Twentieth century engineering

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TWENTIETH CENTURY ENGINEERING

THE MUSEUM OF MODERN ART

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The Museum of Modern Art
New York

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Introduction

Engineering is defined by the dictionary as an applied science. Concerned originally with the management of engines, it is now understood as the manipulation of physical forces to make structures and machines. Besides bridges, dams and stadia, and enclosures for storage, work, and public assembly, engineering at architectural scale ranges from such quasi-mechanical objects as radar and telescope installations to highways, earth terracing, and artificial islands.

Although engineering has been regarded as an art in the craft sense only, in the twentieth century the art of architecture has sought to emulate its rigorous efficiency and the boldness of its forms. Architects are not alone in finding work by engineers to be beautiful. Dams and bridges, and certain kinds of large utilitarian buildings, are readily admired by a public responsive to effects of monumental scale.

In the twenties and thirties dams, bridges and grain silos were taken as proof of our civilization's ability to match the grandeur of Egyptian pyramids and Roman viaducts. Like the great works of the past our own monumental structures usually employ geometric shapes at enormous scale, and are free of superfluous detail. Engineers were acknowledged to be not only great builders but even great architects, the beauty of their work being understood as the product of rational analysis and the solution of "problems". As architecture itself was directed toward the solving of problems (more often of function rather than structure) it became increasingly difficult to distinguish between the engineer's craft and the architect's art. So long as we assume that pure forms are beautiful; that purity of form is proof of rational thought; and that rational thought is desirable, the rational work of the engineer will seem to us inherently beautiful. What role is left for the architect?

Ruskin defined architecture as the decoration of structure. For Le Corbusier it is the play of forms in the light, and decoration is irrelevant. Frank Lloyd Wright regarded space as the truth of architecture, the forms that enclose and define space being subordinate, at least theoretically, to the revelation of what is intangible and essentially mysterious. Mies van der Rohe, although his earliest work was largely dependent on the manipulation of space, has rejected the primacy of such concepts and now sees architecture as structure alone.

It is this post-World War II phase of Mies's work that has brought architecture closer to engineering than ever before. That Mies uses such semi-structural elements as mullions for decorative purposes does not invalidate the consistency of his approach, but he has opened the way for others to restate Ruskin's depressing conclusion: that architecture after all is only the decoration of structure. And from unnecessary decoration it is a short step to unnecessary structure.

Architecture in the United States, with or without the aid of rational argument, is moving toward the elaboration of form for its own sake. As buildings become heavier and more sculptural, structure again tends to be merely one of several sources for formal invention. Under these circumstances the craft of the engineer has become in its own way "artistic", and structural complications disproportionate to the actual problem are often praised for their "imaginative" daring. Nevertheless, the engineer is still rightly regarded as a particularly responsible kind of technician, a role the architect often appears to disdain.

Engineering offers encouragement, or at least solace, but for the wrong reasons. The objectivity of engineering is a myth. All things being equal there would be as many styles of engineering as there are engineers, but of course all things are seldom equal. It is true that a concrete dam inserted into a rock canyon in Iran will not look like a concrete dam built in the Tennessee Valley, because differences in site conditions, in the kinds of tools economically feasible in each place, and in the problems dams are designed to solve—including problems of social engineering—are bound to result in visible differences of form. But even projects designed under equal conditions still reveal important formal differences, and these can only be attributed to the fact that engineers do have subjective, if not actually arbitrary, preferences for certain kinds of shapes. The more these subjective preferences are concealed, the more carefully they are linked in a chain of rational decisions, the more decisive are their effects.

Differences in engineering style may be compared to attitudes toward craft. The engineer may take pride in the single-minded consistency of his solution to diverse and often contradictory problems, expecting us to share his satisfaction in elegance, lightness, and the apparent ease with which difficulties are overcome. The bridges and buildings of Robert Maillart, for example, are perhaps for the twentieth century the supreme example of this aristocratic taste. Alternatively, the engineer may glory in the sheer effort his work involves, and by exaggerating the importance of details he may achieve that operatic expressiveness his audience will want to applaud. Extravagance for its own sake is not always as gratifying in engineering as it is in music, and yet the heroic forms and quasi-structural embellishments sometimes used to solve relatively simple problems by the great Italian engineer, Pier Luigi Nervi, do indeed move us by their exuberant virtuosity.

If engineering may be regarded as a performing art, or entertainment, we are offered a choice between the magician whose sleight of hand discloses neither preparation nor effort but appears to bring about miracles; and the weight-lifter whose rippling muscles and disturbing grunts allow us to share the joy of successful effort. Indifferent to the lessons of psychology, architects and engineers habitually mark out for themselves separate and supposedly contrasting roles. The architect sees the engineer as a clumsy technician; the engineer sees the architect as a willful esthete. In this argument both sides are wrong: the engineer is no less a willful esthete than the architect.

A more useful debate for the development of architecture in what is left of this century would have to do with the relevance of those forms engineers give us. For the engineer working to enclose space, the most challenging problem is the clear span at giant scale. The vaults or domes that usually solve this problem most economically seldom answer the formal requirements architects are likely to have in mind: how will the roof be connected visually to the ground; how will entrances be made; how will glazing be incorporated without concealing or distorting the essential structure; how will accessory buildings be related to the initial concept; and how will the structure relate to its environment. If architects have not always succeeded in providing satisfactory solutions to these problems, engineers have too often been altogether indifferent to them. The majority of buildings in this exhibition are defaced by amateurish architectural details, some of them so gross as to make an appreciation of structural merit an act of charity. Many of these problems arise from the enthusiasm of architects and engineers alike for forms unsuited to human use. The shape of a cooling tower such as Carling (19) for example, does not really lend itself to the functions of an auditorium, even when Le Corbusier himself adapts it for the Assembly Hall at Chandigarh.

The Carling towers illustrate very well those aspects of engineering to which architects are so susceptible. Mathematically graceful curves and heroic scale are sufficient to overcome any hesitation we may feel about the cluttered design of the base. Even this esthetically unconvincing detail contributes to Carling's deliberate, purposeful grandeur. Small houses nearby, unhappily dwarfed, must finally seem to us a petty distraction, and we may imagine the landscape's equilibrium restored by removal of the houses rather than the towers. It is this conflict between the traditional scale of houses and even cities, and the new scale of industrial buildings, highways, and dams that we have not yet resolved.

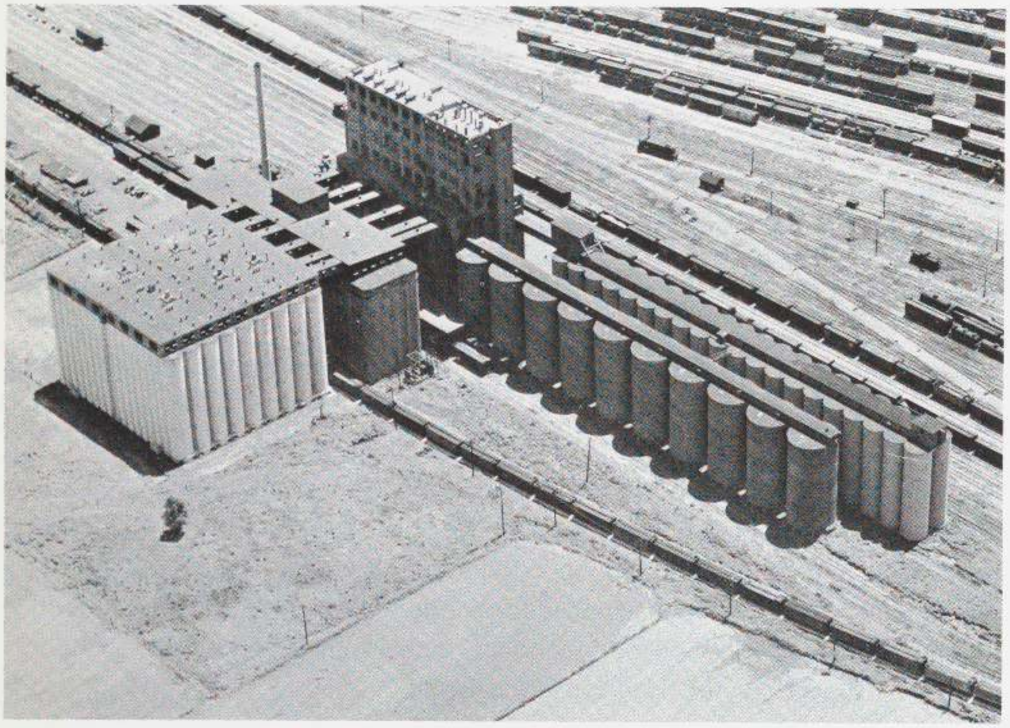
The problems engineers solve cut across economics, politics, science and art, affecting the lives of all men—on this planet now and eventually somewhere else as well. Even engineering's worst offenses—superhighways, for example—are often intrinsically beautiful and suggest answers to some of the problems they now help to perpetuate. Engineering is among the most rewarding of the arts not only because it produces individual masterpieces but because it is an art grounded in social responsibility. Today we lack the political and economic apparatus that would facilitate a truly responsible use of our technology. But it may be that a more skillful and humane use of engineering depends on a more knowledgeable response to its poetry.

Arthur Drexler

1 Grain elevators.
Kansas City, Missouri. 1904-30.
Folwel-Ahlskog Company.

2 Oil refinery.
Baytown, Texas. 1937.
C. F. Braun and Company.

3 Nuclear power station.
Chinon, France. 1960.
Electricité de France.



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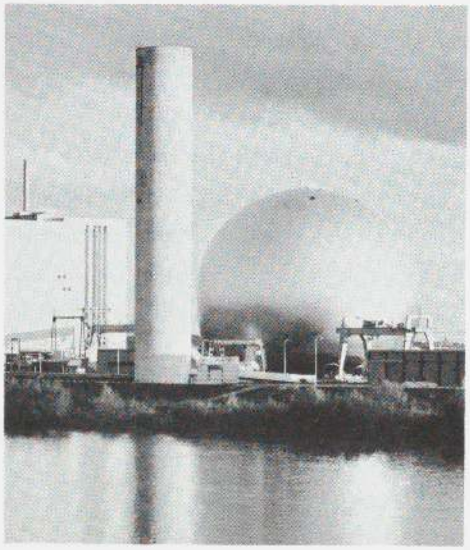

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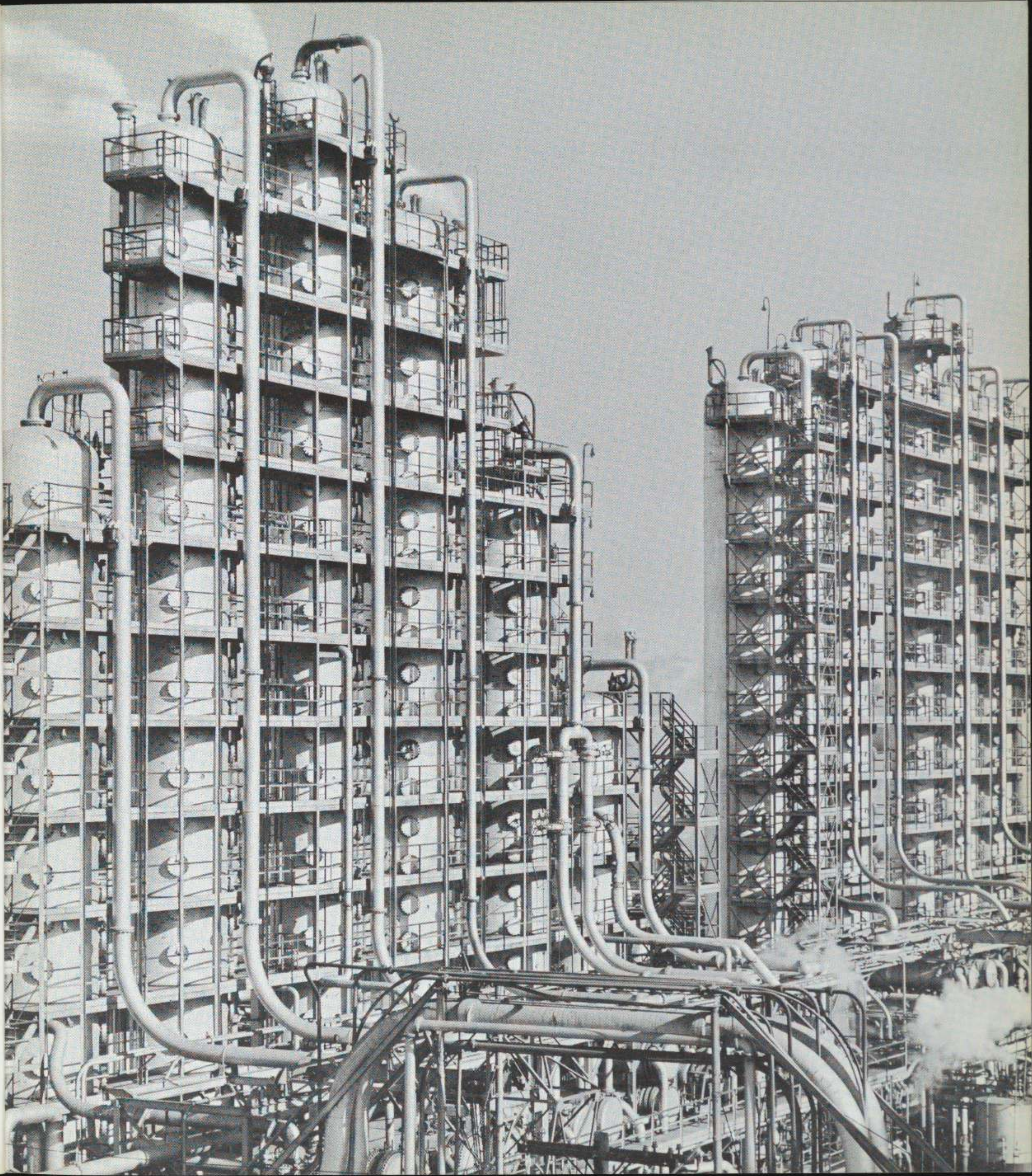
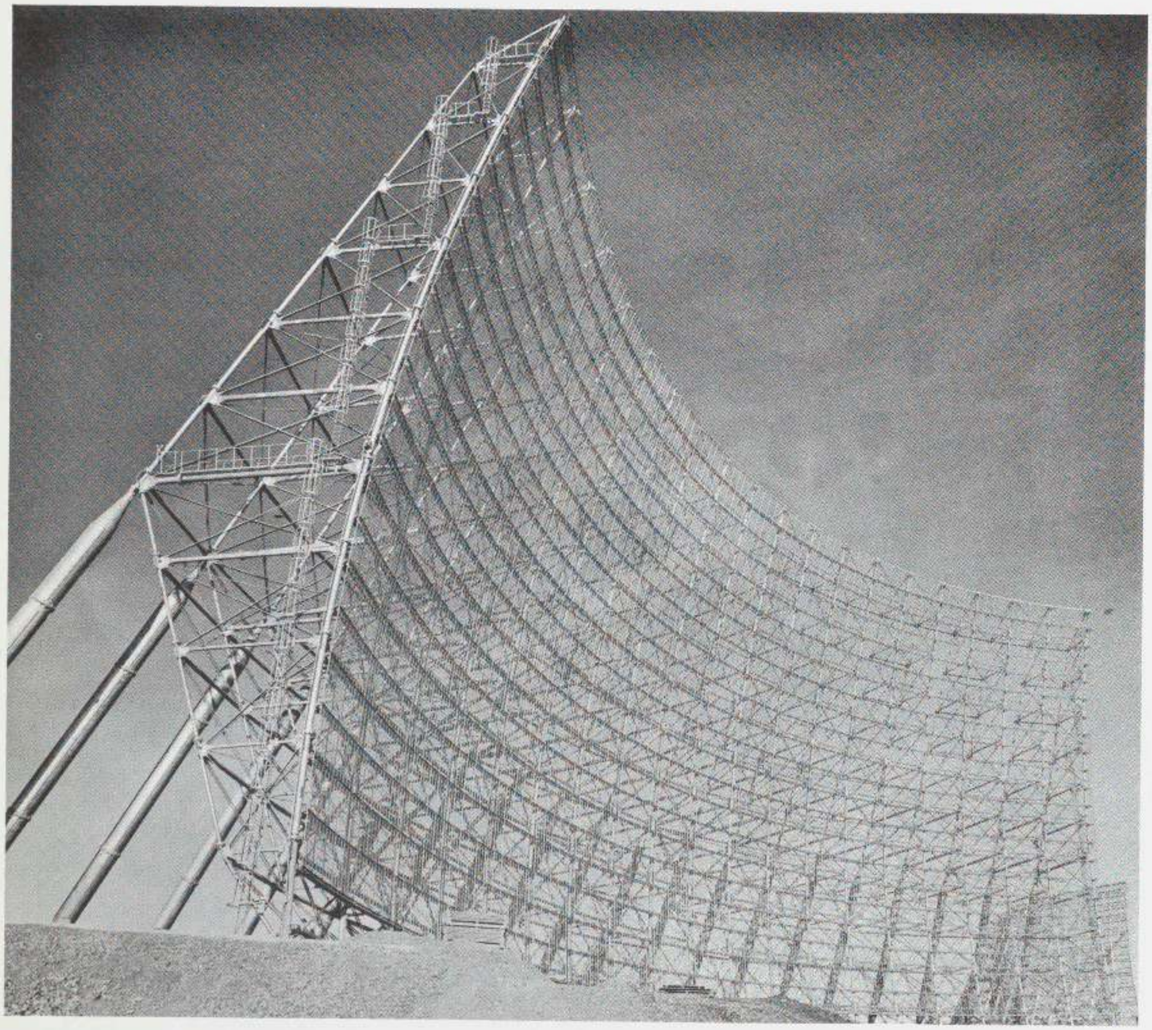


4 Radar antenna.
Ballistic Missile
Early Warning System (BMEWS).
Thule, Greenland. 1960.
Kennedy Antenna Division of
Electronics Specialty Company.

5 Radar telescope.
Stanford, California. 1963.
Stanford Research Institute
(Ray L. Leadabrand).



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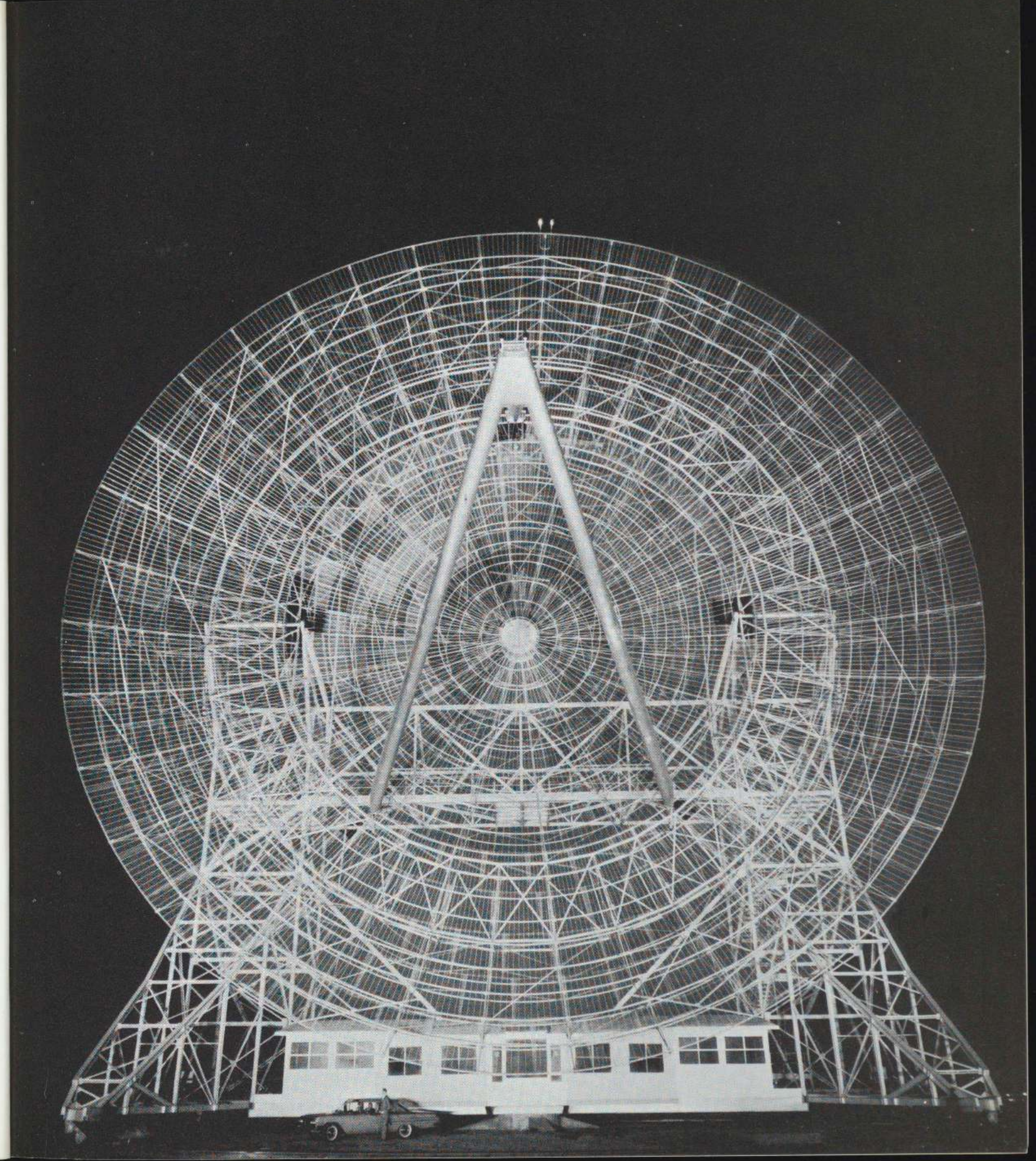
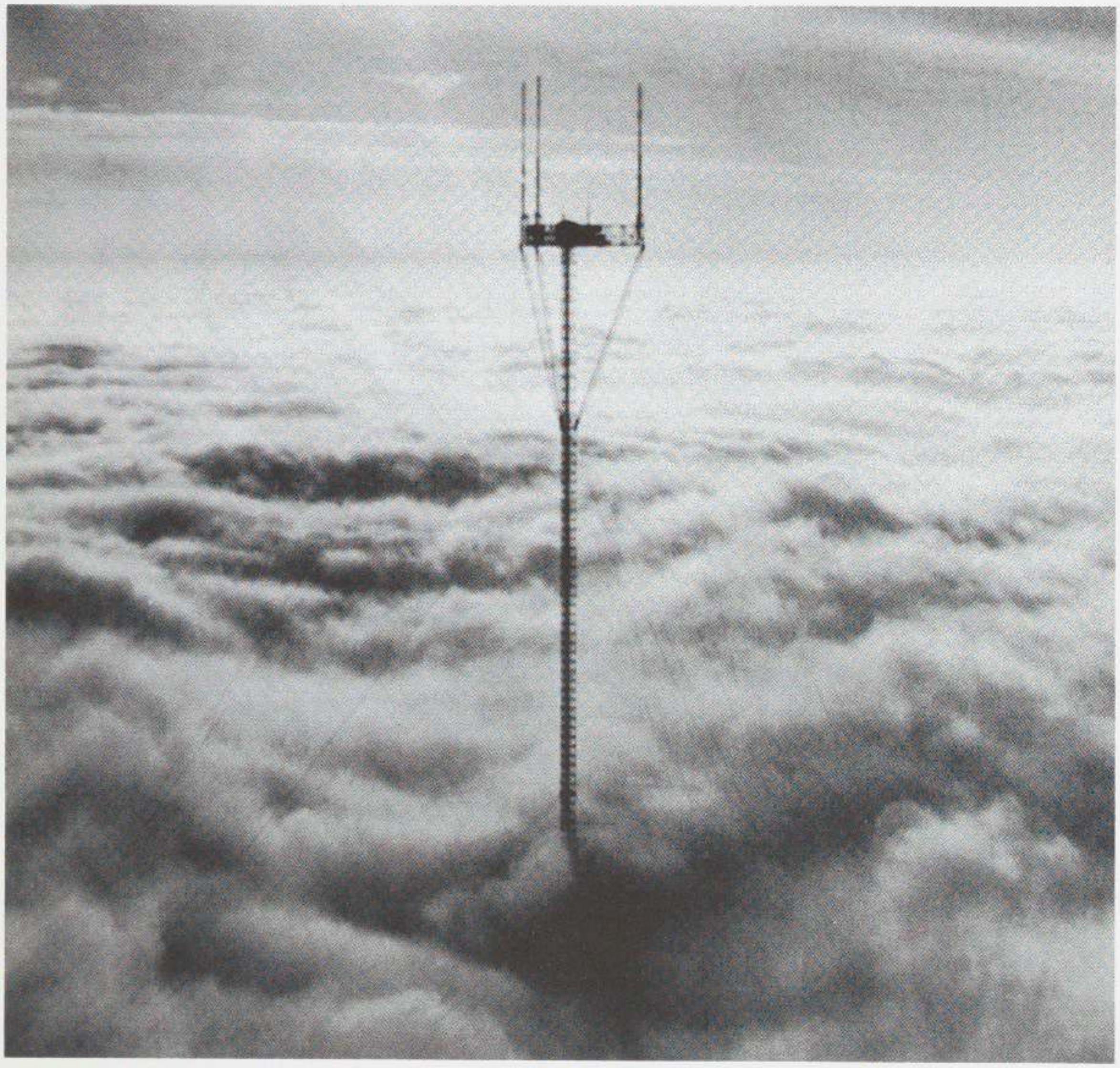


6 Television antenna.
Sacramento, California. 1961.
Dresser-Ideco Company.

7 Radio antenna.
Budapest, Hungary. 1933.
Blaw-Knox Company (Ira W. Marshall).

8 Television antenna.
Fargo, North Dakota. 1963.
Kline Iron & Steel Company
(F. L. Anderson).

9 Prototype tension-compression mast.
1959.
Designer: Kenneth Snelson.



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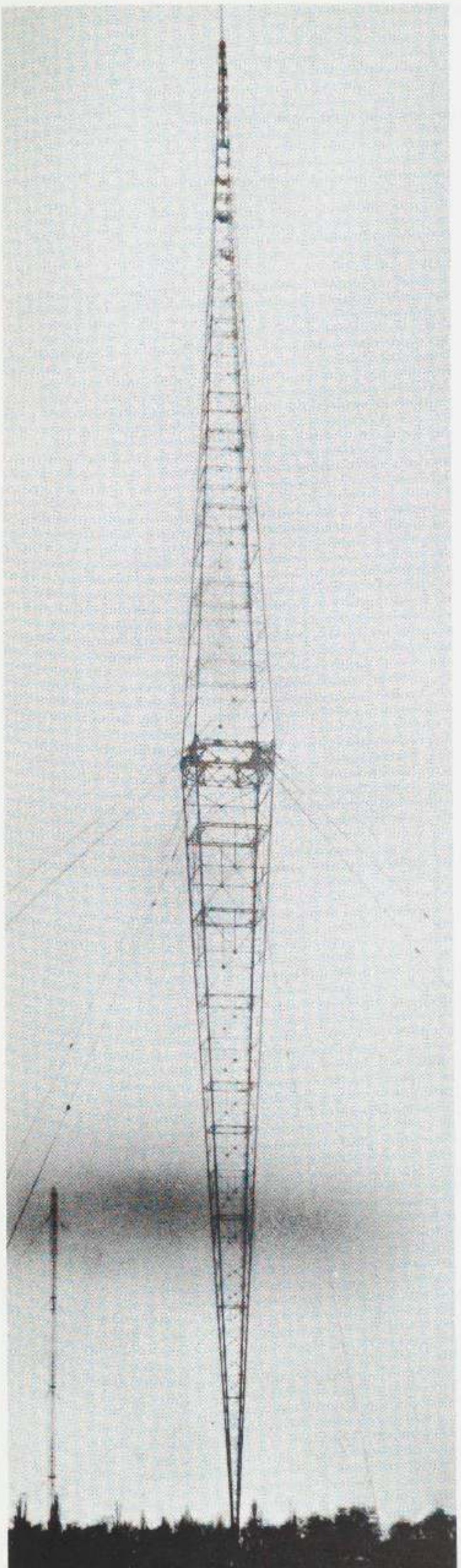
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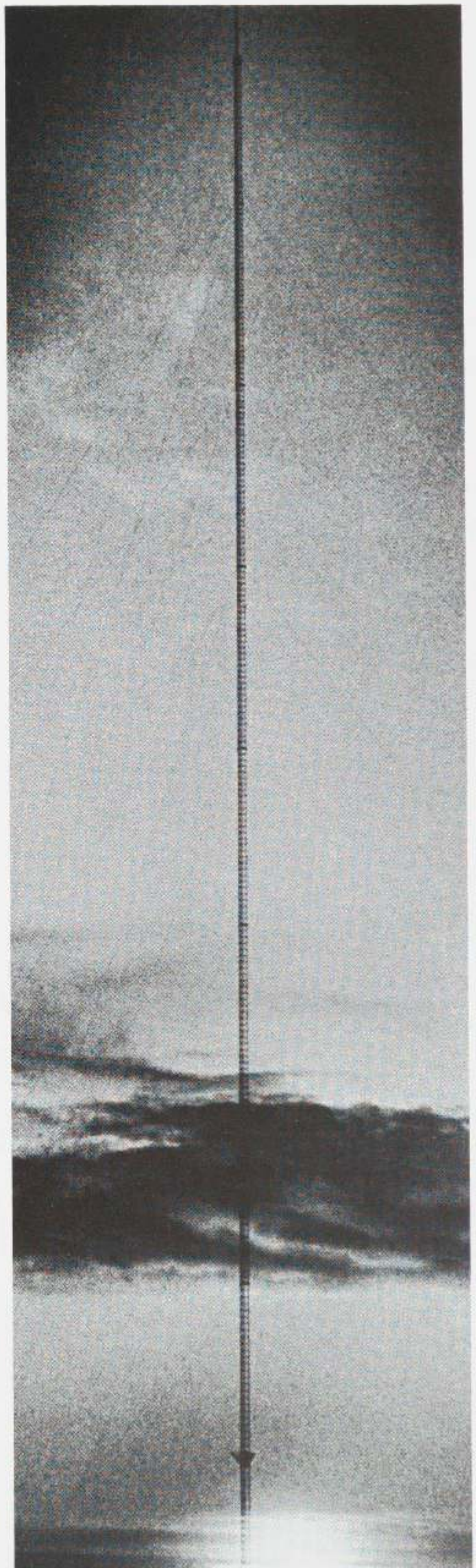
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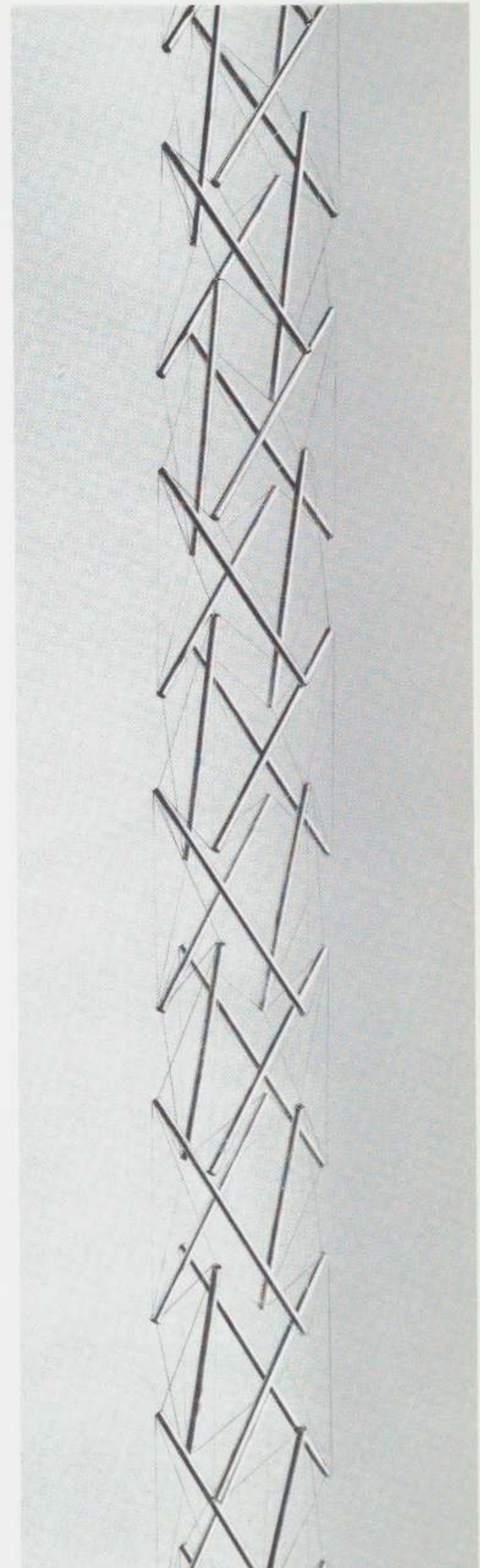
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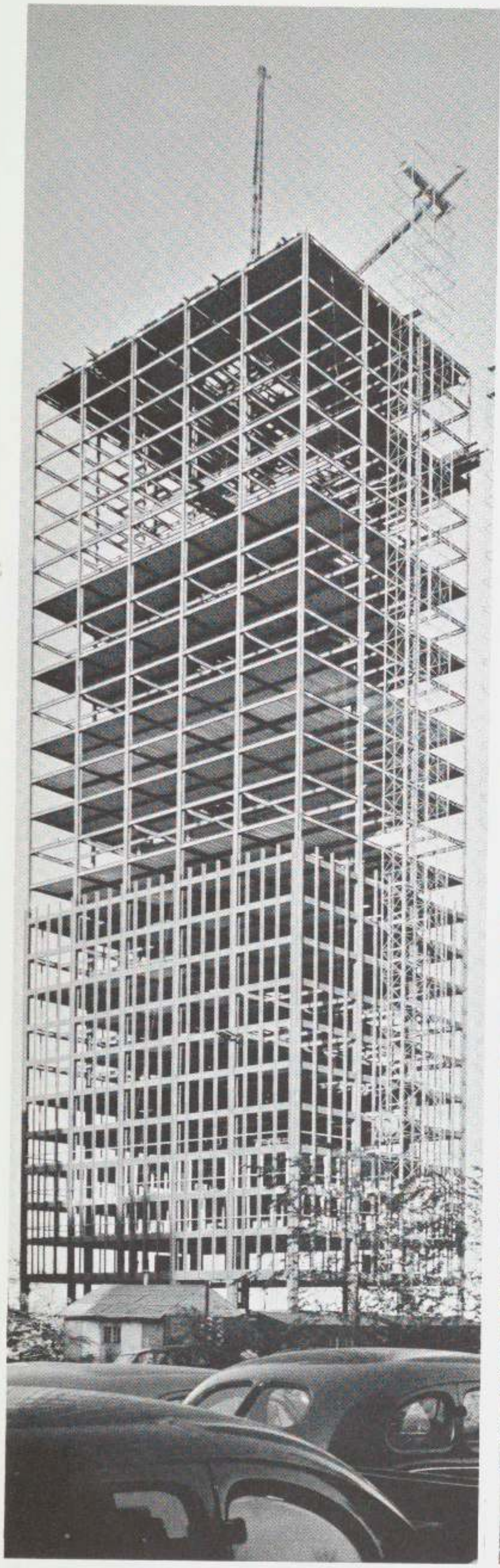

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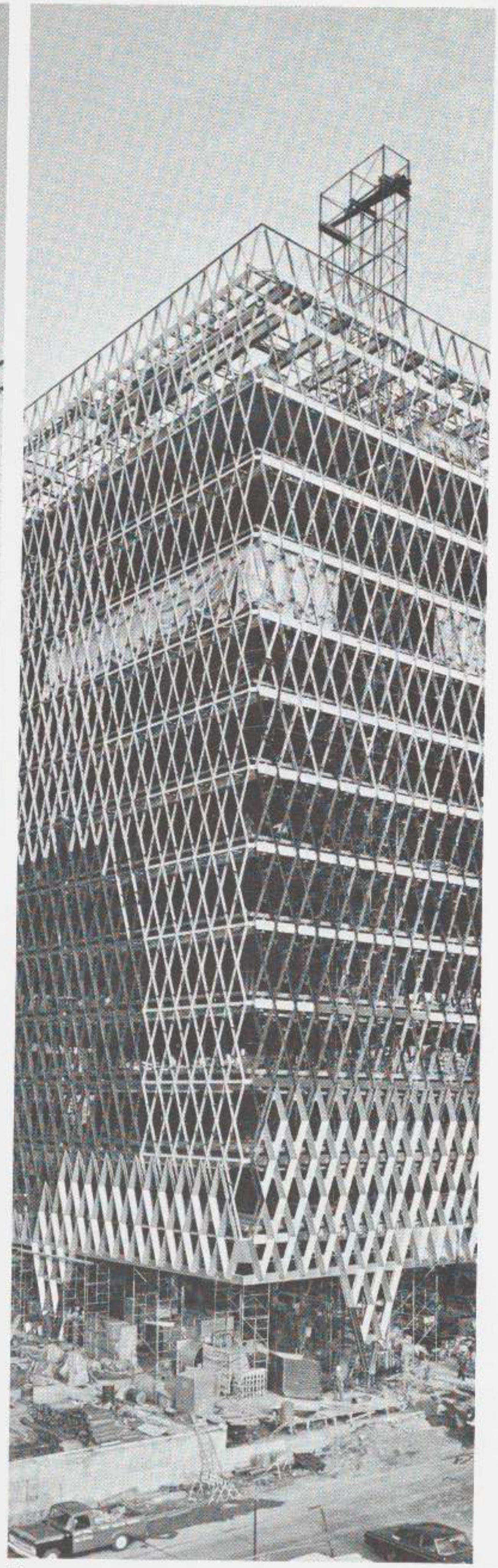

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10 860 Lakeshore Drive apartment building.
Chicago, Illinois. 1951.
Frank J. Kornacher.
Architect: Ludwig Mies van der Rohe.

11 IBM office building.
Pittsburgh, Pennsylvania. 1964.
Worthington, Skilling, Helle & Jackson.
Architect: Curtis & Davis, New Orleans.

12 Vertical Assembly Building. Advanced
Saturn C-5 Launch Complex 39.
Merritt Island, Cape Kennedy, Florida.
Under construction.
Engineer/Architect: URSAM
(Urbahn-Roberts-Seelye-Moran).

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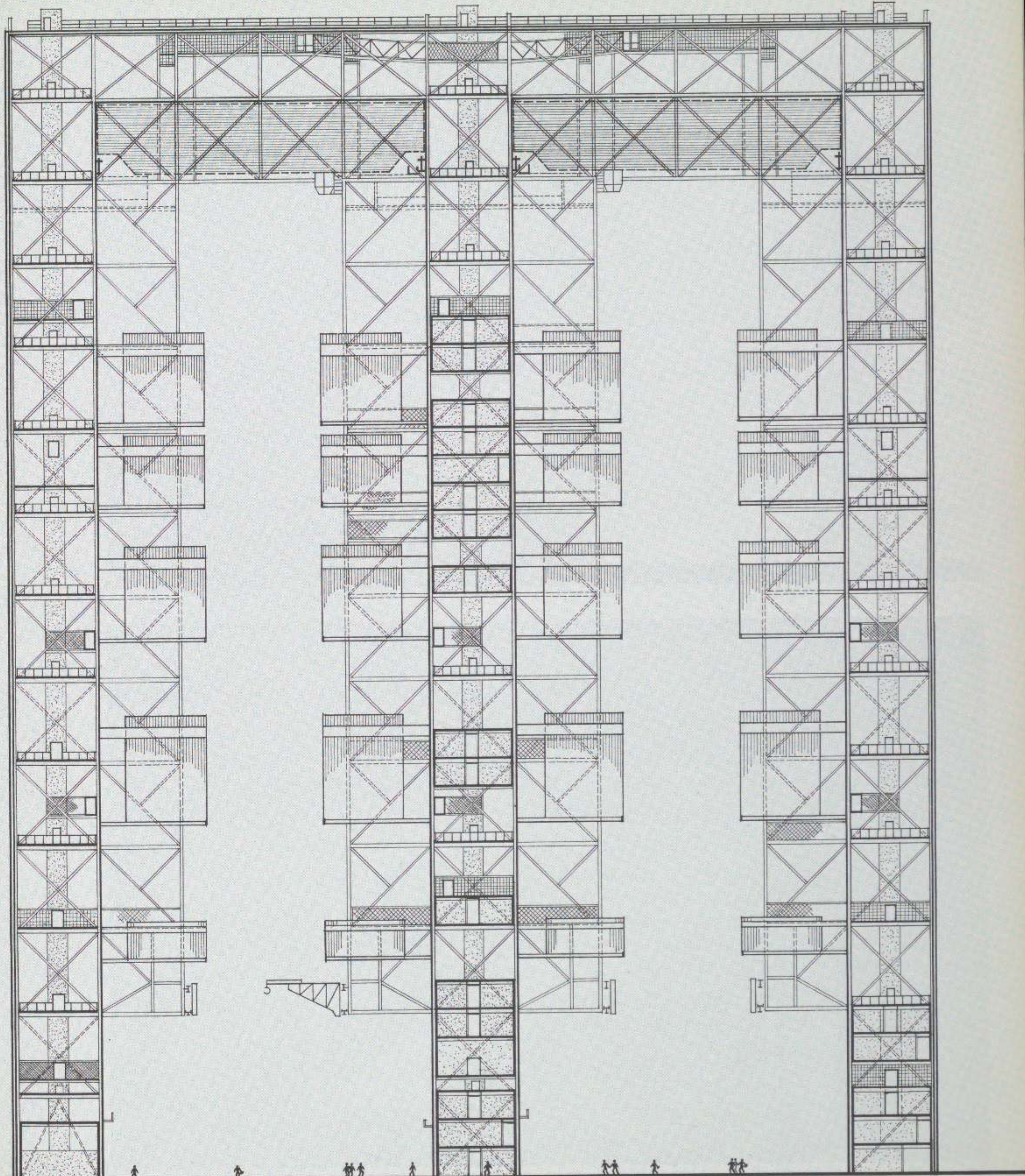

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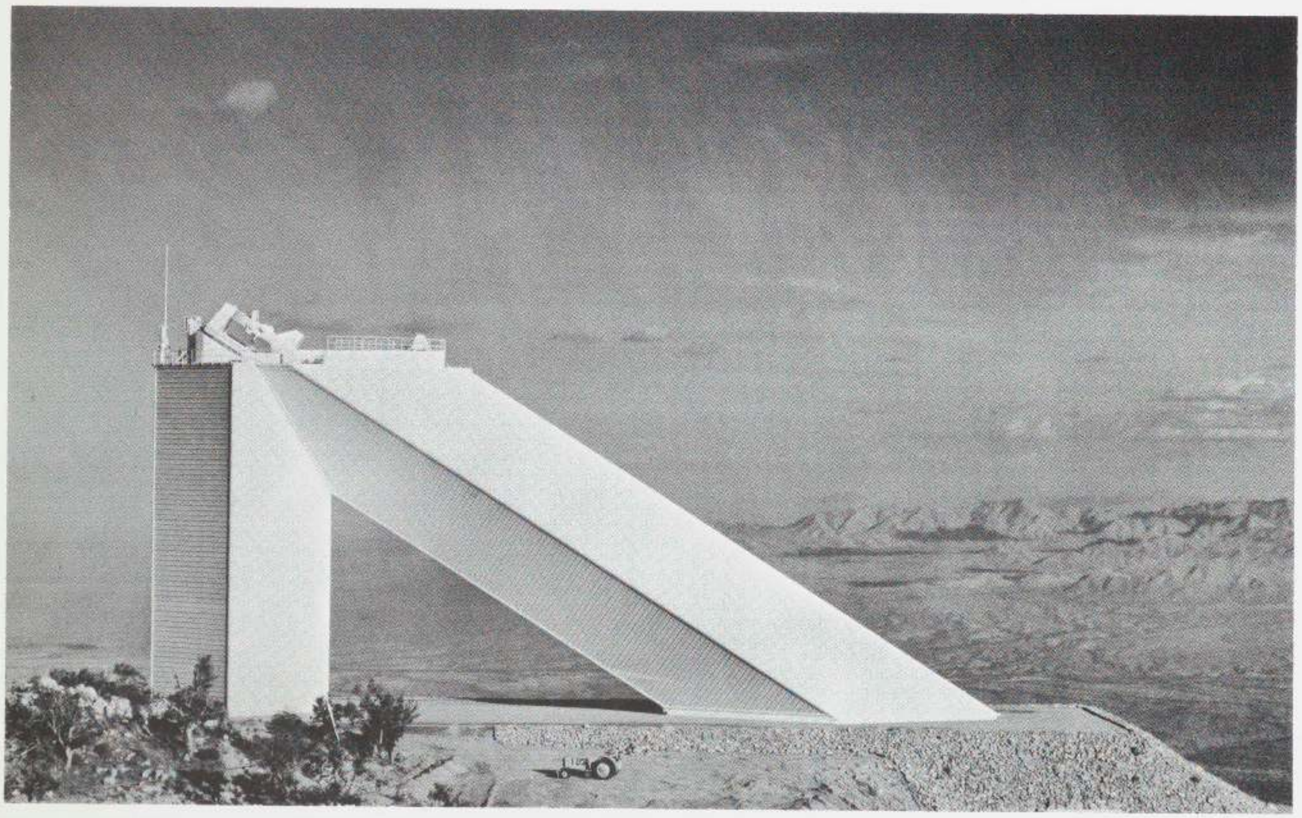

