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A FORECAST OF BRIDGE ENGINEERING

1980— 2000

by

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Faculty Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

A three-pronged study was undertaken to forecast the nature of bridge engineering and construction for the years 1980 to 2000. First, the history of bridge engineering was explored to extrapolate likely future developments. Second, a detailed questionnaire on the future of bridges was sent to authorities on the subject, and their responses were analyzed. Third, an extensive body of literature dealing with the future was examined for information relating directly or indirectly to bridges. From all of this, both specific and general conclusions concerning bridge engineering for the last part of this century were determined. Also presented is a list of research that is needed to meet the challenges ahead.

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INTRODUCTION

Good planning, in virtually every activity, requires looking ahead in time. Bridge engineering is no exception. Forecasting future needs and directions are important in enabling judicious decisions to be made; decisions that should be compatible with future circumstances. All those persons dealing with bridge engineering — as designers, consultants, researchers, educators, builders, fabricators, government officials and others in regulatory agencies — should find this report of value.

The study has attempted to realistically appraise the future of bridge engineering and construction extending from the year 1980 to the end of the twentieth century.

PROCEDURE

Forecasting is obviously an uncertain science. However, bridge engineering and construction, unlike some of the newer space-age technologies, seems to steer a generally steady course, as based on historical evidence. Consequently, the first phase of this study was to examine the development of the subject from the early part of this century to the present in an effort to trace both the events taking place and their causes. From this background, an extrapolation of developments likely in the last part of the century was made. To exclude local perturbations, the technique of examining developments in twenty-year periods was used. Thus, periods 1920 through 1939, 1940 through 1959, and 1960 through 1979 were selected as the bases of forecasts for the twenty-year period from 1980 to 2000.

The literature reviewed in developing the historical information on the periods from 1920 to 1979 is presented in items 1 through 22 of the REFERENCES section of this report. As the writer lived through all but the first four years of this period, his personal observation of events also proved very helpful.

To focus on particular aspects of bridge engineering and construction likely in the 1980-2000 period, an eight-page questionnaire was prepared and sent to seventy-two leaders and experts in the field of bridge engineering and construction. The mailing list included people in design, consulting, research, education, and state and federal agencies, including the military. Questions were asked in the categories of Loads and Geometric Considerations, Structural Materials, Methods of Analysis and Design, Substructure Design, Superstructure Design, Miscellaneous Design Factors, Nontechnical Concerns, Contracts, Construction Practice, Maintenance, and an open section on Other Comments or Forecasts. A complete sample questionnaire is included as Appendix A.

Of the seventy-two people in the United States, Canada, and England who were sent questionnaires, forty-four replied; forty-two in the U. S. and one each in Canada and England.

A third source of information was searched for clues as to the direction of bridge engineering in the future; namely, the published technological forecasts by others. Some of these forecasts deal with issues relating directly to bridges or transportation, while some deal with technological developments that may have an indirect relationship. Both were studied because of possible future interactions. This literature is listed in items 23 through 45 of the REFERENCES section.

The following section, headed "FINDINGS", summarizes each of the three directions of investigation separately. The section entitled "CONCLUSIONS" synthesizes these same three areas of study to develop a composite forecast of bridge engineering from 1980 to 2000. In addition, probable future problems requiring special research efforts are cited.

To illustrate the point that the future of bridge engineering is still open and exciting, a number of proposed and visionary bridges are presented in Appendix B.

"Futurists" have developed many strategies for medium range forecasting up to about 26 years; strategies such as the Delphi method, scenario building, gaming, network analysis, simulation, historical analogy, extrapolation techniques, brainstorming, probabilistic forecasting, statistical models, individual experts, expert panels, operational models, causal models, relevance trees, cross-impact analyses, and operational models. Of all these, the three described were judged to be the most appropriate for this study.

FINDINGS

This section is subdivided into three categories as described in PROCEDURE; namely, A) Historical Developments, B) Questionnaires, and C) Forecasts by Others.

(A) HISTORICAL DEVELOPMENTS BY PERIODS (1) 1920-1939, (2) 1940-1959, AND (3) 1960-1979.

Each period of this section is further subdivided into five sections; namely, (A) Lengths of Major Bridges Constructed — by Types, (B) Major Developments in Bridge Engineering, (C) Strengths of Bridge Materials, (D) New Types of Bridges to Come Into Use, and (E) Nontechnical Factors.

(A.1.A) HISTORICAL DEVELOPMENTS (1920-1939). LENGTHS OF MAJOR BRIDGES CONSTRUCTED — BY TYPES (SUB-LISTING BY DATE OF COMPLETION, LENGTH OF MAIN SPAN AND LOCATION).

<u>Simply Supported Steel Truss</u>

1922/700 ft./Tanana River, Alaska

1929/716 ft./Ohio River at Paducah, Kentucky

1933/665 ft./Ohio River at Henderson, West Virginia

<u>Continuous Steel Truss</u>

1935/839 ft./Duisburg, Germany

<u>Steel Plate Girder</u>

1939/250 ft./Perth Amboy, New Jersey

<u>Steel Arch</u>

1931/1675 ft./Bayonne, New Jersey

1932/1650 ft./Sydney, Australia

<u>Steel Cantilever</u>

1927/1100 ft./Carquinez Strait at San Francisco, California

1930/1200 ft./Columbia River at Longview, Washington

1936/1400 ft./East Bay at Oakland, California

Steel Suspension

1924/1632 ft./Bear Mountain at Peekskill, New York

1926/1750 ft./Delaware River at Philadelphia, Pennsylvania

1929/1850 ft./Detroit, Michigan, to Windsor, Ontario, Canada

1931/3500 ft./Hudson River at New York, New York

1936/2310 ft./Oakland Bay at Oakland, California

1937/4200 ft./Golden Gate at San Francisco, California

1939/2300 ft./East River at New York, New York

Steel Moveable

1927/525 ft., swing/Mississippi River at Fort Madison, Iowa

1934/540 ft., lift/Burlington, New Jersey

1935/544 ft., lift/Cape Cod Canal, Massachusetts

Reinforced Concrete Arch

1923/430 ft./St. Pierre du Vauvray, France

1930/612 ft./Plougastel, France

1934/595 ft./Tranberg, Sweden

Bridges of exceptionally long overall lengths are the San Mateo to Hayward, California, bridge, 7.25 miles long, completed in 1929, and the San Francisco to Oakland, California bridge, 5.2 miles long, completed in 1936.

(A.1.B) HISTORICAL DEVELOPMENTS (1920-1939). MAJOR DEVELOPMENTS IN BRIDGE ENGINEERING.

Because many developments must be interpreted as growing trends rather than specific events, precise dates within this twenty-year time frame cannot be assigned. Listing is by subject only.

Development of welding of structural steel members

Use of structural aluminum, mostly for repairs

Use of cellular steel decks

Use of vibrators for placing concrete

Construction of large concrete batching plants

Development of spinning machines for suspension bridges

Use of diesel engines on construction equipment

Development of hydraulically controlled bulldozers

Development of techniques for the construction of large and deep caissons (300 ft. long and 216 ft. deep)

Development of the science of soil mechanics

Use of model testing of bridges

Introduction of Hardy Cross moment distribution method

Introduction of the parkway system in the U. S. with the concept of grade separation bridges

Organization of the AASHO bridge committee for the establishment of standard specifications

(A.1.C) HISTORICAL DEVELOPMENTS (1920-1939). STRENGTHS OF BRIDGE MATERIALS.

The average allowable stress for ordinary carbon structural steel used was about 18 kips per square inch; however, higher stresses were used on some major bridges by means of special alloy steels containing silicon or manganese. Ultimate stresses of these alloy steels were 80 to 90 ksi. Steels used in the cables of suspension bridges were also alloys, with yield stresses as high as 243 ksi, although the average used was closer to 184 ksi.

The allowable stress for concrete in general use was about 1,000 psi. On several bridges in Europe, the ultimate stress (f'_c) was as high as 8,500 psi, with working stresses up to 1,400 psi.

Timber was not used as a material for major bridges in this period.

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(A.1.D) HISTORICAL DEVELOPMENTS (1920-1939). NEW TYPES OF BRIDGES TO COME INTO USE.

Continuous steel trusses

Continuous steel plate girders, riveted

Steel Vierendeel trusses, welded

Tied arches of reinforced concrete

Rigid frames of reinforced concrete, for grade separation

Horizontally curved arches of reinforced concrete

Skewed bridges

Bridges with little or no ornamentation

(A.1.E) HISTORICAL DEVELOPMENTS (1920-1939). NONTECHNICAL FACTORS.

During this period, the population of the U. S. increased from 105,710,620 people to 131,669,275, representing a gain of 25%. In the state of Virginia alone, the population increased from 2,309,187 to 2,677,773 people, representing an increase of 16%. (Population figures are from the U. S. Bureau of Census.)

Costs of construction also rose. Based on figures from the Engineering News Record Index, construction costs in the U. S. increased by a factor of 2 from 1920 through 1939. In the state of Virginia (based on Virginia Highway and Transportation Department sources) the cost of bridge construction rose by a factor of 1.9 during this period, which was slightly less than the national average for all construction.

World War I, which occurred in the years just preceding the 1920-1939 period, brought with it a stimulated economy. However in 1929, the U. S. economy collapsed, and it was not until about 1933 that economic recovery began.

(A.2.A) HISTORICAL DEVELOPMENTS (1940-1959). LENGTHS OF MAJOR BRIDGES CONSTRUCTED — BY TYPES.

Continuous Steel Truss

1943/845 ft./Mississippi River at Dubuque, Iowa

1945/835 ft./Duisburg-Rheinhausen, Germany

Steel Plate or Box Girder

1941/300 ft./Hartford, Connecticut

1950/375 ft./New Jersey Turnpike

1952/676 ft./ Dusseldorf, West Germany

1957/856 ft./Sava River at Belgrade, Yugoslavia

Steel Arch

1950/1080 ft./Birchenough, Rhodesia

Steel Cantilever

1943/1500 ft./Hooghly River at Calcutta, India

1958/1575 ft./Mississippi River at New Orleans, Louisiana

Steel Suspension

1940/2800 ft./Tacoma Narrows, Tacoma, Washington (First)

1950/2800 ft./Tacoma Narrows, Tacoma, Washington (Second)

1951/2150 ft./Delaware River at Wilmington, Delaware

1957/2000 ft./Delaware River at Philadelphia, Pennsylvania

1957/3800 ft./Mackinac, Michigan

Steel Moveable

1940/333 ft.,bascule/Black River at Lorain, Ohio

1941/336 ft., bascule/Michigan-Ontario ship canal

1949/386 ft., bascule/Anacosta River at Washington, D. C.

1952/500 ft., swing/Yorktown, Virginia

1959/558 ft., lift/Arthur Kill River, New York

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Reinforced Concrete Arch

1940/645 ft./Esla, Spain

1943/866 ft./Kraurfors, Sweden

1952/752 ft./Dnieper River, USSR

Prestressed Concrete Girder

1949/242 ft./Marne River at Esbly, France

1950/160 ft./Walnut Street, Philadelphia, Pennsylvania

Relocatable

1941/240 ft., Bailey steel truss

Bridges of exceptionally long overall length are the bridge over Tampa Bay, Tampa, Florida, 15.2 miles long, completed in 1954, and the first Lake Pontchartrain Bridge near New Orleans, Louisiana, 23.83 miles long, completed in 1956.

(A.2.B) HISTORICAL DEVELOPMENTS (1940-1959). MAJOR DEVELOPMENTS IN BRIDGE ENGINEERING.

Use of high strength bolts

Use of elastomeric bearings

Use of air entrainment of concrete

Use of lightweight aggregates for bridge decks

Use of composite construction of decks

Introduction of limit design for steel

Use of orthotropic construction for steel decks

Development of aluminum bridges, riveted and welded

Use of deep steel and prestressed concrete piles (up to 194 ft.)

Development of a wide variety of specialized machinery for construction, including helicopters

Use of dynamic tests for wind and impact

Use of electronic computers for analysis

Construction of prestressed concrete bridges, pretensioned and posttensioned

Development of cantilever method of construction of prestressed concrete bridges

Development of horizontally curved, prestressed concrete bridges

Massive federal funding for the U. S. interstate highway system.

(A.2.C) HISTORICAL DEVELOPMENTS (1940-1959). STRENGTHS OF BRIDGE MATERIALS.

The allowable stress for bridge steel in routine use was 20 ksi, although higher stresses were used for alloy steels with yield stresses of about 90 ksi.

The allowable stress for structural concrete averaged about 1,200 psi, but stresses up to about 1,500 psi were used on some bridges in Europe.

Prestressed concrete bridges, introduced in this period, require concrete of higher strength than ordinary reinforced concrete. For these purposes, allowable stresses used were between 1,600 and 1,800 psi, based on ultimate stresses between 4 and 5 ksi.

(A.2.D) HISTORICAL DEVELOPMENTS (1940-1959). NEW TYPES OF BRIDGES TO COME INTO USE.

