

ANALYSIS OF SPANS FOR SUBMERGED PIPELINES

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DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the analysis of spans in offshore pipelines including risers and provides guidance for such analyses. Aspects included in this DEP are:

- span analysis methodology;
- design loads to be considered;
- span modelling requirements;
- design equations;
- span acceptance criteria.

Span analysis is necessary to assess the potential for pipeline damage at the location of a span due to:

- possible external loads from activities in the area of the pipelines. Examples of such activities are the anchoring of construction or supply vessels for pipelines in the vicinity of installations and trawling;
- over-stressing and deformations from bending due to weight and hydrodynamic loads;
- fatigue due to vortex-induced vibration (VIV).

NOTES:

1. Operating pressures and temperatures affect the response of a span and also need to be considered during a span analysis.
2. Vortex shedding occurs behind a cylinder when subjected to a lateral current. Oscillating forces, both transverse and in-line with the current, are imposed by this vortex shedding and may cause significant vortex-induced vibrations (VIVs) if the frequency of these forces and the natural frequency of the bending cylinder can align. VIVs can occur in the direction of the current (in-line) or perpendicular to the current direction (cross-flow). Analysis of span damage due to fatigue from cyclic wave loads is not a concern in water depths of 100m or more and is therefore not addressed in this DEP. In shallower waters this should be addressed using accepted methods of determining hydrodynamic forces on cross sections under cyclic loading and accounting for the proximity of the seabed.

Cases where there are significant variations in flow velocity along the length of the span (as is for instance the case in catenary risers) are not addressed in this DEP.

This DEP can be applied:

- to the design of new pipelines, to provide a design concept which results in the prevention of pipeline span damage at minimum life cycle cost. This requires that all possible span-related costs are addressed, i.e. seabed preparation before pipeline installation (such as seabed levelling) and span correction after construction and/or during operation;
- for the analysis of spans observed from surveys during construction and pipeline operations, in order to decide whether they can be (temporarily) accepted or require correction.

Design equations included in this DEP apply to single-pipe pipeline concepts only. Whilst the basic principles for formulating these design equations apply also to other pipeline concepts such as bundles or pipe-in-pipe pipelines, they differ depending on the selected concept.

Other span assessment criteria may be applied if justified, and if approved by the Principal. The minimum requirements are that all load categories listed in this DEP shall be addressed, and the factor of safety on the mean fatigue life shall be at least 10 unless otherwise specified by the Principal.

This is a revision of the DEP of the same number dated December 1997; see (1.7) regarding the main changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them.

This DEP is intended for use on offshore pipelines.

When DEPs are applied, a Management of Change (MOC) process should be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regard to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties supplied by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Span - section of a submerged pipeline not in contact with the seabed over its length.

NOTE: Generally applicable definitions and requirements for pipeline engineering can be found in DEP 31.40.00.10-Gen.

1.4 ABBREVIATIONS

SMYS - Specified minimum yield strength

VIV - Vortex-induced vibrations.

1.5 SYMBOLS

Amended per
Circular 01/10

α	linear thermal expansion coefficient for the pipeline steel	$^{\circ}\text{C}^{-1}$
δ	logarithmic decrement of damping of the span in still water	-
ρ	density of the seawater	kg/m^3
ν	Poisson's ratio	-
ζ	modal damping ratio in still water	-
a	frequency factor	-
b	Euler constant	-
A	cross-sectional area of the steel pipe based on nominal wall thickness	m^2
A_f	cross-sectional area for flow of transported fluid	m^2
d	fatigue damage	-

ID	internal pipeline diameter	m
E	Young's modulus	N/m ²
f ₁	first natural frequency of span	s ⁻¹
G	the average gap between the seabed and the bottom of the spanning pipe along the central one-third of the span	m
I	moment of inertia of the pipe	m ⁴
k	Euler buckling wavenumber calculated in accordance with Equation 5.1	m ⁻¹
K _C	Keulegan-Carpenter number	-
K _S	stability parameter	-
L	span length	m
M	bending moment in pipe	Nm
M _e	effective mass per unit length of pipeline including added mass and mass of pipe content	kg/m
n	predicted number of stress cycles	-
N _e	effective axial compressive force in pipeline (see Equation 2.1)	N
n _f	number of stress cycles resulting in pipeline failure due to fatigue	-
N _i	residual axial tension in the pipeline from installation	N
OD	outside diameter of pipeline including coating(s)	m
OD _{st}	nominal outside diameter of the steel pipe	m
P _i	maximum allowable operating pressure	N/m ²
t	nominal pipe wall thickness	m
ΔT	difference, at the location of the span, between the predicted maximum pipeline operating temperature and the pipe temperature during installation	°C
T _s	wave period associated with the significant wave	s
V _c	steady current velocity perpendicular to the pipe, at top of pipe level	m/s
V _r	reduced velocity	-
V _w	wave-induced velocity, perpendicular to the pipe at top of pipe level	m/s
W	force, per unit length of pipeline, resulting from the combined weight and hydrodynamic loads	N/m
y	mid-span span deflection due to in-line VIV	m

1.6 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (8).

1.7 SUMMARY OF MAIN CHANGES SINCE PREVIOUS EDITION

This DEP is a revision of the DEP of the same number dated December 1997. The following are the main, non-editorial changes.

