The Evolution of
Modern Thin Stone Veneer Systems
1950-1980

Sarah Ripple

Sarah Ripple

Submitted in partial fulfillment of the requirement for the degree of Master of Science in Historic Preservation

Graduate School of Architecture, Planning, & Preservation

Columbia University
May 2012
<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Technical &amp; Aesthetic Developments in Stone Veneer Since 1900</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2</td>
<td>Stone in Architecture</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Attributes of Stone as Applied in Architecture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geological Information of Stones used Commonly in Architecture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stone Selection</td>
<td></td>
</tr>
<tr>
<td>Chapter 3</td>
<td>1960s Thin Stone Veneer Specifications</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Finishes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Panel Dimensions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Joint Configurations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mortar and Sealants</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dampproofing</td>
<td></td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Thin Stone Veneer Anchorage and Support Systems</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>A Brief History of Anchors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Purpose of Stone Anchors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basic Anchor Typologies: 1950-1980</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evolution of Thin Veneer Anchors</td>
<td></td>
</tr>
<tr>
<td>Chapter 5</td>
<td>A Case Study: Stone-Clad Architecture of Wallace K. Harrison</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Case Study Selection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lincoln Center for the Performing Arts</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>The Metropolitan Opera House</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>The Philharmonic Hall</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rockefeller Center, West Expansion</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>The Celanese Building</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>The Exxon Building</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>The McGraw-Hill Building</em></td>
<td></td>
</tr>
<tr>
<td>Conclusion</td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>Appendix A</td>
<td>Midtown Modern Stone-Clad Survey</td>
<td>89</td>
</tr>
<tr>
<td>Appendix B</td>
<td>The Career of Wallace Harrison</td>
<td>93</td>
</tr>
<tr>
<td>Bibliography</td>
<td></td>
<td>97</td>
</tr>
<tr>
<td>Photo and Image Credits</td>
<td></td>
<td>101</td>
</tr>
</tbody>
</table>
Abstract

The architectural and technical treatment of stone changed dramatically with the development of Modern architecture and the introduction of stone cladding, which resulted in the departure from stone as a load bearing material. As with every novelty in architecture, thin stone veneer experienced a period of trial and error from 1949-1980, without real precedence or comprehensive understanding of how it would perform. This reduction in stone thickness for cladding purposes required a rethinking of the systems for attachment to the structural framework, materials and detailing, and the stone selection process. Consequently, the Modern architecture movement encapsulates the period of greatest change within stone veneer development.

During this time, aesthetic preferences shifted from an architectural tradition based on European architectural styles to the Modern movement. The heavy ornamentation gave way to a very monolithic, spare language, utilizing manmade, repetitive features; the craft aesthetic gave way to the machine. The Modern architecture movement was the first time period when stone was consistently used in one and a half to three inch thicknesses. With the thinning of stone also came a change in the performance of stone; the anchorages, which were established to secure the stone to its substrate, became central to successful performance. The anchors slowly evolved to perform an increased level of adjustment. Additionally, the selection process of stone became ever more important, because the intricacies of the physical properties had a greater effect on thin stone. Finally, moisture control, specifically damp proofing and joint material, and other specifications as we know them today were tested and began development during the Modern architecture movement. These facets of the thin stone veneer system have been presented within the framework of the Modern architecture movement to provide a comprehensive analysis of the evolution of this system. Five stone-clad buildings of Wallace K. Harrison were used to help illustrate the development: The Metropolitan Opera House and Philharmonic Hall, and The Celanese, Exxon, and McGraw Hill Buildings.
There are a number of people without whom the completion of this project would not have been possible. First and foremost, I’d like to thank Theo Prudon, my thesis advisor, for his insight and interest in the subject, and especially for seeing potential in both this project and me. My thesis readers Kimball Beasley and Lorie Robinson were a tremendous help. The technical advice and information Kim offered, and his willingness to allow me to learn about his work was crucial to the success of this study. Lorie graciously provided resources, and I am incredibly appreciative of the time and effort she took to improve my work. To all three, I thank you for your honesty and patience.

The preservation faculty must be commended for their enthusiasm. My time at Columbia would not have been nearly as fun or successful without them. To the faculty of the Drawing and Archives Department in Avery Library, Janet and Jason, I cannot express enough gratitude for your assistance.

My classmates who took the journey with me provided encouragement in a way that only comrades can. I am profoundly grateful to Sajid, my constant supporter, who rallied my resolve when things became difficult, who was my constant companion despite the distance and late nights, and who made sure I never felt alone in this process.

Finally, I need to express my overwhelming gratitude to my family. My brother Michael supplied constant support and empathy, and reminded me to have confidence in myself. My amazing mother kept me on course by providing unending love and prayers. Lastly, I thank my father – I could not have done this without him, my teacher, my editor, my cheerleader, and my rock. Thank you for guiding me through the rough times and carrying me on your shoulders.

In loving memory of my Granny, an inspiration for strength of will, grace and humility. Thank you for being with me the entire way and keeping me close to your heart.
Preface

Engineers and architects practicing renovation or rehabilitation of buildings need to know the specifics of obsolete construction in order to work in a nondestructive and unobtrusive manner. This includes understanding both the physical construction materials, systems, and details that were used and the designers’ mindset, which serves as the context for those physical realities.¹

- Donald Friedman

The preservation of thin stone veneer buildings from the Modern architecture movement has increasingly become an issue as the structures have reached or neared the end of their service lives. The buildings, although now of appropriate age for landmarking or preservation efforts, are not necessarily perceived by the general public as having historic value. With the hope that this opinion may change and that repairs to Modern stone-clad buildings will one day be treated with the same level of gravitas as the restoration of a much older structure, this thesis is intended to add to the body of knowledge on early thin stone veneer structures.

My interest in thin stone veneer structures began as a superficial appreciation for stone. The natural beauty, variety, classic timelessness, and impression of durability appealed to my senses. Then, I became interested in architecture of the Modern movement, because it seemed that would be the generation of buildings that would most need the attention of a preservation-minded individual in the coming years. Combining these interests in stone and Modern architecture to focus on thin stone veneer structures of that time seemed natural; and then came the realization that an understanding of the anchors behind the stone, and the systems into which that stone is built, told an even more interesting story.

This study began with a modest survey of stone-clad structures built between 1950 and 1980 located in Midtown and Lower Manhattan. Initially, only location and type of stone were documented. I began the survey hypothesizing that I would find distinct trends in stone use, that for any given period of time one stone would dominate in construction before giving way to a new stone trend. I limited the survey to Midtown after deciding Lower Manhattan lacked the substantial cluster of stone-clad structures for which I was searching. To my surprise after completing the survey, what I found was a lack of trends in stone use; every stone used commonly for architectural cladding (marble, granite, limestone, travertine, and sandstone) was in use during every decade, and no one stone dominated. Granted, marble and granite were used more frequently, the difference was not by much. Research then informed which architects were the most prolific designers of

¹ Donald Friedman, Historical Building Construction, Design, Materials, and Technology (New York: W.W. Norton & Company, 2010), 12.
stone-clad buildings, and the decision was made to focus on the buildings of Wallace K. Harrison.

A cross-referencing of historic stone and architectural trade catalogs told the story of popular stone anchors between 1949 and 1981, which could then be compared to contemporary ASTM Specification Manuals to determine if that time period had a lasting effect on thin stone veneer systems. An exploration through Harrison’s original drawings for stone veneer and anchor detailing illustrated how his buildings fit within the general development of the thin stone veneer system. The performance of these buildings was also considered. The results of this consideration reinforced the concept that Modern thin stone veneer buildings are in need of attention, and that attention should to be prefaced on the now outdated.
Technical and Aesthetic Developments in Stone Veneer since 1900
The eventual use of stone as a thin veneer material is inherently linked to the development of the curtain wall, which was driven by the search for a thinner wall system, and thus is preceded by the adaptation of a number of materials to the steel frame. The development of steel framing removed the need for walls to be of structural significance and revolutionized wall construction. Suddenly, wall materials could be used in thinner dimensions, attached to and directly supported by the frame, utilizing anchors and support systems for the first time. The use of framing transformed the purpose of brick; and, the necessary masonry wall thickness would change a number of times before resulting in brick veneer, which required anchors to secure it to the structural wall behind. More influential to thin stone veneer than brick veneer was terra cotta, which may be considered the first true veneer material. The terra cotta industry standardized anchoring and support systems earlier than any other industry, effectively setting precedence for the masonry, concrete and stone industries regarding material testing and installation technology. The growth of precast concrete use signals a transition from concrete as only a load-bearing, cast-in-place, material to an exterior cladding material adapted to the steel frame. Precast concrete systems continued the use of anchors and would become intimately involved in the thin-stone veneer systems as a structural reinforcement facing the back of stone panels. The theory of curtain walls was taken to its height with the wide-spread use of glass and metal facades, where the sole purpose was protection from the elements. The wall system reached its thinnest with glass curtain walls requiring a rethinking of the installation process, and it introduced new mechanical systems for installation. The transition of brick, terra cotta, and concrete, and the introduction of glass and metal, to exterior wall cladding signifies the desire for thinner walls leading to the development of stone as veneer and influencing the anchorage and support systems involved in the installation.

The significant transition in framing, occurring around the turn of the twentieth century, was the change from the cage frame to the skeleton frame. Essentially, the cage frame system had two parts, a frame and a self-supporting wall. Although the cage frame is structurally separate from the frame, it resembles the bearing wall.

---

1 Donald Friedman, *Historical Building Construction, Design, Materials, and Technology* (New York: W.W. Norton & Company, 2010), 169. A distinction must be made between stone “veneer” and “thin stone veneer.” A stone veneer is “A nonload-bearing facing of stone attached to a backing for the purpose of ornamentation, protection, or insulation,” while thin stone veneer is specifically designated for stone facing that is two inches thick or less, From ASTM International, “Standard Terminology Relating to Dimension Stone, Designation: C119-11,” 2011.. The period of time when thin stone veneer grew in popularity coincides with the Modern architecture movement and is highlighted within this thesis. For further clarification on stone terminology, refer to ASTM C119-11.
in construction and was thicker than skeleton walls. One of the significant novelties of the cage frame was the ability for the frame to be built independently of wall, the practice of which became standard. The adoption of the skeleton frame, more commonly addressed as steel framing, is more significant in the history of the stone veneer system, because the wall loads are born by the frame, either by spandrel beams or shelf angles. This type of system became known as the curtain wall and is the system to which thin stone veneer complies. Loads were also at times supported on the floor plane, above the spandrel beam. The spandrel beams and shelf angles were employed to transfer the weight of the façade to the frame at each floor level (Figure 1.1). While the different framing systems would overlap in use around the turn of the century, the skeleton frame eventually became the choice system, heavily influencing the thinning of the wall system.

As a result of the adoption of steel framing in construction, the role of brick changed completely from the original load bearing purpose. Brick’s new purpose under the ascendancy of steel framing was to protect the metal from the heat of fire and destruction of water, and to provide the occupants protection from

---

2 “The 1892 code allowed a relatively small reduction in thickness for a nonbearing wall as opposed to a bearing wall. This was an impediment to cage construction, since the cage-wall height was figured the same way as a bearing-wall height, so that the walls would be relatively the same thickness. Curtain walls on skeleton frames, in contrast, are only as tall as the floor-to-floor height, and so would be substantially thinner in the lower floors of a building than cage or bearing walls,” From: Friedman, Historical Building Construction, 68-69.

3 Curtain wall: An exterior wall supported wholly by the structural frame of a building and carrying no loads other than its own weight and wind loads, From: Francis D.K. Ching, A Visual Dictionary of Architecture (New York: John Wiley & Sons, Inc., 1995), 269. The curtain wall is a type of wall system and does not infer a certain material for construction.

4 The cage frame lacked resistance against lateral loads and depended on the rigidity of the walls for stability. It also utilized other metals at times, including iron. Conversely, the skeleton frame used only steel, provided its own lateral load resistance, and minimized the need for brick or stone except as decorative curtain walls only.
the elements. \(^5\) Previously, walls were built to reflect the loads they carried. For instance, bearing walls, those that carried the floor joists, were required to widen at the base to accommodate the limited compression strength of the bricks. The 1892 New York City building code acknowledges that the skeleton frame employ wall support at each floor level by reducing the required thickness and ridding the wall of widening at the base. \(^6\) However, these first brick curtain walls were still a relatively thick twelve inches, and the requirement for cage frame walls continued to include a widening (Figure 1.2). Not until the wall thickness determination method changed from empirical to calculated would the necessary thickness be reduced again to eight inches. \(^7\) At this time, stone was commonly used as a 4” thick (or thicker) veneer to brick structures, a practice which was continued through the 1940s despite engineering experience, improved construction methods and stronger frames reducing restrictions on wall weights. The 4” thick stone facing was attached by strap anchors to the structural masonry wall behind carried by the frame. The masonry wall was typically 8” thick, to adhere to the required wall thickness of 12”. Other uses of stone during this time were for monumental, building-bottom, and ornamental purposes; and for this type of use, the stone would be in cubic block form. A number of masonry anchors were developed to secure the brick or stone veneer to the

---

7 Ibid.

---

Figure 1.3
The fabrication of terra cotta pieces involved pressing clay into molds. However, only enough clay was used so as to take the shape of the mold and be a few inches thick, leaving an open cavity in the backside of the terra cotta piece. During the construction process, the cavity would be filled with either brick or concrete, or sometimes simply attached using wire ties and anchors, to secure the piece to the building frame. Image A shows Plate No. 6 from the 1914 National Terra Cotta Society publication, which demonstrates terra cotta blocks to create a rusticated wall, one of the many ways terra cotta may be employed. Image B shows the detail from the bottom of Plate No. 6, which illustrates the concrete or brick infill required to secure in place the terra cotta blocks.
framing, including the common corrugated strap anchor and wire tie-back. However, the anchors used in masonry construction lacked standardization and depended on the preference of the mason.

Conversely, terra cotta standardized anchorage systems and manufacturing standards. It flourished as a façade material in the first decades of the twentieth century. Due to the method of fabrication, terra cotta was less expensive than stone, easier to produce, and offered a stone aesthetic. It may also be considered the first, true veneer material. The terra cotta itself was very thin and clad the brick back up that filled the terra cotta shell (Figure 1.3). The standardization of anchors may first be noted in the 1914 National Terra Cotta Society publication; the anchors illustrated here continued to be used through the life of terra cotta popularity (Figure 1.4). They also heavily influenced the anchors used by the stone industry in the beginning years of thin stone veneer.

The materials in use in construction at any given time are equally influenced by technological advancements as they are by public taste, and at the turn of the century, tastes were looking to the past. The rise of the American enterprise during the second half of the nineteenth century brought an influx in construction of corporate buildings in the first decades of the twentieth century.

---

8 However, problems eventually emerged with the material due to its porous bisque and irregular glazing, which damaged easily and was difficult to repair. Terra cotta weathered poorly in the difficult climates of the northeast and Midwest; it cracked and spalled which would allow water infiltration to corrode the anchor straps and further crack the face of the “stone.” The prospect of terra cotta masonry falling from buildings created a concern for safety. “Weathering concerns reevaluated use of brick and terracotta, while natural stone’s durability remained attractive,” Michael D. Lewis, “Modern Stone Cladding: Design and Installation of Exterior Dimension Stone Systems,” ASTM International (Philadelphia, 1995), 13.

9 Further discussion of these terra cotta anchors will occur in Chapter 3.
century. Companies desired corporate headquarters that they felt reflected their success and stature. “Never before had the American economy and American architecture been so dominated by the quest of ultimate economic performance, becoming a mechanism for generating maximum profit.” Consequently, construction of corporate architecture increased and the idea of what should be the aesthetic began a series of transformations that began with the revival of historic European architecture in the early twentieth century.

The popularity of the stylistic language of the Renaissance and ancient Greece and Rome led to the creation buildings of “braggadocio” with traditional use of stone as thick cladding and interior and architectural decoration. The Flatiron Building, designed in the manner of a Renaissance palazzo, and the Singer Building (demolished in 1968), a Beaux Arts influenced building, are two early skyscrapers finished in 1902 and 1908 (Figures 1.5 & 1.6). The language of these European styles disguised the novelty of the steel framing that lay beneath. Their faces were clad in rusticated stone and terra cotta that imitated load bearing buildings. The Woolworth Building, finished in 1913, reached fifty-seven floors utilizing the most modern form of steel framing at that time; the Neo-Gothic building is clad in white terracotta and has strongly articulated, vertical piers that accentuate the height of the tower (Figure 1.7). The American Radiator Building, another Gothic-inspired skyscraper, designed by Raymond Hood was finished ten years after the Woolworth, and in similar fashion to the other buildings designed with European influence, it conveyed the appearance of traditional masonry (Figure 1.8).

By the mid-1920s, popularity of the Art Deco aesthetic was on the rise in architecture, and it would remain in use through much of the 1930s. Many of New York’s most famous skyscrapers were designed in the Art Deco style. The Chrysler Building, completed in 1930, is perhaps the most iconic example of Art Deco architecture. Its Art Deco design features sleek lines, geometric shapes, and bold colors. The building is adorned with large Art Deco stained glass windows and a series of Art Deco style sculptures. The Waldorf Astoria Hotel, completed in 1931, is another example of Art Deco architecture. Its Art Deco design features a grand staircase, luxurious rooms, and a large Art Deco style chandelier. The东方大厦, completed in 1933, is another example of Art Deco architecture. Its Art Deco design features a grand staircase, luxurious rooms, and a large Art Deco style chandelier. The Oriental Building, completed in 1933, is another example of Art Deco architecture. Its Art Deco design features a grand staircase, luxurious rooms, and a large Art Deco style chandelier. The New York Post Building, completed in 1934, is another example of Art Deco architecture. Its Art Deco design features a grand staircase, luxurious rooms, and a large Art Deco style chandelier. The New York Life Building, completed in 1935, is another example of Art Deco architecture. Its Art Deco design features a grand staircase, luxurious rooms, and a large Art Deco style chandelier.
York's iconic buildings are of this style and time period including the Empire State Building, RCA Building, and the Chrysler Building. Stone entered a transition period, caught between the empirically driven way of the stone trade and the engineered or calculated method of construction that emerged. The New York City building code at that time dictated a twelve inches as the required minimum wall thickness. The Empire State Building (1931), in accordance with this code, represents an early curtain wall using brick backed limestone, which measured a combined 12” (Figure 1.9). The steel frame has two spandrel beams per floor, one for the live loads (inboard) and another to carry the weight of the wall (outboard). Conversely, the RCA Building (1932), the centerpiece of Rockefeller Center, is rendered relatively ground breaking by employing 8” limestone from sidewalk to roof. The aesthetic of the Rockefeller Center limestone is also quite novel as it was finished with a shot-saw, which provided a linearly textured surface (Figure 1.10).

