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Experimental Work on Tin Cans to Study Behavior of Thin Shell Cylindrical Tanks Under Axial Compression

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***Abstract*— In this paper cold drink cans are taken for the experimentation to get idea of buckling occurred under axial compression. The experimentation is carried out in three phases. In the first phase, two empty cans are observed to see the buckling pattern and to calculate the buckling stress. In second phase, buckling pattern is observed after the total collapse of tin cans. The load is applied by the foot pressure. While in the third phase, the cans are incorporated with horizontal and vertical imperfections representing weld failure at the joints. In the first and third phases the load is applied by the universal compression testing machine. The purpose of the study to have primary idea of behavior of buckling in different conditions as mentioned above. This study may help in exploring other aspects of experimental or analytical work.**

Keywords— Thin shell; liquid tanks; shell buckling

I. Introduction

Steel tanks for the storage of oil or other liquid are having very small average thickness compared to height and diameter of the tanks. These tanks are thin shell structures. Due to the circular geometry, hoop stresses can be balanced at the lower thickness. However, the tanks observed buckling in earthquakes due to increase of axial stress.

The soft drink cans are also made of thin shells comprises full capacity drinks and also vulnerable of buckling. Therefore, it is decided to carry out experimental tests on such tin cans to study the primary behavior and the characteristics of damages.

So far there are two popular codes in practice. One is API 650[1] and the other is NZSEE[2]. API 650 is developed by the American petroleum Institute while NZSEE is developed by the New Zealand group of researchers. NZSEE has provided some provisions and checks against buckling in designs.

Researchers like Rinne[3] and Manos[4] have attempted to estimate realistic value of impulsive acceleration in terms of coefficient to get the difference between design acceleration and the one derived from the their formulas. For particular aspect ratios the formulas observed sound in perfect prediction of buckling.

II. Experimental Test Setup for Phase 2

First phase of experimental test was carried out with Two tonne compression testing machine. Two tin cans were used to observed critical load and buckling characteristics. The details are as follows in the table 1.

TABLE 1. TIN CANS PROPERTIES AND BUCKLING DETAILS

Sr. No.	Samples	Dimension (cm)	Thickness (mm)	Buckling load (Ton)
1	Tin can 1	5 x 10	0.102	0.125
2	Tin can 1	5 x 10	0.102	0.125

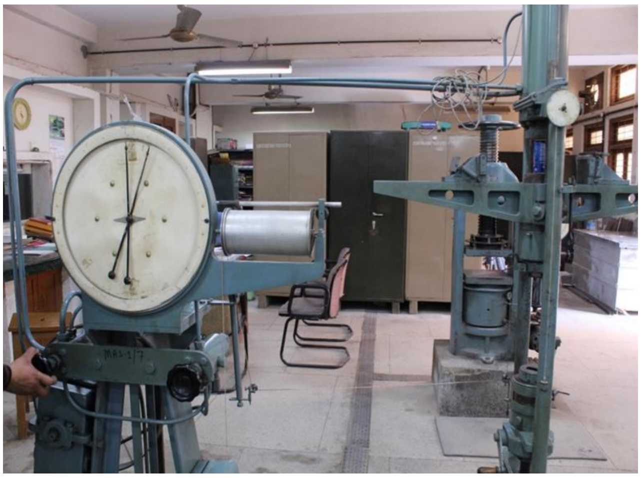

Fig. 1. Compression testing machine (2 Ton)

Observations: gradual axial load applied until failure, is observed. The first specimen is buckled with around 0.1-ton load with two diamond shaped buckling occurred at 3 cm from top (Fig. 1).

While the second specimen (Fig. 2) is observed buckled under 0.125-ton load, in which diamond shaped buckling was observed at 5 cm (i.e. mid portion) from the top.

