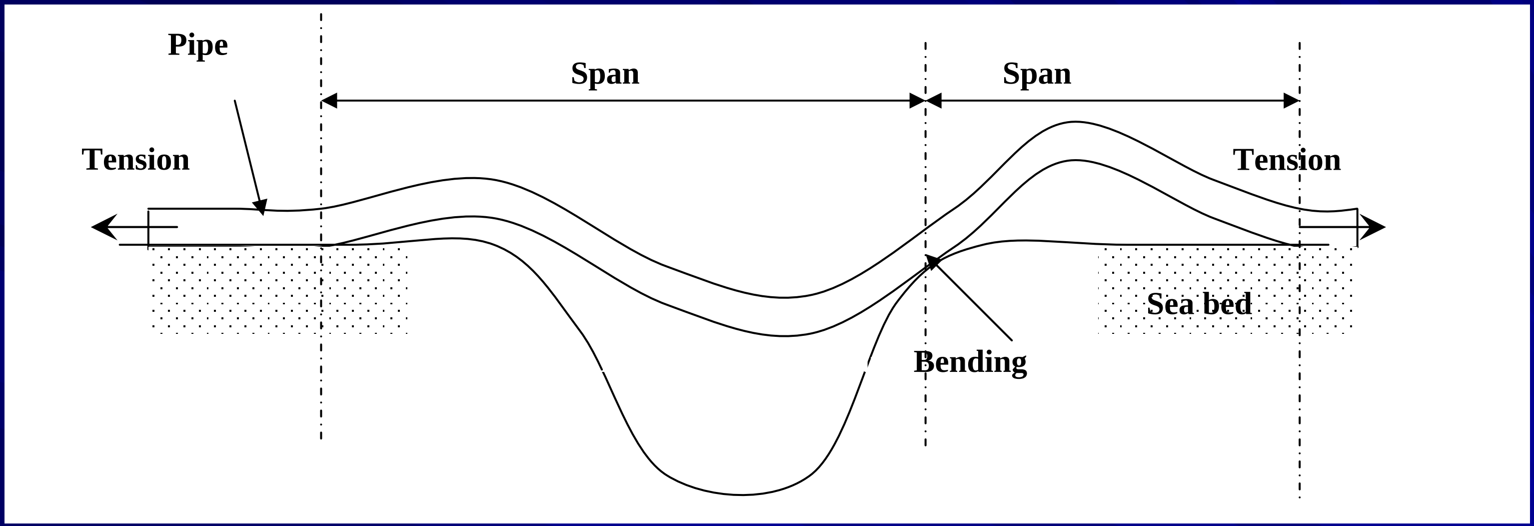
Introduction

- Pipeline spanning occurs when the contact between the pipeline and seabed is lost more than the allowable value due to seabed irregularities and scouring
- In addition, the flow of wave and current around the pipeline will result in vortices. The vortices are caused by turbulent flow. This will cause the pipe span to vibrate and fail by fatigue
- Thus, assessment shall be done to evaluate the maximum allowable span
- If the actual span exceeds the allowable value, then correction is needed to reduce the span

