

Forecast of Bridge Engineering: 1980-2000

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Presented is a summary of the responses to a questionnaire on the future of bridge engineering sent to leaders in the field of bridge engineering and construction. The questionnaire requested information on loads, geometry, materials, analysis, design, contracts, construction, maintenance, and other, nontechnical concerns. From the replies, as well as incidental related information on the future contained in current literature, a composite forecast of the future of bridges through the rest of this century is developed. A list of topics on which research is needed to attain the expected developments is also presented.

The forecast presented here was obtained in a three-pronged study undertaken to ascertain 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 that related directly or indirectly to bridges. From all of this, both specific and general conclusions about bridge engineering for the last part of this century were determined. Also developed was a list of research needed to meet the challenges ahead. A full description of the study is presented elsewhere (1).

This paper focuses primarily on the second phase of the study, in which a questionnaire was prepared and sent to 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 11 categories, as noted in the following section.

ABSTRACT OF QUESTIONNAIRE REPLIES

Loads and Geometric Considerations

1. "What changes in live loadings on highway or railway bridges do you foresee?"
 - a. Heavier highway loading by approximately 10-20 percent
 - b. Gross vehicle weights up to 445 kN (100 000 lbf) or 534 kN (120 000 lbf)
 - c. Greater attention to actual number and spacing of wheels
 - d. More specificity regarding dynamic loads caused by wheel impact, wind, and seismic forces
 - e. Reduction in live loads for bridges longer than 152.5 m (500 ft)
 - f. Increase in loads by military vehicles
 - g. No increase in railroad loading
 - h. In Europe, greater coordination of loadings on highway bridges between countries
2. "What changes in lane widths or vertical clearances on bridges do you foresee?"
 - a. No width change likely
 - b. Increase in vertical clearance on highway bridges of approximately 10-15 percent on key routes
3. "Do you foresee any traffic separation on bridges for automobiles, trucks, and bicycles, as well as for pedestrians? Comment."
 - a. In urban areas, a separation of vehicles, bicycles, and pedestrians
 - b. Some reserved lanes for public transit systems, e.g., buses
 - c. On some long-span bridges, separate lanes for trucks and automobiles
 - d. In some locations, separate bridges for trucks on truck-only highways
4. "Other comments relating to loads and geometric considerations."
 - a. Vehicle redesign that will force changes in loading
 - b. Bridges for airplanes at airports in order to adapt to new aircraft designs
 - c. Air-cushion vehicles that will cause loads to be reconsidered
 - d. More automatic monitoring and stricter enforcement of truck weights
 - e. More realistic fatigue effects

Structural Materials

1. "What changes in concrete strength and quality do you foresee?"
 - a. Ultimate stresses of 48-69 kPa (7-10 ksi) to become commonplace
 - b. Ultimate stresses of 83-100 kPa (12-14 ksi) used for special work
 - c. More use of lightweight aggregates
 - d. Concretes that will have better durability
 - e. New admixtures that will inhibit corrosion of reinforcing steel and protect against deterioration by salts and weather
 - f. Better quality control and testing procedures
 - g. Use of specialty concretes, e.g., polymers
 - h. Development of a concrete that is electrically conductive for deicing of bridge decks
 - i. In some areas, decreases in concrete strength and quality due to scarcity of good aggregates
2. "What changes in the reinforcement of concrete do you foresee?"
 - a. Some small strength improvement in steel rebars
 - b. Use of more high-strength wire mesh or bar mats
 - c. Greater use of corrosion-resisting coatings, e.g., epoxy and galvanizing
 - d. Greater use of fiber reinforcement, metallic and nonmetallic
 - e. Possible development of nonmetallic, noncorrosive reinforcement, e.g., fiberglass
 - f. Changes in bar sizes due to conversion to metric units
 - g. More automatic welding of steel rebars
 - h. Increase in percentage of reinforcement to limit cracking
 - i. Reduction in percentage of reinforcement to reduce cost
 - j. Greater confinement of concrete, by spirals or stirrups, to increase compressive ductility
3. "What changes in prestressing concrete or tendons do you foresee?"
 - a. Continued increase in ultimate strengths of concrete
 - b. More use of prestressing in comparison with ordinary reinforced concrete
 - c. More prestressing of decks transversely
 - d. More use of posttensioning methods
 - e. Greater use of partial prestressing
 - f. Greater control of stress losses
 - g. More reliable, smaller, and simpler anchorages

