

Effect of Wave Short-Crestedness for Pipelines

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ABSTRACT

The effects of short-crestedness on wave-induced loads on a pipeline are investigated. Reduction factors are derived that may be applied to loads or velocities in a 2-D (long-crested) calculation to account for short-crestedness effects. Appropriate reduction factors for a 40-in pipeline in 40-m water depth are about 0.85 applied to forces or 0.92 applied to velocities. For most pipelines values nearer 1.0 will apply. The use of significant velocity in calculations with reference to "spreading effects" is inappropriate.

NOMENCLATURE

D : pipeline diameter (steel)
 E : Young's modulus for pipeline steel
 F : destabilizing force (e.g., hydrodynamic lift or horizontal force)
 F_m : maximum (2-dimensional) value of force, horizontal or vertical, corresponding to velocity u_m
 I : 2nd moment of area of pipe section
 L : length of pipeline affected by forces
 L_p : crest length of wave height or velocity along pipe axis
 L_w : wavelength in mean wave direction ($=1/N_{max}$)
 M : moment at a cross section of pipeline
 N : number of zerocrossings per unit length at angle θ to mean wave direction
 N_{max} : number of zerocrossings per unit length in mean wave direction
 N_{min} : number of zerocrossings per unit length along direction perpendicular to mean wave direction
 n : exponent in cosine spreading function
 R : reaction force at each end of pipeline length L
 s : pipeline specific gravity, also exponent in half-angle spreading function
 T : tension in pipeline
 T_u : period of wave-induced oscillatory velocity
 t : steel wall thickness
 U : amplitude of wave-induced oscillatory velocity at pipeline
 u : flow velocity due to waves
 u_m : maximum flow velocity component perpendicular to pipeline due to waves (2-dimensional value)
 V : steady current velocity
 W : resisting force acting over length L (i.e., pipe weight in vertical plane or soil resistance in horizontal plane)
 x : coordinate along pipe axis from left-hand end of length L (Fig. 3)
 y : deflection (Fig. 3)
 γ : short-crestedness
 δ : maximum pipeline deflection due to combined forces W

and F

ζ : coordinate along pipe axis from centre of length L (Fig. 3)
 θ : angle measured from mean direction of wave travel
 θ_p : angle of perpendicular to pipeline axis relative to mean wave direction
 χ : x/L
 \mathcal{L} : L/L_p
 \mathcal{F} : F/W
 \mathcal{F}_m : F_m/W
 \mathcal{R} : R/WL
 Π : M/WL^2
 τ : $TL_p^2/(EI)$

INTRODUCTION

The natural wave field is short-crested, and the effect of pipeline flexural stiffness and tension tends to average the loads over a certain distance. Design velocities applied in a 2-dimensional static stability calculations are usually reduced from peak values (e.g., to significant velocity as in common engineering practice, or with a factor 0.7 as in DnV 1976 pipeline rules) to account for this lower averaged load. These reduction factors are rather arbitrary and the present paper develops rational factors taking into account wave spreading and pipeline flexibility.

Using a spectral approach Battjes (1982) has considered the average force on a long, infinitely stiff body at an arbitrary angle to 3-D waves. For a very long but flexible body this method could be used after determination of an appropriate length, dependent on flexural stiffness, over which to apply the averaged force and provided the forces are linearly related to the wave height, e.g., for structures dominated by inertia forces. For structures where drag or other nonlinear forces dominate, the spectral approach cannot be used. Pipelines will usually fall into this category.

The starting point for the present analysis is a description of the wave profile along a pipeline placed at an arbitrary angle to a short-crested sea. This determines the velocity and force profiles. Through a structural representation of the pipeline the maximum load to give the pipeline a specified maximum deflection is then calculated. The effects of short-crestedness on the maximum loads that may be carried without exceeding the specified maximum deflection are studied. The analysis yields reduction factors on loads or velocities that may be applied to 2-D (long-crested) calculations to account for short-crestedness effects.

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