Restoring a Solid Foundation

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TRADITIONAL MASONRY

The methods and materials used to build masonry in the 19th and early parts of the 20th century were very different than those used for modern buildings. Traditionally, until concrete block or reinforced concrete became economically available, at least the foundations were constructed using natural building stone to form thick masonry walls. The thickness was considered essential, not only for structural considerations—natural stone was most often selected because of its proven durability, since clay brick was well known to be susceptible to rapid deterioration when saturated.

Whether the above-grade portion of foundation stone masonry units were fabricated to be square cut and coursed (ashlar) or random coursed rubblestone depended on the price the owner was prepared to pay. The selection of the source of stone depended upon local availability or, again, the price the owner was prepared to pay. However, the exposed masonry above the foundation walls was typically selected to be brick or fabricated, dressed dimension stone. (Sometimes the front elevation was built using more expensive masonry materials, while the rear and side elevations were built using cheaper units.)

METHODS OF CONSTRUCTION

Unlike symmetrically shaped units, such as brick, block and speed tile, natural stone could not be laid into walls with horizontal coursing and multiple, collar-jointed wythes. Therefore, the method of building the below-grade foundations was typically for the full thickness of the assembly to be constructed to a certain height using irregular shaped rubble-stone, with the middle portion ("core") filled with small off-cut rubble pieces bound with a highly workable lime-based mortar or grout. The building work would continue moving horizontally while allowing the adjacent mortar to "set up." The masonry would then continue to the

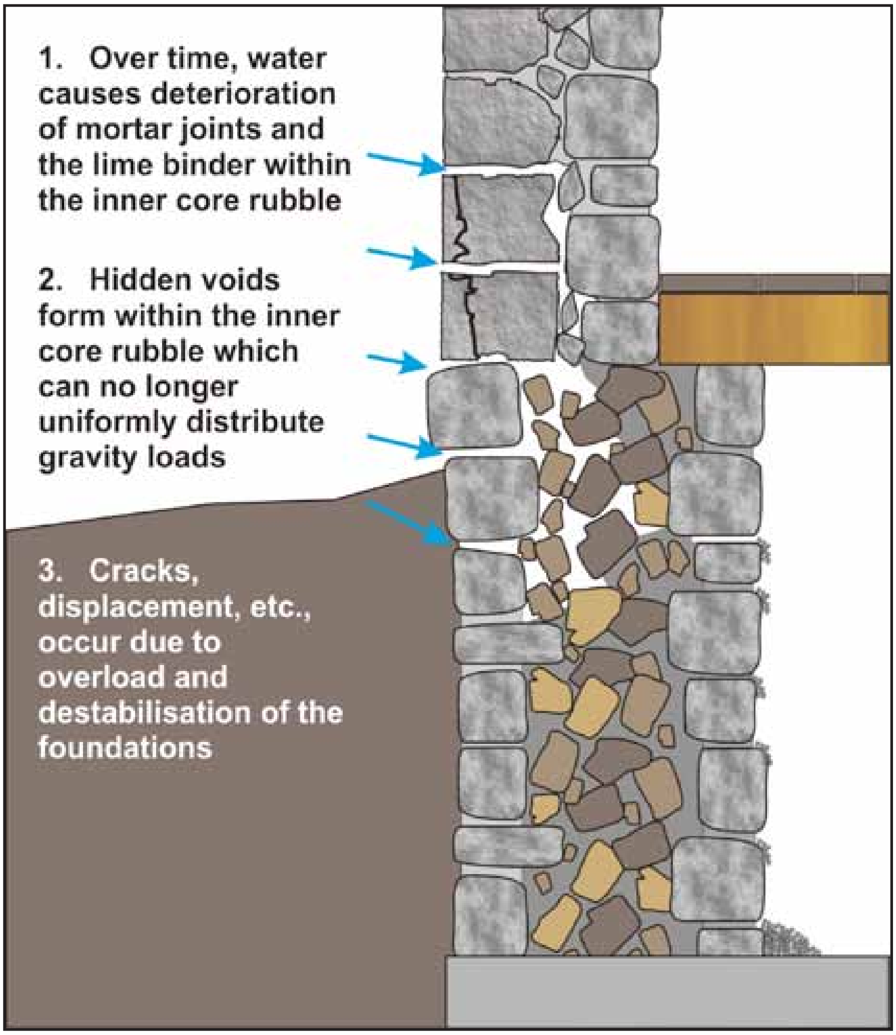

Figure 1. A schematic representation of a typical traditional foundation wall and deterioration mechanisms. All photographs and figures courtesy of PJ Materials Consultants Ltd.