Seabed Irregularity

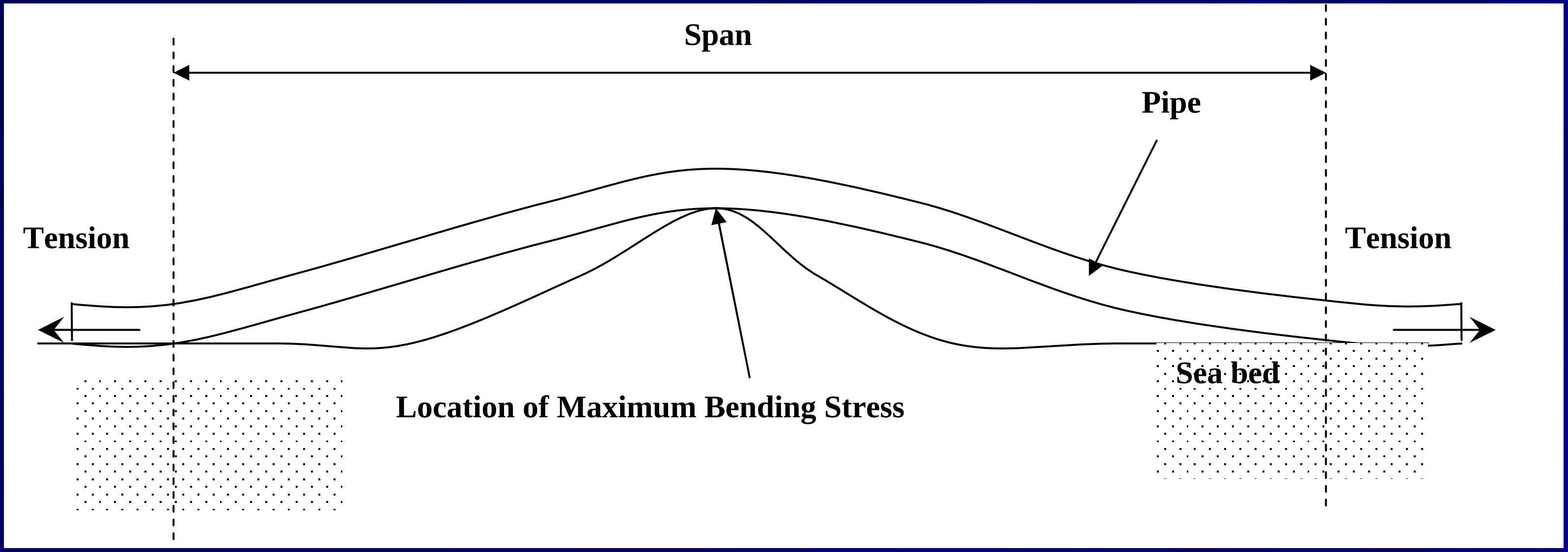
- During installation of a pipeline, the pipeline will cross elevated obstruction or lowered depression along the pipeline route. The crossing of the seabed irregularity will induce span and bending stresses in the pipe
- This induced span and bending stress shall be kept within the allowable limit to prevent the pipeline from overstress
- If the span and stress limit is exceeded, measures shall be taken to mitigate the situation
- The common seabed interventions are rock dumping, trenching, burying, pre-sweeping and placing grout bags underneath the pipeline to reduce the span and stress

Stress Due to Low Depression



- The maximum bending stress reduces as the applied tension in pipe increases
- For a large depression spans, the inclusion of the pipe tension reduces pipe stresses
- In addition, the length of induced pipe span outside the depression reduces too

Stress Due to Elevated Obstruction



- The maximum bending stress does not affected by applied pipe tension. However, the pipe span increases as the applied pipe tension increases

Analysis Methodology

- The structural behaviour of the pipeline along the pipeline route is commonly analysed using finite element simulations such as ABAQUS and OFFPIPE
- The loading conditions during installation, hydrotest and operation phases are simulated to determine the pipeline in-place behaviour
- Based on the analysis, the location of the pipeline which requires seabed intervention will be identified.
- However, a simple beam approach can be used to determine the maximum allowable static span for the pipeline

Analysis Methodology

- The maximum allowable static pipe span, *L* is given by

$$L = \sqrt{\frac{20 I \sigma_{ab}}{wD}}$$

- I = Moment of inertia for pipe
  D = Outer diameter of steel pipe
  w = Uniform distributed load per unit length (inclusive of pipe weight and hydrodynamic forces)
  σ_{ab} = Allowable bending stress
- The allowable bending stress due to span effect is determined using the equivalent stress equation. The allowable bending stress is computed by setting the allowable equivalent stresses to its allowable limit and deducting the stress due to internal pressure, curvature and temperature effect

Vortex Shedding

- When water flow across a pipeline span, it induces the formation of vortex shedding at the top and bottom of the pipe
- The vortices induce an oscillating force
- The oscillating force has two components, namely, cross flow (vertical component) and in-line flow (horizontal component)
- If the frequency of the vortex is close to natural frequency of the pipe span, resonance occurs and pipe span vibrates. This motion might induce fatigue damage in the pipe.
- There are two ways to assess vortex shedding for pipeline span