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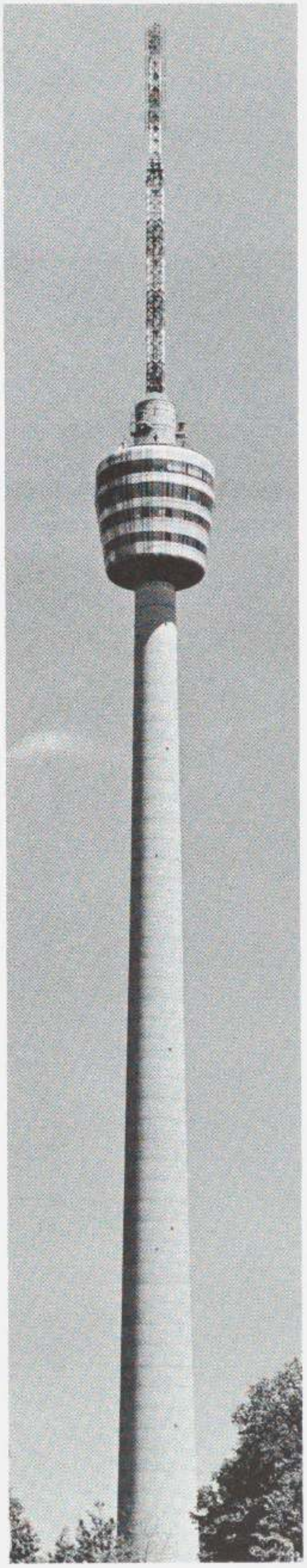

13 Prototype air traffic control tower.
Under construction.
Severud-Elstad-Krueger.
Architect: I. M. Pei & Associates.

14 Solar observatory tower.
Kitt Peak, Arizona. 1962.
Engineer/Architect: Skidmore, Owings & Merrill, Chicago.

15 Television tower.
Stuttgart, Germany. 1956.
Fritz Leonhardt.

16 Water tower.
Marshalltown, Iowa. 1962.
Chicago Bridge & Iron Company.

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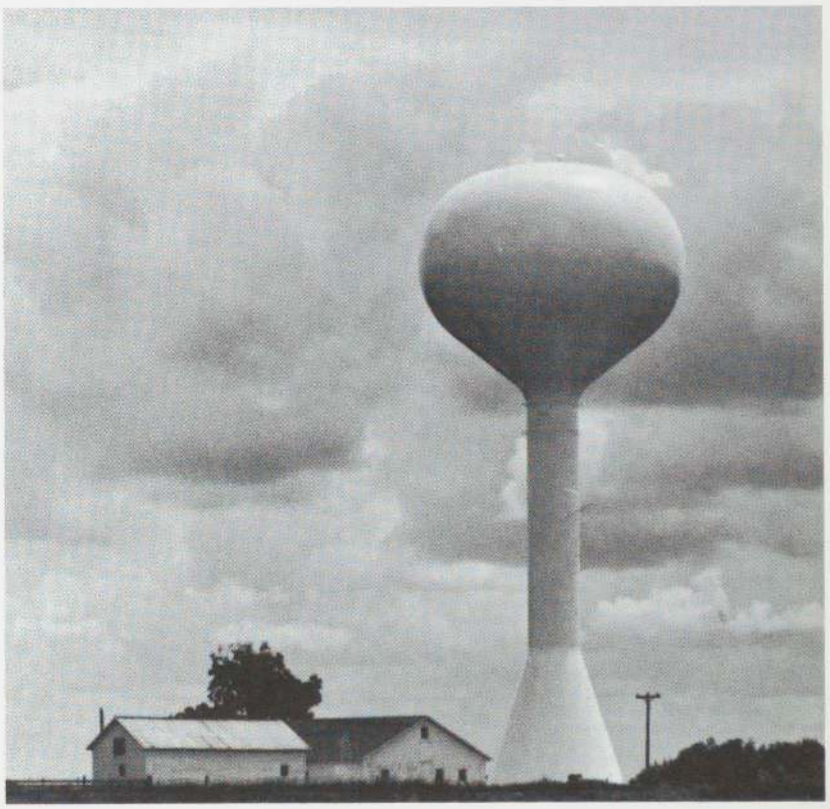

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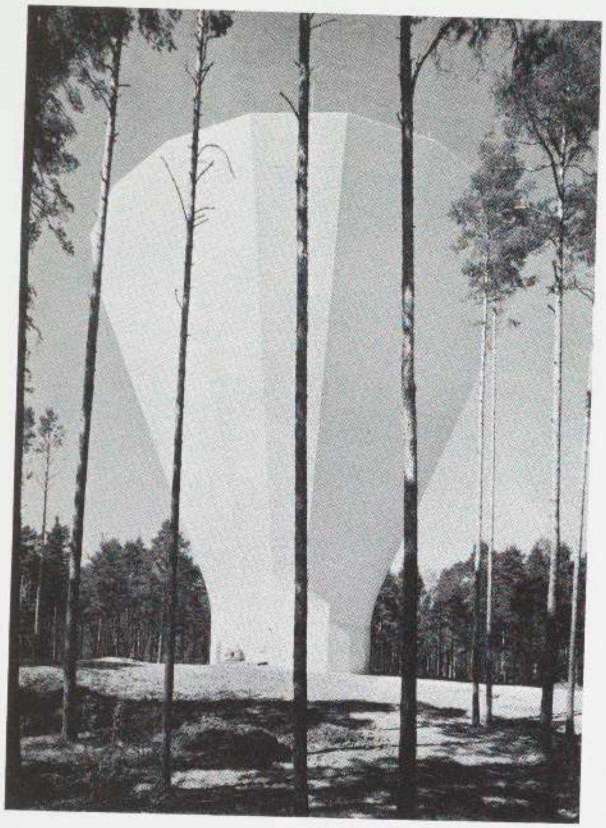

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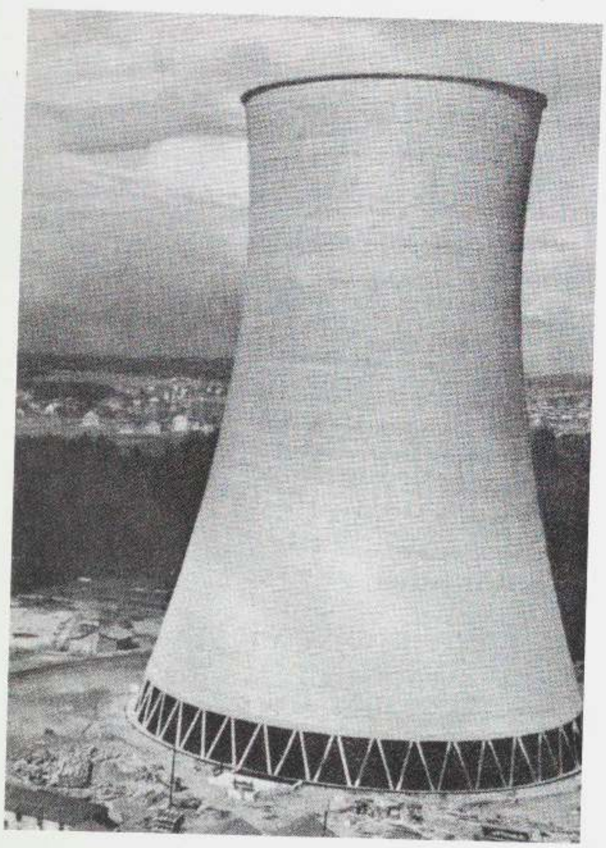

17 Water tower.
Uppsala, Sweden. 1958.
AB Vattenbyggnadsbyrån.
Architect: Sune Lindström.

18 Water tower.
Lauttasaari, Finland. 1958.
P. Simula Engineering Company.
Architect: Department of Construction
City of Helsinki.

19 Cooling tower.
Carling, France. 1949.
Entreprises de Génie Civil de Lens.

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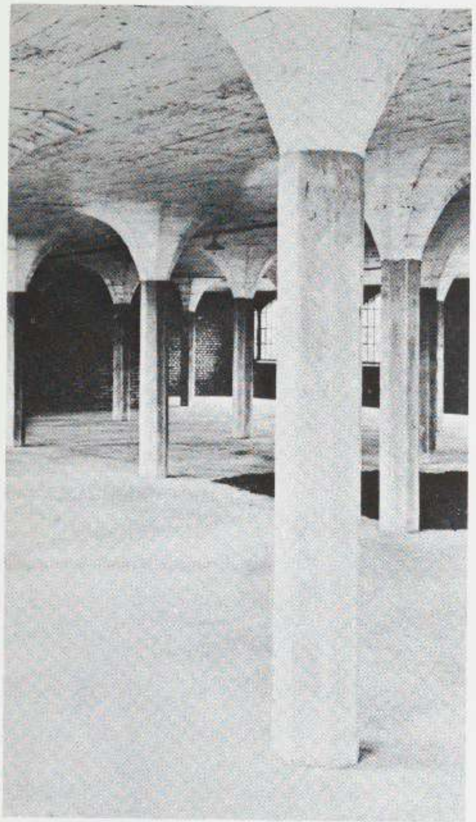
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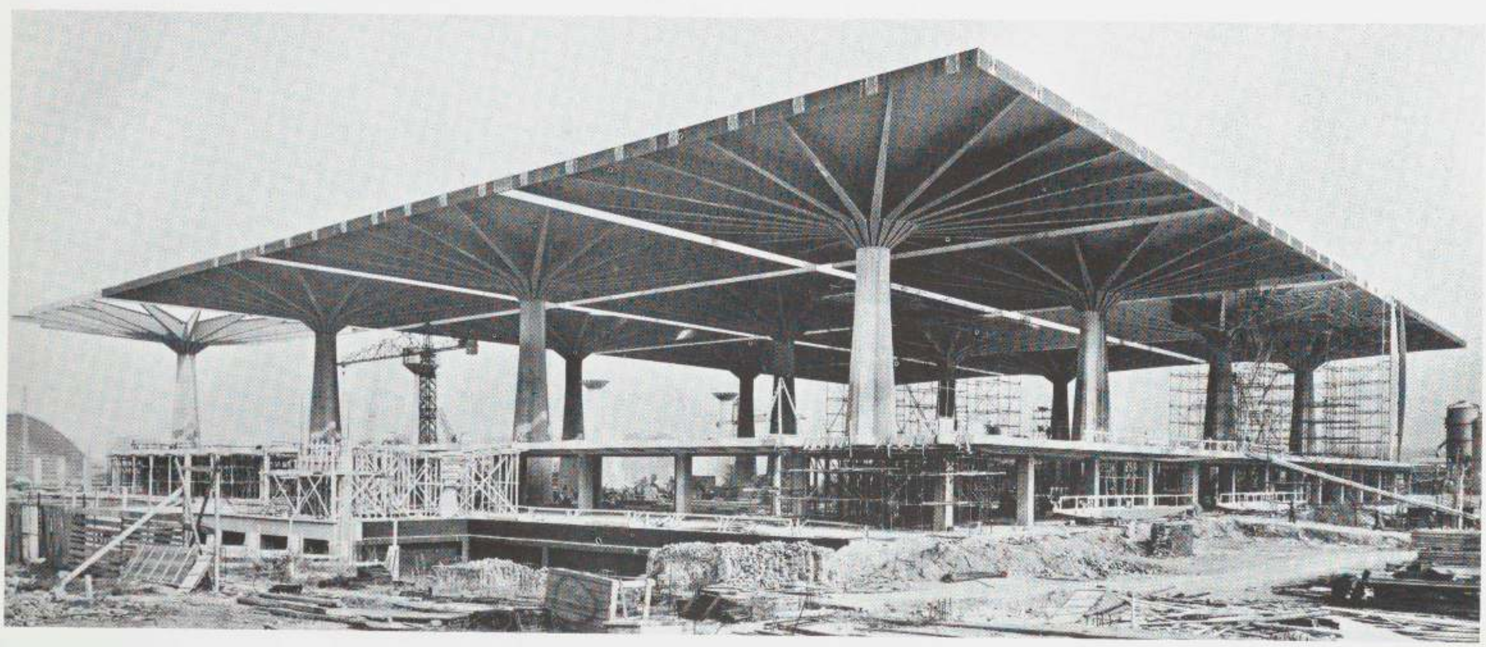
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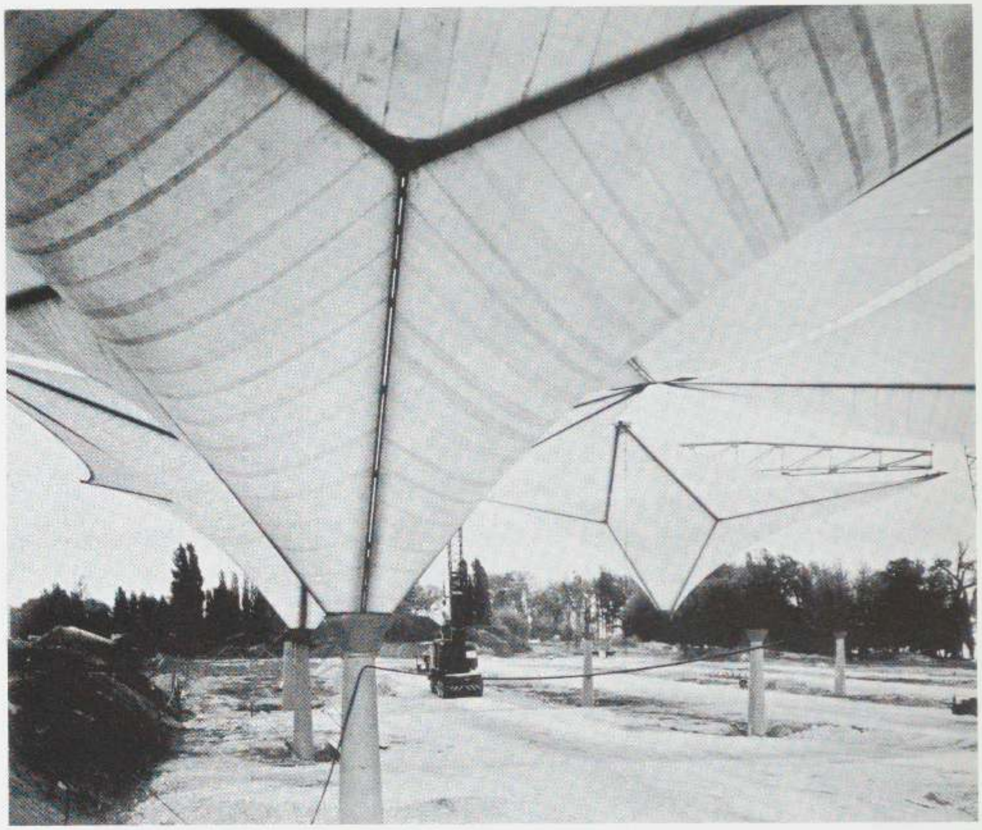
20 Zürcher Lagerhaus-Gesellschaft warehouse.
Zürich-Giesshübel, Switzerland. 1910.
Robert Maillart.

21 S. C. Johnson & Son Inc.
Administration Building.
Racine, Wisconsin. 1939.
Architect: Frank Lloyd Wright.

22 U. S. Exhibition Pavilion.
Moscow, U.S.S.R. 1959.
Albert G. H. Dietz.
Architect: George Nelson.

23 Sector 5 Pavilion, EXPO 1964.
Lausanne, Switzerland. 1964.
Heinz Hossdorf.



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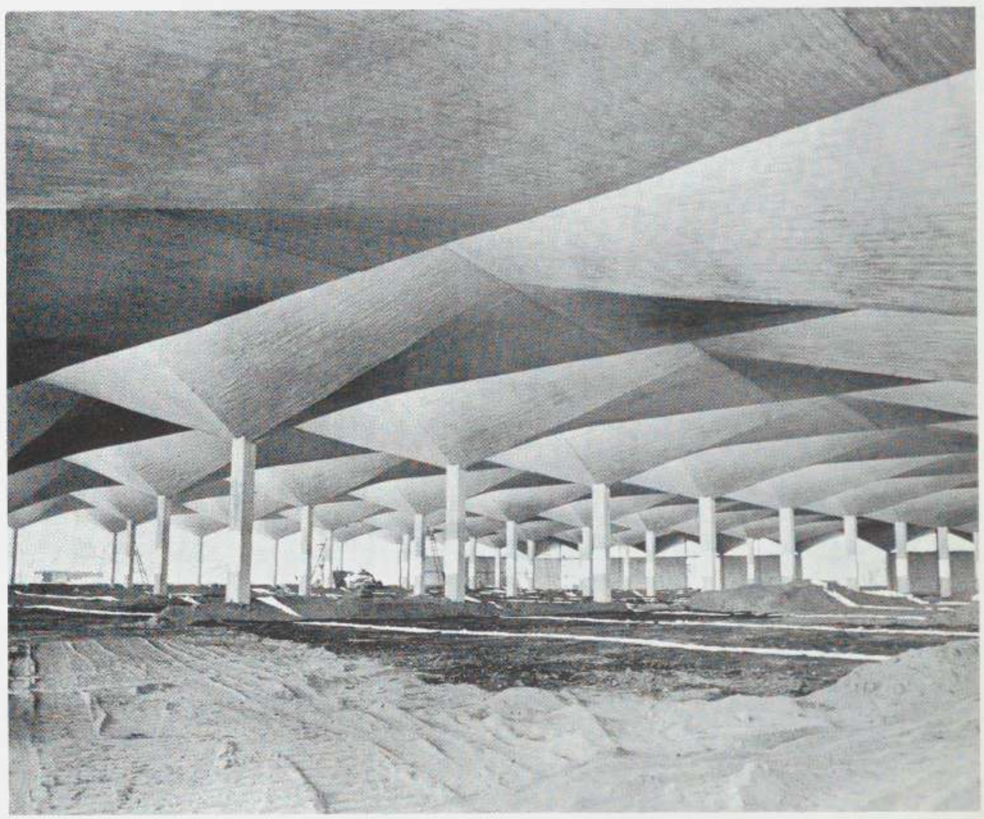
24 Palazzo del Lavoro exhibition hall.
Turin, Italy. 1961.
Engineer/Architect: Pier Luigi Nervi.

25 Nacional Distribuidora S.A. warehouse.
Mexico, D.F., Mexico. 1960.
Felix Candela.



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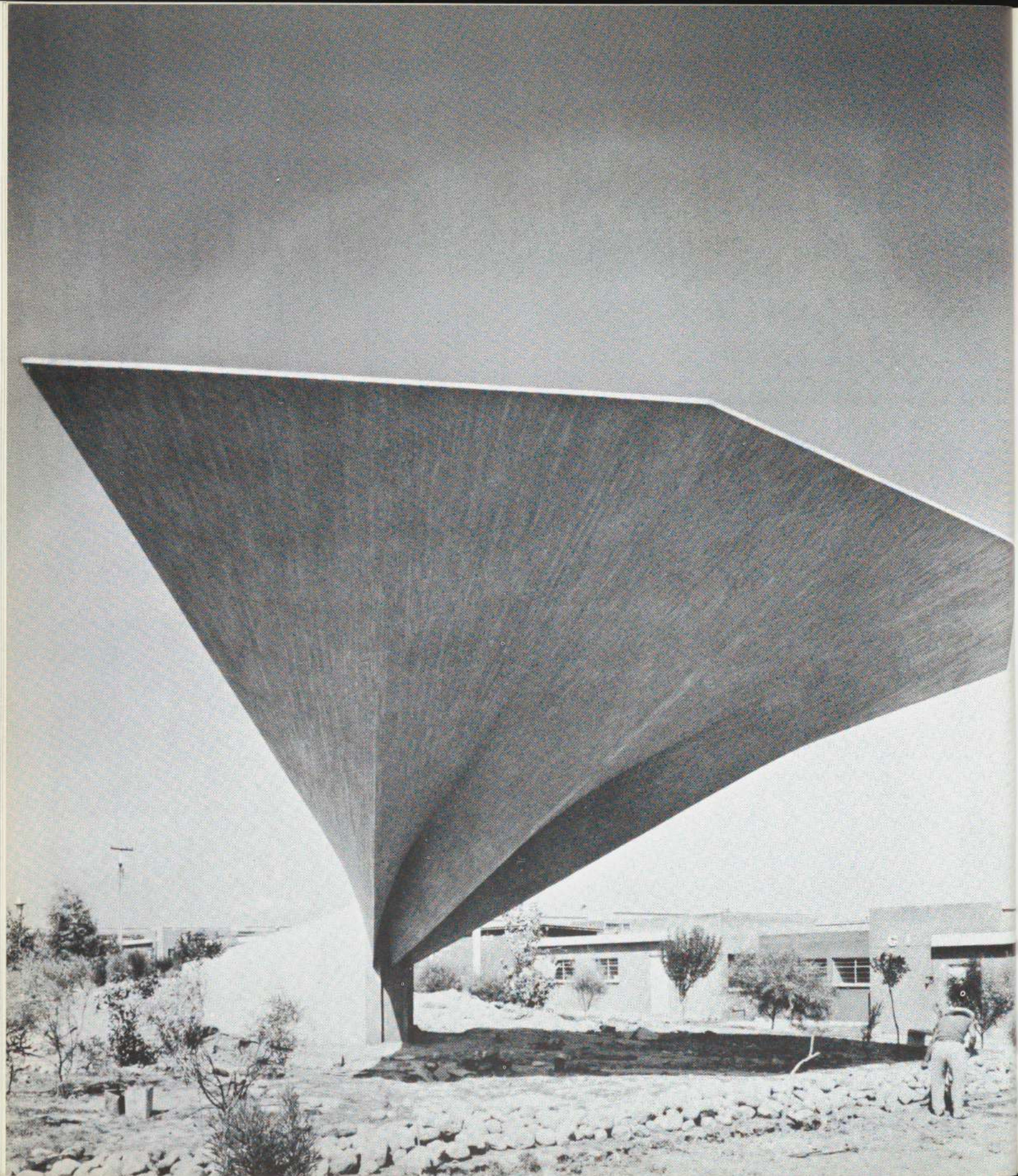

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26 Seguro Social housing development band shell.
Santa Fé, D.F., Mexico. 1956.
Felix Candela.

27 Small aircraft hangars.
Grimbergen-Lez-Bruxelles, Belgium. 1950/51.
A. Hardy.

28 National Airlines Hangar.
Miami, Florida. 1958.
Ammann & Whitney. Architect:
Herbert H. Johnson Associates.

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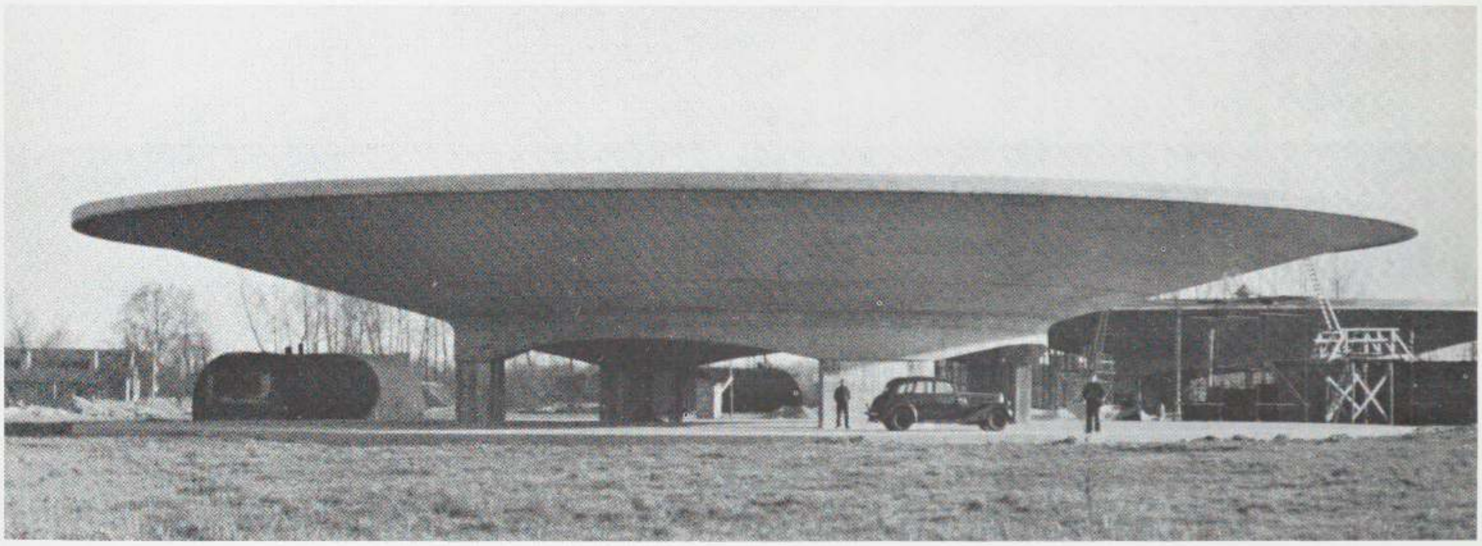

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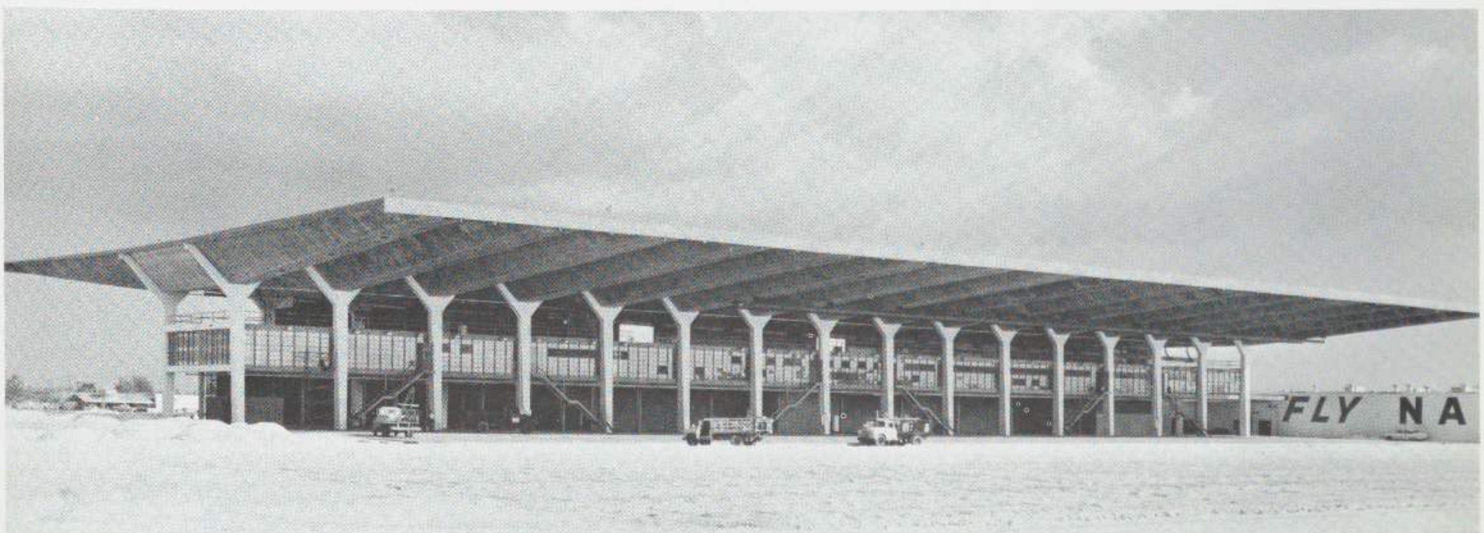

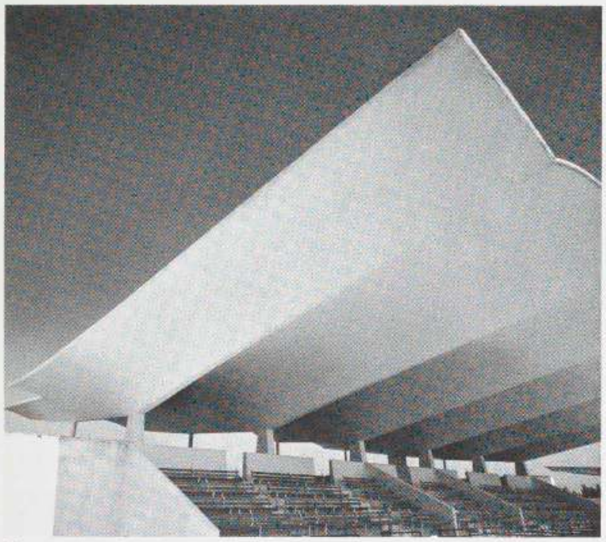
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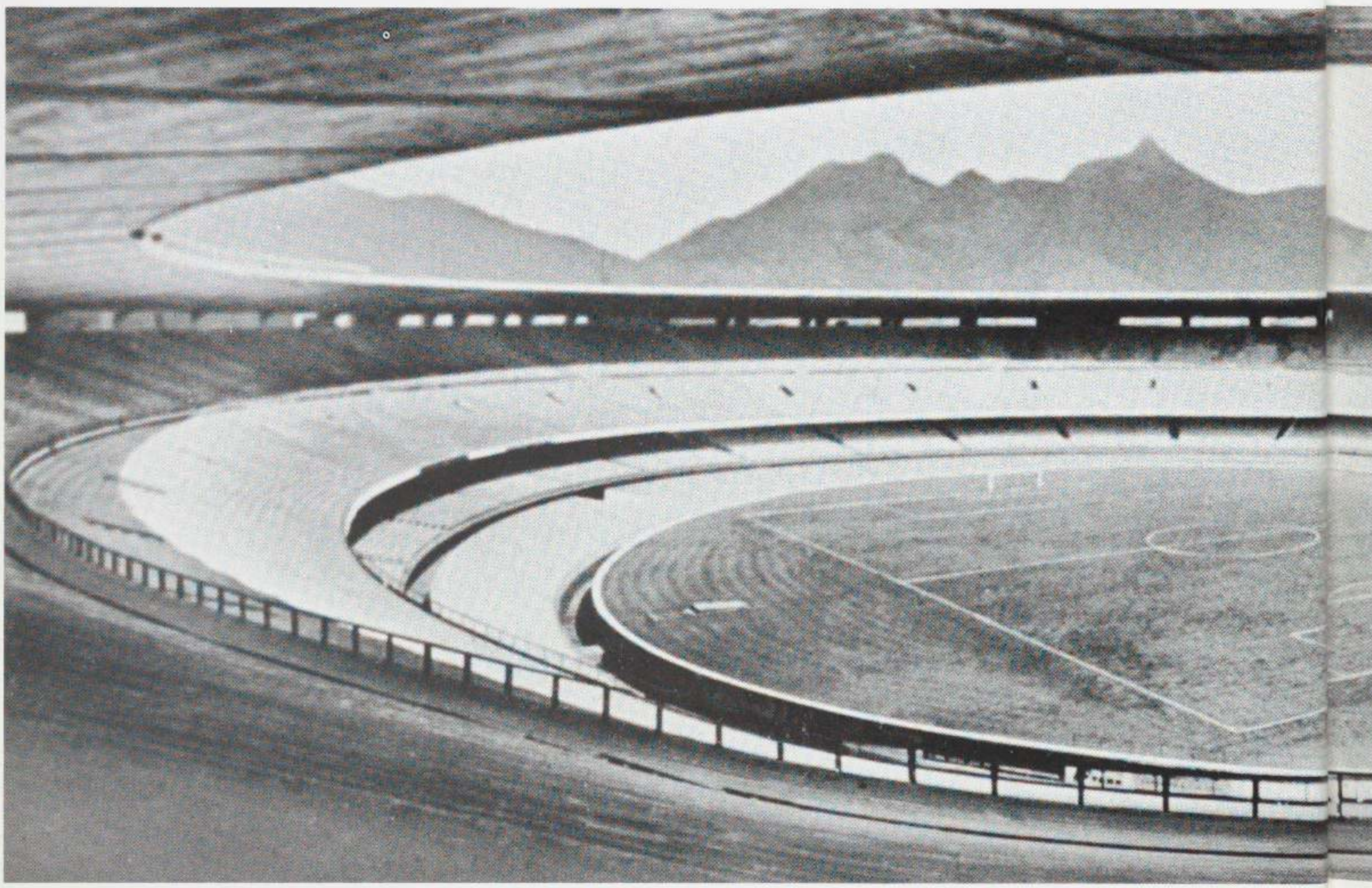

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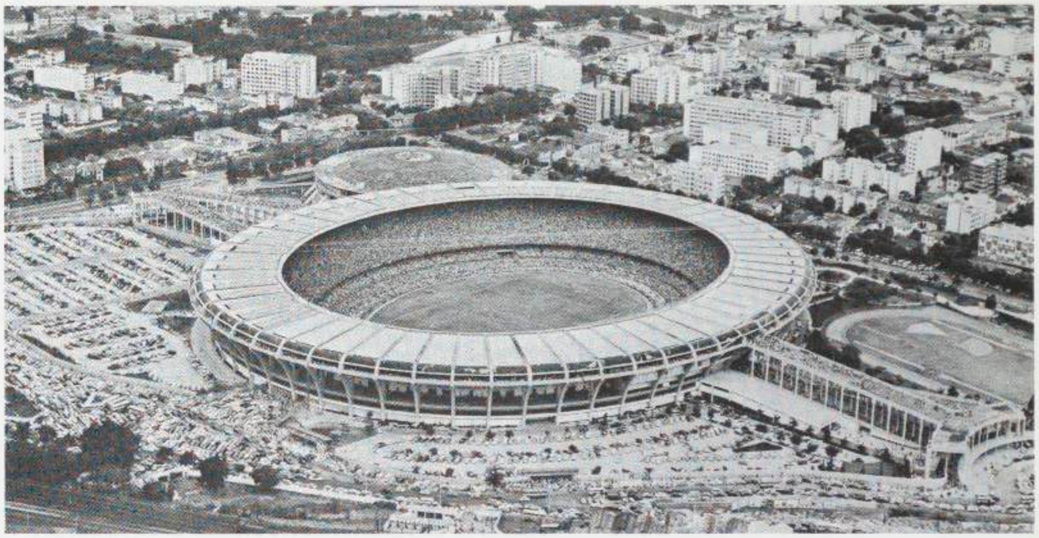
29 La Zarzuela Racecourse.
Madrid, Spain. 1935.
Eduardo Torroja.

30 Club de Fútbol Stadium.
Barcelona, Spain. 1958.
J. L. de la Guardia, O. Lobato.
Architects: J. Soteras, F. Mitjans,
L. Garcia-Barbon.

31
32 Maracanã Stadium.
Rio de Janeiro, Brazil. 1952.
Fragoso, Noronha, Baungart, Costa.
Architect: Galvão, Bernardos Bastos,
Dias Carneiro, Azevedo.



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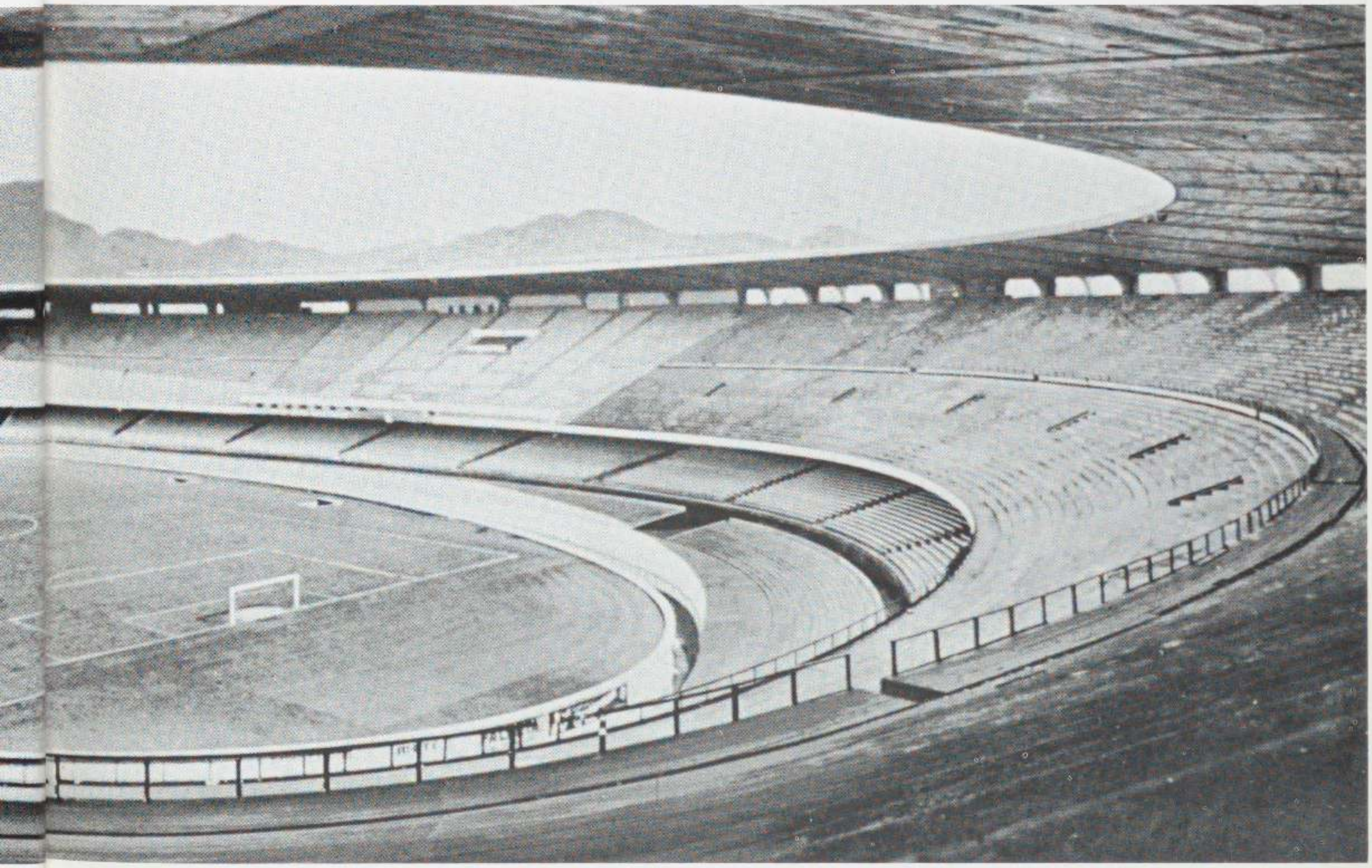

33 Airship hangars.
Orly, France. 1921 (destroyed 1944).
Eugène Freyssinet (Entreprises Limousin).

34 Central Station.
Reims, France. 1932.
Entreprises Limousin (Le Marec),
M. Ridet.

35 Jefferson National Expansion Memorial.
St. Louis, Missouri. Under construction.
Architect: Eero Saarinen & Associates.

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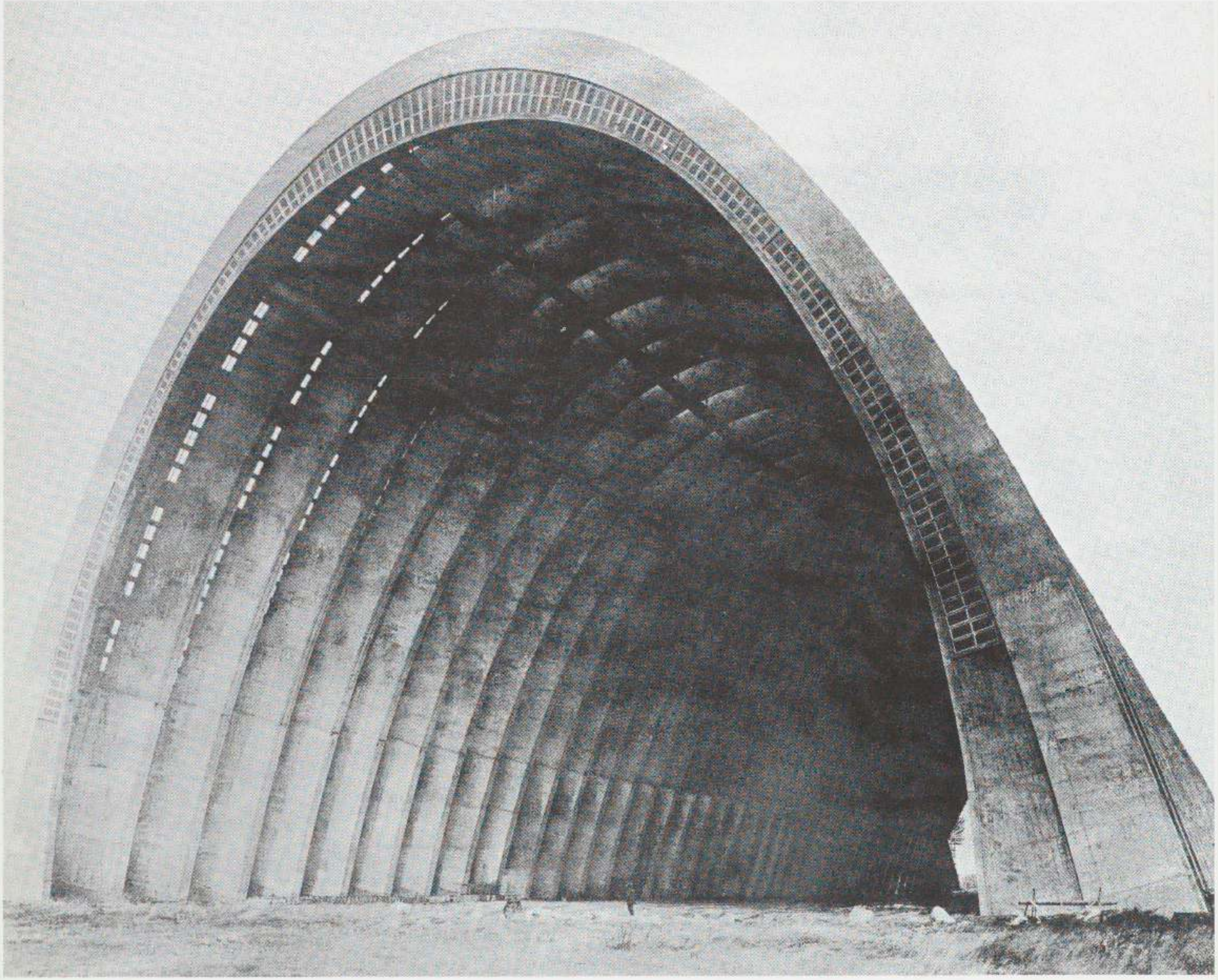

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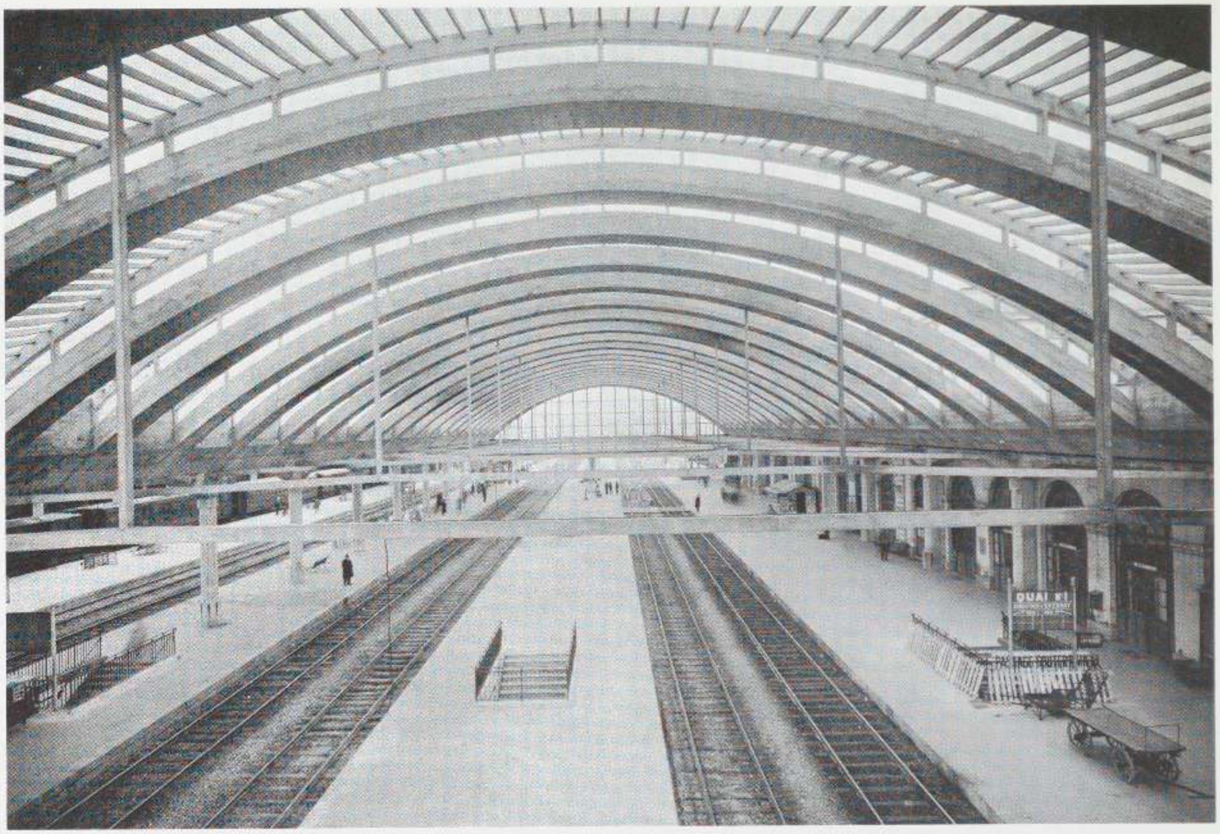

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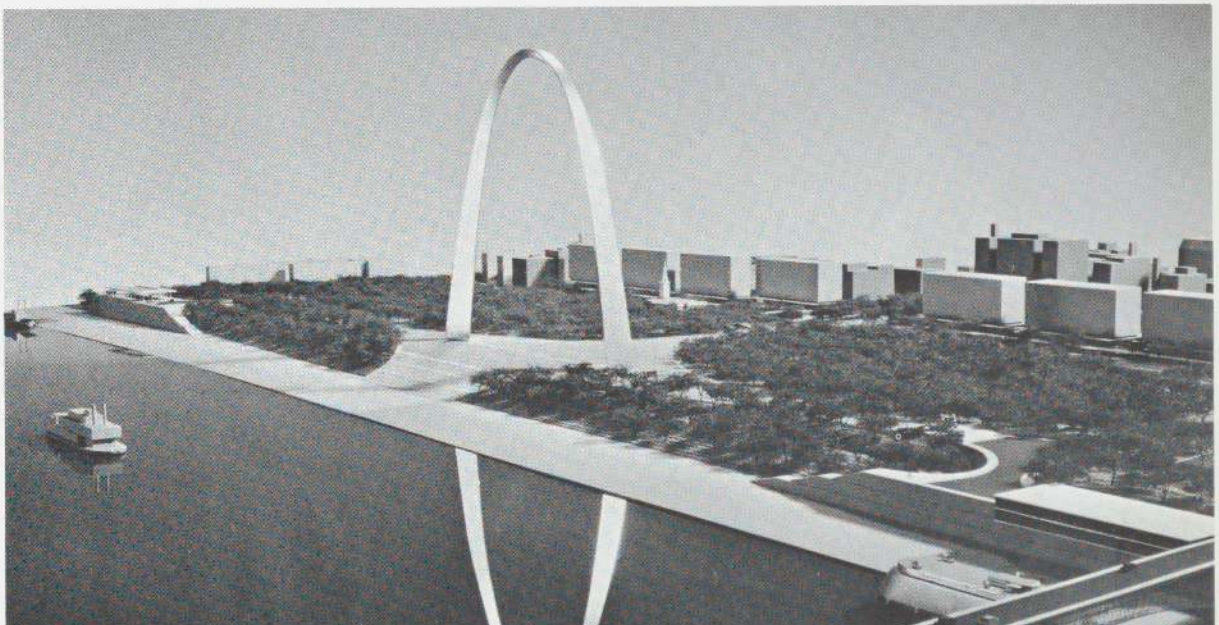

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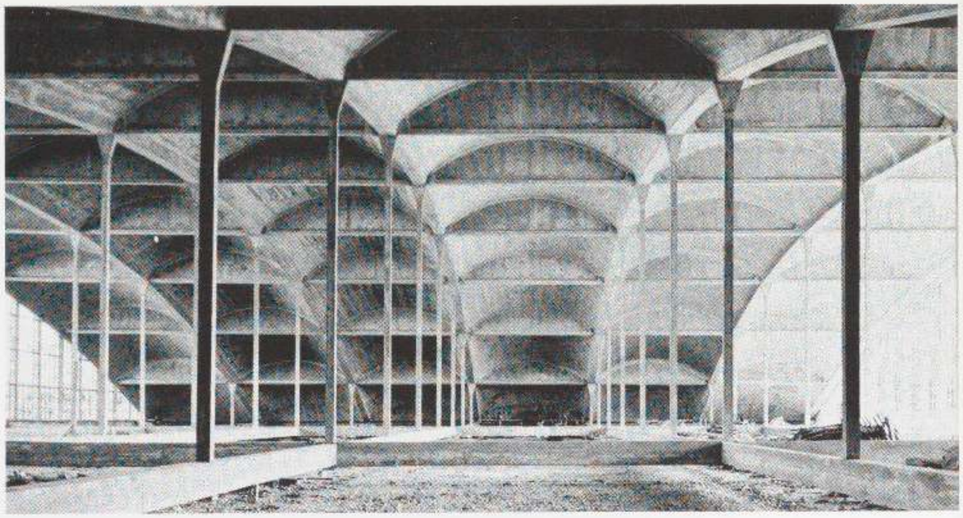
37 Hangars.
Marignane, France. 1952.
Nicolas Esquillan (Entreprises Boussiron).
Architect: Auguste Perret.



