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Tube Collapse Under Combined Pressure, Tension and Bending Loads

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ABSTRACT

The paper presents an FEM analysis of the collapse behaviour of thick tubes ($10<D_0/t<40$). The loads and load combinations considered in this paper are: external pressure, combined pressure and tension loads, combined pressure and bending loads. The effects of initial ovality, residual stress, strain-hardening, yield anisotropy and loading paths are included in the analysis. The analysis procedure is validated through a systematic comparison with excellent experiments published. Sensitivity studies on the factors affecting tube collapse have been carried out since it is easy to control parametric variables in the FEM procedure. Collapse envelopes (interaction curves) from the FEM analysis are presented for the load combinations. Equations to predict collapse strength and collapse envelopes are discussed.

NOMENCLATURE

D_0 : tube mean diameter
E : Young's modulus
M : bending moment
M_{co} : collapse moment
M_{co*} : collapse moment when only moment is applied
M_0 : yield moment, $\sigma_0 D_0^2 t$
n : strain hardening parameter
P : pressure
P_{co} : collapse pressure
P_{co*} : collapse pressure for tubes free from residual stress
P_{co*} : collapse pressure when only pressure load is applied
P_E : linear buckling pressure, $P_E = 2E(t/D_0)^3/(1-\nu^2)$
P_0 : yield pressure, $P_0 = 2\sigma_0 t/D_0$
S, S_θ, S_r : yield anisotropy parameters
t : tube thickness
T : tension
T_{co} : collapse tension
T_0 : yield tension, $T_0 = \pi D_0 t \sigma_0$
Δ_0 : initial ovality parameter, $\Delta_0 = (D_{max}-D_{min})/(D_{max}+D_{min})$
κ : tube curvature
κ_0 : t/D_0^2
κ_{co}^* : collapse curvature when only curvature load is applied
ν : Poisson's ratio
$\sigma_{\theta r}$: circumferential residual stress
σ_y : yield parameter
σ_0 : API yield stress, corresponding to strain $\varepsilon_0(=0.005)$
ε_y : linear strain limit
λ : slenderness ratio $\lambda = (P_0/P_E)^{1/2} = (D_0/t)[(1-\nu^2)\sigma_0/E]^{1/2}$

INTRODUCTION

Thick tubes are widely used in deepwater pipelines, oil casing, tendons of tensionleg platforms and risers in offshore engineering. The high ambient pressure in deep water requires use of tubular with lower diameter-to-thickness ratios, D_0/t, normally between 10 to 40. Practically, when a pipeline is pulled through a J-tube, some tension load exists due to pulling of pipelines, while large plastic curvature is applied together with high external pressure. This type of load combination also occurs in the sag bend of tubes in laying pipe. In this situation, all three loads are moderate. The combination of external pressure, tension and bending loads is also encountered in tendons of tension leg platforms (TLPs). During large storms such as hurricanes or in ship collision accidents, the tendons of TLPs are subjected to large pressure induced by deep water as well as steady and time-varying tension and bending loads due to the storms or the impacts.

The present study is devoted to an FEM analysis of the collapse behaviour of the thick tubes subjected to external pressure, tension and bending loads as well as their combinations. It is intended to provide a numerical data basis for the development of thick tube design codes.

The collapse behaviour of thick tubes is strongly influenced by D_0/t, material properties (yield stress and strain-hardening parameters), and initial imperfections. Depending on loading situations, the collapse modes of thick tubes can be classified as:

(1) Hoop collapse: Collapse due to circumferential, elastic-plastic buckling of rings, defined as maximum pressure capacity of the tubes.
(2) Bending collapse: Collapse due to a combination of ovalization of the cross-section and yielding in the longitudinal direction of the tubes. The collapse is defined as maximum bending moment capacity point.
(3) Tension collapse: Collapse due to large tension load, defined as maximum tension capacity for tubes under combined tension and pressure.
(4) Tension tearing rupture: Collapse due to ductile fracture, defined as the point where extreme fibre strain exceeds a strain criterion(based on fracture mechanics).

Early studies on the collapse behaviour of thick tubes under external pressure were well outlined by Timoshenko and Gere (1961). Due to increasing needs in offshore engineering, careful experimental and analytical investigations have been carried out (Tokimasa and Tanaka, 1986; Yeh and Kyriakides, 1986, 1988). An extensive survey of literature has been presented in their papers. Using the FEM approach, Tokimasa and Tanaka (1986) investigated the effects of initial ovality, residual stress and strain hardening. They finally derived a set of formulae to predict the

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KEY WORDS: Collapse, thick tubes, pressure, combined pressure and tension, combined pressure and bending, initial ovality, residual stress, yield stress, hardening parameter, anisotropy parameter.