Building Collapse Due to Roof Leakage

5

Ozymandias

I met a traveler from an antique land,
Who said: Two vast and trunkless legs of stone
Stand in the desert. Near them, on the sand,
Half sunk, a shattered visage lies, whose frown,
And wrinkled lip, and sneer of cold command,
Tell that its sculptor well those passions read,
Which yet survive, stamped on these lifeless things,
The hand that mocked them, and the heart that fed:
And on the pedestal these words appear:
"My name is Ozymandias, King of Kings:
Look on my works, ye Mighty and despair!"
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away.

— **Percy Bysshe Shelley,** *In memoria Leo A. Foster, 1792–1822*

5.1 Typical Commercial Buildings 1877–1917

In the period from post-Civil War Reconstruction to about World War I, many of the small and medium towns that now dot the Midwest were settled and built. In general, the sequence of town building in each case was similar. Homesteads were built first, which congregated around crossroads, river fords or ports, depots, mines, sawmills, or other natural points of commercial activity. This was followed by the construction of temporary tent and wood-frame commercial buildings. When business activity was sufficient, the temporary wood-frame buildings were replaced by more permanent masonry commercial buildings. Many of these masonry buildings still populate the original downtown areas.

In general, these permanent masonry commercial buildings followed a similar structural design. A typical front elevation is shown in Figure 5.1. Most were made of locally quarried stone or locally fired brick. It was com-

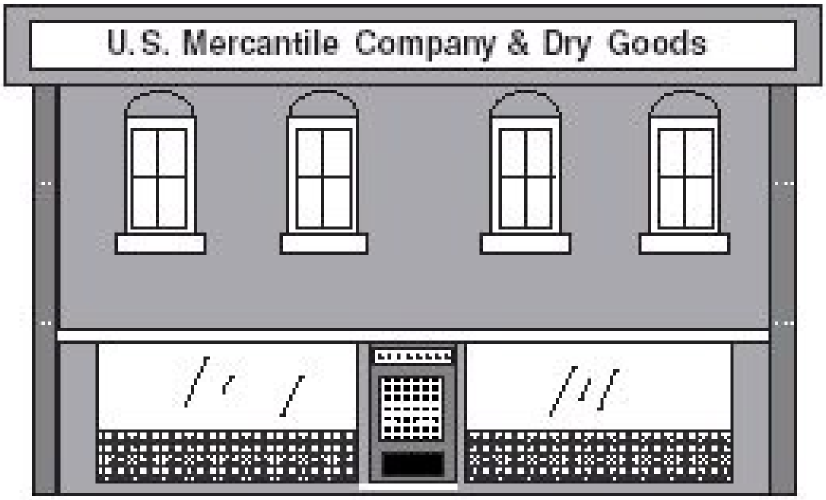

Figure 5.1 Typical two-story commercial building with load bearing, masonry side walls.

mon for the interior wall to be stone and then faced with brick on the exterior side. Sandstone and limestone were commonly used. The mortar for both the stonework and brickwork was generally quicklime from local kilns, and sand from local riverbeds or deposits. The front width of the building was usually 1/2 to 1/4 the length of the building. The long side walls carried most of the structural load.

The roof was simply sloped at a low angle. The high side of the roof was at the front and the low side at the back, as shown in Figure 5.2. Usually, the front of the building had a large facade parapet wall for advertising, as is shown in Figure 5.1. The sides also usually had parapet walls. However, the rear portion of the roof usually did not have a parapet wall. Thus, rainwater

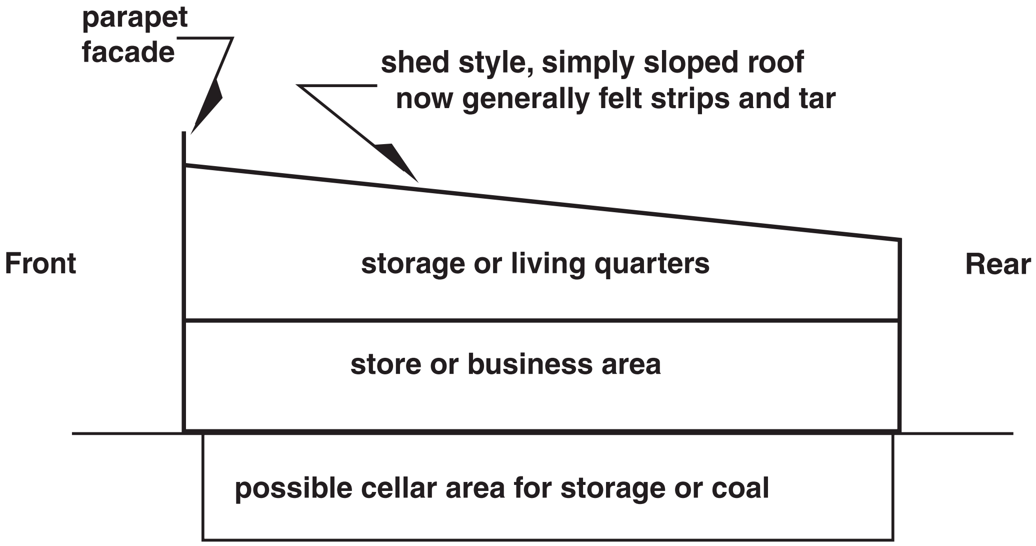

Figure 5.2 Cutaway view showing roof slope and floor usage.

