NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **53**

PRECAST CONCRETE ELEMENTS FOR TRANSPORTATION FACILITIES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **53**

PRECAST CONCRETE ELEMENTS FOR TRANSPORTATION FACILITIES

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- PAVEMENT DESIGN
- BRIDGE DESIGN
- CONSTRUCTION
- RAIL TRANSPORT

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1978

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP Synthesis 53

Project 20-5 FY '76 (Topic 8-05)
ISSN 0547-5570
ISBN 0-309-02857-4
L. C. Catalog Card No. 78-65707

Price: $5.60

Notice

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, serving government and other organizations. The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities but also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America.

PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to bridge engineers and others seeking information on design, fabrication, construction, and maintenance of precast concrete elements. Detailed information is presented on bridge members and other highway appurtenances of precast concrete.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

There are many applications of precast concrete for transportation facilities.

This report of the Transportation Research Board reviews design and construction aspects and fabrication techniques and describes numerous specific applications. Research needs are identified, and recommendations for making better use of current technology are offered.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Gay Leslie.

Special appreciation is expressed to Arthur L. Elliott, Sacramento, Calif., who was responsible for collection of data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Thomas Alberdi, Jr., Deputy Design Engineer, Florida Department of Transportation; James M. Barker, Post-Tensioning Institute; Brice E. Bender, Vice President and General Manager, Construction Products Corporation; Harry E. Brown, Research Engineer, Virginia Highway and Transportation Research Council; John D. Coursey, Chief, Construction Specifications and Operations Branch, Federal Highway Administration; E. T. Franzen, Chief Engineer, Design and Construction, Missouri Pacific Railroad; Heinz P. Koretzky, Head, Prestressed Concrete and Municipal Structure Section, Pennsylvania Department of Transportation; A. M. Lizzio, Structural Engineer, Office of Development, Federal Highway Administration.

William G. Gunderman, Engineer of Materials and Construction, Transportation Research Board, and Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies, precast concrete manufacturers, and railroad companies. Their cooperation and assistance were most helpful.

PRECAST CONCRETE ELEMENTS FOR TRANSPORTATION FACILITIES

SUMMARY

Although precast concrete has hardly been used for more than 100 years, it is likely almost anything that can be made of concrete has been made by precasting.

The primary advantages of precast concrete are economy and convenience. Bringing precast items to a job site eliminates much of the expensive field work. Rapid production time and the availability of some items from "shelf stock" mean time savings in construction. Disadvantages include fastening and connecting difficulties and weight problems where there are hauling or lifting limitations.

For precasting to be economical, a plant or yard and forms should be available, or enough units must be required to make establishing a yard worthwhile. Although precast units produced in a commercial plant will not necessarily be of better quality than those made at a job site, the plant does start with the advantages of established procedures; permanently installed provisions for concrete batching, placing, and curing; and a crew that does substantially the same work every day.

Using standardized designs, at least on a regional basis, would provide cost savings. This would enable a manufacturer to invest in a set of forms and produce an item on short notice and at a lower cost.

Although many precast items are cast in conventional wood or metal forms, those that are prestressed are often cast on a prestressing bed. Prestressing beds may be 200 to 500 feet (60 to 150 m) long and arranged to take a wide variety of forms and prestressing cable configurations.

Match casting is a technique for construction of beams and superstructures where the length or weight precludes transporting the entire member from plant to site. The member is cast in short segments using the previously cast segment as an end form. The segments are brought to the site, glued together with epoxy, and, usually, post-tensioned together.

Commonly precast bridge superstructure elements include: complete superstructures where the deck and beams are a single unit, such as tees (single, double, and bulb), boxes, and hollow beams; carrying members such as I-beams, inverted tees and channels, and trapezoidal beams; panels for deck forms; and full-depth deck slabs. Precast substructure elements include: caissons, floating box piers, piles, pier caps, and abutments. Other precast structural elements include: bulkheads, retaining walls, and floating bridges.

Highway appurtenances of many types are increasingly being precast. Among these are pavement patches (full and partial depth), pipe, inlets, manholes, culverts, headwalls, energy dissipators, median barriers, light poles, railings, and noise barriers.

Railroads also have become major users of precast concrete. They use such precast items as trestles, signal poles, signal equipment housings, and ties.

Some aspects of structural design affecting precast concrete still lack complete information; research on fatigue, service life, load history, shear design, and check-

ing of prestress force is warranted. There is also a need to narrow the disparity in quality among commercial plants. The most pressing need is for more standardization, as this should lead to greater availability and use, and to lower cost of precast items. This is particularly important because it would speed the necessary replacement of many short-span bridges and would save great amounts of time and money.

CHAPTER ONE

GENERAL DISCUSSION

HISTORY AND SCOPE

Although reinforced-concrete construction is only slightly more than 100 years old, it has become one of the world's most-used construction materials. The benefits of creating large, often irregularly shaped, monolithic masonry members were immediately recognized as a tremendous advantage over the age-old methods of masonry construction which fitted natural stone blocks together, cementing them with various mortars. The ability to cast the material into various intricate shapes had great appeal. In fact, the first use of reinforced concrete was supposedly by a French gardener who reinforced the concrete he was using to make garden containers and birdbaths. The abundance of gargoyles and intricate fresco effects, which adorned structures built around the turn of the century, amply demonstrates the full realization of concrete's ability to adapt to complicated patterns and forms.

Possibly some of the earliest uses of concrete were in a precast form, like the Frenchman's birdbaths, because it was possible to cast intricate shapes that previously had to be laboriously chiseled from native stone. However, the possibility of reaching across long spaces with reinforced concrete soon started the cast-in-place concrete revolution that has resulted in some of the world's largest structures.

As the technology developed, larger and larger structures were built and the advantages of monolithically casting large structural elements were realized. However, the cast-in-place structures had one serious drawback—the fresh concrete had to be supported on a forest of forms and falsework during construction. All of this underpinning is still accepted in many types of structures as the only feasible way to get the job done. However, because of the hazards of traffic running through falsework, the labor cost of installing forms and falsework in remote places, and other reasons, contractors and designers have turned increasingly to precasting concrete items in centrally located or commercial yards where labor and materials are usually more available, mass production principles can be applied, and work can be carried out under cover in all kinds of weather. Precast members can be transported to the job site where they are erected as components of a total structure.

As precast concrete became a familiar building material, people tried to use it for everything from concrete boats to objects of art. In fact, it is difficult to think of anything in concrete that someone has not tried to precast. Probably the only limitation is the weight or size. Thus, a state-of-the-art consideration must start with the premise that virtually everything can be and has been precast in concrete; then one must try to determine which of these objects are still feasibly and economically precast under present-day influences and labor rates.

Maybe there is a semantic question: What is "precast"? Ordinarily in the construction industry, one would think of something "precast" as being concrete cast in some permanent shape, probably in a commercial concrete plant, and then transported to the construction site where it is incorporated into the final structure. This concept will also cover many large concrete objects not ordinarily thought of as precast. For instance, it covers caissons, floating piers, pontoons, floating fenders, and all manner of large concrete foundations for marine structures. Of course, it also covers beams, slabs, pipes, and boxes readily available from concrete plants. It also covers cases where there is sufficient repetition of a single section to profitably set up a temporary casting yard adjacent to the job site and precast members rather than casting them in place. In short, we must consider as "precast" every concrete object that is cast in other than its intended place of use.

Prestressing

Although the subject of this synthesis is precast concrete, it is evident that the majority of today's precast concrete members (excluding concrete block and architectural decorations) are being prestressed. Therefore, in discussing the manufacture, handling, design, and erection of precast concrete members, it will be necessary to deal with prestressing equipment and practice.

Prestressed concrete incorporates high-strength tendons that are highly stressed so that almost the entire concrete cross-section is held in compression. Besides making it nearly impossible for cracks to appear, prestressing makes the members stronger and capable of supporting greater loads with shallower depths than could be done with conventionally reinforced concrete.

There are two different ways of obtaining the stress in the tendons. The first, known as pretensioning, is by arranging the casting bed so that the concrete is cast around tendons that are already under stress. Then after the concrete has set, the tension in the tendons is released at their anchorage, and the stress transfers to the concrete, placing it in compression. The second method is known as post-tensioning. Open holes are cast in the concrete, usually by thin-wall metal conduits. After the concrete has set, the tendons are pulled through the holes and then tensioned. The relaxed tendons may be in the conduits before concrete is cast, but should there be water leakage, there is danger of their corroding before they are stressed. The choice of the tensioning procedure usually depends upon circumstances. When members are not too big to be transported to the job, it is often more convenient to cast the members in a yard with pretensioning facilities. Cast-in-place work is usually post-tensioned.

Corrosion protection is of prime importance. Post-tensioned tendons must be protected by pressure grouting the conduits, injecting a mastic into the conduit or, if the tendons are in the open, wrapping them.

ADVANTAGES

Many advantages make precast concrete construction attractive to the designer, builder, or owner. Most of these benefits are economic or convenient; for example, precasting can be done under shelter and thus not be bothered by the weather.

Although precast concrete construction has been called higher quality compared to cast-in-place, presumably because the precast items were cast in a yard under controlled conditions, this is not a consistently valid claim. It is true that some materials (such as wire fibers, superplasticizers, and wax beads) may be handled more easily in a plant operation than in the field, but equally good work can be done in the field with good care and quality control. Poor work can be done under the best conditions, and good work can sometimes be done under what may seem like impossible conditions.

Bringing any precast item onto a job automatically eliminates the labor and cost of forms to cast it in place. It speeds the field work and minimizes the more expensive field labor. This may mean greater safety and convenience if forms and falsework can be eliminated. If precast beams can be designed to span from pier to pier, the interference and hazard to traffic may be minimized except for the short period during the erection of the members. This factor alone may be very attractive in some cases. The sheer convenience of bringing an item out to the job and immediately setting it into place—as contrasted with the tedious erection of falsework and forms, placing the concrete, and then stripping the forms—is enough to turn many decisions to precast work.

When there are a number of similar units to be made, great economies can be realized by setting up a yard at the job site, getting some good metal forms, and then turning out the units as a mass-production item. Some astoundingly cheap bridges have been built this way. Having the yard near the job eliminates long hauls and increases both the economy and convenience to near those of a commercial plant.

Economies can also be obtained by reusing precast items. For example, detour bridges built of precast concrete beams may be easily dismantled and the beams can be used again elsewhere. Precast median barriers can be used for temporary work site protection and then used permanently in the median or reused on another project.

Precast concrete construction can be very rapid. After California's San Fernando earthquake, one important freeway bridge over a railroad had to be replaced as soon as possible. A local plant began casting beams the next day, and in just 29 days after the earthquake, a very wide, three-span bridge was opened to traffic. The precast, prestressed concrete beams proved to be the fastest and also the most economical solution to an emergency situation. A similar experience with rapid replacement occurred in the Poconos in Pennsylvania in 1955 when Hurricane Diane washed out a bridge.

Most commercial plants aim at a 24-hour cycle for their casting beds. Allowing for a 24-hour air seasoning and another day for hauling to the job, the production and delivery time may well average about three days.

A few producers maintain a stock of precast concrete beams as a "shelf item." Concrete pipes and piles are commonly stocked as well as some beams for which there may be a local demand.

Precasting often makes cantilever construction an attractive method. By precasting short sections of the entire bridge cross-section (usually 5 to 10 ft (1.5 to 3 m)) and then fastening them onto the extending cantilever arm, spans of 250 ft (75 m) and up can be stepped across the landscape with minimum disruption on the ground and gratifying speed in the air. Started in Europe, this construction method is gaining popularity in the United States. In some cases it is advantageous to cast the cantilever extensions in place, but where the units can be handled, it is more convenient and faster in the field to cast them in a yard and then take them to the site and swing them into place.

When advantages are being considered, it is natural to compare concrete with other possible materials. The weight of the concrete, which upon occasion might be regarded as a disadvantage, is often a real advantage. Heavier structures are less prone to vibrate and shake than those of lighter materials. Concrete generally makes a stiffer structure. All concrete by its nature has the ability to take a beating without showing too much distress. One seldom sees a concrete member that failed under stress outside of a laboratory. Cracked maybe, but concrete seldom suddenly and completely fails under day-to-day loads.

DISADVANTAGES

All materials have certain inherent characteristics. Some of these are plus values; some are minus. It is the responsibility of any designer to weigh the pros and cons and choose the available material that best suits the purpose. The disadvantages of precast concrete depend largely upon local circumstances. What might be a disadvantage in one situation could be an advantage in another.

The primary disadvantage of precast concrete construction is the same as that for any rigid, prefabricated member—how to fasten it into the structure and to the other members. Without good connection details, a long trestle or a building made up largely of precast members takes on some of the characteristics of a house of cards; a strong earthquake may shake the whole thing to pieces, not because the members failed or were inadequate, but simply because the connections were not strong enough. Good details have been worked out for fastening precast concrete members together. Some tie the ends of girders together using a closing pour with interlocking reinforcing bar hairpins or even with the projecting ends of the reinforcing bars welded together.

Sometimes a group of precast members is held together by post-tensioning. Sockets may be used in caps into which piles or girders may be grouted. Holes may be provided in the beams with hold-down anchor bolts. These devices all provide the positive restraint required to resist movement caused by earthquakes, steep grades, superelevation, and centrifugal forces. It is not sufficient, as is done in some poor designs, to merely set the member on a narrow ledge and trust that its weight and the proximity of the other members will hold it there. This may work well in the absence of earthquakes or extreme impact loads but can fall apart if subjected to a severe shake. The Anchorage, Alaska earthquake demonstrated this graphically. The section on "Practical Aspects of Precasting" in Chapter Two contains further discussion of the connection problem.

Weight and length of precast members may or may not become a disadvantage. Concrete members are always heavy—usually heavier than other materials that might also carry the load. However, the weight can not be called a disadvantage until it exceeds the capacity of the equipment readily available to lift the members into place. Restrictions on the hauling of very long girders may also be regarded as a disadvantage in some cases.

All concrete, precast or not, cracks.

> ". . . cracks have been experienced normally in reinforced concrete for many years. As a matter of fact, reinforced concrete is designed on the assumption that it will crack. Prestressed concrete has been established as a means of preventing cracking in concrete. In this feature it has been partly responsible for the increased interest in prestressed concrete in recent years. It is true that most designs of prestressed concrete members provide against flexural or diagonal tension cracking under service loads." (*1*)

Prestressing minimizes the cracking because it creates a constant compression in the concrete that holds the cracks tightly shut and prevents the moisture and dirt from getting in. Probably most of the precast members used in transportation structures today are prestressed. This has been beneficial in keeping the cracks closed and reducing corrosion of the tension elements.

Another disadvantage of precast structures is their lack of aesthetic appeal. Too often they look just like what they are—a lot of pieces just piled on one another. Piers may consist of exposed round or square piles under an oversized cap. The girders merely sit on the cap without any evident continuity and, in a long bridge, it is about as appealing as a timber pile trestle. However, precast structures do not have to be ugly. With a little imagination, the piles might be capped and a more interesting pier shaft used. The cap could be raised until it extended to the underside of the deck and the girders set into sockets in its side. The end of the cap could be given some treatment to harmonize with the girders and make the lines of the structure flow longitudinally.

CONSTRAINTS AND LIMITATIONS

The principal constraint on any precast concrete construction is the weight of the completed member and whether it can be transported and lifted into position. If adequate lifting equipment is available, there is no problem; but when the weight of the proposed girders exceeds the lifting capacity of the readily available equipment, economic considerations dictate a careful weighing of the relative benefits.

Some designers are somewhat cavalier about this matter of weight, feeling it is the responsibility of the contractor to provide the necessary equipment. There is some basic truth in this attitude, but if the weight is too great and thus requires equipment that is highly specialized and difficult to obtain, then the designer has severely penalized the job and possibly run the cost up out of reason. Around population centers, truck cranes lifting as much as 140 tons (127 Mg) may be readily available, but it becomes very expensive to transport these heavy cranes a great distance from their base of operation. The whole problem becomes one of relative economics. Unless there are compelling reasons for some unusually large members, it is best to stay within the capability of the equipment readily available to the local contractors.

Many locations restrict the length of girders they permit to be hauled over the highways. These restrictions generally limit girder lengths to about 100 to 120 ft (30 to 36 m). Some states are quite liberal about giving overlength permits, others are not inclined to be generous. The designer may find that the local rules will effectively limit the length of precast members to be hauled, thus possibly limiting the length of the spans. This restriction may be avoided by casting the girders at the job site so they will not have to be transported over the highways. The restriction may also be avoided by bringing the girders in two or more pieces and joining them by post-tensioning at the job site. This type of segmental construction will work out very well as long as equipment is available that can lift the completed girders. If such equipment is not available, then the segments may be supported on falsework until they are stressed together. However, if traffic is

passing under the supported segments or if the span is over a railroad, there is an undesirable hazardous period until the members become self-supporting. The hazard may rule out this procedure.

If the contractor is not building a casting bed, the available sizes of girders may be limited by the capability of the local casting yard. Designers have called for girders with very large prestressing forces, only to find that none of the local precasting and prestressing beds were capable of developing that large a prestressing force. Again, it pays to know the capabilities of the local industries.

Some parts of the country are blessed with excellent aggregates, some are not. If higher than ordinary concrete stresses (say 5 000 psi—35 MPa—and up) are called for, the designer should be certain that aggregate that will achieve those strengths is available. There have been cases where aggregates had to be imported over great distances at considerable cost just to meet the strength requirements that a designer had specified. The designer should be certain that the additional cost of the extra concrete strength is really worthwhile.

From the standpoint of the producer, a definite constraint to having beams available as a shelf item is the propensity of designers to call for unique beam sections. This is frequently—in fact nearly always—unnecessary. Designers should realize that if they stay with a few standard shapes and sizes, the fabricators will be able to maintain forms on hand and the precast beams will become cheaper and more readily available.

Another requirement for successful precast construction, especially if it is anticipated that the contractor will build a temporary precasting bed, is that there be a sufficient number of similar members to make the expensive reusable forms and casting bed economically attractive. Unless there is a precasting plant available with forms of the proper dimensions, it is usually not economical to precast only a few members. An exception may be where heavy traffic conditions or difficult foundation conditions make it desirable to precast the girders and raise them into place with a minimum of traffic disruption and without intermediate falsework. In these cases, contractors have cast the beams on the site where they may be picked up and swung into place. The forms are often one-use forms such as might be used for cast-in-place construction, and much less expensive than the demountable metal forms usually used for repetitive casting operations.

CHAPTER TWO

DESIGN AND CONSTRUCTION ASPECTS

PRACTICAL ASPECTS OF PRECASTING

In the enthusiasm to extensively precast a structure so it may be taken to the site and quickly put together like a toy construction set or a pre-cut kit, one may go too far. One must carefully determine that point where the benefits of precasting are overshadowed by the difficulties of construction or the awkwardness of design. When one passes that point, precasting loses its economic, and sometimes its practical, benefit.

Already discussed was the fact that precasting may become unattractive when the weight of the members becomes so great that the difficulty of providing equipment to carry and lift them becomes a problem. One designer was considering 300-ton (270-Mg) girders to be erected over water. No equipment was readily available for such a lift. Granted that it could be developed or brought in from some distance, but the designer should realistically consider the possibility that the construction costs might well outweigh the benefits of using the big girders—and consider some other solution. The development of special equipment can be very costly. The smart and practical designer will know the equipment available and tailor the structure to fit the existing capacities.

However, where there is to be a large number of duplicate operations, it may be expedient and economical to design special equipment to handle larger than usual precast sections. Such a case arose when a stream was to be carried longitudinally under a highway in a conduit. A waterway cross-section of 175 ft^2 (16 m^2) was needed. One large concrete pipe, precast and placed in sections, was used. The sections were so big and so heavy that special crawler equipment was designed to reach out and pick up a section of pipe, carry it some distance and then set it in place against the previously laid section. The carrier was an expensive item, but the convenience of using the large precast sections, as well as the great number of sections to be laid, made the expenditure advantageous.

Economic Constraints in Completely Precast Bridges

Engineers seeking more economical construction methods always dream of a completely precast bridge. Computer enthusiasts have proposed giving the computer the general geometrics of a structure and then having it draw up a set of plans using a selection of previously-designed precast elements. These ideas all have possibili-

ties, but there must be special circumstances to make them work. In California one time it was thought the ideal situation had been achieved. Far out in the desert, 26 bridges were to be built over dry washes, which during cloudbursts could become raging torrents. The bridges were all fairly short, of less than half a dozen spans. They were to be built with low clearance above the desert washes, usually not more than about 10 ft (3 m). Aggregate, water, and labor had to be provided many miles from the nearest railhead. It was proposed that entirely precast bridges be designed for fabrication in a plant at the railroad terminal. The precast pieces would then be trucked to the job and put together with a minimum of expensive site labor. The 26 bridges would provide enough repetition to make such a project feasible.

The 26 bridges were designed entirely precast. Piles, caps, abutments, long walls to lead the water to the opening, girders, and deck slabs were all designed as precast units. As an afterthought, provision was made for the contractor to build the bridges cast-in-place if he so chose.

The outcome is almost irrelevant, but it does illustrate the influence of economics. Just before the bids were advertised, someone at an administrative level, obviously unaware of the nature of the project, decided that the job was too large and divided it into two smaller contracts, one with 12 bridges and the other with 14. As luck would have it, two different contractors got the contracts, and there were not enough bridges in either contract alone to make it worthwhile setting up the necessary yard to do the precasting. All of the bridges were eventually cast in place, and the experiment did not materialize.

This provides a lesson in the economics of precasting. If there is a commercial plant available or, if a contractor has a yard and forms available, precasting can be economical. If none of these is available, then for the one-time job it will usually be more economical for the contractor to build the forms and cast the structure in place. Designers should not assume that precast elements are going to materialize out of thin air. If precast units are to be specified, the designer should be certain that facilities are available for supplying them. On the other side of the coin, suppliers looking for business will find that if they make the investment in the yard and the forms and let it be known that they can supply precast units for various usable sizes and shapes, a market will frequently develop. Manufacturers must have a number of repetitive units to make a small yard and a set of forms profitable.

Combining Precast and Cast-in-Place Constuction

There are many combinations of precast and cast-in-place construction; the best one for a given job will depend upon local conditions. Many designers and contractors have profited from a shrewd analysis of a situation. The manner of using the precast members is also of great importance. Some designs have the precast girders fitting into sockets in pier caps or resting on a wide ledge without any cast-in-place concrete necessary to anchor them or lock them in place. This arrangement is quite widely used as it is effective in reducing the labor required at the site, but it may be of doubtful stability in an earthquake and often leaves something to be desired aesthetically. Unless carefully designed, the joints look cumbersome and the structure usually lacks smooth and flowing lines.

Another approach to using precast girders is supporting them on falsework and pouring the caps in place to encase the ends, giving the appearance of a completely cast-in-place structure. This will produce a cleaner looking structure, but it too has certain difficulties. Until the caps are poured, the heavy precast concrete is supported only on falsework. An errant vehicle wiping out a few of the falsework posts can bring the whole span down in a horrible mess. In one case the bridge had considerable superelevation so the falsework also sloped. The bracing between the girders was inadequate, something failed, and all of the girders rolled over and down the sloping falsework caps and crashed onto a busy railroad track.

The best solution is a combination of dry connections and cast-in-place connections. The dry connection is one in which a socket or permanent bench is provided so each girder is set into its permanent position and supported by the pier rather than by falsework. In this manner, the girders may be erected and set into their final resting place with full support from the permanent caps. Then, after all the girders have been erected, their ends may be locked in with a pour into a slot in the cap, in boxed recesses, or maybe by placing an entire top on the cap to encase all of the girder ends. This procedure eliminates the period of suspense when the heavy girders are sitting on falsework and are vulnerable to being knocked down.

Precasting potentials may encourage overenthusiasm and may even trap the unwary into uneconomic and even inconvenient designs. Concrete has been heralded as the perfect building material because of its versatility. The fluid concrete may be cast in forms to make a statue of the Venus de Milo or a fancy cornice for a building, or it may be placed against the roughness of a rocky foundation—fitting every nook and cranny to give perfect conformance with the rough surface. All of this is a great convenience when compared with the labor of shaping timber, stone or metal to conform to anything other than straight lines. However, anomalously, when concrete is precast its convenience and versatility are to an extent being ignored and it is being returned to the rigidity of stone. This is in no way to deny the obvious benefits that come from precasting concrete but only to emphasize that fine line between the situations where it is good to precast and where it would be better to cast in place. Frequently designers become so enthused with the great convenience of precasting and putting a structure together like a toy construction set that they specify a job for precasting when it would have been easier and better to cast it in place. Fortunately the two methods may be combined to get the best features of both.

PLANT VS. SITE MANUFACTURE

As already discussed, it is not necessarily true that a precast concrete member manufactured in a commercial plant is of any better quality than one manufactured at the job site. However, a good commercial plant starts with considerable advantage over a contractor who leases a farmer's corn field in which to set up a casting yard. Commercial plants can have automatic batching, overhead cranes to handle forms, built-in vibrators, and permanently installed heating and curing arrangements, plus the advantage of a crew that does substantially the same thing every day and therefore is less prone to error. All of these benefits may certainly be realized by a contractor in a temporary yard, but it will not happen without careful planning and insistence on thorough execution. Because field procedures may sometimes be somewhat slipshod and the quality control somewhat casual, the plant product is generally considered better quality than the field-manufactured product. This is not a bad assumption to follow until a contractor proves able to get quality work from a temporary field yard. It should be noted that commercial plants too can become sloppy in their operations and can turn out a deficient product. Quality in any location is not accidental and must be constantly worked for by everyone concerned.

Generally, a commercial plant that is efficiently designed and run can turn out concrete products cheaper than starting from scratch in a temporary yard. This economy could be realized if standard designs could be widely accepted so that commercial plants could have the forms and maybe even a small stock of specific items that were frequently used. The nightmare of any producer is the designer who comes up with a slightly different design for every project. There would be true economy if there could be at least regional standardization of, say, the beams and slabs for 40-, 50-, and 60-ft (12-, 15-, and 18-m) spans of two-lane bridges such as might be used in rural areas. This would result in millions of dollars being saved during the next twenty years when tens of thousands of short, county bridges will have to be replaced.

CURING PRACTICES

Concrete may be cured in a variety of ways. The old reliable method is to keep it continuously wet for five days. Now there are a number of more exotic curing methods ranging from radiant heat to vacuum curing, which, if carefully done, can cure the concrete in a few hours. All acceptable methods give good concrete. The most convenient way to apply heat for curing is with steam or hot water, either as live steam within an enclosure or as radiant heating through pipes. Hot oil is also successfully used to generate radiant heat from pipes. Electric heating has been used but is generally too expensive to compete with either steam or hot water. The curing heat is not applied until after the initial set. Some agencies require an additional waiting period of up to six hours after the initial set. The vacuum process started strong but developed difficulties so it is seldom used and then only with great care and expensive equipment. Additional water may be added directly to the concrete while curing by any of the radiant heating systems.

Steam Curing

There are many ways of applying steam to heat concrete. It may be injected live into metal, wood, or canvas housings over the casting bed. These housings are usually segmental and are set in place as soon as the finishing is completed. Steam is then turned on and regulated to maintain the desired heat in the concrete. Raw steam also maintains a high humidity that is beneficial to curing. Steam may also be used in pipes installed either permanently or temporarily within the housing structure giving a dry but usually more easily controlled, uniform heat.

Hot Water Curing

Hot water may be piped along the bed to provide the necessary curing heat. Where the heat is obtained from pipes, the bed is best arranged so the pipes are a permanent installation. Figure 1 shows a very good installation with a depressed casting bed and three finned hot water pipes running along each wall of the depressed section to provide the curing heat. A gantry that travels along and over the bed has a heavy tarp that rolls out to cover the bed and seal in the heat during curing. This gives an excellent uniform heat and avoids the hot spots that sometimes occur with live steam.

Water Curing

Where a fast cycle time is not essential, excellent curing can be done with plain water. The water may be fogged or sprayed onto the concrete as soon as it is set. The concrete should be kept continuously wet for the specified curing time, usually five days. Heating the water will hasten the curing process.

Curing Temperature

There is disagreement as to the proper curing temperature. Because the higher the temperature, the faster the cure, most manufacturers are anxious to use the highest permissible heat. However, there is evidence that temperatures greater than 180 F (82 C) may be harmful to the concrete. Others feel that 150 F (66 C) is adequate and avoids the possible dangers of the higher temperature. A reasonable compromise is probably 160 F (71 C), although some agencies specify a 150 F (66 C) maximum.

