

CLADDING THE MID-CENTURY MODERN:
THIN STONE VENEER-FACED PRECAST CONCRETE

Sarah Sojung Yoon

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Advisor

Dr. Theodore Prudon

Adjunct Professor at Columbia University
Principal, Prudon & Partners

Reader

Sidney Freedman

Director, Architectural Precast Concrete Services
Precast/ Prestressed Concrete Institute (PCI)

Reader

Kimball J. Beasley

Senior Principal,
Wiss, Janney, Elstner Associates, Inc. (WJE)

ABSTRACT

Cladding the Mid-Century Modern: Thin Stone Veneer-Faced Precast Concrete

Sarah Sojung Yoon
Dr. Theodore Prudon, Advisor

With significant advancements in building technology at the turn of the twentieth century, new building materials and innovative systems changed the conventions of construction and design. New materials were introduced and old materials continued to be transformed for new uses. With growing demand after WWII forcing further modernization and standardization and greater experimentation; adequate research and testing was not always pursued. Focusing on this specific composite cladding material consisting of thin stone veneer-faced precast concrete – the official name given at the time – this research aims to identify what drove the design and how did the initial design change over time. Design decisions and changes are evident from and identified by closely studying the industry and trade literature in the form of articles, handbooks/manuals, and guide specifications.

For this cladding material, there are two major industries that came together: the precast concrete industry and the stone industry. Literature from both industries provide a comprehensive understanding of their exchange and collaboration. From the information in the trade literature, case studies using early forms of thin stone veneer-faced precast concrete are identified, and the performance of the material over time is discussed. This cladding material seems to appear on the US market generally in the 1960s and 1970s. Three fundamental questions were asked: 1) What were the designs and how did they evolve over time; 2) what kind of issues or failures came about; and 3) what measures were taken to address them; 4) what changes were made to mitigate future failures?

Technical design decisions are dependent on physical performance of the individual materials and the interaction between the two. Other conditions such as economy, client demand, and architectural trends influence those decisions. As the architecture from this era now enters into the realm of preservation, it is important to understand and assess the historical and technical context and background of this composite material and system in order to allow for informed choices to be made regarding preservation strategies.

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“It is clear that modern technology has made possible an unprecedented range of structural possibilities. It is also very clear that they are only partially and sporadically employed in the mass of American building. The most advanced technology on earth flourishes in a landscape filled with a preponderance of unsafe, obsolete and unattractive structures. The sources of this paradox lie largely outside technology itself, however.”¹

-James Marston Fitch-

Chapter 1. Introduction

With the rapid advancements in building technology at the turn of the twentieth century, new building systems and materials have emerged and completely changed how we build. New building materials were introduced and old building materials were transformed for new uses. Stone as a result of this transformation shifted from functioning as bearing wall masonry to thin stone cladding. As a result, mid-century Modern architecture best reflects the experimental nature of this era. As Fitch mentions the range of structural possibilities due to modern technology is unprecedented; however, when the process of application and environment is not well thought out, the paradox is low quality performance from advanced technology.

1.1 Definition of the Problem:

The experimentation and creation of new materials, particularly composite cladding materials, was an amalgamation of the following conditions: industry trends, client budget, and design intent. Through the process of standardization and mass production, the speed of construction became a driving force in the industry and its developments. During the Industrial Revolution, standards to regulate production was necessary because of the lack of knowledge associated with developing technology and its lack of quality control. There was also a level of obsession with standardizing building construction and architectural design that can be traced back to some of the Modernists architects and designers. The ideas behind pre-fabrication and machine aesthetics dominated design and construction for the Modernists. A combination

¹ Fitch, J. M. (1966). *American building* (2nd ed., Vol. 2). Boston: Houghton Mifflin. 228-229.

of these movements and rationale regarding technology and innovation continued into the twentieth century, and by the 1960s and 1970s production and implantation of new materials was, once again, highly encouraged and explored at an incredible pace. The speed at which innovation was encouraged and implemented gave little time for research and testing resulting in various forms of material and systematic issues and failures. In the design process, there is also a lack of assigned accountability. A large majority of these new products were being designed by architects or fabricators that did not have a full understanding of the material performance. Some studies connect the lack of clear accountability with the poor quality or “disposable” mentality effecting design in the United States, particularly after World War II.² Unfortunately, involvement from the structural engineers and the technical experts usually occur after a failure, which is seen consistently in respect to façade failures. Although the building industry continues to change and improve by learning from these past attempts, there are still a large number of buildings constructed from this time period that are faced with these types of performance issues.

Thin stone veneer-faced precast concrete panels-

Thin stone veneer-faced precast concrete panels was an engineered cladding material that appeared around the 1960s.³ Natural stone is a building material that has been used for its strength, durability and aesthetics. It was finished in varying thicknesses depending on the type of stone, and mechanically attached to architectural precast panels with the appropriate anchors. The finished panel is then then hung off the structural frame of buildings. A variety to stone types are used at different tolerances to accommodate movement. The natural stone gave architects and designers a certain aesthetic and the precast concrete component gave the panel performance stability and control. Used extensively during the 1960s – 1970s, *thin stone veneer-faced precast concrete* gains acceptance as a cladding material by the industry, and is still supplied by precasters working in collaboration with stone manufacturers today. Precast panels have the

² Cohen, J. M. (1991). Cladding Design: Whose Responsibility? *J. Perform. Constr. Facil. Journal of Performance of Constructed Facilities*, 5(3), 209.

³ PCI Designer’s Notebook DN-7 Stone Veneer-Faced Precast. 2000.

advantage of reduced cost and speed of assembly on site. This cladding material is one of many innovative design solutions that responded to the building conditions and demands of the time.

Evaluating the evolution and performance of this material can provide significant information regarding the trends of the building industry. Buildings from this era face more scrutiny today in regards to performance and re-habilitation because of their outdated or inefficient systems. Some are also facing questions of preservation and restoration. What significant values do these buildings and their technology provide and how can that information be communicated in the preservation context? Also, how do we deal with the technical issues of material deterioration and keep it compliant with today's standards without losing historic value? These are some of the important questions that the profession is faced with in the present context.

1.2 Scope of the Research:

This thesis aims to study the evolution and development of the cladding material recognized as *thin stone veneer-faced precast concrete panels*, and how technology has transformed architecture and construction. After World War II the United States emerged as a dominant power and by the second half of the Twentieth century, there were substantial developments in technology that transformed traditional building materials for modern use. This study will focus on the United States and its context during the construction of mid-century Modern architecture. Stone becomes a contemporary cladding material when it is applied to curtain wall systems as a thin, lightweight material. During the 1960s and 1970s, thin stone cladding was integrated with precast concrete panels and became a popular thin lightweight cladding material that was used extensively in the North American context. Due to its rapid development and use, the industry began standardizing production and took interest in writing regulations and specifications for their new products. Historically, the development of standards and specs are often a result of unforeseen problems and/or failures, but the investigative processes for writing these specs pushed for optimizing the design. The

investigation of these standards help in understanding the design and use of the product. There are many different stakeholders that contributed to the development of this product, and in the case of thin stone veneer-faced precast concrete panels, both the stone manufacturers and precast manufactures are heavily invested. In the form of product demand, architects, engineers, and significant clients contributed to the product development. The technology, industry, and demand tell the story of this composite cladding materials evolution and contribution to architecture and construction.

1.3 Literature Review:

This composite cladding materials needs to first be understood as a collaboration between trades. Two distinct industries worked together to produce *thin stone veneer-faced precast concrete panels*: the stone industry and the precast concrete industry. Although stone and concrete are building materials that are enormously important to building and construction today, at the turn of the century the introduction to concrete and the process of precast was fairly new and innovative. The stone industry was faced with changing material demands and new competition when it came to precast concrete and building cladding.

Stone Industry: Thin stone veneer-

Thin stone veneers systems were already available as a cladding material at the end of the nineteenth century. The demand for stone is one that has ebbed and flowed through the ages, but it was the panelization of stone that allowed it to remain competitive as a building material during the early twentieth century. A “resurgence in popularity of stone, corresponding with the popularity of the post-modern style of architecture resulted in dramatic increase in the use of stone as an exterior cladding material.”⁴ The improvements in the cutting and transportation of materials allowed for the transformation and experimentation of stone as a cladding material. “By placing thinner stone slabs or stone facing upright on

⁴ Gerns, Edward, A. “*Design Issues for thin-stone cladding systems.*” RCI Symposium of Building Envelope Technology. 2002. 23.

precast concrete panels (collectively known as thin-stone veneer) in front of the structural frame like in the metal and glass curtain wall and anchoring them back into the structure, a new construction methodology emerged.”⁵ The most commonly used stones were marble, granite, limestone, travertine and slate. The architectural discourse between aesthetic and technology pushed for the development of thinner lighter building materials; however, the physical transformation of these materials came with mechanical consequences. According to Scheffler’s writing regarding thin-stone veneers in *Thin-stone veneer building facades: Evolution and preservation*, the longevity of stone was altered with its new form of thin panels because of the change in material thickness and the new methods of construction.⁶ The rapid distress and failures associated with thin stone veneer was foreign to the industry. The durability of the thin stone and the new systems of support developed through a process of trial and error. Design considerations begin to address problems with the material and the system on which the cladding is attached. The accuracy of the details became an engineering task that determined the success and failure whole system. Material failures such as spalling, corrosion of fasteners, moisture barriers, and inaccurate tolerances for movement became critical issues to the overall system because these materials depended on accurate performance predictions in order to be successful.⁷ For the actual panelized stone, significant bowing was also a new sign of distress that was not common to traditional masonry construction. Bowing is a sign of distress that comes from intergranular fracturing along the natural grains of the stone due to thermal cycling in a process known as hysteresis.⁸ Other signs of distress for thin stone veneer can be described in the following conditions: warping, fractures, spalls, cracks, and delamination. The cause of distress can be for a number of reasons such as lack of tolerance for movement, intrinsic material quality, moisture intrusion, environmental conditions such as freeze-thaw, or poor workmanship.⁹ Sealants and anchors were other aspects of the

⁵ Prudon, Theodore H.M. *Preservation of modern architecture*. Hoboken, N.J.: Wiley, 2008. 474-475.

⁶ Scheffler, M. (n.d.). Thin-Stone Veneer Building Facades: Evolution and Preservation. *APT Bulletin*, 28.

⁷ Gerns, Edward, A. “*Design Issues for thin-stone cladding systems*.” RCI Symposium of Building Envelope Technology. 2002. 23-28.

⁸ Beasley, K. J. (2001). Contemporary and Traditional Wall-System Failures. *J. Perform. Constr. Facil. Journal of Performance of Constructed Facilities*, 15(2), 44.

⁹ Kuriyama, J., & Dillon, S. (2010). Thin Stone Marble Facade Systems. *Journal of Architectural Technology*, 27(4), 1-8.

mechanical systems that started to deteriorate. Since early systems did not consider the effects of water penetration into the cladding system, galvanized steel connections in the form of shelf angles, lateral straps, and bolts began to corrode.¹⁰

Precast Industry: Concrete precast cladding panels-

The precast concrete industry dates back to the early 1920s and 1930s in the United States and Canada.¹¹ However, it wasn't until the 1950s when the use of precast concrete became significant. Towards the end of the 1950s, a new method of casting panels was introduced to the United States called Schokbeton or "shocked concrete" which allowed for an even distribution of material components of the concrete for an even finish.¹² Like the thin stone veneer industry, precast concrete panels was made possible by the advancements of building technology and the curtain wall systems. Precast concrete panels were specified for a variety of reasons, such as speed of construction and customization, but the impact of this modern building material extends to all aspects of construction. Since it was a manufactured building material, the process of production included "batch design and mixing, mold design and fabrication, the tying and placing of reinforcing steel, casting, curing, finishing, transport of the product to the job site, and erection."¹³ The use of this material required the collaboration of multiple fields: architects, engineers, and precast manufacturers. Even for the sake of communication, the need for standards became quite obvious. "The economy of precast concrete cladding (curtain wall) units is achieved by paying close attention to detailing of the precast concrete units...Standardization reduces costs because fewer molds are required. Also, productivity in all phases of manufacture and erection is improved through repetition of familiar tasks.

¹⁰ Gerns, Edward, A. "Design Issues for thin-stone cladding systems." RCI Symposium of Building Envelope Technology. 2002. 23-28.

¹¹ Freedman, S. (n.d.). Architectural Precast Concrete: A Material for the 21st Century. *Exterior Wall Systems: Glass and Concrete Technology, Design, and Construction*. 131.

¹² Pyburn, J. (2008). The Role of Precast Concrete Technology in Postwar Building Construction (K. Normandin, Ed.). In T. Prudon (Ed.), *Restoring Postwar Heritage* (Preservation technology dossier 8). New York: DOCOMOMO. 114-115.

¹³ Ibid. 114.

There is also less chance of effort.”¹⁴ The innovative nature of the precast industry expanded into areas of aesthetics by exploring textures, aggregates, and even color. Structurally, precast had the advantage of being structural when casted with reinforcement. This gave versatility to the building material and much experimentation was done in exploring the potential of this material and how it could be utilized in construction. In the process, limitations start to emerge for the process to be economical.

*“As a general rule, the precast concrete panels should be made as large as possible without creating special handling requirements or losing repetition. Flat panels should not be made any thicker than necessary for obvious economical and/or weight reasons. Neither should they be made so thin that structural or performance requirements cannot be fulfilled. Because of the multitude of combinations of sizes, functions, applications, and finishes, no chart for sizing has been attempted.”*¹⁵

The systematically engineered part and whole relationship of the material makes the panelization process, in general, very intricate and complex. Success of this system depends on the joint collaborative effort in the design process. When extra time is spent during the developmental stages of the project, there is cost savings during accelerated construction; therefore, it is always recommended that designers seek out professional advice from the producers in the early stages of design.¹⁶ Like other panelized systems, both material and mechanical failures exist within the system. In the case of precast concrete, the issues can stem from the design mix of the concrete or the corrosion of attachment members to the structural frame. Accounting for tolerance due to shrinkage was also an important factor that needed to be considered when designing the panel and the securing mechanisms.

¹⁴ Freedman, S. (n.d.). Architectural Precast Concrete: A Material for the 21st Century. *Exterior Wall Systems: Glass and Concrete Technology, Design, and Construction*. 132.

¹⁵ Ibid. 134.

¹⁶ Ibid. 150.

Composite Cladding Material: Thin stone veneer-faced precast concrete panels-

With a strong emphasis on “transformations concerning the built environment,” experiments with composite building materials start to pick-up around the 1960s.¹⁷ The use of thin stone veneer-faced precast concrete panels was advantageous for a couple of reasons. Economic assembly, quality control of products, and the speedy construction of units on-site. However, since it is a composite building material, each component, as well as the combination of the two materials, must be taken into consideration when designing the final product. The facing veneer stone will have certain inherent properties such as tensile, compressive, and shear strength, modulus of elasticity, coefficient of thermal expansion, and consideration of volume change. Then there are the properties of precast concrete that deal with the shrinkage during curing, stresses during handling, transport, and construction, and coefficients of thermal expansion. As a rule of thumb, it is ideal to have a concrete backup with low shrinkage and a thermal expansion coefficient that closely match the stone veneer. Along with the different properties of the two building materials, the way they are connected is another important design question. The size of the hole for the anchors, insulation, length, material, and uses of various epoxies are all components of the anchorage connection. Designs need to be fully tested and approved before they can make it into the market. Veneers are connected with anchors that are specified according to the stone properties. This final product must perform as a one system that needs to withstand environmental conditions.

¹⁷ Moran, B. (2014). Architecture in North America since 1960. In D. Rifkind & E. Haddad (Eds.), *A Critical History of Contemporary Architecture: 1960-2010*. Ashgate Publishing, 139.

Failure of building materials: public and client perception-

Almost as soon as it was introduced, problems and failures regarding thin stone veneer and its response to the natural environment surfaced immediately. Some of the more well-known cases are Finlandia Hall designed by Alvar Aalto and the former Amoco building in Chicago. The thin stone Carrara marble cladding installed at Finlandia Hall started to show signs of failure six years after its completion in 1971. In 1997 the

decision was made to reclad the building with the same material with specifications that adjusted the thickness and anchor placements of the panel to address the deterioration and bowing that occurred. Despite the efforts, the marble panels, once again, began to bow as a result of hysteresis. In terms of historic preservation, it became a unique



Figure 1.1 Finlandia Hall - Helsinki, Finland

example of a failing building material and system on a significant piece of architecture.¹⁸ The former Amoco building, now known as the Aon Center, was another example of thin stone cladding failure, but this was on a building that rose up 83-stories, into the skyline of Chicago. Completed in 1974, this high-rise building was also clad in Carrara marble with a thickness of 1 inch. At the time of completion, the attention the project received was due to its innovative structural framing that used a chevron column system and the use of thin stone veneer cladding.¹⁹ However, an inspection of the building in 1985 revealed significant failures in the thin stone panels and further testing showed the impact of weathering in relation to strength. By 1988, 30% of the marble panels were bowing outwardly by 1/2 inch to 1-1/2 inch.²⁰ Due to

¹⁸ Prudon, Theodore H.M. *Preservation of modern architecture*. Hoboken, N.J.: Wiley, 2008. 492-495.

¹⁹ Levy, M., & Salvadori, M. (1992). *Why buildings fall down: How structures fail*. New York: W.W. Norton. 191.

²⁰ *Ibid.* 191.

the public's previous interest in the building and the alarming issues of life safety that the bowing marble panels displayed, the project instigated changes in cladding design standards. The exterior of the building was completely recladded with a 2 inch thin stone granite. The legal responsibilities between the client and



Figure 1.2 Aon Center- Chicago, IL

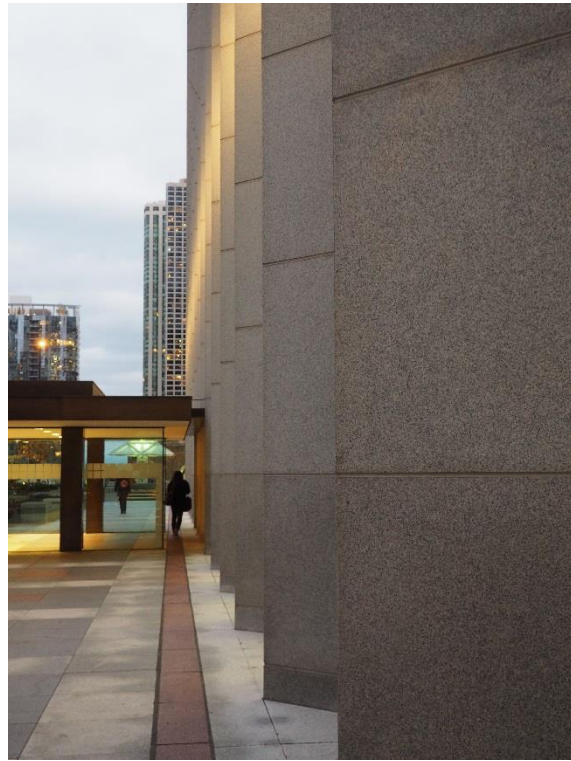


Figure 1.3 Granite Cladding – Chicago, IL

the designers/contractors was settled in court; however, it is now remembered as one of the most expensive high-rise reclad projects in the United States.²¹ As for the discourse in historic preservation, the method of repair raises the question of authenticity because of a replacement of Carrara marble to granite even though the repairs were done in respect to preservation values.²² Since these projects, much research has been conducted to efforts to understand the properties of thin stone veneers, especially marble. In the issue of *Restoring Postwar Heritage* by Docomomo-US, Martii Jokinen wrote specifically about Finlandia Hall and the many issues that arose after the restoration of the original façade. In Helsinki the Public Works

²¹ Ibid. 193.

²² Prudon, Theodore H.M. *Preservation of modern architecture*. Hoboken, N.J.: Wiley, 2008. 492-495.

Department of the City launched research projects such as MARA in 2001 to study the long-term durability of marble facades.²³ The biggest issue with the stone veneer was the bowing of the marble. For a relatively understudied cladding material, research and testing methods were developed to help create specifications for the marble cladding. Questions about the “life span” of a particular material and the selecting process for natural materials became an important topic for discussion. Amidst their research they discovered another case study which also used Carrara as the thin stone veneer cladding. Built around the same time as Aalto’s Finlandia, the thin marble did not warp or bow due to the environmental conditions. The Karjaa office building, west from Helsinki, used the same Carrara marble as cladding with a thickness of 1 cm, but it was backed by 1-3/8” of concrete which was also pre-stressed to counter the shrinkage of the concrete. It was a composite cladding material that was experimented with during this time of lightweight thin skin cladding.²⁴ Influential architecture projects such as the ones listed above were highly publicized due to the new technology and also the scale the projects. The system failures of these significant projects ended up having a great impact on the field. In both cases, there was the essential fear of safety and unpredictability, but the economic burden that the clients faced as a result of these system failures became an issue. Cohen describes it as a “disastrous economic consequences” to the building owners when the façade cladding fails.²⁵ Both projects had to be recladded and cost the client a substantial amount of money. Repairs required additional research regarding the individual modes of failure that was not well understood. The level of research that was focused on thin stone veneers was a response to building failures. In an attempt to address the reasons for failure, many tests and studies have been conducted over time. Although all the questions regarding failure and performance cannot be addressed, there is a better understanding of the material’s performance and characteristics due to the results derived from these studies. Connecting this process back to the composite material of *thin stone veneer-faced precast concrete*, the studies on stone properties and its performance as a cladding material inform, in part, the performance of *thin stone veneer-faced precast*

²³ Jokinen, M. (2001). Renovation of the Marble Cladding of Finlandia Hall. *Docomomo- US, Dossier 8*. 103.

²⁴ Ibid. 106.

²⁵ Cohen, J. M. (1991). Cladding Design: Whose Responsibility? *J. Perform. Constr. Facil. Journal of Performance of Constructed Facilities*, 5(3), 214.

concrete. The results may differ in terms of measured performance; however, the same types of performance questions are being addressed. The findings on thin stone veneer systems serve as background information for understanding *thin stone veneer-faced precast concrete*.

In the 1960s and 1970s, there is evidence of different types of cladding material being utilized on the market. This sheds some light on the experimental nature of the building and construction field of this time. Much of the changes in building techniques and methods is to assimilate these new building materials into the market. Large scale buildings were the prominent projects in the United States and the economic savings of the new composite materials made them the perfect choice for these projects. “Building complexity and scale emerged as major trends transforming architectural design and production with the rise of industrialism in the nineteenth century, but interest in them as characteristics governing practice is more recent.”²⁶ Unprecedented change meant the long-term effects of these designs and their material performances were yet to be determined. The various experiments with cladding material and the failures of the design and implementation of the materials is revealed in the literature. The continuous evolution of these building materials continues; however, there is a limited information regarding the composite material *thin stone veneer-faced precast panels* from the 1960s and 1970s. This relatively understudied composite material is significant to the discussion of building material innovation because it was a material that was a product of changing times that contributes to the narrative of material and building technology. By looking specifically at an understudied material that was heavily used in the industry, an overall history of how new materials are gradually assimilated into the field can be examined, along with knowing the basics for asking appropriate questions in times of repair.

How, exactly, does the evolution of this one building material tell the history of building technology? Also, it asks the larger question of how do conservationists and contemporary architects deal with

²⁶ Gutman, R. (1988). *Architectural practice: A critical view*. New York, NY: Princeton Architectural Press. 33.

historically innovative building technology that has since evolved? What sorts of questions are appropriate for these building components?

1.4 Research Question / Methodology

The goal of this thesis is to understand the design decisions made during the mid-century Modern period of the 1960s through the 1970s and how those decisions influenced building technology. This study will focus on the specific composite architectural cladding material described as *thin stone veneer-faced precast concrete panel*, as called in the field, and how it came to be used extensively in the 1960s and 1970s. It will look at how the material failures have been mitigated or addressed over time, and what kind of questions it poses for preservation. The methodology for this study will be conducted in a two-fold process. The first section will focus on the analysis of the technical literature associated with this cladding system and its development. The technical literature will be from both the manufacturing industry of precast concrete and the marble stone industry. The second part of the study will include a deeper analysis of specific case studies that have used this composite system of cladding and how they have been maintained and repaired over time. The aim of evaluating various case studies from the 60s and 70s is to understand the types of projects that were willing to experiment with new materials and physically evaluate their current conditions. As a final result, the information obtained will help provide the foundations for discussing the recommendations of how to deal with mid-century Modern architecture as heritage and what kind of interventions are appropriate or preservation purposes.

Chapter 2. Mid-Century Modern Architecture

Mid-century Modern refers to the middle of the twentieth century. During this time, many schools of thought emerged, particularly in the field of architecture and design in the United States. Many influential figures developed their theories and practices that shaped a progressive era of building, and their ideas still resonate throughout the professional world of building and design today. This chapter will look at the economical and theoretical trends of this specific time period to better understand the context and development of new building materials such as *thin stone veneer-faced precast*.

2.1 Influence of the Modernists:

Modernism, for the field of architecture, was a school of thought that was promoted by a group of highly influential educators and practitioners. In regards to contemplating the impact of cladding and the processes of standardization, there are two individuals that introduced the potential of these two ideas in the field: Walter Gropius and Adolf Loos. Founder of the Bauhaus School, Walter Gropius was an important contributor to the Modern architecture movement and the International Style. His position as chairman of Harvard's architecture school continued to widen his influence on the profession. Gropius had a specific vision for architecture and it was connected to the machine aesthetic and standardization process. "Our age has initiated a rationalization of industry based on the kind of working partnership between manual and mechanical production we call standardization which is already having direct repercussions on building."²⁷ As one of the great minds that influenced the field of architecture in the twentieth century, Walter Gropius saw standardization as the rational direction for construction and pre-fabrication as the method of implementation. For him standardization was an immediate prerequisite for the development of civilization.²⁸ For those who viewed standardization as a threat to individuality, this was his response: "In

²⁷ Gropius, W. (1965). *The new architecture and the Bauhaus*. Cambridge, MA: M.I.T. Press. 33.

²⁸ Ibid. 34.

all great epochs of history the existence of standards – that is the conscious adoption of type-forms – has been the criterion of a polite and well-ordered society; for it is a commonplace that repetition of the same things for the same purposes exercises a settling and civilizing influence on men’s mind.”²⁹ He also pushed for this idea of “dry assembly” by means of pre-fabrication. As an industry construction has always been dependent on weather conditions because of on-site work restrictions. With pre-fabrication, not only can the building parts be fabricated with a high level of quality control, moisture can be eliminated from the system. “Moisture is the direct cause of most of the weaknesses of the old methods of building. It leads to badly fitting joints, warping and staining, unforeseen piecework, and serious loss of time and money through delays in drying. By eliminating this factor, and so assuring the perfect interlocking of all component parts, the pre-fabricated house makes it possible to guarantee a fixed price and a definite period of construction. Moreover the use of reliable modern materials enables the stability and insulation of a building to be increased and its weight and bulk decreased.”³⁰

Adolf Loos, an influential theorist and architect, influenced the field of architecture, specifically the modernists, through his work and his writings. His work, as well as his writings, were very progressive and had the insight of predicting what was to come. By the late 1890s Loos was already considering the consequences and repercussions of cladding as a building material that would act independently from the structure of the building. In 1898 he wrote a short essay titled “The Principles of Cladding” in the *Neue Freie Presse*.³¹ Loos draws a distinction between “protection” and “sufficient protection.” The idea of “protection” is like covering or cladding for effect of feel. When he refers to “sufficient protection” this is more along the ideas of structure and functional demand. The order in which architects think of these things will depend on the individual; however, “stability and practicality demand materials which may not harmonize with the function of the building.”³² There is the recognition that the designers aim in terms of

²⁹ Ibid. 37.

³⁰ Ibid. 43.

³¹ Loos, A., Opel, A., Opel, D., & Loos, A. (2002). *On architecture*. Riverside, CA: Ariadne Press. 201.

³² Ibid. 42.

atmosphere and the realities of construction may not coincide, in which case cladding may be the only option. Considering architecture a high form of art, Loos believed that cladding functioning as an imitation of real materials is a disgrace. For him the law for using cladding was as follows: “there should be no possibility of confusing the cladding with the material it covers. To give an example, wood can be painted any color apart from wood color.”³³ Although deemed quite advanced in thought for his time, already in 1898 architects acknowledge the possible separation between function and aesthetics. The need to compromise is present in the formation and use of materials; however, for Loos, there is absolutely no compromise for imitation materials. If the aesthetic of stone is desired, real stone must be used. Any form of imitation or copy of real stone is “falsehood” and not art. His appreciation for the inherent qualities in materials can be seen in this statement:

*“Each and every material has its own vocabulary of forms and no material can appropriate the forms of another. Forms develop out of the way a particular material is produced and the ways in which it can be worked, they develop with and out of the material. No material willingly suffers an intruder among its forms and anyone who thrusts one on it will be branded as a forger. But art has nothing to do with forgery, with falsehood. The path of art is torn but pure.”*³⁴

Although it is impossible to determine what Adolf Loos might have thought of the composite material *thin stone veneer-faced precast concrete*, the development of this cladding material was to utilize the real material in an economic way. In other words, the material is not trying to imitate stone but redesign its conventions to fit the criteria as a cladding material. Going one step further, his arguments on the imitation versus the real also echoes contemporary discussion on acceptable material repairs when modern-day imitations can now mimic the real with almost indistinguishable accuracy. Loos was able to contemplate cladding questions that would arise in the twentieth century through his writings.

³³ Ibid. 44.

³⁴ Ibid. 43.

These ideas begin to shape the field and its rationale, and its impact can be seen in the pace and practice of architecture, particularly in construction methods of the 1950s to the 1970s. Much of the 1950s through the 1970s was a time period when the building industry and designers alike were pushing the boundaries of technology, yet trying to retain certain traditional aesthetic qualities. They explored limits that were very much undefined. The technological developments of the following areas changed the way building materials were obtained and assembled: the curtain wall cladding, industrial equipment, and engineered building materials. For the purpose of this thesis, it will specifically address the issues dealing directly with the development of the composite material *stone veneer faced-precast concrete panels*.

2.2 *Industrialization of Industry:*

“Throughout history, the evolution of construction practices has been motivated by the desire to build cheaper, faster, and easier.”³⁵ Changes that allowed things to be done cheaper, faster, and easier depend on developing technologies and machinery. The need to build arose with large scale projects, and people began to look for more economical ways to build. Industrialization can be categorized into two parts: 1. equipment/fabrication and 2. process.

Curtain Wall Cladding-

Cladding systems became extremely important because of the structural capabilities found in curtain walls. No longer was the exterior of the building required to share the load of the building. This gave designers the freedom to experiment with various types of materials that were previously deemed unsuitable because of the lack of structural performance. Exterior wall cladding is defined as such: “the outermost layer of material that encloses a building. Cladding is considered nonstructural in the sense that it is not intended to support the building structurally.”³⁶ With this change in function to the exterior wall, materials such as glass,

³⁵ Young, R. A. (2008). *Historic preservation technology*. Hoboken, NJ: John Wiley & Sons. 81.

³⁶ *Ibid.* 175.

metal and thin stone begin to appear on the façade of new buildings. The selection of materials became a choice of style and a new aesthetic convention was created. An example of this would be the flat curtain wall finish that was completely flush and smooth along the surface popular in the 1960s and 1970s.³⁷ These types of aesthetic decisions started to dictate the technical components of the systems, and it was during this time when the industry began to invest significantly on the development of mechanical fasteners and adhesives.³⁸ The development of the cladding systems has “historically been described mostly in stylistic terms, with more attention given to the technical advances that made these stylistic developments possible only recently.”³⁹ Condition assessments of these systems reveal their true performance, and cladding technology is one that continues to evolve today.

Industrial Equipment-

The building industry also experienced changes in production through new machinery which allowed them to push the performance of their materials beyond their limits. Specifically for the stone industry, the quarrying techniques and the cutting of stone changes how the material is used.

“The use of industrial diamonds for tipping the teeth of circular saws developed in the late 19th century, mainly in the United States, superseding the older frame-saws...During the last two decades of the 19th century improved machines were introduced with large diameter blades for sawing, facing and edging stone, and with fitted teeth.”⁴⁰

By 1932 the stone industry was capable of producing stone veneers as a cladding component with a thickness of 1 inch using the gang-saw which could then be honed down even further using a Carborundum wheel for finishing. In the 1950s, stone could be cut down to a thickness of 7/8”, and then the 1970s and

³⁷ Friedman, D. (2010). *Historical building construction: Design, materials and technology*. New York: Norton. 180.

³⁸ Ibid. 180.

³⁹ Prudon, Theodore H.M. *Preservation of modern architecture*. Hoboken, N.J.: Wiley, 2008. 107.

⁴⁰ Jones, P. D., & Simons, E. N. (1961). *Story of the saw: Published to mark the second centenary of the world's oldest sawmakers, Spear & Jackson, Limited, 1760-1960*. Newman Neame (Northern) Limited. 45-46.

1980s was the introduction of diamond-studded cables to slab blocks and frame saws with metal abrasives allowing stone to be cut down to 1/8" in thickness and used as facing material for developing composite building units.⁴¹ Even though the overall process is an ancient practice, new industrialized methods and equipment changed the way stone was quarried and finished. Stone was an old material but the change in thickness made it into a completely new product.

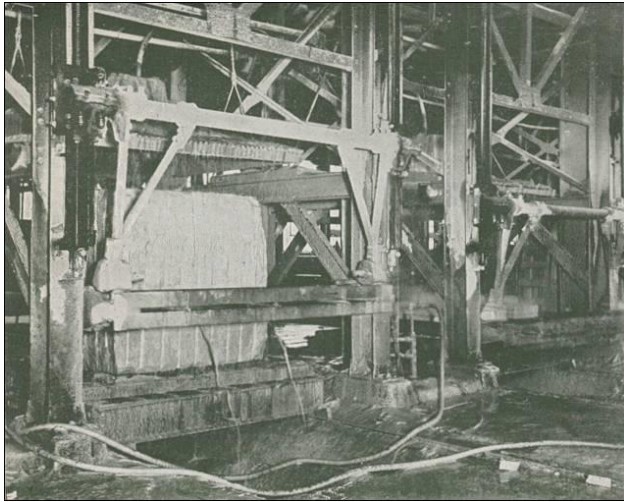


Figure 2.1 Gang-saws – Georgia Marble Quarries



Figure 2.2 Diamond Wire – Stony Creek Quarry
Branford, CT (2016)

Fabrication of Engineered Building Materials-

Fabricating engineered building materials like concrete was widely experimented with during the nineteenth and early twentieth century, but the demand became monumental in the twentieth century. Concrete is an engineered material that has a history dating back to the time of the ancient Romans; however, the technical advancements associated with concrete in the twentieth century, such as reinforcement and super plasticizers transformed our cities. Although there is no debate on the importance of concrete as a building material today, it took some time for the building community to accept and implement the use of this new material in the beginning. As concrete technology develops, its capabilities expand. In the twentieth century,

⁴¹ Scheffler, M., & Gerns, E. (2014). Thin Stone Veneer. In T. C. Jester (Ed.), *Twentieth-Century Building Materials: History and Conservation* (2nd ed.). Los Angeles, CA: Getty Conservation Institute. 137.

reinforced concrete and precast fabrication greatly impact the industry specifically pertaining to *thin stone veneer-faced precast concrete*.

There are not many instances where one material can change a field, however, reinforced concrete did this for the field of architecture. The use of reinforcement in concrete revolutionized construction.

