Note: The Figures and/or Tables mentioned in this sample chapter do not appear on the Web.

Chapter One
INTRODUCTION

THE STONE TRADITION

Stone has always been valued as a material of great durability and permanence. The use of stone has been traced to humankind's beginnings in pursuit of shelter. Fieldstones were collected by hand and set side by side, then stacked one upon another to create walls. Wood timbers were used to support roofs composed of split stone, such as slate if available, or flat stones. As societies developed, the use of stone increased to solve basic problems, such as in defining property with stacked stone walls, paving roads with cobblestone to bring goods to market, and building monuments to honor the gods. Much of our recorded history has been learned through our study of the art and architecture produced by ancient civilizations; these examples exist today because the edifices of those early cultures were constructed of stone. The history of civilization has been captured in stone, a material used originally as simple protection and later evolving to a symbol of wealth, strength, and status.

The methodology used for the extraction and processing of stone is basically the same today as it was in ancient times. When the early builders discovered outcrops of slate and cliff faces of sandstone exposed through natural weathering, they learned that larger units of stone could be removed from these deposits than they had been able to gather from the fields by hand. Techniques were developed whereby the natural faults could be exploited to aid in the extraction of stone from their deposits. Slate faces could be split into thin sheets and used as roofing material. Sandstone boulders could be pried from their benches with levers, and smaller stone blocks could then be shaped with metal pick axes. These small blocks could be used to build load-bearing walls for homes and places of gathering. These are the same basic techniques that are used today for quarrying natural stone; the difference, however, is that we have 4,000 years of experience to drive the high technology available to us today.

The marble quarries of Carrara have been in continuous operation for more than 2,000 years, the quarriers passing on the tools and traditions generation after generation. As the Romans built their empire conquering new lands, prisoners of the various campaigns were often brought to work the quarries of Carrara for the rest of their lives as slaves. Today it is not uncommon to see quarry workers who have strong Nordic features, whose ancestors have lived in the Apuan Alps Alps for centuries working the quarries, originally for the emperor of Rome. In the early days, wood wedges were driven into the natural cracks of a marble deposit and wet with water. As a wedge expanded, it was replaced with a larger wedge, and so on, continuing for days, until the block separated from the quarry ledge. The irregularly shaped blocks were squared with hammer and chisel, then rolled over logs to the base of the mountain (see Figures 1-1 and 1-2).

Yesterday's quarryman has been replaced by modern-day geologists who survey stone deposits with lasers and sonic devices and plan the sawing of a deposit based on the naturally occurring faults within the quarry bench. Continuous wire loops are embedded with diamonds and driven by pulleys almost effortlessly, sawing a smooth-faced rectangular block from the deposit in a matter of hours. The blocks are transported by truck to nearby processing plants, which fabricate the stone to specific dimensions as directed by an architect, possibly from another continent.

The nature of stone being of large mass and weight has historically dictated its use as large scale masonry units and facings within the composition of a grand-scaled building. For this reason, the stone trades have evolved very slowly for several thousand years until the end of the nineteenth

and toward the beginning of the twentieth century, when the ingenuity that blossomed during the industrial revolution began to modernize the equipment of the stone industry. It was not until the introduction of the skyscraper that dramatic change was realized in the industry, with its requirement of thinner and lighter-weight materials. The development of high-rise architecture introduced the concept of attaching a non-load bearing skin to a steel building frame, which turned the stone industry on its head. To meet the demands of high-rise buildings, stone had to be sawn to uniformly thin dimensions; slabs were needed that could be produced in thicknesses of 3/4 in. and 1 1/8 in. These challenges have been met by technology, which has changed the processes of quarrying, processing, and fabricating natural stone faster in the past 60 years than has been witnessed in the previous 2,000 years.

HISTORICAL USE OF STONE AS A BUILDING MATERIAL

The early shelters built by ancient peoples were round huts, which were easy to construct using flat stones stacked to form walls without the use of mortar; this technique is referred to as *rubblestone* construction. A round hut design was easier to build than squared buildings with complicated corners, and where slate deposits were found, thatched roofs were replaced with pieces of slate (see Figure 1-3). Interestingly, this type of construction has regained popularity in modern design, using split-face stone as a decorative masonry facing, and is referred to as *dry stack*. In those early times when transportation as we know it did not exist, builders were limited to using indigenous materials. Every region had its own stone types, which were quarried or collected by hand. The buildings produced with local materials blended with the landscape and expressed the color and character of the geologic region. As these techniques developed and more buildings were erected of the same indigenous stones, whole villages took on the characteristic appearance provided by the use of stones from the surrounding landscape. With more experience, builders were able to incorporate larger stones into their structures, using them as oversized jambs and headers to create focal points at the entries of their homes. Early forms of cement were developed, and plaster was mixed to cover the rubblestone walls; however, the feature stones continued to be expressed, which is the origin of quoining at building corners.

As trade flourished between villages, roads were built to connect them. Originally, the walking surfaces between villages were of beaten earth; later the surfaces were covered with crushed rock. The earthen streets of the villages were surfaced by burying cobblestones--stones found in nature, usually found in stream beds or gravel deposits. As stones were discovered that were capable of being split, such as porphyries, roads were built of handsplit cubes set in a bed of sand or fine aggregate.