UNIT HANDLING

Methods of handling the precast units will vary with the equipment available. The well-equipped yards have gantry cranes that can service the full length of the beds and also run out over a wharf or area for loading onto barges or trucks. Truck or crawler cranes may also be used conveniently.

Most precast concrete units are cast with lifting rings. These are well-anchored within the beam, slab, etc., and

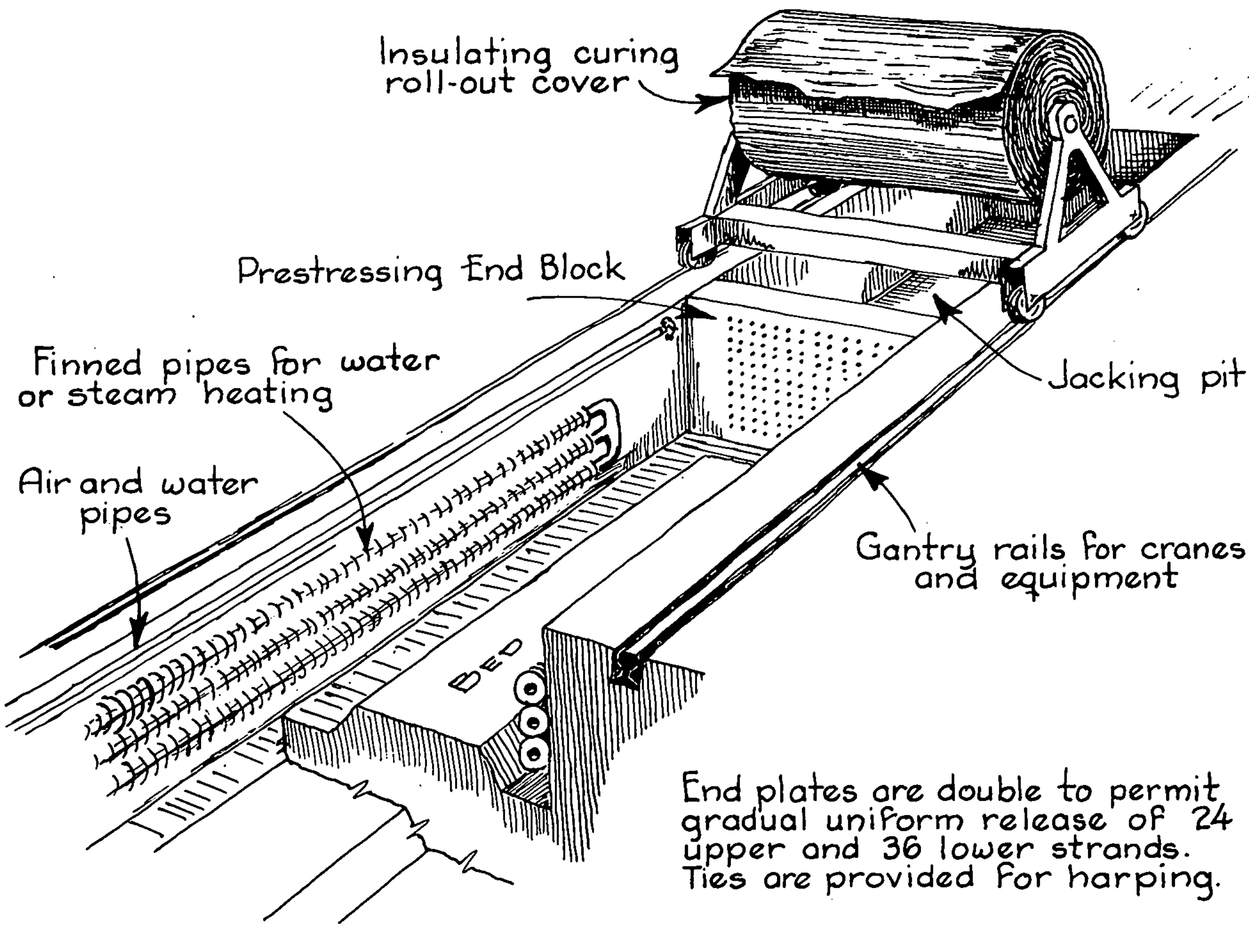


Figure 1. Some elements of a depressed pretensioning bed.

provide an easy method of picking the unit out of the forms. Piles are usually lifted from the forms with slings at the quarter points, although some plans will specify the pick points where various length piles are to be supported with a given number of slings.

Careful handling of precast and prestressed members is of utmost importance. Support in modes for which the member was not designed can cause irreparable damage. Long prestressed members must be stiffened and held in line during transportation. Beams that have inadvertently been allowed to bend out of a straight line have literally exploded. The concrete is under heavy compression, and misalignment can at least cause large spalls to break out.

CHAPTER THREE

FABRICATION TECHNIQUES

TYPES OF PRECAST CONCRETE PRODUCTS

Numberless items may be or have been cast in concrete. It is impossible to name them all, but the following are a few of the items that have been more or less regularly precast for transportation facilities:

- Architectural—Gargoyles, friezes, cornices, rail balusters, textured wall panels, window frames, blocks (plain, colored, and decorated).
- Water Conduits—Pipes, pipe inlet and outlet structures, manholes, drop inlets, catch basins, rectangular box culverts, slabs, arched culverts, energy dissipators, erosion preventers.
- Structural members—Beams (I, T, TT, channels,

boxes), slabs (half-thickness, cored, and solid), caps, columns, diaphragms, highway replacement slabs, bridge replacement sections, wall and window panels, exposed aggregate panels.

- Foundations—Piles (solid and cored, conventional and prestressed), columns, footing blocks, floating box piers, pier forms, caissons, abutment walls, wingwalls, training walls with supporting concrete H-piles, railroad ties.
- Miscellaneous—Caisson anchors, railroad communication equipment houses, battery boxes, signal poles, light poles, power poles, pole bases, septic tanks, water tanks, dragon's teeth, tetrapods, temporary construction barriers, median barriers, curbs.

CONVENTIONAL FORM CASTING

A great many concrete objects are still cast in conventional forms. The forms may be of wood, fiber glass, or metal, metal being generally used where they are to be continually reused. The forms are usually designed so they are demountable after the concrete has set (Fig. 2). Some units, such as T-beams, are sometimes designed with a slight draw or taper so they may be lifted out of the forms without the necessity of a release to get clearance. Some items cast in this manner include: drop inlets, battery boxes for RR signals, electrical equipment houses for RR signal systems, unstressed poles and posts, large concrete pipes (cast on end with demountable forms with attached vibrators), septic tanks, manholes (free standing

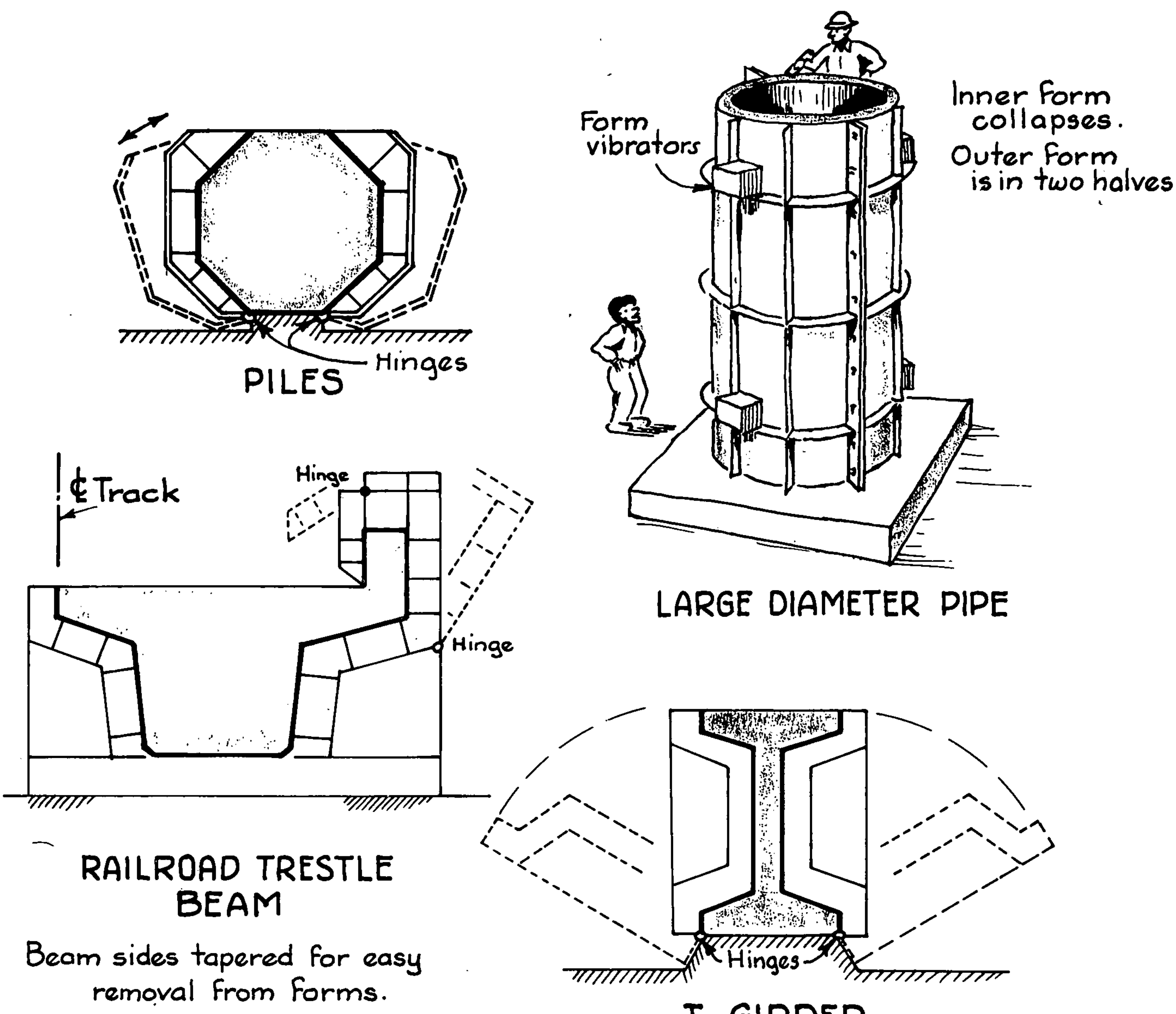


Figure 2. Reusable forms. Beam and pile forms are usually built on a prestressing bed so units may be prestressed.

and attached to pipes), non-prestressed beams for railroad trestles, and bridge railings.

PRESTRESSING BED CASTING

With the increased popularity and use of prestressed concrete, more and more conventional forms are being adapted for use on a prestressing bed so the units may be provided with a prestressing force at the time they are cast. A well-equipped precasting yard may have prestressing beds 200 to 500 ft (60 to 150 m) long, so arranged that a wide variety of forms may be set to enclose the prestressing cables.

Bed Designs

Bed designs vary widely. Temporary installations may use a couple of concrete piles, girders, or steel struts for horizontal compression members and set the forms and prestressing cables in the space between (Fig. 3). See Figure 1 for an example of a well-equipped prestressing bed. The end forces may be taken by exposed struts, by independent pile buttresses, or by a compression beam that runs under or around the stressing bed (Fig. 4). The end blocks may be permanent with fixed holes for the cables, when only one item [such as an 18-in.-octagonal (450-mm) pile] is being cast on the bed, or the blocks may be made up of a series of slots or holes that permit an almost infinite variation in strand position.

Temporary Beds

Temporary beds are usually used where only a few units are to be cast at a time and where the investment in a permanent bed is not considered warranted. The only requirement is a smooth surface upon which the forms for the unit to be cast can be built and maintained in position, and a couple of strong compression members to provide the resistance to the prestressing force in the cables. Two or more concrete piles or a variety of steel or concrete beams are often used as struts to take the required compression. Care must be taken to hold the compression beams down and in line so that they do not suddenly buckle and catapult the whole assembly into a mass of wire, broken forms, and wet concrete, not to mention injured workers. The basic ideas are simple and, carefully done, quite safe. However, tremendous forces are involved and, carelessly done, a stable arrangement can be an explosive trap. Figure 3 illustrates the general form these temporary beds take.

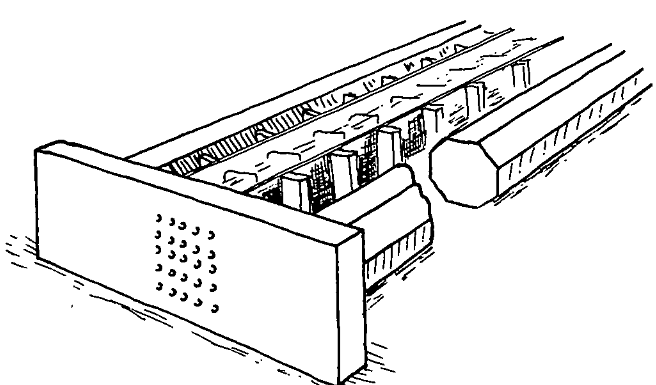


Figure 3. Temporary stressing arrangement using a pair of concrete piles as compression struts.

Permanent Beds

Good permanent prestressing beds are not inexpensive; a well-designed one may easily cost $500,000. A location on rocky ground may enable the end buttresses to be anchored in solid rock, but the more common practice is to use anchor piles. The better designs have continuous compression beams between the end buttresses, buried in the ground and flush with the ground surface, with the top of the compression beam acting as the working surface for the bed. A good installation is one that utilizes a buried, three-sided box girder with the top open (Fig. 1). The box is wide enough for all the proposed units that may be cast, with their forms and work room, and also contains permanent heating pipes, which may utilize steam or hot water. Fins on the pipes give good distribution of the heat to the bed. A permanent bed will probably be not less than 200 ft (60 m) long and will preferably be about 500 ft (150 m) between end blocks.

The end blocks have a wide variety of shapes to support a number of different strand arrangements. Very few beds are made to cast only a single item, and therefore it is important to make the end blocks adaptable to many different strand positions. One system, comprising two parallel girder lines on a single bed, is shown in Figure 4. The vertical slots give a wide selection of strand positions. The cross beam that spans between the two end blocks makes it possible to use the bed for casting wide slabs with prestressing cables spaced across the width.

Beds are provided with hold-downs at various points so that the strands may be draped as desired.

Tension Release Mechanisms

There are two ways of releasing the tension on the strands in a prestressing bed. The first is by burning off the strands. The second is by using jacks to release the tension.

In the first system the strands are rigidly fixed at each end of the bed, and release is achieved by burning off the strands after the concrete has reached the required strength. As each strand is cut, the tension on the remaining strands increases until there is sufficient pull to stretch out and break the remaining strands. The final break produces a slight jar of the beams and sometimes small spalls around the strand ends—both of which some critics find objectionable.

The second method provides a double set of blocks at the end so jacks can be inserted, a slight additional strain

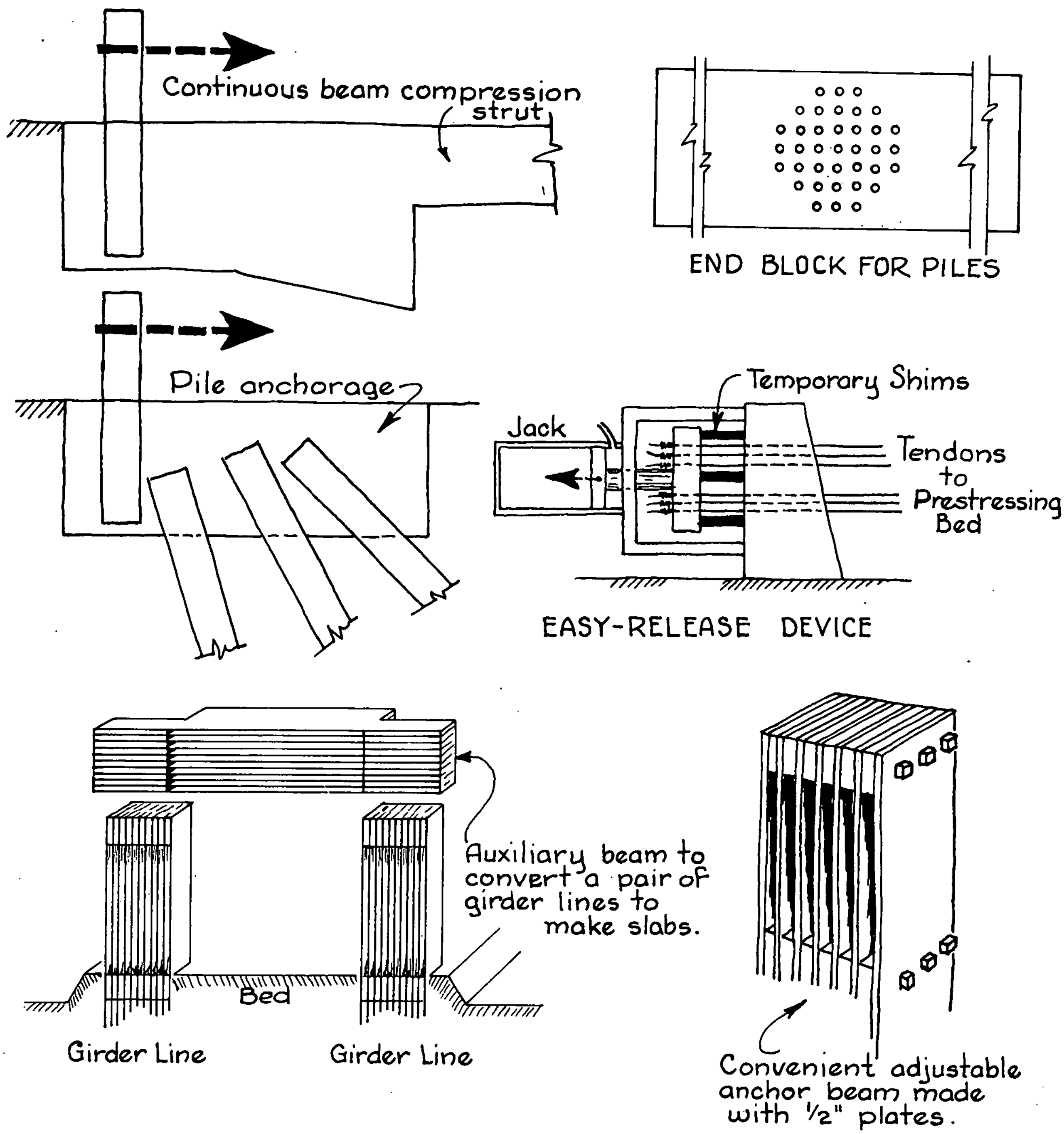


Figure 4. Some prestressing details.

taken so the wedges can be removed, and then all of the strands are slowly released. Some critics of this method do not like the additional strain that is applied after the concrete has set. The wires between individual beams are still burned in two, but because the main stress has been released, the shock is not as violent.

Both systems have their advocates, and modern beds are operating with both methods of release. It is difficult to prove that one method is measurably better than the other.

Continuous Casting Arrangements

Several types of members lend themselves to continuous casting techniques. These are generally members having undraped, parallel tensioning strands. Piles, square and octagonal, solid and hollow; box beams with rectangular or circular voids; and slabs, both solid and voided, have been cast continually with great success. If the member has voids formed by pulling along a mandrel, the concrete must be very dry. However, if the form for the void remains in place until the concrete has set and is then

removed, considerably wetter mixes can be used. By covering the members immediately after the casting machine has passed and applying steam curing, the members are usually ready for removal the next morning, and a 24-hour rotation schedule may be maintained. Although the casting machines are expensive, continuous casting without side forms saves considerable time and money over having to set and then release permanent forms for each pour.

Systems for Providing the Voids

Most concrete members are so heavy that casting voids into the cross-section will usually save material as well as handling costs. A number of different schemes have been devised to provide the open space in the interior of the concrete member. The simplest and most direct approach is to use a form that either remains in place or is later collapsed and removed. Used lumber, prefabricated cardboard, and collapsible metal or rubber forms have been used in this manner. One of the major problems with any void in concrete is keeping the form for it in place. It has a strong natural tendency to float and therefore must be securely fastened to keep it in proper position. Inflated rubber tubes have been used for the round void in the center of concrete piles. After cure, the air is released from the rubber tube, and it collapses and is easily pulled out. Some continuous casting systems use either a metal mandrel or an inflated rubber tube. The mandrel is pulled along with the casting machine, trailing it by a short distance to give interior support until all the vibration has moved away. The concrete is placed very dry and sustains its shape very well as the machine moves away from it. The piles may either be cast to length, using intermediate headers in the forms, or they may be cast longer and sawed to length as desired.

All voids should be vented to allow heated air to escape and drained so water can not collect.

At least two proprietary systems provide voids for cored slabs and wall panels. One system deposits loose, dry, lightweight aggregate in the space to be voided. Although the concrete mix is not too dry, it is dry enough so that no thin mortar runs into the dry aggregate. After the slabs have set, they are upended and the loose aggregate runs out, leaving a rough but nevertheless quite satisfactory void. In wall panels, this space is often filled with a plastic foam to give added insulating qualities. Another system uses a spiral tube that rotates its way through the wet concrete, leaving a spiral void in the slab. These slabs are often cast continuous for the full length of the bed and then are sawed to length as needed.

MATCH CASTING AND SEGMENTAL CANTILEVER CONSTRUCTION

Another precasting technique is used for cantilever construction and also for spans where the units are either too long or too heavy to be hauled from a plant to the site. The technique uses from two to twenty or more individual sections that are joined together and then post-tensioned to form a long span. In the case of the cantilever construction, the units are placed one at a time and then tensioned to hold them in place as they become a part of the cantilever arm reaching out into the span. Another system supports the several segments on falsework and then post-tensions them all at once to form one full span. With either of these systems, it is very important that the segments match well to transmit the compressive stresses. They may either be set tight together in a butt joint locked by epoxy paste and some keys, or they may be held apart and a closing pour made that locks in the protruding reinforcing dowel bars and gives a good bearing on both surfaces.

It takes almost laboratory conditions and care to get perfect ends so that adjacent pieces will fit together. Because such conditions usually do not prevail, the match-casting technique was developed, and it assures a perfect joint every time. The idea is to use the previously cast unit as the end form for the next unit. This way every variation in the first unit is duplicated in the second, and the two fit together perfectly because they were cast that way. The Chillon Viaduct in Switzerland carried this system to a high degree of perfection. This project is described in more detail in Appendix B.

Match casting has been used for almost every kind of joint where precast pieces are to be joined together. The advantages are obvious because it enables the pieces to be joined together with a perfect fit and only a thin layer of epoxy paste is required between sections. The alternate to match casting is to make a closing pour or provide a thick layer of grout to fill the gap between the units. This means the units must be rigidly supported in position while the cement or grout sets.

Joints have been made by very carefully casting the beam ends against precisely made steel plates, using extreme care to see that the beam ends were identical. The beam ends were also carefully prepared by sandblasting. These have worked, but the precision required usually far exceeds the normal procedure in most casting yards. Hence, match casting provides a much easier and more practical way to obtain good results with the end matching problem. And tests found that the epoxy joint was stronger than the concrete itself (*2*). However, care should be taken that the most suitable epoxy formulation is used. There are many different formulas on the market, and other epoxy adhesives are being developed.

Segmental Construction

Recognizing that it is not always possible to haul long precast beams to every site, a study was made by Concrete Technology Corporation of Tacoma, Washington, to determine the characteristics of a long beam made up of a number of short sections glued with epoxy and post-tensioned together (*2*). The Washington standard beam Type 100 was chosen for the test. It was made of nine 8-ft (2.4-m) center sections with a 10-ft (3-m) section on each end, making a total beam length of 92 ft (28 m). The sections were smooth-ended, match-cast, and glued with epoxy. The beam was tested with equivalent AASHTO loads. It was concluded from the test that:

> "The performance of the segmental beam exceeded the ultimate load criteria specified by AASHTO for monolithic prestressed concrete construction. The concept of match-cast segments, glued together and post-tensioned, is not only practical, but more than satisfies the technical requirements for highway bridges."

This approach can be used where hauling is a problem or where limiting the hauls to smaller units is desirable. It is necessary to temporarily support the units prior to stressing, but this can be done on the ground before setting the completed beam into position. Hauling the longer complete units will usually be more economical, but this segmental procedure offers the benefits of the long precast members in special cases where they can not be transported in one piece.

Match-casting is also used for simple box girder construction as well as large units featuring a complete bridge cross-section such as was used in the Hammersmith Flyover in England, the Chillon Viaduct in Switzerland (see Appendix B), the Corpus Christi Ship Canal bridge in Texas, and several others (*3, 4, 5, 6*). In these cases the weight and transportability of the units are the limiting factors. In some cases, each unit is individually post-tensioned as soon as set in place, cantilevering out without falsework. In others, the entire span is erected on falsework and then stressed together into a unit. Either way, the fit between units is near perfect and immediate, and there is no need to wait for closing pours to set.

CHAPTER FOUR

STANDARDIZATION AND MARKETING

STANDARDIZATION

To propose standardization generally evokes an argument. There are always those free spirits who think that any kind of standardization robs them of their right to exercise initiative. Others claim that the only ones to benefit from standardization are those who happen to have the forms for the standard units. As always, there is some truth on both sides, and the circumstances may radically alter the considerations. Granting that standardization does to some extent rob the designer of his initiative, it will also return a real saving to the public or the owner who ultimately has to pay the bill for the total cost.

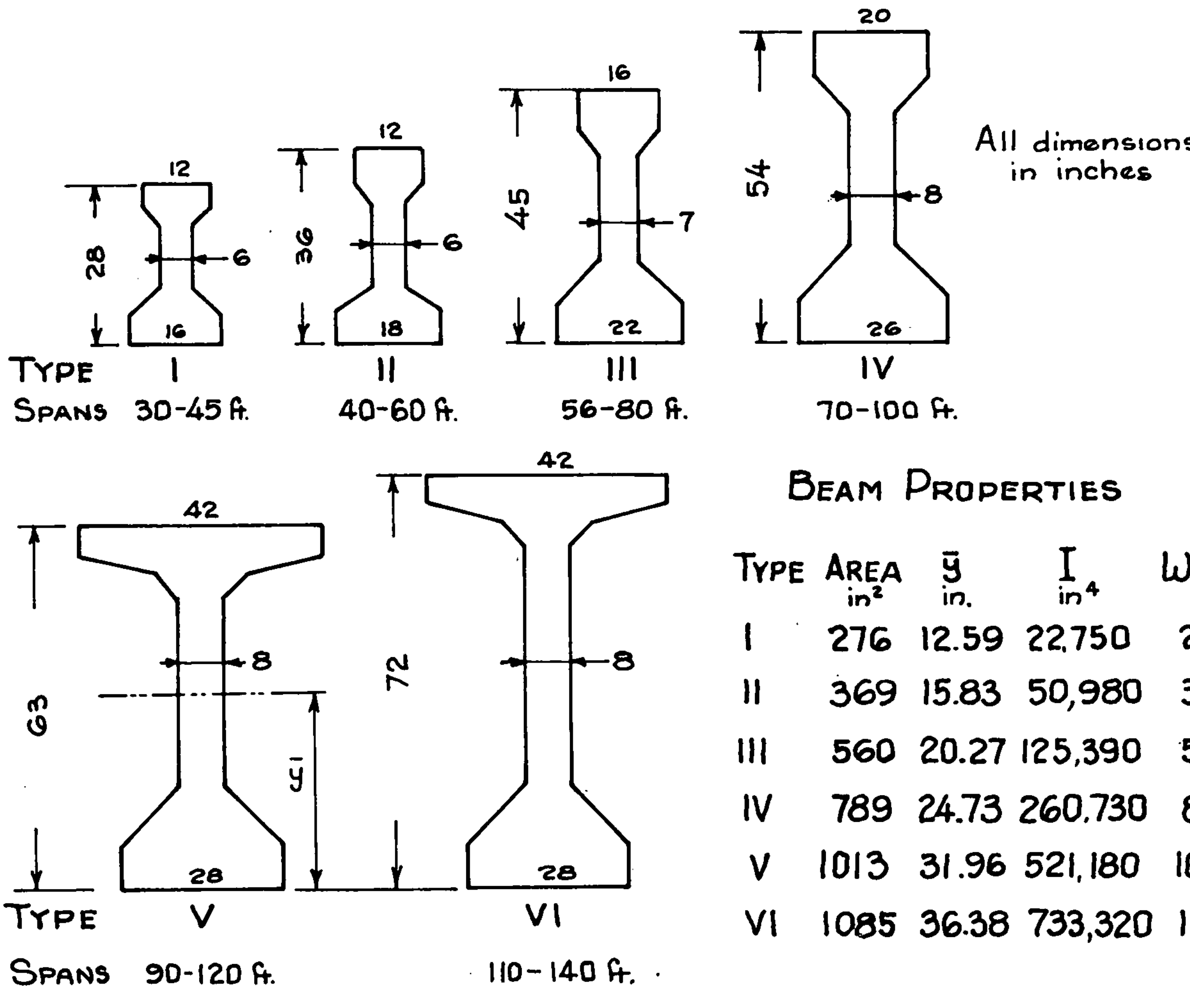
The country as a whole—states, counties, and cities—is facing a crisis in the replacement of literally thousands of decrepit bridges. This crisis is rapidly approaching and is getting more and more attention at all levels. It seems highly likely, because of the huge amounts of money involved, that the effort may well be mounted on a nationwide basis. This will result in a great impetus to replace many, many bridges at the same time. Most of these bridges will be less than 200 ft (60 m) long and could well be replaced by a standardized precast, prestressed trestle-type slab structure with 40- to 60-ft (12- to 18-m) spans—if the research has been done in advance and the best, most economical, most adaptable designs worked out. The use of standardized structures for the replacement of small bridges throughout the country or at least in sizeable regions would bring enormous savings.