Prestressed concrete girder

Aluminum girder

Orthotropic steel superstructure

Cable-stayed, steel

Relocatable (Bailey truss)

(A.2.E) HISTORICAL DEVELOPMENTS (1940-1959). NONTECHNICAL FACTORS.

During this period, the population of the U. S. rose from 131,669,275 to 179,323,175 people, representing a gain of 36%. In the state of Virginia, the increase was 48%, up from 2,677,773 to 3,966,949 people.

Nationwide, the cost of construction increased by a factor of 2.5 during this period. In Virginia, the cost of bridge construction alone rose by a factor of 2.3.

The U. S. was involved in two major wars between 1940 and 1960. World War II lasted from 1941 to 1945 and the Korean War from 1950 to 1953. The stimulation of these wars brought a generally expanding economy, with only short periods of economic slowdown totaling not more than three years.

In Europe, the destruction of the war required extensive building or rebuilding of hundreds of bridges at a time of severe material shortages. Many new methods and materials came into being as a result.

(A.3.A) HISTORICAL DEVELOPMENTS (1960-1979). LENGTHS OF MAJOR BRIDGES CONSTRUCTED — BY TYPES.

Simply Supported Steel Truss

1975/750 ft./Chester, West Virginia

Continuous Steel Truss

1966/990 ft./Kumamoto, Japan

1966/1232 ft./Columbia River at Astoria, Oregon

1976/1066 ft./Yamaguchi, Japan

Steel Box Girder

1967/600 ft./Mississippi River at St. Louis, Missouri

1967/750 ft./San Mateo, California

1974/984 ft./Rio-Niteroi, Brazil

1977/541 ft., curved/Brussels, Belgium

Steel Arch

1964/1200 ft./Frazer River in British Columbia, Canada

1966/1247 ft./Ultova River at Zdakov, Czechoslovakia

1973/1255 ft./Willamette River at Portland, Oregon

1977/1700 ft./New River, West Virginia

Steel Cantilever

1974/1644 ft./Delaware River at Chester, Pennsylvania

1974/1673 ft./Osaka, Japan

Steel Suspension

1964/3300 ft./Firth of Forth, Scotland

1964/4260 ft./Verrazano Narrows at New York, New York

1966/3240 ft./Severn River, England

1966/3323 ft./Lisbon, Portugal

1967/2336 ft./Orinoco River, Venezuela

1968/2150 ft./Wilmington, Delaware

1970/2190 ft./St. Lawrence River, Quebec, Canada

1973/2336 ft./Honshu to Kyushu, Japan

1973/3524 ft./Bosporus, Istanbul, Turkey

1979/4626 ft./Humber River, England

Reinforced Concrete Arch

1963/885 ft./Oporto, Portugal

1964/951 ft./Parana River between Brazil and Paraguay

1964/1000 ft./Parramatta River at Sydney, Australia

1966/813 ft./Krka River, Yugoslavia

1968/520 ft./Cowlitz River at Mossyrock, Washington

1968/540 ft./Sill Valley, Austria

1968/689 ft./Lingenan, Austria

1972/550 ft./Selak Creek, Washington

1979/1280 ft./Krk Island, Yugoslavia

Prestressed Concrete Girder

1960/500 ft./Medway, England

1964/682 ft./Rhine River at Koblenz, West Germany

1970/755 ft./Shikoku to Kochi, Japan

1973/787 ft./Shizuoka, Japan

1974/876 ft./Tiel, Netherlands

1975/450 ft./Pine Valley Creek, California

1976/787 ft./Hamana to Chashi, Japan

1978/790 ft./Palau Islands of the Pacific Trust Territory of United States

1979/640 ft./Sanora, California

1979/700 ft./Shubenacadie River, Nova Scotia, Canada

Aluminum Box Girder

1960/80 ft./Nassau County, New York

1961/100 ft./Petersburg, Virginia

Steel Cable-Stayed

1960/988 ft., unbalanced/Cologne, West Germany

1969/1050 ft./Rhine River at Dusseldorf, West Germany

1970/1148 ft./Rhine River at Duisburg, West Germany

1971/1109 ft./Melbourne, Australia

1973/450 ft./Sitka Harbor, Alaska

1975/994 ft., unbalanced/Bratislava, Czechoslovakia

1975/1325 ft./Loire River at Brittany, France

1978/1082 ft./Zarate, Argentina

1979/1235 ft./Mississippi River at Luling, Louisiana

1979/1500 ft./Hooghly River at Calcutta, India

Concrete Cable-Stayed

1972/925 ft./Beida, Libya

1973/485 ft./Main River at Frankfurt, West Germany

1976/1050 ft./Seine River, France

1979/981 ft./Columbia River, Washington

Steel Delta Leg

1962/240 ft./Yakima River at Yakima, Washington

1972/630 ft./Houston, Texas

1976/240 ft./Maury River in Rockbridge County, Virginia

Concrete Stress Ribbon (Footbridges)

1967/131 ft./Bircherweid, Switzerland

1971/138 ft./Freiburg, West Germany

1971/446 ft./Rhone, France

1974/447 ft./Germany

Pontoon

1960/6560 ft./Seattle, Washington

1963/7998 ft./Seattle, Washington

1978/6074 ft./Demerara River, Guyana

Bridges of exceptionally long overall length are the Chesapeake Bay Bridge Tunnel near Norfolk, Virginia, 17.6 miles long, completed in 1964, and the second bridge across Lake Pontchartrain near New Orleans, Louisiana, 23.87 miles long, completed in 1969.

(A.3.B) HISTORICAL DEVELOPMENTS (1960-1979). MAJOR DEVELOPMENTS IN BRIDGE ENGINEERING.

Placement of concrete by pumping

Use of vibrating sonic pile drivers

Use of lasers for construction

Slip forming of piers

Development of construction methods for deep caissons (270 ft. deep)

Development of deep off-shore platforms (up to 945 ft. high)

Development of large mobile cranes (up to 250 tons)

Development of large earth boring machines (up to 12 ft. diameter operating to depths of 1,600 ft.)

Use of large hoisting equipment (up to 6,000 tons)

Development of remote controlled construction machinery for use underwater

Development of stressed skin aluminum girders

Use of push-sliding erection of superstructures

Development of aerodynamic shapes for box girders

Routine use of curved steel girders

Development of aseismic designs for bridges

Development of ultimate load factor design for bridges

Use of critical path methods of construction management

General use of pedestrian overpass bridges over highways

Use of safety parapet separation of vehicles and pedestrians

(A.3.C) HISTORICAL DEVELOPMENTS (1960-1979). STRENGTHS OF BRIDGE MATERIALS.

The allowable stress for bridge steel in routine use remained at 20 ksi, with allowable stresses of 27 ksi used for high strength, low alloy steel.

The allowable stress for structural concrete rose to about 1,600 psi for general use and up to 2,250 psi for special situations.

For prestressed concrete, the average allowable stress was about 2,000 psi for an ultimate stress of 5 ksi. In special situations, ultimate stresses up to 8 ksi were used. Steel used for prestressing tendons had a yield stress of about 242 ksi.

(A.3.D) HISTORICAL DEVELOPMENTS (1960-1979). NEW TYPES OF BRIDGES TO COME INTO USE.

Cable-stayed, concrete

Cable-stayed, asymmetrical

Long span segmental concrete

Delta and slant leg rigid frames

Stress-ribbon

(A.3.E) HISTORICAL DEVELOPMENTS (1960-1979). NONTECHNICAL FACTORS.

In this period, the population of the U. S. rose from 179,323,000 to approximately 220,000,000 people, representing a gain of 23%. In the state of Virginia, the increase was from 3,967,000 to approximately 5,250,000 people, a gain of 32%.

Nationwide, the cost of construction rose by a factor of 3.5, fueled by a relatively high economic inflation rate toward the later part of the time period. In Virginia, the cost of bridge construction increased by a factor of about 3.0.

Between 1964 and 1973, the U. S. was involved in the war in Vietnam and the outer space program, landing the first man on the moon in 1969. Both activities greatly stimulated research and development efforts in basic and applied technology.

Because of massive federal funding of the interstate network of highways, many thousands of new bridges and miles of new highways were constructed throughout the country. Interstate highways led to the generation of increased mobility and vehicular use. At the same time, the cost of energy, particularly gasoline, became higher.

In the later part of this time period, the escalating cost of energy had an adverse impact on the economy, causing a leveling off of overall construction activity. Rising concerns over the quality of the environment also contributed to a slowdown of certain kinds of new construction, including highways.

By early 1979, there was evidence suggesting that the previously ever rising standard of living in the U. S. had reached a steady state condition.

(B) QUESTIONNAIRES

A questionnaire as shown in Appendix A was sent to seventy-two English speaking people or organizations who were experts or leaders in fields relating to bridge engineering and construction. People in a variety of categories were included, as described under "PROCEDURE". Although no questionnaires were sent to Europeans, questionnaires were sent to firms doing business abroad as well as to U. S. offices of European based firms. The return of replies represents a statistically satisfactory 61.1%.

A total of forty-four questions were asked in ten basic categories; namely, Loads and Geometric Considerations (A), Structural Materials (B), Methods of Analysis and Design (C), Substructure Design (D), Superstructure Design (E), Miscellaneous Design Factors (F), Nontechnical Concerns (G), Contracts (H), Construction Practice (I), Maintenance (J), and Other Comments or Forecasts (K).

The following represent a general selection of responses to each of the forty-four questions. Individual quotations of special note as well as the synthesis of typical replies are presented. To some degree, the responses may reflect "wishes" rather than firm forecasts. As it is impossible to separate the two, the responses are presented as received.

(B.A.1) QUESTIONNAIRES. LOADS AND GEOMETRIC CONSIDERATIONS. "WHAT CHANGES IN LIVE LOADINGS ON HIGHWAY OR RAILWAY BRIDGES DO YOU FORESEE?"

Heavier highway loading by approximately 10% to 20%

Gross vehicle weights up to 100,000 or 120,000 pounds

Greater attention to actual number and spacing of wheels

More specificity regarding dynamic loads caused by wheel impact, wind and seismic forces

Reduction in live loads for bridges over 500 ft. span

Loads by military vehicles will increase

No increase in railroad loading

"In Europe, a coordination of loadings on highway bridges is taking place between the nine member states of the EEC. This will in time be extended to cover all Europe." (O.A.K.)*

(B.A.2) QUESTIONNAIRES. LOADS AND GEOMETRIC CONSIDERATIONS. "WHAT CHANGES IN LANE WIDTHS OR VERTICAL CLEARANCES ON BRIDGES DO YOU FORESEE?"

No width change likely

Increase in vertical clearance on highway bridges of approximately 10% to 15% on key routes

(B. A.3) QUESTIONNAIRES. LOADS AND GEOMETRIC CONSIDERATIONS. "DO YOU FORESEE ANY TRAFFIC SEPARATION ON BRIDGES; AS FOR AUTOMOBILES, TRUCKS AND BICYCLES, AS WELL AS PEDESTRIANS?" COMMENT.

In urban areas, a separation of vehicles, bicycles and pedestrians

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*Key to persons quoted is found at the end of section (B) on Questionnaires.

Some reserved lanes for public transit systems as buses

On some long span bridges, separate lanes for trucks and autos

In some locations, separate bridges for trucks on truck only highways

(B.A.4) QUESTIONNAIRES. LOADS AND GEOMETRIC CONSIDERATIONS. "OTHER COMMENTS RELATING TO LOADS AND GEOMETRIC CONSIDERATIONS."

Vehicle redesign will force changes in loading

Bridges for airplanes at airports will adapt to new aircraft designs

Air cushion vehicles will cause loads to be reconsidered

More automatic monitoring and stricter enforcement of truck weights

Fatigue effects will be more realistic

(B.B.1) QUESTIONNAIRES. STRUCTURAL MATERIALS. "WHAT CHANGES IN CONCRETE STRENGTH AND QUALITY DO YOU FORESEE?"

Ultimate stresses of 7-10 ksi will become commonplace

Ultimate stresses of 12-14 ksi used for special work

More use of lightweight aggregates

Concretes will have better durability

New admixtures will inhibit corrosion of reinforcing steel and protect against deterioration by salts and weather

Better quality control and testing procedures will be used

Speciality concretes, as with polymers, will be used

Development of a concrete that is electrically conductive for deicing of bridge decks

In some areas, concrete strength and quality will decrease due to scarcity of good aggregates

(B.B.2) QUESTIONNAIRES. STRUCTURAL MATERIALS. "WHAT CHANGES IN THE REINFORCEMENT OF CONCRETE DO YOU FORESEE?"

