

# Evaluation of Steel Tanks Due to Hurricanes

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## Abstract

Tanks are vital infrastructure in the Caribbean islands. They allow the storage of different elements, mainly water, oil, and petrochemical products. The instability of liquid storage tanks under considerable wind loads is of interest in many parts of the world. Specially in areas which have seasonal winds and hurricanes. Evaluation of these structures is necessary to analyze critical loads that cause failure of tank shells. There are several previous works regarding similar studies, but they only include analyses of tanks without roof. In this work we are modeling a steel tank with a cone roof subjected to wind loads. The observation of damaged tanks provides a good idea of the mode shape. These shapes help us to find a critical load, which causes a similar mode shape. In order to obtain such shape, we applied different distributions of pressure on the roof and compare the results.

## 1. INTRODUCTION

The search for adequate modeling of loads due to natural hazards is of great importance for the prediction of the safety of structures. There are various ways in which this is done at present. On the experimental side one can perform a full scale test on a real structure or instrument it until an event occurs. The

use of small scale is another possibility. Computer modeling of the environmental action on the structure is now possible, specially thanks to Computational Fluid Dynamics advances. And there is the possibility of linking the failure of uninstrumented structures to the loads that led to the failure. This work explores the last possibility within the context of tanks exposed to hurricanes winds.

The failure of tanks employed to store water and oil in Puerto Rico and the U.S. Virgin Islands has been studied in recent years (Flores and Godoy, 1998). Buckling of above ground circular steel tanks with and without roof was observed in St. Croix in 1990 (hurricane Hugo), St. Thomas in 1995 (hurricane Marilyn), and in Puerto Rico in 1998 (hurricane Georges). For the tanks without a roof, or for those that lost the roof before the cylindrical part buckled, it was possible to reproduce the expected behavior using computer modeling. For example, a tank without a roof that failed in St. Thomas was modeled using standard pressure distributions around the circumference such as those plotted in Figure 1. For such a pressure, the computer model displays buckling for the wind speeds usually found during a hurricane.

However, a far more difficult job is faced in an attempt to model the failure of the cylindrical shell in a tank with a conical roof. The main questions regarding the pressure distributions in the roof are not answered within the current state of the art. In the following we employ computer modeling to identify adequate pressure distributions which are compatible with the structural evidence.

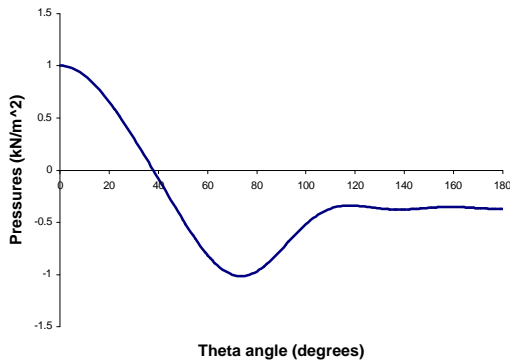


Figure 1. Winds pressure variation.

## 2. THE COMPUTER MODEL

The theme structure in this study is a tank with variable thickness, as shown in figure 2. The structure is a thin-walled shell and it failed by elastic buckling, i.e. a sudden change in the shape of the cylindrical part, figure 3. Buckling is a phenomenon by which a structure cannot withstand loads with its original shape and suffers a drastic change in the shape. The structure was modeled using finite elements method and the computer package ALGOR®.

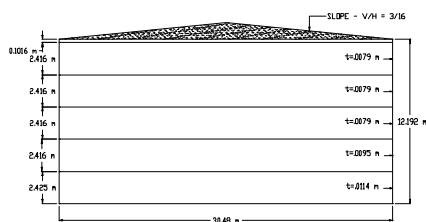


Figure 2. Dimensions of the steel tank.



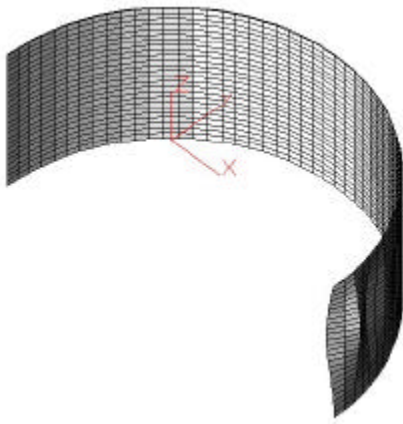
Figure 3. Steel cylindrical tank, which failed during hurricane Georges, 1998.

It was assumed that the pressure distribution around the circumference was as shown in figure 1. This pressure variation has positive values on the windward meridian, and negative pressure (suction) on the rest of the cylinder. Plate and shell elements will be employed to produce a discretization of the structure, and material properties should include elasto-plastic behavior, for this reason computer models of some types of tanks, using finite elements analysis are required.

## 3. PRESSURES ON THE ROOF

The main question posed in this case is the actual pressure distribution due to wind on the conical roof; thus, we have explored different scenarios and compared them with the structural evidence. First, the cylindrical tank clamped at the top was considered. This lead to a buckling mode consistent with what was observed in the structure, but for a load factor of  $\ddot{e}^c = 3.35 \text{ kN/m}^2$  (or wind speed of  $v = 66.9 \text{ m/s}$ ). For a simply supported condition on top, the values changed to  $\ddot{e}^c = 3.33 \text{ kN/m}^2$  and  $v = 66.7 \text{ m/s}$ . This model shows a buckling mode shape similar to the real mode illustrated in figure 3. For a free condition at top the load factor changed

to  $\ddot{e}^c = 1.3605 \text{ kN/m}^2$  or 42.6 m/s, but the mode shape from such computations was very different to figure 1.



