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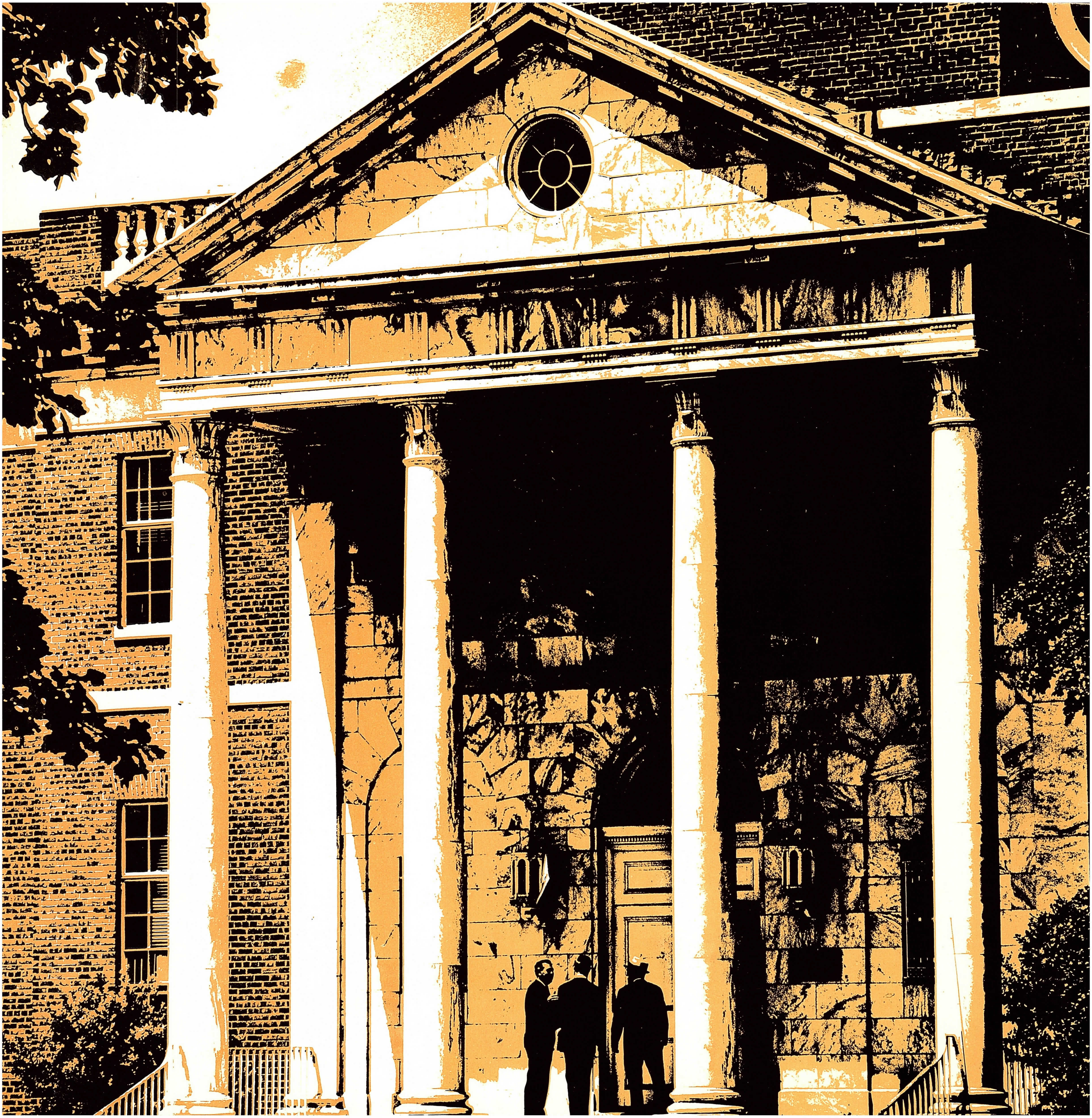

student publication
of the school of design
volume seventeen number one

BUILDING SKELETONS

an investigation of ten buildings : brian shawcroft
and twenty students of the school of design
north carolina state university
raleigh, north carolina
winter 1967

BUILDING SKELETONS

BRIAN SHAWCROFT was born in Nottingham, England in 1929. After completing a five year course of study at South West Essex Technical College and School of Art in 1953, he was engaged in the design of Schools in London and studied photography at the Central School of Arts and Crafts. In 1956, he joined the firm of Page and Steele, Architects, of Toronto, Canada. A senior designer at the time of his departure, he took the degree of Master in Architecture at Massachusetts Institute of Technology in 1960. During this period a number of books and journals in the United States and Canada published both his photographic and written commentary. He served as a design critic at the Boston Architectural Center, and is presently an Associate Professor of Architecture in the School of Design at North Carolina State University in Raleigh. Having been a co-winner of the 1962 Homes for Better Living Award of Merit, he has also established his own practice in Raleigh, completing ten residences in this area, and serving as Consulting Architect for the design of the Science Building, East Carolina College, Greenville, North Carolina, School of Nursing and School of Dentistry, University of North Carolina at Chapel Hill.

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This magazine was originated by the students of the School of Design in 1950, and is maintained as an independent student project. The publication is supported by student fees, proceeds from the Annual Art Auction, donations of patrons, and the sale of individual issues.

The Student Publication of the School of Design is available by mail order. The price of this issue is $2. Back issues, Vol. 9 and earlier, are $1.50 if not out of print. All prices are net and provisional.

Address all inquiries to Student Publication of the School of Design, P. O. Box 5273, Raleigh, North Carolina 27607.

Distributors: Wittenborn and Company, 1018 Madison Avenue, New York, New York 10021; Alec Tiranti, Ltd., 72 Charlotte Street, London W. I., England.

TECHNICAL INFORMATION: The plates for this publication were executed in black ink on white board, then photographically reduced to approximately half size and printed on 60 lb. cover stock. Force arrows were overprinted in a warm red ink from tracing paper overlays. The text appears in Century 10 pt., with titles in Inserat Grotesque 36 pt.

BUILDING SKELETONS:

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brian shawcroft and twenty students
of the school of design·student
publication of the school of design©·
volume seventeen number one·
north carolina state university·
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The staff of the Student Publication extends their thanks to the following persons:

For his continued interest and support,

Dean Henry L. Kamphoefner

For their secretarial assistance,

Anne Craddock
Janet Vermillion
Winifred Hodge
Rita Westhoff
Betty Hill

For their special interest and technical assistance,

Keyes, Lethbridge and Condon
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FARNSWORTH HOUSE	**1B**	*Coleman Hughes Bynum Jr.*
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INTRODUCTION: In the course of practice and teaching Architecture, one of the problems that has concerned me consistently is the lack of understanding of structural systems rather than a misunderstanding of structural principles. My own introduction to the subject consisted of fragmentary and unrelated detail information. It was only after several years of consulting closely with excellent structural engineers, that I was able to synthesize some of the knowledge. Architectural students have traditionally been expected to design complex buildings with very sparce information of structural systems and how they work, and are sometimes expected to invent new systems to solve their problems without the necessary input of knowledge. Another aspect of the problem has been the medium in which this necessary information has been presented. The medium of the Architect is principally three-dimensional, therefore, he must learn to think in three-dimensional terms. It would seem necessary that a system of graphics that adequately represents whole spatial concepts would be the most readily understood.

With a class of fourth year students in the School of Design, we have 'taken apart' graphically a group of simple framed buildings in an attempt to understand how they were 'put together' physically. The aim of the investigation was to synthesize graphically how a system was used, how the forces acting externally and internally were resolved by the structure, and the forms that were created. It is in no way a criticism of the buildings chosen nor is it a thesis that the structure is the only determinate of form.

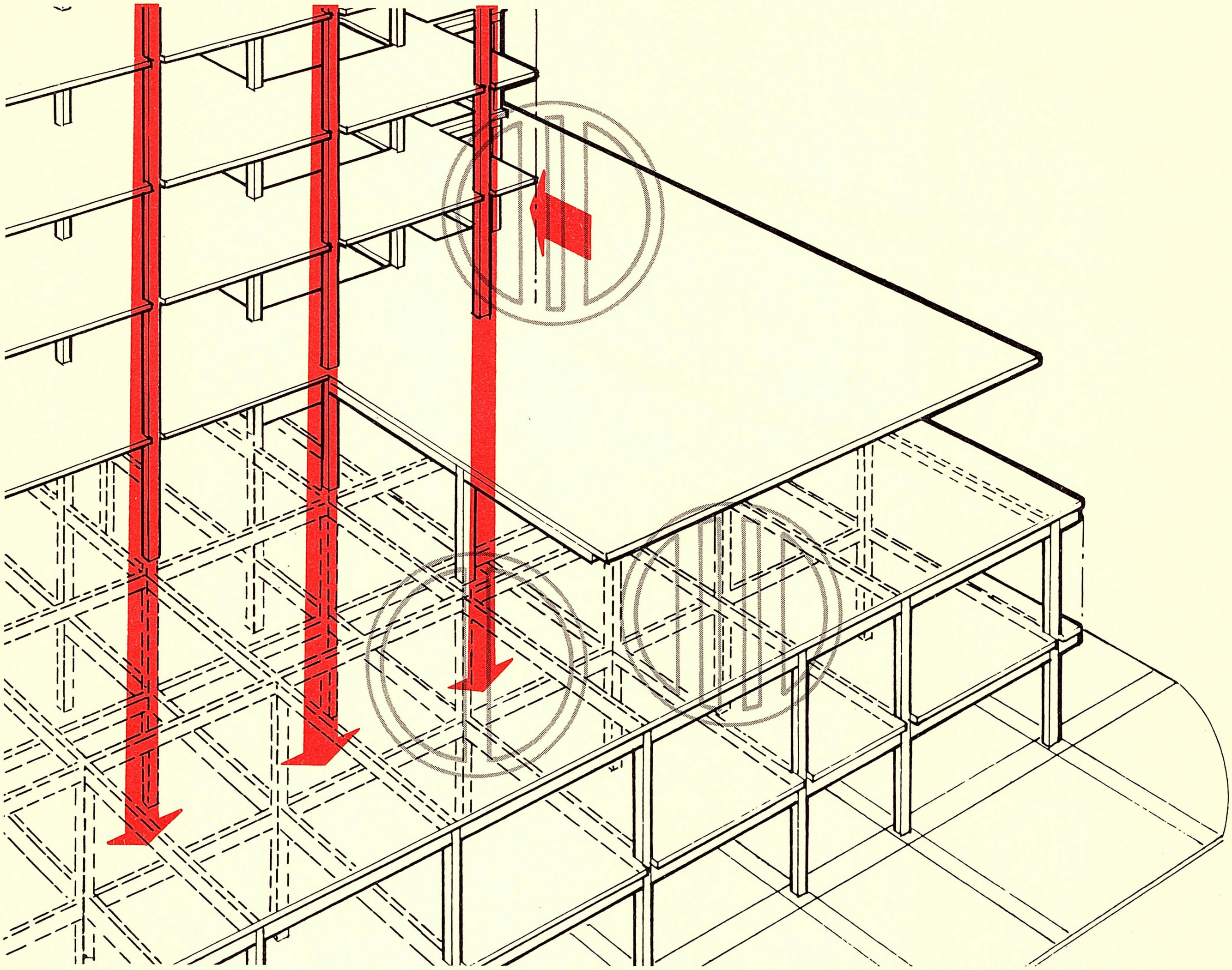
BRIAN SHAWCROFT

PREFACE: Concern for clarity, accuracy, and the potential of a strong graphic statement directed students and faculty in the selection of the ten buildings to be examined. Research was then initiated by each pair of students, followed by an unrestricted preliminary presentation. These initial efforts employed isometric, axonometric, perspective system, and various line conventions for section lines, ground lines, hidden lines, etc. After review and consideration, the perspective system and line convention used in this presentation were established. Arrows have been employed to further clarify the resolution of internal and external forces. While not a quantitative expression, they do serve to strengthen the accumulative and directional quality of the forces acting on and within the structure.

The value to each student involved with this project, in terms of research, analysis, synthesis, and delineation is readily apparent. However, in this presentation of the work, the full extent of detail and analysis is neither attempted nor implied. More importantly, by defining a vocabulary basic to all the systems investigated, we have tried to clarify the critical elements and interactions of each building.

The project is not, in any interpretation, an expression of the comparative scale of the buildings. Rather, the scale has been varied as required from drawing to drawing, to facilitate the understanding of each structural system, which is at once the impetus and objective of each image.

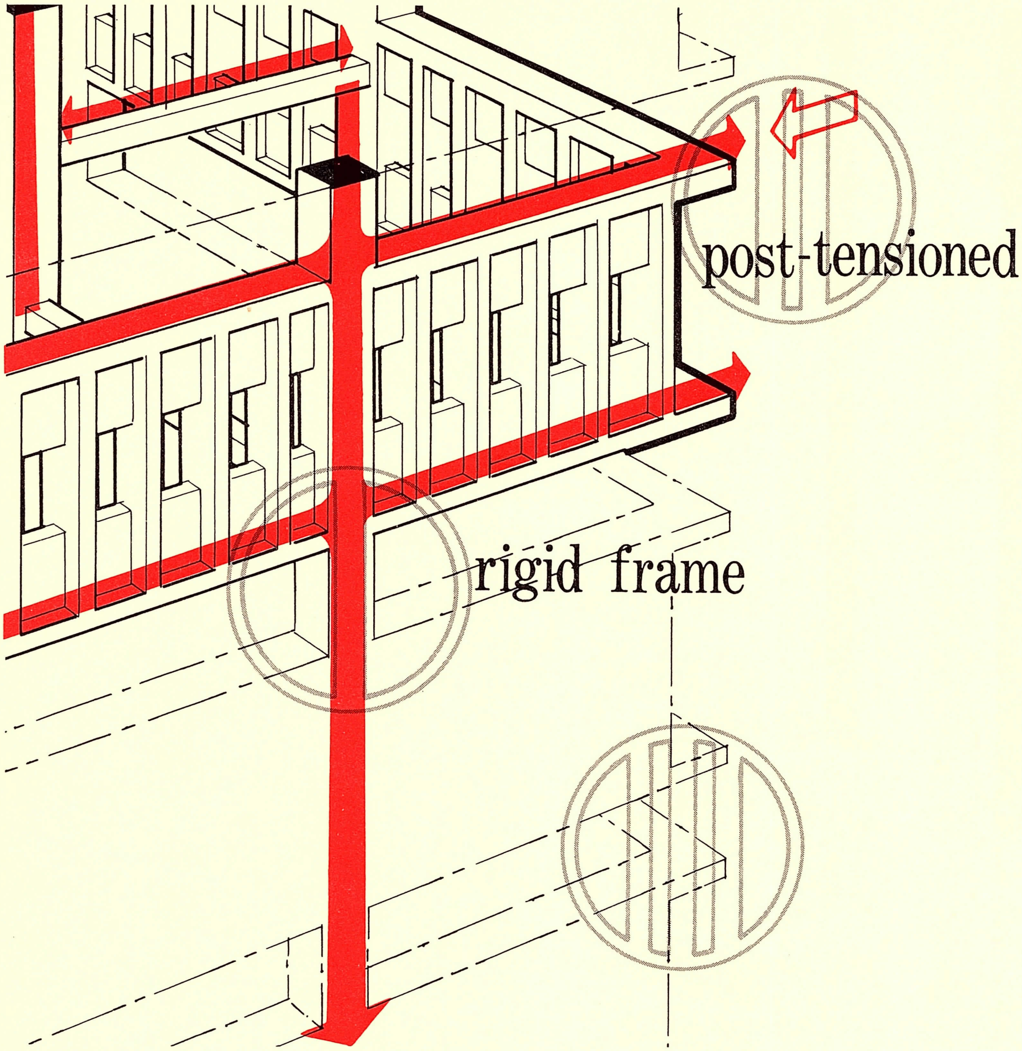
RANDOLPH R. CROXTON



TAPERING OF ARROWS REFLECTS THE ACCUMULATION OF LOADS IN DESCENT.

WIND FORCES: SOLID ARROWS PERPENDICULAR TO THE BUILDING'S VERTICAL AXIS.

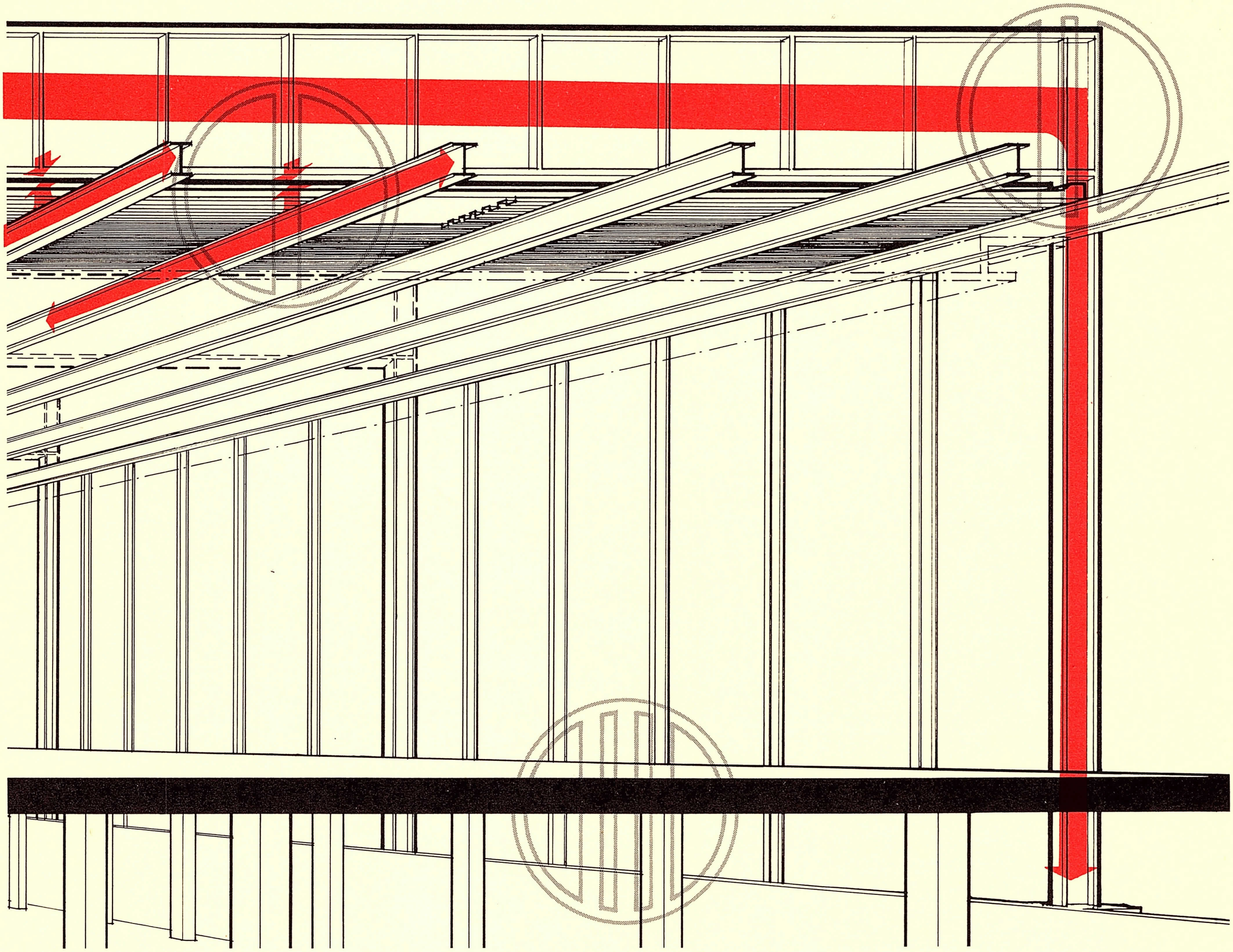
HIDDEN LINES: ELEMENTS OF THE SYSTEM NORMALLY UNSEEN IN EACH DRAWING.