  \- Vortex frequency is kept below the natural frequency of the pipe span (i.e. no vibration is allowed)

  \- Onset of vibration is allowed but the stress and fatigue damage cannot exceed the allowable limit

Vortex Shedding – No Vibration Allowed

- The vortex frequency must be kept below the natural frequency of the pipe span so that no onset of the vortex shedding is allowed
- This is the common practice.
- The vortex frequency, f is given by

$$f = \frac{S_t V}{D_T}$$

- S_t = Strouhal number (Refer to Figure A.2 of DNV 1981)

  V = Flow velocity normal to pipe axis

  D_T = Total outer diameter of pipe including coating
- The natural frequency of pipe span, fn given in various codes is slightly different

Vortex Shedding – No Vibration Allowed

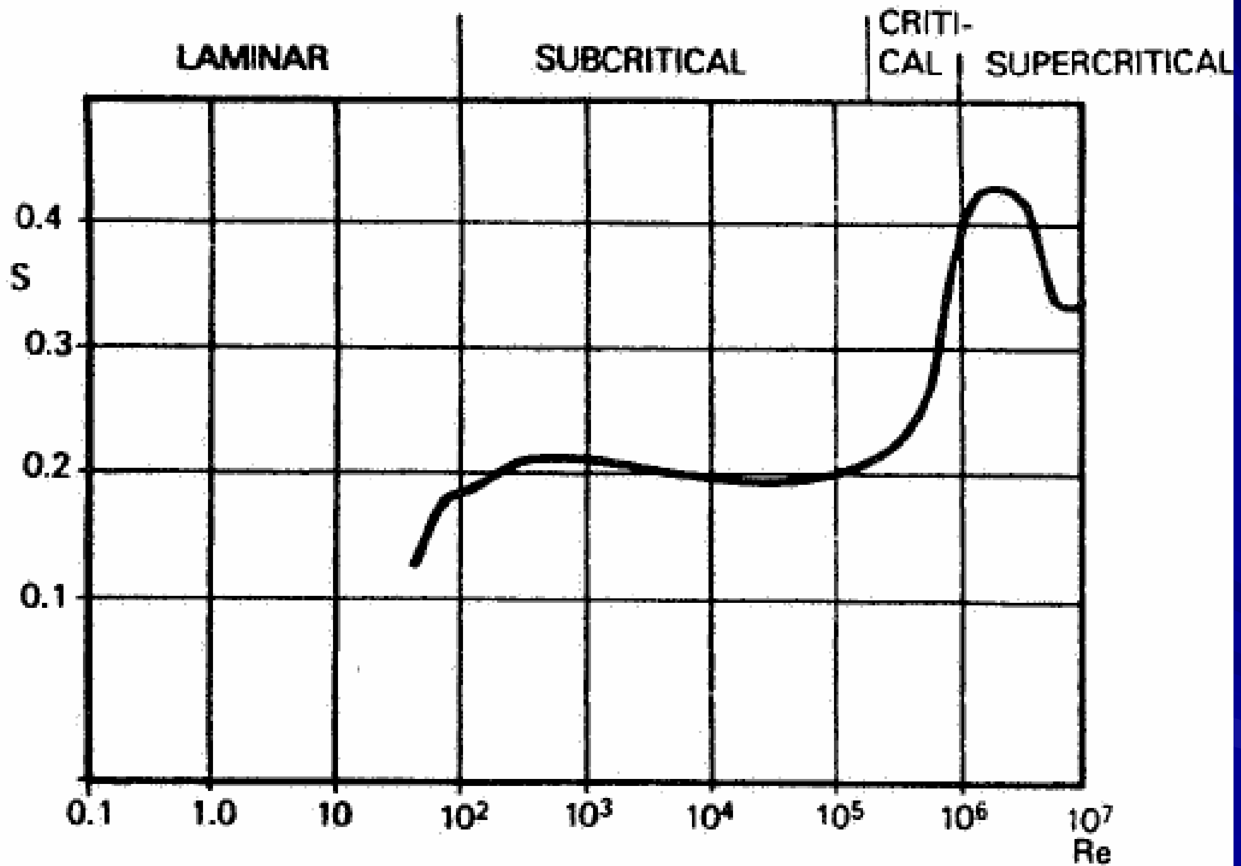


Fig. A.2. Strouhals number for circular cylinders as function of reynolds number. Ref. A.8.