The past experience with standard designs has not been encouraging. The principal difficulty is that the designs offered as standards have not been as good as the lighter, stronger designs developed by further research. Therefore, many states have not adopted the standard units, preferring to hold their options open if a better design comes along. Many states have developed their own designs that are more satisfactory and more economical for their particular situation.

Although the advantages of standardization become very clear in the case of a nationwide effort to replace many bridges, the same benefits are available on a day-to-day basis. Some years ago AASHTO and PCI hoped to promote uniformity by issuing plans for a number of prestressed I-beams (Fig. 5) (*7*). The beams were heavy and were not the most economical designs, although about 24 states have used some of the AASHTO standard beams. A number of states, including California, Colorado, Pennsylvania, and Washington, had already developed their own, more economical designs, and they became local standards. Because of the vast distances in the west, not many suppliers are seeking to service more than one state market so these local standards are not too troublesome. However, in locations where one supplier might well ship beams into a number of states, a variety of standards could be disastrous.

Precast concrete items other than bridges could be standardized with advantage. A joint AASHTO-ARTBA-AGC Task Force has been working on the development of standards for precast concrete highway appurtenances. This uniformity of design should result in both convenience and economy.

In proposing a limited measure of standardization, there is no desire or intent to take away a designer's prerogatives in creating new designs. However, the design of a small structure, 15 or 20 ft (5 or 6 m) off the ground and only 100 or 200 ft (30 or 60 m) long, seldom taxes the ingenuity or contributes to the reputation of a designer.



BEAM PROPERTIES

TYPE	AREA in^2	$\bar{y}$ in.	I in^4	WT/FT lbs.
I	276	12.59	22,750	288
II	369	15.83	50,980	384
III	560	20.27	125,390	583
IV	789	24.73	260,730	822
V	1013	31.96	521,180	1055
VI	1085	36.38	733,320	1130

1 in. = 25.4 mm; 1 ft = 0.3048 m; 1 in.^{2} = 645.16 mm^2; 1 in.^{4} = 41.623 cm^4; 1 lb/ft = 1.488 kg/m.

Figure 5. AASHTO-PCI standard prestressed beams.

MARKETING CONCEPTS

Precast concrete units are available from a variety of sources. Most states have plants that will offer practically any precast concrete product for which there is a demand. Most suppliers prefer to cast the beams to order and thus avoid the investment in stockpiled units. When they have the forms on hand though, the beams can be supplied on very short notice. If a steady market develops for certain beams, most suppliers are willing to make them available as a "shelf item." Counties are especially appreciative of this availability so they can meet emergencies.

Some states stockpile a few precast concrete beams in commonly used lengths just for emergency use. This is excellent insurance. States that are aware of the dilapidated state of some of their secondary bridges would do well to set a few girders aside for the inevitable day when the bridges reach the end of their service.

In the early days of prestressing, a few companies specialized in planning a precast or prestressed operation. The knowledge of prestressing has become so general now that it would be difficult for such a technical service to find much market. Many capable suppliers will gladly offer technical assistance to states, counties, and cities to help them find economical solutions to their problems through the use of precast concrete. Design charts and sample plans are readily available so any designer can, with minimum assistance, provide a workmanlike and economical bridge. These design aids should be of great assistance to municipalities, railroads, consulting engineers, or others interested in broadening their use of precast concrete. In addition to the information published by suppliers, a number of industry publications, such as those by the Prestressed Concrete Institute, give the latest available information (*8*).

CHAPTER FIVE

BRIDGE SUPERSTRUCTURE ELEMENTS

COMPLETE SUPERSTRUCTURES

Complete superstructures are those in which the precast units provide both the supporting members as well as the deck.

Tees, Double Tees, and Bulb Tees

Because of the deck form work that is required with the precast I-beams, the Tee section was developed (Fig. 6). The flanges of the Tees may be made to span the space between beams completely so no intermediate forms or falsework are necessary—or almost completely, in which case a narrow strip is left between units for a closing pour to lock the two units together. Other Tee designs have a fixed top flange width of, say, 60 in. (1.5 m), and a complete deck slab is placed on them much as with I-beams. The wide flanges reduce the required deck forms, however. Contractors claim a form cost saving of as much as \$1.50/ft^2 (\$16.00/m^2) by using the wide-flange Tees and double Tees.

The double Tee is merely a combination of two Tees to provide a wider and stiffer deck section (Fig. 7). Because of the weight and size problem, double Tees are usually found in shorter spans, probably less than 60 ft (18 m), although the size and span may vary with the availability of hauling and lifting equipment.

As spans become longer, it becomes more of a problem to get enough tendons into the thin stem of the Tee. The difficulty in getting the steel in and getting enough concrete cover has detracted from the popularity of the double Tee. This space problem in the thin webs of Tees led to the development of the bulb Tee, in which the base of the web or stem is enlarged to encompass the required number of tendons. The bulb Tees shown in Figure 8 are those used by the State of Washington; they cover span ranges of 50 to 180 ft (15 to 55 m). Figure 6 showed bulb Tees designed by California. If the deck section is cast with the bulb-Tee section, it may be adapted for segmental construction. The large fillet of the Tee section acts as a haunch for the deck and provides the strength necessary to carry the heavy, transverse negative moments resulting from concentrated wheel loads. The section is very efficient and offers a high span/depth ratio so the resulting shallow girder is open and attractive.

Inverted Channels

The inverted channel is another form of Tee-beam bridge for the 40- to 60-ft (12- to 18-m) span range. In this case, the joint between members falls on the centerline of the beam. The deck spans between the beams and may be precast to full thickness, in which case the traffic runs on the web of the channel, or may be partial thickness with provision for a concrete wearing surface to be cast in place.

It is very difficult to cast and place channel sections such that the resulting deck surface is smooth enough to run on. It is usually necessary to have at least a 2-in. (50-mm) asphaltic wearing surface to provide a smooth roadway.

Good keys must be provided to transmit the shear between the channel sections. In one case, trouble arose where a longitudinal joint was located at the edge of the truck lane; after a few years, the pounding of the heavy wheel loads broke the keys and caused a major longitudinal crack in the deck. In that case, a thin asphaltic smoothing and wearing surface had been placed over the channel sections. A better solution is to design the system to have at least 4 in. (100 mm) of wire-mesh reinforced concrete

BEAM PROPERTIES

Type	Area in²	ȳ in	I in⁴	Wt/ft lbs.
36	599	14.60	91,900	624
42	641	17.21	138,300	668
48	683	19.86	195,900	711
54	725	22.56	265,900	755
60	767	25.29	348,700	799

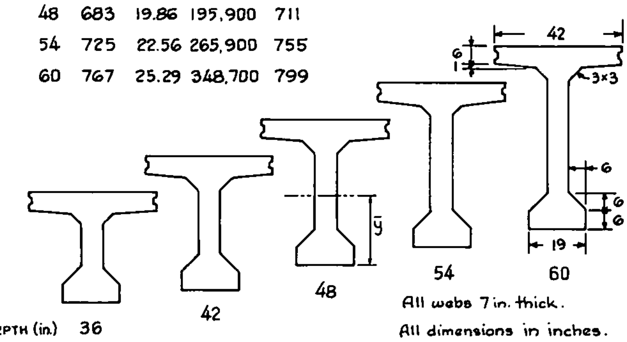


Figure 6. California prestressed T-beams.

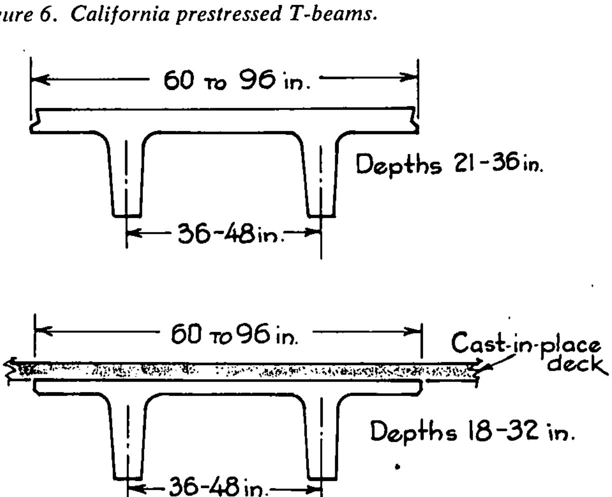
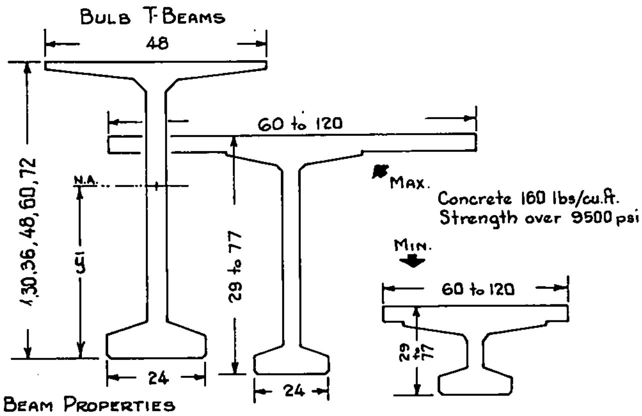


Figure 7. Double T sections for spans up to 60 ft (18 m).



d in	A in²	ȳ in	I in⁴	Wt/ft. lbs
24	380	12.14	28,900	422
30	410	14.95	51,100	456
36	440	17.78	80,700	489
48	500	23.51	164,000	555
60	560	29.29	283,200	622
72	620	35.12	447,800	689

Figure 8. Bulb T-beams (Washington).

deck placed over the entire surface with special attention to see that there is extra reinforcement in the deck over the joints.

Segmental Construction

Segmental construction is a system wherein short lengths of a complete bridge cross-section are precast, lifted into position, cemented with an epoxy mastic on the contact faces, and then post-tensioned into place. This may be done one segment at a time and cantilevered out from a pier, or the segments may be assembled on falsework and tensioned all at one time. The segmental system works equally well for a number of short pieces or when the beam is divided into two or three pieces to enable it to be transported to the site. In recent years, the sections have become larger until now, if transportation facilities are available, complete deck sections are carried to the job, lifted into place and stressed. The Hammersmith Flyover in England had its entire deck cross section cast in manageable thin slices that were carried out to the job and lifted into place. The Chillon Viaduct in Switzerland had its entire cross section cast in about 15-ft (4.5-m) units that were carried to the job, swung out under an overhead erection truss, and lowered into place (see Appendix B). The match-cast ends were coated with epoxy and stressed into place while the overhead crane held them. Pennsylvania has constructed an experimental 120-ft (37-m) span, curved segmental bridge (Fig. 9). Segmental bridges have been completed or are under construction in several other states (*4, 5, 6*).

Segmental cantilever construction has great possibilities, limited only by the capability of transporting and lifting the heavy segments into place. Where the terrain or other circumstances make it impossible to transport the heavy units, they must be cast in place, as was done in the Pine Valley Bridge in California. The principal is the same. The unit is either placed or cast onto the end of the cantilever and stressed back into place, working out from each pier. Then the equipment is moved out on top of the last unit and another unit is set and stressed until the units meet in the middle of the span. The falsework saving is considerable, and the speed with which a large bridge may be erected is very appealing.

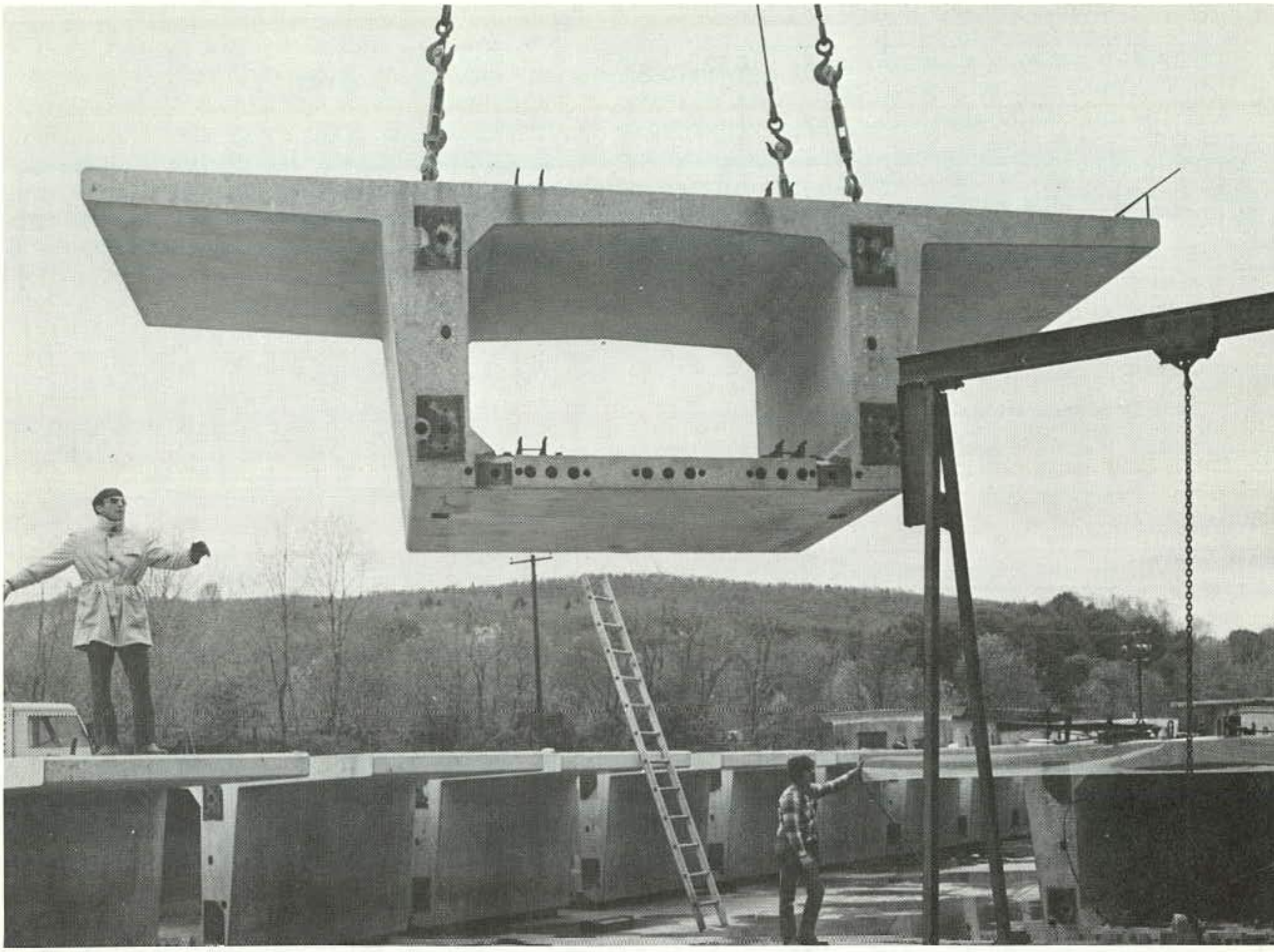
Boxes and Hollow Beams

Boxes are easily precast, usually prestressed and pretensioned, but occasionally post-tensioned. The sizes range from very shallow beams, which are really cored (or uncored) slabs, to large, deep boxes that are actually girders—usually a maximum depth of 60 in. (1500 mm) for highway bridges and 72 in. (1800 mm) for railroads. The boxes are designed to be spaced and used as girders or placed tightly side-by-side to create a wide, multicellular box girder bridge. Some of the first designs (as early as 1950) were proprietary, and one of the first box girder bridges was built near Hershey, Pennsylvania in 1951. Currently many designs are available for boxes of almost any proportion (Figs. 10, 11, and 12). Figure 13 shows a box girder bridge being constructed in Delaware and the underside of a completed bridge in Pennsylvania.

Prestressed boxes are popular for short, simple spans. Many counties have found them an economical replacement for aging short-span bridges. The outer boxes can be cast with an integral curb, and when the boxes are set in place on simple abutments and the joints grouted, the bridge is ready to use. Figure 14 shows a simple two-span bridge in Yellowstone National Park. Ten boxes, a pier, and two simple abutments provided a quick and easy bridge leading to a campground. Many back-country locations would be well-served by a similar bridge. Guardrails could be bolted on if desired.

Some boxes are cast in shorter sections, supported on falsework and post-tensioned in place. In these, the tendons may be run through the girders and grouted after tensioning, or they are sometimes run through the open boxes, in which case corrosion protection must be provided. In some cases the boxes are also tensioned laterally or provided with tie rods to hold them together and make them act as a unit.

The keys between the boxes are very important. As in adjacent channel sections, the joints may be severely stressed by heavy loads. When only a bituminous surfacing is used over the boxes, in a few years a crack and continual movement may develop adjacent to the truck lane as the boxes supporting the truck loads break their bond with the other boxes and begin to act independently. For main-line bridges or those anticipated to carry heavy loads in the curb lane, special provision should be made to assure the lateral continuity between the boxes. Better than the bituminous surfacing, which provides no rigidity across the joints, is a reinforced concrete slab at least 4 in. (100 mm) thick that will spread the loads across the joints and prevent disintegration of the shear keys and subsequent independent action of the boxes. Lateral prestressing, tierods, or specially designed, substantial shear keys will also make the boxes act as a unit.



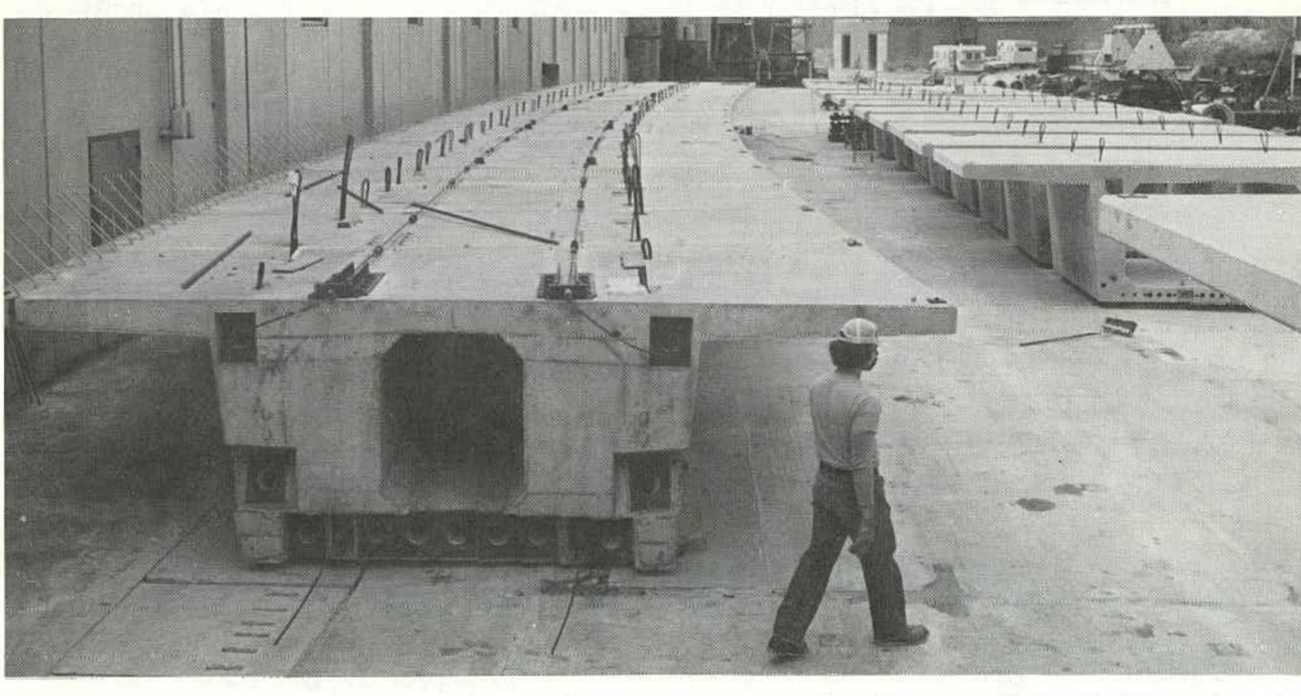


Figure 9. Curved segmental bridge in Pennsylvania. The precast segments are shown being assembled in the fabricator's yard. The bridge consists of two girders of 17 segments each.

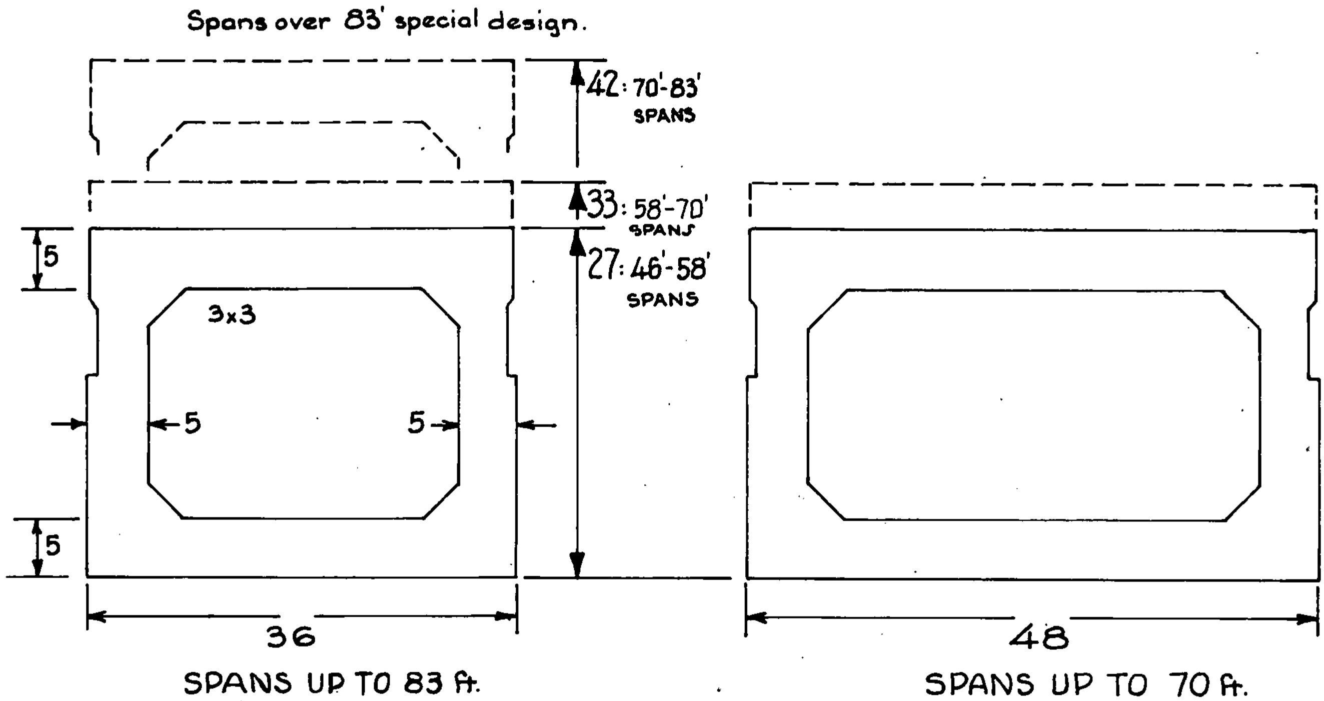


Figure 10. Precast prestressed box girders (California).

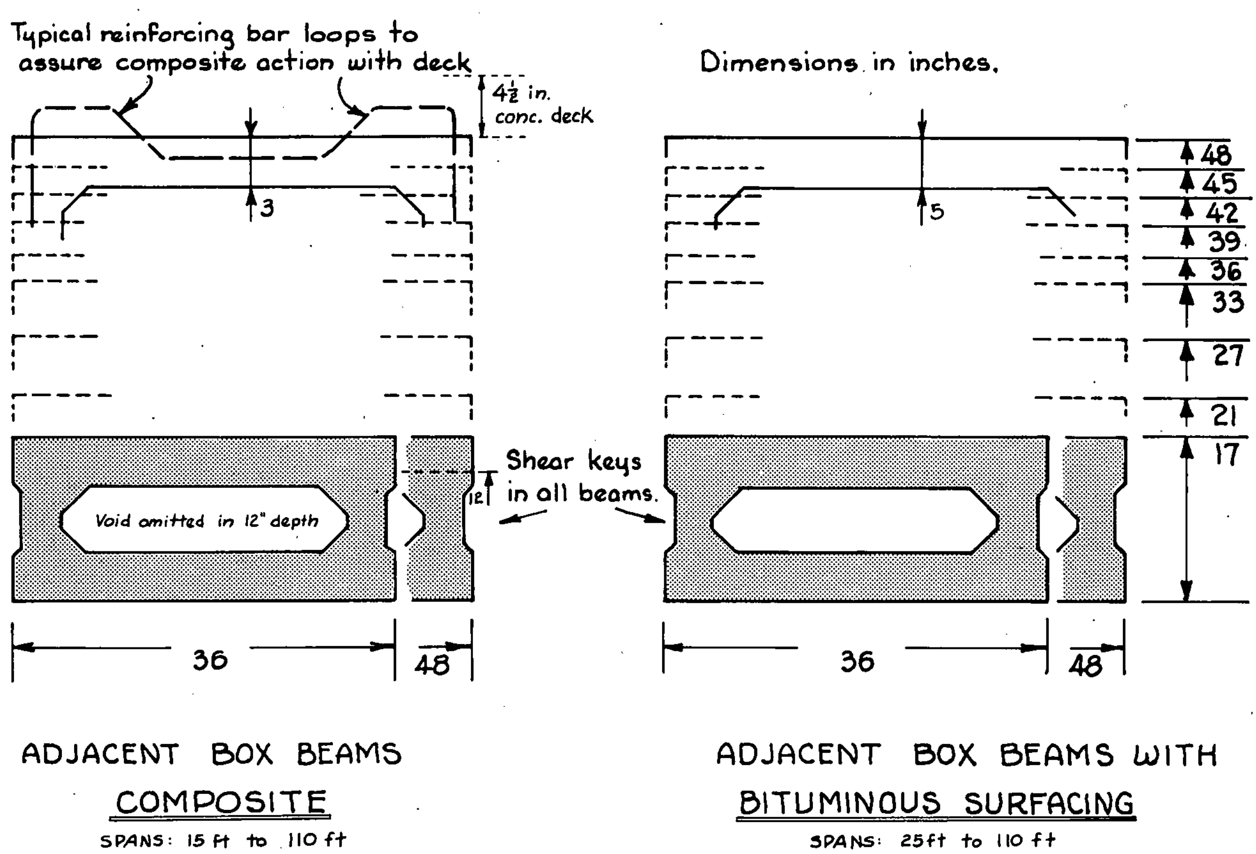


Figure 11. Adjacent box beams (Pennsylvania).

