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Static Calculation of Pipeline Free Spans

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INTRODUCTION

Pipeline free spans are often calculated as a continuous beam, without the *effective* axial force taken into account and, particularly, without the sliding of the pipeline towards the span taken into account. Correspondingly, oscillations are usually calculated as for a straight beam with zero axial force. Such calculations are not correct, except for "medium" spans if the effective axial force happens to be zero. Shorter spans are usually subjected to a compressive effective axial force; longer spans may be subjected to tension and may have considerable sag. The tension and the sag imply that the span acts partly as a suspended cable, so that the static capacity is large compared with a beam of the same dimensions. The tension and the sag may also affect the *dynamic* behaviour of the span.

One reason a pipeline span does not behave as a beam is the pipeline's tendency to elongate when set in operation. A pipeline that is not restrained will elongate. If it is restrained, a compressive effective axial force will act in it instead. A free span is a special case of reduced restraint, where the pipeline takes the opportunity to elongate towards the span from both sides in order to get rid of the compressive effective axial force in it. For longer spans even tension, combined with sag, may be necessary for the vertical equilibrium of the span.

EFFECTIVE AXIAL FORCE AND TRUE AXIAL FORCE

The notion *effective axial force* is used above to make clear that it is *not* the force acting in the pipe wall. The effective axial force is an important quantity in the calculation of pipeline behaviour, particularly the behaviour of free spans.

The relation between the effective axial force (S) and the pipe wall force ("true" axial force, N) is:

$$S = N - p_i A_i + p_e A_e \tag{1}$$

where

p_i = internal pressure
p_e = external pressure
A_i = internal cross-sectional area (= $A_e - A$)
A_e = external cross-sectional area
A = cross-sectional (steel) area

(S and N positive when tensile.)

Calculating N for a restrained pipeline during operation, and introducing N into Eq. 1 results in:

$$S_o = H - p_i A_i (1-2v) - \alpha \Delta T E A \tag{2}$$

if the pipeline was laid empty and with (residual) horizontal pull H.

v = Poisson's ratio
α = coefficient of thermal expansion
ΔT = temperature increase relative to the installation temperature
E = modulus of elasticity

Note that p_e disappears from Eq. 2 if the pipeline is laid *empty* (airfilled), which usually is the case.

S_o is an important quantity even for pipelines in which S_o can not exist (due to insufficient restraint). If only a force S can exist, an elongation per unit length equal to

$$\varepsilon = \frac{S - S_o}{EA} \tag{3}$$

will *necessarily* take place.

As certain points on a pipeline are fixed, the elongation must be taken up by deflection. One must assume that this deflection usually takes place in the horizontal plane. A span is a special case where the deflection takes place in the vertical plane, and under the (additional) action of the submerged weight of the pipeline. What happens in a span is otherwise much the same as what may happen at a location with less than average lateral restraint.

The effective axial force (S_s) that can (or must) exist in a span is usually less negative (or more positive) than S some distance away from the span.

ELONGATION AND SAG

A span of length L will usually cause deflection of a somewhat larger length (L_1) and elongation of a considerably larger length (L_2) (which may be several kilometres for a larger pipeline).

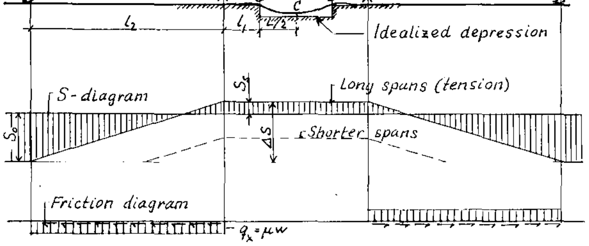

Fig. 1 Idealized situation if $|S_o| \leq |S_{th}|$, i.e., if the pipeline does not buckle.

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