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Fig. 2 (Test specimen I), (a) & (b) D.S. buckling observed around 3 cm from top

Fig. 3 (Test specimen II), D.S. buckling observed around 5 cm from top

A. Calculation of critical stress and comparison with Timoshenko's theoretical buckling formula

Timoshenko [5] have worked on developing analytical and empirical formulations along with the experimental work on thin shells. Timoshenko's Critical stress formula is

$$\sigma_{cr} = \frac{Eh}{a\sqrt{3(1-\upsilon^2)}}$$

Where, E- Young modulus of shell material, h- thickness of shell, a- radius of the tank, υ- poisson's ratio of the material

TABLE 2. COMPARISON OF ACTUAL CRITICAL STRESS AND THEORETICAL CRITICAL STRESS

Sr. No.	Specimen	σ_{cr} Actual (MPa)	σ_{cr} Theoretical (MPa)	σ_{cr} Actual/ σ_{cr} Theoretical (%)
1	Tin specimen 1	47.62	383.87	12.4
2	Tin specimen 2	59.52	383.87	15.5

It is very clear from the table 2 that actual critical stress is very less compared to the theoretical stress.

III. STUDY OF BUCKLING BY APPLYING THE FOOT LOAD

Commonly without any mean of experimental setup axial stress can be applied by the foot pressure also. However, it is not precise way to know the critical load but buckling characteristics can be known. A tin can was tested under the foot load. Before applying the foot load, markings are placed (as shown in fig.4) at the top and bottom so as both will be in single plane.

Fig. 4. Test specimen with Top and bottom marking

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Fig. 5 (a) and (b). series of small Diamond shaped buckling formed along with twisting and axial bending due to foot loading

As shown in the above figure 5, eccentricity has been observed during applying the foot load. In addition to it, slight twisting is also occurred as shown in the figure as both the markings are not in the same plane. There are series of small diamond shaped buckling has been observed. It is may be due to small hole at the top which shifts the shear center of the can outward. There should be provision of design eccentricity similar to the buildings described in the clause 7.8.2 of IS 1893:2016 (part 1)[6], Further analytical investigation can be made on shear stress due to the imperfection.

Schematic sketch showing the action occurs while applying the foot load is demonstrated in the fig. 6. Where eccentricity may be due to the positioning of applying the foot load but twisting may be possible due to the weld deficiency or imperfection, material strength and the aspect ratio of the shell.

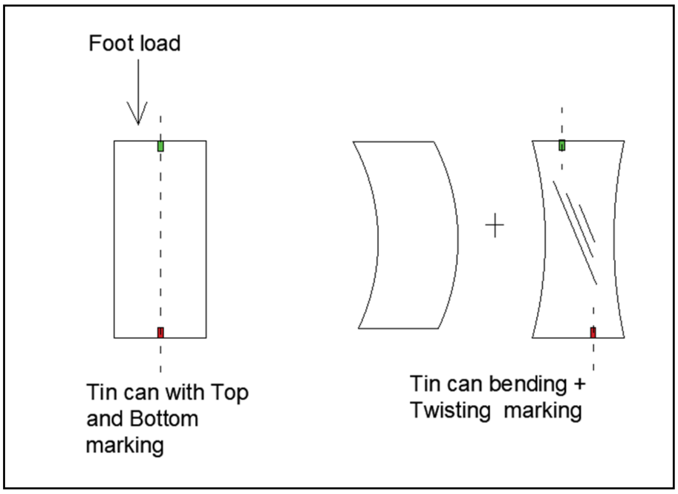

Fig.6. schematic sketch showing bending and twisting of tin can after foot loading

IV. STUDY OF IMPERFECTION IN SHELL

The third round of the study is carried out in the computerized compression testing machine. The experiment was aimed to observe the critical load and buckling characteristics on the shells having defects. However, the minimum load (around 1 Ton along with plate having approx. 10 kg weight) in the testing machine is quite more to study the buckling load. Therefore, only buckling characteristics are considered in the study.

Two shells with horizontal and vertical defects are considered for compression testing along with specimen with no defects for the study mainly to see if the twisting occurred on the cans. However, there is no any signal could be captured about the twisting as tins primarily failed in compression. The diamond shaped buckling was observed near the cuts (Fig. 7).