Figure 2. Water can enter the foundation wall above- and below-grade through deteriorated joints.

ground level, where the floor joists would be built to rest on the interior wythe. The main above-grade masonry would be built as a thinner assembly or the ground floor joists would extend into the core and the masonry would continue to be built upward at the same thickness. See *Figure 1* for a schematic representation, which includes the effects of deterioration mechanisms that we will discuss later. The above-grade masonry was selected generally based on cost and/or availability and could be natural stone, brick or a combination of stone on the exterior and brick on the interior. In some cases, speed-tile was used on the interior.

TRADITIONAL LIME

Traditional mortars were predominantly hydrated and lime-based; that is, unlike portland cement, they did not set and harden by reactions with the mixing water; although techniques were sometimes used to create hydraulic reactions by blending clay or ground brick. Without the presence of portland cement, freshly mixed hydrated lime mortar first undergoes a stiffening process, since a considerable amount of the mixing water is absorbed into the masonry materials or evaporates from the exposed "skin" portion. Then, the mortar hardens over time by the lime reacting chemically with atmospheric carbon dioxide; a process known as carbonation. Thus, strength development occurs very slowly, beginning first with the exposed portion, forming a "crust." The products of the carbonation reactions—predominately calcium carbonate—slowly block the pore structure; thus, the rate of the reactions continues to diminish as the gas diffuses through the thickness of the mortar. (This is why pointed mortar can sometimes be scratched to find it is much softer once the fully carbonated layer has been removed.) The time required for hydrated lime to fully carbonate within the masonry core can be measured in decades and will be dependent upon the availability of carbon dioxide and moisture, which are both essential for the chemical reactions.

DETERIORATION MECHANISMS

As hydrated lime carbonates and hardens, the mortar gradually changes the way in which it accommodates stresses developed as the masonry undergoes natural movement from temperature change, loads, etc. At first, the "soft" mortar can "absorb" these stresses. However, as the lime undergoes the process of carbonation, this ability diminishes and, eventually, after many decades, cracks can begin to form within the exterior portion of the more rigid joints. This subsequently leads to the penetration of rainwater to saturate the masonry, typically resulting in a disintegration mechanism from the effects of freezing, thawing and further moisture ingress (see *Figure 2*).

A further problem is that poorly carbonated lime is very susceptible to being dissolved in the water that is penetrating the masonry, which leads to two effects: an increase in the volume of water that can more easily ingress the masonry through the ongoing formation of voids, and the destabilization of the inner core rubble or collar joint. This can be a more serious problem if the below-grade portion of a foundation wall is not waterproofed or adequately pointed.

Once water penetrates the core, it naturally gravitates, dissolving whatever poorly carbonated lime is available in its path. Thus, more and more voids are formed as the lime continues to pass into solution and percolates the mortar, leaving behind a granular debris. When it dries, the debris can subsequently filter downward, following the path formed by the lime solution and often emerging though deteriorated joints to accumulate as a loose powder at lower levels.

Over many years, masonry walls can become further destabilized as the loosely-bound rubble becomes mobile and larger voids begin to form. Often, gravity loads and differential movement are sufficiently accommodated by the weakened masonry. But, sometimes, the change in distribution of loads can cause concentration of stresses which, in turn, can cause the bulging, displacement and/or cracking of masonry units.

INVESTIGATION AND EVALUATION

When investigating deterioration of masonry walls, the potential for the foundation walls to have become destabilized should be considered. If possible, the investigator should attempt to verify the existence of hidden voids or cavities; the author has often used ground-penetrating radar techniques for this purpose (see *Figures 3 and 4*). Although rarely attempted due to budgeting purposes, it is sometimes preferable for the volume of hidden voids and their locations to be estimated, although experts can often arrive at relatively reliable estimates by empirical calculations. A "rule of thumb" guide one can follow is that voids can typically range from five to 15 per cent of the volume of the masonry.

Figures 3. Using ground penetrating radar technique to investigate hidden conditions.

However, consideration should be given to whether the volume of voids justifies grouting techniques to be employed to restore the masonry to a stable condition, or whether the latter can be achieved with just the installation of masonry ties across the assembly. Consideration should also be given to the fact that, if left unfilled, voids could potentially provide "reservoirs" for subsequent water infiltration and potentially greater damage.