Complete Short-Span Bridges

Because of the weight, it is not practical to precast a whole bridge span and transport it any distance unless it may be barged by water. Nevertheless there are many special situations where entire spans have been cast at one side of their final locations and then slid sideways into place. This procedure, although certainly more expensive than building the bridge in its final location, provides a very attractive solution when a short span on a very busy highway or railroad must be replaced.

When new carrying members must be provided, it is difficult to replace the bridge a bit at a time, working in the middle of the night. But with a little planning, it becomes a fairly simple operation to build the entire span alongside the span carrying the traffic and then demolish the old bridge and jack the new span sideways either on rollers or greased skids. Within a few hours, the new span can be in position, lowered onto its abutments, the joints at the ends filled, and the traffic released to roll again, often unaware that anything has taken place.

The Missouri Pacific Railroad has a continuing program for central yard precasting of single-track railroad trestle bridges in two halves—split down the centerline (Fig. 15). Piles are driven between the old stringers, caps are cast on them and then, with minimum train delay, the two half-bridges are slid into place, the ballast placed and tamped under the existing rails and ties, and the span is back in service. Missouri Pacific can average one span a week per crew replacing an old timber trestle with a new precast concrete structure. Heretofore these half-bridge sections had been conventional concrete. However, the company is now completing a prestressing bed in its Little Rock, Arkansas yard and will henceforth prestress all of the concrete half-bridge spans. They estimate this will save around $250 per section on steel reinforcing alone.

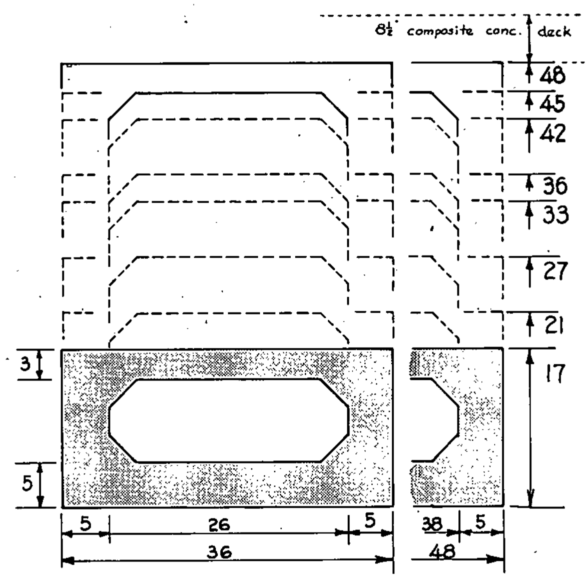


Figure 12. Spread box beams (Pennsylvania). These are used as separated individual beams with an 8.5-in. (220-mm) composite concrete deck for the most economical design. Complete design charts are available for all of these beams, as well as for those in Figure 11.

CARRYING MEMBER UNITS

I-Girders

The most common precast bridge members currently being used are probably the I-girders. They are frequently prestressed to achieve longer spans with lighter weight. Shorter spans can be conventional concrete depending upon the lifting and carrying capabilities available. Figures 16, 17, and 18 illustrate cross sections of girders developed by the states of Washington, California, and Colorado. There are many others, but these illustrate the poular trends and are some of the best girder designs being used in the country today. Those interested in more data on the beams may contact either the states involved or the concrete manufacturers or their associations.

The design of prestressed beams is readily adaptable to computer solution, and programs are available to most designers doing this work. The computer programs have also been reduced to graphs from which all the necessary design information may be easily picked. Figure 19 shows one such design chart prepared by Pennsylvania. The originals are printed in three colors, which makes them somewhat easier to use. The Pennsylvania Department of Transportation has more than 20 sheets of design curves for I-girders and another 20 sheets of curves for box girders (*9*). Figure 20 shows girders constructed using the Pennsylvania design charts. Stanley Structures of Colorado has a computer program to print out complete design data curves for a wide variety of precast and prestressed I-beams and will share the information with anyone interested in the design process (*10*).

There are several striking things about the beams in Figures 8, 16, and 18. The first is their extreme thinness; second, the heavier concrete—160 lbs/ft^3 (2 600 kg/m^3) as compared with the usual 150 lbs/ft^3 (2 400 kg/m^3); and third, the average concrete strength of more than 9 500 psi (66 MPa). In explanation, it should be noted that western Washington is blessed with extremely good aggregate, making concrete strengths of 10 000 psi (69 MPa) attainable. Colorado also has fine aggregate available. It should also be noted that these beams are manufactured under the most exacting conditions to assure both the quality and the dimension. The quality of agggregate is a natural condition that can not be controlled, so the concrete strengths are just not that high in most of the country. The workmanship could be duplicated elsewhere but, under current competitive conditions, it is usually not.

Therefore, designers would do well to tailor their beams to fit the capabilities of the plants that will probably be making them. Those designers who are fortunate enough to have fabricators such as Washington and Colorado's can design thinner and more economical beams. Those who are not sure of their suppliers had better stay with

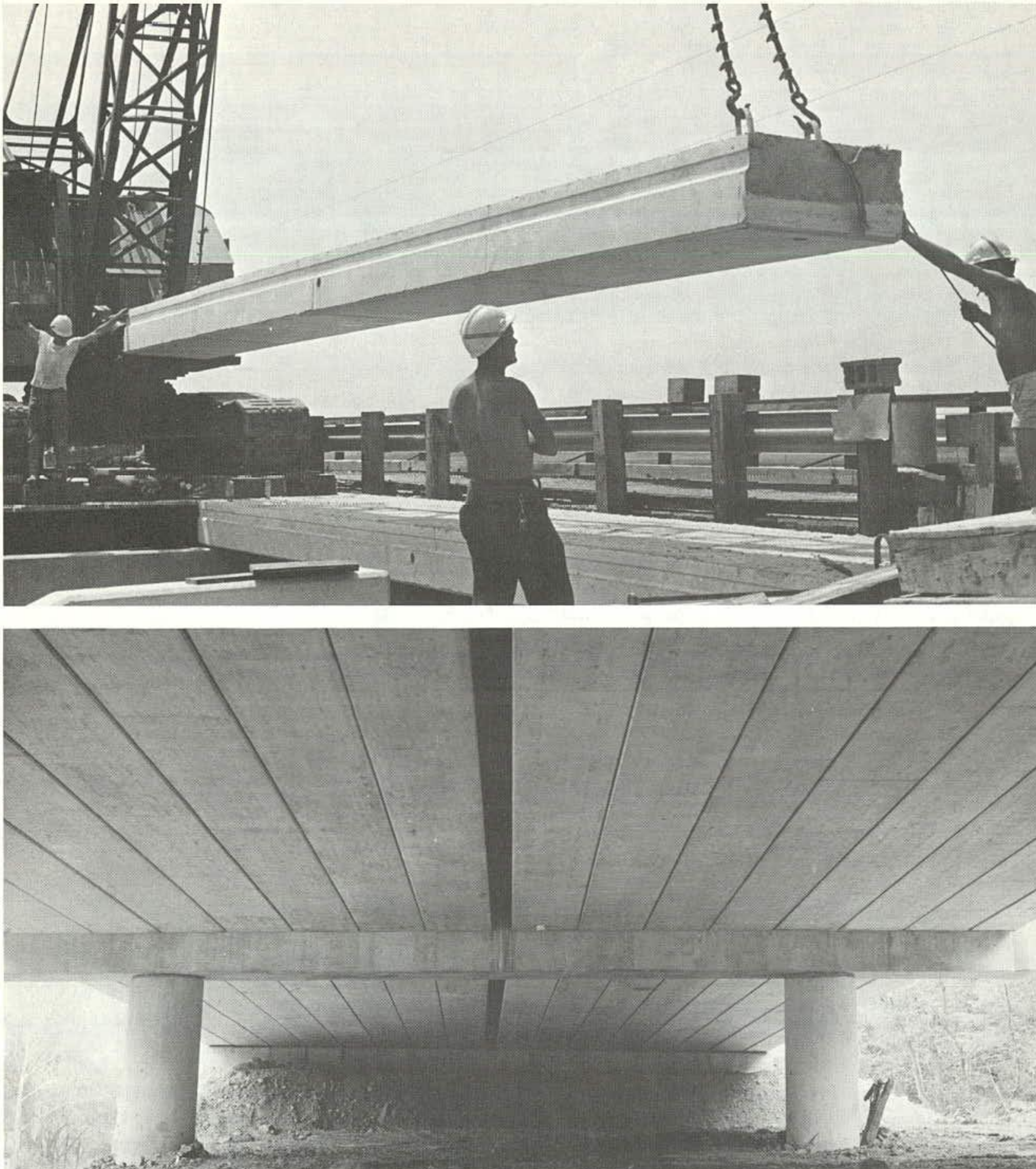


Figure 13. Adjacent box beam bridges. Top photo shows a box being lowered into position on a Delaware bridge. Lower photo is the underside of a bridge in Pennsylvania.

the thicker sections, looser dimensional controls, and lower concrete strengths; they will still end up with a very successful structure. For most of the country, aggregates are such that about 5000 psi (35 MPa) is the maximum that reasonably may be expected. Most designs are therefore tailored to that maximum concrete strength.

Inverted Tees, Double Tees, Trapezoidal Beams, and Channels

The attractive, smooth soffit lines of a concrete box girder can be simulated by using inverted Tees—single or double. When precast the full span length, they eliminate

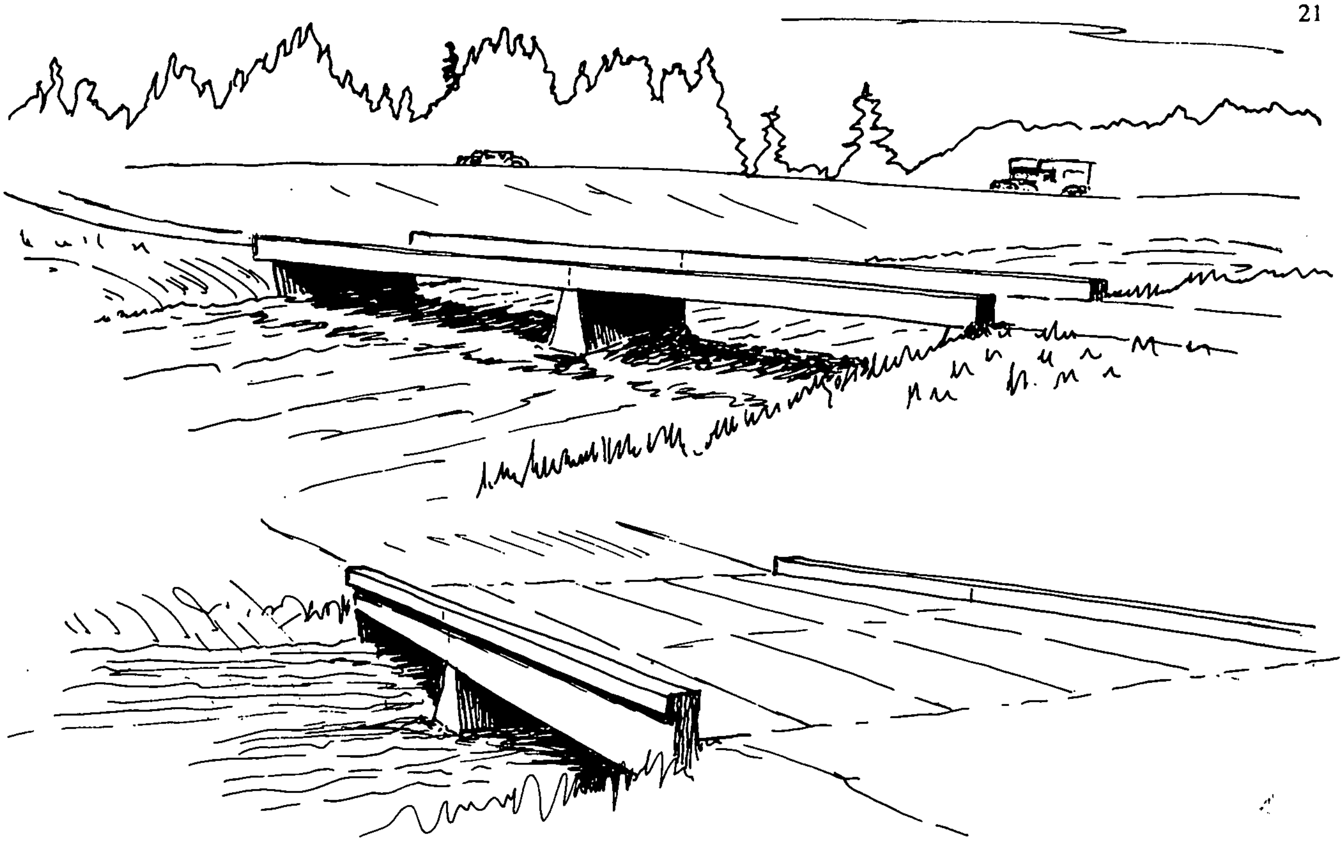


Figure 14. Simple two-span precast concrete bridge in Yellowstone National Park, a complete superstructure with 10 precast sections.

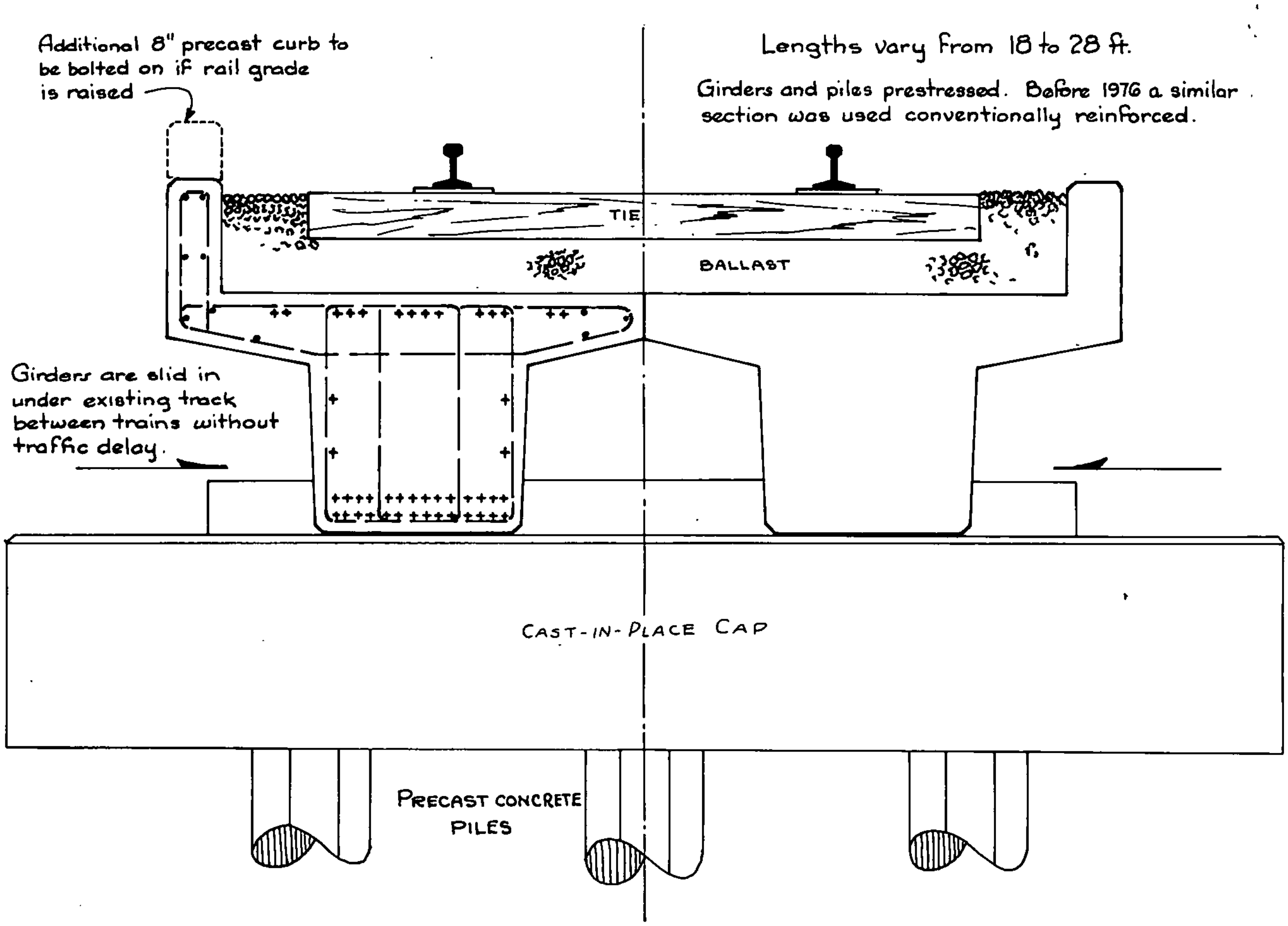


Figure 15. Precast concrete trestle replacement girders (Missouri Pacific RR).

Type	Area in²	ȳ in	I in⁴	Wt/ft lbs
40	253	15.16	31,000	264
60	332	18.63	70,100	346
80	476	22.53	154,900	496
100	546	27.90	249,000	569
120	626	35.60	456,000	652

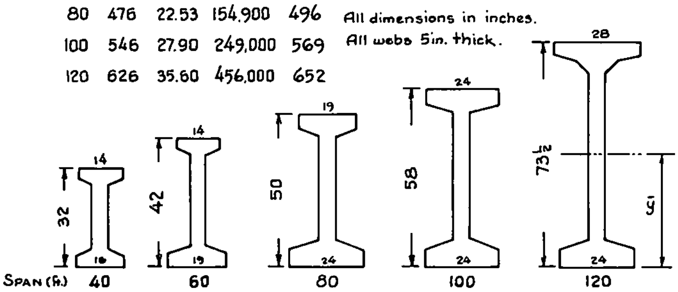


Figure 16. Prestressed I-beams (Washington).

BEAM PROPERTIES

Type	Area in²	ȳ in.	I in⁴	Wt/ft lbs.
36	432	18.9	63,300	450
42	474	22.0	95,000	494
48	516	25.2	137,300	538
54	558	28.3	187,800	581
60	600	31.4	248,600	625
66	642	34.4	318,000	669

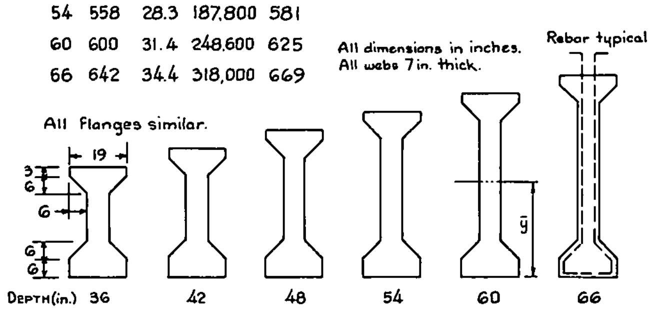


Figure 17. Prestressed I-beams (California).

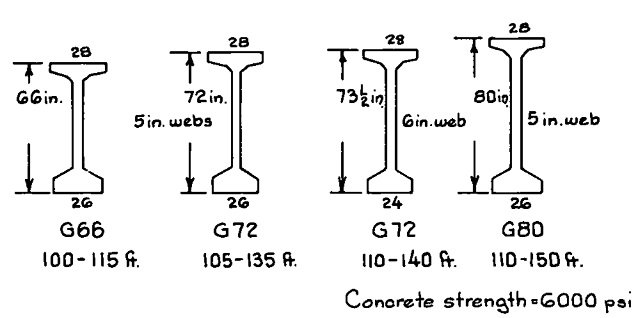


Figure 18. Prestressed I-beams (Colorado).

the necessity for intermediate falsework. Obviously, an expendable form must be provided for the cast-in-place deck slab, but supporting ledges or bolts can be cast into the stem of the Tee to make the deck a fairly simple form job. The elimination of the falsework can, in some cases, reduce costs or improve safety and make this approach attractive. For shorter spans, it would probably be better to use an entire box and eliminate the need for the form for the deck slab. Because there are usually better solutions, the inverted Tees are not too often used.

The same benefits and the same problems result from using inverted channels to obtain a smooth soffit. The adjacent legs of the channels may be locked or bolted together to create a multi-cellular box girder structure.

For the longer spans, trapezoidal beams may be used to obtain an economical and also good-looking structure. The Ontario Precast Concrete Manufacturers Assn. has made an extensive study of this type of girder and has developed some trapezoidal sections (Fig. 21) that will provide an economical and aesthetic method of bridging spans of 100 to 150 ft (30 to 45 m) (*11*). Temporary bracing must be provided for the open trapezoids to maintain their geometry until the concrete deck is placed, adding the necessary additional stiffness.

PRECAST DECK FORM PANELS

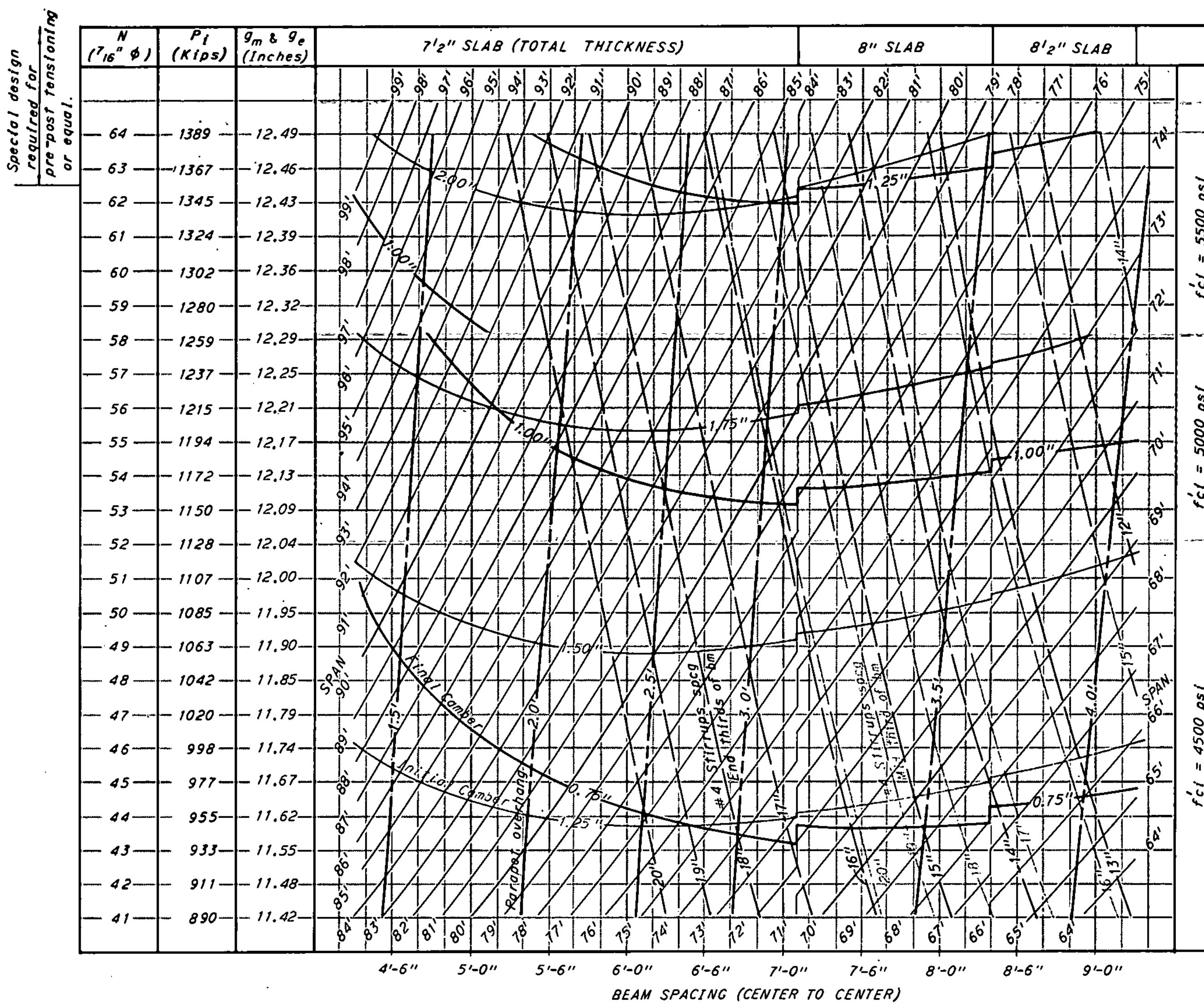
An application that is rapidly gaining in popularity is the use of precast concrete panels as stay-in-place deck forms, then casting the remaining deck thickness in place as a single monolithic slab (Fig. 22). (These deck forms are also known variously as deck planks, panel subdecks, or half-slabs.)

The precast deck form system eliminates the need to set forms for the deck slab and the need to strip them after the concrete has set. The idea has been used successfully in buildings, wharves, and highway bridge decks. The panels are usually cast in a commercial yard and trucked to the bridge site. If care is taken with the quality control and good metal forms are used in the plant, the finish on the under side of the panels should be good enough so no field attention will be required.

The precast panels are usually pretensioned with the full amount of steel required for the full-thickness slab. However, it is also feasible to use only conventional reinforcement and follow the same procedure. All of the tension steel is placed in the precast panel, and then the remaining temperature and compression steel is placed in the upper portion, which is cast-in-place. The thin pretensioned panels are usually stiffer and less apt to be damaged than the conventionally reinforced panels.

The precast deck form panels, either prestressed or conventional, are cast 3 or 4 in. (75 or 100 mm) thick and are placed on the supporting beams with a gap of about 6 in. (150 mm) between slabs at the top of each beam. The slabs span the distance between the beams and act as a form for the deck slab. The reinforcing is usually allowed to project about 4 in. (100 mm) beyond the ends of the panels. Where extreme rigidity is desired, the projecting ends of the reinforcing bars are sometimes welded together, although generally this is not necessary. When the concrete for the upper part of the slab is placed, it fills the gap between the panels, encasing the reinforcing stubs as well as any stirrup ends, loops, studs, or dowels that are protruding from the top surface of the girders, locking them all together. On steel beams, studs or other shear devices are welded to the beam flanges to bond the deck to the beams. The total effect closely simulates monolithic construction.

The panels may be set on either expansion material or grout to provide both an even bearing on the beams and



STRAIGHT STRANDS

INSTRUCTIONS FOR USE

Given: beam size, design span, and beam spacing.

1. Enter the design graph at the given beam spacing (abcissa) and proceed vertically to intersect the span curve corresponding to the given design span. This intersection is Point A.
2. From Point A, move vertically either up or down to the *nearest* integral number of strands line (ordinate). This is Point B.
3. Parapet Overhang: Using Point B, interpolate between the parapet overhang curves to find the most desirable parapet overhang.
4. Slab Thickness and Beam Concrete Strength: Determine the slab thickness and f'_{ci} regions in which Point B lies. Slab thickness regions are noted at the top of the graph; f'_{ci} regions are noted by the gray shading and are identified on the right side of the graph.
5. Number of Strands and Initial Prestress Force: Proceed horizontally from Point B to obtain N and P_i required. For spans less than 30 ft., use 3/8-in. diameter strands, otherwise use 7/16-in. strands.
6. Center of Gravity of Strands: Determine g_m and g_e. For straight strand designs, these two values are equal and are given opposite the required values of N and P_i.
7. Estimated Camber: Using Point B, interpolate between the applicable camber curves within the f'_{ci} region (determined in Step 4) to obtain the design values for initial and final camber at mid-span.
8. Stirrup Spacing: Using Point B, interpolate between the applicable stirrup spacing curves to obtain the required spacing for both the middle third and end thirds of the beam. If Point B lies to the left of the curve for the largest stirrup spacing shown, then this maximum value should be used.
9. Horizontal Shear (Bond): Determine whether u_h is less than or greater than 225 psi. If Point B is to the left of the horizontal shear $u_h = 225$ psi curve, u_h is less than 225 psi, otherwise u_h is greater than 225 psi.