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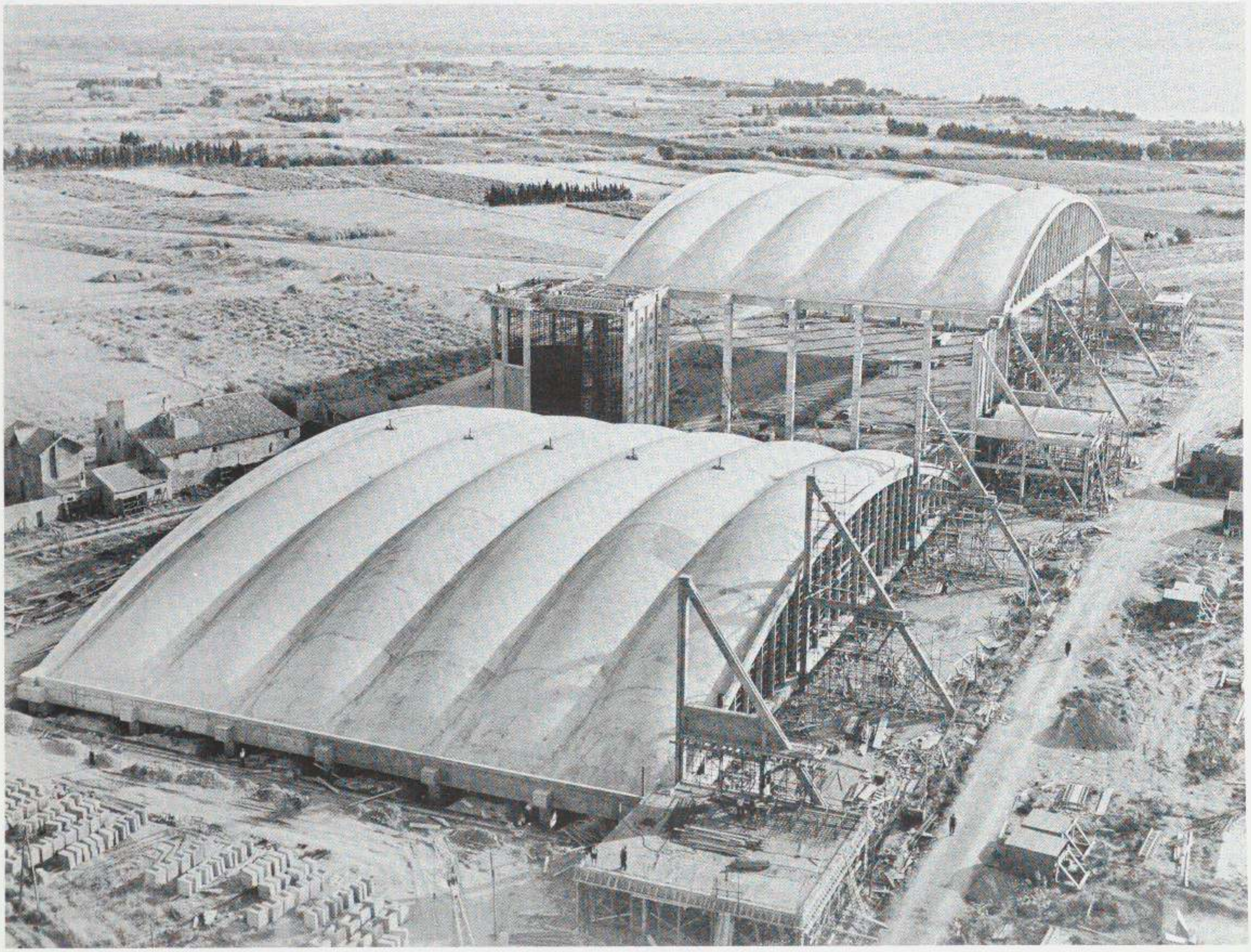
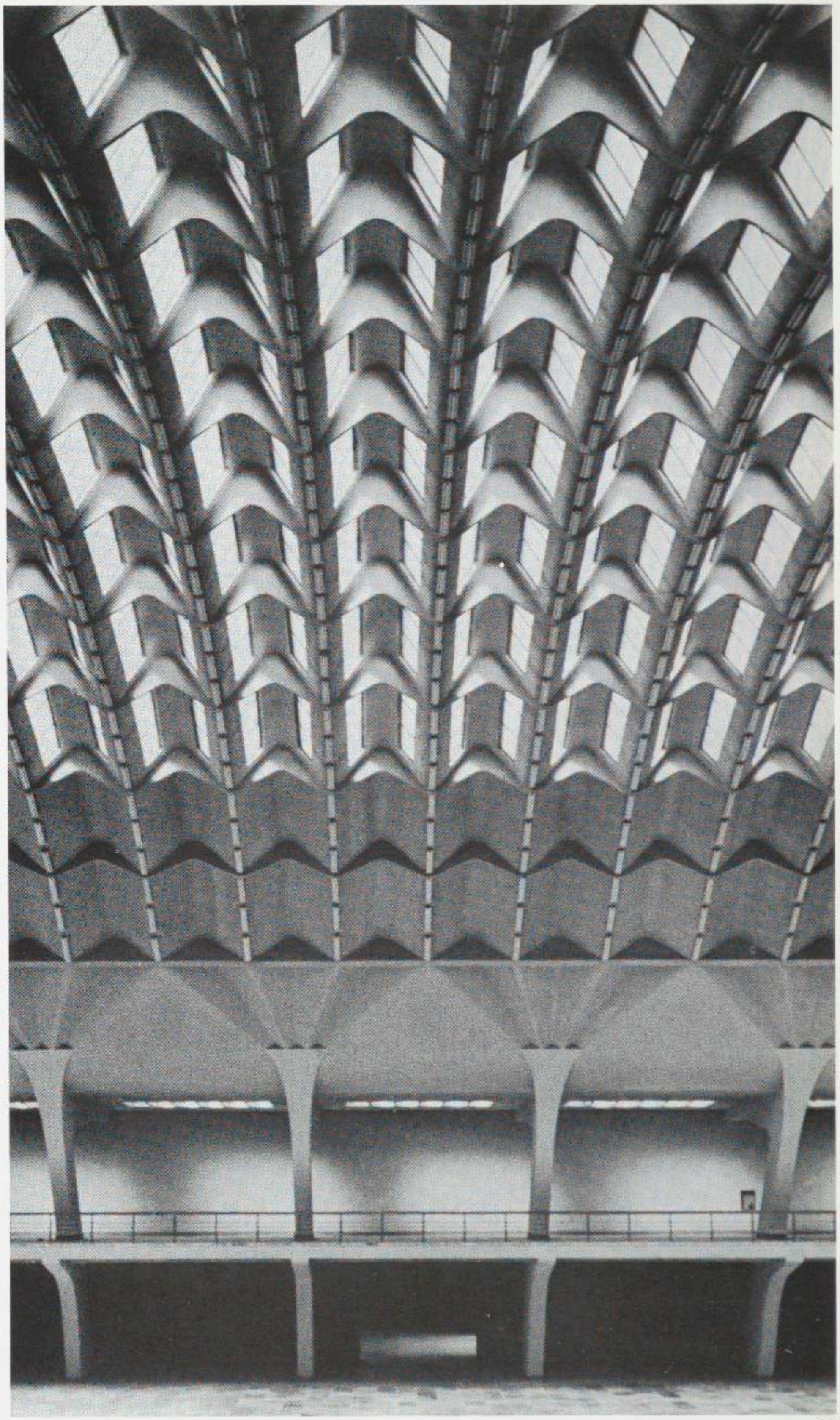
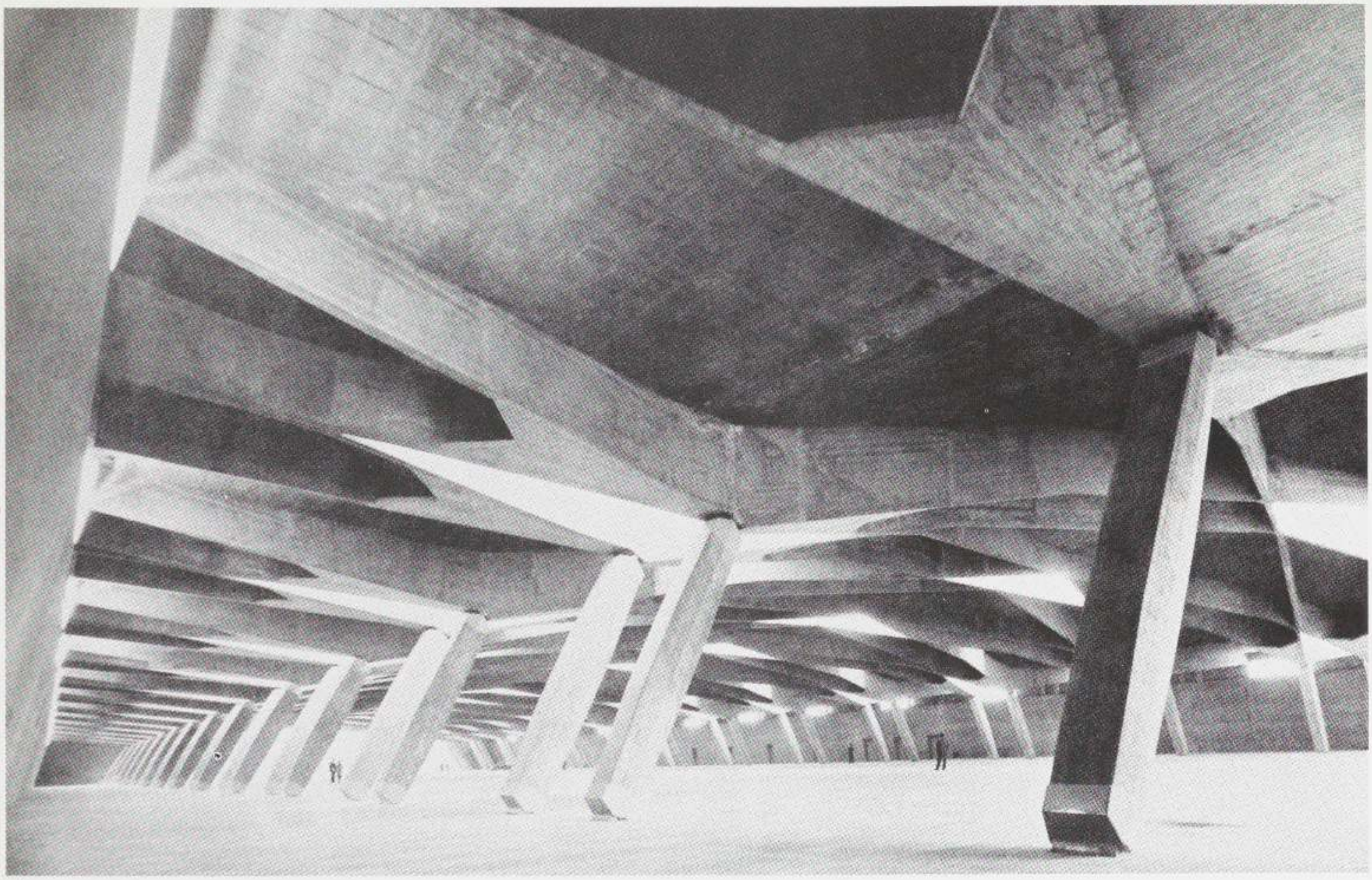


38 Exhibition hall.
Turin, Italy. 1948.
Engineer/Architect: Pier Luigi Nervi.

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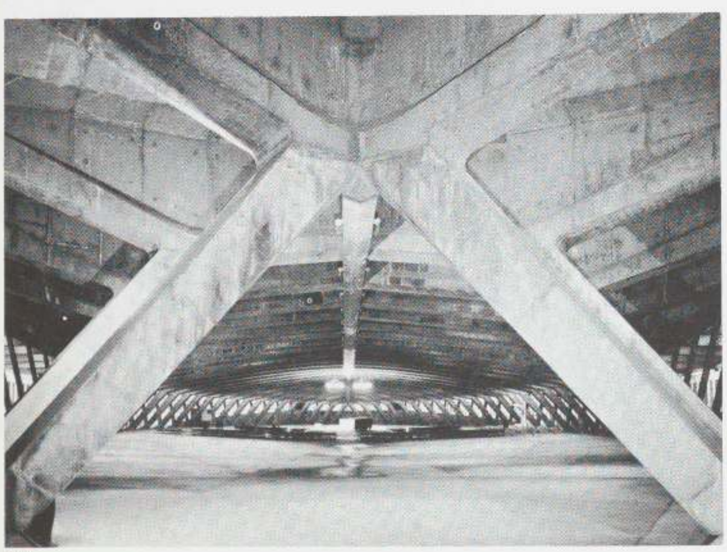
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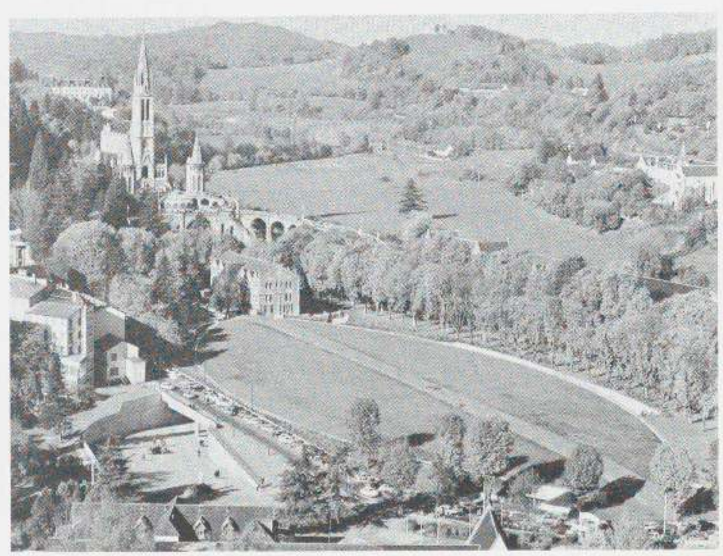
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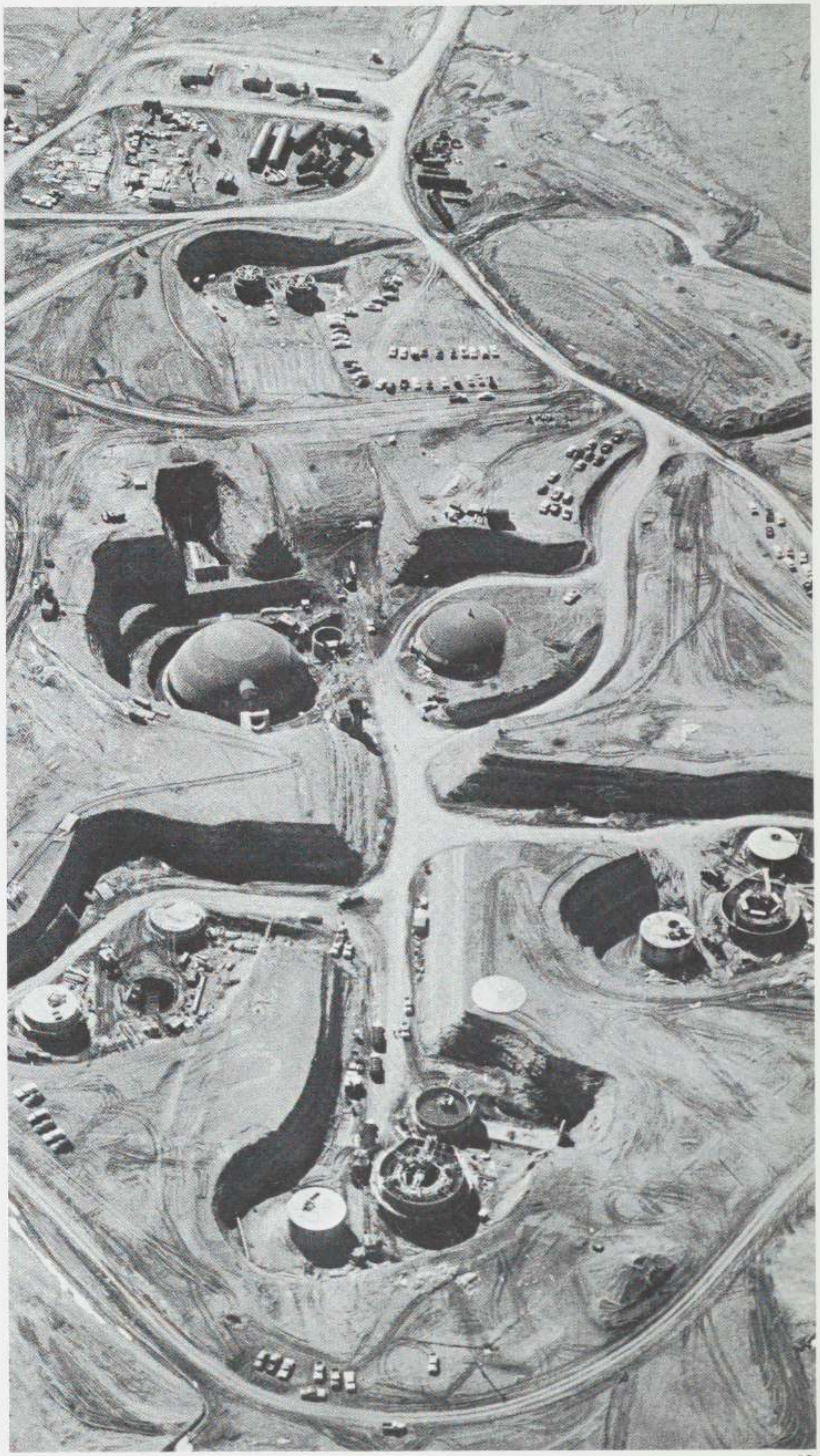
39 Parco del Valentino exhibition hall.
Turin, Italy. 1959.
Riccardo Morandi.

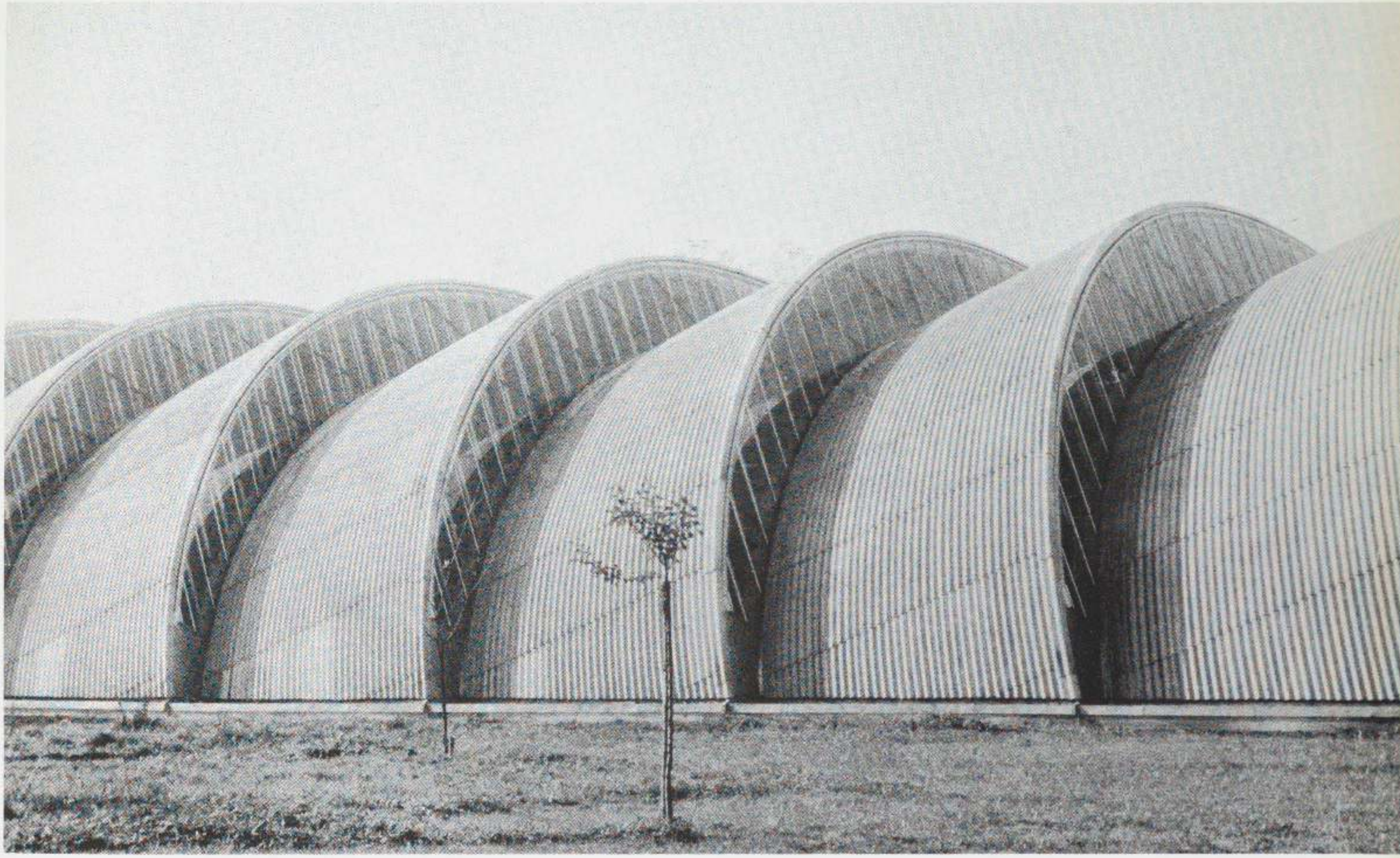
40

41 St. Pius X Basilica.
Lourdes, France. 1958.
Eugène Freyssinet. Architect: Vago, LeDonne and Pinsard.

42 Titan I Launch Complex,
Lowry Air Force Base.
Denver, Colorado. 1961.
Daniel-Mann-Johnson-Mendenhall Associates; Rust Engineering Company; Leo A. Daly.




Prader & Co.
Ingenieure
Zürich



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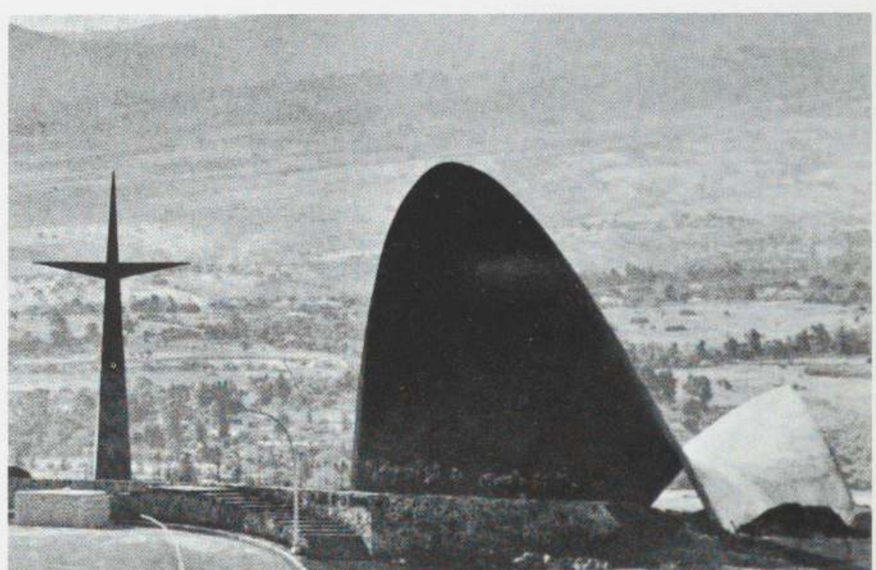
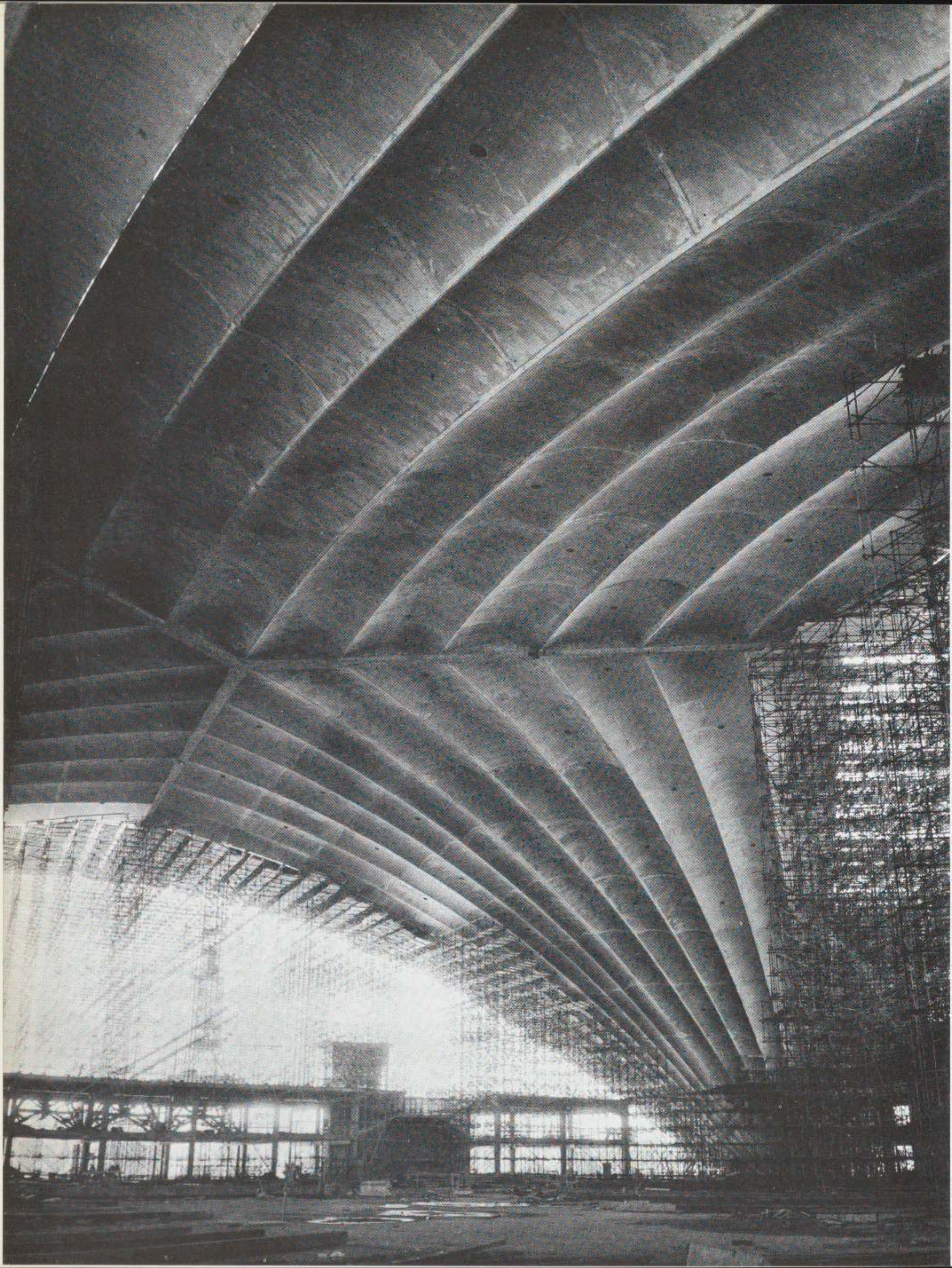
43 Cement Industries Hall,
Swiss National Exhibition.
Zürich, Switzerland. 1939.
Robert Maillart.

44 Gold-Zack Factory.
Gossau, Switzerland. 1954.
Heinz Hossdorf. Architect: Danzeisen & Voser.

45 Lomas de Cuernavaca Chapel.
Cuernavaca, Mexico. 1958.
Felix Candela.





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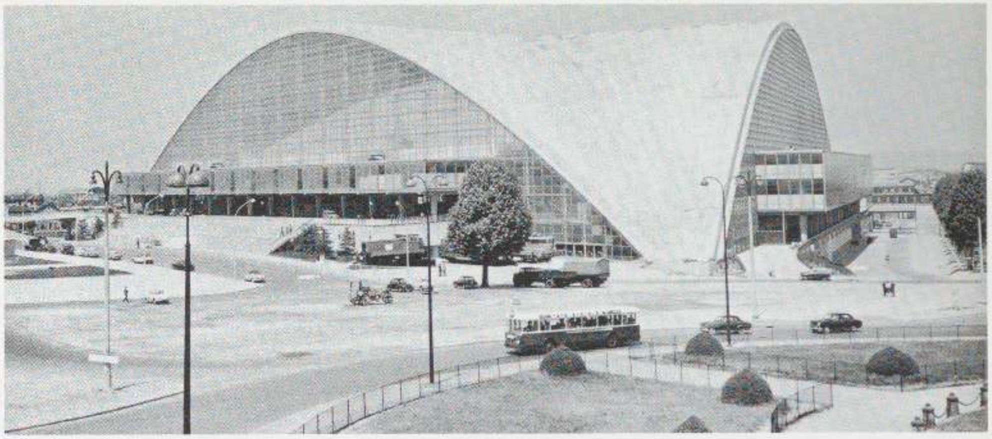
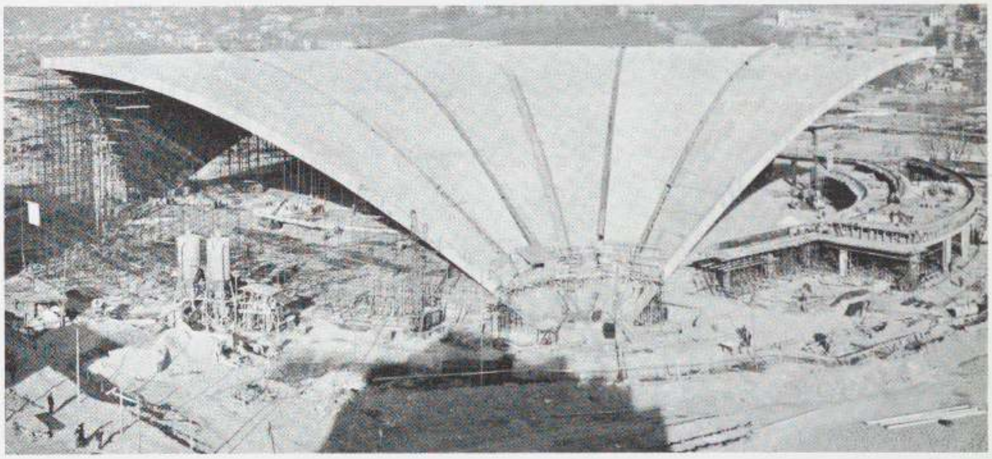
47 Centre National des Industries et Techniques (CNIT) exhibition hall.
Paris, France. 1958.
Nicolas Esquillan. Entreprises Balency et Schuhl; Entreprises Boussiron; Constructions Coignet. Architect: R. Camelot, J. DeMailly, B. H. Zehrfuss.

48
49 Palazzo delle Mostre exhibition hall.
Turin, Italy. 1961.
Franco Levi, Nicolas Esquillan.





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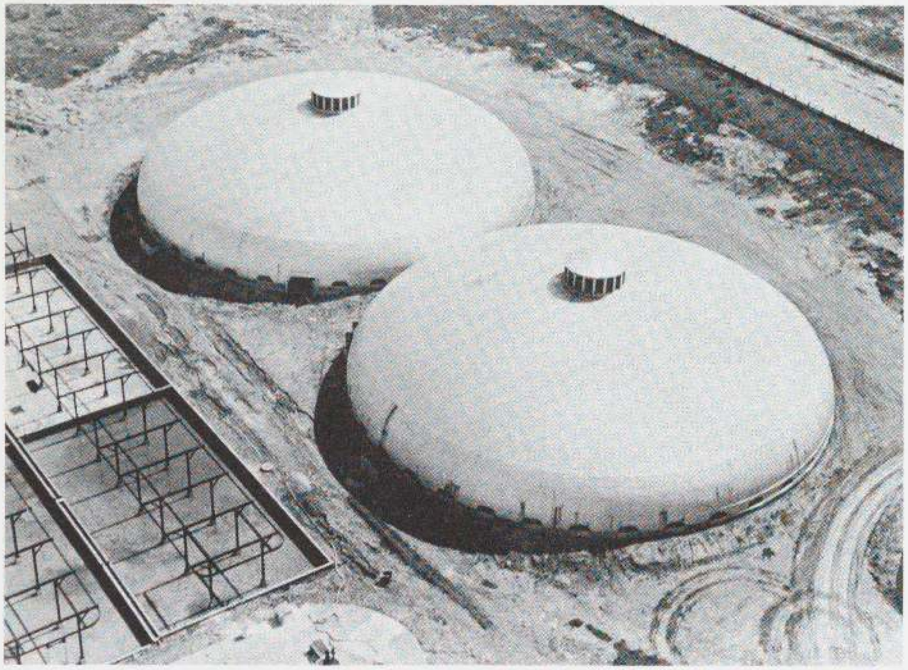

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50 Sewage treatment plant.
Hibbing, Minnesota. 1939.
Roberts and Schaefer Company
(Anton Tedesko). Architect:
J. C. Taylor.

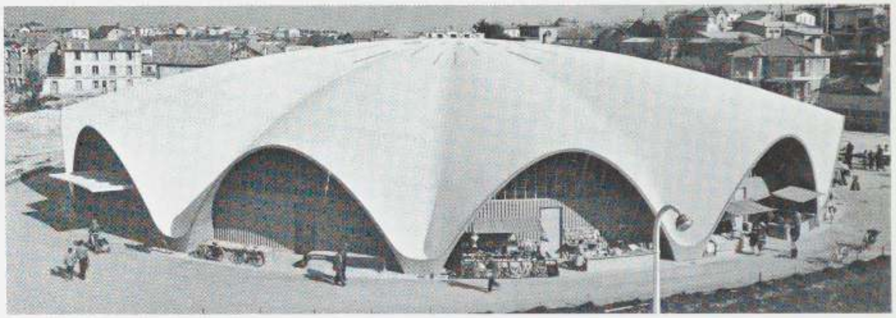
51 Market hall.
Royan, France. 1958.
R. Sarger. Architect:
Louis Simon, André Morisseau.

52 Fieldhouse.
Munster, Indiana. Under construction.
Kolbjorn Saether & Associates.
Architect: Bachman & Bertram.

53 University of Illinois Assembly Hall.
Urbana, Illinois. 1963.
Ammann & Whitney. Architect: Harrison
& Abramovitz.

54 Mount Avila cablecar
terminal station.
Caracas, Venezuela. 1956.
Architect: Alejandro Pietri.

51



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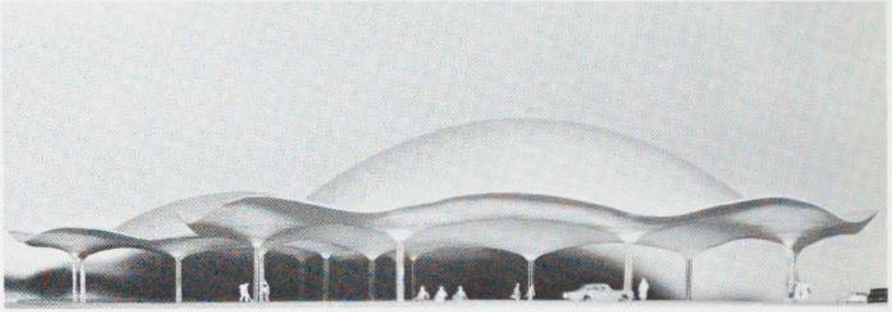

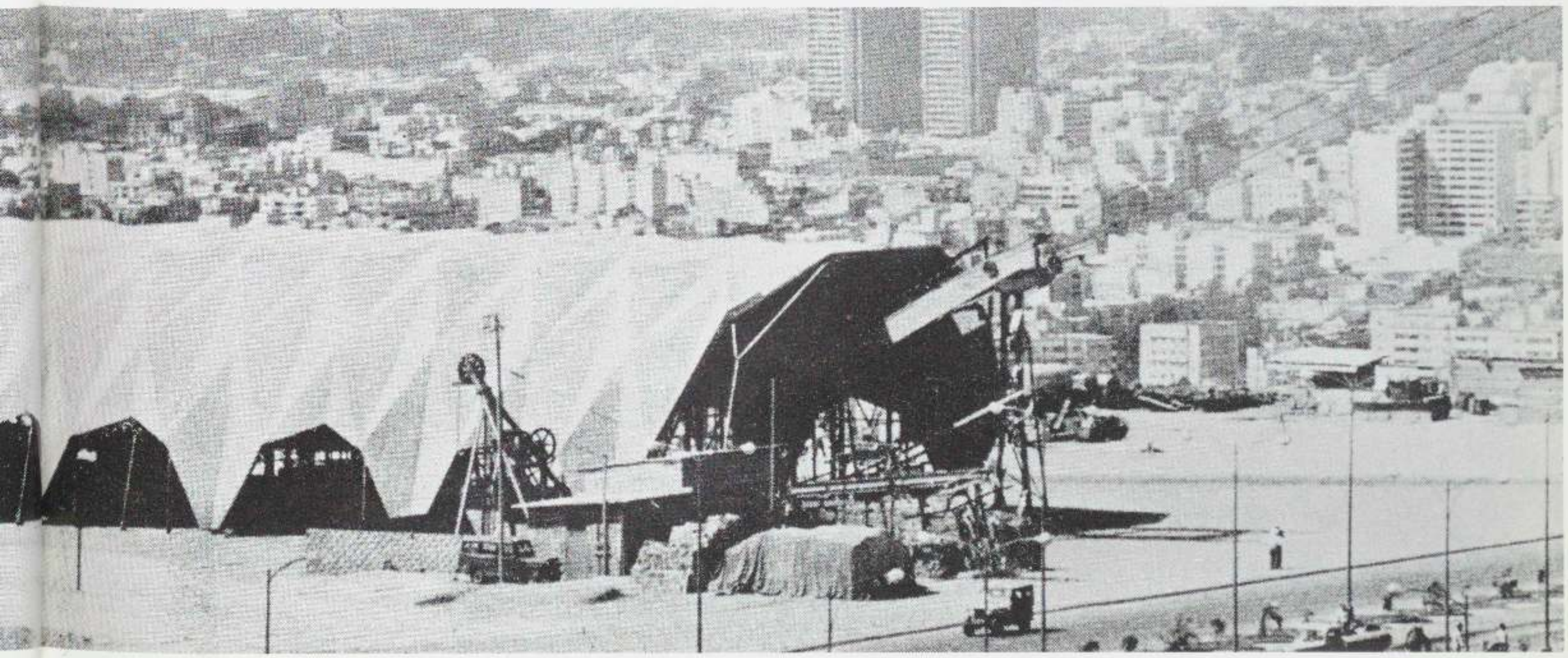

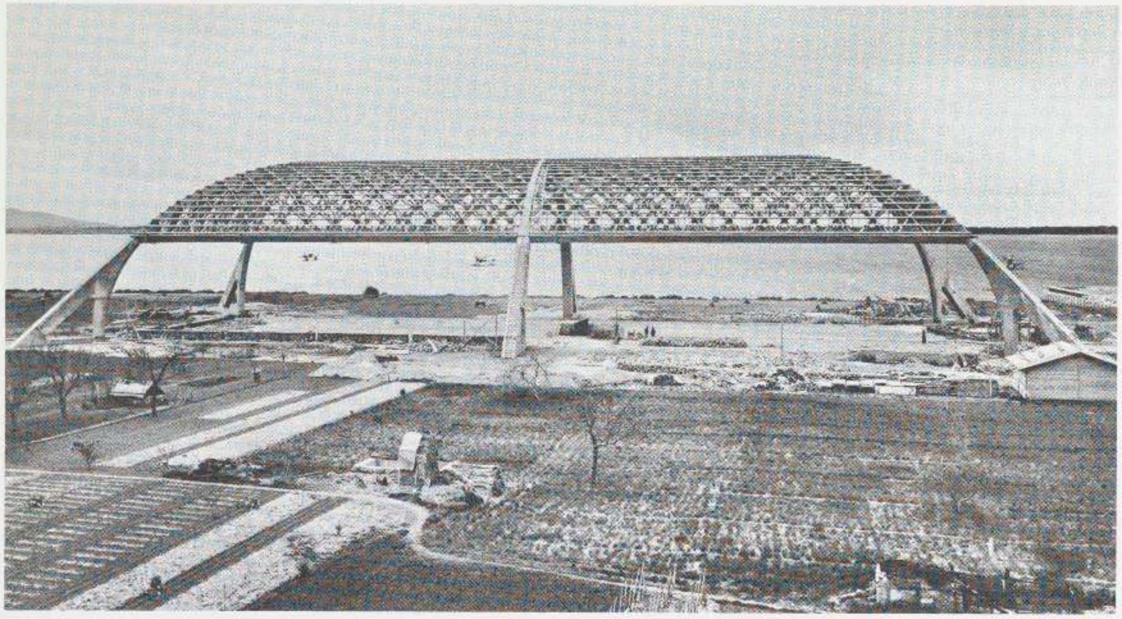
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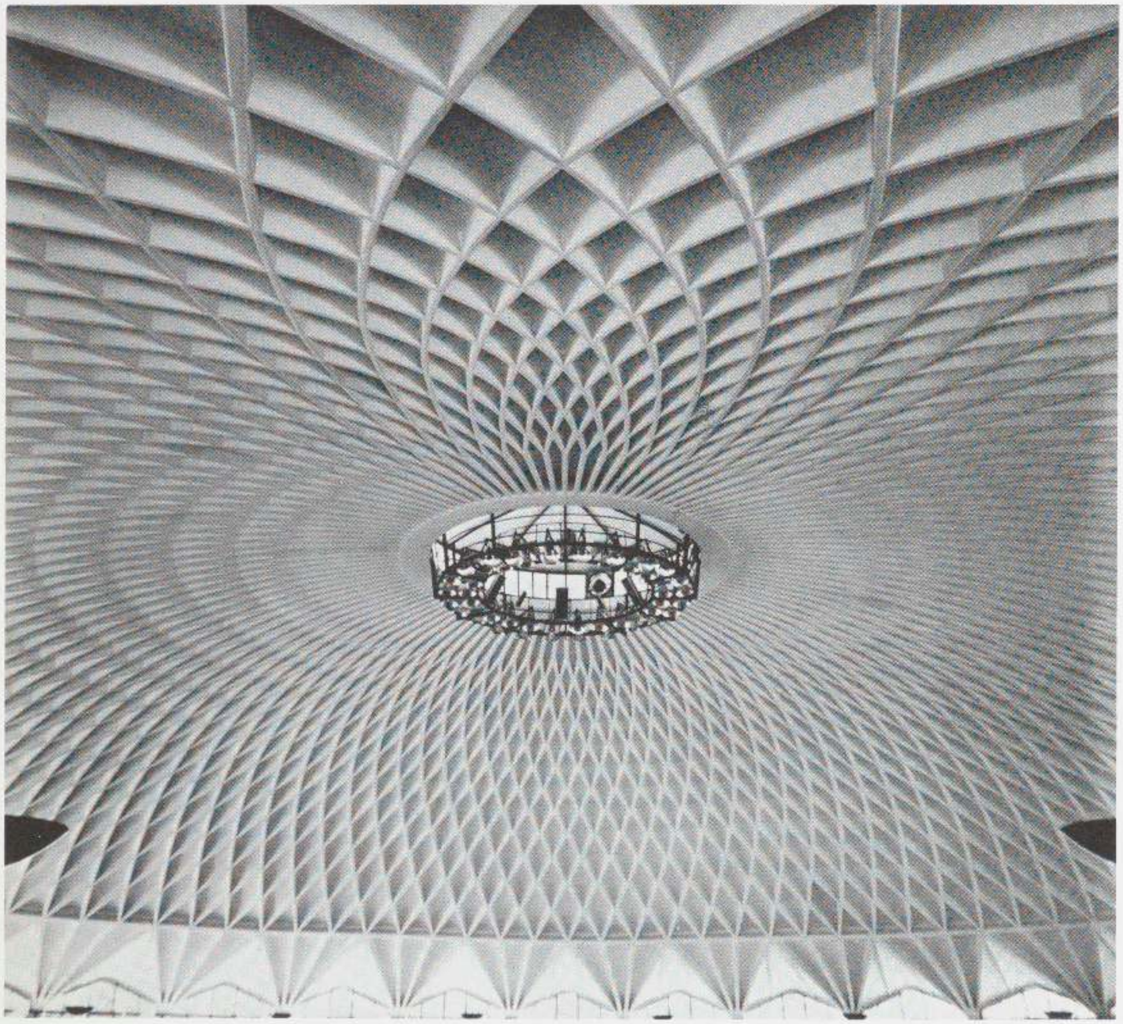
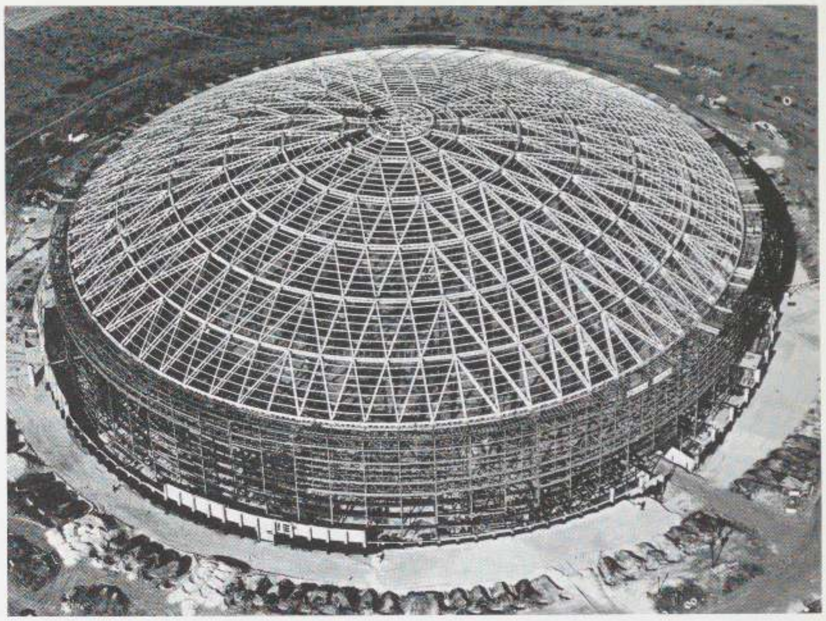

56

55 Hangar.
Orbitello, Italy. 1940. (destroyed 1944)
Engineer/Architect: Pier Luigi Nervi.

56 Palazzetto dello Sport.
Rome, Italy. 1957.
Pier Luigi Nervi. Architect:
Annibale Vitellozzi, Pier Luigi Nervi.

57 Harris County Domed Stadium.
Houston, Texas.
Under construction.
Walter P. Moore; Praeger-Kavanagh-Waterbury; Roof Structures, Inc.
Architect: Lloyd & Morgan;
Wilson, Morris, Crain & Anderson.