Some small strength improvement in steel rebars

More high strength wire mesh or bar mats will be used

Greater use of corrosion-resisting coatings, as epoxy and galvanizing

Greater use of fiber reinforcement, metallic and nonmetallic

Possible development of nonmetallic, noncorrosive reinforcement, as fiberglass

Changes in bar sizes due to conversion to metric units

More automatic welding of steel rebars

Increase in percentage of reinforcement to limit cracking

Reduction in percentage of reinforcement to reduce cost

Greater confinement of concrete, by spirals or stirrups, to increase compressive ductility

(B.B.3) QUESTIONNAIRES. STRUCTURAL MATERIALS. "WHAT CHANGES IN PRESTRESSING CONCRETE OR TENDONS DO YOU FORESEE?"

Continued increase in ultimate strengths of concrete

More use of prestressing in comparison with ordinary reinforced concrete

More prestressing of decks transversely

More use of posttensioning methods

Greater use of partial prestressing

Greater control of stress losses

More reliable, smaller and simpler anchorages

Use of larger sizes of tendons for pretensioning

"Possible development of tendons from some plastic formulation." (D.A.F.)

Better protection of tendons against corrosion

More precise layout of tendons in accordance with actual stress patterns

(B.B.4) QUESTIONNAIRES. STRUCTURAL MATERIALS. "WHAT IMPROVEMENTS IN STEEL OR MATERIALS USED IN JOINING STEEL DO YOU FORESEE?"

Continued improvements in quality and strength of steel

Increased use of corrosion-resisting steels, as weathering steels

More automated welding procedures

Improvements in fabrication and testing against weld and brittle fracture failure

Development of fatigue-free welding procedures

Improvements in bolting, reducing the size of bolted joints

New automatic fasteners, developing proper tension upon installation

"Factory pre-assembled joints." (L.Z.)

Increased use of adhesives, as high strength epoxies, in place of welding or with bolting

(B.B.5) QUESTIONNAIRES. STRUCTURAL MATERIALS. "IN WHAT NEW WAYS WILL WOOD (EITHER SOLID, LAMINATED, OR RECONSTITUTED) BE USED IN BRIDGES?"

Continued limited use for short spans in rural areas, for temporary or pedestrian bridges or for special conditions of esthetics

Use of posttensioning of laminated decks

Use of reconstituted wood products with improved properties in special situations

"Glulam will be further extended in use for longer span bridges". (O.A.K.)

(B.B.6) QUESTIONNAIRES. STRUCTURAL MATERIALS. "WHAT NEW STRUCTURAL MATERIALS DO YOU FORESEE BEING INCREASINGLY USED IN BRIDGES (AS ALUMINUM, REINFORCED PLASTICS, POLYMERIZED CONCRETE, LAMINATES AND SPACE-AGE COMPOSITES)?"

Better lightweight concrete

Increased use of polymerized concrete, particularly for decks

Fiber material, as fiberglass, in the form of bars and strands for concrete reinforcement

Laminates of various kinds, some with plastics

Plastic stay-in-place forms

Epoxy impregnated decks

Increased use of aluminum in retrofitting

"Exotic" materials and composites for bearings, joint seals and special applications

Increased use of recycled materials, including concrete and steel

(B.B.7) QUESTIONNAIRES. STRUCTURAL MATERIALS. "WHAT BRIDGE MATERIALS DO YOU FORESEE BECOMING TOO SCARCE OR EXPENSIVE TO USE IN CONVENTIONAL WAYS?"

None were listed as vanishing completely, but the following were listed as growing scarce or expensive.

Timber

High strength and corrosion-resisting steels

Aluminum

Concrete, in some areas

Continued trend away from steel toward concrete, because of cost

(B.B.8) QUESTIONNAIRES. STRUCTURAL MATERIALS. "OTHER COMMENTS RELATING TO METHODS OF ANALYSIS AND DESIGN"

"Future emphasis on lightness". (L.Z.)

"Use what we have in better, more imaginative ways, and take better care of what we have". (T.V.G.)

"Perhaps an attempt will be made to develop materials, in particular steel, with very much higher moduli of elasticity". (O.A.K.)

"As we dig deeper into our basic reserves of materials, it will become obvious that we must recycle structural materials. ... We must get over the idea that it is better (cheaper) to scrap all the old materials and rebuild with new. At the rate we are using our basic resources, we cannot afford to waste and throw away". (A.L.E.)

(B.C.1) QUESTIONNAIRES. METHODS OF ANALYSIS AND DESIGN. "WHAT CHANGES IN METHODS OF ANALYSIS DO YOU FORESEE (SUCH AS LOAD FACTOR METHODS OR COMPREHENSIVE DYNAMIC ANALYSIS)?"

More exact analysis of secondary factors as thermal stresses, seismic forces, fatigue, residual stresses, creep, erection stresses and progressive collapse

More sophisticated computer analysis, as with finite element methods, on standardized programs

Concern for overall interactive three-dimensional behavior

Increased use of load factor design

New determination of safety factors

Greater use of probabalistic concepts

(B.C.2) QUESTIONNAIRES. METHODS OF ANALYSIS AND DESIGN. "WILL DESIGN PROCEDURES BE CHANGED (AS BY GREATER COMPUTERIZATION, INCREASED REGULATORY STANDARDS, OR MORE EXACT DESIGN EQUATIONS)? COMMENT."

More design by computer, with standard programs

Design procedures to be changed by continuing research in regard to realistic equations

Greater concern for fail-safe design

"There will be further tendencies to refine design procedures with computer accuracy. We must be careful that the exactness of design does not outstrip the obtainable field quality." (A.L.E.)

"Attempts will be made (to be resisted) to enforce mandatory design codes which will stultify initiative. At the same time pressure will continue from academics to elaborate design methods to the point of absurdity." (O.A.K.)

(B.C.3) QUESTIONNAIRES. METHODS OF ANALYSIS AND DESIGN. "DO YOU FORESEE ANY CHANGES IN REGARD TO BRIDGE TESTING AT EITHER THE SMALL-SCALE OR FULL-SCALE LEVEL? COMMENT."

Continued but limited use of small-scale laboratory tests

More full-scale testing for understanding of realistic behavior

More testing of older bridges for load rating and to minimize repair or replacement

Instrumentation for long-term measurements of in-service bridge

"Less interest." (J.M.H.)

(B.C.4) QUESTIONNAIRES. METHODS OF ANALYSIS AND DESIGN. "OTHER COMMENTS RELATING TO METHODS OF ANALYSIS AND DESIGN."

"New design methods must be calibrated to assure that reserve strength levels provided in new structures are uniform and consistent with levels provided in existing bridges. Design at inventory and operating stress levels, with different live loads at the two limits, may be required to achieve this." (R.K.)

"We should (and I hope will) see more emphasis on the design itself and also on fabrication procedures and methods." (D.A.F.)

"More emphasis on deformations as opposed to stresses." (B.C.G.)

"Presently undergoing testing and analysis (rational) of bridges will have far-reaching impact on future bridge designs." (L.Z.)

"Analysis and design must not become so refined and exact that the normal defects in a structure become catastrophic. There are no perfect structures built. Defects will always exist in welds, steel, concrete, design and fabrication. It does no good to design to a refinement that cannot tolerate these defects." (A.L.E.)

"Bridge design specifications are unnecessarily cluttered with too many design analysis methods. The AASHTO bridge specs should be restructured with this in mind in addition to a better format to avoid redundancy and different interpretations of the same spec." (S.L.P.)

(B.D.1) QUESTIONNAIRES. SUBSTRUCTURE DESIGN. "WHAT CHANGES DO YOU FORESEE IN GEOPHYSICAL EXPLORATION?"

More reliable methods of obtaining borings, with new measuring devices

Increased use of sophisticated subsurface surveys using sonic and electrical resistance techniques

Increased use of aerial remote sensing

More standardization of exploration methods and tests

More uniform classification of materials

More precise prediction of soil-bearing capacity, settlement, ground water flow and earthquakes

(B.D.2) QUESTIONNAIRES. SUBSTRUCTURE DESIGN. "WHAT DEVELOPMENTS IN REGARD TO HYDRAULICS OR WATER FLOW CONTROL AROUND BRIDGES DO YOU FORESEE?"

Greater knowledge of flood conditions

Greater use of hydraulic model studies

Developments in ice flow understanding

More reliable methods of scour analysis

More use of spur dykes and scour blankets

More emphasis on non-disturbance construction, as by fewer piers

(B.D.3) QUESTIONNAIRES. SUBSTRUCTURE DESIGN. "WHAT NEW DEVELOPMENTS IN THE CONTROL OF SOIL AND ROCK PROPERTIES DO YOU FORESEE? "

Greater use of procedures as pressure grouting, slurry walls, filter cloth reinforcement of soils, chemical and thermal modification of soils, rock bolts and prestressing, vibratory and impact methods of compaction, along with massive compaction methods of granular soils

(B.D.4) QUESTIONNAIRES. SUBSTRUCTURE DESIGN. "DO YOU FORESEE ANY NEW DEVELOPMENTS IN PREFABRICATION OR INDUSTRIALIZATION OF FOUNDATIONS? COMMENT."

Increased use mostly in connection with precast piers, pier caps, abutments and piles

Use of precast foundations for underwater and mud sites

Increased use based on currently known methods, otherwise little or no change

(B.D.5) QUESTIONNAIRES. SUBSTRUCTURE DESIGN. "WHAT CHANGES IN THE DESIGN OF PILE FOUNDATIONS DO YOU FORESEE?"

Greater use of dynamic analysis (by computers) for piles and pile group driving and design

Trend toward fewer piles with larger load capacities

"A major development will be with the use of high strength, highly reinforced precast piling set in drilled holes and pressure grouted to lock to the soil." (B.C.G.)

Greater use of root-pile (Fondedile) systems

Better control in placing

More knowledge of tip behavior

Better pile splices and tips, possibly prefabricated

More quick in situ load tests

(B.D.6) QUESTIONNAIRES. SUBSTRUCTURE DESIGN. "OTHER COMMENTS RELATING TO SUBSTRUCTURE DESIGN."

Large-scale in situ foundation tests may lead to better foundations

Reduction in safety factors in foundation design will occur as a result of better knowledge

Load factor design will be extended to foundations as well as superstructures

More attention paid to seismic conditions

"Greater use of soil-structure bridges and reinforced earth." (R.K.)

"Provision of flexible piers to avoid expansion bearings and joints." (O.A.K.)

Improved caisson and sheet piling techniques

Cofferdams for underwater work will be prefabricated members joined by tremie concrete or grouting

Foundations in water may be similar to off-shore drilling platforms

Better fendering and warning systems will be used for protection of bridge piers in navigable waters

"In mountainous areas the use of cable supports directly from rock anchors in the mountain can eliminate difficult or expensive substructure work." (D.A.F.)

(B.E.1) QUESTIONNAIRES. SUPERSTRUCTURE DESIGN. "DO YOU FORESEE ANY NEW TYPES OF SUPERSTRUCTURE CONFIGURATION BECOMING POPULAR (AS STRESS-RIBBON OR TUBULAR)? COMMENT."

More box girders, some extremely novel

Growing use of prestressed segmental construction in U. S.

Growing use of cable-stayed structures

More delta frame bridges

Some stress-ribbon and space frame bridges

"Emphasis on membrane behavior." (L.Z.)

"New concepts will have difficulty." (R.K.)

(B.E.2) QUESTIONNAIRES. SUPERSTRUCTURE DESIGN. "WHAT CURRENT TYPES OF SUPERSTRUCTURES (AS ARCHES OR SIMPLE SPAN GIRDERS) DO YOU FORESEE LOSING IN POPULARITY?"

Steel truss bridges of all types

Built-up plate girders

Concrete arches and tied arches, except for esthetic purposes

Fewer simple span girders, although still to be used in many situations

Replacement of short span bridges by arch culverts

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Less cast-in-place concrete superstructures

Decreased use of steel in favor of concrete in superstructures

(B.E.3) QUESTIONNAIRES. SUPERSTRUCTURE DESIGNS. "DO YOU EXPECT FREE SPAN LENGTHS OF VARIOUS BRIDGE TYPES (AS GIRDER, TRUSS, RIGID FRAME, ARCH, CABLE-STAYED AND SUSPENSION) TO GENERALLY INCREASE? COMMENT."

Yes, because of the need to eliminate piers for overpasses and in water

Yes, because of better materials and higher strength-to-weight ratios of structures

Increases especially in prestressed concrete and cable-stayed types

(B.E.4) QUESTIONNAIRES. SUPERSTRUCTURE DESIGN. "WHAT ADVANCES IN MOVEABLE OR FLOATING BRIDGES DO YOU FORESEE?"

Advances will be slow as so few will be built (generally replaced by fixed high level bridges)

"Floating bridges and floating submerged tunnels will show a significant increase for use in deep water and unstable soil under seismic loading." (B.C.G.)

Will have wide military use

Structures will be lighter as by orthotropic construction

"The development of inflatable floating bridges." (O.A.K.)

More automatic and solid state electronic controls

(B.E.5) QUESTIONNAIRES. SUPERSTRUCTURE DESIGN. "AT WHAT LOCATIONS AROUND THE WORLD DO YOU ANTICIPATE SEEING MAJOR NEW BRIDGES?"

