Plate 2.2 Relatively moderate wind caused collapse of tank during construction due to insufficient bracing.

Andrew caused widespread damage to residential and light commercial structures in Florida, even in areas that had experienced measurable wind speeds less than the minimum threshold required by local codes. This is notable because Florida building codes are some of the strictest in the U.S. concerning wind resistance. Additionally, Florida is one of the few states that also requires contractors to pass an examination to certify the fact that they are familiar with the building code. Despite all these paper qualifications, however, in examining the debris of buildings that were damaged, it was found that noncompliance with the code contributed greatly to the severity and extent of wind damage insurance claims.

The plains and prairie regions west of Kansas City are famous for wind, even to the point of having a "tall tale" written about it, the *Legend of Windwagon Smith*. According to the story, Windwagon Smith was a sailor turned pioneer who attached a ship's sail to a Conestoga wagon. Instead of oxen, he harnessed the wind to roam the Great Plains, navigating his wind-driven wagon like a sloop.

An old squatters' yarn about how windy it is in Western Kansas says that wind speed is measured by tying a log chain to a fence post. If the log chain is blowing straight out, it's just an average day. If the links snap off, its a windy day. In fact, even the state's name, "Kansas," is a Sioux word that means people of the south wind.

According to a publication from Sandia Laboratories (see references), Kansas ranks third in windy states for overall wind power, 176.6 watts per square meter. The other most windy states with respect to overall wind power are North Dakota (1), Nebraska (2), South Dakota (4), Oklahoma (5), and Iowa (6). Because of Kansas' windy reputation, it is hard to imagine any contractor based in Kansas, or any of the other windy Midwestern or seaboard states for that matter, who is not aware of the wind and its effects on structures, windows, roofs, or unbraced works in progress.

2.2 Some Basics about Wind

Air has two types of energy, potential and kinetic. The potential energy associated with air comes from its pressure, which at sea level is about 14.7 pounds per square inch or 1013.3 millibars. At sea level, the air is squashed down by all the weight of the air that lies above it, sort of like the guy at the bottom of a football pile-up. Like a compressed spring, compressed air stores energy that can be released later.

The kinetic energy associated with air comes from its motion. When air is still, it has no kinetic energy. When it is in motion, it has kinetic energy that is proportional to its mass and the square of its velocity. When the velocity of air is doubled, the kinetic energy is quadrupled. This is why an 80-mph wind packs *four times* the punch of a 40-mph wind.

The relationship between the potential and kinetic energies of air was first formalized by Daniel Bernoulli, in what is now called Bernoulli's equation. In essence, Bernoulli's equation states that because the total amount of energy remains the same, when air speeds up and increases its kinetic energy, it does so at the expense of its potential energy. Thus, when air moves, its pressure decreases. The faster it moves, the lower its pressure becomes. Likewise, when air slows down, its pressure increases. When it is dead still, its pressure is greatest.

The equation developed by Daniel Bernoulli that describes this "sloshing" of energy between kinetic and potential when air is flowing more or less horizontally is given in Equation (i), which follows.

$$\text{total energy} = \text{potential} + \text{kinetic}$$

$$[P_{atmos}/\rho] = [P/\rho] + v^2/2g_c \tag{i}$$

where P_{atmos} = local pressure of air when still, ρ = density of air, about 0.076 lbf/ft^3, P = pressure of air in motion, v = velocity of air in motion, and g_c = gravitational constant for units conversion, 32.17 ft/(lbf-sec^2).

It should be noted that Equation (i), assumes that gas compressibility effects are negligible, which considerably simplifies the mathematics. For wind speeds associated with storms near the surface of the earth and where

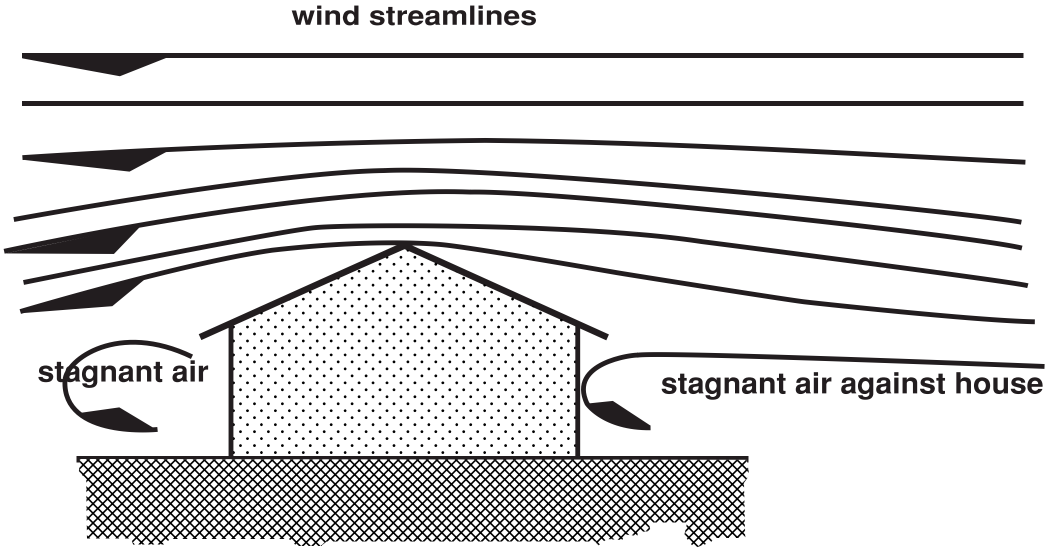

Figure 2.1 Side view of wind going over house.

air pressure changes are relatively small, the incompressibility assumption implicit in Equation (i) is reasonable and introduces no significant error.

Wading through the algebra and the English engineering units conversions, it is seen that a 30-mph wind has a kinetic energy of 30 lbf-ft. Since the total potential energy of still air at 14.7 lbf/in^2 is 27,852 lbf-ft, then the reduction in air pressure when air has a velocity of 30 mph is 0.0158 lbf/in^2 or 2.27 lbf/ft^2. Similarly at 60 mph, the reduction in air pressure is 0.0635 lbf/in^2 or 9.15 lbf/ft^2.

What these figures mean becomes more clear when a simplified situation is considered. Figure 2.1, shows the side view of a house with wind blowing over it. As the wind approaches the house, several things occur.

First, some of the wind impinges directly against the vertical side wall of the house and comes more or less to a stop. The change in momentum associated with air coming to a complete stop against a vertical wall results in a pressure being exerted on the wall. The basic flow momentum equation that describes this situation is given below.

$$P = k\rho(v^2) \tag{ii}$$

where P = average pressure on vertical wall, k = units conversion factor, ρ = mass density of air, about 0.0023 slugs/ft^3, and v = velocity of air in motion.

Working through the English engineering units, Equation (ii) reduces to the following.

$$P = (0.00233)v^2 \tag{iii}$$

where P = pressure in lbf/square feet, v = wind velocity in ft/sec.