58 Tokyo International Trade Center
exhibition hall No. 2.
Tokyo, Japan. 1959.
Yoshikatsu Tsuboi. Architect:
Masachika Murata.



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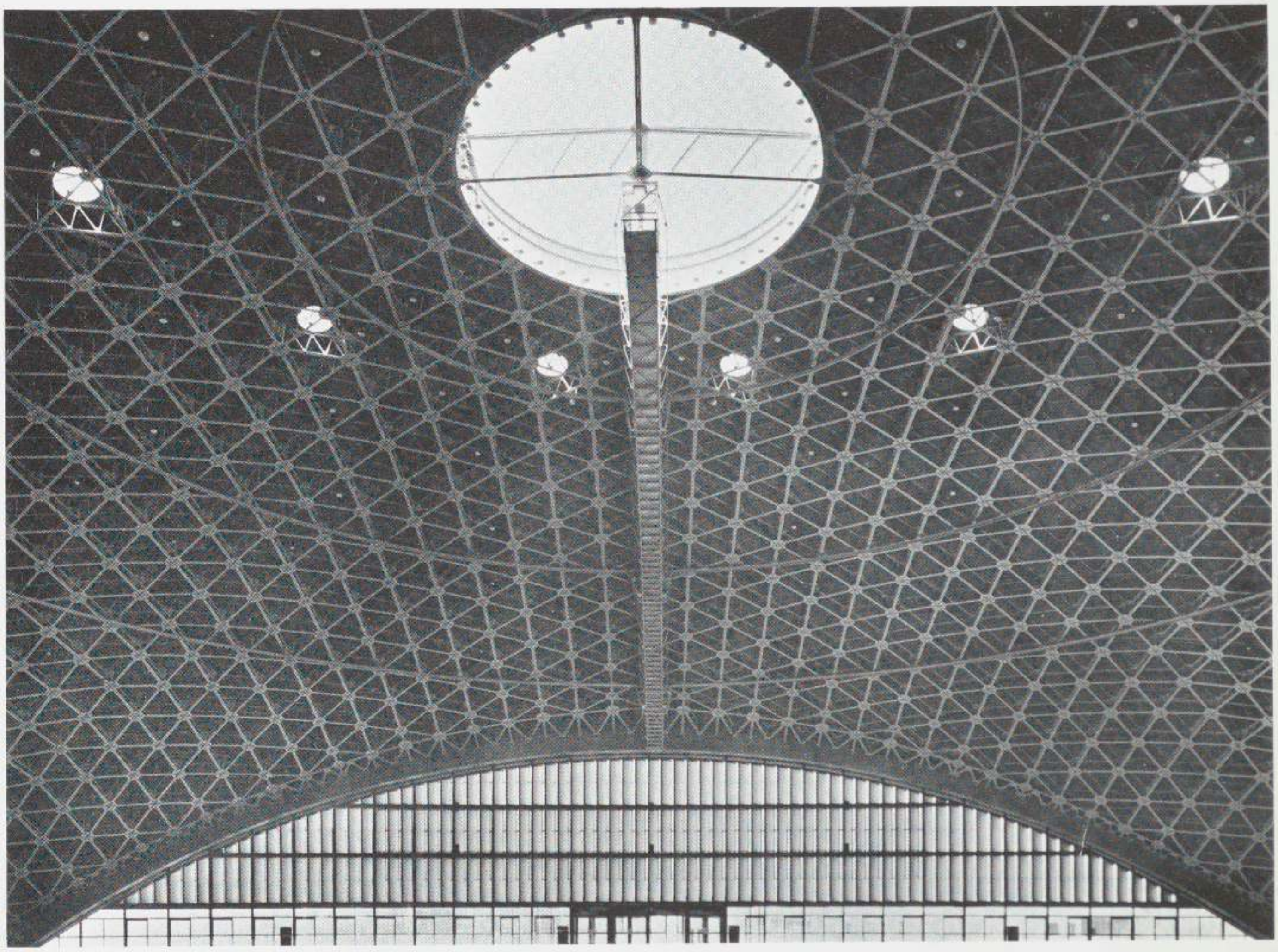

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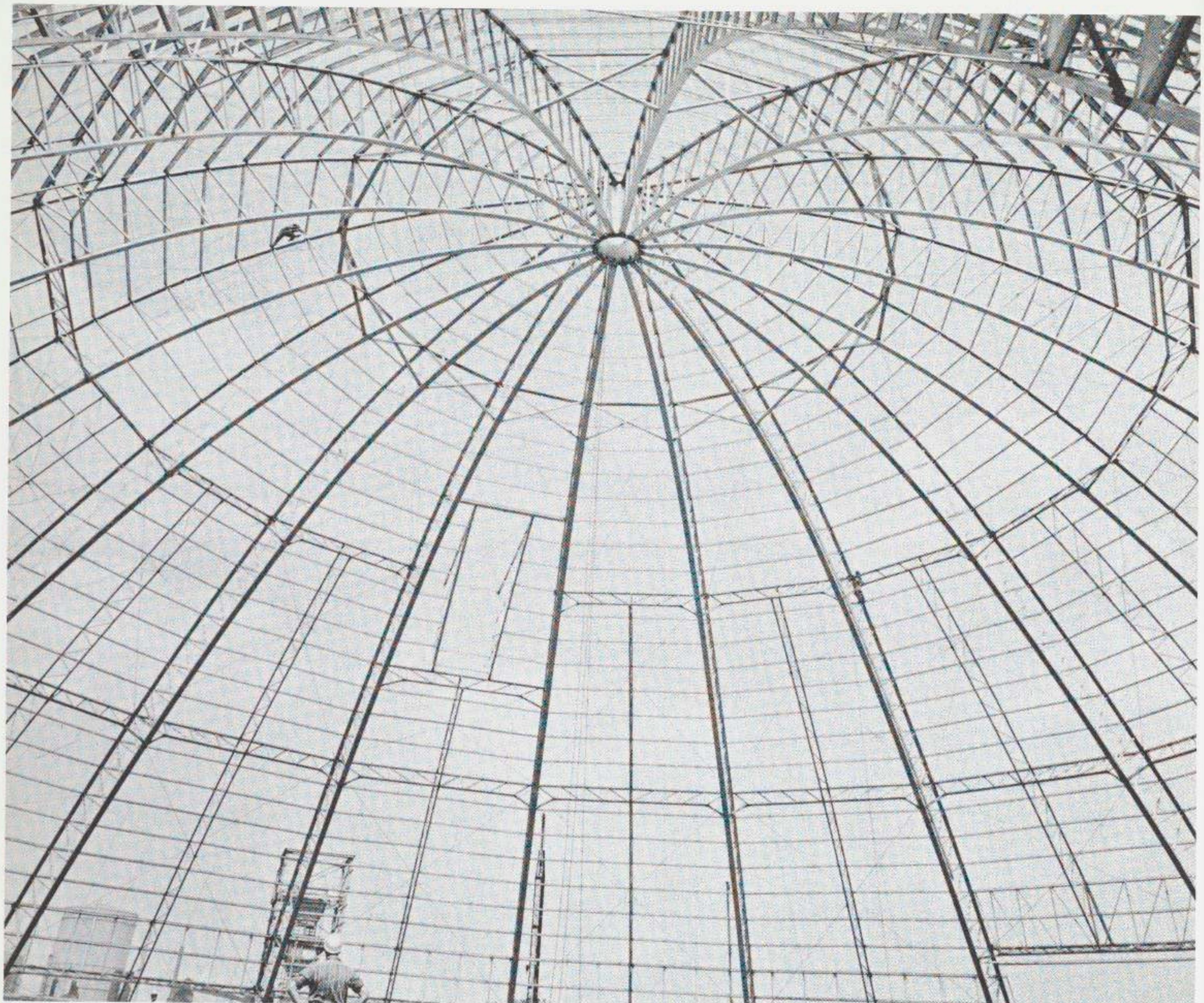

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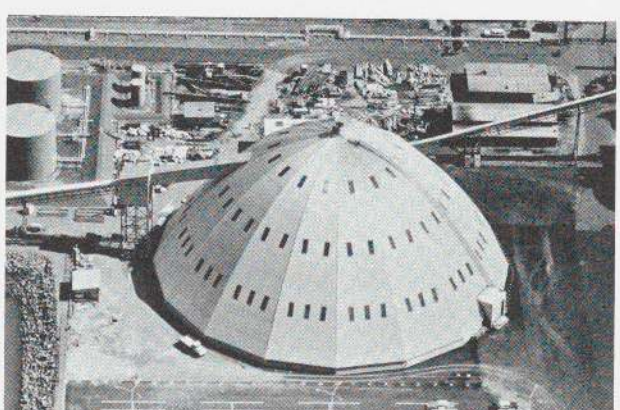

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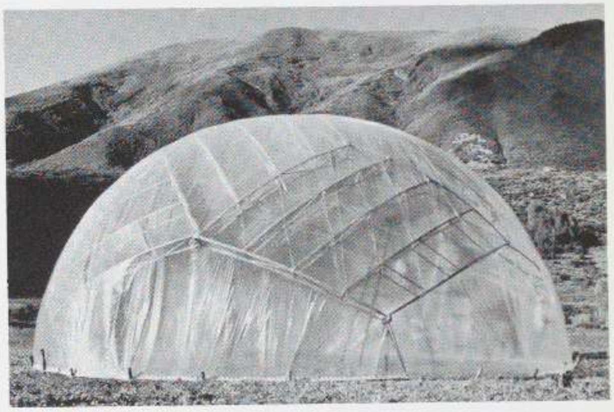

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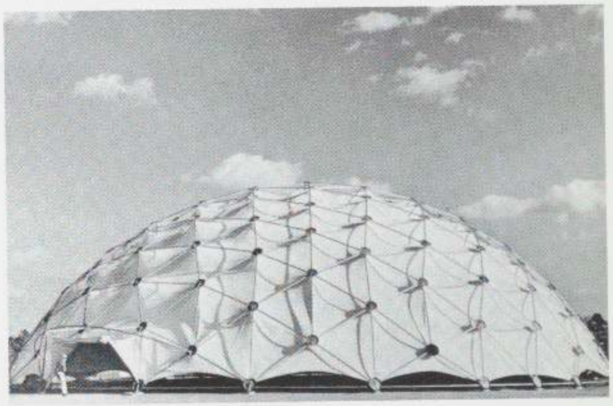

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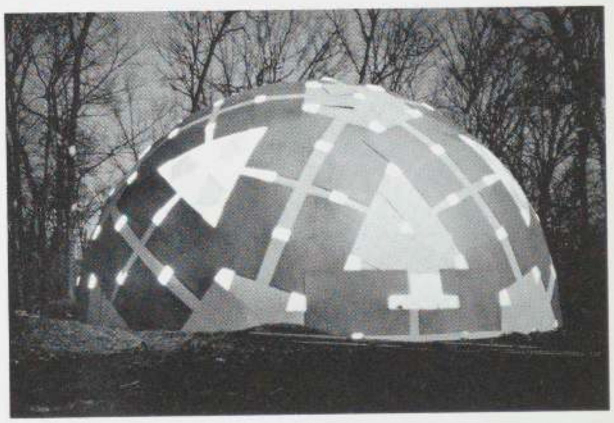

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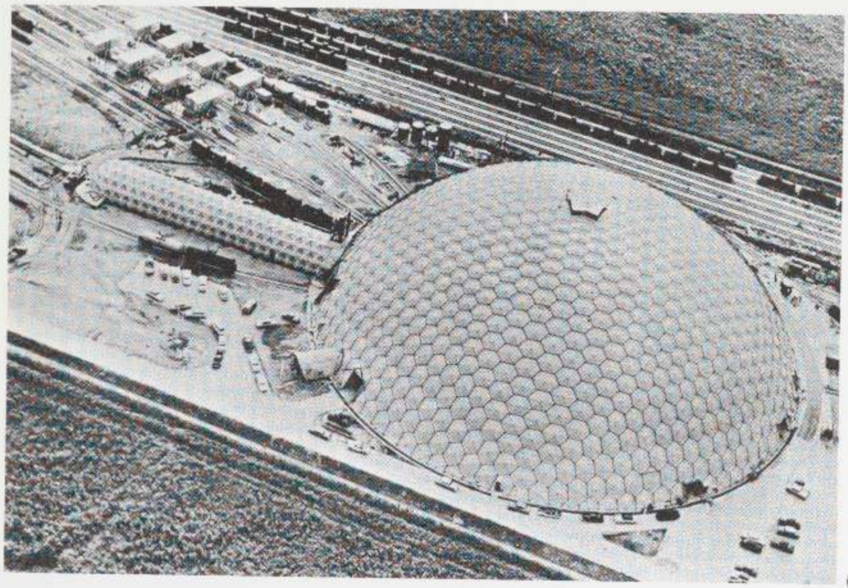
59
60 Raw Sugar Storage Dome.
Charleston, Massachusetts. 1960.
William J. Mouton, Jr.

61 Planetarium.
Jena, Germany. 1922.
Walter Bauersfeld, Dyckerhoff & Widmann KG.

62 Geodesic dome.
Aspen, Colorado. 1953.
R. Buckminster Fuller.

63 U.S. Pavilion.
Trade Fair, Poznan, Poland. 1957.
R. Buckminster Fuller.

64 "Plydome".
Des Moines, Iowa. 1957.
R. Buckminster Fuller.



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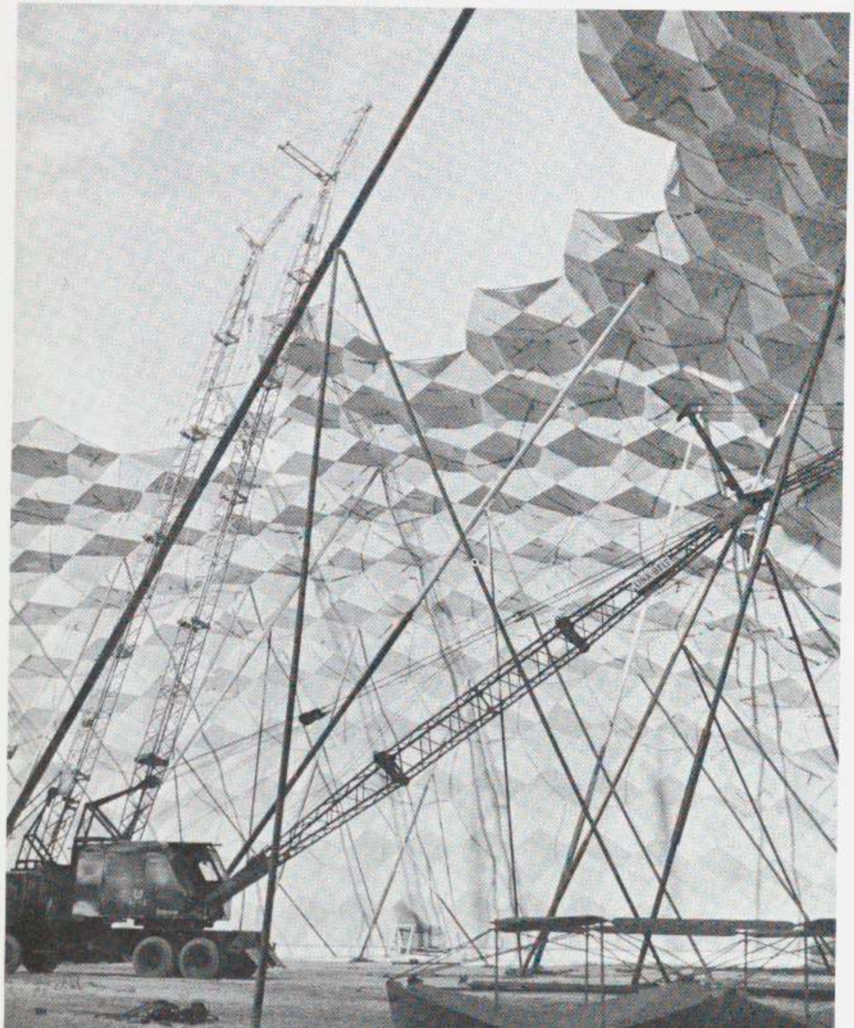

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65
66 Union Tank Car Company
car rebuilding plant.
Baton Rouge, Louisiana. 1959.
R. Buckminster Fuller.

67 Missouri Botanical Garden Climatron.
St. Louis, Missouri. 1960.
R. Buckminster Fuller.

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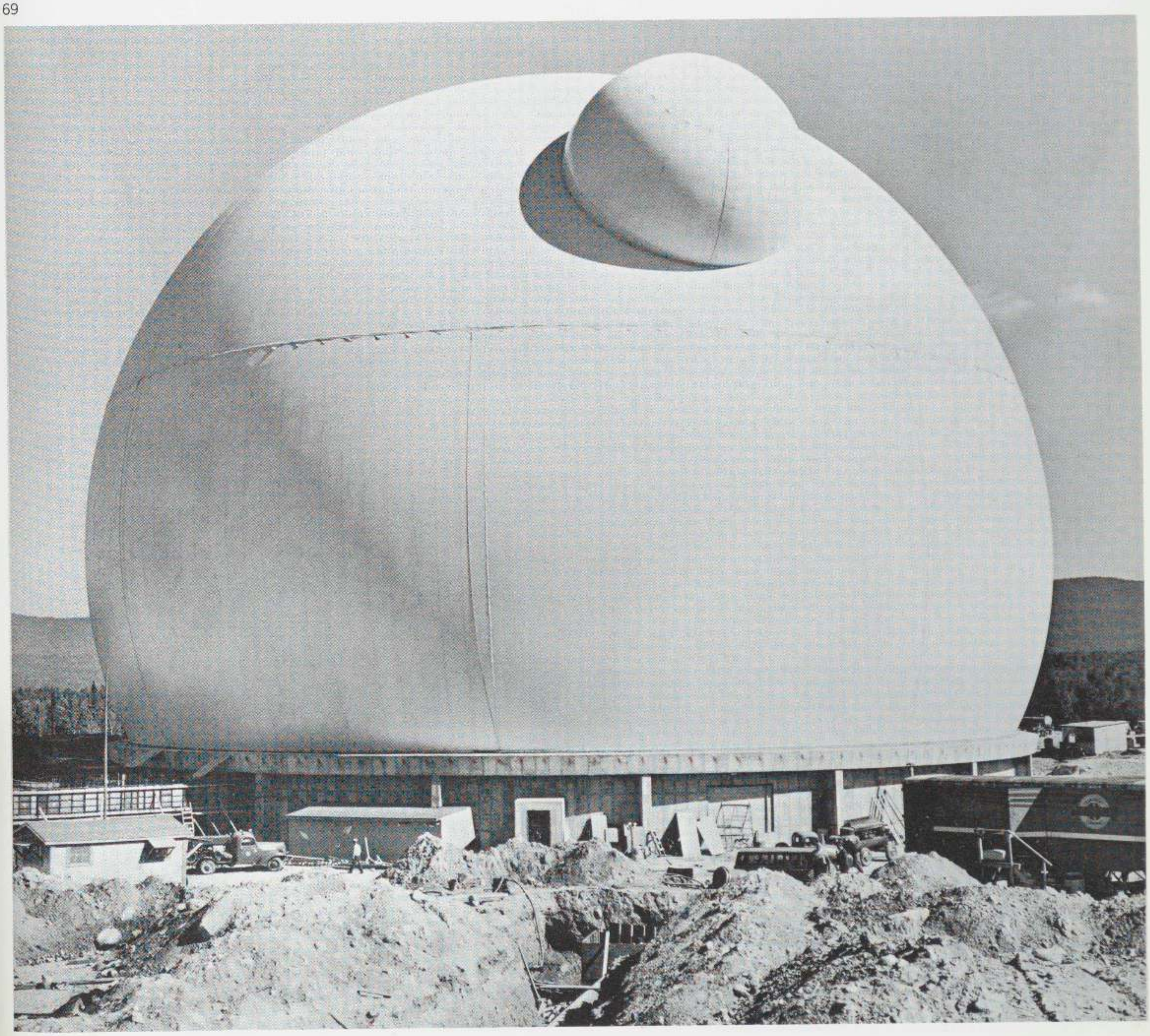
68 Haystack Antenna Radome.
Haystack Hill, Tyngsboro, Massachusetts.
1961.
M.I.T. Lincoln Laboratory, Massachusetts.

69 "Telstar" antenna construction shelter.
Andover, Maine. 1961/62.
Birdair Structures, Inc.

69



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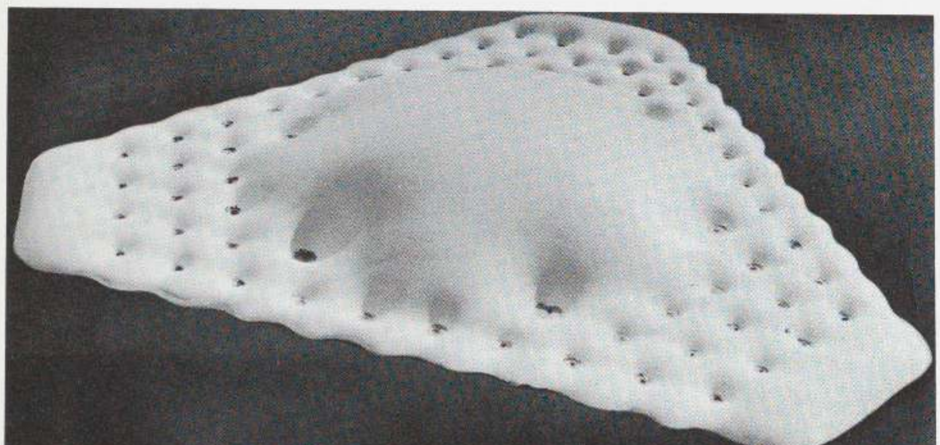
71 Inflated exhibition and congress hall.
Project proposed for
Chicago, Illinois. 1960.
Frei Otto. Architect:
Addis, Kniffin, Childs.

71



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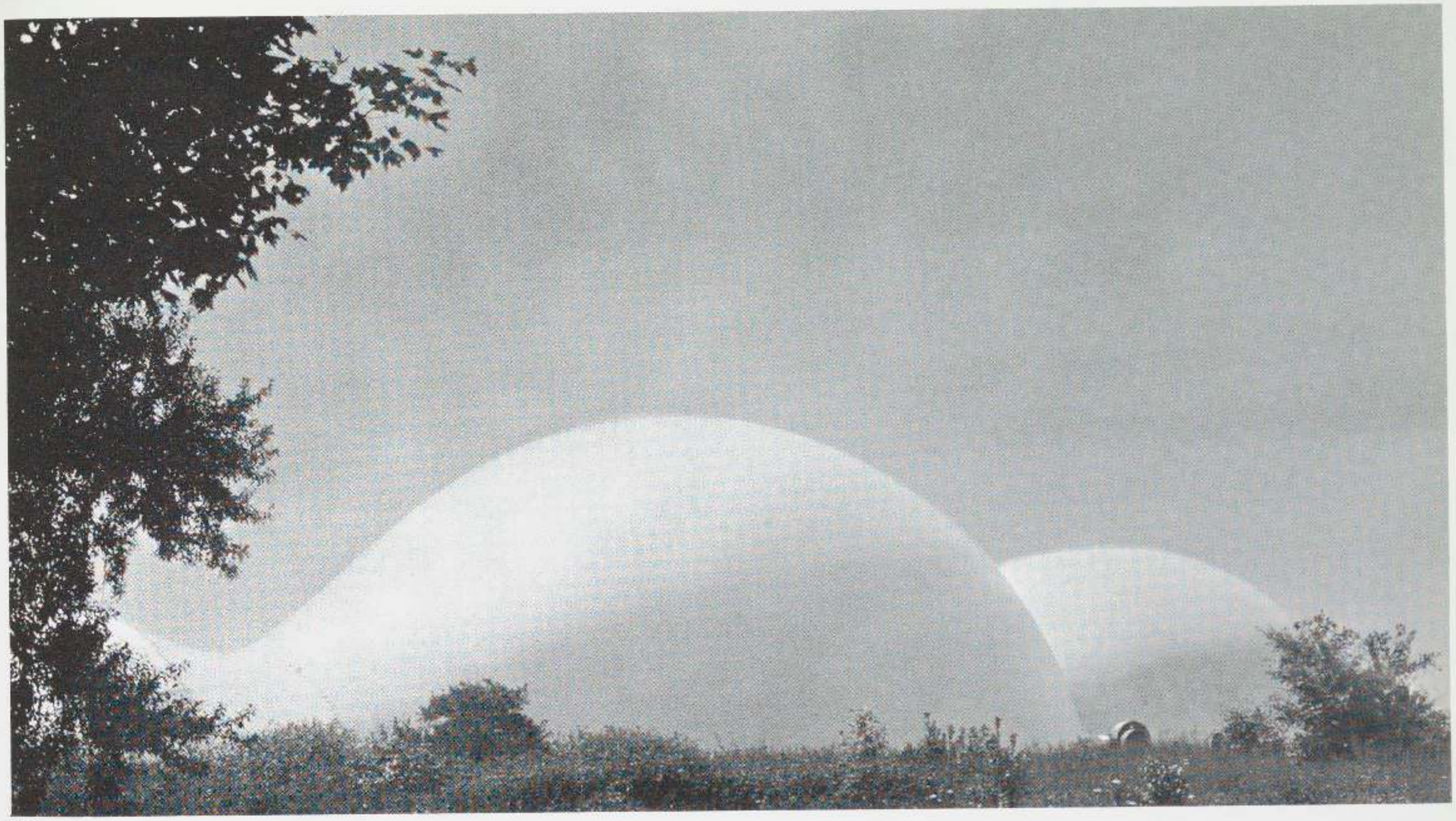

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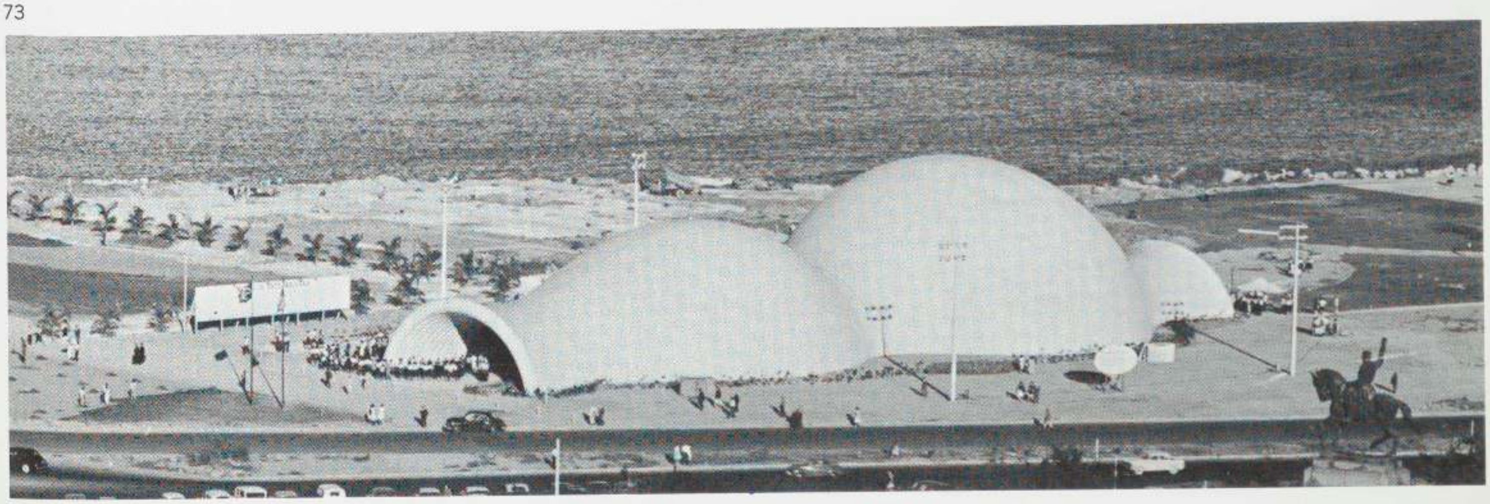
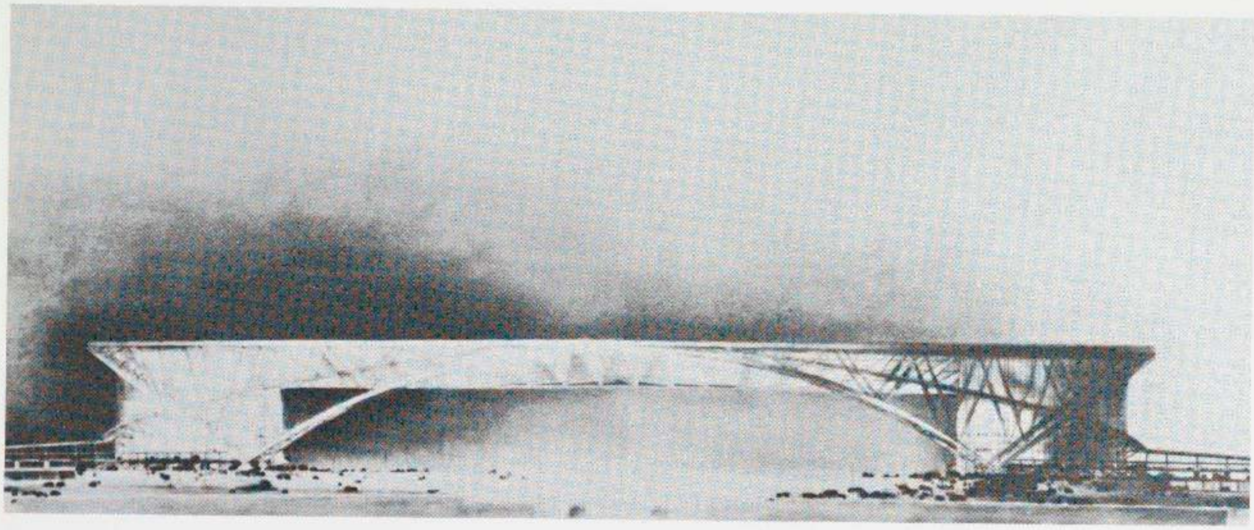
72
73 Atomic Energy Commission inflatable exhibition building. 1960.
Birdair Structures, Inc.
Architect: Victor A. Lundy.

73





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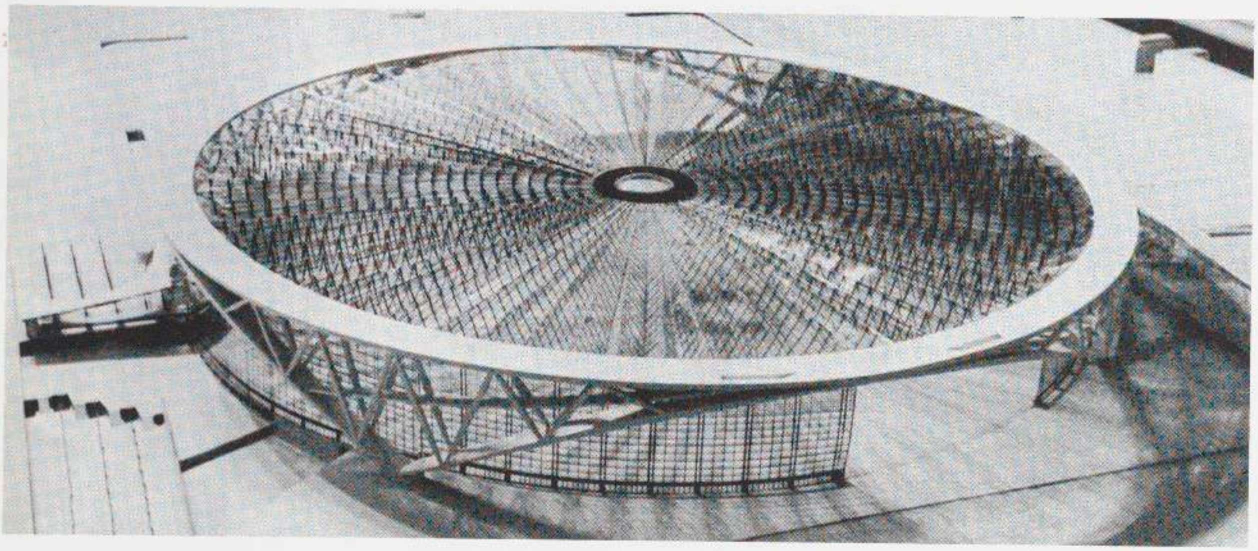
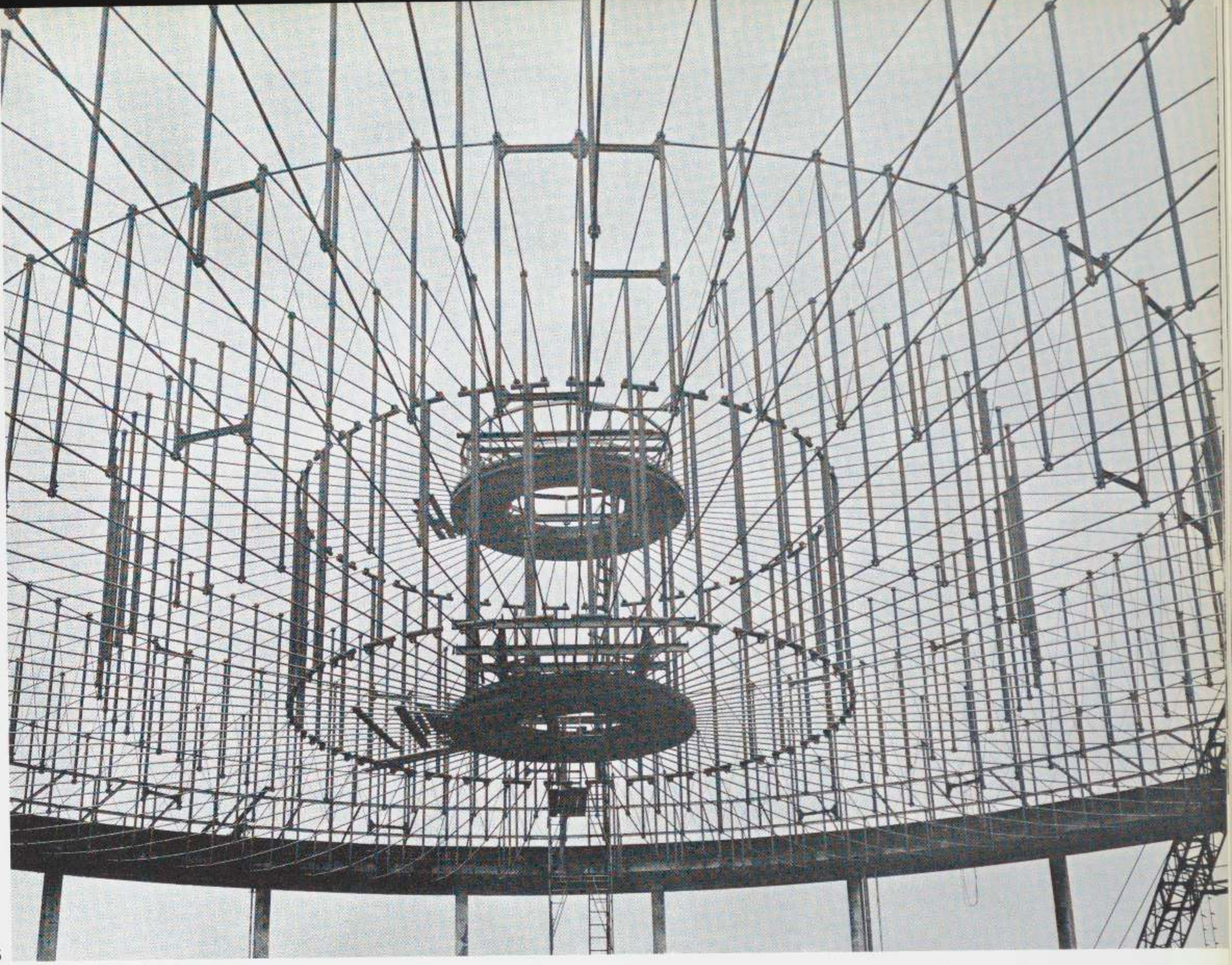


74
75 Exhibition hall.
Competition project, Paris. 1934.
Architect: Eugène Beaudouin,
Marcel Lods.