Japan, between islands

Scandinavian countries, at water crossings

Soviet Union, especially Siberia

Central Europe

In developing countries of Africa, South America, Asia, and the Middle East

In China, Korea, Polynesia, and Turkey

Across the Dardanelles and Messina Straits

In the U. S., not too many, mostly in coastal areas

(B.E.6) QUESTIONNAIRES. SUPERSTRUCTURE DESIGN. "WILL THERE BE A TREND TOWARD JOINT-USE BRIDGES (AS FOR VEHICLES AND HOUSING OR RETAIL STORES)? COMMENT."

Limited development, mostly in some dense urban areas where space is at a premium

(B.E.7) QUESTIONNAIRES. SUPERSTRUCTURE DESIGN. "OTHER COMMENTS RELATING TO SUPERSTRUCTURE DESIGN."

Bridges to be more durable

More concern for esthetics and relationship to the environment

More standardization for short to medium span bridges

"Reconsideration of welded battle-decks in view of their known weld fatigue proneness." (O.A.K.)

"More thought will be directed to the advantages and disadvantages of twisted and parallel stranded cables for stayed girder and suspension bridges." (O.A.K.)

(B.F.1) QUESTIONNAIRES. MISCELLANEOUS DESIGN FACTORS. "COMMENT ON ANY CHANGES YOU FORESEE IN REGARD TO DETAILS AS CORROSION PREVENTION, BEARING DESIGN, SEALANTS, PARAPETS, RAILINGS, LIGHTING, ICE CONTROL AND DRAINAGE."

Use of designs and materials to reduce deterioration and maintenance

Fewer and better joints

Greater use of "catalog" bearings

More ice control details

Better drainage systems

More and better energy-absorbing rails

More extensive use of high mast and energy efficient lighting

(B.G.1) QUESTIONNAIRES. NONTECHNICAL CONCERNS. "COMMENT ON HOW YOU SEE SOCIAL, ENVIRONMENTAL, ECONOMIC, POLITICAL, POPULATION, LABOR, ESTHETIC OR OTHER NON-TECHNICAL CONCERNS AFFECTING BRIDGE DESIGN AND CONSTRUCTION."

"All these factors are involved now and will take a stronger hand as time goes on. The trend has been developed in the last 10 years and I only see them taking on a stronger role in the future." (M.H.H.)

"Initially the pressure groups, social, environmental and so on will continue to have an excessive effect on road projects, to the extent of negativeing them. One hopes that in a few years reason will prevail and a more balanced approach will result." (O.A.K.)

"Engineers must realize that a highway, and especially a bridge, can materially affect the habits, land use, community development, and daily lives of the people who live with it. This being true, they must look at their projects as major community development factors and make sure the impetus is in the right direction. Some bridges, seemingly highly desirable economically, may be completely ruinous to other facets of the community life." (A.L.E.)

"Environmental resistance to projects will reduce as people realize transportation systems must be maintained and renewed." (R.K.)

Bridges designed in special ways just to avoid environmental problems

More use of bridges in certain environmentally sensitive areas as marshes

Greater use of noise barriers in urban areas

More delays because of environmental concerns

More concern for safety against catastrophic occurrences

"Need for new bridges will have to be completely justified to the taxpayers. They will also have to be esthetically pleasing. We will have to consider more labor-intensive designs at a saving of materials." (D.A.F.)

"Labor is having an increasing effect on bridge construction. The efficiency for the most part is not improving but the costs are skyrocketing. This will lead to greater emphasis on precast plant-made elements which can be swung into place and locked on the job with a minimum of field labor. Process will be developed to minimize the necessity for individual, careful hand labor." (A.L.E.)

Continued shortage of skilled workmen

More attention to life-cycle costs, instead of first cost

Trend toward use of concrete and away from other materials because of greater utilization of domestic resources and energy considerations

(B.H.1) QUESTIONNAIRES. CONTRACTS. "WILL THERE BE ANY CHANGES IN REGARD TO THE WAY BRIDGE DESIGNERS ARE AWARDED CONTRACTS? COMMENT."

"Competitive bidding for engineering services will increase, particularly for projects involving total design and construction." (W.H.)

"Bidding on design fees may result in poor designs unless carefully controlled. Fee competition can be very bad." (T.Y.L.)

More concern over the cost of design

"As costs mount, states will get back to doing their designing." (A.L.E.)

There will be a trend toward one organization to plan, design and build, with variations in the nature of design-build teams of allied planners, designers and builders

(B.H.2) QUESTIONNAIRES. CONTRACTS. "COMMENT ON WHAT CHANGES YOU FORESEE CONCERNING THE PREPARATION OF CONTRACT DOCUMENTS AS DRAWINGS, SPECIFICATIONS, AND OTHER LEGAL INSTRUMENTS."

"Contract documents which allow some flexibility for contractors to use their special talents or equipment to reduce costs are gaining popularity. This includes providing alternative designs, permitting options on certain products or details, greater use of end result specifications, and allowing cost reduction proposals by the contractor." (R.L.)

Documents will become increasingly performance oriented, with less drawings by designer and more by builder.

Increase in preparation of alternate designs and materials, to obtain lowest cost

More use of computers, especially for drawings and spec writing

Possible national or international specifications

National laws relating to time limitations for design responsibility

Procedural changes to reduce the number of contract claims

"Present trend is for more complexity and legality in the preparation of contract documents. More reliance on the Courts in the case of disputes. More undesirable tendencies and one can only hope that common sense will eventually prevail and simple procedures return." (O.A.K.)

(B.H.3) QUESTIONNAIRES. CONTRACTS. "WILL THERE BE ANY CHANGES IN THE MANNER OF PAYMENT FOR SERVICES, EITHER TO THE DESIGNER OR BUILDER?"

Not much change

Possible incentive payments for savings due to more sophisticated designs

"Less use of unit items; instead use linear measurement or per span etc. This greatly simplifies field work, measurement and payment. At the same time the plans should reflect quantities for estimating purposes." (S.L.P.)

"Possibly cost plus a fixed fee method will gain in popularity, both in design and construction, because fees based on percentage of cost are mistrusted while contractors rely more and more on claims." (O.A.K.)

(B.H.4) QUESTIONNAIRES. CONTRACTS. "OTHER COMMENTS RELATING TO CONTRACTS."

"Time of construction will be more closely controlled — using CPM scheduling for overall projects." (B.C.G.)

"We may see a procedure in which several selected firms will be asked to prepare preliminary conceptual plans. An award jury will make the selection for final detail design. All firms will be paid for the cost of their preliminary design on a fixed fee basis." (D.A.F.)

"I think that further development of contract documents that encourages contractor innovation has enormous potential for reducing costs. The problem for the engineer is in finding ways to allow flexibility without losing control of the end product. This concept requires intimate involvement of the designer throughout the construction period." (R.C.)

"We are getting very close to a labor and material contract where we pay the contractor by the day to build what we specify. This is wrong but probably irreversible. ... It is probably folly to hope that we will ever get back to having contractors take the risk and winning, make their profits." (A.L.E.)

(B.I.1) QUESTIONNAIRES. CONSTRUCTION PRACTICE. "WHAT CHANGES ARE LIKELY IN THE AREA OF EARTH AND ROCK EXCAVATION?"

Use of larger machines, especially for rock excavation, although small machines will also be used where suitable

Better control on demolition of rock work

Further improvement in tunneling techniques, particularly for vertical rock boring

Development of alternate methods of excavating as by high pressure jets, lasers, vibration and vacuum

Use of clean atomic explosives for major excavations

More transportation of excavated materials in slurry form

(B.I.2) QUESTIONNAIRES. CONSTRUCTION PRACTICE. "WHAT DEVELOPMENTS IN EQUIPMENT OR MACHINERY USED FOR FABRICATION OR ERECTION OF BRIDGES DO YOU FORESEE?

Heavier lifting equipment

More standardized machines and equipment

More automatically controlled fabricating systems with better quality control

Innovations in concrete casting forms

Growing use of overhead construction methods

Development of special erection equipment, as launching machines and cableways, for segmental construction

Special new erection equipment to speed up bridge repair and replacement

Airborne and floating equipment with large capacities

New equipment for producing the new materials of the future

(B.I.3) QUESTIONNAIRES. CONSTRUCTION PRACTICE. "WHAT NEW METHODS ARE LIKELY TO BE EMPLOYED FOR THE RAPID REPAIR OF BRIDGE STRUCTURES?"

Greater use of prefabrication

More use of precast components and prestressing systems, particularly posttensioning

Use of chemicals or injections to strengthen existing concrete

Development of a workable structural adhesive for repair

Improved field welding techniques

Development of repair techniques requiring access from only one site

(B.I.4) QUESTIONNAIRES. CONSTRUCTION PRACTICE. "ARE DESIGN-BUILD BRIDGE COMPANIES AS EXISTING IN EUROPE LIKELY TO GAIN IN PRACTICE IN THE UNITED STATES?"

Some gain

(B.I.5) QUESTIONNAIRES. CONSTRUCTION PRACTICE. "OTHER COMMENTS RELATING TO CONSTRUCTION PRACTICE."

Reduction of on-site construction, time and labor

"The emphasis should be on prefabricated or factory construction of components." (R.D.S.)

A growth of companies specializing in bridge repair work and special construction methods

Improvements in underwater construction methods

"A good case can be made for the fact that government should build the country's roads and bridges." (A.L.E.)

(B.J.1) QUESTIONNAIRES. MAINTENANCE. "COMMENT ON CHANGES YOU FORESEE IN REGARD TO MAINTENANCE, REPAIR, STRENGTHENING OR WIDENING OF EXISTING BRIDGES."

"We are sitting on a time bomb in literally thousands of old flimsy county bridges ready to fall down. Most are beyond efficient repair. The next 25 years will see major efforts mounted toward maintaining what we have. Even the Interstate System, which we think of as new and still shiny, is fading rapidly and the mechanism has not been set up to maintain it properly. We went through years of building like mad to get out of the mud and establish a system. Now we must sit down and develop an equally broad mechanism for maintaining what we have, protecting our investment, and keeping up with needed progress." (A.L.E.)

Many old bridges normally replaced will instead be rehabilitated and upgraded

More funding will be needed for inspection, maintenance, rehabilitation and upgrading of bridges

More effort directed toward standardizing repair procedures

"This phase of bridge engineering has the brightest future." (T.V.G.)

(B.J.2) QUESTIONNAIRES. MAINTENANCE. "WHAT NEW DEVELOPMENTS DO YOU FORESEE DIRECTED TOWARD MAINTENANCE-FREE BRIDGES?"

Higher quality concrete for decks

Polymerized concrete decks

Better sealants for decks

More use of rapidly replaceable prefabricated components, possibly precast polymerized units

Maintenance-free joints

Continuous spans with flexible piers and few joints

Increased use of noncorroding reinforcing materials

More use of weathering steel

More use of plastics in certain components

Increased use of zinc rich paint systems for steel

Use of deicing materials other than salt

(B.J.3) QUESTIONNAIRES. MAINTENANCE. "OTHER COMMENTS RELATING TO MAINTENANCE."

"Must be recognized as a major activity in order to protect investment in bridges." (R.K.)

Value engineering to be applied to bridges on a life-cycle basis

Deterioration of prestressed members may require special methods of restressing them

Better methods of removal of debris from decks and joints to reduce deterioration from trapped water and salt

"Monitoring devices will be developed for detecting and watching the propogation of cracks." (O.A.K.)

"We will work for better concrete, better metals, and better protection against corrosion. But we will never get away from having to maintain what we build. ... In the not far distant future, the maintenance department will be larger than the construction department. ... Designers will be working on solutions of maintenance problems rather than designing new bridges. ... We are in a transitional period from a pioneer nation with a frontier to an established nation with a heritage to maintain." (A.L.E.)

(B.K) QUESTIONNAIRES. OTHER COMMENTS OR FORECASTS.

"There is a need for much greater research in all phases of bridge engineering. Money spent in research can pay great dividends in the reduction in first bridge costs as well as maintenance." (D.A.F.)

"In the bridge field there is a possibility for major improvements in construction, design and maintenance. I hope we will have the ingenuity and the motivation to apply the same talent and creativity as we did to the space program." (T.V.G.)

"Most road transport vehicles will be much as they are now ... up to 2000." (O.A.K.)

"Money for highways will become scarce." (C.F.G.)

"The future will be very exciting." (A.L.E.)