On larger projects, a full scale on-site trial carried out in advance of the development of specifications can be beneficial so that procedures and potential volumes of grout can be determined. Critical information obtained from the trial can then be included in the contract documents.

Sometimes, the excavation of inspection pits or trenches can provide valuable information regarding the condition of the masonry; trial drilling with long bits through joints can also sometimes confirm the presence of voids (see *Figure 5*).

During the investigation process, consideration should be given to the need to provide restraint to grout pump pressures, as well as an improvement in the composite reaction of the masonry assembly to gravity loads. On-site pre-project trials of masonry tie installations should, therefore, be considered, particularly since tie diameter, length and spacings can then be ascertained, together with tensile load capacity of the installed ties (see *Figure 6*). Further, potential installation procedures, which can vary, depending upon the make-up of the masonry, can then be evaluated for inclusion in the specifications.

THE IMPORTANCE OF GROUT PROPERTIES

It is critical that the selected grout has compatible properties with the masonry assembly components. In particular, the grout should be sufficiently fluid to flow under low pressure through gaps and fissures within the core rubble so it can satisfactorily fill voids; it should also be a stable medium that will not readily separate when it meets resistance to pump pressures. Further, the core rubble grout should be formulated to be the weakest part of the masonry when hardened, so that it can preferably be sacrificial under overload conditions. It should

Figures 4. An example of computerized interpretation of the data.

Figure 5. Trial drilling within an excavated inspection trench.

not undergo significant shrinkage, and it should have only sufficient mixing water to provide optimum hydration so that the inner core does not become saturated.

Before the introduction of cement, pure lime mixed with water was traditionally used as the grouting medium. However, over the years, the choice has often been between neat cement/water and cement/fly ash/water blends, although hydraulic lime grouts have become more widely used over the last decade or so. A superplasticizing admixture is often included so that adequate fluidity can be achieved using less mixing water.

From about the mid-1990s, the author pioneered—in Canada—the use of a cellular foamed cement for core rubble grouting (see *Figure 7*). This material was selected for its low strength, lightweight properties—typically 3.0 to 5.0-MPa (50 to 750-psi) and 720 to 800-Kg/m^3 (45 to 50-lb/ft^3), respectively. The fact that it requires considerably less total water to produce the desired pumping properties means that less free-water is available to wet the inner masonry after hydration than would be the case should other materials be used. The material also has the ability to deform considerably under load at a constant yield stress and redistribute damaging point load stresses. A thixotropy-inducing admixture is used within the mixture so that the grout does not continue to flow once pumping has been stopped.

GROUTING EQUIPMENT

Although grouting voids within the inner core rubble to stabilize deteriorated masonry walls is a long established practice, methods have changed over the years, ranging from historic gravity grouting using hand placement techniques through to the use of modern pumping techniques that included hand and power-operated diaphragm pumps, aerated pressure systems and vacuum systems. However, with some exceptions, most of the more modern techniques were developed for handling large volumes of grout for civil

Figure 6. Installing and testing stainless steel helical masonry ties.

engineering applications. Therefore, they are not necessarily readily adaptable for masonry projects, where relatively small volumes are required and consistently low pressures are essential during the injection process.

This problem is further exacerbated by the fact that most grouting companies have developed their expertise and skills from contracting to the civil engineering and construction industries, and they are not necessarily comprehensively knowledgeable regarding the specialist nature of masonry core rubble grouting. Further, the companies having the specialist knowledge are few in number and limited to the major Canadian cities. Faced with overcoming these problems, the author typically specifies that grouting can only be carried out by a company providing evidence that they have been trained by the specified supplier of the grouting materials and equipment. (On-site training is permitted by prior arrangement.)

To date, this approach has introduced two or three specialist masonry companies to core rubble grouting and they have either purchased or rented the necessary specialist equipment (see *Figures 8 and 9*). Full scale mock-ups are also typically specified to prove the skills of the grouting contractor before grouting begins.

GROUT INJECTION

For grout injection, it is usual for lengths of plastic tubes to be inserted into predrilled holes that penetrate a few inches into the inner core rubble through mortar joints. The holes are typically located at the junction between header joints and horizontal joints. Care should be taken to ensure the ends of the hole do not "dead-end" within stone—usually, the operator can determine whether or not this is the case by the "feel" of the drill and the bit as it penetrates the masonry. The holes are

Figure 7. Producing and injecting cellular foamed grout using low pressure grouting techniques.

