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Failure Analysis of a GRP Tank

Design and Structural Analysis

Case Study

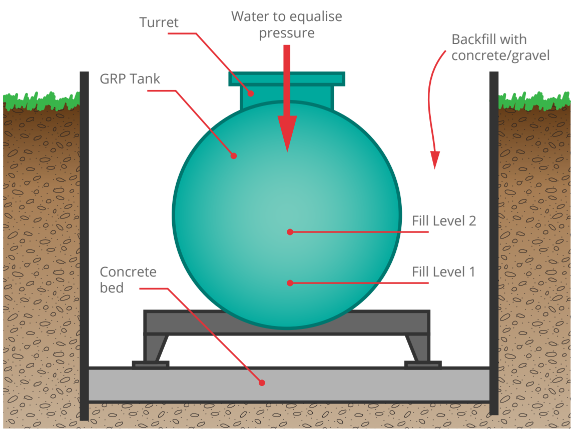
Background

Glass-reinforced plastic (GRP) tanks/vessels are used to store liquids underground. Catastrophic failure of the tank can lead to serious consequences, even if the contents of the tank are not hazardous. Therefore, during the installation phase, a tank must be handled very carefully; it is important that due consideration is given to the protection of the tank, and to the local environmental and site conditions.

Coventive Composites was approached by a client to analyse evidence relating to a GRP tank that had ruptured during the process of installing the tank underground. Calculations were made to characterise samples of the material, and structural analysis - using the finite-element method - was carried out to establish whether the construction and fabrication of the tank were of the required standard (BS 4994/BS EN 13121).

Installation of such a tank involves excavating earth to sufficient depth to provide a chamber in which the tank will reside. The perimeter of this chamber is then shuttered to form a mould, into which concrete is poured, to provide a berth for the tank.

When the concrete has set, the tank is lowered horizontally into the chamber. The tank's legs are anchored to the berth, and then the chamber is back-filled, in stages, with more concrete. While the back-filling



Schematic of tank in excavated chamber prior to backfilling

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is taking place, water is poured into the tank, approximately 100 mm above the level of the concrete, to help equalise the internal and external pressure on the tank.

During the second or third pour of concrete, the GRP tank ruptured at the circumference of a strengthening band (a GRP profile moulded into the tank wall).

Coventive analysed the pictures and specimens, and carried out finite-element analysis (FEA) to determine whether the rupture had occurred as a result of mishandling the tank during the installation, or as a result of substandard workmanship in the design or fabrication of the tank. The tank was approximately 5.50 m in length, with a diameter of approximately 2.50 m.

Physical Analysis

The client supplied photographs and drawings of the tank and the installation, along with physical specimens of some of the GRP recovered from damaged, and from undamaged, areas of the tank. Details of the construction of the tank (i.e. the method of fabrication and the thickness of the GRP) were evident from the specimens supplied.

Evidently, the tank was constructed by the 'spray-up' method: introducing glass fibres into a stream of resin, which is sprayed over a mould. It can be seen from the surface finish on the inside of the tank that a male mould was used.

From physical-characterisation tests it was determined that the thickness of the GRP ranged from approximately 2.00 mm to 3.50 mm; in regions close to the rupture, the GRP thickness measured as little as 2.01 mm. Some specimens exhibited significant delamination between sprayed-up layers, and the thin areas around the rupture appeared to be very dry (i.e. there is too little resin to bond, and allow stress to be transferred, to the fibres). Composite-density measurements also showed that voids accounted for a significant part of the material's volume.

It is not unusual for the region around a rupture of this nature to appear to be resin-poor. However, when volume and density calculations were carried out on a small piece of GRP cut from the samples, it could be seen from the sectioned specimens that other areas of the GRP showed delamination between the sprayed-up layers.

The density of the GRP was found to be ~1350 kg/m3, which suggests a fibre volume fraction of only 10%. A similar calculation carried out on a disc cut from the turret yielded a composite density of 1410 kg/m3, consistent with a fibre volume fraction of around 16%. A typical value for the volume fraction of fibres in a sprayed-up GRP composite is 25%. A result of 10% in a composite that looks so dry suggests there is a significant quantity of air (debonding and voids) within the composite material. It should be noted that there was also evidence of delamination in the disc cut from the turret.

