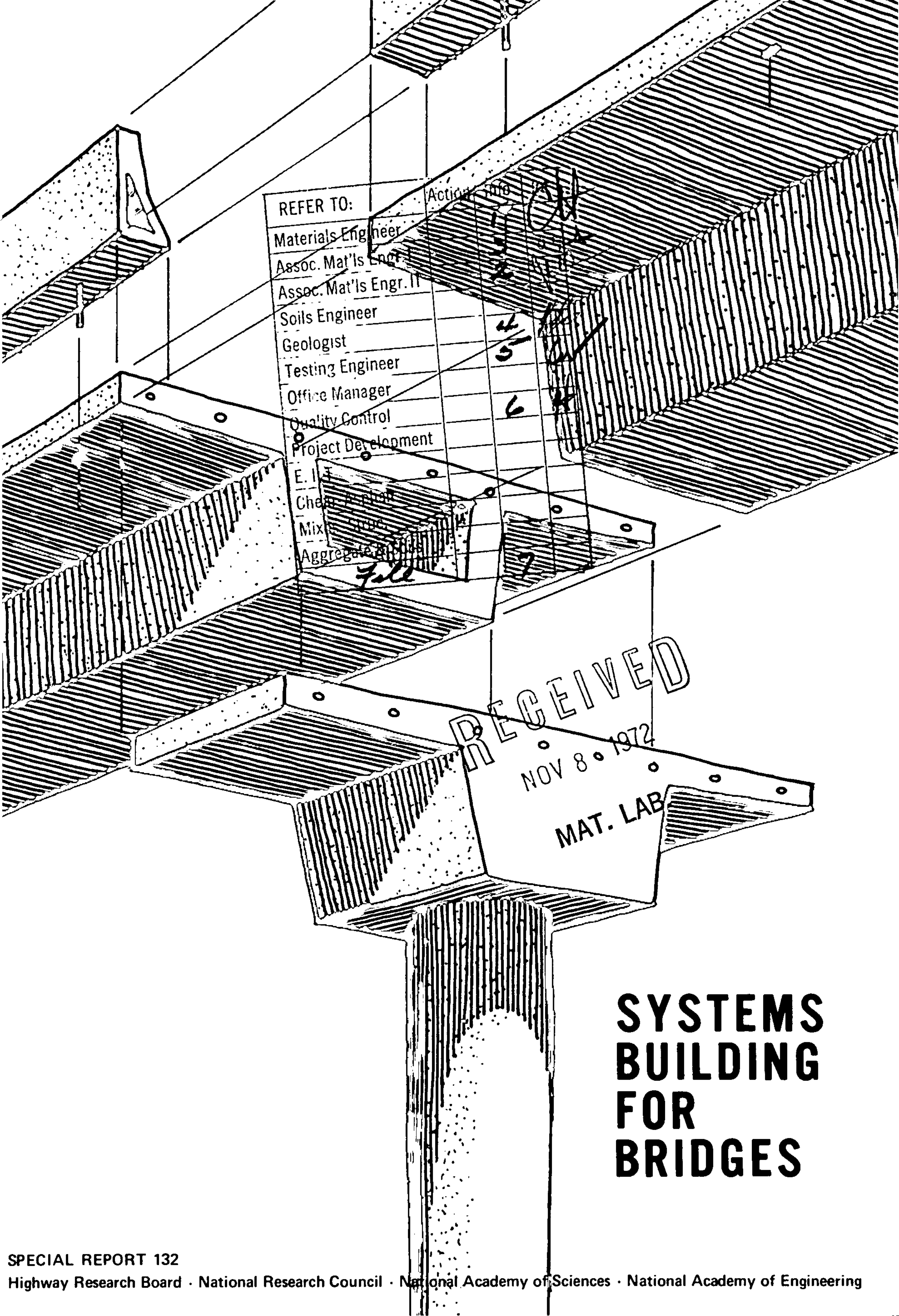

SYSTEMS BUILDING FOR BRIDGES

SPECIAL REPORT 132

Highway Research Board · National Research Council · National Academy of Sciences · National Academy of Engineering

1972
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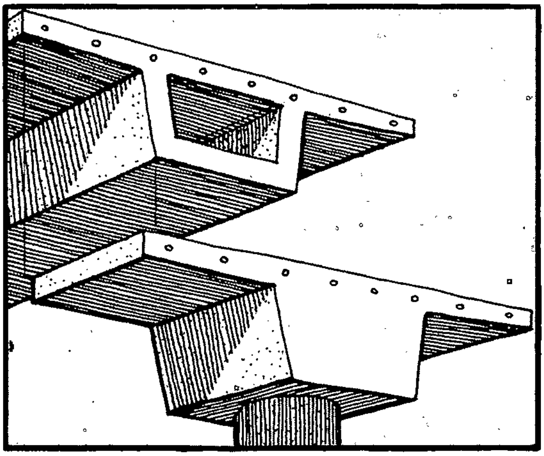

SYSTEMS BUILDING FOR BRIDGES

Proceedings of a workshop held May 17-19, 1971

Subject Areas

27 Bridge Design
33 Construction
62 Foundations (Soils)

Highway Research Board · Division of Engineering · National Research Council
NATIONAL ACADEMY OF SCIENCES ● NATIONAL ACADEMY OF ENGINEERING
Washington, D.C. 1972

Notice

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FOUNDATIONS, PIERS AND ABUTMENTS, SUPERSTRUCTURES, AND DETAILS AND APPURTENANCES OF SYSTEMS BRIDGES

STEEL, CONCRETE, ALUMINUM, AND TIMBER IN SYSTEMS BRIDGES

Introduction

Harry E. Brown, Wallace T. McKeel, Jr., and William G. Gunderman

A workshop on systems building for bridges, held May 17-19, 1971, grew out of a request from the Virginia Highway Research Council to the Highway Research Board that the Board use its resources to stimulate thinking in the area of systems bridges. An Advisory Planning Committee arranged a 2½-day workshop as part of an effort to develop means for reducing bridge construction time in urban areas through the use of a systems approach, i.e., through the increased use of industrialized procedures leading to the extensive use of prefabricated components from foundations to roadway surfaces.

This Special Report comprises the proceedings of the workshop. The first papers are those presented at the introductory session; they review the current status of bridge building, materials, and systems building. Presented next are the summary reports of the chairman of the 3 working sessions and of the chairmen of each of the 4 groups into which the sessions were divided. The report concludes with comments by participants during an informal discussion at the final workshop session.

Participating in the workshop were nearly 50 representatives of industry, government, and educational and research institutions. They explored in depth the advantages and limitations of a systems approach to bridge building, the ramifications of adopting such an approach, and the problems anticipated.

During the planning of the workshop, an attempt was made to get good state-of-the-art coverage for concrete, steel, and foundations as used in the systems building of bridges. It is believed that good coverage was obtained for concrete. The coverage of foundations and steel was less complete. Although an extensive effort was expended in attempting to locate a speaker on the subject of steel systems building, it was not possible to find anyone who could cover the work being done outside the United States, and apparently the major efforts are not occurring in this country.

Harold Elsasser requested time to present the state of the art of systems bridge construction from the point of view of the American steel industry and was included on the program. However, because it was believed that the coverage for steel was still insufficient, reprints of a paper that had been presented at the January 1971 meeting of the Highway Research Board by Elmar Koger, on the use of a fast-assembly steel bridge in Hanover, Germany, were distributed. That paper, which was published in Highway Research Record 372, is also included in this Special Report.

From the beginning of the planning for the workshop, there was a general feeling that design philosophy would be the key to the ultimate acceptance of systems construction for bridges; and, although maximum opportunity was afforded for the expression of design philosophies, the offerings were less than fully satisfying. It is possible that, had the group discussion of this topic been programmed closer to the end of the workshop, a little more progress might have been made. It is still believed, however, that one of the major keys to the ultimate acceptance of the systems approach lies in a change in the design philosophy of consultants, owner agencies, and design engineers.

With regard to manufacturing, transportation, and erection, it was apparent from the workshop that the technology for these is currently available.

In a breakdown by segments, foundations present a real problem and although progress here is not impossible it appears that it will be extremely difficult to achieve and will probably be slow. With respect to piers, abutments, superstructures, and details and appurtenances, systems building techniques are now being used, and their continued use for these items should not present a problem. From the point of view of technology, however, there is a price advantage, for the time being at least, for concrete.

In a breakdown by materials, there is a strong feeling that better use can be made of those available. Further developments in all materials appear to offer considerable benefits to systems building. Because of the vast experience gained with concrete, it is the yardstick by which the other materials must be measured. There was a feeling at the workshop that the steel industry in general needs to become more innovative and more competitive with the prestressed concrete industry. The aluminum industry faces the problem of becoming more competitive in cost. Timber is used in somewhat limited applications because it cannot be used for long span lengths, it is quite vulnerable to vandalism, and engineers today are not familiar with its uses as a construction material. Experience in Europe indicates that, with the new automated techniques for fabrication, steel can be used more than it has been in this country. These techniques are also applicable to aluminum and timber fabrication. The reduced weight and corrosion resistance of these materials should aid in making them more attractive for urban use.

At the closing session of the workshop, the following areas were delineated as those needing more attention and at the same time showing the most promise:

1. Design, manufacture, and construction of bridges must be accomplished under one responsibility (the turnkey project);
2. Competition will be necessary for the development of systems, and construction time should be an important parameter in systems evaluations;
3. A certain minimum market will be required to justify the costs for systems development; and
4. Government agencies and professional and trade associations will have to accept the principles of systems building and promote further developments.

A realistic look at the future of systems building of bridges shows that much of the necessary technology, no doubt a sufficient amount to start, now exists. The effort is worthwhile, practical, and to a large extent feasible today. Neither the technology nor the effort needs a different set of contractual or administrative rules or new specifications though these would foster innovation. The success of systems building of bridges requires only that a modest market be made available and that open-minded acceptance by engineers and administrators be forthcoming.

What Direction in Bridge Building?

Robert G. Bartlett

As our highly mobile nation moves into the decade of the seventies, several observations are particularly relevant. We are altering the patterns of land use for residential, commercial, and recreational facilities; sociological maturation is enabling us to achieve a closer bond in the brotherhood of men; and we are imposing more qualitative bases for decision-making in the public sector. In short, the soaring seventies will witness many changes, and it is particularly appropriate for us to challenge rather than cherish our particular fields of expertise in the disciplines of bridge design, component fabrication, and site construction. This is a time for creative stimulation that will serve as a basis for real progress. Bridge building will continue to be in great demand in the years to come, and we must be receptive to new concepts. As John Gardner stated, "If we have the wisdom and courage to demand much of ourselves—as individuals and as a profession—we may look forward to continued vitality and progress."

Is it possible to reduce bridge construction time and cost through the use of systems building concepts? Are we ready to adopt increased applications of industrialized, mass production techniques? Can we integrate planning, design, manufacture, construction, scheduling, financing, and management into a disciplined method of mechanized production of bridges?

Bridges have been important throughout history. Greeks and Romans used bridges extensively for their military conquests. Bridge building in ancient Rome was considered so important that the head of religious affairs adopted the title Pontifex Maximus or Chief Bridge Builder.

The earliest bridges were, undoubtedly, logs set across a stream. Because timber cannot endure for thousands or even hundreds of years, there are no known remaining examples of this early type of bridge construction. A notable wooden bridge resting on piles was constructed by Julius Caesar across the Rhine River in Germany in 55 B.C. A pedestrian stone-slab bridge over the River Meles in Smyrna, Asia Minor, which according to legend was used by the ancient Greek epic poet Homer, is probably the oldest bridge in existence.

The Romans used stone arches for the construction of both aqueducts and highways. Many examples of their work remain today not only in Rome but throughout what was once the vast Holy Roman Empire extending into Spain and France. The decline of the Roman Empire was followed by a period during which no new bridges of any importance were constructed for several centuries. Not until the Middle Ages, when the Crusades began, did bridge building resume to any significant extent. Stone masonry arch construction continued to be the principal type of bridge structure from the twelfth century until the eighteenth century. Although the Romans had specialized in the construction of semicircular arches, the bridges of this period varied from the pointed or Gothic arch to the flat or elliptical arch.

The Middle Ages produced a number of stone and masonry arch bridges, among them the famous London Bridge. The revival of arts, letters, and learning in Europe during the Renaissance marked the transition to a more scientific approach to bridge design and construction. Galileo, the Italian physicist, published in 1638 the first book on structural analysis. In 1678 Robert Hook devised the law of proportionality of stress and strain. After that, Mariotte and then Bernouilli in 1694 calculated deflections.

The eighteenth century marked the beginning of a new era in bridge design with the founding of the Ecole des Ponts et Chaussées in Paris, which is the first engineering school in the world. During the late eighteenth century and the first half of the nineteenth century, new materials and new bridges began to appear. The first of these new materials was cast iron, used in the construction of an arch bridge in England, and wrought iron chains, used in 1796 in the construction of the first suspension bridge in the United States at Uniontown, Pennsylvania.

The use of iron, combined with the development of the railroad, stimulated a new interest in bridge design and produced truss, cantilever, and suspension bridges. The old construction materials, wood, stone, and iron, slowly yielded to the materials of modern bridge construction, steel, concrete, aluminum, and even paper. The modern era of bridge building can be said to have begun with the development of the Bessemer process of making steel in 1855 and of the open-hearth process a few years later. The emergence of steel led to reinforced and prestressed concrete as a bridge material.

Since the end of World War II a number of technological advances in the field of bridge construction have occurred:

1. Long-span steel girder bridges were introduced, with some spans measuring more than 400 ft in length, and have largely replaced the shorter truss spans;
2. Use of welding rather than riveting in shop fabrication of plate girders has become widespread;
3. Use of high-tensile strength bolts has largely replaced field-driven rivets;
4. Prestressed concrete came into use in the middle 1950's and is now a widely accepted type of construction; and
5. Steel composite box girders and orthotropic steel decks were recently developed (the Poplar Street Bridge in St. Louis, Missouri, the first major orthotropic steel plate deck and box girder bridge built in the United States, has a center span of 600 ft).

The applications of new techniques, new materials, and equipment open new horizons in bridge construction. Significant savings in materials, labor, time, and other items of cost have been achieved through recent innovative developments, and we must continue our progress. The possibilities of more attractive structures more and more intrigue the bridge designer. The late Dr. Steinman said: "The bridge designer of this era has to be an engineer and an artist combined. To a thorough understanding of structural design and function he must add a strong feeling, both innate and trained, for beauty of form, line and proportion." However, we must combine the often-conflicting standards of aesthetics, engineering, and economy into a proper blend.

As a former highway official in Pennsylvania, and member of both the Delaware River Joint Toll Bridge Commission and Interstate Bridge Commission, I am clearly aware of the need to replace many existing outdated bridge structures, to provide new ones, and to provide safer grade separations at intersecting highways and railways.

Systems building for those bridges may be the major development of the current era. Consider the labor savings if bridges are made by the mile and sold by the foot. Systems building, however, raises some difficult questions. Where will we find the necessary supply of trained workers to produce the number of new bridges required?

Can we reduce construction time and thus reduce the time workers are exposed to relatively hazardous conditions? Can we reduce inconvenience to the public by reducing time of construction? Will we be able to achieve cost savings and thus increase the number of new structures for the same amount of tax dollars? Systems building will also require basic changes in attitudes and methods: changes in engineering standards and in manufacturing techniques, wider acceptance of new materials such as glass and paper, new developments in steel and concrete, and new methods of component transportation and site construction.

Systems Building: Foundations

William B. Wigginton

My interest in systems building has been primarily related to industrialized building for the shelter industry. Foundations appear to be an afterthought and the most neglected portion of the industrialized building process. Heavy dependence on on-site labor, coupled with lack of standardization and dimensional coordination, appears to place foundation subsystems out of step with the industrialized approach. Building systems seem to be superstructure oriented.

At a national conference on foundations for systems building and modular housing in February 1971, speakers discussed systems building in general, the foundation subsystem, innovations in foundations and subfloor construction for light-housing construction, and the influences of code and factory housing law. Conference discussions revealed that the foundation system requires much more attention and study.

In light housing, the foundation used does affect the choice of materials for the subfloor. Therefore, major materials associations and industries have been busy developing foundation techniques and subsystems. There is some skepticism as to whether heavy construction, including bridge construction, can be truly systematized. Michael Praszker stated in regard to the systematization of soil engineering, "Use one soil engineering solution for two sites—I wish it could be so, but I will say it is not." Guy Rothstein checked with all the European high-rise concrete prefabrication plants and found that no research on the foundation subsystem had been undertaken because it was considered that the foundation problems were unique for each site. Jack Healy, on the other hand, has been working on a reduction of the myriad of foundation types to a limited set of subsystem types best suited for various foundation soil conditions on a worldwide basis. From an industrialized manufacturer's standpoint, Daly indicated that "the foundation remains the weakest point where we have made the smallest progress." Operation Breakthrough spokesmen echoed this when describing the program sponsored by the U. S. Department of Housing and Urban Development to revolutionize building processes and uses of material. They could not point to a single case where other than traditional foundation subsystems were used at the demonstration sites.

For systems building in general, Ezra Ehrenkrantz described programs where bids on construction are invited on a basis of other than cost alone; the ultimate objective is to invite a bid on the basis of cost plus time plus performance. On a "fast-track" approach, it may make sense to commence construction of foundations before the

Figure 1. Precast concrete bell piers used in Richmond-San Rafael Bridge in California.

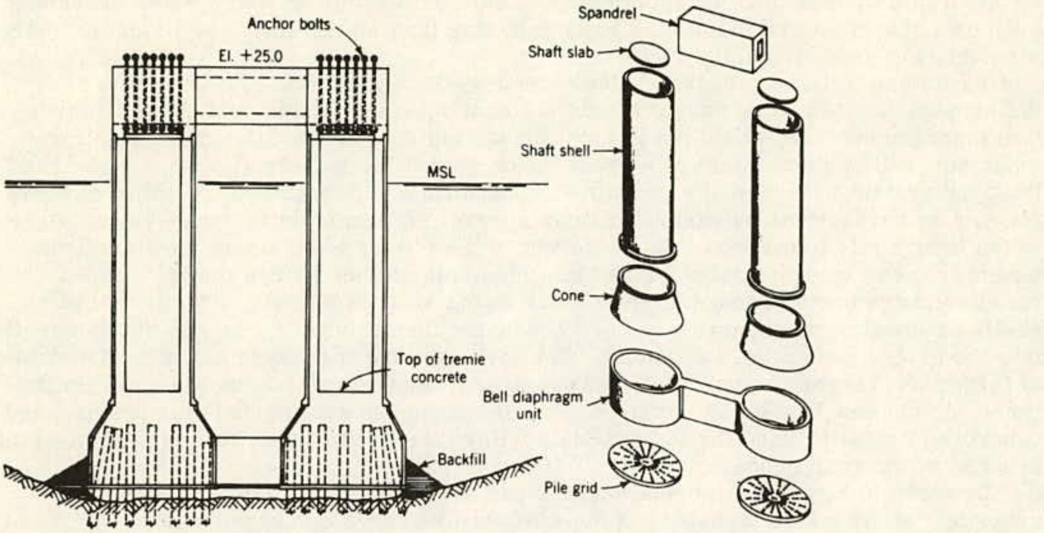


Figure 2. Sinking prefabricated bridge pier.

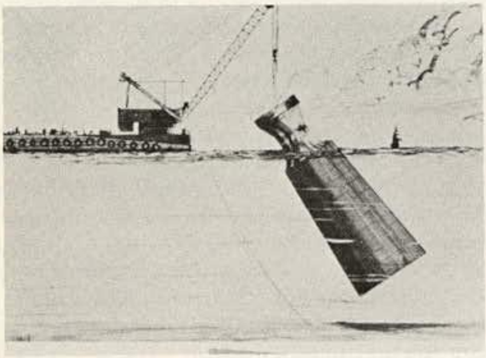


Figure 3. Yee's computer design approach.

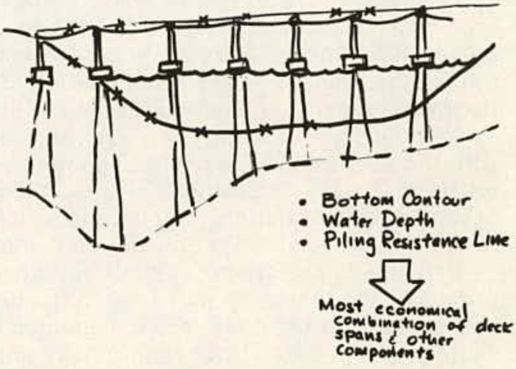
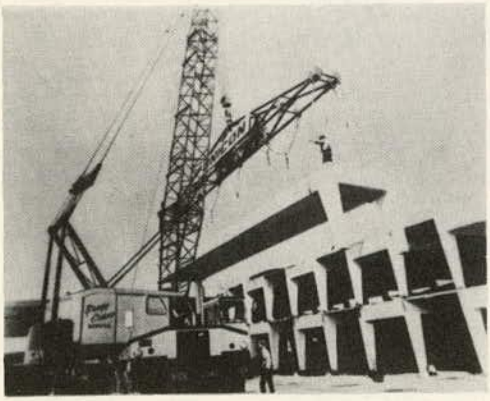


Figure 4. Unicon parking structure system.



superstructure is even designed. To take this approach for bridges would require considerable dimensional coordination. It could be feasible on many water crossings, such as Lake Ponchatrain and San Francisco Bay (San Mateo-Hayward Bridge), where straight, low-level trestles are used.

Guy Rothstein is a proponent of the closed-system approach. According to his philosophy, a single firm should handle the design, construction, and post-construction management. He would put present bridge building in the category of a tailor-made suit rather than in that of a ready-made suit of the industrial age. By contrast, the open system with modular coordination permits a wide interchangeability of components or subsystems by various manufacturers. An example of open-system usage is the bridge pile foundation subsystem where the pile cap acts as an interface component between various manufactured pile elements and the bridge pier. Various manufacturers today produce off-site stock items such as thin segmented steel pile shells or prestressed concrete piles. These are then brought to the site for integration into the bridge foundation subsystem. We have seen the increased use of prefabrication of larger and larger components. Only size and weight appear to be the main limitations. In the San Francisco Bay area, 900-ft continuous casting beds for prestressed concrete piles were used for the San Mateo-Hayward Bridge. T. Y. Lin described the process at the conference.

The move to larger prefabrication in urban areas has been primarily for water crossings where water transport to the site permits large components (Fig. 1). Lin described a proposed bridge between Alaska and Siberia where it is envisioned that a bridge pier, 300 ft high, is prefabricated at a site such as Seattle, towed to the site, placed upright, and sunk into the foundation soils. Post-tensioning cables are strung top-to-bottom with rock anchors at the bottom of the ocean (Fig. 2).

In the design or software phase, much is being done to speed up the bridge-building process. Increased reliance on the computer is in evidence. Alfred Yee, in a recent issue of Engineering News-Record, described the development of a means of determining the most economic combination of deck spans and other precast components. Computer input is a combination of the bridge site conditions (Fig. 3).

In the bridge industry, one area that could stand some improvement to keep pace with the shelter industry is the mobile or relocatable bridge, used mostly by the military (Bailey or pontoon bridges, for instance) at this time. The adaptability to urban bridges of building systems developed for relocatable multilevel parking garages is obvious (Fig. 4). The foundation can be utilized as a post-tensioning element.

Bridges do not appear to trail buildings in the use of the industrialized building process, and they may well lead in the use of large-scale prefabrication. The foundation subsystem is, however, a neglected link and requires more attention. Larger scale prefabrication has begun to take hold in the foundation subsystem with the accompanying simplification and reduction of the number of elements in the bridge substructure. Some of those attending the conference believe in the uniqueness of soil foundation conditions, or that problems at each site prevent a true systematization of the foundation. Others, including me, are working to truly integrate the foundation subsystem into the building system as a whole. This would appear to lead toward a reduction in foundation types, increased prefabrication, and a reduction in bridge construction time.

Systems Concepts for Precast and Prestressed Concrete Bridge Construction

Arthur R. Anderson

During the past 20 years, some significant changes in concrete bridge construction have taken place, mainly because of the developments in precast and prestressed concrete. The rate of change has recently intensified because of steep labor costs for job-site construction trades and the demand for longer clear spans to improve highway safety and aesthetics. Thus, the trend in highway bridge construction will be strongly influenced by economics, safety, short time schedules, and environmental impact.

During the past 50 years, the steel industry has taken the lead in the development of improved structural shapes and higher working stresses. For example, until 1923, the standard steel I-beam had a thick web and a relatively narrow flange. A Carnegie beam of this style compared with a modern wide-flange beam of equal weight is shown in Figure 1. The old-style section was rolled in depths ranging from 3 to 24 in., and a total selection of 29 beam sizes and weights was available in 1 quality of steel, with a specified working stress of 12,500 psi. During the intervening years, the steel industry developed a wide variety of very efficient beam shapes. These are available in 6 qualities of steel with yield strengths ranging from 36,000 to 100,000 psi.

In comparatively recent times, the quality of factory-produced concrete has advanced from the commonly accepted 2,500-psi compression strengths of the 1940's to today's concretes in the 7,000 to 12,000 psi range. Similarly the heavy massive concrete sections of previous times have been supplanted by the more efficient prestressed concrete sections shown in Figure 2.

The AASHO standard beams have found wide application for grade-crossing separation structures in most regions of the United States. Types III and IV have been most popular, satisfying needs for bridges in the span range of 50 to 90 ft. Concrete strengths of 4,000 psi at transfer and 5,000 psi at 28 days have prevailed. On the other hand, the Washington State practice has featured mainly the type 80, 100, and 120 beams, for spans ranging from 75 to 145 ft. Concrete strengths have been in the range of 5,000 to 8,500 psi at transfer and of 6,000 to 10,000 psi at 28 days. For average work, a transfer strength of 5,000 psi and a 28-day strength of 6,000 psi have been usual. Figure 3 shows the results of 28-day cylinder tests of concrete produced in Washington State for prestressed bridge beams. The majority of the tests ranged from 8,500 to 11,000 psi.

High-strength concrete in refined cross sections is achieved by the use of a water-cement ratio of 0.33 to 0.35, resulting in 0 to ½-in. slump. A pan mixer is preferable,

Figure 1. Standard I-beam of the early 1900's and modern wide-flange section.

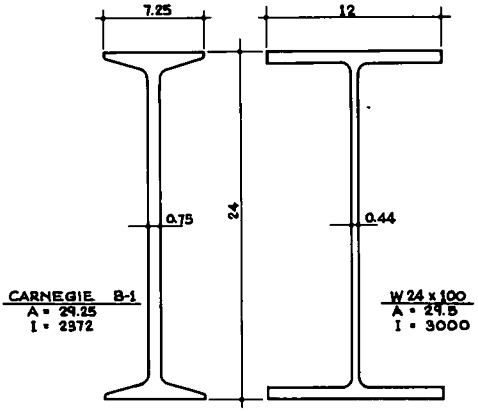
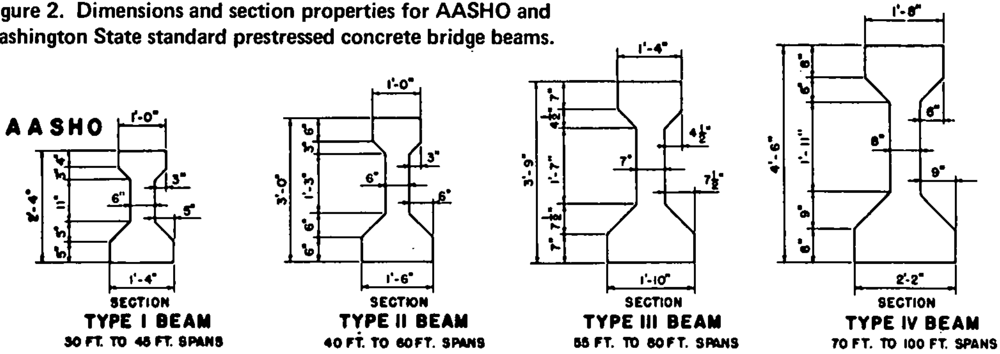


Figure 2. Dimensions and section properties for AASHO and Washington State standard prestressed concrete bridge beams.

