CHAPTER 7

SUMMARY AND CONCLUSION

A brief account of the salient features of the research work undertaken in this project is summarized in this chapter. The conclusions drawn from the results of the investigation are briefly presented along with suggestions for future extension of research work in this area.

7.1 SHAPE GENERATION

The research work reported in this thesis was undertaken to explore the possibility of choosing a surface of revolution for a liquid container in order to integrate the side wall and base slab and suspend it from a ring beam to obtain a tension tank. If a shape with only positive curvature were chosen, the membrane stress distribution due to liquid load would vary from tension at the bottom to compression at the top of the tank. This compressive stress is eliminated by choosing a negative curvature for the upper region of the tank. For optimum utilisation of material, membrane stresses were taken to be equal to the permissible tensile stress at all points in the tank wall. Freedom of radial displacement should be possible at the support if the assumed membrane stress is to prevail everywhere.

The equilibrium equation for an element of the tank wall membrane was transformed into a differential equation and further modified incorporating a nondimensional shape constant C. The nondimensional tank shape of height unity having a constant wall thickness and defined by its volume v was obtained for any assumed value of C by a numerical approach which involved an iterative procedure. Every value
of C gives a corresponding tank shape and each one of these shapes is a stress optimized shape. Economy of tank material was chosen as the criterion to suggest a range of shape for the designer from among the several possible shapes. The practical range for the C value was found to be between 2 and 8. A value of \( v \) equal to unity is recommended for the volume of tank material to be minimum. A variety of other shapes is also given for the designer to choose from. (Figure 2.8).

The possibility of partly supporting and partly suspending the tank was also investigated as such tanks may find applications in reservoirs at ground level or those mounted on mounds. The bottom support radius of the nondimensional tank shape was varied from 0.1 to 0.7. For each support radius, several shapes are possible and here again material economy was chosen as the criterion to suggest an economical shape for each bottom radius of nondimensional tank shape. Economical shape for each value of \( \beta_0 \) is shown plotted in Figure 2.11. A value of \( \beta_0 \) ranging between 0.2 and 0.5 is recommended so as to have vertical supporting columns for the ring beam that do not foul with the tank.

In order to design a tension tank for a given volume \( V \), a nondimensional tank shape defined by \( v \) is chosen and the height of tank is obtained from the expression \( V = vH^2 \). For the given allowable stress \( \sigma \) in the material, the thickness is obtained from the expression \( t = \frac{wH^2}{c \sigma} \). The shape is obtained by using the Table 2.1 or 2.3 depending upon whether the tank is fully or partly suspended. Since the tank shape has been expressed in terms of a nondimensional parameter, they can be used for any material with their corresponding material properties substituted. Stainless Steel with its large permissible stresses is suitable for large capacity tanks while plastics is a desirable alternative for medium
and small capacities. Stainless steel or plastics can be considered as a structural material where corrosion is a problem.

7.2 EXPERIMENTATION

Since plastics is fast replacing a category of conventional tanks and is a desirable alternative material for surface structures, plastics has been chosen as the structural material in this research. It was proposed to study the creep behaviour of plastic suspended tank using the economic shape obtained when $v = 1.0$.

7.2.1 Fabrication of test tank

The facilities available for fabricating the new shape suggested in this research were limited. Therefore, it was proposed to fabricate the test tank in the laboratory by developing a suitable cutting pattern and using cyano-acrylate as adhesive. The fabrication method chosen was possible because flexible plastics were used. PVC lamina with a thickness of 0.45 mm had the advantage of flexibility and maximum strength and hence this was chosen. In order to arrive at a suitable stress value $\sigma$, the failure load, load corresponding to a kink in the load-extension curve, creep and cyclic loading were considered as the criteria. While the failure stress was as high as 210 kg/cm$^2$, even at a stress level of 36 kg/cm$^2$, sharp increase in deformation due to creep and cyclic loading was noticed (Figures 3.8 and 3.10) and this value was taken as the critical stress and adopted for the present research. However, a factor of safety of 2 to 3 may be applied on this critical stress to arrive at a safe design stress for the service tanks.
A piece of rod in the case of steel or a cube/cylinder in the case of cement concrete is usually chosen for determining the elastic properties. Since a thin plastic sheet was used in this research, a strip of plastics was chosen to determine the values of $E$ and $\mu$ with respect to time. The ASTM [12] and BS [13] codes were consulted regarding the choice of strip dimensions, rate of cross head movement, stress level etc.