RIGID FRAME: CONTINUITY OF COLOR INDICATES STRUCTURAL CONTINUITY.

POST TENSIONING: HOLLOW ARROWS ORIENTED ALONG THE AXIS OF TENSION.

GHOST LINES: INDICATING THE TOTAL EXTENT OF THE BUILDING.



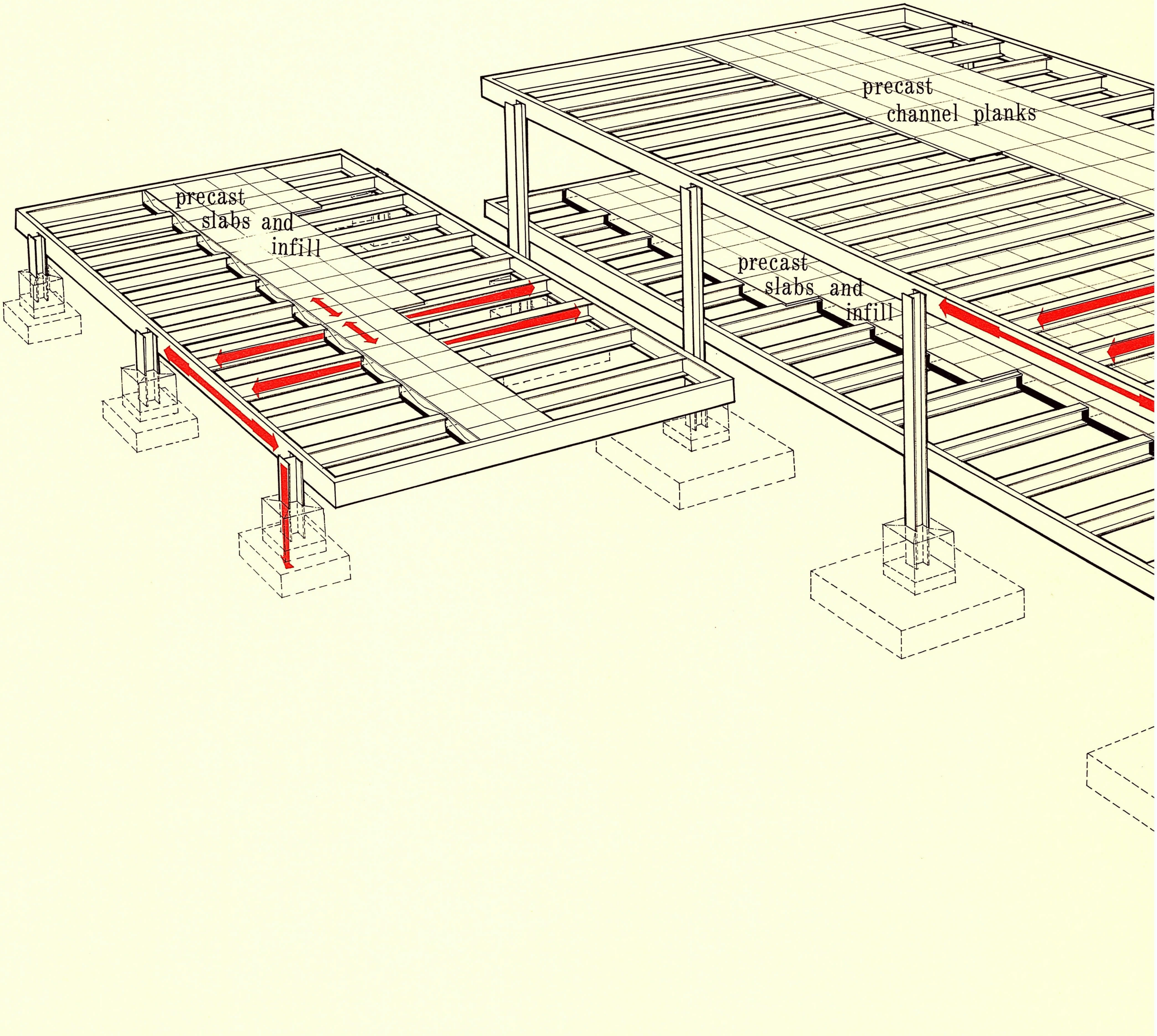
SPECIAL CONDITION: IMPORTANT CONNECTION, NOT STRUCTURALLY CONTINUOUS.

RIGID BENT: CONTINUITY OF COLOR INDICATES STRUCTURAL CONTINUITY.

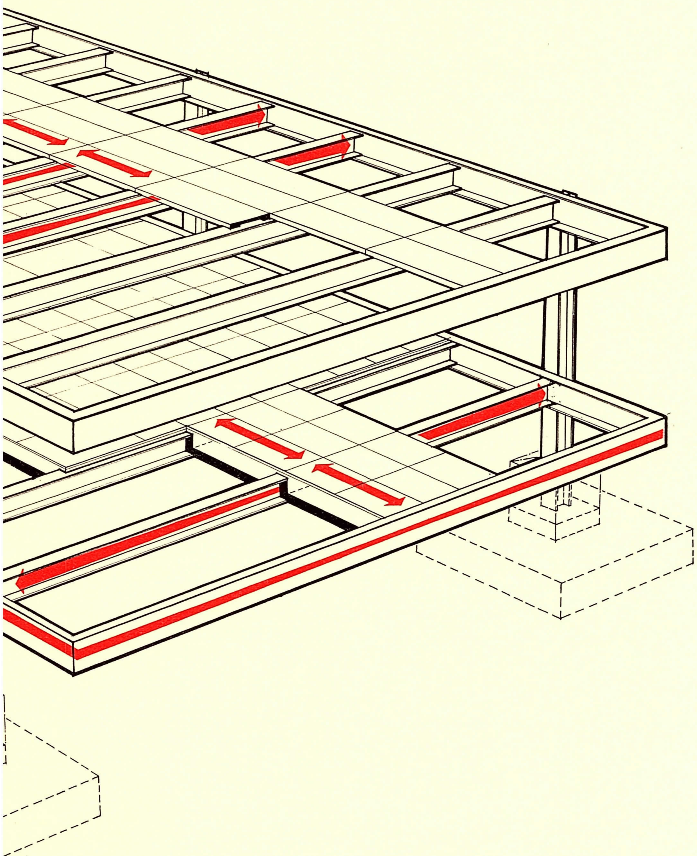
ALL SECTIONS ARE INDICATED BLACK IN THE PLANE OF THE CUT.

In the past, financing of the Publication was realized through proceeds from student fees, sale of issues, and the Annual Art Auction. Additional, timely, and significant support was also received from interested persons outside the School of Design. This support, in the form of annual pledges for each issue, has been confused by the announce-as-published policy necessitated by the increasing scope and complexity of the work. In anticipation of support requirements for the second book of this volume, and as a clarification of the timing of such assistance, this request is now directed to the past supporters of the Publication and all other interested parties. All donors (fifty dollars or more) and patrons (sixteen dollars or more) of record are presented with this issue in the hope that it will not only justify your continued support, but also represent a worthy addition to the literature of the profession.

RANDOLPH R. CROXTON



precast
slabs and
infill
precast
channel planks
precast
slabs and
infill



FARNSWORTH HOUSE

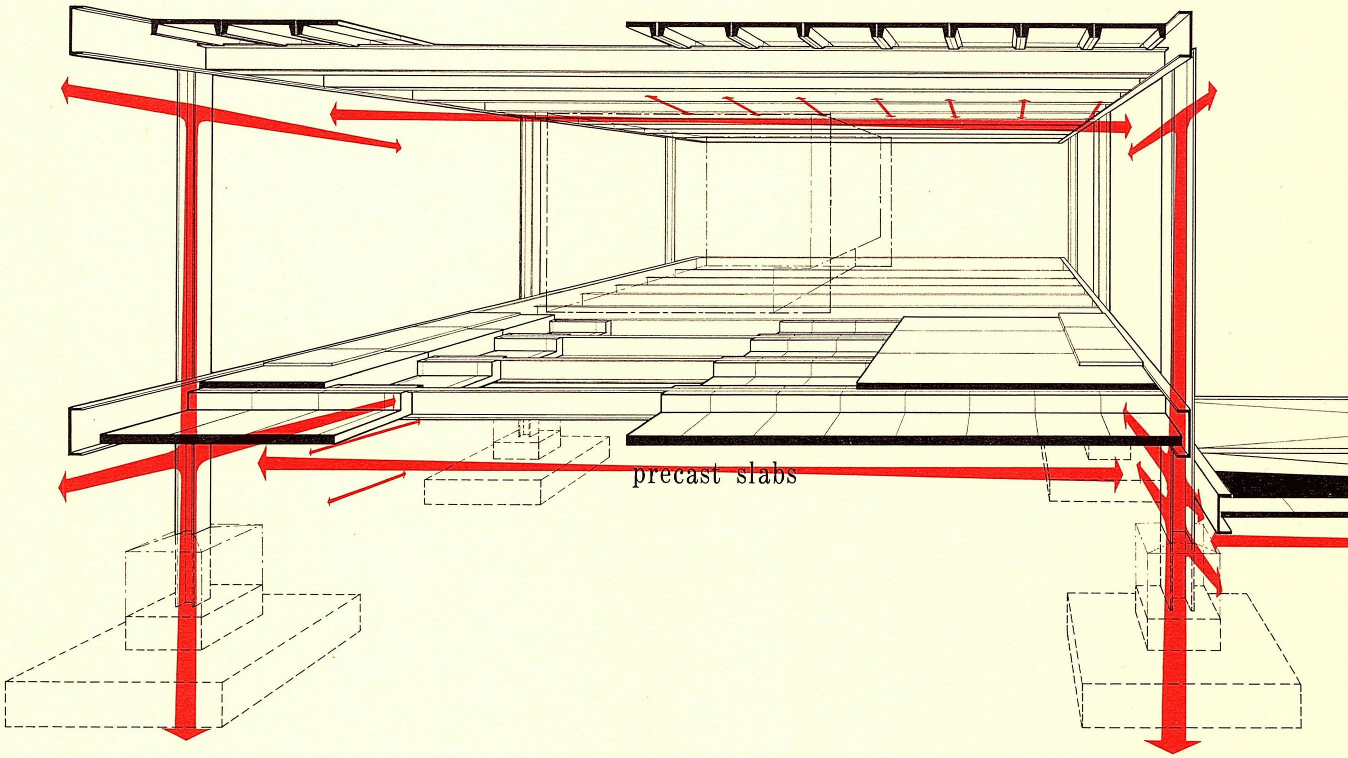
Plano, Illinois **1950**

Architect: Mies van der Rohe
Structural Engineer: Office of Mies van der Rohe

Maurice Durr Gulledge

Structural System

The structural frame of welded steel is supported on individual footings. The roof and floor planes have perimeter channels supporting I-beams that span in the short direction. These planes are supported above the ground by widely spaced columns. All horizontal dimensions are on a 2 foot x 2 foot 9 inch module. The deck is 22 feet x 55 feet and the house is 28 feet x 77 feet. The design determinants were: proportion, simplicity of form, and separation from the land.

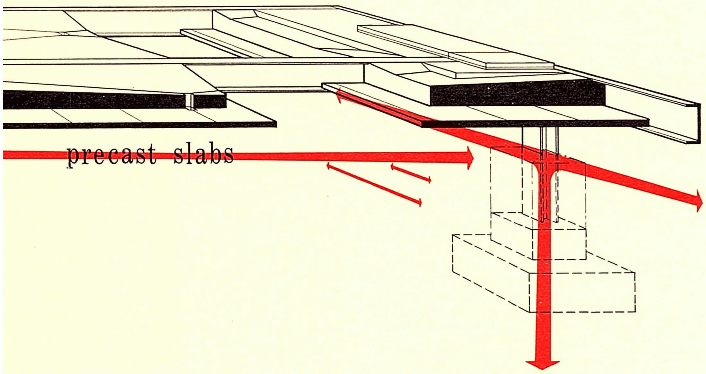

precast slabs

FARNSWORTH HOUSE

Plano, Illinois **1950**

Architect: Mies van der Rohe
Structural Engineer: Office of Mies van der Rohe

Coleman Hughes Bynum Jr.



Floor System

The floor and roof are a system of precast and poured-in-place concrete slabs, combined in a manner to fit within the steel framework, and resulting in thin floor and roof planes. The roof consists of precast channel-planks spanning between the secondary beams. The interior and exterior floors, although similar, differ slightly in construction. In both a precast slab is laid between beams, then, using this slab as a permanent form, a second slab is poured over it. The exterior slab, however, slopes toward an opening in the center for drainage. Both interior and exterior floors are finished in 2 foot x 2 foot 9 inch travertine marble.

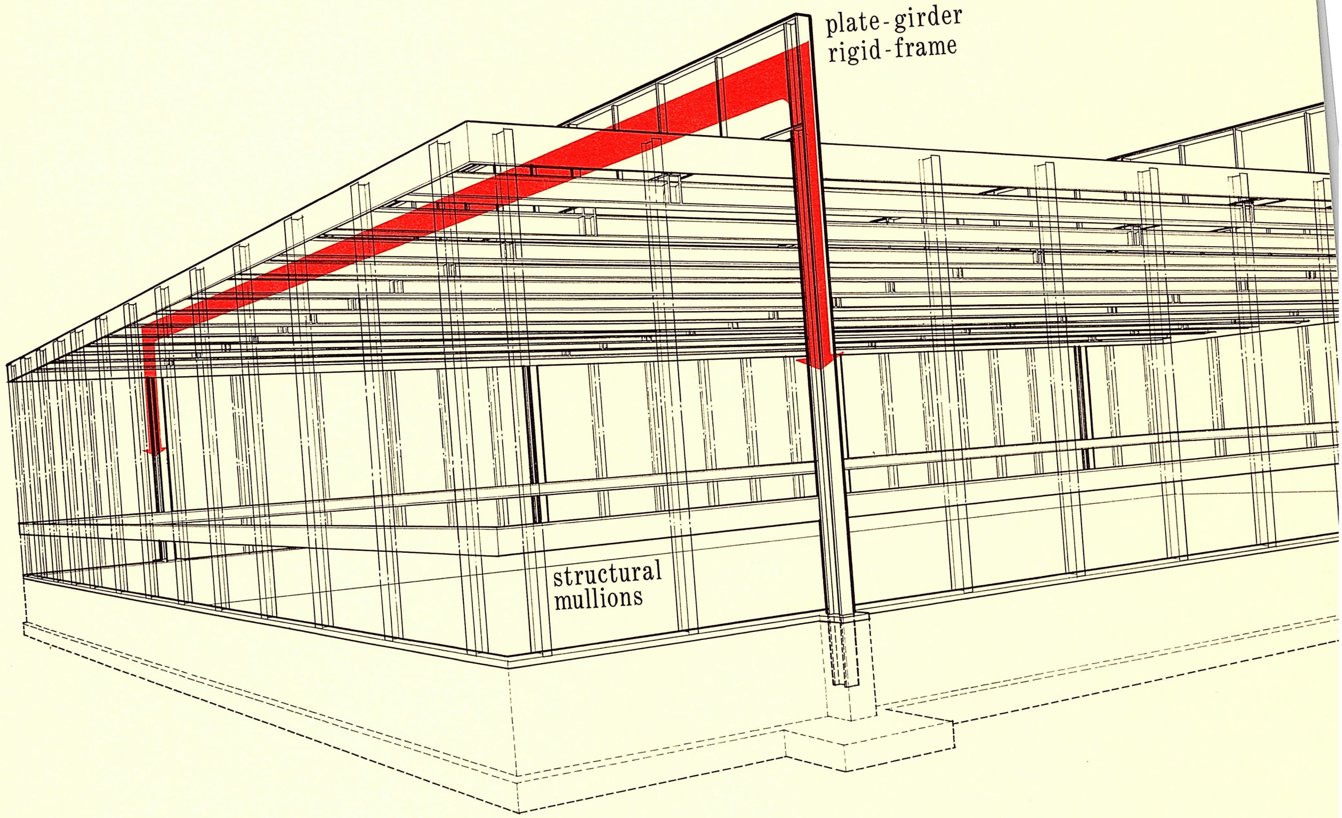
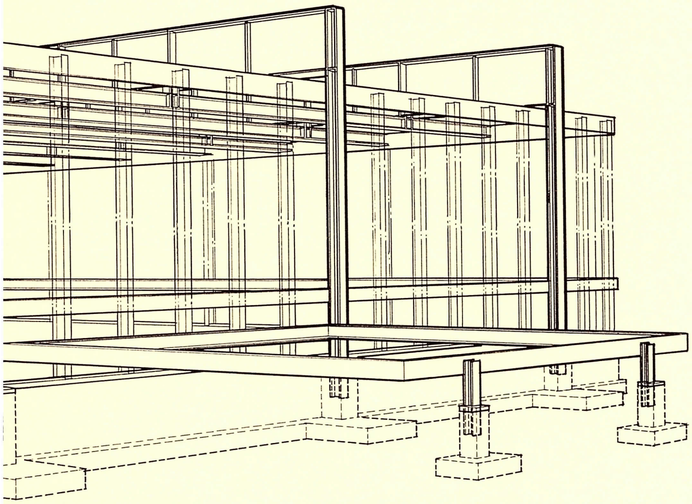


plate-girder
rigid-frame
structural
mullions



CROWN HALL I.I.T.