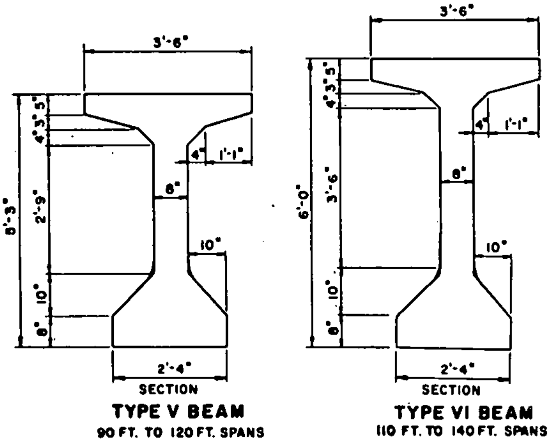


SECTION
TYPE I BEAM
30 FT. TO 45 FT. SPANS

SECTION
TYPE II BEAM
40 FT. TO 60 FT. SPANS

SECTION
TYPE III BEAM
55 FT. TO 80 FT. SPANS

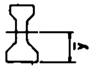
SECTION
TYPE IV BEAM
70 FT. TO 100 FT. SPANS



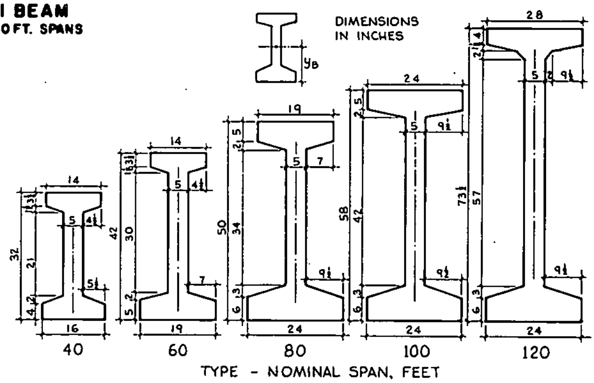
SECTION
TYPE V BEAM
90 FT. TO 120 FT. SPANS

SECTION
TYPE VI BEAM
110 FT. TO 140 FT. SPANS

BEAM PROPERTIES



BEAM TYPE	AREA Inches²	ȳ Inches	Moment of Inertia Inches⁴
I	276	12.59	22,750
II	369	15.83	50,980
III	560	20.27	125,390
IV	789	24.73	260,730
V	1013	31.96	521,180
VI	1085	36.38	733,320



WASHINGTON

BEAM PROPERTIES

TYPE	AREA IN²	y_b IN.	MOMENT OF INERTIA - IN⁴
40	253	15.16	31,000
60	332	18.63	70,100
80	476	22.53	154,900
100	546	27.90	249,000
120	626	35.60	456,000

and compaction of the concrete requires form vibration. With automatic moisture control, uniformly high concrete quality is maintained. It is not unusual to achieve 6,000-psi strength in 16 hours, ensuring daily turnover of the stressing beds.

Because of the very low water-cement ratio and excellent compaction, concrete cover of ½ to ¾ in. over the web reinforcement has proved to be adequate for beams exposed to severe climate for 20 years. Thus, it is practical to utilize 4-in. web sections for bridge beams produced with high-quality concrete.

In 1959, Concrete Technology Corporation developed the bulb-T section shown in Figure 4. This section possesses very desirable properties in that the wide top flange ensures lateral stability for transportation and erection.

Also, the flange simplifies the placing of the cast-in-place concrete deck slab. Structurally, the flange serves as a haunch for the deck slab in resisting transverse bending due to concentrated wheel loads. Five-inch decks acting compositely with the flange have been tested with 64-kip concentrated loads, producing only hairline cracks. Contractors report a formwork saving of $1.50/sq ft of deck with the bulb-T beam. Moreover, a substantial saving in transverse deck slab reinforcement is possible because of the haunch effect of the bulb-T flange.

Several constraints to achieving high performance from factory-produced pretensioned beams should be evident to bridge designers.

Rapid turnover of the stressing beds is obtained by the prestress being transferred to immature concrete at about 50 percent of its eventual strength. For this reason, many producers favor low specified strengths (3,500 psi) at transfer. This practice is self-defeating, for it limits the stress level ($0.6\ f'_{ci}$) conferred on the concrete. To overcome this handicap, one can design bridge beams with combinations of pretension and post-tension. A good ratio is about ⅔ pretension and ⅓ post-tension. This ratio produces enough pretension to almost counteract the beam dead-load bending, with moderate compression in concrete at transfer. The beam usually has 0 camber at this condition. Daily turnover of the stressing bed is easy to accomplish, and the beams can be stored until the concrete matures to full strength. At this time, the post-tension is introduced, which in effect means that the transfer strength f'_{ci} may also be nearly the full ultimate strength f'_c. By this means, the author has been able to achieve transfer strengths $f'_{ci} = 8,500$ psi, permitting 4,500-psi prestress levels in high-performance beams. This most effectively increases the span-load capacity of the beam.

Another advantage of the combination pretension and post-tension arrangement is the possibility of maximizing the eccentricity of the tendons, as shown in Figure 5.

An interesting comparison can be made regarding relative performance of the 3 bridge beam types described above. One direct measure of performance based on cross section alone is the relation between the beam's section modulus and its section area. Obviously, for a given section modulus, the least practical section area is to be desired. As with steel beams, the highest moment capacity-to-weight ratio within practical limits should be the designer's goal. Figure 6 shows graphically the relation between section modulus and section area for the AASHO, Washington State, and bulb-T standard bridge beams.

When one combines the advantages of high section modulus to section area ratio with the use of very high strength concrete and combination pretensioning and post-tensioning, the results become dramatic. Not only do the span load capabilities mount upward but also the ability to transport and erect very long beams becomes possible. Figure 7 shows graphically the maximum span capability for the AASHO, Washington State, and bulb-T standard beams for various beam spacings under HS20-44 live loadings on simple spans. To date, beams up to 147 ft in length have been delivered over the road in Washington State, and barge shipments of beams 167 ft long have been accomplished.

In 1969, the author developed a decked bulb-T bridge beam in which the bottom flange and web are cast from 160-pcf, 8,500-psi concrete.

A deck flange of 120-pcf, lightweight 6,000-psi concrete is cast monolithically to the web. This bridge beam, designated DBT (decked bulb-T), is practical for simple spans up to 190 ft, with depths ranging from 29 to 77 in. Deck widths of 4 to 10 ft are offered. Figure 7 also shows graphically the span-spacing capacity for the decked bulb-T beams. Since the beam depths given represent the total depth of section from finished roadway to beam soffit, the high span-to-depth ratio for this section is noteworthy.

Figure 3. Strength of 28-day cylinders for bridge-beam prestressed concrete.

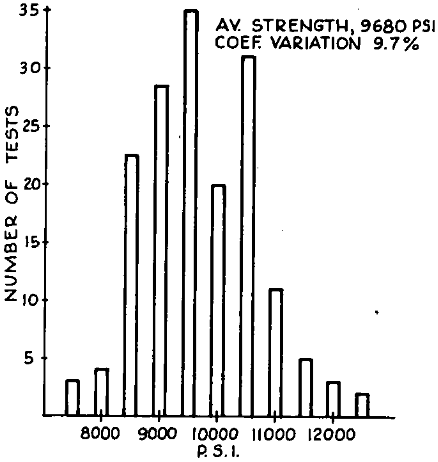
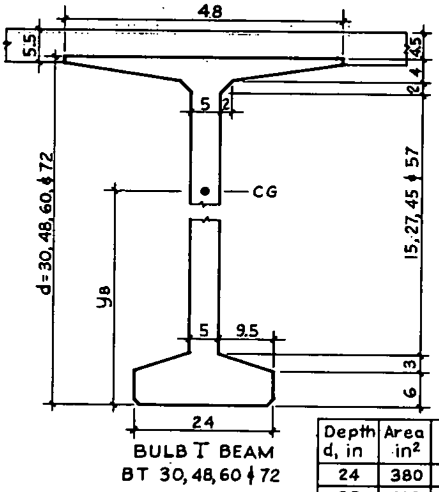
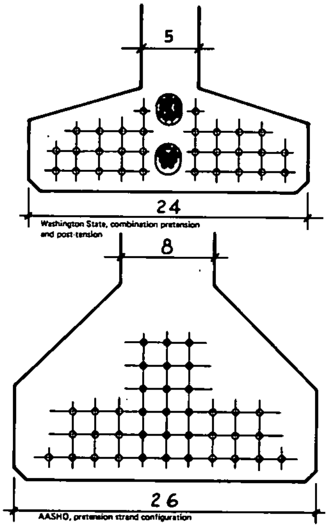


Figure 4. Bulb-T beam properties.



Depth d, in	Area in²	y_B in	Moment of inertia in⁴
24	380	12.14	28,900
30	410	14.95	51,100
36	440	17.78	80,700
48	500	23.51	164,000
60	560	29.29	283,200
72	620	35.12	442,800

Figure 5. Comparison of tendon eccentricity of beams.



Washington State, combination pretension and post-tension

AASHO, pretension strand configuration

Figure 6. Section modulus and section area relations for prestressed concrete bridge beams.

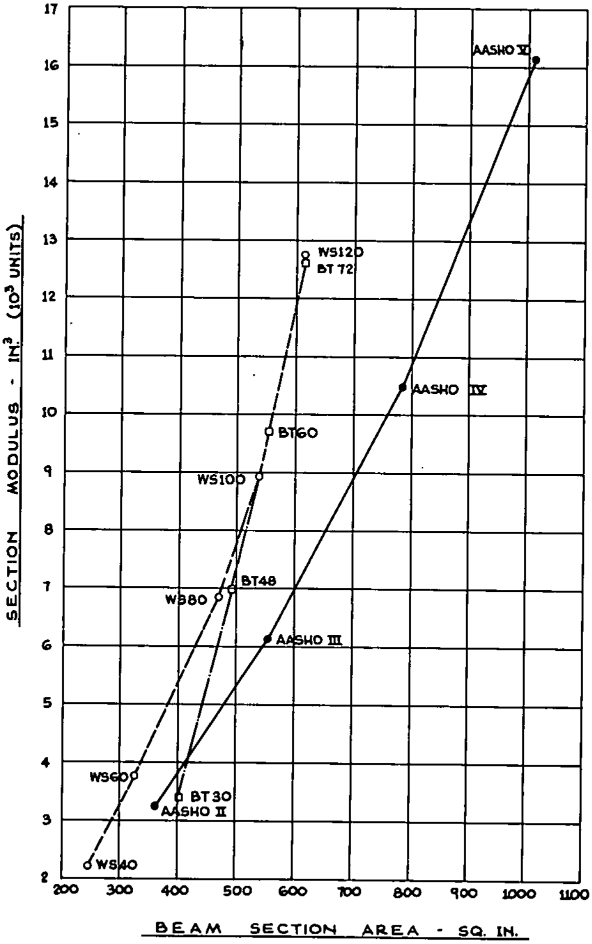


Figure 7. Span-spacing capacity for standard beams.

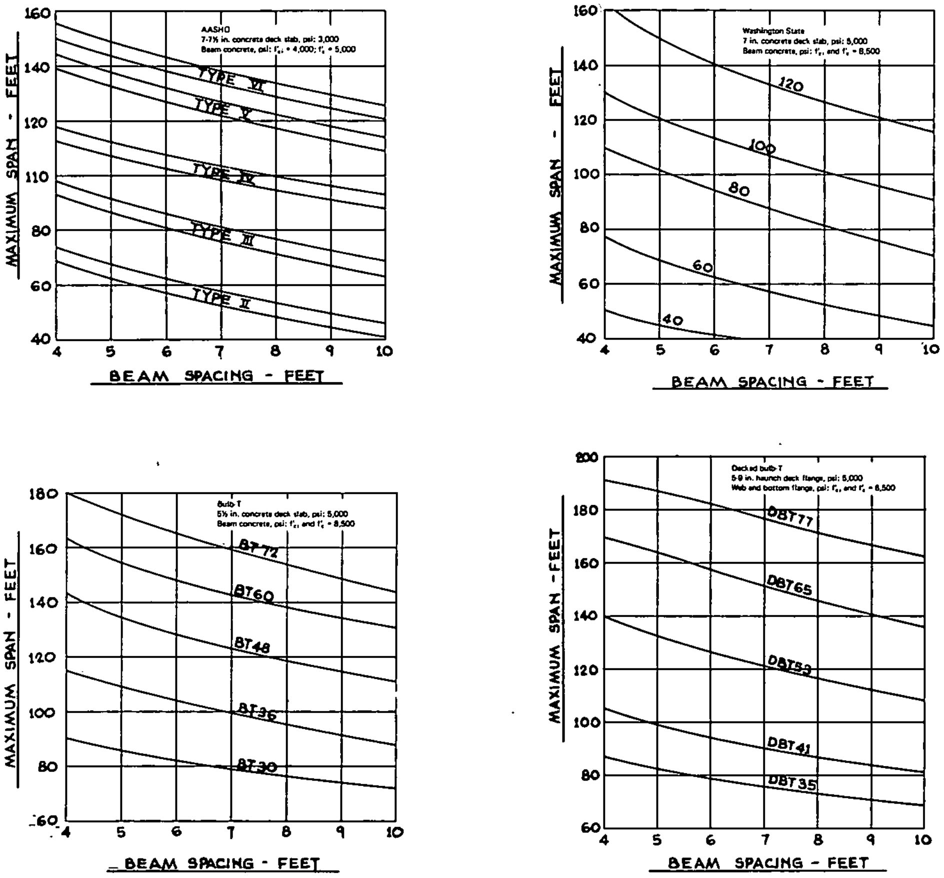
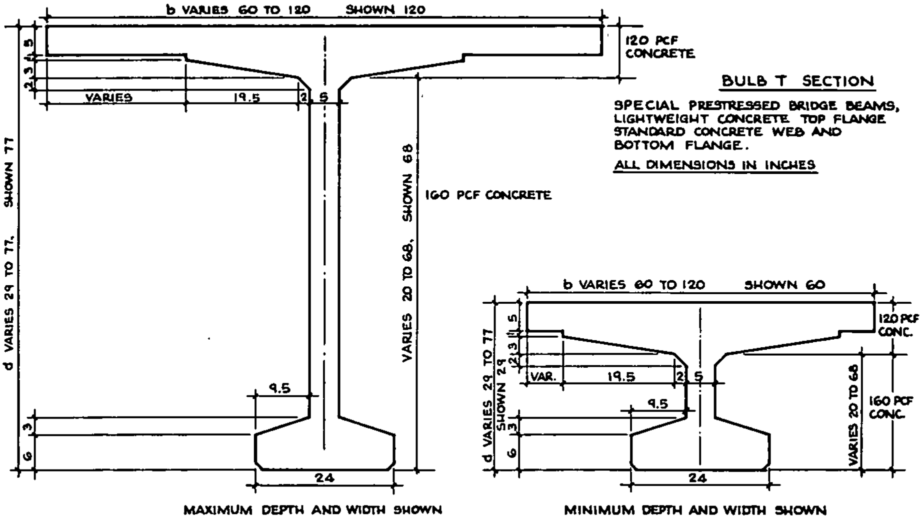


Figure 8. Decked bulb-T beam sections.



The cross sections for the DBT beam are shown in Figure 8. In the calculation of the properties for design, the lower elastic modulus of the deck flange lightweight concrete is compensated by transforming the section as shown in Figure 9. The elastic modulus of the top flange is 50 percent of the modulus for the web and bottom flange. Thus, the top flange is assumed to be half width in the calculation of the section centroid, moment of inertia, and section modulus. Of course, since plane sections remain plain during bending, the true top flange stress is actually one-half the value calculated for the transformed top flange.

The more efficient utilization of concrete with Washington State and bulb-T standard bridge beams has been clearly demonstrated. But the saving in prestressing steel for the longer spans is also impressive, as shown in Figure 10. For example, the bulb-T 72 spaced at 6-ft centers can reach a 160-ft span with 48 one-half in. 270k strands, whereas the AASHO VI beam spaced 6 ft requires 68 strands to reach a 140-ft span. It is also noteworthy that the bulb-T 72 and the decked bulb-T 65 and 77 reach out to spans of 160 to 180 ft with no more than 50 one-half in. 270k strands. The span-depth ratio can sometimes exceed 30, which is attractive when restricted clearance is a problem.

Thus, on the basis of materials and structural dead load alone, the savings offered by lighter, high-performance beams are impressive. From the standpoint of transportation and erection, economic implications are also evident. Highway truck-loading regulations pose serious contraints, for they place definite limitations on maximum weights transportable over highways. Freight tariffs escalate rapidly as the weight of haul increases. For example, the state of Washington has 6 tariff steps by weight categories. Step 1 is the lowest tariff, free of surcharge, and applies to prestressed beams below 52,000 lb. Above step 1, surcharges mount rapidly for overweight permits, extra axles, flagmen, and pilot cars. Costs per kip in the 6 tariff steps for 50-mile hauls in Washington State are as follows:

Tariff Step	50-Mile Haul Cost ($/kip)	Maximum Load (kip)
1	1.80	52
2	2.51	67
3	3.54	77
4	3.84	83
5	4.11	107
6	4.11	154

Table 1 gives the longest standard beam permissible within the weight limit of each tariff step.

Construction techniques play an important part in the economy of bridges. For example, the elimination of expansion joints over the piers of grade-crossing structures by introducing continuity for live load is attractive. In Washington State, longitudinal bars have been placed in the deck slab over intermediate piers to develop negative moments. The beams are placed on 4-in. wood blocks (Fig. 11d). The cast-in-place diaphragm over the pier fills the 4-in. space behind the block to provide the bearing. When the diaphragm concrete has matured, the deck slab is placed continuously over the intermediate piers. This concept not only eliminates costly expansion joints and bearing materials but also extends the span capacity of the beams beyond their simple span limits.

In the interest of safety and aesthetics, the trend for bridges over Interstate highways is to eliminate the intermediate piers (Figs. 11a and 11b). The author has proposed the elimination of all intermediate piers within the right-of-way by the introduction of inclined struts, as shown in Figure 12. This structure, with a 200-ft clearance at freeway grade, can be constructed with bulb-T 60 beams. The 120-ft beams, anchored to the exterior strut, reach beyond the interior strut, the cantilever arm supporting 120-ft drop-in beams. After assembly, the three 120-ft beams are post-tensioned together, creating a 3-span continuous structure.

Figure 9. Transformed sections of decked bulb-T beams.

TRANSFORMED SECTION BEAM PROPERTIES				
b/2	d	AREA	y_B	MOMENT OF INERTIA
30	29	456	15.24	48,200
	35	486	18.35	78,900
	41	516	21.46	118,400
	53	576	27.63	225,700
	65	636	33.77	374,400
	77	696	39.89	568,900
36	29	486	15.93	51,800
	35	516	19.17	84,600
	41	546	22.39	126,700
	53	606	28.76	240,600
	65	666	35.07	398,100
	77	726	41.32	603,400
42	29	516	16.54	55,100
	35	546	19.91	89,700
	41	576	23.23	134,100
	53	636	29.79	254,200
	65	696	36.25	419,800
	77	756	42.63	635,200
48	29	546	17.09	58,000
	35	576	20.56	94,300
	41	606	23.99	140,800
	53	666	30.72	266,600
	65	726	37.33	439,700
	77	786	43.85	664,600

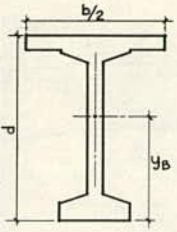


Figure 10. Strand requirements for prestressed bridge beams spaced at 6-ft centers.

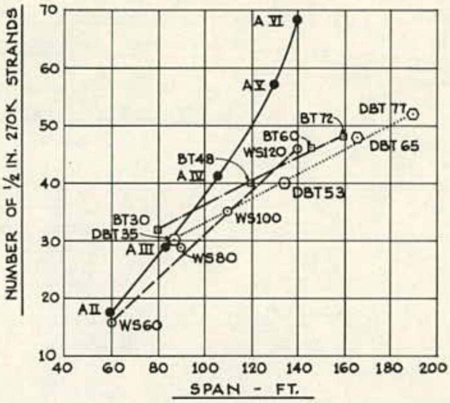
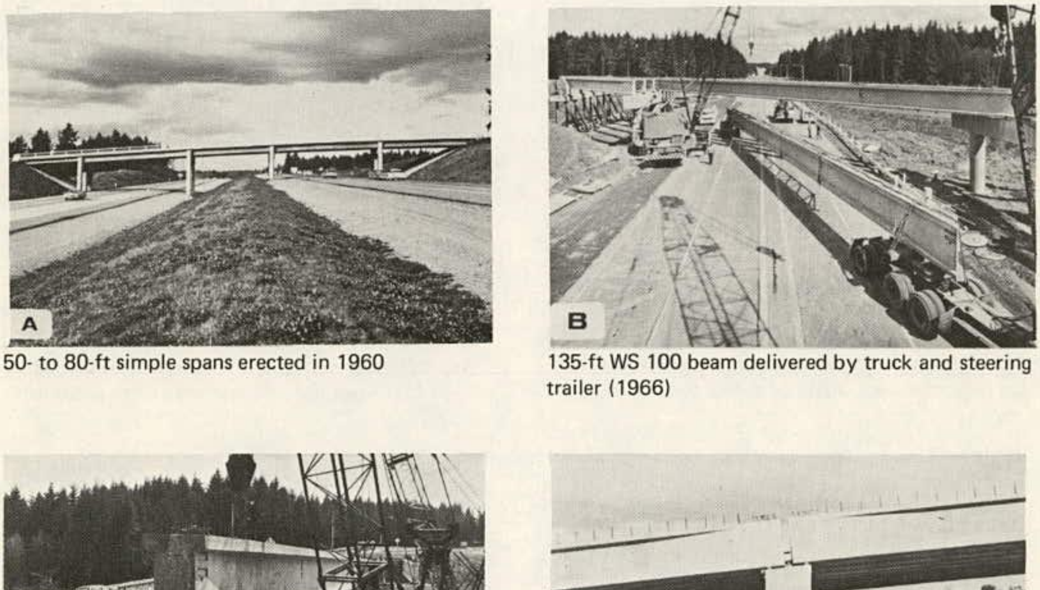
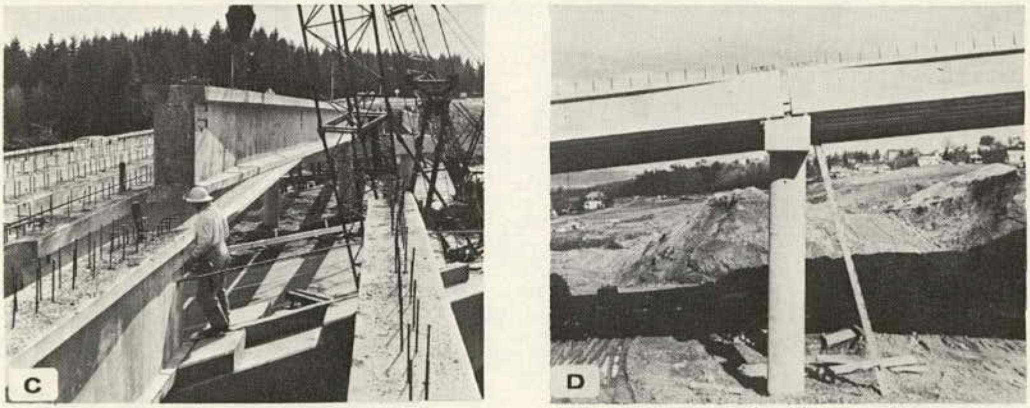


Figure 11. Washington State bridges.



50- to 80-ft simple spans erected in 1960

135-ft WS 100 beam delivered by truck and steering trailer (1966)



135-ft beam erected from truck by 2 mobile cranes (lifting weight, 21 tons per crane)

Prestressed beams on 4 x 4 in. wood blocks; space under beam ends filled with concrete for bearing

Figure 12. Bulb-T beam bridge with 200-ft clear opening at grade.

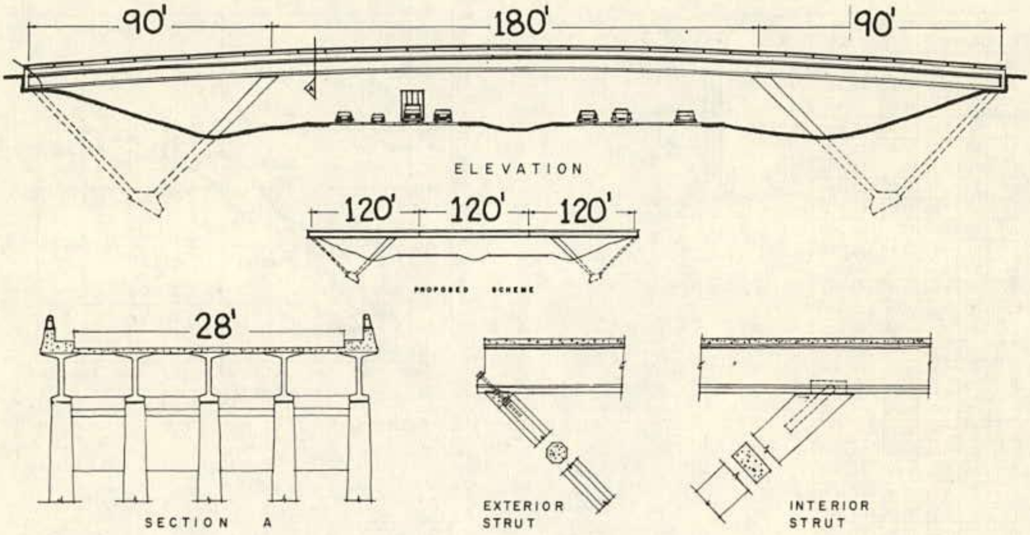
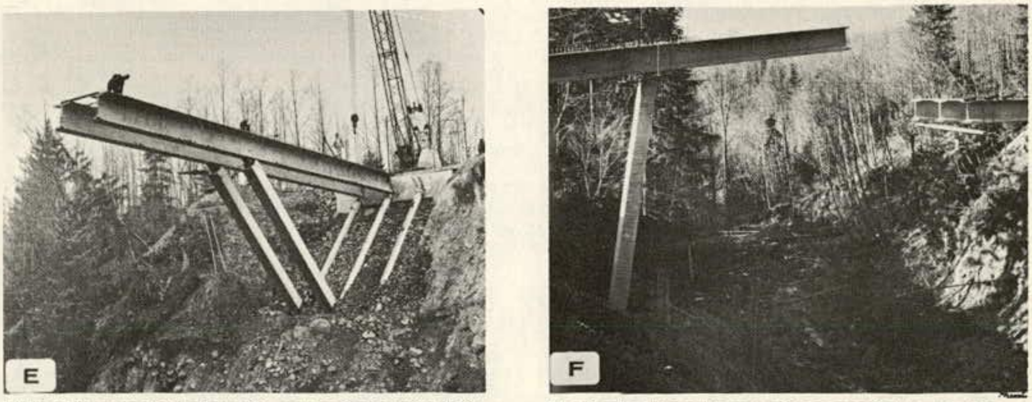


Figure 13. Inclined strut bridges.