For the thickness of PVC sheet chosen (0.45 mm) the value of maximum permissible membrane tension works out to 162 kg/m. Choosing $H = 0.8$ m, $T$ worked out to 155 kg/m and the volume of tank 510 litres. The point of contraflexure was at 0.52 m. The shape thus obtained was fabricated by a suitable cutting pattern evolved (Figure 3.11).

### 7.2.2 Testing

A rigid cubical frame of 2 m side was made using angles and channels. A ring beam was suspended from the mild steel channels which transfer the load to the cubical frame (Figure 4.1). A convenient pumping arrangement was made to fill up the tank or to empty it. Since the plastics was thin strain gauges could not be used. Pasting the strains gauges would stiffen the flexible material and the strain measured may not represent the actual strain. Therefore it was proposed to measure the displacements only. Since displacements are large and they have to be measured on a flexible and curved surface, conventional displacement measurement devices like dial gauges were not found to be suitable. Instead, a disk displacement meter available in the laboratory was found to be convenient for this research, (Figure 4.6) in which a linear displacement is converted into an angular rotation. Any large displacement can be
measured by this device. It was proposed to measure the displacements at heights of 0.1 m, 0.3 m, and 0.52 m and 0.8 m from the bottom of the test tank. They were also measured on diametrically opposite points.

The main parameter that was varied in the experimental study was the type of loading. The simplest of loading conditions is the case of Instant loading which consisted of supporting the test tank, filling it with water, releasing the support as quickly and gradually as possible and studying creep deformation for 24 hours. The gradual loading was considered next which was done by filling up the tank gradually till the tank became full. The filling time was 20 minutes. The creep study was made from the instant the filling operation was started till 24 hours. It is common knowledge that in practical situations, the tank will not be full always and it will be subjected to increase and decrease of water levels during the day. Therefore, the last method chosen for the study was cyclic loading. During the cyclic loading the depth of water was varied from 50 cm to 70 cm. For each depth of water, the creep study was made for 1 1⁄2 hours. Each cycle consisted of creep study at 50 cm, 60 cm, 70 cm, 60 cm and 50 cm water depths and it took 7 1⁄2 hours to complete the first cycle. The second and third cycles took 6 hours each. The total time taken for all the three cycles was 19 1⁄2 hours.

7.3 ANALYSIS

The object of analysing the tank was to compute the membrane stresses and displacements for the given geometry, loading and support condition. Structural analysis programme SAP IV [14] with shell elements was found to be suitable and convenient for analysing the suspended tank. Since the tank
material was flexible, a hinged condition was assumed at the support. The tank was discretized into trapezoidal elements except at the bottom where triangular elements were chosen. Liquid pressure was assumed to act at the mid-height of each element. The shape and loading was axi-symmetric. Since the self weight of the tank was negligible (3 Kg.), it was not considered in the analysis.

The values of E and $\mu$ were required for the analysis of the test tank. In creep study, these material properties are defined in Section 5.2. Since, the observations during testing revealed large displacements, a method to take account of creep and large displacements was adopted and the same is briefly given below:

The creep curve was idealized into three linear ranges. The displacements and membrane stresses were computed for each range. The geometry at the end of any chosen range was revised before proceeding to the next range of time in creep curve. The change of geometry was ignored when the creep curve became nearly flat.

As an alternative to this lengthy procedure, which is termed as the Incremental method, a simpler approach, termed as Direct method, was also tried. Influence of change in water level due to change in shape was studied for Instant and Gradual loading. It was found that the Direct method can be used for predicting the displacements while Incremental method is preferred for better prediction of stresses.

7.4 CONCLUSION

The aim of this thesis is to obtain the shape of a suspended liquid container which is both economical and
aesthetic. Flexible plastics has been chosen as the structural material.

1. The equation of equilibrium of an element of a membrane was considered. The membrane stresses were made equal to the permissible value, so that the material of the entire tank is under the same tension throughout. The thickness of membrane was assumed to be constant. Such a tank of uniform strength itself is an economical proposition. The membrane equation was transformed into a differential equation and the same was expressed in a nondimensional form introducing a shape constant $C$. Since closed form solution was not possible to solve the differential equation, simple computer programme was written to obtain a numerical solution. The value of $C$ was varied from 2 to 8 which appears to be the practical range. Within the chosen range, several shapes are possible, though all of them are stress optimized. Seeking a criterion for the choice of shape on the basis of material economy yielded a shape with $v = 1.00$.