Figures 8 and 9. Left: Equipment and materials for generating foam. Right: Equipment set up for producing foamed grout.

typically installed at regular spacings no more than about 600 mm (24 inches) apart in any direction.

Specifications usually require grout to be injected using the lowest pressure possible but typically up to about 35-kPa (5-psi) greater than the pump pressure, while the flow of grout is non-restricted. Often, the length of grout hose will be restricted by specifications to be no more than 15-lin metres (50-lin.feet) and a calibrated pressure gauge will be mandatory. Injection generally commences from the lowest injection point and continues to refusal—when the pressure rises above 3.5-kPa (5-psi). Grouting is usually permitted to continue while the grout is free-flowing beyond no more than four injection tubes, with each tube being plugged once grout is observed. Injection will typically continue through horizontally aligned tubes up to about 1 metre maximum height before providing a delay for the grout to set-up.

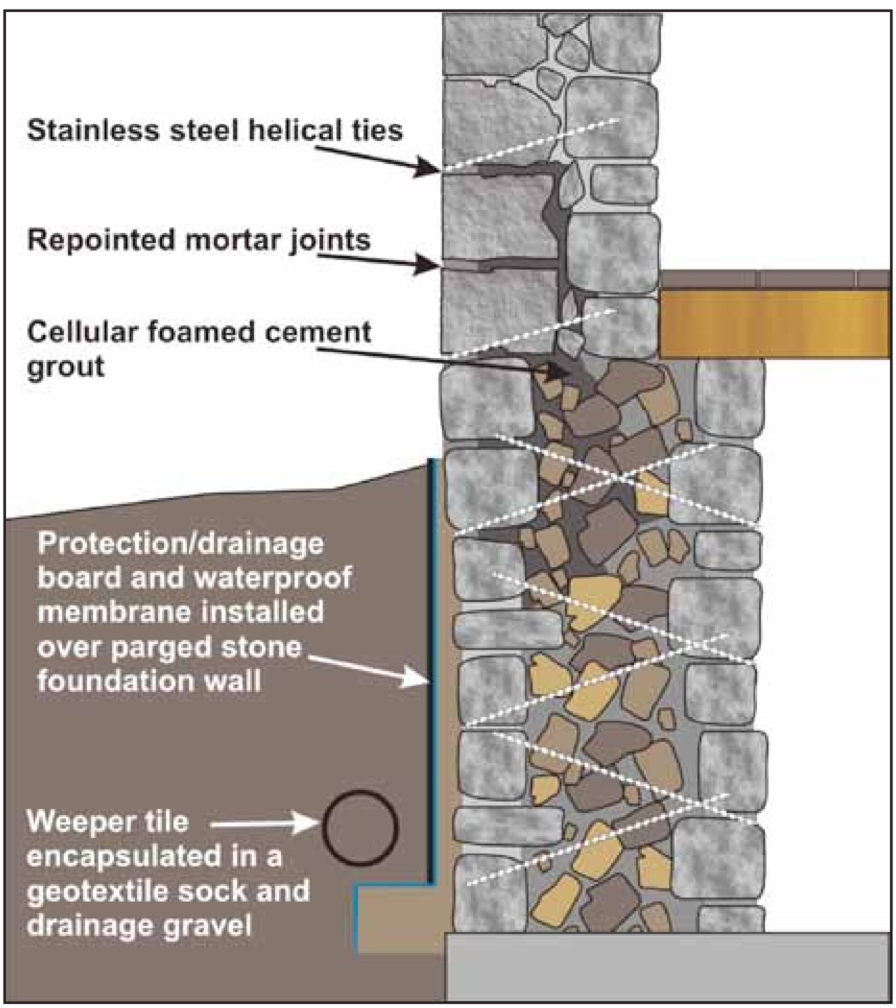

Figure 10. A schematic representation of a typical restoration strategy for foundation wall stabilization.

CONCLUSIONS

There are many older buildings that are, no doubt, suffering from the effects of hidden deterioration of their masonry foundation walls. Most of them probably remain undiagnosed, with deterioration often proceeding at an accelerated rate. Sometimes, restoration strategies address the result of the problems without fully understanding the cause. Consolidation and stabilization of the walls using grouting techniques should be an essenwtial part of a restoration strategy for these buildings, provided the original cause or causes of accelerated deterioration—water infiltration through joints above and below-grade, cracks, poor waterproofing and flashing details, etc.—are also addressed. ■

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