Essential it was a strong building material that could easily be molded into a specific shape. When used a masonry unit, cured concrete has great compressive strength like stone, but with the addition of reinforcement in the form of metal rods or metal mesh, the concrete will now perform well in tension and shear. For the United States, the history and use of reinforced concrete beings with S.T. Fowler who patented a reinforced concrete wall in 1860; however, in 1877 Thaddeus Hyatt published *An Account of Some Experiments with Portland Cement Concrete, Combined with Iron, as a Building Material* which paved the way for this newly engineered building material's acceptance.⁴² From that point on there is a long list of experimentation and patents conducted by numerous individuals related to rebar design which indicates the lack of standardization up until 1910. Then in



Figure 2.3 Notre-Dame de Raincy
Le Raincy, France (Auguste Perret)

1949 the American Iron and Steel Institute (AISI) finalized the specifications regarding rebar.⁴³ The use of reinforced concrete gained the full attention of the architecture world with the construction of Notre Dame de Raincy (1922, Perret) located in France and soon became a common material for building.⁴⁴

⁴² Slaton, A. E., Gaudette, P. E., Hime, W. G., & Connolly, J. D. (2014). Reinforced Concrete (T. C. Jester, Ed.). In *Twentieth-Century Building Materials: History and Conservation* (2nd ed.). Los Angeles: Getty Conservation Institute. 61.

⁴³ Friedman, D. (2010). *Historical building construction: Design, materials and technology*. New York: Norton. 166.

⁴⁴ Prudon, Theodore H.M. *Preservation of modern architecture*. Hoboken, N.J.: Wiley, 2008. 512.

Precast concrete also contributed to the changes of building technology. With the first documented use of architectural precast concrete again going back to Auguste Perret's Notre Dame du Raincy in Le Raincy, France for the screen walls and infill.⁴⁵ The conversations about the potential for this material and this process of manufacturing go back even further to the 1890s and 1900s.

“From the viewpoint of a nineteenth-century engineer or builder, the use of precast reinforced-concrete units in construction was a logical extension of the use of ‘off-site pre-fabricated’ steel, timber, and masonry units. Structural materials were manufactured, brought to the site, and then assembled, as opposed to finish materials such as plaster, which were often made by artisans on site.”⁴⁶

Once concrete and its uses become a part of the construction dialogue, it becomes a popular means of producing architecture. It gain a reputation of being efficient, controlled, and high quality. Consequently, this new engineered building material fit the criteria of the Modernists. It was a new material that allowed them to break away from the traditions of architecture and supported the machine aesthetic. By the 1950s the use of precast concrete was widespread.

2.3 Economics of Building:

Change in construction practices is motivated by economic values. The desire to build faster and cheaper appealed to all parties involved in the process. Technological progress needs to be motivated by profitability in order to compete.

“The driving force behind product innovation is the constant search by companies to retain or increase their market share, enabling them to grow – or survive – and to enhance profitability. To

⁴⁵ Freedman, S. (2014). 10 Architectural Precast Concrete. In T. C. Jester (Ed.), *Twentieth-Century Building Materials: History and Conservation* (2nd ed.). Los Angeles, CA: Getty Conservation Institute. 77.

⁴⁶ Friedman, D. (2010). *Historical building construction: Design, materials and technology*. New York: Norton. 162.

*be successful they must produce something cheaper or better to offer an attractive combination of cost and quality compared with alternative materials.*⁴⁷

With the developments of new systems and building materials, not only are architects and engineers faced with the task of design, they are dealing with developing the technology to support economic goals. According to Morton and Jaggar, economic changes related to building can be explained on these three ways: innovation, economies of scale, and competition. Innovation is referring to a breakthrough. In this case, there are a number of breakthroughs that change the method of construction completely: curtain wall structures with the developments in steel, efficient machinery for quarrying and finishing stone, and reinforced/precast concrete. As an end result, innovation improves quality and range of materials and reduces production cost.⁴⁸ The economies of scale is interrelated with innovation in that it cannot exist without the other. As stated before, innovative technology permits the industry to improve quality and reduce production costs. This is often with the development of an efficient process or product that controls production. This will enable the increase in production scale with a profitable return. Lastly, the idea of competition is one that is quite relevant to building technology in many ways. The twentieth century is one that brings a number of building materials to the periphery: natural building materials, newly fabricated natural building materials, synthetic materials and composites. Not only do the individual manufacturers of each type of building material compete within their market, there is a market competition between the variants of building materials. The economic theories that surround this phenomenon pertaining to building and construction is referred to as ‘oligopoly’ which is defined as: “the competition in the production of one commodity between a few firms, each of which is large enough to affect the total market and each of which is aware of its competitors’ activities.” In other words, not a full on monopoly but not a perfectly competitive industry.⁴⁹ The economic forces and values that dictate the choices of building and design cannot be taken lightly. Especially during the twentieth century onward where the market continues to

⁴⁷ Morton, R., & Jaggar, D. (1995). *Design and the economics of building*. London: E & FN Spon. 59.

⁴⁸ Ibid. 57.

⁴⁹ Ibid. 64-65.

expand globally. Many of the choices made by the industry are highly dependent on this value, and this is also true with the advent and use of *thin stone veneer-faced precast concrete panels*.

2.4 Preservation Discourse:

During this time of rapid change in the field of architecture and building technology, the field of historic preservation was established in the United States. Although historical significance and value can be determined by different criteria, in terms of a preservation discussion, the United States continues to abide by age value. According to the National Register of Historic Places Program: National Register Federal Program Regulations under criteria considerations, it states that a property is no eligible for the National Register if it is within 50 years.⁵⁰ Also within the field of architectural preservation, the notion of retaining the original fabric and its link to “authenticity” still dictate the decisions that are made for conservation. With that being said, the ethics behind conservation does not intend to ban change, but rather to mitigate loss.

“Historic buildings and districts are not stage sets or the setting for a theme park; nor are they museum artifacts to be protected under glass. They are our own homes, workplaces, gathering places, monuments, places of leisure, and the sources of several things necessary for human happiness, including the sense of pride, orientation, belonging, and participation in a community life longer and greater than one’s own individual life span.”⁵¹

Building off of this criteria, architecture from the 60s and 70s are now beginning to enter the discourse of preservation and conservation. Focusing on mid-century Modern architecture built and completed in the 60s and 70s, these buildings can be argued to be most at risk from a preservation standpoint. Not only does the general public have difficulty perceiving these buildings as historic, these buildings are facing

⁵⁰ United States. National Park Service. (n.d.). National Register of Historic Places Federal Program Regulations. Retrieved January 23, 2016.

⁵¹ Semes, S. W. (2009). *The future of the past: A conservation ethic for architecture, urbanism, and historic preservation*. New York, NY: W.W. Norton & Company. 35.

many issues when it comes to performance and sustainability according to today's codes and regulations. The issue of service life or life cycle and conservation is also a major component of the current discussion on how to deal with the deterioration of these systems. The innovation and new materials and systems produced during this time relates to both design decisions and aesthetic trends. Structural systems involved high levels of engineering and calculations due to the nature of fabrication. And as mentioned in *Preservation of Modern Architecture* by Theodore Prudon, "Many of the new materials introduced into the building process were the result of scientific or manufacturing developments in other industries, byproducts of other industrial processes that were unaffordable until commercial production methods became available..."⁵² This was also a time of cross disciplinary sharing of technology. The preservation of "authentic" fabric may not be the most appropriate way to distinguish the significance of this type of exchange, evolution of practice, and the functional aspects of innovative systems to future generations.

Accounting for roughly 55% of the nonresidential building stock today, mid-century Modern architecture (1950-1970) is part of a significant dialogue that explains the trends of building technology in the past and the direction of how the building industry needs to move forward in the United States.⁵³ Along the lines of serviceability, many of these systems are also coming to the end of their service life at fifty years. Some systems have experienced severe deformation after years of environmental impact. As a significant part of our building history, how do we communicate the importance of this period of experimentation and building, while bringing back serviceability? How can that be achieved by looking at smaller components of the whole system?

The processes of pre-fabrication was presented as a method of simplifying and rationalizing the act of building; however, by the 60s and 70s the complexity of these prefabricated building components was

⁵² Prudon, Theodore H.M. *Preservation of modern architecture*. Hoboken, N.J.: Wiley, 2008. 77.

⁵³ Elefante, C. (2007). The Greenest Building Is...One that is Already Built. *Forum Journal*, 21(4), 26-38. Retrieved February 12, 2016.

evident. As an engineered system, building envelopes became particularly intricate. Not only had material functions changed, new synthetic materials were introduced.

“The design of the enclosure has become much more complicated with the advent of modern synthetic and composite materials, sophisticated new fabrication systems, new methods of construction, trends toward lighter and more economical skins, stresses on energy efficiency, and the requirements for a highly controlled interior environment.”⁵⁴

Of those systems, the composite cladding material of thin stone and precast combines both old and new technologies. By looking at the changes in the technical literature and the standards/codes related to *thin stone veneer-faced precast concrete panels*, the building industry and its evolution over time can be understood in detail. Advancements in structural engineering, steel production, reinforced concrete, and the curtain wall systems changed the function of the building envelope, and the cladding systems changed the way clients and designers view, choose, and design architecture. Understanding the cladding material explains the role that modern building systems had in the development of construction, and mid-century Modern structures are the perfect medium to discuss the use of this technology.

High levels of progress is followed by a certain level of uncertainty, especially when working with new materials. Due to the speed and experimental nature of the technology, there was a learning curve associated with these new products. With the various systems and materials used, there was little information regarding performance and durability. Many times, the decisions were based on goals such as aesthetic quality and lowering construction costs. The repercussions of those decisions were dealt with and continue to be addressed.

⁵⁴ Brock, L. (2005). *Designing the exterior wall: An architectural guide to the vertical envelope*. Hoboken, NJ: John Wiley. 5.

Chapter 3. Technical Literature & Design Standard Specifications

The two industries that are involved in the manufacturing of the cladding material *thin stone veneer-faced precast concrete panels* are the precast concrete industry and the stone industry. As the two materials are combined, a new composite cladding material with new complexity and differential performances was created. There are a variety of choices when it comes to natural stone and they have varying degrees of durability and levels of performance. Precast concrete is highly dependent on mix design, quality control, and workmanship. These material require in-depth knowledge and extensive testing for proper design decision to be made; however, cladding materials for architectural use was “typically designed nontechnically by architects”⁵⁵ and it was the manufacturers that provided the detailing information according to the knowledge that they acquired from past experiences in dealing with the material.⁵⁶ This combination resulted in two different outcomes. One, design without sufficient technical testing and data. Two, design responsibilities and accountability is unclear. Historically, building codes and specifications were a result of some sort of failure or tragedy. In the case of new materials and their performance, it was a combination of creating a common language for the industry and response to failure. Both reasons are fundamentally rooted in a demand from the market.

Specifically for the United States, there are thousands of standards written by both the government and the trade industry. Generally speaking, there are five distinct types of standards and four general standards that are based on consensus: individual companies, industry standard, government standard, and full consensus standard.⁵⁷ According to ASTM International, full consensus standards are developed through a process of participation with stakeholders whose interests are in the development and use of the

⁵⁵ Cohen, J. M. (1991). Cladding Design: Whose Responsibility? *J. Perform. Constr. Facil. Journal of Performance of Constructed Facilities*, 5(3), 208.

⁵⁶ Ibid.

⁵⁷ Mintz, M., Dowling, J., & Cammer, D. (1989). *Understanding building codes and standards in the United States*. Washington, D.C.: Technical Services Dept., National Association of Home Builders of the United States.

product.⁵⁸ Standards are created through a process of rigorous committee consensus and standardized testing. In terms of building construction, design specifications, also referred to as specs, are essential for controlling the quality of the construction. Although each design project will differ in terms of detailing, design specs are commonly refer to standard parts. And, large design companies tend to have their own collection of standard details and specifications that is a part of their resources. The use of standard specifications that have been developed my other major sources are increasing in use.⁵⁹ Due to the all-inclusive process of establishing standard specifications, changes that are made to them indicate some kind of trigger or event. It can also signal new advancements or developments pertaining to that specific design. By 1966 there was a commission report proposing intergovernmental reform of the building codes in the United States. Some of the relevant report goals are: modernize building code, stimulate building research, and expedite the acceptance of new building products.⁶⁰ This report explains the current restrictions with the existing building codes and how they do not support the major changes in the building industry and demand. “The building industry itself has a major role in the development of testing procedures and standards that may be incorporated in government regulations and codes applying to materials and construction methods.”⁶¹ This report touches on the impact of innovation and new materials and the recent issues that occurred at the time.

“Problems in using new materials. Difficult enough as they are, problems that confront a building materials producer who wants to introduce a new idea, material, or system, are exacerbated by the baffling array of provisions written into building codes by local jurisdictions. In the first place, the merits of an idea are hard to gauge because the success of a new material often depends on a complex interaction with other parts of a building. It is difficult to determine the behavior of composite materials in the presence of heat, cold, moisture, ultra-violet, and many other natural causes of aging.”⁶²

⁵⁸ ASTM International - About ASTM FAQ. (n.d.). Retrieved April 09, 2016.

⁵⁹ Ambrose, J. E. (1992). *Building construction and design*. New York: Van Nostrand Reinhold. 36.

⁶⁰ *Building codes: A program for intergovernmental reform*. (1966). Washington.

⁶¹ *Ibid.* 1-2.

⁶² *Ibid.* 5-6.

The introduction of new materials is recognized but the report connects the government's lack of supportive jurisdiction for new materials playing a role in the producers' inability to focus on more rigorous material research. Without the proper study and research of this technology, the problems will accelerate and there will be a lack of quality control. This outcome may seem very logical; however, without the support of the government and changes in the outdated codes and specifications, the conditions will only worsen.

Building materials' suppliers are, for the most part, spending their available research funds on the actual development of materials and material systems and cannot be expected to carry the burden of developing basic test criteria. Some authorities argue that the product-by-product approach of existing test procedures in evaluating the performance of a new material is wholly inadequate.⁶³

The proposed reforms for building codes are to encourage adequate research and testing for new building technology and materials. On its own, the construction industry is not a field that quickly adapts to change; however, the demands for construction during the 1960s and the 1970s required large projects quickly. This required new methods. This level of change and demand could only be met with federal level intervention.

They contend that the problem is too big for any industry as a whole. Acceptance of innovations utilizing traditional materials such as lumber, gypsum, steel, and brick is much easier than it is with those using newer products such as plastics. Not only must manufacturers of some of the new materials overcome restrictive building code requirements, they must also devise better performance standards, better tests, and quality control production techniques to prove their durability of the passage of time."⁶⁴

The mid-1960s, the 1970s, and even into the early 1980s, market demand drove the industry to make changes in production methods, and the federal government needed to respond to the rapid changes that

⁶³ Ibid. 5-6.

⁶⁴ Ibid. 5-6.

were occurring in the construction and manufacturing industry. It was during this time of change when new building materials like *thin stone veneer-faced precast concrete panels* were developed and utilized.

The complex market demands and lack of industry regulations is the context in which the cladding material *thin stone veneer-faced precast concrete panels* was created. This along with the practices of thin stone veneer and precast concrete panelization were some of many different systems and materials that emerged on the market. As some of the poorly designed cladding systems started to fail, studies and investigation of distress became important. Also, around the 1970s the manufacturers of building materials begin to publish manuals regarding industry practices and standards. An important point to highlight in regards to regulations and standards is that there is a time lag in how long it actually takes to have regulations published and distributed and the fact that these are usually a set of rules that require the bare minimum in terms of performance. As a resource, however, it is a written agreement and document that tracks the progression of a practice. Change is usually a response to some sort of condition. The changing and developing building market is a response to market demands, and the development of industry standards, albeit retroactive and slow, is a written history of the action that take place. To understand the development of *thin stone veneer-faced precast concrete panels*, this chapter will explore the technical literature and specifications developed by the precast concrete industry and the stone industry, specifically marble.

3.1 Prestressed/Precast concrete Industry:

The concrete industry, particularly prestressed and precast concrete, gained popularity in the early 1950s. This thesis focuses specifically on the cladding literature produced by the precast/prestressed concrete industry that made its appearance on the market in the 1960s. The industry literature representative of precast concrete will be from Precast/Prestressed Concrete Institute (PCI), which was legally chartered

under the name Prestressed Concrete Institute in 1954.⁶⁵ This institute was organized at a time when the industry needed organization and unity, and PCI provided a number of written resources for the industry. The following list of publications from PCI provide valuable information regarding the history and evolution of the industry: PCI Journal, Architectural Precast Concrete Design Manual, PCI Design Handbook, PCI Manual for Structural Design of Architectural Precast Concrete, PCI Designer's Notebook, and PCI Manual for Quality Control for Plants and Production of Architectural Concrete Products. The industry literature is released at different intervals and updates occur according to new relevant information. As one of the leading organizations of precast concrete in the United States, a review of their technical literature and design standard specifications provides valuable insight on building material development.

PCI Journal-

PCI published its first specification on prestressed concrete in 1954 and published the first issue of the PCI Journal in 1957. By 1961, the PCI Journal began to introduce articles on precast concrete, where before, much of the content was devoted to prestressed or pretensioned concrete. From 1971 to 2008 the journal published 6 issues a year, and from 2009 until the present, PCI Journal publishes 4 issues a year.⁶⁶ All of the editions and articles published in the PCI Journal are available on the website and keyword search functions are available to narrow down searches. When the keywords "precast panel" is searched, there is a total of 335 articles. When "stone faced" is searched it produces 5 articles, and when the keyword is "stone veneer" there is a total of 3 articles. This search reveals a lack of written information regarding *thin stone veneer-faced precast concrete panels* within the PCI Journal. One of the earliest articles published on stone faced precast was in the 1967 PCI Journal written by Bryant McDaniel titled *Marble-Faced Precast Panels*. McDaniel starts by asking the question "Why the marble industry entered the precast picture."⁶⁷ Although the nomenclature for the panel is slightly different from the present, this is referring to the product known

⁶⁵ PCI History. (n.d.). Retrieved February 16, 2016, from https://www.pci.org/About_PCI/History/.

⁶⁶ Ibid.

⁶⁷ McDaniel, W. B. (1967). Marble-Faced Precast Panels. *PCI Journal*, 12(4), 29.

today as *thin stone veneer-faced precast concrete panels*. As a building materials industry, the marble manufacturers realized that this shift in demand and speed of construction will, indeed, impact business. In response to this there was an effort to conduct research and development.

“About 10 years ago the National Association of Marble Producers decided to do something about the problem. They employed the Illinois Institute of Technology (then Armour Research Institute) for a thorough study of the marble industry’s products and their adaptation to modern building techniques. At the same time, many of the individual marble companies had their own research facilities hard at work on the same problem.”

The first cohesive literature on *stone veneer-faced precast concrete panels* was published in the *New Stone Technology, Design and Construction for Exterior Wall Systems, ASTM STP 996* by Sidney Freedman. This book is a compilation of papers presented at the Exterior Stone Symposium in 1987. This paper acknowledges the use of thin stone veneer on precast panels for high-rise projects as a relatively new occurrence.⁶⁸ The article goes into detail about the technical qualities of the stone, precast concrete panels, the anchorage systems, the property testing of materials and the handling of the final product. The complex and functional details regarding anchors and bondbreakers is addressed, however, the end goal is a well communicated design and manufacturing process that produces quality products that fulfill the owner’s request for a cladding material of stone with economic benefits. Freedman writes another article on *stone veneer-faced precast concrete panels* for the *PCI Journal* in 2000. This article goes over much of the same content with the most updated information regarding design specifications and anchoring details.⁶⁹ This article also provides examples of current projects that utilized the composite cladding material. Some of the more famous projects include the Joslyn Art Museum in Omaha, NE designed by Sir Norman Foster and Partners, 388 Market Street Building in San Francisco, CA designed by SOM, and the Airline Pilots Association Building in Washington D.C. designed by Vlastimil Koubek.⁷⁰

⁶⁸ Freedman, S. (1988). Stone Veneer-Faced Precast Concrete Panels. *New Stone Technology, Design, and Construction for Exterior Wall Systems*, 89.

⁶⁹ Freedman, S. (2000). Stone Veneer-Faced Precast Concrete Panels. *PCI Journal*, 77-79.

⁷⁰ Ibid. 86-90.



Figure 3.1 Joslyn Art Museum – Omaha NE
(Sir Norman Foster and Partners)



Figure 3.2 Airline Pilots Building – Washington D.C.
(Vlastimil Koubek)

Architectural Precast Concrete Design Manuals- (Appendix E)

The target audience for the *Architectural Precast Concrete Design Manuals* is the architect. The first edition was printed in 1973 and 1974. The second edition was printed in 1989 and the third edition was printed in 2007. Currently, the third edition is the most recent version. As mentioned in the preface of the design manual, “by the mid-1960s, architectural precast concrete as cladding and loadbearing element had gained widespread acceptance by architects and owners.”⁷¹ The value in these manuals is the continuous updates and presentation of the current practices of the industry at that time.

The first edition of the design manual was published in 1973 and is organized into six chapters: Chapter 1- State of the Art, Chapter 2- Design Concepts Related to Usage and Economics, Chapter 3- Design Considerations, Chapter 4- Detailing, Chapter 5- Specification Considerations, and Chapter 6- Short Form Specification. The preface of the manual sets the context of architectural precast concrete as a twentieth century modern technology that is “almost without precedent.”⁷² Architectural precast concrete gained popularity during this time but the knowledge regarding the material was still scattered and

⁷¹ *PCI Architectural Precast Concrete* (3rd ed.). (2007). Chicago: PCI.

⁷² *PCI Architectural Precast Concrete* (1st ed.). (1973). Chicago: PCI.

unavailable to architects, engineers and even precasters. The lack of a reliable resource defined the parameters for this manual. For technical accuracy, the content was reviewed by profession members of the PCI committee and qualified architects, engineers, precast producers, material suppliers and other affiliated industries.⁷³ As a disclaimer, the manual makes very clear that all published content illustrates what has been practiced and not future possibilities. “This Manual will help the Architect to define his own potential and will provide it, through proper knowledge of this exciting material.”⁷⁴ Introducing the advantages of architectural precast concrete, the manual is filled with example projects and photographs of construction sites erecting large pieces of precast concrete units. The principle advantages of utilizing architectural precast concrete cladding panels are: design- design freedom, quality control, plasticity; functional- structural capabilities, efficient building envelope, durability, low maintenance,; construction site- economical erection, trade scheduling, time saving, low noise level; economics.⁷⁵ One of the aesthetics advantages for precast concrete was the ability to create textures and apply finishes. Although compatibility of different materials with the precast concrete must be studied further, the literature expresses the exciting opportunities for architects to explore different finishes. The grouping of the finishes are as follows: 1. Smooth; 2. Aggregates exposed by retarders or water wash, form liners, sandblasting; 3. Aggregates exposed by acid-etching, bushhammering, hammered ribs (fractured fins) finishes, ceramic or tile facing; and 4. Honing, polishing, cut stone (veneer) facing.⁷⁶ By this time, natural stone finishes are already well established in the industry and some of the issues that have emerged over the years have made it into the literature. In the section that deals with textures (3.4.2), it warns the architect about paying close attention to bowing of precast units with cut stone facing. Cracking of stone due to fastener/anchor details, as well as bonding issues and shrinkage creating bowing are all mentioned in this section. The consideration of

⁷³ Ibid. 1.

⁷⁴ Ibid.

⁷⁵ Ibid. 9-14.

⁷⁶ Ibid. 66.

bond-breakers and the erecting full scale mock-ups to study differential movement and conditions suggests that the industry has already seen a lot of this occurring in the field.⁷⁷

The second edition was published in 1989. This edition goes into very specific technical details and expands a great deal on material performance and the roles of the engineer and general contractor. It continues to illustrate the materials within the context of actual projects in construction and detail shop drawings. Highlighting many of the same advantages and benefits of precast as was done in the first edition, the second edition has a section devoted to stone veneer-face precast concrete panels (3.5.12). The advantages for this method of finish was listed as follows: 1. Veneer stock can be used in thin sections because of short spans between anchoring points; 2. Multiplane units (eg. Column covers, spandrels with integral soffit, etc.); 3. Erection is faster and more economical than handset construction; and 4. Span column to column, thereby reducing floor edge loading.⁷⁸ The 2nd edition develops performance issues and addresses methods of controlling bowing and warping of panels. The literature first recognizes the issues of differential shrinkage and bonding. Unlike the previous edition, this edition proposes methods to mitigate the issues of bowing and warping by listing different ways they are being addressed: two layers of reinforcement in areas that have sufficient thickness, adding reinforcing trusses, concrete ribs on back of panels, mid-point connections, and a minimum thickness of 5” to 6” of backup concrete.⁷⁹ It also goes into the technical details of stone size, tolerance, and anchorage placement. In comparison to the previous edition, not only is the content more robust, it reflects the level of detail the architect is also interested in. Looking very much like the *PCI Design Handbook*, which is a publication dedicated to the engineers, the design manual for architect now looks at both technical design and performance of the material.

⁷⁷ Ibid. 62.

⁷⁸ *PCI Architectural Precast Concrete* (2nd ed.). (1989). Chicago: PCI. 118.

⁷⁹ Ibid. 119.

The third edition was published in 2007 and it is the most current edition. Almost double the size in page numbers from the 2nd edition, the information provided in the third edition is heavily descriptive and filled with both photographs of projects and technical details and charts. For ease of navigation, the sections have been broken down into subsections and the technical details are expanded to the level found in the *PCI Design Handbooks*. Since the previous edition, the stone veneer thicknesses have been updated to the current thicknesses and the limestone has been specified to Indiana Limestone. In the advantages section it also states the elimination of elaborate temporary scaffolding when using this product for construction as another economic benefit. As a general consideration, the appointment of a coordinator that oversees the work and scheduling is recommended. This responds to the complexities of coordinating different industries and construction schedules. It also goes further and explains the typical responsibilities of the precaster as “responsible for precast concrete and stone layouts and details”, while the stone-veneer fabricator is responsible for the “stone-fabrication drawings and drilling of anchor holes.”⁸⁰ The different ASTM tests that are required are also incorporated into this edition. In terms of the technical information, they are in agreement with the *PCI Design Handbooks*. Interestingly, this manual addresses the idea of “watertightness due to bondbreaker.” This is referring to the bondbreaker between the stone veneer and the concrete backup functioning as an unintended water vapor barrier. Solutions to this issues are also presented in the section titled *Panel Watertightness* (3.5.12.6).⁸¹ The use of stone veneer-faced precast concrete panels is well established by the third edition and goes further than just addressing the issues by becoming solutions.

PCI Design Handbooks-

The PCI Design Handbooks are intended for structural engineers. The handbook is currently in its seventh edition, 2010. The first edition was printed in 1971 in conformity with American Concrete Institute (ACI 318-71) and the Uniform Building Code Standards (UBC-70). By the fourth edition in 1992, the Standard Building Code (SBC) and the National Building Code (NBC) are also consulted. The sixth and seventh

⁸⁰ Ibid. 211.

⁸¹ Ibid. 217.

editions of the PCI Design Handbook references ACI, International Building Code (IBC), American Society of Civil Engineers (ASCE), and the National Earthquake Hazards Reduction Program (NEHRP). The PCI handbook is publically respected and recognized by the industry; therefore, a great reference for understanding the developments and trends of the industry. The *PCI Design Handbook* is one of many publications intended to advance the industry. The primary objective of the handbooks are to act as a working tool in “assisting the designer in achieving optimum solutions in minimum time.”⁸²

The first edition was published in 1971. (Appendix F) The handbook was divided into twelve parts with the following titles: Part 1- Assembly Concepts, Part 2- Framing Considerations, Part 3- Product Information and Capability, Part 4- Design Procedures, Part 5- Design Aids, Part 6- Connections, Part 7- Related Considerations, Part 8- Specifications and References, Part 9- Structural Response to Volume Changes, Part 10- Earthquake Design, Part 11- General Design Information, Part 12- Notation and Index. The *PCI Design Handbook* has with minimal photographs of actual projects as seen in the *PCI Architectural Precast Concrete Design Manual*. This publication is focused on load calculations and tables. Section drawings of components are accompanied with tables calculating loads, deflections, normal weights, spans, and moments of inertia among other things. Graphs communicate stress-strain relationships between concrete and reinforcements. In the first edition Part 4 addresses precast concrete wall panels and the various types that exist for building construction. It also notes that they are available in a variety of surface finishes, but does not go into much detail. Reinforced flat panels are also mentioned in this part, (4.3.2). The reinforcement is “mild steel rather than prestressed when stresses due to handling are sufficiently low.”⁸³ Anything thicker than 4 inches would normally be prestressed. Throughout the literature, it reiterates the need for fabrication drawings to be approved by both architect and general contractor before and work is done. In terms of any specifications regarding stone veneer facing, this surface finish is not addressed.

⁸² *PCI design handbook; precast and prestressed concrete* (1st ed.). (1971). Chicago. PCI. ii.

⁸³ *Ibid.* 4-29.

The second edition of the design handbook was published in 1978. (Appendix F) In terms of content, the handbook as eight parts and follows the same type of layout as the first edition: Part 1- Assembly Concepts, Part 2- Product Information and Capability, Part 3- Design of Precast, Prestressed Concrete Components, Part 4- Analysis and Design of Precast, Part 5- Design of Connections, Part 6- Related Considerations, Part 7- Specifications and References, and Part 8- General Design Information. According to the preface, significant revisions occurred due to the changing building codes, ACI 318-77. It also references the 1977 publication of *PCI Manual for Structural Design of Architectural Precast Concrete*.⁸⁴ Looking specifically at stone veneer facings, this edition does not mention any further information regarding finishes in stone.

When the third edition is published in 1985, there are significant changes in terms of content. (Appendix F) According to the forward in the handbook, the third edition is basically a combination of the second edition handbook and the 1st and only edition of the *PCI Structural Design of Architectural Precast Concrete* (1977). This edition also takes into account the newly updated building codes, ACI 318-83. Part 7- Special Topics for Architectural Precast Concrete is where the details of veneer panels first appear in the design handbooks. As the section talks about non-load bearing cladding walls, it lists brick, tile, or natural stone as facing elements for precast concrete panels.⁸⁵ The first two editions excluded any information on stone facing material, although it was used quite extensively during the 1960s and 1970s. With the development of architectural precast concrete, a major industry emerged and many innovations in architecture and architectural precast concrete followed. Veneered panels are addressed along with their tendencies for bowing and cracking. The literature suggests mechanical connections of the stone veneer to the concrete backup with the use of a bondbreaker. This is to minimize bowing, cracking and staining of the veneer.⁸⁶ The recommended methods of bondbreakers is as follows: 1. Liquid bondbreaker of sufficient

⁸⁴ *PCI design handbook; precast and prestressed concrete* (2nd ed.). (1978). Chicago. PCI. ii.

⁸⁵ *PCI design handbook; precast and prestressed concrete* (3rd ed.). (1985). Chicago. PCI. 7-19

⁸⁶ *Ibid.* 7-23.

thickness, 2. 6 mil polyethylene sheet, 3. 1/8” polyethylene foam pad. The exception to this idea of creating a flexible connection is the Limestone industry. They are in favor of having a rigid connection with the backup precast concrete.⁸⁷ The stone types that the literature referenced was marble, granite and limestone. Information about tolerance, minimum thickness of stone, and dimensions of the stone panel was specifically listed in this section regarding veneer panels: natural stone, (7.5.3). The literature expresses uncertainty of performance for different stone types; therefore, suggests a full scale mock-up to measure bowing and anchor performance before approval of fabrication plans. The mock-up should be measured over several weeks in realistic production conditions.⁸⁸ Although it is an accepted form of cladding in the industry with exact specifications, much study was still requested for understanding performance.

The fourth edition was published in 1992. (Appendix G) Veneered panels with natural stone as a finish is in Part 7.5.3. Although the overall design of the composite panel has not changed, many adjustments appear in this edition. Travertine and its properties are added to the list of stones. In regards to the issues of bowing and warping panels, this edition offers recommendations for control. Along with the minimum thicknesses of stone, the literature talks about a minimum thickness for the backup concrete for flat panels to “control bowing” at 5” to 6”, and 4” for small panels.⁸⁹ In order to control bowing and warping of the panel the use of mid-point tie-back connections is also mentioned in this edition.⁹⁰ The specifications on where and how many anchors should be placed is addressed in more detail. Also the use of epoxy in the literature appear in this edition. Although the Limestone industry used epoxy in their design to maintain a rigid connection, this is the first time that epoxy is introduced to the other stone types. The purpose of the epoxy is to fill the dowel or spring clip holes to prevent the intrusion of water and “increase the shear capacity and rigidity of the anchor”, however the long-term service of the epoxy is “questionable”, and if it is not specified specifically, it will not be used. It is preferable to use a fast-curing silicone or a low

⁸⁷ Ibid. 7-21.

⁸⁸ Ibid. 7-24.

⁸⁹ *PCI design handbook; precast and prestressed concrete* (4th ed.). (1992). Chicago. PCI. 7-12.

⁹⁰ Ibid. 7-12.

modulus polyurethane sealant according to this manual.⁹¹ Once again, a full scale mock-up is suggested; however the purpose for the mock-up has changed from the previous edition. “There is now a good background of experience in the production and erection of stone veneer-faced precast concrete panels. However it is recommended that, for new and major applications, full scale mockup units be manufactured to check out the feasibility of the production and erection process.”⁹² Previously, the purpose of the full scale mock-up was to measure bowing and performance to help determine stone sizes and fastener placements. In the fourth edition, the mock-up is to determine feasibility of production. At this point, the literature seems confident about the design of the composite panels and its performance. As a final adjustment, in the specifications and references, the literature suggests that the reinforcing steel cages be supported from the back of the panel rather than using chairs or spacers because they ruin the finishing of the surface.⁹³ The fourth edition changes suggest improvements, but there is also a level of confidence in understanding the performance of the material.

In 1999 the fifth edition of the design handbook was published. (Appendix G) This edition based changes by taking the updated ACI 318-95 Building Code and other publications by PCI into consideration. Overall, the biggest changes in this edition applied to the minimum thicknesses of the stone veneers in comparison to the previous PCI literature. Marble’s minimum thickness changes from 7/8” to 1”; travertine’s minimum thickness was 3/4” to 1-1/4”; granite was 3/4” to 1-1/4”; limestone was 1-1/4” to 1-3/4.”⁹⁴ In terms of testing parameters, PCI began specifying tests and testing parameters in their literature starting in the previous edition. Of the various tests recommended for the stone and testing stone properties, the fifth edition makes the suggestion of load testing the stone/precast concrete in both the normal and transverse directions of the panel.⁹⁵ In this case transverse loading refers to forces being applied

⁹¹ Ibid. 7-18.

⁹² Ibid. 7-18.

⁹³ Ibid. 10-25.

⁹⁴ *PCI design handbook; precast and prestressed concrete* (5th ed.). (1999). Chicago. PCI. 7-17.

⁹⁵ Ibid. 7-17.

perpendicular to the longitudinal axis, while normal loading refers to anticipated loads. The distinction in the two load testing suggests the lack of complete testing data in the past that is now trying to be addressed in this edition. This also suggests an emphasis on scientific testing methods for obtaining data to support decisions for fabrication. According to an interview with Sidney Freedman from PCI, the fifth edition's extensive revision of stone thicknesses is a response to the recladding of the Aon Building in Chicago.⁹⁶ The failure and expensive recladding of the high-rise tower instigated the revisions on stone thicknesses for the PCI Design Manual.