Chicago, Illinois **1956**

Architect: Mies van der Rohe
Structural Engineer: Frank Kornacker

Richard John Green

Structural System

The steel structural system utilizes four rigid-frame bents in the form of plate-girders from which the roof is suspended. These rigid-frames are 60 feet on center and span 120 feet. By placing the vertical elements outside the building, a column-free major space on the first floor is created. All steel connections are welded.

Wind forces on the building are transferred through the wide-flange exterior mullions into either the plate-girder at the top of the structure, or into the channel section at the first floor level. The forces carried by the steel plate at the top of the mullion are transmitted to the plate-girder which, in turn, transmits these forces to the ground. Since no connection exists between the steel columns and the channel, forces on the channel are taken by the concrete floor system.

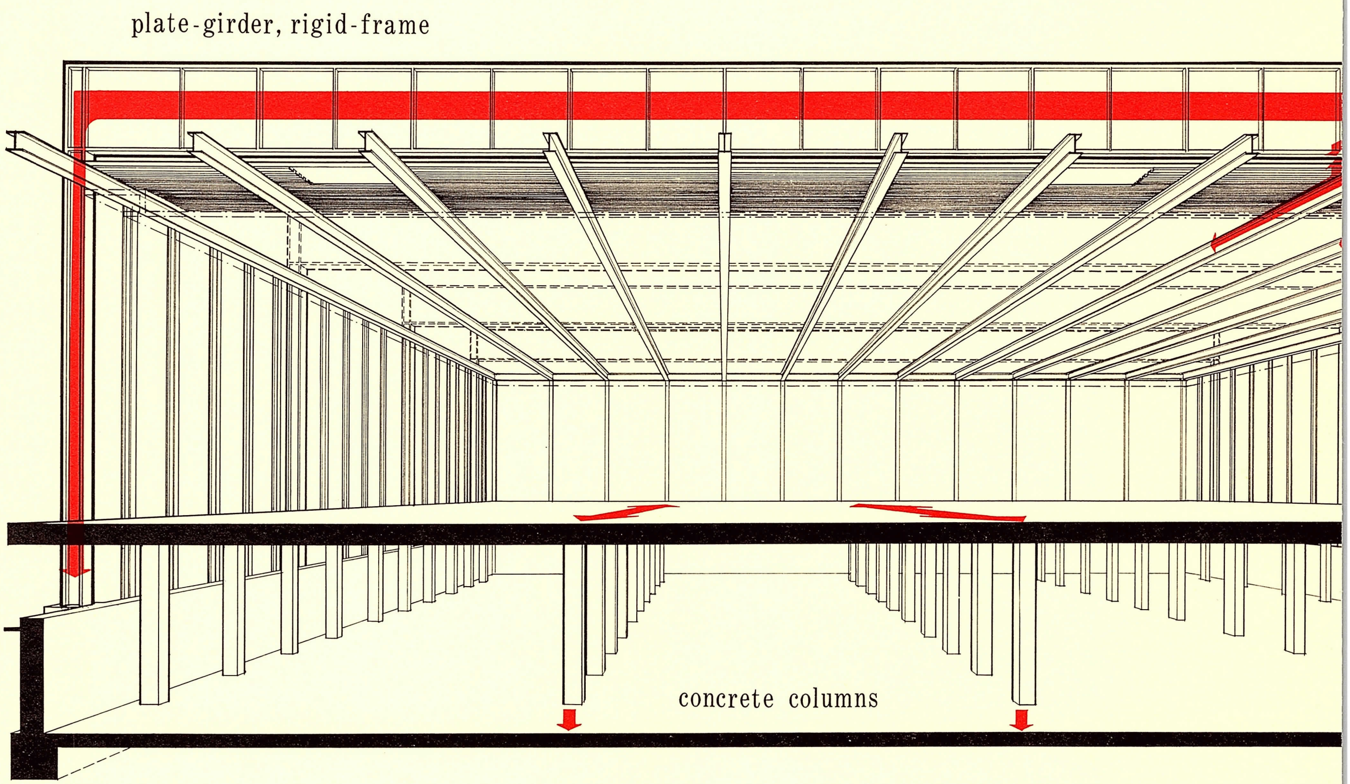
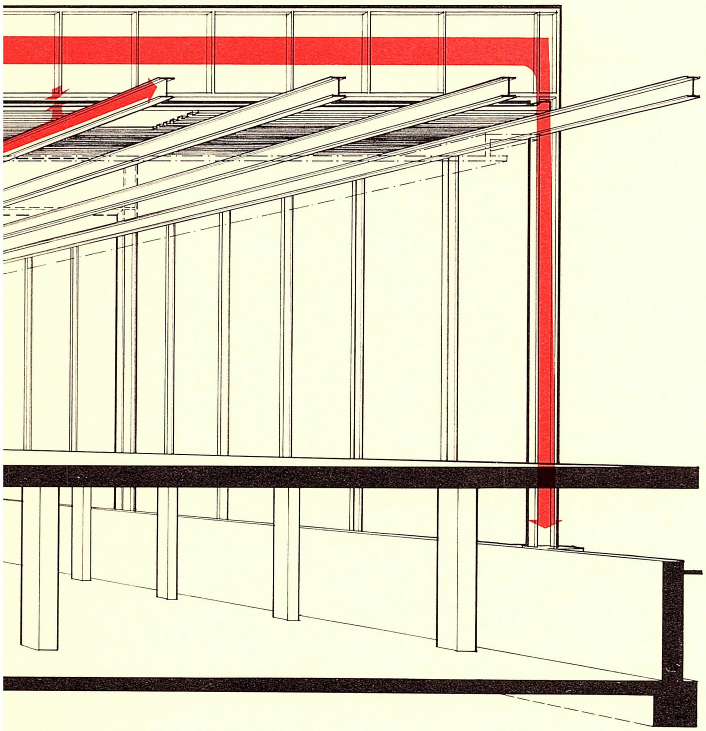


plate-girder, rigid-frame
concrete columns



CROWN HALL I.I.T.

Chicago, Illinois **1956**

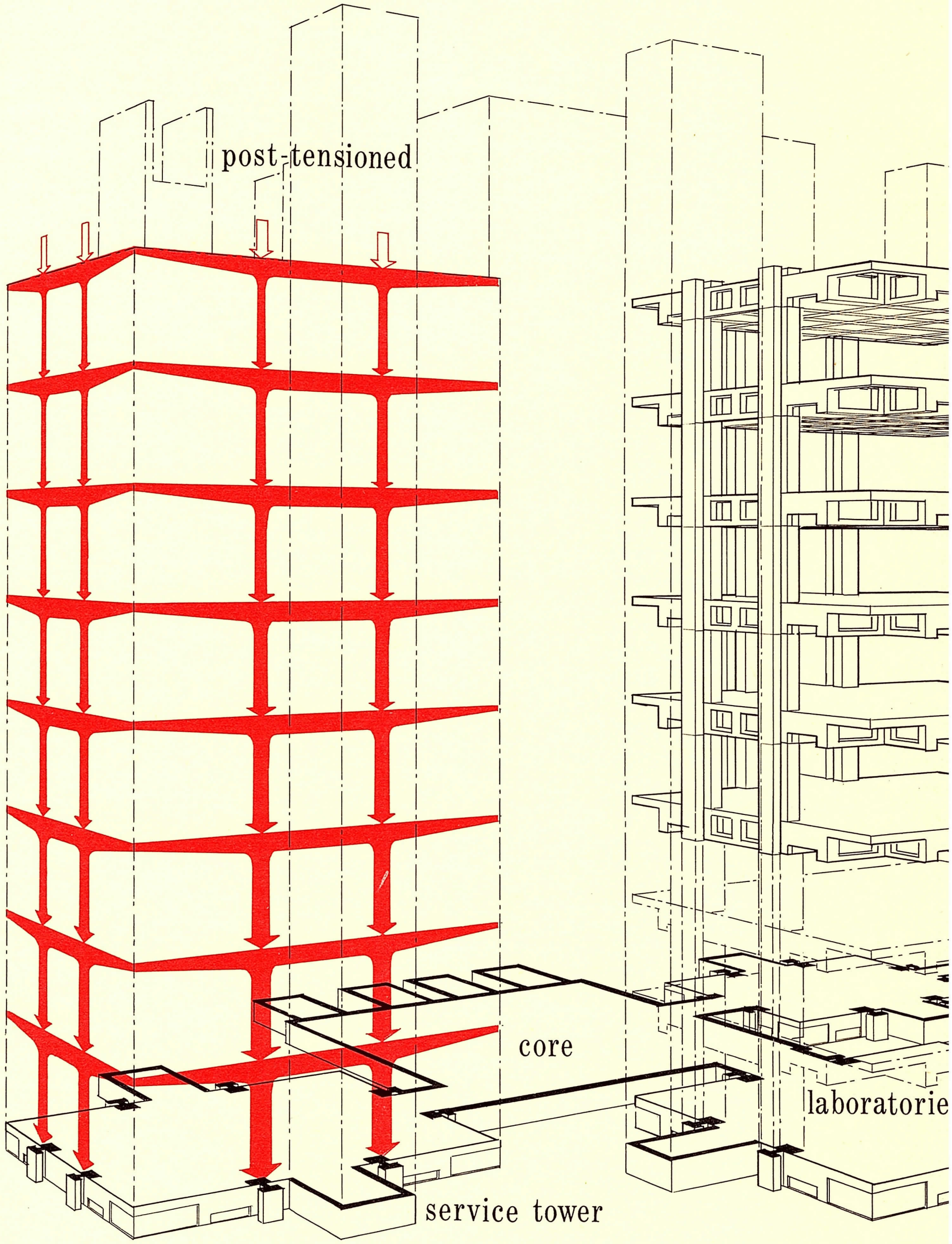
Architect: Mies van der Rohe
Structural Engineer: Frank Kornacker

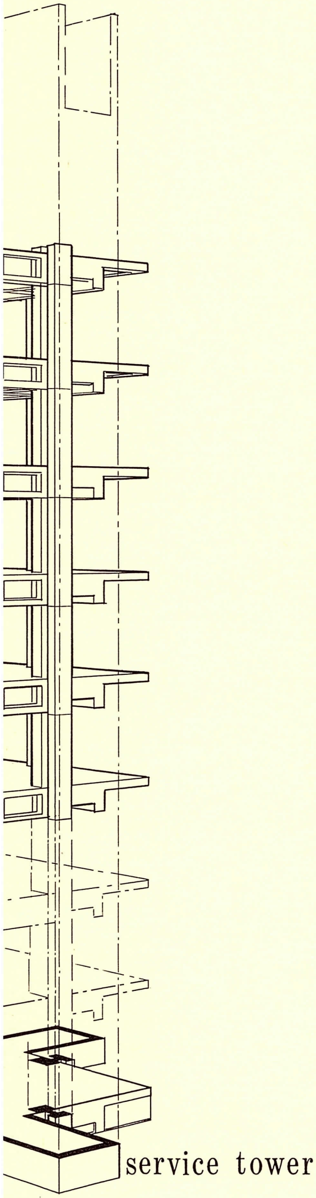
Thomas Matson Shadoin

Floor System

Separated from the rigid-frame, the floor system resolves all forces acting on the first floor level. The floor is a reinforced concrete slab supported on columns which are positioned on a 20 foot x 20 foot grid. The varied functions of the basement are easily contained within the columnar system.

The roof is a suspended system which utilizes steel beams to span between the rigid-frames. All connections between the roof beams and the overhead, supporting plate-girder are rigid.


post-tensioned
core
laboratorie
service tower



RICHARDS MEDICAL BUILDING

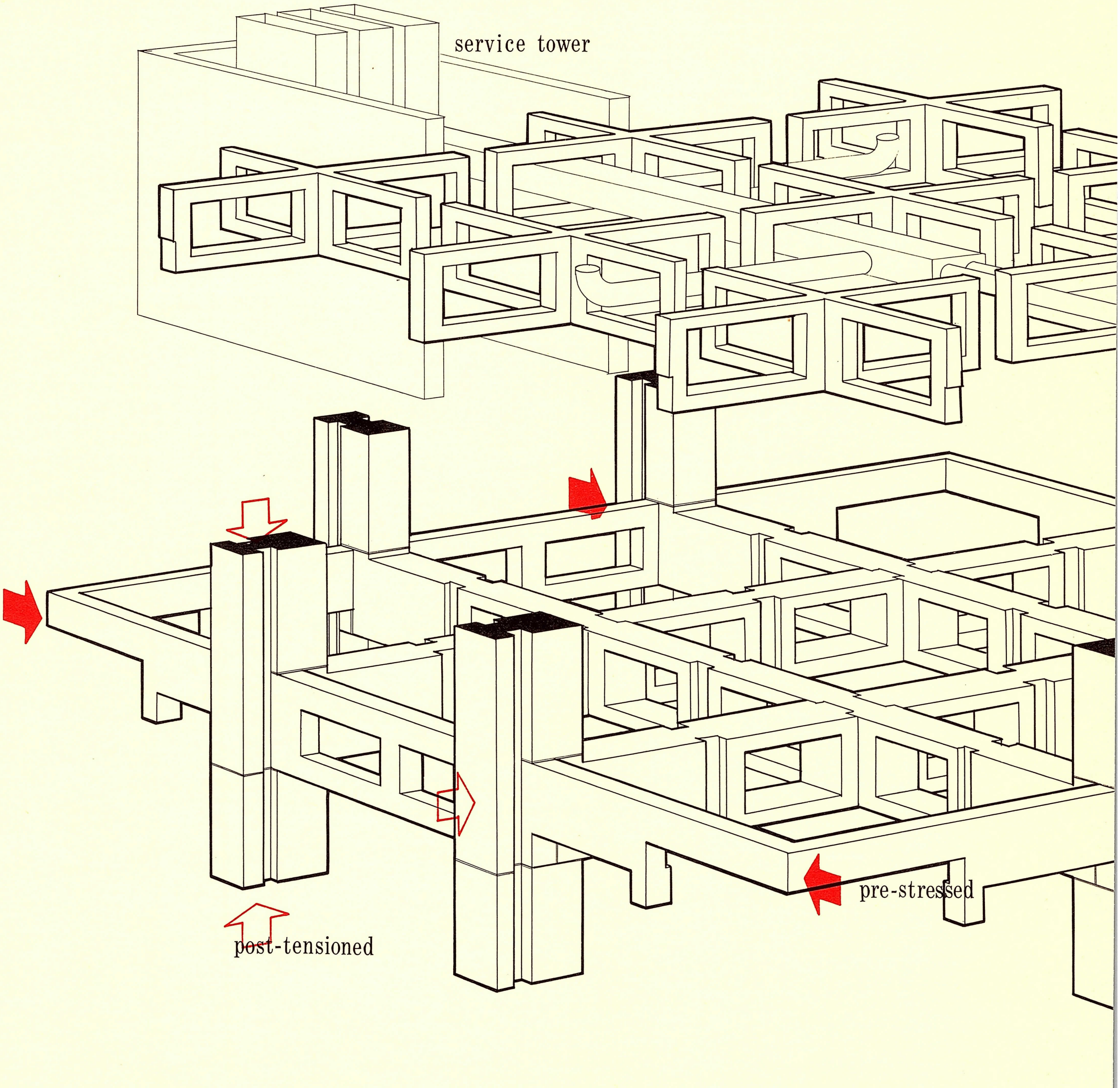
University of Pennsylvania
Philadelphia **1961**

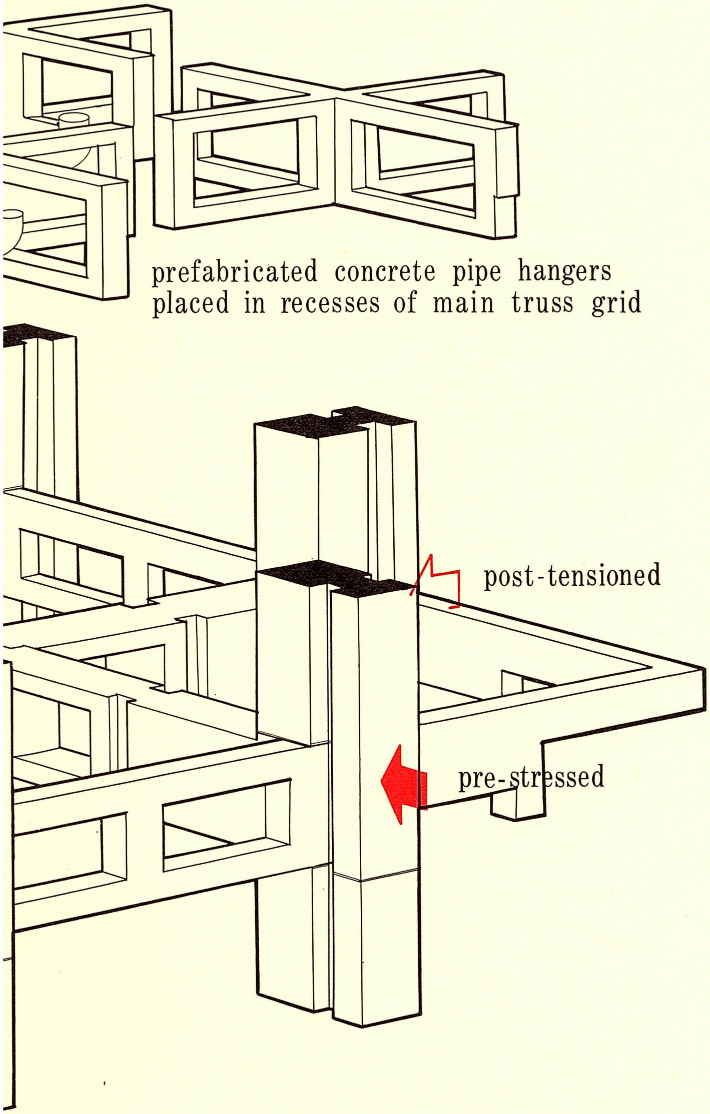
Architect: Louis I. Kahn
Structural Engineer: Dr. August E. Komendant

John Wesley Kinney Jr.