- h. Use of larger sizes of tendons for pretensioning
 - i. Development of tendons from plastics
 - j. Better protection of tendons against corrosion
 - k. More precise layout of tendons in accordance with actual stress patterns
4. "What improvements in steel or materials used in joining steel do you foresee?"
 - a. Continued improvements in quality and strength of steel
 - b. Increased use of corrosion-resisting steels, e.g., weathering steels
 - c. More automated welding procedures
 - d. Improvements in fabrication and testing against weld and brittle fracture failure
 - e. Development of fatigue-free welding procedures
 - f. Improvements in bolting that reduce the size of bolted joints
 - g. New automatic fasteners that develop proper tension on installation
 - h. Factory preassembled joints, as in off-shore oil rigs
 - i. Increased use of adhesives, e.g., high-strength epoxy resins, in place of welding or use of bolting
 5. "In what new ways will wood (either solid, laminated, or reconstituted) be used in bridges?"
 - a. Continued limited use for short spans in rural areas, for temporary or pedestrian bridges, or for special conditions of esthetics
 - b. Use of posttensioning of laminated decks
 - c. Use of reconstituted wood products that have improved properties in special situations
 - d. Glulam (a wood laminate) for longer-span bridges
 6. "What new structural materials do you foresee being increasingly used in bridges (e.g., aluminum, reinforced plastics, polymerized concrete, laminates, and space-age composites)?"
 - a. Better lightweight concrete
 - b. Increased use of polymerized concrete, particularly for decks
 - c. Fiber material, e.g., fiberglass, in the form of bars and strands for concrete reinforcement
 - d. Laminates of various kinds, some with plastics
 - e. Plastic stay-in-place forms
 - f. Epoxy-impregnated decks
 - g. Increased use of aluminum in retrofitting
 - h. "Exotic" materials and composites for bearings, joint seals, and special applications
 - i. Increased use of recycled materials, including concrete and steel
 7. "What bridge materials do you foresee becoming too scarce or expensive to use in conventional ways?"
 - a. None were listed as vanishing completely, but the following were listed as growing scarce or expensive: timber, high-strength and corrosion-resisting steels, aluminum, and concrete, in some areas
 - b. Continued trend away from steel toward concrete, because of cost
 8. "Other comments relating to methods of analysis and design."
 - a. Emphasis on lightness
 - b. More imaginative use of our resources
 - c. Greater use of recycled materials
 - d. Steel that has increased modulus of elasticity e.g., thermal stresses, seismic forces, fatigue, residual stresses, creep, erection stresses, and progressive collapse
- b. More sophisticated computer analysis, e.g., finite-element methods, on standardized programs
 - c. Concern for overall interactive three-dimensional behavior
 - d. Increased use of load-factor design
 - e. New determination of safety factors
 - f. Greater use of probabilistic concepts
2. "Will design procedures be changed (as by greater computerization, increased regulatory standards, or more exact design equations)? Comment."
 - a. More design by computer, with standard programs
 - b. Design procedures to be changed by continuing research in regard to realistic equations
 - c. Greater concern for fail-safe design
 - d. Greater use of computers that will require safeguards against excessive faith in computer-generated numbers
 3. "Do you foresee any changes in regard to bridge testing at either the small-scale or full-scale level? Comment."
 - a. Continued but limited use of small-scale laboratory tests
 - b. More full-scale testing for understanding of realistic behavior
 - c. More testing of older bridges for load rating and to minimize repair or replacement
 - d. Instrumentation for long-term measurements of in-service bridges
 4. "Other comments relating to methods of analysis and design."
 - a. More emphasis on new concepts in design
 - b. More concern about deformations
 - c. Current basic research to have important influence on future bridges
 - d. Analysis and design to take heed of real-world defects in materials and construction
 - e. Clarification of currently confusing American Association of State Highway and Transportation Officials (AASHTO) specifications