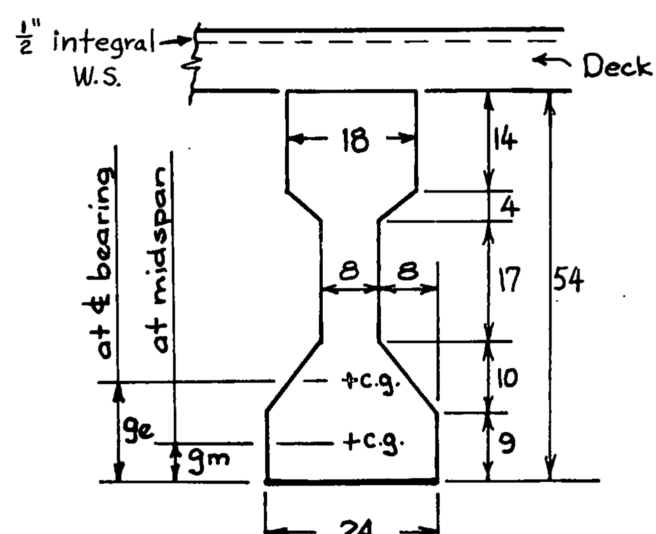


Figure 19. Design chart for 54-in. (1370-mm) composite prestressed concrete I-beam (Pennsylvania).

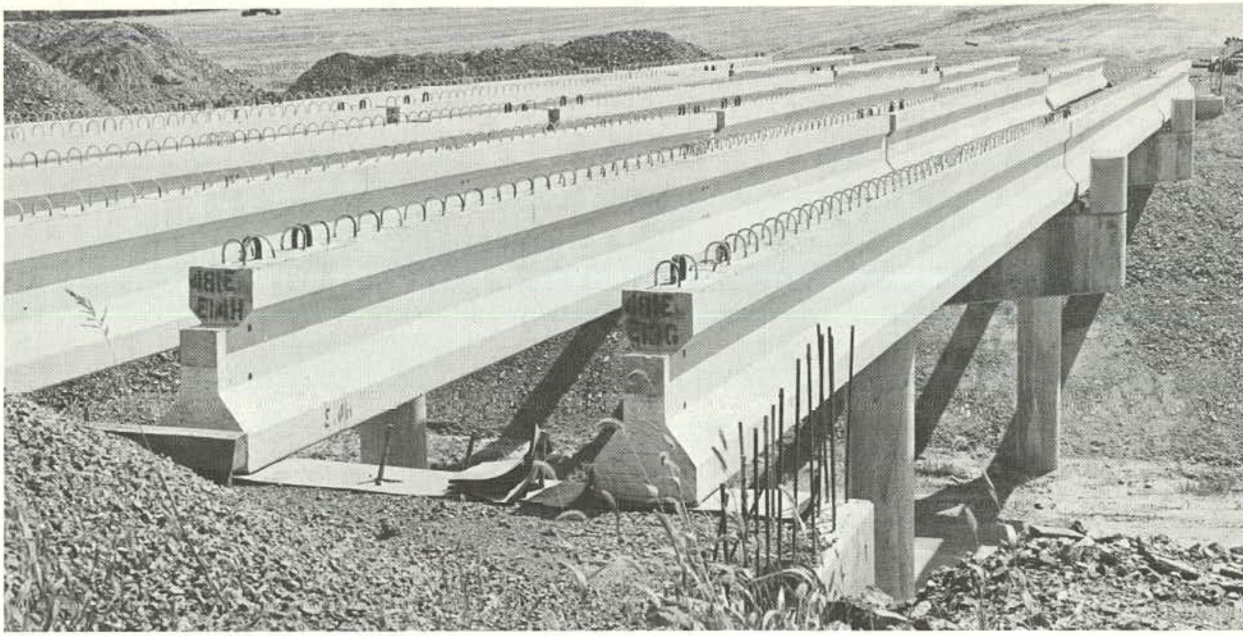


Figure 20. Prestressed I-beams. These beams were designed using the chart shown in Figure 19.

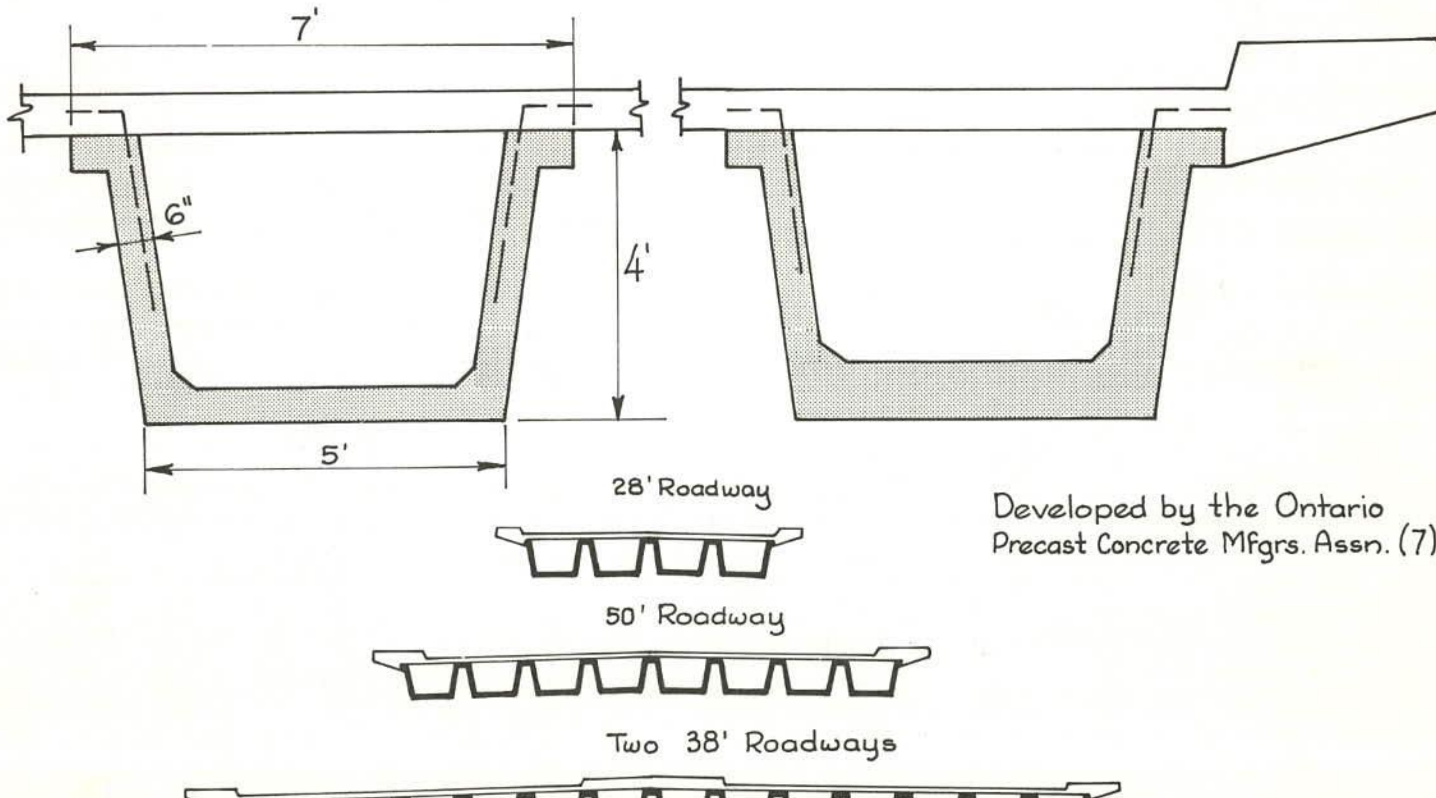


Figure 21. Precast trapezoidal beams.

a seal so the cast-in-place concrete will not leak through. The grout bed (either cement or epoxy grout) seems the most widely used. Under certain circumstances, particularly with prestressed I-beams, the horizontal shear at the junction of deck and beam may exceed allowable limits because of the narrow shear-bond area of the grout beds; this should be checked in the design stage.

The sides of the panels are merely butted together or may have a simple half-lap joint, which is usually quite effective and requires no additional seal. Tongue and groove joints have been used, but the projecting tongues are so thin they are frequently damaged in handling.

Precast deck form panels work best on bridges that are on tangent without superelevation. However, many fabricators have developed adjustable forms that can be twisted, warped, and reshaped to make the panels fit the field conditions. Special fitting is necessary at joints, bridge ends, and variations in deck width. If the odd-shaped panels are not provided by adjustable forms, they are sometimes sawed to shape from full-sized panels in the field. The savings in field work and forms justifies the necessary shop work to make the panels fit the variable conditions.

There has been some concern about the bond between the precast deck form panel and the cast-in-place slab. Research has shown that merely roughening the top of the panel provides perfectly adequate bond between the precast and cast-in-place concrete without any loops or other shear reinforcing (*12*). Sufficient roughness is ob-

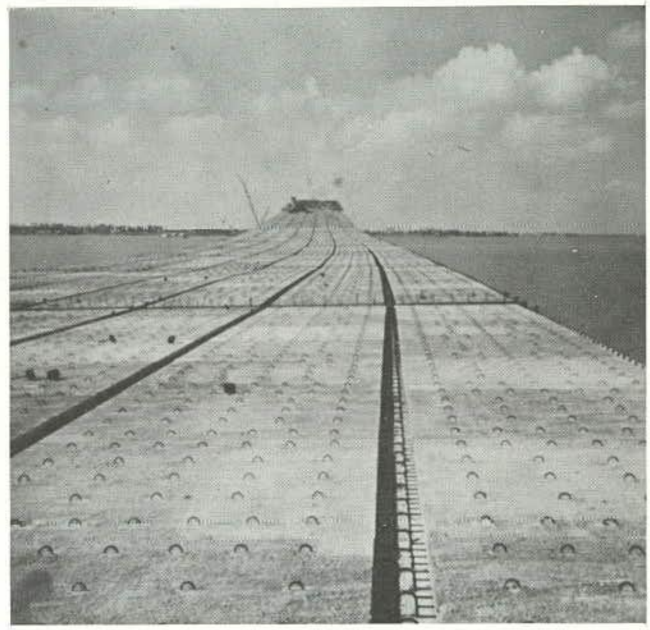


Figure 22. Precast concrete deck forms (Texas).

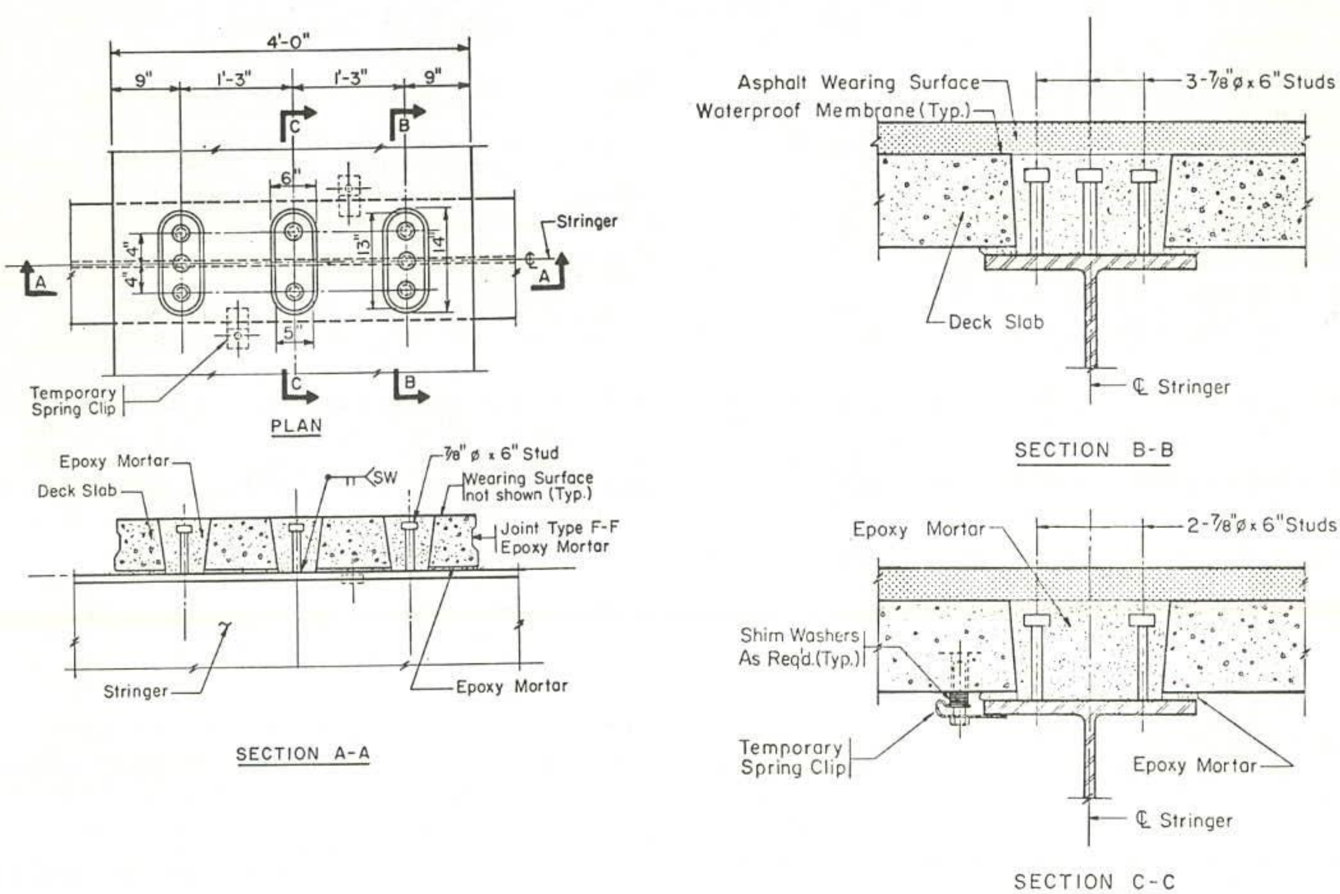


Figure 23. Welded stud connection for precast slabs to steel beams (New York Thruway).

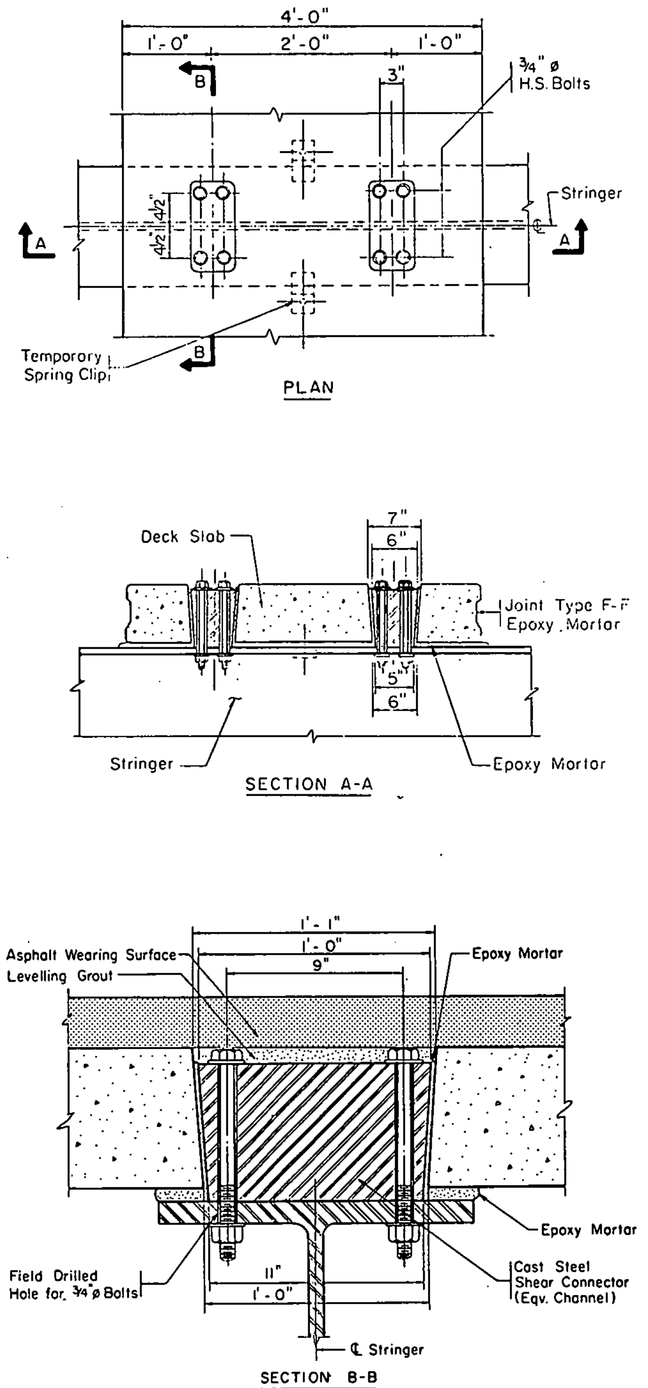


Figure 24. Bolted connection for precast slabs (New York Thruway).

tained by raking the surface of the precast panel to a depth of about 0.25 in. (6 mm) just after the concrete has taken its initial set. However, most engineers feel more secure if there are some shear loops or bars to physically restrain the two halves of the panel and, under severe loading, keep them together and prevent laminating. In addition, loops provide a convenient method of handling the panels. The shear devices may be individual hairpin loops, half-exposed spiral coils or truss bars, zigzag bars, as well as keys or lugs formed into the concrete.

Using the precast panels is economical where there are a large number of similar spans. If the volume of work is sufficient, a contractor may set up a yard to cast panels. More and more commercial plants are recognizing this new market and are often able to supply the panels cheaper than the contractor can make them. In any event, a saving in forms, falsework, and the time involved in erection and stripping can be realized when the panels are hauled to the job and easily set in place.

Many states have already adopted the precast deck form system, and more are accepting it and adding it to their standards. Some states have accepted the system at the request of contractors who see in it an opportunity to speed up the job. In Tennessee, a contractor proposed using precast deck forms to recover considerable lost time; permission was given to make the change, and now the system is included in the standard plans. Some years ago, a large oil dock on San Francisco Bay was built using precast deck form panels. The form saving in the restricted area between the piles and underneath, low over the water, was considerable.

These panels have a bright future saving money and time. Decks built with these panels do not seem to be unduly affected by salt, and there are examples that have been in service for 20 years without any problems. One state, however, has reported some reflection cracking over the panel joints. More information and references can be found in Barker (*13*) and Transp. Res. Circ. 181 (*12*).

COMPLETE DECK SLABS ON BRIDGES

Precast full-depth slabs have been used on bridges for a number of years with indifferent success. The main difficulty is in properly holding them down. Normally, they work fine for a time but, as deflections and permanent warps and twists develop either in the slabs or in the supporting members, the concrete gradually cracks around the hold-down arrangements and eventually breaks away and leaves the slabs loose. In one case, lightweight slabs were bolted to the steel stringers of a bascule span in California. The bolts were carefully cushioned, and the bearing of the slabs on the steel beams was also carefully adjusted for the required variations in thickness. This arrangement worked well for a time, but the deflection of the steel stringers under loads and the movement caused by raising the bascule span from the horizontal to near vertical finally destroyed the solid bearing. The corners broke out near the bolts and the slabs had to be replaced with a cast-in-place deck. On bridges that are not movable, the chances of success are better, and the anticipated life of the slabs is greater.

Fastening full-thickness slabs to steel or concrete beams is a problem that has not been completely solved. The New York Thruway Authority has developed eight schemes for fastening precast bridge deck slabs to steel girders (*14, 15*). One scheme uses holes cast in the slabs to fit over studs welded to the girders (Fig. 23). The holes are then filled with epoxy mortar to tie the slab to the

girder. Another scheme uses bolts placed through field-drilled holes in the girder flange into cored holes in the precast slab (Fig. 24). A cast steel sleeve and epoxy mortar complete the connection. In each case, the slabs are set either on epoxy-mortar beds or on neoprene pads to equalize small variations in bearing contact. The finished deck is covered with a waterproof membrane and a 3-in. (75-mm) asphalt wearing surface.

Redecking Under Traffic—Highway and Railroad

Where the bridge is being redecked under heavy traffic, precast slabs have been used successfully with special hold-down devices. During the few early morning hours when the lane can be closed, a section of the deck is broken out and replaced with a precast slab. By the time the morning rush of traffic comes, the bridge is back in service. A life of only 5 to 10 years is usually quite acceptable in these cases, and the ability to get the bridge open again each morning makes it worth the extra effort of setting and securing the slabs.

This system was used recently to redeck a busy two-lane bridge over the Delaware River between New Jersey and Pennsylvania (*16*). The 1 928-ft (588-m) bridge could not be closed long enough to do the entire job so 800 ft (244 m) were replaced with precast deck slabs 16 × 20 ft (4.8 × 6.1 m). The precast slabs were delivered to the job complete with curbs, sidewalks, railing, and attached deck beams, which were welded to the bridge girders. The 16-ton (14.5-Mg) sections were placed at the rate of two each night. The entire job was anticipated to take just 16 weeks.

Precast slabs are also successfully used on railroad bridges on steel stringers and under the track ballast (*17*). Usually they replace a timber deck. The deck is removed and the steel sand-blasted clean. Then thin strips of ⅝-in. (16-mm) plywood are bonded along each side of the top flanges of the stringers. These act as spacers to raise the slabs above the rivet heads. The space between the thin strips is then liberally filled with an epoxy grout, and the slabs set in place, with the epoxy grout acting as a levelling bearing and also as a spacer to hold the slabs above the projecting rivet heads in the top flange. The edges of the slabs are tight at the bottom but tapered to be open 0.25 in. (6 mm) at the top. The joints are filled from the top with an epoxy-sand grout. Treated timber curbs are then bolted in place to provide added security against slab movement. The Santa Fe Railroad has used this procedure experimentally to replace more than 25 track-feet (8 track-m) of deck per day with the track being out of service for only 8 hours. Although the concrete deck slabs are more expensive than timber, the labor is about the same, and the expected greater life will result in substantial savings.

CHAPTER SIX

OTHER STRUCTURAL ELEMENTS

SUBSTRUCTURES

Caissons

Many bridge substructures have started as precast concrete caissons (often looking like very deep honeycombs) built in drydock, towed to the site, and sunk in position. This is the traditional method of building deep-water foundations. After they are correctly placed in the mud, the underlying material is excavated and the caissons sink into place. Early in this century, the excavation was done by hand labor working under compressed air. The more modern method is to use open dredging wells and do the excavation with clam-shell buckets and high-pressure water jets. As the top of the caisson nears the water level, additional lifts of concrete are cast in place. After the caisson has reached the solid bottom, some or all of the open dredging wells are filled with concrete. Should the caisson show a tendency to shift during sinking, it can be redirected by replacing the domes on the dredging wells and pumping in air to create an uplifting force to gradually pull it back into line. The San Francisco-Oakland Bay Bridge and the second Carquinez Strait Bridge are notable examples of open dredging well caisson construction.

Floating-Box Piers

Another precast concrete application frequently used for deep-water substructures is the floating-box pier. The floating box avoids the necessity of digging inside the pier and coping with an irregular bottom. A concrete box, with dimensions the same as the pier of the bridge, is precast in a drydock. Through holes in the box, large piles will be driven to support the pier. The piles may be steel H-piles, concrete piles, or circular caissons 6 ft (1.8 m) or more in diameter. In construction, the box is launched and floated to the bridge site where it is carefully anchored. The piles are dropped through the holes in the box and dug or driven to bearing. The box is then clamped to the piles and filled with concrete, locking the pier to the piles. The top of the pier is then completed above water. The box is locked to the piles at a low water elevation so the bottom of the

box is never exposed above water. This system was used for the Martinez-Benicia Bridge across the upper part of Carquinez Strait and has also been used for many other bridges. The system avoids all underwater hand work, either under compressed air or by divers, and provides a very satisfactory foundation.

Precast Concrete Substructure

The substructure of the Richmond-San Rafael Bridge across the north end of San Francisco Bay is an outstanding example of the use of precast concrete to simplify construction. To anyone familiar with the difficulties and cost of caissons and the problems of working in deep water, the simplicity of the San Rafael operation is most impressive. Working in water nearly 70 ft (21 m) deep and using largely precast concrete units, most of the operation was carried out above water. Across the bridge, 62 of the 79 piers were constructed with precast concrete units, which were subsequently filled with tremie concrete to lock them into a homogeneous unit. The sequence of construction is described in Appendix B.

Precast Piles

The most elementary bridge foundation (other than a simple spread footing) is the pile bent. Precast concrete piles have been effectively used in railroad and highway bridges, wharves and buildings, and all manner of structures supported by piles. Piles were among the earliest uses of precast concrete. The early piles were conventionally reinforced concrete; most present day piles are prestressed (Fig. 25). They handle well and drive with a ring like a steel pile, but they will not stand up under hard driving.

The first piles were square in section. As they got larger, weight was saved by making them octagonal or hexagonal. They were heavy and took big hammers to drive, but they offered great durability. Shrinkage cracks were always an entry point for water to get into the concrete and corrode the reinforcing steel. After about 20 years, concrete piles in the salt water tidal range were often badly spalled and deteriorated. With prestressing, the picture improved somewhat. The stressed piles are stiffer, lighter, and easier to drive. The basic compression throughout the section tends to keep the shrinkage cracks closed, and the denser, less permeable concrete seems to provide better protection for the steel. It is customary to provide extra concrete cover over the tendons for salt water exposures.

The first piles were cast in fixed forms. Then hinged forms were devised, which are still often used where a great number of similar piles are to be cast. In order to reduce the weight, many different schemes have been used to cast a void into the center of the pile section. Continuous casting also works well when the volume of work justifies the expense of the machine. Stop blocks may be inserted in the line to regulate the length of the piles, or the piles may be cast the full length of the bed and then sawed into the required lengths after the concrete has set. Precast concrete piles have also been spun like concrete pipe, either stressed or unstressed. The pile form is spun, and the concrete is introduced along its length in sufficient quantity to produce the desired wall thickness. The center void results automatically. It may be necessary to provide air vents for hollow piles. When form material is left in the void, it may react with the water and create gas that can develop dangerous pressure.

Precast concrete piles are widely used and are one of the most successful precast concrete items.

Precast Pier Caps

Although precast concrete pier caps (Fig. 26) have been used very successfully where pile-driving conditions were well controlled and alignment assured, a cast-in-place cap is probably more popular and usually results in a better job. If the caps are to be precast and locked to the piles, sockets must be provided for the pile butts. This requires a close tolerance in the pile driving and cut-off so that the piles fit into the sockets and hold the cap at the proper grade. The space around the pile butts in the sockets is then grouted, usually through an access hole in the cap. For the ordinary trestle, it is usually better to drop a complete metal form for the cap around the pile butts, place adjustable seals around the piles in the bottom of the cap form, set the cap reinforcing in as a unit with adequate space around the pile butts to allow for driving variations, and then cast the cap in place. Grip on the piles and the grade and position of the cap are thus assured with a minimum of labor. Either method produces a satisfactory end product, but unless the piles are driven very accurately (usually with a template), they can be difficult to fit into a socket.

The St. Louis-San Francisco Railway started replacing timber caps with prestressed concrete caps in 1967 and two years later had more than 700 such caps in service. The cap is a crucial member in a trestle and is usually the first to fail. By using the concrete caps, they believe they are adding about 15 years to the useful lives of their trestles. The Southern Railroad started using concrete caps even earlier on their bridge across Lake Ponchartrain. More details of the caps and their construction will be found in Reference *18*.

A problem in a railroad trestle is getting the maximum unified structural strength. Caps held to piles only by dowels do not provide a very rigid bent. For this reason, many engineers continue to use cast-in-place caps to assure the most rigid connection between piles and caps. Southern Pacific Railroad uses pipe piles or steel H-piles and welds them to plates embedded in the underside of a precast concrete cap. The Missouri Pacific Railroad is currently developing other arrangements of dowels with a precast cap that look promising for producing a rigid bent structure.

