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.