Structural System

The central tower is poured-in-place concrete with simple floor slabs and load-bearing walls. The peripheral towers utilize a precast concrete frame and column system to achieve a 45 foot clear span on each floor with a double cantilever at each corner. Column segments are set in place and post-tensioned at each successive floor as construction progresses. Each peripheral tower is surrounded by independent load-bearing service towers housing either mechanical facilities or vertical circulation.


service tower
post-tensioned
pre-stressed



RICHARDS MEDICAL BUILDING

University of Pennsylvania
Philadelphia **1961**

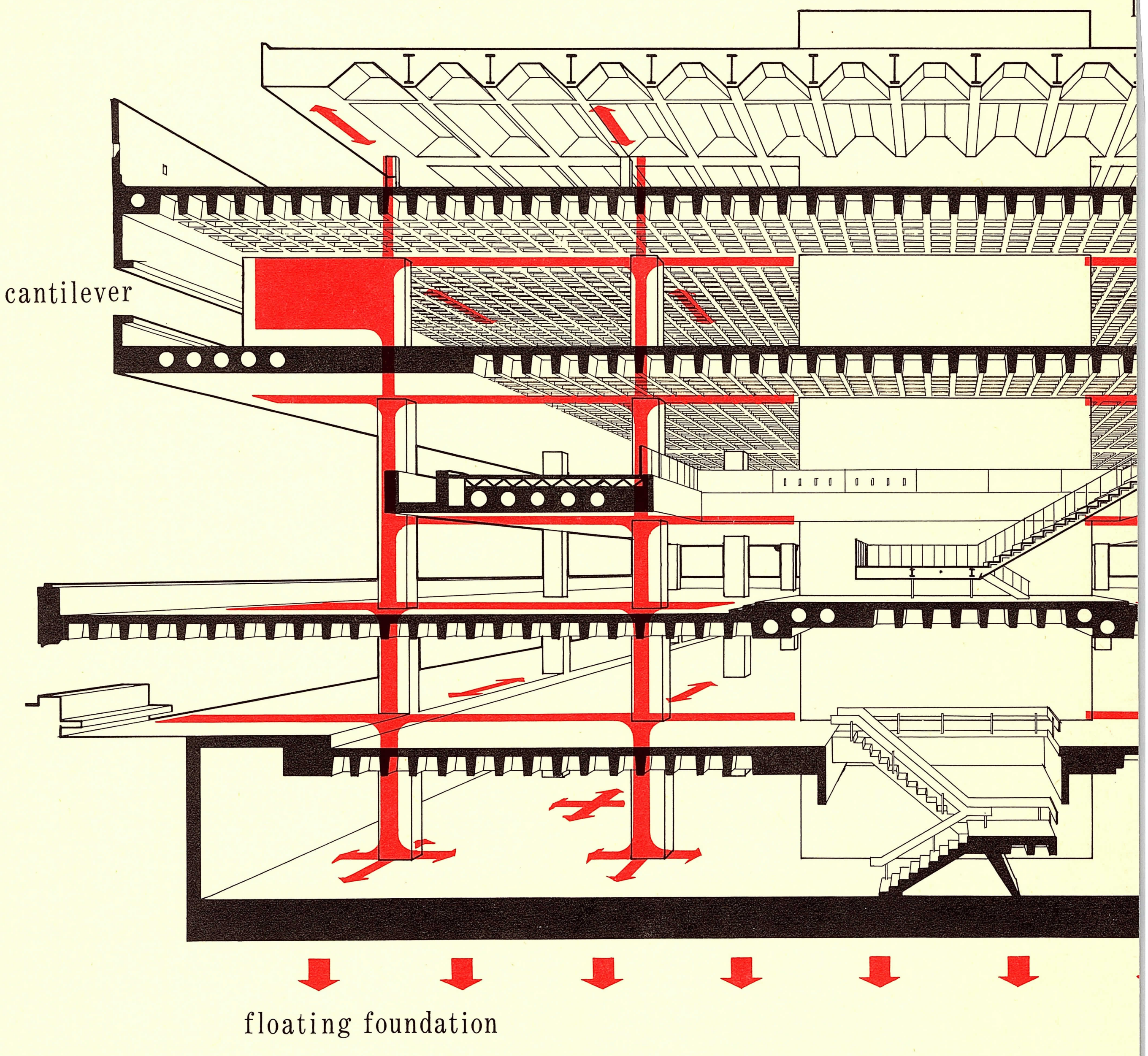
Architect: Louis I. Kahn
Structural Engineer: Dr. August E. Komendant

Reinhard Karl Goethert

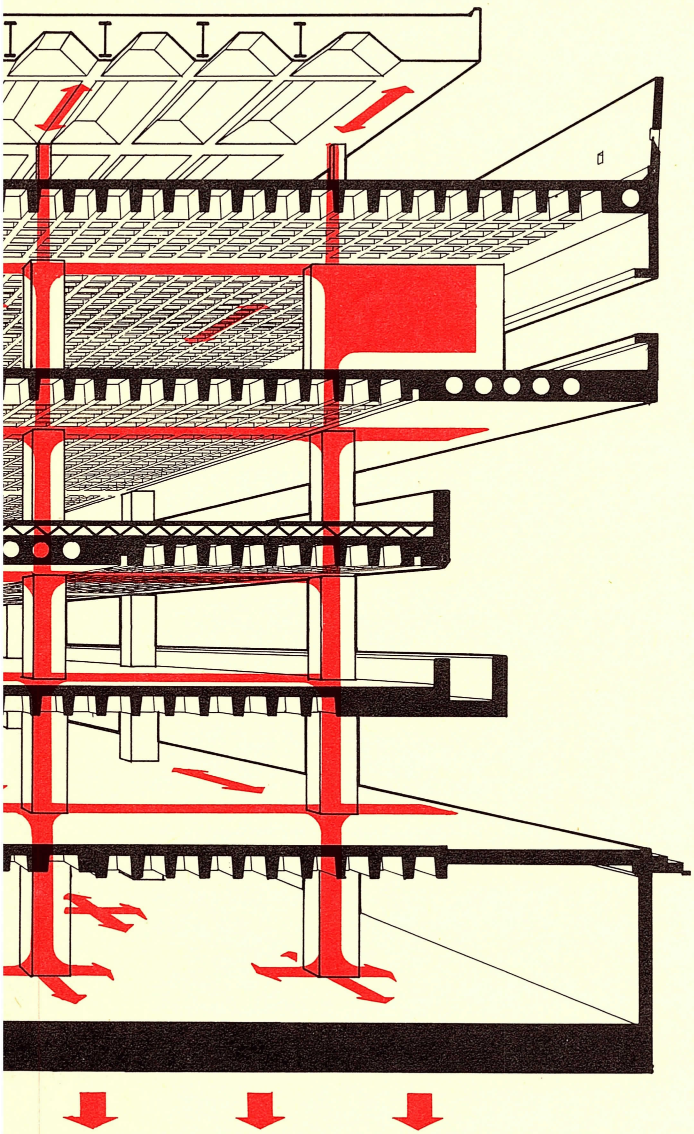
Floor System

Each floor system is composed of six precast elements. These elements form two complete pretensioned rigid frames, two segmented post-tensioned rigid frames, four pretensioned spandrel beams, four post-tensioned columns, and two-element pipe hangers. All main spanning elements are interconnected by the vertical post-tensioned cables which pass through the spandrel, the column, and the rigid frames. The pipe hangers, which allow exposed mechanical services, are also integrated into the floor-supporting frame system.

RICHARDS MEDICAL RESEARCH BUILDING 3b


cantilever
floating foundation

tructural steel roof system



STUDENT CENTER M.I.T.

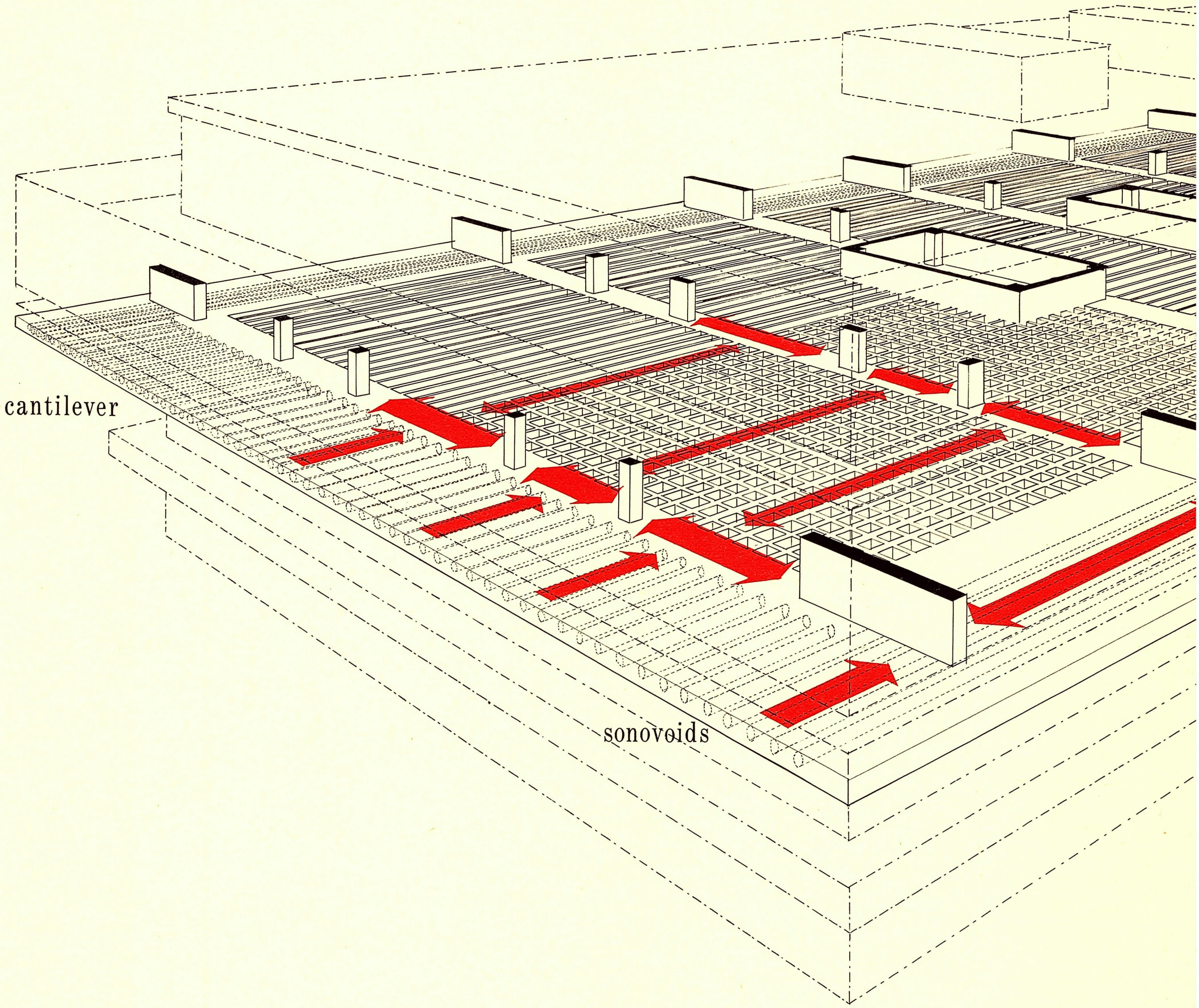
Cambridge, Massachusetts **1963**

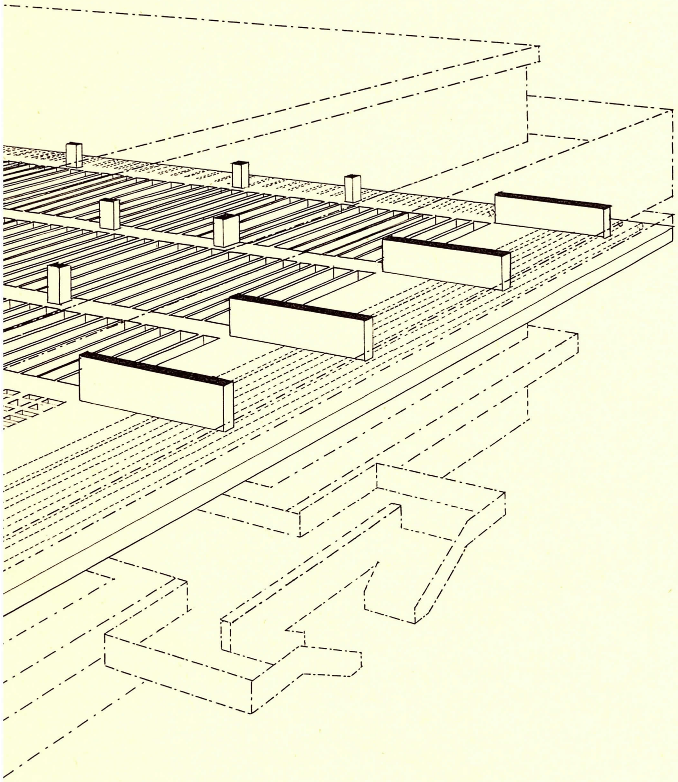
Architect: Eduardo F. Catalano
Structural Engineer: Paul Weidlinger

Christina Chen

Structural System

The Student Center is built of poured-in-place reinforced concrete, with the exception of the roof which is constructed of light structural steel. The structure consists of a system of columns and beams spanning in the transverse direction which support a one-way rib floor system. To compensate for poor soil bearing capacity, the foundation, basement walls, and floor slab form a monolithic floating foundation 15 feet below grade.


cantilever
sonovoids



STUDENT CENTER M.I.T.

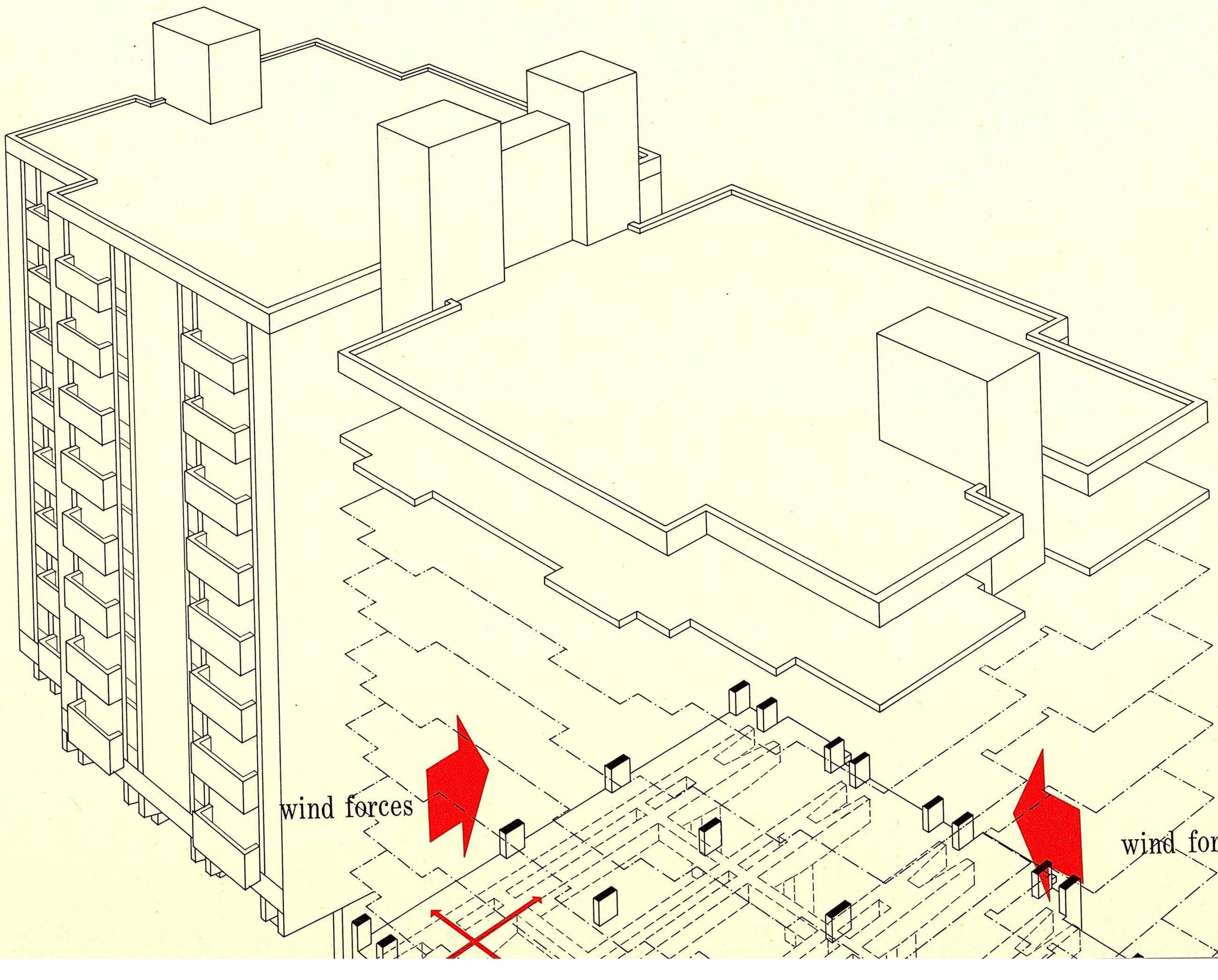
Cambridge, Massachusetts **1963**

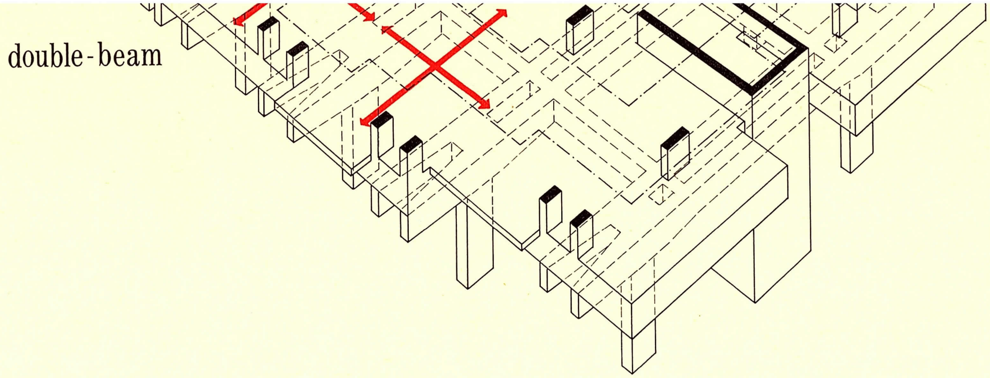
Architect: Eduardo F. Catalano
Structural Engineer: Paul Weidlinger

Betty Cushing Surbeck

Floor System

The floor structure is a pan system which has structural ribs spanning in one direction only, with non-structural ribs in a perpendicular direction giving the ceiling the appearance of a waffle grid. This system permits flexibility in the sub-division of space and provides an exposed ceiling texture. The lower solid slab is lightened by the use of sonovoid tubes. The outer bays of the upper two floors are cantilevered from the columns by the use of floor-to-ceiling depth wall beams. Two concrete, poured-in-place mechanical cores are located in the center of the building. The system for carrying ducts from these cores varies from floor to floor.


wind forces
wind forces



Floor System

The structure is a monolithic, reinforced concrete system. The forces from the floor system are collected by sets of six columns which are perpendicularly aligned to the long axis of the structure. These six columns remain dimensionally constant, as do the eight floors they support.