Bulb-T beams erected on pin-connected struts that are prestressed and first connected to footing

Vertically braced beam pin-connected to top hinge, walked out over canyon, and secured to abutment

Table 1. Limiting beam length by tariff step for 50-mile haul in Washington State.

Beam Type	Unit Weight per Foot (lb)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
AASHO III	580	88					
AASHO IV	820	63	82	94	101	115	
AASHO V	1,050	49	64	73	79	102	140
AASHO VI	1,130	46	59	68	73	95	136
WS 80	528	98					
WS 100	605	86	111	127			
WS 120	695	75	96	111	120	154	
BT 36	490	106					
BT 48	550	94	120	139			
BT 60	620	84	108	124	134	160	
BT 72	690	75	97	111	120	155	180

A number of inclined-strut bridges have been constructed for forest road bridges, such as the example shown in Figure 13. These bridges are designed for extra-heavy loads, approximately 3 times AASHO HS20-44, i.e., HS60 to HS70 loadings.

The organization of structure greatly simplified the construction, eliminated costly falsework over deep ravines and box canyons, enabled rapid assembly of the precast and prestressed elements, and resulted in substantial economy. The structure shown in Figure 13 was completed for the Weyerhaeuser Timber Company 6 weeks after receipt of the order to proceed with design.

During the past 5 years, construction costs have skyrocketed because of phenomenal escalation of site labor wages. Not only have construction hourly rates doubled in some regions but, even more serious, the availability of skilled construction journeymen has steadily declined. This trend will continue, which challenges bridge designers to resort to industrialized construction techniques. In other words, construction will turn toward manufacturing and assembly.

A good example of a totally prefabricated, prestressed, and precast concrete bridge construction is shown in Figure 14. Since this bridge was erected in the Olympic Peninsula of Washington State, 80 miles from the nearest ready-mix concrete source, and long-distance travel pay was required for construction labor, a high degree of prefabrication was indicated. On the other hand, logging operations in the vicinity of the project made cranes and bulldozers economically available.

A 66-ft span for a logging road was required to cross a river subject to sudden floods. This called for rapid construction during a short low-water period. The river banks were sound rock covered by 2 to 3 ft of overburden. Conditions suggested precast concrete abutments supported on 4 short columns, with a rock rip-rapped spill-through embankment. After the banks were cleared of overburden, holes were drilled into the rock to receive reinforcing bars projecting from the abutment columns.

Four DBT 35 beams constituted the superstructure. The beams were fabricated to identical camber, and the top surfaces were accurately finished to provide a uniform riding surface. Combination pretension and post-tension was applied to achieve high span-load capability with uniformity of camber.

When the site was ready, with favorable low stream flow, the 2 abutments were delivered, and in 1 day those pieces were erected. The reinforcing bars stubbed out of the columns were inserted into grout-filled holes in the rock. The abutments were completely installed on 1 day, and the 4 superstructure beams were delivered and erected in 8 hours a few days later.

Shear transfer between beams was developed by a galvanized steel K-shaped diaphragm at midspan. These were bolted to plates embedded and anchored to the concrete. The edges of the beam flanges were connected by weld-connecting steel inserts located at 6-ft intervals. The keys in the edges of the flanges were then filled with a stiff high-strength cement mortar. A few days later, the approach fill was placed and compacted, and the guardrails were installed. The bridge was then opened for traffic.

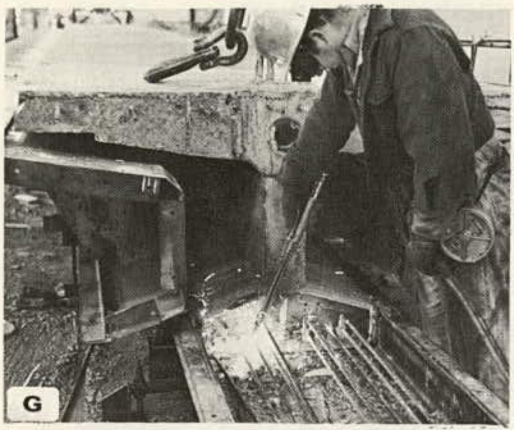
The contract price for all site work was $7,500, or $4.50 per square foot of bridge. The client, whose budget was $12,500, was naturally pleased.

Precast and prestressed concrete beams and girders for straight highway bridges are now commonplace throughout all of the United States. Considerable standardization has taken place, and design procedures have become routine. Much of the ultimate potential for prestressed concrete yet remains latent, waiting for discovery by bridge engineers everywhere.

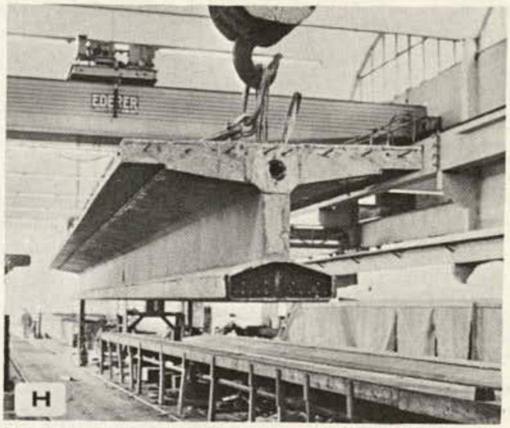
A recent project that has exploited some of the latent potential of prestressed concrete is the monorail for Disney World in Orlando, Florida. This structure in effect is a bridge for a rubber-tired vehicle, with fairly heavy wheel loads, shown in section in Figure 15.

Some 7 miles of 6-span continuous prestressed concrete box girder sections, supported on precast concrete columns, were constructed according to details shown in Figure 16. The girders, about 350 in number, spanned from 90 to 110 ft. Half of the girders were straight, and half were on vertical and horizontal curves to radii from 350 ft upward. Figure 17 shows that the hollow girders were of variable sections, 26 × 48 in. at midspan and 26 × 80 in. at the ends. The girder soffits were set to a parabolic configuration, whose curvature varied inversely with girder length.

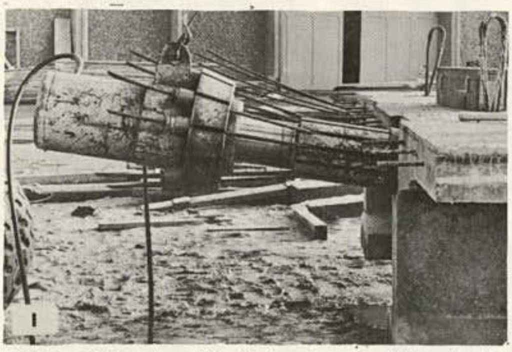
Figure 14. Totally precast decked bulb-T bridge.



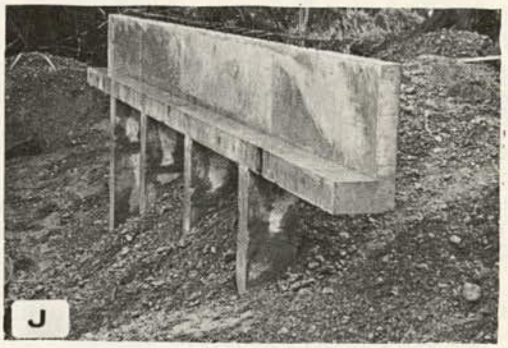
Beam prestressed and removed from stressing bed; tension released on hydraulic rams; strands then cut with torch



Beam removed from 0 camber to storage until strength reaches 8,500 psi

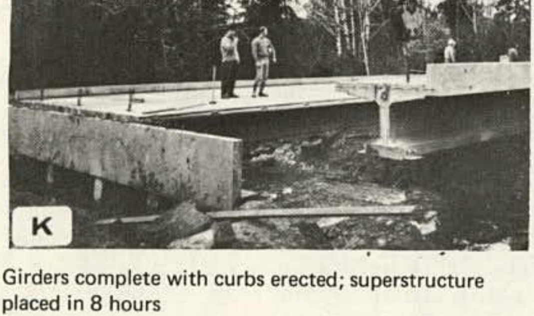


Beams post-tensioned to design stress level (camber in all beams identical)



Precast abutment with stub columns anchored in solid rock; spill-through backfill placed

7



Girders complete with curbs erected; superstructure placed in 8 hours

Steel diaphragm bracing bolted to embedded steel plates to provide shear transverse between neighboring beams

Figure 15. Girder loading of Disney monorail vehicle.

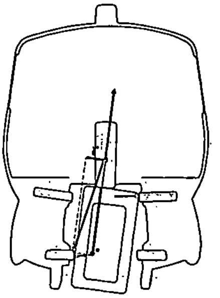


Figure 16. Main structural elements of Disney monorail.

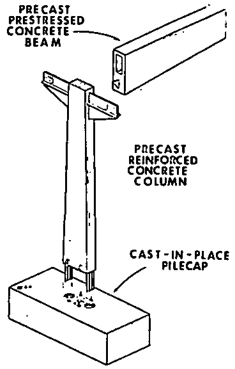


Figure 17. Structural details of Disney monorail guideway (all dimensions in in.).

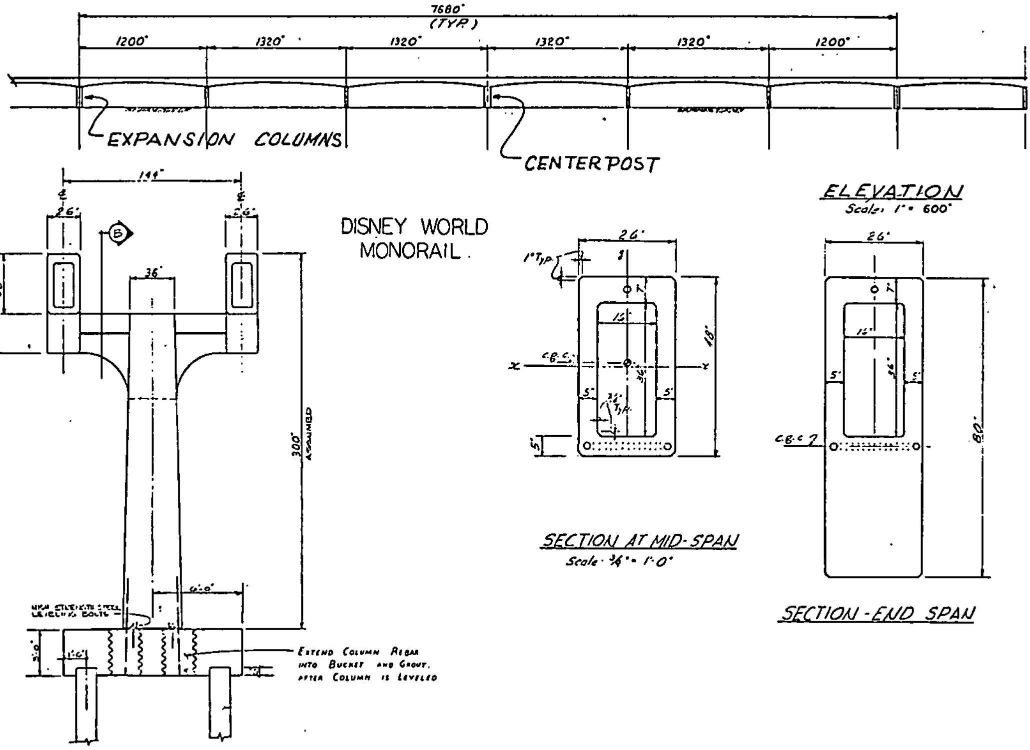


Figure 18. Strength of Disney monorail 28-day cylinders (avg strength, 8,600 psi, and coefficient variation, 5.67 percent).

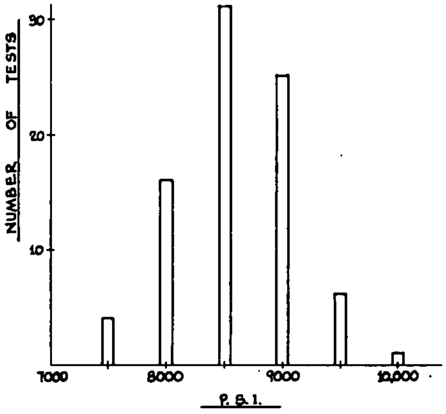


Figure 19. Geometrics for monorail system.

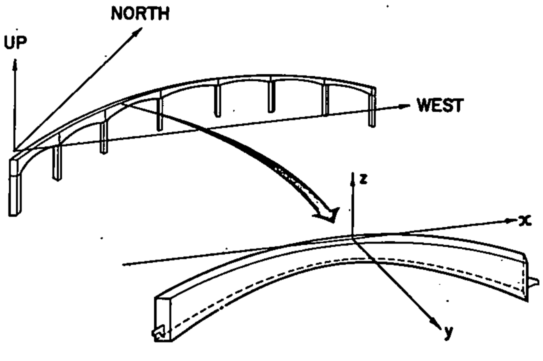
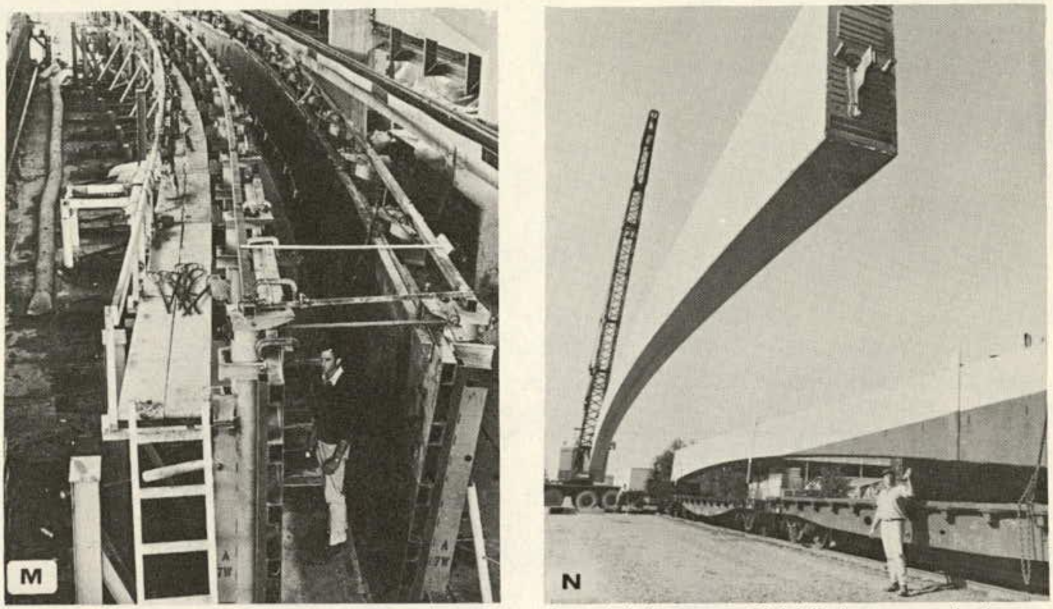
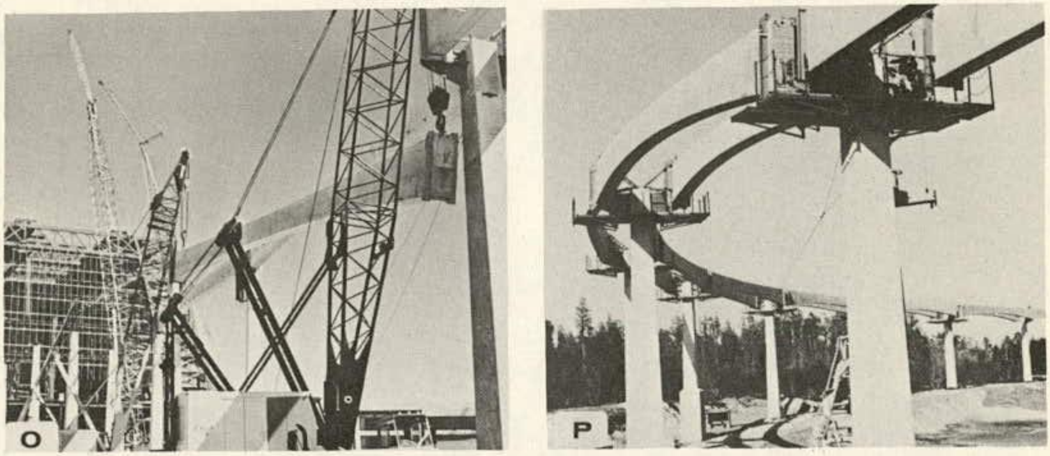


Figure 20. Construction of monorail at Disney World.



Variations in horizontal, vertical, and superelevation permitted by adjustable forms for curved sections of monorail

Curved girders stressed initially by post-tensioning at factory to compensate for dead-load bending (ducts for field post-tension cables project from girder end)



Girders erected and temporarily supported on projecting steel lugs

Cable ducts coupled by sleeves and gap between girders filled with cast-in-place concrete (6 girders connected into continuous spans)

Strands pulled through ducts; tendons 640 ft long post-tensioned and grouted

80 percent of expansion joints eliminated by continuity through post-tensioning; smooth guideway ensured by camber and deflection control

Both curved and straight girders were partially prestressed sufficiently at the factory to compensate for the dead-load bending of the girder. Concrete strength for the girders was 4,500 psi at transfer and 7,000 psi at 28 days. The actual strengths achieved are shown in Figure 18. Noteworthy is the fact that more than 90 percent of the tests exceeded 8,000 psi. The 5.76 percent coefficient of variation for production concrete represents first-class quality control.

To meet Disney's criteria for passenger comfort and smooth riding qualities required that the beamway dimensional tolerance be set at 0.1 in. True position for the columns was set at 0.1 in. laterally and 0.25 in. longitudinally and vertically.

The geometry of the monorail was defined by a system of north-south, east-west, and vertical coordinates that were established. All dimensioning was in inches and decimals. The X, Y, and Z coordinates of the beamway centerline at 100-in. stations were defined by mathematical equations. Mathematical labor was reduced by computerizing the geometrics. From the generalized coordinates of the system in space, a transformation was developed to define the geometry of the formwork for each girder, as shown in Figure 19. Horizontal and vertical curvature and superelevation angles up to 8 deg were required for the curved girders. Since no 2 curved girders were alike, the cost of a separate form for each girder would have been prohibitive. It was found more economical to build an elaborate, flexible steel form capable of bending to the shape of each and every curve in the project. The adjustable form is shown in Figure 20m.

The straight beams, usually 100- and 110-ft spans, were built in straight side forms, with an adjustable soffit, which accommodated the changes in the parabola curvature for each girder length. Zero-slump concrete was placed and compacted with powerful form vibration. One girder per day was produced in each form, with 16-hour strengths reaching 5,000 psi. Stage 1 prestress for balancing girder dead-load bending was by pretension in the straight girders and by post-tension in the curved members. When delivered and erected, the girders had virtually no camber from stage 1 prestress. Figure 20n shows girders being loaded on rail cars for delivery from the plant to the job site.

For erection, temporary support on the steel crosshead was provided by a projecting 1.75-in. thick steel plate at each end of the girder. The girders were placed to 0.1-in. true position tolerance on the crosshead by using precision survey instruments, including laser-beam equipment. Adjustable steel bracing hardware (Figs. 20p and 20q) was provided to fix the girders in true position. The protruding post-tension ducts (Fig. 20n) were coupled together, and the spaces between girder ends at all interior piers of each 6-span continuous girder series were filled with concrete.

For the typical series of 6 continuous spans, the post-tension cables, 650 ft long, were pulled into the ducts. They were stressed with hydraulic jacks (Fig. 20q) at the expansion ends, and then pressure grouted. For straight spans, no friction during stressing was experienced, and stressing was done from one end only. On the other hand, the effects of friction in the curved girders were minimized by jacking the tendons from both ends.

Although the Disney World monorail was a complex and challenging project, demanding the highest quality and perfection in workmanship, the project was executed to Disney's standards, and it promises to give the public a very smooth and comfortable ride. We hope the monorail system may be the answer to urban public transportation in many cities where existing land and rights-of-way may permit elevated structures over existing streets and highways. The application of prestressed concrete is an ideal solution to the problem.

Construction Economy Through Systems Building

Lev Zetlin

The systems buildings concept has been with us for more than 20 years. Eastern Europe and, of course, Russia has spent tens of billions of dollars on systems building. When I say building, I mean it in a general sense; it applies to bridges as well. In the United States, there are more than 200 companies that are becoming involved with systematized and industrialized construction. Systems building is, or could be, the solution to building needs. Many people, and I am among them, believe it is the solution to the problems that face us. I was involved for years in systems construction of housing and other structures and visited many countries that were supposed to be leaders in industrialized construction. Our firm is developing rapid transit systems for the Delaware River Authority through systems components. Nevertheless, we must acknowledge that there is no systems building as yet. There are no systems as we understand them. Actually, to compare what we have today to systems building is like comparing the Saturn Rocket with the Goddard Rocket. However, there is a tremendous activity in the area, and the bridge construction profession has to take a very thorough look at what should be done and what could be done.

I do not dispute the beauty of the bridges of Maillart and Leonhardt in Europe, but they are not systems bridges. We are not criticizing those bridges; however, through a systems type of approach we can build bridges cheaper. Because of my experience and exposure to the problems of rapid transit, industrialized bridges, and industrialized building components, I would like to share with you some thoughts on the problems of bridge construction costs.

Skyrocketing costs of construction demand that traditional construction methods be closely reevaluated for their applicability to present projects. Traditional methods of construction have served us well for many years and have been the mainstay of the construction industry. They are, however, primarily applicable to a set of economic conditions that are rapidly changing in our modern life. Our present and projected economic climate dictates optimization in the economy of construction. Too often engineers are called on to make significant innovations, if not breakthroughs, by using traditional tools and by working under the same set of circumstances that are applicable to conventional, routine designs. Often requirements for innovations occur in a company engaged in a panic program that has unrealistic deadlines. This forces the engineer to rely on handbook approaches. The job gets done, but the opportunity to save millions of dollars in the construction is lost.

What is needed are programs that permit advanced engineering studies at the very preliminary conception of a project idea to ensure that, during the final design phase, all possible cost-cutting innovations can be included. Such preliminary studies to foresee cost-cutting techniques during final design have proved their validity. However, development and realization of cost-cutting techniques require initiative and willingness on the part of both the engineer and the client. It must first be recognized that, because of the spiraling construction cost, drastic cost cutting must be done. This cannot be accomplished by the laborious savings of only construction materials through sophisticated analyses of standard conventional construction components. What is needed is a total design approach that considers the basic requirements of a project and results in an optimized design concept that is the most applicable, both functionally and economically. That is to say, the geometric form of the entire structure and its components should not be predetermined before the needs of the problem are studied. The geometric form and shape should be a result of such study.

Although drastic cost cutting is desirable, it must be done through the process of evolution rather than revolution. One evolutionary process, for example, consists of using a basic concept developed in other industries not related to the bridge industry and adjusting that component to a bridge.

When innovating cost-cutting solutions for construction are developed, the following major items must be emphasized:

1. Reduction in the number of skilled laborers as well as in their man-hours,
2. More efficient use of labor by moving it from the field to the assembly line under cover,
3. Simplicity of design details and construction assemblies,
4. Larger permissible tolerance of error in construction of the bridge, and
5. Determinacy of the design and construction program to ensure accuracy of the initial cost estimate of construction and its correspondence with final construction cost.

What must be flagged first is the word "simplicity." The military preassembled bridges of AVCO are erected kinetically on top of tanks through a series of hinges. Although they are beautiful and sophisticated, they are not simple. They are a piece of machinery. We in the construction industry have to come up with the simplest possible solutions. To design a simple detail, one might have to go through an extremely complex design process. In our firm, we have repeatedly found that the use of advanced design methodology is worthwhile. Unfortunately, too many of us think that simplicity in design means simplicity in thinking and simplicity on the drafting boards. It is just the other way around. Your thinking may be the most complex and and your design equipment may be the most complex, but they must be used, to produce a construction detail that is as simple as possible.

Not only are construction costs very high but also construction needs are great. The combination of construction costs and needs can bankrupt the nation. However, our biggest problem today is that the actual cost of completed construction is much higher than the estimated cost of construction made during design stages, and we cannot even predict how much higher. We think it is possible to achieve a close relation between initial estimated cost and final construction cost. It certainly should be a factor for anyone who considers preassembled bridges.

The skyrocketing cost of labor requires that the engineer and all others involved be attuned to the amount of man-hours required to assemble the components of a designed structure. As the engineer develops the details, he must be sensitive to the numerous hours that can be wasted in constructing complicated connections that require a high degree of precision and watchmaking operations. Innovative concepts must result in designs and construction details that minimize contingencies in preplanning field operations. The basic approach to cost cutting in construction must also consider the proper balance between policy and technology. There is a tendency to think that there is too much technology and that only policy will solve our problems. Within policy I include considerations, such as aesthetics and ecology. Of course policy should always be given due importance in any project. In modern society, however, technology always affects policy, and de-emphasis on technology could lead to misguided policy decisions. Therefore, we must maintain a proper respect for both the development and the application of technology to ensure that the adopted policy consists of all the tools available to effect maximum economy in construction. Any type of construction is a result of a compromise of many parameters. We sometimes find we have cornered ourselves because we emphasized one parameter more than the others.

We can develop innovative structural systems that will lead to economical construction by using the following available tools:

1. Modern methodology and analyses;
2. Lighter and more versatile materials;
3. Geometry of structural components and systems to obtain strength resistance;
4. Interdisciplinary approach to the design and solution of problems;
5. Industrialization (this, of course, was the prime purpose of this conference);
6. Extrapolation of proven concepts (for example, those in the aerospace industry) to innovations in construction designs; and
7. Modern fabrication and erection techniques.

I think that the bridge industry particularly should be more aware of and more flexible in accepting the experience of those in other fields of technology. We will not be able to lift ourselves by our own boot straps; we cannot improve by inbreeding. We have to learn from others and possibly involve other disciplines in the bridge construction industry. Some of these statements sound like cliches; nevertheless, they are worth consideration.

I think that we can make better use of available materials and tools than we have. It is the use of these tools in proper combination that is important. Someone has already stated that using modern analysis techniques on conventional structural components for the sole purpose of reducing material and weight will not result in significant cost cutting. Why should we not be building bridges at 20 percent of today's cost instead of reducing costs by 5 or 10 percent? The use of modern analyses and techniques on a new design concept that capitalizes on the efficient use of both the geometry and the lighter and more versatile materials can lead to drastic cost cutting. The new materials could be plastics, improved concrete, light-gauge steel, or any combination of these materials. As I said before, our purpose is evolution, a step-by-step progress. The engineering profession must recognize its role as one component of the entire scientific community and as one of the various talents required during design development. Input from other disciplines involved in a project must be considered to ensure an overall applicable solution.