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*Key to quotes on questionnaires

A.L.E. — Arthur L. Elliott, Consultant, California
B.C.G. — Benjamin G. Gerwick, Consultant, California
C.F.G. — Charles F. Galambos, Federal Highway Administration, Virginia
D.A.F. — D. Allan Firmage, Brigham Young University, Utah
J.M.H. — John M. Hanson, Wiss, Janney & Elstner, Illinois
L.Z. — Lev Zetlin, Consultant, New York
M.H.H. — Marvin H. Hilton, Highway & Transportation Research Council, Virginia
O.A.K. — O. A. Kerensky, Freeman Fox & Partners, England
R.C. — Robert Cassano, Department of Transportation, California
R.D.S. — Robert D. Schmidt, Department of Transportation, Illinois
R.K. — Robert Kamp, Department of Transportation, New York
S.L.P. — Sidney L. Poleynard, Raymond Technical Facilities, New York
T.V.G. — Theodore V. Galambos, Washington University, Missouri
T.Y.L. — T. Y. Lin, Consultant, California
W.H. — Wayne Henneberger, Department of Highways & Public Transportation, Texas

(C) FORECASTS BY OTHERS

Presented in this section is a collection of forecasts in various areas related to bridge engineering, directly or indirectly. A variety of sources of information were used, most of which are listed in references 23-45.

Starting with forecasts directly relating to bridge building, there are a number of major bridges (many very unusual) being planned or proposed for future construction, possibly to be built by the year 2000. All have been conceived by reputable engineers, many with well-known names as Pier Nervi, Ulrich Finsterwalder, T. Y. Lin, and Arvid Grant.

- 4,996 ft. main span steel suspension bridge in Japan
- 5,840 ft. main span steel suspension bridge in Japan (between Houshu and Shikoku)
- 4,429 ft. main span steel suspension bridge in Hong Kong (between Kowloon and Lantau Island)
- 6,000 ft. main span steel suspension bridge in Australia (across Port Phillips Bay)
- 9,840 ft. main span steel suspension bridge between Europe and Africa (across the Straits of Gibralter)
- 10,890 ft. main span steel suspension bridge between Italy and Sicily (across the Messina Straits)
- 3,000 ft. main span concrete suspension bridge in Northern Ireland
- 1,300 ft. main span curved steel suspension bridge in California (at Ruck-A-Chucky) (See Appendix B)
- 1,706 ft. main span steel cable-stayed bridge in France (at Le Harve)
- 2,137 ft. main span steel cable-stayed bridge in Germany
- 1,300 ft. main span concrete cable-stayed bridge in Florida (at Jacksonville)
- 1,200 ft. main span (50 miles overall) concrete cable-stayed bridge in Alaska (across the Bering Strait)

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- 600 ft. main span concrete girder (prestressed sequential) bridge in Washington (over the Columbia River)
- 548 ft. main span concrete stress-ribbon bridge for vehicles in West Germany (at Cologne)
- 1,109 ft. main span concrete stress-ribbon bridge for vehicles in Japan (at Naruto)
- 1,346 ft. main span concrete stress-ribbon bridge for vehicles in Turkey (across the Bosporus) (see Appendix B)
- 1,508 ft. main span concrete stress-ribbon bridge for vehicles in Switzerland (across Lake Geneva)
- 1,617 ft. main span steel stress-ribbon bridge for vehicles in Australia
- 330 ft. double bascule moveable bridge in Washington (at Seattle)
- 12,210 ft. long mid-water bridge-tunnel between Italy and Sicily (at Messina Straits) (See Appendix B)

Spans as great as 2,000 ft. for stress-ribbon bridges and 4,900 ft. for steel cable-stayed bridges have also been predicted. In regard to foundations, a record breaking one is being designed for a bridge in Japan; it is 423 ft. deep and 246 ft. by 210 ft. in plan.

Many other new bridge types have been proposed, although in less specific terms and in an open-ended time frame. Among these are the following, some examples of which may be seen in Appendix B.

Segmental prestressed metal bridges

New forms of suspension bridges

Tubular bridges of concrete and metal, in which roadway is within the tube

Reinforced plastic footbridges

Adjustable length bridges

Actively controlled long span bridges, in which tendons pull the structure with controlled amounts of force to stabilize the spans

High esthetic bridges whose esthetic features go well beyond the normal

New forms of multiple use bridges, including adaptive use of old highway and railway bridges for architectural uses

Related to bridge construction are the materials from which future bridges will be built (or old ones rebuilt). The following is a summary of forecasts by researchers and other experts pertaining to materials.

Development of high strength, lightweight aggregates for concrete

Development of concrete with ultimate compressive stresses as high as 20 ksi for routine use and as high as 60 ksi for special purposes (probably by improved polymerizing processes)

Use of polymerized concrete with ultimate tensile stresses as high as 2,000 psi

Development of case hardening of concrete by polymerization

Use of steels with ultimate stresses as high as 3,000 ksi

Improved weldability of high strength steels

Continued trend toward use of concrete as compared with steel for bridges. (Between 1960 and 1979 new bridges of concrete in the U. S. have risen from approximately one-half of the total to two-thirds, while steel bridges have decreased from about one-half to one-third of the total.)

Greater use of reconstituted and polymerized wood

Greater use of high strength glass and plastics

Growing use of adhesives for connections, with such new adhesives as epoxies, cyanoacrylates and anaerobic polyester resins. (McDonell Douglas Aircraft Co. is currently testing a fuselage held together almost entirely by adhesives.)

Special purpose use of super-strength composite materials as graphite-epoxies, boron-epoxies and aluminum with silica fibers. (The pure whisker strength of graphite is 3 x 10^6 psi; of aluminum, 2.2 x 10^6 psi; and of silica, 2 x 10^6 psi.)

No exhaustion of currently used materials by year 2000, but there will be a gradual rundown, resulting in higher prices and occasional difficulties of supply.

The cost of construction also has an important influence on bridge building. Economic projections indicate that the cost of construction in the U. S. will be about five times higher in the year 2000 than in the year 1980, with the hourly wage for those in the building trades being somewhere between $25 and $60 per hour. For bridge construction specifically in the state of Virginia, the increase will be somewhat less of about four times, due to the generally conservative policies of the state. These figures reflect not only normal inflation trends, but some expected recession as well. In the event of more severe conditions as wars, these economic predictions are invalid, and in all probability costs will be much higher.

Bridge construction is indirectly affected by population, as population increases place pressures on transportation systems, of which bridges are an important part. Development of any new modes of transport, as rapid rail, will cause a surge in the growth of specialized bridge construction over and beyond highway and heavy railway bridge construction. Although the rate of population growth in the U. S. is showing a decline, the overall population in the country is forecast at about 260 million people at the end of this century, which represents an increase of 18% over the 1980 figure. In Virginia, the projected population is about 6.4 million, or a 22% growth over the 1980 number.

New bridge construction in general is, therefore, likely to be modest in the U. S. except for certain high growth areas. High growth areas currently are in the southern sunbelt states and toward urban areas. The pattern is expected to continue for the rest of the century. The Census Bureau expects 85% of the country's population to be living in cities by the year 2000, with half the population being contained in 50 major cities, each with populations in excess of one million people.

Except for special growth areas, most bridge work will be in replacement and rehabilitation of unsafe and inadequate old bridges, of which there are about 100,000.

Just as population has an indirect effect on bridge construction so too does the general state of the economy. In viewing bridge construction as related to the general U. S. economy in the past, short-term recessions are seen to have slowed down bridge construction but not to have stopped it. The need for bridges, as pushed by population, generally overrides the effects of economic slowdowns. Because the planning and design of bridges is a long-range operation, short-term economic factors are not as influential on bridge building as on other sectors of the economy. At worst, needed bridge projects are generally only delayed rather than killed because of poor economic conditions. The repair of existing bridges is another area that may be curtailed in economically bad times. This curtailment, too, is only a delaying action as needed repairs must be done eventually.

Over the 1980-2000 time span, the economy in the U. S. can be expected to go both up and down as it has done historically over a span of twenty years. Generally major up cycles last much longer than down cycles, so a forecast by extrapolation looks favorable over a long time span.

A current stimulus, over and beyond the usual state and federal funds for highway bridge construction, is a federal authorization of $4.2 billion for the replacement and rehabilitation of older bridges. This money is to be spent for fiscal years 1979 through 1982. In all probability additional funds will be appropriated after 1982.

War is an ever present possible madness of mankind that must be considered in any extensive forecast. Its effects on bridges are manyfold. In a direct enemy attack, bridges are generally one of the first targets for destruction because of their importance in the transportation system. In military assault situations, bridges often have to be constructed where none existed before. On the home front where no actual battles rage, economic priorities for the war effort generally result in less funding for bridge construction or maintenance. Finally, at the conclusion of a war, a program for rebuilding bridges is generally required. Paradoxically, postwar rebuilding of bridges can actually be progressive in terms of bridge engineering, as innovative ways of construction are demanded as constrained by material, monetary, and manpower shortages. The post-World War II rebuilding of bridges in Europe is a notable case in point where new developments in prestressed concrete, cable-stayed bridges, and orthotropic deck construction came into being. Even during a war, developments can take place. An outstanding example of wartime developments is the Bailey bridge, a relocatable, variable span, truss bridge used initially in World War II by the military and subsequently for temporary bridges the world over.

The occurrence of one or more wars around the world between 1980 and the year 2000 is a virtual certainty, given the tensions and state of armaments of nations and rebel groups in many places worldwide. A prediction of the direct involvement of the U. S. in a war is somewhat more probabilitic; however, based on the military record of the U. S., there is a strong probability that it will be involved. (It is to be hoped that such an engagement will be a short and limited one.)

The following is a list of miscellaneous forecasts, as culled from opinions of experts given in references 23-45, which are related directly or indirectly to bridge construction.

Increased concern for manpower safety on construction projects

Requirement for warranties on all construction

More conservation and recycling of materials, accompanied by more research for synthetics and substitutes

For air pollution control, covering of demolition projects by large plastic envelopes

Monitoring of field work by video cameras controlled in a central office

Greater use of computer links between field and office work

Retention of basic craft system by construction labor force; a mix of union and nonunion personnel, with little change from present arrangement

Use of solar powered heating elements in bridge decks for deicing

Development of quilt pile driving methods

Increased use of lasers in construction

Use of shaped charge explosives

Inexpensive design and fabrication of "one of a kind" items through automation and computers

Some use of "slave" machines as robots

Repair of equipment by plug-in units, with repair of these units by low paid mechanics in foreign countries

Development of very innovative new major bridges in developing countries because of few restricting regulations. Design and construction, however, will be done by engineers in highly industrialized countries

Conversion to metric (System International) units

Greater restrictions on the use of private vehicles, especially in cities

More separation of vehicles and pedestrians in urban areas, as by walkways over the street (as currently seen in Minneapolis, Cincinnati and Houston)

Some development of automated highways

Increasing concern for the preservation of historical bridges

Rise of frustration and limitation of decisive action caused by increasing, conflicting, and often impossible demands by citizens on government.

A few quotations pertaining to general aspects of the future follow:

> "Before the end of the century, the U. S. will probably pass through a series of material crises." (H. B. Stussman, ref. 28, p. 359, in reference to shortages of materials.)
>
> "Nonusers may fall by the wayside." (A. J. Fox, Jr., ref. 28, p. 425, in reference to the use of computers.)
>
> "As people may recognize that going from A to B faster and more often does not always make them happier than staying at A, if A is a pleasant spot. In this unlikely event, the demand for transport might decline." (D. King-Hele, ref. 33, p. 82.)

> "Slow changes are symptomatic of high inertia systems. The wheeled automobile is imbedded in our economy and probably could not be replaced by another form of personal transportation (for example, hovercraft) very rapidly." (T. J. Gorden, ref. 40, p. 169.)

It is noteworthy that forecasts of future transportation systems as perceived by experts in the socialistic society of the USSR, as contained in the book "The Future of Society" (ref. 37), closely parallel those of western analysts and experts. In other areas, however, there are differences. Soviet forecasters tend to be more optimistic than others in regard to reserves of energy, minerals, food and the like. Philosophically, they see solutions to their problems through social control and heavy reliance on science and technology, all under a central authority. Their view that social problems can be solved with technology is unlike the opinion of many in democratic societies, where there is a growing love-hate relationship with technology and a disenchantment on the part of many with technology as a panacea for the world's ills.

CONCLUSIONS

The conclusions drawn from the FINDINGS portion of this report are presented in two sections. The first section (I) relates to probable developments in bridge engineering and construction between the years 1980 and 2000. The second section (II) cites topics or areas of research that are needed to effect the desired future of bridge engineering and construction. By conducting and implementing the needed research in section II, many of the developments forecast in section I virtually become self-fulfilling prophecies.

I. Probable Developments

As an overview, engineers generally tend to be optimists about the future. Problems are seen as challenges which by hard work and ingenuity can be solved. Except when there is undue political interference, this position is borne out by the history of technological development. Continued forward development then can be expected. However, changes in bridge construction will be by evolution rather than revolution, as most bridge engineers are conservatively progressive in their outlook. (With lives and large amounts of money at stake in bridge construction, this position is understandable.)

Economic downturns, wars and other deleterious political events play only a short-term role in technological development. In the long term, technological developments continue to go forward worldwide, motivated by mankind's needs and inner creativity. In modern society, the aspirations for a satisfactory standard of living for large masses of people cannot be attained without benefit of technology.