Vortex Shedding – No Vibration Allowed

- However, the commonly used equation is as follows

$$f_n = C\sqrt{\frac{EI}{mL^4}}$$

- E = Young's modulus of steel pipe

  C = Constant which depends on the end condition (2.45 for fix-pin end condition)

  m = Combined mass of the pipe and added mass of pipe per unit length

Vortex Shedding – No Vibration Allowed

Code	Criteria	Remarks
API RP 1111	$f < f_n$	
Mousselli	$f < 0.7f_n$	Offshore Pipeline Design, Analysis and Methods
DNV 1981	$f < kf_n$	$f_n = \frac{V}{V_R D_T}$ V_R = Reduced velocity(Figure A.3 and Figure A.5) K = Constant related to reduced velocity (0.2 to 1)

Vortex Shedding – No Vibration Allowed

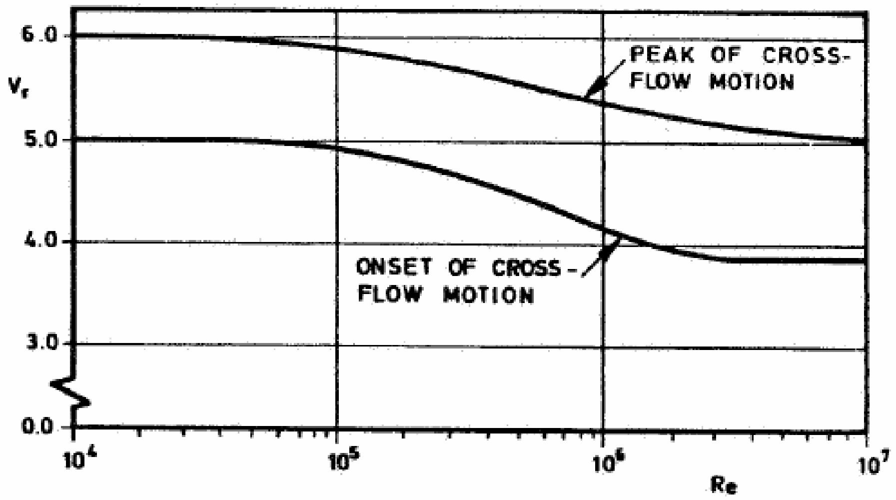


Fig. A.5. Flow speed for onset of cross flow motion. Ref. A.2.