I would like to discuss some specific projects involving preassembled construction. Both the projects and their engineering solutions are varied. Familiarity with varied projects can help solve some of the problems in systems bridges. I do not mean that we must apply the construction details to bridges but that, by knowing what has been done on structures other than bridges, we may more easily find solutions for problems related to preassembled bridges.

In the Delaware River Port Authority program, there have been about 66 systems developed. Most of them consist of components for uses such as subway linings, viaducts, bridges, stations, retaining walls, cuts, overpasses, and other related rapid transit structures. The systems components developed for the Delaware River Port Authority have the following characteristics, which I think should also be the key characteristics for preassembled bridges: ease of construction of connections, minimum amount of field labor, and savings in construction time. Most of the components are mass produced under a roof by traditional production techniques. Another important feature of the components is their interchangeability. For example, a retaining wall component serves also as an overpass component. Numerous elements may be nested during shipping, reducing site delivery cost. The universal use of these elements for various rapid transit facilities reduces the construction operation to repetitive operations and results in speed and economy. In most cases, the structural material for the component is concrete, except that the weight is less than it would be were components of traditional form. One of the reasons for this lighter weight is structural geometry. Concrete, however, is not the only material used in this program. A combination of concrete and light-gauge metal or plastic has proved to have great merit. Retaining wall and viaduct structures could be built out of the same components.

The figures discussed below show some preassembled structures that are being used today both in this country and in Europe.

Figure 1 shows a conoid element that is used for overpasses and retaining walls.

Fill embankments are quite expensive with today's labor cost; they are a carry-over from the past when labor costs were lower. Figure 2 shows an attempt to replace all embankments with open-latticed structures. This structure is not a viaduct; it has functions entirely different from a viaduct. Elements are interchangeable. The railroad station and the structure that replaces the fill consist of the same elements. An important feature is that the structural elements are telescopic, giving the contractor an opportunity to use identical elements irrespective of the ground elevation. Telescoping is accomplished through the serrated detail.

Figure 3 shows a preassembled viaduct truss. The Bailey bridge has served well, but its trouble is a lack of homogeneity and the indeterminacy of deflections. The particular truss shown in Figure 3 consists of modular portions of truss components where shear resistance is supplied through post-tensioning in the field. In this manner one does get a homogeneous continuous structure that can be analyzed as if it were monolithic, and its behavior can be predicted.

Figure 4 shows an attempt to have a continuous prestressed viaduct that consists of individual pretensioned units. It has a vertical stem connection rather than a conventional top and bottom flange connection. We find that this is a much more economical type of connection, and it permits that previously mentioned margin of error to the contractor.

Figure 5 shows what we call a super-perlin. It is one-half of a complete structural unit with 2 legs and only half a flange. This way it becomes very versatile for use in many applications. Figure 6, for example, shows it being used for a subway station.

Figure 7 shows some more studies for replacing fills in embankments. Consideration of the impact and rolling effect of trains is of prime importance. Because there is quite a bit of information avialable on the behavior and response of structures, it is possible to design preassembled systems for impact loads.

Figure 8 shows a stretched membrane to be used in railroad stations. Railroad stations built by the use of conventional techniques are costly. Actually, railroad stations do not have to be heavy; they could be light, preassembled, brought to the site, and erected rapidly.

Figure 9 shows a system for preassembled floating units to support a STOL airport on water; stability is provided through buoyancy. The idea is for the preassembled units to be brought to the site and anchored into the water bed.

Figure 10 shows the availability of a wide range of materials today. The top line shows a material that has a strength of 3 million psi with modulus of elasticity of 100 million psi. In other words, this material is 100 times stronger than steel but has only 3 times its modulus of elasticity. Obviously, high-strength materials have tremendous advantages and are being more frequently used. However, because the modulus of elasticity is relatively low, structures built with such materials will be too flexible for practical use. We must, therefore, devise different forms for structures; namely, let geometry of structure, rather than quantity of material, resist deformations.

Figures 11 and 12 show the versatility available in the space industry. A mat used for helicopter landing is also used to cover shelters. Skin or membrane structures have tremendous advantages because of their geometry. This hyperbolic paraboloid could be built out of identical strips that in turn could be mass produced and assembled in the field by unskilled labor.

Figures 13, 14, and 15 show the American Airlines hangars in San Francisco and Los Angeles. They were erected on the ground and lifted up and thereby saved about 60 percent of weight, saved time in construction, and enhanced the aesthetics. Skin structures can be built out of almost any material: aluminum, steel, or thin concrete. The hangars in San Francisco and Los Angeles can stand 15 percent error in welds.

Figure 1.

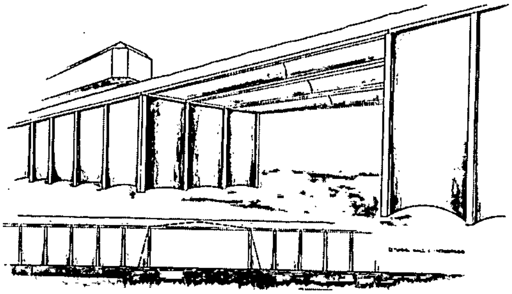


Figure 2.

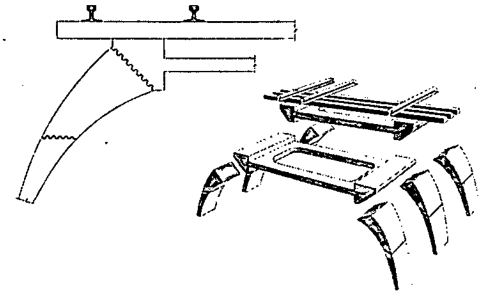


Figure 3.

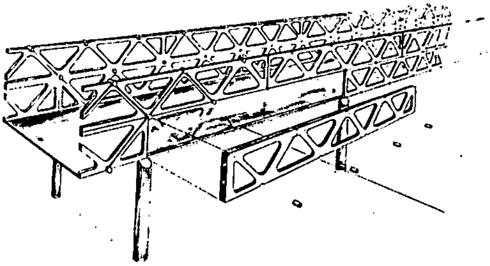


Figure 4.

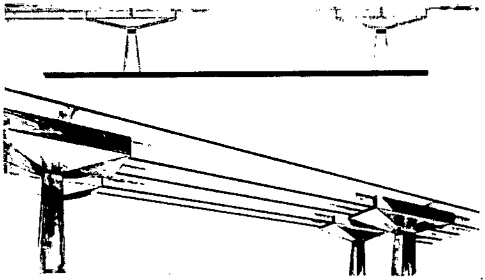


Figure 5.

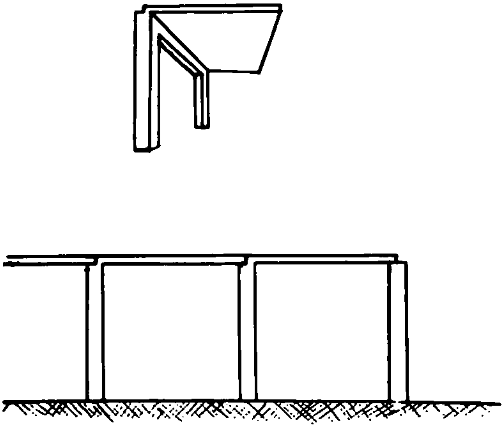


Figure 6.

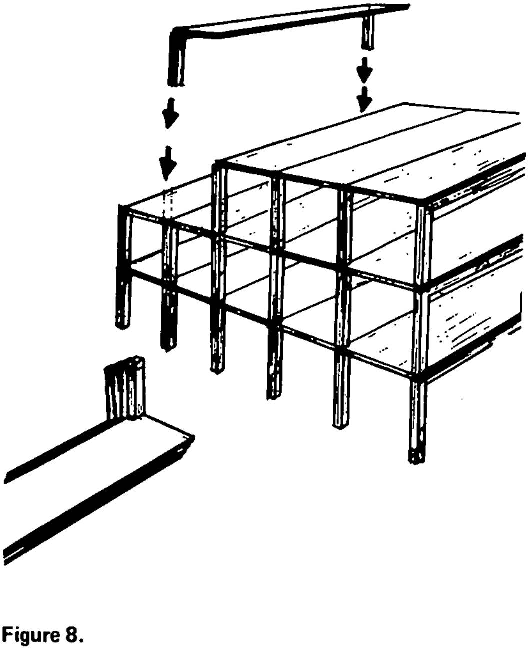
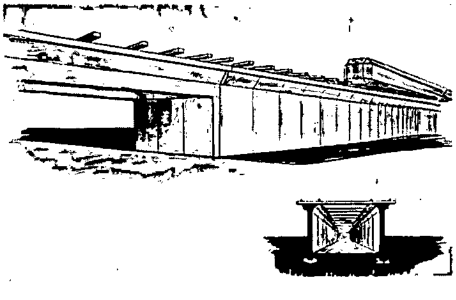


Figure 7.



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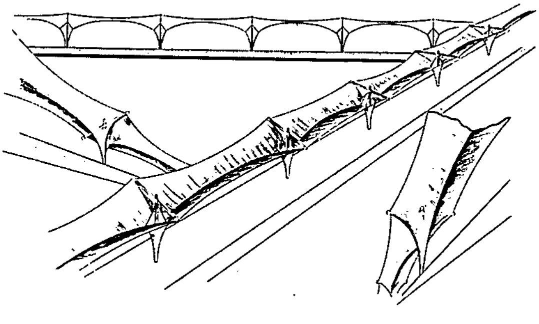


Figure 9.

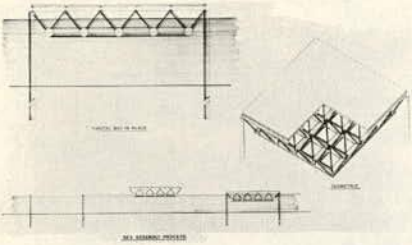


Figure 10.

MATERIAL	TENSILE STRENGTH, X10^6 psi	MODULUS OF ELASTICITY, X10^6 psi
Graphite whiskers	3.0-3.5	98
Silicon carbide whiskers	3.0	100
Alumina whiskers	2.2	76
Iron whiskers	1.9	28
Silica fibers	1.0-3.0	10
Carbon steel wire	0.6	30
Boron filaments	0.5	55
Stainless steel wire	0.5	29
Tungsten wire	0.4	50
Beryllium wire	0.2	45

Figure 11.

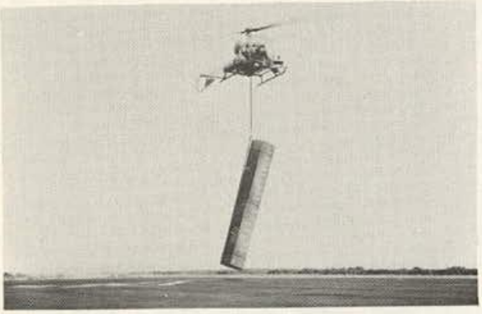


Figure 12.

Figure 13.

Figure 14.

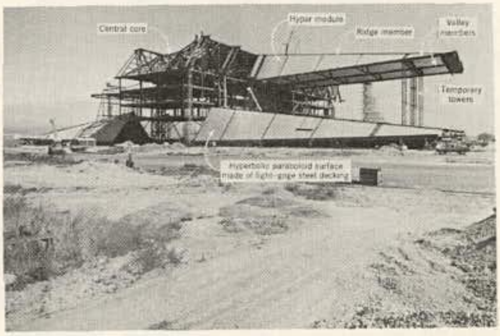


Figure 15.

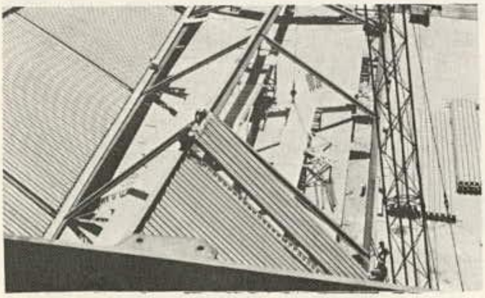


Figure 16.

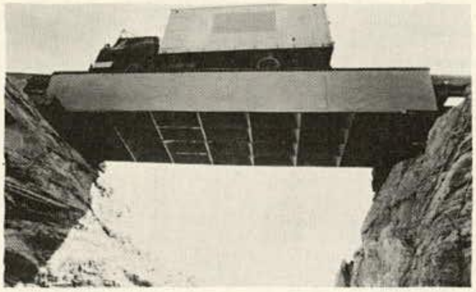


Figure 17.

Figure 18.

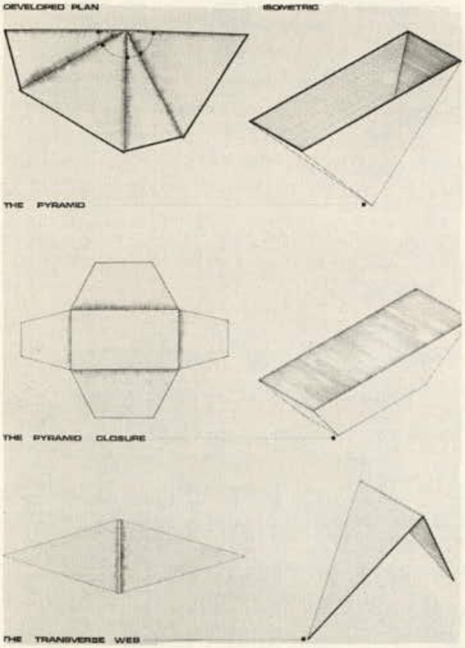


Figure 19.

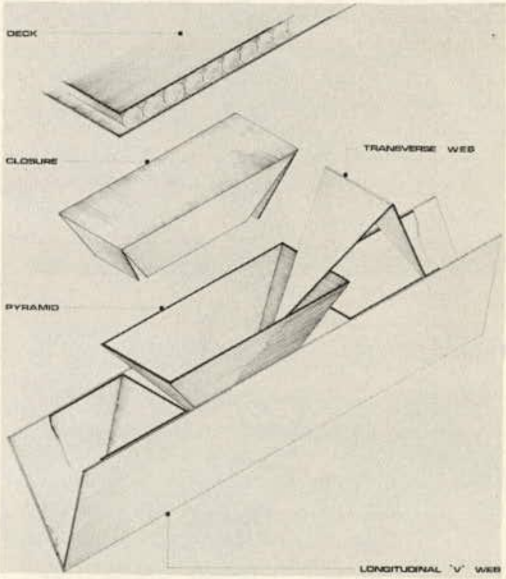


Figure 20.

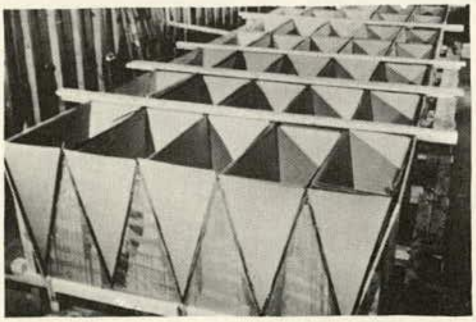


Figure 21.

Figure 22.

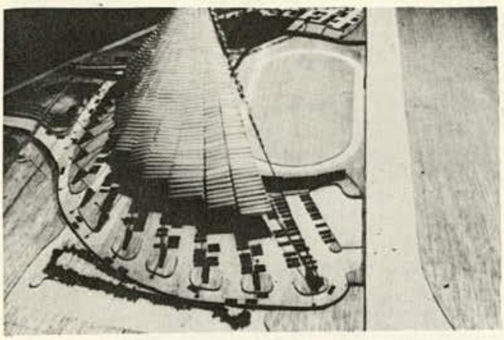


Figure 23.

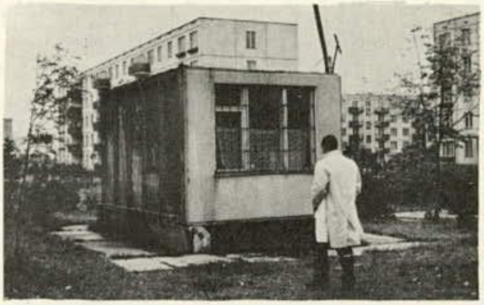


Figure 24.

Figure 25.

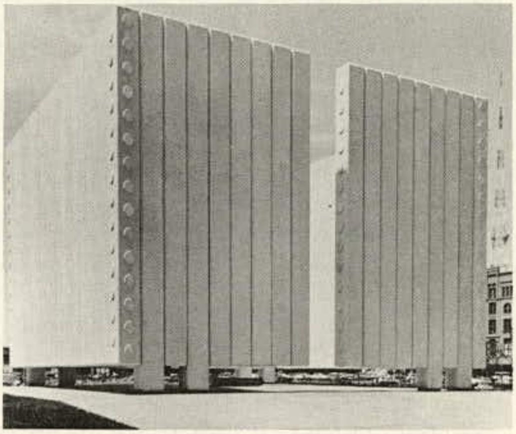


Figure 26.

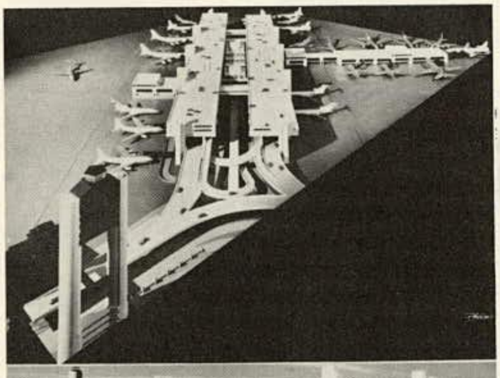


Figure 27.

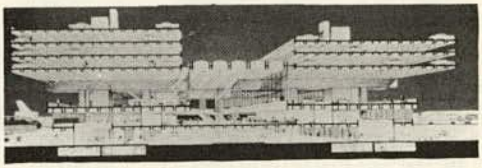
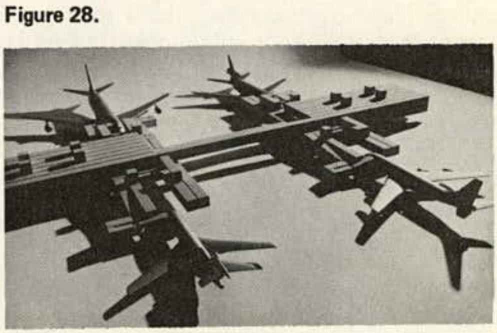


Figure 28.



The reason is that the strength of the welds in a given area depends on the "statistical" average strength of hundreds of welds rather than on an individual weld. In conventional trusses and structures today, theoretically if one of the connections fails, the whole structure collapses.

Figures 16 through 20 show a bridge constructed out of paper. A bridge constructed out of paper with the conventional slab and beam approach would weigh as much as concrete. In this case, however, a "molecular" approach was used, i.e., geometry of each molecule (a 4-ft hollow pyramid), its skin resistance, and statistical average strength. The weight of the bridge was reduced to 20 percent of that of concrete, and dead load was only a fraction of live load. Paper as a material is just an example. One could use the same approach with many other materials. The bridge was transported by helicopter and dropped into place. One can see the egg-crate appearance underneath and, instead of welding, glue was applied to the surfaces. Notice the deck of the bridge, which is hollow and is built out of paper tubes.

In my opinion, we do not correlate building concepts to foundation conditions. I believe that we have to adjust the shape of structures to the foundations in the same way that we have to adjust the shape of our structures to the materials and labor. For example, maybe we should permit a building or a bridge to sag or permit larger settlements in the foundations. In such cases, the concepts of the buildings should be such that the buildings can accommodate themselves to distortions without affecting their functions. Successful solutions in this direction have been achieved.

Figure 21 shows a preassembled stadium. It has an 800-ft span and consists of identical hyperbolic paraboloid units, which are connected together creating a lightweight steel shell. Figure 22 shows a preassembled stadium for Saudi Arabia; it consists of cables and inflated tubes manufactured in the United States. The cables are wound on reels and all components are packed tightly and shipped for erection by relatively unskilled labor. Figures 23 and 24 show an example of systems buildings in Russia. The boxes are stacked one on top of the other. A typical feature of a systems building is that every component has many inserts so that the component is integrated into the whole building rather than serving only a structural function. Figure 25 shows the Kennedy Memorial in Dallas. Its main structural feature is that it consists of identical elements. Vertical elements are put together and post-tensioned to create the interesting shape of the Memorial, which is eccentric.

In the United States we are in urgent search for systems, be they for buildings or bridges. We have tried to import European systems buildings. I think that one has to evaluate whether we should be importing European systems at all. What is right for us? I think that, even though we may not produce systems overnight, we will gradually develop them, step by step, as each step becomes profitable.

Today in the United States, when we use precast concrete structures, we try to integrate functions instead of building the way we used to build—which is like an onion-peel structure, i.e., a frame covered with insulation and then with something else. We are trying today to integrate the structure, the mechanical features, and the finish, all in one mass-produced unit. Integrated modular components, i.e., building components that serve simultaneously structural, architectural, and mechanical functions and are repetitive could contribute vastly to cost cutting.

Figures 26 and 27 show a 90 million dollar terminal in Boston, with attached roads, bridges, and overpasses, and a parking garage for 3,000 cars on top of the terminal. Compare this project with a possible future project of a novel geometric concept, shown in Figure 28, that utilized modern technology, both in material and manufacturing techniques. The concept consists of extruded pipes of synthetic materials. People move within tubes. A passenger has the feeling that he is getting into an airplane without going through a large open terminal. The estimated cost of this terminal is $7 million, as compared to $90 million.

This is the reason why I am optimistic about the future and why I think we will be able to cut construction costs drastically. The Delaware River Port Authority study has shown, as have other studies, that drastic cost-cutting techniques are possible. To achieve this advantage will require that every field of technology be utilized. As new techniques are applied, the change in construction methods should be gradual and evolutionary.

Current Practices in Steel Construction

Harold B. Elsasser

I do not represent myself as an expert on systems building or an expert in modular construction or an encyclopedia of new developments and ideas. However, I do believe that a brief review of current practice in steel construction will be helpful to those interested in systems building. Therefore, my purpose is to describe briefly current practice in steel construction, placing it in terms and perspective of systems building, and to examine ways of reducing on-site construction time of bridge building.

Systems building, of course, involves the standardizing of the dimensions and the strengths of the individual components so that they can be combined in different ways to meet a variety of needs. The dominant requirement for reducing on-site construction time is to minimize the number of pieces to be handled and the connections to be made at the site. Over the years the steel suppliers and fabricators have, in my judgment, done an outstanding job within the limits of technical knowledge and owner acceptance. Those limits include economics of providing a variety of types of steel and shapes of sections in standard modular sizes separated by practical increments. This is not necessarily to their credit because the economics of the marketplace has virtually dictated this.

The basic components of all steel construction are the rolled shapes and plates that have been readily available for years. Wide flange sections are available in depths from 6 to 18 in. in 2-in. increments and from 18 to 36 in. in 3-in. increments. I-beams come in 1-in. increments from depths between 3 and 8 in. and in increments of 2, 3, or 4 in. in depths from 8 to 24 in. All other types of rolled shapes are similarly available. Other steel components have also been standardized extensively. The more familiar ones include line pipe, corrugated pipe, corrugated sheets, stay-in-place metal forms, plate culverts, open-web joists, steel grating, wire rope, and reinforcing bar. In recent years, as we aimed toward orthotropic steel plate decks, standard closed-stiffing ribs have been offered. Also, in recent years, prefabricated parallel wire strands have been added to the list. All of these individual components are supplied in a range of strengths. Structural steels are available with minimum yield strengths in tension of 36, 50, 60, 70, and 100 kips/in.^{2}, all conforming to standard requirements described by the American Society for Testing and Materials.

Systems building also involves subassemblies. We find that current practice has already taken maximum advantage of this technique. Nearly all steel work is "prefabricated" into the largest subassemblies that can be reasonably shipped and handled. Because time and work at the site are expenses, to minimize the number of pieces to be handled and the number of connections to be made at the site usually means the least expense.

The subassemblies, however, are neither standardized nor stocked for the simple reason that they are not the same from job to job. The chances of being able to use a particular fabricated beam from one bridge in the next bridge are too remote to justify stocking. However, within a given structure or project, it is common practice to detail the pieces so that maximum duplication is achieved. This reduces cost by allowing the use of manufacturing techniques to produce large quantities of identical pieces; it allows the use of jigs to speed assembly and increase accuracy. To obtain this duplication, we sometimes give away weight by extending thicker plates or heavier sections into areas where their additional strength is not needed.

The advent of numerically controlled equipment has made practical the manufacture of identical pieces that are such exact duplicates that they can be interchanged. It has made practical the fabrication of pieces to such accuracy that the desired geometry can be maintained regardless of the length or shape of the finished structure. It has eliminated the need for reaming, riveting, making bolt holes, and assembling parts in order to obtain good fit and proper geometry. On numerous structures the individual members have been drilled with full-sized holes, shipped, and erected easily without any assembly of mating pieces until they came together in their final position in the structure. This use of numerically controlled equipment has other advantages. If one piece is lost or damaged, another of the same erection mark can be substituted to keep the erection going. A duplicate can be made in full confidence that it will fit.

The use of numerically controlled equipment makes possible the fabrication of pieces in exact modular dimensions and, thus, makes systems building practical for steel bridge members. It is common practice to subassemble sections of the structure at the bridge site into the largest piece that can be handled. In the construction of suspension bridges, float-in techniques have been used for complete spans weighing more than 1,000 tons, and it is common practice to assemble a large section weighing as many as 400 tons and to pick and place this piece. The ultimate of this subassembly technique is the roll-in technique that is often used in constructing railroad bridges whereby the complete new bridge is assembled adjacent to its permanent position and in a matter of one or two days the old bridge is rolled out of the way and the new bridge is rolled into place. The limitations, of course, on both shipping and field subassembly are size and weight, i.e., what can be handled.

In short, then, the economics of construction has forced the steel industry into miminizing on-site time as much as possible within the bounds of technology. It seems doubtful that much additional time saving can be realized in the steel construction. I do not think, therefore, that it is fruitful to spend time trying to squeeze a little bit more time out of that phase of construction.

However, there is an area in steel construction to which I think we should direct our attention. One of the major deterrents to systematized steel construction in my judgment seems to be the individual sovereignty of the various owners and designers. Although designs generally follow the requirements of AASHO and design tables have been provided by both industry and consultants, the details of design vary considerably. For example, one state will not put lateral connection plates on the web of a girder, and most states will. This kind of thing totally precludes prefabrication in the sense of making up standard components and having them in stock. It precludes the use of standardized manufacturing techniques.

Something else that inhibits the stocking of material is the cost of having pieces in inventory. Probably the chief deterrent to systems building in bridge steel superstructures is that every bridge is unique, mainly through geometrics. Immediately there comes to mind a plate girder bridge with parallel plate girders in which the girders flare down and out so that no two pieces in the bridge are the same. There was no piece in that bridge that could be used in any other bridge. Its seems to me that if we are going to have systems building in steel superstructures, the owner is going to have to standardize on design requirements, and he is going to have to be willing to give up some of the flexibility and uniqueness of each of his structures. Indeed in steel the trends have been quite the opposite. The trend has been to facilitate unique design. In addition, the use of welding and the advent of welding 3 plate beams have made available an infinite variety of members. The designer takes full advantage of this infinite variety, and it would be foolish for anyone in the steel business to stock prefabricated sections for bridge superstructure.