Cladding in metal became a fashionable option in the 1930s, also as part of the Art Deco movement, and glass facades followed in the post war era. Both materials would continue in high use into the 1950s. Popularity was due to light weight, quick installation, and elimination of weather dependency. Furthermore,
The Woolworth Building is a landmarked building designed by Cass Gilbert. It was completed in 1913. The building lobby is clad in Skyros veined marble while the rest of the building height is sheathed in white terra cotta. A “Gothic crown” adorns the top of the building, but gothic ornamentation details the building on every level.

233 Broadway, between Park Place and Barclay St.
Willensky and White, *AIA Guide to New York City*, 60.
Figure 1.8
The American Radiator Building, now the American Standard building, is located across the street from Bryant Park. It was designed by Hood & Fouilhoux in 1924 but underwent an addition in 1937 by Andre Fouilhoux. The gothic design of the building is accentuated by black brick and gold terra cotta ornamentation. 40 W. 40th Street, between Fifth & Sixth Avenue. Willensky and White, *AIA Guide to New York City*, 239.

Figure 1.9
The Empire State Building, New York’s most iconic building, was the design of Shreve, Lamb & Harmon circa 1931. This landmarked building is clad in limestone from sidewalk to spire. 350 Fifth Avenue, between W. 33rd and W. 34th Street. Willensky and White, *AIA Guide to New York City*, 213.

Figure 1.10
The shot-sawn limestone of Rockefeller Center, pictured here on the Sixth Avenue side of the RCA Building, is not a common finish for this stone. The buildings of Rockefeller Center broke the New York City building code of the time which required 12” thick curtain walls and have 8” thick walls. This breach of regulation was waived due to the great economic depression of the 1930s. The construction of the center supplied jobs to many men during a time of great need. 1932-1940, Reinhard & Hofmeister; Corbett, Harrison & MacMurray; Raymond Hood, Godley & Fouilhoux. W. 48th to W. 51st Streets between Fifth and Sixth Avenues (originally) Willensky and White, *AIA Guide to New York City*, 272.

Figure 1.11
The spire of the Chrysler Building is noted as the first architectural use of stainless steel. The metal is actually 22 gauge Nirosta Steel made by Krups of Germany, the first company to discover stainless steel, but is very close to contemporary 302 stainless steel. 1930, William Van Alen; 405 Lexington Avenue Hammarberg, Eric, “A Case Study of Early Steel Curtain Wall: The Chrysler Building,” *Structure Magazine*, December 2005, 10.
man made products such as glass and metal could be standardized and produce expected results. Their initial rise to desirability was in part due to the manufacturing and installation efficiency. Glass and metal curtain walls utilized the grid strut mechanical system of installation, which would later be adapted to thin stone veneer. The Chrysler Building (1931) exhibits a number of cladding materials including dark Shastone granite on the base, white Georgia marble on the second through fourth floors, and white, grey and black brick; however, the cladding novelty lay with the use of aluminum as spandrel panels and stainless steel veneer on the building spire (Figure 1.11). It was the first architectural use of stainless steel sheet metal; the structure of the spire beneath the stainless steel tapered from 12” of back up brick and terra cotta, to six inches of brick, to anchoring the sheet metal directly to the structural steel. This concept of applying sheet metal to a thin layer of masonry would be applied to entire elevations and continued in popularity through the 1950s. For instance in 1956, the Socony-Mobil Building was completed, clad entirely with seven thousand embossed stainless steel panels (Figure 1.12). However, glass and metal curtain walls were not completely understood and had problems early on. The lack of insulation and flexible sealants in the early 1950s led to condensation, leakage, and corrosion in the glass and metal curtain walls, which proved to be the primary issue with stone veneer systems as well. Additionally, by the early 1960s, environmental concerns, primarily focused on thermal performance, affected the perception of the glass curtain wall. Together, the poor performance of glass and metal facades, combined with new aesthetic preferences, sparked a renewed interest in stone as a façade material.

While construction had slowed due to the economic depression of the 1930s, the spread of new ideas about the direction of world architecture did not. In 1931, the Museum of Modern Art had an exhibition, produced by Philip Johnson and H.R. Hitchcock, on Modern architecture which brought the ideas of the European style to New York; the title of their book that recorded the exhibition, “The International Style,” became the accepted name for their aesthetic. They presented the architectural theories of the style, emphasizing expression of structure, process of manufacture, industrialization, expression and use of newest methods of construction. It marked the emergence of a new idea of the wall where “the skin or veneer of a structure should be detailed to express a thin, continuous surface.” The materials specifically called out to be used for this purpose were “painted stucco or tile…aluminum, thin slabs of marble or granite, and glass, opaque and transparent.” This

20 “There is no question that it costs more to hear a building with a preponderance of glass exterior…this was studied in detail…using a building model with 70% masonry and 30% glass, and another with 30% masonry and 70% glass. Test showed that the heat loss in the building with an exterior predominantly of masonry was 3,420 btu’s an hour. On the other hand, the heat loss in the predominantly glass building was more than twice as great – 7,180 btu’s an hour,” From Edmond J. Bartnett, “Glass Walls Add Light and Beauty to Buildings but Create Problems, Too,” New York Times, February 21, 1961.
22 Robinson, Thin Stone Cladding, 8.
23 Henry-Russell Hitchcock and Philip Johnson, The International
proposal of a sleek, unornamented façade marks a tremendous change in style, which allowed a reduction in material thickness. The International Style exploited the desire “for bigger windows, more light and view from the higher vantage, and maximum rentable area” by thinning the building exteriors. The technology to produce, mount and maintain glass curtain walls reflected the “functionalistic fashion” of the International Style.

Following the Depression, the Second World War also put a strain on the building industry. Funds and materials were allocated for the war effort; especially affecting construction was the need for metals – steel, aluminum, and copper, among others, were needed to produce weapons, planes and wires. Adjustments were made in construction, which encouraged the use of bond courses to tie in face material, corrosion protected iron rather than brass, bronze, or monel wire anchors and straps, and smaller shelf angles cut to four inches long and used intermittently. This time period is marked by a dramatic increase in prefabricated materials and buildings, such as industry worker housing, and a reduction in building of other sorts.

Interest in precast concrete panels as non-structural, exterior cladding grew concomitantly with that of thin stone veneer in the post-war era. Previously, precast concrete was commonly used in a structural capacity as cast stone, while the precast concrete panels utilized much of the same anchorage and support systems as thin stone veneer to perform a cladding purpose.


Thickeneight of the concrete panels ranged roughly from two inches, if secured in direct contact with the concrete back up, to four inches, if secured by anchor to the back up with a cavity between the fascia panel and back up (Figure 1.13). The precast concrete was used in a number of manners, each progressively covering more surface area. Concrete is easily cast as spandrel panels and wall panels in either one story or multi-story heights (Figure 1.14). Precast concrete would be used in conjunction with thin stone veneer to create a composite system. The reinforced concrete added strength and flexure to the system and reduced the cost by lessening the amount of stone.

The desire for thinner walls, as illustrated within the brick, terra cotta, concrete, glass and metal industries, encouraged the stone industry to adapt. The capability to produce stone as thin as 7/8" existed since at least 1931, as advertised by granite manufacturers. Although the manufacturers actually recommended 2" thick veneer as the most appropriate for exterior use, which qualifies as thin veneer by today’s modern standards (Figure 1.15). Then in the late 1950s, diamond bladed tools were refined. They improved fabrication efficiencies, which made stone more economical; and the installation costs lessened, because the large panel size which could cover more area at a faster rate. Due to an increase in production efficiency, stone began to be incorporated into glass and metal facades either for cladding building bases or serving as spandrel panels. Gang saws cut the quarried blocks into rough, relatively

---

equally thick slabs using vertical blades that wandered less when sawing back-and-forth than the previously used wire saws. In the 1960s, industrial diamonds were added to the blades. The whole system became further standardized in order to increase construction efficiency, which included both preassembling more parts offsite and standardizing parts for quicker assembly onsite.

One process of prefabrication was to anchor the stone veneer to preassembled trusses and to then transport the entire truss to the site to be erected. “New skills, new equipment, and accelerated schedules dramatically changed how labor was used. Completion quickened, standardization maximized interchangeability, and quality increased at lower costs.”

Significant to the era of Modern architecture is the standardization of thin stone veneer thicknesses that remains today. By the early 1950s, the most common thin stone veneer face dimensions were 3x3” and 4x4” and were offered in thicknesses of 7/8”, 1 ¼”, 1 ½”, and 2”. This was the key to keeping stone from becoming a sparingly used material of luxury: the ability to produce it as thinly, efficiently, and cost effectively as possible.

Producers were able to ship internationally for less, since the weight per unit area was less than before, which expanded the market. This was the key to keeping stone from becoming a sparingly used material of luxury: the ability to produce it as thinly, efficiently, and cost effectively as possible.

Significant to the era of Modern architecture is the standardization of thin stone veneer thicknesses that remains today. By the early 1950s, the most common thin stone veneer face dimensions were 3x3” and 4x4” and were offered in thicknesses of 7/8”, 1 ¼”, 1 ½”, and 2”.

32 Ibid, 18.
Despite the range, stone was typically recommended in 1 ½-2” for exterior purposes. The composite system of stone with precast concrete developed in the late 1950s from the growth of precast concrete panels used as cladding. The composite system allowed stone to be cut to the thinnest dimension available and still remain structurally sound when used as an exterior cladding due to the added strength of the concrete. Hair pin wires or dowel anchors, used as mechanical fasteners, were imbedded in the stone panel prior to casting (Figure 1.16). A bond breaker was introduced to the composite system in the late 1960s between the stone facing and precast concrete in the composite panels to avoid cracking of the stone, which was caused by shrinking of the concrete during setting and differences in thermal expansion coefficients. The liquid bond breaker would be applied to the back of the stone prior to concrete casting. Stone thickness remained relatively consistent in the years following, and the standard thicknesses of most thin stone veneer did not stray from the 7/8”-2” range.

When thin stone veneer began to climb the facades of buildings in the postwar era, the technology behind the stone grew more complex. The anchorage, support systems, and specifications became the key to success for thin stone veneer walls. The common anchor types remained relatively consistent from 1949.

40 Exceptions do exist. Travertine, for example, should not be used in a thickness less than 4” when solid stone; it can be used in thinner dimensions when in conjunction with precast concrete.

41 “Comprehending the behaviors between interconnected cladding and framing parts became the hidden formula to properly designing lasting curtain walls with stone and masonry,” from Lewis, “Modern Stone Cladding,” 15.
1981, although a few additions were made over the years. The placement of anchors especially affected the performance, as improper detailing could cause cracking, spalling, and flexure. Expansion joints were not included in wall specifications prior to the Second World War, and the addition of such joints following the war allowed an appropriate amount of movement to avoid undue stress on the panels. In the 1970s, new mechanical systems were developed, most notably the grid strut system adopted from the metal and glass curtain wall, in which the need for anchors was eliminated; however, the grid aesthetic differed considerably from the stone-to-stone aesthetic provided by anchorage systems (Figure 1.17). Significant to the weather-proofing capability of veneer walls, and thus overall performance, sealant formulas were altered over time to become more flexible. The anchorage systems and specifications will be covered in further detail in following chapters.


Although thin stone veneer was being used in the 1950s, its placement was primarily limited to the exterior ground floor and interiors. The most compelling reason for the limited use of stone appears to be the dominance of the early Modern architectural language made popular from European transplants who preferred glass and metal over stone. The United Nations Secretariat Building (1952), the physical culmination of international diplomacy following the Second World War, was built as a rectangular slab with primary building faces of glass curtain walls, with limited amounts of marble cladding on the narrow sides, from top to bottom (Figure 1.18). Finished the same year as the Secretariat was the Lever House, designed by Gordon Bunshaft, which in common

43 This statement is concluded from the preliminary building survey. Park Avenue North of 42nd Street is lined with such buildings.
thought epitomized the Early Modern curtain wall with what Robert Stern called “a play of light and shadow on glass, an art of literal transparency and surface reflectivity” (Figure 1.19). The aesthetic of the sleek machine was expressed to “emphasize capitalist individuality,” and over time, the result of many Lever House imitations was architecture that lost its stylistic integrity and relationship with people. Michael Lewis believed that, “without precedents or formal references, the oversized style lost human relationships. The expansive, smooth shiny surfaces offended the human sense. Building-scapes became increasingly glaring and noisy. Streets became alienating caverns of characterless reflections.” While this statement makes a grand presumption, it hints at the fact that people became less committed to the aesthetics of entirely glass facades.

Departing from the Early Modern aesthetic accentuated by heavy use of glass and metal, the 1960s introduced the Modern and Brutalism aesthetics that used more stone and concrete for exterior cladding. Brutalism especially is marked by the use of concrete in a range of aesthetics, from precast to exposed aggregate. In 1965, the American Concrete Institute held a symposium on precast concrete wall panels that influence the way concrete was used as an exterior material. The Yale Art and Architecture School (1963) is exemplar of the exposed aggregate aesthetic expressed through use of precast panels (Figure 1.20). The Pirelli Building (formerly the Armstrong Rubber Company Building, 1969) in New Haven, Connecticut, exemplifies the multifaceted precast concrete aesthetic that became ever more popular into the 1970s (Figure 1.21). Stone use as veneer became increasingly popular in the 1960s and 1970s. New York City’s skyline saw multiple stone clad additions. The GM Building (1964-8), accentuated by alternating, vertical marble piers, marked Fifth Avenue with a stone high-rise (Figure 1.22). On the other side of town, Lincoln Center for the Performing Arts

46 Ibid, 16.
The Yale University Art and Architecture Building, now Paul Rudolph Hall, exhibits corrugated, exposed aggregate concrete panels. “To form the rough walls, concrete was poured into corrugated forms and the rigid surfaces were broken with a hammer to expose the aggregate to weathering elements.”

1963, Paul Rudolph, New Haven, CT.
Daniel Fox, Yale University Art and Architecture Building Fiche, DOCOMOMO: docomomo-us.org

“Breuer exploited concrete’s ability to be cast into an endless variation of forms. Because of this, one material could fulfill the needs of structure and aesthetics. The concrete panels, which were pre-cast, were made of white cement with a dark aggregate that was exposed via light sandblasting.”

1970, Marcel Breuer, New Haven, CT.
Cristiana Pena, Pirelli Tire Building Fiche, DOCOMOMO: docomomo-us.org

The height of the General Motors Building, designed by Edward Durell Stone and Emery Roth & Sons, is accentuated by uninterrupted marble piers from the sidewalk to the roof.

1968, 767 Fifth Avenue, between East 58th and East 59th Streets.
Figure 1.23
Each building of the Lincoln Center complex is clad in travertine. This was one of the first uses of travertine as an exterior veneer. Pictured here in the center is the Metropolitan Opera House, with (moving clockwise) the Philharmonic Hall (now Avery Fisher Hall) and the New York State Theater (now David H. Koch Theater). 1962-1968, Wallace K. Harrison, Max Abramovitz, and Philip Johnson. West 62nd to West 66th Streets, between Columbus and Amsterdam Avenues.

Figure 1.24
The CBS Building is nicknamed the “Black Rock,” because of the dark, Canadian granite that clads the tower in pointed piers. “One of the several buildings of its time to depart from established post-and-beam framing, CBS supports its floors instead on its central core and a dense grid - in effect a bearing wall - at the exterior.”

1965, Eero Saarinen & Associates
51 West 52nd Street
Willensky and White, AIA Guide to New York City, 274-5.
Arts (1962-69) was fully clad in travertine, a stone not typically employed for exterior use (Figure 1.23). The CBS Building (1965), nicknamed the “Black Rock” because of the near-black Canadian granite used to clad the exterior, added a dramatic display of granite cladding to the New York skyline (Figure 1.24). The utilization of concrete and stone continued extensively into the 1970s and was encouraged following the energy crisis of the early 1970s. The energy efficiency of buildings became an important point of design, and the construction materials were an integral part of achieving sustainability. Following Lincoln Center in the application of travertine veneer was the WR Grace Building (1974), designed by Gordon Bunshaft; the curved, fifty story façade exhibits the travertine in a very different manner (Figure 1.25).

While the progression of stone to thin veneer followed in a long line of material developments, it could not be fully realized without the acceptance of the Modern movement in architectural design. A number of technological refinements, including stone cutting equipment, steel framing, and anchorage and support systems, were necessary before thin stone veneer could be applied to building elevations. The Modern movement expressed the desire for clean, sleek facades devoid of any classical or traditional ornamentation, which allowed stone, a conventional building material, to reemerge for a new, modern purpose.
Figure 1.25
The W.R. Grace Building was designed by Skidmore, Owings & Merrill and completed in 1974. The travertine and glass facade gently slopes upward from West 42nd Street.
41 West 42nd Street, between Fifth and Sixth Avenues
Willensky and White, AIA Guide to New York City, 238.
BIBLIOGRAPHY


STONE IN ARCHITECTURE
PART 1: ATTRIBUTES OF STONE AS APPLIED IN
ARCHITECTURE

“As stone is the oldest building material known to man, most of the oldest structures in any society are built of, or clad in some type of stone product. However, modern architectural applications of stone… require a much greater understanding of some stone properties than were needed for cubic, load-bearing stone structures.”