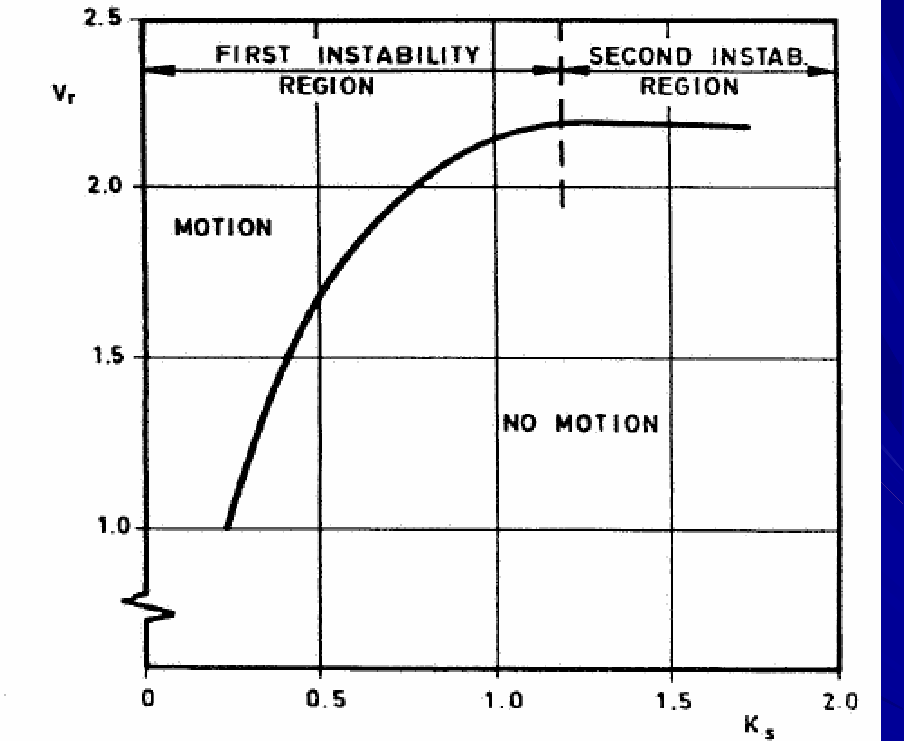


Fig. A.3. Flow velocity for onset of in-line motion. Ref. A.2.

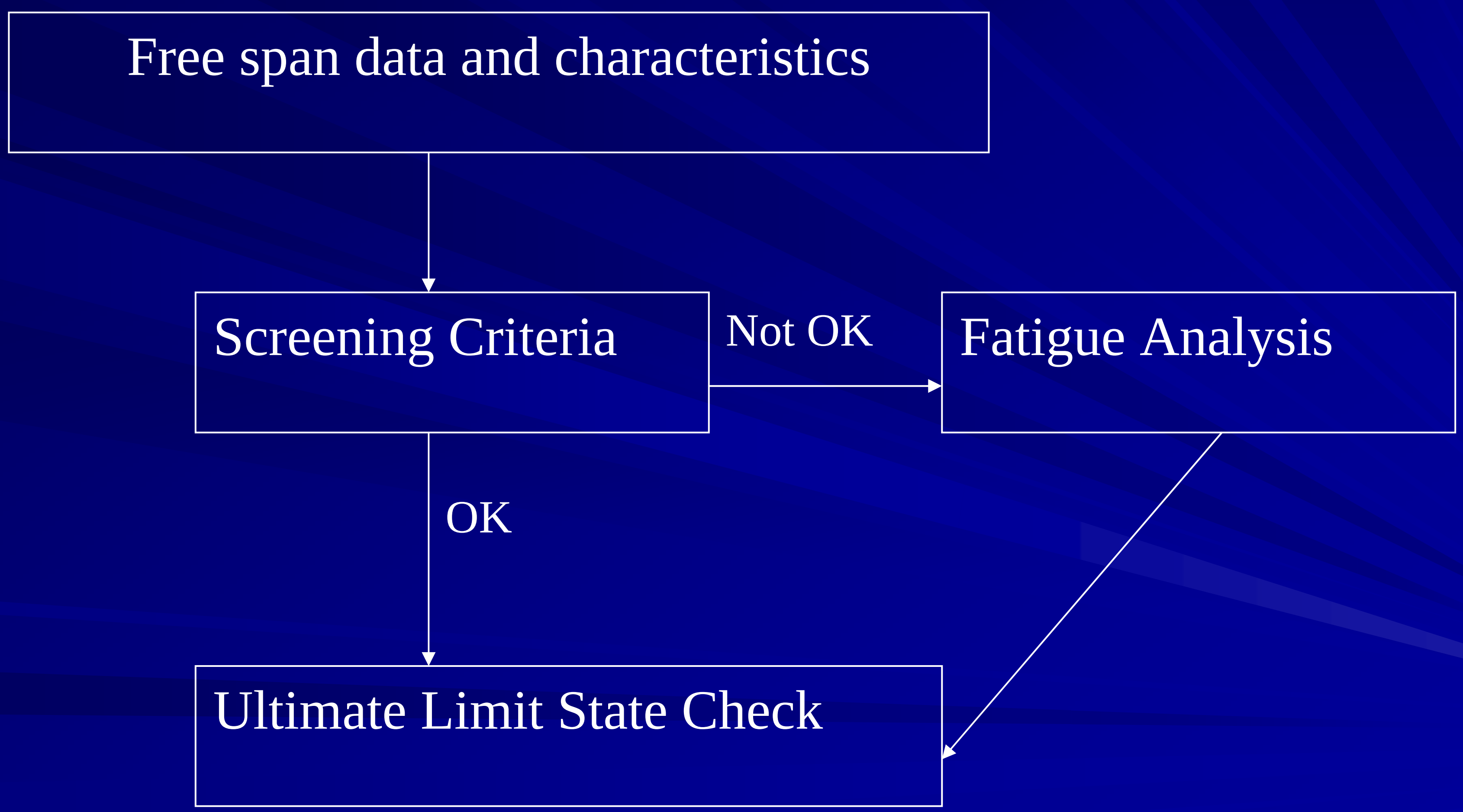
$$K_s = \frac{2m\delta}{\rho_w D_T^{\;2}}$$