Another inhibitor of systems building is that every owner insists on his own particular specifications and his own particular inspection. There have been instances in which even a relatively standard butt weld was rejected because the owner's inspector did not happen to be there at the time it was made. If we are going to have systems building, we are going to have to have relatively standard specifications, to have relatively standard inspection techniques, and to devise the mechanism whereby pieces that are fabricated well in advance and perhaps even stocked can be accepted by an owner on the basis of somebody else's inspection or somebody else's quality control. Maybe this would mean having inspectors licensed by the state or, as is frequently done in the case of weld qualification, having the state accept the judgment and certification of an independent inspecting agency.

Fast-Assembly Bridge Over The Aegidientorplatz In Hannover

Elmar Koger

•WITHIN our large cities, the sudden increase in motor traffic during the past years has very often resulted in bottlenecks that lead to traffic congestion, especially at peak times. Responsible building authorities had to find means to both open new ways for the increasing traffic and obstruct as little as possible the traffic in the vicinity of the construction site while new roadways have been built. The solution of these novel building problems requires a novel bridge type, and in recent years there have been developments of this kind in various countries. This paper outlines how such urban bottlenecks can be overcome speedily and without major traffic impediments by steel bridge construction and briefly gives a typical example of building the fast-assembly bridge across the Aegidientorplatz in Hannover.

"Fast-assembly bridge" means a bridge structure that can be quickly procured and rapidly assembled and disassembled. It must be versatile and conveniently adaptable to changed traffic conditions. Contrary to permanent bridges, fast-assembly bridges are intended for uses limited in time, and it frequently happens that the bridge has to be adapted to changing site situations during its first term of service. After the first job has been completed, the fast-assembly bridge must be capable of being reused quickly without loss of material and without difficulties under greatly different conditions at another place.

What are the properties that a fast-assembly bridge must have to meet the requirements just stated? The bridge must be designed on the sectional principle so that it can be put together from a few different standardized components. By means of jigs and fixtures the components must have been manufactured so accurately that they can be assembled without reaming of fitted holes and, therefore, can be interchanged. Com-

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Presented at the 50th Annual Meeting and published in Highway Research Record 372.

ponents have to be connected and disconnected in the simplest way. Connection of the components is mostly made by fitted bolts. Because friction faces would require special treatment, there is no advantage in using high-strength friction grip bolts. Riveting and welding also do not offer any advantage because they do not permit an easy disassembly. In order to make the equipment versatile, the bridge must be variable in its cross-sectional width and span lengths. For the same reason, it should be possible to locate the main girder supports at any point on the main girder. The bridge may have to be curved in both its vertical and horizontal planes, the curvature being variable. Previous experience in building the bridges shows the necessity for having wide variations in the bridge layout because of factors, such as traffic areas below the bridge, utility lines, trees, and the like, that must be considered when the bridge is erected. The fast-assembly bridge systems of the Rheinhausen type, used for the bridge across the Aegidientorplatz in Hannover, fulfills all of these conditions.

The basic elements of the fast-assembly bridge of the Rheinhausen type are the main girders (Fig. 1). These main girders are designed with an open cross section and consist of the upper roadway plate with transverse roadway ribs, web plates, lower flanges, and welded-in cross girders in the main girder center. Four alternatives are manufactured: 2-web, 12 m long; 1-web, 12 m long; and 2-web and 1-web, 6 m long.

Main girders 6 m long will mostly be assembled at the bridge ends. They can be supplied with a uniform web height and with a raised web. The height of web plate is uniformly 1 m for all main girder types. Variation in the design of the bridge cross section is possible with the use of these main girder components. The variation is shown in Figure 2. For the 1-lane bridge cross section, a 2-web main girder component is used. Should the useful lane width of 3 m be insufficient, the roadway width could be increased up to about 3.20 m, as has been done in Hannover, by enlarging the component, or up to about 3.80 m by arranging a special curb. Two-lane and multilane bridge cross sections can be obtained by combining the required number of 1-web main girders with the 2-web main girder component. In this way useful roadway widths of 3, 6, 9, or 12 m are reached.

Roadway widths in between these figures are also feasible. For the fast-assembly bridge of Hannover, for instance, it was necessary to have 2-lane roadway widths of 7.50 m (Fig. 3). They were formed by arranging two 2-web main girders of 3.20 m each on the outer edges of the cross section and installing an intermediate plate of 1.10-

Figure 1. Main girders.

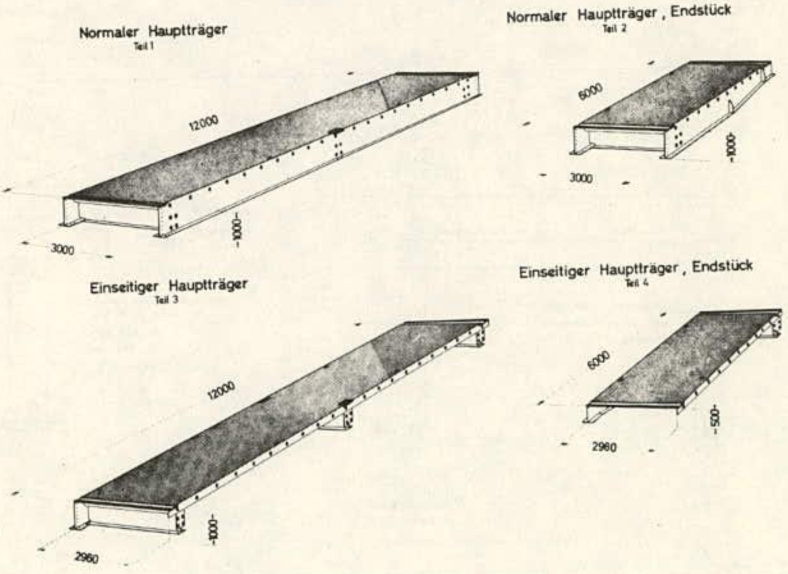


Figure 2. Variation in design.

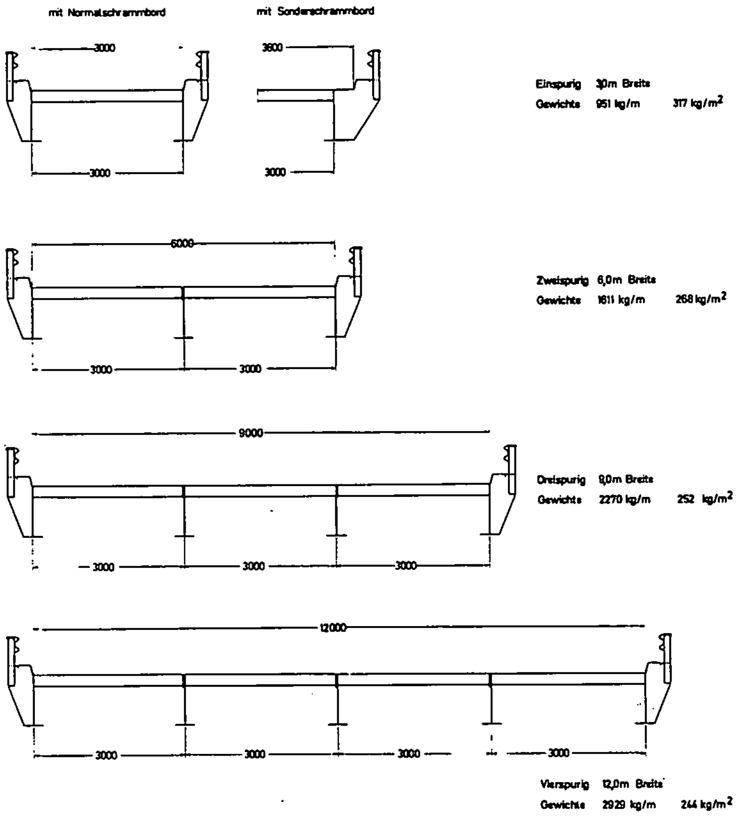
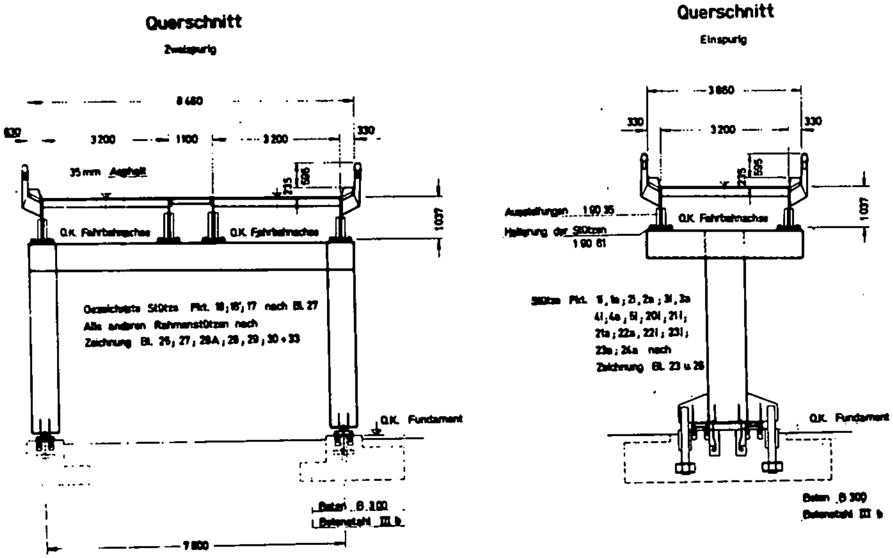


Figure 3. Design of fast-assembly bridge in Hannover.



m width. This cross section design also offers the advantage that the 7.50-m wide 2-lane cross section can be split up into 2 separate 1-lane roadways of 3.20 m each.

As a rule, the main girder components are completely welded ready-made units of the stated sizes. They can be transported on trucks or by rail without complications. For transport to very distant places, say, overseas countries, however, they should be sent in smaller shipping units. In such a case, the fast-assembly bridge system offers the possibility of disassembling the main girder into the individual elements: roadway plate, cross girder, and main girder web with lower flange. These can be shipped separately and assembled in the field by means of fitted bolts into 1-web or 2-web main girder components.

Of the cross girders spaced 6 m apart, every second cross girder is securely shop-welded into the main girder elements at the main girder center. The cross girders located at the joints are delivered as separate units and assembled when the main girder transverse joint is closed. All field connections are made by fitted bolts of 40-mm diameter and material quality 5 D. They are galvanized.

The bridge when fully completed forms a longitudinally and transversely continuous, flexurally rigid beam grillage. Under service conditions, a jointless roadway deck over the whole bridge area is thus obtained. The static computation is based on Bridge Class 30 of the German DIN 1072. With variable bearing positions, the standard type permits span lengths up to about 30 m.

The main girder elements normally are fabricated as straight units. If bridges are to be curved in their plan view or elevation, a curvature is sufficiently approximated for practical use by a broken polygon course with breaks at the joints at intervals of 12 m. Vertical curves have large radii of curvature, and the breaks at the joints can be achieved by a wedge type of drilled-web splice plates. Plan view curves, however, can have very small radii. In those cases, a wedge type of drilled splice plate arrangement generally will not do. Special wedge plates have to be provided at distances of 12 m to form the curvature required. The wedge plates are variably dimensioned and can be suited to any curve. As compared with the design for a continuous curve, this design with a polygon-shaped approximation of curvature offers the great benefit that, on reuse of this bridging equipment, splice plates and wedge plates need only be exchanged to overcome curves of great variety and all main girder elements and cross girders need have no modification.

In addition, the design of the main girder units allows giving the completed bridge any one-sided crossfall. If necessary, this can be changed in longitudinal direction of the bridge in accordance with the horizontal curvature. The one-sided crossfall is achieved by appropriately inclining the support points of the main girder webs. Because the completed bridge structure represents a torsion-soft structure, transverse inclination is possible by twisting the bridge while it is being erected, without appreciable additional stresses.

Within the limits of the maximum span lengths the fast-assembly bridge system of the Rheinhausen type largely grants freedom with regard to the arrangement of bearings. Bearings can be provided at any point on the main girder web or below the cross girders. The axes of the support frames need not be at right angles to the longitudinal bridge axis but may be set in oblique-angled arrangement. When the bridge is being erected on the site, bearing stiffeners are mounted by way of additional bores for force transmission purposes. When the equipment is used at several places, the same main girders allow different positions of bearings. It is also not necessary that, on a support frame, all main girder webs be supported on the bearings directly. If it is required by traffic below the bridge, outside main girder webs can be supported indirectly by additional cross girders within the superstructure, whereas the inside webs arranged over bearings directly transmit their forces to the support frame. Tie rods can be installed easily.

At the ramp ends, the bearing bodies are designed as fixed, knife-edge, rocker type of bearings or roller bearings moving on one side and made of steel. Bearings provided between superstructure and steel rocker posts are fixed, knife-edge rocker type of bearings made of steel or reinforced neoprene. Because of impact and noise suppression, softer supports are preferred.

For roadway transitions subject to major movements, finger-grip constructions have successfully been applied. At the bridge end with fixed bearing, a simple edge protection is sufficient.

Depending on local conditions, the fast-assembly bridge of the Rheinhausen type can be delivered with longitudinal continuous drainage piping or individual downpipes along the whole bridge. The gap approximately 10 mm wide arising between the individual main girder elements is suitably sealed off by a permanently flexible synthetic cement so that the decking is made completely watertight.

As a standard feature, the fast-assembly bridge of the Rheinhausen type is provided with guiding devices that consist of about 12-cm high curbs and crash barriers of cap section opened downward and that were made especially for this bridge type. The crash barriers are supported at intervals of 3 or 6 m. At the crash barrier posts and, if existing, on the footpath brackets, provision has been made for the attachment of light poles. When there are sidewalks or bus stops below the fast-assembly bridge, it is recommended that special splash protection be provided. It consists of a sheeting arranged between curb and crash barriers and prevents pedestrians from being splashed by water from the roadway surface.

Great flexibility and variability are demanded of the fast-assembly bridge. This condition especially applies to the supports of a fast-assembly bridge. Normally the support arrangement consists of 1-leg or multileg steel frame structures. Their shape greatly depends on different local conditions so that standardization does not offer any benefit; it is better to study and redesign the support frames for every new requirement. For intermediate supports of the fast-assembly bridge in longitudinal direction, the frames are designed as rocker frames with a point rocker type of bearing at the frame bases. Where traffic areas below the bridge have to be kept clear of bridge structures, it is often necessary to provide frame legs not only below the bridge but far outside of the bridge by using large transom span lengths or frames with cantilevering transoms.

Because the traffic conditions in the vicinity of a fast-assembly bridge seldom allow sand-blast derusting and painting work to be done at the site, anticorrosion work must be carried out as far as possible in the fabrication shops and any field work must be limited to a minimum. The extent of the corrosion protection largely depends on the local circumstances. Basically, however, paint materials should dry and harden quickly. Only in this way can damage to the shop coats during transport and erection be reduced to the unavoidable minimum. Two-component resin paints with zinc chromate and iron mica nearly comply with those requirements.

Surfacing work, too, must in many cases be done in the shops. Under design aspects of the steel structure, both thin plastic surfacing with minerals sprinkled in and asphalt surfacing in thicknesses ranging between 3 and 6 cm are suitable for the fast-assembly bridge of the Rheinhausen type. The choice of roadway surfacing depends on the time the bridge is to be in service. For a short use of 1 to 2 years, synthetic surfacing offers the advantage that it can be applied under controlled working conditions in the steel fabricating shops and requires little site work afterward. Because these surfaces are wear-prone, especially when spiked tires are frequently used, and can be repaired only in favorable weather, this surfacing should be adopted for short-term use only. For long-term use, an asphalt surfacing is recommended. In this case, too, an essential portion of the surfacing work, i.e., derusting and application of the adhesive primer, can be done in the fabricating shops. On the other hand, the mastic layer and asphalt should preferably be applied on the site, although, in principle, it is technically possible to apply asphalt surfacing on the main girder units prior to erection work. Apart from a better and less weather-dependent repair possibility, asphalt surfacing offers the advantage of impact cushioning and noise suppression.

The fast-assembly bridge system of the Rheinhausen type has been built by Krupp several times. Bridging equipment of this kind was delivered to Barcelona, Caracas, Rotterdam, Hannover, and Duisburg.

Figure 4. Fast-assembly bridge in Essen where, because of traffic areas underneath, supports are located away from bridge.

The installations in Essen, Duisburg, and Caracas are shown in Figures 4, 5, and 6. The best example of the versatility in design is the bridge across the Aegidientorplatz in Hannover. This installation is shown in Figure 7.

The Aegidientorplatz is an important traffic center in the city of Hannover. Altogether, 7 streets converge into the roundabout. Two of these are 1-way streets; the remaining five have 2-way traffic. Five 2-way tram lines pass to and from the Aegidientorplatz. The trams run for long distances below the fast-assembly bridge parallel to the longitudinal bridge axis and also in the zones of the end ramps. Therefore, the end ramps had to be split into 4 separate branches to provide passages for the trams. The fast-assembly bridge crosses 4 motor roads and 3 tram lines and has to allow for 2 thread-outs of tram lines at the bridge axis. In addition, urban utility lines and old trees represent other factors that had to be considered in the design.

The fast-assembly bridge was built to create a relief roadway for one of the main traffic flows. Streets at the ground level remained unchanged. A subway construction site is expected to appear in the area of the Aegidientorplatz in the near future. The bridge is scheduled for 10 years' use at this location.

The fast-assembly bridge is composed of a 2-lane central portion having a travel way 7.50 m wide and four 1-lane descent branches 3.20 m wide each. The 2-lane central roadway is 222 m long, and the total length of the 1-lane descent branches is twice 253 or 506 m; the length of the fast-assembly bridge is thus 728 m. The 1-lane concrete ramps are 2 by 106 or 212 m long. The span lengths are between 11 and 28.5 m. The structure consists of 78 two-web main girders, 18 intermediate plates, and about 40 wedge plates. The steel superstructure weighs about 1,023 tons corresponding to 311 kg/m^2, and the supports weigh 175 tons corresponding to 53 kg/m^2. The longitudinal grade changes from 0 to 6 percent. Maximum change in longitudinal grade at a bending point is 1 percent. Transverse grade is designed from 1 to 3 percent in accordance with the horizontal curves. In horizontal plane, the fast-assembly bridge is considerably curved. The angle at the center of the curvature circle is about 80 deg, and the curvature radius is about 90 m. Because of the length and considerable horizontal curvatures, the bridge was subdivided into 3 sections, which are separated from each other by expansion joints of a finger type of transition. Roadway surfacing consists of the adhesive primer already applied after sandblast derusting in the fabricating shops, a 1-cm thick mastic layer, and a 2-cm thick melted asphalt layer. Mastic and melted asphalt layers were applied when the bridge was erected.

The individual components of the superstructure were fabricated by Krupp in its Rheinhausen plant and by MAN in its Gustavsburg plant. By rail and road, the components were brought to a branch factory of Krupp in Hannover where the support frames were made and where the individual components were preassembled into erection units, each consisting of one 12-m long main girder with brackets, curbs, and crash barriers. As far as necessary, the intermediate plates were also attached to the main girders.

Erection at the site was completed on 5 weekends; in each case work was done from 4 o'clock on Saturdays until 3 o'clock on Mondays. A rigid time schedule was necessary, and punctual execution of the erection work could only be achieved with the extensive assistance of all municipal authorities. Subdivision of the 5 erection sections was made according to the traffic requirements so that car and tram traffic was only interrupted in the respective erection section during one weekend whereas, in the re-

Figure 5. Fast-assembly bridge in Duisburg.

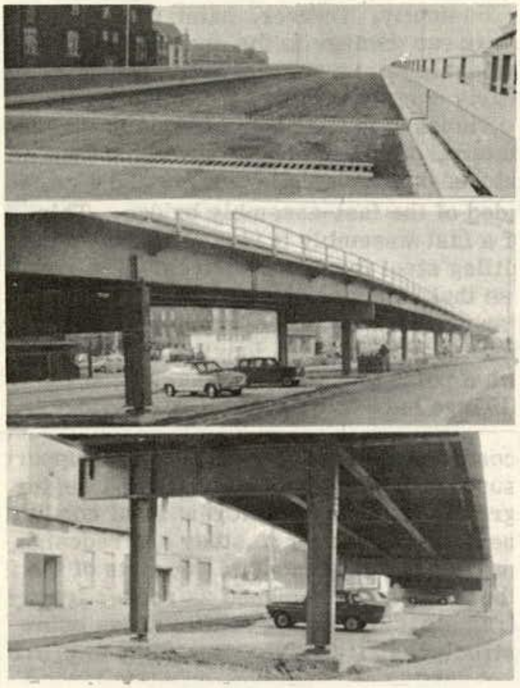


Figure 6. Fast-assembly bridge in Caracas.

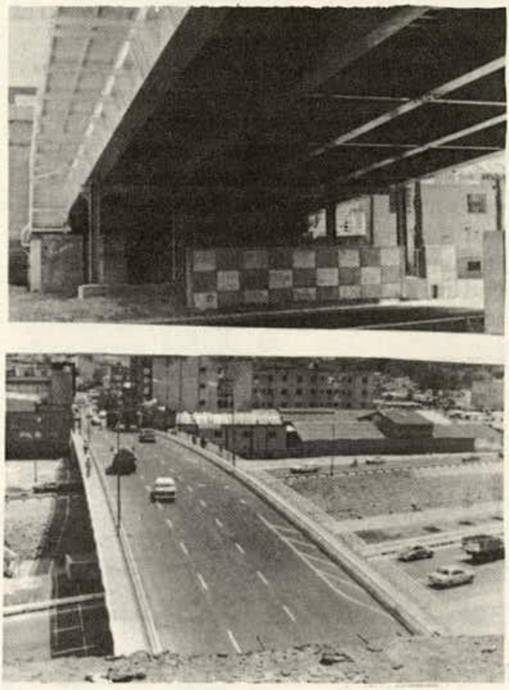
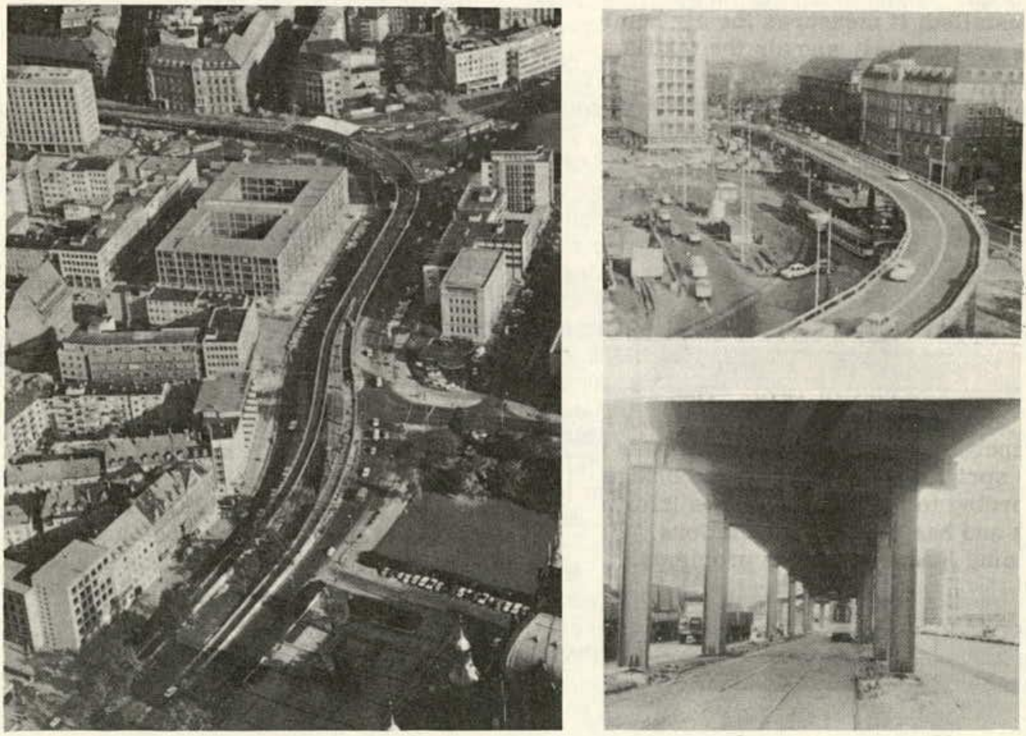


Figure 7. Fast-assembly bridge in Hannover.



maining sections of the Aegidientorplatz, traffic continued to run smoothly. The order was awarded to Krupp on May 17, 1968. The steel structure was erected on 5 weekends from September 21 to October 20, 1968. Prior to that time, foundations and concrete ramps were already made. The melted asphalt work was carried out from October 8 to October 30, 1968. As planned, the fast-assembly bridge was opened to traffic on November 1, 1968. There were 5½ months between order placement and opening. For fabrication and erection, about 4 months only were available.

In 1968, the contract price amounted to 1.785 million DM for the superstructure and the supports and to 285,000 DM for the foundations and concrete ramps, a total of 630 DM/m^2 of roadway area of the fast-assembly bridge. The fast-assembly bridge has been in service without interruption for 2 years. It is readily accepted by drivers, even by bus and truck drivers, although ground-level travel is still possible. Because of the melted asphalt surfacing, there is scarcely any traffic noise.

Despite the asphalt surface thickness of only 3 cm and a 6 percent longitudinal grade, the melted asphalt surfacing so far has shown only minor damage, which was easily repaired, although there were unusual climatic conditions during the winter of 1969-1970 and the summer of 1970. There have also been no difficulties with snow. At the bridge, an ice-signaling instrument has been installed; it measures the air humidity and temperature and, when the measure values are critical, signals the traffic service crew to sprinkle sand or clear the bridge.

According to the municipality's information, the fast-assembly bridge has been a success and has met all expectations. Fast-assembly bridges are a valuable help in overcoming innercity traffic problems.

Design, Manufacture, Transportation, and Erection of Systems Bridges

summary

Thomas A. Hanson

DESIGN

In addition to utility, safety, and appearance, systems bridges must incorporate standardization of details and sections. Thus the economies of repetitive forms, jigs, tooling, and design can be achieved. Timber railroad bridges, for example, have been standardized with 16-ft spans.

There is some question regarding the permanence of present design standards. There is a tendency toward larger trucks and smaller automobiles. If European trends are adopted here, the use of bicycles will grow. Two paths are open to us: We can assume that present regulations are permanent and perhaps design structures for particular uses, or we can design structures with flexibility of usage such as converting three 12-ft lanes to six 6-ft lanes.

An attempt should be made to stabilize design concepts. In-depth studies should yield the best solutions, and then designers should use these solutions. For example, the concepts of continuity and reduction in the number of expansion joints could be studied in this way.

The relative merits of American versus European systems should be examined. Legal, political, and practical problems may exist, but trials may be instructive. The European system is generally as follows:

1. An engineer establishes design parameters and sometimes prepares designs;
2. His specification allows submission of alternate designs;
3. The specification also points out that the lowest cost solution may not be selected, but, on occasion, 4 or 5 qualified bidders are selected, and the decision is based on cost alone;
4. A jury is selected to judge the entries;
5. The engineer checks submissions to see that design parameters and specifications are met (if the engineer requires more steel, for example, this must be paid for by the contractor out of pocket); and

6. The owner requires the contractor to carry insurance, and the insurance company's engineers check the design (the policy rates will vary according to the risks involved with the particular design).

Work is needed on load factors. For instance, concrete suffers from a 1.5 factor on dead load. If a concrete bridge is designed for a 1.5 dead load factor and the actual dead load is 1.0, the resulting live load factor would be 10 or more.