Substructure Design

Methods of Analysis and Design

1. "What changes in methods of analysis do you foresee (such as load factor methods or comprehensive dynamic analysis)?"
 - a. More exact analysis of secondary factors,

1. "What changes do you foresee in geophysical exploration?"
 - a. More reliable methods to obtain borings by using new measuring devices
 - b. Increased use of sophisticated subsurface surveys by using sonic and electrical-resistance techniques
 - c. Increased use of aerial remote sensing
 - d. More standardization of exploration methods and tests
 - e. More uniform classification of materials
 - f. More precise prediction of soil-bearing capacity, settlement, groundwater flow, and earthquakes
2. "What developments in regard to hydraulics or water-flow control around bridges do you foresee?"
 - a. Greater knowledge of flood conditions
 - b. Greater use of hydraulic model studies
 - c. Developments in understanding ice flow
 - d. More reliable methods of scour analysis
 - e. More use of spur dikes and scour blankets
 - f. More emphasis on nondisturbance construction, e.g., fewer piers
3. "What new developments in the control of soil and rock properties do you foresee?"
 - Greater use of such 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, and massive compaction methods of granular soils
4. "Do you foresee any new developments in prefabrication or industrialization of foundations? Comment."
 - a. Increased use mostly in connection with precast piers, pier caps, abutments, and piles
 - b. Use of precast foundations for underwater and mud sites
 - c. Increased use based on currently known methods; otherwise little or no change
 5. "What changes in the design of pile foundations do you foresee?"
 - a. Greater use of dynamic analysis (by computers) for piles and pile-group driving and design
 - b. Trend toward fewer piles that have larger load capacities
 - c. Use of high-strength, highly reinforced precast piling set in drilled holes and pressure grouted to lock to the soil
 - d. Greater use of root-pile (Fondedile) systems
 - e. Better control in placing
 - f. More knowledge of tip behavior
 - g. Better pile splices and tips, possibly prefabricated
 - h. More quick in situ load tests
 6. "Other comments relating to substructure design."
 - a. Large-scale in situ foundation tests that may lead to better foundations
 - b. Reduction in safety factors in foundation design that will occur as a result of better knowledge
 - c. Load factor design extended to foundations as well as superstructures
 - d. More attention paid to seismic conditions
 - e. Greater use of soil-structure bridges and reinforced earth
 - f. Provision of flexible piers to avoid expansion bearings and joints
 - g. Improved caisson and sheet-piling techniques
 - h. Use of cofferdams for underwater work that are prefabricated members joined by tremie concrete or grouting
 - i. Foundations in water that may be similar to off-shore drilling platforms
 - j. Use of better fendering and warning systems for protection of bridge piers in navigable waters
 - k. In mountainous areas, use of cable supports tied directly to rock anchors in the mountain
 - e. Replacement of short-span bridges by arch culverts
 - f. Fewer cast-in-place concrete superstructures
 - g. Decreased use of steel in favor of concrete in superstructures
 3. "Do you expect free-span lengths of various bridge types (e.g., girder, truss, rigid frame, arch, cable-stayed, and suspension bridges) to generally increase? Comment."
 - a. Yes, because of the need to eliminate piers for overpasses and in water
 - b. Yes, because of better materials and higher strength-to-weight ratios of structures
 - c. Increases especially in prestressed concrete and cable-stayed types
 4. "What advances in movable or floating bridges do you foresee?"
 - a. Advances to be slow since so few will be built (generally replaced by fixed high-level bridges)
 - b. Increased use of floating bridges and floating submerged tunnels in deep water
 - c. Wide military use
 - d. Structures to be lighter, e.g., by orthotropic construction
 - e. Development of inflatable floating bridges
 - f. More automatic and solid-state electronic controls
 5. "At what locations around the world do you anticipate seeing major new bridges?"
 - a. Japan, between islands
 - b. Scandinavian countries, at water crossings
 - c. Soviet Union, especially Siberia
 - d. Central Europe
 - e. In developing countries of Africa, South America, Asia, and the Middle East
 - f. In China, Korea, Polynesia, and Turkey
 - g. Across the Dardanelles and Messina Straits
 - h. In the United States, not too many, mostly in coastal areas
 6. "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
 7. "Other comments relating to superstructure design."
 - a. Bridges to be more durable
 - b. More concern for esthetics and relationship to the environment
 - c. More standardization for short- to medium-span bridges