The updated ACI 318-02 and various other PCI publications informed the changes made to the sixth edition of the *PCI Design Handbook*. (Appendix H) There is a stronger focus on scientific data in this edition, which was published in 2004. Significant changes correlated to the testing conditions that look at temperature and weather conditions. The thermal testing values have gone up by 20°F. The previous thermal cycling tests was set at heating 150°F and cooling at -10°F. This edition states the heating conditions at 170°F.⁹⁷ For testing thermal conditions, the number of laboratory freeze-thaw testing was increased by 50%. In the previous editions, the recommended number of testing cycles was 50, but edition six requires 100 cycles to be run in order to determine the “reduction of strength.”⁹⁸ The testing conditions are more controlled and the literature no longer request samples or full scale mock-ups for measuring deterioration or determining feasibility. Changes also were made to the angles of the anchors and dowel placement; however, there is no real explanation for these decisions. The angles of the anchors change from a range of 30-45 degrees to plane to a range of 30-40 degrees to plane. The angles also change for the dowels as well. The previous edition stipulates the angle range at 45 degrees to 75 degrees to plane, where the new literature suggests an angle range of 45 degrees to 60 degrees to plane.⁹⁹ These are the anchors that are to be embedded into the stone and mechanically connect the stone to the precast concrete backup. Since the fourth

⁹⁶ S. Freedman, personal communication, April 21, 2016.

⁹⁷ *PCI design handbook; precast and prestressed concrete* (6th ed.). (2004). Chicago. PCI. 7-17

⁹⁸ *Ibid.* 7-17.

⁹⁹ *Ibid.* 7-20.

edition, the use of epoxy appeared in the handbook literature. It was introduced as a means to fill the holes for the anchors and eliminate the intrusion of water into those spaces, however, the long-term service of the epoxy was stated as “questionable.”¹⁰⁰ When first introduced, the literature also suggested the use of either a fast-curing silicone or a low modulus polyurethane sealant; however, the sixth edition omits the fast-curing silicone and only suggest the low modulus polyurethane sealant as an epoxy sealant.¹⁰¹ The level of tolerance has also changed for the length and width of the veneer panels. In the previous handbooks, the tolerance was set $\pm 1/8$ ” for the length and width of the veneer but the tolerance was changed to $\pm 1/16$ ” for this edition. The change in the tolerance level was accompanied by an extension of the distance range for anchor positions from 6”-9” to 6”-12” from the edge with not over 30” between anchors for the veneer panels.¹⁰² The sixth edition had many changes in regards to measurements and specific testing parameters.

The most current edition of the *PCI Design Handbook* was introduced in 2010. (Appendix H) Like the sixth edition, many of the changes occurred in areas of testing. According to the foreword, there was an emphasis placed on both architectural and structural products and systems starting in 2004. The committee was devoted to “monitor technical advancements within the industry” and culminated their efforts into the seventh edition.¹⁰³ In terms of the arrangement of the handbook, some changes were made in how the information was organized. This edition is based on the updated ACI 318-05 Building Code and other PCI publications. This edition of the handbook also went through a rigorous review process that involved many individual from the industry and PCI committee members over the course of four years.¹⁰⁴ This edition included different testing standards that were not included in the editions before such as Absorption test ASTM 97, ASTM E488, and/or ASTM C1354. In addition to the freeze-thaw cycling, an additional test was added to simulate chemical weathering. This test includes the pieces to be submersed in a solution with

¹⁰⁰ Ibid. 7-18.

¹⁰¹ Ibid. 7-20.

¹⁰² Ibid. 7-20.

¹⁰³ *PCI design handbook; precast and prestressed concrete* (7th ed.). (2010). Chicago. ii.

¹⁰⁴ Ibid. ii.

a pH of 4.¹⁰⁵ This edition also specified the limestone to “Indiana Limestone” and changed the minimum thickness to 2” from the previous thickness of 1-3/4”.¹⁰⁶ The technical loading and testing aspects have been expanded with more information on coefficient of thermal expansion for stones and aggregates and ultimate shear capacity of spring clips. The use of a liquid bondbreaker was omitted from this edition and the design of epoxy filler for the holes in the stone was modified. In consideration of the differential thermal expansion of the stone, the literature states “the coefficient of expansion of the stone and epoxy should closely match. However, this may be overcome by keeping the oversizing of the hole to a minimum, thereby reducing epoxy volume and using stone flour or fines or fine sand as a filler for the epoxy to reduce the coefficient of thermal expansion of the epoxy and the shrinkage.”¹⁰⁷ This practice of using fines or stone flour to alter the thermal expansion of the epoxy is one that is new in the literature. Although the overall concepts of design and performance have not changed drastically, many additional testing requirements have been added over the subsequent years. The accuracy and accumulating knowledge of the materials and their performances have changed tolerances, the thicknesses of limestone, and anchor placements.

PCI Designer’s Notebook-

The *Designer’s Notebook* is available as an on-line resource that select specific topics or materials and go into a detailed description of the design specifications. This is a resource to inform architects, engineers and others involved in the construction process about the general considerations of the product and the technical aspects of performance and example case studies. The *Designer’s Notebook (DN-7)* edition is one that was made available in the winter of 2000 that focused on Stone Veneer-Faced Precast. This edition discusses the present-day context of *thin stone veneer-faced precast concrete panels* and goes into the details for design considerations such as stone properties, anchorage methods, joint conditions and repairs.¹⁰⁸ This publication also acknowledges the use of stone veneer-faced precast to the 1960s. The main

¹⁰⁵ Ibid. 7-33.

¹⁰⁶ Ibid. 7-33.

¹⁰⁷ Ibid. 7-35.

¹⁰⁸ PCI Designer’s Notebook DN-7 Stone Veneer-Faced Precast. (2000).

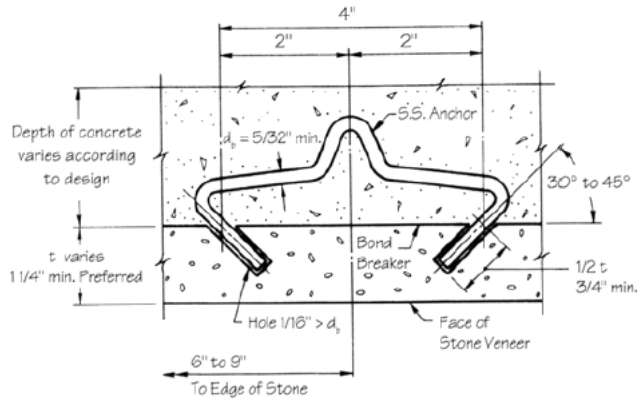


Figure 3.3 Typical Anchor for Marble Veneer

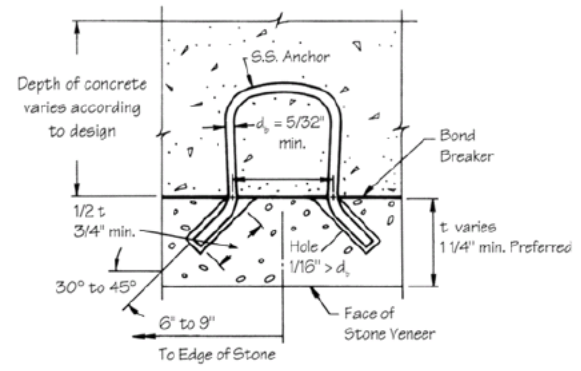


Figure 3.4 Typical Anchor for Granite Veneer

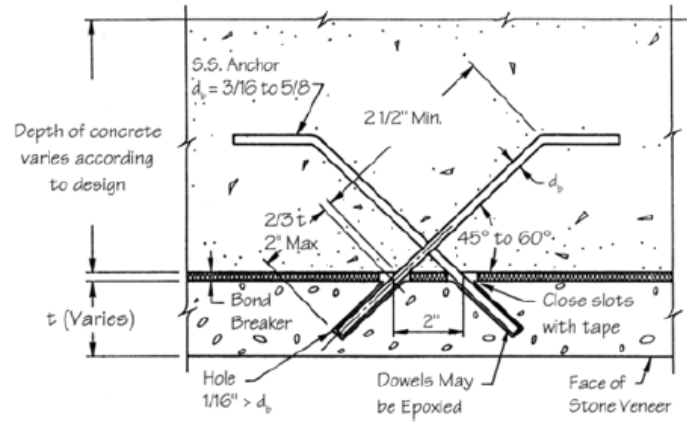


Figure 3.5 Typical Cross Anchor Dowels for Stone Veneer

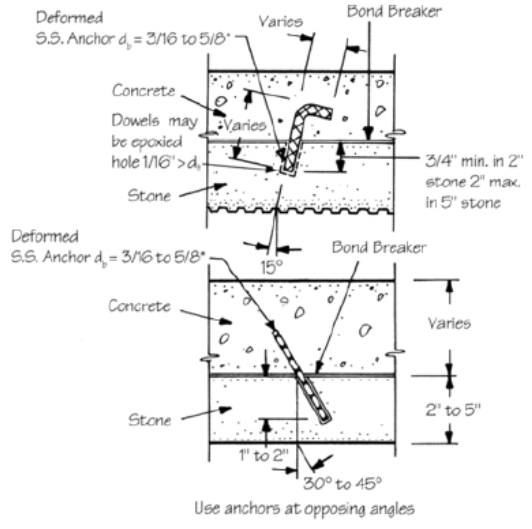


Figure 3.6 Typical Anchors for Limestone Veneer

benefits for using this material include the following reasons: 1. veneer can be used in thinner sections and anchor points can be placed closer together, 2. multiplane units like column covers, spandrels with integrated soffit and sill section, deep reveal window frames, inside and outside corners, projections and setbacks, and parapet sections can now be assembled more economically, 3. precast concrete backup systems allow for faster enclosure, 4. veneered precast concrete panels have the advantage of spanning column-to-column and, therefore, reducing floor-edge loading and ridding the need for temporary

scaffold.¹⁰⁹ In this literature, it also addresses the possibility of material bowing due to the differences in material properties. With that being said, there are suggestions on how to deal with this condition and what material characteristics the designer must consider before designing a system. Although a general stone strength can be determined, natural stone can have a different structural make-up depending on the bedding. The most common material tests suggested by the literature are the Flexural tests (ASTM C880) and the Absorption tests (ATM C97). These tests help the conservators and/or architects to understand the initial properties of the stone to then help predict performance. Due to the collaborative nature of the composite panel's construction, this literature also defines the roles and responsibilities of the different industries.

“The stone fabricator or precaster appear to have the dominant responsibility for conducting the anchor tests, with the architect or engineer of record occasionally determining the type of anchorage. However, it is preferable for the architect to determine anchor spacing so that common information can be supplied to all bidders (refer to ASTM C1242).”¹¹⁰

As an engineered composite material, defining responsibilities becomes an important issues for liability. A large portion of the literature is also devoted to mechanical anchors and structural dimensions. Anchor design is dependent on stone type (marble, granite, limestone, etc.) and the tolerances between individual connections such as anchor and stone, anchor and precast, and stone and precast. Mitigation of moisture and maintaining a break in adhesion between the natural stone and the precast concrete is critical for the performance of the material. Temperature differentiation, coefficient of expansion, moduli of elasticity, shrinkage of concrete, and stone bedding are just some of the components that need to be considered for each material that is a part of the composite panel. Overall, the economic benefits resonate in the manufacturing of the panel and the speed of construction. It is a cladding material that prevails in both the desired aesthetic of natural stone and the benefits of precast construction.

¹⁰⁹ Ibid. 2.

¹¹⁰ Ibid. 6.

3.2 Marble Stone Industry:

The expectation for stone as a building material comes from its performance over history and the image of permanence that stone has in its relationship with significant built structures. The Marble Institute of America, Inc. (MIA) is an organization that traces its beginnings back to 1907 with the National Association of Marble Dealers. Over the following years, they are combined with the National Association of Marble Producers in 1944 and the National Association of Marble Builders in 1962. The institution officially associates themselves with the name Marble Institute of America in 1944.¹¹¹ MIA's membership today consists of a worldwide network of natural stone producers, fabricators, suppliers, and finishers. MIA supports the stone industry with accreditation programs, awards, and scholarships, but written publications regarding specifications and manuals is a one of their most significant and trusted contributions to the field.

As an official manual publication, MIA started the *Dimension Stone Design Manual* in 1971. The manual incorporated earlier material from the MIA on both interior and exterior specifications and provided guide specifications, spec-data sheets, and the opportunity to introduce their products in detail. This publication is still used by professionals today, and they are currently on the 7.2 edition. Prior to the manual, there were individual specifications published and handbooks that were published for the benefit of architects and professions in the construction industry. With the objective of promoting the use of marble and stone, these written documents serve as both a source of technical knowledge and product promotion. This thesis will review the specifications and manuals provided by MIA to understand *thin stone veneer-faced precast concrete* by looking at the products and decisions made prior to the development of the composite cladding materials and the types of design changes that occurred after its initial introduction.

¹¹¹ *Dimension stone design manual* (7.2th ed.). (2011). Cleveland, OH: Marble Institute of America.

Early Marble Specifications Literature- (Appendix I)

In a 1948 publication by MIA titled *Architect's Handbook: Standard Specifications for Interior Marble and Exterior Veneer*, it is made clear that this was a supplemental reference for professionals to use when creating their specifications on projects that used marble. The origins of this particular text was to go “into detail on certain subjects concerning which architects and the trade have indicated a desire for information or clarification.”¹¹² The use of marble at this time was still highly concentrated to interior conditions. In fact, it limits the use of marble on the exterior to a height restriction of two stories and only for store fronts. And the section detail for anchorage of exterior marble indicates the use of a “mortar spot” defined as spots of mortar (non-staining Portland cement and accelerator or bonding cement) around and near the anchors for setting into place.¹¹³ (Appendix A: Exterior Wall Section) In the twenty plates incorporated into the handbook, fifteen of the plates are devoted to interior conditions, and only three of the twenty pages of text is devoted to exterior conditions. The use of marble on the exterior is still limited to very traditional uses such as floor tiles, ashlar, wall base coverings, columns, and coping. In the collection of plate details towards is one for a mausoleum (Appendix B: Plate 10 - Marble Treatment for Mausoleums) where marble is used like a façade cladding. Starting from the base of the mausoleum and going up 4’2”, the exterior marble cladding is specified at 7/8” in thickness. This is immediately covered in W.P paint which is backed by a significant layer of cement and then concrete. At this time, precast members are used for the structural beams. Recommendations for metals was not based on levels of corrosion resistance, and anchor holes were recommended to be filled with non-staining cement mixes and mortars.¹¹⁴ Although this publication does not introduce the idea of stone veneer and precast concrete used as a single composite, the used of the individual products of thin marble stone and precast concrete is present. Some interesting findings in this literature is the lack of specificity in anticipation of movement by setting tolerances. Edges and joints are being “battered” with non-staining mastic or Portland cement and there is an overall promotion of “stick”

¹¹² *Architect's handbook: Standard specifications for interior marble and exterior veneer. Marble information and marble service.* (1948). Mount Vernon, NY: Marble Institute of America. 2.

¹¹³ *Ibid.* 18.

¹¹⁴ *Ibid.* 18-19.

of bond between materials, usually in conjunction with anchors.¹¹⁵ In terms of setting practices in the late 1940s, Portland cement, accelerators or bonding cement, and Plaster of Paris were used. The Plaster of Paris is specified as a temporary application on the back of the marble while the cement mortar sets.¹¹⁶ It is made clear through the text writing and the plates of technical drawings that marble, particularly thin marble, is mainly used for interior spaces.

In 1955 the MIA publishes the *American Standard Specifications for the support, anchorage and protection of exterior marble veneer two inches and less in thickness and exterior marble used in curtain or panel walls*. Unlike the *Architect's Handbook*, this publication is formatted as a specification and was adopted as American Standard A-94.2 – 1955; UDC 691.2; 624.022.¹¹⁷ This literature creates a distinction between marble veneer and marble in curtain or panel walls by having a separate set of specifications for both. For the purpose of this thesis, the standard specifications for stone veneer is more applicable to understanding *thin stone veneer-faced precast panels* because marble stone used in curtain or panel walls is described as being directly set into the structural frame without any masonry backing. This category introduces three different conditions: (a) veneer against prebuilt masonry wall, (b) veneer setting concurrent with masonry back-up, and (c) veneer setting against reinforced concrete or masonry wall, where required by the building code. There is no indication in the text that any of these methods are done by means of prefabrication. Within these conditions, the use of stone and precast as a cladding material does not yet exist; however, these are the conditions prior to the invention of the composite cladding material of *thin stone veneer-faced precast concrete panels*.¹¹⁸ Largely, the specifications are divided into the following sections regarding physical characteristics: extents and thickness, jointing, supports, setting and anchorage, anchors, flashing, building codes, cleaning, and maintenance. First of all, there is a strong emphasis on the

¹¹⁵ Ibid. 18-19.

¹¹⁶ Ibid. 19.

¹¹⁷ *American standard specifications for the support, anchorage and protection of exterior marble veneer two inches and less in thickness, and exterior marble used in curtain or panel walls*. (1955). Mount Vernon, NY: MIA.

¹¹⁸ Ibid. 7.

architect making the design decisions. All decisions are based off of architectural drawings and shop drawings approved by the architect. In comparison to the 1948 *Architect's Handbook*, this publication is much more detailed in terms of technical information. Specific material recommendation appear in regards to metals and mortar. The literature still suggests a cementitious pointing material for holes and joints; however, it starts to specify lime mortar for solidly pointing joints.¹¹⁹ In regards to metals, stainless steel is encouraged over structural steel and non-ferrous metals for flashing. Also in the 1955 specifications, there is a concern for structural performance that was not present seven years prior in the *Architect's Notebook*. Anchor types, such as the plate anchors, and installation processes are outlined in detail. Issues of load and load-bearing limitations for the veneers are expressed in the specifications under supports indicating vertical loads and taller construction with the veneers which was discouraged in 1948. The joint sizes are determined by the thickness of the veneer, and the provision of vertical expansion joints at every 30' for large veneers marks the beginning uses of large sized veneers as exterior cladding.¹²⁰ Various types of anchors and tie back methods are used to keep exterior marble wall facings in place. (Appendix C: Plate NO. B - Anchors Used in Marble Work) Cleaning procedures after the work is completed is included in the specifications because it explains what can and cannot be done to the marble such as no acid or abrasive cleaning tools like steel wire brushes are to be used in the surface cleaning process.¹²¹ The detailed specifications in this literature is a result of the industries knowledge of the material; however, there is a disclaimer that states all specifications are subject to change and conform to local building codes if necessary. Thin stone veneer-faced precast is not addressed in this literature. The significance of this literature is in the importance placed on the thickness of material and the considerations for thermal expansion and contraction. Unlike the text from 1948, not only has the size of the marble veneers become larger in size, it is looking at vertical load-bearing factors. Special attention is placed on the performance and materiality of the individual units that fasten and support the stone like anchors, tie-backs, and flashing material. One thing that hasn't changed is

¹¹⁹ Ibid. 6.

¹²⁰ Ibid. 7.

¹²¹ Ibid. 13.

the use of mortars and cement for pointing and filling joints. The focus, in that regard, is still on waterproofing and less on flexible movement of the joints.

In 1961 the MIA publishes the *American Standard Specifications for Thin Exterior Marble Veneer (2 inches and less in thickness) and for Thin Exterior Marble in Curtain or Panel Walls*. This publication follows the same format as the previous publication in 1955. One difference from the previous edition is in the naming of the material. The 1961 edition calls exterior marble “thin.” These specifications were also adopted as American Standard A-94.2 - 1961; UDC 691.215; 624.022.¹²² The level of specificity in regards to the jointing details is very exact. It addresses the expansion and contraction on all levels and there are specifications for how to deal with horizontal expansion joints where the weight of the super-imposed materials may cause the pointing in the joints to squeeze out.¹²³ In this specification, the role of the general contractor is introduced along with the responsibilities of the architect. A whole new section is created to describe the setting of materials. Following the same three veneer conditions introduced in the 1955 edition, it goes over anchors details, installation and back-up building of the materials. Some of the significant changes in the 1961 edition is the jointing compound. In previous years, non-staining pointing mastic or neat white cement lime mortars as jointing compound was specified; however, this edition asks for a non-staining elastic jointing compound (polysulfide or similar synthetic rubber base or regular mastic type) with the option of cement lime mortar still offered as an option.¹²⁴ There is also mention of factory mixes for the jointing compounds in the specifications. As a side note in the anchorage section, it reads “In all areas, anchorage must be positive and mechanical and shall not rely in whole or in part on “bond” provided by mortar spots around anchors and between marble and backup wall.” This statement implies two things. One, they previously had incidents where designs were relying on the “bond” provided by the mortar spots, and

¹²² *American standard specifications for thin exterior marble veneer (2 inches and less in thickness) and for thin exterior marble in curtain or panel walls: With detail plates showing samples of installations*. (1961). Washington, D.C.: Marble Institute of America. 6.

¹²³ *Ibid.* 9.

¹²⁴ *Ibid.* 9.

second, they still desire a type of bond between materials. Finally, the 1961 MIA specification addressed marble faced precast reinforced concrete panels as a separate topic. Plate E13 illustrates the mechanical connections between the stone and the precast unit by drawings the various components. (Appendix D: Plate E13 Exterior – Marble Faced Precast Reinforced Concrete Building Panels) The section and isometric drawings indicates the full panel with a thickness of 3-1/2” and the dimensions of the panel is 6’ by 6’ with six 3’ by 2’ panels of stone. The complex sections show the following order of materials working from the outside surface in: marble of 7/8” thickness, 1/4” protective coat white cement, and hard concrete with some sort of reinforcement.¹²⁵ The “protective coat” is 1 part white waterproof cement, 2 parts medium sand, add sika “c” bonding agent and then let it set for about one hour on the surface, then the hard concrete mix can be poured and agitated with hand tamper. The function of this protective coat is to aid the bonding of the hard concrete to the marble. As one of the first written specs for stone veneer-faced precast concrete panels, the marble is cut to the thinnest dimension and the bonding of the stone to the precast is encouraged with a protective coat.

The early literature produced by MIA from 1948 to 1961 shows a range of small and large scale changes of how the stone is used and how the systems transform to accommodate for shifting building trends. Looking at the early literature used by the marble industry, it is easy to detect the rise of taller buildings and their developing demand for veneer stone. This contributes to the design details necessary to address thermal movements of expansion and contraction on the façade. There is also a shift in pointing material from cement to lime cement to elastic compounds. Once tolerance levels becomes an important factor in design, flexible pointing material and its performance in movement starts to appear. Lastly, the most interesting finding was the idea of bonding between materials. Although the back-up precast concrete the thin marble more massive, the specifications for marble faced precast concrete panels encouraged a tightly bonded surface between the stone and the precast concrete, along with mechanical anchors.

¹²⁵ Ibid. 28.

Dimension Stone Design Manual-

MIA's design manual on stone started to "provide products of marble that satisfy design concepts of the space age while retaining all the outstanding qualities for which it has always been respected."¹²⁶ The forward and introduction statement from the first edition referenced the space age and emerging computer technology that reveals an excited tone towards science and technology in the United States. Although MIA consciously root the stone industry back to the architecture of the Greeks and the Romans by saying, "the work of these ancients have survived down to today with little visible sign of change. Even today, few building materials can compare with marble in durability and lasting beauty," they are aware of the changing market demands.¹²⁷ Taking the initiative and creating a manual, they explain the technologies and new products made from this ancient building material as a way to inform the building industry about the innovative steps being made by the stone industry to meet modern demands. "Above all, the American marble industry is determined to keep pace with the times, while providing a quality product which meets the design and construction requirements of America's buildings of tomorrow, as well as today."¹²⁸

In the first edition of the *Dimension Stone Manual* published in 1971, the Marble Institute of America decided to create a manual that collected their earlier literature into a comprehensive reference that also included data sheets used in the industry. (Appendix J) Divided into two major parts, the first part of the manual was devoted to general information regarding the product and its production methods. The technical data provided information regarding the physical properties of the marble which included strength, thermal expansion and fire resistance, to name a few. The second part of the manual was devoted to product use. Largely divided into exterior use and interior use, the exterior used of precast concrete with marble facing was addressed in its own section. As an overall introduction, the mechanical properties of the material and its structural performance is based on the reinforced precast concrete; however, "marble does

¹²⁶ *Dimension stone design manual* (1st ed.). (1971). Cleveland, OH: Marble Institute of America. ii.

¹²⁷ *Ibid.* ii.

¹²⁸ *Ibid.* ii.

play a part in the strength of the panel.”¹²⁹ A number of detailed drawings are provided that demonstrate the anchor placement and the joint detail. The literature goes into the technical details where the minimum thickness of the marble is 7/8” and the “resilient bonding material (if required)” at 40 mil in thickness.¹³⁰ As a practice, the marble facing is both bonded and anchored to the reinforced precast concrete panel. According to the SpecData sheet, the technical data is from ASTM C503. The following are the tested physical properties: absorption, specific gravity (calcite, dolomite, serpentine, and travertine), compressive strength, and modulus of rupture. Marble with significant natural voids is recommended to be “parged approximately 1/4” in thickness.”¹³¹ Since the properties of marble can vary, most of the manufacturing process is to try and make the marble stiffer in hopes to make it stronger. This can be concluded from the specifications to bond and parge the natural material.

A revised 1st edition was published in 1976, followed by the second edition in 1983. (Appendix J) The second edition manual follows the same format as the first; however, in terms of the content regarding precast concrete – marble faced panels, no information is provided. Although there is a heading for the topic in the table of contents, the page directs the reader to “contact the pre-cast supplier for details.”¹³² This was also the case for the third manual published in 1985. (Appendix J) The page for stone-faced architectural precast concrete reads “refer to recommendations published by the Pre-Stressed Concrete Institute (201 North Wells, Chicago, Il 60606); or contact the Pre-Cast Supplier for details.”¹³³ The two publications of the *MIA Dimension Stone Design Manual* both acknowledge the existence of stone-faced precast concrete panels; however, they do not address the technical details of the material as they had done in the first edition. Both of the manuals from the 1980s directs the reader back to either PCI or the precast supplier. Although MIA’s approach in these two editions is unclear, one speculation is liability.

¹²⁹ Ibid. 03410.101.

¹³⁰ Ibid. 03410.302, 03410.401.

¹³¹ Ibid. 03410.401.

¹³² *Dimension stone design manual* (2nd ed.). (1983). Cleveland, OH: Marble Institute of America. 04420.000.

¹³³ *Dimension stone design manual* (3rd ed.). (1985). Cleveland, OH: Marble Institute of America. 03450.101.

The fourth edition of the manual is published in 1991. (Appendix K) This literature is organized in a different format and the last white tab is devoted to information regarding Stone-faced precast panels. Divided into three sections, supplemental information, typical detail drawings, and data sheet, this information provides the basic information regarding the material, its basic properties and a section drawing. The literature makes it clear that the provided guidelines require appropriate approval that will depend on the geographical conditions of the site.¹³⁴ The physical properties of the stone is dependent on the following properties: tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, and volume change. This literature recommends a mockup for testing different conditions and “joint performance under the most severe wind and rain conditions.”¹³⁵ Keeping the information general, PCI is recommended for obtaining additional information. In contrast to the information provided in the first manual 20 years prior, the minimum thickness of the marble facing is now 1” in contrast to the original specifications of 7/8”. Another difference is in product fabrication. According to the 1971 literature, the marble veneer facing was “bonded and anchored” to the reinforced precast concrete. The section detail illustrates a “resilient bonding agent or parge coat” between the stone and the concrete.¹³⁶ In the 1991 literature, the detailed section drawings indicate a “bond breaker” being applied between the stone and the concrete.¹³⁷ The shapes of the anchors have also changed when comparing the first edition to the fourth. The anchors in the first edition sprang inwards, while the anchors in the fourth edition spring outward in the shape of a “U”.¹³⁸

The fifth manual was published in 1999. (Appendix K) This edition, in comparison to the previous edition, did not demonstrate any changes in regards to the section on stone-faced veneer precast concrete panels except in the installation section where they refer the readers to the PCI Handbook for detailed

¹³⁴ *Dimension stone design manual* (4th ed.). (1991). Cleveland, OH: Marble Institute of America. 801.1.

¹³⁵ *Ibid.* 801.1.

¹³⁶ *Dimension stone design manual* (1st ed.). (1971). Cleveland, OH: Marble Institute of America. 03410.201.

¹³⁷ *Dimension stone design manual* (4th ed.). (1992). Cleveland, OH: Marble Institute of America. 801.2.1.

¹³⁸ *Ibid.* 801.2.1.

information.¹³⁹ There are no changes in the detail drawings and there are no changes when comparing the two data sheet. In 2003 excluding the addition of Serpentine ASTM C1526-02 and Travertine ASTM C1527-02 to the variety of stones in the technical data section of the literature, the sixth edition also remains unchanged from the previous edition.¹⁴⁰ (Appendix K) Editions 7.1 and 7.2 were published in 2007 and 2011 respectively. (Appendix L) Edition 7.2 is the most updated version of the *MIA Design Handbook* and between the two, no major changes occurred in the literature in regards to the stone-faced veneer precast concrete panels. The only visible change that was detected between the sixth edition and the 7.1 edition was in “U” cramp bar being called a “Hairpin” spring clip anchor and the angle of the slope for the sill being at 79.648 degrees, which was a change from an angle that was not disclosed in the previous literature. This angle was only featured in the detail drawings and not in the written literature.¹⁴¹ Besides the first MIA Design Manual in 1971, the sections regarding stone-faced veneer precast concrete was never fully elaborated on in terms of technical detail. In fact, after the first edition and the absence of mentioning any information on *stone veneer-faced precast concrete* in editions two and three, the following manuals addressed the material in a minimal fashion and always referred to the PCI literature.

3.3 Evolution of thin stone veneer-faced precast cladding:

After reviewing the industry manuals and technical literature, the design shift of the composite cladding material moves from the stone industry to the precast concrete industry. The design manual literature from both the stone industry and the precast industry reflect this change. In the earlier literature, it was the stone industry that spearheaded the use of thin stone veneer as a cladding material and drafted the specs for marble faced precast in 1961. Then MIA’s literature refers to PCI for the details in their 1983 and 1985 manuals and does not provide any information on stone faced precast concrete panels. In conjunction to the changes

¹³⁹ *Dimension stone design manual* (5th ed.). (1999). Cleveland, OH: Marble Institute of America. 209.

¹⁴⁰ *Dimension stone design manual* (6th ed.). (2003). Cleveland, OH: Marble Institute of America. 304.

¹⁴¹ *Dimension stone design manual* (7.1 ed.). (2011). Cleveland, OH: Marble Institute of America. 20-D-2.

in MIA's literature, PCI expands their literature on stone faced precast concrete starting in 1985. As a highly performing composite material, important changes in the design of the material as a whole can be observed in the following areas: 1. thickness of natural stone material, 2. the use and functions of bonding agents and bondbreakers, 3. types of epoxy sealants and 4. scientific testing parameters.

The changes in the minimum thickness of natural stone used to face precast concrete can be detected through the technical literature from both the stone industry and the precast concrete industry. When looking at MIA's literature from 1961, the thickness of the stone is specified at 7/8" and a total panel thickness of 3-1/2". The MIA literature from 1971 also lists the minimum thickness of the marble at 7/8" in its use as a facing material. It is not until the 1991 edition of the *Dimension Stone Design Manual* where the MIA makes changes to the minimum thickness of the marble to 1". From this point on, the MIA design manual keeps the minimum thickness at a consistent thickness of 1" but also recommends the PCI Handbook as a reference for further information. In the PCI literature, there is a wide variety of change in regards to the minimum thickness of the material. In the *PCI Architectural Precast Concrete Design* literature from 1989, marble specifically is specified at a minimum thickness of 7/8", but the most recent edition that was released in 2007 specifies the minimum thickness of marble at 1-1/4" in thickness when used as a facing material for precast concrete. The *PCI Design Handbook* from 1985 and 1992 still specifies the minimum thickness of marble at 7/8" but the very next edition, which was published in 1999, made changes to the minimum thickness for marble from 7/8" to 1". It is also important to recognize that the minimum thicknesses for the other stones also changed in the 1999 edition. (eg. Travertine, granite, and limestone). These changes occurred after PCI began to expand on the literature regarding natural stone faced precast concrete. PCI's 2010 edition of the Handbook finalizes the minimum thickness of marble at 1-1/4". The increase in the thickness of the natural stone material speaks to the performance of the material and not the industry's fabrication technology. Looking just at marble over the span of roughly 50 years, the minimum thickness of marble increase from 7/8" to 1-1/4". Along with the thickness of the natural stone,

the panel thickness has also increased. The 1961 MIA literature detailed the backup concrete panel at 2-3/8” and by 2010 the PCI literature details the precast concrete backup panel with a minimum of 5” to 6”.

In combining two materials, thin natural stone and precast concrete panel, the biggest goal is to have the two materials perform as one composite unit. MIA’s early literature reveals a design that bonds and anchors the stone to the precast concrete. This practice is confirmed by the literature’s use of the word “bonding agent”, and in the early literature by MIA, the mix of ingredients for the “protective coat of white cement” that acts as a bonding agent with the addition of the Sica “C” bonding agent. The MIA publication continues with this practice into their first manual publication in 1971 and then takes the opposite approach in their 1991 manual. No longer do they recommend the use of a bonding agent, but the drawings indicate a bondbreaker that prevents the bonding between the stone and the precast concrete. PCI’s literature in 1985 first mentions natural stone facing on the precast concrete and suggests the use of a bondbreaker. Beyond this point, there are fluctuations on the types of bondbreakers to use and the liquid bondbreaker was suggested early on in the literature and then disappears by the 2010 manual published by PCI.

The stone fabricators are responsible for drilling holes in the back of the stone for the anchors. Since the literature encourages mechanical anchors as the main method of connection between the stone and the precast concrete backup, the details and specification regarding this detail is important to the overall performance of the panel. Anchor placements and tolerances vary according to the stone properties; however, PCI’s literature introduces the idea of using epoxy for filling in the anchor holes to improve or “increase shear capacity and rigidity of the anchor” and also “eliminate intrusion of water into the holes” in 1992.¹⁴² The use of epoxy as a filler was not a mandatory requirement; however, after its introduction, it continued to make its appearance in the literature. The recommendations for the type of epoxy to be used was either a fast-curing silicone or low modulus polyurethane, then in 2004 the fast-curing silicone was

¹⁴²*PCI design handbook; precast and prestressed concrete* (4th ed.). (1992). Chicago. PCI. 7-18.

taken out of the literature. The most recent edition of PCI's handbook recommends a two-part polyester or epoxy. The literature also elaborates on the fact that the thermal expansion of the epoxies need to be properly formulated so that they do not expand and crack the stone. They suggest using "stone flour or fines or fine sand as a filler for the epoxy to reduce the coefficient of thermal expansion of the epoxy and the shrinkage."¹⁴³

Scientific testing increased over time. Both the stone and precast concrete industries relied on creating full scale mock-ups to observe changes and material performance over time. The literature recommended samples as part of the development and decision making process until PCI's third edition of the Design Handbook (1985). By the fourth edition of the Design Handbook (1992) the literature claims that the samples or mock-up are no longer for the purpose of observation and study of performance because now there is a good background knowledge. Samples and mock-ups are recommended for checking feasibility of production and erection. Then in the sixth edition (2004) stipulations on testing parameters and the number of test cycles increase. The seventh edition (2010) also include new ASTM tests to obtain more information about the material properties. This emphasis on testing engages environmental weathering conditions such as temperature values and freeze-thaw cycles. The environmental conditions that impact the exterior of the building is now tested in a controlled laboratory setting. Design decisions are now based on scientific data and testing results, which explains the increase in types and cycles of tests.