Stone has been a building material of choice for centuries because of its inherent beauty which endures without failure and with minimal maintenance. However, the increased complexity of modern thin stone veneer necessitates “extensive and objective evaluation” of stone and its intended application during the selection process. Empirical evidence can easily illustrate the way stone has performed previously, but even stone with a satisfactory performance history still needs to be tested and evaluated, because its application has wholly changed from a load bearing to a thin veneer use. When thin stone veneer does fail, it is more often than not due to “improper application, rather than the inherent properties of stone.”

The natural characteristic of stone has positive attributes that prove suitable to thin veneer application, but stone certainly has limitations. A comprehensive assessment of physical characteristics will illustrate these attributes and allow a comparative analysis of selected stone types.

The strength and durability of stone is empirically proven from historical use. This can be explained by an understanding of the physical properties which set stone apart from other building materials. Three properties of stone which effect performance are its low coefficient of thermal expansion, relatively low level of permeability, and high level of compressive strength. The latter two characteristics imply that stone has a high density, or bulk specific gravity, relative to other building materials which is a good “preliminary indicator of the stone’s durability and moisture resistance.” While this is true of stone in

3  Ibid, 1.
4  Ibid.
5  “Placing stones in unsuitable environments, faulty fabrication, installation, or construction practices, and incompatible associated materials are frequent causes of stone system failures (for example, high-porosity stones in subgrade applications, inadequate anchorage or expansion space, mortars leaching alkalis, inappropriate strength mortars, staining grouts, voids in setting beds, and pavement stones with inadequate resistance to abrasion).”
general, all types of stone are not created with the same level of density; however, each will perform well if used appropriately. A higher density suggests “less microscopic voids, faults, and perhaps a more intact crystalline structure,” and less ability to absorb moisture.7 Moisture can potentially break apart even the strongest stone over time through cycles of freeze and thaw.8

While stone has proven to be relatively durable, the case studies that have provided this empirical knowledge are traditional stone structures built from cubic stock. Permeability changes with a change in thickness, since moisture penetrates a greater percentage of the stone’s mass when in thinner dimensions. The slight damage done to a block of stone from freeze and thaw cycles has a greater impact on thin stone veneer and affects the structural integrity of the veneer. Additionally, the thermal performance of stone changes as well when cut to thin veneer. As mentioned, stone has a small coefficient of thermal expansion and is considered a relatively volume stable material. “However, certain uniform-textured, fine-grained, relatively pure marbles, retain a permanent small incremental volume increase after each heating cycle.”9 This is known as hysteresis and is exhibited by a bowing of thin stone panels, particularly marble (Figure 2.1).10 Furthermore, the compressive strength of stone, which has proven to be of significant value when

---

7 Lewis, 65.
8 Freeze thaw cycle: Water freezes in the pore structure of the given stone; since ice takes greater volume than water, it expands within the pore creating pressure on structure. Cracks are created among the crystalline structure from the expansion, which creates a larger pore. The cycle continues creating more cracks and a larger pore until the stone ultimately fractures.

10 “The permanent residual expansion occurs in the surface region exposed to the higher temperature, and the hysteresis effects are restrained or are accommodated by the unaffected portion of the veneer. However, for thin marble veneers, dilation of the surface region can overcome the restraint of the backside portion and cause bowing. The bowing is actually a dishing of the marble veneer because of the greater expansion across the diagonal axis of the stone. The compressive force at the backside of the veneer causes creep, which assists in retention of the dish shape,” from R. Ian Chin, John P. Stecich and Bernard Erlin, “Design of Thin Stone Veneers on Buildings,” Proceedings from the Third North American Masonry Conference (Arlington: The Masonry Society, June 1985), 10-6.
utilized in construction as a bearing material, is of little importance for thin stone veneer systems in which stone plays no structural role. The physical property that is of worth is flexural strength, and stone has very poor flexural ability. Stone is a very brittle material; it does not deform under stress before failure. It offers little warning before failure, which is “characterized by sudden rupture,” or cracking. Finally, the chemical weathering of stone, which became a greater problem in the last fifty years from the increased release of chemicals into the atmosphere during the twentieth century, has a greater effect on thin stone veneer than it does on cubic blocks. Stones made of calcium carbonate (limestone, dolomites, and marbles) are vulnerable to “attack by sulfurous and sulfuric acids, and to a lesser extent by carbonic acid and ammonium salts. These substances react chemically, the sulfur-based acids forming gypsum, and the carbonic acid and ammonium chemicals causing dissolution of the lime component.” This is essentially decaying of the stone and will weaken a thin stone panel much more quickly than it will cause failure in a block of stone.

11 Lewis, 61.
12 Chin, 7.

Figure 2.2
Three common building materials used together: terra cotta (ornamental column and panel), brick, and stone (granite). The terra cotta panel is finished to imitate stone cladding but exhibits cracking patterns typical to its true material.

Figure 2.3
A colorful, glazed terra cotta column stands adjacent to a glazed terra cotta block, meant to mimic marble. The crazing (cracking pattern) on the block’s face is common to glazing, and is one of the reasons terra cotta is susceptible to water infiltration between the glaze and the terra cotta body. When this occurs, spalling of the finish is almost inevitable.

Figure 2.4
At the base of a building, real granite cladding sits opposite cast stone imitation, which uses aggregate of the same color range.
Despite these limitations of thin stone veneer, it continues to be chosen for such use in large part for its aesthetic qualities. The colorful and textured surface of stone has been mimicked in a number of other mediums including terra cotta glazing, paint, and cast stone (Figure 2.2-2.4). It is appreciated and valued as a material that offers visual warmth and a sense of prestige and permanence. It is considered a material of high worth used for institutional and monumental architecture. “The rich variation in color and texture, as well as its ability to age gracefully in the exterior environment, has made stone one of the most popular materials for construction, sculpture and monuments.”13 This variety in aesthetics is heightened by the ability of stone to take different finishes, which can range from glossy or mirror-like to rough, corrugated or abrasive.

This variety of color and texture is due to the heterogeneity of the mineral structure, which creates a difficulty in understanding or predicting the way thin stone veneer might perform. The heterogeneity of the mineral structure means that a piece of stone is made from a number of minerals. As a result of the varied mineral composition, stone from the same quarry, and even from the same block, could have tremendously varying physical properties. The level of heterogeneity ranges within the category of stone. The heterogeneous nature of the material also means that the grain size of a stone varies within a given area, which is referred to as anisotropic. The implication this holds is that the physical properties of stone are location dependent. Veining and bedding are signs of this and act as natural points of weakness (Figure 2.5). “Bedding planes can result in significant differences in strength, cause poor weathering performance (e.g. splitting along bedding planes), and influence the behavior of anchorage systems.”14 Not only will one slab perform differently from another, but the same slab will perform differently when positioned differently and stresses are applied differently. This physical property is known as nonlinear elasticity. The American Society for Testing and Materials (ASTM) developed a number of testing methods to help challenge this performance variability and identify stone that is appropriate for use as thin veneer, which may be referred to for further information.15

14 Chin, 7.
15 ASTM C97 (Absorption and Bulk Specific Gravity), C99

Figure 2.5
The marble on the interior of the New York Public Library is a fine grained, white marble that clearly exhibits veining.
Another positive attribute of stone, and perhaps the most obvious, is that it can be found in nature, and is ready to be used upon extraction. The convenience of ready-made material was fully realized once machinery took over the job of cutting and finishing the stone that was previously done by hand. The ability to be extracted and finished by machine made thin stone veneer cost effective. This ready-made, natural aspect of stone also means that quantities are limited. Sometimes a specific stone may only be found in one quarry, which not only raises the issue of sustainability but also that of repair. When stone on an existing building needs replacing, but the original quarry has been depleted, precise matching of original materials can be extremely challenging.

Although thin stone veneer use clearly has limitations, it has not been detrimental to continued use as a veneer choice. The limitations have simply been reconciled, and the structures onto which the stone is installed accommodate them. Over the last fifty years and through much testing, these structural systems have improved, refinements in veneer technology have been made, and the criteria for stone selection have become more exact. Consequently, the decision as to which type of stone to use is based on a thorough understanding of the geological characteristics balanced with aesthetic considerations.

(Modulus of Rupture) and C880 (Flexural Strength) are especially helpful in this regard. “Absorption and Bulk Specific Gravity can be good preliminary indications of the stone’s durability…it is more indicative of a stone’s potential resistance to weatherability.” “Modulus of Rupture measures the combined shear strength with diagonal tension strength, which is most applicable in predicting the stone’s capacities at its points of engagement with anchors.” “Flexural strength measure tensile strength and is most applicable in predicting the (flexural) capacities of the stone panel itself between the anchorages,” (Lewis 66-67).

PART 2: GEOLOGICAL INFORMATION OF STONES USED COMMONLY IN ARCHITECTURE

Limestone

“Sedimentary rocks, or layered rocks, are formed either by the accumulation of fragmentary rock material by streams, waves, or wind, or as organic accumulations and chemical precipitates.”

- Erhard M. Winkler

Limestone is a sedimentary, monomineralic rock consisting of calcium carbonate (CaCO₃), known as calcite, “the double carbonate of calcium and magnesium (dolomite), or a mixture of the two.” It is formed by the precipitation of calcite from ocean water often including skeletal organisms. In addition to calcite, limestone contains minute quantities of iron-bearing minerals, clay and organic material from the organisms, which is darker in color and peppers the stone (Figure 2.6). Due to the uniformity of deposition, limestone often lacks a distinct cleavage plane, which means it can be machined or cut in any direction without danger of splitting; however, “some limestone is ‘anisotropic,’ or directionally specific in their physical and visual properties, and have a preferred splitting direction.” Consequently, some limestone is more suitable for thin veneer purposes. The gray to buff colors of limestone come primarily from the oxidation of the organic matter by ground water moving down through the stone deposit.

---

18 Ibid.

Figure 2.6
Fossils of the organic material are evident in limestone facings. The general pattern is noticeable even from a relatively distant perspective, but the fossils are even clearer upon closer inspection.
Marble

Geologically, marble is limestone that has undergone metamorphosis. When the limestone is subjected to increased pressure and temperature, it recrystallizes to create “new minerals which chemically resemble the parent material but are more stable under the greater heat and pressure.”19 The size of the mineral grains depends upon the “metamorphic intensity” of the process, which lasts millions of years. The higher the intensity, the larger the grain.20 The grain size of marble reflects its ability to withstand the effects of natural weathering; “marbles with a fine-grained, equigranular texture tend to be less weather-resistant than those with a medium to large grained, inequigranular texture.”21

Given that marble originates from limestone, it is also composed of calcium carbonate and may include magnesium carbonate. Within the geological definition of being a metamorphosed limestone, “the term marble is correctly applied only to rocks comprising crystallized grains of calcite (calcium carbonate) or dolomite (calcium magnesium carbonate), or both.”22 Marble varies in color from white to pink and brown due to mineral impurities left from the limestone that are affected during the metamorphosis.

Travertine

Travertine, although a type of limestone, has a differing creation process. The creation of travertine is through chemical precipitation, which “results primarily through the transfer (evasion or invasion) of carbon dioxide from or to a groundwater source leading to calcium carbonate supersaturation, with nucleation or crystal growth occurring upon a submerged surface.”23 The key part of this process is the reduction of carbon dioxide gas from a calcium bicarbonate solution which results in the calcium carbonate deposition. The characteristic voids of travertine are product of the presence of gases during formation (Figure 2.7). When travertine is used for an architectural purpose, whether flooring, cladding, or ornamental, the voids are often filled with a cementitious or resinous filler “to increase durability and facilitate maintenance of the material.”24 The aesthetic that the voids create is often the reason for choosing travertine over another stone, however if it is applied inappropriately with vertical bedding, the voids can allow water infiltration and cracking as a result of freeze/thaw cycles.25 Despite travertine’s geological

19 Winkler, 25.  
20 “Low metamorphic zones lead to the formation of slates, fine-grained marbles, and granite-gneisses, whereas higher metamorphic processes form schists and coarse-grained marbles.” Winkler 25  
21 “…the latter usually has an interlocking texture (grains with irregular boundaries, that interlock by mutual penetration,” from

25 Ibid. “A limited number of travertine materials are suitable for exterior use, particularly in horizontal applications subject to
classification as a limestone, it is occasionally categorized with marble because of its ability to take a high shine.

**Granite**

“Igneous rocks, also called primary rocks, crystallize from a hot silicate melt, the magma.”

- Erhard M. Winkler

Granite, composed of quartz, feldspar, mica and sometimes ferro magnesium minerals, is an igneous rock, created from liquid earth that slowly cooled and hardened. The more slowly the liquid cools, the larger the grain size of the stone; typically granite is “visibly granular.” The large, inequigranular structure of granite results in a very hard, incredibly dense, and almost nonporous stone that is most suitable for use in contact with the ground or exposure to severe weather and climate. It takes a very high polish and ranges in colors from dark grays to pink and green (Figure 2.8).


26 Winkler, 3


28 “Dark granular igneous rocks, classified petrographically as gabbro, anorthosite, basalt, or diabase, are also included in the granite group and often referred to as ‘black granites,’” from ASTM International, “Standard Guide for Selection of Dimension Stone,” 3.
Quartz Based

“The term ‘Quartz-Based’ is a general commercial term including a variety of rocks, all of which consist of high contents of quartz and silica.”29 Included in this category is sandstone, a type of stone often employed in the exterior cladding of buildings.30 It is a sedimentary rock, bonded together by silica or calcium carbonate, that has prominent bedding planes and anisotropic properties.31 The mineral grain size within sandstone ranges greatly from coarse to fine. Together the varying grain size and bedding planes have a tremendous impact on the performance of the stone. The bedding planes act as natural rifts along which the stone is more likely to fracture when under stress or the effects of weathering. The grain size affects the type of possible finish; fine grained sandstones can achieve a smoother finish than coarse grained sandstones.32

PART 3: STONE SELECTION

The discussion in Part 1 of the broad characteristics of stone illustrated the reasons why stone is valued as an architectural veneer material, as well as the limitations that must be respected in a thoughtful design. Part 2 explained the individual characteristics of each stone used commonly in architecture; it also demonstrated that each stone type is compositionally different, thereby affecting the performance of the stone. This section is meant to shed light on the selection process of stone and how one stone might be superior to others.

The process of stone selection involves a number of factors including cost, aesthetic, available, and durability. Naturally these factors are intertwined. The initial cost of stone is primarily driven by the availability and workability, the latter of which is defined as the level of effort and money required to cut and finish a piece of stone. The long term cost must consider the required maintenance, which depends on the durability of the stone and the applied finish – for instance, a high polish finish requires more frequent maintenance than a rough finish. Price may initially limit the number of options, but the ultimate decision is often a balance of aesthetic and performance criteria.

When considering the aesthetic of a stone, the weathering, or soiling, and finish must be evaluated; a smooth, matte finish might hide soiling better than a rough or polished finish. Additionally, a more durable stone will withstand deterioration and maintain the desired aesthetic longer. Frequently the desire for a certain stone’s aesthetic or color outweighs all cost and performance concerns. Ideally, responsible designs would not place stone in unsuitable situations, such as sandstone face bedded at a building base, but this certainly happens.

Historically, accessibility and cost had a significant impact on which building stones were being used.33 Softer stones, such as marble and limestone, were chosen due to their ready availability and ease of extraction.

32   Ibid.

33 A few trends present themselves in the hundred years leading to the Modern architecture movement. Marble and limestone were the stones most frequently chosen to dress whole building elevations; they were often selected for monumental or institutional purposes. The physical properties for these two stones is such that they perform relatively well, and both are easily accessible. Granite, when used on the exterior, was more often than not left for ornamental purposes or used sparingly. Difficulty exists in the working of granite; it is the hardest of the stones, making it very expensive to cut. Sandstone was employed at times for cladding building exteriors, but was more commonly known for its small scale, residential purposes, such as the houses that took the name “brownstones” after the brown sandstone that clad the exteriors.
The high compressive strength of cubic stone supported the development load bearing nature of construction from antiquity through the early twentieth century. All of this changed with the mid-century Modern architecture movement. Transportation and cutting costs lessened, which created a more level playing field among stone types; consequently, accessibility and cost became less significant factors in the stone selection process. Furthermore, the use of stone as a thin veneer material meant that it no longer carried any load, and the important criteria, aside from aesthetic preferences, transferred from compressive strength to the durability of stone as defined as the level of absorption, density, and flexural strength.

Stone’s ability to absorb moisture is detrimental to its structural integrity. Freeze/thaw cycles, in which trapped water freezes and expands to create a larger space than before, slowly creates microfractures in the stone’s grain structure until it fails. The level of absorption is dependent on the porosity of the stone – the greater the percentage of interconnecting voids, which also helps indicate the density value, the greater the ability to absorb moisture. For instance, limestone and sandstone, which have density values ranging from 110-160 lb/ft$^2$ and 125-150 lb/ft$^2$ respectively, are the most absorbent stones, able to take in up to 3.12% and 3.8% of their weight. However, the numbers do not tell the whole story. For instance, marble and granite have the lowest absorption percentages at .2% and .4%, and despite marble’s superior absorption percentage, granite typically performs better when in contact with water because of its granular structure (Figure 2.9). As mentioned previously, the large, inequigranular structure weaves together tightly to minimize water absorption. For these reasons, granite is the stone most suitable to placement at building bases. Conversely, sandstone exhibits high porosity and stratification. Stratification aids deterioration, because the layers act as natural lines of fracture especially when freeze/thaw cycles create pressure from within the pore structure. Consequently, stones with clearly demarcated bedding planes are limited in appropriate use. Travertine, like sandstone, exhibits stratification through the characteristic voids; these stones perform successfully when laid in the natural bedding orientation. If placed vertically, the stone is prone to spalling; water enters the travertine from the top and filters through the slab, and sandstone panels absorb water from beneath and slough off flakes following freeze/thaw.