Superstructure Design

1. "Do you foresee any new types of superstructure configuration becoming popular (e.g., stress ribbon or tubular)? Comment."
 - a. More box girders, some extremely novel
 - b. Growing use of prestressed segmental construction in the United States
 - c. Growing use of cable-stayed structures
 - d. More delta-frame bridges
 - e. Some stress-ribbon and space-frame bridges
 - f. Emphasis on membrane behavior
 - g. New concepts to have difficulty
2. "What current types of superstructures (e.g., arches or simple span girders) do you foresee losing in popularity?"
 - a. Steel truss bridges of all types
 - b. Built-up plate girders
 - c. Concrete arches and tied arches, except for esthetic purposes
 - d. Fewer simple span girders, although still to be used in many situations

Miscellaneous Design Factors

- "Comment on any changes you foresee in regard to such details as corrosion prevention, bearing design, sealants, parapets, railings, lighting, ice control, and drainage."
- a. Use of designs and materials to reduce deterioration and maintenance
 - b. Fewer and better joints
 - c. Greater use of "catalog" bearings
 - d. More ice-control details
 - e. Better drainage systems
 - f. More and better energy-absorbing rails
 - g. More extensive use of high-mast and energy-efficient lighting

Nontechnical Concerns

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

- a. All these factors to become increasingly important
- b. Special interest groups to continue to exert pressure, resulting in delays and frustration
- c. Bridges designed in special ways just to avoid environmental problems
- d. More use of bridges in certain environmentally sensitive areas, e.g., marshes
- e. Greater use of noise barriers in urban areas
- f. More delays because of environmental concerns
- g. More concern for safety against catastrophic occurrences
- h. Continued shortage of skilled workers that will result in greater use of prefabrication
- i. More attention to life-cycle costs, instead of first cost
- j. Trend toward use of concrete and away from other materials because of greater utilization of domestic resources and energy considerations

Contracts

1. "Will there be any changes in regard to the way bridge designers are awarded contracts? Comment."
 - a. Competitive bidding for engineering services to increase, particularly for projects that involve total design and construction
 - b. More concern over the cost of design
 - c. As costs mount, states possibly to do their own designing
 - d. Trend toward one organization to plan, design, and build, along with variations in the nature of design-build teams of allied planners, designers, and builders
2. "Comment on what changes you foresee concerning the preparation of contract documents, e.g., drawings, specifications, and other legal instruments."
 - a. Contract documents that will allow flexibility for contractors to use their special talents or equipment in order to allow alternative designs, options on certain products or details, greater use of end-result specifications, and cost-reduction proposals
 - b. Documents to become increasingly performance oriented and to have fewer drawings by designer and more by builder
 - c. Increase in preparation of alternative designs and materials in order to obtain lowest cost
 - d. More use of computers, especially for drawings and specification writing
 - e. Possible national or international specifications
 - f. National laws relating to time limitations for design responsibility
 - g. Procedural changes to reduce the number of contract claims
3. "Will there be any changes in the manner of payment for services, either to the designer or to the builder?"
 - a. Not much change
 - b. Possible incentive payments for savings that result from more sophisticated designs
 - c. Less use of payment per unit item and more of payment per linear measurement or per span
 - d. Possible gain in popularity of payment based on cost plus a fixed fee
4. "Other comments relating to contracts."
 - a. Time of construction to be more closely controlled
 - b. Trend toward awarding contracts based on competitive design or construction proposals
 - c. Contract documents to encourage contractor innovation