Focusing on matters more specific to bridges, conclusions are presented first with regard to the maintenance and rehabilitation of existing bridges and then with regard to the design and construction of new bridges, with the recognition that a certain amount of overlap does exist.

There is almost unanimous agreement that the maintenance and rehabilitation of old bridges will assume a very high percentage of time and money budgeted for bridge work in the years to come. Except for the many vitally needed new replacement bridges, the level of completely new bridge work will be considerably less than in preceding years. With the growing high cost of new construction, rehabilitation of old bridges will be seen as a desirable and feasible alternative. New rapid methods of repair will of necessity be developed. New materials and equipment specifically intended for rehabilitation will become available to assist the process. Among these might be high strength adhesives for repair and chemicals for impregnation of old concrete for strengthening. New equipment might include apparatus that enables repair work to be done from only one side of a structure (to speed repairs and minimize the disruption of traffic).

Old bridges will be subjected to rigorous inspection in the interest of public safety and many will be instrumented with automatic recording equipment to determine with exactness loads, stresses, deformations, cracks and the like. Computer analysis, using three-dimensional theories, will be used, along with field load tests, to ascertain the true strength of many old and rehabilitated bridges.

The engineering aspects of revitalizing old and deteriorating bridges will become upgraded and refined to a new level of excellence and respectability. Many useful and cost-saving standardized procedures will result.

Confrontation with the growing problem of repair of existing bridges is expected to lead to a number of changes in the design and construction of new bridges through the incorporation of features that will result in less or easier maintenance. A digest of these follows.

Use of concrete with better durability

More durable concrete decks, as by use of better sealants or polymerized concrete

Reinforcing for concrete and prestressing tendons more corrosion resistant, possibly nonmetallic

Greater use of prestressing to eliminate cracking in concrete

Use of metals with improved fatigue and brittle fracture resistance

Increased use of weathering steel

Better drainage and ice control systems

Better bridge safety rails

Fewer joints, as by use of continuity and flexible piers

More easily repairable construction, as by use of removable prefabricated components

More attention to possible seismic forces

Overpass bridges of longer span with fewer piers, to reduce collision damage

Greater vertical clearances for overpass bridges, to minimize collision damage

More secure foundations, through better subsurface investigations

Better flood and scour resistant foundations

New bridges and bridge practices will change for other reasons and in other ways as well. The following is a brief summary of the major changes expected. A detailed listing may be found in the section entitled "FINDINGS", parts B and C.

Because of population pressures, many thousands of new bridges, both large and small, will be constructed the world over. Many, perhaps most, of the major long span structures will be built in developing countries with record breaking spans. There will be a growing use of cable-stayed and prestressed segmental box girder bridge types for the longer spans. Some relatively new bridge types are likely to emerge, as stress-ribbon and tubular.

In the industrialized countries, including the U. S., there will be a continued concern for esthetics and environmental harmony. In urban areas, concern for safety will promote greater separation of vehicles and pedestrians as by divided or separate bridges. However, as counterpressures of economy become significant, there probably will be some easing of environmental considerations; although close regulation of construction by federal and state authorities will remain, if not increase.

Costs of construction will rise dramatically in both material and labor sectors. To offset high labor costs, better and more automatic equipment will be developed and used. There will be more prefabricated and less on-site, labor-intensive construction. Conventional bridge materials as concrete and steel will become more expensive and, at times and places, in short supply. Efforts will be made to do more with less, as by use of higher strength materials, more optimum designing and the use of recycled materials. The use of concrete as compared with steel is expected to grow as concrete strengths become higher, and prestressed concrete will become favored over ordinary reinforced concrete. Some use of substitute materials as reinforced plastic is also anticipated. The use of wood as a structural material for bridges will continue to be limited, and when used will generally be as a pressure treated laminate.

Electronic computers will penetrate further into almost every aspect of design, construction and management. Analysis and design procedures will become more exact and complex, although the availability of standard computer programs will serve to make the operations more manageable. A shift to metric (SI) units is expected; first as a "soft" numerical conversion, then as a "hard" produce conversion.

II. Research Needed

Only those subjects relating directly to the design and construction of bridges are listed. Also, the list is not represented as being complete. Rather, the issues are particular ones brought out by this study which may be of value to those concerned with bridges of the future. Unless a number of the research problems listed are resolved, the larger anticipated developments in bridge work are not likely to materialize; and so these research projects assume a very important role. Research on many of the items has already begun; however as development and improvement is a never ending process, all the items may be seen as future objectives to be reached.

Acquisition of reliable data concerning actual static and dynamic loads on bridges of different lengths and types, now and in the future.

Development of concrete with characteristics of high strength, light weight and great durability at a reasonable cost, polymerized or nonpolymerized.

Development of noncorrosive reinforcing material for concrete, either coated steel or a nonferrous material as glass or plastic.

Developments in prestressing, particularly posttensioning, to reduce cost through simplification

Improvements in welding procedures to reduce fracturing

Development of low cost substitute or recycled materials to replace conventional steel and concrete

Development of standardized computer programs for reliable three-dimensional analysis and design of structures

Development of less labor-intensive ways to construct foundations, perhaps through prefabrication

Improvements in methods of determining sub-soil conditions

Comprehensive study of structural forms and methods to optimize materials, energy, labor and the like

Development of maintenance free discontinuities as joints and bearings

Development of rapid repair methods for rehabilitating old bridges

Development of a reliable structural adhesive

Development of standardized short to medium span variable length bridges

Investigation of active control systems for long span bridges

Development of solar powered or other automatic system for deicing of decks (other than by salt)

Establishment of practical ways to preserve selected historic bridges

In forecasting any future, some surprises are expected; however, a consensus of authorities on the subject described in this study holds that continued and generally predictable evolutionary developments will take place this century. As for the twenty-first century, few are so bold as to make predictions.

ACKNOWLEDGMENTS

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APPENDIX A

QUESTIONNAIRE

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FORECASTS IN BRIDGE ENGINEERING
FOR THE YEARS BETWEEN 1980 and 2000

Name and organization ______________________________

Permission to quote in report: yes ______________ no ______________

A. LOADS AND GEOMETRIC CONSIDERATIONS:

1. What changes in live loadings on highway or railway bridges do you foresee?

2. What changes in lane widths or vertical clearances on bridges do you foresee?

3. Do you foresee any traffic separation on bridges; as for automobiles, trucks, and bicycles, as well as pedestrians? Comment.

4. Other comments relating to loads and geometric considerations.

B. STRUCTURAL MATERIALS:

1. What changes in concrete strength and quality do you foresee?

2. What changes in the reinforcement of concrete do you foresee?

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3. What changes in prestressing concrete or tendons do you foresee?

4. What improvements in steel or materials used in joining steel do you foresee?

5. In what new ways will wood (either solid, laminated, or reconstituted) be used in bridges?

6. What "new" structural materials do you foresee being increasingly used in bridges (as aluminum, reinforced plastics, polymerized concrete, laminates and "space-age" composites)?

7. What bridge materials do you foresee becoming too scarce or expensive to use in conventional ways?

8. Other comments relating to structural materials.

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C. METHODS OF ANALYSIS AND DESIGN:

1. What changes in methods of analysis do you foresee (such as load factor methods or comprehensive dynamic analyses)?

2. Will design procedures be changed (as by greater computerization, increased regulatory standards, or more exact design equations)? Comment.

3. Do you foresee any changes in regard to bridge testing at either the small-scale or full-scale level? Comment.

4. Other comments relating to methods of analysis and design.

D. SUBSTRUCTURE DESIGN:

1. What changes do you foresee in geophysical exploration?

2. What developments in regard to hydraulics or water flow control around bridges do you foresee?

3. What new developments in the control of soil and rock properties do you foresee?

4. Do you foresee any new developments in prefabrication or industrialization of foundations? Comment.

5. What changes in the design of pile foundations do you foresee?

6. Other comments relating to substructure design.

E. SUPERSTRUCTURE DESIGN:

1. Do you foresee any new types of superstructure configuration becoming popular (as stress-ribbon or tubular)? Comment.

2. What current types of superstructures (as arches or simple span girders) do you foresee losing in popularity?

3. Do you expect free span lengths of various bridge types (as girder, truss, rigid frame, arch, cable-stayed, and suspension) to generally increase? Comment.

4. What advances in moveable or floating bridges do you foresee?

5. At what locations around the world do you anticipate seeing major new bridges?

6. Will there be a trend toward joint-use bridges (as for vehicles and housing or retail stores)? Comment.

7. Other comments relating to superstructure design.

F. MISCELLANEOUS DESIGN FACTORS:

1. Comment on any changes you foresee in regard to details as corrosion prevention, bearing design, sealants, parapets, railings, lighting, ice control and drainage.

G. NONTECHNICAL CONCERNS:

1. Comment on how you see social, environmental, economic, political, population, labor, esthetic, or other nontechnical concerns affecting bridge design and construction.

H. CONTRACTS:

1. Will there be any changes in regard to the way bridge designers are awarded contracts? Comment.

2. Comment on what changes you foresee concerning the preparation of contract documents as drawings, specifications, and other legal instruments.

3. Will there be any changes in the manner of payment for services, either to the designer or builder?

4. Other comments relating to contracts.

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I. CONSTRUCTION PRACTICE:

1. What changes are likely in the area of earth and rock excavation?

2. What developments in equipment or machinery used for fabrication or erection of bridges do you foresee?

3. What new methods are likely to be employed for the rapid repair of bridge structures?

4. Are design-build bridge companies as existing in Europe likely to gain in practice in the United States?

5. Other comments relating to construction practice.

J. MAINTENANCE:

1. Comment on changes you foresee in regard to maintenance, repair, strengthening or widening of existing bridges.

2. What new developments do you foresee directed toward maintenance-free bridges?

3. Other comments relating to maintenance.

K. OTHER COMMENTS OR FORECASTS:

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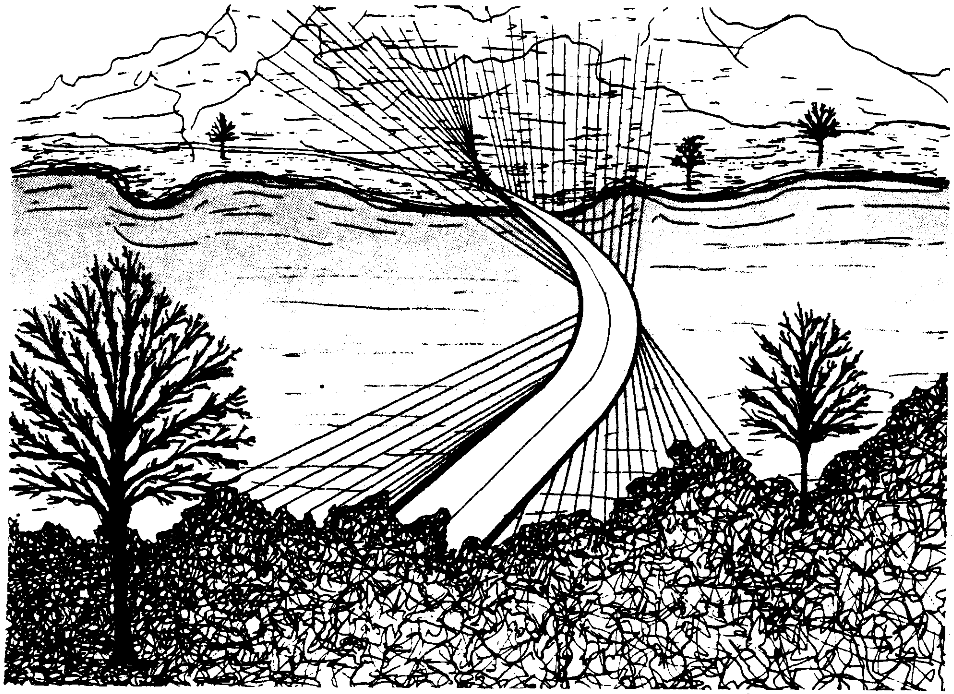
APPENDIX B

SOME PROPOSED BRIDGES OF THE FUTURE

(Arranged in terms of technological development, beginning with structures needing the least amount of new technology)

Papago Freeway, Phoenix, Arizona, by Johannessen and Girand

This urban skyway for vehicles is to be constructed of precast concrete 100 ft. above the ground and with piers 170 ft. apart. Helical interchanges connect the skyway with surface roads. The great height above the ground is to psychologically minimize the impact of the elevated roadway on inhabitants below.

