MODERN STONE CLADDING
Design and Installation of Exterior Dimension Stone Systems

MICHAEL D. LEWIS AIA
ACKNOWLEDGEMENTS

While many contributed immeasurably to this effort, the inexhaustible patience of my wife Marianne and my two sons Jensen and Alexander made this work possible.

They sacrificed endless evenings and weekends through the last ten years to study, practice, and share the technology of ... “rocks” on buildings.

Without their support and infinite patience, this book would not be possible.
CONTENTS

ABSTRACT ix

FOREWORD xi

1 INTRODUCTION TO MODERN STONE CLADDING:
Approaching Design with Rational Principles 1

The Professional’s Design Responsibility
The Development Of Cladding Fundamentals
   Boundary Conditions for Stone Cladding
   Legitimate Testing in Comparison to Existing Skins
   Organization of the Evaluation Process
   Engineering Decisions That Derive Designs
   Partnering Makes This Approach Successful
How Future Architecture Benefits from Modern Stone Cladding

2 PRECEDE NT S TO MODERN STONE CLADDING:
How Stone Became Thin on Building Skins 7

Stone’s Tradition As Shelter
The Ascent of the Bearing Wall
Wall Metamorphosis Caused by the Iron Skeleton
Slender Iron Members Replace Massive Masonry Piers
The Masonry Curtainwall Is Born from Fire
Commercial Momentum Outpaces Masonry’s Conventional Limits
Consequences Learned from Freeing the Facade from the Frame
Architectural Fashion Exploits a Skin Separate from Skeleton
Reluctant Rejection of Traditional Style
Unexpected Problems with Early “Thin” Walls
Engineering Analysis Evolves with Construction Ingenuity
Adapting Stone to Fit into Metal Curtainwalls
Modernized Dimension Stone Manufacturing
Stone’s Potential in the Future’s Architecture
3 THE FUTURE OF STONE CLADDING:
Toward Load-And-Resistance Factor Design for Exterior Stone Cladding 23

4 DETERMINING RESPONSIBLE DESIGN VALUES:
Formulating Load-And-Resistance Factor Design for Exterior Stone Cladding 27

Failure Means Fracture
Risks Compared with Their Consequences
Reliability with Changing Variables
Load Derivation and Design Applications
Consolidated Uncertainties in Current Stone Engineering
Segregated Uncertainties in a Limit-State Approach
Factors for Loads and Resistances

5 GUIDE SPECIFICATION FOR STONE CLADDING SYSTEMS 39

Scope and Applicability of This Guide Specification
Why Thin Stone Requires a Unique Engineering Process
The Structure of The Engineering Process
A Stone System’s Boundary Conditions
The Engineering Sequence
A Case Study That Applies the Sequence
The Approach Related to Existing Practices

Standards for Depicting and Specifying Stonework
Standards for Presenting Stonework in Contract Documents
Limits and Dependencies on Interfacing Work
The Special Abilities of a Qualified Stone Cladding Designer

Materials Used to Construct Interfacing Systems in Exterior Walls
Metal Integrity and Compatibility
Joint Filler Function and Capability

How to Keep Exterior Joints Weathertight
Stone Panel Movement Freedom
The Environmental and Structural-Proof Function Of The Joint
Isolation of Components That Occupy the Joint
Static Effects That Influence Joint Sizing
Dynamic Effects That Influence Joint Sizing
Effects That Change Horizontal Joint Widths
Effects That Change Vertical Joint Widths

Testing Used to Design Stone and Its Anchors
Factors That Influence Stone and Anchorage Performance
An Approach to Objectively Evaluate These Influences
Standard Methods from The American Society for Testing and Materials
Geological Mineral Compositions of Stones
Properties That Affect Natural Stone Structural Performance
Tests Sequenced to Quantify Stone-Clad Wall System Characteristics
Test Value Interpretation
Tests Designed to Evaluate Anchorages
Tests Designed to Prove the Capacity of an Assembly
Anchorage Device Mechanics
The Function of the Stone Anchor
Proper Design and Installation Philosophy
Correct Anchorage Device Configuration
Handling Stone During Installation
Basic Anchor Device Types
Proper Application and Optimization of Kerfs
Proper Application and Optimization of Dowels
Case Study Testing Applied to the Design Process
ASTM Standard Tests for Material Unit Strengths
Theoretical Panel Test by Finite-Element Structural Analysis
Actual Panel Test for Preliminary Load Capacity
Anchor Capacity and Effective Engagement Length Test
Complete Assembly Full-Panel Chamber Test

BIBLIOGRAPHY

INDEX
THIS book documents a sequenced procedure to design exterior dimension stone cladding. The design approach avoids arbitrary safety factors by considering performance variables that can establish true safety and durability. This text presents a process to select, design, and install dimension stone cladding and support systems.