Paramount to the success of stone as a thin veneer material are the modulus of rupture and flexural strength. The modulus of rupture test essentially examines point loading on stone in ‘cubic’ dimensions, which tells much about how a stone panel will perform at points of anchorage. Marble, travertine, high density

---


36 ASTM C99 and C880 were designed for these testing purposes. The modulus of rupture is “most applicable in predicting the stone’s capacities at its anchorage’s engagements” (Lewis, 66). ASTM C99 calculates the combined shear and diagonal tension strengths. ASTM C880 “measures the stone’s primarily tension strength by bending, which is most applicable in predicting the capacities of the stone panel itself between the anchorage” (Lewis, 67). Please refer to ASTM C99 and C880 for more information on these testing procedures.

37 Lewis, 66.
limestone, and high density sandstone have a minimum modulus of rupture of 1000 psi. Granite, on the other hand, has a modulus of rupture of 1500 psi, which infers that a thin granite veneer panel can withstand greater pressure. Granite also has a greater flexural strength than the other stones, illustrating its ability to withstand loads before failure. That the flexural strength for limestone or sandstone is not even provided in the corresponding ASTM specifications and the modulus of rupture is given attests to the fact that they are ill-suited for thin veneer uses. Marble, while a very popular thin veneer material because of relative abundance and easy workability, is often used in conjunction with precast concrete materials to provide further flexural strength.


Bibliography
1960s Thin Stone Veneer Specifications
The successful performance of exterior wall systems does not merely depend upon the inherent qualities of the main cladding material or even the technology used to secure it to the structure; the success of a system is often dependent on the specification and detailing of the assembly. The construction specifications of a time period can offer much insight into why things did or did not work, and indicate an understood at that time of the limitations of materials and systems. To understand why Modern thin-stone veneer buildings have had performance problems since the time of completion, it is important to return to the source which is the original technical specifications. The specifications addressed panel configuration and thickness, accommodation for movement, moisture control, and fastening systems. This chapter addresses the first three subjects, and leaves the fastening systems to be discussed in intimate detail in the following chapter.

The decade of the 1960s represents a seminal point in the development of thin stone veneer systems, because enough of the system’s limitations were understood to have implemented many standards that still stand today, but much had yet to be fully resolved. In the pre war era through the 1950s, stone made a transformation from a load bearing material to a cladding, but thin stone cladding was still in its infancy. By the 1960s, thin stone veneer had become cost effective and more widely used. Since that time, thin stone veneer has experienced continued evolution and refinement. For much of the twentieth century, the Marble Institute of America (MIA) and Indiana Limestone Institute (ILI) were the authorities of their given stone; each institution produced literature addressing their material and how it ought to be implemented in architecture. Consequently, the 1960 specification manuals from these companies, primarily the MIA, are used here to discuss the detailing in use at such a significant time in the evolution of stone fasteners.

**FINISHES**

The finish of stone has a direct impact on its aesthetic, and it can also directly affect the performance of a stone panel (Figures 3.1-3.3). Consequently, while the choice of exterior finish may seem to only be of ornamental value, it is of far greater significance. The common marble finishes of the early 1960s included the polished, honed, and sand or abrasive finishes. The polished finish created a “mirror-like glossy surface which brings out the full color and character” of the marble and was not recommended for exterior use by the MIA. The polish was expected to grow dull with

---

1 The finishes discussed here are the most commonly advertised in stone catalogs, and perhaps the most popular popular of that time.
2 Marble Institute of America, Inc, “American Standard Specifications for Thin Exterior Marble Veneer (2 Inches and Less in Thick-
weathering as an exterior finish and would need more frequent maintenance than other finishes. By contrast, the sand or abrasive finish performed well for exterior use; it was a “flat, non-glossy surface” that masked signs of weathering. The honed finish entailed a “velvety smooth” aesthetic “with little to no gloss.” Limestone was offered in a few different finishes appropriate to its mineralogical composition. The shot finish was a rough gang-saw finish “produced by sawing with coarse chilled steel shot or pellets,” which created a range of roughness from a “medium, pebbled surface to heavily rippled, irregular, rough grooves.” The chat finish created a more uniform, granular appearance, and the sand finish, similar to that of the marble finish, produced a “fine to coarse, granular finish.” Finally, the remainder two common architectural limestone finishes were the smooth and tooled finishes, the latter of which was a custom designed aesthetic that offered textural finishes.

The number and type of options available today for stone finishes are generally the same of those of the 1960s. Perhaps the preference of aesthetic has changed over time due to the decrease of pollution since the mid-twentieth century. The change in air quality might have lessened the frequency of required maintenance or diminished the detrimental impact on the stone aesthetic; although an interesting point of comparison, this hypothesis requires further research. The finishes

---

3 Conversely, granite can take a high gloss as an exterior finish and perform well due to its superior weathering abilities.
5 Ibid.
8 Ibid.
available today, not categorized by which stone it corresponds, are the polished, honed, thermal (or flamed), sanded (or sandblasted), bushhammer, 6/8 cut (or 6/8 point), split (or splitface), rockface (or hand-hewn, rockpitched, pitched), smooth (also machine smooth or diamond ground), sawn, natural cleft, sand rubbed (or abrasive), machine gaged, natural strata (or quarry face), and tooled.\(^9\)

---

\(^9\) ASTM International, “Standard Guide for Selection of Dimension Stone,” Designation: C1528-12 (ASTM International, 2012), 10-11. The following descriptions are taken from ASTM C1528. Polish: “is a smooth, glossy and highly reflective finish produced by mechanical abrasion and buffing.” Hone: “a smooth, nonreflective finish produced by varying degrees of mechanical abrasion.” Thermal or Flamed: “is produced in granite, granite-like, quartz-based, and dolomitic limestone materials by a brief exposure to a high temperature flame. The process results in an exfoliation of the surface, creating a textured finish.” Sanded or Sandblasted: “is produced by ‘sandblasting’ the material with abrasive particles at high velocities. The resultant finish is a finely textured surface, which is generally lighter in appearance than the untreated stone; color and veining are not as prominent through this finish.” Bushhammer: “made with a pneumatic hammer and a carbide tipped head having numerous points. The resultant finish is a textured surface with a relief of up to several millimetres.” 6/8 Cut or 6/8 Point: “made with a pneumatic hammer and a carbide tipped chisel having 6 or 8 closely spaced straight blades. As the pneumatic hammer traverses that stone, the chisel is rotated 10 to 30 degrees producing a ‘her-ringbone’ effect.” Split or Splitface: “refers to the natural cleft surface left when the rock is broken. The breaking of the stone is done with driven wedges.” Rockface: “is an embellishment to a split surface. The split surfaces are ‘hand-pitched’ with carbide tipped chisels to produce a protruding or ‘pillowed’ profile.” Smooth: “is a smooth surface with a minimum of surface interruption. This finish can be achieved by either sanding or grinding.” Sawn: “a general term describing a surface that has been cut, shot, sand, or diamond sawn. It is comparatively rougher than ‘ honed’ or ‘smooth.’” Natural Cleft: “is achieved by splitting the material along its natural cleavage plane…most commonly associated with slate.” Sand Rubbed or Abrasive: “a nonreflective, matte finish with a slight grain or stipple pattern visible on the surface.” Machine Gaged: “a surface that has been ground smooth with circular abrasive heads. The degree of smoothness may vary from one producer to another. Slight, circular patterend swirl marks may be visible in some material.” Natural Strata or Quarry Face: “a rough, uneven finish, similar to splitface, but the surface of the stone is left as it naturally occurs at the top layer of the sedimentary formation, quarry seam, or bedding plane.” Tooled: “a finish with a linear textural pattern, with concave parallel grooves usually 6, 4, 6/8 Cut or 6/8 Point, split (or splitface), rockface (or hand-hewn, rockpitched, pitched), smooth (also machine smooth or diamond ground), sawn, natural cleft, sand rubbed (or abrasive), machine gaged, natural strata (or quarry face), and tooled.\(^9\)

---

\(^9\) ASTM International, “Standard Guide for Selection of Dimension Stone,” Designation: C1528-12 (ASTM International, 2012), 10-11. The following descriptions are taken from ASTM C1528. Polish: “is a smooth, glossy and highly reflective finish produced by mechanical abrasion and buffing.” Hone: “a smooth, nonreflective finish produced by varying degrees of mechanical abrasion.” Thermal or Flamed: “is produced in granite, granite-like, quartz-based, and dolomitic limestone materials by a brief exposure to a high temperature flame. The process results in an exfoliation of the surface, creating a textured finish.” Sanded or Sandblasted: “is produced by ‘sandblasting’ the material with abrasive particles at high velocities. The resultant finish is a finely textured surface, which is generally lighter in appearance than the untreated stone; color and veining are not as prominent through this finish.” Bushhammer: “made with a pneumatic hammer and a carbide tipped head having numerous points. The resultant finish is a textured surface with a relief of up to several millimetres.” 6/8 Cut or 6/8 Point: “made with a pneumatic hammer and a carbide tipped chisel having 6 or 8 closely spaced straight blades. As the pneumatic hammer traverses that stone, the chisel is rotated 10 to 30 degrees producing a ‘her-ringbone’ effect.” Split or Splitface: “refers to the natural cleft surface left when the rock is broken. The breaking of the stone is done with driven wedges.” Rockface: “is an embellishment to a split surface. The split surfaces are ‘hand-pitched’ with carbide tipped chisels to produce a protruding or ‘pillowed’ profile.” Smooth: “is a smooth surface with a minimum of surface interruption. This finish can be achieved by either sanding or grinding.” Sawn: “a general term describing a surface that has been cut, shot, sand, or diamond sawn. It is comparatively rougher than ‘ honed’ or ‘smooth.’” Natural Cleft: “is achieved by splitting the material along its natural cleavage plane…most commonly associated with slate.” Sand Rubbed or Abrasive: “a nonreflective, matte finish with a slight grain or stipple pattern visible on the surface.” Machine Gaged: “a surface that has been ground smooth with circular abrasive heads. The degree of smoothness may vary from one producer to another. Slight, circular patterend swirl marks may be visible in some material.” Natural Strata or Quarry Face: “a rough, uneven finish, similar to splitface, but the surface of the stone is left as it naturally occurs at the top layer of the sedimentary formation, quarry seam, or bedding plane.” Tooled: “a finish with a linear textural pattern, with concave parallel grooves usually 6, 4,
require a minimum of 3” in thickness. The panel thickness can increase depending on a number of features. If a panel is larger than 16 square feet or is placed in a high wind pressure, the thickness must increase. If the panel experiences “greater weather exposure,” it must increase in thickness. If the service life is expected to be greater than that of its exemplar and if the anchors cannot be placed so that the stresses are reduced, the thickness must increase. Finally, an increase must occur to accommodate shipping and handling concerns or architectural features such as finishes or reveals, which reduce the structural capacity of the panel. These dimensional adjustments are all intended to lessen the risk of panel failure by means of flexure, cracking or severe weathering.

JOINT CONFIGURATION

Another means of avoiding panel failure is by expansion control through joint configuration and composition. The MIA called for expansion joints in the early thin marble veneer panel systems saying, “A provision shall be made for thermal expansion and contraction…in large areas of exterior marble veneer, or where there are ‘long runs’” such as spandrel belts. Horizontal expansion joints were recommended on at least every other floor height, and vertical joints were specified at 20’ intervals. ‘Long runs’ or spandrel belts were recommended to have no more than one expansion joint every 20’. These joints were required to be 3/8” in width and “backfilled with an inert type resilient material” (cotton rope, sponge rubber, or plastic) not to exceed half of the joint depth. For the front half of the joint, polysulfide or similar synthetic rubber base caulking compound was suggested to solidly fill the void. Also suggested, specifically for horizontal expansion joints, was the application of “load bearing resilient spaces of hard rubber, neoprene, or similar materials to help maintain proper joint width.” The placement of horizontal expansion joints was required “directly beneath relieving angles when such angles occur(ing) at each story height.”

Although materials and suggested location may have changed for expansion joints over time, at the heart of this suggestion lies the fact that thermal movement was generally understood early, by the start of the 1960s. Furthermore, this issue was addressed by the addition of plastic joints, a method still used in contemporary construction. This indicates that architects and engineers of that time were knowledgeable of building movement and had a clear theoretical understanding of the importance and application of joints. Missing at this time, however, was empirical data due to the relative novelty of the system. Performance issues with early thin stone veneer wall systems arose in the decades following completion. These problems could also potentially attest that masons at that time continued to build as their tradition taught, without regard to the new calculated requirements of the architects and engineers; or, it might simply prove that the performance is dependent on the workmanship of the workers on site, which is very difficult to guarantee. Nonetheless, by this time in the evolution of thin stone veneer wall systems, it was understood that tolerances needed to be made for thermal movement and that calculated efforts led to the addition of expansion joints.

13 Ibid.
14 Ibid.
17 Ibid
18 Ibid
The specifications for joints with no anticipated movement were similarly prescriptive. The MIA specified different joint sizes for panels of varying thicknesses. Marble panels 7/8” thick required joints 1/16” or 1/8” in width, while 1 ¼”, 1 ½”, and 2” thick panels needed 3/16” wide joints. All joints were to be filled “solidly with non-staining elastic jointing compound” (such as a polysulfide or similar synthetic rubber base or regular mastic type), or with cement lime mortar. Plastic or aluminum cushions were needed to maintain weight bearing joints. The ILI was more specific about the mix of the pointing and setting mortars. It was ill-advised to use a strong mix for a pointing mortar, because it could create “a condition favorable to spalling.” Mortar mixes (varied) in proportions from a hard mixture” of one part cement of one part lime to four parts sand (1:1:4) by volume, “to a flexible mixture (1:1:9).” The hard mixes were known to create stress between the stone and mortar in vertical joints since the thermal coefficient of mortar expansion is greater than that of stone.” Very flexible mortars were also inappropriate because they did not have sufficient resistance to weathering. The use of Portland cement was also not advised because of its salt content, which contributes to efflorescence. Experience led the ILI to recommend a standard mix of 1:1:6 as most appropriate. To improve bonding strength, the ILI suggested adding hydrated lime or “like amounts of ground limestone,” which would increase initial shrinkage but also improve the working ability. All the mortar joints, anchor slots, lewis holes, etc. were to be completely filled with these materials to prevent water from entering and freezing to cause fracture, and the cavity in cavity walls needed to be kept clear of mortar droppings during construction to allow effective drainage within the wall. Caulking, of the polysulfide, butyl, silicone rubber, and acrylic types, was suggested as a satisfactory alternative to traditional mortar. “Ordinary caulking,” meaning oil and resin based caulks mentioned in the MIA specifications, were no longer suggested by this time, because they “required painting to prevent evaporation of the oils, and the oils can impregnate the stone and cause staining.”

The 1960s were a significant time in the history of jointing materials, as many of the sealants used contemporaneously were first developed then. The steady progress sealants have made since then has most likely prompted the greatest change in wall efficiency. The use of sealant as a joint material, a compared to mortar, was dramatically increased as a percentage of the wall. Although continued refinements have occurred

---

19 Ibid.
21 Ibid.
22 Ibid.
24 The following information is taken from, Michael J. Scheffler and Richard Cechner, “The Development of Sealants and Their Significance to the Modern Curtain Wall,” Preserving the Recent Past, 1995: 31-35. Polysulfide sealant: “is a high performance sealant that is based on a synthetic polysulfide polymer or rubber, based on the polysulfide polymer developed by the Thiokol Chemical Corporation in 1929” (32).
Butyl: “are butyl rubber-based, became available to the building construction industry in the mid 1950s,” “are one-component and have a limited movement capacity…typically for glazing joints and splice seals in window units and not used between joints in certain wall components that are exposed” (33).
Silicone: “are high performance sealants that did not become widely available to the building construction industry until around the 1960s, although the development of the silicone polymer used in silicone sealants dates from the early 1800,” “are most frequently used for non-porous surfaces in high-movement joints…commonly for metal and glass cladding substrates. Staining of porous substrates and dirt accumulation have been an ongoing problem for some silicone sealants” (32).
Acrylic: “first became available to the building construction industry in the early 1960s,” but is based on “acrylic polymer technology that dates to 1843” (33).
25 Ibid.
over the past fifty years, the 1960s joint specifications showed fundamental understanding of three issues: the implications of water intrusion and freeze/thaw were generally understood; the quality and type of mortar is important to veneer performance; and an understanding of the dynamic nature of the wall is clear from promotion of soft joints and sealants. Regarding moisture intrusion, the requirement for anchoring holes to be completely filled, the cavity wall to be kept open for drainage, and sealants to bond well to other materials exhibits the knowledge that water intrusion must be limited or, at the very least, controlled. Cracking is most commonly attributed to pressure from either freeze/thaw cycles or ferrous corrosion due to moisture. Secondly, a complete understanding of mortar behavior is demonstrated by clarifying the type and quality of mortar mix appropriate for use. A balance between mortars that are too hard and too soft is required; the mortar must be softer than the stone in use, yet have adequate weathering abilities to provide a decent life of functionality. Finally, the use of caulking as an alternative to mortar, particularly for expansion joints demonstrates that joints were being understood as either fixed or anticipating movement. This proves that it was understood that thin stone veneer walls act dynamically, as opposed to the relatively static nature of traditional load bearing construction, and requires plastic joints to accommodate movement tolerances. That tolerances were built into thin stone veneer systems was vital to its success and illustrates that masonry cladding was moving towards being a fully engineered, dynamic system and away from the more static masonry tradition.

DAMPPROOFING

Furthering the effort to limit or control moisture intrusion, methods of dampproofing were specified to create an inner and outer boundary for moisture protection. First, a moisture barrier was specified for installation between the thin stone panel and concrete structural back up whenever the two were placed in contact with one another. This technique was used to prohibit salts from within the concrete being carried into the stone by moisture flow. However, this barrier could be forgone if a 1 ½” cavity was maintained between the stone and concrete. Utilized with the cavity condition was a second, inner barrier created by parging, the placing of a ½” coating of setting mortar on the back of all stones. Alternatively, asphalt emulsion dampproofing, vinyl lacquer sealer, or a cement based water proofing were also to be used on the face of the back up or on the back of the stone. Additionally, the external barrier was created by an application of water repellant over the mortar joints to inhibit water infiltration, which when entering the joint had the potential to freeze, expand and then fracture the mortar. External treatments were usually one of three types: stearates, silicone resins in a solvent, and a sodium methyl silicate in an aqueous solution.