3.4 Gate Precast Site Visit:

Today, there is a different level of understanding when it come to the composite cladding material of thin stone veneer faced precast concrete panels. Although building materials also operate in response to trends, this building material is still casted and utilized in construction today. As an industry, PCI operates a

¹⁴³ *PCI design handbook; precast and prestressed concrete* (7th ed.). (2010). Chicago. PCI. 7-35.

certification program for plants that manufacture these products. This certification guarantees a level of quality that architects and contractors trust. Gate Precast is one of the largest manufacturers of architectural and structural precast concrete. To better understand the production process of precast concrete panels faced with natural stone, a site visit to Oxford, North Carolina was conducted on February 24, 2016. The North Carolina facility has state-of-the art batch plant equipment and material handling within an enclosed space of 41 acres and a yard for storage and finishing. They have the capacity to do full scale mock-ups and have gantry cranes that span 150' and 40-ton travel lifts. The working surfaces inside the facilities are on top of vibrating elevated platforms for pouring concrete.¹⁴⁴ The typical production process of stone veneer-faced precast concrete panels is as follows:

1. The stone (red granite facing of 1-1/4" in thickness) is carefully placed in the wooden form. There is insulation foam placed in between the granite panels to maintain the specified joints. This will later be removed after the casting is completed.
2. The visqueen plastic bondbreaker is placed and taped into position.
3. The anchors are then hand set into the stone according to the specified distances. These anchors are set and the holes are filled with epoxy, if specified. Stone comes pre-drilled by the stone manufacturers according to the specifications dictated by the engineers.
4. The rebar is set and secured into the mold or placed into position using plastic bar chairs. The rebar will sit at the middle of the precast concrete portion of the panel.
5. The concrete is then poured as the working platform surface vibrates the concrete into place. The concrete is also worked with a shovel into the corners of the mold.
6. Load bearing connector and lateral tie-back are placed and casted into the precast. Gate precast limits 2 load bearing connectors to one panel. These are the main methods of attaching the panels to the superstructure of the building.

¹⁴⁴ Precast Concrete Systems. (n.d.). Retrieved February 26, 2016, from <http://www.gateprecast.com/>.



Figure 3.7 Gate Precast Demonstration: a.) stone and bondbreaker in wood mold b.) anchors and epoxy c.) secured rebar d.) pouring of concrete e.) finished panel surface with red granite f.) side view of precast concrete, bondbreaker, and granite

Interesting Findings-

An important reason why stone is still selected as a facing material for cladding is its diverse aesthetic appearance. A process called blending is done to pre-arrange the distribution of the stone facings to create a specific aesthetic quality. The variety that stone offers and the ease of precast construction allows for this cladding material to be favorable for large-scale projects today. A list of current projects is available in the PCI catalogue as well as project portfolios of individual manufacturers. Another veneer product that has started to re-gain popularity recently is terra cotta. Unlike stone, no bondbreaker is used and the back of the terra cotta is manufactured with keys to encourage a stronger bond when the concrete is casted. Lastly, there is a definite push in the precast industry for developing concrete panels that mimic stone aesthetics. Experiments with different colored aggregates and finishes is an ongoing endeavor that the industry would like to expand and implement in the near future.

3.5 Conclusion:

The development of new building materials requires the right combination of demand and technology. In the case of *thin stone veneer-faced precast concrete panels*, there was a demand for building and the technology was present in both the stone and precast industries to pursue its development. Although it is difficult to pinpoint the first use of the material, the technical literature from both the marble stone industry and the precast concrete industry acknowledge its relevance by including the composite cladding material into their manuals and literature. By tracing the composite panel through the industry literature, a few conclusions could be achieved. First of all, MIA was an organized industry that detailed the innovative use of thin stone marble with the precast concrete before the precast concrete industry. MIA's literature also revealed the logic of the industry and how they expected the panels to perform when it was first designed. As the stone industry faced new challenges posed by the technological developments of construction, they began to respond by conducting their own research and fabricating new ways to comply with the changing demands. With MIA using the term "marble faced precast reinforced concrete building panels" in 1961, this was the beginning of the composite material *thin stone veneer-faced precast concrete panels*. It is clear that the composite panel system was a complex connection of separate parts that needed to work in collaboration with one another. This also mirrored the collaboration that was necessary between the two industries for the development and sustainability of the material. After the initial realization of *thin stone veneer-faced precast concrete panels*; however, performance challenges instigated design changes of the panels over time. These improvements were indicated in the changes found in the manuals over time. Also, the role and responsibility that the precast concrete industry acquired was reflected in the manual literature produced by both the stone industry and the precast concrete industry. In conclusion, the changes and development of the material was not a revolutionary but gradual and based on performance.

Chapter 4. Evaluation of Case Studies

This chapter identifies a number of case studies that used the composite material of *thin stone veneer-faced precast concrete panels* as a cladding material and investigate the current condition of the façade. These projects are relatively well-known and have undergone various phases of repairs and/or renovations over the years. The purpose of this chapter is to see how conservation work on the building has been handled in the past, and document the current conditions of the exterior as it stands today. The assessment will be limited to obtainable documentation of drawings and records of work, news articles and current visual observations of the site. The following case studies were selected with the intent to compare the repair work done on significant historic buildings versus a building without historical significance, and also projects that could be accessible by the author.

4.1 Case Study: Cultural Educational Center (CEC), Albany, NY:

Located in Albany, the capital city of New York, the Cultural Education Center (CEC) is located at the south end of the Empire State Plaza. This ambitious large scale project is a series of governmental buildings situated along the plaza credited to the Governor Nelson A. Rockefeller. The Office of Cultural Education (OCE) operates the New York State Museum, State Library, and the State Archives. The architecture of the CEC building is three stories below ground and eleven stories from ground level. Although it is clad in marble, it is often described as a brutalist building due to its form, and it was



Figure 4.1 Empire State Plaza during Construction
(Source NYS Library)

designed by Wallace Harrison and Max Abramovitz. Taking nearly sixteen years to complete, the Empire State Plaza covered 98 acres of downtown Albany.¹⁴⁵ The project faced criticism and controversy from the very beginning when they had to destroy over 1,150 structures, mostly private homes, and displaced close to 9,000 people.¹⁴⁶ The project cost over \$1 billion dollars to complete, which was about double the

estimated amount. With the completion of the CEC building in 1976, the plaza was also pronounced complete.¹⁴⁷

The plaza was brightly lit by the white marble which was used in conjunction with granite and concrete. Visually, the CEC building anchored the



south end of the plaza and across from the New York State Capital

Figure 4.2 Historic view of New York State Capitol before Construction
(Source Times Union Archives)

building which is an ornate nineteenth century masonry building. According to planning documents from 1966, the construction budget for the CEC was projected at \$45 million dollars; however, due to design changes and construction delays, the actual cost of the project soared.¹⁴⁸ Design changes required extra infrastructure and significant deviations from the original site planning, which also changed the project costs dramatically.¹⁴⁹

¹⁴⁵ Faber, H. (1978, May 28). After 16 years, downtown Albany's Empire State Plaza is completed: A major tourist attraction used of carriages considered. *New York Times*. Retrieved April 10, 2016.

¹⁴⁶ Rodat, J. (2002, August 13). A TALE OF TWO CITIES: In the shadow of the gleaming, imperial structure of the Empire State Plaza, classic examples of historic architecture sit deteriorating. Is this a tragedy, or a fantastic field for renewal? *Metroland*. Retrieved April 10, 2016.

¹⁴⁷ Weisman, S. R. (1976, July 2). In Marble's White Glare, a Debut for Albany Plaza. *New York Times*. Retrieved April 10, 2016.

¹⁴⁸ NYS ARCHIVES. GOV.SOUTH MALL-PLANNING 1966. March 16, 1966

¹⁴⁹ Boyd, J. H., & Holcomb, C. R. (2012). *Oreos and Dubonnet: Remembering Governor Nelson A. Rockefeller*. Albany: State University of New York Press. 40.

4.1.1 Condition of cladding: thin stone veneer-faced precast concrete-

The archival drawings found at the New York State Archives inside the CEC building are dated 1966. According to these technical drawings, the cladding material on the elevation is labeled as “marble”. The elevation drawing on sheet 64/4-47 called out the marble, exposed concrete, and granite.¹⁵⁰ In the 1966

exterior wall sections on sheet 64/4-54, 2” marble veneer anchored into 8” thick brick backup was specified.¹⁵¹ The typical wall section for the building was illustrated as a 1-1/4” thick marble casted to a floor fill cement with a thickness of 1-1/4” anchored into the backup concrete or concrete blocks. The detailed section does not show any use of dowels or pins to secure the connection between the marble veneer-facing. The drawings do indicate the cast in place clip angles that attaches to the backup with a chinch anchor.¹⁵² In terms of the section cut through the upper marble fins, the 1966

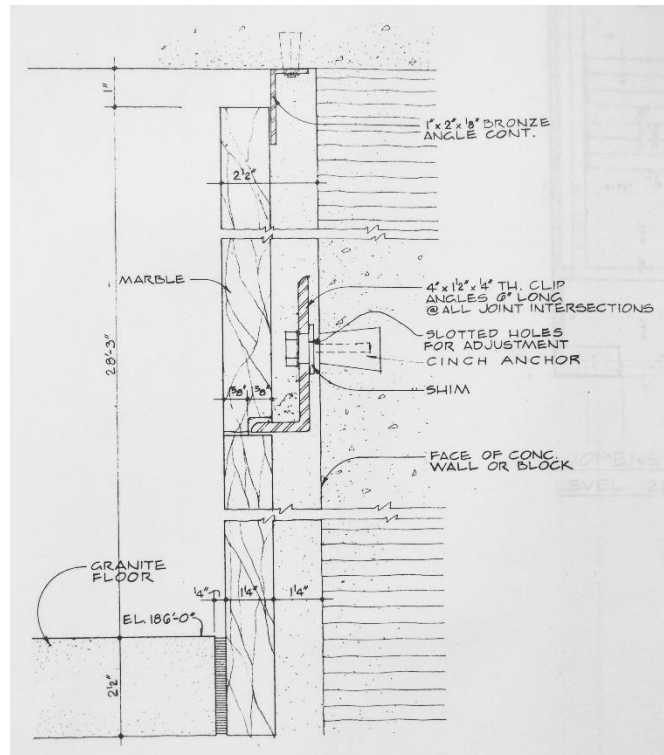


Figure 4.3 CEC – Typical Wall Section, 1966
(Source NYS Library)

drawings show a marble veneer facing of 2-1/2” with a gap of 1-1/2” and the concrete surface to be treated with a damp proofing on the surfaces. These marble veneers are anchored into the 8” concrete back-up and only the coping on top had dowels.¹⁵³ When comparing these drawings with the copy at Avery Library the marble veneer has changed to marble faced-precast concrete panels from the marble veneer. The drawings at Avery Library are dated 1968. On sheet 64/4-104, the elevation illustrates the upper fins that surround the window openings as marble faced precast concrete panels. This is a change from the 1966 drawings

¹⁵⁰ CEC Drawings (1966) 64/4-47. NYS ARCHIVES.

¹⁵¹ CEC Drawings (1966) 64/4-54. NYS ARCHIVES.

¹⁵² CEC Drawings (1966) 64/4-43. NYS ARCHIVES.

¹⁵³ CEC Drawings (1966) 64/4-44. NYS ARCHIVES.

which specified them as marble. The section elevation thru the façade depicts the wall sections with details that indicate the facing material as precast concrete with marble. The 1966 façade section indicated a marble veneer facing attached to the back-up with anchors.

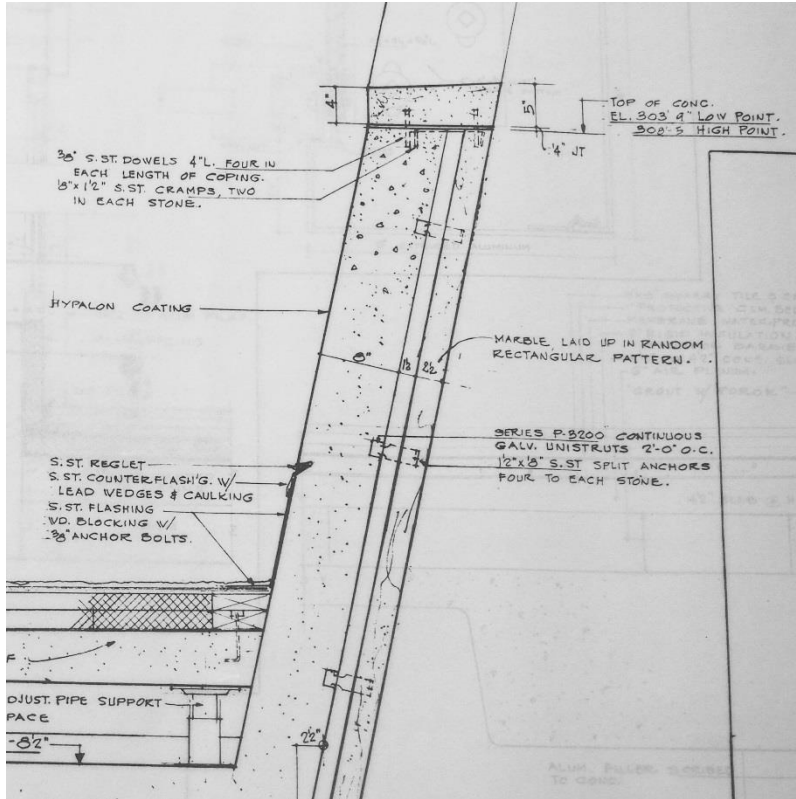


Figure 4.4 CEC – Section of Marble Fin, 1966 (Source NYS Library)

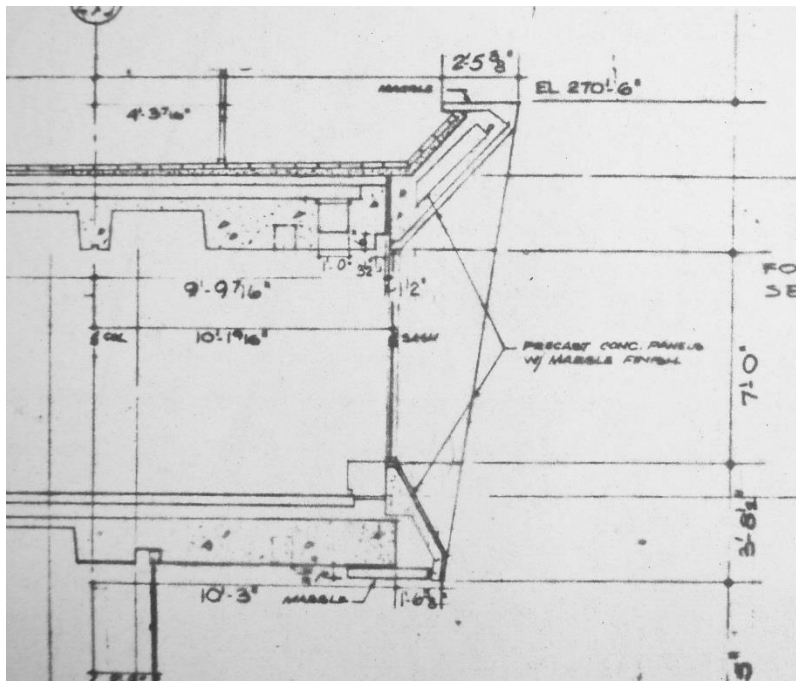


Figure 4.5 CEC – Section of Marble Fin, 1968 (Source Avery Library)

The on-site inspection was conducted during the afternoon of February 26, 2016. The inspection was a visual analysis and photographically documented. The building has four major horizontal elements with three levels of vertical fins as a design that clads the exterior and shades the windows. The base area has supporting columns that dominate the ground level of the structure. The columns are also mirrored on the very top roof level but with less of a vertical span. The building is clad in a white marble, exposed concrete, and glass. The scale of the building makes it quite difficult to observe the panel systems on the façade, and due to the repair work in progress on the main staircase over Madison Avenue, access to the observation deck was prohibited. The

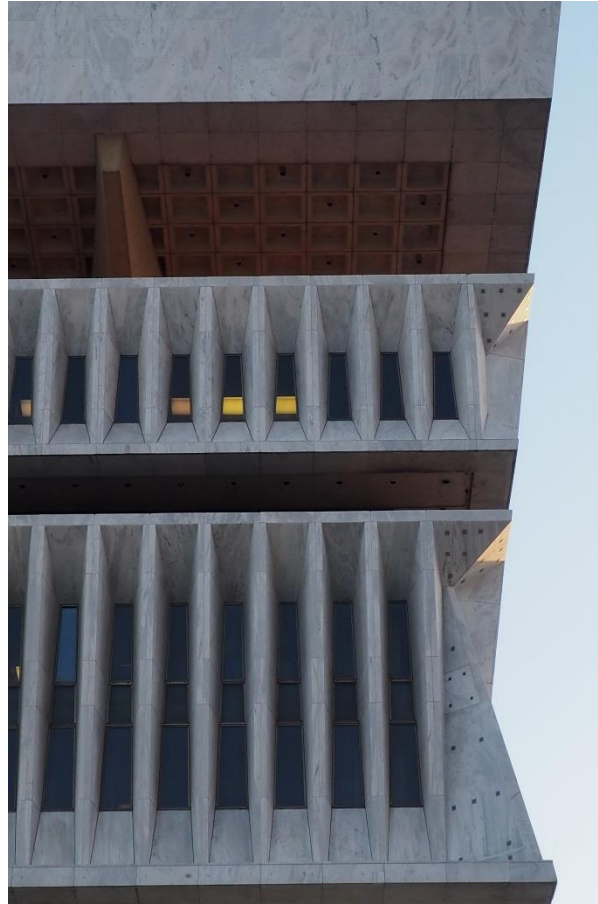


Figure 4.6 CEC – Bolting of Edge Panels

Georgia Cherokee white marble is a very rich cream color that is swirled with striation patterns throughout the entire façade, and according to Kyle Normandin's article, the thickness of the marble ranges from 7/8" to 2" throughout the entire building.¹⁵⁴ Some mechanical straps were detected on some of the panels and upon closer examination of the façade, and there are pieces of the marble fins have been bolted in. The discrepancies in the shadows formed along the edges where the fin panels meet suggests the movement of the panels. The corner fins that extrude out from the building in sharp angles have all been bolted into place. This suggests that there is some type of movement that is destabilizing these panels. Although it was difficult to detect at first, the top level of flat panels are all bolted into place. When the light hits the surface at the right angle, the bolts become visible. There are roughly two different panel sizes, and they are

¹⁵⁴Normandin, K. C. (2003). Stone-faced precast panel technology. In *Stone in modern buildings: Principles of cladding* (pp. 38-41). Paris: Docomomo International. 39.

arranged in a vertical direction. The large panels have six bolts around the edges and the smaller panels have four bolts to secure them into place. Over the years, repairs have been done to the CEC building by a number of firms including Wiss, Janney, Elstner Associates, Inc. and Simpson Gumpertz & Heger. This case study depicts the early uses of *stone veneer-faced precast concrete panels* and how repairs have been handled over time. As an important government building that has a significant history, the repairs respond to this status.

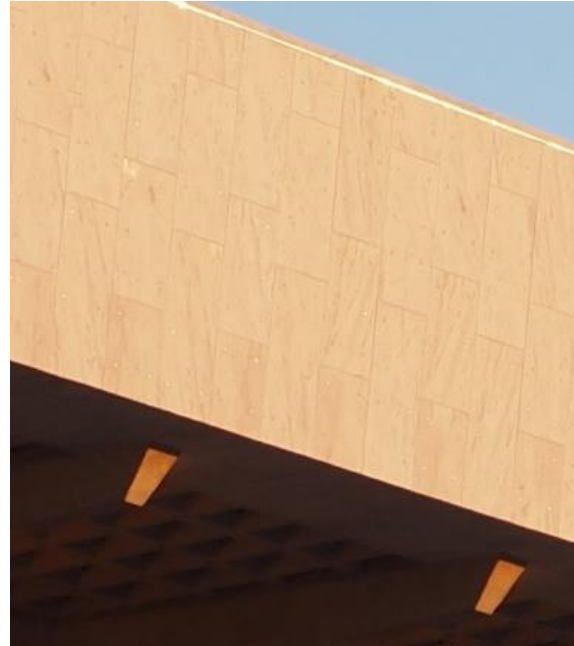


Figure 4.7 CEC – Bolting of Flat Panels

4.2 Case Study: Juilliard School of Music at Lincoln Center, New York, NY:

Founded in 1905, the Juilliard School for the Performing Arts is now a part of the Lincoln Center in New York. The Lincoln Center project started in the fall of 1955 and was considered the “biggest and boldest complex devoted to the arts ever attempted in the United States.”¹⁵⁵ The planning of the Lincoln Center included some of the most notable architects of that time, and challenged the notion of what a cultural center entailed, however, this large scale project was met with many challenges and controversy. The only design choice that the architects all agreed on instantly was the selection of Roman travertine stone as the cladding building material.¹⁵⁶ Ironically, this was an unwise choice of stone for the environmental conditions of the site. This was at the suggestion made by Pietro Bulluschi who, in association with Eduardo Catalano, designed the Juilliard School for the Performing Arts. Although Belluschi was involved in the Lincoln

¹⁵⁵ Clausen, M. L., & Belluschi, P. (1994). *Pietro Belluschi: Modern American architect*. Cambridge, MA: MIT Press. 254.

¹⁵⁶ Goldberger, P. (2003, July 07). West side fixer-upper. *The New Yorker*, 79(18).



Figure 4.8 Juilliard School of Music – 1970
 (Source *Pietro Belluschi: buildings and plans 1932-1972*)

Center project from the very beginning, the project was set back due to site, budget, and program issues that ultimately dragged the project on for fifteen years. This is why the Juilliard School did not open with the formal opening of the Lincoln Center in 1962 but opened in 1969.¹⁵⁷ The changes in budget and programming resulted in cost-cutting design decisions such as the exposed concrete in the lobby

which was originally designed with wood paneling.¹⁵⁸ The building is located between West 65th street and West 66th street and Broadway and described as a brutalist building. Today, it is connected to the Lincoln Center Plaza with a pedestrian bridge over West 65th street and the building. Continuing the same visual image with the other buildings at Lincoln Center, the Juilliard School is clad in Travertine. Moving from its original location on Claremont Avenue, the building was said to have cost about \$29,500,000 and the travertine marble was donated by the Republic of Italy.¹⁵⁹ At its opening in 1969 the building had six floors above ground level and four underground. It has ‘free floating’ walls and floors and performance halls for opera, dance, drama, instrumental music, classrooms, studios, two libraries and recording facilities.¹⁶⁰ The architecture was accepted with praise by architecture critics like Ada Louise Huxtable of the *New York Times* as “not avant-garde, but its refinements and simplicities are timeless.”¹⁶¹ She also

¹⁵⁷ Clausen, M. L., & Belluschi, P. (1994). *Pietro Belluschi: Modern American architect*. Cambridge, MA: MIT Press. 259.

¹⁵⁸ Olmstead, A. (1999). *Juilliard: A history*. Urbana: University of Illinois Press. 184.

¹⁵⁹ Gent, G. (1969, October 27). Juilliard School Dedication Marks Completion of Lincoln Center: The Juilliard School is Dedicated. *New York Times*. Retrieved April 10, 2016.

¹⁶⁰ *Ibid.*

¹⁶¹ Huxtable, A. L. (1969, October 8). Juilliard's New Building: Esthetic Reality. *New York Times*. Retrieved April 10, 2016.

considered the Juilliard building an “upbeat” conclusion to the “cultural confusions” of the rest of the Lincoln Center.¹⁶² Unlike the other building at Lincoln Center which are clad in thin stone travertine panels, the Juilliard School was clad with travertine faced precast concrete panels. They were manufactured at an offsite plant and hoisted into place during construction. By combining precast concrete and thin travertine, Belluschi was able to obtain both aesthetic continuity with the rest of Lincoln Center and capitalize on the advantages of prefabrication. These stone veneer faced panels were used on all four facades.¹⁶³ A redesign of the Lincoln center that highly impacted the design of the Juilliard School from its largely rectangular shape happened in 2003 with a large opening triangular canopy that was completed in 2009. The firm selected for the design was Diller Scofidio + Renfro. The goals of the design was to create new entrances



Figure 4.9 Juilliard School of Music – 1970
(Source *Pietro Belluschi: buildings and plans 1932-1972*)

and enhance a pedestrian-friendly movement that engaged it with the surrounding community.¹⁶⁴ As a cultural icon of New York City, Lincoln Center is a historically significant landmark, and any changes and/or repairs made to the Juilliard School are subject to debate for approval.

4.2.1 Archival Drawings and Condition of cladding: thin stone veneer-faced precast concrete-

According to the archival drawings that were produced by the architect Pietro Belluschi and Eduardo Catalano and Helge Westermann, Associated Architects in 1966 the section details indicate the use of travertine faced concrete panels for the cladding. (Sheet A-49) The travertine stone on the Juilliard School

¹⁶² Ibid.

¹⁶³ Normandin, K. C. (2003). Stone-faced precast panel technology. In *Stone in modern buildings: Principles of cladding* (pp. 38-41). Paris: Docomomo International. 39-40.

¹⁶⁴ Lentz, L. C. (2011, February). The Juilliard School: New York City. *Architectural Record*, 199(2), 96-98.

and the Alice Tully Hall was 7/8” thick, attached to a precast reinforced concrete panel with a thickness of 3-6”.¹⁶⁵ Since the completion of the building in 1969, there have been a series of repair work done. In 1986 there was a stabilization program implemented at the Lincoln Center for the Performing Arts, which includes periodic on-site inspections and monitoring of the travertine exterior cladding.¹⁶⁶ Past surveys documented façade conditions that demonstrated multi-directional cracking of the travertine, predominately on the east and north elevations. Additional laboratory testing indicates deterioration is a result of cyclic freezing. There was water infiltration into the system, which accelerated the deterioration of the travertine. In some instances, the travertine veneer delaminated from the precast concrete substrate and there were signs of water intrusion and frost behind the travertine. Shims would slip in areas due to movement and panels would become offset from one another.¹⁶⁷

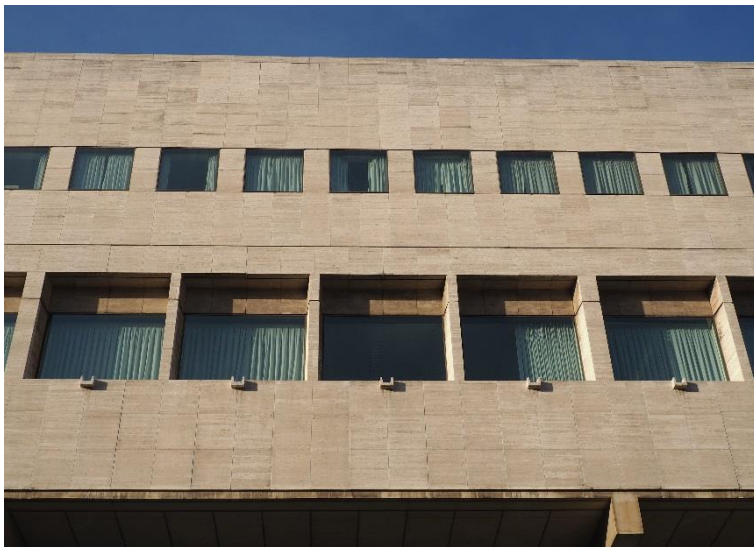


Figure 4.10 Juilliard School – Travertine Panels

Due to the severe exterior weather conditions in New York, the properties of the travertine, and a history of cladding instability at the Lincoln Center, close examination and façade inspections are necessary. The most recent façade inspection report filed in compliance with the Local Law 11 was in 2013. The work was conducted by

WJE Engineers & Architects and the status was declared as OK-safe. Records of the past three façade inspections can be found dating back to 2004.¹⁶⁸

¹⁶⁵ Juilliard School of Music Architectural Drawings (1965). A-49. Syracuse University.

¹⁶⁶ Normandin, K. C. (2003). Stone-faced precast panel technology. In *Stone in modern buildings: Principles of cladding* (pp. 38-41). Paris: Docomomo International. 40.

¹⁶⁷ In conservation and reports from Kim Beasley. Permission granted for use.

¹⁶⁸ NYC Department of Buildings. BIN: 1028834. 2013.

During the site visit that was conducted on April 9, 2016 the façade of the Juilliard building was visually observed and photographic documentation was made. The south elevation, overall, does not show any signs of deterioration or severe discoloration. The panels all seem to be in good condition and visually, all the panels look rigid and flush. From a distance, there are panels of travertine that are lighter in color than the surrounding panels, which suggest it may be a replacement. There are indications of soiling on the surfaces of the travertine panels that are deeply recessed and on the surfaces of the exposed concrete underneath the panels. On the underside of the panels on the west elevation, cracking sealant and some rust color run-off is visible across the surface of a few panels. There are signs of dutchmen (indents) repairs on a couple of the parapets on the west elevation. There were also signs of horizontal and vertical cracking of the concrete slabs under the travertine faced panels along the crevice.



Figure 4.11 Juilliard School – Travertine Spall

On the west elevation, there was an edge that was cracking and spalling around the column. This was not a precast panel but just a panel of thin travertine. Panels on the ground level towards the north elevation were moving out of place by 3/4". The overall color of the façade on this elevation was darker and less maintained than the West 65th street elevation. Despite the noticeable color and movement of the lower panels, no panels were missing or visibly broken or severely deteriorated. At the bottoms of the panels, there is an additional travertine piece that covers the underside of the panel for aesthetic purposes. In many instances, the caulking that is sealing the bottom travertine covers is cracking or peeling out due to moisture. In some areas, these pieces are experiencing flexural cracking and retaining moisture. The east elevation of the building demonstrates a strong visual of the intervention done by Diller and Scofidio. It is faced with glass on both the upper and lower levels.

Overall, the Juilliard School is a case that used the thin stone veneer-faced precast concrete panels for cladding the building; however, it is a unique case due to its significance. Any project or site decisions involve many stake holders. During the stabilization repairs of the Juilliard School, the types of repairs needed to address both structural integrity and making sure the aesthetic decisions stayed true to the design intent of the architect. The use of dutchmen (indents) are forms of patch repairs of the stone versus a full panel replacement.¹⁶⁹ The level of care and concern in regards to this projects is a reflection of the architectural significance of this building. The overall conditions of the exterior façade looks like it is in good condition and the visible repairs looks like full panel replacements with very limited uses of dutchmen (intents) as a repair method to ensure the design intent of the architect.

4.3 Case Study: Former Life of Georgia Tower, Atlanta, GA:

This building is a modest office building located at the corner of Spring and West Peachtree Street in downtown Atlanta, GA., former known as the “Life of Georgia Tower.” It was completed in 1968 and designed by the architects Bodin and Lamberson and the associate architect was Eggers and Higgins. The mention of this building and its use of thin stone veneer-faced precast concrete panels was from the PCI Journal article published in 1967 as a new project using marble faced precast panel as a cladding material.¹⁷⁰ The building was designed with 28 floors and a total of 375,000 square feet of office space. Today, it is known as the “One



Figure 4.12 Former Life of Georgia Tower – Atlanta, GA

¹⁶⁹ Normandin, K. C. (2003). Stone-faced precast panel technology. In *Stone in modern buildings: Principles of cladding* (pp. 38-41). Paris: Docomomo International. 41.

¹⁷⁰ McDaniel, W. B. (1967). Marble-Faced Precast Panels. *PCI Journal*, 12(4), 37.

Georgia Center” on Peachtree Street. With the downtown building boom that occurred in Atlanta, many of the mid-century buildings are getting retrofitted or re-furbished to comply with market demands. This was the case with the former Life of Georgia Tower renamed One Georgia Center with a \$25 million dollar renovation by the owners Steinemann & Company but financed by General Electric Credit Corporation in 1986.¹⁷¹ The owner at the time of the grand opening of the One Georgia Center included a tribute to Atlanta’s architectural heritage with the Atlanta Historical Society. Although the building has always enjoyed a Class-A status, the renovations were deemed necessary to upgrade and modernize the building to the standards of the 1980s.¹⁷²

4.3.1 Condition of cladding: thin stone veneer-faced precast concrete-

Archival drawings could not be obtained for this building. According to the commemorative plaque located on the exterior of the building, the building was known as the “Life of Georgia Tower” and the general contractor was Daniel Construction Company. During the site visit conducted on March 28, 2016 it was clear that the site was well managed and cared for, and there was good accessibility to the building. The observations were limited to visual observations and photographic documentation. Since the visit was done on a weekday and after working hours, not many people were on the site to conduct interviews. From a distance, the white colored Georgia Marble reflects the light off the repeating modular window fins of precast concrete faced with thin stone marble. Retaining the overall character of the building, the repeating shapes are elegant and bold. From a distance, not much information can be gained in terms of the conditions of the façade other than its bold repetitious form. The ground level is a floor to ceiling glass window cladding that gives you visual access into the lobby spaces and the ground floor offices. Above this is another high ceiling space with large openings. On top of this level is the very first band of vertically oriented windows are lined with six square panels going up vertically on either ends with a panel across the top and bottom. Going up vertically, there are twenty one levels of square windows that are half the height

¹⁷¹ Grand Opening of on Ga. Center Announced. (1986, October 23). *Atlanta Daily World*. Retrieved April 09, 2016.

¹⁷² Ibid.



Figure 4.13 Former Life of Georgia Tower –
Panel Deterioration and Repairs

of the first band of windows with three square panels high and another panel across the top and bottom. At the very top of the tower there are two stories that are covered without window openings and finished with a stone grid. Upon closer observation, the marble faced pre-cast was demonstrating very curious patterns of cracks on the surface of the marble. All elevations show web-like cracks that have been filled with a dark grey caulking material on the large flat panels. Some of the cracks on the panel seem to be starting from the center of the panel extending outwards towards the edges. In some instances, the cracks are accompanied by a number of holes that are also filled in with the same silicone type of caulking material. This type of cracking pattern is detected on the flat panels as well as the small panels that line the inside of the modular window fins. There is no pattern associated with the panels that are affected. On the west elevation there is an area where there are two large horizontal cracks that extend over two large panels that has been sealed in with a grey mortar. The amount of cracking detected on the modular fins is quite extensive on all visible elevations. On the east elevation there is a bridge that connects the second level with the street level sidewalk on West Peachtree St NW. This bridge is also cladded with large panels that demonstrate both cracks and flexural cracking. There are some areas edge conditions that show spalling of the marble. Although the conditions of the marble panels were recognized and addressed, it is clear that the problem has not been solved. The extensive amounts of cracking and damage of the marble indicates the use of thin marble. There were no missing panels or part of the façade that looked like it was in danger of detaching. Although this building is well integrated into

the city, the use of caulking as a repair method indicates a less rigorous concern of the building's aesthetic integrity.