The use of stone in construction was increasingly appreciated, and rulers of ancient civilizations understood the permanence of stone edifices. The great pyramids of Giza and the nearby Sphinx, constructed more than 4,000 years ago, are among the grandest monuments of humankind, and a testament to the durability of stone. The pyramids of Giza were constructed of limestone, and the Great Sphinx was carved from sandstone. The limestone used for the Great Pyramids was quarried across the Nile and transported by boat to the desert valley. Most likely, timbers were used as rollers to drag the blocks to the site of the pyramid. The same technique for rolling blocks was used in the quarries of Carrara for centuries to follow.

Temple building continued through the rise of Greek and Roman civilizations. Many temples were built at the threshold of the classical period of Greek civilization. Temples whose primary purpose was to house images of the gods and to preserve the offerings of the faithful were built of stone using post and lintel construction techniques. Temples such as the Temple of Aphaia, built of limestone circa 500 B. C., and the Temple of Hera II, also constructed of limestone, circa 460 B. C., are examples of the development of Greek architecture incorporating the massive use of stone. The most famous of all stone edifices, the Parthenon, was built on an enormous limestone rock

overlooking Athens. The entire structure was built of Pentelic marble, including the roof tiles, and is considered to be one of the greatest buildings of the world. The post and lintel structural system was pushed to its limits; refining the Doric order by using slender columns of additional height added grace to the colonnade, and reducing the mass of the entablature increased the temple's proportion of height.

The Roman Empire was expanding, and great civic centers were planned throughout its reaches. Its planners solved problems of water supply for many of the new towns by diverting nearby springs and building grand aqueduct systems to transport the water. The largest of these is the Segovia aqueduct in Spain, which is built of granite blocks without the use of mortar and is 2,400 ft long and 95 ft tall. The Romans discovered a method for the production of concrete that used a drier mixture of cement, with rubblestone added as aggregate. This enabled their builders to move beyond the limitations of post and lintel construction, producing structures with tremendous spans. During this period one of the more adventurous uses of stone was as facings or claddings of concrete and stone structures, such as in the Coliseum at Rome. Although today the exterior of the Coliseum has the appearance of being bullet ridden, in actuality the holes in the surface are the locations of the original anchors that attached marble veneer panels to the structure.

The products of quarries were often so easily available and quarried that the stones were used for the ballasts of ships. The trading ships of Britain, during the seventeenth and eighteenth centuries, carried sandstones as ballast that were off-loaded when they reached the southern states of America, where the ships were then loaded with cotton. Many of the buildings found in the old commercial centers of the United States were built of sandstones from Britain. The town centers of early America were paved with solid blocks of limestone and granite, and many country roads were surfaced with crushed stone.

An early use of limestone was for agricultural purposes. Small limestone blocks were collected and burned in makeshift kilns. Upon firing, the resulting material, calcium oxide, was raked out and mixed with water to produce calcium hydroxide, or lime. This material, when spread over farmland, acted as a fertilizer by counteracting the natural buildup of acidity from humus deposits, thus promoting healthy plant growth.

MODERN USE OF STONE AS A BUILDING MATERIAL

During the past two centuries the use of stone in construction was limited to government buildings, large-scale public gathering places, and homes of the wealthy. The reason was that the same labor-intensive stone-processing techniques used for centuries previous were still practiced, making the use of stone exclusive because of its high cost. Nearly every train station of the urban centers of the world, every state capital in the United States, and monuments of major significance, such as the Lincoln Memorial and the Washington Monument, were built of stone. All of these stone structures were built of massive load-bearing masonry units. The heights of buildings were limited, because the mass required at the base increased as a building grew taller, reducing the useable areas at the lower levels. The walls grew thicker, and openings for windows and doors were reduced in size and quantity. Yet the real estate markets were demanding the opposite: larger windows with views and open floor areas for retail use at the pedestrian levels. The solution was introduced during the latter half of the nineteenth century: iron and steel structural frames that supported a lighter-weight exterior skin or facade. Now buildings could go taller without consuming so large a proportion of the floor area. The masonry industry jumped on the concept and developed the early panelized wall systems built of brickwork attached to a frame that could be installed at the perimeter of the building structure. The stone industry, however, was slow to follow the requirements of the emerging American skyscraper.

As architects of the day explored newer materials to achieve the design generated by the

international movement, multimaterial curtain wall systems were developed using various metals, terracotta, glass, and masonry. Many of the systems were successful, but some were not. The appetite for the beauty of natural stone was growing stronger, and the stone industry was finally caught up in the momentum. Stone producers developed new methods of block extraction, and fabricators invented more efficient equipment to process stone with precision, and most important, thinner dimensions. Stone producers realized the increased market potential of thin dimensional stone resulting from lower material and shipping costs. By the middle of the nineteenth century the integration of stone veneers within true curtain wall systems had begun.

Technology has dramatically changed the stone industry in the past 25 years and has enabled producers to process stone into thin modules, thereby reducing waste. And because of improved delivery systems, a material that was once considered a luxury, is now available to the general public. To produce a stone floor as recently as 1950 required a stone module of a minimum 3/4 in. thickness and utilizing a full mortar bed, for a total of 2 to 3 in. overall thickness. The finishing of this floor required grinding and polishing the stone in place, which was time-consuming and costly. A stone floor could be installed only in government buildings or for the very wealthy. Through technology, machinery has been developed capable of producing uniformly thin stone modules to a now standard dimension of 3/8 in., which can be thin-set in a mortar bed of 1/8 in., at a price that the average construction budget can accommodate.