2. When a tank has to be built at an elevated ground level, the possibility of apportioning the load to the ground support and to a suspension system can be considered. This study resulted in a partly suspended and partly supported tank. The support radius $\theta_0$ was varied from 0.10 to 0.70 and the material economy was again considered. While higher values of $\theta_0$ are preferred for material
economy, values of $\beta_0 = 0.20$ to 0.50 are recommended so as to have vertical supporting columns for the ring beam lying outside the tank's lateral dimensions.

3. A semi-graphical method for generating the shape of suspended tank is presented in this thesis. This method is preferred when a tank shape other than those included in this thesis is needed by the designer.

4. Since the differential equation governing the shape has been expressed incorporating a non-dimensional shape constant $C$, which is equal to $wh^2/T$, and $T = \sigma t$, the shapes suggested can be used for any material, provided material properties are defined.

5. While shape with $v = 0.25$ results in a narrow and deep shape, the shape with $v = 1.00$ gives a broad and shallow shape, for the same volume. The shape with $v = 0.25$ will require greater thickness than the other one. A range of shapes have been suggested to suit practical considerations and meet aesthetic requirements.

6. The study has proved that the limited tensile strength of plastics can be made use of for designing suspended tanks of small and medium capacities provided due allowance is made for creep effect.

7. The tests on the flexible plastics chosen exhibited the same material properties in the
length and width directions. This rendered their use for making the stress optimized test tank ideal.

8. A method to obtain a critical stress for plastics, similar to yield point in mild steel, is suggested. This method makes use of discontinuities observed in the load-extension, creep and cyclic loading cases explained in section 3.2. A safe stress may be obtained by applying a factor of safety of 2 to 3 on the critical stress. The test tank was designed for the critical stress itself, which is about one-sixth of the failure stress of 210 kg/cm², so as to study the behaviour till actual failure.

9. The creep study was made for Instant loading, Gradual loading and Cyclic loading. The Gradual loading resulted in greater displacements. The cyclic loading weakened the material and caused the failure of the tank by developing a rupture at the bottom resembling a star-like shape. Since the membrane stresses were maximum at the bottom and equal to each other, such a failure could conceivably be characteristic of a stress optimized fully suspended tank.

10. The method detailed in Section 5.2 to compute stresses and displacements which takes into account creep and large deformation is found to yield reasonable degree of accuracy. SAP IV
computer programme is useful in analysing the tension tank.

11. The theoretical predictions of vertical displacements were closer to the experimental values. The deviation of the horizontal displacements in the upper region of the tank is due to lower values of hoop stress occurring there compared to the higher and constant value of stress used for determining material properties.

12. For the tank tested under Instant loading the maximum vertical displacements did not occur at the bottom but at about one eighth of the height from the bottom. Its value was about $H/12$ where $H$ is height of the tank. The maximum horizontal displacement occurred at about one fourth of the height and its value was a third of the maximum vertical displacement. When the same tank was tested under Gradual loading, the maximum vertical and horizontal displacements occurred at the same locations as for Instant Loading but their values were 1.5 times those for Instant Loading.

13. The test tank shape was generated by assuming membrane stress conditions and the procedure assumes freedom of radial displacement at the support also. The test tank was actually suspended from the ring beam which leads to a hinged condition devoid of radial freedom. Therefore, the computed stresses were closer to
the constant stress assumed in the tank shape generation near the bottom region but substantially different nearer the top support. The hoop stress is zero at top and gradually reaches the meridional stress value near the mid height of the tank. The stresses calculated were lower than the stress assumed originally.

14. In all the three cases of loading tried in this work all theoretical predictions are based on material properties obtained via strip test. If such predictions are ventured for any other variety of plastics, either its properties at different load stages, time intervals and sequence of loading should be available through charts/tables or they be determined for companion specimens through strip test as was done in this investigation.

7.5 SUGGESTIONS FOR FUTURE WORK

1. The case of cyclic loading, which is the most realistic pattern of loading, needs deeper studies both for making reasonable predictions on displacements and stresses and for gauging the effect of repeated loading on the material. Fatigue tests involving repeated and cyclic loading are necessary to suggest design stresses for plastics nearer to the critical stress discussed in this thesis.

2. The possibility of using the tank shape generated in this thesis for rigid plastics,
sheet metal, stainless steel and reinforced concrete materials may be explored.

3. The versatility of using the suspended shapes for other practical applications like storage of grains, etc. can be studied. The adoptability of partly suspended and partly supported shapes for water and sewage treatment works can be investigated.

4. Inlet and outlet pipe connections to the tank under consideration with suitable covering at top and supporting system all need further careful study.