26 The mortar must be softer than the stone, so that it acts sacrificially, and deteriorates first, in order to preserve the structural integrity of the stone.

28 Ibid.
29 “Stearates are metallic soaps and are limited in water repellency and durability. It is a coating only and is of little benefit to Indiana Limestone. Silicone resins, in solvent solution, cure by reaction between the silicones and the silicate portions of the substrate. Silicate is present in concrete masonry or brick but limestone has only carbonate lattice. The neutral nonionic character of solvent type water repellents can do little to promote any bonding between carbonate and silicone to produce permanent bond. Also, discoloration can result from some solvent carriers. Sodium methyl silicate, in aqueous solution, cure by reaction with carbon dioxide in the air. By its basic and ionic character, it leaches out a few of the carbonate ions and substitutes silicone ions to give a chemical bond. Because limestone is of a hydrophilic character and the basic material or substrate will not absorb water, the surface of each particle of substrate is readily wetted with an aqueous solution and even distribution and penetration of the silicone is permitted. Research indicates that an aqueous solution is better for limestone,” from, Indiana Limestone Institute of America, Inc., “Indiana Limestone Handbook,” #.
The use of dampproofing on the backside of stone panels and repellants on mortar joints or the face of stone panels was soon disproved in the 1980s. Exterior repellants trap water within the wall system by not allowing it to evaporate through the mortar joints; the moisture is then forced to evacuate through the stone panel, which creates the opportunity for deterioration. The dampproofing system has improved to include better coatings for the face of concrete back up and a system of flashing and weeps to control moisture within wall systems.

The specifications from the MIA and ILI demonstrate that the technology involved with the transition from thick, bearing to thin veneer systems was generally well established. The fundamental issues that dictated whether the systems would succeed or fail (thermal movement, moisture intrusion, and structural loading) were understood fully in theory. These elemental issues were analyzed and building designs illustrate the responses to them – expansion joints, plastic jointing materials and configuration, panel dimensions, and moisture control. Either the issues were not fully resolved or the improvements were not appropriately applied in the early years of transition from traditional to veneer construction, but with each problem or issue that arose, the systems evolved to become more efficient. The progress from 1960 to today was in the form of ongoing and incremental refinement, rather than total transformation, because many of the key aspects of thin stone veneer detailing and construction were established at that time.

**BIBLIOGRAPHY**


THIN STONE VENEER ANCHORAGE AND SUPPORT SYSTEMS
Chapter 4

A Brief History of Anchors

The origin of masonry anchors cannot be pinpointed to a specific date in time, but it is hypothesized from the pockmarked ruins of ancient Rome that their buildings originally used dowels as part of the system to attach marble and travertine cladding to the brick and tufa structures (Figure 4.1). While anchoring systems of the twentieth century continued the use of dowels and rod anchors, the number of anchoring types had expanded tremendously. The proliferation of anchors for use with stone veneer of two inches or less in thickness may have originated from within a number of other construction practices: the brick and terra cotta anchoring systems, interior stone anchoring, and the construction of glass curtain walls.

Brick and terra cotta cladding systems were heavily influential on the anchors used in thin stone veneer systems at the beginning of the Modern architecture movement. Standard strap anchors were used in masonry walls to connect the outer wythe of facebrick to the structural wall substrate, and was also included in terra cotta trade manuals as a standard anchor (Figure 4.2). The terra cotta systems also employed rod anchors and wire ties extensively in addition to shelf angles, which were used to carry the weight of terra cotta pieces.1

Interior stone installations also used wire ties and dowels in conjunction with an adhering agent, such as plaster of Paris, to secure the stone to the structure.2 According to the Marble Institute of America, stone then made a natural progression from adorning interior spaces to building entrances and store fronts, and then finally to cladding entire structures.3

2 Plaster of Paris was used because it had a very quick setting time, which minimized construction time.
The development of stone veneer systems may also have had a connection to the systems of Modern glass curtain walls of the 1940s and 1950s, as well as the precast concrete systems of the 1950s and 1960s. Stone was often incorporated into curtain wall design as spandrel panels or other decorative features; the grid strut mechanical system for stone veneer, which was essentially a framing system composed of struts and gaskets, is similar to the grid system of glass, which effectively eliminates the need for traditional anchors.\(^4\) The systems also have a commonality in the systematic fastening and application of large panels and the requirement to be able to make on-site adjustments.

**Purpose of Stone Anchors**

As stone thinned from twelve inches to less than two by the middle of the century, the anchoring system became central to the success of stone veneer. Previously in bearing walls, the wall played every role; the masonry component supported its own weight, it managed lateral movement, supported and transferred lateral loads, and even acted as the load bearing structural member. All of this changed with the thin veneer system, and the anchorages assumed much of the responsibility for maintaining the structural integrity of the very thin walls by connecting the thin stone veneer to the structural support. They provide two types of support: lateral stability and gravity loads. When carrying the load of the panel, the anchor must divide the weight evenly to control or eliminate stresses on the panel. The anchorages must accommodate the need for installation adjustment between the connection of the anchor to the structure in order to set the panels plumb, but the connection between the stone and anchor must be stable. Any movement between the anchor and stone has the potential to create stresses on the panel. Additionally, anchors aid in resisting lateral loads and flexure.\(^5\)

**Basic Anchor Typologies: 1950-1980**

**Flat Stock Anchors**

Flat stock anchors, adapted from the brick and terra cotta industries, were made of flat, narrow, metal bands. Commonly referred to as “strap anchors,” this typology was most frequently used to provide lateral support to thin stone veneer panels. The ends of these anchors, which was most often fashioned into a dovetail or a bent flange, identified the type of back up support with which it was meant to be used (Figure 4.3). The dovetail was used for engagement into a box anchor which was cast into concrete back up, while the flange could be used with either masonry or concrete. The other end, which fastened into the stone panel, could take a number of forms. A “U” or “Z” shaped anchor took form if the stone end of the anchor was another flange bent upward or downward (Figure 4.4). For the purposes of

---


this study, the anchors will be called by their shape, for instance U strap or U cramp and Z strap. An anchor that had a split flange was called a two-way strap or “split-tail” anchor due to the dual direction of the flange (Figure 4.5). Finally, a dowel set perpendicularly to the strap was another common fastener; for easy reference this will be called a T-strap (Figure 4.6). These strap anchors were also available with a twisted strap in order to fasten the panel on its vertical edge and provide lateral stability (Figure 4.7).

Round Stock Anchors

The category of round stock anchors was comprised of rod anchors, dowels, and wire ties. Unlike the flat stock, which were made from flat strips of metal, the round stock anchors were rounded, and made from wire or rods. Rod anchors were available in the same U, Z, and T design as strap anchors (Figure 4.8). The T-rod anchor is made from an eye-rod and a dowel. Dowels were essentially a straight rod anchor with a diameter smaller than bent rod anchors and were available as either plain or threaded (Figure 4.9). They were typically used in conjunction with another piece, such as a rod, strap, or shelf angle. The wire of wire ties had an even smaller diameter and are twisted and bent to create an anchor that performs essentially the same job as the U, Z, or T strap and rod anchors (Figure 4.10). Wire ties required a dovetail-shaped cut, notch or hole in the stone back up, which would be filled with mortar to set the anchor.

6 Wire ties of all shapes were used to fasten ornamental terra cotta early in the twentieth century. It is possible that the use of wire ties in veneer anchoring could have been a direct transfer from one industry to another. Wire ties were also used previously in the anchoring of interior veneer and could be another origin for exterior anchoring systems.
Support Anchors

Specific anchors were used for soffit hanging, including the Lewis bolt and cinch anchors, which would be bolted to structural steel beams (Figure 4.11). Shelf angles carried the load of the panels and were made in a number of different lengths (Figure 4.12). Continuous angles ran the length of the stone, while clip angles were shorter and interspersed. Adjustable box insert anchors were made for use in concrete structures and worked in conjunction with bolt anchors (Figure 4.13).

Evolution of Thin Veneer Anchors

While these anchors were some of the most basic and consistently available over time, many more anchors, each with their own subtle differences, were developed and used. However, the design concepts did not change tremendously; instead, the complexity of the anchors increased through simple refinements. Essentially, the “new” anchors were simply the previous anchors with an added level of installation adjustability. The anchors also changed in materiality; between the end of World War II and 1980, anchors made a transition from ferrous to non-ferrous materials, particularly stainless steel. Aside from the added adjustability and material change, the only other significant change in anchorage systems was the transfer of responsibility from stonemasons to engineers and architects. Anchorage systems slowly shifted from a field of responsibility of the masonry trade to being an engineered and calculated system specified by architects. Anchorage systems slowly shifted from a field of responsibility of the masonry trade to being an engineered and calculated system specified by architects. Due to the large number of available anchor types and a significant transitional period of load bearing and thin veneer systems, each stone veneer building had a customized system that adhered to the specific load needs, design curriculum, and contractor’s preference. As a result, it is now very difficult now to predict what system is in place behind a façade of this period, which is in need of repair, unless a thorough investigation is performed. Consequently, the following anchor development narrative is intended to decipher the significant trends within Modern thin stone veneer anchorage development, and possibly clarify unknown conditions.

The anchors illustrated by the Indiana Limestone Institute in 1949 reflected the relatively straightforward veneer system that was still in use. The anchors provided in this manual do not differ significantly from the basic masonry anchors previously established within the brick and terra cotta industries. Flat stock anchors included the Z strap, U cramp, dovetail strap, and twoway dovetail strap. Also illustrated was a rod anchor designed specifically for fastening on the panel’s vertical or horizontal edge, called simply “rod anchor,” and a rod cramp anchor. Shelf angle supports with adjustable box anchors, Lewis bolts, and cinch anchors are detailed as well (Figures 4.14-4.18). The box anchor was the first fastener with the ability to adjust anchor height built in to the design. While the list of anchors is common, their designation to different panel thicknesses is significant. The 3” and 4” slabs were specified with the Z, U, and split tail strap anchors. Conversely, the 2” was specified with a T-strap anchor, and the 1 ¾” slab was fit with a less invasive system of shelf angles with a dowel or a welded rod. These designations reflect the understanding that the use of a strap anchor flange in a 1 ¾-2” panel would require a significant kerf in the stone that would reduce panel strength and risk failure.

---

8 The T strap for the two inch panel required a half inch hole drilled for the 3/16x2” pin. The shelf angle pin and welded bar needed a 5/16” hole for the pin and roughly less than 1/2” for the 3/8 square inch bar.
Two years later in 1951, Ramsey and Sleeper released the fourth edition of their book *Architectural Graphic Standards*, which was a principal source of information for architects. At this time however, architects used the standards for thin veneer that had been established by the stone industries. Consequently, the thin veneer anchor information for *Architectural Graphic Standards* was acquired from the Marble Institute of America, National Granite Building Quarries Association, and Indiana Limestone Institute, which were the dominant sources for their given stone, and the anchoring diagrams are segregated according to stone type. The marble diagrams showed basic anchors: a T-strap dovetail anchor, shelf angle, and wire anchors (Figure 4.19). While later editions of *Architectural Graphic Standards* would specify different anchors for different thicknesses, this edition did not, although it did articulate 7/8”-1 ¼” thick marble panels for one or two story structures and 1 ¼”-2” panels for anything taller. The MIA required three galvanized anchors per 2-4 square feet, four for 4-12 square feet, and six for 12-20 square feet. The granite anchor details were even less specific, showing only corner, lintel and soffit sections (Figure 4.20). Presumably, this meant that granite was still considered a luxury or ornamental stone. It could be prepared in thicknesses ranging 1-2 ½”, but the National Building Granite Quarries Association recommended 2” thick panels for most instances. The drawn anchors were simple galvanized or non-corroding Z strap anchors and shelf angle supports, and only two anchors in the top

---

10 The fourth edition had an 80% increase in volume than the previous edition because of changes in building technology.
12 The National Building Granite Quarries Association explains that the economy of granite is not because of its “thinness, but because, if properly designed and detailed, it can be produced almost entirely by machine processes.” Fabrication of panels less than 2” thick cost more than 4” panels. (NBGQA Manual, 1931 & 1959).
The data for general masonry anchors was supplied by the Indiana Limestone Institute. The limestone supports included a few which were not in the 1949 manual, including a “tie-to” anchor insert, dowel and block, and anchor bolts (Figure 4.21). The tie-to anchor was inserted into concrete forms and seemingly ran the height of the concrete. The continuous verticality of this anchor allowed easy adjustable fastening along the entire length. The dowel and block anchor was not compatible with thin veneer but was used to structurally secure bulky, ornamental elements. Anchor bolts were another means of hanging soffit stone panels, in addition to Lewis bolts and cinch anchors. The limestone panels were illustrated as either 2” thick facing

13 Ramsey, 63.
or 3-4” thick cladding for one story structures (Figure 22). As the 1949 ILI manual and the 1951 AGS were the first manuals published during the Modern architecture movement to comprehensively address anchoring and specifications for stone veneer, they set the foundations by which later developments would be measured.

Two later Marble Institute of America manuals, published six years apart, provide almost identical information, which supports the hypothesis that veneer anchorages generally remained the same for roughly fifteen years, until at least 1965. In the years leading up to 1955, basic strap, dovetail, and wire anchors were still in use, which included the T-strap, Z strap, U cramp, and two-way strap, a rod cramp, wire tieback, dovetail anchors, and dowels. In the new 1955 manual, the Marble Institute of America introduced the twisted strap for vertical edge anchors, which does the work of the vertical edge rod anchor previously shown in the Indiana Limestone Institute’s 1949 manual (Figure 4.23). Significant to the 1955 publication is MIA’s designation of certain anchors for certain panel sizes; the marble slabs are shown in diagram as either 7/8” or 1 ¼,” consistent with the 1951 Architectural Graphic Standards. Where the thinner panels are supported by the combination of shelf angles and dowels, the stone required another stone piece 7/8” thick, called a strip liner, adhered to the back of the face stone with bronze dowels, in order to stabilize the panel for the load and pressure point of the dowel (Figure 4.24). By contrast, the 1 ¼” thick panel could bear upon
the shelf and dowel support without a strip liner (Figure 4.25). Brass was specified for all dowels, wire tiebacks, and rod cramps, while the remaining anchors, which were all strap anchors, received a general specification of “non-ferrous.” The Marble Institute of America manual issued in 1961 added one new anchor – a wire tieback with dowel (Figure 4.26). This anchor might have been a cheaper version of the T-strap and T-rod anchors. The required type of metal is not specified and only says that “all anchors and attachments are to be rust-resistant and

15 Marble Institute of America, “Marble Handbook” (Marble institute of America, 1955), plate B.

Figure 4.21
The tie-to anchor insert illustrated by the 1951 Architectural Graphic Standards.

Figure 4.22
The Indiana Limestone Institute provided anchorage information for 2” thick cladding for the 1951 Architectural Graphic Standards, which included standard shelf angle supports with perpendicular dowels. This form of anchorage provided both lateral and gravity support.

Figure 4.23
The twisted strap for vertical edge anchors provided by the Marble Institute of America in 1955.

Figure 4.24
The 7/8” thick marble panel requires a strip liner, which transfers the weight of the panel to the shelf angle. (1955).

Figure 4.25
The 1 1/4” thick panel bears directly onto the shelf angle.

Figure 4.26
The wire tieback with dowel illustrated by the 1961 MIA Marble Manual.
However, one diagram does identify the dowel in use as aluminum, which marks a difference from the previous brass specification.

By the early 1960s, granite was available in thicknesses ranging from 1 ¾” to 2 ½”, although a thickness of 2” was recommended for most exterior uses, and simple strap anchors, dowels, and rod anchors available in varying sizes were specified for different thicknesses. The 2-3” thick panels required a stainless steel anchor with a 9/16” radius bend and 1/16” thickness. Panels over 3” in thickness could accept anchors 1/8” thick with a 5/8” radius bend (Figure 4.27). As usual, dovetail anchors were illustrated for concrete structures, and split tail anchors were suggested for adjoining pieces of granite. While panel thickness and anchor type were the

![Figure 4.27](image1)

Figure 4.27
Anchors suggested by the Cold Spring Granite Company in 1961.

![Figure 4.28](image2)

Figure 4.28
The Cold Spring Granite Company illustrated why they believed strip liners were ill-advised saying, “A fragile condition is obtained in drilling anchor holes in thin veneer resulting in a loss of strength. Less supporting strength obviously is obtained when a piece must be attached for bearing support. The small bearing area means pointing difficulties, lack of stability and potential leakage.”

Figure 4.29
The disc and rod, plate and bolt, and cramp with dowel anchors illustrated by the Indiana Limestone Institute in 1968. These were new additions.

Figure 4.30
The addition of the expansion bolts by the ILI in 1968 indicates that anchors were gaining an increasing level of adjustability. The illustration states, “This type of connection is being used more and more with large limestone panels “hung” from building frames and holds much promise. These anchors offer multi-directional adjustability and are a recent development of a major anchor manufacturer.”


17 Ibid.


same as specified by other catalogs, anchor materiality was different. The granite industry specified stainless steel straps for all uses.\(^{20}\) Another significant change is the increase in number of anchors required per panel, which demonstrates an understanding of the engineering involved in thin stone veneer systems; the new 1959 specification was double that from the 1951 *Architectural Graphic Standards* - two anchors in the top bed and either two in the bottom or one in each side bed. The Cold Spring Granite Company also made two suggestions contrary to previous manuals. Firstly, “precision-cut machined anchor slots” were recommended over drilled or hand cut holes, because the latter risks fracturing thin stone.\(^{21}\) Due to concerns of installation failures, most granite companies advertised only strap anchors with their stone. Secondly, Cold Spring Granite advised against MIA’s practice of adhering strip liners to the back of panels with dowels, because a “fragile condition is obtained in drilling anchor holes in thin veneer,” resulting in loss of strength.\(^{22}\) Furthermore, less support was obtained when using strip liners and shelf angles (Figure 4.28). The granite industry consequently recommended thicker stone for a larger bearing area, which would take the strain off pointing and result in stability and less risk of leakage.