Abutments

Abutments too may be precast concrete. When the abutment consists only of a sill, it would not be hard to precast it and then properly bed it into the ground in the field. Larger abutments present more problems for pre-

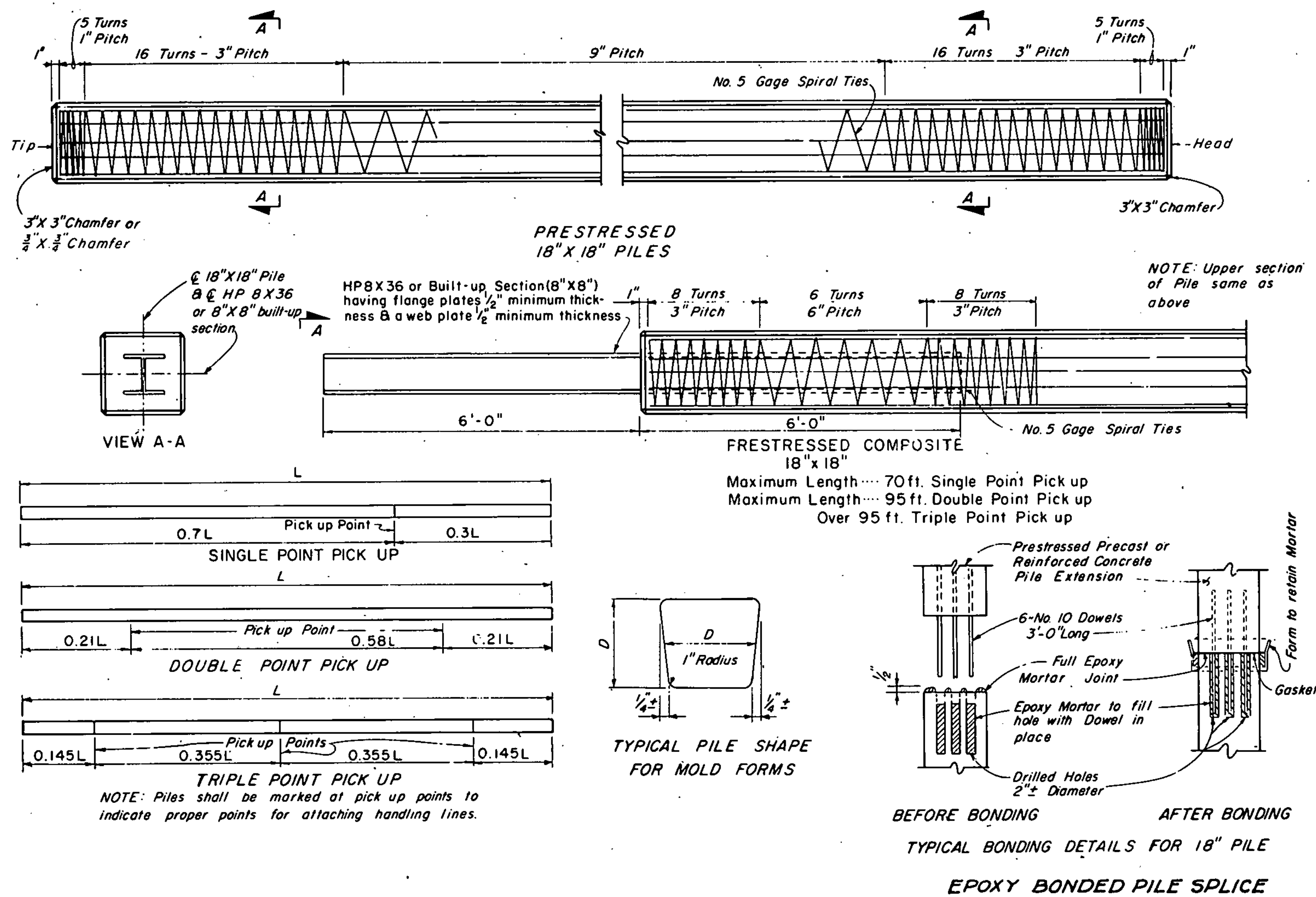


Figure 25. Typical precast prestressed concrete pile (Florida).

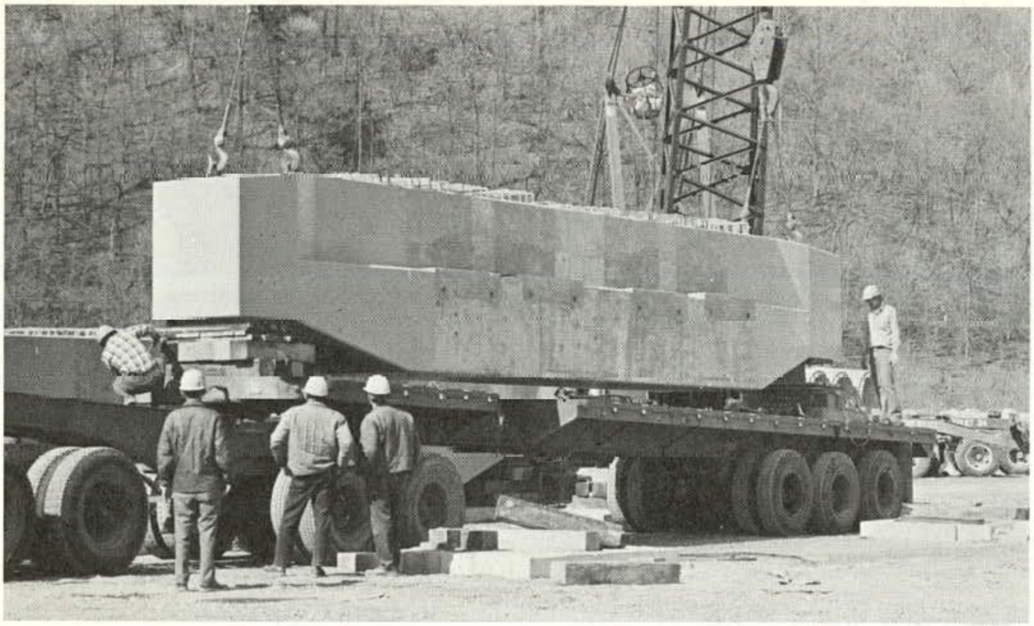


Figure 26. Precast post-tensioned pier cap (Pennsylvania).

casting. Because they should be well-seated and keyed into the ground, it is better to cast them in place and have the concrete intimately contact all of the irregularities of the foundation surface. If the abutment is to sit on piles, it may be precast but again the piles must be accurately driven so they will fit into the sockets in the abutment.

In relatively level and accessible locations, various systems have been worked out for precasting abutments and wingwalls, setting them in place, and then pouring a footing to lock all the pieces into position. One plan, illustrated in a PCI bulletin (*8*), starts with excavation for the footing. Next concrete pads are cast in place under the corners and where the joints in the precast walls will come. The precast wingwalls and abutments are then set on the pads and anchored back to deadmen. The wall sections have reinforcing bars projecting out of their bottom edges. After the whole abutment is in place, the footing is cast in place. This gives the footing a perfect fit against the foundation material and also locks the bases of the abutment and wingwall sections so they will then support the approach fill loads.

RETAINING STRUCTURES

Retaining Walls and Training Walls

Like abutments, it is generally not feasible to precast entire sections of retaining walls because of the need for intimate contact with the earth to obtain stability. There are many modifications, however, in which precasting can play an important part. Aesthetic surfaces consisting of exposed aggregate, special paneling, or other treatment that can best be done in a plant, can be set into the face of a wall by precasting thin wall panels and then using them as the front form for the wall itself. These panels are usually cast the full height of the wall and some convenient module in width such as 6, 8, or 10 ft (2, 2.5, or 3 m). The panels are then set in place and supported, and the remainder of the wall concrete is placed against their back faces.

Retaining walls also can be created of precast concrete bars, about the size of railroad ties, that are notched to fit together and form cribbing. These cribs are built to great heights and, with some back slope into the hill, they will support large areas of unstable hillside.

Training walls are peculiar to the desert where they direct the wide-ranging water from the desert cloudbursts into openings provided under the highway. These training walls may run 200 to 300 ft (60 to 90 m) or more, fanning out from the bridge into the desert to funnel the water through the opening. A good precast design has been developed with large H-shaped posts being driven, or set into drilled holes, and backfilled. Then precast concrete planks are slipped into the slots formed by two adjacent H-posts. A very economical training structure results (Fig. 27). A similar construction using steel posts on a cast-in-place footing has been used for small retaining walls (Fig. 28).

Other earth-retaining structures have been built with precast concrete panels anchored to piles that have been driven into the hillside. Another system is to drill holes into the hillside or earth to be retained, enlarging the bottom of the hole somewhat. Concrete is then placed in the bottom of the holes, anchoring prestressing rods or cables. The restraining precast slabs are then placed over these anchor holes and the tendons stressed to hold the slabs tight against any earth movement.

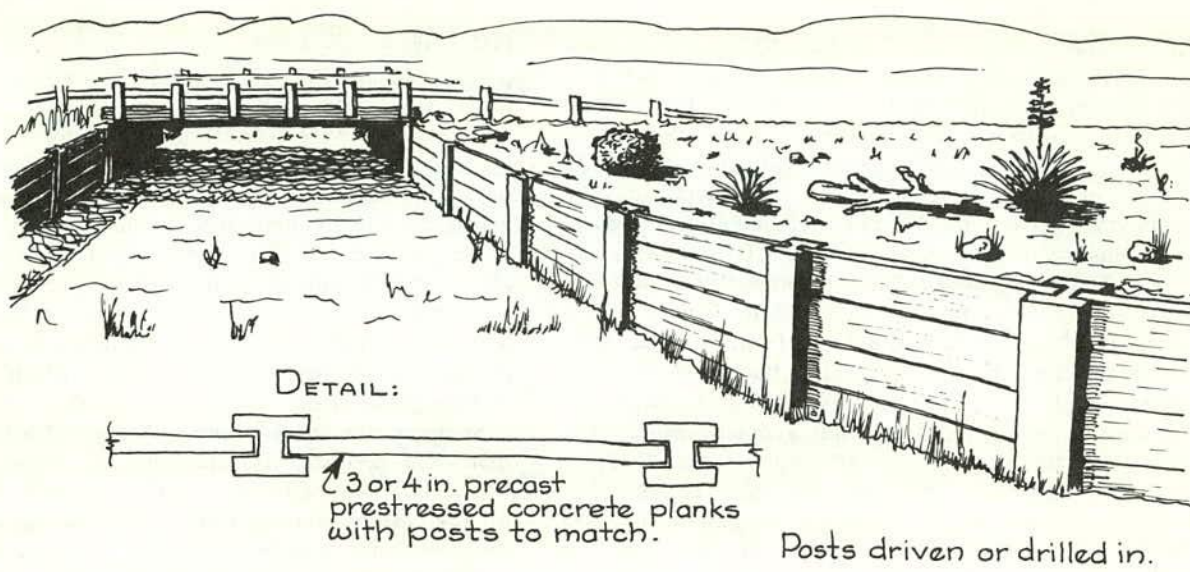


Figure 27. Simple retaining or training wall.

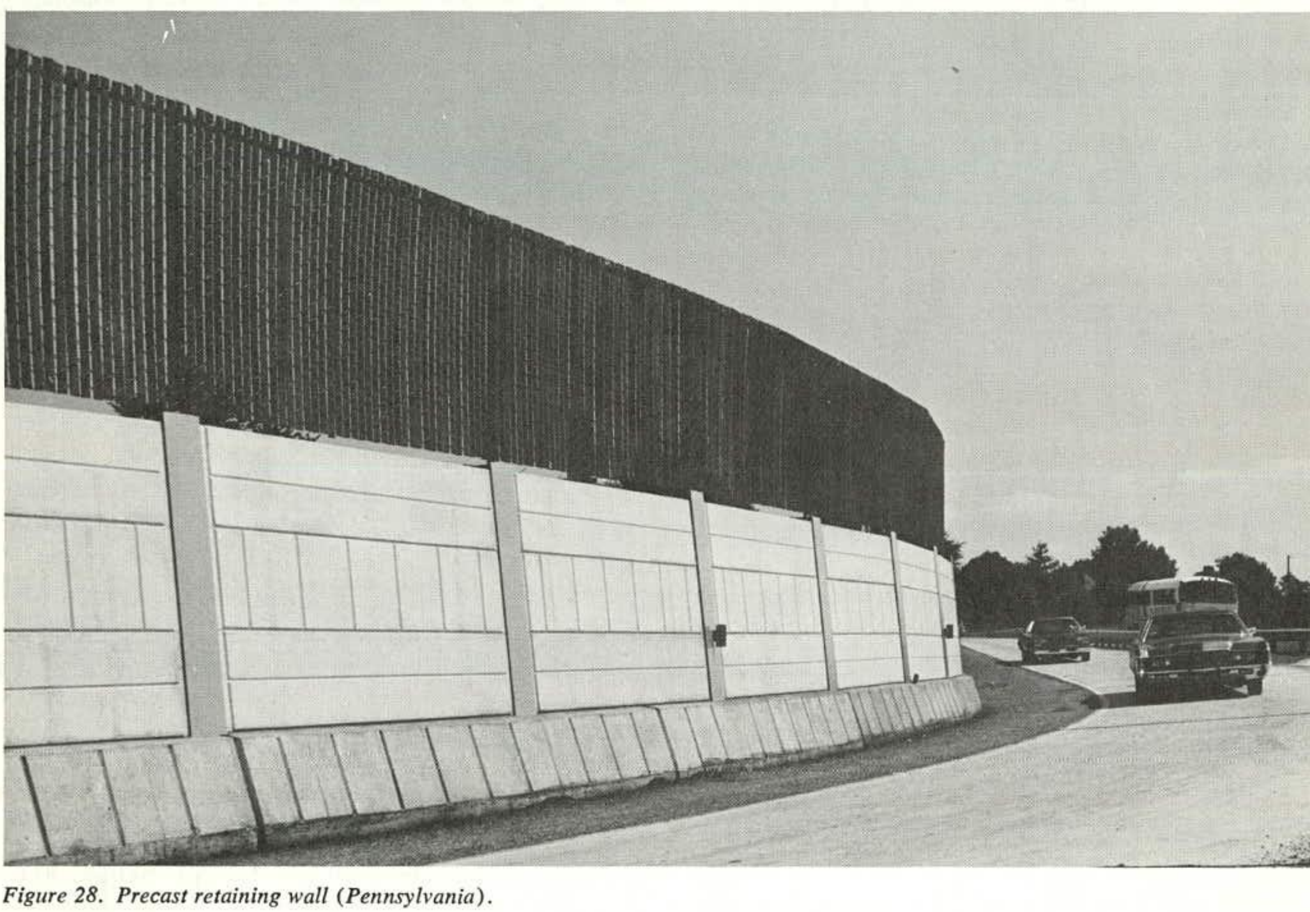


Figure 28. Precast retaining wall (Pennsylvania).

Reinforced Earth is a patented process for constructing vertical retaining walls (*19*). Thin, horizontal metal strips tied to the wall face are used to reinforce the embankment material. Precast concrete panels are often used for the wall faces.

Bulkheads in Coastal Areas

Florida makes extensive use of precast concrete to construct bulkheads to retain earth fills in coastal areas. The bulkheads are constructed of 18-in.-square (460-mm)

precast concrete piles on 7-ft (2.1-m) centers grouted into 30-in.-diameter (760-mm) holes drilled at least 6 ft (1.8 m) into the underlying rock (Fig. 29). Precast wall panels 6 ft-10 in. × 9 ft-0 in. × 10 in. (2.1 m × 2.7 m × 250 mm) are then placed on the back side of the piles. The bottoms of the bulkhead slabs are also anchored into the underlying rock in a trench at least 18 in. (460 mm) deep. A cast-in-place cap 3 ft-8 in. wide × 2 ft-0 in. thick (1.1 m × 0.6 m) then is placed to lock the precast units together.

When underlying rock is not available, Florida uses a driven bulkhead secured to a row of anchor piles. The precast concrete sheet piles are 8 in. thick × 30 in. wide (200 × 760 mm) (Fig. 30). The first pile driven and the anchor piles are pointed with a double bevel. The sheet piles are made with a single bevel that tends to keep them tight against the last driven pile. A cap 3 ft-2 in. wide × 2 ft-0 in. (1.0 × 0.6 m) is cast in place on the top of the sheet piles. A small cap containing the anchorage for the backstay rods is also placed on the top of the anchor piles. A 3-ft-2-in. end beam is cast-in-place at the end of the row of piles and tied to the cap to provide end restraint.

FLOATING STRUCTURES

Pontoon Bridges

In locations were foundation conditions are difficult or the water is deep, pontoon bridges have been used successfully. The most satisfactory material is precast concrete, which has fewer maintenance requirements than steel and a long service life even in salt water. The designs are always special, unique to the particular situation. Anyone starting to design a floating bridge should review those that have been built with special attention to the peculiar physical requirements of that locality which the bridge was designed to meet.

Some of the early pontoon bridges developed faults that were corrected in later designs. Being over deep water, most floating bridges must be designed to be opened for the passage of water traffic. The opening mechanisms cause so much trouble because of the extreme exposure and corrosion problems that later floating bridges have been built with some fixed piers and bridge spans in the air to clear the navigation channel. The combination of the fixed and floating bridges works well, and the arrange-

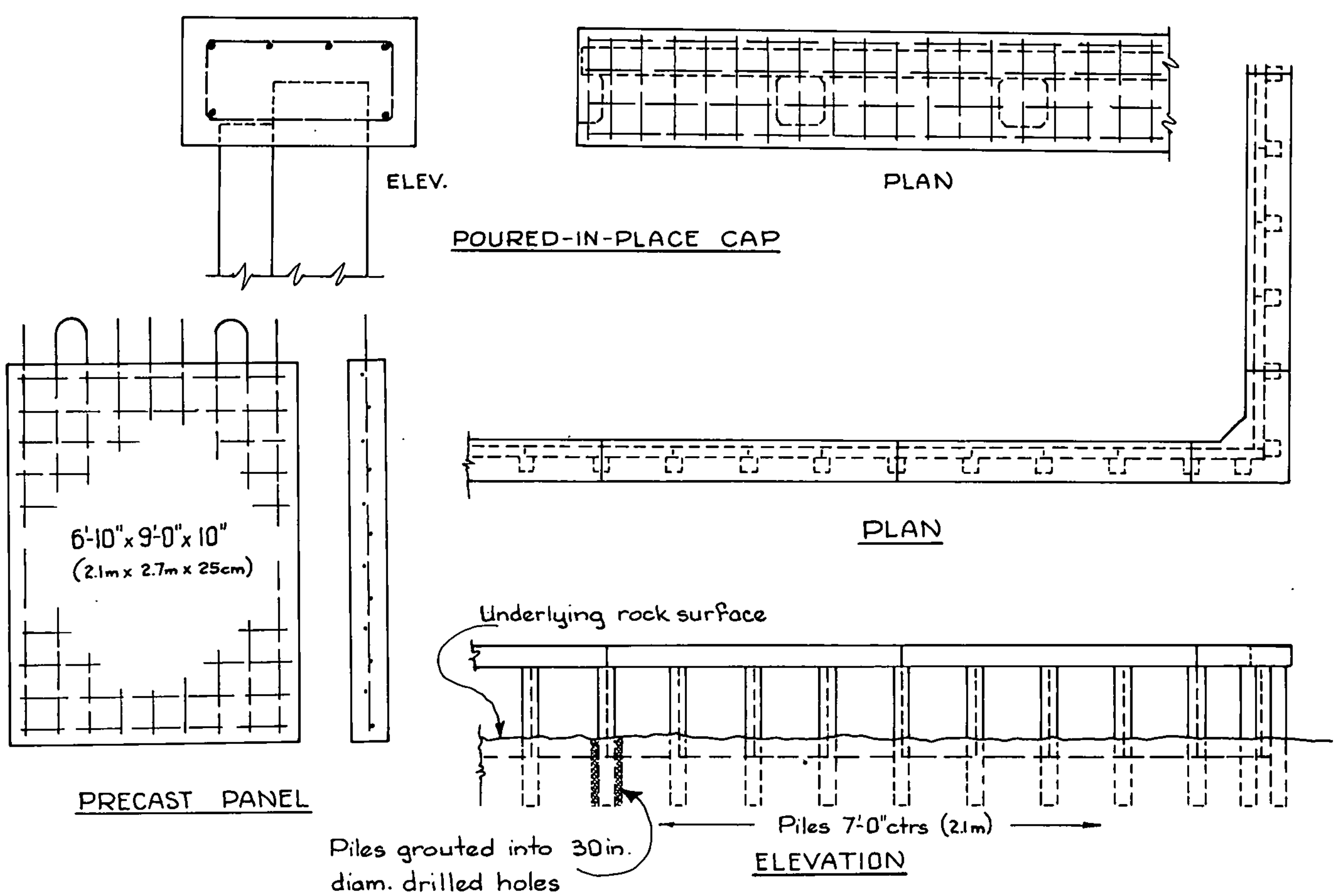


Figure 29. Precast pile and panel bulkhead (Florida).

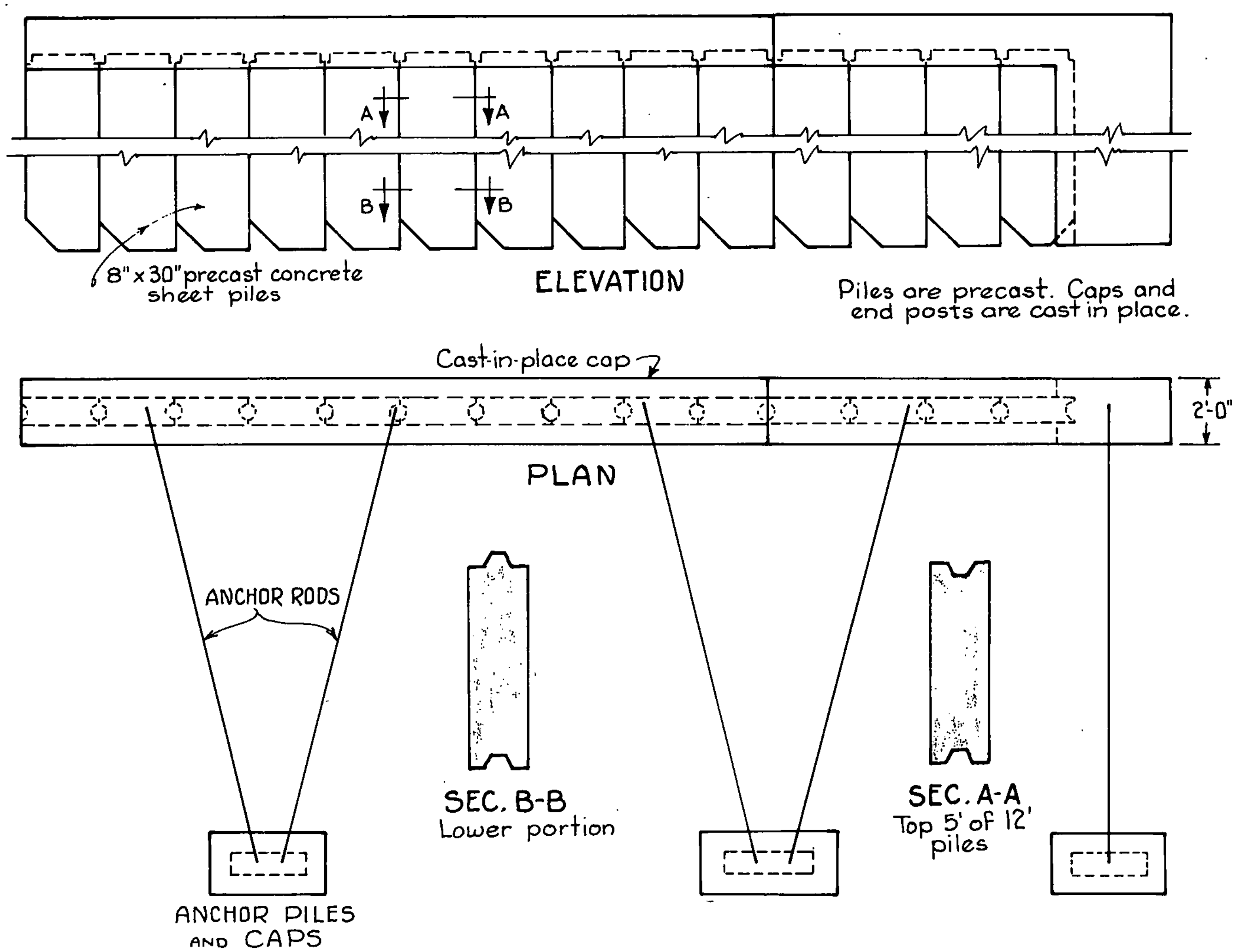


Figure 30. Anchored bulkhead (Florida).

ment avoids the headaches connected with maintaining an openable span. Some notable examples of floating bridges are to be found in Washington on Lake Washington in Seattle and across the Hood Canal, an arm of Puget Sound.

Ships and Barges

Precast concrete ships and barges are also associated with transportation. It is probably a semantic question whether they, or for that matter floating bridges, are classed as "precast" or not. Certainly they are poured-in-place at the time of construction and come under a broad definition of precast concrete only because they are moved around extensively. They probably do not fall within the intended scope of this synthesis, but nevertheless it seems worthwhile noting that many of these ships and barges qualify as transportation structures and are made of concrete. The first experiments with concrete ships and barges started during wartime in an effort to save valuable steel. A few of these old concrete ships are still to be found anchored in backwater harbors. More recently, concrete ships again are being built and a few are plying the seas. Barges are a popular form of concrete ship and serve their purpose well. A notable example is a barge in Indonesia that serves as an LP gas storage facility. It is 461 × 136 × 56.4 ft (140 × 41 × 17 m) and displaces 66 000 tons (60 000 Mg). Beside its liquid propane capacity of 375 000 bbl (60 000 m^3), it has quarters for a crew of 50. It was designed and built in Tacoma, Washington and is fully prestressed. There are many other concrete barges in use but this is one of the largest.

Canoes

A somewhat frivolous but nonetheless interesting use of precast concrete in a transportation sense is the annual design contest for concrete canoes sponsored by American Society of Civil Engineers student chapters among university engineering schools. The students exert all of their ingenuity to create a concrete canoe that will float and be maneuverable enough to carry them to victory.

CHAPTER SEVEN

HIGHWAY APPURTENANCES

Although the major highway uses of precast concrete are in bridges and drainage structures, many other appurtenances are also of precast concrete—including replacements of the concrete surfacing itself. With most precast appurtenances, careful attention must be paid to preparing the bed and setting the precast elements. This will assure that the proper line and grade are obtained.

PRECAST PAVEMENT REPAIR

A number of techniques have been developed whereby sections of defective concrete pavements are either partially or completely removed and then replaced with precast panels. NCHRP Synthesis 25 (*14*) illustrates several examples. In one, a machine was developed to cut rectangular holes either partial or full depth of the pavement. Precast concrete panels that closely fit the hole are then dropped into place. The panel size may run from a few square feet, which one man can handle, to full lane widths, which must be placed by a crane (Fig. 31). The traffic can be turned over the repair in a short time after replacement.

HYDRAULIC STRUCTURES

Hydraulic structures were probably one of the first beneficiaries of precast concrete practice. Precast concrete pipe made its appearance many years ago and was the forerunner of many other precast units to carry water and drainage.