Within a sequenced format, extensive explanations with new engineering applications enhance recognized industry practices and include successful exemplars to guide objective and rational decisions.

This approach increases awareness of the individual influences that affect exterior wall performance. These influences, termed “uncertainties,” can each be researched to establish their impact on the risk of failure. They must be correlated to existing work. Evaluated individually, they formulate load and resistance factor design for dimension stone. This approach tends to provide safe and durable stone projects.
THE intent of this manual is to outline the process of selecting, designing, and installing stone cladding systems for exterior walls. Stone’s physical nature and cladding retention systems vary widely. Their potential applications are widespread.

The engineering process should recognize exemplars before tests. Modern construction should include successful walls enduring in the real-world “laboratory.” It should not duplicate the failures. These past lessons, not just fresh tests, should guide selection, testing, design, engineering, and installation. This approach identifies those variables known to influence stone cladding system performance. Each variable is considered separately within the process to optimize the solution. Applying this process results in better projects for all parties involved. Better walls are more efficient to construct and maintain. Well-constructed walls are more durable. And more durable walls are safer and create more comfortable space for the public. This manual is not a code that formulates objective limits. Further structured practice and research can objectively measure the variables that influence performance. This manual organizes the principles that base such research on those variables.

Chapter 1, Introduction to Modern Stone Cladding and Chapter 2, Precedents to Modern Stone Cladding, discuss the history of stone as it evolved into modern “thin,” non-loadbearing cladding.

Chapter 3 on Determining Responsible Design Values and Chapter 4 on The Future of Stone, outline a variable-based design procedure analogous to load-and-resistance factor design.

Chapter 5, Guide Specification for Stone Systems, advises owners, architects, engineers, and contractors about the specialty of modern stonework.

This manual comprises a process that assists users to rationally select, design, and install stone cladding for exterior walls.

This manual is sponsored by Committee C-18 on Dimension Stone.
ABOUT THE AUTHOR

AS LEAD CONSULTANT for the Facade Group at THP Limited in Cincinnati, Ohio, Lewis works on both existing and new building facades. He investigates existing facade distress and its causes and develops rehabilitations to restore their integrity. Using knowledge from these exemplars, he develops new stone facade systems that simplify production and installation techniques while optimizing quality and durability. His combined environmental, structural, architectural, and installation expertise allows a comprehensive approach to facades. He is also an Adjunct Professor of Architecture at the University of Cincinnati, teaching construction theory, structural economy, and curtain wall science.

Mr. Lewis is a registered architect and holds a Master of Science in Structural Engineering. His facade expertise includes historic preservation, construction management, and building technology. Notable recent projects include repair of the terra cotta facade of Cincinnati's Central Trust Tower (34 stories designed by Architect Cass Gilbert), rehabilitations for the College Conservatory of Music at the University of Cincinnati (Architects Pei Cobb Freed and NBBJ-Roth), the stone skin for the Dubai National Bank Headquarters on the Persian Gulf shore, Harrah's Jazz Casino in New Orleans (Perez Ernst Farner, Architects) and the Federal Reserve Bank of Cleveland (Architects Hellmuth, Obata, Kassabaum with VanDijk Pace).

Lewis began his professional career researching and developing special lightweight dome, cable, and envelope structures with the engineering firm of Geiger-Berger Associates PC of New York. He then was project engineer for specialty facade subcontractor Industrial First and directed engineering of the stone facades of two Chicago high-rises; 190 South LaSalle (42-stories by Architect Philip Johnson and John Burge) and AT&T Corporate Center (70-stories by Architect Skidmore, Owings, and Merrill). Later, Lewis joined Harmon Contract W.S.A.'s Commercial Construction Division as a Project Manager in the Major Projects Group. With Harmon he directed the engineering, manufacture, assembly, installation, and contract administration of total envelope systems for Cincinnati's Chemed Center (32-stories by Architect Skidmore Owings and Merrill) and the University of Cincinnati's Engineering Research Center (8-stories by Architect Michael Graves and KZF).

As chairman of ASTM C18.06 on Dimension Stone Anchors and Anchoring Systems, Lewis directs standard development for cladding engineering such as ASTM C1242 Standard Guide for the Design, Selection, and Installation of Exterior Dimension Stone Anchors and Anchoring Systems, under the advisement of many experts on the committee. He is also an active member of other C18 committees responsible for specifications, testing, and durability standards for dimension stone. As a member of Committee E6 on Building Performance, he is also involved with promulgating standards for exterior building wall performance, historic building technology, and rehabilitation.

Mr. Lewis is a member of the American Institute of Architects, the Marble Institute of America, the National Trust for Historic Preservation, the Association for Preservation Technology, and Terra Cotta Conservation Group. He has authored and contributed to articles published in Stone World, Dimensional Stone, Architecture, and Standardization News and has presented lectures on exterior cladding to many audiences.