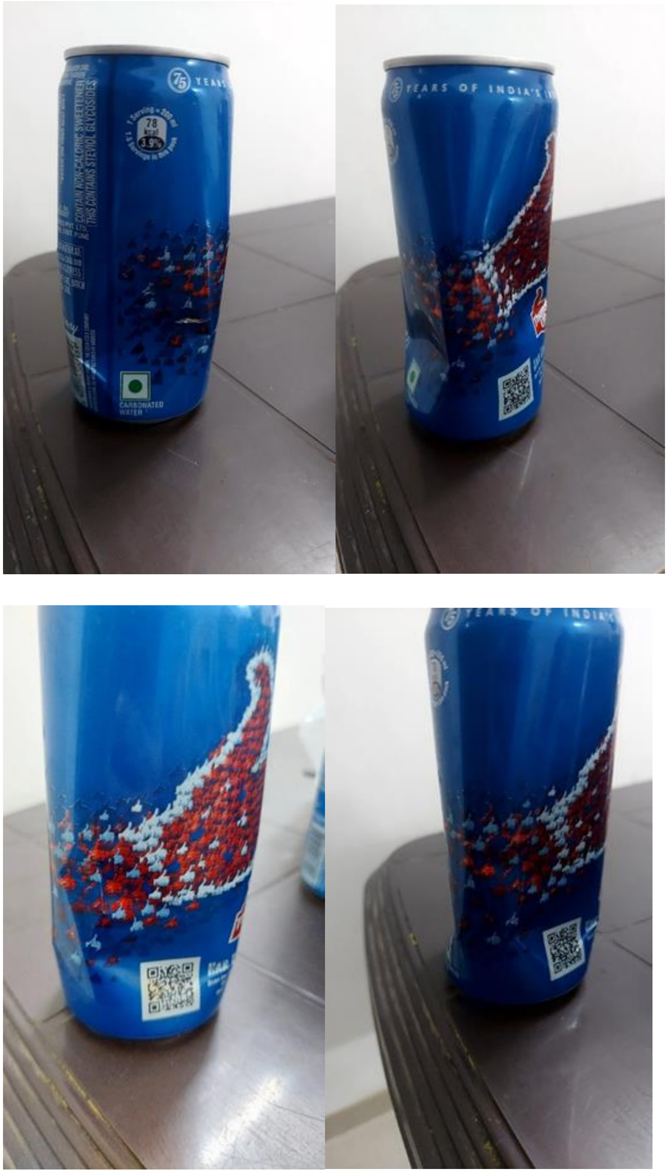

Fig. 7. Buckling of test specimen with horizontal and vertical defects

One specimen with full of liquid having some free board provisions is also considered for the testing (Fig. 8). In this case, buckling is observed at upper portion (nearly at the free board region) unlike the other cans as shown in the below. The buckling observed with relatively increased load in comparison with the load given to the other specimens. This clearly indicates that hoop stress due to hydrostatic load enhances the buckling stiffness considerably.

Fig. 8. Buckling of test specimen with full of liquid

V. CONCLUSIONS AND DISCUSSIONS

Some notable and important observations are made:
(1) The critical stress observed are quite less compared to theoretical critical stress.
(2) In all the test specimens, Diamond shaped buckling is observed. It means the diamond shaped buckling is first common damage occurred at the lower most critical stress value.
(3) During the foot pressure some amount of twisting observed. Twisting can create shear stress. Further analytical study can be made accordingly.
(4) It is interestingly observed that the can full of liquid had buckling at the upper portion where there is freeboard. It shows hoop stresses due to hydrostatic pressure increases stiffness against buckling.
(5) Buckling observed at the portion of the cans where horizontal and vertical cuts are provided. This buckling may lead to progressive buckling surrounding to that portion. In addition of it, as stress concentration focused at the cuts, the critical stress limits are also increased.
(6) Detailed experimentation can be made on steel shells with small specimens of different aspect ratios.
(7) Most of tin cans are observed with the Diamond shaped buckling at the mid or just below the mid-level of the cans.
(8) It can be believed that buckling is at the local level which occurs at very low value of axial stress. Therefore, it may possible that the buckling may occur at low seismic impulsive acceleration too.
(9) It is common observation that the structures with thin shell like oil tanks need to strengthen or stiffened in order to make it earthquake resistant.

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