Concrete Pipe

Precast concrete pipe may be obtained in almost any size and connection arrangement. Drain pipes with diameters as small as 3 or 4 in. (75 or 100 mm) are readily obtainable, and huge pipes 21 ft (6.4 m) in diameter and so heavy that special equipment had to be designed to carry and set them have been used for special conduits. The joining systems range from simple bell and spigot joints through neoprene compression rings to integral

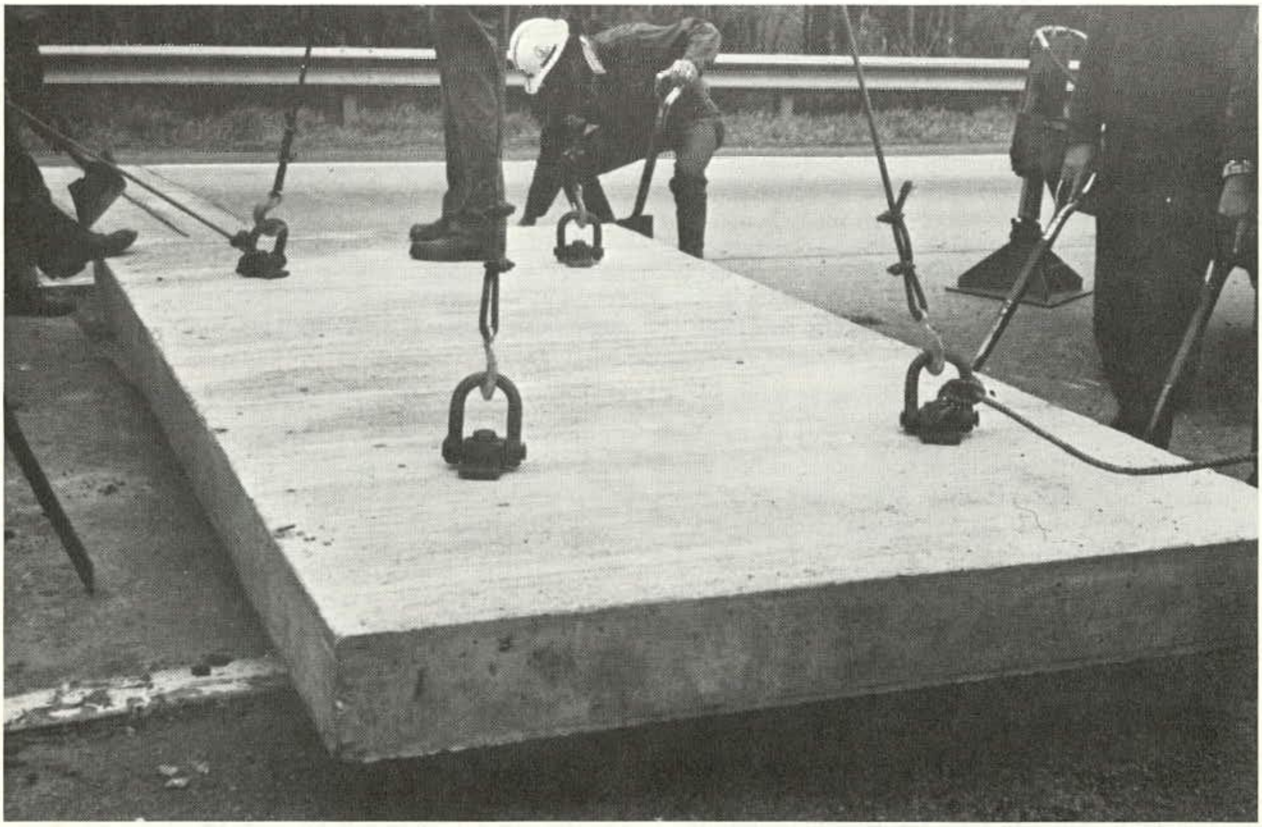


Figure 31. Full-width, full-depth precast concrete slab for pavement repair (Virginia).

steel shells in the pipes or pipe ends that are welded together and then grouted in. The casting methods vary also. Most popular is a simple split metal form standing on end (Fig. 2, Chap. 3). The internal form and the reinforcing steel are placed and the fresh concrete introduced at the top and distributed throughout by vibrators attached to the metal forms. Another method, which was proprietary, spun the forms on a horizontal axis. The concrete was introduced along the length of the pipe, and the centrifugal force threw it to the outside and held it in place against the outer form. Prestressed pipe is also made, and the pipe form must be adapted to either a horizontal or vertical prestressing bed. Pipes are made of plain concrete, reinforced concrete, prestressed concrete; with a steel inner shell, with steel shells only at the ends so they may be welded together; and also sealed on the inside (and/or outside) with an asphalt or epoxy coating to prevent corrosion of the concrete or reinforcing. Concrete pipe is probably the most prevalent precast concrete product.

Precast concrete pipes have attained huge proportions. Fifteen-ft (4.5-m) pipes were used to reroute a steam under a freeway south of Bakersfield, California. Now a water conduit 21 ft (6.4 m) in diameter and nearly 10 miles (16 km) long with 21-in.-thick (530-mm) walls is being built in Arizona.

One commercial supplier in Birmingham, Alabama, casts a section of sewer pipe with an integral manhole with the proper throat length. A special shorter section of straight pipe is supplied to make the manhole come at the proper location in the street. This saves cutting a hole in the pipe and fitting a manhole later. Even manholes that are fitted after the pipe is laid are usually precast and then grouted to the main-line pipe around a field-cut hole. Drop inlets are also commonly precast, set in the field, and then connected to a main drain pipe.

Precast concrete pipe sections have been used in the reconstruction of failing drainage structures of all sorts. The largest possible concrete section is worked into the hole longitudinally and joined by bell and spigot or compression seals. The space between the outside of the pipe and the failing structure is then usually grouted to transfer the load to the new pipe and prevent settlement. This method has also been used as a maintenance procedure to reline an existing pipe and repair abrasion wear and deterioration.

Precast concrete pipes have been used to form voids in concrete girders to produce a sort of hollow box girder with tubular interior openings. This technique has not been widely used because the pipes are heavy to handle, hard to hold in place, and somewhat more expensive per cubic foot of interior opening produced than other ways of producing rectangular openings.

Drop Inlets

Contractors have long been precasting drop inlets for use in medians, along curbs, and in gutters. These precast units work very well. They are made to a height called for by the location and are provided with holes to fit the drainage pipes being used. The boxes are easily set to line and grade and represent a considerable saving over the old practice of digging the hole and then forming the drop inlet in place.

Manholes

Manholes, like drop inlets, are precast to proper height and then set to grade in proper place with a considerable saving over the cast-in-place cost. Manholes may also be precast as concrete rings which are then stacked in place to give the required depth of hole. This same technique has been used to line water wells.

Box Culverts

Under some conditions it has proved easy and economical to precast concrete box culverts. The bed is prepared, and precast sections of a size convenient to handle are set end to end. They may have tongue and groove or lap joints. They may all be post-tensioned to hold them together. On rare occasions, the precast sections have been jacked through a high fill. Details are very flexible, and the feasibility of precasting depends upon the local conditions. Figure 32 shows a section of precast box culvert.

Minnesota has installed several precast box culverts using a modified version of the ASTM Standard C 789 (AASHTO M 259) (*20*). The design was by a computer program developed by the American Concrete Pipe Association. The computer program will handle a wide variety of overfills and loadings. The first project was a pair of culverts each 10 ft (3 m) wide and 9 ft (2.7 m) high. They were designed for three different overfills—16 ft (4.0 m), 25 ft (7.6 m), and 32 ft (9.8 m)—based upon the ultimate strength concept. The precast boxes were made in 5-ft (1.5-m) lengths. Experience on the project in curing, handling, and backfilling the units indicated that it is desirable to use reinforcing steel in the inside face of the side walls to control cracking even though the loading would not seem to require it.

The units were provided with a tongue and groove joint, which was sealed with a 1-in.-diameter (25-mm) preformed mastic. The units were tied together with 1-in.-diameter U-bolts that fit into precast holes. The installation of the 268 ft (82 m) of double box took less than four days. The 2 barrels were placed 3 ft (1 m) apart with granular material between. Two attractive features of the precast approach are that the culverts may be easily salvaged and used elsewhere or, should the need arise, they may be easily extended. Precast sections were also used to extend existing cast-in-place culverts. The precast sections were made with reinforcing extending out through one end. The existing box was then broken back to expose its reinforcing and a short cast-in-place section was placed to tie the old and new sections together.

Headwalls

Where there are many similar headwalls to be placed, they too sometimes may be economically precast. A bed may be prepared and then a footing cast-in-place under

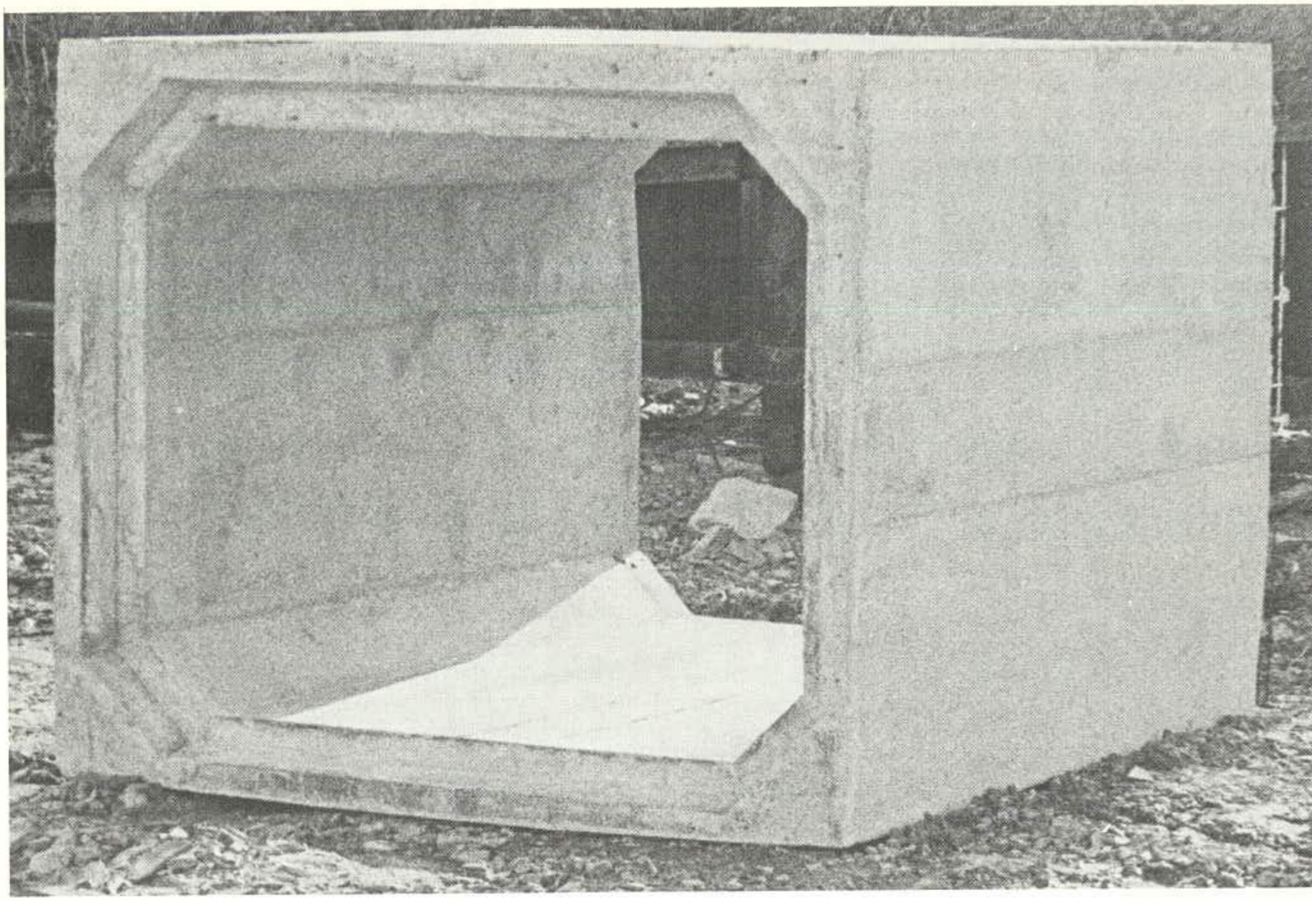


Figure 32. Precast concrete box culvert.

the precast headwall or, in some circumstances, the precast headwall may be complete, only needing some grout to seal the opening around the pipe.

Energy Dissipators

Where water velocity is high, it can wash out fills and cause considerable damage. To slow the water down and minimize its destructive force, precast concrete shapes are used to impede the flow. The shapes are as diverse as designers' imaginations, running from tetrahedrons to three-dimensional crosses looking like an enlarged version of a little girl's jacks. The dissipators are used in the outfalls of culverts, in flumes, and along streams to reduce the scour hazard. The Army Corps of Engineers has used them along the sea coast to reinforce jettys and minimize damage from wave action. Precast concrete is an ideal material for this use.

MEDIAN BARRIERS

Across the country, the concrete median barrier with the sloped face is generally accepted as being the best from the standpoint of public safety and general maintenance. These median barriers are being precast and set in place, often with a minimum of anchorage. Sometimes they are linked together, sometimes dowled into the ground. Although they may be very successfully slip-formed in place, precasting is still competitive.

Temporary Barriers

Precast median-barrier units are often used to separate a work site from traffic. The units are heavy enough so that they are not moved far even by a serious collision, and they do redirect the vehicle and prevent it from hitting the work site. Repair after a collision consists merely of shoving the units back into line with the bumper of a pickup. These units are readily reusable; contractors can carry them from job to job, or they can be moved to a permanent location in the median when no longer needed to protect the work site. The barriers are cast in various lengths determined by ease of handling and sufficiency of inertia to held them in place. Units as short as 3 ft (1 m) are being used, but the most popular length is 10 ft (3 m) (Fig. 33).

LIGHTING AND SIGNAL POLES

More and more precast concrete poles are being used to support lighting and traffic signal heads. Their weight and inertia as compared to some of the lightweight, break-

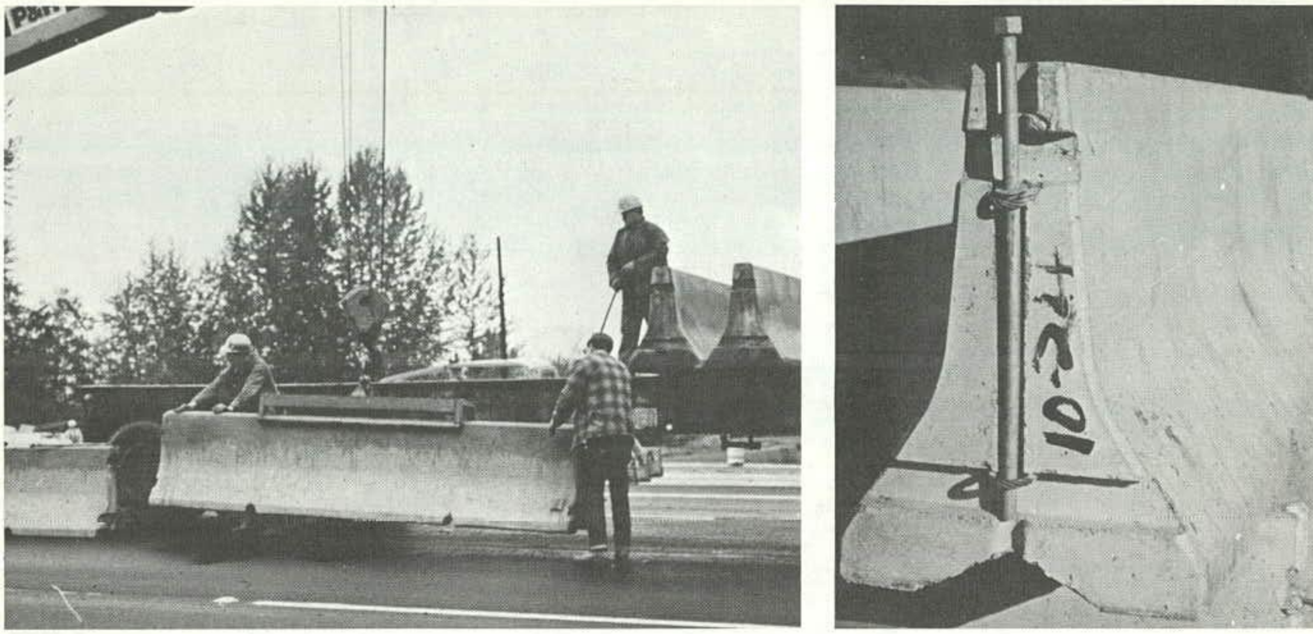


Figure 33. Precast concrete median barrier.

away poles may be a detriment, but their economy and long life make them attractive for many protected installations.

There is a wide variety of precast pole arrangements. Some have textured surfaces, and others have smooth painted surfaces to simulate a steel pole. The bases are often cast as a separate unit with the pole fitting into a socket in the base. In some cases, the bases come precast and prewired. Roadway lighting poles of concrete are generally not over 40 ft (12 m) high, but power transmission poles have been built considerably higher. Railway signal poles may have bases that incorporate a box to house the signal equipment. Where they can be used, concrete poles are attractive because of their durability and freedom from insect attack.

DECORATIVE RAILINGS AND PYLONS

Bridges built early in this century were heavily decorated with precast concrete items. It was the fashion to have railings with fancy circular ballusters. These were all precast and set in place on the job. Fancy light standards, decorative end pylons, even intermediate decorative concrete benches were to be found on some of the old bridges. Precast concrete was well known in those days.

ROADSIDE MARKERS

Survey markers, right-of-way markers, plaque supports, mileage posts, and roadside markers of many other types are often precast concrete. They do their job well and are not susceptible to the weather, bugs, and decay that made the old timber posts unsatisfactory.

ROADWAY CURBS

Some cities have used precast concrete curbing. An older practice was to use slabs of hewn granite. The precast concrete is far cheaper and easier to shape than the granite. Unless a continuous casting machine is readily available, the precast curbs will be most economical.

ROADSIDE REST AREAS

Many of the appurtenances and even some of the buildings used at roadside rest areas are made of precast concrete, often with an architectural finish. Some of these items are benches, tables, shelters, trash bins, and light poles (Fig. 34).

The septic tank used for roadside rest areas is commonly precast of concrete and works very satisfactorily. Some of the smaller distribution structures to serve the leaching fields are also precast concrete.

SOUND BARRIERS

Although they do not retain the earth, more and more walls are being built as sound barriers alongside highways. These have taken every form that could be devised to inhibit the passage of sound waves. Probably the best and one of the cheapest walls is made of precast concrete. It is used as blocks, slabs, and precast panels with decorative effects (*21*).

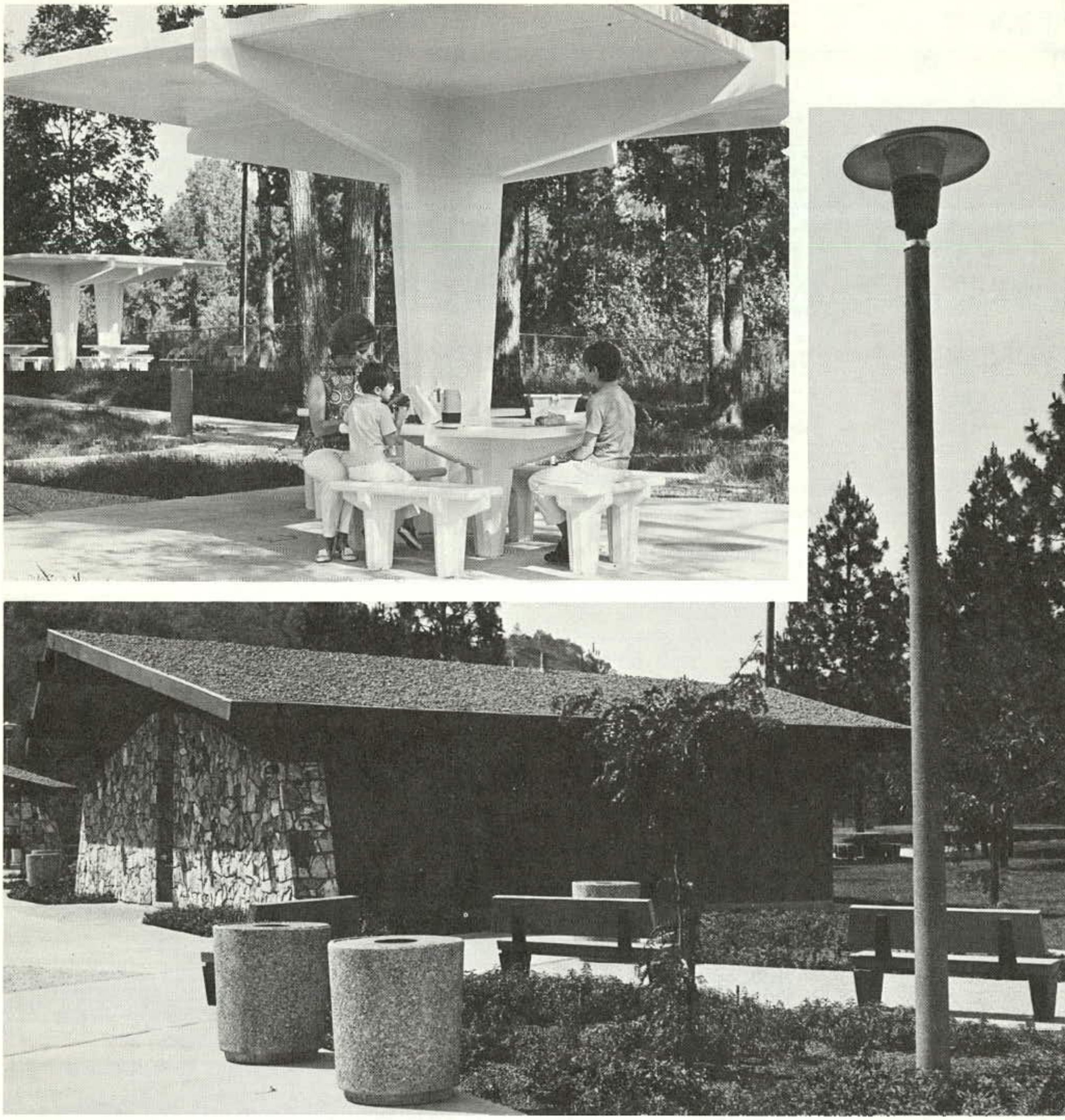


Figure 34. Precast concrete shelter, benches, trash bins, and light poles in roadside rest areas (Louisiana and California).

CHAPTER EIGHT

RAILROAD STRUCTURES AND APPURTENANCES

The railroads traditionally built many of their shorter structures of timber. The country was and still is dotted with many timber trestles carrying railroad tracks. With the decline in structural timber quality experienced over past years and the general susceptibility of timber to deterioration and damage by insects, borers, and fire, more and more railroads are turning to concrete as a longer lasting and extremely serviceable substitute (Fig. 35).

The use of precast concrete for trestle caps and for entire trestles has been covered in Chapter Five, "Bridge Elements." However, many other appurtenances are also made of concrete. The railroad drainage structures are substantially the same as the highway structures. The railroads make similar use of precast concrete pipes and precast boxes, along with drop inlets and other drainage facilities.

SIGNAL POLES

Some railroads are using precast concrete poles to support signals, control wires, and other train control equipment. Most poles are also prestressed for more strength at somewhat lighter weight.

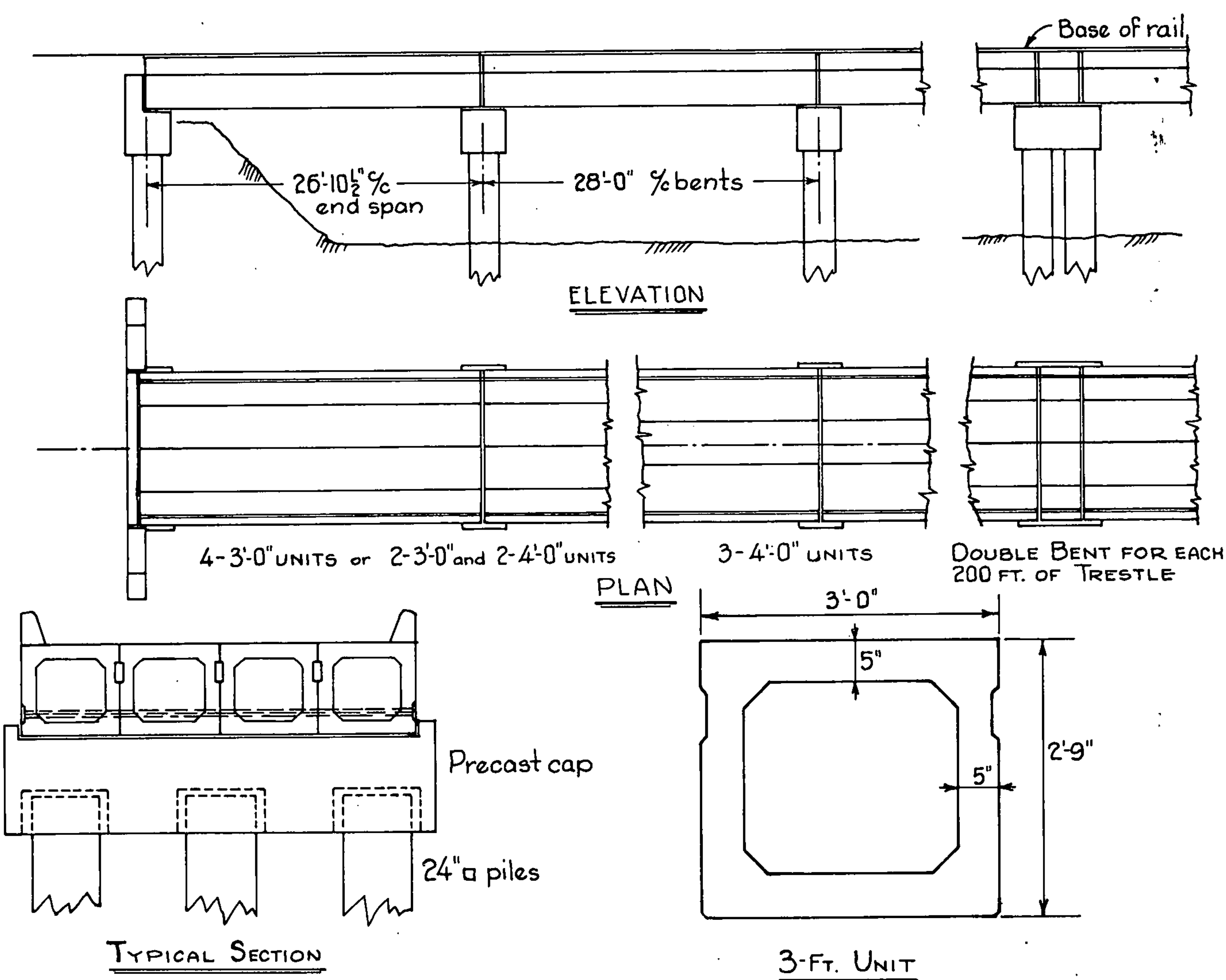


Figure 35. Precast prestressed concrete railway trestle (American Railway Engineering Assn.).

SIGNAL EQUIPMENT HOUSING

The electronic control of trains has necessitated more electrical equipment out along the line. This has required better and safer housing. A supplier in Memphis, Tennessee has metal forms for a small concrete house about $6 \times 6 \times 8$ ft ($1.8 \times 1.8 \times 2.4$ m) with a pitched roof that is cast in one piece and set out on the railroad tracks to house electronic control equipment. The same company is making precast concrete battery boxes for signal systems. It also has a precast assembly for signal poles consisting of three pieces: foundation, a round concrete pad; base, a hollow box to contain the signal equipment; and the pole, which fits into the other two pieces and carries the signal head.

TIES

The use of concrete ties in railroad tracks offers a vast precasting opportunity. U.S. railroads currently use about 25,000,000 wood ties per year. Although there has been some lowering of timber tie quality in recent years, reliable estimates indicate that an ample supply of timber is available to meet the continuing needs of American railroads for timber ties. Timber ties have served the railroads well for many years, but demand for concrete ties has been spurred by (1) the large increase in the price of timber ties; and (2) a need for a strong track structure to carry the heavy axle loads of modern cars.

Concrete ties have been used successfully in many countries, but their acceptance has been slow in the United States. Early designs for concrete ties were patterned after European practice. These early designs were generally unsatisfactory because (1) a stronger tie was needed for American axle loads; (2) ties were installed in road-beds of poor quality; and (3) large spacing of ties, up to 30 in. (760 mm), was used to reduce the over-all cost. Continued testing has resulted in development of a concrete tie that is capable of carrying heavy American axle loads. Testing has also shown that concrete ties should be spaced about 25 in. (640 mm) and supported in good quality, clean ballast with a substantial depth under the ties. (See Appendix A for references on concrete ties.)

Rebuilding the track structure under traffic has been one of the problems causing slow acceptance of concrete ties. Equipment is available from European manufacturers that will permit complete rebuilding of existing tracks with the finished product having new rail on new concrete ties supported on new ballast. This is a costly procedure, however, and requires taking a track out of service for several hours, which may be difficult to do on heavy traffic, single-track main lines.

Track constructed with concrete ties will be more costly than track constructed with timber ties. The higher cost can be justified where a stronger track structure is needed to provide better support and better anchorage for the rails in locations such as on sharply curved track. The higher cost can also be justified on the basis of evidence that track built with concrete ties will be more stable than track built with timber ties. These factors should encourage the use of concrete ties, particularly for construction of new tracks where work can be done without interference from traffic.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Precast concrete has already had a long and varied experience. It is not a Johnny-come-lately, nor is it a new technology that has yet to be mastered. Probably someone has already tried to precast in concrete anything that can be made of concrete. Some things are best precast, and others are best cast in place. Economic success results from being able to determine which is which.