By the mid 1960s, stone anchoring systems still had not significantly changed. In 1966, Ramsey and Sleeper released the Fifth Edition of *Architectural Graphic Standards*, which was a reprint of the 1956 edition. The stone veneer information is repetitive between the editions, presenting no new information. Only the basic anchors are illustrated (Z strap, T strap, twisted rod anchor, clip and loop, dowel and anchor bolts, U

---


\(^{21}\) Cold Spring Granite Co., 4aCo-4.

\(^{22}\) Ibid.
cramp, dovetail strap, and adjustable anchor inserts). The anchors are specified simply as “non-corrosive,” or galvanized.

Up to the late 1960s, stone veneer anchoring systems remained largely unchanged. However, the 1968 Indiana Limestone Institute manual was a turning point. The manual had seven new anchors and a new category, “expansion bolts,” in addition to the basic types. The ILI adopted the twisted strap, T-strap, dovetail with dowel, and wire tieback anchors, which were illustrated previously in MIA catalogs demonstrating a shift towards the consolidation of the anchoring information between facets of the stone industry. The disc and rod, plate and bolt, and cramp with dowel anchors were also new to the limestone manual (Figure 4.29). The disc and rod was able to perform the function of a number of anchors and in a number of panel locations. For instance, it could connect two panels in a vertical joint, previously achieved by the two-way strap, and T-strap and T-rod. It could also secure a panel from the top and bottom beds through kerf slots, previously achieved by strap and rod anchors of almost all types. This flexibility meant the disc and rod could be used in almost any position, which diminished the need for more than one type of anchor. The disc and rod became a very popular anchor. Furthermore, an entirely new category, expansion bolts, was added and marked another shift in the installation process towards adjustability (Figure 4.30). “This type of connection is being used more and more with large limestone panels ‘hung’ from building frames and holds much promise.”

The novelty of these anchors was the capability for multidirectional adjustability at the time of installation, thus allowing a higher level of accuracy. The 1968 manual is also the first time stainless steel is recommended by the Indiana Limestone Institute as an anchor material. Bronze and eraydo alloy zinc were also suggested.

The seventh edition of Architectural Graphic Standards (1971) marked another turning point, because it was the first to be taken over by the American Institute of Architects. In previous editions of the book, each major stone producer (the MIA, ILI, and NBGQA) submitted information they thought important to the thin stone veneer trade, and the Architectural Graphic Standards simply published that information verbatim and without consolidating it. Consequently, those early editions had

---

23 Other fasteners for specific uses are included. Lewis bolts were used to hang soffit stones. The bolted T-rod, marked as the anchor on steel frame, seems to be for ornamental stone work. The “tie-to” anchor seems to be another anchor used for concrete structures. The dowel and block anchor is shown as connecting vertically oriented ornamental stone, such as a column and the block above. Cinch bolts had soft lead collars around small steel cones that gripped the sides of the hole. Stone keys were also used to connect stone parts, but were rarely used, if ever, to fasten stone veneer.

24 Charles G. Ramsey and Harold R. Sleeper, Architectural Graphic Standards for Architects, Engineers, Decorators, Builders, Draftsmen, and Students (New York: John Wiley & Sons, Inc., 1966), 148-149. At this time, the limestone panels are shown as either two or four inches thick; the four inch thick panels are specified for one story structures and are shown with two-way strap anchors or a shelf angle with dowel. The two inch panels are supported by clip angles with dowel and a T-wire anchor. Just as in the fourth edition, the granite and marble panels are two inches and seven-eighths of an inch. Unlike the limestone specifications, marble anchors are not designated according to panel thickness. The two inch granite panels are shown supported by Z strap anchors and shelf support.

25 Indiana Limestone Institute of America, Inc., “Indiana Limestone Handbook” (Bloomington: Indiana Limestone Institute of America, Inc., 1968), 34, 38-40. However, the combination cramp and dowel anchors had previously appeared in Architectural Graphic Standard as a means for fastening banisters to handrails. These manuals, stone industries and Architectural Graphic Standard, categorized all masonry anchors together; consequently, not all listed are for veneer anchoring, such as the combination cramp and dowel anchor.

26 Ibid, 34.

27 According to the ILI, expansion bolts were a “recent development of a major anchor manufacturer,” however, adjustability had been available as early as the 1949 ILI manual. Anchor boxes were in use since at least 1949 and allowed a certain level of adjustament.

28 Indiana Limestone Institute of America, Inc., 1968, 34. Eraydo zinc alloy is a zinc copper alloy that is white metal that is extremely resistant to corrosion and staining and can be extruded and soldered.
the anchor information divided into marble, limestone, and granite sections. Beginning in this 1971 edition, the editors utilized architects or engineers to compile the information and draw the details to provide consolidated information. This change from the stone industries to the AIA providing information helps further demonstrate the shift that occurred throughout the Modern architecture movement from the masonry tradition driving thin stone veneer specifications to engineered and calculated regulations established by engineers and architects. The AIA illustrated ten new anchors: the slotted clip, flat hook and bolt, soffit straps, U-strap and rods, clip and power stud, strap and rod cramp, tamp-in anchor, adjustable wire, adjustable insert wire, and lug and nut inserts (Figure 4.31). The information is streamlined to present standard anchor sizes and materials. Chromium-nickel stainless steel (types 302 and 304) and eraydo zinc alloy are highly recommended as the most corrosion and stain resistant; suggested materials of lesser quality included the traditional copper alloys, galvanized steel, and monel. The AIA recognized 3-4” stone as cut stone and reserved the title “veneer” for stone less than 2” thick. Despite the difference in title, there seemed to be no difference in which type of anchor could be used; strap anchors were illustrated with 3-4” stone, support angles with dowels were used with 1 ¼” stone, and vice versa. However, the 4” thick cut stone was typically used in a “stacked” wall system, in which the stone was not supported and transferred the weight to the foundation. Stacked panels required only a strap anchor for lateral stability, while the thinner dimensioned stone typically used a shelf angle to carry the loads of the veneer. This edition also introduces the Zibell system, a grid strut anchoring system (Figure 4.32). With this kind of system, the stone panels are prepared with kerf slots on the top and bottom which then rest upon channel anchors bolted to the grid strut. The grid strut systems easily supported the thinnest stone veneer (2” and less) without anchor stresses, because it removed the need for traditional anchors. The grid strut system introduced a new way to construct a veneer wall that would ideally have fewer problems and easier installation; however, the grid aesthetic of the façade broke the clean stone-to-stone aesthetic of the anchored wall.

In 1971, MIA also updated their veneer manual. A few introductions were made to the anchor list to include the shim, spring clip, “L” stud and disc, and soffit hangers (Figure 4.33). The “L” stud and disc anchor and soffit hangers had already been accounted for by Architectural Graphic Standards and the Indiana Limestone Institute, and their insertions into the Marble Institute of America manual speaks to their success. The addition of the shim is significant. In contemporary design, it is common knowledge that shims are necessary for a stone veneer façade to function properly. Shims are used during the setting of the stone and are employed to help position it plumb to the wall. Additionally, shims help distribute

29 The slotted clip is a refinement of a basic Z strap by allowing the strap to be installed at the same time as the stone panel; it can be used with a precast panel. The soffit straps afforded adjustability. The U-strap and rods secured the stone and precast concrete in composite panel. The clip and power stud is for fastening to concrete back up. The strap and rod cramp is simply a refinement of cramps. The adjustable wire and adjustable insert wire were made for concrete back up and is similar to the “tie-to” anchor. The lug and nut anchor were also made for concrete back up and allowed adjustability.

30 “Standard flat stock anchors are made from strap 1” and 1 ¼” wide by 1/8”, 3/16”, and ¼” thick. Lengths vary up to 6”, 8”, 10” and 12” standards. Dovetail anchors are usually 4 ¼” overall with 3 ½” projection from the face of the concrete. Bends are ¼”, 1”, and 1 ¼”. Round stock anchors are made from stock of any diameter: ¼” and 3/8” are most common for rods; 1/8” (#11 gauge) through 3/16” (#6 gauge) for wire anchors; and ¼” and 3/8” are most common for dowels. Dowel lengths are usually 2” to 6”, from Ramsey 1971, 172.

Figure 4.31
These ten anchors were new additions to the Architectural Graphic Standards of 1971, which was a major turning point in the history of the book series. The 1971 edition was the first to be published under the influence of the AIA.

Figure 4.32
The Zibell Anchoring system was also introduced for the first time by the Architectural Graphic Standards in 1971. Mechanical grid systems were already commonly used by this time, and the Zibell system is another grid system that rejected the traditional system of stone anchors.
Figure 4.32

**GRID STRUT SPACING RELATIVE TO SLAB HEIGHT - MARBLE**

<table>
<thead>
<tr>
<th>HEIGHT OF SLAB UP TO</th>
<th>GRID STRUT SPACING</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 1/2&quot; THK. 1 1/4&quot; THK.</td>
<td></td>
</tr>
<tr>
<td>2'-6&quot;</td>
<td>4'-9&quot;</td>
</tr>
<tr>
<td>3'-0&quot;</td>
<td>4'-6&quot;</td>
</tr>
<tr>
<td>3'-6&quot;</td>
<td>4'-3&quot;</td>
</tr>
<tr>
<td>4'-0&quot;</td>
<td>4'-0&quot;</td>
</tr>
<tr>
<td>4'-6&quot;</td>
<td>3'-9&quot;</td>
</tr>
<tr>
<td>5'-0&quot;</td>
<td>3'-6&quot;</td>
</tr>
<tr>
<td>6'-0&quot;</td>
<td>3'-3&quot;</td>
</tr>
<tr>
<td>6'-6&quot;</td>
<td>2'-3&quot;</td>
</tr>
<tr>
<td>7'-0&quot;</td>
<td>2'-3&quot;</td>
</tr>
</tbody>
</table>

*For slabs over 4'-6" height use intermediate vertical joint anchoring.

**GRIDAnchor SPCING & STRUT SIZE - MARBLE**

<table>
<thead>
<tr>
<th>MAXIMUM SPACING</th>
<th>STRUT SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH, DEPTH AND SHAPE</td>
<td></td>
</tr>
<tr>
<td>7 1/2&quot; THK. 1 1/4&quot; THK.</td>
<td></td>
</tr>
<tr>
<td>4'-0&quot;</td>
<td>5/8&quot; x 1 1/8&quot;</td>
</tr>
<tr>
<td>6'-0&quot;</td>
<td>5/8&quot; x 2 7/16&quot;</td>
</tr>
<tr>
<td>10'-0&quot;</td>
<td>9'-0&quot;</td>
</tr>
<tr>
<td>15'-0&quot;</td>
<td>13'-0&quot;</td>
</tr>
<tr>
<td>FOR DIM &quot;X&quot; SEE DETAIL 1 ABOVE</td>
<td></td>
</tr>
<tr>
<td>&quot;X&quot; = 1 1/8&quot; FOR 7 1/2&quot; MARBLE</td>
<td></td>
</tr>
<tr>
<td>&quot;X&quot; = 1 3/4&quot; FOR 1 1/4&quot; MARBLE</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:**

Flashings & Caulking required at certain points has been omitted in order to retain clarity of drawing at small scale. See pages on Flashing & Caulking.
loads properly and prevent point loading. For instance, a dowel is intended to secure the panel laterally and not provide load support, which is the responsibility of the strap; a shim is needed at the base of the dowel in order to place weight on the strap anchor and not the tip of the dowel.34 Should the dowel carry the load, pressure will be concentrated and cause cracking at that point. The spring clip (also known as a “hairpin” anchor) is an anchor designed for the connection of stone and precast concrete in a composite panel (Figure 4.34). Although precast panels were available more than ten years before, this is the first time the spring clip is included in the MIA manual.35 The manual also detailed multiple types of mechanical systems that entail grid strut systems and do not require anchors. Following these additions, little to no changes occurred between the 1971 and 1976 MIA manuals.

By the end of the decade and entering into the 1980s, the popularity of the grid strut system was aided by the fabrication ease and economy of preassembled panels. It afforded savings in on-site labor and allowed precision joining of component stone units. It also required less on-site joint sealing; greater quality was assured with off-site joint sealing.36 The preferred type of anchors narrowed to those that could directly connect to the steel or concrete building frame. Stone continued to be advertised at 1 ¼”-3”, with 2” being the most structurally stable, and the trend of anchors in use was consistent with the previous three decades – split-tail and twisted strap anchors, shelf angles with dowels or welded bars, wire tiebacks, and rod anchors.37

35  Marble Institute of America, “Marble Handbook” (Marble Institute of America, 1971), 0005.03.
37  Ibid.
The narrative of thin stone veneer anchorage development between 1950 and 1980 is not one of sweeping changes, but instead is a story of small alterations and refinements that largely affected the installation and performance of the systems. By the mid-twentieth century, many aspects of veneer were already determined. Stone was already available at its standard dimensions of 7/8”-2”, and the most common veneer anchors in use in 1949 were still being used thirty years later, although they experienced a distinct increase in the level of adjustability. Veneer walls were made much more efficient when on-site adjustments could be made with anchors. The added level of installation adjustability, in addition to changes in the anchor material, are clearly the most significant modification within the development of thin stone veneer anchors between 1950 and 1980.

Figure 4.34 The spring clip, although more plain than the one illustrated by the MIA in 1971, is fastened to the stone prior to the concrete casting, and consequently secures the two materials internally.
**BIBLIOGRAPHY**

“Architectural Granite: The Noblest of Building Stones.” 


Chapter 5

CASE STUDY SELECTION

The selection of Wallace K. Harrison’s Rockefeller Center west expansion and Lincoln Center buildings as appropriate case studies was founded on a number of factors. Based on the survey conducted at the beginning of this thesis, Harrison was one of the more prolific New York based architects from the 1950s through the 1970s. Furthermore, Harrison also designed many of his works to be clad in stone, using a number of types of stone, including limestone, granite, marble, and travertine, which offers a basis for comparison of anchoring systems. Furthermore, his design aesthetic is in line with the Modern architecture movement; despite his early study of classicism, he committed himself to the Modern aesthetic soon after the beginning of his career. Finally, Harrison left an indelible mark on Manhattan through his large-scale projects. He worked with a number of renowned contemporaries from Raymond Hood to Philip Johnson. His stellar career began with O.W. Norcross Company, the contractors who worked closely with H.H. Richardson and McKim Mead & White, and who owned their own stone quarries. The incorporation of stone veneer into Harrison’s most prominent buildings is perhaps no coincidence but a testament to his early roots with O.W. Norcross. Few architects have the privilege to boast of such a career, and yet Harrison is often overlooked. Examining a collection of Harrison’s projects with a focus on stone veneer anchoring systems helps illustrate the point that within the era of mid-century Modern architecture, a multitude of anchoring systems were in use, that each system was customized to the project at hand, and that the behavior of stone veneer systems can vary depending on attachment detailing and installation.

LINCOLN CENTER FOR THE PERFORMING ARTS

In a two-day period in 1955, two friends approached Harrison with offers for two different commissions that he would then turn into a focal point of his architectural legacy. Arthur Houghton, Jr., asked Harrison to design a new home for the New York Philharmonic Society a day after Robert Moses asked him if he were interested in designing an opera house for the Metropolitan Opera. The idea to combine the two and

---

1 Refer to Appendix A for more information on the survey.
2 Refer to Appendix B for more information on Harrison’s career.
3 The first of these, the United Nations complex, was not used due to limited access to resources.
4 Arthur Houghton, Jr., was the great-grandson of the founder of Corning Glass Works and eventually inherited the family business. Harrison worked for this family on a number of other occasions to design 717 Fifth Avenue and the Corning Glass building in Corning, New York. Houghton’s cousin was Alice Tully, trained operatic singer and musician, who funded Alice Tully Hall, part of the Juil-
create a center for the performing arts is only partially accredited to Harrison, because it was Moses, the construction coordinator for New York City, who had the vision to utilize the project to refresh the blighted area of the Lincoln Square neighborhood. Moses’ urban renewal scheme removed seventeen blocks of the neighborhood to make space for the cultural center, which he saw as the metaphorical “cure-all” for urban blight.

Those two days led to ten years worth of work on what came to be known as Lincoln Center. The project began on May 14, 1959, and it involved the visions and input of some of the most well known architects of the time including Max Abramovitz, Pietro Belluschi, Eero Saarinen, Gordon Bunshaft, and Philip Johnson, all of whom designed portions of the complex. The collaboration of so many celebrated architects resulted in a clash of architectural egos and a divide in design concepts, however, they did agree on two unifying elements: Roman travertine cladding and glass façades facing the central plaza. Although travertine was used on each of the center’s buildings, the anchorage systems and detailing were different; and despite the prestige, education, and experience of the group of architects, many of the buildings required significant repairs within twenty years of completion. An analysis of the buildings designed by Harrison and Abramovitz reveals how two wall systems, designed within the same tradition and with the same materials, can behave differently and why.

---

6 The site is located between West 66th and 62nd Streets facing Columbus Avenue.

---

7 Abramovitz: Philharmonic Hall (now Avery Fisher); Belluschi: Juilliard + Alice Tully Halls; Saarinen: Vivian Beaumont Theater; Bunshaft: New York Public Library for the Performing Arts; Johnson: New York State Theater (now David H. Koch Theater). Others such as Marcel Breuer, Alvar Aalto, Sven Markelius, and Henry R. Shepley were involved in the original site studies.
The Metropolitan Opera, designed by Harrison, is the centerpiece of the Lincoln Center scheme standing between the Philharmonic Hall (Avery Fisher) and the New York State Theater (Figure 5.1). Dramatic arches, multi-stories in height, define the east façade and enhance the visual prominence of the building within the complex. The columns of the arches are clad with 2 ½” thick travertine panels, while the travertine fins of the other three elevations are 5” thick (Figure 5.2). The fins, of which there are 340, are spaced 2’-8 ½” apart and project roughly 1’ 8” from the glass wall that backs them (Figure 5.3). The building is 450’ x 180’ in plan and 95’ in height from the plaza level. A condition assessment of the building was conducted in 1986; the work included a visual condition survey using binoculars, a close-up investigation of areas of observed points of stress, an examination of selected travertine anchorages, and laboratory analyses of the stone.