Figure 4.14 Former Life of Georgia Tower – Flexural Cracking



Figure 4.15 Former Life of Georgia Tower – Panel Deterioration and Repairs

4.4 Conclusion:

All three of these projects were constructed around the same time period. Although each project vary in scale, function, and climate conditions, they all utilize the composite cladding material, *thin stone veneer-faced precast concrete panels*, that was introduced in the 1960s. Interestingly, they all demonstrated some type of façade deterioration and all three projects approached the repair differently. The Cultural Education Center (CEC) in Albany, New York is a large-scale government building that experienced design changes from the start. In a span of two years, a decision was made to change the marble veneer detail to a marble veneer-faced precast concrete panel. The exact reason behind this change is not certain; however, the overall project was both extremely over budget and behind schedule. The building today reveals repairs done with careful precision to preserve the aesthetic quality of the façade, and in some areas the repairs are very obvious. It is likely that the repairs were done at different times and possibly with different companies. In the case of the Juilliard School, the architectural significance of the project involves many stake holders and their positions regarding any significant repair or changes. The aesthetics is important to preserving the designer's intent and any implementation is examined with a critical eye. Currently the façade is very well

maintained and demonstrate no blatant repairs, however, records show that issues with the façade have been repaired. Lastly, the tower case study in Georgia demonstrates a level of distress on the marble faced panels that is quite extensive. Although more testing is required to determine the reasons for deterioration, the aesthetics of the structure is marred by the poor repairs. Unfortunately, failures are associated with the *thin stone veneer-faced precast concrete panels* used during this time period with these three case studies, and stabilization work has been conducted. In terms of repairs, if the building had a significant historical value, the repairs were done with the intent to preserve the visual qualities of the façade, but not necessarily the physical fabric. With less significant buildings, repairs were done with the goal of stabilizing the existing fabric, not preserving an aesthetic.

Chapter 5. Investigation

In the PCI journal from August of 1967, an article featured a number of architectural projects that utilized marble faced precast concrete panels. The first example was the former “Georgia Archives and Records Building” located in Atlanta, GA.¹⁷³ As of 2016, the former Georgia Archives Building, known as “Ice Cube”, has been standing in its original location for the past 51 years. It is an expression of Modern architecture designed by a local architecture firm A. Thomas Bradbury and Associates at the end of the 1960s. Despite the initial excitement that was felt at the opening of the building, today it is in a dilapidated state.

5.1 Case investigation- former Georgia Archives Building:

The former Georgia Archives Building is located on 330 Capitol Avenue SE Atlanta, GA 30334. Less than 10 minutes away from the Georgia State Capitol building, it is located near the crux of the city and near some of the busiest highways in the US. The building is 16 stories and 568,000 square feet of floor space. Originally proposed as a \$6.6 million dollar project, this marble building was designed to provide “consolidation of record-keeping and adequate storage facilities.”¹⁷⁴ One of the main focuses of the archives was to be a repository for microfilm which was seen as the technology of choice to “preserve, and catalogue all the papers which record the creation and development of our lives in Georgia.”¹⁷⁵ The building was designed with vaulted ceilings and state of the art



Figure 5.1 Former Georgia Archives Building – Atlanta, GA

¹⁷³ McDaniel, W. B. (1967). Marble-Faced Precast Panels. *PCI Journal*, 12(4), 29.

¹⁷⁴ Ground Broken in Georgia for State Archives Building. (1962, June). *History News*, 17(9), 122.

¹⁷⁵ *Ibid.* 122.

conditions of humidification, heating, and fireproofing to keep important documents and papers in good storage conditions. The design intent for this building was to equip it with the most advanced archival technology. The architect's sketch provided for the article in *History News* written July of 1962 was a black and white perspective sketch that illustrated a base of evenly spaced columns lofting two stories and a

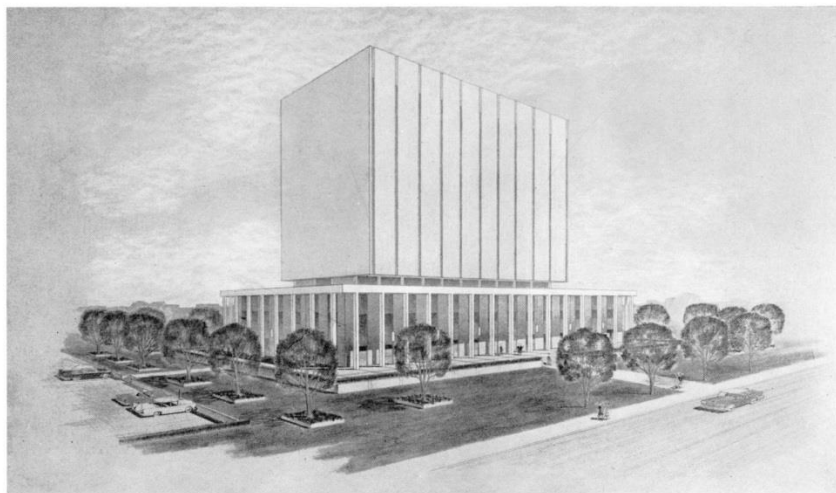


Figure 5.2 Architect's Sketch, 1962
(Source *The American Archivist*)

windowless rectilinear massing centered on top of the base. According to this article, it was a building that was anticipated after a long campaign by the secretary of state Ben Fortson and Mrs. Mary Givens Bryan, who was the state archives director.¹⁷⁶

The building was opened to the public on August 16, 1965 and dedicated in October of 1965. The new building housed the following collection: 10,000 cubic feet of official records and special documents of Georgia history, 8,000 books, 19,500 manuscripts book records, a million manuscript pieces, 14,000 reels of microfilm, and 5,000 record center boxes. And the underground levels were capable of parking 1,100 cars.¹⁷⁷ At its opening in 1965, the building was well received

“...hailed as the most modern archival facility in the country: its fireproof construction and gas-powered air conditioning were touted as providing the finest security possible for historical records, and researchers exclaimed over the grand accommodations made for them in walnut and marble. Even the exterior of the building excited comment. One article reported that the building ‘stands

¹⁷⁶ Ground Broken in Georgia for State Archives Building. (1962, June). *History News*, 17(9), 122. Retrieved March 10, 2016.

¹⁷⁷ Georgia Dedicates Archives Building. (1965). *History News*, 20, 12th ser., 267. Retrieved March 11, 2016. 267.

in such solitary splendor between the ribbed circle of Atlanta Stadium and the gold-domed state capitol that it is almost a traffic hazard.’”¹⁷⁸

Mary Givens Bryan, who was the Director-Archivist of Georgia’s Department of Archives and History and Fellow and former president of the Society of American Archivists, was the leading figure in the campaign for promoting the State archive building. It started as a grassroots effort that, essentially, involved the community on both national and local levels. Her strong feelings on the matter is expressed in the following statement: “It was necessary to remind our people of our rich heritage in a State now having a population of nearly 4 million people with an annual income of over a half-billion dollars.”¹⁷⁹ Not only did her strategy involve groups like the Daughters of the American Revolution and the Georgia National Guard, she also got local church groups involved. “Local and State newspapers cooperated by taking advantage of every chance to publicize our archival program and our great need for a building.”¹⁸⁰ It was only after these efforts, the archive building was able to become a reality. Once the motivation was established and the right people got involved, the proper steps were taken to make the building a reality.

“An act of the legislature in 1961 made provision for the building. Groundbreaking ceremonies were held on June 7, 1962. A dream of the people, of Secretary of State Fortson, and of his Archivist became a reality after 15 years of unified campaigning – a case study in perseverance.”¹⁸¹

The public outpour and involvement in the project was a direct result of community involvement from the beginning of the project. Once the plans for the new building was underway, the various organizations and various individuals that had been involved in getting the project off the ground “embraced the idea enthusiastically. Offers poured into Mr. Ben’s office from patriotic organizations and regular citizens

¹⁷⁸ Carmichael, D. W. (2005). Building on the Past: Construction of the New Georgia Archives. *Provenance, Journal of the Society of Georgia Archivists*, 23(1), 10-11.

¹⁷⁹ Bryan, M. G. (1964, October). The Georgia Archives Building - A Case Study in Promotion. *The American Archivist*, 27(4), 499.

¹⁸⁰ Ibid. 500.

¹⁸¹ Ibid. 501.

offering sponsor murals and dioramas...¹⁸² Unfortunately, Mary Givens Bryan died on July 28, 1964 and did not get to see the dedication of the archive building.

The architect of the former Georgia Archive building was A. Thomas Bradbury. He was trained as both an architect and a lawyer. A large portion of his works were associated with government buildings in his native Georgia. Born in Atlanta on April 4, 1902, he studied at Georgia Institute of Technology and received a certificate in 1923.¹⁸³ In his early years, Bradbury worked for a number of different design firms and also worked briefly for Hentz, Adler, and Shutze, an influential Atlanta architecture firm best known for their Beaux-Arts style of architecture, in 1935.¹⁸⁴ In 1943, Bradbury established A. Thomas Bradbury and Associates and the architecture produced by the firm demonstrated an interest in a “progressive functional style of modernism.”¹⁸⁵ Actively involved in the architecture scene in Georgia, Bradbury’s firm worked on a number of projects with academic institutions and government buildings. Bradbury designed the Agriculture Building and Law and Justice Building near the Georgia Capitol, along with buildings on the Georgia Tech campus and the Georgia Mental Health Institute which is now part Emory University.¹⁸⁶ Bradbury was also the lead architect during the renovations of the Georgia State Capitol, which began work in 1957.¹⁸⁷ The former Georgia Archives building, completed in 1965, is considered the firms most minimalist work quoted as “a monumental box-on-pedestal.”¹⁸⁸

Since its opening in 1965, the Georgia Archives building was well utilized and appreciated by the community; however, structural issues began to plague the building. Although it was built to the highest

¹⁸² Carmichael, D. W. (2005). Building on the Past: Construction of the New Georgia Archives. *Provenance, Journal of the Society of Georgia Archivists*, 23(1), 10.

¹⁸³ A. Thomas Bradbury (1902-1992). (n.d.). Retrieved February 08, 2016.

¹⁸⁴ Ibid.

¹⁸⁵ Ibid.

¹⁸⁶ Deal, S. D., Dickey, J. W., & Lewis, C. M. (2015). *Memories of the mansion: The story of Georgia's Governor's Mansion*. Athens, GA: University of Georgia Press. 25.

¹⁸⁷ Ibid. 25.

¹⁸⁸ A. Thomas Bradbury (1902-1992). (n.d.). Retrieved February 08, 2016.

standards of archival technology at its opening, over time the building systems and technology started to deteriorate. Managing building humidity and temperature levels with outdated HVAC systems were one of the challenges, but the most serious issue was the building foundation. According to an engineering study conducted in 1998 by Robinson Associates Consulting Engineers, the building was sinking. The water saturation levels of the soil in conjunction with the disturbances and vibrations from the major highways nearby caused instability, and the southwest corner of the building had settled as much as 4-1/2” and the levels of water saturation of the concrete walls caused a number of structural issues.¹⁸⁹ The sinking caused unanticipated movement of the building resulting in the delamination and instability of the marble panels from the façade, and records indicate massive panels of marble falling off the façade of the building and crashing into the sidewalk.¹⁹⁰ The safety hazards that this situation created can quickly escalate into a life safety issue. In the building’s 30th year of service, the city of Atlanta was going to host the 1996 Summer Olympics. With the safety issues the marble panels posed and the large number of people expected to visit with the festivities of the summer Olympics. The state officials decided to secure the panels with large bolts into the façade.¹⁹¹ With the ongoing issues regarding the building façade and the foundation, a decision was made to move the archive to a new location. This was determined after hearing the estimated costs for repairing the current building came to \$40 million dollars.¹⁹² In April of 2001, a budget increase for a new building was solidified and groundbreaking occurred that same year in October. The archives started its move to a new building in Morrow, GA on February of 2003 and the new archives opened its door on May 3, 2003.¹⁹³ The former Georgia Archives Building has been vacant for the past 13 years.

¹⁸⁹ Carmichael, D. W. (2005). Building on the Past: Construction of the New Georgia Archives. *Provenance, Journal of the Society of Georgia Archivists*, 23(1), 11.

¹⁹⁰ Ibid.

¹⁹¹ Ibid. 12.

¹⁹² Hendricks, G. (2002, April 09). History's records are on the move State Archives going from a crumbling building in Atlanta to a new home in Morrow. *The Atlanta Journal - Constitution*. Retrieved April 05, 2016.

¹⁹³ Carmichael, D. W. (2005). Building on the Past: Construction of the New Georgia Archives. *Provenance, Journal of the Society of Georgia Archivists*, 23(1), 12.

5.2 Building description:

According to the official drawings submitted by the architect's office dated 1962, the Georgia Archives Building utilized thin stone marble panels as cladding for certain areas of the building, as well as marble-faced precast panels. The aesthetic effect that the marble panels give the building is a solid, yet modern look of minimal architecture. The contract drawings detail the building and its construction. The architecture firm leading the project was A. Thomas Bradbury and Associates, Architects and Engineers located on 60 Fifth Street N.E. Atlanta, GA. The structural engineer was Harald Lagerstorm, the mechanical engineers were Ammons, McClure and Cladwell, and the electric engineer was Morris Harrison.¹⁹⁴ Of the architectural drawings there are 7 wall section drawings. Of the seven drawings there is one sheet devoted to the detailing of the exterior marble with the pre-cast wall panels. (A-24.) From these drawings many facts about the construction of the building can be confirmed. First of all, the building is designed with four basement levels and then a ground level. The basement floors are used mostly for parking and the ground floor is where the loading dock and south door entrance is located. Due to the sloping grade of the site, only the west or front façade of the building has an entrance on the first floor. According to the drawings, the building is faced with White Cherokee Marble. The first two floors of the building were spaces for public access. These are the only floors that have windows and the exterior is “surrounded on three sides by a colonnaded podium” that is covered.¹⁹⁵ The building sits on an elevated pre-cast paving surface that extends 25 feet from the exterior walls.¹⁹⁶ The following is a list of the programmed spaces on the first floor: vestibule, auditorium, microfilm reading room, conference room, rare manuscripts, state archivist, offices, receptionist area, Memorial Hall (two stories high), Search Room, and Patriotic Reading & Typing room. These areas have large window openings which allow a large amount of light into the space, with the exception of Memorial Hall which is in the center space.¹⁹⁷

¹⁹⁴ A. Thomas Bradbury and Associates (1962). *Archives and Records Building Contract Drawings*. Georgia State Office Building Authority.

¹⁹⁵ Georgia Dedicates Archives Building. (1965). *History News*, 20, 12th ser., 267. Retrieved March 11, 2016. 267.

¹⁹⁶ A. Thomas Bradbury and Associates (1962). *Archives and Records Building Contract Drawings*. Georgia State Office Building Authority. Drawing A-8 of 47.

¹⁹⁷ *Ibid.*

The second floor is largely devoted to open office spaces. The center section of the floor space is an extension of Memorial Hall from the first floor. As the offices circle the periphery of the floor space, they also receive natural light through the windows that are systematically placed around the entire perimeter of the building. The remaining floors of the building are all enclosed without any windows. The following floors are recessed from the floor dimensions below and the rectangular massing that rises up the remaining floors is 426 feet by 42 feet.¹⁹⁸ The base level of this area is known as the “Loft” and it was two sets of stairwells on the east and west side with two elevators and a freight elevator in between. This Loft area, which is essentially the 3rd floor, is programmed as a storage space. Above this floor, there are 8 levels of vaults. This is where the majority of the collection is housed. The top floor is for mechanical equipment.¹⁹⁹ The overall presence of the building is monolithic in appearance due to the

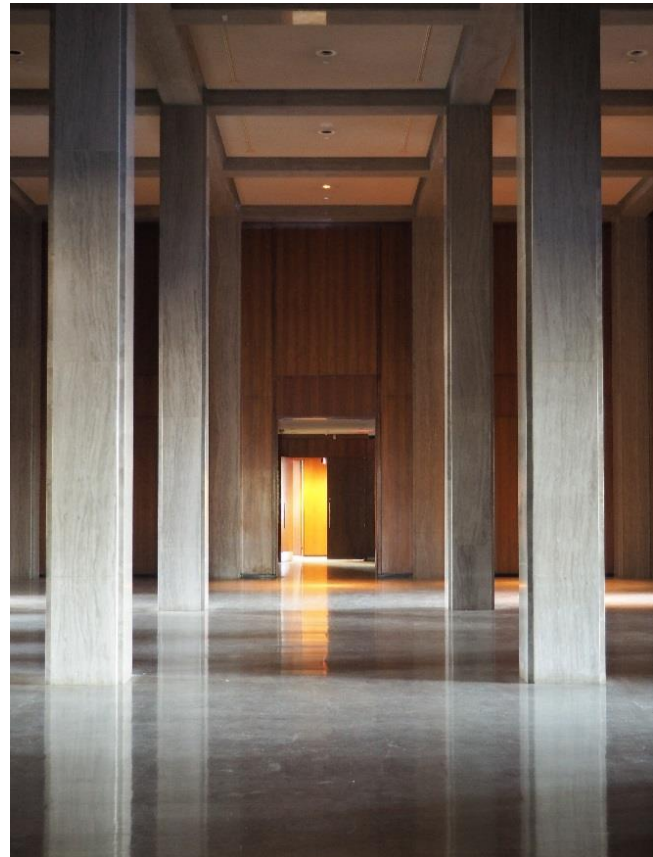


Figure 5.4 Interior – Memorial Hall

marble. The building is void of any classical ornamentation and the light plays off the individual marble panels. The vertical patterns created by the marble gives the building an elongated look and there are vertical marble “fins” that break up the pattern on the facades, which also cast vertical shadows on the surface throughout the day. The light colored marble’s interplay with light is quite elegant. The unique modernist design still stands in contrast to the surrounding context and draws attention to the unassuming visitor.

¹⁹⁸ Ibid. A-10 of 47.

¹⁹⁹ Ibid. A-13 of 47.

5.3 On-site investigation:

A site visit was conducted on March 28, 2016, with the approval from Georgia Building Authority representatives, and lasted from 1:30 pm to 4:00 pm. The visit was divided largely into two parts. The exterior visual assessment was done upon arrival from 1:30 pm to 2:30 pm and from 3:10 pm to 4:00 pm. The interior observations were conducted in the presence of a representative from the Georgia Building Authority due to limited access. This was done during the hours of 2:30 pm to 3:10 pm. Although the main objective of the visit was to assess the exterior conditions of the building, the interior observations helped to gain a better understanding of the overall design of the building, and also provided desired views of exterior conditions that were not possible to achieve when standing outside at ground level. As a method of visual analysis, conditions were documented using digital photography and mapped on elevation drawings. Archival research to obtain a comprehensive understanding of the site and its values was also done. The architectural drawings of plans, elevations and sections were also obtained by the Georgia Building Authority to understand the methods of construction.

Visual assessment: west elevation (front façade along Capitol Ave. SE)-

On the first and second floors the thin stone marble facings on the visible narrow surfaces of the columns are all bolted into the backup. The longer vertical pieces have three bolts (one in the center and the other two on either sides) and the shorter pieces have two bolts (one on either edge). The stone veneer marble facing on the flat surface where the columns meet the low roof is also bolted into the backup. There are three pieces of stone in between each column. The two smaller panels on the edges have two bolts and the center panel has three. These horizontal pieces also



Figure 5.5 Exterior Detail – Bolted Panels

conform to the same spacing as the vertical pieces on the columns. From the shadow castings on the surfaces, it is clear that the individual pieces of marble are bowing and do not meet flush with the pieces that they are butt up against. Although the bolting is following a certain principal, it is apparent that the work was done by hand due to the inconsistent locations of the bolts on the marble. The columns are sheathed with marble panels and the smaller panels are located on the west and east sides, which are bowing and warping significantly. The larger marble panels on the north and south side are not showing those properties. To address the bowing, every single marble panel on the west and east side of the columns are bolted into place. There is also significant soiling of the marble on the east side of the columns. The large marble panels on the exterior walls of the building look stable and show no significant signs of distress or bowing. These pieces of marble are placed in a way to show verticality; however, there are some areas where the jointing material changes from mortar to caulking. Some of the caulking was debonding from the surface of the marble around some of the joints. One of the vertical fins near the ground where it meets the precast paver near the south west end was sheared off. The underside of the extended low roof show signs of soiling and water damage that have caused the stone to change color, particularly at the corner joint on the far south west corner. Metal brackets have been put into place to keep the stone panels on the ceiling stationary and secure. The solid stone façades are bolted inconsistently. Some of the bolted marble pieces look like new replacements due to the lack of conformity in terms of color and marble veining. Each of the bolted panels have three bolts. The pieces with the bolts are also the ones that show signs of warping and bowing. They



Figure 5.6 Exterior Deterioration – Soiling

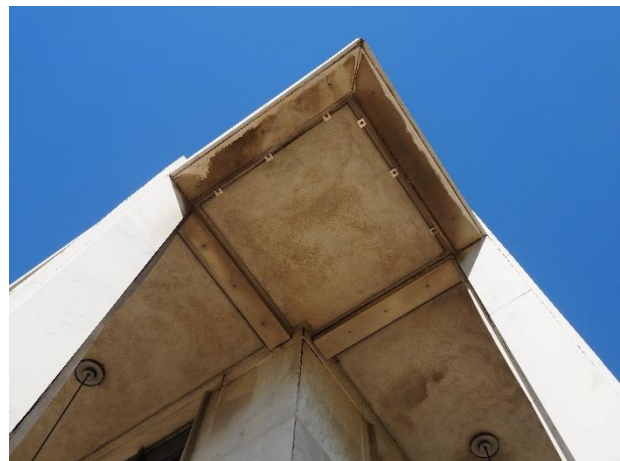


Figure 5.7 Exterior Deterioration – Metal Brackets

are not flush around the edges with the surrounding pieces. Upon closer observation the marble pieces, those with a yellow tint are most likely not replacement panels. They are the panels with small horizontal cracking. There are two areas on the upper right hand side of the façade where there are what looks like brownish circular rust marks on the surface of the replacement marbles. Both are not in the areas around the bolts but slightly to the bottom edges of the pieces. There are a total of 26 window openings on this façade. The aluminum sash seem to be the original sash. Although there is soiling on the vertical marble surrounding the windows, the marble slabs are all in its proper location. The main doors have a decorative aluminum grill element that appears to be clean and in working order. There is a total of 14 hanging light features that are all present. Finally, the base of the building is built up in a granite and has precast concrete pavers that make up the staircase from the sideways up to the platform surrounding the entrance of main entrance. The precast concrete pavers also have planters that surround the edges of the platform made of



Figure 5.8 Exterior Deterioration – Horizontal Cracking



Figure 5.9 Exterior Deterioration – Moisture in Foundation

the same precast concrete material as the pavers. The granite touching the ground looks saturated with water. In the far north corner of the granite base, the joints of the granite pieces are separating from one another. Not only is the caulking material failing, the movement of the stones is causing the gap to widen with some gaps measured at 1-1/2”.

Visual assessment: north elevation (façade along Memorial Dr. SE)- Like the conditions on the west elevation, the north elevation also shows repair work done on the main marble facing material. The side entrance is covered in a lighter granite. Visually the granite sets the entrance apart from the main building and above the entry are the precast planters. Built-in gutter fixtures allow for the water to run down the surface of the granite into the tree planters below. As see on the west elevation, the marble facings that bulge out are all bolted back into the backup material. The horizontal marble facings on the lower roof are heavily soiled with a black streaks. In terms of the light fixtures, one of the seven hanging light fixtures is missing and the windows all seem to retain the original aluminum sash. When compared to the west or front façade of the building, there are less horizontal cracks or fractures on the stone. The base granite also demonstrates conditions of moisture saturation.

Visual assessment: east elevation (façade along Fraser St. SE)-

The east elevation is divided into a north and south section due to the extruding interior of the Search Room. When observed from the second level interior, sections of the marble parapet are lifting out of place. The joint repairs done in silicone caulking is debonding from the surface. The overall elevation has patches of replacement marble panels throughout the whole façade. The deterioration or failure of the façade panels do not seem to follow any sort of definite pattern, and the areas with replacement panels seem sporadic. It is common, however, for a cluster of panels to be replaced as opposed to just a single panel. One of the more noticeable conditions on this elevation is the missing panel on the south east end of the facade. This missing piece appears to be a marble fin that deviates from the flat panel replacements. The void indicates that the whole piece, including the precast concrete, has fallen out but the piece above the missing piece is still in place. To the right of this missing piece there is another missing piece, but this one is missing a portion of the thin stone marble and the precast backup is still in place. The marble piece has split horizontally across the middle. This particular piece does have a bolt located in the bottom piece which is still attached to the precast backup. Around the edges towards the left of the façade, there are two areas where there are half-moon shaped spalls. At the very top of this façade in the far left hand corner a missing

corner piece was replaced and then bolted into the backup. All of the edge panels along the horizontal piece of the lower roof is bolted and the vertical pieces of the columns are also bolted in from bowing outwards. These same edge pieces around the extruding interior space has also been bolted. The horizontal marble elements that face the top of roof surfaces show soiling patterns in the form of back streak



Figure 5.10 Exterior Deterioration – Missing Marble Fin and Bolting Repairs

marks down the stone faces. Of the three hanging light features hanging on the north east façade, only one remains. The south east façade has two of the three hanging light features hanging in place. The granite base of the building on this elevation is also saturated with water, which could be seen even from a distance.

Visual assessment: south elevation (façade along Ralph David Abernathy Fwy.)-

The south façade has limited visual access due to the surrounding highways and the immediate areas being fenced off. This elevation does not appear to have any major losses or missing full panels; however, there seems to be a chipped piece of marble on the upper east side of the south façade. There was a lot of sunlight casted on this side of the façade during the time of the visit making it difficult to identify any fractures or cracks on the surface of the marble from the ground level. Due to a recent storm that plagued the area, high winds caused one of the hanging light fixtures to shatter after crashing into the wall. Another observation around this area are the remaining bullet shells on the ground. When briefly speaking with one of the representatives from Georgia Building Authority, it was confirmed that there have been instances where people are shooting at the empty building's white marble façade. This may explain the small marble pieces

found all along the building. The bowing of the marble on the inner columns is detected along with the moisture saturation and is clearly visible at the base of the building where the material is granite.

Visual assessment: fountains on west elevation (façade along Capitol Avenue, SE)-

The two fountains near the main entrance of the building are a part of the original design. The failing caulking and mortar between the joints of the marble has caused the stones to pull apart from one another. The stress in movement has also chipped corner of the marble off and exposed interior shims and shelf angles that are now open to moisture and additional corrosion. Some of the openings measured at nearly 1-3/4" in height and 4" in length. The deteriorating caulking is cracking and flaking off allowing moisture to penetrate and corrode the structural systems. The marble cladding that makes up the fountains have mechanical damage as well as serious deterioration leading to delamination and sugaring of the marble. The grains are visibly loose and the stone panel no longer meet with flush edges.



Figure 5.11 Exterior Deterioration –
Moisture in Foundation

Summary of visual assessment-

In summary the visual conditions of the façade, in regards to the marble cladding, vary tremendously; however, there are signs of major repairs to the marble veneer-faced precast concrete panels on all elevations. The deteriorating of the marble veneer-faced precast concrete cladding and the penetration of moisture by means of capillary uptake at the base of the structure are major concerns. The observations are generalized and placed in the following conditions of *good*, *fair* and *poor*. *Good* indicates that current conditions are acceptable and does not need additional intervention. *Fair* indicates the current conditions are acceptable but there are minor improvements or interventions that may be required to mitigate any further deterioration. *Poor* indicates the current conditions requiring immediate intervention for stabilizing

and addressing a major issue. This summary is to get an overall understanding of the exterior conditions specifically related to the panels. This should be followed up by a series of testing to determine the actual performance of the materials.

Good Condition:

- The overall performance of the windows and doors seem to be in good condition. The aluminum sash and door grilles are well kept, and the marble that surrounds the openings are well kept
- First and Second floor exterior wall marble facing is in good condition without any visual evidence of bowing or spalling of the stone

Fair Condition:

- Precast concrete planters and pavers need some patch work in certain areas, but overall it is in fair condition
- Soiling of the marble surfaces, especially concentrated on the tops of soffits and horizontal panels

Poor Condition:

- Severe bowing of the marble panels around the columns located at the base of the building
- Missing and cracked panels that have detached from the backup material on the east elevations.
- Intense flexural cracks on the flat marble panels located on the façade of the building, especially noticeable on the west elevation.
- Open joints at granite base and shifting granite slabs.
- Missing mortar in joints and cracking silicone caulking in the mortar joints
- Cracking and deteriorating stone panels under the ceiling of the lower roof due to water infiltration
- Excessive moisture absorption at base of the building
- Sugaring and grain loss of marble panels in certain areas such as the underside of the lower roof and the fountains
- Soiling of marble and granite surfaces
- Biological growth on joints and granite base surfaces

The visual analysis conducted on site confirmed the conditions of the actual marble panels as they stand.

The missing joints and the wet foundation conditions need to be addressed immediately. The marble has been stabilized in most areas, but the repairs take little to no consideration of aesthetic integrity or design intent into account.

5.4 Conditions assessment of thin stone veneer-faced precast concrete:

Visually, the marble on the building gives it a massive presence and an image of stability and significance.

The two lower floors, with the use of large window openings, gives the building light and accessibility on

a human scale. According to the archival drawings for the building, the White Cherokee Marble is utilized in a number of different ways. The marble is: 1. set as veneer panels of 3” thick and tied back into a brick backup and 2. Used as a facing material of 7/8” thickness faced onto precast panels with an average thickness of 4’-2”.²⁰⁰ The section drawings illustrate the marble veneer-faced precast in three different heights: 17’- 4-3/4”, 16’-5-8”, 18’- 8-1/4”.²⁰¹ The marble facings on the precast is attached in long linear strips that are tightly butted up against each other. Additionally, the marble is also used to sheath the columns and used as pilaster caps and parapets.²⁰² Failure of the cladding material is detected on all areas of the façade.

Marble veneered-faced precast concrete flat panels-



Figure 5.12 Exterior Deterioration – Delamination of Marble from Concrete

The section details of the thin marble at 7/8” faced on precast concrete does not indicate the use of mechanical anchors; however, the site photographs of an area on the east façade shows a delaminated piece of marble from the initial precast with two holes located on the left hand side. It is difficult to determine if the holes are, in fact, for mechanical anchors; however, the

delaminating marble is a serious concern. A large majority of the marble failures is the thin marble stone veneer-faced precast concrete flat panels. As mentioned in the visual assessment of the building, this failure of the marble is seen on all four facades of the building. When inspecting the surfaces of the marble, the shadows indicate a twisting or bowing of the marble faces that create a gap between the two materials that can result in delamination. Bowing conditions, especially when it comes to marble, is often due to hysteresis.

²⁰⁰ A. Thomas Bradbury and Associates (1962). *Archives and Records Building Contract Drawings*. Georgia State Office Building Authority. Drawing A-24 of 47.

²⁰¹ Ibid. A-22 of 47.

²⁰² Ibid.

The building owner decided to address the issue by bolting any loose or bowing panels with white color bolts. This decision addressed the danger of falling marble pieces; however, did very little to address or understand why the marble was delaminating from the precast in the first place. Also, looking at the variety of colors and striations of the bolted marble, it makes one question if these pieces are replacements. On top of this issue, the flexural cracking of the marble is another concern. Flexural cracks, in this instance, can be caused by the materials relationship with the backing material of different thermal expansion qualities or hysteresis; however, the reasons for the horizontal cracks cannot be confirmed without of testing. There may be a correlation between water absorption and freeze-thaw that is causing the observed conditions for this building. The following is not an example of marble faced precast, however, marble veneers are located on the interior areas underneath the covered ceiling demonstrated severe bowing. Also, along the covered ceiling below the low roof, most of the veneer pieces have been bracketed and bolted into place; however, there are a number of pieces that have either spalled, cracked, or gone missing. Overall, the damage is quite extensive and visible to the attentive eye.

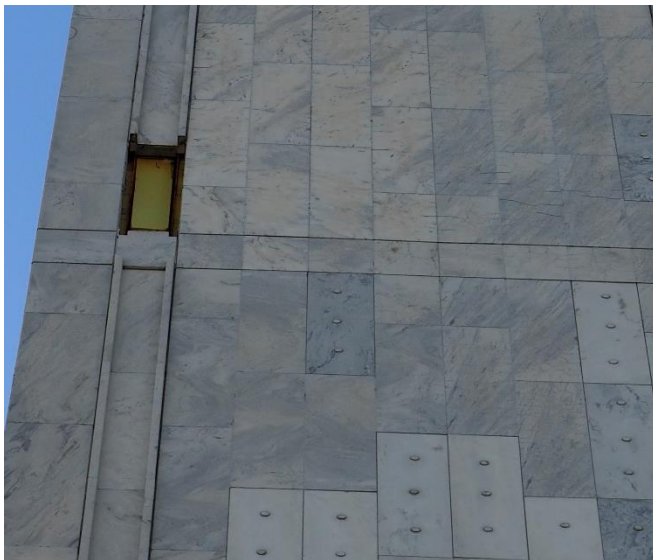


Figure 5.13 Exterior Deterioration – Exposed Façade Systems

Marble veneer-faced precast concrete fins-

The marble fins are a façade detail located between the flat panels, and are also a major source of concern. On the east façade, a fin is missing, therefore, exposing a weak spot for the system. According to the archival drawings, these fins were supposed to be three, 2” thick, solid marble pieces anchored into place with shelf angles at two separate points.²⁰³ The actual execution of the marble fins do not conform to

²⁰³ Ibid.

these specifications. The fin above the void reveals a thin marble veneer-faced precast piece supported by shelf angles. This visual observation does not explain why the change occurred from the original drawings; however, it is interesting to note that this decision was made after the original design, and possibly during the construction process. The reason for the failure of the missing fin piece is hard to deduce from visual analysis. Additional tests and construction documents need to be examined for understanding if this is a design failure or a material performance issue.

Marble veneered exterior columns-

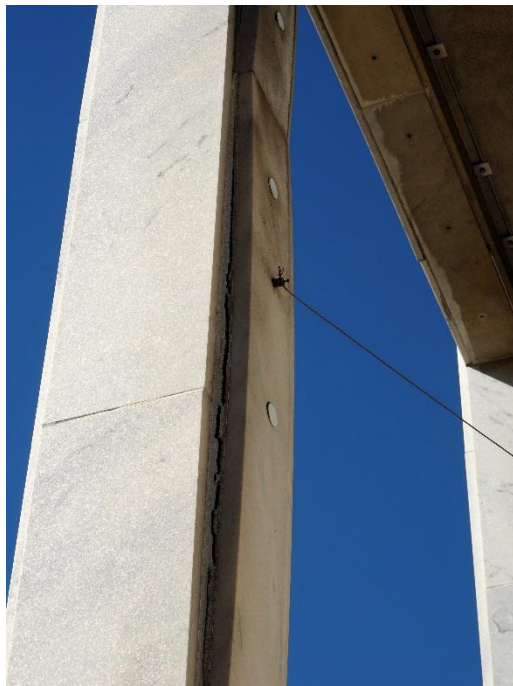


Figure 5.14 Bowing Marble Panel on Column

Another failure of the marble is detected in the sheathing of 39 exterior columns. The column details on sheet A-27 of 47 illustrates the structural I-beam encapsulated in concrete. This is then covered with 2" thick marble veneer anchored into place with dovetail anchors. Special caulking has been specified for the joints, but the two veneers that span over the shorter dimension of the column has a void space that is 1-1/4". Even though the anchors are specified in the drawings as "cast into column" the design required it to stretch out over a longer void compared to the other adjacent side. During the visual analysis, it was very clear that the marble veneer with the wider void was performing poorly. In most places, the

marble was bowing away from the column. All of the marble panels that bowed around the column were bolted, but even with this treatment the marble veneers continue to bow.