Construction Practice

1. "What changes are likely in the area of earth and rock excavation?"
 - a. Use of larger machines, especially for rock excavation, although small machines also to be used where suitable
 - b. Better control on demolition of rock work
 - c. Further improvement in tunneling techniques, particularly for vertical rock boring
 - d. Development of alternative methods of excavating, as by high-pressure jets, lasers, vibration, and vacuum
 - e. Use of clean atomic explosives for major excavations
 - f. More transportation of excavated materials in slurry form
2. "What developments in equipment or machinery used for fabrication or erection of bridges do you foresee?"
 - a. Heavier lifting equipment
 - b. More standardized machines and equipment
 - c. More automatically controlled fabricating systems that have better quality control
 - d. Innovations in concrete casting forms
 - e. Growing use of overhead construction methods
 - f. Development of special erection equipment, e.g., launching machines and cableways, for segmental construction
 - g. Special new erection equipment to speed up bridge repair and replacement
 - h. Airborne and floating equipment that has large capacity
 - i. New equipment for producing the new materials of the future
3. "What new methods are likely to be employed for the rapid repair of bridge structures?"
 - a. Greater use of prefabrication
 - b. More use of precast components and prestressing systems, particularly posttensioning
 - c. Use of chemicals or injections to strengthen existing concrete
 - d. Development of a workable structural adhesive for repair
 - e. Improved field welding techniques
 - f. Development of repair techniques that require access from only one side
4. "Are design-build bridge companies as they exist in Europe likely to gain in practice in the United States?"

Some gain
5. "Other comments relating to construction practice."
 - a. Reduction of on-site construction, time, and labor
 - b. Emphasis should be on prefabricated or factory construction of components
 - c. Growth of companies that specialize in bridge repair work and special construction methods
 - d. Improvements in underwater construction methods

Maintenance

1. "Comment on changes you foresee in regard to maintenance, repair, strengthening, or widening of existing bridges."
 - a. Many old bridges normally replaced to be rehabilitated and upgraded instead
 - b. More funding to be needed for inspection, maintenance, rehabilitation, and upgrading of bridges
 - c. More effort directed toward standardizing repair procedures
 - d. This phase of bridge engineering to grow in importance

2. "What new developments do you foresee directed toward maintenance-free bridges?"
 - a. Higher quality concrete for decks
 - b. Polymerized concrete decks
 - c. Better sealants for decks
 - d. More use of rapidly replaceable prefabricated components, possibly precast polymerized units
 - e. Maintenance-free joints
 - f. Continuous spans that have flexible piers and few joints
 - g. Increased use of noncorroding reinforcing materials
 - h. More use of weathering steel
 - i. More use of plastics in certain components
 - j. Increased use of zinc-rich paint systems for steel
 - k. Use of deicing materials other than salt
3. "Other comments relating to maintenance."
 - a. Recognition as a major activity
 - b. Value engineering to be applied to bridges on a life-cycle basis
 - c. Deterioration of prestressed members that may require special methods of restressing them
 - d. Better methods of removal of debris from decks and joints to reduce deterioration from trapped water and salt
 - e. Development of monitoring devices for detecting and watching the propagation of cracks
 - f. Engineers to be diverted from designing new bridges to working on maintenance-related problems

Other Comments or Forecasts

1. Need for much greater research in all phases of bridge engineering
2. Future to offer a great possibility for major improvements in construction, design, and maintenance
3. Road transport vehicles to be much as they are now
4. Money for highways to become scarce

CONCLUSIONS

Probable Developments

Engineers generally tend to be optimists about the future. Problems are seen as challenges that 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, since most bridge engineers are conservatively progressive in their outlook.