δ = Logarithmic decrement of structural damping (0.126)

Vortex Shedding – Onset of Vibration Allowed

- In recent years, less stringent criteria are adopted in which the onset of in line and cross flow vibration is allowed if the stress and fatigue damage is not exceeded
- The analysis is detailed fully in DNV RP F105
- The screening criteria is apply to fatigue caused by vortex shedding, direct wave loading in combined current and wave loading conditions
- The screening criteria have been calibrated against full fatigue analyses to provide a fatigue life in excess of 50 years
- If the screening criteria is exceeded a full fatigue analysis is required

Vortex Shedding – Onset of Vibration Allowed



Vortex Shedding – Onset of Vibration Allowed

2.3.3 The in-line natural frequency $f_{0,IL}$ must fulfil:

$$\frac{f_{0,IL}}{\gamma_f} > \frac{U_{c,100year}}{V_{R,onset}^{IL} \cdot D} \cdot \left(1 - \frac{L/D}{250}\right) \cdot \frac{\gamma_{IL}}{\overline{\alpha}}$$

Where

γ_f	Safety factor on the natural frequency, see 2.6
γ_{IL}	Screening factor for inline, see 2.6
$\overline{\alpha}$	Current flow ratio= $\max\left(\frac{U_{c,100year}}{U_{w,1year} + U_{c,100year}}; 0.6\right)$
D	Outer pipe diameter incl. coating
L	Free span length
$U_{c,100year}$	100 year return period value for the current velocity at the pipe level, see 3
$U_{w,1year}$	Significant 1 year return period value for the wave induced flow velocity at the pipe level corresponding to the annual significant wave height $H_{s,1year}$, see 3
$V_{R,onset}^{IL}$	In-line onset value for the reduced velocity, see 4.

If the above criterion is violated, then a full in-line VIV fatigue analysis is required.

2.3.4 The cross-flow natural frequency $f_{0,CF}$ must fulfil:

$$\frac{f_{0,CF}}{\gamma_f} > \frac{U_{c,100year} + U_{w,1year}}{V_{R,onset}^{CF} \cdot D} \cdot \gamma_{CF}$$

Where

γ_{CF}	Screening factor for cross-flow, see 2.6
$V_{R,onset}^{CF}$	Cross-flow onset value for the reduced velocity, see 4

If the above criterion is violated, then a full in-line and cross-flow VIV fatigue analysis is required.

Span Assessment - Example

- OD = 457.2 mm, WT = 14.2 mm
- External Corrosion Coating = 4 mm 3 LPE
- WD = 42 m, H = 5.2 m, T = 12.3 s, Sea state = 3 hrs
- Current = 0.38 m/s @ 1 m above sea bed
- Soil type = sand, grain size = 0.25 mm
- Design Pressure = 5 MPa
- Design temperature = 30 ºC
- Ambient temperature = 25 ºC