The travertine of the fins, veneer, and column cladding each has a different anchoring system. The 5” thick travertine fins are anchored to the structural precast concrete mullions by stainless steel T-strap anchors, which are secured to the concrete by cast-in iron “G-lock” insert anchors and bolts (Figure 5.4). The bedding plane of the fins is vertically oriented. The bases of the panels are secured by ½”x6” stainless steel dowels that have stainless steel caps soldered over the top to protect from moisture (Figure 5.5). Each fin has two dowels in the bottom of the panel. The 2 ½” thick veneer panels are anchored on one side of the expansion joints with two ½”x4” dowels. Stainless steel split-tail anchors

---

8 It opened on September 16, 1966.
9 Information gathered from personal communication with Kimball Beasley. I have been given permission by K. Beasley to discuss this information.
10 Ibid.
(twisted and not twisted) are used in every vertical and horizontal joint (Figure 5.6).  

The assessment determined that about fifty of one hundred exposed panels had unstable or loose stone fragments. The travertine veneer on the east façade suffered only surface soiling, while the travertine fins on the north, south and west facades exhibited more significant problems. The fin panels suffered from decay, fractures, bedding plane delaminations, crazing cracks, and outward displacement (Figure 5.7). Determined from petrographic examination, the decay was found to be from cyclic freezing and acid rain. The vertical orientation of the panels’ bedding contributed heavily to the delamination and fracturing along the natural planes; water had entered the stone from the top of the panel and traveled its length through the bedding plane, expanding during freezing cycles and decaying the stone with sulfuric acids. The steel shims and iron G-lock insert anchorages had corroded, and the rust scale caused outward displacement, which furthered moisture invasion through the opened caulk joints. Most of the Metropolitan Opera’s performance problems were caused by water infiltration. For instance, much of the cracking could be attributed to the forces caused by freeze/thaw or corrosion of anchors. The outward displacement of stone panels was also the result of anchor corrosion, and acid rain caused the decay. The vertical bedding orientation facilitated the downward movement of moisture through the travertine panels.

The suggested repair included a total caulk replacement program, replacement of fin panels having

---

11 Metropolitan Opera Working Drawings, Wallace K. Harrison Collection, 1960, Drawing and Archive Department, Avery Library, Columbia University.
12 “Secondary gypsum found at finely laminated bed interfaces indicated a chemical reaction of the travertine calcite with atmospheric sulfurous and sulfuric acids,” (personal communication with K. Beasley)
large pockets of decay, Dutchmen repair for panels having small pockets of decay, securing of delaminated panels using epoxy-injected stainless steel threaded rods across fins, and epoxy-ejected stainless steel cramps for other cracking.\textsuperscript{13}

Philharmonic Hall (Avery Fisher Hall)

The Philharmonic Hall, now known as Avery Fisher Hall, was the first of the Lincoln Center buildings to reach completion, on September 23, 1962. Although Max Abramovitz designed the Philharmonic, the building is included in this study because Abramovitz was a partner with Harrison. The hall is reminiscent in form of traditional Roman arcades, but utilizes the language of the Modern architecture movement (Figure 5.8). A covered balcony, or upper-level arcade, shelters the glass façade facing the main plaza, which is articulated by travertine clad columns softened by entasis (Figure 5.9). The building is 240’x192’ in plan and used 32,000 cubic feet of travertine.\textsuperscript{14} The Philharmonic Hall underwent the same assessment as the Metropolitan Opera.

The travertine veneer on the hall is backed by 8” thick precast concrete panels; the stone panels are typically 3-4” thick, with the exception of the column cladding which has 2 ½” thick veneer.\textsuperscript{15} Stainless steel split-tail ties fasten the panels cladding the columns. The soffit panels were also anchored with split-tail

\textsuperscript{13} Taken from personal communication with K. Beasley. A Dutchman repair involves the removal of the deteriorated stone by saw cutting a small area and replacing with a block of the same stone, which fits into the void.

\textsuperscript{14} Taken from personal communication with K. Beasley.

\textsuperscript{15} Taken from personal communication with K. Beasley, and Philharmonic Hall Working Drawings, Max Abramovitz Collection, 1956-1960, Drawing and Archive Department, Avery Library, Columbia University.
ties in addition to mid-soffit shelf angles. Mortar was specified for most joint work, with the exception of sealing all exterior architectural metal (windows, doors, and railings) that required Thiokol, a polysulfide sealant. The polysulfide sealant allowed for movement between the stone and architectural metal; conversely, mortar was used for joints between panels, because those joints were meant to transfer weight. This system is referred to as “stacking,” and it functions more similarly to traditional masonry construction.

While the Metropolitan Opera displayed signs of deterioration, the Philharmonic Hall showed no signs

---

16 Taken from personal communication with K. Beasley. The working drawings for the project specify different anchors, which marks the reality of construction that buildings are not always (or often) built to the specifications. The drawings called for the dovetail strap anchor with slot inserts, which were to be a minimum of 8” long unless otherwise specified. All anchors, “including dovetail slots, anchors, crimps, dowel pins, and all flashing reglets,” were to be of stainless steel. Standard dowels of 3/8” diameter and 4” long were specified for connecting two stones at top and bottom joints. For hanging soffits, Lewis anchors were required. All carbon steel support angles were to be galvanized. The Philharmonic Hall Working Drawings, Max Abramovitz Collection, 1956-1960, Drawing and Archives Department, Avery Library, Columbia University.
of significant stress. The stone exhibited typical soiling, a surface deposit that could be removed easily (Figure 5.10-5.11). Other than minor soffit cracks, which did not show any lateral movement, and minor spalls at projecting corners and edges, which was surmised to have been from impact at the pedestrian level or window washer equipment, the building had weathered extremely well. The recommended repairs included patching of small spalls with conventional Portland cement mortar, reinforcing by stainless steel wire drilled and epoxied into the stone, and stone cleaning.

The comparison of the performance of these two buildings, which were finished only four years apart, designed by the same architectural team, and clad with the same stone, is exemplary of how important the detailing is for veneer systems. The faulty detailing of the Metropolitan Opera is what made a real difference between the two; the system failed because of the application of vertically oriented bedding planes and iron anchors. Conversely, the Philharmonic’s thin veneer system, which required only minor repairs is an example of successful design. The specifics of each system aside, a few general observations may be made. First, the anchors used on both systems allow very little tolerance for setting the panels plumb and the expectation of building movement. Although the use of mortar, rather than sealant, was needed for the stacking system, vertical expansion joints were employed to accommodate the expected movement. Secondly, the desired aesthetic, which was produced by the vertical bedding orientation, was clearly chosen over known performance issues, primarily water infiltration which leads to cracking and failure. The decision was made against better judgment. A group of highly distinguished architects, such as the Lincoln Center group, had to have known about this limitation of travertine prior to construction, especially Harrison who worked with stone while employed at O.W. Norcross. Additionally, the systems used steel and iron anchorage pieces, such as shims, despite knowledge that non-ferrous metals should be used. Thirdly, the timing of these projects as part of the transitional period between the masonry trade and engineered standards is highlighted by the discrepancies of anchorage systems between historic drawings and the as-built condition. The explanation for these discrepancies could be that at this time, architects drew conceptual anchors into the project drawings, and the masons or stone installers made the decision as to which specific anchor was suitable for use.

17 A stacked panel system such as these requires hard joints for transferring loads, because the 4” thick travertine is more similar to traditional bearing construction.
The three buildings came to be known as the “X, Y, &Z” buildings.

Celanese Building (now News Corp. Building)

The southernmost building of the composition, the Celanese Building was finished in 1974. Located at 1201 Avenue of the Americas, the forty-five story tower was originally built for the corporation after which it derived its name, the Celanese Corporation, although it now houses the Fox Entertainment Group.

The façades of the Celanese Building are articulated with alternating, vertical limestone piers and glazing (Figure 5.13). The limestone-clad panels are 3 5/8” thick and supported by shelf angles with a dowel, which are bolted to the steel framing (Figure 5.14). The stone is held laterally secure by the aluminum window washing rig channels and gaskets (Figure 5.15). Stainless steel strap anchors are used for connection at the coping, and dowels are employed to secure the bottom of the panels at the base of the building (Figure 5.16).

In 2000, in accordance with the New York City Department of Buildings Local Law 11 of 1998, the Celanese building underwent a “critical examination of all building facades with the aid of high-resolution binoculars from ground level, building setbacks, and the roof, and a close, physical inspection of the south façade

ROCKEFELLER CENTER WEST EXPANSION

Rockefeller Center’s westward expansion across the Avenue of the Americas was first proposed in 1963. Harrison was commissioned for this project directly through the Rockefeller family, as many of his projects were. Harrison designed the three buildings, the Celanese, McGraw-Hill, and Exxon Buildings, to be identical to each other, each accentuated by narrow, vertical, stone-clad piers in a “half-hearted attempt to relate them to the older buildings of the complex” (Figure 5.12).

18 Harrison was a personal friend of the family and had become a kind of architectural advisor to the Rockefellers. He married the sister-in-law to Rockefeller, Jr.’s only daughter.

19 Newhouse 160. Harrison’s Time & Life Building, located directly adjacent to the XYZ buildings but finished roughly ten years prior, had received praises. Following that success, Harrison designed the limestone striation of the XYZ Buildings to reflect the slender piers of the Time & Life.

20 Celanese Building Drawings, Max Abramovitz Collection, 1956-1960 (Drawing and Archives Department, Columbia University).

21 Celanese Building Drawings, Max Abramovitz Collection, 1956-1960 (Drawing and Archives Department, Columbia University).
from a suspended scaffold. The inspection report details a number of issues with the building’s cladding. Cracking and spalling was evident, and the report suggests this is due to pressure on the panel from corroding, expanding anchors. These anchors had been specified in the original drawings as stainless steel, and typically, stainless steel is corrosion resistant, although that is not to say it never rusts. This could suggest a few things about the anchors on the Celaneses Building: they were not actually stainless steel; water infiltration was extreme enough to corrode even the stainless steel anchors; or, the cracking was not from anchor corrosion, and perhaps from thermal expansion. The inspection report surmises that the panel displacement was caused by “excessive water infiltration and subsequent freeze/thaw forces or expanding force of a corroding steel anchor;” however, neither nondestructive

nor destructive investigation was conducted to confirm suspicions. Despite the confirmation, water infiltration was certainly an issue, which supported further by the report that the mortar had appreciably eroded; the sealant in the expansion joints had also “failed because of lack of adhesion to the substrate.”

The suggested repairs included a mixed level of intervention. Patching was suggested for some of the cracking and spalling, while total removal and replacement was dictated for the more severe failures. Displaced panels were to be removed and set plumb. Finally, all jointing material whether mortar or sealant was to be removed, if extant, and reapplied.

---


24 Hoffman, 5.

Exxon Building (now Standard Oil Building)

The Exxon Building is the northern-most building of the three, located at 1251 Avenue of the Americas. Built in 1971 for the Exxon Oil company, it is the tallest of the three, standing at fifty-four stories.

Set within an aluminum frame, the Exxon Building has 2" thick granite veneer on the ground floor and 4" thick limestone-clad precast concrete paneled piers alternating with glazing and glass spandrel panels for the remaining height (Figure 5.17). The stone veneer is supported at the bottom of the panels by shelf angles and held in place with stainless steel cramps at the top of the panel (Figure 5.18). The ground floor columns have a composite system of 2” thick limestone panels with precast concrete backing, and a neoprene bond-breaker between the two; stainless steel hook anchors secure the two panels together (Figure 5.19).26

The Exxon Building has experienced a few rounds of repairs in the last twenty years. In 1990, not yet twenty years since completion, the building underwent a “large façade restoration project” which included saw cutting the spalled and cracking limestone, patching with new material, and resealing the horizontal joints.27

---

26 Exxon Building Drawings, Max Abramovitz Collection, 1956-1960, Drawing and Archives Department, Avery Library, Columbia University.
27 Domingo Diaz, Local Law 11/98 Examination Report: 1251 Av-
Then ten years later, the Local Law 11 Report of 2000 reported more problems including: cracking and spalling of the limestone, panel displacement, mortar and sealant erosion, and cracking at the parapet. As the report notes, each of these problems most likely indicates water intrusion and metal corrosion. Another set of repairs was undertaken to patch cracks, replace or reset panels, refill joints with either mortar or sealant, and repair failed fireproofing.28

The next LL11 Report in 2005 found less significant problems but did suggest minor repairs to cracking, corroded steel anchors, pinning lose limestone panels and resealing joints. This series of repairs, no more than ten years apart, reflects either that the building is plagued with a poor water proofing system, or the repairs have not been thorough as to address the cause of the problems. Whichever the reason, the Exxon Building is yet another case of problematic water infiltration.

\(\text{enue of the Americas, Technical Report: Periodic Inspection of Exterior Walls and Appurtenances (New York City: New York City Department of Buildings, 2006).}\)

28 Diaz, 10.
The McGraw-Hill Building, fifty-one stories in height, was the first to be finished, in 1972. Located at 1221 Avenue of the Americas, it takes the central location of the trio. The McGraw-Hill publishing company was the primary tenant at completion and remains today.

The McGraw-Hill building is clad in 2 ½” thick granite and precast concrete panels, which are part of the “aluminum, fixed window, vertical curtain wall” system (Figure 5.20). Various anchors are illustrated in the original drawings for anchoring the granite to the precast concrete including the split-tail anchor (the split-tail is secured in the concrete), hook anchor, or, more commonly, hairpin anchor. The panels are secured to the frame using stainless steel shelf angles with dowels in the base of the stone (½” x 5” long, two per stone) or angles bolted to the back of the concrete (Figure 5.21-5.22).

The joints were sealed with neoprene rope, sealant, and neoprene weeps. The 2000 Local Law 11 report designated the building as safe with a repair and maintenance program, although the issues were minimal. The 2005 building façade inspection revealed no unsafe conditions, only minor cracking and spalling; however, forty percent of the sealant had failed and required replacement. The sealant failure on the Celanese and Exxon building resulted in a high level of deterioration, in comparison with the McGraw-Hill, which had only minimal issues. The successful performance of the McGraw-Hill could be attributed to a more effective, original moisture control system, more frequent maintenance program, or simply the use of granite, a more durable stone, rather than limestone.

The performance issues exhibited by each of the Rockefeller Center buildings, cracking, spalling.
panel displacement, mortar and joint deterioration, and cracking at the coping level, are also common problems faced by most stone veneer systems. While thermal movement could cause cracking, the presence of water within the wall would have a greater detrimental impact on the performance. Furthermore, the anchorage system and joint configuration provided for movement tolerances, which limits the negative effects of thermal expansion. Consequently, the larger issue with the Celanese, Exxon, and McGraw-Hill Buildings is the need for a more effective moisture control system, because their wall performances suggest that an efficient system had not yet been fully established.

Furthermore, a difficulty in analyzing the information on the performance issues was created by a difference in the types of sources. For instance, the repairs on the Lincoln Center buildings were driven by private concerns, from the building owners who willingly had the buildings assessed. Conversely, the Rockefeller Center buildings were assessed due to a publically or governmentally driven mandate, which evokes an attitude of “do what needs to be done.” The difference in concern meant that the Lincoln Center buildings were given a thorough investigation including panel removal for ulterior inspection and lab testing of the stones for physical properties, while the regulation driven investigation was conducted primarily visually without any destructive or nondestructive investigation. As a result, the Lincoln Center investigation confirmed the root cause of problems, while the Rockefeller center, and any other Local Law 11/98 investigation, required only repair of the symptoms and hypothesized causes. While the Local Law 11/98 regulation requires building owners to maintain their building facades and keep them safe, it is not necessarily in line with preservation philosophy.

CONCLUSION
The performance problems exhibited by these buildings illustrate common problems with veneer systems overall and can be condensed to a few overarching concepts. In this period of thin stone veneer’s relative novelty (1950-1980),

…anchors and supports evolved from being a relatively static system to having dynamic capabilities,

…non-ferrous specifications for anchors were not implemented in totality,
...a successful moisture control system had not been fully established,

...the value of flexible sealant joints were not fully appreciated,

...the capabilities and limitations of stone as a veneer material were generally understood,

...and aesthetic preferences occasionally outweighed technological knowledge.

The anchor systems employed by these Lincoln Center and Rockefeller Center buildings follow the general trend of progression from minimal adjustability to multi-directional adjustability as discussed in Chapter 4. Unfortunately, ferrous anchors were occasionally used, which caused failure and panel displacement, despite the specification for stainless steel in original drawings. The use of ferrous materials suggests either a disregard for or incomplete understanding of the detrimental effects of anchor corrosion. Furthermore, sealant formulas, dampproofing methods, and moisture control in general were still relatively unrefined and would continue to be an issue through today. The sealant that had been developed was used sparingly or reserved for expansion joints, despite the known capabilities. Additionally, the use of travertine and limestone in thinner dimensions than granite indicates at least a broad understanding of the correct application for each stone, as prescribed by their physical properties. Finally, the decision to use stone in a manner that would almost certainly lead to structural failure was made in order to accomplish aesthetic goals; unfortunately, this is common. Accordingly, the performance implies that the veneer anchors specifically were not inherently problematic, unless made of a ferrous material, and that issues or failure occurred due to inappropriate detailing, poor craftsmanship, or unrefined materials. Consequently, the reality of thin veneer systems is that repairs are inevitable due to the service life of waterproofing materials, and that routine maintenance, especially to joint materials, is necessary.
BIBLIOGRAPHY


Conclusion
The Modern architecture movement proved to be a principal period in the development of stone veneer systems, the establishment of which was possible only through the timely marriage of technological and aesthetic evolutions. Aesthetic preferences shifted from an architectural tradition based on European architectural styles to the Modern movement. The heavy ornamentation gave way to a very monolithic, spare language, utilizing manmade, repetitive features; the craft aesthetic gave way to the machine. This aesthetic revolution paved the way for thin stone veneer.