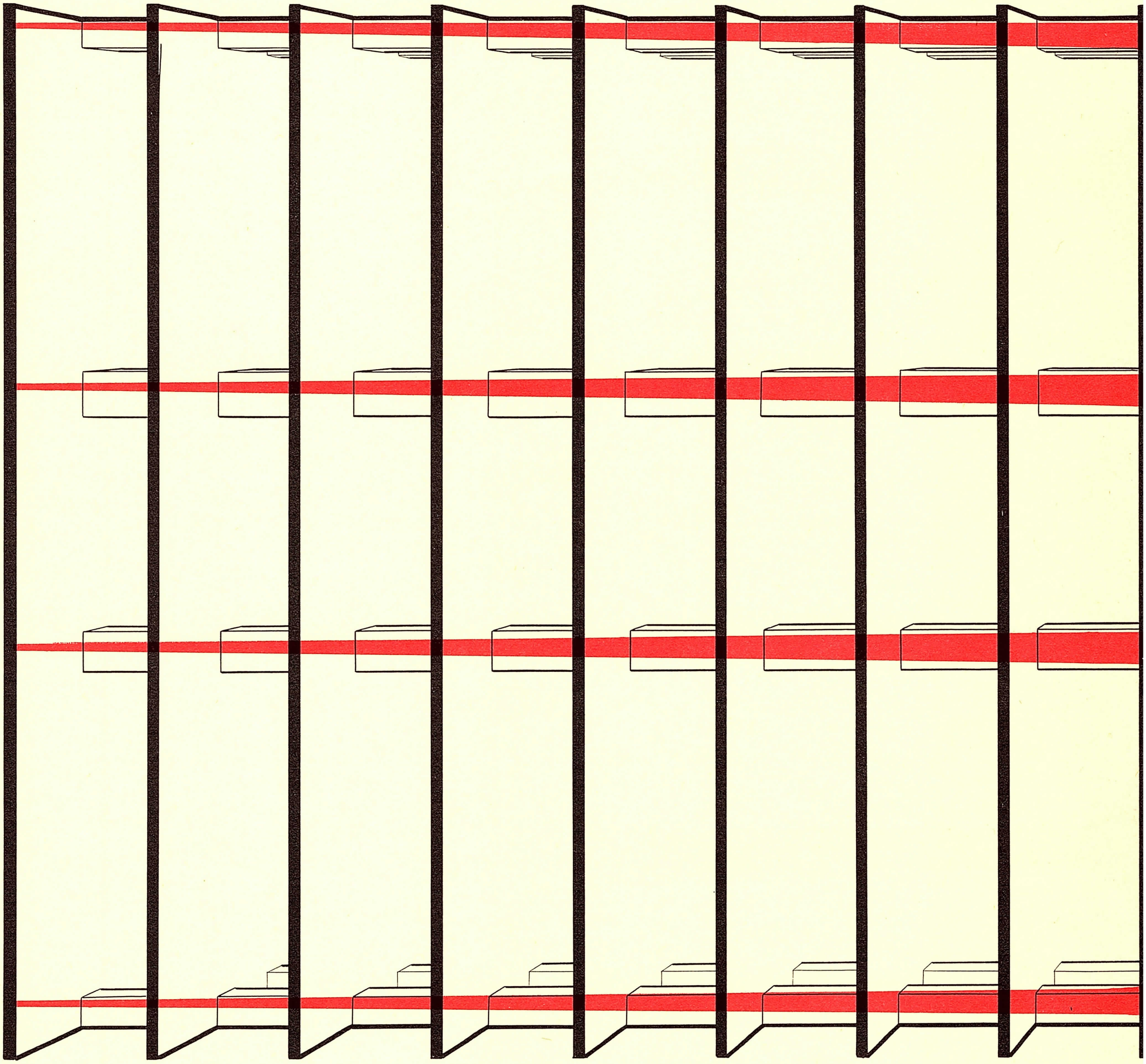
TIBER ISLAND APARTMENTS

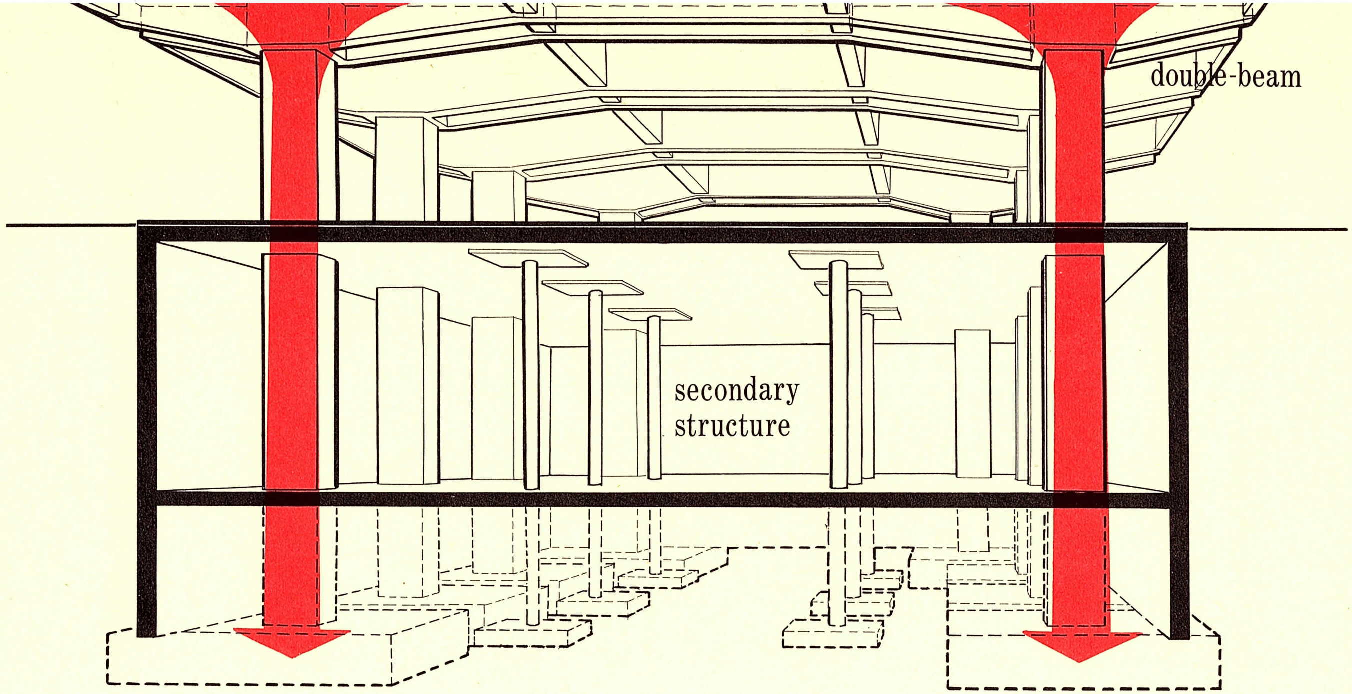
Washington, D. C. **1964**

Architects: Keyes, Lethbridge & Condon
Structural Engineer: Carl Hansen

James Francis Dugan III

TIBER ISLAND APARTMENTS 5a





Structural System

In order to provide a larger space at the entry level, a double-beam collects the six columns carrying the floor system and is supported by two pairs of major columns. Because of the large spacing between these major columns, a secondary set of columns provide support for the ground floor slab. The entire system, due to poor soil conditions, is founded on large, shallow pads. The wind forces are resisted by the shape and orientation of the columns in the narrow dimension, and by the shear walls of the stair towers in the long dimension of the structure.

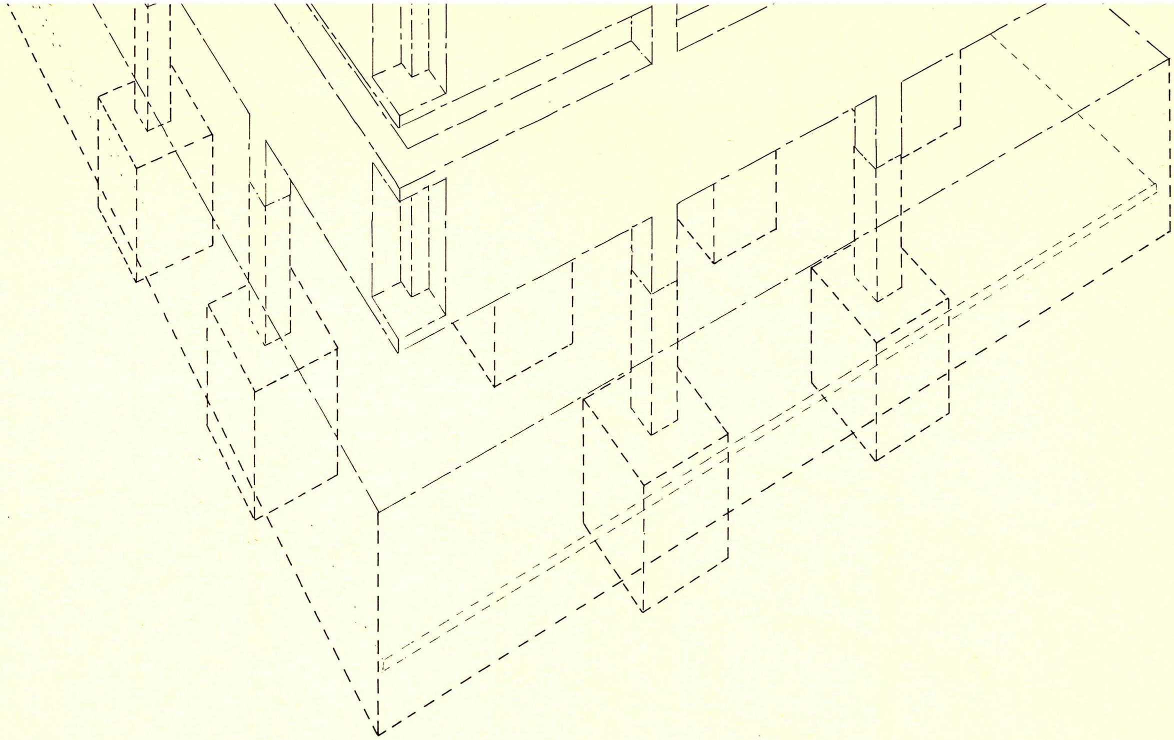
TIBER ISLAND APARTMENTS

Washington, D. C. **1964**

Architects: Keyes, Lethbridge & Condon
Structural Engineer: Carl Hansen

John Earl Lawrence

TIBER ISLAND APARTMENTS 5b



Structural System

The elevator core is slipformed and encompassed by the four interior columns. Precast, prestressed girders span from each interior column to the eight exterior columns which support the story-height, cantilevered rigid-frames. These 28 rigid-frames, seven on each facade, are composed of precast concrete chord units strung on high strength steel rods and post-tensioned. All columns are founded on concrete piers extending below the basement, whereas the service core rests on a continuous footing below basement level.

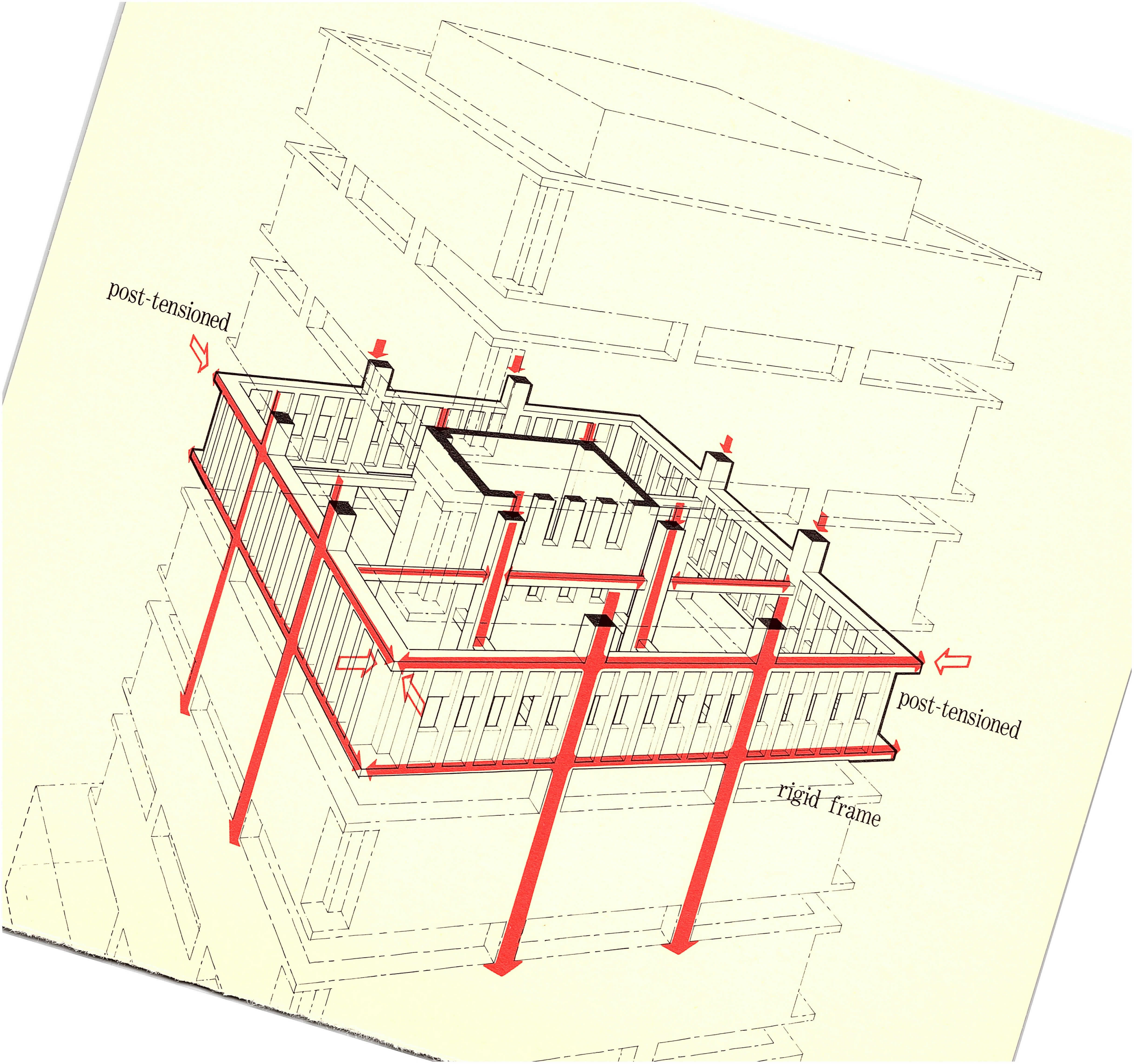
NORTH CAROLINA MUTUAL LIFE INSURANCE BUILDING

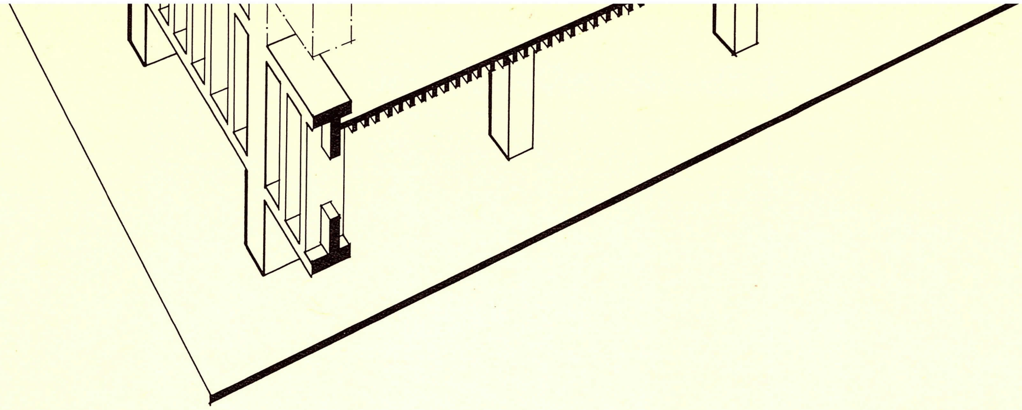
Durham, North Carolina 1964

Architect: Welton Becket and Associates
Structural Engineers: Seelye, Stevenson, Value, and Knecht

Joseph Albert Chipman

N.C. MUTUAL INSURANCE BUILDING 6a


post-tensioned
post-tensioned
rigid frame



Floor System

The floor system is composed of precast, prestressed double-T beams spanning between the girders and carrying a unifying poured-in-place slab. In order to fully utilize the story-height rigid-frame along each facade, the double-T beans span in perpendicular directions on adjacent floors.