76 Utica Memorial Auditorium.
Utica, New York. 1960.
Lev Zetlin.
Architect: Gehron & Seltzer.

77 Swimming pool hall.
Wuppertal, Germany. 1957.
Fritz Leonhardt.
Architect: F. Hetzelt.



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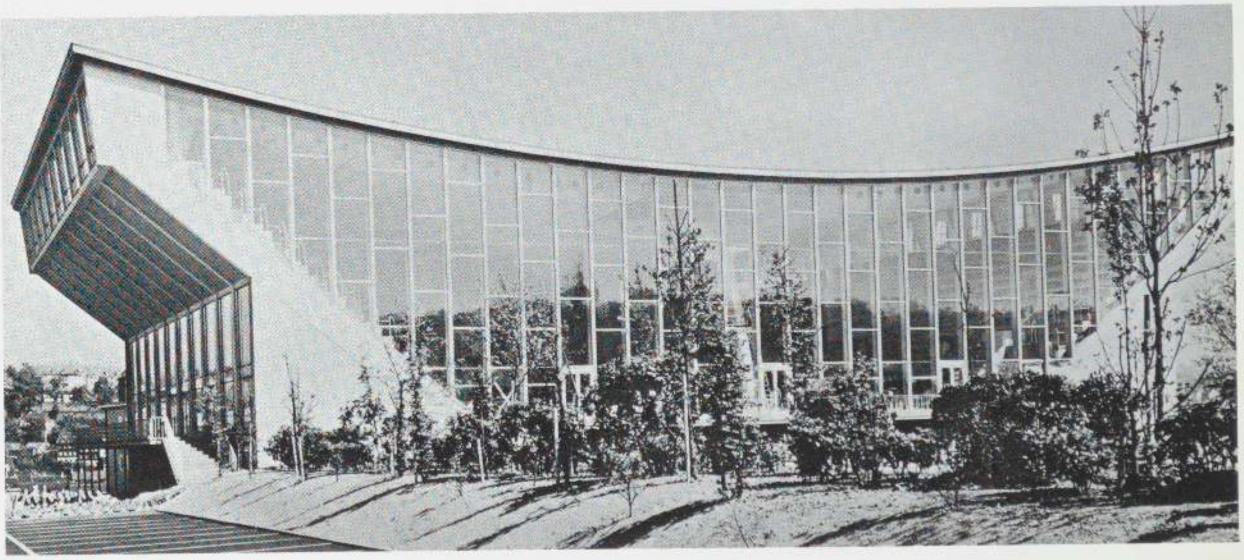
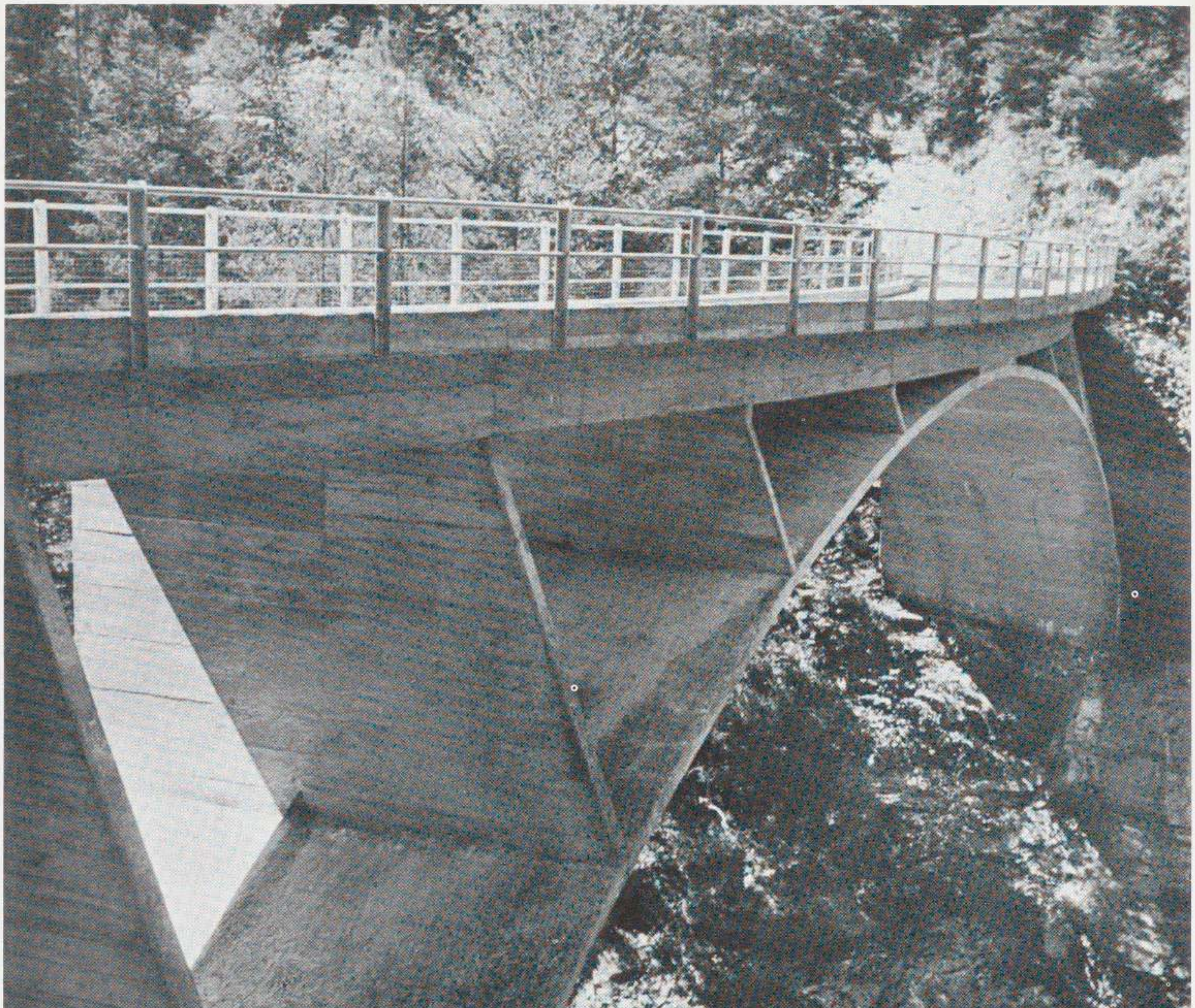


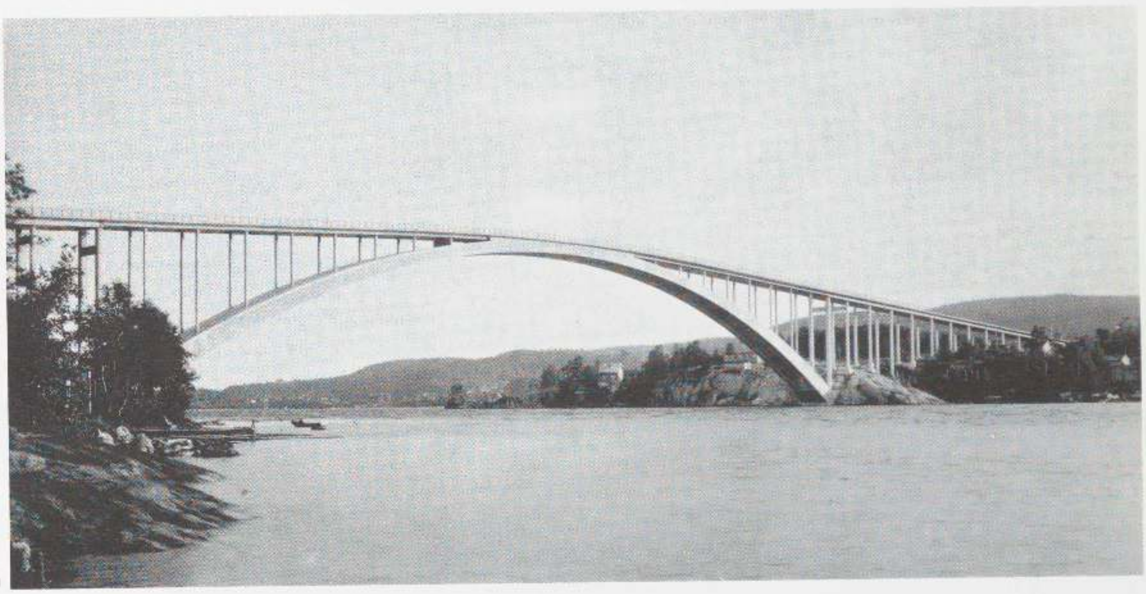


78 Schwandbach Bridge.
near Schwarzenberg, Switzerland. 1933.
Robert Maillart.

79 Sandö Bridge over Angerman River.
Sweden. 1943.
AB Skånska Cementgjuteriet.

80 Bridge over Seine.
Saint Pierre du Vauvray, France. 1922.
Eugène Freyssinet.

78



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81 Gueuroz Bridge over Trient Glacier.
Gueuroz, Switzerland. 1933.
Alexandre Sarrasin.

82 Poggettone and Pecora Vecchia Viaducts.
Autostrada del Sole, Bologna-Florence section, Italy. 1960.
Arrigo Carè, Giorgio Giannelli.

83 San Giuliano Viaduct.
Autostrada del Sole, Florence-Rome section, Italy. 1963.
Maurizio de Lieto, Massimo Varano.

84

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86

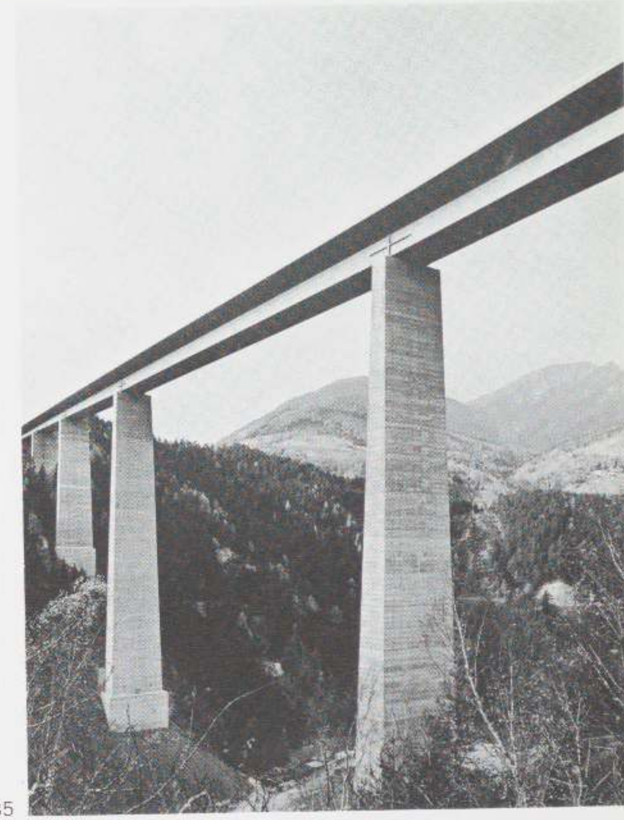
8

84 Wentbridge Viaduct.
near Doncaster, England. 1961.
S. Maynard Lovell.

85 Europa Bridge over Sill River.
Innsbruck-Schoenberg, Austria. 1963.
Vereinigte Österreichische Eisen- und
Stahlwerke A.G.; Waagner-Biro A.G.

86 Savines Bridge over Durance Reservoir.
Savines, France. 1960.
Société des Grands Travaux de Marseille.

84



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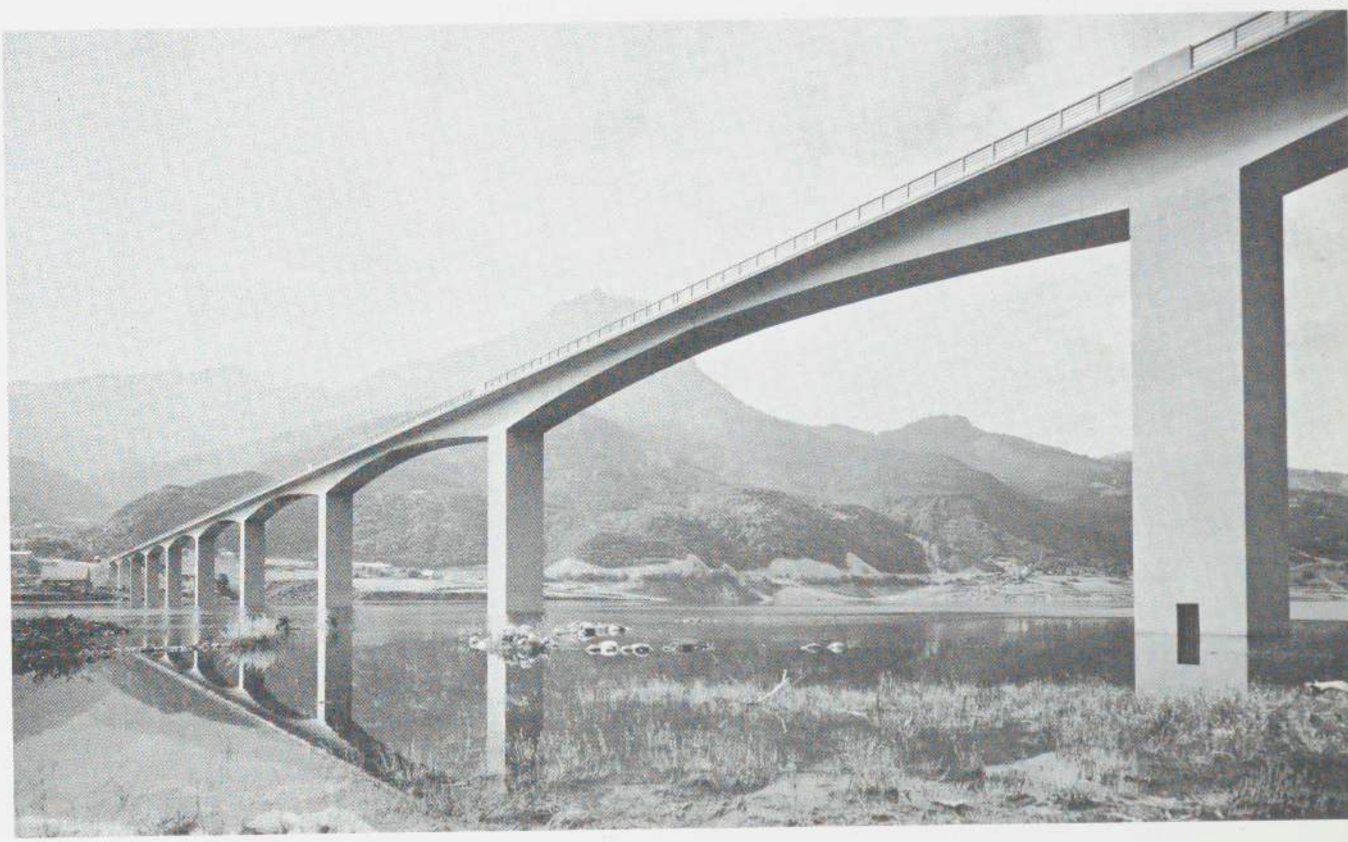
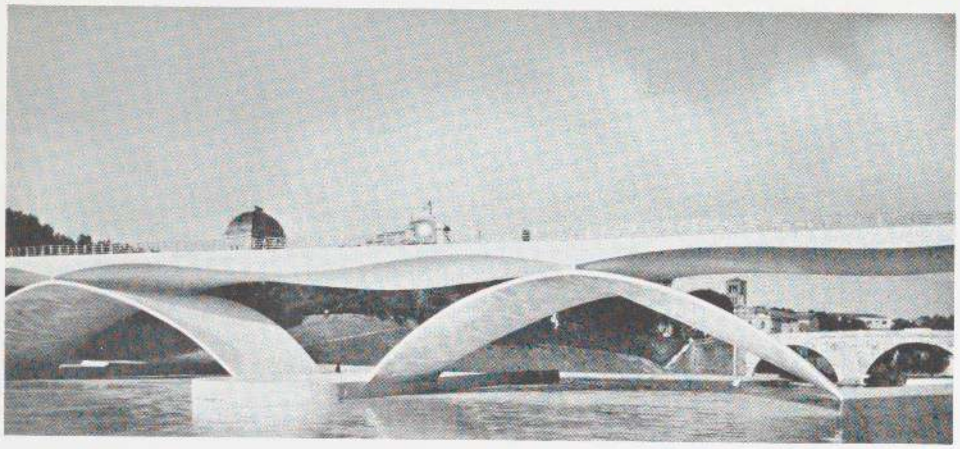
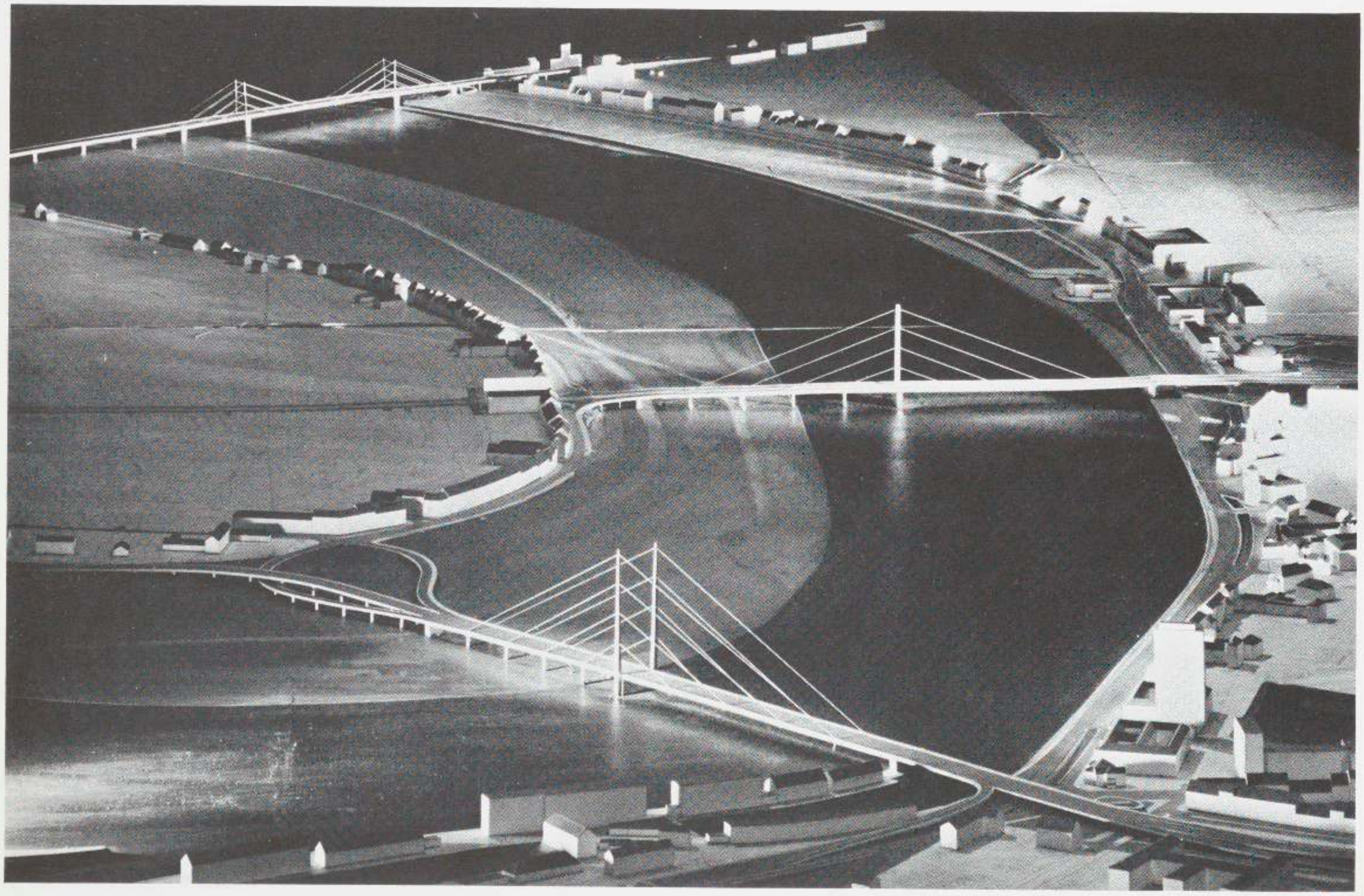




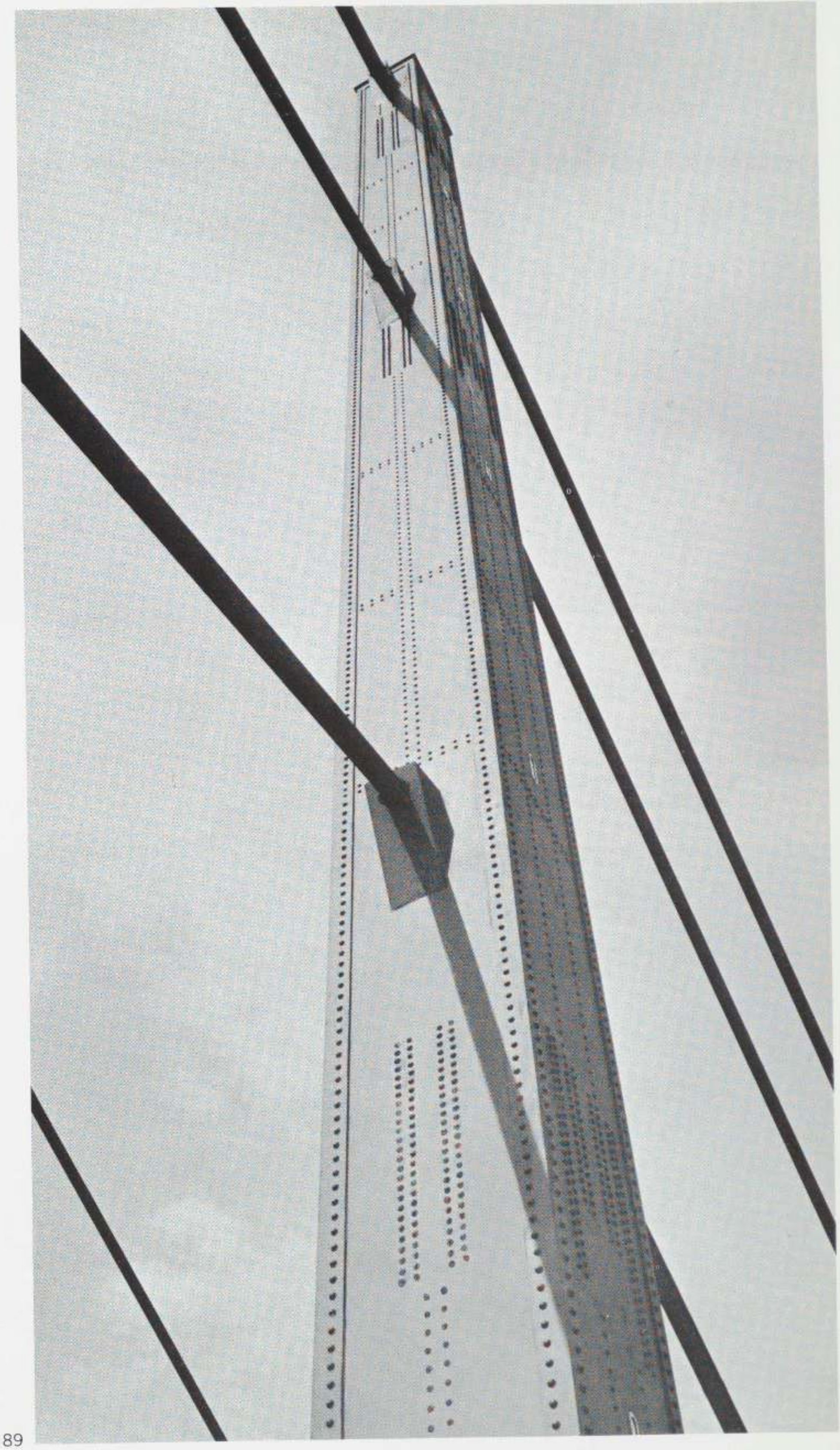
87

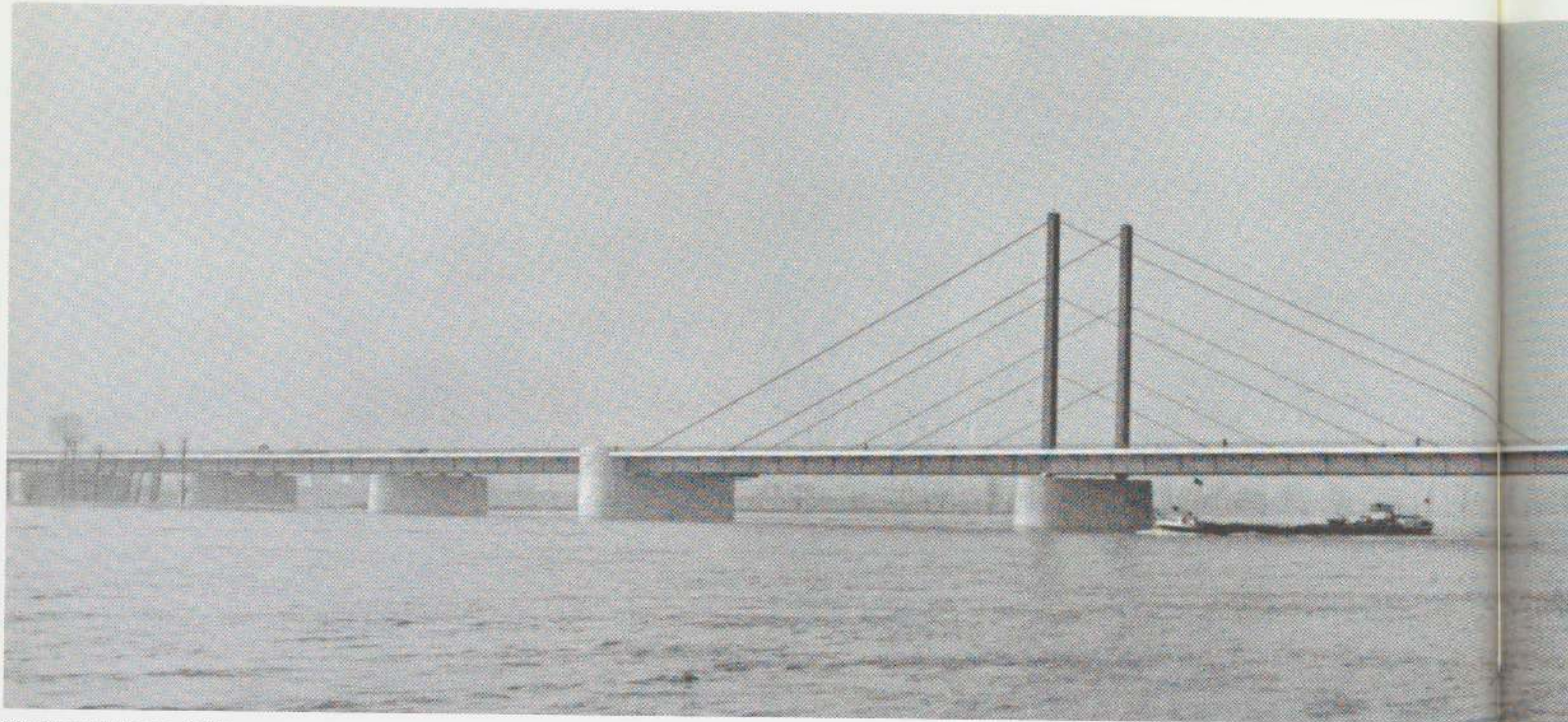
87 Garibaldi Bridge.
Competition project, Rome. 1955.
Carlo Cestelli-Guidi.
Architect:
Antonio di Carlo, James D. Ferris,
Myron Goldsmith, Bruno Zevi.



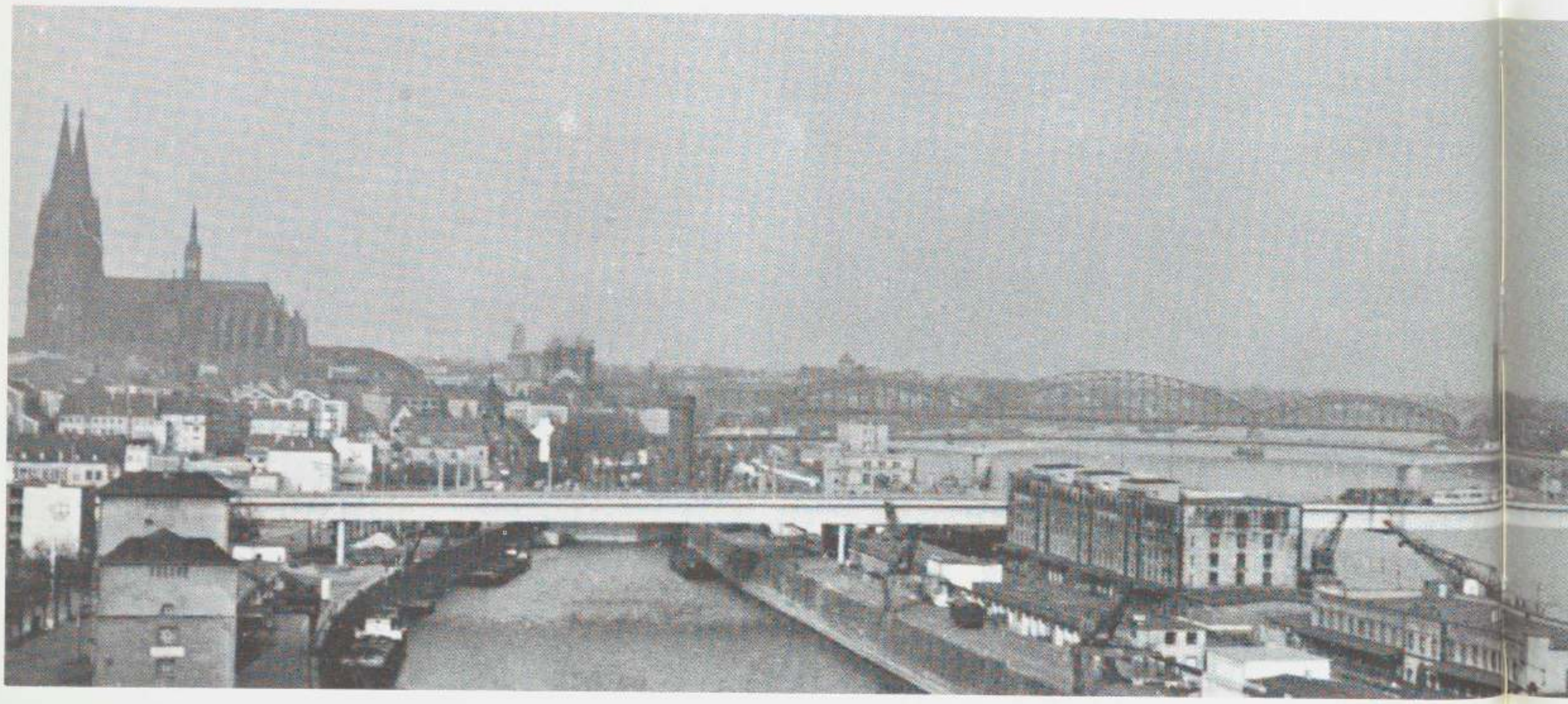
88 "Family of Bridges" over the Rhine River
Model (from top to bottom)
Theodor Heuss Bridge. 1957.
Oberkasseler Bridge. Project
Knie Bridge. Under construction.
Düsseldorf, Germany.
Department of Bridge Construction, City of Düsseldorf, Architect:
Friedrich Tamms.

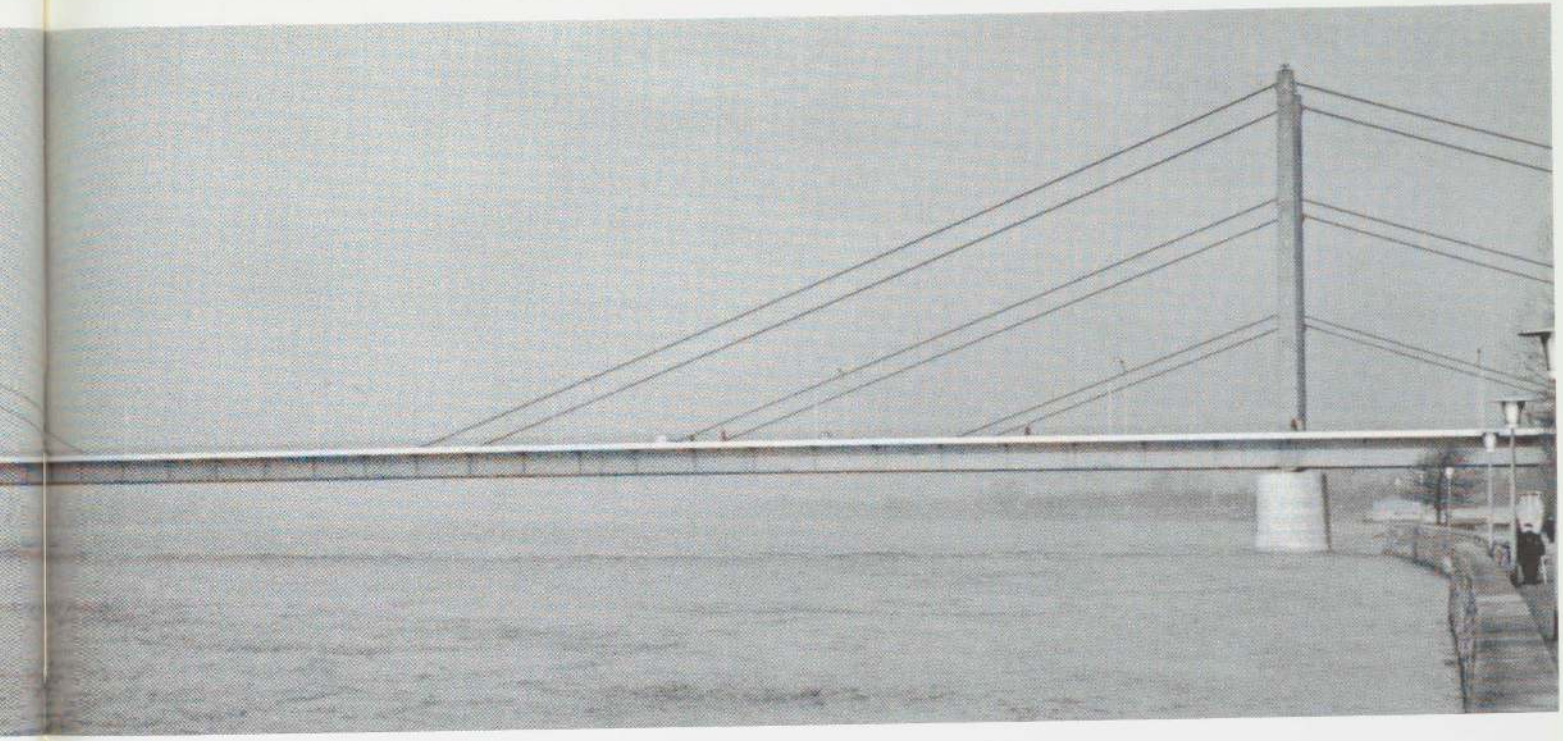
89 Theodor Heuss Bridge
over the Rhine River
Düsseldorf, Germany. 1957.
Dept. of Bridge Construction,
City of Düsseldorf.
(Franz Schreier); Fritz
Leonhardt; Karl Schaechterle;
Louis Wintergerst.
Architect: Friedrich Tamms.





90 Theodor Heuss Bridge
over the Rhine River
Düsseldorf, Germany. 1957.
Dept. of Bridge Construction,
City of Düsseldorf.
(Franz Schreier); Fritz
Leonhardt; Karl Schaechterle;
Louis Wintergerst.
Architect: Friedrich Tamms.



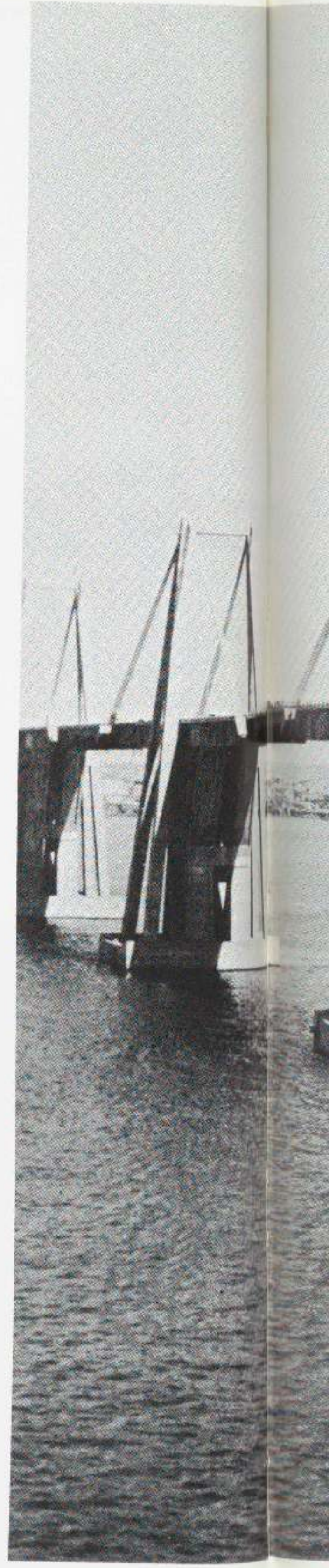


91 Severin Bridge over the Rhine River.
Cologne, Germany. 1959.
Gutehoffnungshütte.
Architect: Gerhard Lohmer.

92 Verrazano-Narrows Bridge.
New York City. Under construction.
Ammann & Whitney.

93 General Urdaneta Bridge.
Laguna de Maracaibo, Venezuela. 1962.
Riccardo Morandi.

93



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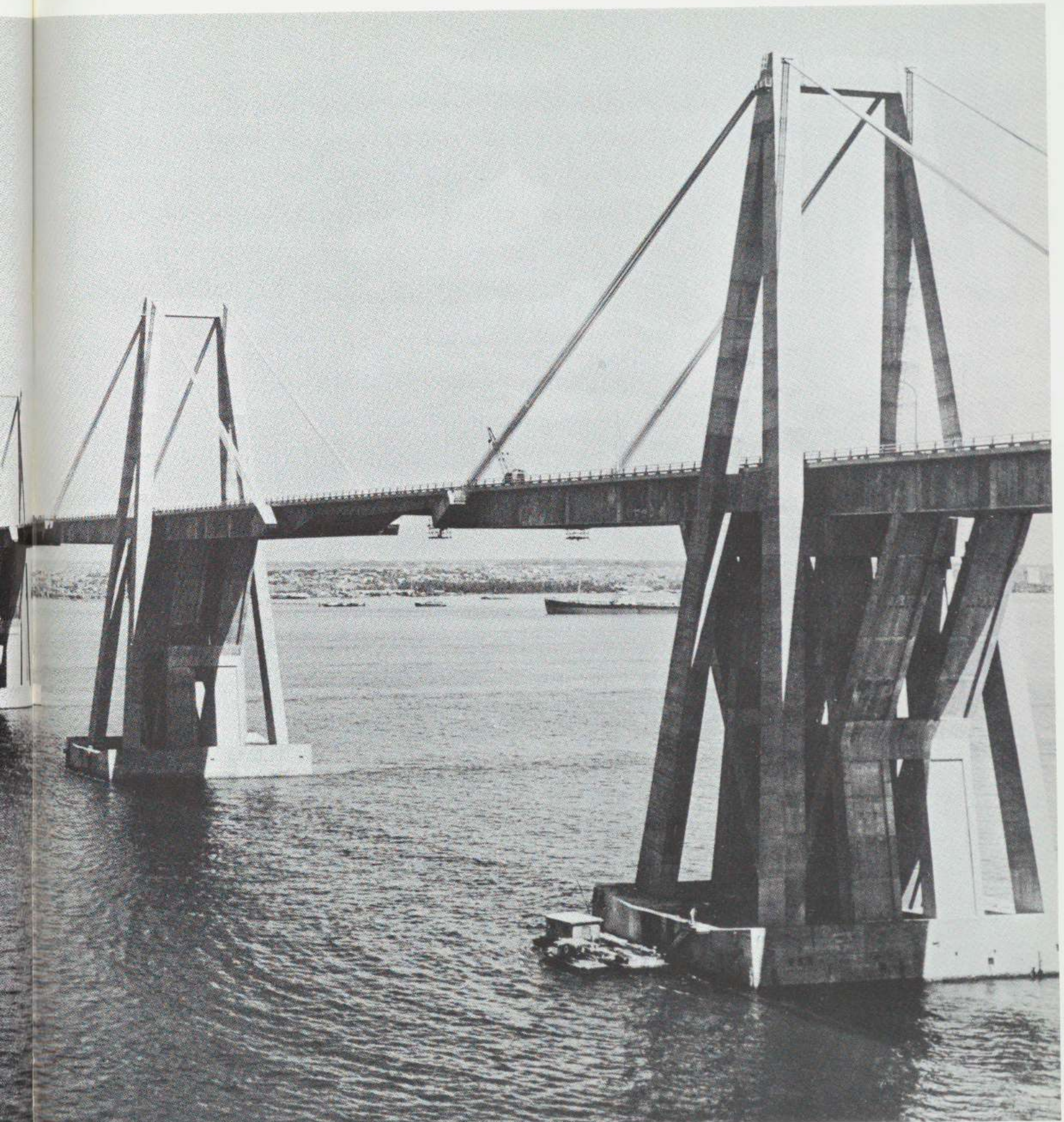

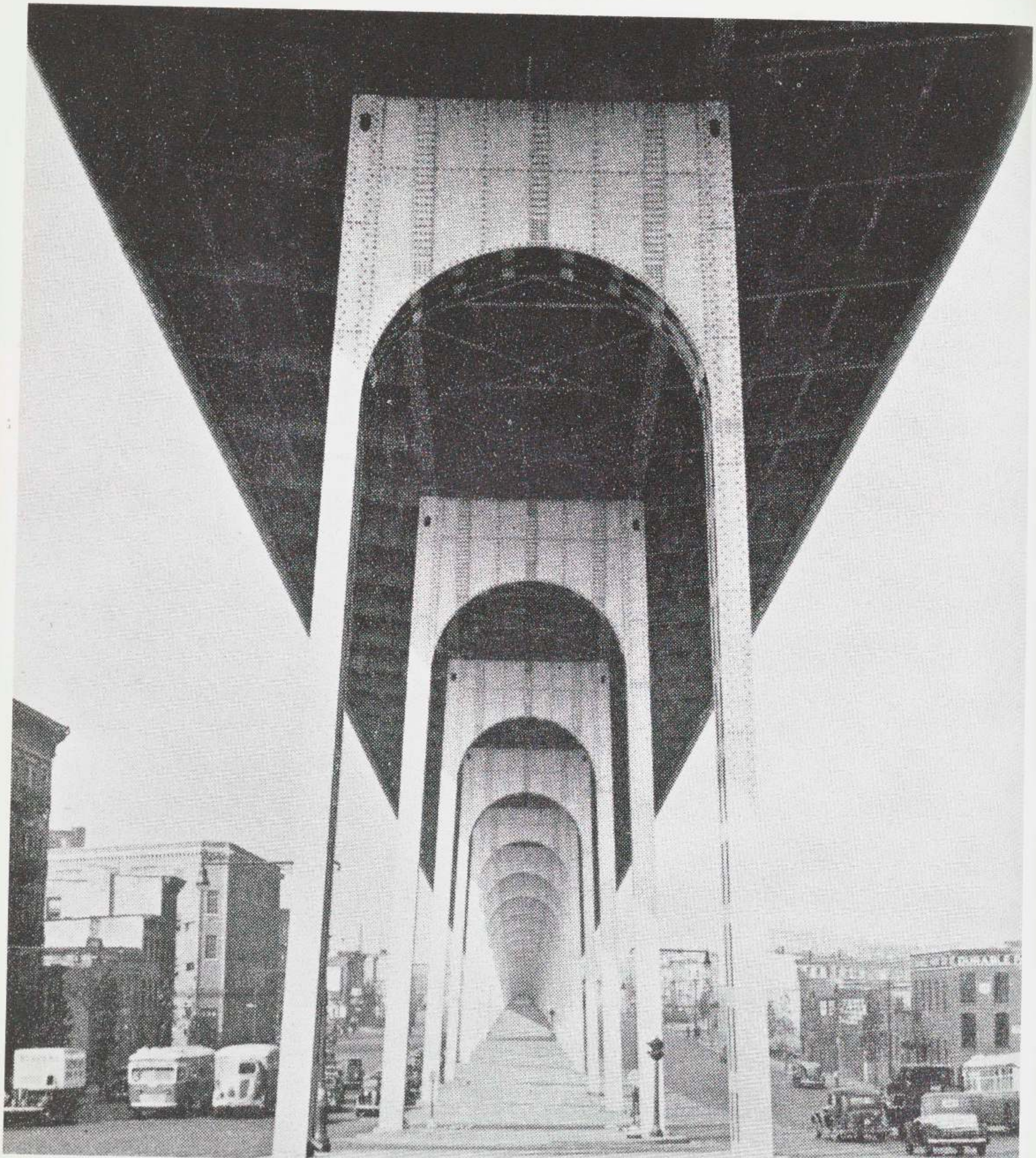

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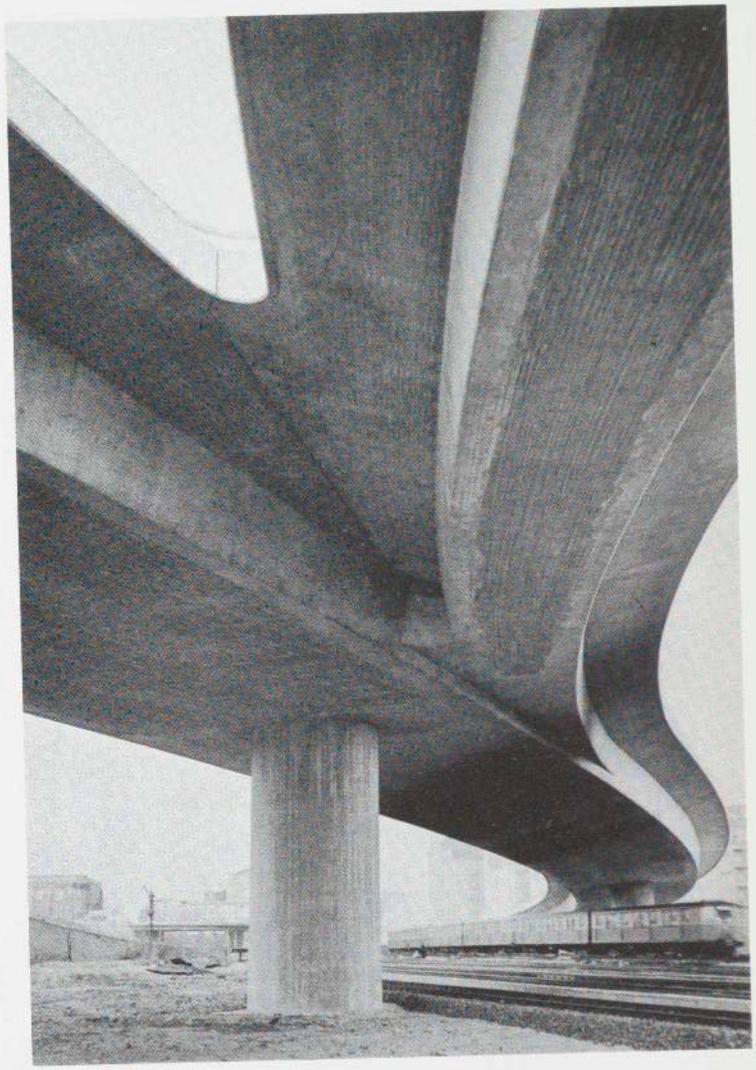
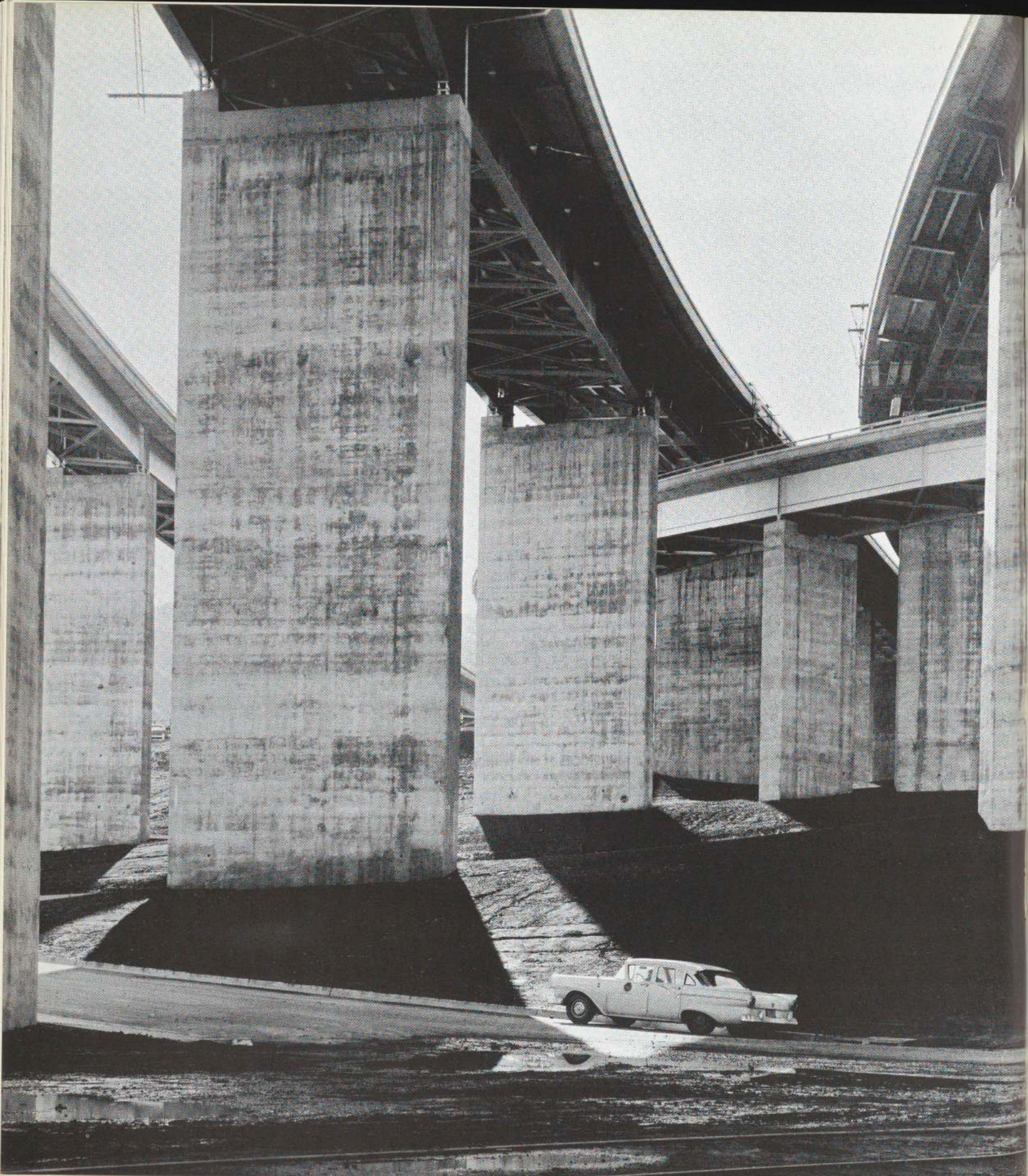


94 Gowanus Elevated Parkway.
Brooklyn, New York. 1941.
Madigan-Hyland.

95 Elevated highway.
Berlin, Germany. 1963.
Department of Construction and Housing,
City of Berlin.

96 Hammersmith Flyover.
London, England. 1961.
G. Maunsell and Partners,
Joseph Rawlinson.
Architect: Hubert Bennett.

96



97
98 Carquinez Bridge approach.
Crockett, California. 1958.
California Division of Highways.