Finite Element Analysis

Different load cases (representing the conditions experienced by the tank during installation) were created for two laminate thicknesses at two depths of concrete. The tank ruptured during the second or third pour of concrete; the client estimated that the depth of concrete at this stage was between 400 mm and 900 mm. Load cases were applied using the 'effective pressure' of the concrete at pour-depths of 400 mm and 900 mm. For the FEA simulation, the wall of the tank cylinder is taken to be 2 mm at its thinnest and 3.5 mm at its thickest.

The FE model was fixed (no translation or rotation permitted) at the legs; the GRP was assumed to be isotropic, and any rupture was assumed to begin at the onset of material failure.

It is evident from the physical samples taken from the ruptured tank that the thickness was very close to 2 mm in the regions of interest. Using the approach recommended in BS 4994*, the strength of the manufactured GRP was calculated to be approximately 51 MPa - i.e. should the tank experience a stress greater than 51 MPa, it could fail.

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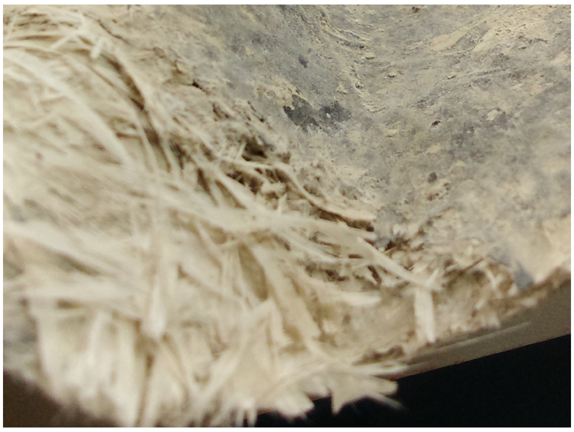
The simulations showed that the lowest value of stress the tank would have to withstand in these regions was nearer to 91 MPa, and that the highest was over 340 MPa - both far beyond the estimated strength of the material. To withstand such conditions, the tank would have to have been 7 mm thick. Simulations using strength values for a typical 25% fibre-volume fraction showed that a 4 mm thickness of GRP would have met such conditions.

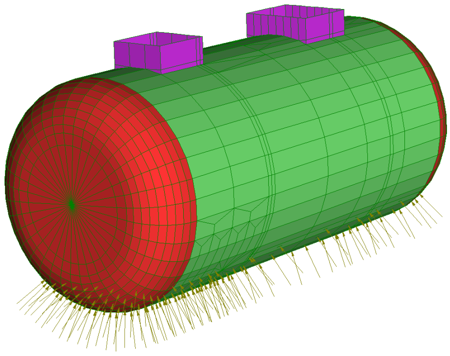
Given the information supplied, i.e. the photographs, the drawings, and the physical samples, Coventive concluded that the GRP was of poor quality, and, therefore, that the tank was below the acceptable standard of fabrication and inadequate for the design requirements.

The physical evidence was invaluable to this case study, as it allowed us to input real numbers - the wall thickness of the tank cylinder - to the simulation, giving us confidence in the FEA results.

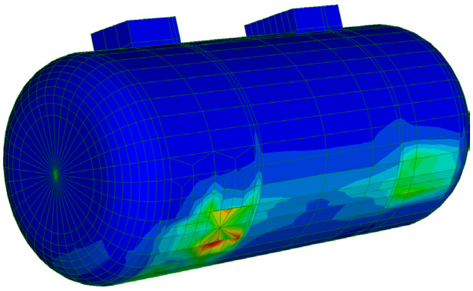
**In fact, the data for chopped-strand mat (CSM) described in BS 4994 (1987) do not represent an exact analogue of the spray-up method, but give higher values than would be expected to be achieved by sprayed-up GRP. However, it is sufficiently relevant to provide 'benchmark' values for the strength of a typical GRP composite made from CSM.*



Visual inspection of sample showing debonding and voids



Model showing tank geometry and applied load



Results showing peak stress of 340 MPa

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