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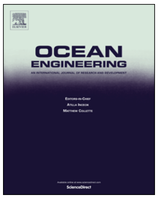

Plastic buckling of axially compressed thick unstiffened steel cones

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ABSTRACT

The paper examines the effect of material modeling behavior on the elastic–plastic buckling of relatively thick unstiffened steel cones subjected to axial compression. Cones are assumed to be made from mild steel with radius-to-thickness ratio, (r_2/t) of 34.3 and cone angle of 26.56°. Three material models were considered: (i) elastic-perfectly plastic, (ii) engineering stress–strain and (iii) true stress true strain. The accuracy of numerical predictions as compared to experimental results was seen to be strongly dependent on the material modeling strategy. Plastic mechanism design approach previously proposed for cones under axial compression was modified to widen the range of its applicability by catering for the effect of excessive plastic deformation. The proposed model utilizes the concept of true stress true strain nature of constitutive equation in determining the squash load. Predictions of collapse load given by the modified constitutive model were compared with initial plastic mechanism design approach and available design codes (API, ECCS, and ASME code case 2286-2) for published experimental data on axially compressed unstiffened steel cones in the elastic–plastic range. Results indicate that the proposed model gives much better predictions of load carrying capacity than both the initial design approach and the available design codes.

1. Introduction

Thick cones subjected to axial compression are used as structural components in marine and offshore structures such as piles for holding jackets when driven into the sea bed, and the legs of off-shore drilling rig. When used as piles for jackets holding, they are, subjected to axial compression only. In the case of off-shore drilling rigs, they are under combined loading, i.e., some part of the structures is subjected to external pressure, in addition to axial compressive force in the legs of the drilling rig. Cones used for these applications, usually fail in the elastic–plastic range.

Details about experiments of axially compressed unstiffened cones can be found in (Arbocz, 1968; Blachut et al., 2011; Blachut and Ifayefunmi, 2010; Chryssanthopoulos and Poggi, 2001; Easwara Prasda and Gupta, 2005; El-Sobky and Singace, 1999; Foster, 1987; Gupta et al., 1997, 2006; Lackman and Penzien, 1961; Mahdi et al., 2002; Mamalis and Johnson, 1983; Mamalis et al., 1984, 1986; Ramsey, 1977; Tong, 1999; Weingarten et al., 1965a, 1965b).

Seide (1956, 1961) first derived an expression based on Donnell-type shell theory for the critical elastic buckling load for an axisymmetric mode in a conical shell subjected to axial compression. Seide's formula may be written as:

$$F_{crit} = \frac{2\pi E t^2 \cos^2\beta}{\sqrt{3(1-\nu^2)}} = F_{cyl}\cos^2\beta \quad (1)$$

Thus, the critical elastic buckling load of a cone is the same as that of a cylinder multiplied by the square of the cosine of the cone semi-vertex angle. Using Galerkin method for asymmetric buckling mode, Singer (1965), also obtained the same magnitude of elastic buckling load as given by Seide (1956).

One of the first contrasts between elastic and plastic buckling of axially compressed cones was presented by Ramsey (1978). Chryssanthopoulos and Poggi (2001) used the plastic mechanism approach to determine the collapse strength of unstiffened conical shells under axial compression. In their approach, the use of elastic perfectly plastic material modeling behavior was adopted. However, for thicker cones under axial compression, at collapse the wall undergoes large plastic straining with a plastic hinge being formed at the small radius end (upper part) of the cone, Blachut and Ifayefunmi (2010). Then, the effect of plasticity is likely to influence the load carrying capacity of such cones at collapse. Hence the modeling of the material is likely to be important.

The current paper examines the effect of material modeling behavior on the plastic buckling of relatively thick unstiffened steel cones subjected to axial compression. The paper also presents a

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modified constitutive model for plastic buckling of steel cones under axial compression to widen the range of applicability by catering for the effect of excessive plastic deformation of the previously proposed design approach by Chryssanthopoulos and Poggi (2001).

2. Material data extractions

In order to obtain the material data, two flat slices '*A*' and '*B*', were cut from the 202 mm long by 252 mm diameter piece from the long solid billet—as sketched in Fig. 1. Seven round tensile specimens were designed according to the British standard BS EN 10002-1: 2001 (2001).

Coupons T_1, T_2, S_1 and S_2 were cut in the axial direction of the billet whilst T_3, T_4 and S_3 were cut in the transverse direction (perpendicular to the billet's longitudinal axis). All seven coupons were subjected to uni-axial tensile test using INSTRON testing machine as shown in Fig. 2. Coupons T_1 and S_1 were strained gauged. The coupons with strain gauges were tested twice, first to obtain the elastic constant of the material, and then to record the stress–strain curve. The remaining five coupons were tested until they failed with an extensometer for calculating the values of strain. The speed rate of loading was 0.2 mm/min. Fig. 3 shows the round tensile test coupons after being tested. It can be seen from Fig. 3 that the coupons in the axial direction (i.e., T_1, T_2, S_1, and S_2) failed by necking. Whereas, for coupons in the transverse direction (i.e., T_3, T_4, and S_3), brittle failure was noticed.