The Modern architecture movement was the first time period when stone was consistently used in one and a half to three inch thicknesses. This was a period of trial and error when stone transitioned from being a load bearing to curtain wall material. This was also the time when the architectural use of stone evolved from simple to complex. The irony of the complexity is that as the technology swung from simple to complex, the architectural language did just the opposite. Consequently, what appears to be very simple in the architectural language actually requires a much greater complexity of detailing. Everything about the system compounded: the stone selection process, the types and configuration of anchors, the specifications, and the wall design. The responsibility for the anchoring systems shifted from masons of the trade to engineers and architects who determined the appropriate system through calculations.

With the thinning of stone also came a change in the performance of stone, and the anchorages, which were established to secure the stone to its substrate, became central to successful performance. The anchors slowly evolved to an increased level of adjustment. Additionally the selection process of stone became ever more important, because the intricacies of the physical properties had a greater effect on thin stone. Finally, moisture control (damp proofing and joint material) as we know it today was tested and began development during the Modern architecture movement.

The reality of thin stone veneer walls is that they will need maintenance and repair. The trial and error nature of the period within which these buildings were constructed is reflected in the unperfected systems that are now failing or in need of repair. Further complicated the issue is that each building is essentially one of a kind, if not because of its customized anchorage system then because of the unique loading conditions of the building’s location. Consequently, the preservation or repair of these buildings requires a thoughtful approach and a sense of humility. The performance issues of these buildings are frequent, increasing the need for preservation standards. Unfortunately, preservation standards from the Secretary of the Interior do not address thin stone veneer buildings specifically and leave much room for inappropriate repair or alteration.
APPENDIX A
SURVEYED BUILDINGS
<table>
<thead>
<tr>
<th>Building Title</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cromwell-Collier Building</td>
<td>640 Fifth Ave</td>
</tr>
<tr>
<td>United Nations Secretariat</td>
<td>199 Church Street</td>
</tr>
<tr>
<td>New York State Insurance Fund Building</td>
<td></td>
</tr>
<tr>
<td>The Canada House</td>
<td>680 Fifth Ave</td>
</tr>
<tr>
<td>The 1 Rockefeller Plaza (form. Time &amp; Life Building)</td>
<td>1271 Sixth Ave</td>
</tr>
<tr>
<td>Lincoln Center for the Performing Arts</td>
<td>10 Lincoln Center Plaza</td>
</tr>
<tr>
<td>CBS Building</td>
<td>51 W. 52 St.</td>
</tr>
<tr>
<td>Church of the Holy Family</td>
<td>315 E. 47th Street</td>
</tr>
<tr>
<td>Civic Center Synagogue</td>
<td>47 White Street</td>
</tr>
<tr>
<td>Jacob K. Javits Federal Building</td>
<td>26 Federal Plaza</td>
</tr>
<tr>
<td>The Ford Foundation Building</td>
<td>321 E. 42nd Street</td>
</tr>
<tr>
<td>General Motors</td>
<td>767 Fifth Ave</td>
</tr>
<tr>
<td>Astor Plaza</td>
<td>1515 Broadway</td>
</tr>
<tr>
<td>Pace College Civic Center Campus</td>
<td></td>
</tr>
<tr>
<td>Exxon Building</td>
<td>1251 Sixth Ave</td>
</tr>
<tr>
<td>J.P. Stevens Company Tower</td>
<td>1185 Avenue of the Americas</td>
</tr>
<tr>
<td>Elmer Holmes Bobst Library &amp; Study Center</td>
<td>70 Washington Square S.</td>
</tr>
<tr>
<td>McGraw Hill Building</td>
<td>1221 Sixth Ave</td>
</tr>
<tr>
<td>Park 900</td>
<td>900 Park Ave</td>
</tr>
<tr>
<td>The Celanese Building</td>
<td>1211 Sixth Ave.</td>
</tr>
<tr>
<td>AT&amp;T Long Lines Building</td>
<td>33 Thomas Street</td>
</tr>
<tr>
<td>The 100 William Street</td>
<td>100 William Street</td>
</tr>
<tr>
<td>The N.Y. Telephone Co. Building</td>
<td>1095 Sixth Ave.</td>
</tr>
<tr>
<td>The Solow Building</td>
<td>9 W. 57th St.</td>
</tr>
<tr>
<td>WR Grace Building</td>
<td>1114 Sixth Ave</td>
</tr>
<tr>
<td>The N.Y. Telephone Co. Switching Station</td>
<td>375 Pearl St.</td>
</tr>
<tr>
<td>Piaget Building</td>
<td>650 Fifth Ave</td>
</tr>
<tr>
<td><strong>Architect</strong></td>
<td><strong>Year</strong></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Leonard Schultze &amp; Associates</td>
<td>1950</td>
</tr>
<tr>
<td>Wallace K. Harrison</td>
<td>1950</td>
</tr>
<tr>
<td>Lorimer Rich Associates</td>
<td>1955</td>
</tr>
<tr>
<td>Eggers &amp; Higgins // Marazio &amp; Morris</td>
<td>1957</td>
</tr>
<tr>
<td>Harrison, Abramovitz &amp; Harris</td>
<td>1957-59</td>
</tr>
<tr>
<td>Eero Saarinen</td>
<td>1961-5</td>
</tr>
<tr>
<td>George J. Sole</td>
<td>1965</td>
</tr>
<tr>
<td>William N. Breger</td>
<td>1967</td>
</tr>
<tr>
<td>Alfred Easton Poor // Kahn &amp; Jacobs // Eggers &amp; Higgins</td>
<td>1967</td>
</tr>
<tr>
<td>Roche Dinkeloo</td>
<td>1967</td>
</tr>
<tr>
<td>Edward Durell Stone // Emery Roth &amp; Sons</td>
<td>1964-1968</td>
</tr>
<tr>
<td>Ely J. Kahn &amp; Der Scott</td>
<td>1970</td>
</tr>
<tr>
<td>Harrison, Abramovitz &amp; Harris</td>
<td>1971</td>
</tr>
<tr>
<td>Emery Roth &amp; Sons</td>
<td>1971</td>
</tr>
<tr>
<td>Phillip Johnson &amp; Richard Foster</td>
<td>1968-72</td>
</tr>
<tr>
<td>Harrison, Abramovitz &amp; Harris</td>
<td>1972</td>
</tr>
<tr>
<td>Philip Burnbaum</td>
<td>1973</td>
</tr>
<tr>
<td>Harris</td>
<td>1973</td>
</tr>
<tr>
<td>John Carl Warnecke</td>
<td>1974</td>
</tr>
<tr>
<td>Davis, Brody &amp; Assocs. // Emery Roth &amp; Sons</td>
<td>1974</td>
</tr>
<tr>
<td>Kahn &amp; Jacobs</td>
<td>1974</td>
</tr>
<tr>
<td>SOM</td>
<td>1974</td>
</tr>
<tr>
<td>Skidmore, Owings &amp; Merrill (Gordon Bunshaft)</td>
<td>1974</td>
</tr>
<tr>
<td>Rose, Beaton &amp; Rose</td>
<td>1976</td>
</tr>
<tr>
<td>John Carl Warnecke</td>
<td>1978</td>
</tr>
</tbody>
</table>
APPENDIX B

THE CAREER OF WALLACE K. HARRISON
The Career of Wallace K. Harrison

The life and career of Wallace K. Harrison (1895-1981) is a story of upward mobility achieved through the winning combination of persistence, charm, and leadership. Harrison effectively started his career at age 17 working for the O.W. Norcross construction firm after his mother died. He soon realized that designing appealed more to him, and he left his job for the Worcester architecture firm Frost & Chamberlain. He took night courses in engineering and architecture at Worcester Polytechnic Institute. Harrison noticed that Boston architects were hired for the large projects in Worcester and New York based architects were hired for the large projects in Boston. Consequently, he left for New York at age 21 with $35 to his name, and began working for McKim, Mead & White before serving in the US Navy during World War I. Following the war, Harrison pursued his desire to study the traditional monuments and architecture of Europe and enrolled at the Ecole des Beaux Arts for one year. He then traveled for another two years on a Rotch Traveling Scholarship.

When Harrison returned to New York in 1923, he began working for the firm of Bertram Goodhue until Goodhue died. He then worked for Helmleand and Corbett as a junior partner until 1935; while with this firm, he was part of the team that designed Rockefeller Center. Corbett nurtured Harrison's concept of futuristic design and influenced his aesthetic, the product of which is said to be seen in the design of Lincoln Center and Albany Mall. Following the work with Corbett, Harrison formed a partnership with J. Andre Fouilhoux, with whom he designed the Trylon and Perisphere buildings of the 1938-39 New York Worlds Fair (Fig. needed). In 1941, Max Abramovitz joined the partnership, and the firm became Harrison, Fouilhoux, & Abramovitz until Fouilhoux's death in 1945. Harrison and Abramovitz would remain partners until 1976.

As a team, Harrison and Abramowitz were extremely successful, with a firm of more than 200 people at its height, drawing blueprints for well over $1 billion in buildings of varying kinds and styles all over the world. They worked on a number of notable projects including, but certainly not limited to, the Rockefeller Center west extension, Empire State Plaza in Albany, United Nations complex, Corning Glass Works Complex, the First Presbyterian Church in Stamford, CT, and multiple buildings in the Lincoln Center complex including the Metropolitan Opera and Philharmonic Hall (Fig.s 1-5). Harrison won a number of awards through his career including the New York Architectural League's Gold Medal in 1936 and the American Institute of Architect's Gold Medal in 1967.

Opinion of Harrison's work lacks consensus. His designs have been called a "curious mix of a sort of bureaucratic, banal, corporate style and of daring, theatrical gestures," "innovative yet reactionary, flamboyant yet restrained," "indecisive and uncommitted," and "superficial and derivative." Ada Louise Huxtable,

2 The firm was "divided into antagonistic camps of Gothicists and classicists. Harrison belonged to the latter group." Upon Goodhue's death, the Gothic group held control, and Harrison felt the firm was not the right place for him. (Newhouse, 26)
3 Ibid, 27.
a prominent architectural critic for the New York Times from 1963-1982, admitted that Harrison’s reputation had “not been high among hard-line modernists and critics” despite his work with some of New York’s most prestigious projects since the 1920s. Rem Koolhaas attempted to reestablish Harrison’s standing through an 1980 exhibition on the architect’s work at the Institute for Architecture and Urban Studies. He presented Harrison as a postmodernist, 40 years ahead of its time, due to Harrison’s interested in curves. The thesis of the exhibition was that Harrison was naturally pulled to the curve, but he fought in the inclination in order to accommodate to reality and returned to the straight line. He “calls the work ‘undogmatic’ where others called it indecisive and uncommitted.” The exhibit convinced a critic, who labeled Harrison’s office towers “banal,” that nothing Harrison did was “completely devoid of some sort of attempt to break out of the mold of standardized designs.” The consensus following the exhibit was that Harrison was a romantic pragmatist, a superb coordinator of “diverse and often temperamental talents,” and an architect that sought visual pleasure, “delight, not dogma.” He was not one to follow the cannon of Modern architecture, and his body of work may be dotted with aesthetically unsuccessful attempts at originality that became labeled as a “monument manqué,” but the fact remains that Wallace Harrison’s work has something to say for that moment in architectural history.

6 Huxtable, D2.
7 Goldberger, C15.
8 Huxtable D2.
9 Goldberger, C15.
10 Ibid. Von Eckardt, A6. Harrison called the type of project where many architects or designers are involved “gang architecture.”
BIBLIOGRAPHY
Bibliography


Goldberger, Paul. “Architecture: Harrison Respec-


Photo & Image Credits


1.3 Architectural terra cotta, standard construction (Plate No. 6). Image reprinted with permission from the National Terra Cotta Society.

1.4 Terra cotta anchorage systems (Plate No. 70). Image courtesy of the National Terra Cotta Society Publication, 1914, and reprinted with permission from the National Terra Cotta Society.

1.5 The Flatiron Building. Photo credit to S. Ripple, 2012.


1.7 The Woolworth Building. Photo credit to S. Ripple, 2012.

1.8 The American Radiator Building. Photo credit to S. Ripple, 2012.

1.9 The Empire State Building. Photo credit to S. Ripple, 2012.

1.10 Shot sawn limestone of Rockefeller Center. Photo credit to S. Ripple, 2012.


1.12 The Socony Mobil Building. Photo credit to S. Ripple, 2012.


1.15 Illustration of the basic principles and economical use of granite sawing and carborundum machine work. Image courtesy of Sweets Catalog, 1961. Reprinted with the permission of the National Building Granite Quarries Association.

1.16 Anchorage of precast-composite systems. Image courtesy of The Masonry Institute of America (Marble and Stone Slab Veneer, 1989).

1.17 Mechanical grid system. Image reprinted with the permission of the Marble Institute of America.


1.22 The General Motors Building. Photo credit to S. Ripple, 2012.

1.23 Central buildings of Lincoln Center (Metropolitan Opera House, Philharmonic Hall, and New York State Theater). Photo courtesy of Wikicommmons.

1.24 South facade of the CBS Building. Photo credit to S. Ripple, 2012.


2.1 Hysterisis of marble panels on Finlandia Hall. Photo courtesy of Wikicommmons.

2.2 Three common building materials used together: terra cotta, brick & granite. Photo credit to S. Ripple, 2012.

2.3 Crazing of a glazed terra cotta column and panel, meant to mimick marble. Photo credit to S. Ripple, 2012.

2.4 Granite adjacent to mimicking cast stone. Photo credit to S. Ripple, 2012.

2.5 Veining of the fine grained marble in the New York Public Library. Photo credit to S. Ripple, 2012.

2.6 Fossils within a limestone panel. Photo credit to S. Ripple, 2012.

2.7 Characteristic voids of travertine. Photo credit to S. Ripple, 2012.

2.8 Color and grain size range of granite. Image courtesy of Sweets Catalog, 1961. Reprinted with the permission of the National Building Granite Quarries Association.
2.9  Marble base deterioration.
Photo credit to S. Ripple, 2012.
3.1  Tooled finish of Stoney Creek Granite.
Photo credit to S. Ripple, 2012.
3.2  Bushhammer finish of Stoney Creek Granite.
Photo credit to S. Ripple, 2012.
3.3  Thermal and polished finishes of Stoney Creek Granite.
Photo credit to S. Ripple, 2012.
4.1  Holes from dowel anchors in ancient Roman ruins.
Photo credit to S. Ripple, 2011.
4.2  Standard strap anchors.
Image courtesy of the National Terra Cotta Society Publication, 1914, and reprinted with permission from the National Terra Cotta Society.
4.3  Bent flange and dovetail ended anchors.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.4  Z strap anchor and U strap (or “cramp anchor”).
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.5  Two way (or “split tail”) anchor.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.6  T-strap anchor.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.7  Twisted strap anchor.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.8  Z, U, and T rod anchors.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.9  Plain and threaded dowels.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.10  Wire-tie anchor.
4.11  Lewis bolts and cinch anchor.
4.12  Shelf angles.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.13  Adjustable box insert anchors.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.14  Z strap, U cramp, dovetail strap and two way dovetail strap anchors.
4.15  Rod anchor.
4.16  Rod cramp anchor.
4.17  Lewis bolts and cinch anchors.
4.18  Shelf angles with adjustable box anchors.
4.19  Anchoring of exterior marble veneer.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.20  Anchoring of exterior granite veneer.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.21  “Tie-to” anchor.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.22  Anchoring and support of limestone veneer.
Image courtesy of Architectural Graphic Standards, 1951, Reprinted with permission from John Wiley & Sons.
4.23  Twisted strap anchor.
4.24  Support of 7/8” thick marble panel, incorporates a strip liner.
4.25  Support of 1 1/4” thick marble panels, no


4.31 Slotted clip, flatbook and bolt, soffit straps, U-strap and rods, clip and power stud, strap and rod cramp, tamp-in anchor, adjustable wire, adjustable insert wire, lug and nut inserts. Image courtesy of *Architectural Graphic Standards*, 1971, Reprinted with permission from John Wiley & Sons.


5.1 Lincoln Center for the Performing Arts. Photo credit to S. Ripple, 2012.

5.2 North facade, fins of the Metropolitan Opera. Photo credit to S. Ripple, 2012.

5.3 Fins of the Metropolitan Opera are backed by a glass facade. Photo credit to S. Ripple, 2012.

5.4 Stainless steel T-strap anchors, each with two dowels. Photo courtesy of Kimball Beasley, 1986.

5.5 Panels are secured at the base by dowels with stainless steel caps soldered over. Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.6 Stainless steel split tail anchors used in horizontal and vertical joints. Photo courtesy of Kimball Beasley, 1986.

5.7 Performance issues and failure of the travertine fins on the Metropolitan Opera. Photo credit for 5.7a to S. Ripple, 2012. Photos 5.7b&c courtesy of Kimball Beasley, 1986.

5.8 Main facade of the Philharmonic Hall. Photo credit to S. Ripple, 2012.

5.9 Tapered columns of the Philharmonic Hall. Photo credit to S. Ripple, 2012.

5.10 Surface depositions and soiling on the Philharmonic Hall. Photo credit to S. Ripple, 2012.

5.11 Soffit cracking of the Philharmonic Hall travertine. Photo credit to S. Ripple, 2012.

5.12 East facades (from Avenue of the Americas) of the “XYZ” buildings. Photo credit to S. Ripple, 2012.

5.13 Main facade of the Celanese Building. Photo credit to S. Ripple, 2012.

5.14 Support and anchoring of the limestone on the Celanese building. Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.15 Lateral support of the facade panels of the Celanese. Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.16 Dowel anchoring of panels at base of the building. Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.17 Main facade of the Exxon Building. Photo credit to S. Ripple, 2012.
5.18 Limestone support at the top of the panel using cramp anchors. 
Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.19 Anchorage of column veneer panels. 
Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.20 Main facade of the McGraw Hill Building. 
Photo credit to S. Ripple, 2012.

5.21 Support and anchoring of composite granite and precast panels using shelf angles with dowels. 
Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.

5.22 Another form of anchoring using angles bolted to the back of the precast concrete. 
Images Courtesy of Avery Library, Wallace K. Harrison & Max Abramovitz Collections, Drawings and Archives Department, Avery Library, Columbia University.