To stimulate innovation requires that there be an incentive of future jobs to amortize the investment in special equipment. This can be accomplished by market aggregation, such as awarding 50 or 100 bridges at a time. The Munich-based firm of Dyckerhoff and Widmann utilized market aggregation when it built 800 railroad bridges during a 7-year period. Some ideas relating to bridge design philosophy may be garnered from other industries. The Steel Joist Institute, for example, has set out a range of joist designations, each having certain moment and shear ratings. The manufacturers, then, prepare unique designs that meet the established ratings. The designs are approved in advance by the Institute so that further approvals are not needed for each project. In a similar manner, prior approval could be given to designs prepared by any industry. These designs could then be bid as alternates in competition with the base bid. This method encourages innovation by each industry, whereas the establishment of so-called "standard" designs could stifle future developments and improvements.

MANUFACTURING

Some of the major advantages of systems bridges will appear in the manufacturing phase. Tooling, materials, labor, special equipment, and handling of products and assemblies all provide opportunities for cost-saving innovations. Some of these are as follows:

1. Substructure—With precast, prestressed piles, the pay item increments in most specifications require too many stock lengths. Larger increments should be used. Pressure treating of wood piles is no limitation, but lengths should be kept under 100 ft. At the top of steel piles the need for a bearing plate is questioned.
2. Pier Caps—Prefabricated pier caps should be designed for the moments that occur during handling, not just for the in-place condition. If the member weight is excessive, segmental construction should be considered. Consideration should be given to permanent steel forms, filled with concrete. The cap and pier could be one piece. Laminated construction should be used for large wood piers.
3. Bearings—Elastomeric bearing pads are suggested for steel, concrete, or timber bridges. Selective inspection of bearing pads should be adopted, rather than complete inspection of all pads, which is time-consuming and expensive.
4. Girders—With precast, prestressed girders, spaced box beams should be considered, formed shear keys for composite construction should be eliminated, diaphragms in box and I-beams should be omitted, ½-in. diameter 270-k strand should be used, and bond should be broken at the ends to reduce cracks. With timber girders, laminations should be used for longer beams in lieu of sawed timber, and wood beams with a composite concrete deck should be tried. On steel bridges, weathering steel or aluminum should be used in lieu of painting. Only critical welds should be tested, and secondary welds should be spot-checked. In all materials, short spans should be standardized to permit stockpiling of members.
5. Deck—Transverse segmental slabs may be used, monolithic with the guardrails. Conversely, longitudinal precast slabs more easily allow the development of composite action.
6. Expansion Joints—Sliding plates and finger plates are time-consuming and hard to make. Mechanical attached joints such as Transflex or extruded joints are recommended.
7. Drains—If drains are located along the center of the bridge, half as many can be used.
8. Automation—The ultimate development of systems bridges must involve labor-saving and time-saving devices. Plants are already in operation that are controlled by

a man seated at a single console and assisted by computers. Improved efficiency of materials, equipment, and labor has made it possible for some plants to produce, for example, precast concrete products on a 12-hour cycle rather than a 24-hour cycle.

TRANSPORTATION

The advantages of factory production are offset somewhat by the need to transport large and heavy units. However, it is not unusual to see huge laminated wood arches being shipped from one coast to the other. The modes of transportation considered include truck, rail, truck on rail (piggyback), barge, and helicopter. With minor modifications, existing methods of transporting are adequate.

Road regulations are generally not a limitation for systems bridges. We should strive for uniformity among the various states because many shipments cross state lines.

When designing a bridge structure, the designer should consider the transportation limitations. If necessary, long or heavy members can be produced in segments to be joined at the site.

FIELD WORK

On urban bridges, where traffic interruptions are difficult and hazardous, the erection of systems bridges must proceed quickly. Field work must be kept to a minimum. Ways to accomplish this include the following: Use the largest pieces that can conveniently be shipped and erected; put as many operations as possible in the shop; consider precast footings; eliminate test piles, use piles that can be easily spliced, and drive until needed capacity is reached; consider pier shafts that are an extension of the piles; prefabricate pier shafts and caps; prefabricate medians and parapet walls; award contracts with performance specifications (including time); conduct contests with awards for optimum designs; consider design-and-build contracts; have regular conferences among designers and contractors to exchange ideas; and provide contractor with bonus for early finish.

design

Arthur L. Elliott

We took for granted the usual basic tenets of good design philosophy: that any design should perform with good utility; that it should provide the greatest possible safety; and that it should present a good appearance. Our main purpose was to find design applications that would minimize field work (because labor costs in the field are higher than those in the shop) and traffic disruption during construction. We wanted to find ways to fabricate more of the bridge under shop conditions, to bring it to the job in larger pieces, and to put it together in the field in less time.

The first thought that occurs to everyone is, To what extent can we standardize our units? The term "standardization" does not mean the same thing to all people. We concluded that we did not mean "standard" bridges—carbon copies turned out like lead soldiers from a mold. Neither for the most part did we mean standard stock girders as on-the-shelf items. Although in some special cases the stocking of girders is possible, it does not really fulfill the intended purpose.

We did mean, however, the sort of standardization that permits many duplications. Multiple uses of forms and jigs are the factors that make a repeating process economical. Details also can be made similar. Expansion joints, bearings, drains, railings, beam sizes, and column shapes and diameters—those are the things, used and reused, that permit a contractor or a fabricating plant to work economically. Yet, these items may be frequently duplicated without stereotyping the structures or creating a monotony of design.

Although we recognized the undesirability of extreme standardization of span and member, we remembered that the timber industry actually did standardize in this manner for trestle bridges. Railroads were standardized on 16-ft spans and highways on 19-ft spans. For these, standard lengths of timbers were available.

Moreover, we were not certain that current lane or shoulder widths will remain the standard. What would happen if many very small cars were developed and used? Is it possible that the ecology enthusiasm will result in greater bicycle use and a demand for bicycle lanes on structures and along freeways? These foretell very possible changes, but such changes come slowly. The standards we now have will remain with us long enough for fabricators and contractors to recover their tooling costs. Therefore, we regarded the geometrics as relatively permanent.

Load factor design is generally regarded as a more accurate method of assigning loads to a structure. However, concern was expressed that the design methods are becoming so exact that we are not leaving any reserve strength in structures. We also recognized that, if all structures were designed by the same load factor relationship, the concrete structures on a route would generally have greater reserve strength than the steel ones. The load factor approach has more effect on the longer spans. It seems wise to include some allowance for reserve strength, higher loadings on highways in the future, or multiple overloads even though to some extent these allowances negate the advantage of the load factor approach.

The American contractual system was examined in contrast with the European system where design and construction are often combined. This combination enables the designer to utilize the best capabilities of the contractor, and in turn the contractor can see that the design fits his best abilities. We agreed that there would have to be rather extensive changes in the American system of administration before a complete design-and-build philosophy could be adopted.

The European system embodies several refinements that we do not yet have. The codes and specifications must be very specific so that the designs are acceptable and comparable. The system uses referee consultants with broad powers to control the work and insurance or guarantee of the work during a period of years or either of these. As a result, the European contractor's overhead runs about 6 to 8 percent. In contrast, an American contractor may operate on about 2 percent overhead.

Some steps in the design-and-build direction are being made in this country, and we felt it might be very instructive if a few contracts of this sort were arranged on an experimental basis. The problem of selecting the winning bidder is a tough one. European contractors are not always happy with their selection process. The American requirement that the work go to the low bidder does much to eliminate conflict, argument, and pressure.

Value engineering or cost incentives are being used to try to realize some of the benefits of contractor participation in the design process. This has not been overwhelmingly successful. Contractors do not usually have time within the contract limits to go through the procedures of redesigning and securing approval. Consulting engineers make their money by getting the job done in the minimum time and do not like to take time to develop a number of innovations or to explore a variety of novel ideas.

The possibility of allowing alternate designs apparently has pitfalls too. After one designer has turned out a design, another designer can take the plans and almost certainly develop savings through skimping here and there. Thus, they are really not competing on an equal basis, and it is doubtful whether the designs are entirely equal in capabilities.

Any system has its shortcomings, and any system in wide use must have benefits that people consider worthwhile. It is beneficial, therefore, to continue to try to adapt the best parts of the various systems to achieve greater perfection.

There is an evident need, in our system, to stimulate innovation. A contractor must have some assurance of future use so that he can amortize his investment in a new idea or expensive adjustable forms. The designer's and the owner's philosophies must be progressive. Ways must be found to reward innovation or else it will never appear. Many old practices are becoming obsolete, and we must seek to change them for the better.

manufacturing

Jacob O. Whitlock

Because the soil-supported spread footing and drilled caissons were not in our general domain, loads to soils were considered with piles only. In general the piling types in common use do not present a problem in either manufacture or supply. There are, however, some revisions in specifications and design policy that would contribute to an overall economy and saving of time. Among these are pay increments in 5 ft on concrete piling to minimize inventory and ensure continuous driving from test pile to specified length placement, elimination of capping plates on steel H-piles where a concrete distributor cap is used, and awareness of maximum lengths of timber piles available in a given area to preclude delivery delays.

Completion of the substructure by use of a distribution cap to provide the superstructure bearing surface was considered in 3 materials. Concrete can be precast in the plant in basically any configuration and fastened to the piles or pier stems by grouting or post-tensioning. The main concern is to keep the size of the piece within highway transportation limitations. Timber caps in long lengths and large cross-sectional sizes should be specified to be laminated rather than to be sawed from a single piece. Single stem piers with hammerhead caps might well be fabricated of steel-skin plate properly reinforced internally and filled with concrete after erection. The fabricated steel serves as a stay-in-place form.

We agreed that bearings should be elastomeric in every condition where they can be utilized. No one likes the effort required to fabricate for or design around rollers, rockers, sliding plates, or other combinations of a similar nature. The forgiving nature of elastomeric bearings under conditions of workmanship or load conditions beyond the original intended limits of the design can be a most worthwhile asset.

The prestressed concrete box beam placed in intimate contact across the roadway and, thus, providing an immediate structural deck is the greatest single time-saver. The box-beam deck can be used immediately to carry traffic even though a mat is placed at a future date.

Timber girders in the longer spans can best be supplied as laminated in lieu of sawed timber. Decking of laminated panels covered with an asphalt wearing surface has proved itself a time-saver on many jobs.

Two avenues seeming to hold the most promise in utilization of construction on bridges with steel girders are the use of weathering steel and revisionary testing procedures for welding. The problem in weld-testing procedures seems to be the failure of some highway agencies to recognize that all welds are not of equal importance, and 100 percent perfection is not necessary throughout the girder. General acceptance of modular span lengths in maximum increments of length would be most beneficial in all materials.

The deck in most bridge construction is one of the largest consumers of construction time, and most of this time is expended in forming and placing reinforcing steel. A most logical approach then to the concrete deck is the use of stay-in-place concrete forms. An additional benefit can be derived by using prestressed concrete plank forms that not only provide the forming surface but also replace a portion of the positive moment steel. The precast, prestressed segmental deck for use on steel beams is rapidly coming to be recognized as a construction time-saver. Segments consist of a prestressed slab 6 in. thick and 8 ft wide with a curb parapet cast on each end. The length of the slab then becomes the out-to-out dimension of the roadway. Slabs are set on the girders with their long axis at right angles to the girder lines and fastened to the girders with bolted flange clips. The slabs then are post-tensioned parallel to the centerline of the roadway through preformed holes in the slabs. Closure at expansion joints and abutments is cast in place and encloses the post-tensioned fittings. This procedure provides the structural deck, wearing surface, and parapet or curb in one operation.

The wearing surface should be considered as an expendable item and isolated from the structural integrity of the deck. Field construction time is an inverse function of the degree of prefabrication in the structure, but all the basic materials manufacturers agree that the cosmetic touch necessary for good ridability is difficult to obtain in total prefabrication.

Expansion joints of the sliding, finger, or open types are difficult to fabricate and install and are a never-ending source of trouble. Plant-manufacturing and field-fitting problems are minimized when a compression or mechanical rubber joint is utilized.

Conservation of field construction time is within the immediate horizons of present knowledge and techniques. Maximum cooperation among all facets of the industry, wherein the state of the art is allowed to function and express itself without the encumbrance of obsolete specifications, is an important parameter.

transportation

James C. Holesapple

Transportation modes for use in systems bridge construction include truck, rail, truck-rail combination, barge, and helicopter. We agreed that in most cases truck or a truck-rail combination would be used, that is, short hauls by truck and long hauls by a truck-rail combination. Helicopters are useful only as erection equipment because of the danger in transporting over occupied areas. We generally agreed that, with minor modifications existing, transportation equipment is adequate and there is no pressing need for new or special equipment.

The present limitations placed by regulatory agencies on length, width, height, and weight of transportation equipment and load do not make it impossible to design and transport a systems bridge. Limitations in Virginia are as follows:

Roadway	Overall Length (ft)
2-lane	90
4-lane, undivided	100
4-lane, divided	110

In addition, the overall length can be increased to 125 ft when the over-the-road haul is 25 miles or less. These limitations are similar to those of most other agencies. The maximum weight in Virginia is 115,000 lb, and the width is limited to 10 ft. Some group should be established to work with and through AASHO to secure more uniformity among various regulatory agencies especially where shipments pass through the jurisdictions of more than one agency. Also this or some other group should determine what length, width, and tonnage will satisfy most of the present and future needs. In general, the length and weight limits are at or near the safe maximum limits that will not cause undue harm to existing roadways and structures.

The systems bridge criteria considered were length of 100 to 110 ft, width of 6 to 8 ft, and depth of 8 to 10 ft. A 2-lane structure having 2 girder members and a field insert between the girders could be erected in a minimum time. By addition of standard systems components, the structure could be expanded to any width required. A systems girder longer than 110 ft may have some limited usage in urban areas, but the transportation problems created by physical limitations imposed by existing structure would outweigh its usefulness. This type of structure would be keyed, bolted, or welded with a minimum of field labor. With large components and a full-length longitudinal splice, precise shop quality control is very necessary. To compensate for any misalignment between adjacent components requires that the surface be field-coated with a wearing surface.

Under previously mentioned limitations, systems structures of steel, concrete, wood, or aluminum could be constructed to support present highway loading. The systems bridge should be designed to support the AASHO HS20 loading with military modifications, complying with the Interstate System standards. Prime considerations in design should be usage, initial construction cost, time of construction, aesthetics, and maintenance cost. Any design adopted should accommodate grade-level, elevated, and depressed roadways; the most probable usage would be over depressed roadways.

There must be coordination among those responsible for transportation and for cover design, shop quality control, and erection because these latter areas dictate the size and shape of the pieces for shipment. Who is responsible for the shipping of the structure? The responsibility for fabricating an item for shipment is at present that of the fabricator and should remain so because he alone knows the route, equipment, and final requirement. The designer must also consider the limitation placed on transporting the structure by both legal and physical conditions. At the present time there are some older structures in the existing system that will place weight limits on the size of any component that may be transported, and this problem will exist for several years because the existing system was designed by using several criteria.

We do not think a systems approach to bridge design will create any major problems in transportation even with existing equipment and over existing structures.

erection

H. B. Elsasser

The subject of erection has the most direct and obvious application to the purpose of the workshop and that was to develop means for reducing the on-site construction time for short-span highway bridges in urban areas. The speed of performing on-site construction work will be increased by achieving duplication in the various parts, by minimizing the requirements for on-site labor, by using construction techniques that are relatively independent of weather conditions, and by developing connections that provide adequate adjustment to accommodate normal tolerances.

The primary advantage of having duplication in parts is to justify the development and use of mechanized production techniques and to enable the repeated use of temporary devices such as forms. These developments should also reduce the unit cost of the various components. Up to some point, the gains are proportional to the quantity. However, beyond some minimum quantity at which the optimum technical methods are used, there will be no further benefit. This minimum quantity will vary with the component being considered. For some items the quantity on one project may be sufficient; for other items it may be necessary to have duplication covering many projects. This may require standardization throughout a state or region in order to obtain quantities sufficient to justify the establishment of industrialized manufacturing techniques and the maintenance of an inventory of component parts. Even with standardization throughout a state, the quantity necessary to justify industrialized manufacture might constitute the total number of items used in a complete year or more. Therefore, it would be necessary for the manufacturer to produce the total supply for one year and to carry these items in inventory until they were sold.

In regard to duplication, the most important, but not the only, factor is size. Duplication requires that the dimensions of various parts be either identical or modular so that finished components of different size can be readily manufactured or assembled by using different numbers of identical parts or forms. The dimensions chosen should take into account the standard dimensions of materials normally used in manufacture. For example, cast-in-place concrete should be dimensioned in some integer multiple or fraction of the 4-ft by 8-ft plywood sheet, which is normally used to make forms.

For any items that are to be manufactured and stored in advance of and in anticipation of an order, duplication also requires that the material type, strength, and finish be identical. This may require some apparent structural inefficiency in order to obtain the economic advantage of duplication. For example, it may become desirable to specify a single size of bridge bearing throughout a project; that size would be determined by the most severe loading condition and would be more than that required structurally for all other locations. For other items, such as cast-in-place concrete, the variation in material type or strength may not be a deterrent to rapid on-site work.

An additional incidental benefit of this dimensional modularity or duplication will be to increase the efficiency of both the shop and site workmen by reducing the amount of training and skill required. Learning curves will be steeper, and normal production should be faster. New personnel will not have to learn as many variations; experienced production personnel will not have to be as alert to detect variations. Presumably, the multitude of small variations that currently exist will be eliminated.

On-site labor requirements can be minimized, obviously, by transferring as many operations as possible into the manufacturing plant. This can be accomplished by designing and allowing for the maximum use of precast and prefabricated components made in the manufacturer's plant either in the largest pieces that can be shipped and handled or in modular pieces that increase duplication. This maximum prefabrication is already being done normally in the case of structural steel and precast concrete. The problem is to increase the use and application of these materials in place of monolithic construction requiring a high input of on-site labor. In addition, many operations that are normally performed at the construction site could be performed in the manufacturing plant. For example, in multiple-coat painting systems, all coats except the last could be shop-applied instead of simply the first (primer) coat as is now done. The shop paints should be chosen so that coats can be applied every 16 to 24 hours under shop conditions in order not to inhibit excessively the flow of material through the shop. Significant touch-up of the shop-applied coats might still be necessary at the site, but the total time and labor required would be less than that now required for an application of complete intermediate coats. The final coat may still be applied at the site with the structure in place in order to achieve a uniform appearance in the finished structure. Undoubtedly, there are many other construction operations that could be performed prior to delivery.

The transfer of work to the manufacturing plant from the construction site should yield other additional benefits. The quality of materials and workmanship should improve because of the superior working conditions and controls available in the shelter and permanent installation of the plant. The superior working conditions for labor should help to stabilize the working force and attract more capable personnel.

In many places, the occurrence of adverse weather is responsible for major prolongations in the construction time. The complete sheltering or enclosure of even small bridge sites will be practical only under extreme conditions. Short of this, there is probably no way to prevent the interruption of work during periods of actual precipitation. However, it is practical to develop and use construction techniques that do not require optimum weather conditions so that work can continue during marginal weather such as damp, foggy, cold, hot, or windy conditions. In short, the materials and techniques should not require any better weather conditions than the personnel so that the work can be performed whenever the personnel are willing. The maximum use of prefabrication will facilitate this goal. In addition, it is necessary to design on-site connections between prefabricated units, connections that can be properly made in a wide range of weather conditions with the level of skill and equipment normally available at the site. The need for highly trained experts or highly specialized equipment, which may not be readily available to meet the construction schedule, is not desirable. For these reasons, bolting is preferred to welding or cast-in-place materials for on-site connections.

Another major requirement for rapid erection is the ability to accommodate variations from the detailed dimensions of both the shop and the field construction. On-site connections must provide adequate adjustment without sacrificing structural integrity. The economy of systems building will be lost if an excessive accuracy is required in prefabricated components in order to obtain proper on-site assembly. Tolerances must be allowed that are obtainable by using regular and economical manufacturing methods. In some cases, it may be less expensive totally to use a relatively small amount of relatively expensive cast-in-place material at a joint rather than to require the greater accuracy necessary to allow the use of a prefabricated joint. The small areas and volumes involved in joints could be formed with relative ease.

The susceptibility of the various parts of bridges to significant improvement in on-site construction time varies widely in approximate proportion to the irregularity and requirement for on-site labor involved in present practice. Those parts that are already highly prefabricated will show the least improvement. Other parts that are least susceptible to prefabrication will also show only a slight improvement. Significant increase in speed can only be achieved for those items that can be made modular and prefabricated but that are not under present practice.

Spread footings could be precast to modular dimension but would present some difficulties. The variety of soil conditions will require modular components that can be connected into assemblies of various sizes and strength. Provision will have to be incorporated for adjustment to achieve correct alignment and grade on rough or inaccurate excavations. This might be accomplished by casting a grout underneath prefabricated units. The prefabricated units could be supported on piles to accept the loads during construction of the upper part of the substructure until the grout cured sufficiently to accept the additional construction loads and the permanent loading.

The construction of foundations on piles could be expedited by eliminating the time-consuming practice of making and loading a test pile. This can be done by using steel piles with an easy splice and simply continuing to add lengths and to drive until adequate resistance is encountered. This could also be done with timber piles if construction personnel are trained in adequate and easy splicing methods. In the case of large concrete piles, additional time can be saved by making the concrete pier shafts an integral extension of the concrete pile.

The upper portions of the substructure, including the pier shafts and caps, which are not in contact with the ground, can all be made of precast units. The main superstructure beams do not present much opportunity for significant savings because they are already prefabricated and erected with relative rapidity. Standardization would increase the rate of prefabrication and the feasibility of maintaining an inventory of readily available members. The various deck elements, including parapets and median barriers, as well as the roadway deck itself could all be precast or prefabricated.

The major change necessary to achieve these improvements is better and more imaginative coordination between the requirements of design and those of construction. This will be brought about effectively only by providing an economic incentive. Engineers should write performance specifications that include time as a parameter and that allow the contractor as much freedom as possible in the choice of design, materials, and methods. Owners might award "design and construct" contracts that enable the contractor to optimize the design to suit his particular construction skills and equipment. Major owners might conduct contests offering awards for the design of optimum systems. The awards would have to be sufficient to attract the interest of experienced and skilled industrial organizations. Within states or regions, there should be regular conferences among designers and contractors to exchange ideas and develop compromises between any conflicting requirements of design and construction. Under the present system, contracts should provide a bonus for early completion as an incentive to the contractor to reduce construction time.

Foundations, Piers and Abutments, Superstructures, and Details and Appurtenances of Systems Bridges

summary

Arthur L. Elliott

The basic purpose of systems bridge building is to create better structures faster and with less money. The goal is to minimize the amount of field hand labor, which is a most expensive item, and to reduce the construction time at the site, thus reducing traffic interference and danger as well as neighborhood noise, dust, and confusion. It is hoped that a greater proportion of work done in organized plants will also result in a higher quality of construction.

FOUNDATIONS

Probably the field of foundations shows the least progress toward the goal and at the same time offers the greatest difficulty in using a uniform, prefabricated approach. Almost without exception, foundations are unique. Materials and their configurations differ widely and traditionally have required individual attention. On the other hand, there is probably greater need in this area than in any other for some improvement in method and technique. It is not uncommon for all bridge work to be below ground for months or even years, and progress seems negligible to the not-too-patient public.

One way to make progress is to reduce the number of variables. One wide variable is the nature and consistency of the soil. There are many procedures that will more or less bring different types of soils to a uniform degree of consistency so that some sort of standardized foundation treatment may be used. These include precompaction, injection grouting of granular soils, application of additives to the soil, use of explosives to consolidate and disintegrate, and use of sand piles and grout columns. After some measure of soil stabilization has been obtained, more can be done toward use of uniform footing types. Piles and prefabricated footing blocks available in modular sizes are possibilities. Excavations are costly. Piles and slurry trenches offer means of compensating for otherwise unsuitable soils so that foundations can be placed at a higher elevation. When poor soil conditions make construction expensive, compensation will possibly offer a better solution than elimination. In other words, if a foundation is likely to settle, it may be easier to provide for means of compensating for the settlement than it is to eliminate it altogether.

Little has been done with many of these procedures toward the ultimate goal of systematized construction. Many of the procedures have been used in part to facilitate some phase of the construction operation. Therefore, one might conclude that the ideal sought is not impossible or impractical; it merely needs the economic and sociological pressure to force its adoption and make it work.

PIERS AND ABUTMENTS

The roadway geometry may affect the prefabrication of substructure elements. Urban separation structures are usually curved, skewed, and superelevated. These factors all increase the difficulty of prefabrication. They are not insurmountable, however; and with proper planning and tooling the most complicated geometry should be satisfactorily dealt with in a modern precasting yard. Aesthetics and multiple land use dictate the use of the longest possible spans and the fewest number of columns.

It is estimated that plant labor is four times as effective as field labor. This in itself makes the prefabrication of all possible elements most desirable. Piers should not be segmented but should be prepared as a total pier element that is then fastened to the foundation unit. In narrow bridges, columns and caps may be shop-fabricated. Wider bridges will have to have the columns and caps separate but prestressed together. The standardization of column and cap configuration would be helpful. With care and imagination it should be possible to greatly improve the aesthetics of beam and cap bridges now being built in some locations.

Abutments lend themselves to prefabrication in sections of about 12 ft in length. These, in the shape of a channel, could be set on a concrete foundation and then prestressed the long way of the abutment to lock it into a unit. The bridge seat or abutment cap could be fabricated in one piece and then fastened to the assembly. It is practical to drive piles and precast a foundation block to fit the pile configuration, leaving a socket to fit over each pile. The piles are then grouted into the sockets. This is already being done.

The technology now exists to do this prefabrication work. There is an opportunity to improve the aesthetics of many bridges because of the ability to cast more intricate and complicated shapes in a plant. To achieve success requires a concerted nationwide drive to promote more universal acceptance of the systems approach. The trade associations and AASHO could be useful in getting this acceptance.

SUPERSTRUCTURES

It is important to select for systems building only those parts of the structure that will really result in a saving of field work. The technology exists now to do many of these things, but a wider acceptance and a volume of use are needed to make it practical. It does not seem practical to standardize in the sense that there would be precast elements available off the shelf.

Prefabricated stringer bridges of both metal and concrete can support precast concrete roadway slabs. A variety of clever systems can be worked out for setting in either long slim sections prestressed together laterally or entire cross-sectional pieces stressed longitudinally. There are other techniques of casting deck sections upside down integrally with the stringers and then placing the deck system as a unit. Partial thickness deck slabs that would eliminate deck forms are also being used. Cantilevering the superstructure out from the piers is done extensively in Europe by using precast or cast-in-place units. It is time that this was tried in this country to either prove or disprove the feeling that prohibitively expensive field work is involved in this method.

Connections are always a major problem. Care should be taken that they do not devolve into such accuracy that they become "watchmaking." There are ways of using wedges and tapered faces to make good connections and reasonable tolerances compatible. Good planning could get a supporting structure across the span after which all work could be on top of the bridge with uninterrupted flow of traffic underneath. It should be constantly remembered that minimizing the interference with traffic and neighborhood life is one of the prime objectives of the exercise.

A well-designed, mobile precasting plant that could be moved to the job would obviate the problems of transporting huge girders and deck assemblies.