drained from the front and sides of the building toward the rear. When the buildings were first built, there would often be rain barrels at the rear corners of the building to catch the runoff.

The original roof was usually a wooden board deck over simple wood beam roof joists. The deck would be covered with various layers of felt and bitumen, roofing rolls, or in some cases, overlapping galvanized metal sheeting. In recent years, many of these roofs have been converted to conventional tar and gravel built up roofs (BURs), or rubber membrane roofs.

The floor and roof decks were generally supported by simple wood joist beams. When it was necessary to splice joists together to span the distance across the side walls, the joists would be supported in the middle by a beam and post combination. Splices were often accomplished by overlapping the two pieces where they set over the support post, and nailing or bolting them together. In many cases, however, the joists were simply overlapped and set side-by-side on top of the post with no substantial fasteners connecting them. It was presumed that the decking or flooring nailed to their upper surface would hold them in place. Additionally, the joists were usually, but not always, side braced to ensure they would stay vertical.

The floor and roof joists were supported at the ends by the side walls. A bearing pocket would be created in the side wall, and the end of the wood joist was simply set into the bearing pocket. Often, the end of the joist was mortared into the bearing pocket so that it would be rigid and vertical.

Usually the bearing pocket only extended about halfway through the thickness of the wall. In some buildings, however, the bearing pocket would go all the way or nearly all the way through the side wall, such that the ends of the floor and roof joists could be seen from the outside. To keep the ends of the joists from weathering, the butts would be covered with mortar, tarred, or painted. Roof decking and floor decking were nailed directly on top of the joists. Figure 5.3 shows the basic structural support system as described.

5.2 Lime Mortar

Lime or quicklime for the mortar in these buildings was generally obtained by roasting calcium carbonate in kilns. The calcium carbonate may have come from local limestone deposits, chalk deposits, or even marble deposits. The fuel for the roasting process was usually wood and charcoal, although coal and peat were occasionally used when it was convenient.

The chemical process for converting calcium carbonate to quicklime is simple. The raw material is heated in a kiln to above 1000°F, usually 1400 to 2000°F. At this temperature, the calcium carbonate decomposes into calcium oxide and carbon dioxide. The liberated carbon dioxide may then sequen-