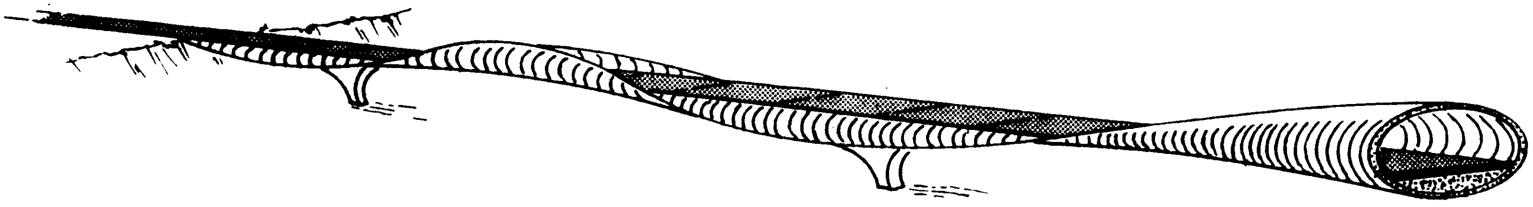


Ruck-A-Chucky Bridge, California, by T. Y. Lin

This suspension structure is unique by virtue of the horizontally curved roadway and cable anchorage system into the walls of the canyon. The span is 1,300 ft. and the centerline radius of curvature is 1,500 ft.

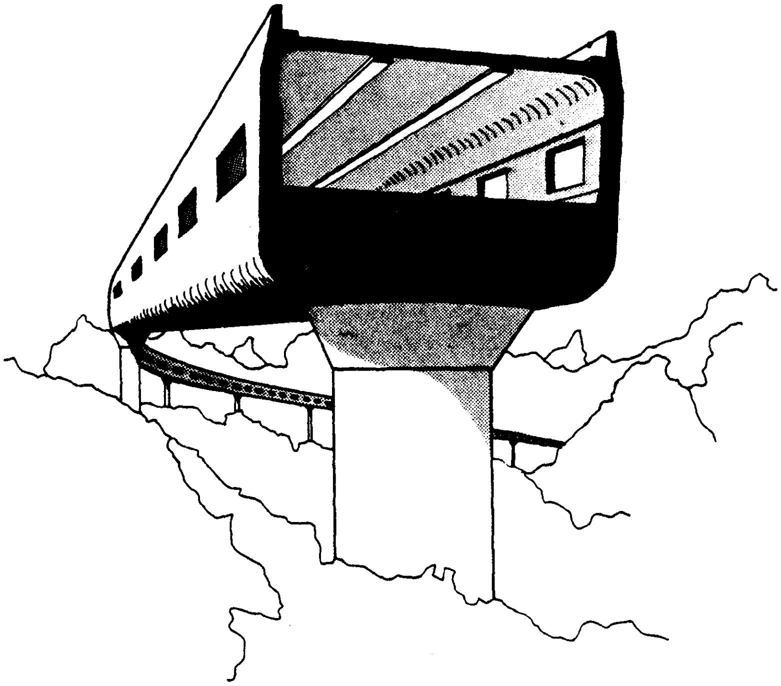
Baltimore Harbor Bridge, Maryland, by Lev Zetlin

Spanning 840 ft. between towers, this bridge is supported by an innovative "cat's cradle" system of force and counterforce cables providing stability against static and dynamic loads.



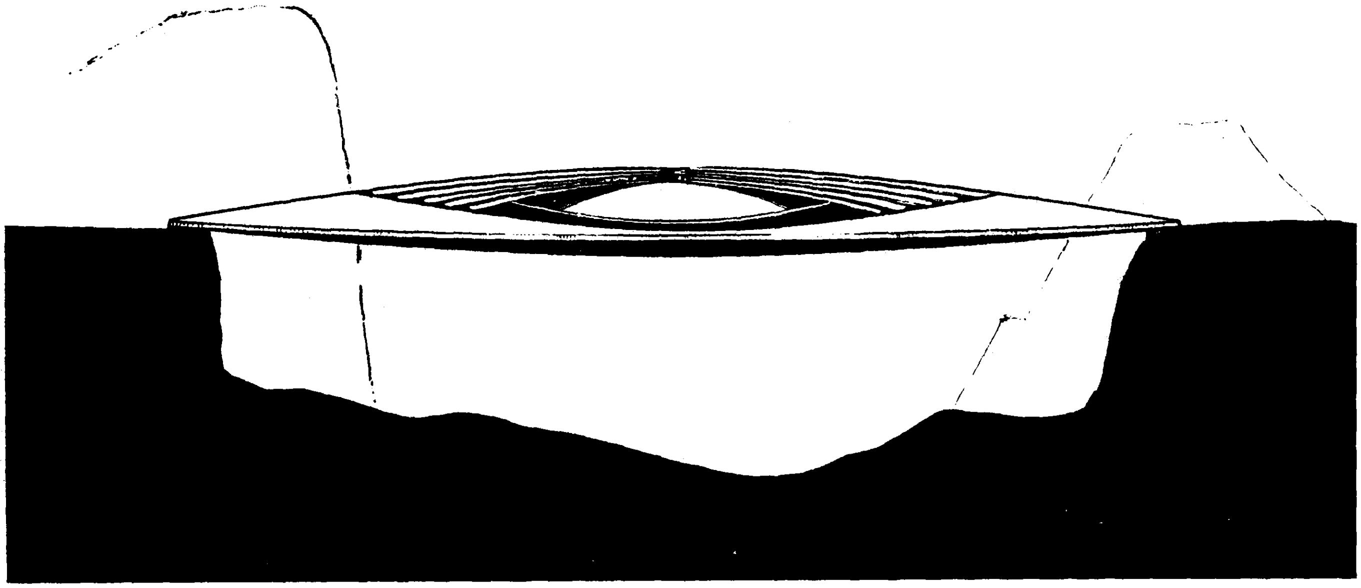
Open Tube Bridge by Paolo Soleri

Made of reinforced concrete, the bridge displays an elegant union of esthetics and engineering. The gracefully flowing shapes nicely match the differing structural needs along its length.



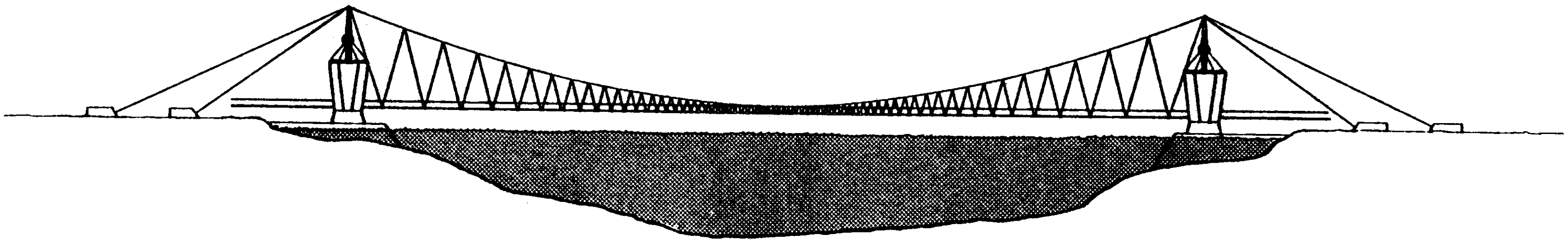
Trans-Alaska Bridge, from Prudhoe Bay to Valdez, by T. Y. Lin

The upper levels of this 800 mile long tubular bridge of prestressed concrete are for wheeled vehicles, and the lower chambers are for oil and gas pipe lines. The tube, supported by piers every 350 ft., stands 50 ft. above the ground.



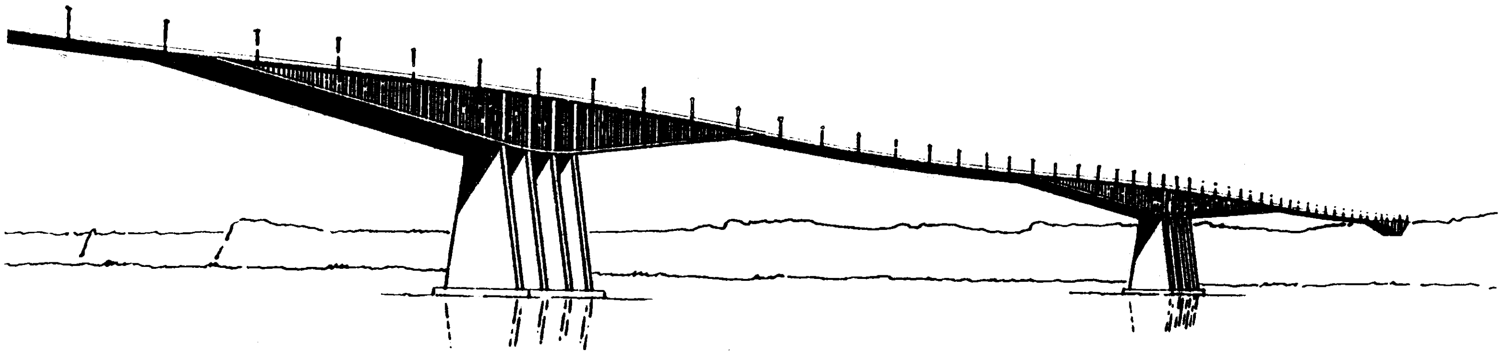
High Esthetic Bridge by Paolo Soleri

Although the design is highly influenced by esthetics, it is a structurally stable form functioning as a stiffened flat tied arch.



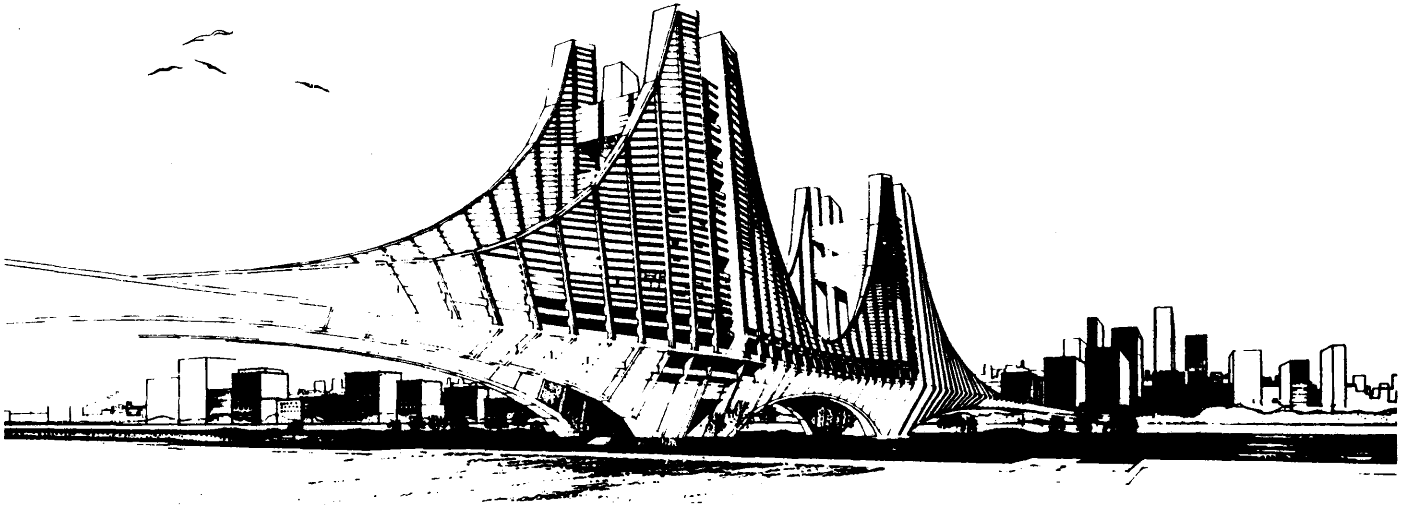
Messina Strait Bridge, between Italy and Sicily, by Pier Luigi Nervi

With a free span of 9,900 ft., this suspension bridge would more than double all existing span lengths.



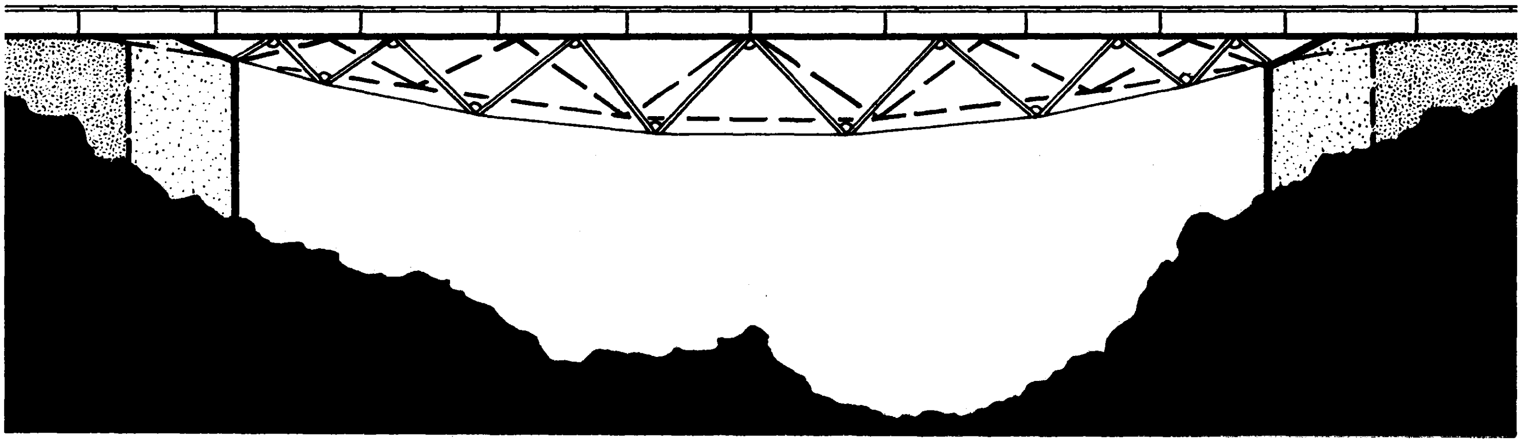
Bosporus Bridge, Turkey, by Ulrich Finsterwalder

Of prestressed concrete, the spans are flat catenaries or stress ribbons anchored at the land ends. The main center span is 1,346 ft.