DETAILS AND APPURTENANCES

If structural units can be assembled in the field, they can also be demounted and reused. That is, of course, not the intended objective, but the early obsolescence of many structures, mainly because of lack of capacity, gives rise to the thought that the effective life of many structures may in truth be rather short. Some measure of effective salvage might have an unexpected value.

Field-bolting steel structures often saves labor. Field-welding is usually expensive and often leads to on-the-job welding schools and a large turnover in welding personnel before an effective crew is assembled. Insofar as possible, details like bearings, expansion joints, drains, grates, railings, and miscellaneous hardware of a structure should be standardized. These items, seldom viewed critically by the public, may be used and duplicated on bridge after bridge without becoming aesthetically monotonous. They facilitate both construction and maintenance and will go far toward simplifying field work.

foundations

Martin S. Kapp and William Zuk

To avoid delays and the attending disruptions caused by lengthy foundation construction (often a year) requires that more rapid methods be found to install foundations for bridges. The problem is difficult, however, because each site presents a different soil and topographic condition. Present methods of excavation and foundation work are also often more expensive than they should be because the contractor is forced to have a great deal of field labor.

To date, very little has been done in the area of prefabricated foundations. There have been only a few projects in Europe, Russia, and the United States, and these were for buildings and pavements. Railroad bridge builders have for many years used prefabricated trestles. These consist of steel or wood piles (left extended to form the trestle legs) capped with prefabricated sections. Almost nothing has been done on prefabricated highway bridge foundations.

IMPROVING SOIL UNIFORMITY

Attempts have been made in the United States and Europe to minimize the wide variation in soil conditions such that some sort of standardized foundations might be used. The techniques used include precompaction, injection grouting of granular soils, addition of lime or cement to the soil, use of explosives to break up and compact nonuniform materials, and use of sand piles and grout columns. The use of grout columns is a new technique in which 1- to 5-in. diameter holes are drilled in the soil at close spacing. The holes are then filled with grout to reinforce the soil. The sand-pile technique is similar except that the holes are larger (2 to 4 ft in diameter) and are filled with sand. All of these methods serve to upgrade a weak soil such that prefabricated spread footings might be used.

STANDARDIZATION

Some research work is currently being done to match soil types with foundation types. Type of piles could also be matched with stratified soil conditions. Work of this sort could serve to standardize the number of different foundation types in use for bridges.

Foundation dimensions should also be standardized to some module, even at the expense of small overdesigns. To this end, holding superstructure dimensions also to some module would allow further standardization in foundations. Such dimensional standardization would make it possible to assemble a catalog of desirable pile types and sizes and prefabricated spread-footing sizes. It is further desirable to minimize the hauling weight of such prefabricated components by investigation of more optimum shapes (such as thin shells). Efforts in this direction are being made by Candela and Lin. Materials other than concrete should also be considered.

USE OF PILE AS PIER

Having the pile (where piles are used) extend above grade as the pier would simplify and speed up foundation construction. However, to do so will require that extra attention be paid to the pile appearance and to its driving alignment. Where it is not feasible to leave the pile extended above grade, an above-grade column could be spliced directly to it. Inexpensive bayonet or screw type of connectors in use in Europe are available.

MINIMIZING EXCAVATIONS

Deep excavations are both costly and time-consuming. Several ways are available to avoid such practices for bridge foundations. Using precast piles would require little or no excavation. If deep footings are required, extra digging and sheet piling may be eliminated by the use of the bentonite slurry method. In this method, a special slurry is introduced to retain the trench wall as the trench is dug. Reinforcing steel is placed in the slurry, after which tremie concrete is placed in the trench to displace the slurry. If necessary (e.g., at an abutment wall), excavation can be made along one face after the concrete has hardened.

ADJUSTABILITY OF FOUNDATIONS

Contrary to current practice, foundations could be placed on poor or unconsolidated soil to save cost of excavation or time for consolidation. However, if that is done, the foundation must have designed into it a provision for settlement adjustment. Numerous building foundations have been constructed with such adjustment provisions that include using either permanent in-place jacks or removable jacks. A few bridges also have been built with such a feature. The extra cost of such a feature could be offset by the reduced cost of constructing a less difficult foundation. Should the anticipated settlement be small enough, deflection accommodation could be made by providing a more flexible superstructure rather than by using foundation jacks. In general, it is desirable to have bridge foundations so designed with tolerances or adjustment that placement of the superstructure need not be quite so exact.

ENVIRONMENTAL FACTORS

The public is now demanding that noise, dirt, and air pollution be minimized, particularly in urban areas. Many cities even have ordinances controlling tolerable levels. In foundation construction, which generally employs large machinery, special care has to be taken. Piles may have to be sunk by augers, by sonic driving, or at least by muffled hammers to decrease noise. Air compressors should be of the new silent type. Explosives should be heavily matted for acoustic muffling. Time of construction must be decreased so that existing facilities are not tied up unduly long and that the new facilities are put into use as soon as possible. Currently, many urban construction projects are being held up because environmental factors relating to construction are unacceptable to the public.

SPECIAL FOUNDATIONS

Instead of resting on normal foundations, bridge piers might be supported by an underground cable. The cable in turn would be anchored to adjacent abutments. In urban areas, bridge superstructures might be hung from adjacent buildings or placed on top of buildings. Bridges of this sort have been built in Japan.

CONCLUSION

The major tenet of systematizing is that nothing is gained unless the job in the field can be speeded up. Consistent with this is that year-round construction is inherent in any systematized approach. Therefore, it is important that specification writers learn to work more closely with the designers in order that unnecessary requirements are not imposed. Systematization must not limit itself to any one or two materials but must allow the materials to be competitive. Systematization is a broader concept than that of simply placing conventional forms more quickly. It may involve development of new techniques and perhaps abandoning older approaches entirely; again a thorough review of policy regarding design and specifications seems appropriate. There should be a trend toward fewer types of foundations if a truly systematized approach is to be possible.

We should not make the mistake of limiting ourselves to precast construction only. Some have suggested that, rather than systematize the foundation itself, we should make the supporting soil more uniform by compaction and injection so that the structural foundation can be predetermined. Another direction to be studied should be the elimination of overly sophisticated foundations that require long time periods and the acceptance of simplified foundations with their tolerable future maintenance, such as jacking or pavement releveling.

We must be certain that a systematized approach to foundations does not lead to mass-produced mistakes. A thread that seemed to run throughout the discussion was that the environment of the community must not be sacrificed to mere expediency; noise, appearance, and disruption to the surrounding area must be kept in mind at all times.

piers and abutments

Bernard A. Grand

ROADWAY GEOMETRY

The design of bridges in urban areas generally involves complexities such as skewed crossings and curved roadways with related varying degrees of superelevation. Can the industry meet the rigorous geometric requirements in the prefabrication of piers, caps, and abutments in a systems approach to the construction of bridges? We agreed that all necessary existing geometric criteria could be applied to the prefabrication of substructure elements. We also concluded that, for elevated highways in urban areas, systems bridges should, in general, be designed for longer spans utilizing minimum numbers of piers to avoid existing obstructions and underground utilities. The long-span structures also afford maximum use of the land below.

DESIGN AND FABRICATION OF PIER ELEMENTS

The current high labor cost that will undoubtedly continue to increase, combined with relatively low labor productivity in the field, encourages the trend toward systems building of bridges that utilize prefabricated elements. Labor productivity in a plant is four times what it is in the field, and plant fabrication also results in better quality control.

What would be the best building block element for a pier? We concluded that piers should not be composed of segments subsequently post-tensioned in the field to form a composite unit but that a standardized total pier element should be bolted or post-tensioned to a prepared foundation unit.

Full T-section (cap and stem) should be used for 2-lane bridges and multiples thereof. For bridges with wider roadways, pier and cap would be fabricated separately and assembled in the field by post-tensioning. We agreed that the necessary superelevation of the bridge could easily be incorporated in the shop-forming of the cap.

We advocate standardizing on a number of pier and cap cross sections. For maximum economy in prefabrication, the cross section of the pier would be a function of length so that a large variety of pier lengths could be fabricated by bulkheading the form as required.

The aesthetics of bridges will be improved by making a radical departure from the conventional pier and cap bents now used in most states. We thought that the systems bridges now being constructed in Europe, involving slender pier stems and trapezoidal box sections for the bridges, should be adopted more universally in this country. This latter bridge system would probably be somewhat more costly than the conventional systems bridge formerly described but would be far more aesthetically pleasing. Such a prefabricated bridge system has been constructed in Texas and probably in other states as well.

DESIGN AND FABRICATION OF ABUTMENTS

The systems prefabrication of abutments is readily resolved because of the relative simplicity of these substructure elements. We propose that the abutment element be fabricated as a unit in the form of a channel for the full height of the abutment and in lengths of about 12 ft. The abutment unit could be fabricated with ribs if the height of the unit warrants. The abutment elements would be mounted on a concrete foundation and post-tensioned to it. The abutment units would incorporate a grout key that would be filled after post-tensioning, thus achieving longitudinal continuity in the concrete. The entire abutment length would be fabricated in a series of 12-ft long elements and fractions of that length as necessary.

The abutment cap incorporating the bridge seats would be a shop-fabricated unit that would be post-tensioned to the abutment wall through the transverse U-returns from the abutment face. The abutment cap would incorporate any necessary wing-wall elements.

Pile-supported stub abutments would be fabricated entirely in the shop with indentations provided for mounting on the predriven piling. The indentations in the base of the stub abutment could be pre-existing or could be made to match the locations of the piling as measured in the field.

The abutment elements discussed have, in fact, already been fabricated and used.

IMPLEMENTATION OF PREPARED DESIGN CONCEPTS

We agreed that the technology and means of fabrication were available to create a variety of system elements involving piers, caps, abutments, and box pretensioned and post-tensioned concrete superstructure units. We also agreed that a radical change in design was in order to improve the aesthetics of bridge design. The systems approach to bridge construction could lead to an improvement in the aesthetics of bridges by virtue of shop fabrication of the more complex but architecturally pleasing shapes.

The systems approach to bridge construction has been sporadically instituted in some sections of the country. To achieve a more universal approach to systems building of bridges requires that general standards for substructure elements be developed through joint committee action of AASHO and the Prestressed Concrete Institute. This joint committee would, as in the past, proliferate this design and fabrication data to state highway departments.

superstructures

Gerard F. Fox

We agreed that at the present time it is technically feasible to prefabricate all superstructure elements off-site. These elements would then be shipped to the site and assembled either on the ground or in place. There would be no stockpiling of items to be used off the shelf.

In terms of present technology, prefabricated stringer bridges of both metal and prestressed concrete can support precast, prestressed roadway slabs. These slabs would transversely span stringers and be post-tensioned longitudinally after assembly. Connection to the stringers would utilize clamps as developed by the AREA to connect concrete ties to stringers. Grout would be injected to ensure a uniform bearing along the stringer. These slabs could also be placed longitudinally with a gap between the slabs at the stringer flange. Within the gap would be shear studs for obtaining composite action and also lapped reinforcement. The gap would be filled with concrete after the precast slabs are placed.

A problem is the actual geometric constraints, both horizontal and vertical, that a modern bridge is constructed to. Other problems include the effects of superelevation and skew spans and the differential creep and camber relative to the difficulty of assembling and matching the elements in the field. To solve these problems, we thought that a bridge could be constructed in the shop completely and then cut up and shipped to the site for reassembly. In concrete a longitudinal prestressed hollow core concrete bridge slab could be poured for the total width and length of bridge. Longitudinal steel plates about 3 ft on center would divide the structure into segments. After the concrete has set, the bridge would be post-tensioned in the transverse direction. This post-tensioning would be removed when the segments are shipped to the site. When reassembled, the segments would fit exactly.

A steel or aluminum stringer bridge can be constructed in the shop completely by inverting the stringers and pouring the slab on the floor to the correct superelevation and curvature. Longitudinal steel plates centered between stringers would divide the structure into elements. These segments could then be shipped and assembled in the field to a perfect fit and prestressed transversely.

Segmental construction is now being used successfully in which whole cross sections of a bridge are precast in segments 10 ft long in the shop or at the site and then assembled in the field by launching from the abutments or an erection truss between piers or the cantilever method with or without tie backs. An alternative method would be not to precast the whole cross section but to precast only a part of the section—a so-called spine beam. The other elements of the cross section could be precast and then assembled onto the spine beam in the field.

It might be feasible to have mobile precast plants (concrete) that could be moved around from job to job. Splices now used to join metal members where full moment capacity must be transferred are expensive and are in the range of "watchmaking." Wedges could be used to transfer compression flange stresses and post-tensioned bridge strand to splice tension flanges. Alternatives to the welded ribs of orthotropic bridges, which are expensive, include the use of steel or aluminum castings and sandwich construction.

An important item relative to urban bridges is the inconvenience to the public caused by construction. When one span of an urban bridge is completed, the contractor's operations should be transferred onto the span, and erection of the remaining spans should proceed from above. This would minimize the disruption on the ground from construction of urban bridges.

details and appurtenances

Gordon A. Alison

Consideration of the most effective method of speeding bridge construction through proper selection of details and appurtenances is dependent on a number of factors such as specifications, material, fabrication, erection, maintenance, and cost. Although their relative importance was not known, we judged that construction time and cost could be influenced to a greater extent by attention to details.

If the components and subsystems of a structure are detailed for quick field assembly and erection, does it follow that the structure should be readily demountable for relocation? What is the life of the structure? We assumed that structures are permanent and that demountability might be a by-product of good detailing practice but certainly not a basic consideration.

The basic principles applicable to all details are keep details simple, keep tolerances on the high side, do not try to "build a watch" in the fabricating plant, and develop details that allow for a certain amount of field finishing to keep overall costs down. We considered the following to be important rules:

1. In metal structures, use bolted joints, for they are more economical than field-welded joints, do not require skilled labor, and are not dependent on weather;
2. For steel structures, speed construction by shop-painting (sandblast to clean and apply 3 coats, the top one being an epoxy or vinyl type) and keep field-painting to a minimum by applying only 1 field coat to cover high-tensile bolts and to ensure uniform finish;
3. Keep bearings simple and standard;
4. Allow for misfit of deck beams at anchors by using oversize holes or slots to eliminate the need for a precise fit;
5. In concrete structures, take advantage of precast construction but set tolerances to allow for field-finishing and do not detail for precise fit;
6. At lateral deck joints, post-tension and grout again, and do not detail fancy longitudinal joints requiring precision during assembly;
7. Develop system to allow for controlled grouting in cold weather;
8. Use wood blocks to form grout pads over caps;
9. Use elastomeric pads for abutments and skew;
10. Overdesign details to overcome possible variations in concrete strengths (poured in place versus precast) because concrete strengths cannot possibly be rigidly controlled as can metal strengths that have guaranteed minimum ultimate and yield strengths; and
11. Encourage development of new design details and concepts aimed at speeding erection by building full-scale prototype structures.

The last item has been done in the past (i.e., with the Fairchild aluminum bridge, orthotropic steel bridges, and precast concrete bridges), but a more forcefully programmed, federally financed program is considered desirable. In the design of details and appurtenances for prototypes, full participation and cooperation of the designer, fabricator, contractor, and maintenance engineer are mandatory requirements so that their combined experience is obtained and so that each understands the other's function and problems. This cooperative approach at the planning and design stage will overcome many of the problems being encountered in design, fabrication, erection, and maintenance of structures today because of the relative isolation of each area of responsibility.

The current design of expansion joints was considered relatively complex and not readily adaptable to systematized construction. The use of neoprene "accordian" expansion joints is recommended particularly because they can be molded to suit curbs, are relatively leakproof, and resist the effect and penetration of road salt in northern states.

Bridge decks should be detailed to drain water to edge or center gutters (in the same way highway drainage is handled) and into collector basins. Water should not be allowed to run off the bridge deck onto the road below.

Prefabricated metal crib walls for abutments are recommended because they speed erection and overcome erosion problems now common with many "faced" and "nonfaced" slopes. The use of approach slabs is considered desirable to compensate for settlement and allow for prefabrication.

The use of prefabricated barrier rails that could be integral with deck sections is not recommended because of difficulties in fabrication, shipping, handling, and erection. It is more economical to add barrier rails to the erected structure as is currently done. The use of precast sections with hollow cores such as those now used in many GM or New Jersey types of barriers is recommended. Full-height metal rails with no curb have their safety characteristics; however, the added problem associated with deck drainage requires a curb to be located behind the bridge rail and thus complicates an otherwise very simple solution.

As for barriers, we considered the lighting standards and directional signs to be a special detail that did not permit integration of these items with the structure. If the bridge has lighting standards, it is desirable to locate the conduit in the barrier rail rather than in the bridge deck to simplify construction.

The use of galvanized or aluminum appurtenances and hardware will minimize maintenance costs and prevent staining and field painting.

We did not consider weight to be a vital factor in the choice of material for details and appurtenances because the capacity of available erection equipment is not normally limited by weight considerations.

Steel, Concrete, Aluminum, and Timber in Systems Bridges

summary

Charles F. Scholer

Each of the four materials considered—steel, aluminum, concrete, and timber—has established and proven performance for many bridge applications. Some of the material capabilities are not fully utilized by bridge engineers, however; and education and demonstrations of these capabilities are necessary. In some instances, a combination of these materials may best utilize the materials in systems building.

Two major requirements of tomorrow's bridges are economy and aesthetics. Each material is economically competitive in some situations and is not competitive in others. For example, wood can compete with any other material in both function and economy in a large number of short-span bridges, yet it cannot do so for long-span bridges. Aluminum has many economical applications for bridge appurtenances, but at present it is only competitive for major components in structures such as military bridges and pedestrian bridges.

Aesthetically, each of the 4 materials has enhanced the appearance of a structure in its particular location. The current and future concern for aesthetics will not limit the overall use of any material, but it may be a greater factor in materials selection at any given location as designers fit the bridge into the surroundings.

Quality control, inspections, and tolerances are problems that concern all materials. Quality control to the required level can be ensured for all these materials with present technology. Concrete is possibly most sensitive, yet good quality control can be obtained in concrete production so that the designer can have confidence in strengths and other properties of his materials. Inspection is a requirement whether it is done by a representative of the producer or the owner. Tolerances on many current specifications are not well suited to systems building of bridges. In such systems, as much tolerance as may be allowed is of great help in speeding the erection as well as the fabrication, regardless of the material. However, in some bridge systems some present tolerances are not close enough. It is apparent that tolerances, regardless of the material, must be explicitly stated, set to meet the requirement of that portion of the structure, and not generalized for an entire structure or organization.

Future developments in bridge-building materials promise to aid systems building for bridges. Future concrete use includes adjustable, numerically controlled forms both in precast and in slip-form application. Higher strength concrete, up to 10,000 psi, should become commonplace especially in precast applications using low or no-slump concretes. Better quality control, admixture, and consolidation procedures are now allowing this to occur. Better economy will result from reduced turnaround time in precast operations brought about by several new cements and by improved methods of accelerating the curing of concrete. Use of self-stressing cements seems to be more promising than at any time in the past. Lightweight aggregate will also gain in acceptance as its benefical performance is recognized by engineers.

Steel already has a number of high-strength products available, but further improvements not only in strength but in ease of fabrication are in the future. Numerically controlled fabrication promises to improve not only the speed but also the economy and precision of steel fabrication. It will be beneficial to complex configurations as well as to repetitive standard units.

The great advantage of aluminum is its lightweight and flexibility of fabrication, especially the use of extruded slopes. The relatively higher first cost however eliminates aluminum from many applications. The first cost is expected to be reduced in the future, and aluminum should become competitive for more application in system bridges.

Probably the greatest future development in wood will be in educating engineers regarding the capability of glued and laminated structural timbers for bridge construction. The properties of these structural timbers allow them to be engineered and to form durable structures.

steel

Andrew Lally

Versatility in aesthetically adapting to any geometric structural configuration with economy of construction is an advantage of structural steel for both long- and short-span bridges. In urban areas where speed of erection is important, steel bridges can be erected in the least amount of time and with a minimum amount of interference to traffic. However, the full potential of structural steel in these areas has not been realized, and we explored avenues of prospective changes in construction methods for improved utilization of these inherent advantages.

One of two basic approaches to the problem is to provide a stock of constituent elements of a pre-engineered bridge system that would accommodate a range of span lengths for rapid construction in urban areas. This would include also a system of orthotropic plate deck components prefabricated and shipped in large sections to the job site for rapid erection with the least interference to traffic.

The other approach is to utilize the steel in its currently available standard shapes by recognizing that new numerically controlled systems of drilling and welding and, perhaps, future automated control of other fabricating operations will afford the same advantages as standard repetitive sizes. The numerically controlled equipment can produce the varying sizes for a complex structural configuration as easily as standard repetitive sizes and, perhaps, with greater accuracy because of the elimination of much of the present human error.

The arguments for the first approach, standardized components, have the supporting evidence of success in European applications and especially in Germany where urban bridges have been erected in a surprisingly short period of time with minimum interference to traffic. The standard components, fabricated and shipped in large sections, can accommodate varying span lengths. The steel pier bents and girders are rapidly assembled during periods of the least traffic.

The arguments for the second approach are that although the standard system may be acceptable in Europe the trends and demands here are the opposite in that planners are not going to accommodate to simpler straight alignments even where this may be possible. The cost of additional property in urban areas is one factor, and the demand for aesthetic bridge construction is another. The forest of columns employed in the earlier days of railroad bridges in urban areas is gone, and curved girders replace straight cords, box girders replace stringers, and cable-stayed bridges will probably replace the truss with economies following as they become more standard. The most realistic approach is to recognize this trend and not concentrate on standardized components at the expense of exploring better ways of building the more complex structure, because history and current trends show that the demand will continue to require these curved, spiralled, superelevated, and warped alignments.

Greater tolerances than those currently imposed should be allowed to speed erection wherever this will not affect the structural integrity. An example could be acceptance of oversized or slotted bolt holes for HS friction connections.

Recent investigation at the University of Illinois indicates that current depth-to-span ratio and LL deflection limitations in AASHO specifications are not justified, and perhaps more flexible bridge structures can be built without sacrificing the condition of concrete decks because of increased cracking or without introducing disturbing vibrations that can be uncomfortable to bridge users. The potential use of high-strength steel is greater with this knowledge.

It was agreed that redundant inspection is not the answer for achieving quality, but quality control programs as established in steel-fabricating shops of the American Institute of Steel Construction provide the confidence expected from the product and are effective in achieving results. Unfortunately, inspection requirements are not geared to the qualified fabricators. Unwarranted inspection calling for the same degree of perfection for secondary minimum stress-carrying members as for butt splices of main members is time-consuming and unnecessarily costly.

We agreed that we should concentrate on accommodating the complex geometry of the future urban bridge by use of automated fabricating equipment such as numerical drilling, investigate new decking systems that can be easily adapted to the resulting varying beam spacing, provide greater erection tolerances where practicable to reduce erection time, and provide incentives to the contractor for completing the field work ahead of schedule.

concrete

Donald W. Pfeifer

MATERIALS

The use of portland cement concrete in bridge construction is traditional, and the search for industrialized building procedures to accelerate the efficiency and economy of bridge construction is a natural development. Concrete with compressive strengths of 2,000 psi were common in site-cast bridge construction 50 years ago. With the subsequent development of the precast-prestressed concrete industry and the concurrent development of higher strength portland cements, the industrialized approach to concrete bridge construction appeared in the early 1950's.

This industrialized approach was made by the precast concrete industry using plant-produced pretensioned prestressed concrete bridge elements. These industrialized processes already being used for some 20 years allow for the production of unusually high-quality, high-strength concretes. The technology to produce concrete strengths at 28 days of 7,000 to 10,000 psi is now well known and, in fact, is being practiced on a day-to-day basis at many precast factories in the United States.

Correct mix proportioning procedures, proper mixing and placing procedures, consolidation by external or internal vibration or both, and an appropriate method of accelerating the cure of the high-quality concrete now makes it possible for numerous plants to obtain strengths of 5,000 to 6,000 psi after overnight high-temperature curing. The more recent development of structural lightweight aggregates for use in structural concrete has also been taken advantage of by the precast concrete industry. Such concretes weigh approximately 100 to 120 lb/ft^3 and strengths of 4,000 to 8,000 psi are easily attainable. These lightweight concretes are now being used as an engineered material in bridge construction, and more economical longer span bridges are being plant-produced.

While the precast concrete industry develops more industrialized manufacturing processes that result in higher and higher quality products, the owner-specifier still specifies to the lowest common denominator. This results in artificial restraints on the development of systems building techniques for bridge construction. It is a proven fact that economy can be gained by allowing design compressive strengths to be raised 1,000, 2,000, or 3,000 psi above the present levels. There have been cases where design strength change from 5,000 to 6,000 psi allowed for a greater girder spacing and the elimination of one girder. This example illustrates how excellence in design and production of precast concrete bridges can occur if an incentive for higher quality products is provided by the owner-specifier.

The steel industry provides numerous steel strengths that result in built-in economy that the designer recognizes and utilizes. Such economy can also be gained from the precast industry by providing alternate designs with concretes of 5,000, 6,000, 7,000, and possibly 8,000 psi.

Such alternate designs will accelerate the development of industrialized manufactured precast concrete bridges. There are no disadvantages associated with plant-produced high-strength concretes. On the other hand, numerous technical and economic advantages result. An associated advantage is the general up-grading of machinery, production techniques, and materials in the precast plants that today do not attempt to use highly industrialized processes and available knowledge to produce higher strength concretes. This up-grading will occur when incentives for excellence are provided and higher strength concretes begin to compete with the lowest type of concretes.

Even though the strength spectrum within the precast concrete industry is broad, the technology to raise strengths to higher and higher levels is available. This technology is not complex and is certainly available to the owner-specifier if he wants it.

Once the owner-specifier decides that the industrialized approach is desirable, he must work with the precaster. Inspectors must be educated and trained to handle low- and zero-slump concretes during their quality control program. Aggregate gradings should be controlled and nominal aggregates rejected. The owner-specifier should also recognize that a nondestructive test method is needed for strength observations. Research should be undertaken to validate reasons why such nondestructive methods are either satisfactory or unsatisfactory for use in an industrialized process such as production of plant-produced bridges.

If nominal sands and coarse aggregates are used, concrete quality and strength will suffer. Such materials should not be used, and the owner-specifier should work with the precast concrete producer to eliminate or minimize the effects caused by borderline materials.

SPECIFICATIONS

There are definite specification modifications and changes that will help to accelerate the industrialized process of bridge building. The most important is the use of alternate bid procedures for concrete strength classes of 4,000, 5,000, 6,000, 7,000, and 8,000 psi. Such a procedure will provide the entire precast industry an incentive to industrialized bridge construction.

As strengths increase because of the use of low slump, low water-cement ratio concretes, permeability of the concrete will cease, and cover over the steel reinforcing may be reduced. Concrete cover of ½-in. may prove to be very serviceable when concrete strength is more than 7,000 psi. Additional economy is then attained when this unnecessary deadweight is eliminated.

Several artificial restraints are placed on the curing of precast concrete even though published research and years of experience have shown that the present specifications are extremely conservative. When accelerated-cured concrete reaches strengths of 4,000 to 6,000 psi after overnight curing, there is little justification in specifying that the concrete should have additional curing. Such high-strength concrete is very impermeable, and the water remaining in the concrete is sufficient to hydrate the remaining portland cement not already hydrated during the accelerated curing. Research studies have shown that compressive strengths will increase by 1,000 to 2,000 psi even when no additional curing is provided.

