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Trawl Forces on Free-Spanning Pipelines

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ABSTRACT

Model tests investigating trawl forces for free-spans of up to 6 m in height are described. Results are presented for maximum warp force, maximum force applied to the pipeline and shape of the force-time trace. Effects of tow velocity, span and warp flexibility and trawl door type are quantified. The effects of trawl forces in limiting allowable span lengths and heights are illustrated.

NOMENCLATURE

A : effective cross-sectional area of warp
c : equivalent damping for SDOF system
D : pipe diameter
d_g : trawl door distance from pipe when warp applies forces to span
d_p : distance moved by pipe during trawl-span interaction
E : modulus of elasticity for warp
$f(t)$: trawl force applied to pipe in numerical simulations
F_p : maximum force applied to pipe (kN)
$\mathfrak{I}_P$: maximum reduced force applied to pipe, $F_p/(Vk^{1/2})$
F_w : maximum warp force (kN)
$\mathfrak{I}_w$: maximum reduced warp force, $F_w/(Vk^{1/2})$
F_o : warp force when towing on seabed (kN)
h : span height
k : warp stiffness (kN/m)
k_p : equivalent stiffness of SDOF system
k_x : warp stiffness for design case (kN/m)
L : span length
m : equivalent mass of SDOF system
m_d : equivalent mass of trawl door
t_d : interaction time
t_{do} : reference interaction time (for rigid pipe, V=3 m/s, k=39 kN/m)
t_g : time associated with movement through distance d_g
t_p : time associated with movement of pipe, d_p
t_w : time associated with extension of warp
V : tow velocity
V_x : tow velocity for design case
x : displacement of midpoint of pipe span
$\dot{x}$: velocity of midpoint of pipe span
$\ddot{x}$: acceleration of midpoint of pipe span
σ : stress

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KEY WORDS: Pipelines, trawl forces, spanning pipelines, model tests.

INTRODUCTION

The development of hydrocarbon fields off mid-Norway will present special design problems with respect to free-spanning pipelines. Water depths are typically 250-350 m and the bottom is very uneven, being criss-crossed by numerous iceberg scour marks of depth up to 10 m and width up to 200 m or so. A pipeline laid in this area will not be able to entirely avoid such scour marks, even through careful routing, and the rectification of the resulting free-spans will involve considerable cost. Other areas offshore Norway are also characterised by similar extreme scour marking, e.g., Tromsøflaket.

In order to develop appropriate rectification procedures for pipelines in areas with severe free-spanning, it is necessary to assess the effects of trawling on free-spans for the various construction phases (just after laying, water-filled and in operation). This may be done, for example, through numerical simulation of spans, using as input appropriate time histories of forces from trawling, and determining allowable free-span lengths and heights for each phase. This information, together with similar information for dynamic behaviour (vortex-induced vibrations) and static stresses of free-spans, will determine the necessary rectification for each phase.

The interaction and possible conflict between trawl fishing gear and marine pipelines have been of considerable interest (Gørsvik et al., 1975; Kjeldsen and Moshagen, 1979; Moshagen and Kjeldsen, 1980; Nyhus and Holthe, 1980; Guijt and Horenberg, 1987; Horenberg and Guijt, 1987; Nygaard, 1988; and Valdermarsen, 1989, amongst others). Virtually all of these studies have considered rigid and fixed pipeline sections at relatively shallow water depths (up to 150 m). Considerable investigation into beam trawling equipment has been conducted (Moshagen and Kjeldsen, 1980; Horenberg and Guijt, 1987; Guijt and Horenberg, 1987); however, the beam trawl is not applicable in the water depths of interest to the present investigation and is not considered further here.

The most extensive relevant project conducted to date is a multiphase JIP in Norway between 1974 and 1978 (Kjeldsen and Moshagen, 1979; Moshagen and Kjeldsen, 1980), including field and reduced scale laboratory tests with 16" and 32" diameter pipelines and using various types and sizes of beam and otter trawl equipment. The tests were representative of conditions in