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.

To focus 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 that 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 by means of automatic recording equipment to determine with exactness their loads, stresses, deformations, cracks, and the like. Computer analysis will use three-dimensional theories and 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:

1. Use of concrete that has better durability;
2. More-durable concrete decks, e.g., by use of better sealants or polymerized concrete;
3. Reinforcing for concrete and prestressing tendons that is more corrosion resistant, possibly nonmetallic;
4. Greater use of prestressing to eliminate cracking in concrete;
5. Use of materials that have improved fatigue and brittle-fracture resistance;
6. Increased use of weathering steel;
7. Better drainage and ice-control systems;
8. Better bridge safety rails;
9. Fewer joints, e.g., by use of continuity and flexible piers;
10. More easily repairable construction, e.g., by use of removable prefabricated components;
11. More attention to possible seismic forces;
12. Overpass bridges that have longer spans and fewer piers, to reduce collision damage;
13. Greater vertical clearances for overpass bridges, to minimize collision damage;
14. More secure foundations, through better subsurface investigations; and
15. 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.

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 and will have 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, e.g., stress ribbon and tubular.

In the industrialized countries, including the United States, 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. Nevertheless, close regulation of construction by federal and state authorities will remain, if not increase.

Costs of construction will rise dramatically in both the material and the 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, e.g., concrete and steel, will become more expensive and, at times and places, be in short supply. Efforts will be made to do more with less, e.g., by the use of higher-strength materials, optimum designing, and the use of recycled materials. The use of concrete rather than 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, e.g., reinforced plastic, is also anticipated. The use of wood as a structural material for bridges will continue to be limited and, when it is 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" product conversion.

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 that 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, since development and improvement are never-ending processes, all the items may be seen as future objectives to be reached:

1. Acquisition of reliable data about actual static and dynamic loads on bridges of different

lengths and types, now and in the future;

2. Development of concrete with characteristics of high strength, light weight, and great durability at a reasonable cost, polymerized or nonpolymerized;
3. Development of noncorrosive reinforcing material for concrete, either coated steel or a nonferrous material like glass or plastic;
4. Developments in prestressing, particularly posttensioning, to reduce cost through simplification;
5. Improvements in welding procedures to reduce fracturing;
6. Development of low-cost substitute or recycled materials to replace conventional steel and concrete;
7. Development of standardized computer programs for reliable three-dimensional analysis and design of structures;
8. Development of less-labor-intensive ways to construct foundations, perhaps through prefabrication;
9. Improvements in methods of determining subsoil conditions;
10. Comprehensive study of structural forms and methods to optimize materials, energy, labor, and the like;
11. Development of maintenance-free discontinuities, e.g., joints and bearings;
12. Development of rapid repair methods for rehabilitating old bridges;
13. Development of a reliable structural adhesive;
14. Development of standardized short- to medium-span variable-length bridges;
15. Investigation of active control systems for long-span bridges;
16. Development of a solar-powered or other automatic system for deicing of decks (other than by salt); and
17. 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 in this century. As for the 21st century, few are so bold as to make predictions.

REFERENCE

1. W. Zuk. A Forecast of Bridge Engineering: 1980-2000. Virginia Highway and Transportation Research Council, Charlottesville, Publ. 79-R55, June 1979.

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Bridge and Pier Protective Systems and Devices

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The design of fendering systems, which protect bridge piers against ship impact (or at least retard direct collision), has used basic fundamentals of physics and simple pile equilibrium. Certain assumptions can lead to grossly oversized systems or to inaccurate force evaluation in the entire support system. In order to improve the state of the art and provide accurate design data, while

maintaining simple design standards, a comprehensive design study was initiated by the U.S. Coast Guard. The study included examination of the state of the art in bridge fendering, development of improved design criteria, preparation of spring constant curves for various types of fenders, and presentation of design examples. In the course of the study, it became obvious that a complex com-