These deformed timbers can cause structural load and deflection problems due to second moments associated with eccentric loading. Second moments are those bending moments created when a beam or column is misshapen and the applied forces are no longer centered or symmetric. The eccentrically placed loads cause the beam or column to twist or flex. Trusses with significant second moments, for example, might no longer form a plane but instead flex into a saddle-shaped curve.

Furthermore, wood that has absorbed excess moisture and become softened may allow nails and bolts that are carrying load to loosen or pull out. The loss of fastener integrity can also cause a significant share of structural headaches.

Both of these effects, wood rot and distortion, are readily observable by inspection, and would be expected to occur where the water directly impinges on the wood over a period of time. These areas will also likely be stained by minerals and dissolved materials carried by the water. These minerals and dissolved materials are picked up by the water as it percolates through the building, and are then deposited on the wood during the various wetting and drying cycles.

A less familiar way that water leakage damages roof and floor joists in these older buildings is by chemical attack. Water that makes its way to the bearing pockets reacts with the lime mortar surrounding the wood. The calcium hydroxide in the mortar is soluble in water, and forms an aqueous, caustic solution. The pH of the solution at room temperature may be as high as 12.4, which is more than sufficient to attack the wood embedded in the bearing pocket.

When this occurs, the affected surfaces become discolored, lose mass, and appear dimensionally reduced. Material around the bearing surface, usually on the bottom side of the joist, loses strength and flattens out due to compressive failure. Because of this, the joist will often drop down in the bearing box or become loose within it. This may allow the beam to twist or tip.

With respect to the load-bearing walls, structural weakening by leakage from the roof is accomplished in several ways. The primary way is the leaching of calcium hydroxide, the primary binding ingredient of the mortar, from the mortar by water that percolates down the wall from the roof.

As noted before, about 0.185 grams of calcium hydroxide will dissolve in 100 ml. of water at room temperature. When a roof leak has been present for many years, the water running down the interior side of the wall steadily dissolves the slaked lime from within the mortar. Since the interior side of the wall is not seen by anyone, the mortar is usually rough, unfinished, and unpainted. This makes it easy for the water to wet the mortar, as compared with the exterior side. On the exterior of the building, the mortar is finished and has minimal surface area for water to contact. The exterior wall surface may even be painted, which further protects the mortar from leaching damage.

With the calcium hydroxide dissolved from the mortar, the mortar becomes a very weak, porous material. If leaching damage is sufficiently severe, the wall essentially becomes a pile of loose bricks or stones held together by a slightly sticky sand with a high voids ratio.

It is easy to verify in the field if a wall has been damaged in this way. First, the water stains on the wall will be readily apparent. Secondly, mortar that has been damaged in this way can be easily removed from between the stones or bricks by a penknife, metal key, or even a person's fingers. The mortar will flake and crumble easily, like porous sandstone. In severe cases, it is even possible for a person to remove whole stones or bricks from the wall by digging them out with his fingernails.

5.6 Structural Considerations

The deleterious effect that calcium hydroxide leaching from the mortar has on the structural stability of the wall can be assessed mathematically. This is done by considering the equation that describes the elastic stability of a thin plate under compression, and presuming that it is analogous to the masonry wall under consideration. According to Roark (see references at end of chapter), the critical stress at which buckling occurs when a thin plate is uniformly loaded in compression along two parallel edges is as shown in Equation (iii).

$$\sigma_{crit} = K[E/(1 - \nu^2)][t/b]^2 \qquad \text{(iii)}$$

where t = thickness of wall, b = length of wall, a = height of wall, E = Young's modulus, ν = Poisson's ratio, K = factor to account for ratio of height to length and end conditions of plate, and σ_{crit} = compressive stress at which instability occurs.

The thin plate modeled by Equation (iii) is presumed to be homogenous and isotropic throughout, while the load-bearing walls under consideration are composed of discrete units of brick, stone, and mortar. Despite these differences, however, Equation (iii) suffices to show the overarching principle that applies in this case, especially if the weakest material values in the wall are presumed to apply in the formula.

It is apparent by inspection of Equation (iii) that significant changes in Young's modulus, "E," greatly affect the critical stress at which buckling in the thin plate occurs. If we compare the condition of the wall before leaching occurs, to that after leaching occurs and presume that the dimensions and end clamping conditions of the wall have not changed, then the following is true.

Table 5.1 Young's Moduli for Brick, Stone, and Soil

Material	Typical "E" Value
Limestone	7 to 8 × 10^6 lb/in^2
Sandstone	~3 × 10^6 lb/in^2
Brick	3 to 4 × 10^6 lb/in^2
Concrete	~2 × 10^6 lb/in^2
Soil (unconfined)	0 to 10 × 10^3 lb/in^2

$$\sigma_{crit/}\sigma_{crit}' = [E/(1 - \nu^2)]/[E'/(1 - \nu'^2)] \qquad \text{(iv)}$$

where the prime mark (′) denotes the condition of the mortar after leaching has occurred.

Since Poisson's ratio for most masonry materials is approximately 0.25, Equation (iv) simply reduces to the following ratio.

$$\sigma_{crit/}\sigma_{crit}' = E/E' \qquad \text{(v)}$$

Table 5.1 shows some representative values of Young's modulus for brick, stone, and soil.

In relating the values in Table 5.1 to Equation (v), it is obvious that if the mortar loses significant stiffness by leaching and essentially becomes equivalent to something between a soil and porous sandstone, the wall will be structurally weakened, perhaps becoming sufficiently unstable for buckling to initiate.

This structural problem with the walls is further exacerbated if there has been chemical attack of the wooden joists in the bearing pockets. Since most of these walls were constructed without formal tie-ins, the wooden roof and floor joists act as tie-ins to the rest of the structure and help stabilize the walls. If the wall is considered analogous to a Euler column with respect to buckling, tie-ins divide the wall into smaller columnar lengths. This strengthens the wall against buckling. The joist tie-ins also improve the end conditions of the column sections, which further strengthens the wall against buckling.

Euler's formula for column buckling is given below in Equation (vi). The reader will likely note the basic similarity of Equation (vi) to Equation (iii) taken from Roark's text, *Formulas for Stress and Strain.*

$$\sigma_{crit} = \pi^2 E\, I\, C/L^2 \quad \text{Euler's formula for column buckling} \qquad \text{(vi)}$$

where σ_{crit} = Euler buckling stress, stress at which buckling could occur, E = Young's modulus, C = factor for end conditions of column, L = effective length of column, and I = moment of inertia.