5.5 Future prospects:

After the archives moved to its new location in Morrow, the building has remained vacant and without any permanent users. In 2010 there was a Bid opened for the demolition of the building with the following conditions outlined for the work:

“The building is approximately 575,000 square feet, with 4 levels below the Capital Avenue level and 12 levels above Capitol Avenue. It is a concrete frame building with most areas clad in precast concrete panels with a stone finish. Included in the project scope is the abatement of asbestos containing materials in and outside the building, shoring to support adjacent streets and site elements, demolition of the building and removal of demolished materials from the side, disconnection and capping of utilities, grading and fill, protection of some existing landscape materials, traffic controls during demolition, site stormwater measures, site stabilization and security measure to be left in place, and all necessary permitting fees, and temporary utility costs. An existing surface parking lot on the north end of the site will be retained and must remain in service during demolition and after. The sidewalk on Capitol Ave will be demolished, but a new 15 foot wide sidewalk is included in the scope. Existing street light standards and fixtures on Capitol Ave will be salvaged and reinstalled as part of the project. A new concrete driveway to the existing parking and a small amount of parking striping is included in the work.”²⁰⁴

Plans were in motion for the demolition since 2010; however, the real estate collapse in the area prevented any action to take place by the state, which has preserved the site. The bare minimum has been done to keep the building in a stable condition. In the August 2010 edition of Docomomo’s E-News Briefs, there was mention of the former Georgia Archives Building and the RFQ issued for its demolition. It stated the building being “a favorite of many Chapter members” and “an important example of Modern design in the State of Georgia from this period...”²⁰⁵ Since 2011 the building was listed on Atlanta’s Most Endangered Historic Places published by the Atlanta Preservation Center, which is the city’s private non-profit preservation organization.²⁰⁶ According to an article published in The Atlanta Journal – Constitution on

²⁰⁴ Georgia Archives Building. (2010, December 21). Retrieved February 25, 2016.

²⁰⁵ Little, T. (2010, August). August 2010 E-News Brief. Retrieved April 01, 2016.

²⁰⁶ Atlanta's Most Endangered Historic Places. (2011). Retrieved February 5, 2016.

February 18, 2011, the state had raised \$3 million dollars for the demolition of the building, which was estimated to cost of \$5 million dollars.²⁰⁷ The former Georgia Archives Building is just one of many vacant properties that the city Atlanta is responsible for. Although they are vacant properties, maintenance is still required. One way the city has offset these costs is to open up the locations for movie shoots. By February of 2011, the former Archives building generated more than \$250,000 from these types of productions.²⁰⁸ One of the more recent appearances of the building was in the 2015 movie “Ant-Man”.²⁰⁹ Revenue is being generated from the building; however, these methods do not address the fundamental faults of the building and they are not permanent uses of the building.

The most recent developments surrounding the former archive building is directly tied to the new judicial complex for Atlanta. It has been speculated by multiple sources that this project will produce the “most expensive buildings in state history” and is projected to cost up to \$115 million dollars.²¹⁰ The site for this project is where the former archives building stands. An article from January 14, 2016 confirmed two firms as the architect for the new complex, Atlanta based Stevens & Wilkinson and New York based Robert A. M. Stern.²¹¹ Once praised as the “solitary splendor”²¹² the former archive building is now perceived as “the windowless structure that resembles a concrete block.”²¹³ The future prospects for the former Georgia Archives Building, which has been at 330 Capitol Avenue for the past 51 years, looks quite bleak.²¹⁴ The marble veneer-faced precast concrete panel building that brought a whole community together

²⁰⁷ Stafford, L. (2011, February 18). State-owned building idle amid slump: As it waits for economic rebound, Georgia stuck with vacant properties. *The Atlanta Journal - Constitution*.

²⁰⁸ Ibid.

²⁰⁹ Kahn, M. (2015, October 22). Marble 'Ice Cube' of 'Ant-Man' Fame to Fall for New Court? Retrieved March 25, 2016.

²¹⁰ Salzer, J. (2014, May 15). Low-flying courts building could be state's most expensive. Retrieved April 01, 2016.

²¹¹ Kelley, C. (2016, January 14). News Briefs: New judicial complex; Buckhead Atlanta loses eatery; mobility concierge - Atlanta INtown Paper. Retrieved April 01, 2016.

²¹² Carmichael, D. W. (2005). Building on the Past: Construction of the New Georgia Archives. *Provenance, Journal of the Society of Georgia Archivists*, 23(1), 10.

²¹³ Kelley, C. (2016, January 14). News Briefs: New judicial complex; Buckhead Atlanta loses eatery; mobility concierge - Atlanta INtown Paper. Retrieved April 01, 2016.

²¹⁴ The was demolition once delayed due to budget shortages and market conditions, the demolition of the 330 Capitol Avenue has once again been approved and the Bid process for RFQ has just opened on April 4, 2016 with a deadline

is now a dilapidating building that is too expensive to repair. The innovative and experimental use of marble in the form of marble faced precast panel cladding to create the look of a monolithic structure is a technology that no longer sparks interest and the building awaits its demolition.

The former Georgia Archives Building is an important case study of how *thin stone veneer-faced precast concrete panels* was first used, maintained, and deteriorated. Although the foundational issues with stability and moisture most likely impacted the speed and method of material deterioration, this case study serves as a valuable representation of a wide range issues specifically pertaining to marble thin stone veneer-faced precast concrete panels. This composite cladding material allowed the architect to design for a certain type of aesthetic that gave the building a unique quality. A closer examination and testing of the conditions will provide an accurate assessment regarding the modes of failure; however, the site visit confirmed the cladding material's poor performance and an even more appalling method of repair. The bolting and strapping of the façade cladding is a temporary stabilization, not one that addresses the failure. A material that was praised and widely used for its economic advantages became an economic burden to repair.

date of May 3, 2016 at 2:00 pm. The RFQ is for the new Judicial Complex whose site will be the former State Archives Building at 330 Capitol Avenue on the northwest corner.

Chapter 6. Conclusion

Unprecedented change best describes the field of building in the twentieth century. New theory and experimentation was supported by the advancements of industrialization. The twentieth century was a unique time period where building innovation was encouraged and even more quickly implemented by the industries to keep up with market demands. The building industry of old and new were competing with one another, and the collaboration between the architect and the engineer became less frequent. Even though the building industry produced some of their most progressive projects during this time, it is the evolution of the building materials and systems that enables the field to change. This research focused on a specific new building material, *thin stone veneer-faced precast concrete*, and followed its development over time to understand the larger context of the field. Towards the beginning of this process, a couple of questions were asked: 1.) what and how did the design change over time; 2.) what kind of issues and failures came about; 3.) what measures were taken to address the challenges; and 4.) what changes were made to mitigate future failures? The research methodology called for reviewing industry literature and visual analysis of existing case studies.

6.1 Research Findings:

When new building materials are launched into the market, there is a set process/method of promotional marketing to engage potential clients. New materials have the challenge of proving performance, credibility, and economic advantage in order to compete in the existing market. This information is communicated by standardized testing results and case studies of the product already being used. In order to study the development of a product, looking through the technical literature of the related industries can provide an overall picture. The disadvantage of using industry literature for researching experimental trends and design development is technical literature, as a whole, tend to publish practices that are already accepted in the field. It will not include any information that is experimental by nature or debatable. The other disadvantage

of such a review is in the generalization of how the material is treated in the literature; therefore, it will only provide the bare/basic and minimum requirements and avoids complicated design issues. The advantage/insights from studying industry literature can only be identified and realized if it is approached in a comprehensive manner that encompasses a good majority of the literature. Changes will become apparent if the literature is studied in sequence and in conjunction with other relevant information.

In the case of the composite cladding material *stone veneer-faced precast concrete panels*, the market and client demand for economic advantage was present; however, standardized testing and issues of credibility were still in its infancy when it was first used. Therefore, the technical literature in the form of manuals and handbooks were the only sources that records the development of this composite material from the 1960s in a comprehensive manner. And because it is a composite material, both the stone and precast industries produced their own manuals and handbooks that best represented their industry's position. These writings may have started off as independent sources, but by the 1980s they start to complement and reference one another in their own literature. The stone industry produced some of the first literature relevant to thin stone veneer as a standalone material in the late 1940s. The precast concrete industry did not release an official handbook that addresses stone veneer finishes until the middle of the 1970s. The most intriguing findings from the literature of both MIA and PCI can be summarized as follows:

- Marble Institute of America's (MIA)'s early 1961 literature documented the use of "marble faced precast reinforced concrete building panels" and specified a protective coating with a bonding agent between the marble and the precast concrete. MIA's 1st edition of *Dimension Stone Design Manual* (1971) also mentions a resilient bonding agent or parge coat to be applied between the stone and the precast concrete panel. This practice changes in MIA's 3rd edition (1991) literature where a bond-breaker now replaces the bonding agent that was specified before.
- The use of bond-breakers is first mentioned in 1977 through PCI's literature, *PCI Manual for Structural Design of Architectural Precast Concrete*, and PCI's 3rd edition Handbook in 1985.

- The MIA's *Dimension Stone Manual 1st edition (1971)* mentions "marble faced precast panels" and goes into detailed description regarding the material, then the next two editions (1983, 1985) leave a note directing readers to PCI for any information. It isn't until 1991 when the Stone Manual goes into descriptive mention of the material.
- PCI's handbook makes changes to the minimum thickness of stone used as a veneer facing material for precast concrete panels in the 5th edition (1999): marble 7/8" to 1", travertine 3/4" to 1-1/4", granite 3/4" to 1-1/4", and limestone 1-1/4" to 1-3/4".
- PCI introduces the use of epoxy for filling drilled holes in the stone in the 4th edition (1992) of the handbook. In the most recent 7th edition (2010) it references the use of stone flour or fines as a filler for the epoxy to reduce coefficient of thermal expansion.

The marble industry's shift from bonding the stone to the precast concrete to the use of bondbreakers is one of the most interesting findings after review the technical literature. The use of bondbreakers is now a standard procedure to keep the stone and precast concrete from adhering and bonding to prevent cracking, breaking, and eventual delamination of stone. According to just the technical literature reviewed in this study, this change occurred sometime between the time frame of 1971 and 1977 because MIA's 1971 manual still mentions a bonding agent and PCI's 1977 literature mentions the use of bondbreakers. The trigger for this change is not clear, however, this is a significant change in the design of the composite cladding material that need further study.

The visited case studies all utilized *thin marble veneer faced precast concrete* at a time when the material was just being introduced to the market. In terms of climate, all case studies are located in areas that experience fluctuating temperatures; however, the case in New York is more likely to have the more extreme temperature differences. Three of the four cases used white marble as a facing material and the last remaining case study used thin travertine. All cases required extensive repairs and interventions on the composite cladding material. Of the four case studies, bolting the panels into the back-up was the most common intervention. Bolting is considered to be more a method of temporary stabilization. In some cases, metal straps were also used. The types of failures that were recorded and/or observed were spalling of stone,

delamination of stone from precast concrete, flexural cracking on surface of stone, bowing stone veneers, and missing panels. Only the Juilliard School's travertine did not have bolts in its façade cladding, which means full panel replacements were done. In response to these types of failures and issues, the literature does warn against the bowing qualities of stone and the cracking of stone when it is bonded to the concrete back-up without a bond-breaker.

6.2 Implications for Preservation:

For preserving mid-century Modern architecture, which usually consist of innovative building systems and materials, the preservation concepts of value and authenticity needs to be contextualized to the innovative components. The façade evaluations that take place usually address the failures and deterioration of the composite material. From an engineering standpoint, repairs are done with the main purpose of preventing life-threatening hazards and/or structural failure. The following types of façade repairs were observed in the case studies: complete removal and new replacement of deteriorated panels, mechanically stabilization of panels, re-cladding of entire façade with new material, and the temporary sealing of cracks and joints with caulking and other sealants. Due to the inherent flaws in design caused by things like cutting the marble stone too thin for exterior use, buildings that utilized early forms of *marble thin stone veneer-faced precast concrete* experienced a range of failures as a cladding material.

Traditionally, preservation asks the question of authenticity regarding the built fabric; however, this concept may not be appropriate for these examples. As aforementioned, the case studies were a selection of buildings ranging in historical significance. The façade repairs on historically significant projects tend to value the aesthetic qualities as a priority. This, among other factors such as life safety, direct the design and repair decisions, and as a result, significant buildings tend to favor complete replacement of the fabric. Buildings that lack the historical value tend to retain the original fabric because the methods of repair focus on structural stability. This was observed through the case studies where panels were bolted,

strapped or temporarily sealed and stabilized. Another fact that needs to be taken into consideration when repair decisions are made is the rate of deterioration for the actual material. Building materials all have a life span, and when stone is cut thin, it is now essentially a new material. Conservator and/or preservationist need to be aware of these conditions before specifying a repair. The *thin stone veneer-faced precast concrete* as a building material was designed for a certain aesthetic quality and performance. The preservation question may need to be directed back to this fact and the role of the material technology and its preservation. The set of preservation questions that pertain to architecture from this time needs to be established in a new set of principles and concepts that embrace the significance of the building material.

6.3 Recommendations for Further Research:

The ultimate question is how did this product come into existence? This was the underlying question throughout the whole course of this research. There is no simple answer because it was a complex process. By looking at the literature and reviewing numerous articles related to *thin stone veneer-faced precast concrete*, one can conclude that the strongest selling point for the material was achieving the aesthetic look desired at a lower cost. Every aspect of the design was to save money: thinner stone, precast concrete prefabrication, and fast enclosure time during construction. According to the literature, the stone industry was desperately trying to find a way to fabricate stone to fit the building needs of that era. Thin building envelopes and higher structures required a new type of cladding material that was durable, light-weight, and fabricated with precision. According to the article by McDaniel, who was representing the National Association of Marble Producers at the time, the stone industry approached the precast industry first to create a new cladding material that had “latitude and flexibility of design with marble.”²¹⁵ Throughout the research, these are some questions that come up as topics for further study:

²¹⁵ McDaniel, W. B. (1967). Marble-Faced Precast Panels. *PCI Journal*, 12(4), 30.

- What were the key factors that implemented the use of bond-breakers for the stone industry, particularly the marble industry?
- With the rise of new composite building materials how did industry collaboration impact the design quality of new products?

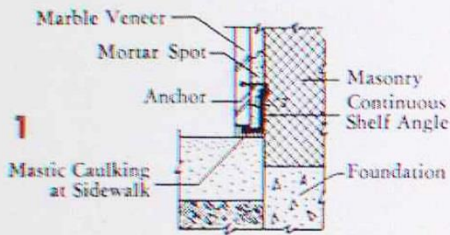
Design decisions are made for a number of reasons, but when it comes down to the building materials, it is a slow process that develops over time. In conclusion, the advancements of the building industry start with the building materials. *Thin stone veneer-faced precast concrete* was a material designed and engineered to fulfill convenience and aesthetic in the 1960s. The design, development, and use of these types of building materials and systems is an important commentary on architecture in the United States during the 1970s and 1980s.

APPENDIX A: Exterior Wall Section

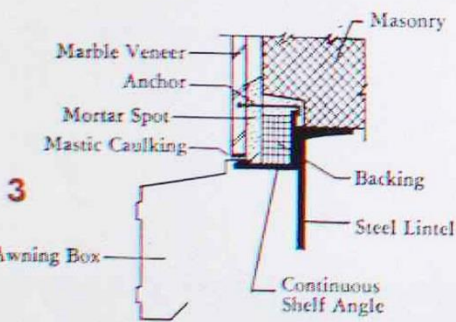
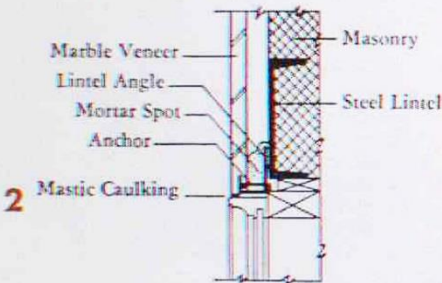
**exterior
marble
veneer**

SUPPORT

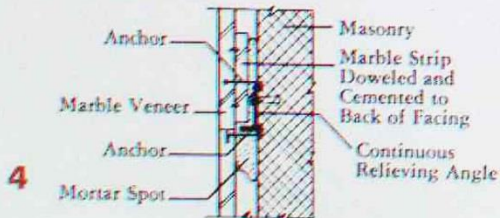
At Sidewalk



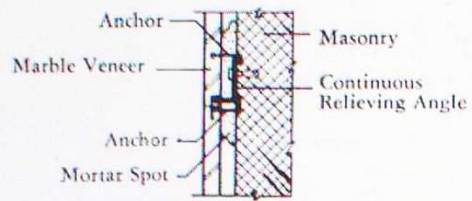
Above Openings



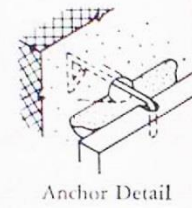
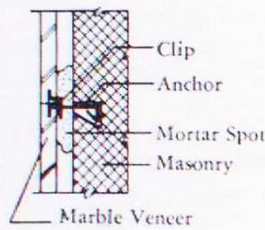
Ashlar Areas



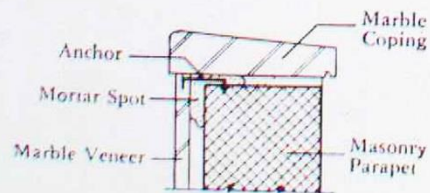
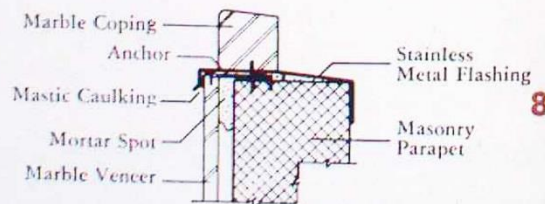
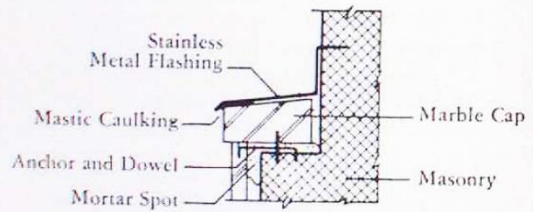
Ashlar Areas (Continued)



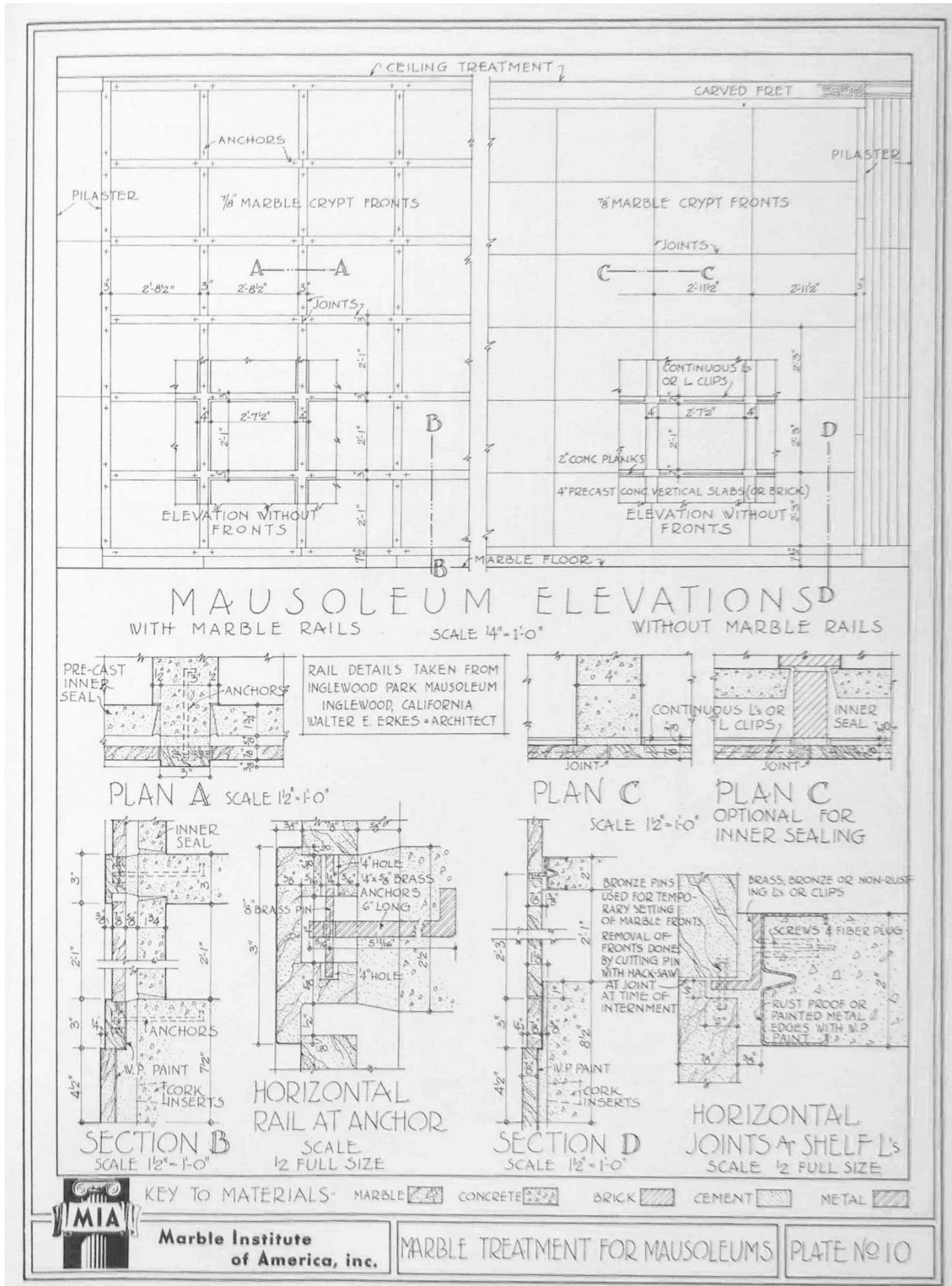
ANCHORAGE



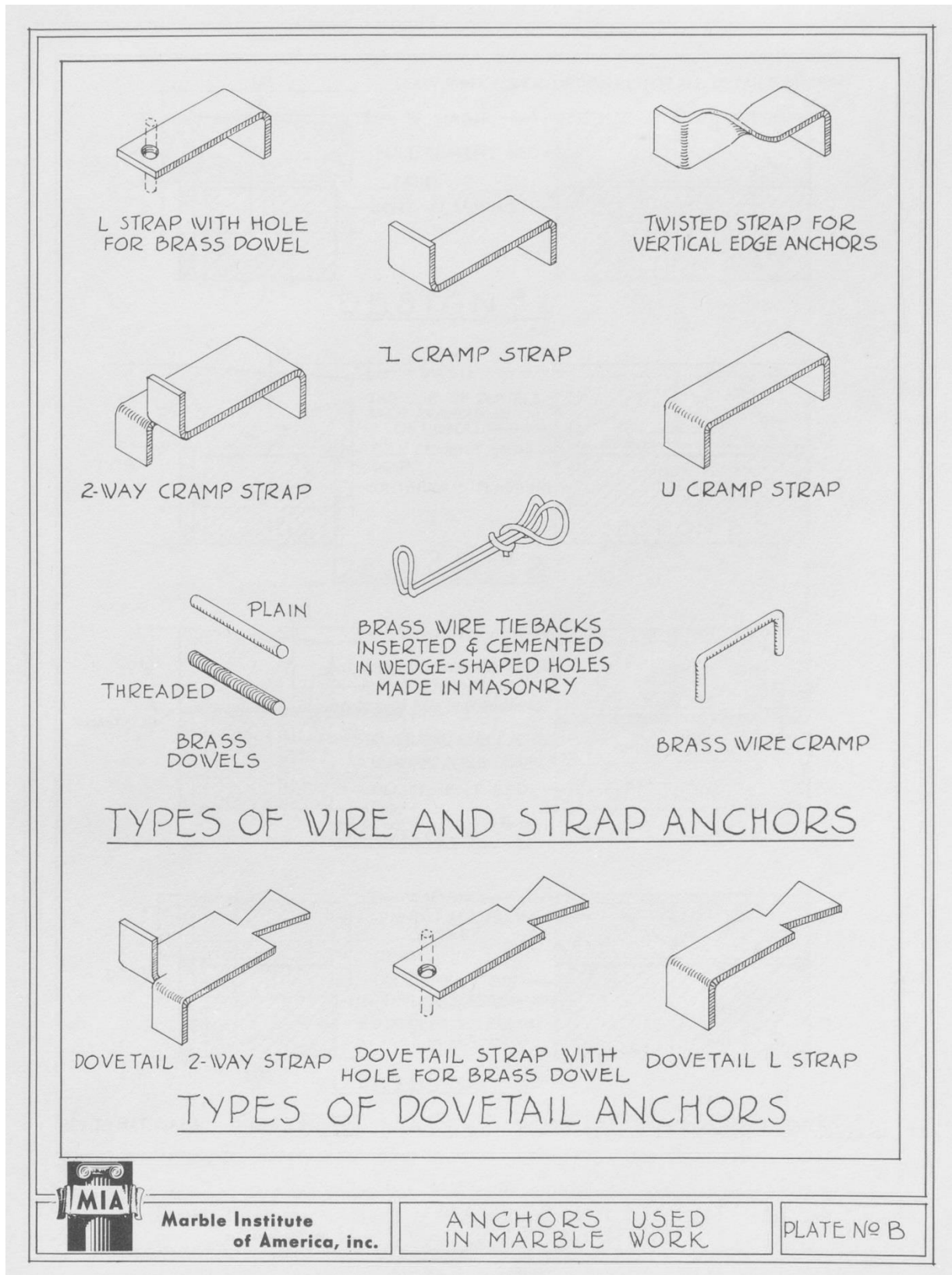
PROTECTION



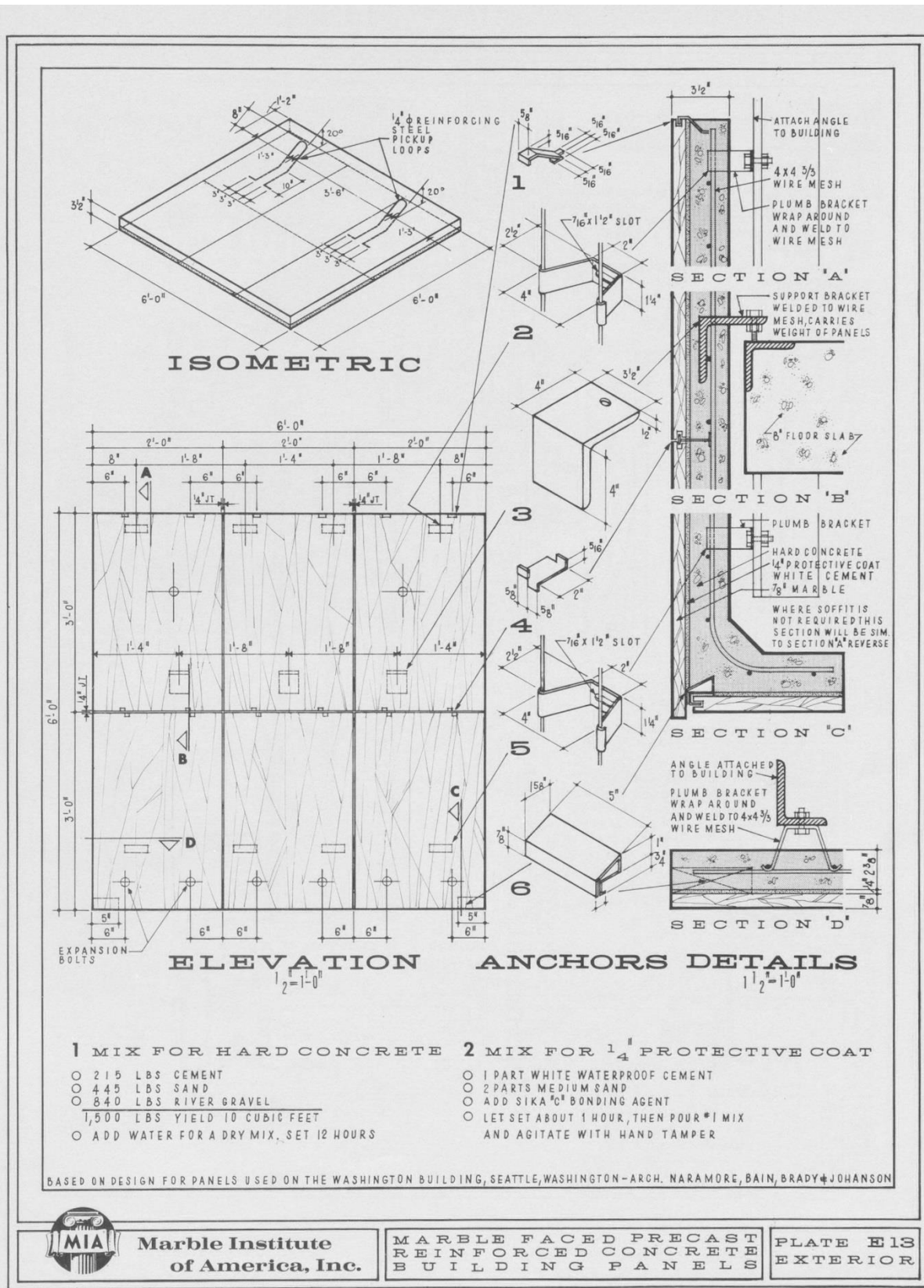
APPENDIX B: Plate 10 – Marble Treatment for Mausoleums



APPENDIX C: Plate NO. B – Anchors Used in Marble Work



APPENDIX D: Plate E13 Exterior – Marble Faced Precast Reinforced Concrete Building Panels



APPENDIX E: PCI- Architectural Precast Concrete Design Manuals 1st ed., 2nd ed., 3rd ed.

PCI Architectural Precast Concrete Design Manual					
Section	1st Edition - 1973	Section	2nd Edition - 1989	Section	3rd Edition - 2007
	<ul style="list-style-type: none"> - Use of bondbreaker to separate veneer and backing - Full scale mock-up to understand properties 		<ul style="list-style-type: none"> - Addresses all details regarding stone veneer finishing as seen in the handbook - Focus on preventing bowing of stone 		<ul style="list-style-type: none"> - Updated veneer thicknesses for marble, travertine, granite and Indiana limestone - Solutions to watertightness due to bondbreaker - Similar to latest handbook
1.3 (Advantages of Architectural Precast Concrete)	<p>Principle Advantages:</p> <ul style="list-style-type: none"> - Design: design freedom, quality control, plasticity - Functional: structural capabilities, efficient building envelope, acoustical insulation, thermal properties, durability, low maintenance, fire resistance, solar protection - Construction site: economical erection, trade scheduling, time saving, low noise level - Economics 	1.3 (Advantages of Architectural Precast Concrete)	<p>Principle Advantages:</p> <ul style="list-style-type: none"> - Design: design freedom, quality control, plasticity - Functional: structural capabilities, efficient building envelope, acoustical insulation, thermal properties, durability, little to no maintenance, fire resistance - Construction site: economical erection, rapid enclosure, trade scheduling, low noise level, elimination of formwork - Economics 	1.4 (Benefits & Advantages of Architectural Precast Concrete)	<ul style="list-style-type: none"> - Durability, Aesthetics, Commitment to quality, life cycle cost, initial cost, energy efficiency, other inherent benefits, environment impact
3.4.2 (Textures)	<p>Finishes with materials other than normal concrete aggregates - natural stone</p> <ul style="list-style-type: none"> - Architect should verify compatibility of different materials with concrete. Differences due to temperature, humidity range, chemical reaction - Consideration of bond-breaker when significant volume change - Emphasis on samples and mock-up to test and investigate durability and performance - Close attention to bowing of precast unit with cut stone facing - Cracking in cut stone may occur if fastening details force the stone to bow with concrete - Control shrinkage of concrete to control bowing - Full scale mock-up to measure bowing and fastening behavior - Great variety of veneer-faced precast panels performing well, but some problems 				
3.4.3 (Cost of Finishes)	<ul style="list-style-type: none"> - Individual plants may price finishes differently <p>Groups of Finishes:</p> <ol style="list-style-type: none"> 1. Smooth 2. Aggregates exposed by retarders or water wash, Form liners, Sandblasting 3. Aggregates exposed by acid-etching, Bushhammering, Hammered ribs (fractured fins) finishes, Ceramic or tile facing 4. Honing, Polishing, Cut stone (veneer) facing 	3.5.1 (Finishes-general)	<ul style="list-style-type: none"> - Individual plants may price finishes differently <p>Groups of Finishes:</p> <ol style="list-style-type: none"> 1. Smooth 2. Aggregates exposed by retarders or water wash, Form 	3.5.1 (Finishes-general)	<ul style="list-style-type: none"> - Surface finishes depend on properly fabricated molds and understanding the capabilities and limitations of mold production

		3.5.1 (Finishes-general)	liners, Sandblasting 3. Aggregates exposed by acid-etching, Bushhammering, Hammered ribs (fractured fins) finishes, Ceramic or tile facing 4. Honing, Polishing, Cut stone (veneer) facing		
		3.5.12 (Stone Veneer-faced precast concrete panels)	Advantages: 1. Veneer stock can be used in thin sections because of short spans between anchoring points 2. Multiplane units (eg. Column covers, spandrels with integral soffit, etc) 3. Erection is faster and more economical than handset construction 4. Span column to column, thereby reducing floor edge loading	3.5.12 (Stone Veneer-faced precast concrete panels)	Advantages: 1. Veneer stock can be used in thin sections because of short spans between anchoring points 2. Multiplane units (eg. Column covers, spandrels with integral soffit, etc) 3. Erection is faster and more economical than handset construction 4. Span column to column, thereby reducing floor edge loading and eliminating elaborate temporary scaffolding
			Control bowing/warping: - Veneered panels are more susceptible to bowing than all-concrete units - Differential shrinkage of the concrete and stone veneer can cause outward bowing - Bowing caused by differences in the coefficients of expansion of the stone and concrete - Thinner stone is less rigid to resist bowing - If thickness is sufficient, two layers of reinforcement used to reduce bowing - Reinforcing trusses to add stiffness - Concrete ribs are formed on back of panel to add stiffness - Minimum thickness of backup 5" to 6" but 4" for small panels - Mid-point tie back connections can minimize convex bowing	3.5.12.1 (General Considerations)	- Appoint qualified coordinator - Typically, precaster is responsible for precast concrete and stone layouts and details - Typically, stone-veneer fabricator is responsible for stone shop-fabrication drawings and drilling of anchor holes
				3.5.12.2 (Stone Properties)	- Stone strength depends on: size, rift, cleavage of crystals, degree of cohesion, interlocking geometry of crystals, nature of cementing materials present, and type of crystals