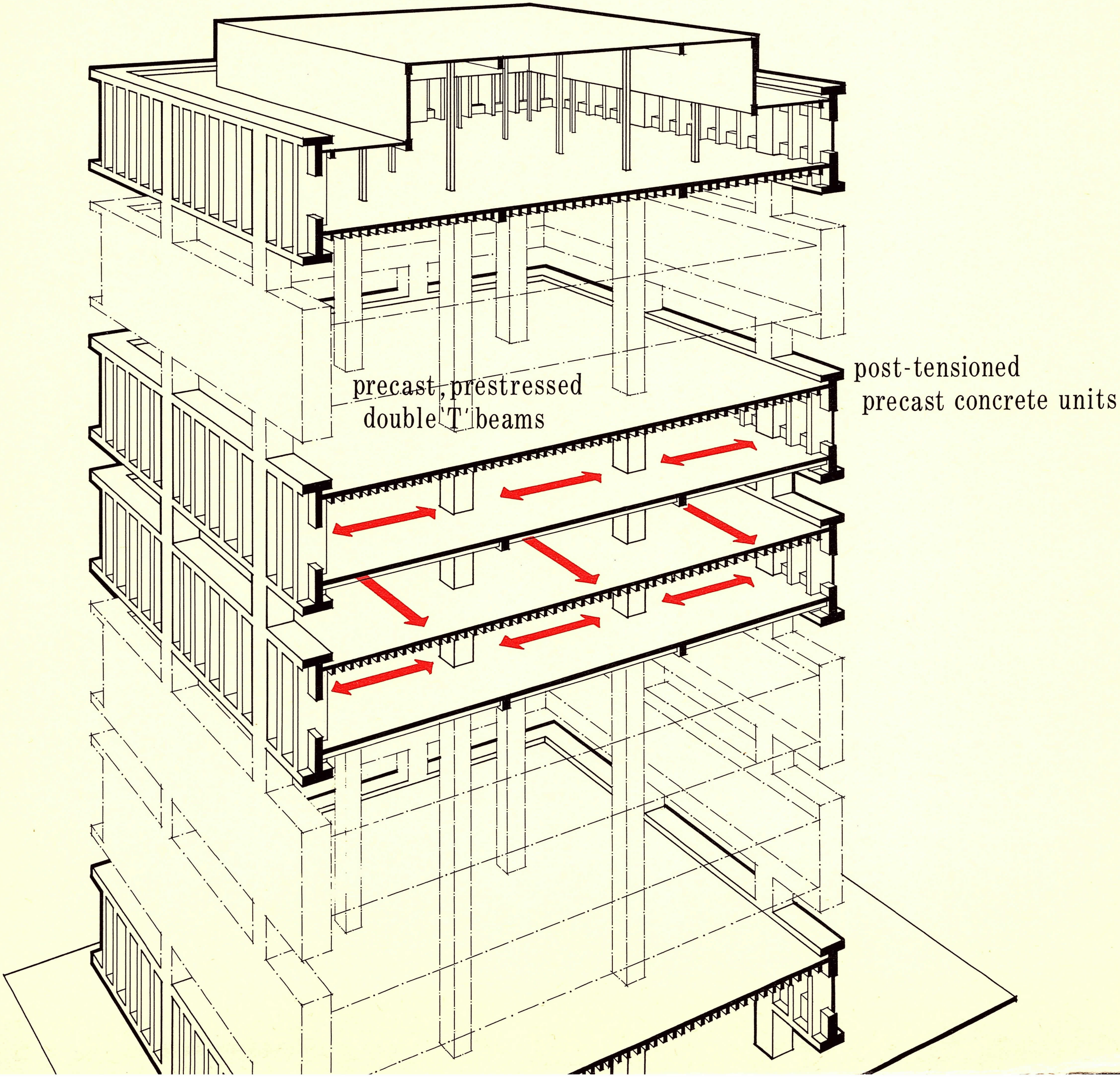
NORTH CAROLINA MUTUAL LIFE INSURANCE BUILDING

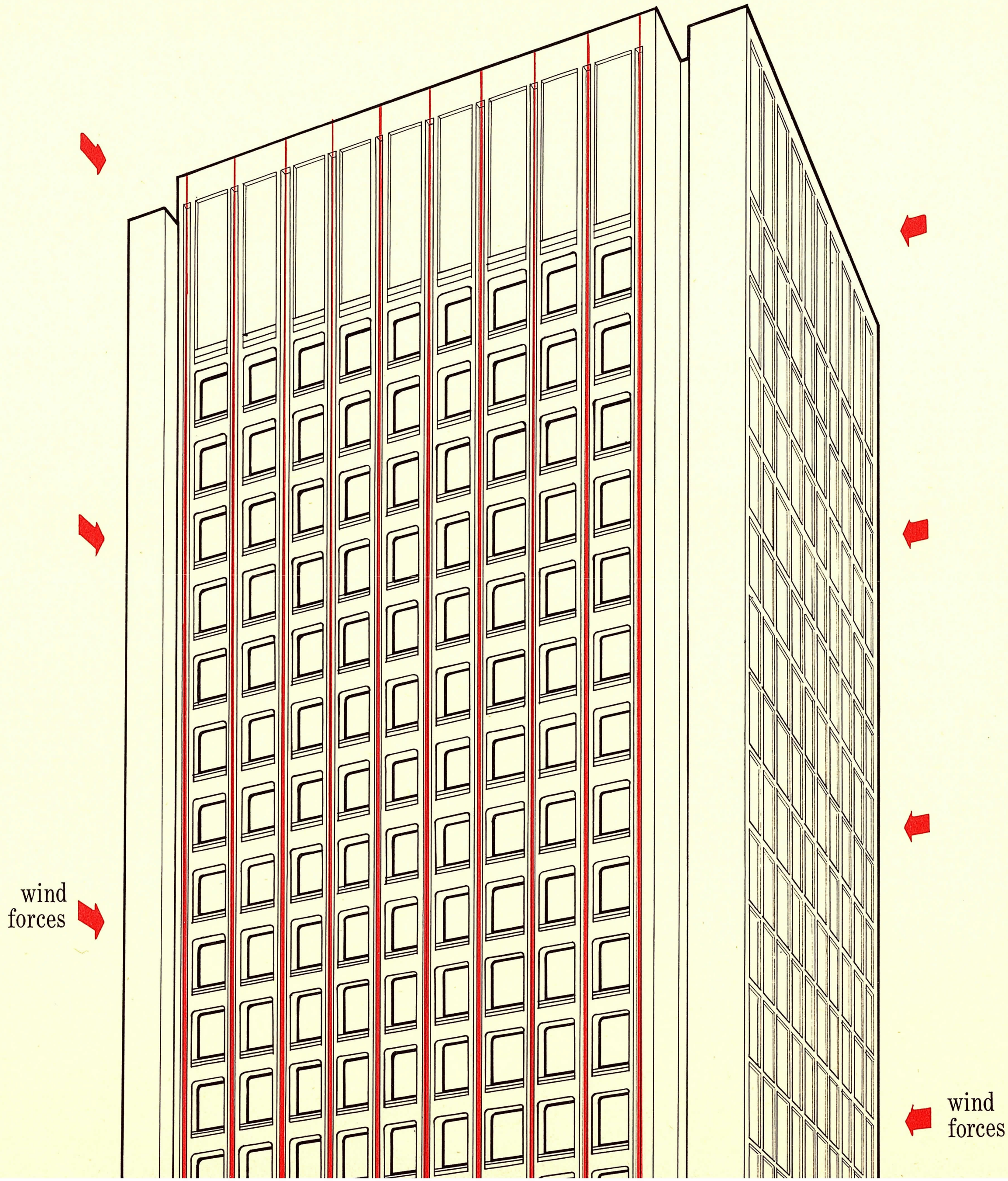
Durham, North Carolina 1964

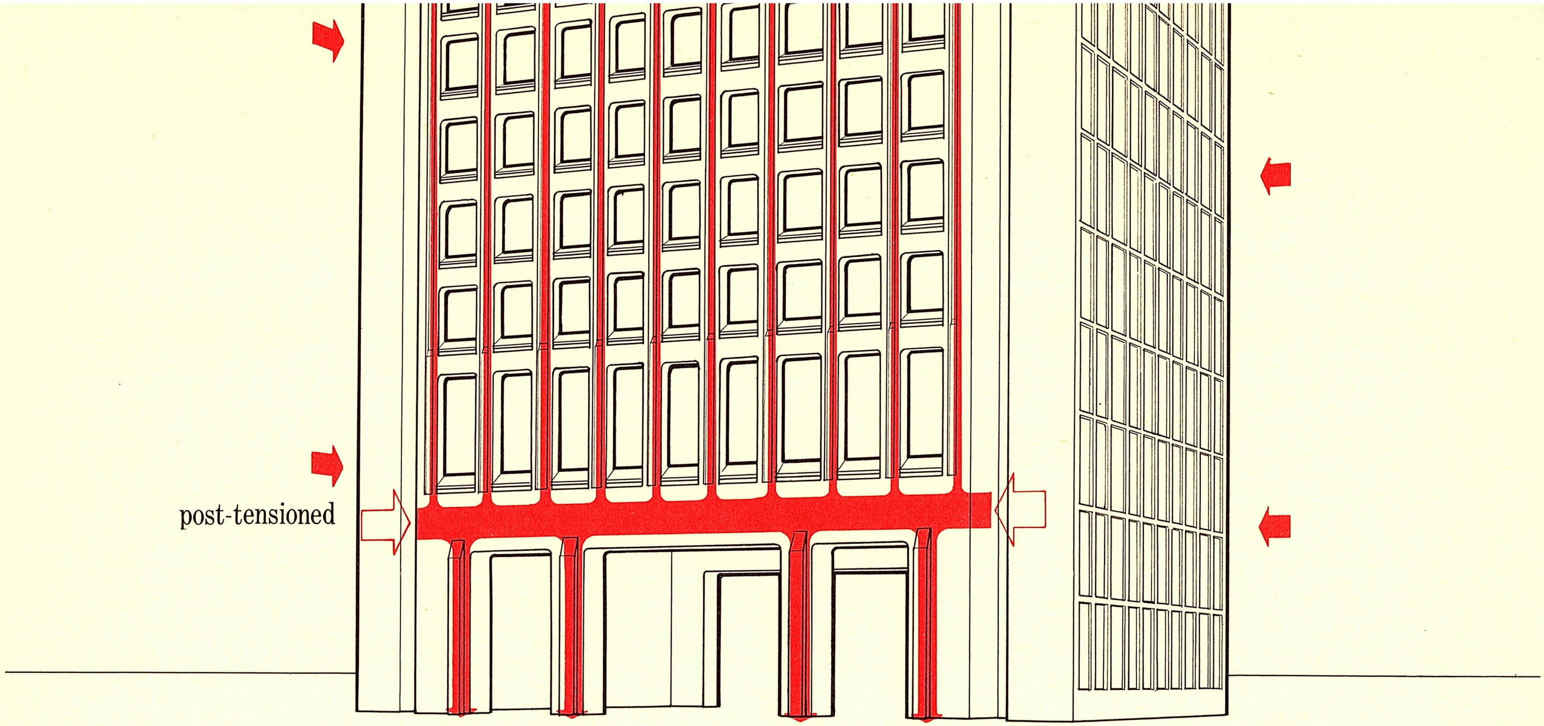
Architect: Welton Becket and Associates
Structural Engineers: Seelye, Stevenson, Value, and Knecht

Randolph Rudisill Croxton

N.C. MUTUAL INSURANCE BUILDING


post-tensioned
precast concrete units
precast, prestressed
double 'T' beams


wind
forces
wind
forces



Structural System

At each floor ten poured-in-place concrete floor girders are supported by bearing mullions which carry the loads to two 10 foot deep post-tensioned girders at the first floor level. The girders collect the loads and transfer them to the foundation, which consists of 392 concrete filled piles of 12 inch diameter with an average depth of 120 feet. Horizontal loads are resisted by two vertical shear walls, one at each end of the building.

EARTH SCIENCES BUILDING M.I.T.

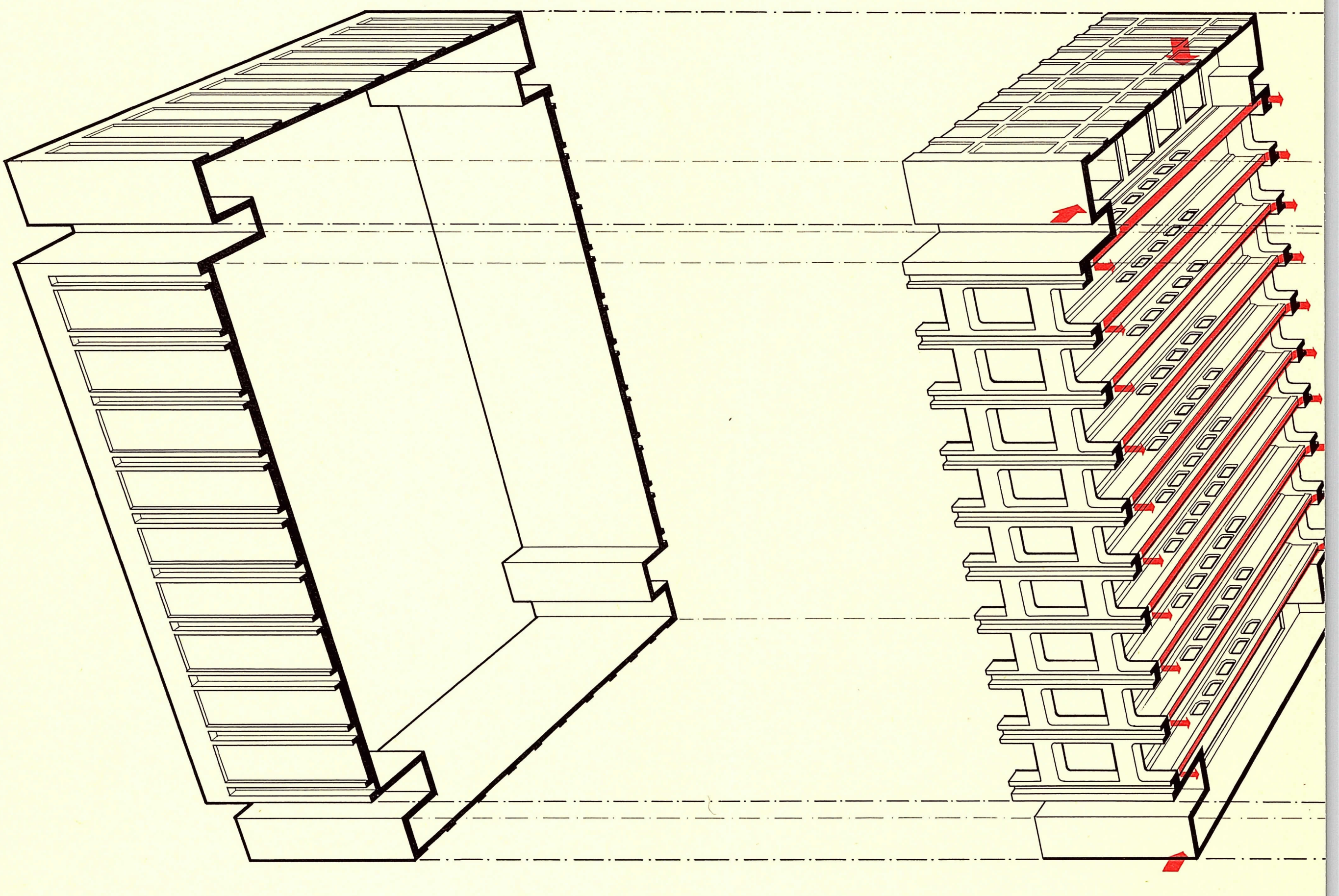
Cambridge, Massachusetts **1964**

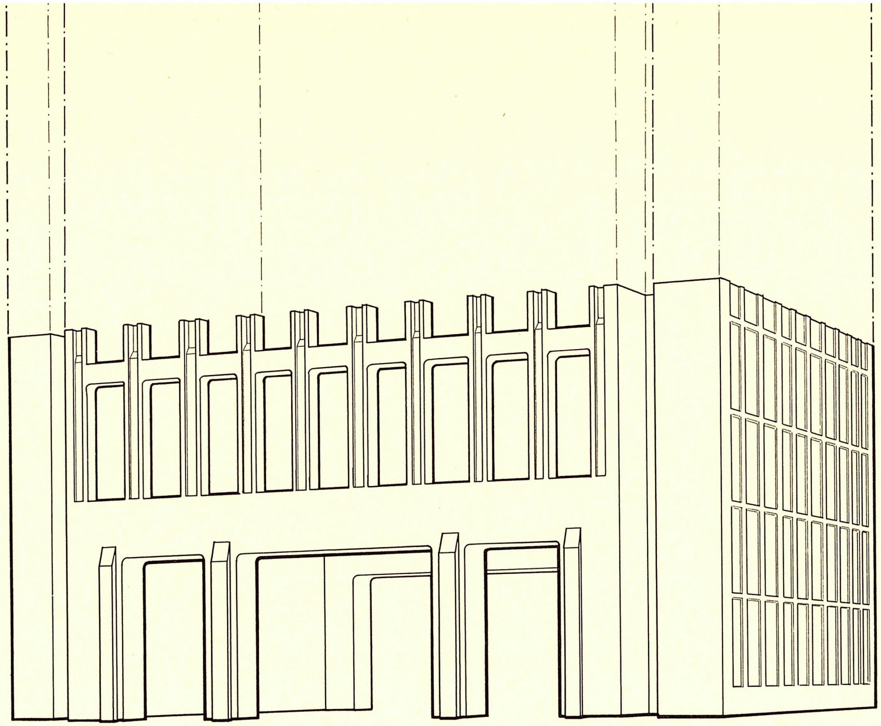
Architects: I. M. Pei and Aldo Cossutta
Structural Engineers: Severud, Elstad, Krueger Associates

Donald Leroy Whitesell

EARTH SCIENCES BUILDING

7a





Floor System

The concrete flat-slab floor system spans nine feet between poured-in-place concrete floor girders. The 42 inch deep girders span 48 feet between load-bearing window mullions. Floor girders are "I" shaped with sections of the web removed to permit the mechanical system to pass horizontally.