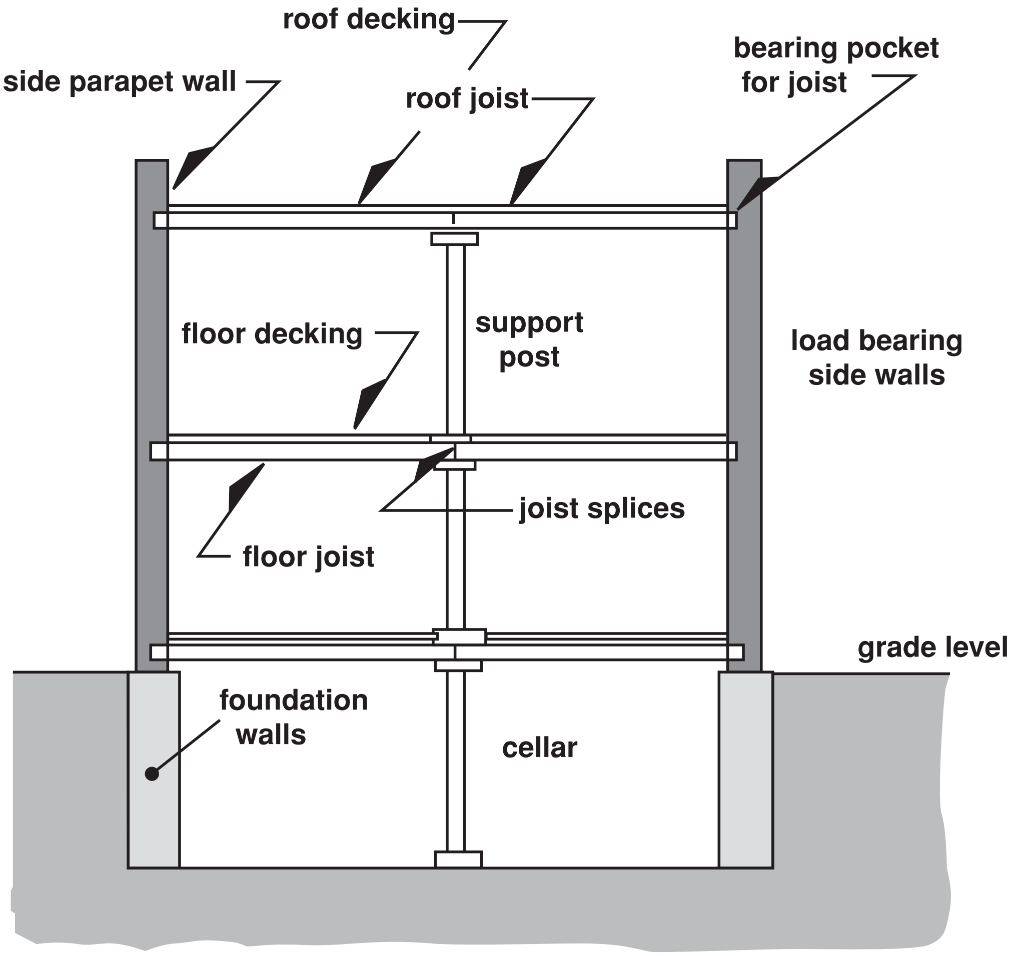

Figure 5.3 Basic structural support system.

tially react with residual moisture, i.e., steam, in the kiln's flue gas atmosphere to form carbonic acid. The carbonic acid precipitates out as a liquid when the flue gases cool below the dew point.

In the environmentally unsophisticated lime kilns built prior to World War I, flue gases were discharged directly into the air without much thought. Typically, a kiln flue stack was not very tall and could not "punch" the flue gases very high to disperse the precipitates. Thus, the carbonic acid vapor in the flue gases usually precipitated out within a short distance downwind of the kiln. Such precipitated carbonic acid often caused significant damage to nearby plant life, especially if the kiln were operated for several years in the same spot.

The basic chemical equation for the conversion process is given in Equation (i).

$$\overset{\text{calcium carbonate}}{CaCO_3} \underset{\text{heat}}{\rightarrow} \overset{\text{calx}}{CaO} + \overset{\text{carbon dioxide}}{CO_2} \tag{i}$$

The residue product of the process, calcium oxide, is whitish or grayish-white in color with a specific gravity of 3.4. Iron impurities in the raw material charge can cause the calcium oxide to have a yellowish or brownish tint. Other names for the calcium oxide residue from the reaction include calx, quicklime, burnt lime, or unslaked lime.

Calcium oxide readily reacts with water to form calcium hydroxide and in doing so, produces an ample amount of heat. This process is called slaking. When the slaked lime is noted to form steam, water must be added and the resulting quicklime paste must be thoroughly mixed to stop steam from forming.

$$\mathrm{CaO} + \mathrm{H_2O} \rightarrow \mathrm{Ca(OH)_2} + \text{heat} \tag{ii}$$

Calcium hydroxide, or slaked lime, is a white-colored material with a specific gravity of 2.34, which is a weight density of about 146 pounds per cubic foot. It loses water at 1076°F, and is slightly soluble in water. Most chemical handbooks report that the solubility of calcium hydroxide in cold water is 0.185 grams per 100 ml of water. It reacts readily with most acids, and absorbs carbon dioxide from the air.

The usual recipe for making quicklime mortar in the era being discussed consisted of two to three volumes of sand to one volume of lime paste. Lime paste was generally two parts by weight of water to one part quicklime. Sometimes the lime mortar would be strengthened by the addition of cement, especially Portland.

These mixing ratios and recipes, however, were simply common rules of thumb. Since there were no quality control standards or building codes, conditions and mixture compositions varied greatly. Incomplete decomposition of the limestone in the kiln, or contamination of the quicklime by combustion materials could greatly affect mortar strength. Further, most masons added water as they saw fit for “workability.”

The sand used in the mixture was usually not sieved for size consistency. Thus, the sand could be well-graded, gap graded, or uniformly graded and have significant amounts of silts and fines mixed in. Mortars containing sand of which 48% is able to pass through a #100 sieve, for example, have only about 1/10 the compressive strength of one in which only 5% passes through a #100 sieve.

Even when good practice was adhered to, lime mortar is inferior to Portland cement type mortar mixtures. A lime mortar with no cement additives, as described previously, will develop a tensile strength of at most 26 pounds per square inch after 84 days of curing . This is about 1/10 the tensile strength that a modern concrete mixture will develop after 28 days. Because of its slow