Old section	New section	Change
General	General	Some minor corrections have been made.
1.1	1.1	NOTE 2 clarified regarding deep and shallow water depths.
1.1	1.1	A paragraph has been introduced to the effect that other span design criteria may be used if approved by the Principal.
2.2	2.2	Table 1 has been reworded. Return periods (Table 2) have been modified.
2.3.2	2.3.2	Analysis requirements have been modified.
4.	4.	Equation 4.4 has been modified. In Equation 4.5, the definition of δ has been changed. Text has been added after Equation 4.6.
5.	5.	Note has been added at the end.
6.1.1	6.1.1	This section has been modified substantially.
6.1.2	6.1.2	Equation 6.4 has been added.
6.1.3	6.1.3	Sentence added for clarification.
6.1.4	6.1.4	Clarifications for fatigue curve determination and use of Miner's rule have been added.
Appendix A	Appendix A	The example has been reduced in scope and revised to ensure that all results are reproducible from the information given, and to make it consistent with the methodology described in the DEP.

1.8 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the DEP Administrator at standards@shell.com. Shell staff may also post comments on this DEP on the Surface Global Network (SGN) under the Standards folder.

2. METHOD OF ANALYSIS

2.1 PROCEDURE

Figure 1 schematises the recommended procedure for the analysis of spans of submerged pipelines outlined below.

The assessment of possible external loads is the first step of the analysis after the necessary input data have been collected.

Spans which pass the external load assessment should then be subjected to a preliminary assessment involving a relatively simple analysis based on conservative assumptions. In this analysis spans are considered acceptable if:

- the analysis of reduced velocities indicates that VIVs will not occur and that, consequently, fatigue damage from these vibrations can be ruled out; and
- the calculated maximum combined stresses under the loads defined in this DEP stay within the limits for elastic stresses in DEP 31.40.00.10-Gen.

Spans which fail the preliminary assessment may still be acceptable if unacceptable damage and/or failure of the span can be ruled out with a more detailed assessment removing some of the conservatism of the preliminary assessment. Spans subjected to the detailed assessment are acceptable if:

- the fatigue assessment demonstrates that fatigue damage from vortex-induced vibrations will not lead to failure during the design or remaining operating lifetime of the pipeline or until the span can be corrected; and
- limits for acceptable plastic strain are not exceeded.

NOTE: Spans have traditionally been assessed against the criteria of the preliminary assessment only. Recent hydrodynamic research on the effect of currents and waves on spanning pipelines has, however, provided information necessary to cautiously quantify stress fluctuations from vortex-induced vibrations. Similarly, research on post-elastic behaviour of pipelines demonstrates that straining of the pipeline beyond the elastic limits can be permitted without impairing the safety of the pipeline.

The requirements, criteria and guidance for each of the above assessments are given in (3) to (7).

(2.2) and (2.3) specify the load conditions and requirements for span modelling to be considered for these assessments.

The length of the span is the critical parameter. Span corrections to reduce the span's length are normally done by dumping rock or seabed material along the entire span, or providing supports along the span. Other methods are water jetting of supports to lower the span into the seabed, or (on sandy seabeds) the placing of artificial seaweed to draw sand into the gap. Requirements for long-term stability should be a main consideration when selecting span rectification method(s).

2.2 LOAD CONDITIONS

Pipeline spans shall be addressed for all phases of the pipeline life cycle. Table 1 shows these phases with the pipeline condition and design loads which shall be considered for span analyses.

Table 1 Pipeline conditions and design loads

Phase	Pipeline condition	Design loads
Construction	- empty pipeline	- residual lay tension - submerged empty pipeline weight - hydrodynamic loads
	- flooded pipeline (see NOTE)	- residual construction loads - submerged flooded pipeline - hydrodynamic loads
Hydrotesting	- pipeline under test pressure, filled with test medium	- residual lay tension - submerged pipeline filled with test medium - hydrodynamic loads - test pressure
Operation	- operating condition	- residual lay tension - submerged pipeline filled with fluid - hydrodynamic loads - pipeline operating pressure - maximum operating temperature
	- flooded pipeline (see NOTE)	- residual lay tension - submerged flooded pipeline - hydrodynamic loads
NOTE: The flooded pipeline case shall be considered in order to prevent damage in the event of accidental pipeline flooding.		

Loads for calculating maximum stresses or strains for comparison with maximum allowable values should be based on:

- the maximum allowable operating pressure for the pipeline;
- maximum pipeline operating temperature predicted at the location of the span;
- maximum fluid density;
- design currents and maximum waves associated with the relevant return period.

Loads for calculating whether VIVs can occur and for fatigue damage calculation should be based on:

- pipeline operating pressure, temperature and fluid density predicted for the location of the span under planned operating conditions;
- design currents and significant waves associated with the relevant return period.

The return period for the hydrodynamic loads should be taken as not less than indicated in Table 2.

Table 2 Return periods for hydrodynamic loads

Case	Return period
Design of safe spans for the pipeline lifetime	100 years
Assessment following survey during construction or operations	1 year if span is discovered and is rectified immediately; or 10 years if span will be rectified within one year of discovery except when discovered and rectified as indicated above; or 100 years if span will not be rectified.