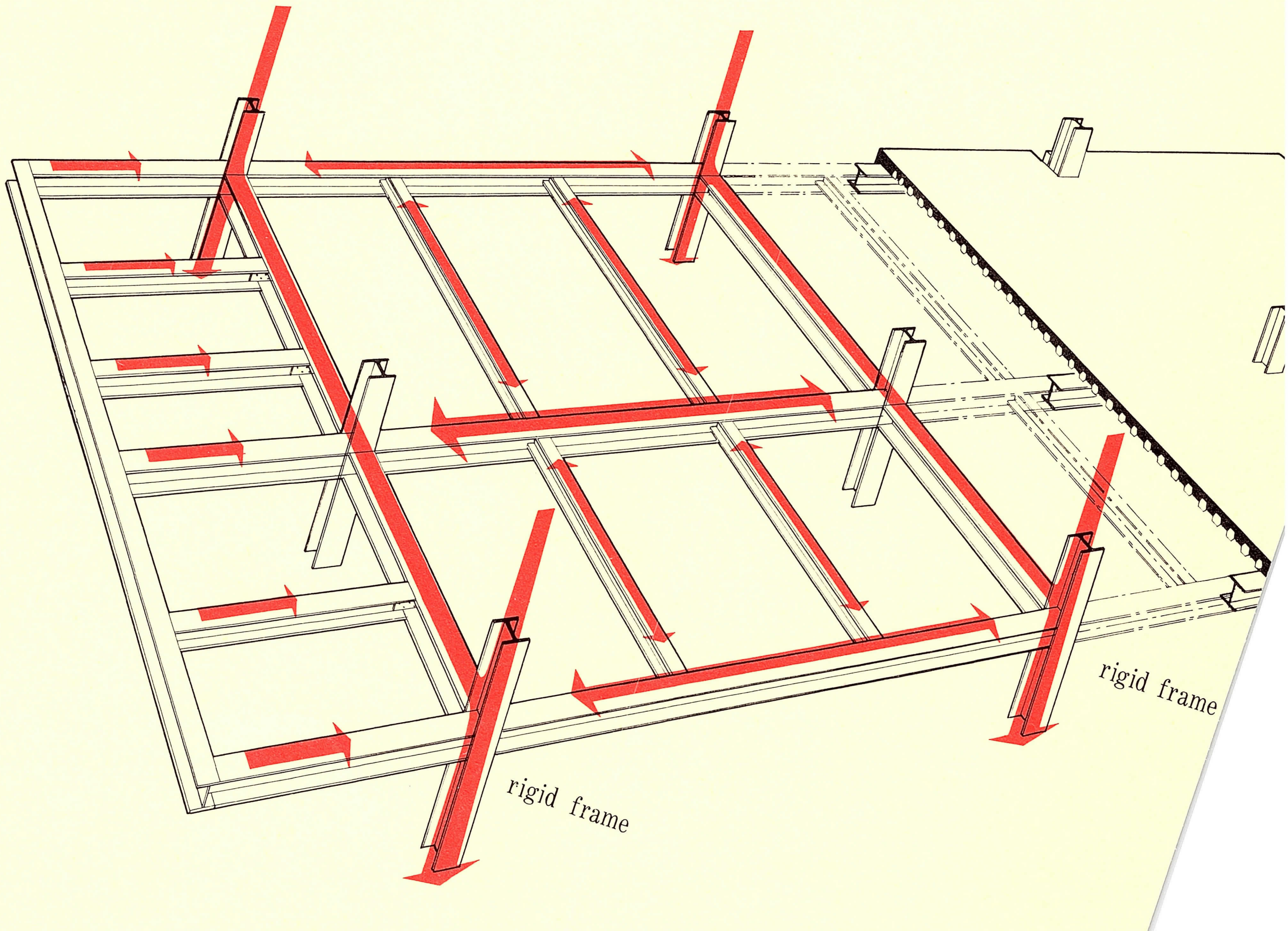
EARTH SCIENCES BUILDING M.I.T.

Cambridge, Massachusetts 1964

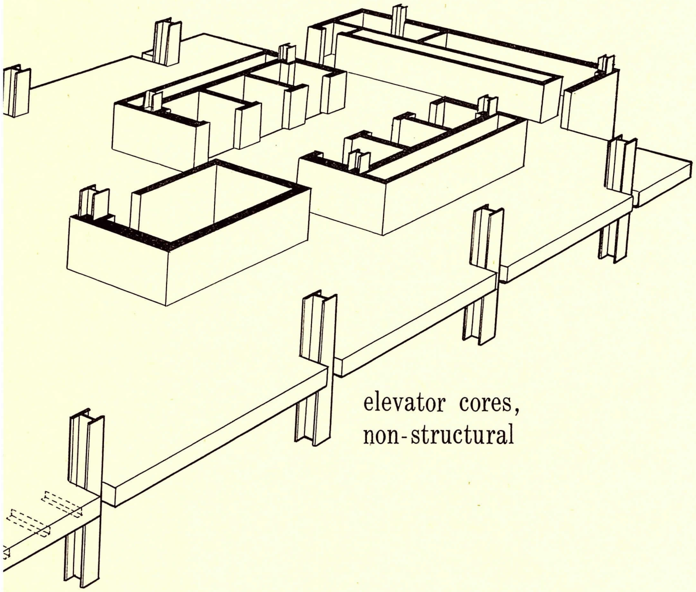
Architects: I. M. Pei and Aldo Cossutta
Structural Engineers: Severud, Elstad, Krueger Associates

James Edward Rink Jr.

EARTH SCIENCES BUILDING



rigid frame
rigid frame



LEVER HOUSE

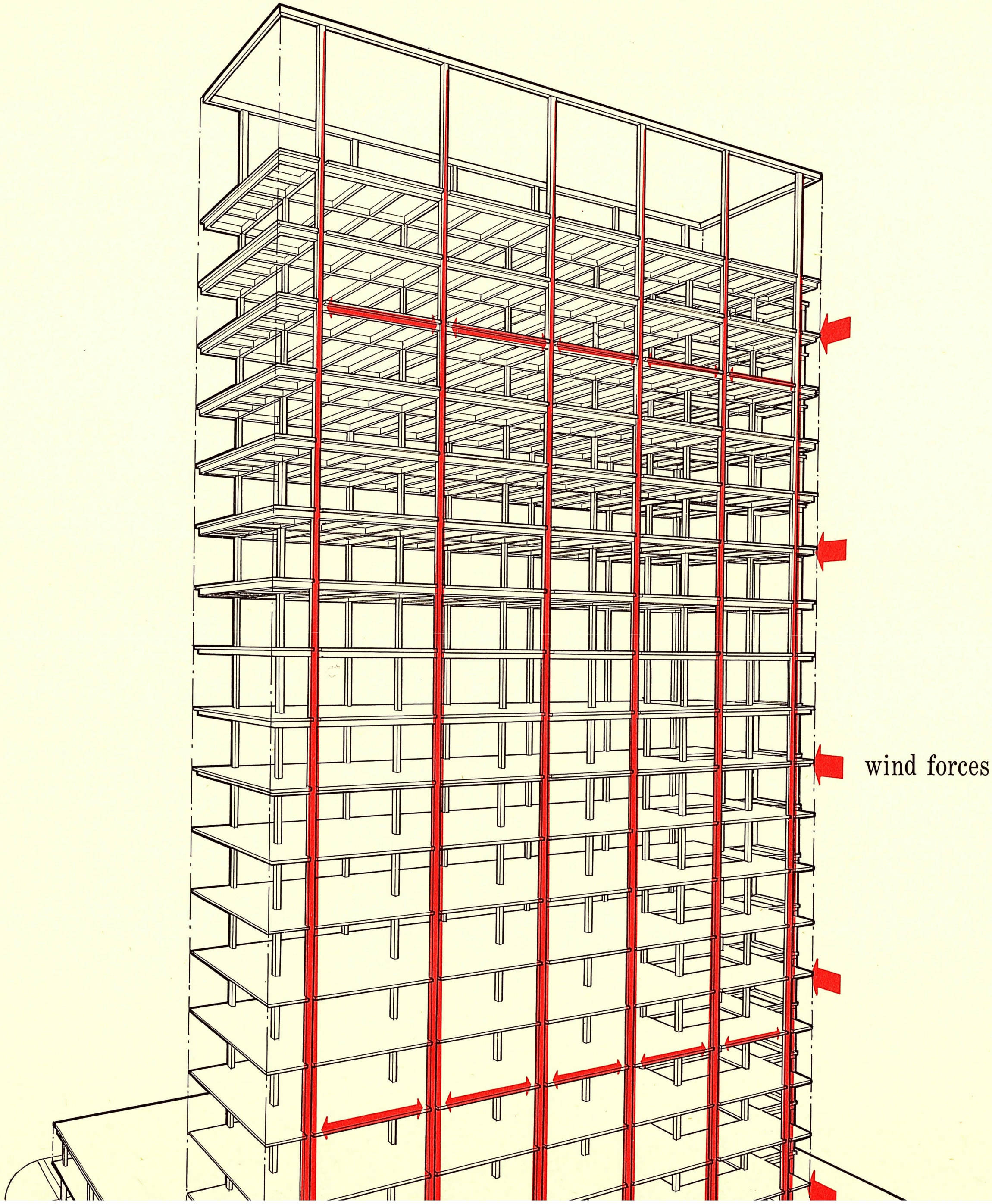
New York, New York **1952**

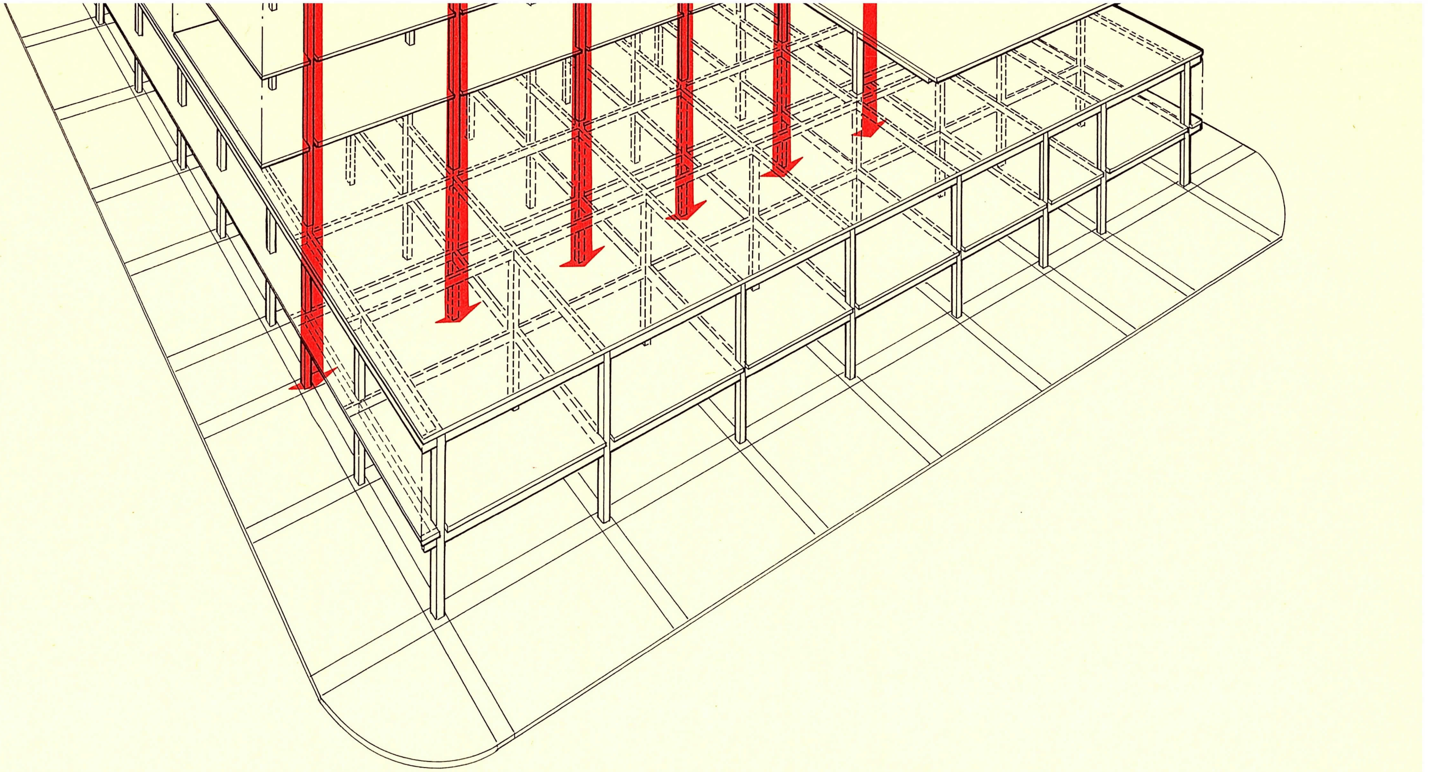
Architects: Skidmore, Owings and Merrill
Structural Engineers: Weiskoff and Pickworth

David Ward Jones

Floor System

The floor system consists of wide-flange beams spanning between columns with rigid, welded joints. Secondary beams span between the wide-flange beams to carry cellular steel decking and lightweight concrete flooring. The cantilevered beams are welded rigid at the columns to produce a continuous beam action with the wide-flange interior beams. Secondary beams in the cantilevered ends span between the wide-flange beams and a fascia beam to distribute the load.


wind forces



Structural System

Lever house is structured in a very conventional manner, using rolled structural steel shapes throughout. Due to the extreme height to width ratio, it was necessary to construct rigid frames spaced 28 feet apart as special wind bracing.

LEVER HOUSE

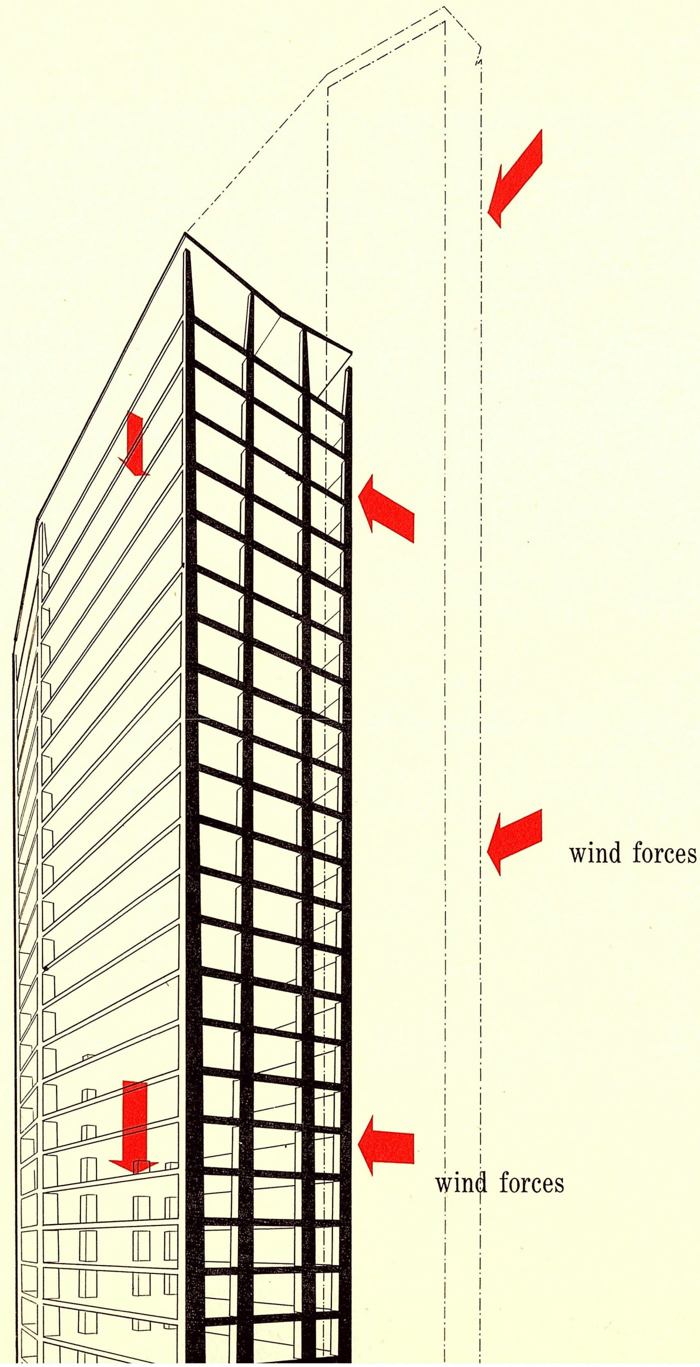
New York, New York **1952**

Architects: Skidmore, Owings and Merrill
Structural Engineers: Weiskoff and Pickworth

Paul Kirksey Thames

LEVER HOUSE

8b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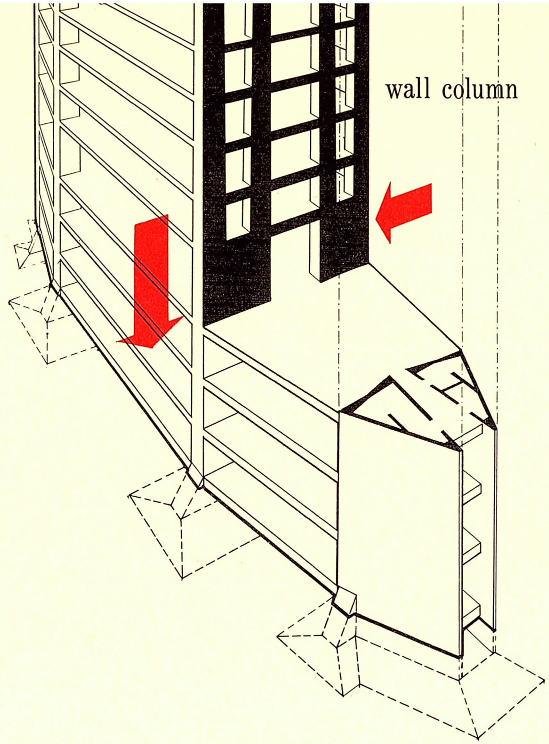


Structural System

The structure consists of four load-bearing corner units, two at either end, and two massive wall columns between them. Each element makes full use of the vertical loads and is shaped to withstand the horizontal forces.

The wall columns taper from a width of six feet seven inches in the basement to a width of one foot at the top of the building. The reinforced concrete skeleton rises 463 feet from a foundation resting on stratified fine sand and clay with injections of grout to a depth of 160 feet.