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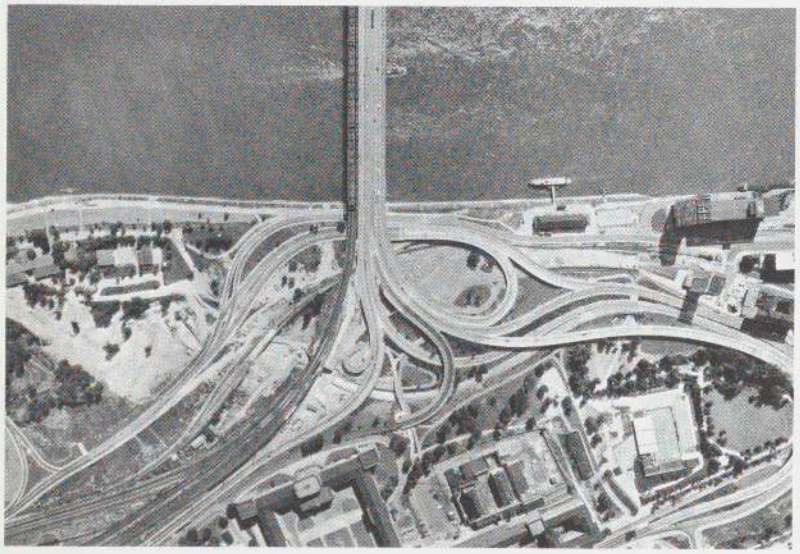


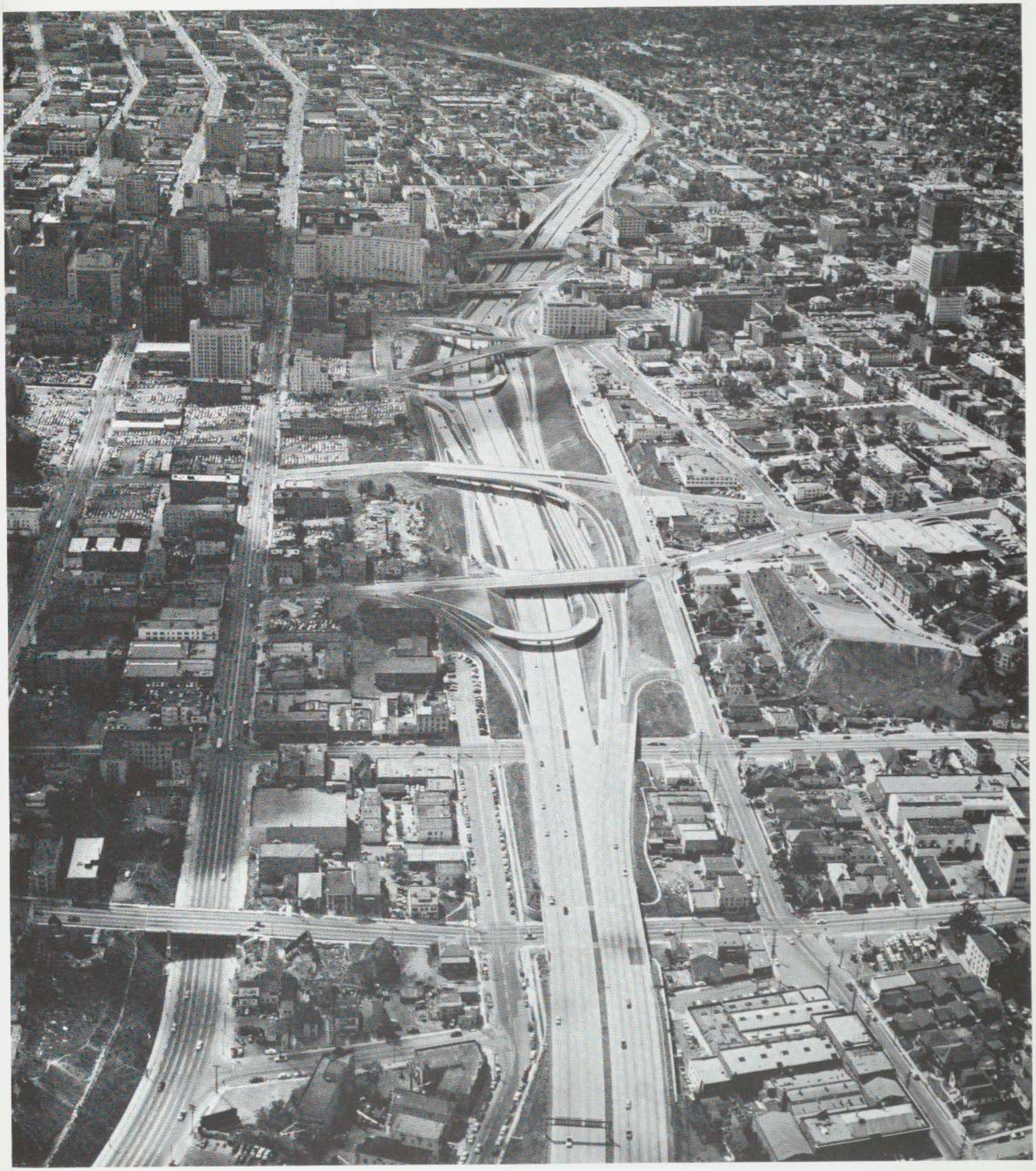
101

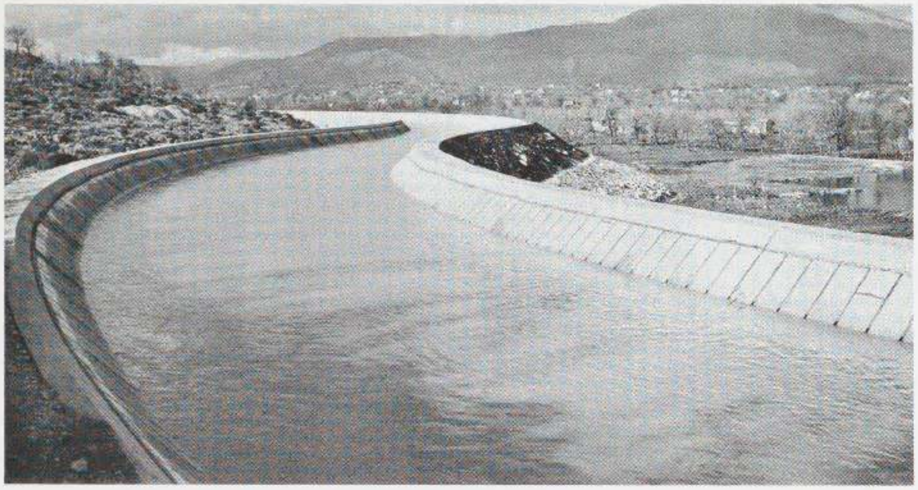
99 Four-level highway interchange. Fort Worth, Texas. 1958. Texas Highway Department.

100 Illinois Tollway interchange. Hinsdale, Illinois. 1958. Harza Engineering Company.

101 Rhine Bridge approach. Mannheim, Germany. 1959. Department of Construction, City of Mannheim.

102 Harbor Freeway. Los Angeles, California. 1954. California Division of Highways.





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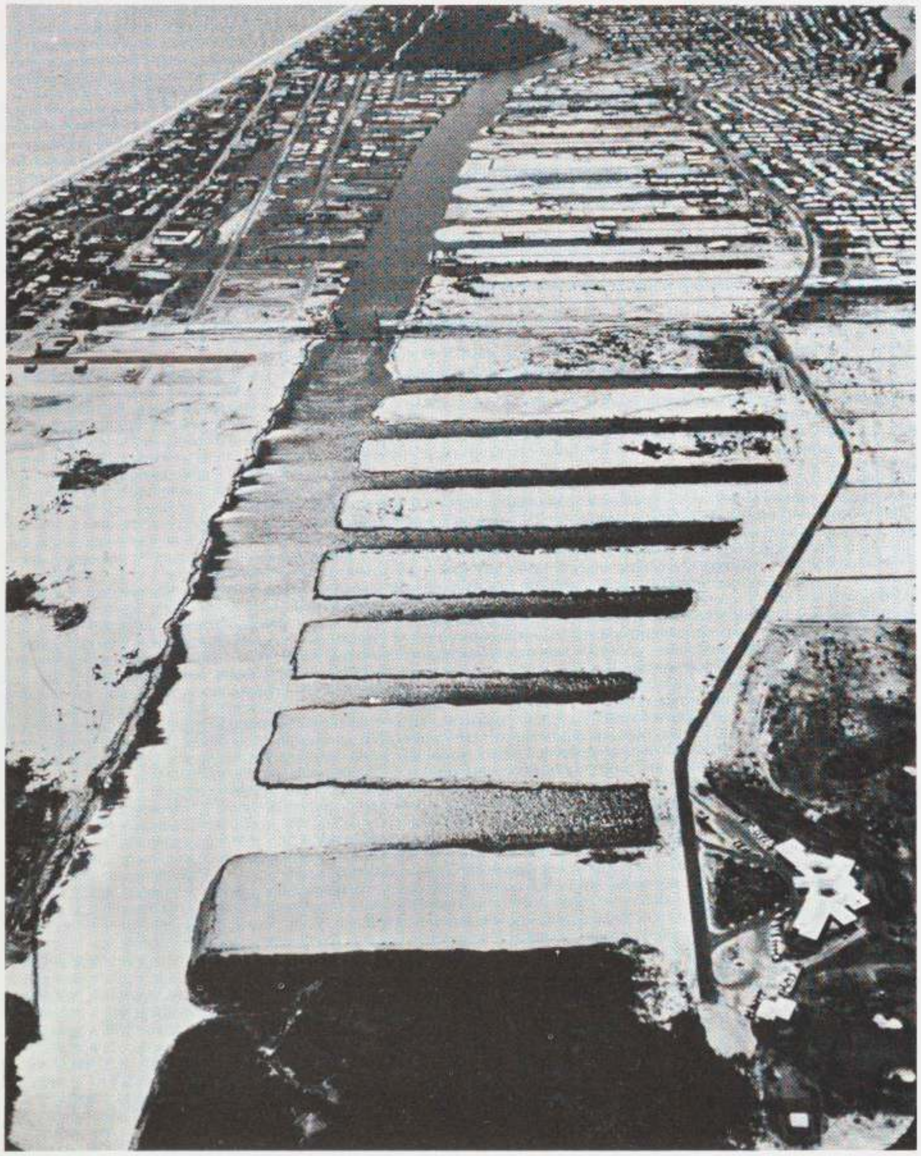

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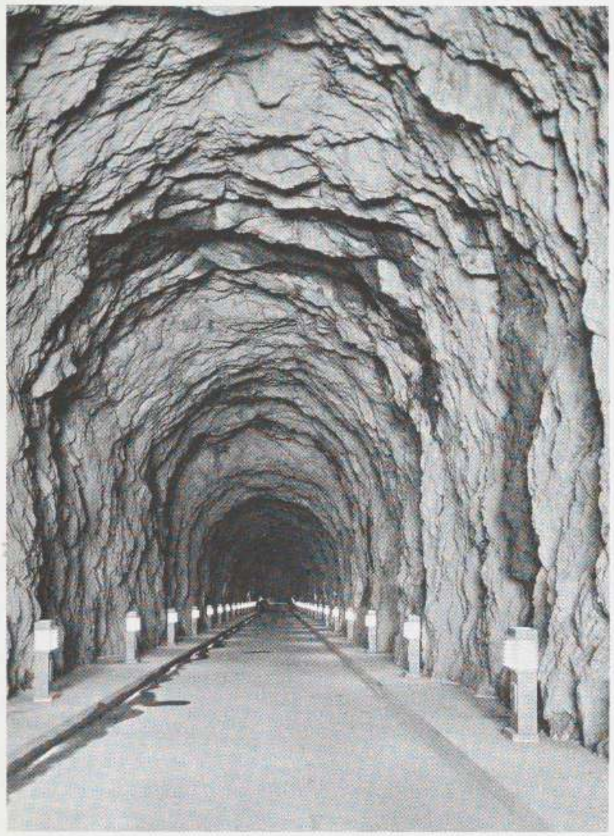
103 Pontecorvo Canal.
Pontecorvo, Italy. 1959.
Silvano Zorzi.

104 Intercoastal waterway.
Fort Lauderdale, Florida. 1956/57.
Intercoastal Dredging Company.

105 Diversion canal. Rhône River Development.
Baix-le Logis Neuf, France. 1961.
Compagnie Nationale du Rhône.

106



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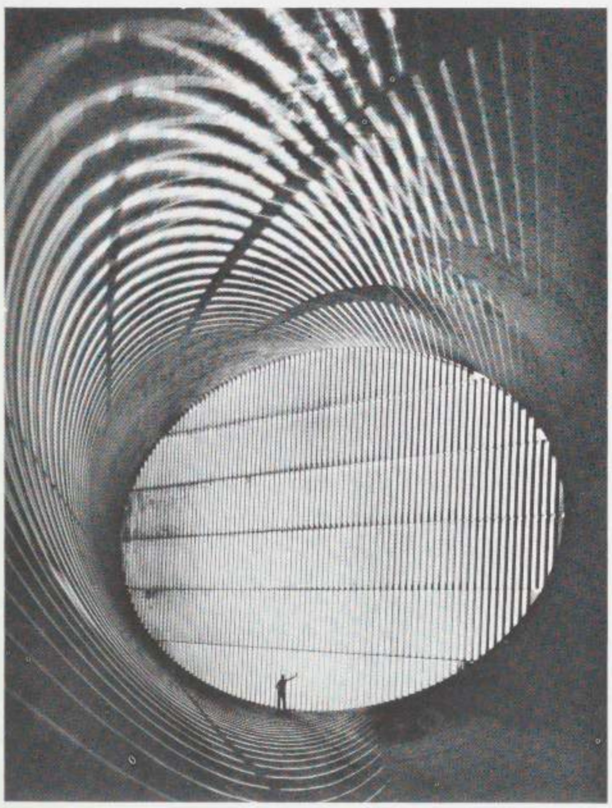

108

106 Randens Power Station
access tunnel.
Isère and Arc Rivers Project,
France. 1954.
Electricité de France.

107 Picote Dam tailrace tunnel.
Douro River, Portugal. 1957.
Hidro-Electrica do Douro.

108 Transonic wind tunnel,
NASA Langley Research Center.
Langley Station, Hampton,
Virginia. 1961.
National Aeronautics and Space
Administration (NASA).

109

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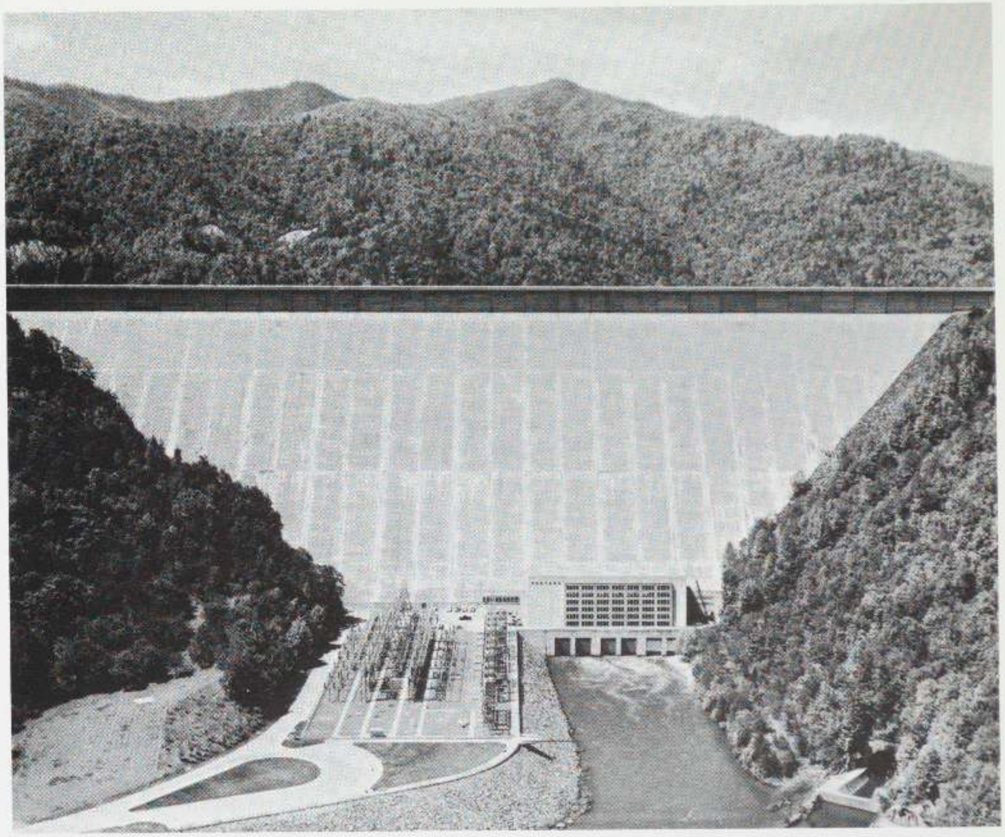

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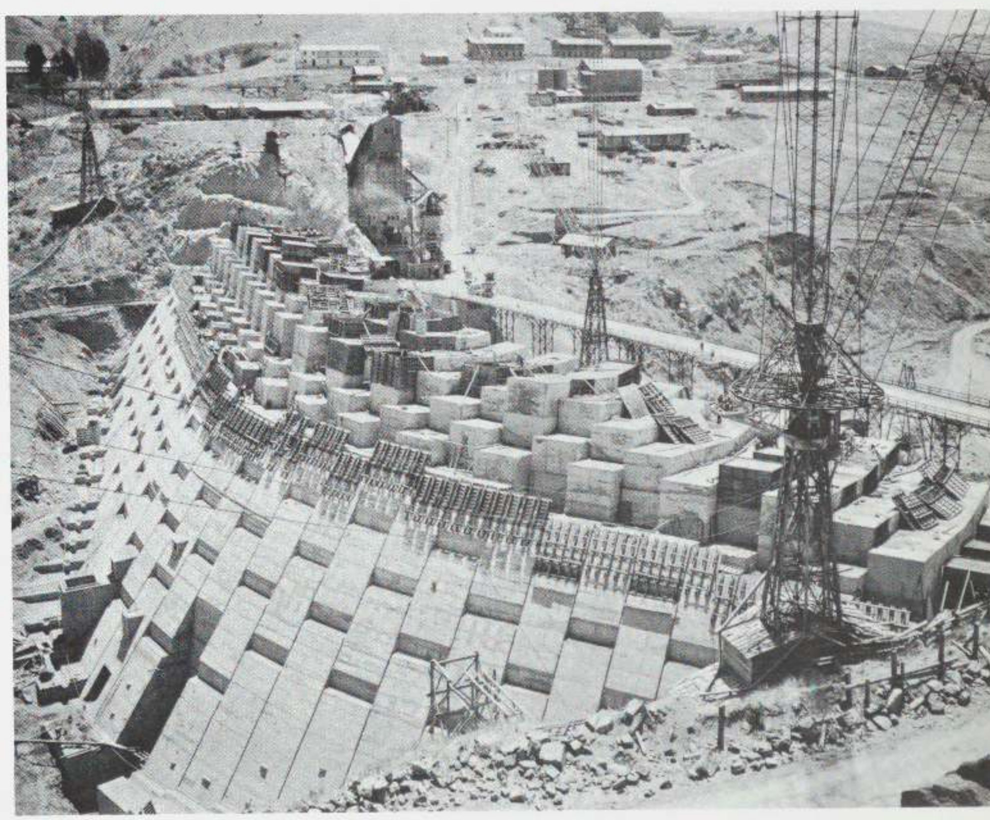


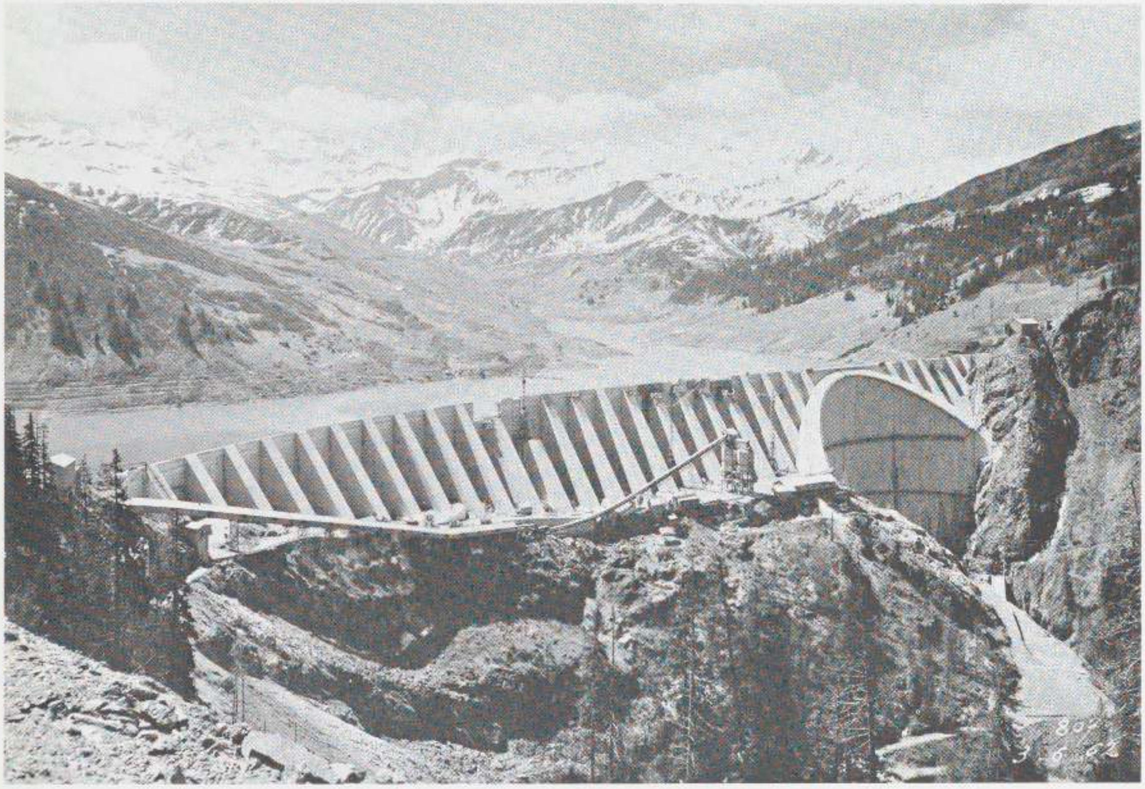
109 Grande Dixence Dam.
Val des Dix, Switzerland. 1962.
Grande Dixence, S.A.

110 Fontana Dam.
Little Tennessee River,
North Carolina. 1949.
Tennessee Valley Authority.

111 Pozzillo Dam.
Salso River, Sicily, Italy. 1958.
Claudio Marcello.

112 Roselend Dam.
Doron de Beaufort River, France. 1961.
Electricité de France; Coyne et Bellier.

113 Meishan Dam.
Huai River, China. 1956.



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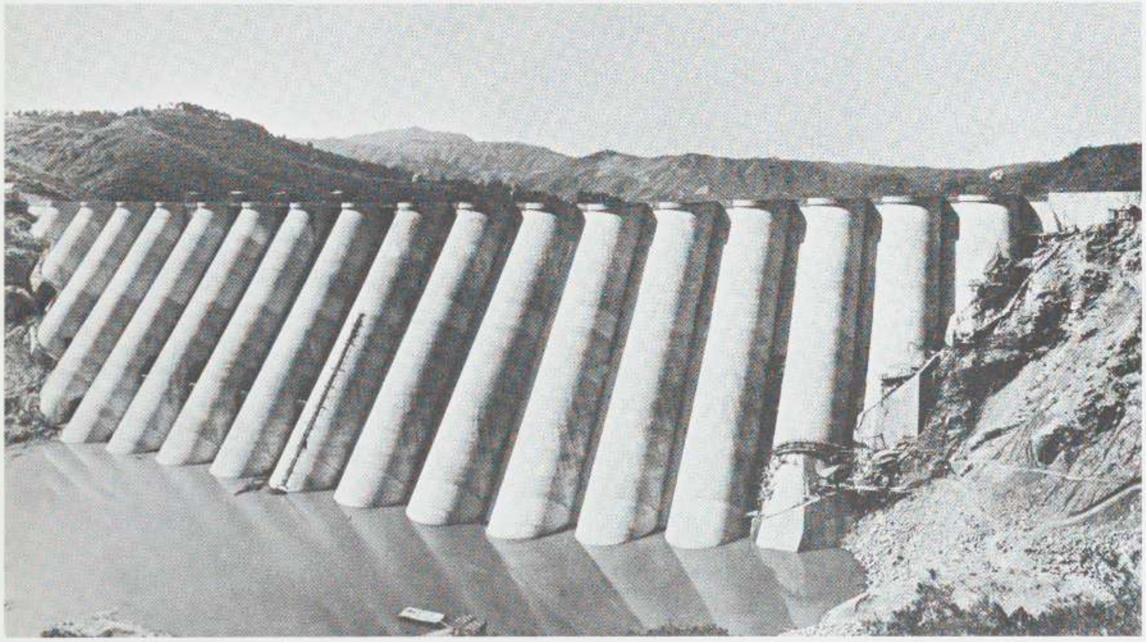
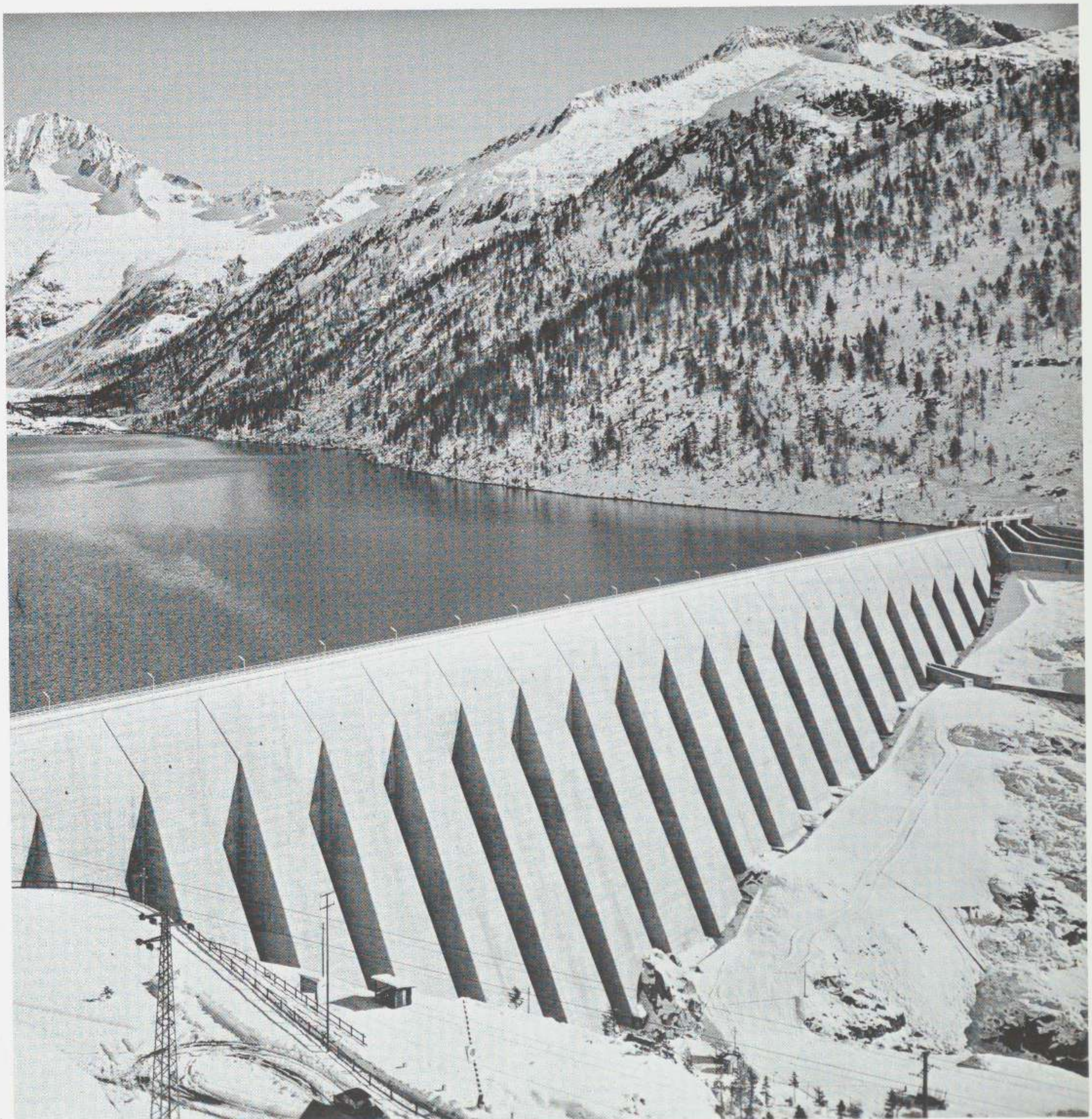
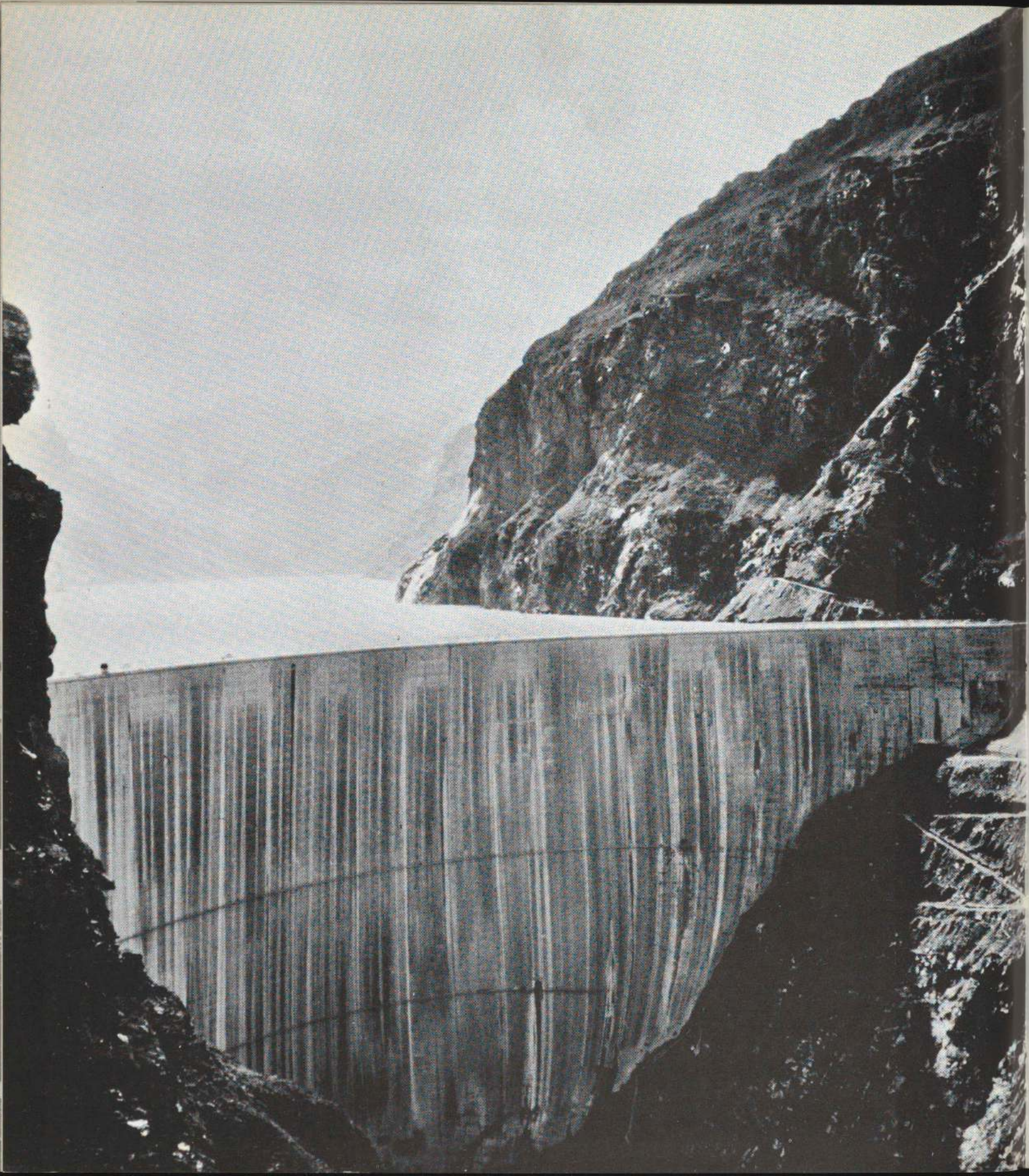


113

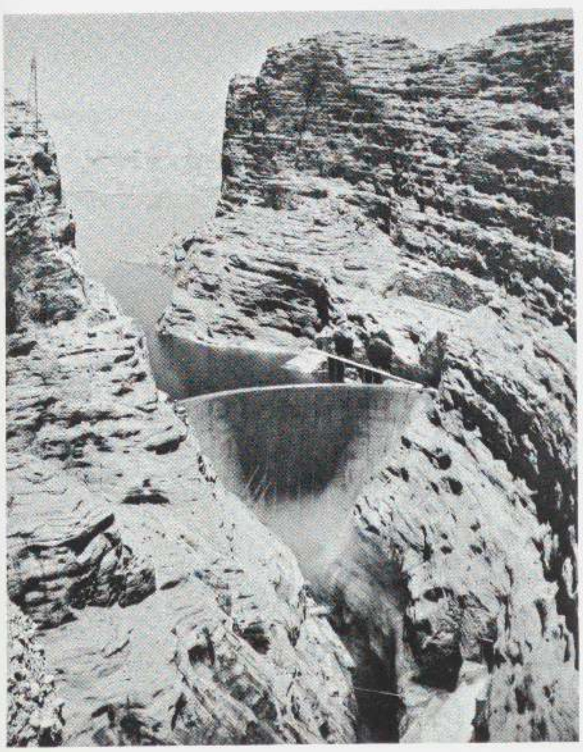
114 Bissina Dam.
Chiese River, Italy. 1957.
Claudio Marcello.





115 Mauvoisin Dam.
Dranse de Bagnes River,
Switzerland. 1958.
Electro-Watt.

116
117 Mohammed Reza Shah Pahlavi Dam.
Dez River, Iran. 1963.
Development and Resources Corporation.



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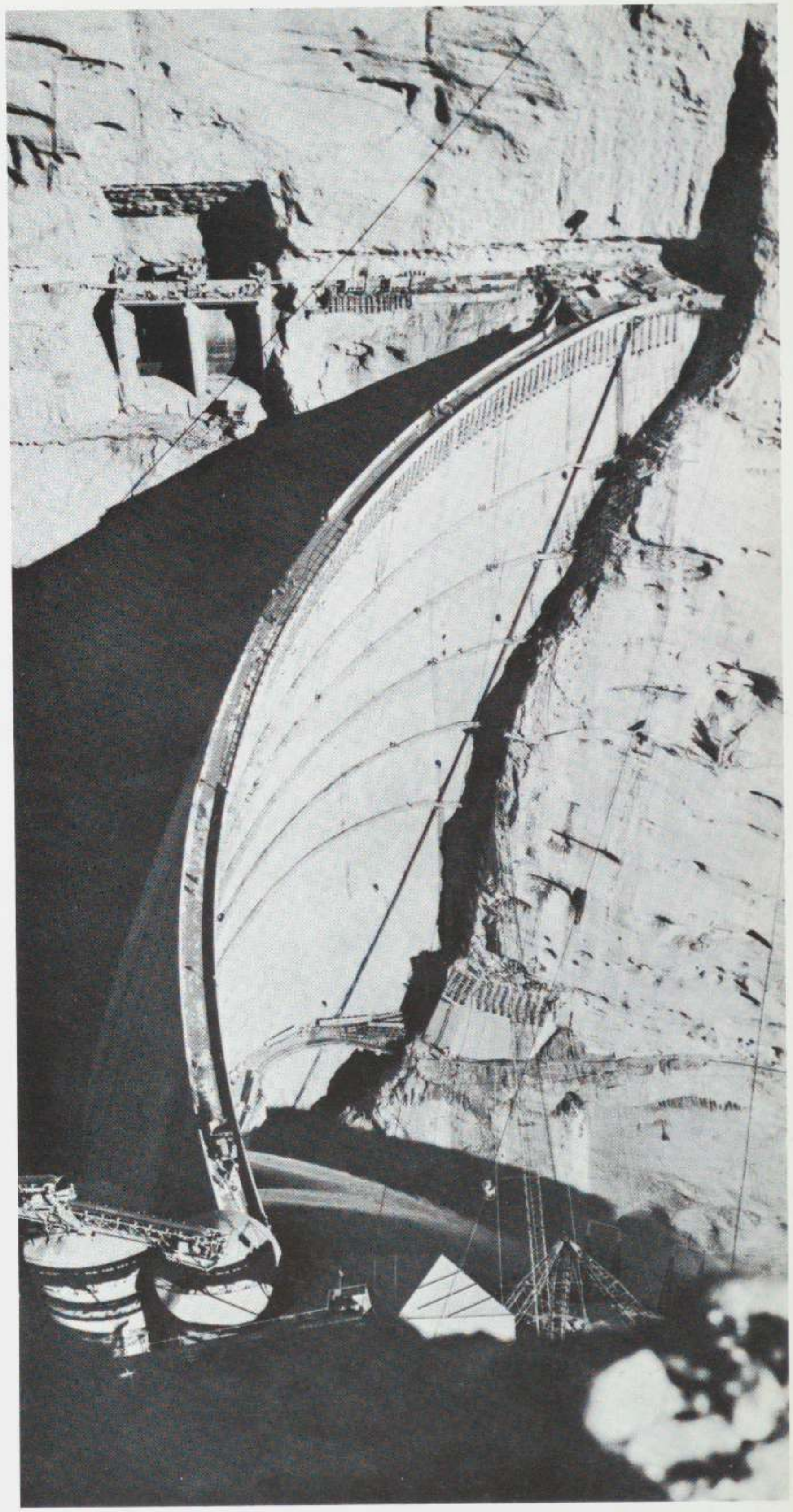

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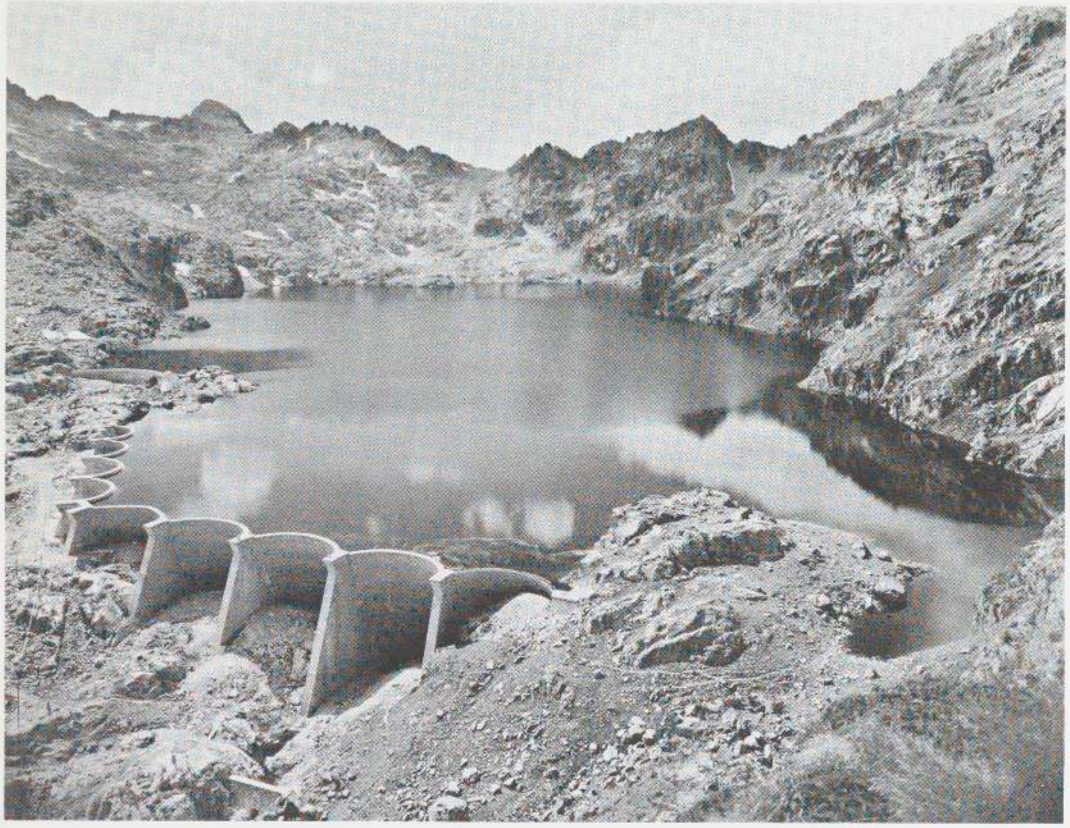

118

119

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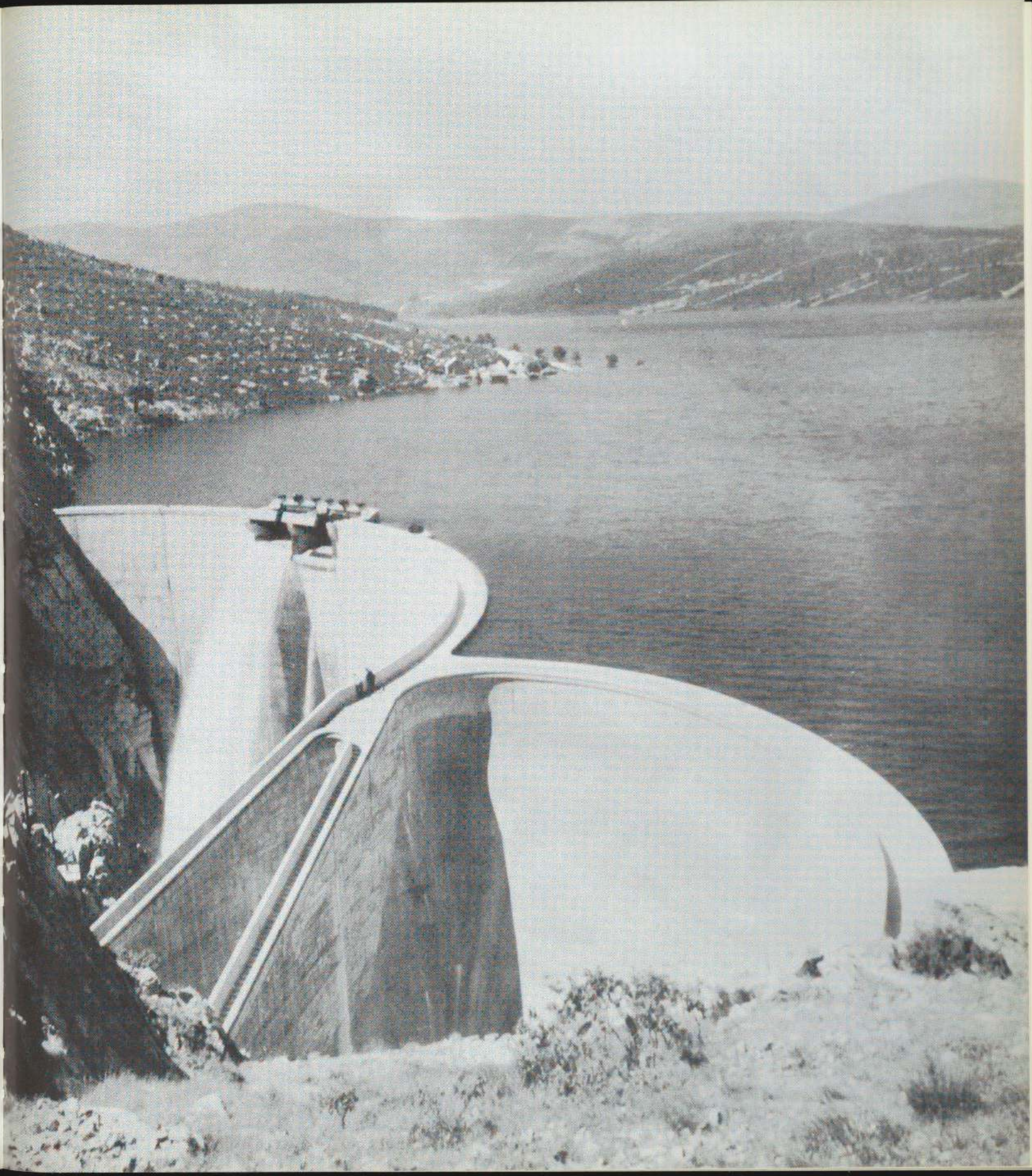
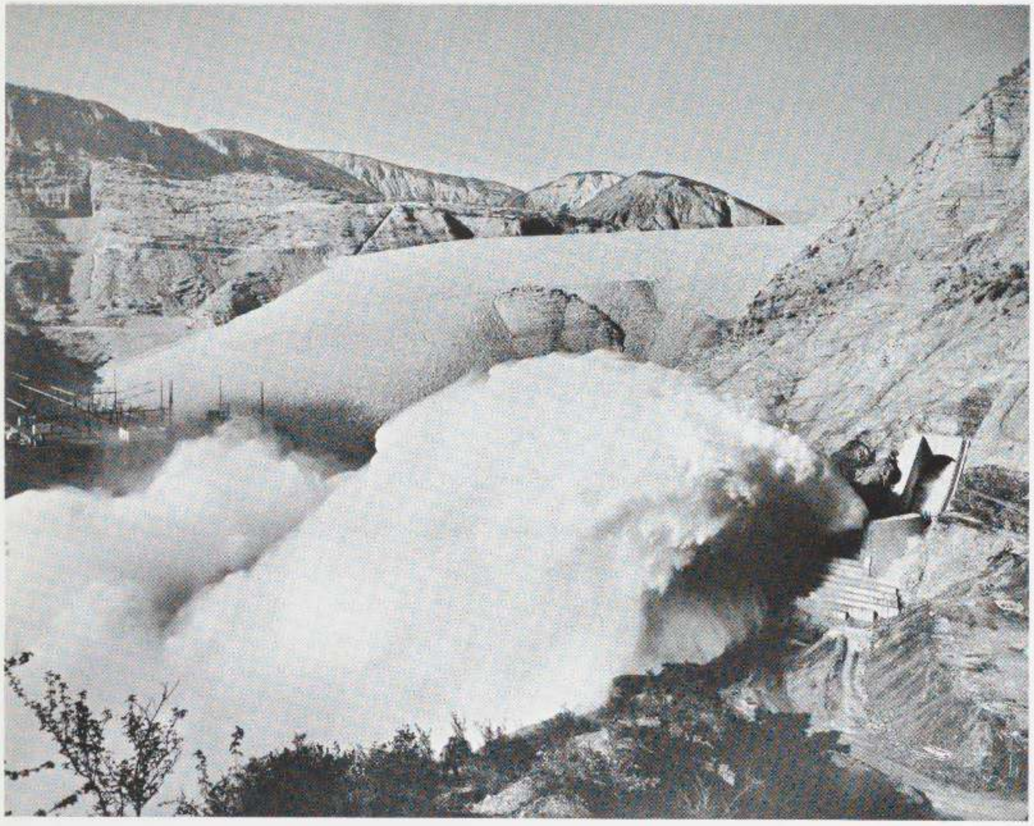
118 Migöelou Dam.
Lake Migöelou, France. 1958.
Electricité de France;
Coyne et Bellier.