The results presented in Table 1 also show that for the specimen in the transverse direction (i.e., T_3, T_4 and S_3) there was no value for the upper and the lower yield. This behavior can be attributed to the presence of impurity in the central portion of the thick steel billet as observed previously by Blachut (1995). The tensile coupons in the longitudinal direction (i.e., T_1, T_2, S_1 and S_2) showed that there were upper and lower yield values and it can be observed that there was no significant difference between the results for these four tests, as shown in Fig. 4a. Therefore, it was decided to exclude the specimen in the transverse direction when calculating the average yield stress. The material properties obtained are: average Young modulus, $E=210.49$ MPa, Poisson's ratio, $\nu=0.281$ and Yield stress, $\sigma_{yp}=230.6$ MPa. This averaged

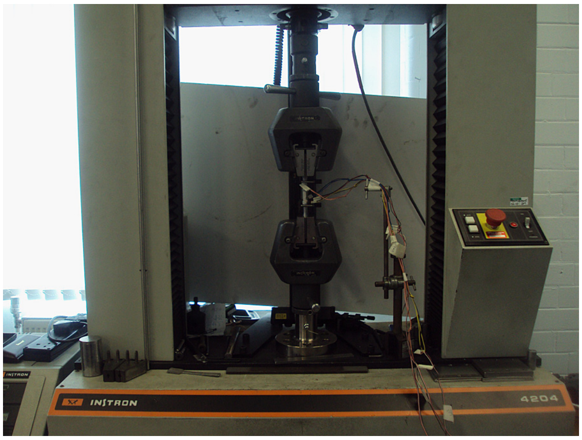

Fig. 2. Photograph of the uni-axial test arrangement for coupon T_1.

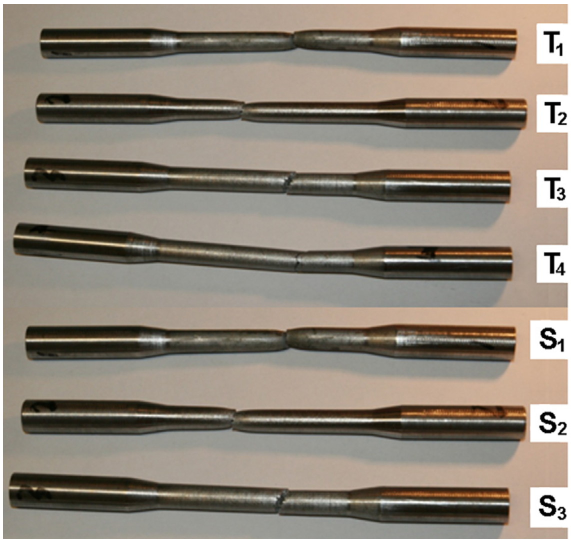

Fig. 3. Tensile test coupons after being tested.

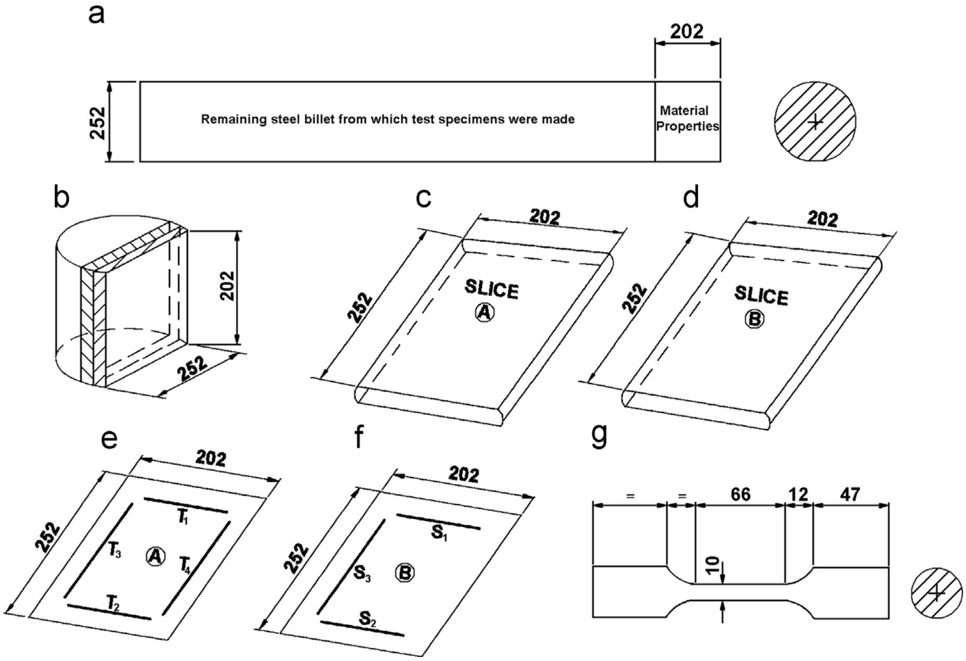

Fig. 1. Cutting pattern for material data specimens. Also, dimensions of round tensile test specimens and the orientation of their cutting. All dimensions are given in mm.