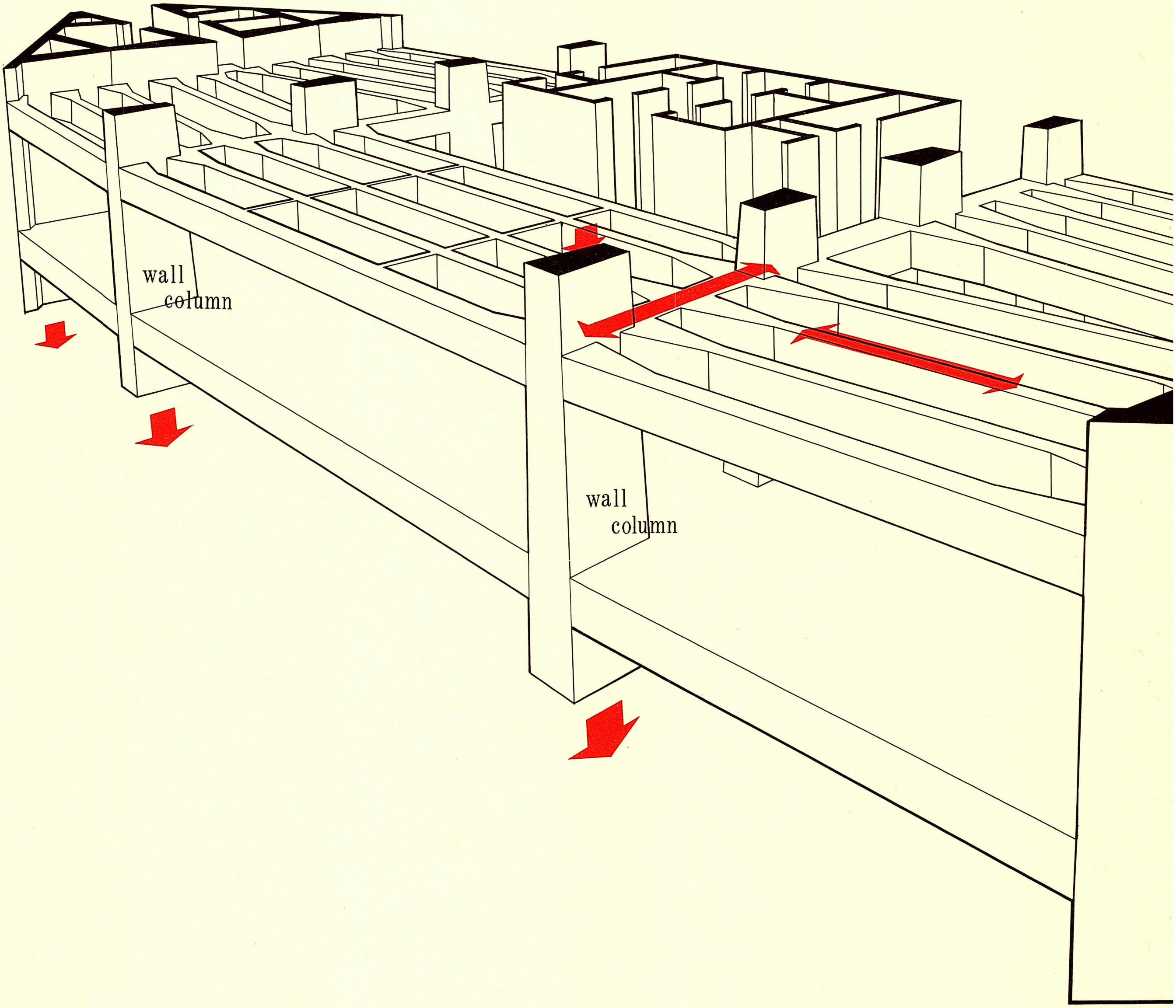
PIRELLI BUILDING

Milan, Italy **1959**

Architects: Gio Ponti, A. Fornardi
Structural Engineers: Pier Luigi Nervi, A. Danusse

James Hassell Ross Jr.

PIRELLI BUILDING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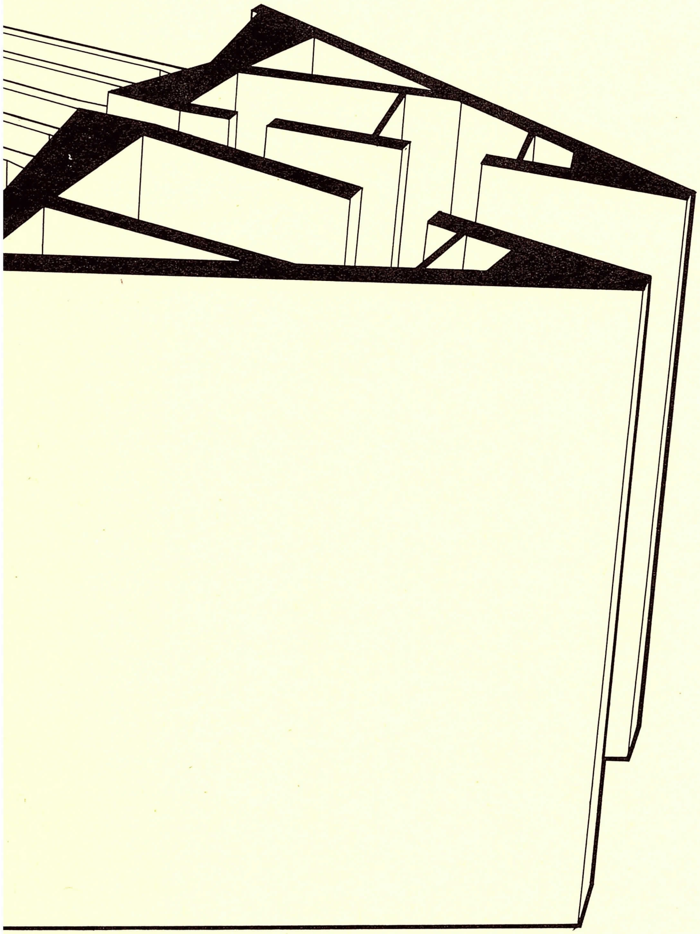


PIRELLI BUILDING

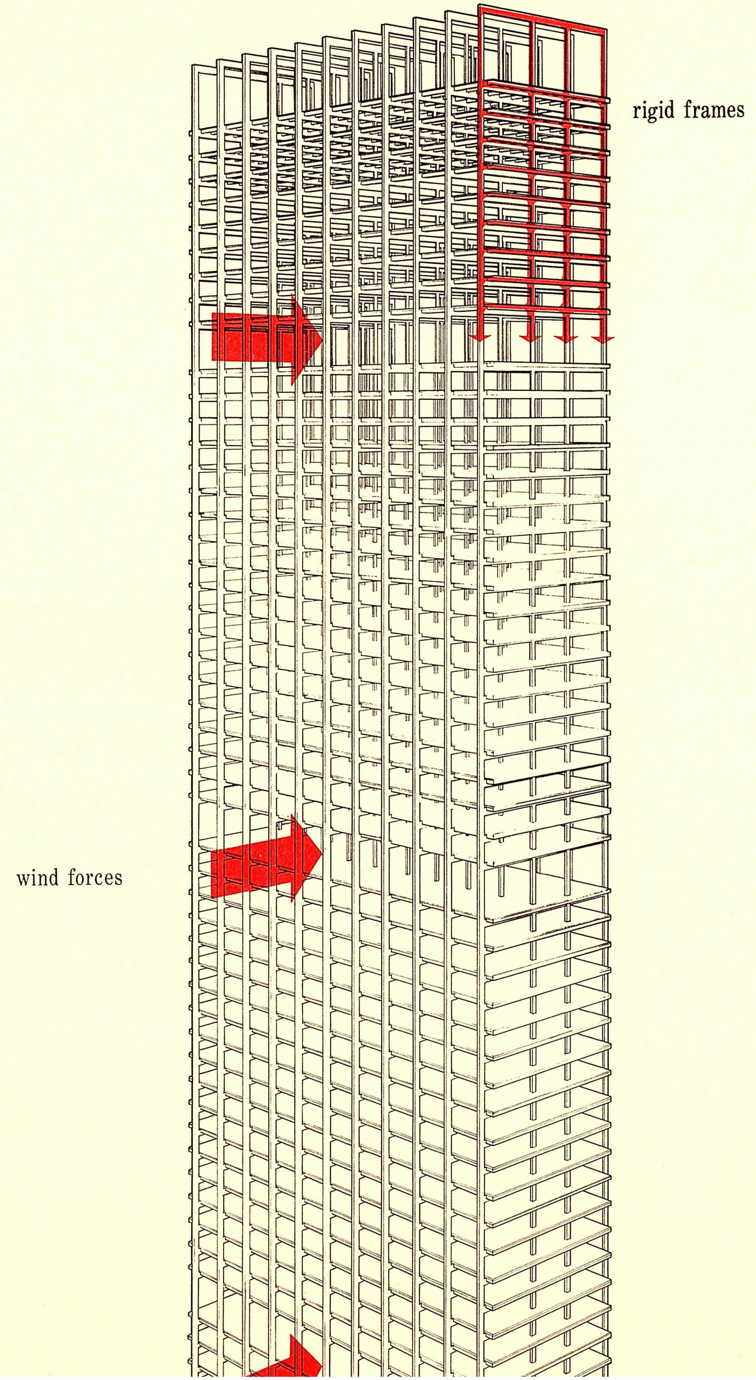
Milan, Italy **1959**

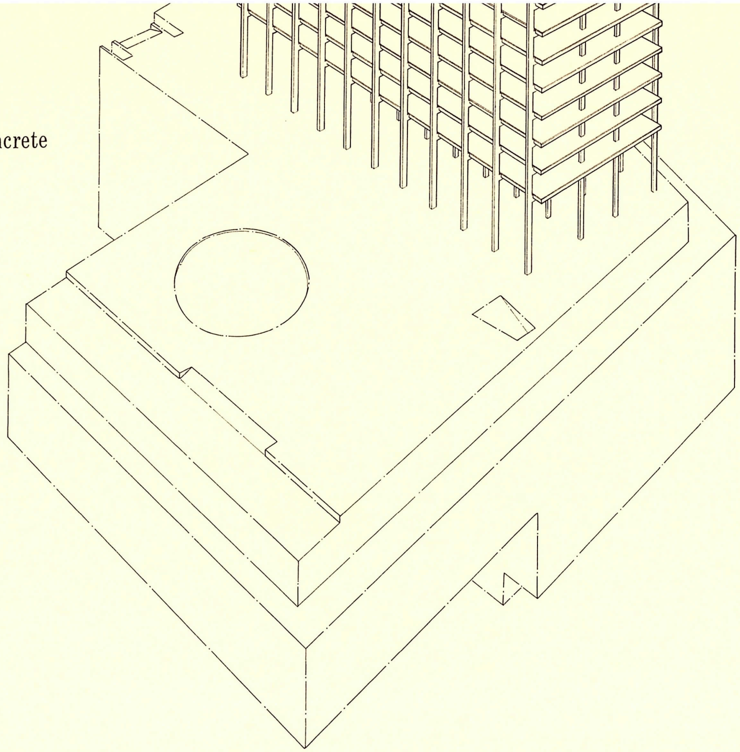
Architects: Gio Ponti, A. Fornardi
Structural Engineers: Pier Luigi Nervi, A. Danusse

Harold Lee Ogburn

Floor System

The floor system consists of reinforced concrete slabs spanning between beams, 79 feet long and spaced five feet on center. These beams are two feet six inches deep and vary from 6½ inches to two feet in width to meet the requirements of shear force and bending moment. Excessive stresses resulting from thermal movement are prevented by constructing the first nine floors on sliding bearings. The upper floors are sufficiently flexible to eliminate this problem.


rigid frames
wind forces



Structural System

All bay sizes on this 60 story steel frame building are based on a 4 foot 10 inch module. The bays measure 29 feet along the longitudinal axis of the building, while along the transverse axis they are of varying dimensions. Transverse double-girders are three feet deep and are fabricated with openings of various sizes through which pass the mechanical systems. Connecting beams are one-half the depth of the girders. All peripheral columns are located on the exterior of the building skin, and like all the major columns, they are joined to the double-girders at each floor by a rigid-weld joint, resulting in the characteristic wind load resistance of the rigid frame.

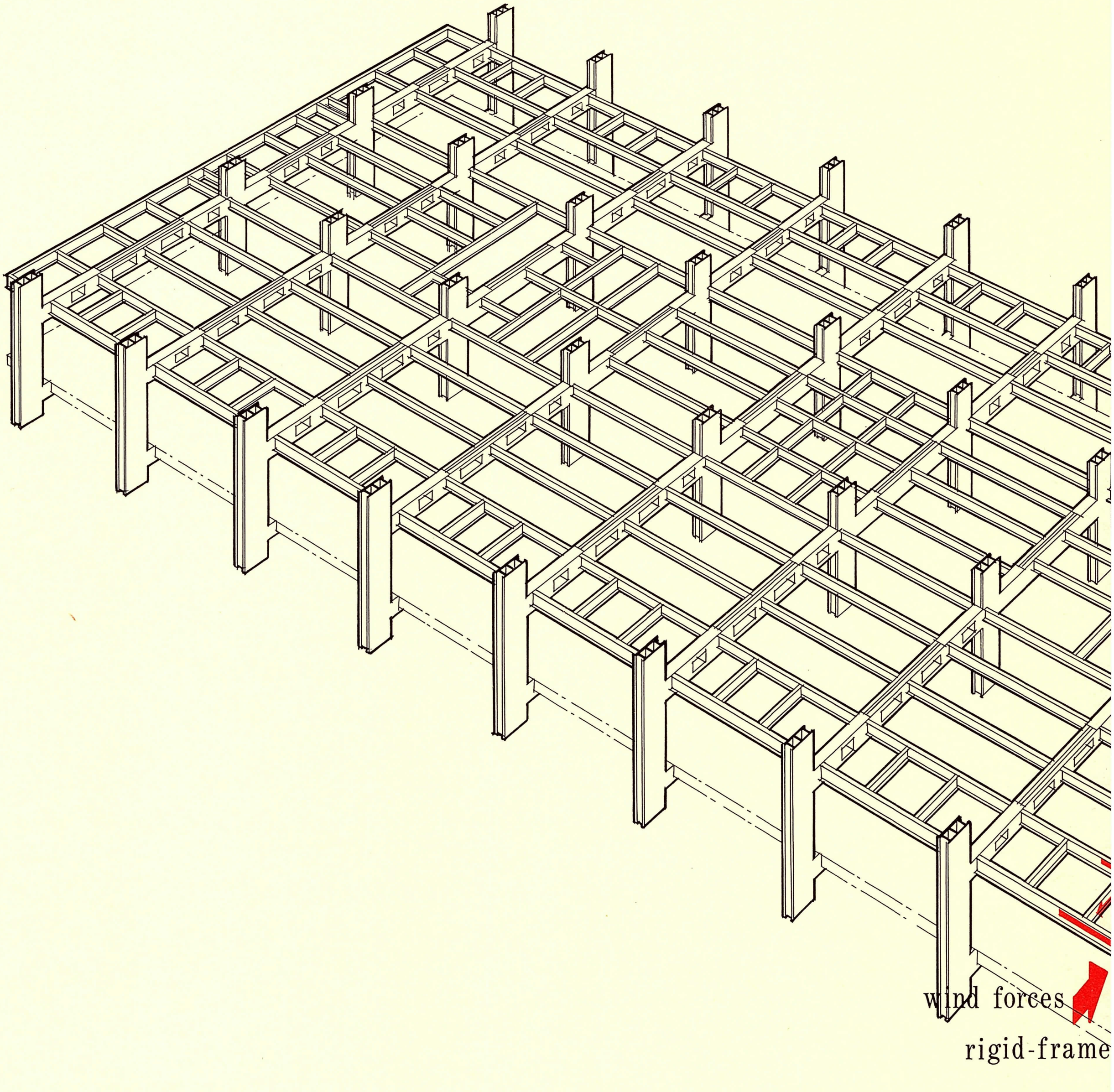
CHASE MANHATTAN BANK

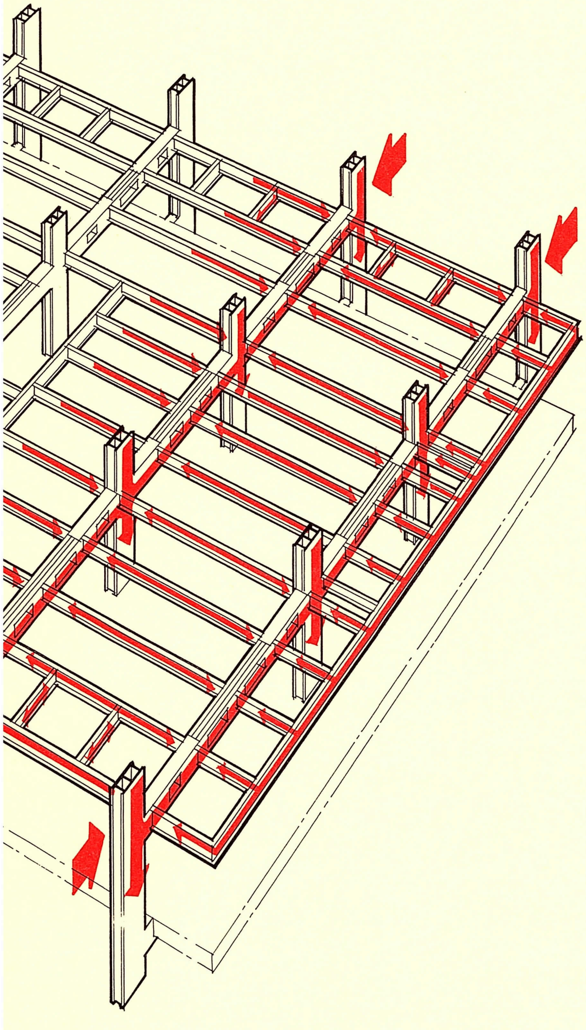
New York, New York **1960**

Architects: Skidmore, Owings and Merrill
Structural Engineers: Weiskoff and Pickworth

Irvin Alexander Pearce

CHASE MANHATTAN BANK


wind forces
rigid-frame



CHASE MANHATTAN BANK

New York, New York **1960**

Architects: Skidmore, Owings and Merrill
Structural Engineers: Weiskoff and Pickworth

John Frederick Warren

Floor System

The concrete floors are poured over cellular decks through which pass the electrical underfloor systems. These decks span between secondary beams supported by double girders which are welded at the columns to form rigid frames.

LAYOUT AND TYPOGRAPHY—RICHARD SAUL WURMAN AND WILLIAM J. BARON

COVER DESIGN—DUNCAN STUART

PHOTOGRAPHY—VISUAL AIDS DEPARTMENT—RALPH MILLS

PRINTING—N. C. STATE PRINT SHOP