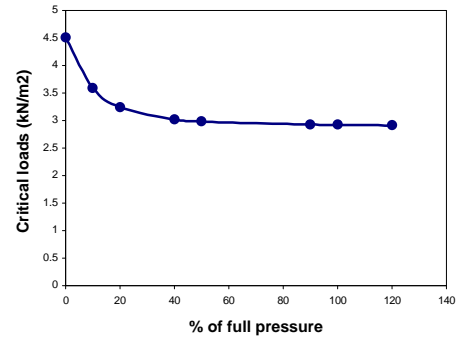
**Figure 3. Buckling mode shape of the tank with pinned condition on top.**

In order to include the roof effects into the model we assumed different patterns of wind pressures acting on the roof. First of all, we decided to include a downward constant pressure as percent of the full pressure shown in figure 1.

For this case we obtained the following results:

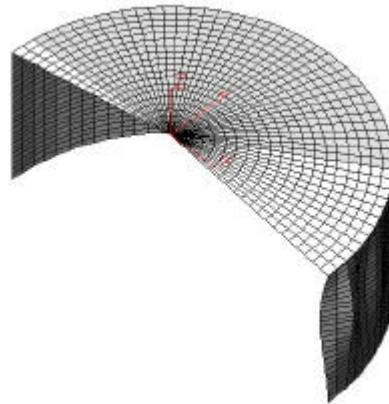
**Table 1: Critical loads due to increasing of constant pressures.**

% of full constant pressure	$\ddot{e}^c$
0	4.4992
10	3.5867
20	3.2414
40	3.0133
50	2.9762
90	2.9272
100	2.9207
120	2.9086



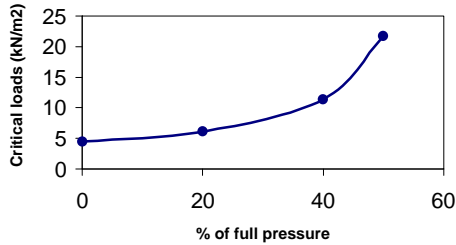
**Figure 4. Variations of critical load due to increasing a constant pressure load on the roof.**

The buckling mode of each of these cases was very similar to the real one, figure 5.



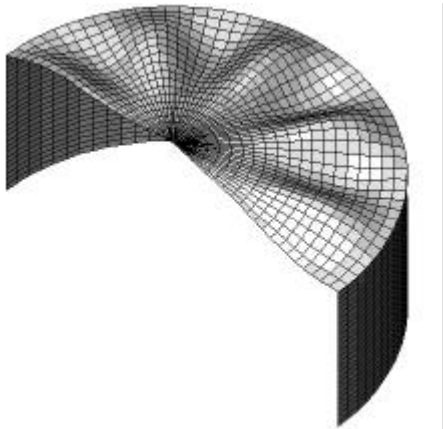
**Figure 5. Buckling mode shape of tank with a constant downward pressure acting on the roof.**

Another case of load that we applied to the model was a variable pressure load acting on the roof. This pressure load has the same orientation as the pressures acting on the walls, varying in a circumferential pattern. Also in this case, the magnitude of the pressures varies according to the direction of winds. The positive pressures produce a downward pressure at the roof, while negative magnitude of pressure produces an upward pressure (suction). The scope of this analysis was the same of the first case, varying the percent of the pressure load to study the variation of the critical load, figure 6.



**Figure 6. Variations of critical load due to increasing of variable pressure load.**

For the last case we decided to apply a fully upward pressure load to the roof. In this model only suction occurs on the roof as the result of the pushing pressures acting on the walls. The buckling mode for this case was very interesting. The roof suffered the buckling fail instead of the walls, and the mode show a totally different shape, figure 7.



**Figure 7. Buckling mode shape of tank with a constant upward pressure acting on the roof.**

#### 4. CONCLUSIONS

According to the numerical results and the buckling modes, the models with the constant pressure acting downward on the roof lead to buckling modes similar to the real case. The critical load values were the lowest, similar in magnitude than those expected in a case where a wind velocity reaches values of around 55 m/s or  $\dot{e}c$  between 2.5 and 3 kN/m<sup>2</sup>.

These values decrease as the percent of full pressure acting on the roof increase. For the same reasons, viewing the results in the case of modeling the tank with different boundary conditions instead of adding the roof, the best result is for the pinned model.

In the cases modeled with a variable pressures acting on the roof, the results of critical loads are very high. This values also changed of magnitude sign if we increase the pressure more than 50% of the full pressure. That means that this kind of pressure distribution is not recommendable to analyze this kind of problem.

For the model that had only upward pressures (suction) acting on the roof, the buckling load occurred on the roof instead of the walls. This is not our case of pressure distribution, because the mode of buckling occurred in a completely different area.

#### 5. REFERENCES

1. Myers, P.E., (1997), **Aboveground Storage Tank**, Mc Graw Hill Companies Inc.
2. Flores, F.G. and Godoy. L.A., (1991), "Instability of shells of revolution using ALREF: studies for wind loaded shells", in **Buckling of shells structures on land, in the sea and in the air**, Elsevier, London, pp. 213-222.
3. Flores, F.G. and Godoy. L.A., (1998), Buckling of short tanks due to hurricanes, in **Engineering Structures**, Vol. 20, Elsevier, London, pp. 752-759.