119 Minidoka Dam, spillway weir.
Snake River, Idaho. 1906.
Bureau of Reclamation.

120 Santa Luzia Dam.
Pampilhoas River, Portugal. 1944.
Eelctricité de France;
Coyne et Bellier.





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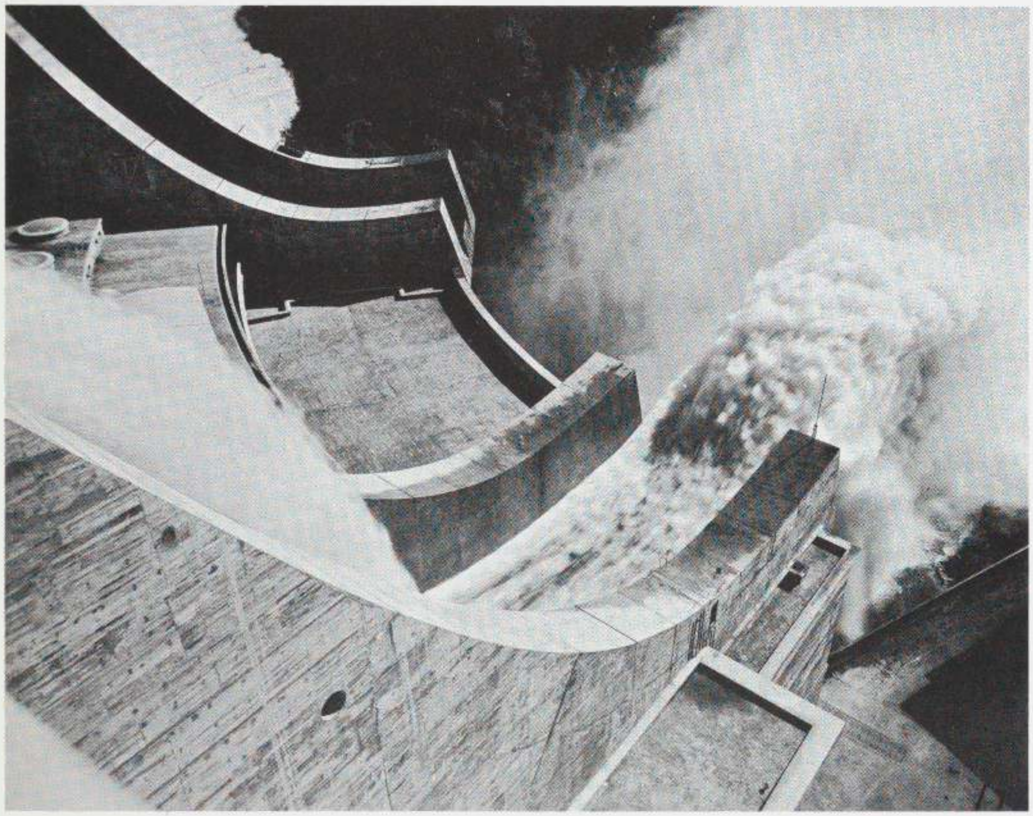

121 Magnitogorsk overflow dam.
Ural River, U.S.S.R. 1931.

122 Serre-Ponçon Dam, diversion outlet.
Durance River, France. 1960.
Electricité de France;
Coyne et Bellier.

123 Le Chastang Dam, spillway.
Dordogne River, France. 1951.
Electricité de France;
Coyne et Bellier.

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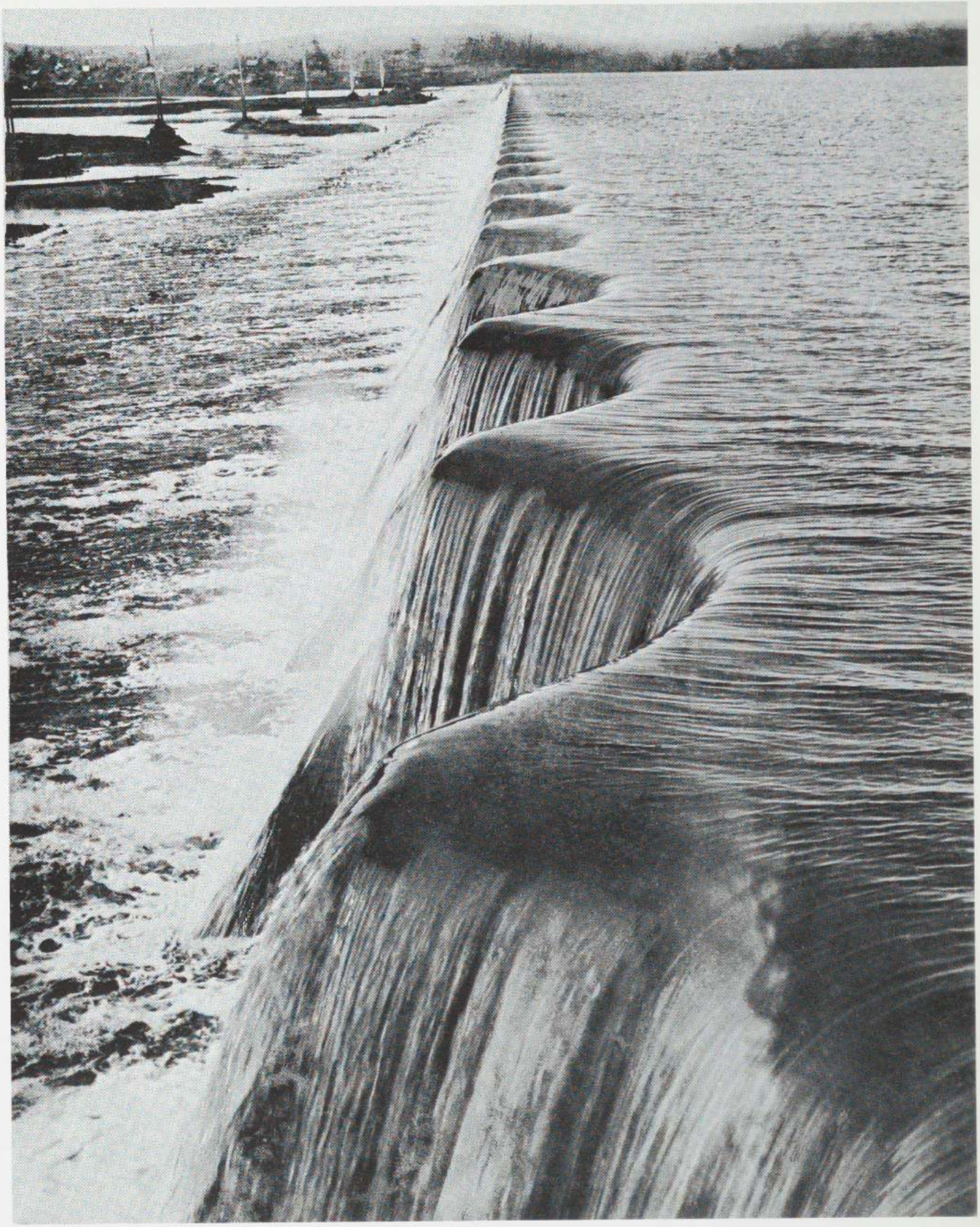

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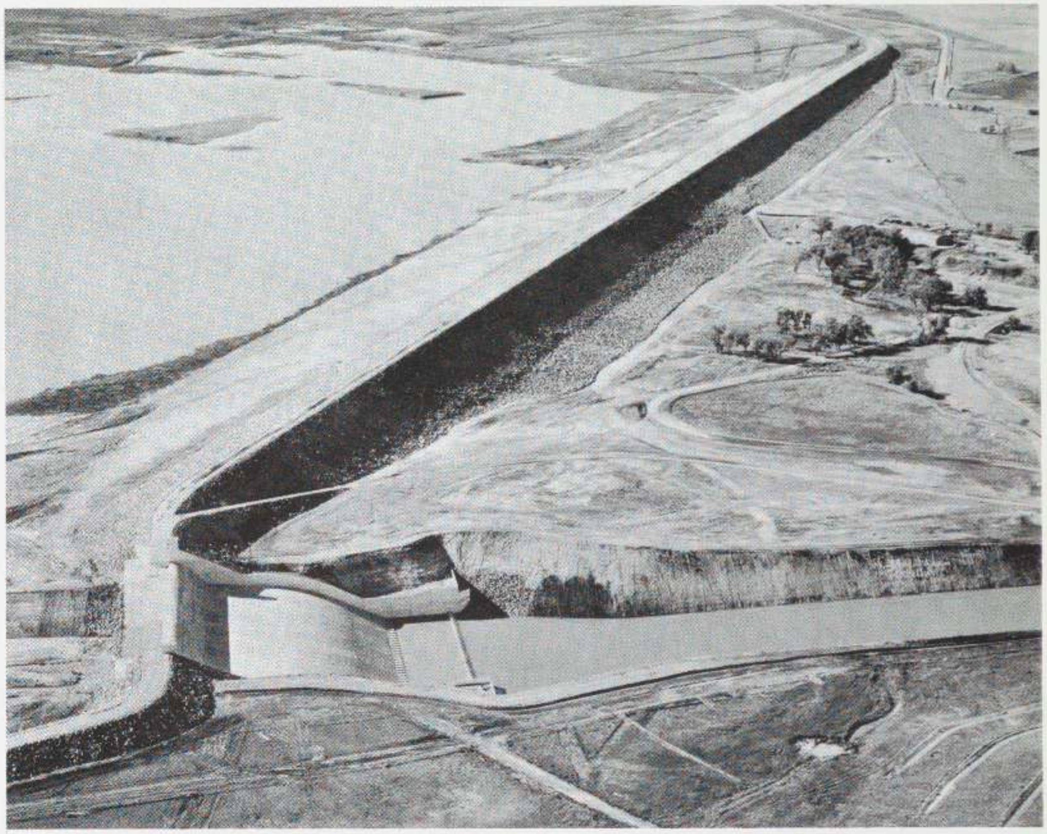

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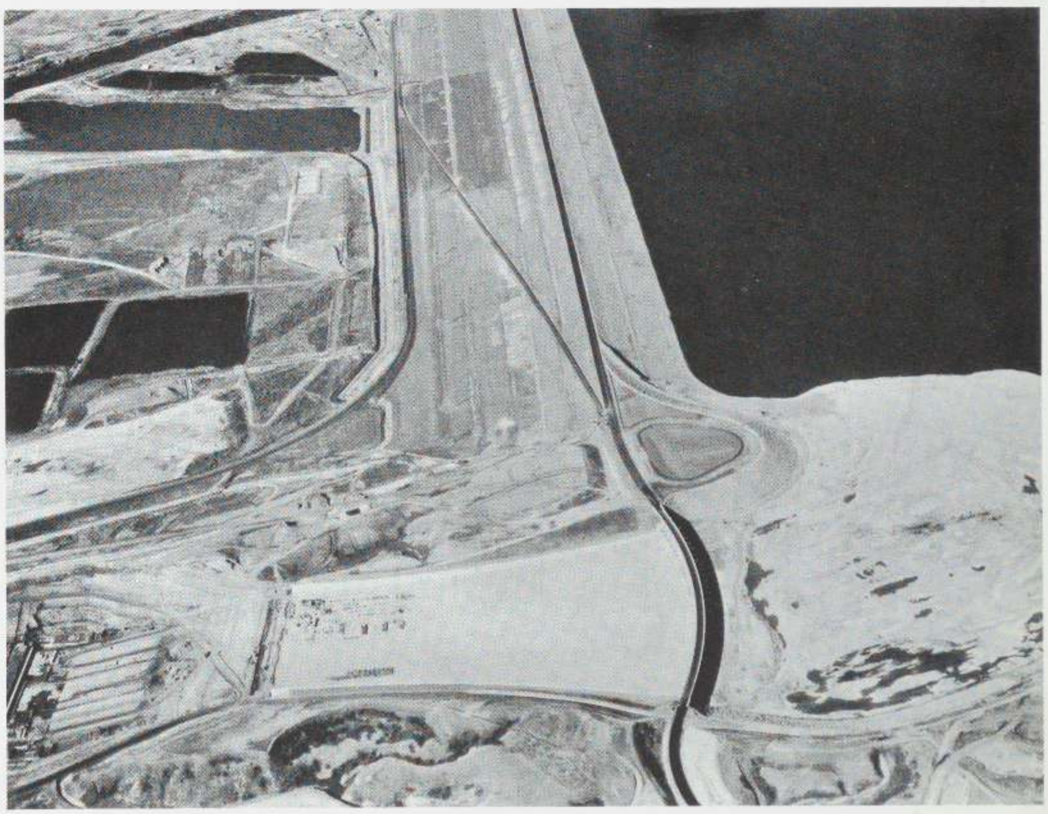


124 Fort Peck Dam, spillway.
Missouri River, Montana. 1940.
Corps of Engineers;
Harza Engineering Company.

125 Kirwin Dam, spillway.
Solomon River, Kansas. 1955.
Bureau of Reclamation.

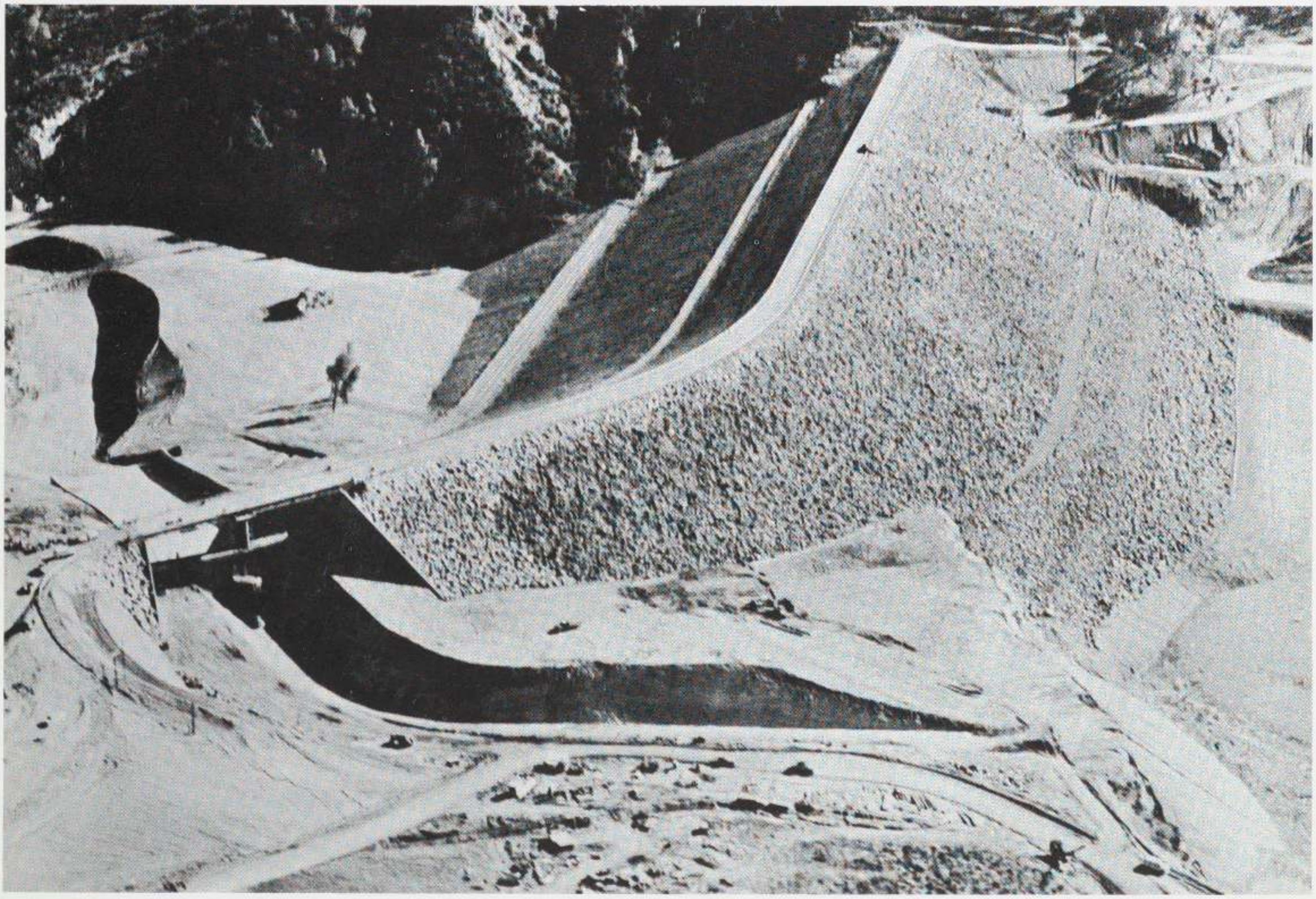
126 Garrison Dam, spillway.
Missouri River, North Dakota.
Under construction.
Corps of Engineers; Charles T. Main, Inc.

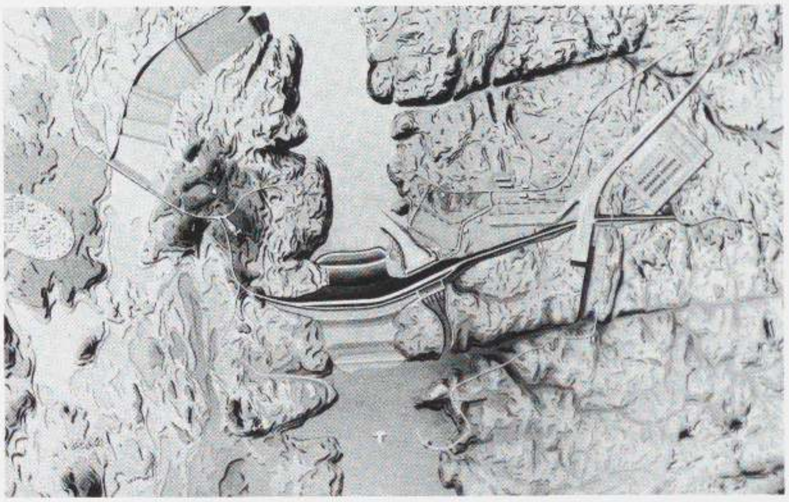
127 Nacimiento Dam.
Nacimiento River, California. 1957.
Bechtel Corporation.

128 Shek Pik Dam.
Lantau Island, Hong Kong. 1963.
Binnie, Deacon and Gourley.

129 Aswan High Dam.
Nile River, United Arab Republic.
Under construction.
Osman Ahmed Osman Company.

127





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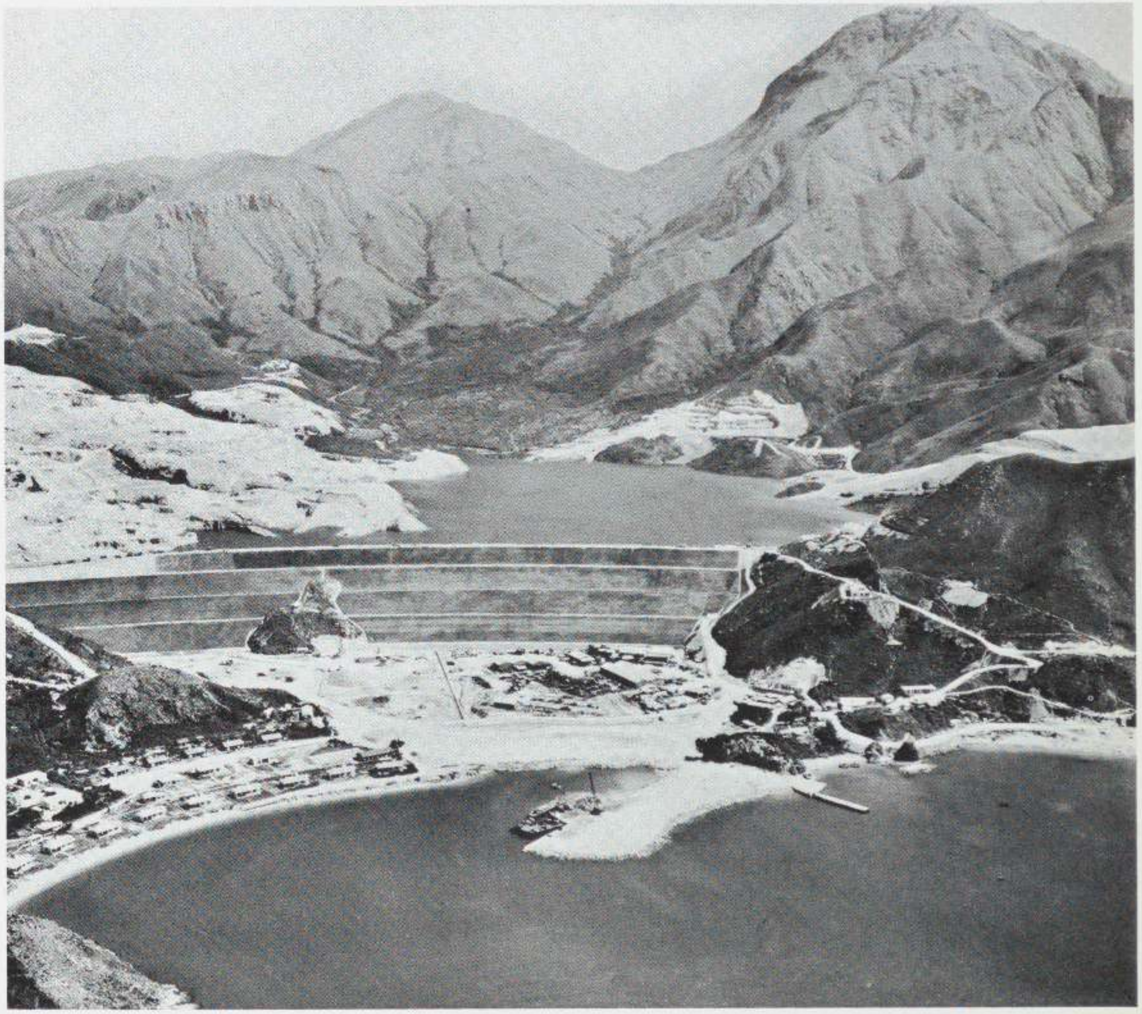

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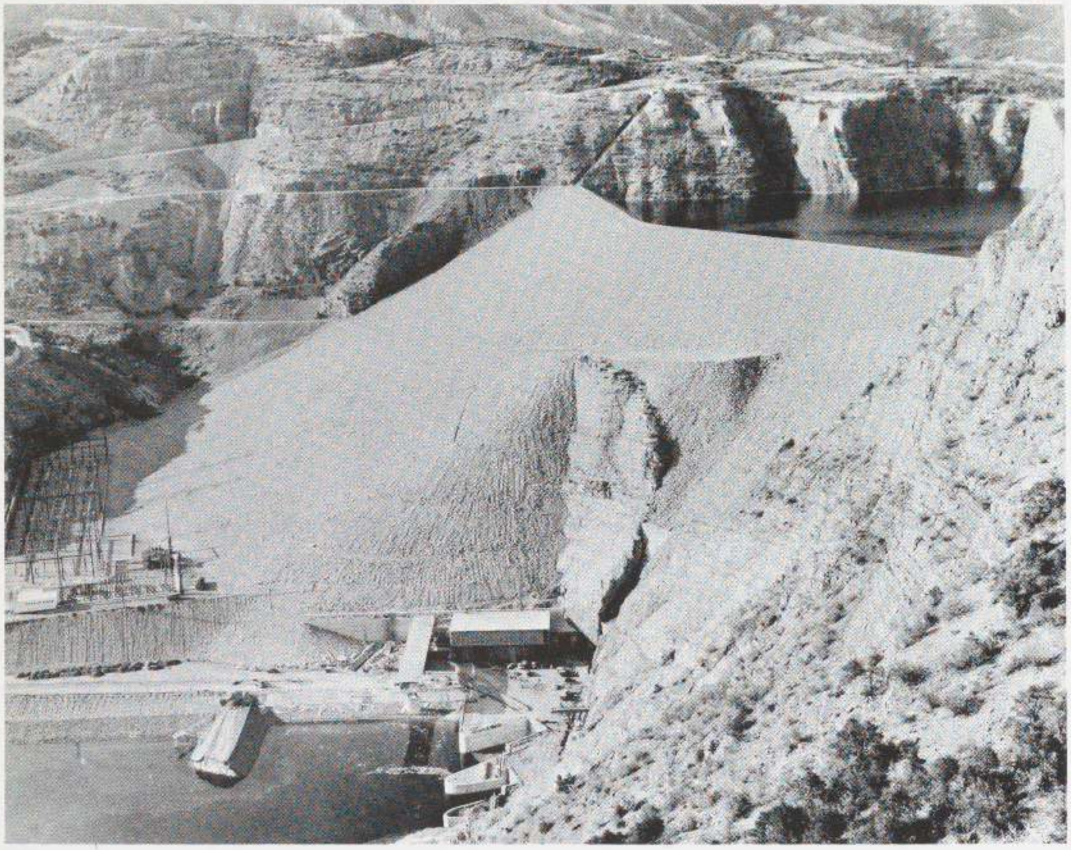

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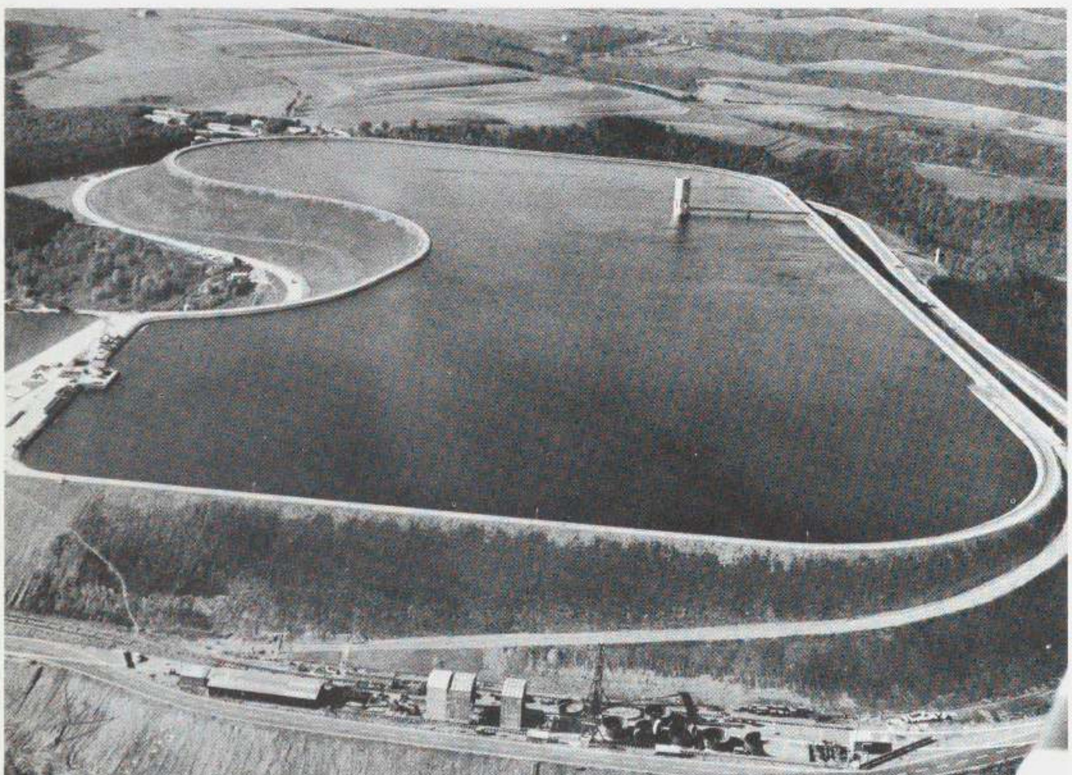


130 Serre-Ponçon Dam.
Durance River, France. 1960.
Electricité de France;
Coyne et Bellier.

131 Goeschenen Dam.
Reuss River, Switzerland. 1960.
Electro-Watt.

132 Pumped storage reservoir.
Power station Vianden,
Luxembourg. 1964.
Société Générale pour l'Industrie.

133 Chuquicamata Mine.
Chuquicamata, Chile. 1915—present.
The Anaconda Company.

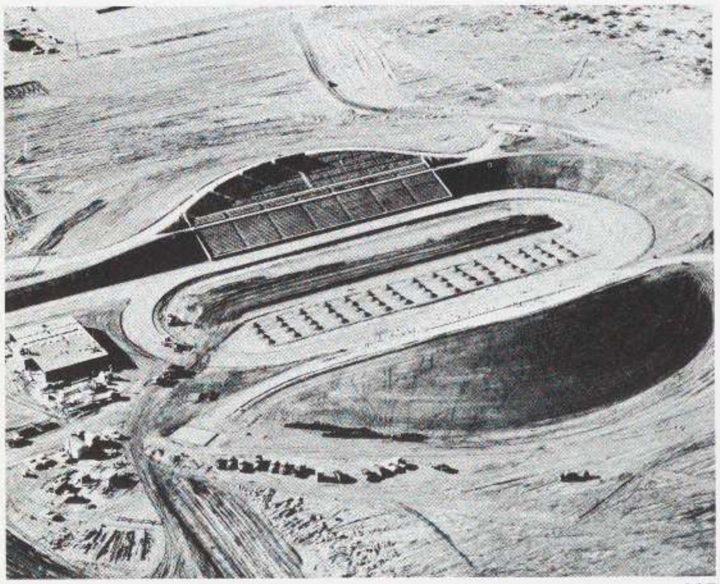
134 Trousdale Estates.
Beverly Hills, California. 1963.
Trousdale Construction Company.

135 San Angelo Stadium.
San Angelo, Texas. 1956.
Caudill, Rowlett, Scott & Associates.
Architect: Max D. Lovett.

136 Olympic ski jump stadium.
Innsbruck, Austria. 1962.
Andreas Peyerl, Oskar Heinz.
Architect: Heini Klopfer.

133

134



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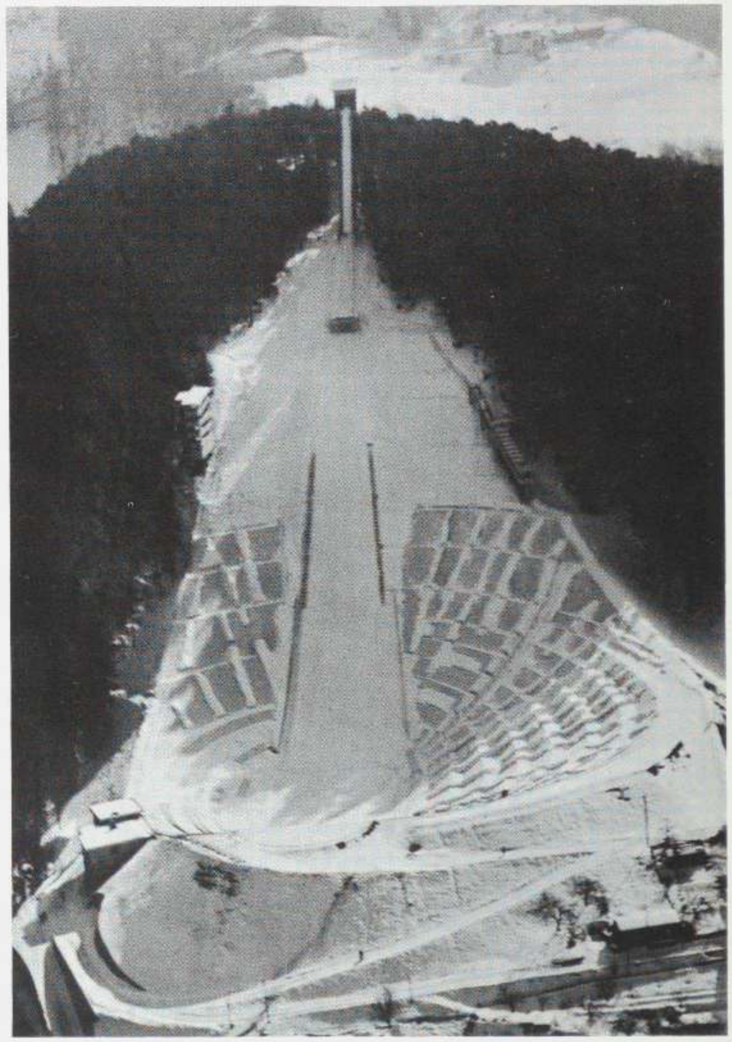

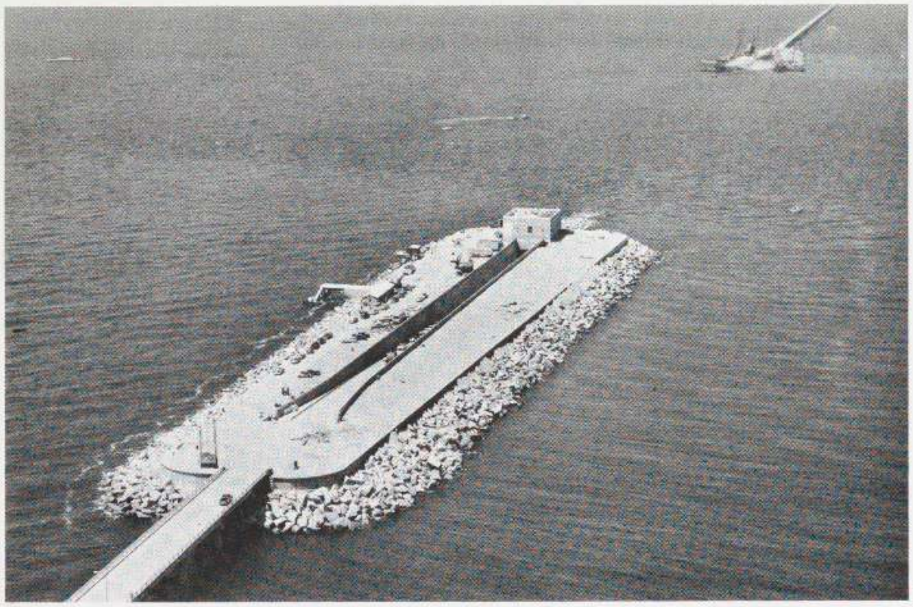
137


138

137 Chesapeake Bay Bridge-Tunnel.
Chesapeake Bay, Virginia. 1964.
Sverdrup and Parcel.

138 Veersche Gat, dyke.
Walcheren-Noord Beveland, Holland. 1964.
Dienst voor der Deltawerken.

139 Artificial island for ventilation
shaft. Miike Colliery.
Kyushu, Japan. 1951.
S. Morita.

The exhibition Twentieth Century Engineering was shown at The Museum of Modern Art, New York, from June 30 through September 13, 1964.

The director of the exhibition wishes to acknowledge with gratitude the assistance of Ludwig Glaeser, who directed research, compiled the catalogue on the following pages, and contributed to every phase of the project; and to Ellen Marsh, whose invaluable research and assistance has greatly increased the exhibition's scope and effectiveness.

The Museum wishes to thank the organizations listed below for their interest and generous cooperation, as well as the many individuals, too numerous to list, whose assistance is deeply appreciated.

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CATALOGUE

For reference purposes, entries are grouped first by functional type and, where possible, according to structural characteristics.

Dates indicate completion of projects.

Data were provided by statements from the engineers or contractors, or from other reliable sources.

Names, if not otherwise indicated, refer to the engineer or constructor responsible for the design of the project shown.

Numbers in brackets indicate reproduction in the catalogue.

Instruments

Nuffield Radio Astronomy Laboratories, radio telescope. Jodrell Bank, England. 1957. *Fully steerable alt-azimuth radio telescope; diameter: 250′, steel.* Husband & Co.

National Radio Astronomy Observatory, radio telescope. Green Bank, West Virginia. 1962. *Movable radio telescope; aluminum mesh covered paraboloid dish, diameter: 300′, surface: 78,000 sq. ft.; steel under structure, supporting towers, height: 87′; largest telescope to date.* Ned L. Ashton Company.

Stanford Center for Radar Astronomy, radio telescope. Stanford, California. 1963. *Steel, aluminum; diameter: 150′, weight: 60 tons.* Stanford Research Institute (Ray L. Leadabrand). (5)

Arecibo Ionospheric Observatory telescope. Arecibo, Puerto Rico. 1963. *Fixed spherical reflector, galvanized welded steel mesh suspended by cables over natural bowl, aperture diameter: 1,000′, depth: 158′; feed structure (enabling a motion of the antenna beam 20° off zenith in any azimuth) suspended from 3 reinforced concrete towers at a height of 485′ above center of reflector; steel feed platform and azimuth feed track; aluminum 96′ line feed arm; total weight: 550 tons.* W. E. Gordon (Cornell University); Praeger-Kavanagh-Waterbury (T. C. Kavanagh); Severud-Elstad-Krueger-Associates.

Ballistic Missile Early Warning System (BMEWS), radar antenna. Thule, Greenland. 1960. *Steel; height: 165′, length: 400′.* Kennedy Antenna Division of Electronics Specialty Company. (4)

Radio antenna. Budapest, Hungary. 1933. *Tower supported on a single point by porcelain insulator; steel; height: 1,005′.* Blaw-Knox Company (Ira W. Marshall). (7)

Television antenna. Milwaukee, Wisconsin. 1962. *Self-supporting tower (highest in the U.S.); high strength steel (90,000 psi), height: 988′, weight: 750 tons (for comparison: Eiffel tower, Paris, height: 984′, weight: 8,075 tons).* Dresser-Ideco Company.

Television antenna. Fargo, North Dakota. 1963. *Steel; height: 2,063′ (highest antenna to date).* Kline Iron & Steel Company. (F. L. Anderson). (8)

Television antenna. Sacramento, California. 1961. *3-station candelabra tower; steel; height: 1,548′.* Dresser-Ideco Company. (6)

Power pylon. Donegani-Cesano-Maderno line, Italy. 1948. *Tower designed for mountainous section of 220 kv transmission line; non-welded tubular steel members; enlarged pivoted base; height: 91′.* Società Montecatini.

Observation tower. Beinn Bhreagh, Nova Scotia. 1907. *Three-leg tower structure, assembled from tetrahedral units, each consisting of six 4′ pieces of galvanized iron pipe and four connecting units; height: 70′.* Alexander Graham Bell.

Prototype Floating Compression Mast. 1959. *Three-way modular spiral-counter-spiral; steel wire, aluminum tubes; height: 10′6″, weight: 10 lbs.* Designer: Kenneth Snelson. (9)

Buildings

860 Lakeshore Drive apartment building. Chicago, Illinois. 1951. *26 story steel skeleton frame; span of bay: 21′.* *Frank J. Kornacher.* Architect: Ludwig Mies van der Rohe. (10)

Chicago Civic Center office building. Chicago, Illinois. Under construction. *Steel skeleton frame; stringer and girder trusses, stepped cruciform columns; structural bay size: 48′4″ x 87′0″ (largest in any office building to date).* Architect: Chicago Civic Center Architects (C. F. Murphy Associates; Skidmore, Owings & Merrill; Loebl, Schlossman & Bennett).

United Air Lines Executive Office Building. Elk Grove Township, Illinois. 1962. *Two-story skeleton frame; post-tensioned reinforced concrete; structural bay size: 60′ x 66′, grid system of beams, 12′ on center, with a uniform depth of 30″.* Engineer/Architect: Skidmore, Owings & Merrill, Chicago; T. Y. Lin & Associates.

Advanced Saturn C-5 Launch Complex 39, Vertical Assembly Building. Merritt Island, Cape Kennedy, Florida. Under construction. *Steel skeleton frame; height (over the 4 assembly bays): 524′; cubage: 125.5 million cubic feet (largest to date).* Engineer/Architect: URSAM (Urbahn-Roberts-Seelye-Moran). (12)

Oil refinery. Baytown, Texas. 1937. *Fractionating unit; steel, alloys; maximum height: 120′.* C. F. Braun and Company. (2)

"City Tower." Project. 1955. *Space frame structure, height: 610′; precast, prestressed triangulated strut frame, integrally braced by the intersecting column system at every 66′ level; spacing of intermediate floors vertically and horizontally variable; maximum span: 60′.* Architect: Louis Kahn, Anne Tyng.

IBM office building. Pittsburgh, Pennsylvania. 1964. *13 stories; steel skeleton and truss wall structure; strength of truss elements varying with height; span (truss wall to core structure): 54′.* Worthington, Skilling, Helle & Jackson. Architect: Curtis & Davis, New Orleans. (11)

Marina City apartment building. Chicago, Illinois. 1964. *Column supported circular floor slabs and core shaft; diameter (including cantilevered balconies): 128′; reinforced concrete, slipform erection of core, maximum wall thickness: 30″; height: 585′.* Engineer/Architect: Bertrand Goldberg Associates.

S. C. Johnson & Son, Inc. Research and Development Tower. Racine, Wisconsin. 1950. *15-story cantilever structure consisting of a cluster of circular core shafts and alternating square floor and circular mezzanine slabs with maximum cantilevers of 21½′ and 12½′; total weight: 8,000 tons, supported by the reinforced concrete core walls, thickness: 7-10″; height of core: 207′ (153′ above ground).* Architect: Frank Lloyd Wright.

"Finance Plaza" office building. Project proposed for the New York Stock Exchange. 1963. *45-story steel frame with 40 floors* *suspended from top of building (90′ x 28′ trusses, 650′ above street level) creating 95,000 sq. ft. column-free space.* Weiskopf & Pickworth. Architect: I. M. Pei & Associates.