Another restraint on curing is the specification that allows only live steam-curing to accelerate the strength of the precast concrete. The owner-specifier should allow alternate methods for providing accelerated high-temperature curing.

All methods such as radiant heat from oil or water lines and electrical radiant heat as well as live steam should be allowed. These curing-procedure specifications would, of course, apply only to concrete bridge elements produced in steel forms or their impervious forms, which will contain all the water within the concrete during the curing cycle. The top or exposed surface must also be covered with an acceptable impervious cover or membrane.

The third restraint on curing is the specification stating that the concrete shall not be exposed to temperatures below freezing for 6 days after casting. High-strength concretes used in precast bridge and building elements have been stored at below freezing temperatures immediately after accelerated curing in numerous plants in the United States and Canada, and no problems have occurred from the so-called "thermal shock" or possible freezing. Even the published research on the damage to accelerated-cured high-strength concrete shows that high-strength concretes do not suffer from exposure to freezing temperatures immediately after high-temperature curing.

The precast industry believes that cast-in-place field concrete has its place in the industrialized process. Field connections of precast concrete and continuity advantages are definite assets. However, the use of low-strength, 2,000- to 3,000-psi, field-placed concrete places a restraint on the total industrialized process. The owner-specifier can obtain from properly designed and maintained equipment field-placed concrete that could have 28-day strengths of 4,000 to 7,000 psi. Use of judiciously placed high-strength field concrete would be an additional advantage to the whole industrialized process.

The 1971 Interim AASHO Specifications for Prestressed Concrete introduced increased allowable tensile stresses (from 3 to $6\sqrt{f'c}$). In the future, when sufficient experience has been gained, additional increases of more than $6\sqrt{f'c}$ for allowable tensile stresses can provide for more serviceable structures with less long-term camber problems. In Germay bridge designs are based on zero allowable tensile stress under 50 percent of the live load.

ECONOMICS

Economy will result from industrialization. Complete economic studies should be made by the owner-specifier comparing the effects of using 4,000- to 8,000-psi concretes. Such studies should include the effect on the substructure, piers, caps, and superstructure when high-strength concrete is used. Once the economic advantages of industrialization are studied and uncovered, a massive educational effort must be made within the precast industry as well as the owner-specifier agencies. Additional economic benefits are sure to follow this educational process.

FUTURE USES AND RESEARCH

The precast industry is constantly watching the research and development activities within the concrete and steel industries. Because drying shrinkage and creep are major problems, an admixture that when added to concrete would prevent the internal water from escaping would be well received. This admixture would eliminate drying shrinkage and significantly reduce creep.

The use of chopped steel wires as web reinforcement to achieve minimum web thickness along with reduced total weight would also be an advancement.

The age-old problem of painting or coating concrete, if solved, would provide new architectural possibilities from industrialized urban bridges.

The precast industry is closely watching the developments taking place in the fields of polymer-cement-concretes, self-stressing expansive cements, and regulated-set (fast-setting) high-strength cements. All three of these new types of concretes and cements will have applications that would benefit the industrialized process of building precast-prestressed concrete bridges.

aluminum

John W. Clark

USE IN HIGHWAY BRIDGES

Aluminum is used extensively in bridge railings and lighting standards mainly because of its appearance, low maintenance, and competitive cost. Easy transportation and erection resulting from aluminum's light weight also help in these applications. The same characteristics of aluminum have dictated its use in pedestrian bridges and in military. Light weight is also the prime factor that has caused aluminum to be used in bridge-decking of old bridges such as the Smithfield Street Bridge in Pittsburgh.

Aluminum has been used as the primary structural material in a number of bridges where the main reason for its use was to gain experience with the material. Some examples of bridges of this kind are as follows:

Use	Length (ft)	Location	Year
Railway girder	100	Massena, New York	1946
Arch span	290	Arvida, Canada	1950
Bascule bridges	100	England	1948, 1953
4-span welded bridge	220	Iowa	1958
Reynolds bridge	97	Petersburg, Virginia	1960
4-span Fairchild bridge	212	New York	1960
Riveted girder bridges	80	New York	1960

LIMITATIONS ON USE IN BRIDGE STRUCTURES

Aluminum is not used more extensively for the main structure in highway bridges because its first cost is higher than that of steel and concrete. The question of cost must be continually reevaluated, however, as new methods of fabrication and erection are introduced. Historically, the price of aluminum has not risen so fast as that of competitive materials and, therefore, cost should not be so great a deterrent to the use of aluminum in the future. Of course, the development of a large market should help to reduce prices.

Limitation on availability of aluminum in needed shapes and sizes—especially large structural shapes—is another factor tending to restrict use of aluminum in bridges. Presumably large structural shapes in standard sizes could be stocked if the demand were sufficient. Although extruded shapes are generally limited to a 24-in. circular size, extrusions can be designed with edges prepared for easy shop welding into larger shapes.

Because the modulus of elasticity of aluminum is about one-third that of steel, aluminum structures will generally deflect farther than their steel counterparts. This factor can be a deterrent to the use of aluminum for structures where deflection limitations are significant. This limitation can be partially overcome in many cases by using aluminum sections of greater depth. Because aluminum weighs about one-third as much as steel, it is possible to use, say, a 40 percent greater volume of aluminum and still have one-half the weight of a steel structure. Other methods of reducing deflection are to spread the load by means of a torsionally stiff design, as in the Fairchild bridge, or even to introduce post-tensioned steel cables.

The coefficient of thermal expansion for aluminum is higher than that for either steel or concrete. However, existing structures demonstrate that the problems thus created can be handled satisfactorily by proper design that either allows for expansion and contraction or resists the forces developed if expansion is restricted.

Another factor that the designer must be aware of is that galvanic corrosion of aluminum can occur where it is electrically coupled to steel. This problem can be taken care of by separating the materials with paint or joint compound. Experience has shown the effectiveness of the protection procedures called for in current specifications.

The heat-treated or strain-hardened aluminum alloys generally used in structures lose some of their strength because of the annealing effect of the heat of welding. This factor is taken into account in current structural specifications (such as those published by the Aluminum Association and adopted by AASHO) in which the allowable stresses are reduced in the vicinity of welds, with the result that the metal that is not affected by welding is not used so efficiently as it might otherwise be. However, the effect of the heat of welding is minimized in new alloys such as 7005-T53, which is now being used in military bridges and in other applications.

The reduction in deadweight that accompanies the use of aluminum may cause a higher ratio of live to dead load stresses and even result in stress reversal. Therefore, the possibility of fatigue failure must be closely checked. However, fatigue tests made on the Fairchild and Smithfield Street designs, as well as field experience to date on all aluminum bridges, indicate satisfactory resistance to repeated load.

POTENTIAL FOR USE IN BRIDGE SYSTEMATIZATION

Aluminum structures generally weigh about one-half as much as corresponding steel structures. Thus, use of aluminum reduces restrictions on size of parts that can be transported to the site and erected in one piece and minimizes on-site time and labor. The size of the part that can be lifted by a given piece of equipment can be effectively doubled, for example. This advantage of light weight is perhaps the most important contribution that aluminum can make to bridge systematization.

Aluminum offers advantages in flexibility of fabrication. The extrusion process produces integrally stiffened panels, parts that snap together to eliminate welding jigs, and parts with bolting or welding flanges at any location to reduce fabrication time and cost. Its excellent resistance to corrosion permits thin-gauge construction that results in savings in weight and material cost. Most aluminum bridges are unpainted. Freedom from painting will reduce traffic stoppage during erection and later maintenance.

Where aluminum is used, it may be advantageous to consider forms of construction different from those normally employed. For example, consideration might be given to orthotropic or sandwich decks to reduce weight, integrally stiffened or corrugated panels to increase stiffness, and tubular truss construction rather than plate girders.

When thinking of advantages of lightweight material, one generally thinks of bridge superstructures. However, it is believed that aluminum should also be considered for piers or columns, bearings and expansion joints, GM guardrails, and temporary structures such as crossover bridges.

CONCLUSION

Aluminum has not been widely used as a primary structural material in highway bridges mainly because its first cost is higher than that of competitive materials. However, it is believed that this cost gap will continue to narrow, and the advantages of aluminum from the standpoint of light weight, ease of transportation, speed of erection, and reduction of maintenance will merit its serious consideration in systems building for bridges.

timber

Thomas G. Williamson

Probably the first use of timber in bridge construction was when a Stone Age man rolled a log across a ravine, chasm, or river and used it as a footbridge. Since then timber bridge construction has evolved through a series of forms, including the famous covered bridges, which are now historically preserved in numerous states throughout the country, the timber trestle railway bridges of which there are thousands in the United States, and eventually the modern-day structural timber construction such as the Keystone Wye Bridge in the Black Hills area of South Dakota.

In order to discuss the subject of structural timber as it applies to the construction of highway or other bridge structures, it is first important to define the materials that are actually involved in modern heavy timber construction. The first of these is solid sawed timber such as that often used for smaller framing members. These are controlled by the regional associations that establish allowable stresses and are included in Section 10 (which contains a table providing all the basic stress data for this type of member) of the AASHO Standard Specifications for Highway Bridges.

A second type of timber used in heavy timber construction is the round timbers, such as timber foundation piles or poles used in highway pier construction. In the past few decades, technological advancements in the areas of gluing and basic lumber strength evaluation have led to the widespread use of glued and laminated structural timber that now forms the basic material for heavy timber construction with respect to large framing members in the superstructure of a highway bridge. Other applications of glued and laminated structural timber in bridge construction are in deck systems.

Because the architectural and engineering profession is relatively unaware of this product, it is important to state what glued and laminated structural timber means. According to the U. S. Commercial Standard 253-63, which covers the fabrication and design of those timbers, the product is defined as follows: "Structural glued laminated timber refers to an engineered, stress-rated product of a timber laminating plant, comprising assemblies of suitably selected and prepared wood laminations securely bonded together with adhesives. The grain of all laminations is approximately parallel longitudinally and the separate laminations shall not exceed 2 in. in net thickness." Because of the modern methods available for fabricating these members, it is possible to achieve almost any shape or size of structural member by using glued and laminated timber.

The results of research indicate that approximately a one-third savings in size can be gained over conventional glued and laminated structural timber by prestressing with high-strength steel tension wires, much in the same manner as prestressed concrete is produced. At the present time, technology for producing these members under routine plant production has not advanced to the stage where this is a common practice. However, the use of this material in the future should be considered.

If timber is to be used in exposed conditions, such as in highway bridges, it is assumed that the members will be pressure-treated or pressure-impregnated with an approved preservative to ensure a long life for this material comparable to the anticipated life of other common structural materials. Those treatments should be in accordance with the American Wood Preservers Association's standards and the AITC Standard 109-69.

STRUCTURAL TIMBER IN SYSTEMS CONSTRUCTION

Timber has a long history of use in systems construction of bridges and other buildings. A systems approach has long been used in the construction of railroad timber bridges in which there are fixed spans and member sizes for both substructure and superstructure elements. For example, in trestle construction, an 8 by 16 solid sawed timber stringer spanning 14 ft is normally used. Another example is the use of a standard sized pier cap of solid sawed or glued and laminated timber in railroad bridge construction. As the source of large solid sawed structural timber members becomes more and more limited, the railroad companies are looking to the use of glued and laminated structural timber as a potential replacement and feel that this material will eventually replace solid sawed timbers. Thus engineers will continue to be provided with structural timber for bridge structures.

In building construction, glued and laminated structural timbers almost invariably form a part of some type of systems approach to reduce erection cost and time. Because of the nature of the fabrication of these members, they are always prefabricated in the laminating plant to exact job-site specifications such that when they reach the erection site they are ready for immediate installation with little, if any, on-site preparation necessary. Because they arrive on the job site cut to exact size and precisely drilled for all connection hardware, assembly and erection of these members is remarkably simple and requires minimum labor to be maintained in the field. This prefabrication procedure also applies, of course, to bridge construction and was used in the construction of the Keystone Wye Bridge that is a twin structure consisting of a curved girder-span lower level structure with 3 prefabricated glued and laminated structural arches spanning the lower structure. In the construction of this bridge, all timber superstructure elements and timber pier elements were prefabricated at the laminating plant, and all hardware was prefit such that when it reached the field the piers were merely placed into their respective positions on the concrete abutments, and the arches were then lowered into position on the pier members. The deck was reinforced concrete; however, it could have been any type of compatible deck surface.

The superstructure is probably the area where timber will find its greatest potential. As previously stated, it is possible to produce both straight or curved systems for simple spans up to 120 ft in length, this being limited primarily by transportation, and glued and laminated arches for spans of 300 ft or more. Thus, timber lends itself to use either in a straight girder type of construction or in an arch type of structure for highway bridges.

The second area where timber can be used in the construction of highway bridges is in the deck system. Several systems are available, including prefabricated nail panels or glued and laminated panels in 4-ft widths and variable lengths that are placed either transversely over girders or longitudinally between piers. The latter configuration forms a major load-carrying element of the superstructure itself. Various surfaces such as asphaltic concrete can be placed over these timber deck panels. Composite action using a cast-in-place concrete deck over timber superstructures is also a proven system as illustrated by the Keystone Wye Bridge and other installations. Plank decks have also achieved widespread acceptance in secondary bridge structures, such as state and county highway bridges.

Timber in pier construction is primarily limited to pile bents or glued and laminated bents prefabricated and shipped to the job site as a unit. These might be used in short-span structures or to be attached to foundation structures, in the case of water crossings where piers can be used with minimal interference.

Timber can be used in the construction of abutments, in pile abutments with timber or concrete caps, in crib construction to prevent scouring and erosion around piers and stream crossings, or in crib walls or wing walls adjacent to main abutment structures. These cribs can be prefabricated and shipped to the job site ready for installation.

Another primary use of timber, particularly round timber piles, is in foundations, particularly in relatively shallow depths where other materials are not economically competitive. In these instances, it is possible to use lighter and less complicated pile-driving equipment and reduce on-site labor and equipment costs.

There are certain advantages and disadvantages related to the use of a certain structural material in lieu of another material, and this applies, of course, to structural timber. The following are some of the advantages of timber construction particularly as it relates to the systems concept.

1. Timber lends itself to a systems approach because of prefabrication of all components that are ready for rapid on-site assembly, thereby minimizing on-site labor costs and time. This is particularly important in urban areas where it is difficult to close other facilities during construction of a structure such as a bridge.

2. Timber is a very lightweight construction material and thus allows for the transportation of larger, more complete structural units such as girders with timber panel decking preassembled at the manufacturing site. This also minimizes on-site construction costs and shipping costs based on a weight basis.
3. Almost any configuration of members can be readily prefabricated including complicated curved girders and arch members so that the bridge designer has complete freedom in his structural component design.
4. The lightweight feature previously mentioned also permits use of smaller on-site construction equipment. That plus the low cost of timber per pound leads to a lower total cost for the initial structure itself.
5. Construction of modular timber units can be accomplished on the site by unskilled labor, and field modifications are possible in instances where tolerances are not satisfied by the plant production, although the necessity of an on-site modification is unlikely.
6. Timber fits into existing environments, particularly in urban and suburban areas where a natural appearance is desired.
7. Timber, as a material, is not affected by chemicals or corrosive materials, and thus possible corrosion such as that caused by de-icing salts is not a concern in a system using a laminated deck with a thin overlay wearing surface.
8. Timber exhibits excellent strength characteristics in dynamic loading situations that occur in highway bridge construction and that might occur in areas of high earthquake possibilities.
9. Timber is one of the few renewable natural resources, and this should be a consideration in any design whether it be highway bridge, a pedestrian footbridge, a school, or a large warehouse.

There are, of course, potential limitations associated with the use of timber in highway bridge construction, and following are examples of these.

1. In pile foundations, it is often necessary to use a splice as soil conditions vary and affect driving length. However, this is primarily a design problem and can be overcome through sound research and design efforts.
2. In general timber members must be deeper than members of other materials, such as steel, to carry a given load and, in locations where roadway clearance is critical, this could be a deterrent to the use of timber. One solution to this problem is to use prestressed timber girders as previously described that reduce the required depth significantly.
3. Fire is always a consideration in timber construction. In general, large timber members burn very slowly, and as they burn they form a char that acts as an insulating surface. This charred surface tends to inhibit further burning of the member, and often in severe fires structural timbers still carry their design loads long after other structural materials have failed. In many instances, it is possible to go into a structure that has been damaged by fire in which heavy timber is the primary structural material and salvage these structures by merely removing the charred material and reanalyzing the structure to ascertain that the remaining section, which is completely structurally sound, is adequate to carry the imposed loads. Of course, it is always possible that vandalism by fire can occur, but this should not represent a primary deterrent to the use of structural timber.
4. The engineering profession is not educated in the use of structural timber in design and construction. College curricula generally do not provide students with opportunities to learn about the designs of structural timber members. Therefore, most graduate engineers are unfamiliar with this material as a major structural element. Also practicing engineers lack experience in the use of timber and are not familiar with the simplicity associated with the design, connection details, and erection of structural timber units.
5. The potential damage to structural members from vehicular accidents and possible resulting fire should be a secondary consideration in material selection and should not be considered a liability for structural timber because of the relative ease of repairing timber members and heavy timbers that might be damaged under such circum-

stances. Related to this is the concept of maintenance of the structural elements in service. Maintenance of timber bridge systems should be minimal; the only maintenance recommended is the application of a periodic (approximately every 10 years) water-repellent stain used to provide a pleasing aesthetic appearance. Paintings and coatings are not recommended because they add unnecessary cost to the project and serve no primary function.

POTENTIAL FOR TIMBER BRIDGES

It is not proposed that structural timber bridges be used in areas where tremendously long spans are involved or in certain urban settings where timber would not lend itself to this type of construction. However, as previously noted, timber is a part of a systems approach to construction and has a long history of use in systems construction because of its prefabricated nature and compatibility with other materials.

One area in which timber bridges should be considered is in the construction of either pedestrian overpass bridges or vehicular bridges in parks or park-like settings where the use of timber would be aesthetically compatible with the natural environment. Such a condition would be found in downtown urban areas or in suburban areas where major highways go from an urban to a rural setting. Timber construction can also be used in temporary structures that are needed when an existing facility is replaced and that have to be erected and removed in very short periods of time. In designing such a temporary timber structure, the engineer may determine that it could actually serve as the final structure with certain additional design considerations, and this should be a consideration during his initial design of this type of structure.

A relatively new approach to the use of timber in systems construction is in the area of completely glued and laminated superstructure elements shipped to the job site with all connecting hardware prefabricated and in place on the members when they arrive at the construction site. These are then spanned by a glued and laminated deck panel fabricated in modular units according to the superstructure design.

It is also possible to preassemble entire bridge superstructures adjacent to bridge crossings and place these as complete units by using cranes or helicopters. An example of this is the construction of a 100-ft span pedestrian and light vehicular bridge in the San Diego area. That bridge was lifted into position in less than 20 minutes by prefabricating the entire unit adjacent to the final crossing and lifting it into place as a single unit.

Another approach to systems construction with timber is a girder-laminated deck bridge system shipped as a preassembled unit in, say, 12-ft widths and spans up to 100 ft in length, depending primarily on transportation limitations. The use of new surface materials, in lieu of conventional asphaltic or reinforced concrete, which can be applied to the laminated deck panels at the fabricating plant and thus eliminate need for on-site paving of roadway wearing surfaces, will undoubtedly be evaluated in the future installations. These epoxy coatings should provide a long-lasting durable wearing surface and add to the reduction in on-site labor and material costs.

CONCLUSION

Timber as a material lends itself to the solution of the current problem of highway bridge construction in either urban or rural areas by its use in systems construction. A systems approach reduces field labor costs and reduces site construction time, both key factors in reducing total cost of construction of highway bridge structures. The use of standardized components such as girders and panel deck systems eliminates excessive design considerations, provides simplified details and cross sections, and lends itself to potential stockpiling of small bridges.

Although each bridge is a unique design, its potential construction using basic modules or units that might consist of structural timber girders and deck systems or other similar types of units should be a consideration. The lightweight characteristic of timber as a structural material and its high strength-to-weight ratio make it ideally suited for reducing on-site labor and equipment costs and in-transit shipping costs. Although the use of timber will not replace prestressed concrete or structural steel for large urban highway bridge facility construction, it should be considered for smaller crossings in areas where aesthetics is of prime concern or in areas where time of construction is limited.

A material should not be considered alone but in combination with other materials for true systems design. Examples of this are timber superstructures placed on concrete substructures with asphaltic concrete decks and timber piling used as substructures for prestressed reinforced concrete piers and steel superstructures. Designers should keep all potential materials in mind when developing bridge systems and determine which material best suits the specific needs regardless of whether it be wood, steel, concrete, aluminum, or some other material. Only by making optimum use of all structural materials can we efficiently build the highway bridges needed at a reasonable cost.

Informal Discussion on Systems Building for Bridges

The closing portion of the final session of the workshop was devoted to an informal discussion of the means through which the goals of the workshop could be realized. The comments of the participants are presented below.

Robert G. Bartlett

One of the leaders in the prefabrication or systems building of bridges has been the military. Many who have served with the U.S. Corps of Engineers are familiar with the Bailey or timber trusses, the steel treadway, and the pedestrian bridges. Perhaps Jim Bolton would comment on some of the work that he is engaged in and what the outlook is for systems building and packaging structures by the military.

James R. Bolton

One of the major things that we are concerned with is tolerances. Tolerance really becomes a problem in bridges that are assembled, disassembled, and reassembled continually. The tighter the tolerance is, the more inspection required and the more cost involved. We are becoming more concerned with the weight of structures. The emphasis right now, at least in my field, which is mobility, is on lightweight aluminum structures. Steel is used more for conventional types of bridges. Concrete structures, that is, precast, post-tensioned structures, have never been suitable to our particular needs.

Robert G. Bartlett

Most bridges that are erected will not be moved from one location to another. Therefore, the ability to disassemble, transport, and reassemble a bridge at a new site is important only to the military. However, the fact was cited that military bridge erection is generally accomplished by unskilled labor, and any bridge system would do well to consider this point.

Many of the workshop discussions were free ranging as they should have been. We must now pull the main points together so that we can determine where we go from here. We have said that the European contractual system is one that we should explore and that we should obtain acceptance of a concept of designing, manufacturing, and building under one jurisdiction. It is known in this country as the turnkey operation. It is now practiced with regard to buildings, and there is no reason why it cannot be practiced with regard to bridge structures. That may mean challenging some of the philosophic bases of the industry. But why not say it more positively: The industry will change if the change is for the better.

The question, then, is, Can we move in this area? And a second related question is, What about performance specifications? Some of the performance specifications issued by the U. S. Department of Housing and Urban Development for housing have been so precise and detailed that they are more like a manual or a cookbook on how to put something together. They eliminated the innovation and creativity of industry. There should be competition, not just price competition, but performance competition and time competition. Those are the things that will make for better progress in the future.

Related to them, of course, is user acceptance. Arthur Anderson revealed that acceptance has been obtained from logging companies for the design and installation of their bridges in the northwest United States. When you are dealing with one industry, you can gain acceptance of this type of system very readily. Too often, governments must segment the industry and review projects in the design, the specifications, the manufacturing, and the production. Sometimes you wonder why the state agency is not also the contractor because, if it wants to limit all of the steps, there is no real place for the competition that has made industry as productive and successful as it has been. The Federal Highway Administration sets the standards and the policies, and the state highway departments through AASHO have to accept those principles and concepts. Therefore, if this system is ever to gain any acceptance or respect within the industry, it must first be accepted by the Federal Highway Administration because we are primarily addressing ourselves to the field of highway bridges.

Another item, and a very valid item, in tooling up for the industrial production of components is market aggregation, which means simply that, if you could guarantee a certain volume, you could amortize the tooling up of a production within the industry and therefore have it become a spread-cost item. Tooling up for a given project or a couple of projects is prohibitively costly unless the volume is great enough to warrant it. We do not like to talk about government subsidies, but maybe they are necessary to "prime the pump." To harness industrial capabilities requires that industry be given the profit incentive. At least some sort of financial inducement is needed to undertake something new. The public will benefit in turn because the taxpayers have to pay for the bridges.

The AASHO Bridge Committee is a very key and influential group that has to accept the principle and encourage further developments of this concept of bridge building. It has been suggested that, at a meeting of the Bridge Committee, there should be some presentation of the highlights of this workshop. This could start new thinking and discussion and the necessary process of accommodation and education. I am sure that we will get the cooperation of this key committee.

I think there has to be distribution of the workshop proceedings to others who did not attend. We have to get this information to the building contractors so that they understand what has to be done and can prepare to accept their responsibilities. It must also go to manufacturing plants, to designers, and to various professional agencies. It has also been suggested that there should be a conference open to more contractors, more designers, more material suppliers, and the like. At that conference, papers would be presented or by that time some demonstration project might be observed or commented on in more detail as to its practicability to the problems that were encountered. In this category, the demonstration project of the Virginia Highway Research Council might indeed be a very effective one to be reported on.

Donald W. Pfeifer

I think the most important item is that the proceedings of this conference be presented to the regional meeting of AASHO.

Simon Kirshen

I think we ought to start right in the drafting room with the standard widths of road lanes, the standard shoulder width on the inside and the standard shoulder width on the outside. The local roads have 24-, 32-, or 40-ft widths with sidewalks. Therefore, we know what the general width of bridges will be. Why then can we not have standard spans? The state highway department can then say to its consultants and to the designers in the drafting room, "Here is the type of bridge, and here is the spacing." Are we going to use a steel beam, aluminimum beam, wood beam, or precast, prestressed concrete? Knowing that, you will now know what the slab is. For a simple span, if the weight of the superstructure is known, the abutment can be designed because the dead load is known, and the live load is determined from the length of the span. What about the foundation? Is it going to pay to excavate a little bit more to reach good material and not use piles, or is the poor material so deep that it is better to use piles? Whenever a consultant does a job for a highway department, he has to record his computation and check his computation. If bridge A is the same as bridge B, the consultant should not be required to submit another set of figures. This concept has to be sold to 50 different people, the bridge engineers from each one of the states, each one with inherent likes and dislikes, but that is where we have to start.

Robert G. Bartlett

That is going to take a lot of education prior to acceptance because for a long time we have placed a great deal of attention on factors of safety and the like No one is readily going to give up that opportunity to review and to check calculations before construction.

Harold B. Elsasser

It seems to me that the specifications for the design requirements and the construction requirements should be adequately coordinated. Some states apparently have a mechanism by which they encourage the designers and state personnel and contractors to exchange ideas on mutual construction problems.

Robert G. Bartlett

This is a very good point. For example, we now have a standing committee in Pennsylvania of design consultants, contractors, and highway officials that meet on a regular basis to review items such as taper on interchange ramps, standards on bridge arches, and culverts. A lot of this information has been segregated, and we have to bring it together. If we are ever going to follow the European contractual system, we have to start talking together and understanding one another's points of view clearly. That is not to say that this is not being done, but I think that it must be accelerated.

Summary

The comments of the workshop participants were directed toward future actions that would encourage the systems building of bridges. The basic need is for user acceptance, in this case by officials and engineers in the federal and state governments. Such acceptance will result in specifications amenable to systems construction, in market aggregation, and, perhaps, in an evaluation of the turnkey or European system of contract administration, all of which would foster the creative atmosphere so essential to progress. The goals of the workshop can best be gained through the education of highway officials regarding the concepts, capabilities, and advantages of the systems approach. It is hoped that these proceedings will serve that purpose.

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