				<p>3.5.12.2 (Stone Properties)</p> <ul style="list-style-type: none"> - Sedimentary and metamorphic rocks exhibit different strengths depending on bedding (eg. marble and limestone) - Surface finish, freeze thaw, temperature fluctuations affect strength and anchorage system - Information about durability and testing by stone supplier - Various tests: flexural test ASTM C880, Absorption test ASTM 97 and performance of anchors attaching the stone (adequate strength of panel to resist loads during handling, transportation, erection, in-service condition) - Finishes that change strength: flame finish on granite thickness by 1/8", bushhammered also reduces effective thickness. - Thermal finishing of Granite surfaces cause microfracturing - Thermal cycling tests: heating 170 F and cooling -10 F while face of the stone is submerged in a 4 pH sulfurous acid solution that simulates chemical weathering. Warm climates at 40 F to 170 F and areas where the pH of rainfall is above 6, the acid solution can be eliminate. - Flexural tests ASTM C880 conducted on both new surface and surface after 100 freeze/thaw cycles
			<p>Stone size:</p> <ul style="list-style-type: none"> - Stone veneers thinner than conventionally set stone (max. size determined by stone strength) - Marble 7/8" thickness or less not desirable - Travertine 3/4", 1", 1-1/4", 1-1/2" (3/4" and 1" not recommended due to excessive breakage) - Granite 3 cm or greater recommended 	<p>3.5.12.3 (Stone Sizes)</p> <p>Stone size: summarized into a chart</p> <ul style="list-style-type: none"> - Marble: 1-1/4" minimum thickness - Marble length: 3-5 ft., width: 2-5 ft. - Maximum area of 20 sq. ft. - Travertine: 1-1/4" minimum thickness - Length range 2-5 ft., Width range 1-4 ft., - Maximum area 15 sq. ft. - Granite: 1-1/4" minimum thickness - Length range 3-7 ft., Width range 1-5 ft.,

			- Limestone 3 cm to 13 cm (less than 1-3/4" not recommended)	3.5.12.3 (Stone Sizes)	- Maximum area 30 sq. ft. - Indiana Limestone: 2" minimum thickness - Length range 4-5 ft., Width range 2-4 ft., - Maximum area 15 sq. ft.
			Tolerance: - Length and width +0 -1/8" - out-of-square is +- 1/16" difference in length of the two diagonal measurements - Flatness tolerances for finished surfaces depend on type of finish - Thickness variations less important since concrete will provide uniform back face, except butt joints - Finished edges should be within +-1/16" of specified thickness		Tolerance: - Veneer length and width: +- 1/16 in. - Out of square: +-1/16 in
				3.5.12.4 (Design Considerations)	- Physical properties of stone facing materials must be compared with concrete backup: 1. Tensile (axial and flexural), compressive, and shear strength 2. Modulus of elasticity (axial tension, flexure, and axial compression) 3. Coefficient of thermal expansion 4. Volume change - Design and production procedures to help minimize bowing: midpoint tie-back connections

		<p>Anchorage of Stone Facing:</p> <ul style="list-style-type: none"> - Preferable for the architect to determine anchor spacing - Contract should define who drills the anchor holes in the stone, type, number and location of anchors, and who supplies the anchors (usually stone fabricator drills holes) - Precast concrete industry recommends no bonding between concrete and stone veneer and the use of flexible mechanical anchors - Bondbreaker types: liquid bondbreaker of a certain thickness, one component: clear polyurethane coating or other thin liquid bondbreaker, 6 to 10 mil polyethylene sheet, closed cell 1/8" to 1/4" polyethylene foam pad - Preform anchors 1/8" to 1/4" in dia. fabricated from Type 304 or Type 302 stainless steel - Location and number determined by five shear and tension tests on single anchor embedded in stone/precast - 4 anchors usually per stone, min. of 2 - 1 anchor per 1-1/2 sq. ft. of stone to 1 per 6 sq. ft. with 1 per 2 to 3 sq. ft. most common - Anchors should be 6" to 9" from edge not over 30" between anchors - Marble: toe-in-spring clip (hairpin), granite: toe-out - Depth of anchor 1/2 of veneer thickness (min. depth of 3/4") at a 30 to 45 degree angle to the plane of stone - Holes approx. 50% oversized; however most holes 1/16" to 1/8" larger 	<p>3.5.12.5 (Anchorage of stone facing)</p>	<ul style="list-style-type: none"> - Architect, Engineer of Record, and stone fabricator should conduct tests to determine anchor type and spacing (refer to ASTM C12412) - Bondbreakers should be used between the stone veneer and the concrete backup to minimize bowing, cracking, staining - Connection should be made with flexible mechanical anchors that accommodate for relative in-place movement - Bondbreaker type: <ol style="list-style-type: none"> 1. 6 mil to 10 mil polyethylene sheet 2. a closed cell 1/8" to 1/4" polyethylene foam pad (during shipment, consideration to prevent cracking due to compressibility of the pad) - See anchor detail for: marble, granite, limestone, cross anchor Anchoring: <ul style="list-style-type: none"> - Stainless steel anchors, usually Type 304 (preformed anchors with a minimum diameter of 5/32") - Anchor location and number predetermined by minimum of 5 shear and tension tests on single anchor embedded in stone/precast sample using ASTM E488 or ASTM C1354 in both normal and transverse to panel - Minimum of 2 anchors per stone but usually 4 anchors - 1 anchor per 1 ½ sq. ft. to 1 per 6 sq. ft. with 1 per 2 to 3 sq. ft. most common - Anchors should be 6" to 12" from edge with no more than 24" to 30" between anchors - Marble anchor detail: toe-in anchor (hairpin) - Granite veneer anchor detail: toe-out - Limestone and Sandstone dowel detail: smooth or threaded
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			<ul style="list-style-type: none"> - Anchor holes should be within +/- 3/16" of specified - Stainless steel dowels, smooth and threaded installed depth of 2/3 the stone thickness (max. depth 2") at a 45 to 60 degree angle to the plane of stone - Dowel size varies from 3/16" to 5/8" and 1/4" to 5/8" for soft limestone/sandstone depending on thickness and strength - Dowel hole usually 1/16" to 1/8" larger than dia. of anchor - Epoxy to fill spring clip anchor or dowel holes to eliminate water intrusion - Elastomeric grommets to overcome rigidity - Long-term service of epoxy questionable 	<p>3.5.12.5 (Anchorage of stone facing)</p>	<ul style="list-style-type: none"> - Depth of anchor into stone: approximately one-half the thickness of veneer (minimum of 3/4") - Minimum stone cover over drilled hole should be 3/8" to avoid spalling during driller and spotting from absorbed moisture - Angle of anchor 30 degree to 45 degrees to plane - Anchor holes should be within +/- 3/16" of specified hole - Depth of dowel into stone: 2/3 stone thickness (maximum of 2") - Angle of dowel: 45 degrees to 60 degrees to plane - Dowel sizes vary from 3/16" to 5/8" except for soft limestone and sandstone at 1/4" to 5/8" - Two-part polyester or epoxy in anchor holes to eliminate moisture condensation - Rigidity from epoxy overcome by elastomeric grommets or sleeves - Use of fine sand as a filler for the epoxy to reduce the coefficient of thermal expansion of the epoxy and the shrinkage - Maybe desirable to fill the anchor hole with low modulus polyurethane sealant - Long-term service of epoxy is questionable
				<p>3.5.12.6 (Panel Watertightness)</p>	<ul style="list-style-type: none"> - Bondbreaker between stone veneer and concrete backup may function as a water vapor barrier keeping moisture in the veneer unless drainage is provided - Solutions: two-point joint: provides an airtight 1" wide urethane seal, bonded to the stone veneer and concrete backup and continuous along both sides and top or Sealant applied to the top and sides - Bondbreaker should not be sealed at the bottom of the panel for drainage

				<p>3.5.12.7 (Veneer jointing)</p> <p>3.5.12.7 (Veneer jointing)</p>	<ul style="list-style-type: none"> - Joints between veneer pieces on a precast concrete component should be a minimum of 3/8" - Use of invisible joint (less than 3/8") is not recommended because need for movement, tolerances -When stone veneer is used as an accent, space between the stone and the precast at 1/2" and then caulked - Sealant between stones or panels should be elastomeric, usually urethane, polysulfide, or silicone that is non-staining
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(Cont. APPENDIX E: PCI- Architectural Precast Concrete Design Manuals 1st ed., 2nd ed., 3rd ed.)

APPENDIX F: PCI- Design Handbook 1st ed., 2nd ed., 3rd ed.

PCI Design Handbook (Engineers) - Natural Stone facings					
Section	1st Edition – 1971	Section	2nd Edition - 1978	Section	3rd Edition - 1985
	<ul style="list-style-type: none"> - Fabrication must have shop drawings approved by both architect and general contractor - No separate section for stone veneer facing - Architectural precast concrete specifications do not include finishes of thin stone 		<ul style="list-style-type: none"> - No separate section for stone veneer facing - No mention in the finishing section regarding to stone veneer faceted precast concrete 		<ul style="list-style-type: none"> - First appearance of veneered panels and natural stone facings introduced as "special topics" - Issues of bowing and cracking veneers is addressed - Suggestions for using bond-breakers for addressing issues with shrinkage and bonded materials - Exception of limestone industry and their practice of rigid connections - Difference of Granite thicknesses by US suppliers and foreign suppliers - Stone details of marble, granite, limestone - Specifications for veneer faced finish appear
4.3.1 (General)	Precast concrete wall panels used in every type of building construction. Available in variety of surface finishes.			7.1 (General)	<ul style="list-style-type: none"> - Rapid growth in the use of architectural precast concrete has created many innovations in architecture - Can serve as a non-load bearing (cladding) walls
4.3.2 (Types of panels)	Flat panel- short flat panels of this section are often reinforced with mild steel rather than pre-stressed when stresses due to handling are sufficiently low			7.5.1 (Veneered panels - general)	<ul style="list-style-type: none"> - Precast concrete panels faced with brick, tile or natural stone combine rich beauty of traditional materials with strength, versatility and economy of precast concrete - Same structural design as precast concrete plus special consideration for veneer material and its attachment to the concrete - Physical properties of both precast concrete and facing materials must be compared (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change with moisture absorption) - natural stone veneers exhibit different properties depending on orientation of the applied force in relation to natural planes of material - cover depth of reinforcing steel should be a min of 1/2" at the veneer surface - Galvanized or epoxy coated reinforcement is recommended at cover depths less than 3/4" - difference in material properties makes veneered panels more susceptible to bowing

				<p>7.5.1 (Veneered panels - general)</p>	<p>compared to all concrete units</p> <ul style="list-style-type: none"> - reinforcing trusses used to add stiffness, concrete ribs on back of panel - facing material bond and/or mechanical anchorage - Anchorage depends on: shrinkage of concrete during curing, handling and erection, different coefficient of expansion by thermal gradients, service load) - Use of mid-point tie-back connection to reduce bowing - Connections of natural stone to the concrete should be made with mechanical anchors that allow relative in-plane movement and needed if bond-breakers are used w/ exception limestone
				<p>7.5.3 (Natural Stone)</p>	<ul style="list-style-type: none"> - Stone veneers casted in precast facing is usually thinner than conventionally set stone
					<p>Stone size:</p> <ul style="list-style-type: none"> - Marble minimum 7/8" thickness (limited to 20 sq ft and max. of dimension of 8 ft)
					<p>Stone size:</p> <ul style="list-style-type: none"> - Granite minimum depends on sawing, handling and finishing and type of anchors. - US fabricators Granite minimum 1-1/2" to 2" thickness. - Foreign suppliers 7/8" thickness. - Depending on color pieces are 3 ft x 3 ft to 5 ft x 7ft
					<p>Stone size:</p> <ul style="list-style-type: none"> - Limestone minimum 1-1/2" thickness (area of 4 to 12 sq. ft.) Thicker pieces will have area of 18 ft. x 8 ft.
					<p>Tolerance;</p> <ul style="list-style-type: none"> - Veneer length and width: + 0, - 1/8" - flatness tolerance depends on the stone - Thickness variations are not important since concrete will provide a uniform back face, except at corner butt joints. (1/16" of specified thickness)

					<p>Recommendation of no bond between veneer and concrete backing</p> <p>- Methods of breaking bond:</p> <ol style="list-style-type: none"> 1. liquid bondbreaker of sufficient thickness 2. 6 mil polyethylene sheet 3. 1/8" polyethylene foam pad
					See anchor detail for: marble, granite, limestone
					<p>Anchoring:</p> <p>stainless steel, Type 304</p>
					<ul style="list-style-type: none"> - Veneers supplied with predrilled holes - Number and location of anchors dependent on height, width, thickness and strength of stone - Anchor size and spacing require special analysis
					<p>Anchoring:</p> <ul style="list-style-type: none"> - Marble anchor detail: 1/8" s.s. wire - Granite veneer anchor detail: 3/16" s.s. wire or rod anchor (dia. 1/4") - Limestone anchor detail: stainless steel bent rebar (deformed bar) 3/4" min. in 2" thick veneer with the use of an epoxy set and moisture barrier (bond-breaker) to eliminate concrete alkali salts from staining
					<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of anchor: approximately one-half the thickness of the veneer (minimum of 1/2") - Granite and Marble approx. 50% oversize - Minimum of 10 tests are needed to determine pull-out and shear strength of each anchor
					<p>Veneer Jointing:</p> <p>Joints between veneer pieces on a precast concrete component should be a minimum of 1/4"</p>
					<p>Veneer Jointing:</p> <p>when stone veneer is used as an accent, space between the stone and the precast at 1/2" and then caulked</p>
					<p>Samples:</p> <p>Recommendation of full scale mock-up to investigate and test conditions for determining final stone size and fastening decisions. Measuring bowing over several weeks</p>

<p>8 (Specifications and Reference s)</p> <p>8 (Specifications and Reference s)</p>	<p>Guide Specification for Architectural Precast Concrete 1. General 2. Design 3. Materials 4. Quality Control 5. Manufacture 6. Handling & Transportation 7. Erection 8. Joints and joint sealants 9. Cleaning</p>	<p>7 (Specifications and Reference s)</p> <p>7 (Specifications and Reference s)</p>	<p>Guide Specification for Precast, Prestressed concrete construction for buildings: 2C. Finishes: standard underside, standard top, exposed vertical ends</p> <p>Code of Standard Practice for precast concrete: 1.2 Architectural precast concrete: precast elements that require architectural finishes and/or exhibit decorative exposed surfaces. (elements include wall panels, window wall panels, mullions, column covers) 7 Finishes: most misunderstandings, therefore, clear contract documents and erection drawings</p>	<p>10 (Specifications and Reference s)</p> <p>10 (Specifications and Reference s)</p>	<p>Guide Specification for Architectural Precast Concrete: 2.03B Fabrication-Finishes: Veneer faced finish - connection of cut stone face material to concrete shall be by mechanical means - provide 3/4" cover for reinforcing steel - no use of metal chairs - provide appropriate embedded anchorages</p> <p>Notes: - Full scale mock-up to measure bowing - Provide a complete bond-breaker between the cut stone face and concrete - Increase cover requirement in environments of severe exposure conditions - Smooth cast facing, stainless steel chairs may be permitted</p>
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(Cont. APPENDIX F: PCI- Design Handbook 1st ed., 2nd ed., 3rd ed.)

APPENDIX G: PCI- Design Handbook 4th ed., 5th ed.

PCI Design Handbook (Engineers) - Natural Stone facings			
Section	4th Edition - 1992	Section	5th Edition - 1999
	<ul style="list-style-type: none"> - Natural stone properties in detail along with testing standards - Addition of Travertine to the stone list - Epoxy covered anchors first appear - Minimum thickness of back up concrete at 5"-6" - Thinner Granite thickness are acknowledged - Specific requirements for anchor placements - Use of mid-point tie-back connections to reduce bowing - Full scale mock-up is for feasibility not for measuring bowing activity - Recommendation of reinforcing cage supported from the back and not chairs due to marring the finish 		<ul style="list-style-type: none"> - No separate section for stone veneer facing - No mention in the finishing section regarding to stone veneer faceted precast concrete
7.1 (General)	<ul style="list-style-type: none"> - Architectural precast is available in complex shapes - Finishes can give attractive appearances 	7.1 (General)	<ul style="list-style-type: none"> - Architectural precast is available in complex shapes - Finishes can give attractive appearances
7.5.1 (Veneered panels - general)	<ul style="list-style-type: none"> - Precast concrete panels faced with brick, tile or natural stone combine rich beauty of traditional materials with strength, versatility and economy of precast concrete - Same structural design as precast concrete plus special consideration for veneer material and its attachment to the concrete - Physical properties of both precast concrete and facing materials must be compared (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change) - natural stone veneers exhibit different properties depending on orientation of the applied force in relation to natural planes of material - cover depth of reinforcing steel should be a min of 1/2" at the veneer surface - Galvanized or epoxy coated reinforcement is recommended at cover depths less than 3/4" - difference in material properties makes veneered panels more susceptible to bowing compared to all concrete units - Minimum thickness of back up concrete of flat panels to control bowing is usually 5" to 6", but 4" can be used for small panels - Stone veneer connections to backup concrete with flexible mechanical anchors - Bond of veneer and concrete should be voided 	7.5.1 (Veneered panels - general)	<ul style="list-style-type: none"> - Precast concrete panels faced with brick, tile or natural stone combine rich beauty of traditional materials with strength, versatility and economy of precast concrete - Same structural design as precast concrete plus special consideration for veneer material and its attachment to the concrete - Physical properties of both precast concrete and facing materials must be compared (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change) - Bowing can be reduced by the following techniques: <ol style="list-style-type: none"> 1. minimum thickness of 5" to 6" backup concrete, depending on panel length 2. use of prestressing in long, flat panels 3. two layers of reinforcement when thickness allows 4. Use of reinforcing trusses 5. concrete ribs formed on the back of the panel 6. intermediate tie-back connections to the supporting structure 7. use bond breakers and flexible anchors with thin stone veneers

<p>7.5.1 (Veneered panels - general)</p>	<ul style="list-style-type: none"> - Anchorage depends on: shrinkage of concrete during curing, handling and erection, different coefficient of expansion by thermal gradients, moisture expansion, service load) - Rigid connection will cause outward bowing - Use of mid-point tie-back connection to reduce bowing - Connections of natural stone to the concrete should be made with mechanical anchors that allow relative in-plane movement and needed if bond-breakers are used 		
<p>7.5.3 (Natural Stone)</p>	<ul style="list-style-type: none"> - Used in various sizes, shapes and colors to provide infinite number of patterns and color possibilities 	<p>7.5.3 (Natural Stone)</p>	<ul style="list-style-type: none"> - Used in various sizes, shapes and colors to provide infinite number of patterns and color possibilities
<p>7.5.3.1 (Natural Stone - Properties)</p>	<ul style="list-style-type: none"> - Natural stone strength depends on: size, rift, cleavage of crystals, degree of cohesion, interlocking geometry of crystals, nature of cementing materials present - Sedimentary and metamorphic rocks exhibit different strengths depending on bedding (eg. marble and limestone) - Surface finish, freeze thaw, temperature fluctuations affect strength and anchorage system - Information about durability from stone supplier - Usually 20 samples for adequate number of testings - Various Tests: modulus of rupture ASTM C99, Limestone ASTM C568, Marble ASTM C503, Granite ASTM C615. - Finishes that change strength: flame finish on granite thickness by 1/8", bushhammered also reduces effective thickness. - Thermal finishing of Granite surfaces cause microfracturing - Thermal cycling tests: heating 150 F and cooling -10 F - Flexural tests ASTM C880 conducted on both new surface and surface after 50 freeze/thaw cycles - High absorption stones need tests in saturated conditions - Tests should also be conducted for stone-concrete assembly to determine strength loss on the shear and tensile strengths of the anchors - Tests for minimum thickness required for satisfactory serviceability - As stone veneers become thinner and thinner, water penetration can cause performance issues 	<p>7.5.3.1 (Natural Stone - Properties)</p>	<ul style="list-style-type: none"> - Natural stone strength depends on: size, rift, cleavage of crystals, degree of cohesion, interlocking geometry of crystals, nature of cementing materials present - Sedimentary and metamorphic rocks exhibit different strengths depending on bedding (eg. marble and limestone) - Surface finish, freeze thaw, temperature fluctuations affect strength and anchorage system - Information about durability from stone supplier - Usually 20 samples for adequate number of testings - Various Tests: modulus of rupture ASTM C99, Limestone ASTM C568, Marble ASTM C503, Granite ASTM C615. - Finishes that change strength: flame finish on granite thickness by 1/8", bushhammered also reduces effective thickness. - Thermal finishing of Granite surfaces cause microfracturing - Thermal cycling tests: heating 150 F and cooling -10 F - Flexural tests ASTM C880 conducted on both new surface and surface after 50 freeze/thaw cycles - High absorption stones need tests in saturated conditions - Tests should also be conducted for stone-concrete assembly to determine strength loss on the shear and tensile strengths of the anchors - Tests for minimum thickness required for satisfactory serviceability - As stone veneers become thinner and thinner, water penetration can cause performance issues
	<p>See moisture permeability table</p>		<p>See moisture permeability table</p>
	<p>n/a</p>		<p>See dimensional parameters of various stone</p>

7.5.3.2 (Size)	Stone size: - Marble thickness for precast: 7/8", 1", 1-¼", 1-½", and 2" (less than 7/8" not desirable) - Marble length: typically 3 to 5 ft. - Marble width: 2 to 5 ft. with maximum area of 25 sq. ft.	7.5.3.2 (Size)	Stone size: - Marble: 1" minimum thickness - Length range 3-5 ft., Width range 2-5 ft., - Maximum area 25 sq. ft.
	Stone size: - Travertine thickness for precast: ¾", 1", 1- ¼", and 1- ½" (3/4" and 1" not recommended) - Travertine length: 2 to 5 ft. - Travertine width: 1 to 4 ft. with maximum area of 16 sq. ft.		Stone size: - Travertine: 1-1/4" minimum thickness - Length range 2-5 ft., Width range 1-4 ft., - Maximum area 16 sq. ft.
	Stone size: - Granite veneer thickness: ¾", 7/8", 1", 1- ¼", 1- 5/8", 2", and 2- ½" (greater than 1 ¼" recommended) - Granite length: 3 to 7 ft. - Granite width: 1 to 5 ft. with maximum area of 30 sq. ft.		Stone size: - Granite: 1-1/4" minimum thickness - Length range 3-7 ft., Width range 1-5 ft., - Maximum area 30 sq. ft.
	Stone size: - Limestone thickness: 1- ¼", 1- ½", 1- ¾", and 2" and 5" also used (less than 1 ¼" in not recommended) - Limestone length: 4 to 5 ft. - Limestone width: 2 to 4 ft. with maximum area of 15 sq. ft.		Stone size: - Limestone: 1-3/4" minimum thickness - Length range 4-5 ft., Width range 2-4 ft., - Maximum area 15 sq. ft.
	Tolerance: - Veneer length and width tolerance: +0, -1/8" - Out of square: +- 1/16" - Flatness: depends on type of finish - Thickness variation: less important, corner butt joints finish edges within +- 1/16"		Tolerance: - Veneer length and width tolerance: +0, -1/8" - Out of square: +- 1/16" - Flatness: depends on type of finish - Thickness variation: less important, corner butt joints finish edges within +- 1/16"
7.5.3.3 (Anchorage of stone facing)	- Bond breakers recommended. No bonding between stone and concrete backup - Bond breaker type: 1. Liquid bond breaker of sufficient thickness 2. 6 mil polyethylene sheet 3. 1/8" polyethylene foam pad 4. One component polyethylene coating	7.5.3.3 (Anchorage of stone facing)	- Bond breakers recommended. No bonding between stone and concrete backup - Exception of limestone which uses rigid connections - Bond breaker type: 1. Liquid bond breaker of sufficient thickness 2. 6 mil polyethylene sheet 3. 1/8" polyethylene foam pad 4. One component polyethylene coating
	See anchor detail for: marble, granite, limestone, cross anchor		See anchor detail for: marble, granite, limestone, cross anchor
	Anchoring: Stainless steel anchors, usually Type 304		Anchoring: Stainless steel anchors, usually Type 304
	- Shear and tension testing for anchor placement should be done to a stone/precast concrete sample Anchoring:		Mechanical anchorage details depend on: 1. shrinkage of concrete during curing 2. stresses from handling and erection 3. coefficients of expansion by thermal gradients 4. moisture expansion 5. service loads - Shear and tension testing for anchor placement should be done in both normal and transverse) to a stone/precast concrete sample

	<ul style="list-style-type: none"> - Minimum of 2 anchors per stone but usually 4 anchors - 1 anchor per 1- ½ sq. ft. to 1 per 6 sq. ft. with 1 per 2 to 3 sq. ft. most common - Anchors should be 6" to 9" from edge with not over 30" between anchors 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Minimum of 2 anchors per stone but usually 4 anchors - 1 anchor per 1-½ sq. ft. to 1 per 6 sq. ft. with 1 per 2 to 3 sq. ft. most common - Anchors should be 6" to 9" from edge with not over 30" between anchors
	<p>Anchoring:</p> <ul style="list-style-type: none"> - Marble anchor detail: toe-in anchor (hairpin) - Granite veneer anchor detail: toe-out - Limestone and Sandstone dowel detail: smooth or threaded 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Marble anchor detail: toe-in anchor (hairpin) - Granite veneer anchor detail: toe-out - Limestone and Sandstone dowel detail: smooth or threaded
	<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of anchor into stone: approximately one-half the thickness of veneer (minimum of ¼ in) - Angle of anchor: 30 degrees to 45 degrees to plane - Size of holes: typically 1/16 in. to 1/8 in. larger than the anchor (up to 50% oversize allowed) - Anchor holes should be within +- 3/16 in. of specified hole 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of anchor into stone: approximately one-half the thickness of veneer (minimum of ¼") - Angle of anchor: 30 degrees to 45 degrees to plane - Size of holes: typically 1/16" to 1/8" larger than the anchor (up to 50% oversize allowed) - Anchor holes should be within +- 3/16" of specified hole
	<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of dowel into stone: 2/3 stone thickness (maximum of 2") - Angle of dowel: 45 degrees to 75 degrees to plane - Dowel sizes vary from 3/16" to 5/8" except for soft limestone and sandstone at 1/4" to 5/8" - Dowel holes usually 1/16" to 1/8" larger in diameter than anchor 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of dowel into stone: 2/3 stone thickness (maximum of 2") - Angle of dowel: 45 degrees to 75 degrees to plane - Dowel sizes vary from 3/16" to 5/8" except for soft limestone and sandstone at 1/4" to 5/8" - Dowel holes usually 1/16" to 1/8" larger in diameter than anchor
	<ul style="list-style-type: none"> - Epoxy fill the spring clip anchor or dowel holes to eliminate intrusion of water - Rigidity from epoxy overcome by elastomeric grommets or sleeves (1/2") - May be preferable to use fast-curing silicone or low modulus polyurethane - Long-term service of epoxy is questionable 		<ul style="list-style-type: none"> - Epoxy fill the spring clip anchor or dowel holes to eliminate intrusion of water - Rigidity from epoxy overcome by elastomeric grommets or sleeves (1/2") - May be preferable to use fast-curing silicone - Long-term service of epoxy is questionable
7.5.3.4 (Veneer jointing)	<p>Veneer Jointing:</p> <p>Joints between veneer pieces on a precast concrete component should be a minimum of 1/4"</p>	7.5.3.4 (Veneer jointing)	<p>Veneer Jointing:</p> <p>Joints between veneer pieces on a precast concrete component should be a minimum of 1/4"</p>
	<p>Veneer Jointing:</p> <p>when stone veneer is used as an accent, space between the stone and the precast at 1/2" and then caulked</p>		<p>Veneer Jointing:</p> <p>when stone veneer is used as an accent, space between the stone and the precast at 1/2" and then caulked</p>
7.5.3.5 (Samples)	<p>Samples:</p> <ul style="list-style-type: none"> - Now a good background knowledge of experience in the production and erection of stone veneer-faced precast concrete panels. - Full scale mock-up recommended for manufacturers to check feasibility of production and erection 	7.5.3.5 (Samples)	<p>Samples:</p> <ul style="list-style-type: none"> - Now a good background knowledge of experience in the production and erection of stone veneer-faced precast concrete panels. - Full scale mock-up recommended for manufacturers to check feasibility of production and erection
10 (Specifications and References)	<p>Guide Specification for Architectural Precast Concrete:</p> <p>2.03B Fabrication-Finishes: Veneer faced finish</p> <ul style="list-style-type: none"> - connection of cut stone face material to concrete shall be by mechanical means - provide 3/4" cover for reinforcing steel 	10 (Specifications and References)	

<p>10 (Specifications and References)</p>	<ul style="list-style-type: none"> - no use of metal chairs - provide appropriate embedded anchorages <p>Notes:</p> <ul style="list-style-type: none"> - Full scale mock-up for realistic production conditions - Provide a complete bondbreaker between natural stone face and concrete. Ceramic tile, brick and terra cotta are bonded to the concrete - Increase cover requirements in environments of severe exposure conditions - If possible, reinforcing steel cages should be supported from the back of the panel, spacers mar the finished surface of the panel. Smooth cast facing permits stainless steel chairs. Wires should be soft stainless steel and clippings should be completely removed from the mold. 		
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(Cont. APPENDIX G: PCI- Design Handbook 4th ed., 5th ed.)

APPENDIX H: PCI- Design Handbook 6th ed., 7th ed.

PCI Design Handbook (Engineers) - Natural Stone facings			
Section	6th Edition - 2004	Section	7th Edition - 2010
	<ul style="list-style-type: none"> - Thermal testing values changed to 170 degrees F - Freeze-thaw testing of 100 cycles - Minimum thickness of Marble is 1-1/4" and maximum area is 20 sq. ft. - Travertine no longer listed - Length and width tolerance is +/-1/16" - Consideration to prevent cracking of stone during shipment due to compressibility of the pad - Anchor position should be 6" to 12" from an edge with not over 30" between anchors - Angle of anchor 30 to 40 degrees - Angle of dowel 45 to 60 degrees - Low-modulus polyurethane sealant for filling anchor holes - Samples not requested 		<ul style="list-style-type: none"> - Testing responsibility of the stone by the stone fabricator - Absorption test ASTM 97 required - Travertine added to the list - Limestone to Indiana Limestone and minimum thickness of 2" - Test includes acid submersion of 4 pH to simulate chemical weathering - ASTM E488 or ASTM C1354 for predetermining number and location of anchors - Angle of anchor back to 30 to 45 degrees - Joints between veneer pieces minimum of 3/8" - Included charts of Coefficient of linear thermal expansion and Ultimate shear capacity - Use of liquid bondbreaker no longer listed
7.1 (General)	<ul style="list-style-type: none"> - Architectural precast concrete refers to any precast concrete unit of special (or occasionally standard) shape that, through application of finish, color, and texture contributes to the finished effect of the structure - In most cases designed by precast specialty engineer, employed or retained by precast manufacturer 	7.1 (General)	<ul style="list-style-type: none"> - Architectural precast concrete refers to any precast concrete unit of special (or occasionally standard) shape that, through application of finish, color, and texture contributes to the finished effect of the structure - In most cases designed by precast specialty engineer, employed or retained by precast manufacturer
7.5.1 (Veneered panels - general)	<ul style="list-style-type: none"> - Precast concrete panels faced with brick, tile or natural stone combine rich beauty of traditional materials with strength, versatility and economy of precast concrete - Same structural design as precast concrete plus special consideration for veneer material and its attachment to the concrete - Physical properties of both precast concrete and facing materials must be compared (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change) - Bowing can be reduced by the following techniques: <ol style="list-style-type: none"> 1. use of bond breakers and flexible anchors with thin stone veneer 2. minimum thickness of 5" to 6" back-up concrete, depending on panel length 3. use of prestressing in long, flat panels 4. concrete ribs formed on the back on the panel 5. Intermediate tie-back connections to the supporting structure 6. avoid veneer material with large expansion or shrinkage characteristics 	7.6.1 (Veneered panels - general)	<ul style="list-style-type: none"> - Precast concrete panels faced with brick, tile or natural stone combine rich beauty of traditional materials with strength, versatility and economy of precast concrete - Same structural design as precast concrete plus special consideration for veneer material and its attachment to the concrete - Physical properties of both precast concrete and facing materials must be compared (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change) - Bowing can be reduced by the following techniques: <ol style="list-style-type: none"> 1. use of bond breakers and flexible anchors with thin stone veneer 2. minimum thickness of 5" to 6" back-up concrete, depending on panel length 3. use of prestressing in long, flat panels 4. concrete ribs formed on the back on the panel 5. Intermediate tie-back connections to the supporting structure 6. avoid veneer material with large expansion or shrinkage characteristics
7.5.3 (Natural Stone)	<ul style="list-style-type: none"> - Used in various sizes, shapes and colors to provide infinite number of patterns and color possibilities 	7.6.3 (Stone veneer-faced precast concrete) 7.6.3.1	<ul style="list-style-type: none"> - Widely used in building construction for strength, durability, aesthetic effect, availability, and inherent low-maintenance costs - Economically viable solution to cladding structures - Coordinator is recommended between precast concrete manufacturer and stone-veneer supplier

		(General considerations)	<ul style="list-style-type: none"> - Typically, precaster is responsible for precast concrete and stone layouts and details - Typically, stone-veneer fabricator is responsible for stone shop-fabrication drawings and drilling of anchor holes
7.5.3.1 (Natural Stone - Properties)	<ul style="list-style-type: none"> - Natural stone strength depends on: size, rift, cleavage of crystals, degree of cohesion, interlocking geometry of crystals, nature of cementing materials present - Sedimentary and metamorphic rocks exhibit different strengths depending on bedding (eg. marble and limestone) - Surface finish, freeze thaw, temperature fluctuations affect strength and anchorage system - Information about durability from stone supplier - Usually 20 samples for adequate number of testings - Various Tests: modulus of rupture ASTM C99, Limestone ASTM C568, Marble ASTM C503, Granite ASTM C615. - Finishes that change strength: flame finish on granite thickness by 1/8", bushhammered also reduces effective thickness. - Thermal finishing of Granite surfaces cause microfracturing - Thermal cycling tests: heating 170 F and cooling -10 F - Flexural tests ASTM C880 conducted on both new surface and surface after 100 freeze/thaw cycles - High absorption stones need tests in saturated conditions - Tests should also be conducted for stone-concrete assembly to determine strength loss on the shear and tensile strengths of the anchors - Tests for minimum thickness required for satisfactory serviceability - As stone veneers become thinner and thinner, water penetration can cause performance issues 	7.6.3.2 (Stone properties)	<ul style="list-style-type: none"> - Stone strength depends on: size, rift, cleavage of crystals, degree of cohesion, interlocking geometry of crystals, nature of cementing materials present, and type of crystals - Sedimentary and metamorphic rocks exhibit different strengths depending on bedding (eg. marble and limestone) - Surface finish, freeze thaw, temperature fluctuations affect strength and anchorage system - Information about durability and testing by stone supplier - Various tests: flexural test ASTM C880, Absorption test ASTM 97 and performance of anchors attaching the stone (adequate strength of panel to resist loads during handling, transportation, erection, in-service condition) - Finishes that change strength: flame finish on granite thickness by 1/8", bushhammered also reduces effective thickness. - Thermal finishing of Granite surfaces cause microfracturing - Thermal cycling tests: heating 170 F and cooling -10 F while face of the stone is submerged in a 4 pH sulfurous acid solution that simulates chemical weathering. Warm climates at 40 F to 170 F and areas where the pH of rainfall is above 6, the acid solution can be eliminated. - Flexural tests ASTM C880 conducted on both new surface and surface after 100 freeze/thaw cycles
	See moisture permeability table		n/a
	See dimensional parameters of various stone		See dimensional parameters of various stone
7.5.3.2 (Size)	<p>Stone size: summarized into a chart</p> <ul style="list-style-type: none"> - Marble: 1-1/4" minimum thickness - Marble length: 3-5 ft., width: 2-5 ft. - Maximum area of 20 sq. ft. 	7.6.3.3 (Stone size)	<p>Stone size: summarized into a chart</p> <ul style="list-style-type: none"> - Marble: 1-1/4" minimum thickness - Marble length: 3-5 ft., width: 2-5 ft. - Maximum area of 20 sq. ft.
			<p>Stone size:</p> <ul style="list-style-type: none"> - Travertine: 1-1/4" minimum thickness - Length range 2-5 ft., Width range 1-4 ft., - Maximum area 15 sq. ft.
	<p>Stone size:</p> <ul style="list-style-type: none"> - Granite: 1-1/4" minimum thickness - Length range 3-7 ft., Width range 1-5 ft., - Maximum area 30 sq. ft. 		<p>Stone size:</p> <ul style="list-style-type: none"> - Granite: 1-1/4" minimum thickness - Length range 3-7 ft., Width range 1-5 ft., - Maximum area 30 sq. ft.