"Times Square" office building. Project proposed for New York. 1963. *40-story tensile structure; slip formed concrete core and cable suspended concrete floor slabs precast on site.* Architect: Clive Entwistle.

Towers

Association of Universities for Research in Astronomy, solar observatory tower. Kitt Peak, Arizona. 1962. *Reinforced concrete, steel superstructure for water cooled copper windscreen; allowable lateral movement: 1/1000″ in 25 m.p.h. wind; height: 100′; length of optical tunnel; 480′.* Engineer/Architect: Skidmore, Owings & Merrill, Chicago. (14)

Prototype air traffic control tower. Under construction. *Prefabricated cab (pentagonal in plan to minimize window reflection); towers of varying heights, reinforced concrete.* Severud-Elstad-Krueger. Architect: I. M. Pei & Associates. (13)

Television tower. Stuttgart, Germany. 1956. *Reinforced concrete, minimum wall thickness: 7.5″; height: 522′.* Fritz Leonhardt. (15)

Grain elevators. Kansas City, Missouri. 1904-30. *Concrete, steel; maximum height of cylinders: 100′.* Folwel-Ahlskog Company. (1)

Stenungsund power plant, chimney. Stenungsund, Sweden. 1959. *Reinforced concrete chimneys of steam power plant housed underground in rock (first in Europe).* Swedish State Power Board.

Cooling tower. Carling, France. 1949. *Reinforced concrete, height: 279′.* Entreprises de Génie Civil de Lens. (19)

Water tower. Rocher Noir, Algiers, Algeria. 1961. *Reinforced concrete, slip form method of construction; height: 115′, maximum diameter: 75′, capacity: 6,500 cu. ft.* Engineer/Architect: René Sarger (C.E.T.A.C.).

Elevated water tank. Fedala, Morocco. 1956. *Concrete walls of tank prestressed in two directions, hyperboloid shape allows use of straight formwork and stressing bars, thickness of wall diminishing from 11″ to 7¾″ at top; bottom and top vaults made of hollow bricks; maximum diameter: 69′, height: 77′.* Eduardo Torroja.

Water tower. Hälsingborg, Sweden. 1961. *Prestressed concrete, tank cast on ground and lifted; supporting columns cast as lifting proceeded; height: 125′, maximum diameter: 164′, capacity: 2,000,000 gallons.* Skånska Cementgjuteriet. Designer: AB Vattenbyggnadsbyrån.

Water tower. Uppsala, Sweden. 1958. *Prestressed concrete; height: 92′, maximum diameter: 123′.* AB Vattenbyggnadsbyrån. Architect: Sune Lindström. (17)

Water tower. Örebro, Sweden. 1957. *Water tower with observation and restaurant platform; prestressed concrete; water tank cast on ground around core shaft and lifted 164′; maximum diameter: 150′.* AB Vattenbyggnadsbyrån. Architect: Sune Lindström.

Water tower. Lauttasaari, Finland. 1958. *Reinforced concrete, height: 200′.* P. Simula Engineering Company. Architect: Department of Construction, City of Helsinki. (18)

Water tower. Marshalltown, Iowa. 1962. *Horton steel spheroid; height: 71′6″, capacity: 300,000 gallons.* Chicago Bridge & Iron Company. (16)

Columns and Roofs

Zürcher Lagerhaus-Gesellschaft. Warehouse. Zürich-Giesshübel, Switzerland. 1910. *Beamless floor slab on mushroom columns (first structure of its kind). Reinforced concrete, loading 2 tons/3.28 sq. ft.* Robert Maillart. (20)

Azienda Nazionale Idrocarburi, underground gasoline reservoir. Bari, Italy. 1936-1940. *Tank without leakage control; beamless roof slab on mushroom columns; reinforced concrete.* Pier Luigi Nervi.

Gatti Wool Factory basement. Rome, Italy. 1953. *Floor slab with ribs following isostatic lines of principal bending moments; "Ferro-cemento" concrete, column distance: 16′.* Engineer/Architect: Aldo Arcangeli, Pier Luigi Nervi.

S. C. Johnson & Son Inc. Administration Building. Racine Wisconsin. 1939. *Concrete columns, 28′ high, ending in circular slabs of 18′ diameter. Reinforced concrete.* Architect: Frank Lloyd Wright. (21)

Palazzo del Lavoro exhibition hall. Turin, Italy. 1961. *16 reinforced concrete columns, 65′ high, supporting steel roofs, 125′ square.* Engineer/Architect: Pier Luigi Nervi. (24)

Gonzales Rio, and Nacional Distribuidora S.A. warehouses. Mexico, D.F., Mexico. 1954, 1960. *Tilted hyperbolic paraboloid shell umbrellas, 32′ x 49′; height of columns; 15′, with double-curved shell footings; reinforced concrete.* Felix Candela. (25)

U. S. Exhibition Pavilion. Moscow, U.S.S.R. 1959. *90 umbrella type units; fiberglas; height: 20′, diameter: 16′.* Albert G. H. Dietz. Architect: George Nelson. (22)

Sector 5 Pavilion, EXPO 1964. Lausanne, Switzerland. 1964. *24 umbrella type units; glass fiber reinforced polyester; each unit 59′ square.* Heinz Hossdorf. (23)

La Zarzuela racecourse. Madrid, Spain. 1935. *Canopy of hyperboloid shells; reinforced concrete; 43′ cantilever.* Eduardo Torroja. (29)

Seguro Social Housing Development, band shell. Santa Fé, D.F., Mexico. 1956. *Reinforced concrete; 39′ cantilever.* Felix Candela. (26)

Scioto Downs grandstand roof. Columbus, Ohio. 1960. *5 tilted hyperbolic paraboloid thin-shells, each resting on a single column; reinforced concrete, shell thickness: 4½″-5″, length: 116′, width: 60′, height (above track): 65′.* Gensert, Williams & Associates. Architect: Kellam & Foley.

Maracanã stadium. Rio de Janeiro, Brazil. 1952. *Canopy roof. Steel beams, reinforced concrete; cantilever span: 98′; maximum capacity: 220,000 spectators.* Fragoso, Noronha, Baungart and Costa. Architect: Galvão, Bernardos Bastos, Dias Carneiro, Azevedo. (31) (32)

Club de Fútbol stadium. Barcelona, Spain. 1958. *Overhanging seat rows; reinforced concrete; 43′ cantilever.* J. L. de la Guardia, O. Lobato. Architects: J. Soteras, F. Mitjans, L. Garcia-Barbon. (30)

Small aircraft hangars. Grimbergen-Lez-Bruxelles, Belgium. 1950/51. *Circular hangars; reinforced concrete; 45′ cantilever.* A. Hardy. (27)

National Airlines hangar. Miami, Florida. 1958. *Folded plate roof; reinforced concrete; 110′ cantilever.* Ammann & Whitney. Architect: Herbert H. Johnson Associates. (28)

Octet Truss cantilever structure. (The Museum of Modern Art), New York. 1959. *Cantilevered roof, support and base structure of connected tri-directional space frames, Octet Truss type (tetrahedrons with intermittent octahedrons), assembled from aluminum tubes with connectors and rivets; spans of cantilevers: 60′ and 40′, total length: 100′, width: 35′, height: 20′, weight: 8,000 lbs.* R. Buckminster Fuller.

Vaults and Domes

Convention Hall. Project proposed for Chicago, Illinois. 1954. *Two-directional space frame of welded, intersecting steel trusses, 30′ deep, 30′ on center; 720′ square, clear space: 50,000 sq. ft.* Architect: Ludwig Mies van der Rohe.

Air Force Academy Dining Hall. Colorado Springs, Colorado. 1961. *Space frame of 23 Warren steel trusses intersecting at right angles, 14′ on center, supported by 16 columns, clear space: 266′ square.* Engineer/Architect: Skidmore, Owings & Merrill, Chicago.

"Salle des Fêtes." Thonon-les-Bains, France. Under construction. *Tri-directional space frame of prestressed concrete with precast 1½″ thick tetrahedral elements, 5¾′ deep, 8′ on center, clear space (between columns): 98′ x 66′.* Serge Kétoff. Architect: Maurice Novarina, Jacques Giovannoni.

"Studio Arms" Apartment Building, covered patio. Baton Rouge, Louisiana. 1964. *Vaulted space frame of triangular steel truss elements, rise: 16′; weight: 4 lbs./sq. ft.; clear space: 200′ x 100′; covered with tempered glass.* William J. Mouton, Jr. Architect: Paul Mouton, Max Cannon.

St. Pius X. Basilica. Lourdes, France. 1958. *Oval roof slab on 2-hinged portal frames; prestressed concrete; maximum span: 197′, maximum height: 33′; earth covered.* Eugène Freyssinet. Architect: Vago, LeDonne and Pinsard. (40) (41)

Parco del Valentino exhibition hall. Turin, Italy. 1959. *Intersecting beams supported by struts; prestressed concrete; span: 233′; earth covered.* Riccardo Morandi. (39)

Central Station, train sheds. Milan, Italy. 1920 (-31 completion of head building). *5 circular arches of three-hinged lattice ribs with spans of 236′, 148′, 40′, length: 1,118′; iron and steel (for supports); (one of the last great arched train sheds).* Alberto Fava.

Architect: Ulisse Stacchini (winner of the competition, 1913).

Raw Sugar Storage Dome. Charleston, Massachusetts. 1960. *Parabolic dome; latticed trusses and junior beams, light steel; embossed aluminum covering; span: 238′, rise: 110′.* William J. Mouton, Jr. (59) (60)

Jefferson National Expansion Memorial. St. Louis, Missouri. Under construction. *Catenary arch, equilateral triangle in cross section, side length: diminishing from 57′ to 17′ at top; height: 630′, span: 630′; stainless steel plates at exterior, structural steel plates at interior surface, space between filled with concrete, above 300′ with steel stiffeners; each leg of arch self-supporting under construction.* Engineer: Severud-Elstad-Krueger Architect: Eero Saarinen and Associates. (35)

Airship hangars. Orly, France. 1921. (destroyed 1944. *Continuous corrugated arch (25 units); reinforced concrete; span: 295′; rise: 195′.* Eugène Freyssinet (Entreprises Limousin). (33)

Exhibition hall. Turin, Italy. 1948. *Continuous corrugated arch; precast concrete units in reinforced concrete ribs; span: 210′.* Engineer/Architect: Pier Luigi Nervi. (38)

Swiss National Exhibition, Cement Industries Hall. Zürich, Switzerland. 1939. *Barrel-vaulted shell; sprayed concrete; thickness: 2⅜″; span: 53′.* Robert Maillart. (43)

Market hall. Pescia, Italy. 1951. *Vaulted shell, laterally supported by 5 buttress slabs; contiguous reinforced hollow-tile arcs with concreted surface; span: 75′, length: 230′, open on all sides, area covered: 75′ x 230′.* Emilio Brizzi. Architect. Enzo Gori, Giuseppe Gori, Leonardo Ricci, Leonardo Savioli.

Central Station. Reims, France. 1932. *Conoid arch slabs; reinforced concrete; span: 116′, rise: 52′.* Entreprises Limousin (Le Marec), M. Ridet. (34)

Gold-Zack Plant. Gossau, Switzerland. 1954. *7 Barrel-vaulted shells, inclined 70°, connected by steel trusses. Sprayed concrete; thickness: 2¾″; span: 90½′.* Heinz Hossdorf. Architect: Danzeisen & Voser. (44)

Chivas Brothers Limited warehouse. Paisley, Scotland. 1958. *Continuous corrugated catenary (pure compression) arch shell; lightly reinforced concrete, thickness: 2½″, span: 100′ (Ctesiphon system).* J. H. de Warrene Waller. Architect: S. Lothian Barclay.

Covered racecourse. Project. 1961. *Continuous corrugated parabolic arch; rise: 262′; span: 1,312′, length: 1,050′; prefabricated units of aluminum roof plates and profiles with stiffening diaphragms; supporting piers, 50′ on center, of reinforced concrete.* Engineer/Architect: Pier Luigi Nervi.

Centre National des Industries et Techniques (CNIT) exhibition hall. Paris, France. 1958. *Cross-vaulted double shell, triangular in plan; reinforced concrete; thickness: 2⅜-4¾″; span, lateral: 676′, groin: 780′ (longest span to date).* Nicolas Esquillan. Entreprises Balency et Schuhl; Entreprises Boussiron; Constructions Coignet. Architect: R. Camelot, J. DeMailly, B. H. Zehrfuss. (46) (47)

Palazzo delle Mostre exhibition hall. Turin, Italy. 1961. *Cross-vaulted double shell, hexagonal in plan; reinforced concrete; lateral span: 400′.* Franco Levi, Nicolas Esquillan. (48) (49)

Nuclear power station. Chinon, France. 1960. *Containment sphere for nuclear reactor; steel; diameter: 33′.* Electricité de France. (3)

Lowry Air Force Base, Titan I Launch Complex. Denver, Colorado. 1961. *Reinforced concrete domes.* Daniel-Mann-Johnson-Mendenhall Associates; Rust Engineering Company; Leo A. Daly. (42)

Planetarium. (Test building, Zeiss Werke). Jena, Germany. 1922. *Spherical dome; concrete sprayed on iron network (Zeiss-Dywidag system), thickness: 1 3/16″; span: 52½′. (First thin shell dome).* Walter Bauersfeld, Dyckerhoff & Widmann KG. (61)

Wilbur Wright High School fieldhouse. Munster, Indiana. Under construction. *Membrane structure; lightweight prestressed concrete, thickness: 4″, cast on ground, earth form; span of main dome: 210′.* Kolbjorn Saether & Associates. Architect: Bachman & Bertram. (52)

Palazzetto dello Sport. Rome, Italy. 1957. *Shell dome with interior lamella structure; reinforced concrete, 1,620 precast elements; span: 192′.* Pier Luigi Nervi. Architect: Annibale Vitellozzi, Pier Luigi Nervi. (56)

Tokyo International Trade Center, exhibition hall (No. 2). Tokyo, Japan. 1959. *Spherical dome; 2-level, tri-directional steel frame; latticed girders and gusset plates; span: 337′; rise: 97′.* Yoshikatsu Tsuboi. Architect: Masachika Murata. (58)

Sewage treatment plant, trickling filters. Hibbing, Minnesota. 1939. *Elliptical domes; reinforced concrete, maximum thickness: 3½″; span: 150′.* Roberts and Schaefer Company (Anton Tedesko). Architect: J. C. Taylor. (50)

Conservatoire National des Arts et Métiers, auditorium. Paris, France. 1962. *Rotational ellipsoid shell, inclined 23.5°; reinforced concrete, diameter: 105′, height: 33′.* Jean Marie Hereng. Architect: Louis Luc and Thierry Sainsaulieu.

Repair shop. Bagneux, France. 1928/29. *Sheds consisting of conoid thin shells, reinforced concrete.* Eugène Freyssinet.

Hangars. Marignane, France. 1952. *2 bays of toral vaulted shells; reinforced concrete, each bay, 4200 tons, cast on ground and lifted 62′ high; span: 333′.* Nicolas Esquillan (Entreprises Boussiron). Architect: Auguste Perret. (36) (37)

Lomas de Cuernavaca Chapel. Cuernavaca, Mexico. 1958. *Hyperbolic paraboloid shell; reinforced concrete; maximum span: 102′; maximum rise: 72′.* Felix Candela. Architect: Guillermo Rosell, Manuel Larosa. (45)

Market hall. Royan, France. 1958. *Dome of 13 parabolic units; reinforced concrete, thickness: 3 5/32″; span: 163′.* René Sarger. Architect: Louis Simon, André Morisseau. (51)

Aviation Research Institute, wind tunnel. Berlin-Adlershof, Germany. 1932-36. *Vertical wind tunnel for spin tests, reinforced concrete.* Hermann Brenner.

Mount Avila cablecar terminal station. Caracas, Venezuela. 1956. *Continuous folded-plate arch; reinforced concrete; span: 100′.* Architect: Alejandro Pietri. (54)

University of Illinois Assembly Hall. Urbana, Illinois. 1963. *Folded plate dome; reinforced concrete, thickness: 3½″; span: 400′.* Ammann & Whitney. Architect: Harrison & Abramovitz. (53)

Hangars. Italy. (Type A) 1935; (Type B) 1940 (destroyed 1944). *Lamella type vaults; reinforced concrete, precast solid (Type A) and latticed (Type B) members; length: 328′; width: 131′.* Engineer/Architect: Pier Luigi Nervi. (55)

Harris County Domed Stadium. Houston, Texas. Under construction. *Spherical dome; steel, parallel lamella system; span: 642′; rise: 93′, height above ground: 208′ (largest dome to date).* Walter P. More; Praeger-Kavanagh-Waterbury; Roof Structures, Inc. Architect: Lloyd & Morgan; Wilson, Morris, Crain & Anderson. (57)

Geodesic dome. Aspen, Colorado. 1953. *Prototype; aluminum, plastic cover; span: 36′.* R. Buckminster Fuller. (62)

U.S. Pavilion Trade Fair, Poznan, Poland. 1957. *Geodesic dome; aluminum tubes, nylon skin; span: 114′.* R. Buckminster Fuller. (63)

"Plydome". Des Moines, Iowa. 1957. *Prototype, geodesic structure; plywood, thickness: ¼″: no internal frame, span: 42′.* R. Buckminster Fuller. (64)

Union Tank Car Company, car rebuilding plant. Baton Rouge, Louisiana. 1959. *Geodesic dome; 321 hexagonal folded steel panels, dimensionally braced with tubes and rods; span: 384′, rise: 120′.* R. Buckminster Fuller. (65) (66)

Missouri Botanical Garden Climatron. St. Louis, Missouri. 1960. *Geodesic dome; hexagonal double frame, aluminum tubes with plastic infill panels; span: 175′, rise: 70′.* R. Buckminster Fuller. (67)

Haystack Antenna radome. Haystack Hill, Tyngsboro, Massachusetts. 1961. *Geodesic dome; aluminum extrusions with plastic infill membranes; span: 150′, height: 135′. Antenna consisting of microwave feed horn and two reflectors; primary reflector with a 0.075″ precise parabolic contour, diameter: 120′.* M.I.T. Lincoln Laboratory, Massachusetts. (68)

Ballistic Missile Early Warning System (BMEWS), radomes. Fylingdales Moor, Yorkshire, England. 1963. *Radomes assembled of 1,646 pentagonal and hexagonal panels bolted together, consisting of two polyester resin fibre glass skins, thickness: 6″; diameter of radome: 140′, of antenna dish: 84′.* Ministry of Public Building and Works; U.S.A.F.

Inflated exhibition and convention hall. Project proposed for Chicago, Illinois. 1960. *Pneumatic membrane structure; steel mesh reinforced laminated fabric; span (center hall): 656′.* Frei Otto. Architect: Addis, Kniffin, Childs. (70) (71)

Atomic Energy Commission, inflatable exhibition building. 1960. *Pneumatic membrane structure; air-supported double nylon skin; length: 300′; max. width: 126′.* Birdair Structures, Inc. Architect: Victor A. Lundy. (72) (73)

"Telstar" Antenna radome. Andover, Maine. 1961/62. *Inflated dome; rubberized nylon; diameter: 210′.* Birdair Structures, Inc. (69)

"Schjelevator" grain silo. Near St. Louis, Missouri. 1959. *Pneumatic membrane structure; plastic material, restraint by radial cables, wooden ring base; diameter: 197′.* G. T. Schjeldahl Company.

Hanging flexible silos. Project. 1960. *Flexible silos of aluminum coated fabric hanging from guyed steel masts; filling through mast, drop-shaped for easy unloading.* Frei Otto, Berlin.

International Garden Exhibition, "Wave Hall." Hamburg, Germany. 1963. *Canvas membrane structure, supported by cable guyed poles; 8 lateral high and 3 central low points (opened for drainage), length: 269′, width: 66′, height: 33′, area covered: 5,400 sq. ft.* Frei Otto. Architects: H. Habermann, H. Wehrhahn, P. Voigt, B. Romberg, C. Hertling.

Exhibition hall. Project for O.T.U.A. competition, Paris. 1934. *Circular suspension roof; steel cables, glass bricks; height: 171′, span: 1,328′.* Architect: Eugène Beaudouin, Marcel Lods. (74) (75)

National Production Exhibition, central pavilion. Montevideo, Uruguay. 1955. *Suspension roof of inverted spherical shapes consisting of 9,000 trapezoidal precast 2″ concrete slabs and 256 ½″-cables, anchored to a central steel tension ring and peripheral reinforced concrete compression ring, 6′-6″ wide resting on the 4″ thick reinforced concrete cylinder wall, diameter: 310′; cables pretensioned by a 50% overload of bricks.* Leonel I. Viera, Luis Alberto Mondino, Alberto S. Miller; Preload International, Inc.

Utica Memorial Auditorium. Utica, New York. 1960. *Circular suspension roof; two-paired layers of pretensioned steel cables between reinforced concrete compression perimeter ring and steel tension center ring; span: 250′.* Lev Zetlin. Architect: Gehron & Seltzer. (76)

Swimming pool hall. Wuppertal, Germany. 1957. *Suspension roof; prestressed concrete; thickness: 2¼″; span: 131′.* Fritz Leonhardt. Architect: F. Hetzelt. (77)

Bridges

Theodor Heuss Bridge over the Rhine River. Düsseldorf, Germany. 1957. *Steel box girders and orthotropic deck plate suspended by parallel cables from four pylons (Harp system); span: 852′, total length: 476′.* Department of Bridge Construction, City of Düsseldorf (Franz Schreier), Fritz Leonhardt, Karl Schaechterle, Louis Wintergerst. Architect: Friedrich Tamms. (88) (89) (90)

Oberkasseler Bridge, Knie Bridge over the Rhine River. Düsseldorf, Germany. Project and under construction. *Steel girder bridges suspended by parallel cables from one (center) and two pylons.* Department of Bridge Construction, City of Düsseldorf. Architect: Friedrich Tamms. (88)

Severin Bridge over the Rhine River. Cologne, Germany. 1959. *Steel girders suspended by cables from A-shaped pylon; spans: 987′ and 494′; total length: 2,266′.* Gutehoffnungshütte. Architect: Gerhard Lohmer. (91)

Verrazano-Narrows Bridge. New York City. Under construction. *Steel suspension bridge; center span: 4,260′; side spans: 1,215′; height of towers (above mean high water): 690′; total length (including immediate approaches): ca. 3 miles (longest suspension bridge to date).* Ammann & Whitney. (92)

Pipeline bridge over Dora River. Near Ivrea, Italy. 1956. *Suspension bridge for gas pipeline (diameter: 10″) with inspection gangway; horizontally guyed, steel, length: 560′.* Montubi; SNAM.

Pipeline bridge over Danube River. Near Vienna, Austria. 1958. *Suspension bridge for gas pipeline (diameter: 16″) with inspection gangway; Y-shape pylons, steel, span: 1,050′.* Austrian Petroleum Administration; Waagner-Biro.

Bridge over Seine River. Saint Pierre du Vauvray, France. 1922 (reconstructed 1946). *Twin overhead arches; hollow cellular reinforced concrete; mortar coated cables; span: 430′.* Eugène Freyssinet. (80)

Tärendö Bridge over Kalix River, Sweden. 1935. *Twin overhead arches, cross braced; cable suspended deck; reinforced concrete; span: 390′.* AB Skånska Cementgjuteriet.

Fehmarnsund Bridge. Fehmarn Island, Germany. 1963. *Twin overhead arches tangent at top, cable suspended deck; hollow box steel girders; span: 933′, rise: 141′, width of deck (combined road and railway): 69′, total length: 3,160′.* Gutehoffnungshütte. Architect: Gerhard Lohmer.

Sandö Bridge over Angerman River. Sweden. 1943. *Hollow box rib arch; reinforced concrete; height: 170′, span: 866′. Total length: 2,657′.* AB Skånska Cementgjuteriet. (79)

Schwandbach Bridge. Near Schwarzenberg, Switzerland. 1933. *Stiffened slab arch supporting horizontally curved deck; reinforced concrete, thickness: 7½″; span: 111′.* Robert Maillart. (78)

Gueuroz Bridge over Trient Glacier. Gueuroz, Switzerland. 1933. *Deck slab, thickness: 4¾-6″, with solid parapet walls stiffening the 2 arch ribs; reinforced concrete; span: 323′; height (above ground): 623′; total length: 552′.* Alexandre Sarrasin. (81)

Poggettone and Pecora Vecchia Viaducts. Autostrada del Sole, Bologna-Florence section, Italy. 1960. *8 polygonal arches; reinforced concrete; maximum span: 190′, maximum height (above ground): 236′; total length: 1,462′ (1,164′ curved).* Arrigo Carè, Giorgio Giannelli. (82)

Salgina Bridge. Near Schiers, Switzerland. 1930. *Three-hinged arch of box-section integrating the road slab (Maillart system); reinforced concrete, span: 295′, height above ground: 263′, total length: 437′.* Robert Maillart.

San Giuliano Viaduct. Autostrada del Sole, Florence-Rome section, Italy. 1963. *Two pairs of two-hinged hollow arches; reinforced concrete; total length: 1,197′, span: 328′.* Maurizio de Lieto, Massimo Varano. (83)

Garibaldi bridge. Project for a competition, Rome. 1955. *Two concave shell arches supporting hollow box slab varied in depth according to shear and moment; prestressed concrete; span of arches: 132′; total length: 450′.* Carlo Cestelli-Guidi. Architect: Antonio di Carlo, James D. Ferris, Myron Goldsmith, Bruno Zevi. (87)

Highway bridge. Project. 1948. *Beam of tubular sections; welded steel cage sprayed with high strength concrete.* Architect: Paolo Soleri.

General Urdaneta Bridge. Laguna de Maracaibo, Venezuela. 1962. *4 types of piers and spans; center piers with cable supported cantilevers and suspended spans; spans: 771′; reinforced and prestressed concrete; total length: 5½ miles.* Riccardo Morandi. (93)

Savines Bridge over Durance Reservoir (Serre-Ponçon Dam). Savines, France. 1960. *Arches cantilevered from 12 piers; prestressed concrete, hollow box structure, open joints between arches; cantilever 126′; total length: 924′.* Société des Grands Travaux de Marseille. (86)

Bridge over Rhône River. St. Maurice, Switzerland. 1957. *Beams of prestressed concrete; beam depth (at center): 10′; span: 382′ (longest for concrete beam bridge to date); total length: 580′.* Alexandre Sarrasin.

Bridge over Rhine River. Val Nalps, Switzerland. 1958. *Three-span continuous deck slab on 4 inclined struts, prestressed concrete; spans: 46′, 62′, 42′, width of deck: 16′, depth varying between 17″ and 24″.* Emil Schubiger.

Wentbridge Viaduct. Near Doncaster, England. 1961. *Three-span continuous beam on 4 inclined struts; post-tensioned prestressed concrete main beams; spans: 140′, 190′, 140′, height (above ground): 100′.* S. Maynard Lovell. (84)

Europa Bridge over Sill River. Innsbruck-Schoenberg, Austria. 1963. *Steel girders connected to stiff box-type structure and orthotropic deck slab, supported by five piers of reinforced concrete hollow boxes; maximum span: 649′; height above ground: 623′ (highest in Europe); width of deck: 73′; total length: 2,673′.* Vereinigte Oesterreichische Eisen und Stahlwerke A.G., Waagner Biro A.G. (85)

Roads

Gowanus Elevated Parkway. Brooklyn, New York. 1941. *Elevated roadway, steel structure on 43 bents, spaced 66′ apart, height of bents: 16′-77′; total length: 2,934′.* Madigan-Hyland Inc. (94)

Elevated roadway and bridge. Berlin, Germany. 1961. *6 two-span portal frames with* *fixed center supports, 10′ deep hollow box beams and X-shaped piers; prestressed concrete, cantilever method of construction; maximum span: 279′, total length: 3,037′.* Dyckerhoff & Widmann KG; Department of Construction and Housing, City of Berlin.

Le Rovine Viaduct, Autostrada del Sole, Bologna-Florence section, Italy. 1960. *Prestressed concrete beams on standardized reinforced concrete piers; 6 spans, each 79′, total length: 503′ (220′ curved).* Giacinto Turazzo; Alberto Zanon, Dorian Frizzi, Vittorio Nicelli (Giuseppe Torno S.p.A.).

Hammersmith Flyover. London, England. 1961. *Four lane roadway on 16 single piers; prestressed concrete, precast elements (beam segments, cantilever units, road slabs) erected and stressed together on site; maximum spans: 140′. Total length: 2,043′.* G. Maunsell and Partners, Joseph Rawlinson. Architect: Hubert Bennett. (96)

Rhine Bridge approach, elevated roadway. Ludwigshafen, Germany. 1959. *Dual three-lane road slab supported by single circular "mushroom" piers (one in a series anchored, the others carried on roller bearings); prestressed concrete, span: 82′, width: 82′.* Finsterwalder, Department of Construction, City of Ludwigshafen.

Elevated highway. Berlin, Germany. 1963. *Converging highways carried on single piers diagonally over railway tracks; hollow box beam, prestressed concrete; maximum span: 225′; total length: 767′.* Department of Construction and Housing, City of Berlin. (95)

Carquinez Bridge approach. Crockett, California. 1958. *Approach structures for bridge with 3 lanes in each direction; 47 reinforced concrete piers supporting steel girders; maximum height: 123′, maximum span: 205′.* California Division of Highways. (97) (98)

Rhine Bridge approach. Mannheim, Germany. 1959. *Approach system with 20 structures, connecting 4 roads and bridge with 3 lanes in each direction.* Department of Construction, City of Mannheim. (101)

Harbor Freeway-Hollywood Freeway-Arroyo Seco Parkway Intersection. Los Angeles, California. 1949. *Four-level grade separation structure; reinforced concrete.* California Division of Highways.

Highway interchange. Fort Worth, Texas. 1958. *Four-level interchange of 3 three-lane and 1 four-lane roads; reinforced concrete; area covered: ca. 18 acres.* Texas Highway Department. (100)

Tri-State Tollway interchange. Ogden Avenue at Hinsdale, Illinois. 1958. *Cloverleaf interchange of 2 roads with 3 lanes in each direction, 8 ramps; median: 300′, area covered: 25 acres.* Harza Engineering Company. (99)

Harbor Freeway. Los Angeles, California. 1954 (completed 1962). *Section of approximately 4 miles road structure with 4 lanes in each direction; current traffic rate: 190,000 vehicles per day.* California Division of Highways. (102)

Tunnels

Saint Cloud road tunnel. Autostrade de l'Ouest. Paris, France. 1936-46. *Two-lane road tunnel; width: 20′, length: 995 yds. (129 curved); concrete and tile lined.* de Bussevent (Ponts et Chaussées).

Randens Power Station, access tunnel. Isère and Arc Rivers Project, France. 1954. *Two-lane road type tunnel with lighting curb-stones leading to underground power house, length: 590′.* Electricité de France. (106)

Serre-Ponçon Dam, power house. Durance River, France. 1960. *Power house and 4 turbine generator pits carved out of solid rock; ceiling with bridge crane beams in reinforced concrete, span: 55′.* Electricité de France; Coyne et Bellier.

Inland Cold Storage Company underground warehouse. Near Kansas City, Kansas. 1954. *140 acres blasted out of solid rock for storage purposes (served by two railway spurs and tow truck docks).* Sam J. Callahan.

"Klara" underground shelter. Stockholm, Sweden. 1960. *Shelter blasted out of solid rock; total excavation: 2.3 million cu. ft., capacity: 15,000 persons; serves actually as garage for 300 cars; air intake structure: reinforced concrete grid with a 3′ layer of cobble stones.* Jakobsson & Widmark AB.

Brookhaven National Laboratory, Alternating Gradient Synchrotron (AGS). Upton, New York. 1960. *Synchrotron ring tunnel; reinforced concrete, length: ½ mile, height/width: 18′; 10′ earth cover for radiation shielding.* Engineer/Architect: Stone & Webster.

NASA Langley Research Center, transonic wind tunnel. Langley Station, Hampton, Virginia. 1961. *Movable wall test section (boundary layer removal system of wind tunnel); steel and sprayed concrete on insulating board, height: ca. 100′.* National Aeronautics and Space Administration (NASA). (108)

Isère and Arc Development, diversion tunnel. Isère and Arc Rivers, France. 1954. *Diversion tunnel from Isère River reservoir to Randens Power Station; 8,078′ reinforced concrete pipe, diameter: 21′, laid in trench; 38,384′ fully concrete lined tunnel passing through the Grand Arc Massif at a maximum depth of 6,560′.* Electricité de France.

Picote Dam, discharge tunnel. Douro River, Portugal. 1957. *Discharge manifold leading from the three turbine generators of the underground power house into the discharge tunnel; reinforced concrete lining, excavated cubage: 65,600 cu. ft.* Hidro-Electrica do Douro. (107)

Pumped storage reservoir and power station, pressure shafts and tailrace tunnels. Vianden, Luxembourg. 1964. *2 steel lined pressure shafts, length: 2,220′ and 1,574′, diameter: 21′ and 22′, connected by the penstock manifold with 9 turbine generators in the underground power house; 2 concrete lined discharge tunnels, length: 984′ and 1,467′, diameter: 30′ and 33′, leading to outlet structure (serving also as intake structure for the pumping operation); total rock excavation: 368,000 cu. yd.* Société Générale pour l'Industrie.

Chute-des-Passes hydro-power station, penstock manifold. Peribonka River, Canada. 1959. *Penstock manifold connecting concrete lined intake tunnel, length: 6 miles, diameter: 35′, with the steel lined penstocks of 5 turbine generators in the underground power house.* H. G. Acres & Co.

Dams

Fontana Dam. Little Tennessee River, North Carolina. 1949. *Gravity dam; height: 480′; crest length: 2,365′; vol. of concrete: 3,575,500 cu. yd. (largest dam of the TVA).* Tennessee Valley Authority. (110)

Grande Dixence Dam. Val des Dix, Switzerland. 1962. *Gravity dam; height: 922′; crest length: 2,279′; thickness: (top) 72′, (base) 721′; vol. of concrete: 7,540,000 cu. yd. (highest concrete dam).* Grande Dixence, S.A. (109)

Pozzillo Dam. Salso River, Sicily, Italy. 1958. *Flexible gravity dam (to permit movement due to unstable geological conditions). Concrete blocks arranged to form 48 buttresses; joints lubricated with gravel, upstream watertight facing with steel sheets. Height: 139′; crest length: 1,330′; volume of concrete: 366,000 cu. yd.* Claudio Marcello. (111)

Bort Dam. Dordogne River, France. 1951. *Gravity arch dam with stepped downstream face (due to the use of precast concrete blocks); height: 394′, crest length: 1,280′, concrete volume: 765,000 cu. yd.* Electricité de France.

Tignes Dam. Isère River, France. 1952. *Gravity arch dam with cylindrical upstream face; height: 593′, crest length: 967′, concrete volume: 826,000 cu. yd* Electricité de France.

Mauvoisin Dam. Dranse de Bagnes River, Switzerland. 1958. *Arch dam of double curvature; height: 777′; crest length: 1,700′; thickness at crest: 46′, at base 175.5′; concrete volume: 2,660,000 cu. yd.* Electro-Watt. (115)

Valle di Lei Dam. Reno di Lei River, Switzerland. 1960. *Arch dam of parabolic horizontal layout; height: 469′, maximum overhang: 86′, crest length: 1,968′ (widest arch dam to date).* Claudio Marcello (Edison Group).

Mohammed Reza Shah Pahlavi Dam. Dez River, Iran. 1963. *Thin arch dam of double curvature; height: 646′; crest length: 780′, thickness at crest: 15′, at base: 72′; concrete volume: 620,000 cu. yd.* Development and Resources Corporation. (116) (117)

Santa Luzia Dam. Pampilhoas River, Portugal. 1944. *Twin arch dam: thin arch of double curvature and gravity arch dam; crest lengths: 3,318′, 251′; height: 249′, thickness (thin arch dam) at crest: 8.2′, at base: 39.4′, volume of concrete: 104,600 cu. yd.* Companhia Eléctrica das Beiras; Coyne et Bellier. (120)

Florence Lake Dam. San Joaquin River, California. 1926. *Multiple arch dam; height: 154′, crest length: 3,156′.* Southern California Edison Company.

Faux-la-Montagne Dam. Peyrat-le-Château Development. Vienne River, France. 1950. *Multiple arch and buttress dam; arches reinforced sprayed concrete, thickness: 5½-*

7″, spacing between triangular buttresses: 21′, height: 53′, crest length: 426′. Electricité de France.

Meishan Dam. Huai River, China. 1956. *Multiple arch dam, concrete, crest length: 1,830′.* (113)

Migoëlou Dam. Lake Migoëlou, France. 1958. *Multiple-arch dam; 9 arches, thickness: 3¼′; span: 82′; height: 147′; crest length: 820′.* Electricité de France; Coyne et Bellier. (118)

Roselend Dam. Doron de Beaufort River, France. 1961. *Concrete arch and buttress dam. Height: 492′; crest length: 2,636′.* Electricité de France; Coyne et Bellier. (112)

Ancipa Dam. Troina River, Sicily, Italy. 1952. *Concrete dam with straight axis consisting of 9 hollow elements ("Marcello" type); wall thickness: 17½″, width at base: 308′, at top: 15′; crest length: 830′, height: 366′ (highest hollow dam to date).* Claudio Marcello.

Bissina Dam. Chiese River, Italy. 1957. *Buttress dam. (22 hollow elements "Marcello" type); height: 285′, crest length: 1,840′, width of buttress element: 53.5′ concrete volume: 575,000 cu. yd.* Claudio Marcello. (114)

Casoli Dam. Aventino River, Italy. 1959. *Buttress dam (10 button-head buttresses of varied width), height: 177′, crest length: 633′, volume of concrete: 117,000 cu. yd.* Filippo Arredi (Impresa Pietro Cidonio).

Goeschenen Dam. Reuss River, Switzerland. 1960. *Rockfill dam. Height: 509′; crest length: 1,772′; width at base: 2,300′; depth of grout curtain: 330′; volume: 12,-000,000 cu. yd.* Electro-Watt. (131)

Serre-Ponçon Dam. Durance River, France. 1960. *Earthfill dam. Height: 393′; length of crest: 1,968′; width at base: 2,132′, depth of grout curtain: 377′; volume: 15,300,000 cu. yd.* Electricité de France; Coyne et Bellier. (130)

Aswan High Dam. Nile River, United Arab Republic. Under construction. *Height: 346′; crest length: 11,808′; volume: 56,000,000 cu. yd.; reservoir capacity: 104,000,000 acre/ft.; base width: 3,280′.* Osman Ahmed Osman Company. (129)

Bonny Dam. Republican River, Colorado. 1951. *Rolled earthfill dam; height: 158′, crest length: 9,200′, volume: 8,853,000 cu. yd., reservoir capacity: 170,000 acre/feet; irrigation and flood control purposes.* Bureau of Reclamation.

Nacimiento Dam. Nacimiento River, California. 1957. *Rolled earthfill dam; height: 270′; crest length: 1,470′; volume: 3,412,-000 cu. yd. Irrigation and flood control purposes.* Bechtel Corporation. (127)

Shek Pik Dam. Lantau Island, Hong Kong. 1963. *Earthfill dam. Height: 175′; crest length: 2,355′; volume: 6,250,000 cu. yd. Water supply purposes, 15.2 miles tunnels and pipelines (7.3 miles submarine) connecting reservoir with Hong Kong Island.* Binnie, Deacon and Gourley. (128)

Iril-Emda Dam. Oued Agrioun, Algeria. 1954. *Earth dam, upstream face sealed with bituminous concrete; height: 290′, base width: 787′, crest length: 2,296′.* S. A. Truchetet & Tansini, S.A. Monod.

Pumped storage power plant, reservoir. Vianden, Luxembourg. 1964. *Two-basin reservoir with rockfill embankment, average height: 53′; length: 7,544′; surface sealed with bituminous concrete, capacity: 7,316 cu. yd.; height above lower reservoir: 984′. (Largest pumped storage plant for peak energy supply.)* Société Générale pour l'Industrie. (132)

Spillways

Le Chastang Dam spillway. Dordogne River, France. 1951. *Twin spillways, set over powerhouse, ski-jump shaped to dissipate kinetic energy of water; controlled discharge, total capacity: 141,000 cu. ft./sec. Gravity arch dam, height: 279′; crest length: 985′.* Electricité de France; Coyne et Bellier. (123)

Serre-Ponçon Dam, diversion outlet. Durance River, France. 1960. *Spoon-shaped dispersion outlet, 256′ below intake structure; length of diversion tunnel: 1,410′; capacity: 5,900 cu. ft./sec.* Electricité de France; Coyne et Bellier. (122)

Fort Peck Dam spillway, Missouri River, Montana. 1940. *Spillway channel, concrete lined, length: 1 mile; 16 gates, controlled discharge, capacity: 250,000 cu. ft./sec. (Hydraulic earthfill dam, height: 250′, crest length: 21,026′, thickness at crest: 50′, at base: 3,500′; volume content of dam: 125,-628,000 cu. yd.; reservoir capacity: 19,400,-000 acre/ft.* largest earth dam to date*).* Corps of Engineers; Harza Engineering Company. (124)

Bonny Dam, spillway. Republican River, Colorado. 1951. *Uncontrolled concrete-lined chute, and controlled sluice gate below crest; crest length: 121.5′, spillway length: 1,150′.* Bureau of Reclamation.

Kirwin Dam spillway, Solomon River, Kansas. 1955. *Spillway: uncontrolled discharge over crest, controlled through 15 sluice gates at base; crest length: 400′, discharge capacity: 96,000 ft./sec. (Zoned earthfill dam; height: 169′; crest length: 12,646′, volume: 9,537,000 cu. yd.)* Bureau of Reclamation. (126)

Garrison Dam spillway, Missouri River, North Dakota. Under construction. *Spillway channel, concrete lined, width: 1,336′; 28 gates, controlled discharge. (Rolled earthfill dam, height: 210′, crest length: 11,300′, thickness at crest: 60′, at base: 3,400′; reservoir capacity: 24,500,000 acre/ft.; volume content of dam: 66,500,000 cu. yd.).* Corps of Engineers; Charles T. Main, Inc. (125)

Miguel Hidalgo Dam, spillway. Fuerte River, Mexico. 1956. *Fan-shaped free crest spillway; reinforced concrete, length: 1,400′, width: 328′; (Earthfill dam, crest length: 1,372′, reservoir capacity: 2,514 million cu. yd.).* Compania Constructora El Aguila S.A.

Minidoka Dam, spillway weir. Snake River, Idaho. 1906. *Spillway weir (gate-controlled and overflow sections), crest length: 2,385′; reservoir (surface area): 11,800 acres. Irrigation purposes.* Bureau of Reclamation. (119)

Magnitogorsk overflow dam. Ural River, U.S.S.R. 1931. Stepanov, Kaminsky, Gurevich. (121)

Earthworks

Intercoastal waterway. Fort Lauderdale, Florida. 1956/57. *Dredged canal, fill used to create housing peninsulas.* Intercoastal Dredging Company. (104)

Pontecorvo Canal. Pontecorvo, Italy. 1959. *Diversion canal serving power station; parabolic bed covered with flexible prestressed concrete slabs 1.18″ thick; total length: 5½ miles.* Silvano Zorzi. (103)

Rhône River Development, diversion canal. Baix-le Logis Neuf, France. 1961. *Diversion canal and dam serving power station; length: 4¾ miles, width: 700′, moved earth: 65 million cu. ft. (one of 22 development projects).* Compagnie Nationale du Rhône. (105)

Veersche Gat dyke. Walcheren and Noord Beveland Islands, Holland. 1962. *Rock- and sandfill dyke; final gap closed by 7 culvert caissons, concrete with steel gates, 148′ x 67′ x 67′, surface sealed with bituminous concrete; length: 1¾ mile, height (above sea level): 44′. Project of the Delta Plan for closing the Schelde estuary (highest dyke in the Netherlands to date).* Dienst voor der Deltawerken. (138)

Chesapeake Bay Bridge-Tunnel. Chesapeake Bay, Virginia. 1964. *Artificial islands, 4 serving 2 tunnels of the 17.6 mile long complex of trestled roadway, bridges and tunnels; height (above sea bottom): 65-75′, surface: 8 acres; 300,000 tons rock and 1½ millions tons sand fill.* Sverdrup and Parcel. (137)

Miike Colliery artificial island. Kyushu, Japan. 1951. *Head of vertical ventilation shaft for sea bottom mine; rock- and sandfill, cellular concrete blocks; height (above sea bottom): 33′; diameter: 394′.* S. Morita. (139)

Bingham Canyon Mine. Bingham Canyon, Utah. 1915-present. *Open cut copper mine; daily output: 300,000 tons of rock and ore yielding about 600 tons of copper; excavation area: 1,000 acres, depth: 2,310′ (first open pit in copper mining).* Utah Copper Division of Kennecott Copper Corporation.

Chuquicamata Mine. Chuquicamata, Chile. 1915-present. *Open cut copper mine with resources for approximately 40-50 more years.* The Anaconda Company. (133)

Trousdale Estates. Beverly Hills, California. 1963. *Housing development, area: 410 acres, earth moved: ca. 7 million cu. yd.* Trousdale Construction Company. (134)

San Angelo Stadium. San Angelo, Texas. 1956. *Banked earth bowl, playing field 14 ft. below natural ground level.* Caudill, Rowlett, Scott & Associates. Architect: Max D. Lovett. (135)

Olympic Ski Jump Stadium. Innsbruck, Austria. 1963. *Banked earth bowl. Length: 959′; height: 377′. Concrete bleachers for 60,000 spectators.* Andreas Peyerl, Oskar Heinz. Architect: Heini Klopfer. (136)