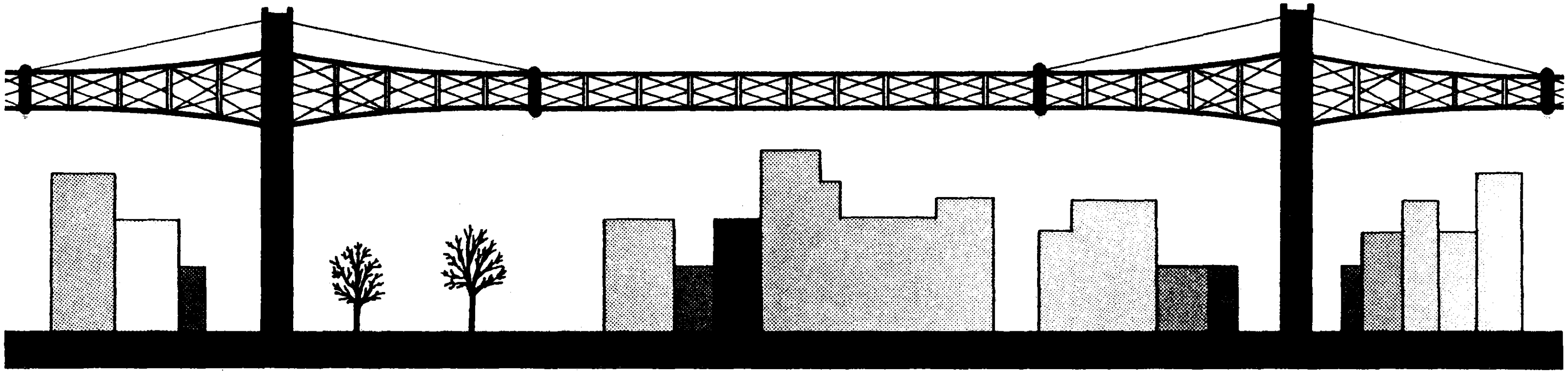
Multiple Use Bridge, across the East River at New York City, by James Chapman and George McClure

In addition to functioning as a vehicular crossing, the bridge contains housing units, parking facilities, a shopping center and recreational areas.



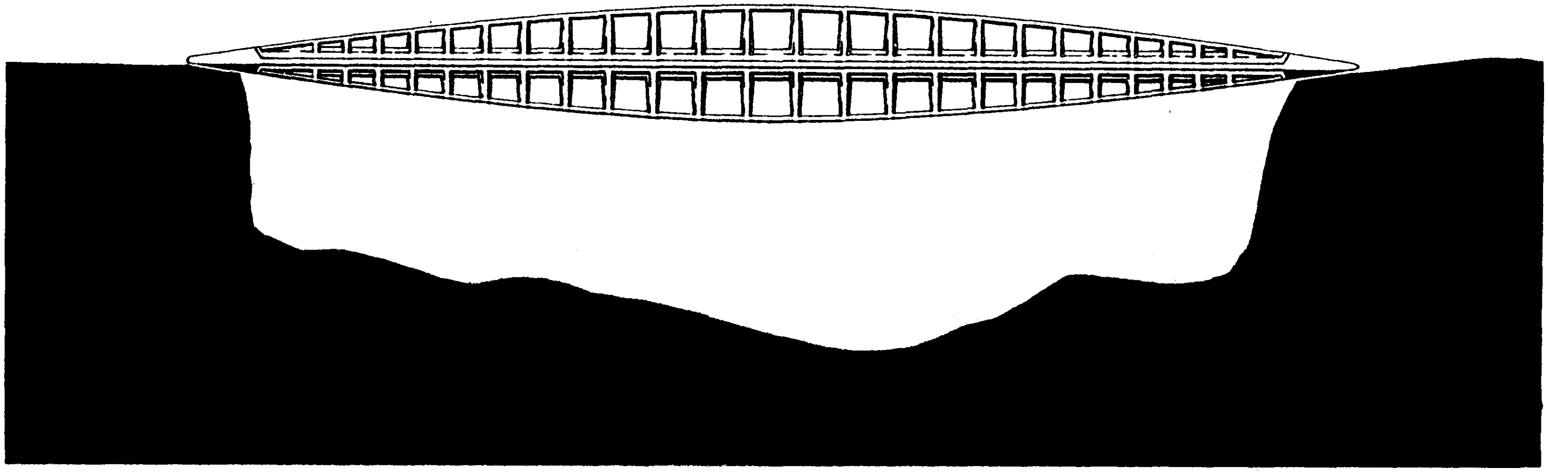
Kinetic Bridge, by William Zuk

This standardized bridge is designed to span a variety of distances by folding or unfolding. The web members are high strength sandwich panels with hinged connectors. The lower chords are prestressed tendons and the upper deck is extruded lightweight concrete.



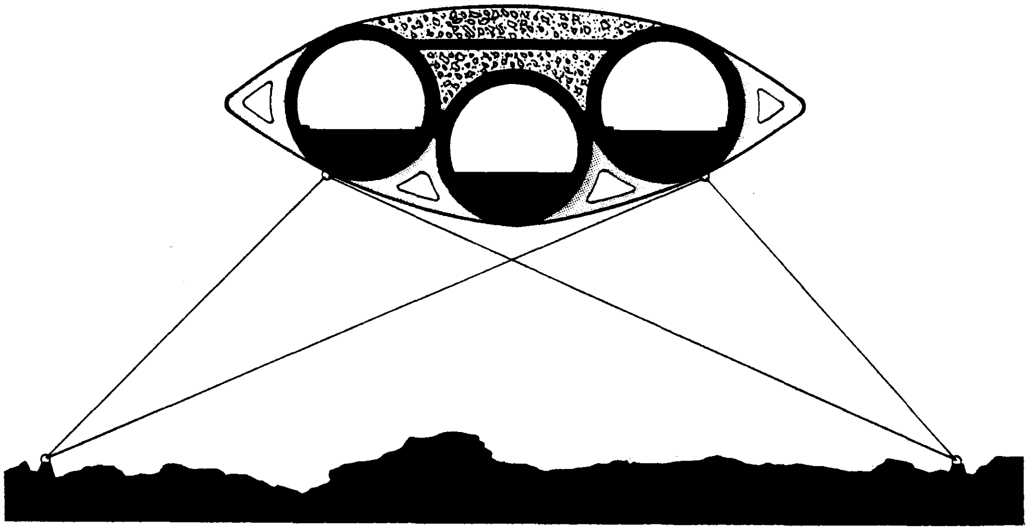
Lattice Tube Skyrail Bridge, by Robert LeRicolais

Designed as a rapid rail system to soar some 300 ft. above congested cities, the bridge is made of circular steel stiffening rings joined by a network of diagonal tension cables. The tube diameter varies from 30 to 50 ft. (large enough to accommodate two trains) and spans 1,500 ft.



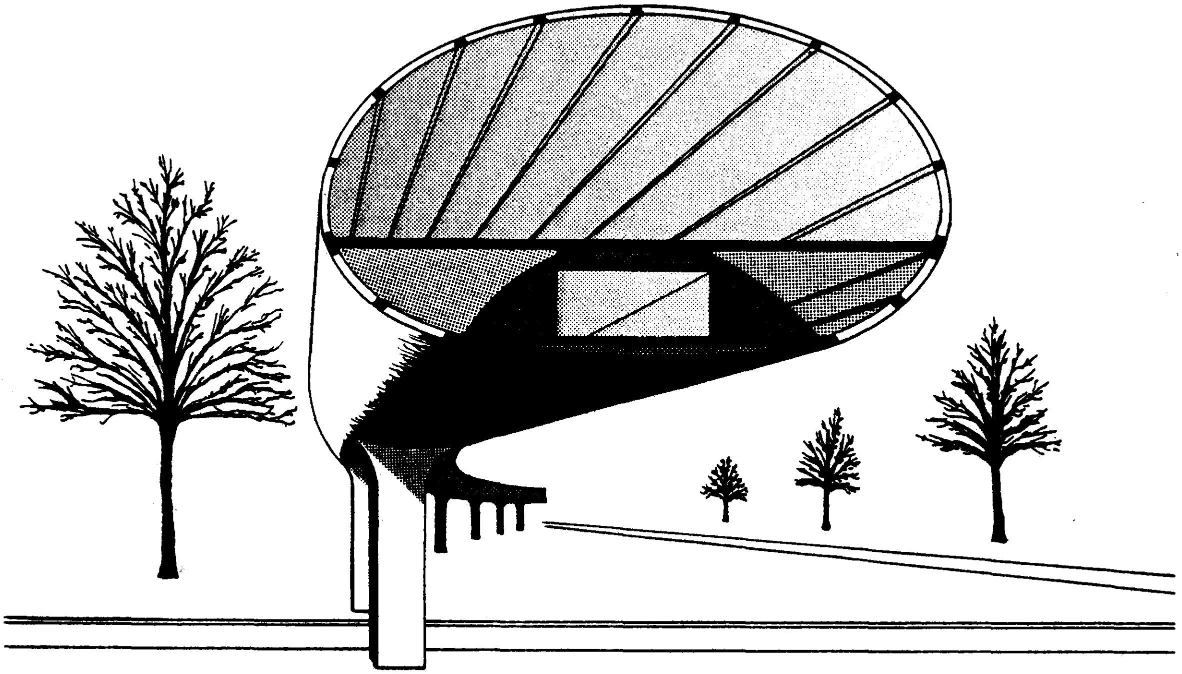
Prestressed Metal and Plastic Bridge, by Paolo Soleri

Made of high strength metal and plastic segments, the units would be locked together by posttensioning tendons. The shape clearly expresses its function.



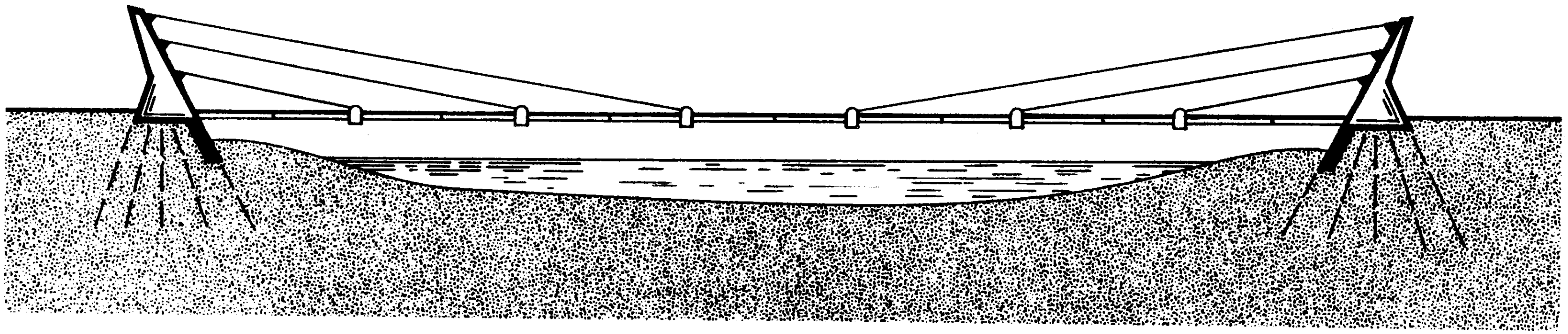
Underwater Bridge, across the Messina Strait, by Alan Grant

Positioned below the surface of the water, the sealed tubular bridge made of concrete and steel is held down (rather than up) by adjustable anchor cables fastened to the sea bottom. This unusual two-mile long bridge would carry both rail and highway traffic.



Plastic Tubular Bridge, by Jan Sulkiewicz and Juhani Virola

The bridge is significant in that it has been designed almost entirely of laminated plastic using double skinned curved sandwich plates. As might be used in an urban area, the upper chamber is for vehicles and the lower ones are for utilities.



Actively Controlled Bridge, by William Zuk

This is a modified cable-stayed bridge where the cables are actively controlled to develop the forces necessary to minimize undesirable deformations caused by static or dynamic loads. Sensors on the deck would detect movements and signal jacks attached to the cables to react appropriately.