	<p>Stone size:</p> <ul style="list-style-type: none"> - Limestone: 1-3/4" minimum thickness - Length range 4-5 ft., Width range 2-4 ft., - Maximum area 15 sq. ft. 		<p>Stone size:</p> <ul style="list-style-type: none"> - Indiana Limestone: 2" minimum thickness - Length range 4-5 ft., Width range 2-4 ft., - Maximum area 15 sq. ft.
	<p>Tolerance:</p> <ul style="list-style-type: none"> - Veneer length and width: +- 1/16" - Out of square: +-1/16" - Flatness: depends on type of finish - Thickness variation: less important, corner butt joints finish edges within +- 1/16" 		<p>Tolerance:</p> <ul style="list-style-type: none"> - Veneer length and width: +- 1/16 in. - Out of square: +-1/16 in
7.5.3.3 (Anchorage of stone facing)	<ul style="list-style-type: none"> - Bond breakers recommended. No bonding between stone and concrete backup - Exception of limestone which uses rigid connections - Bond breaker type: <ol style="list-style-type: none"> 1. Liquid bond breaker of sufficient thickness 2. 6 mil polyethylene sheet 3. 1/8" polyethylene foam pad 4. One component polyethylene coating - Consideration must be given to prevent cracking of stone due to compressibility of the pad 	7.6.3.5 (Anchorage of stone facing)	<ul style="list-style-type: none"> - Architect, Engineer of Record, and stone fabricator should conduct tests to determine anchor type and spacing (refer to ASTM C12412) - Bondbreakers should be used between the stone veneer and the concrete backup to minimize bowing, cracking, staining - Connection should be made with flexible mechanical anchors that accommodate for relative in-place movement - Bondbreaker type: <ol style="list-style-type: none"> 1. 6 mil to 10 mil polyethylene sheet 2. a closed cell 1/8" to 1/4" polyethylene foam pad (during shipment, consideration to prevent cracking due to compressibility of the pad)
	See anchor detail for: marble, granite, limestone, cross anchor		See anchor detail for: marble, granite, limestone, cross anchor
	<p>Anchoring:</p> <p>Stainless steel anchors, usually Type 304</p>		<p>Anchoring:</p> <p>Stainless steel anchors, usually Type 304 (preformed anchors with a minimum diameter of 5/32")</p>
	<p>Mechanical anchorage details depend on:</p> <ol style="list-style-type: none"> 1. shrinkage of concrete during curing and stresses from handling and erection 2. differences in coefficients of expansion by thermal gradients 3. moisture expansion 4. service load <ul style="list-style-type: none"> - Shear and tension testing for anchor placement should be done in both normal and transverse) to a stone/precast concrete sample <p>Anchoring:</p> <ul style="list-style-type: none"> - Minimum of 2 anchors per stone but usually 4 anchors - 1 anchor per 1 ½ sq. ft. to 1 per 6 sq. ft. with 1 per 2 to 3 sq. ft. most common - Anchors should be 6" to 12" from edge with not over 30" between anchors 		<ul style="list-style-type: none"> - Anchor location and number predetermined by minimum of 5 shear and tension tests on single anchor embedded in stone/precast sample using ASTM E488 or ASTM C1354 in both normal and transverse to panel <p>Anchoring:</p> <ul style="list-style-type: none"> - Minimum of 2 anchors per stone but usually 4 anchors - 1 anchor per 1 ½ sq. ft. to 1 per 6 sq. ft. with 1 per 2 to 3 sq. ft. most common - Anchors should be 6" to 12" from edge with no more than 24" to 30" between anchors
	<p>Anchoring:</p> <ul style="list-style-type: none"> - Marble anchor detail: toe-in anchor (hairpin) - Granite veneer anchor detail: toe-out - Limestone and Sandstone dowel detail: smooth or threaded 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Marble anchor detail: toe-in anchor (hairpin) - Granite veneer anchor detail: toe-out - Limestone and Sandstone dowel detail: smooth or threaded

	<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of anchor into stone: approximately one-half the thickness of veneer (minimum of 3/4") - Angle of anchor: 30 degrees to 40 degrees to plane - Size of holes: typically 1/16" to 1/8" larger than the anchor (up to 50% oversize allowed) - Anchor holes should be within +/- 3/16" of specified hole 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of anchor into stone: approximately one-half the thickness of veneer (minimum of 3/4") - Minimum stone cover over drilled hole should be 3/8" to avoid spalling during driller and spotting from absorbed moisture - Angle of anchor 30 degree to 45 degrees to plane - Anchor holes should be within +/- 3/16" of specified hole
	<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of dowel into stone: 2/3 stone thickness (maximum of 2") - Angle of dowel: 45 degrees to 60 degrees to plane - Dowel sizes vary from 3/16" to 5/8" except for soft limestone and sandstone at 1/4" to 5/8" - Dowel holes usually 1/16" to 1/8" larger in diameter than anchor 		<p>Anchoring:</p> <ul style="list-style-type: none"> - Depth of dowel into stone: 2/3 stone thickness (maximum of 2") - Angle of dowel: 45 degrees to 60 degrees to plane - Dowel sizes vary from 3/16" to 5/8" except for soft limestone and sandstone at 1/4" to 5/8"
	<ul style="list-style-type: none"> - Epoxy fill the spring clip anchor or dowel holes to eliminate intrusion of water - Rigidity from epoxy overcome by elastomeric grommets or sleeves - May be preferable to use low-modulus polyurethane sealant - Long-term service of epoxy is questionable 		<ul style="list-style-type: none"> - Two-part polyester or epoxy in anchor holes to eliminate moisture condensation - Rigidity from epoxy overcome by elastomeric grommets or sleeves - Use of fine sand as a filler for the epoxy to reduce the coefficient of thermal expansion of the epoxy and the shrinkage - Maybe desirable to fill the anchor hole with low modulus polyurethane sealant - Long-term service of epoxy is questionable
7.5.3.4 (Veneer jointing)	<p>Veneer Jointing:</p> <p>Joints between veneer pieces on a precast concrete component should be a minimum of 1/4"</p>	7.6.3.6 (Veneer jointing)	<p>Veneer Jointing:</p> <p>Joints between veneer pieces on a precast concrete component should be a minimum of 3/8"</p>
	<p>Veneer Jointing:</p> <p>when stone veneer is used as an accent, space between the stone and the precast at 1/2" and then caulked</p>		<p>Veneer Jointing:</p> <p>when stone veneer is used as an accent, space between the stone and the precast at 1/2" and then caulked</p>
10 (Specifications and References)	Building off the old master	10 (Specifications and References)	

APPENDIX H: PCI- Design Handbook 6th ed., 7th ed.

APPENDIX I: MIA- EARLY LITERATURE (1948, 1955, 1961)

MIA Architect's Handbook - 1948		MIA American Standard Specifications - 1955		MIA Specifications - 1961	
Section	Requirement - Exterior	Section	Requirement - Exterior marble veneer 2" and less in thickness	Section	Requirement - Thin exterior marble veneer (2" and less in thickness)
	<ul style="list-style-type: none"> - No specifications specifically on thin stone panels & thin stone pcc panels - Lots of use of mastic filler, Portland cement, and white cement for filling holes - Setting is used with anchors to "stick" the materials marble to masonry support - Mausoleum Plate no. 10: exterior veneer (7/8") near base is set up against cement with a W.P. paint coat, and cement against concrete. - Mortar spots for area where the stone and anchor meet supporting back 		<ul style="list-style-type: none"> - Standard specifications specifically for exterior use of marble as a veneer and curtain or panel wall - Architect and emphasis placed on architectural drawings and shop drawings as basis for decision making (possibly because this is not an architect' handbook) - Use of lime mortar for pointing appears - Detailed specs on joints and reference to expansion joints - Use of stainless steel is encouraged over structural steel - Concerns of additional loading not being placed on the veneers - Anchor requirement of slab less than 2 sq. ft. - Reference to plate anchors - Specifications for non-ferrous metals in flashing - Cleaning and maintenance added 		<ul style="list-style-type: none"> - Pointing from mastic to elastic jointing compounds (polysulfide or other synthetic rubber base) - Detailed requirements and locations for expansion joints for thermal expansion and contraction - Jointing compounds are factory mix - General contractor duties are pointed out - Distinction between architectural drawings and contract drawings - Note under anchorage a bout not relying on "bond" provided by mortar spots between marble and backup wall - Separated section for "setting materials and methods"
a (extent and thickness)	<ul style="list-style-type: none"> - Extent indicated in drawings - Ashlar thickness: 7/8", 1 1/4" - Ordinary building front not over two stories thickness: 7/8", 1 1/4" - Large areas and northern sections of the country: 1 1/4", 1 1/2" - Exterior use is limited to store fronts not over two stories 	9.0 (extent and thickness)	<ul style="list-style-type: none"> - Extent indicated on architectural drawings - Ashlar thickness: 7/8", 1 1/4", 1 1/2", 2" - Note: greater thickness suggested for multi-story or large pieces or severe climate conditions. Store fronts in 7/8" is entirely proper - Note: large size should be checked with marble size restrictions 	10.0 (extent and thickness)	<ul style="list-style-type: none"> - Extent indicated on the contract drawings - Ashlar thickness: 7/8", 1 1/4", 1 1/2", 2" - Note: greater thickness are suggested for multi-story projects or large pieces, or severe climate. Store fronts and small projects 7/8" thickness is entirely proper - Note: large size should be checked with marble contractor for size restrictions
b (joints)	<ul style="list-style-type: none"> - Extent indicated in drawings - Ashlar thickness: 7/8", 1 1/4" - Ordinary building front not over two stories thickness: 7/8", 1 1/4" - Large areas and northern sections of the country: 1 1/4", 1 1/2" - Exterior use is limited to store fronts not over two stories 	10.0 (jointing)	<ul style="list-style-type: none"> - Extent indicated on architectural drawings - Ashlar thickness: 7/8", 1 1/4", 1 1/2", 2" - Note: greater thickness suggested for multi-story or large pieces or severe climate conditions. Store fronts in 7/8" is entirely proper - Note: large size should be checked with marble size restrictions 	11.0 (Jointing)	<ul style="list-style-type: none"> - jointing show on contract drawings and further developed on approved shop drawings - 7/8" used in wall area, joints shall be 1/16" buttered solidly with non-staining elastic jointing compound (polysulfide or similar synthetic rubber base, or regular mastic type) or with cement lime mortar. - Color matching of joint compound with marble color

				<p>11.0 (Jointing)</p> <ul style="list-style-type: none"> - weight bearing joints shall be maintained by plastic or aluminum cushions - Thickness (1 1/4", 1 1/2", 2) joints of 1/8" or 3/16" shall have joints of a minimum of 3/16" solidly buttered with non-staining elastic jointing compound, maintaining weight bearing joints by plastic or aluminum cushions. ALT: thickness of (1 1/4", 1 1/2", 2) joints of 1/8" or 3/16" shall have joints of a minimum of 3/16" solidly buttered with non-staining setting mortar then rake out to a depth of 1/2" pointing uniformly with non-staining cement lime mortar or non-staining pointing compound - Expansion-contraction: long runs of marble veneer (eg. coping, spandrel belts, etc) provision shall be made for thermal expansion and contraction. - Large areas of ashlar veneer, joints provided horizontally at least every other story height, and one vertically at intervals of about 20 ft. - Coping and spandrel belt courses, expansion joints shall be provided not to exceed every 20 ft. of the "run" - all joints shall be located and detailed by the architect on the contact drawings - Expansion-contraction: joints shall be a minimum of 3/8" in width, shall be back-filled with an inert type resilient material such as a cotton rope, sponge rubber or plastic to not more than 1/2 the depth of joint and remaining from half-filled solid, preferably with a polysulfide or similar synthetic rubber base non-staining caulking compound approved by architect. - Spacer of hard rubber or similar material horizontal expansion joints are required to prevent squeeze out of point material in locations where the weight of super-imposed materials might tend to squeeze out
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				11.0 (Jointing)	<ul style="list-style-type: none"> - Horizontal expansion contraction joints shall be located directly beneath relieving angles when such angles occur at each story height - Jointing compounds shall be factory mixed and used according to manufacturer's instruction. It will not stain marble, corrode metals, or be adversely affected by long exposure to extreme sunlight, atmosphere, temp. - Special patented metal expansion joints incorporated both the necessary resilience and load bearing qualities shall be provided by others if required - Caulking mastics of the oil resin base type shall meet the requirements of Federal Specifications TT-C-598.
C (support)	<ul style="list-style-type: none"> - Veneer supported by continuous horizontal angles of structural steel fastened to the frame or masonry wall. (steel: cleaned of mill scale and rust and coated with non-staining paint before set) - Number of angle supports: (1) grade or sidewalk ,(2) above door, window opening, (3)over awning box, (4 or 5) each story height - When there is no window openings, supports at alternating ashlar courses or along two horizontal lines per story height - For vertical strips, anchors "properly placed to carry the weight of the marble facing above" 	11.0 (supports)	<ul style="list-style-type: none"> - Veneer supported by continuous horizontal angles and attachments furnished and securely fastened to the building (plates H & J) - Notes: non-corrodible metal. Stainless steel, bronze and hard brass. If structural steel is used must be cleaned of mill scale and rust and then coated by others, non-staining paint approved by architect. Paint dry thoroughly before set - Angle support located according to architectural and shop drawings and generally required over all openings and each story height or not more than 20' apart in vertical spacing - Where there are no windows, support shall be given along one horizontal line per story height - Notes: continuous angle at grade recommended on alteration or renovation projects - Veneer shall not be relied upon to support vertical loads other than the veneer material above it. (letters, signs, appliances hung supported by hangers in supporting wall) 	12.0 (supports)	<ul style="list-style-type: none"> - Veneer supported by horizontal angles and attachments furnished and securely fastened to the building by the General Contractor - note: where these angles and attachments are in direct contact with marble they shall be of non-corrodible metal. Short clip angles are preferred to continuous angles to insure proper alignment - Angle supports shall be located as shown on contract drawings or the shop drawings and generally required over all openings and at each story height or not more than 20' apart in vertical spacing - Where there are no window openings, support shall be given along one horizontal line per story height. (same for pilasters and other vertical facings) - veneer shall not be depended upon to support vertical loads other than the veneer material above it. (letters, signs, appliances hung supported by hangers in supporting wall)
d (anchorag e)	<ul style="list-style-type: none"> - Concealed anchors of copper, soft brass or aluminum wire 1/8" diameter - Number and locations of anchors at the discretion of marble contractor, but trade approved: (a) at least 	12.0 (setting and anchorag e)	<ul style="list-style-type: none"> - Refer to drawings for anchor placement - Number and location of anchors up to the discretion of the marble contractor but approved practice by MIA: (a) at least 2 anchors for slabs less than 2 sq. ft. (b) at least 3 anchors for sound slabs 2 	13.0 (anchorag e)	<ul style="list-style-type: none"> - Anchoring of marble shown on contract drawings - Marble Contractor's responsibility to anchor all marble securely

<p>d (anchorag e)</p>	<p>3 anchors for sound slabs 2 to 4 sq. ft. in area (b) at least 4 anchors for 4 to 12 sq. ft. (c) last least 6 anchors for 12 to 20 sq. ft. (d) 1 anchor every 3 sq. ft for slabs over 20 sq. ft. - (6) wire anchors attached to marble by hooked or embedded in cement-filled holes drilled 3/4" deep into the edges and parallel to face. Attached by inserting looped end of wire into a pocket drilled and shaped to receive and retain the loop. Holes filled with non-staining Portland cement mortar.</p>	<p>13.1, 13.3 (anchors)</p> <p>to 4 sq. ft. in area (c) at least 4 anchors for 4 to 12 sq. ft. (d) last least 6 anchors for 12 to 20 sq. ft. (e) 1 anchor every 3 sq. ft for slabs over 20 sq. ft. - Notes: earthquake area, refer to building codes - (a) veneer against prebuilt masonry wall (b) veneer setting concurrent with masonry back-up (c) veneer setting against reinforced concrete or masonry wall, where required by the building code - (a, b) Anchors kinds shall be brass or medium hard drawn copper, at least 1/8" diameter, or stainless steel in flat strips 1/16" thick - (c) Anchors kinds shall be brass, bronze or stainless steel of dove-tail, T-tail type - (a) Anchor installation attached to marble by hooked or embedded in cement filled holes 3/4" deep in the edges of the piece parallel to face. Attached by inserting looped end of wire into a pocket drilled and shaped to receive and retain the loop. Holes filled with non-staining cement mortar with accelerator. - (b) Anchor installation attached to marble by hooked or embedded in cement filled holes 3/4" deep in the edges of the piece, parallel to face. Wall-ends of the anchors shall be bent and securely built into the masonry back-up construction - (c) system of non-corrodible metal slots or boxes built into the concrete wall by others and non-corrodible dove-tail or T-tail wall ties or anchors, properly fitted and satisfactory to architect, embedded in the edges of the veneer pieces, used</p>	<p>13.0 (anchorag e)</p>	<p>- Generally, standing marble practice: minimum of 2 anchors shall be required on all pieces up to 2 sq. ft. in area, minimum of 4 anchors required on pieces up to 20 sq. ft. in area, minimum of 2 additional anchors required on each additional 10 sq. ft. - note: earthquake areas refer to building codes in that area. - note: all areas, anchorage must be positive and mechanical and shall not rely in whole or in part on "bond" provided by mortar spots around anchors and between marble and backup wall.</p>
<p>e (setting)</p>	<p>- In conjunction with anchors, marble held to masonry wall by spots of non-staining Portland cement and accelerator or bonding cement located near anchors and not spaced over 18" apart - Spots of Plaster of Paris used to give temp. backing to marble if Portland cement is used - note: importance of air space as protective layer</p>	<p>12.0 (setting and anchorag e) 13.2, 13.4, (settings)</p> <p>- Cleaning of the face, back and edges before any setting operations - (a) back of marble thoroughly coated with approved damp-proofing or water proofing paint (applied by others) before setting - (b) as the veneer is set, all pieces be completely parged on the back with non-staining cement paste - (c) back of veneer pieces shat not be damp-proofed nor parged when solid grouted - (a) air space and spots: 1" of clearance back of veneer and set each piece rigidly against spots of non-staining cement with accelerator, located at or near the anchors and spaced not further that 18" apart over the back of each piece - (b) masonry back-up: parged slabs be erected in place and maintained in proper alignment, and shall</p>	<p>13.0 (setting)</p>	<p>- All marble shall be cleaned on the face, back and edges before setting - During setting operations any dirt or setting materials in contact with exposed surfaces of marble removed immediately</p>

		12.0 (setting and anchorage) 13.2, 13.4, (settings)	be backed up with the masonry materials specified, all anchors being securely built-in as the wall construction progresses - (c) solid grouting: allow at least 1" clearance between back of veneer and concrete or masonry wall and grout this space full with non-staining cement grout made with clean washed sand, said grout to be poured after each course of veneer is set in place depth not effect alignment (6" for 1 1/4" or thinner and 10" for 1 1/2" or thicker) rodded and puddled and allowed to set enough to carry the weight of the next pour. Joints buttered full with neat white cement lime mortar raked out 1/2" and pointed with non-staining pointing mastic.	13.0 (setting)	
f (flashing)	- note: tops of marble should be covered with marble coping or non-staining metal (lead or aluminum) flashing - note: joints in marble coping should be filled with non-staining mastic compound	14.0 (flashing)	- installed by others - note: all top joints flashed over with non-ferrous, non-staining sheet metal flashing. Coping joints should be covered by a non-ferrous, non-staining weather cap strip pressed into the joint filled with non-staining mastic compound	15.0 (flashing)	- installed by the general contractor - completely waterproof installation must be provided
g (building codes)	- subject to conform to local building cods	16.0 (building codes)	- all above specifications are subject to correction to conform to local building cods	17.0 (building codes)	- all above specifications are subject to correction to conform to local building cods
		15.0 (cleaning)	- marble contractor shall remove all unused surplus materials in connection with contract and give marble a through cleaning to the satisfaction of the architect - no acids or harsh abrasive cleaning or steel wire brushes shall be used - note: fiber brush and clear water for cleaning	16.0 (cleaning)	- marble contractor shall remove all unused surplus materials in connection with contract and give marble a through cleaning with a fiber brush and clear water to the satisfaction of the architect - no acids or harsh abrasive cleaning or steel wire brushes shall be used
		17.0 (maintenance notes)	- decorative marbles require cleaning and reasonable maintenance at least once a year with spray of cellulose acetate or similar plastic lacquer		

				<p>14.0 (setting materials and methods)</p> <ul style="list-style-type: none"> - (a) veneer setting against prebuilt masonry wall, (b) veneer setting concurrent with masonry backup wall, (c) veneer setting against reinforced concrete or masonry wall, where required by the building code - (b) wire anchors shall be stainless steel, brass, medium hard drawn copper, or other non-corrodible metal at least 1/8" in diameter - (c) anchors shall be of stainless steel, brass, bronze or other non-corrodible metal and of the dove-tail or T-tail type as shown on the contract drawings. - (b) as veneer is set, all marble pieces shall be completely parged on the back with non-staining cement mortar - (c) back of veneer pieces to be solid-grouted shall not be damp-proofed nor treated with any material which would tend to impair bonding of the grout to the slab - (b) installation of anchors: anchors shall be attached to the marble by being hooked or embedded in holes 3/4" deep in the edges of the piece, parallel to the face and equidistant from front and back faces. The holes shall then e filled with non-staining cement mortar. Wall-ends of the anchors shall be bent and securely built into the masonry back-up construction. - (c) installation of anchors: a system of non-corrodible metal slots or boxes built into the concrete wall by the General Contractor and non-corrodible dovetail or T-tail wall ties or anchors, properly fitted and satisfactory to the architect, embedded in the edge of the veneer pieces shall be used - (b) masonry back-up: parged slabs shall be erected in place and maintained in proper alignment, and shall be backed up with masonry materials specified, all anchors being securely built in as the wall construction progresses
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				<p>14.0 (setting materials and methods)</p> <ul style="list-style-type: none"> - note: marble set immediately above foundation, foundation should be damp-proofed on top. An air space of 1" above the foundation and 1" behind the marble shall be provided to avoid traveling of moisture - note: if grouting is required between veneer and masonry wall, it should be non-staining cement and clean washed sand poured after each course of veneer is set in place to a depth that will not affect alignment (6" for 1 1/4" or thinner, 10" for 1 1/2" or thicker) rodded or puddled and allowed to set enough to carry the weight of the next pour - note: waterproofing should be omitted from back of marble when grouting is required - (c) solid grouting- allow at least 1" clearance between back of veneer and concrete or masonry wall and grout this space full with non-staining cement grout mixed: (mix ratio provided)
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(Cont. APPENDIX I: MIA- EARLY LITERATURE: 1948, 1955, 1961)

APPENDIX J: MIA- Dimension Stone Design Manuals I, II, III

Dimension Stone Design Manual I - 1971		Dimension Stone Design Manual II - 1983		Dimension Stone Design Manual III - 1985	
Section	Changes	Section	Changes	Section	Changes
	<ul style="list-style-type: none"> - Precast concrete: marble faced panels and marble veneer are separated sections in Part II - Product Use - Limitations include: compatible coefficient of thermal expansion, modulus of elasticity between concrete and marble - Minimum thickness of marble facing unit 7/8" - Marble veneer facing securely Bonded and Anchored to reinforced precast concrete panel - Panel Fabrication: apply a resilient bonding material if required, to the backs of marble facing units approx. 40 mil thick - Marble with natural void are to be parged approx. ¼" in thickness - Joints maintained at 3/16" width - General: 1 spring clip anchor each 2 sq. ft. - Panels should be attached with minimum of 4 connections to the structure - Joints between panels is at least 3/8" wide - Marble should meet Standards: ASTM C503; Tests on completed panels are conducted in accordance with ASTM E72; meet federal specifications SS-S-721C 		<ul style="list-style-type: none"> - Contact the pre-cast supplier for details 		<ul style="list-style-type: none"> - Refer to recommendations published by the Pre-Stressed Concrete Institute (PCI); or contact the Pre-cast Supplier for details
Intro	<ul style="list-style-type: none"> - size of marble faced precast panels limited by forming and erection techniques - marble does play a part in the strength of the panel. Values by marble supplier 		n/a		n/a
Details Drawings (MIA 1970)	<ul style="list-style-type: none"> 1 drawing - anchor inserted into marble detail - joint detail: standard, quirk, butt - elevation & panel section 		n/a		n/a
General	<ol style="list-style-type: none"> 1. Location of marble: 2. Finish: 3. Size, type and location of joints: 4. Dimensions and configuration: 5. Support and anchorage: 6. Pattern: 		n/a		n/a
Description	pertains to the finishing of all marble facing units for precast concrete as indicated on the drawings and described in these specifications		n/a		n/a
Related Sections	<ul style="list-style-type: none"> 3.1 Precast Concrete Panels 3.2 Sealing 		n/a		n/a

Requirements	General the plans, general conditions, supplementary general conditions, executed agreement), certification, samples, shop drawings, delivery, storage and precasting, cleaning, protection		n/a		n/a
Materials	- Marble shall meet requirements of ASTM C503 - Anchors, dowels, cramps: shall be stainless type 302 or 304. All other hardware shall be galvanized iron or steel		n/a		n/a
Fabrication	fabricated in accordance with approved shop drawings		n/a		n/a
Setting material	7.1 Marble joint filler strips: shall be no staining resilient material 7.2 Bonding agent: shall be no staining resilient latex, polyurethane, polysulfide or flexible epoxy 7.3 Portland cement: shall meet the ASTM C150 requirements 7.4 Sand: shall meet the ASTM C144 requirements 7.5 Sealants (by others): shall be a non staining elastic adhesive compound		n/a		n/a
Installation	8.1.1 Clean marble facing units with vacuum or air hose, wash with clean water and clean non-staining rags or sponges 8.2 Place marble facing units with exposed face down in panel form, insert crimp spring clip anchors 8.3 Apply a bonding agent, if required, to the backs of the marble facing units approx. 40 mils thick of approved resilient bonding material 8.4 Marble facing unit joints must be kept free of concrete the full depth and mortar kept from running through to the exposed face of the marble by an approved marble joint filler strip notes: facing units of marble varieties with natural voids require the backs to be parged prior to placement in forms 8.2.1 After sufficient strength has developed, remove carefully 8.2.2 Do not rest panels on face or edge of the marble 8.2.3 Prior to storing the panels for future curing, toughly clean all marble facing units joints		n/a		n/a
SpecDataSheet	Yes		n/a		n/a

(Cont. APPENDIX J: MIA- Dimension Stone Design Manuals I, II, III)

APPENDIX K: MIA- Dimension Stone Design Manuals IV, V, VI

Dimension Stone Design Manual IV – 1991		Dimension Stone Design Manual V - 1999		Dimension Stone Design Manual VI - 2003	
Section	Changes	Section	Changes	Section	Changes
	<ul style="list-style-type: none"> -Detailed recommendations from PCI - Guidelines should be used with appropriate approval due to varying geographic conditions - Drawings indicate the use of "bondbreakers" between the precast concrete and the stone veneer - Thickness of facing stone is generally 1', 1-1/4", 1-1/2", 2", or thicker. Refer to PCI handbook - "U" cramp bar or spring clip anchor in use - list of stone types and the required ASTM standard specification 		<ul style="list-style-type: none"> - No changes since pervious version - Installation refers readers to the PCI Handbook 		<ul style="list-style-type: none"> - Addition of Serpentine and Travertine to the variety of stones
Intro	<ul style="list-style-type: none"> - attention to physical properties of the stone, anchorage of the stone to concrete safety factors, effect of finishes on strength of stone - physical properties: tensile , modulus of elasticity, coefficient of thermal expansion, volume change - mockups for testing wall, window, and joint performance (wind and rain conditions) - qualified personnel for coordinating between general contractor, stone fabricator and precast supplier - detailed recommendations from PCI - guidelines require appropriate approval due to differences in geographical differences 	Intro	<ul style="list-style-type: none"> - attention to physical properties of the stone, anchorage of the stone to concrete safety factors, effect of finishes on strength of stone - physical properties: tensile , modulus of elasticity, coefficient of thermal expansion, volume change - mockups for testing wall, window, and joint performance (wind and rain conditions) - qualified personnel for coordinating between general contractor, stone fabricator and precast supplier - detailed recommendations from PCI - guidelines require appropriate approval due to differences in geographical differences 	Intro	<ul style="list-style-type: none"> - attention to physical properties of the stone, anchorage of the stone to concrete safety factors, effect of finishes on strength of stone - physical properties: tensile , modulus of elasticity, coefficient of thermal expansion, volume change - mockups for testing wall, window, and joint performance (wind and rain conditions) - coordinator between general contractor, stone fabricator and precast supplier - detailed recommendations from PCI - guidelines require appropriate approval due to differences in geographical differences
Details Drawings (MIA 1991)	2 drawings -Typical section -Typical section of sill, soffit and fascia	Details Drawings (MIA 1999)	2 drawings - Typical section - Typical section for sill, soffit and fascia	Details Drawings (MIA 2003)	2 drawings - Typical section - Typical section for sill, soffit and fascia
Data Sheet	1. product name: stone-faced veneer precast concrete panels 2. manufacturer: MIA 3. production description: exterior precast panels - limitations: physical properties of stone compared to concrete (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change) refer to PCI handbook	Data Sheet	1. product name: stone-faced veneer precast concrete panels 2. product description: exterior precast panels - limitations: physical properties of stone (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change) refer to PCI handbook	Data Sheet	1. product description: exterior precast panels - limitations: physical properties of stone (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change.) refer to PCI handbook

<p>Data Sheet</p>	<p>- finishes: polished, honed, thermal, bushhammered, rough, abrasive, natural cleft (polish finish not recommended for marble or limestone) - colors: most of the commercially available varieties are suitable - stone veneer panel size: 1", 1-1/4", 1-1/2", 2", or thicker as specified (refer to PCI handbook) 4. technical data: each stone variety conforms to applicable ASTM standard specification: granite ASTM C615, limestone ASTM C568, marble ASTM C503, quartz-based stone ASTM C616, slate ASTM C629 5. installation: generally installed by the general contractor. refer to PCI handbook</p>	<p>Data Sheet</p>	<p>expansion, volume change.) refer to PCI handbook - finishes: polished, honed, thermal, bushhammered, rough, abrasive, natural cleft (polish finish not recommended for marble or limestone) - colors: most of the commercially available varieties are suitable - stone veneer panel size: 1", 1-1/4", 1-1/2", 2", or thicker as specified (refer to PCI handbook) 3.technical data: each stone variety conforms to applicable ASTM standard specification: granite ASTM C615, limestone ASTM C568, marble ASTM C503, quartz-based stone ASTM C616, slate ASTM C629 4. installation: generally installed by the general contractor. refer to PCI handbook</p>	<p>Data Sheet</p>	<p>- finishes: polished, honed, thermal, bushhammered, rough, abrasive, natural cleft (polish finish not recommended for marble or limestone) - colors: most of the commercially available varieties are suitable - stone veneer panel size: 1", 1-1/4", 1-1/2", 2", or thicker as specified (refer to PCI handbook) 2.technical data: each stone variety conforms to applicable ASTM standard specification: granite ASTM C615-99, limestone ASTM C568-99, marble ASTM C503-99e1, quartz-based stone ASTM C616-99, serpentine ASTM C1526-02, slate ASTM C629-99, travertine ASTM C1527-02 3. installation: generally installed by the general contractor. refer to PCI handbook</p>
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(Cont. APPENDIX K: MIA- Dimension Stone Design Manuals IV, V, VI)

APPENDIX L: MIA- Dimension Stone Design Manuals 7.1, 7.2

Dimension Stone Design Manual 7 .1- 2007-2010		Dimension Stone Design Manual 7 .2- 2011	
Section	Changes	Section	Changes
	<ul style="list-style-type: none"> - "U" cramp bar is changed to "Hairpin" spring clip anchor - Angle of 79.648° for the slope of the sill is added to the detail drawings 		- No changes since the previous version
Intro	<ul style="list-style-type: none"> - attention to physical properties of the stone, anchorage of the stone to concrete safety factors, effect of finishes on strength of stone - physical properties: tensile , modulus of elasticity, coefficient of thermal expansion, volume change - mockups for testing wall, window, and joint performance (wind and rain conditions) - coordinator between general contractor, stone fabricator and precast supplier - detailed recommendations from PCI - guidelines require appropriate approval due to differences in geographical differences 	Intro	<ul style="list-style-type: none"> - attention to physical properties of the stone, anchorage of the stone to concrete safety factors, effect of finishes on strength of stone - physical properties: tensile , modulus of elasticity, coefficient of thermal expansion, volume change - mockups for testing wall, window, and joint performance (wind and rain conditions) - coordinator between general contractor, stone fabricator and precast supplier - detailed recommendations from PCI - guidelines require appropriate approval due to differences in geographical differences
Details Drawings (MIA 2007)	2 drawings <ul style="list-style-type: none"> - Typical section - Typical section for sill, soffit and fascia 	Details Drawings (MIA 2003)	2 drawings <ul style="list-style-type: none"> - Typical section - Typical section for sill, soffit and fascia
Data Sheet	1. product description: exterior precast panels <ul style="list-style-type: none"> - limitations: physical properties of stone (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change.) refer to PCI handbook - finishes: polished, honed, thermal, bushhammered, rough, abrasive, natural cleft (polish finish not recommended for marble or limestone) - colors: most of the commercially available varieties are suitable - stone veneer panel size: 1", 1-1/4", 1-1/2", 2", or thicker as specified (refer to PCI handbook) 2.technical data: each stone variety conforms to applicable ASTM standard specification: granite ASTM C615, limestone ASTM C568, marble ASTM C503, quartz-based stone ASTM C616, serpentine ASTM C1526, slate ASTM C629, travertine ASTM C1527 3. installation: generally installed by the general contractor. refer to PCI handbook	Data Sheet	1. product description: exterior precast panels <ul style="list-style-type: none"> - limitations: physical properties of stone (tensile, compressive and shear strength, modulus of elasticity, coefficient of thermal expansion, volume change.) refer to PCI handbook - finishes: polished, honed, thermal, bushhammered, rough, abrasive, natural cleft (polish finish not recommended for marble or limestone) - colors: most of the commercially available varieties are suitable - stone veneer panel size: 1", 1-1/4", 1-1/2", 2", or thicker as specified (refer to PCI handbook) 2.technical data: each stone variety conforms to applicable ASTM standard specification: granite ASTM C615, limestone ASTM C568, marble ASTM C503, quartz-based stone ASTM C616, serpentine ASTM C1526, slate ASTM C629, travertine ASTM C1527 3. installation: generally installed by the general contractor. refer to PCI handbook

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