Because so much has been tried, it can not be said that a great deal of research is still needed in the field. However, there are some modern aspects of structural design affecting precast concrete that still lack complete information. These would include:

- Fatigue—Not too much has been done on the fatigue of concrete, yet it is undoubtedly a factor in concrete disintegration.
- Service Life—This too has not been widely researched. Probably because concrete structures have often been considerably overdesigned, service life has been a matter of material endurance rather than deterioration under stress. We need to know more about minimally designed members acting near their full design stress.

• Load History—This is in much the same category as service life. Overdesigned structures have absorbed big overloads without apparent distress. When the loads amount to a large portion of the design load, however, there is little evidence available of their effect on a carefully designed concrete member.

• Shear Design—Although shear is one of concrete's modes of failure, it has often been neglected because other factors have made concrete members overly strong in shear. In other cases, the true shear in a concrete member is not accurately evaluated by present design methods. As members are more carefully designed to save weight and material, more must be known about shear.

• Checking Prestress Force—Because much precast concrete is also prestressed, it inherits one of prestressed concrete's problems. Although much research has been done on prediction of prestress losses, there is no way to determine if the original prestressing force still remains in a member after a period of use. Either by burying a strain gage in the concrete or by some simpler method, a way must be devised to accurately and nondestructively check the amount of prestress remaining in the concrete.

• New Systems—New technologies are constantly creating new applications that need careful evaluation before use.

Although most of these items apply to cast-in-place concrete as well as precast, the tendency to make precast members as light and economical as possible emphasizes the need for more knowledge of the action of concrete in these questioned areas.

Research might also be able to narrow the disparity in product quality among commercial plants and in concrete strength in different parts of the country. This research should include the mechanics of obtaining very high-strength concrete and the procedures necessary to assure good concrete in very thin members. When the weight of concrete is often one of its greatest detriments, it is wasteful to have to require 8-in. (200-mm) webs in beams just because it is feared most suppliers can not successfully make them any thinner. Specifications are not enough. There must be a general awareness and demand for the sort of technology that produces the better product.

There is a need for a better self-discipline in the concrete industry. Precast concrete is usually most economically made in a plant. But concrete is easy to make, and anyone can set up a concrete plant and sell concrete products. If we are to strive for better quality and greater refinements in the concrete members we make, and if we are to realize the rewards that will come from better quality and higher-grade workmanship, then there must be greater control of quality. There must be a greater desire on the part of the supplier to furnish a quality product. Free enterprise being what it is, there should be some force within the industry itself to generate a demand from a supplier's peers that his products conform to some standard set for the industry. There are trade associations now in existence that are trying to work in this direction, but their support is not general, and their efforts and backing are confined to the better suppliers who would probably furnish a good product regardless of industry pressure. The problem lies with smaller producers who do not feel obliged to conform to higher standards and who are making a comfortable living turning out something less than top-quality products.

Precast concrete has a bright future. Labor rates, especially field-labor rates, are soaring. Contractors, in order to survive, are forced to develop every method they can to minimize field labor. Precast concrete, made in a plant, is often the cheapest solution to many of their problems. More and more states, sometimes at the urging of contractors, are making it possible to use precast concrete as an alternate method of construction. Precast form panels for bridge decks, which avoid forming and stripping costs, are one notable example. The spiraling construction costs will continue this trend.

Precast concrete may well play an important part in the old-bridge crisis that is now facing the country. Thousands of bridges stand at this moment past due for replacement only delayed by lack of funds. Funds will be forthcoming as the need becomes more apparent. The engineering should all be done ahead of time so the industry will be ready to go. If committees of AASHTO or TRB (or the FHWA) could achieve general, or at least regional, acceptance of standard sections, great savings could be realized.

Although there is much talk, there does not yet seem to be a real swell of public opinion demanding a systematic approach to the old-bridge problem. It is regrettable but probably true that a tragedy in an old bridge collapse will start the ball rolling. The effort will probably be on a national scale and haste will be a prime factor to avoid further catastrophes. Money will be poured into the problem as the ultimate solution, and the effort will go forward on 50 fronts with little real coordination. There will be a multitude of designs and standards, and suppliers will be able to bid only on those designs for which they have forms available. How much easier it would be if everyone in a region was using the same designs and if the same forms would work for many different designs used by states, cities, and counties (most of the effort is going to be at the county level where there is the least broad organization of engineering effort). There is an opportunity here for real planning progress. Precast concrete can have a real stake in its success.

RECOMMENDATIONS

• Efforts should be continued to identify optimum sections, and optimum spans for those sections, for precast and prestressed concrete members. Many different sections are being used, and in many cases the differences are very minor. Standardization would lead to greater availability and use and lower cost of precast members.

• The precast concrete industry should be encouraged to develop methods of motivating and even policing its members to assure uniform high standards of quality. Precast construction in many cases now bears an un-

necessary burden of overdesign just to cover the chance of poor workmanship in fabrication. Assurance of quality could result in material savings.

• Responsible administrators at the state, county, and city levels should enter into the necessary research and planning to develop and have ready for use precast, prestressed concrete designs and plans, standardized as to dimension and loading, and uniform over large areas of the country, if not country-wide, for replacement of short-span, secondary bridges.

REFERENCES

1. "Inspection of Prestressed Concrete." Prestressed Conc. Inst., Publ. No. INS-109-60, 34 pp.
2. MOUSTAFA, S. E., "Ultimate Load Test of a Segmentally Constructed Prestressed Concrete I-Beam." *J. of the Prestressed Conc. Inst.* (July-Aug. 1974).
3. RAY, G. K., "New Design for Long-Span Bridges." *The Mil. Eng.*, Vol. 69, No. 449 (May-June 1977) pp. 184-188.
4. "Segmental Box Girder Bridges Make the Big Time in U.S." *Eng. News-Rec.*, Vol. 200, No. 9 (Mar. 2, 1978) pp. 22-26.
5. BREEN, J. E., "Design of Segmental Bridges." *Pub. Roads,* Vol. 41, No. 3 (Dec. 1977) pp. 101-111.
6. BREEN, J. E., and BALLINGER, C. A., "Design of Segmental Bridges." *Pub. Roads,* Vol. 41, No. 4 (Mar. 1978) pp. 172-180.
7. "Tentative Standards for Prestressed Concrete Piles, Slabs, I-Beams and Box Beams for Bridges . . ." Prepared by Joint Comm. of AASHO and PCI, AASHO (c. 1962) 28 pp.
8. "Precast Prestressed Concrete Short Span Bridges." Prestressed Conc. Inst. (1975).
9. "Standards for Prestressed Concrete Bridges." Pennsylvania DOT (BD 201).
10. JACQUES, F. J., "Study of Long Span Prestressed Concrete Bridge Girders." Prestressed Conc. of Colorado.
11. NAIRN, R. D., "Precast Trapezoidal Beams for Bridges." Ontario Precast Conc. Mfgs. Assn.
12. "State of the Art: Permanent Bridge Deck Forms." *Transp. Res. Circ. No. 181* (Sept. 1976) 18 pp.
13. BARKER, J. M., "Research, Application, and Experience with Precast Prestressed Bridge Deck Panels." *J. of the Prestressed Conc. Inst.* (Nov.-Dec. 1975).
14. "Reconditioning High-Volume Freeways in Urban Areas." *NCHRP Synthesis 25* (1974) 56 pp.
15. BISWAS, M., ET AL., "Bridge Replacements with Precast Concrete Panels." *TRB Spec. Rep. 148* (1974) pp. 136-148.
16. "Modules Used to Rebuild Bridge Deck." *Eng. News-Rec.*, Vol. 197, No. 19 (Nov. 4, 1976) p. 12.
17. "On the Santa Fe: Precast Concrete Slabs are Bonded to Steel Bridges." *Railway Track and Structures* (Oct. 1975).
18. "Concrete Caps Find Favor on the Frisco." *Railway Track and Structures* (Aug. 1969).
19. VIDAL, H., "The Principle of Reinforced Earth." *Hwy. Res. Record No. 282* (1969) pp. 1-16.
20. LAUMANN, F. J., and SANDAHL, J. E., "Precast Concrete Box Culverts A Minnesota First." *Amer. Road Builder,* Vol. 54, No. 2 (Feb. 1977) p. 27.
21. LOKKEN, E. C., "Concrete Walls for Highway Noise Reduction." *Transp. Eng. J. of ASCE,* Vol. 102, No. TE4 (Nov. 1976) pp. 637-649.
22. ANDERSON, A. R., "Systems Concepts for Precast and Prestressed Concrete Bridge Construction." *HRB Spec. Rep. 132* (1972) pp. 9-21.
23. "Designer Uses Bridge Units in Dock Design." *Better Roads* (Dec. 1976).
24. "Bridge Units Used in Dock Design." *J. ACI,* Vol. 74, No. 4 (Apr. 1977) p. N24.
25. "Precast Girders Launched from Cast-in-Place Tees." *Eng. News-Rec.*, Vol. 198, No. 18 (May 5, 1977) p. 16.
26. "Segmented Concrete Box Girder to Use Construction Innovations." *Eng. News-Rec.*, Vol. 197, No. 19 (Nov. 4, 1976) p. 13.
27. "Bridge Redesigned as Incrementally Launched Box Girder." *J. ACI,* Vol. 74, No. 4 (Apr. 1977), pp. N25-N26.

APPENDIX A

SELECTED BIBLIOGRAPHY

ANDERSON, A. R., "Stretch-Out AASHO-PCI Beams Types III and IV for Longer Span Highway Bridges." *J. of the Prestressed Conc. Inst.* (Sept.-Oct. 1973).

BENDER, B., "Segmental Box Girder Bridge Construction." *J. ACI,* Vol. 73, No. 4 (Apr. 1976) pp. 188-190.

"Cable-Stayed Bridge Goes to a Record with Hybrid Girder Design." *Eng. News-Rec.,* Vol. 197, No. 18 (Oct. 18, 1976) pp. 20-21.

"Cycling Brings Low-Cost Concrete Garages in Fast." *Eng. News-Rec.,* Vol. 196, No. 33 (June 3, 1976) p. 23.

"Frisco Goes to Prestressed-Concrete Trestles." *Railway Track and Structures* (Nov. 1967).

"Frisco Says: Concrete Costs More But Lasts Longer." *Railway Age* (Nov. 13, 1967).

"A Guide to Standardized Highway Concrete Drainage Products." Preliminary rep. for AASHTO Task Force 13 (1977).

HENNEBERGER, W., and BREEN, J. E., "First Segmental Bridge in the U.S." *Civil Eng.,* Vol. 44, No. 6 (June 1974) pp. 54-57.

KORETZKY, H. P., and TSCHERNEFF, A. T., "An Experimental Post-Tensioned Segmental Concrete Box Girder Bridge." *Pub. 118,* Pennsylvania DOT (Sept. 1974).

KORETZKY, H. P., and KUO, P. H. "Letter Survey on 'State of the Art' in the USA of Segmental Concrete Box Girder Bridges." *Pub. 118,* Pennsylvania DOT (Sept. 1974).

LACEY, G. C., and BREEN, J. E., "Long Span Prestressed Concrete Bridges of Segmental Construction—State of the Art." *Res. Rep. 121-1,* Center for Hwy. Res., Univ. of Texas (May 1969) 45 pp.

LIBBY, J. R., "Segmental Box Girder Bridge Superstructure Design." *J. ACI,* Vol. 73, No. 5 (May 1976) pp. 279-290.

"Precast Building System Quickly Produces Continuous Shear Walls." *Eng. News-Rec.,* Vol. 197, No. 4 (July 22, 1976) p. 16.

"Precast Concrete: Its Use in Railroading Varies Widely." *Railway Track and Structures* (Aug. 1974).

"Prestressed Piles, Template Put Twin Bridges Ahead of Schedule." *Eng. News-Rec.,* Vol. 197, No. 12 (Sept. 16, 1976) pp. 25-26.

"Richmond-San Rafael Bridge—First Annual Report." Calif. Div. of San Francisco Bay Toll Crossings (1954).

"Standard Specifications for Highway Bridges." AASHTO (1973) 469 pp.

"System Building for Bridges." *HRB Spec. Rep. 132* (1972) 76 pp.

"Tentative Design and Construction Specifications for Precast Segmental Box Girder Bridges." PCI Bridge Committee, *J. of the Prestressed Conc. Inst.* (July-Aug. 1975).

TYSON, S. S., "Full-Depth Repair of Jointed PCC Pavements: Cast-in-Place and Precast Procedures." Virginia Hwy. and Transp. Res. Council (Mar. 1976).

CONCRETE CROSSTIES

"CNR Sets Policy on Use of Concrete Ties." *Railway Track and Structures,* Vol. 71, No. 9 (Sept. 1975) pp. 21-23.

"CNR Starts Program to Install Concrete Ties on Sharper Curves." *Railway Track and Structures,* Vol. 72, No. 12 (Dec. 1976) pp. 14-16.

"The Concrete Tie—New Life for a Faltering Cause." *Railway Track and Structures,* Vol. 73, No. 8 (Aug. 1977) pp. 23-36.

"Concrete Ties." *AREA Bull.,* Vol. 75 (Sept. 1973), p. 85.

"The Florida East Coast Railway Company and the Concrete Crosstie." Florida East Coast Railway Co., Ofc. of Chief Eng., St. Augustine (Jan. 18, 1977) 17 pp.

HANNA, A. N., and WEBER, J., "Development of Standard Specifications for Concrete Ties for Rapid Transit." Phase I, Tasks 1 to 5, final rep., No. TDC-CT-75-1, Constr. Tech. Lab. and Transit Dev. Corp. (Oct. 30, 1975) 117 pp.

"Northeast Corridor Improvement Project Task 202: Concrete Tie Cost and Performance for Track Structures." Fed. Railroad Admin., Northeast Corridor Proj. Ofc., final rep., FRA/NECPO-77/2 (Oct. 1977) 57 pp.

"Plant to Produce 1.5 Million Concrete Ties." *Railway Track and Structures,* Vol. 72, No. 11 (Nov. 1976).

REINER, I. A., "Testing Concrete Ties." *Proc.,* 12th Ann. Railroad Eng. Conf., Pueblo, Colorado (Oct. 1975) pp. 17-26.

WAY, G. H., JR., "New Aspects of Concrete-Tie Track." *Railway Track and Structures,* Vol. 67, No. 12 (Dec. 1971) pp. 22-25.

WEBER, J., "The Latest Concrete-Tie Test Sections: What Has Been Their Performance?" *Railway Track and Structures,* Vol. 22, No. 8 (Aug. 1976), pp. 32-35.

WEBER, J. W., "Development of the Prestressed Concrete Tie in the U.S." Symp. on Railroad Track Mech., Princeton Univ. (Oct. 1975) pp. 32-33.

WEBER, J. W., "New Concrete-Tie Service Test for the Santa Fe." *Railway Track and Structures,* Vol. 71, No. 1 (Jan. 1975) pp. 32-34.

"Why DOT Opted for Concrete Ties in the Northeast Corridor." *Railway Age,* Vol. 178, No. 17 (Sept. 12, 1977) pp. 32-34.

APPENDIX B

OUTSTANDING EXAMPLES

THE DISNEY WORLD MONORAIL

A project illustrating the capabilities of precast concrete is the monorail for Disney World in Orlando, Florida (*22*). The structure, in effect, is a bridge for a rubber-tired vehicle with fairly heavy wheel loads, as shown in Figure B-1.

The project has 7 miles (11 km) of 6-span continuous prestressed concrete box-girder sections, supported on precast concrete columns. There are 350 girders with spans from 90 to 110 ft (27 to 34 m). Half of the girders are straight, and half are on vertical and horizontal curves with radii down to 350 ft (107 m). The hollow girders are of variable sections, 26 × 48 in. (660 × 1 220 mm) at midspan and 26 × 80 in. (660 × 2 030 mm) at the ends. The girder soffits are set on a parabolic curve, varying with girder length.

Both curved and straight girders were partially prestressed sufficiently at the plant to compensate for the dead-load bending of the girder. Concrete strength for the girders was 4 500 psi (31 MPa) at transfer and 7 000 psi (48 MPa) at 28 days.

To provide a smooth riding surface, it was required that the beams be set to 0.1 in. (2.5 mm). The true position of the columns was held to within 0.1 in. (2.5 mm) laterally and 0.25 in. (6.4 mm) longitudinally and vertically. The curved girders required superelevation and horizontal and vertical curvature angles of up to 8 de-

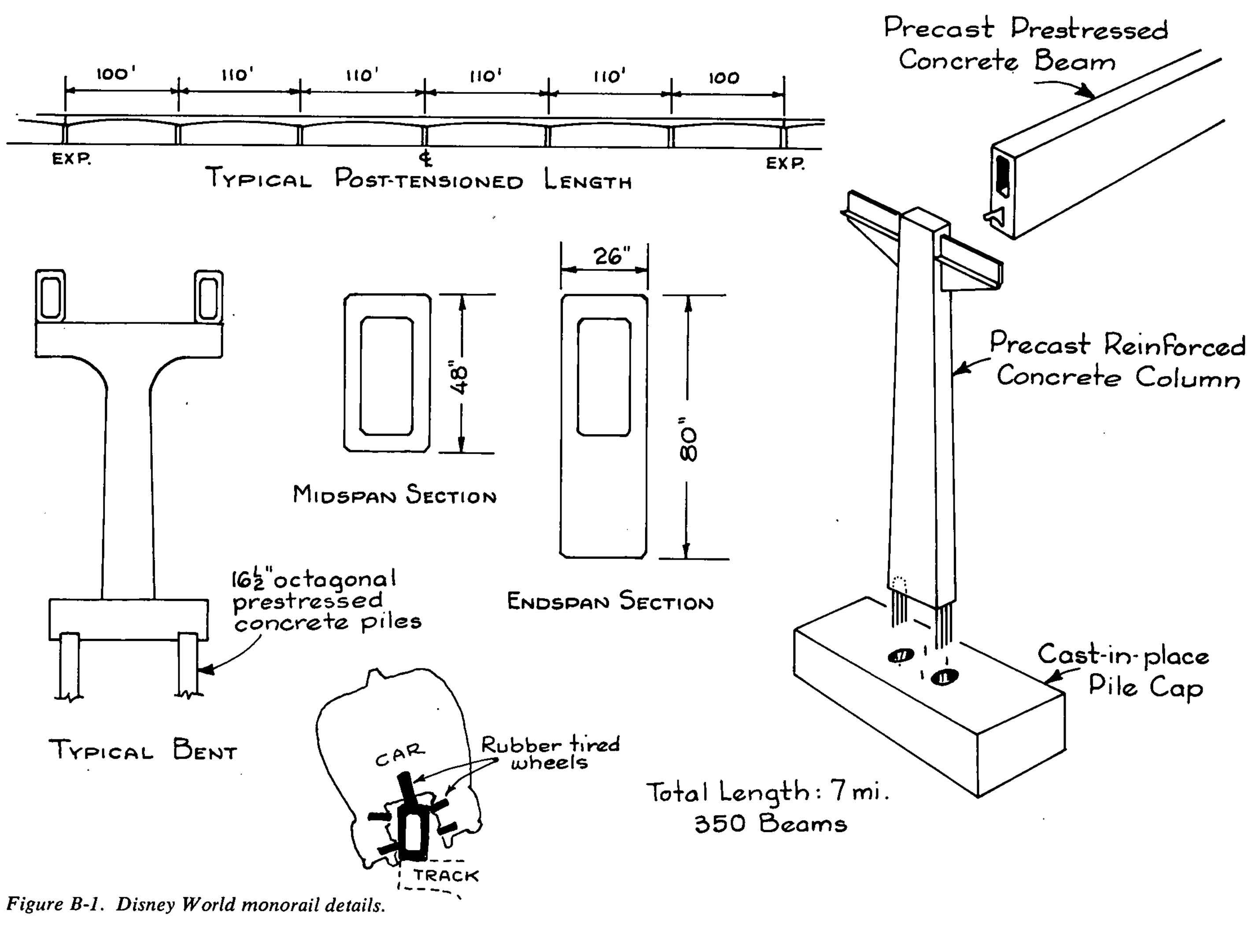


Figure B-1. Disney World monorail details.

grees. Because no two curved girders are alike, a very sophisticated form was built that could be warped into all of the necessary configurations. The straight beams, usually 100- and 110-ft (30- and 33-m) spans, were built in straight side forms with an adjustable soffit that accommodated the changes in parabolic soffit 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 (34 MPa). The girders were stressed only to accommodate deadload stresses so the beams arrived on the job essentially straight. Post-tensioning then brought the beams to the required position with only the 0.1-in. (2.5-mm) tolerance.

This project is a revealing example of what can be done with precast concrete under carefully controlled conditions. The project had many special difficulties, not the least of which was the fact that the beams were cast in Tacoma, Washington, and then carried by railroad across the country to be erected in Florida. The fact that it worked out so well is graphic proof that with care and control precast concrete can be used for many precision projects.

THE CHILLON VIADUCT

The Chillon Viaduct in Switzerland is an outstanding example of segmental cantilever construction as well as the highest order of match casting perfection. The Chillon castle, famed in fiction, sits in the water at the edge of a Swiss lake. A two-lane highway winding along the shore of the lake past the castle was becoming congested. A four-lane divided highway was planned for higher up the heavily wooded hillside. The Swiss concern for beauty determined that a pair of viaducts, each on single column bents, would be threaded through the trees with minimal disruption of the natural landscape (Fig. B-2). It was decided that full bridge sections about 15 ft (4 m) long could be transported out onto the progressing bridge, lowered into position, epoxied, and then stressed in place.

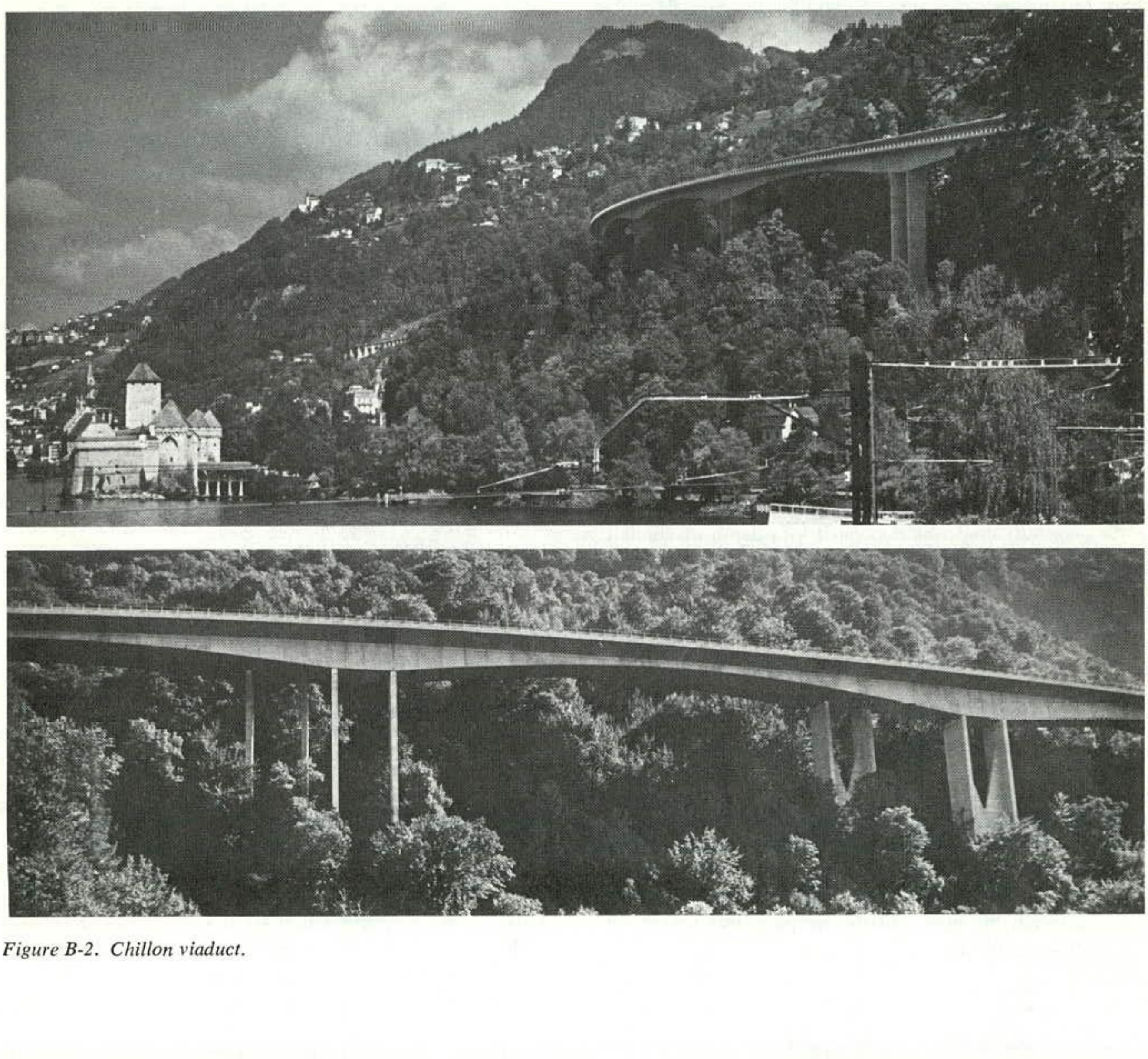


Figure B-2. Chillon viaduct.

Because of the steep hillside and curving shore of the lake, the alignment looked like a snake, and there were few sections on tangent. Almost every section had to have some curvature and superelevation built into it. Further, to assure that the units would fit precisely when swung into place, all units were match-cast. A complex metal form was built to cast a complete unit with a large central box girder and cantilever wings on each side. The form was arranged with jacks under each corner and along the sides so an infinite combination of grades and curves could be built into the unit. Adjacent to the forms was another adjustable support for the unit just previously cast. It too could be tilted or turned to correspond with its final position in the structure. Thus when the unit was cast, it bore the intimate imprint of its neighbor-to-be in the bridge and also had in itself the proper twist and cant to fit perfectly into the grade and alignment. The system worked beautifully, and the bridge stepped delicately along the hillside, disturbing little of the natural surroundings and following the curve of the hill. When completed, surrounded by trees higher than the roadway, the viaduct had the appearance of having been there for many years—a natural part of the landscape. The project was a triumph both for the aesthetic approach and for the high degree of technology used in its construction.

THE SAN RAFAEL BRIDGE SUBSTRUCTURE

The substructure of the San Rafael Bridge across the north end of San Francisco Bay carried precasting to near perfection. A total of 62 piers were built by this method with a minimum of work having to be done under water. The precast method was selected by the substructure contractor, as the bridge site was only a few miles from his casting yard which had water access to the San Francisco Bay. Thus the sections could be cast in his yard and barged to the site. The steel H-piles too were conveniently delivered to a fabricator in Oakland, California, where they were welded to proper length and also barged to the bridge site.

The sequence of operations for the construction of a typical pier was as follows (see Figs. B-3 and B-4):

1. The soft mud was excavated to a depth of about 12 ft (3.7 m). Timber piles were then driven and cut off with an underwater saw exactly to the grade of the underside of the support base and pile template.
2. The base support and pile template resembled a big waffle 1 ft (300 mm) thick. The templates had the proper number of H-slots for the foundation piles to be driven in that pier. The templates were located by careful survey controls on the sighting towers fastened to each template as it was lowered into place by a derrick barge.
3. The 14-in. × 89-lb (360-mm × 132-kg/m) steel H-piles as long as 194 ft (59 m) were then guided through the slots in the template by divers and driven to the required bearing. After driving, the space between the piles and the template was sealed with grout by divers.
4. The lower ring section was then lowered into place on the template by a derrick barge using a triangular-shaped lifting and setting tower. The ring section was centered on the template by steel guides cast into the base. After the ring was carefully leveled, any open spaces between it and the base were sealed and the whole area was thoroughly cleaned. A 5-ft (1.5-m) lift of tremie concrete was placed inside the ring to lock the piles to the pier and support the pier loads.
5. The tapered precast cones with their connecting diaphragm were then set on top of the rings. These were followed by the hollow upper precast shafts which sat on the cones and extended the pier above the water surface. The diaphragm connecting the two tower shafts was cast in place.
6. The surface of the previously placed concrete in the rings and the interior surface of the cones and shafts were then cleaned and the entire pier was filled with concrete up to 5 ft (1.5 m) above the water surface.
7. The tops of the piers with the anchor bolts were then set and poured above water.

This completed the construction of an entire pier. The only underwater work was done by a few divers. Because of a great deal of planning and care, the construction went very smoothly and the many piers were completed expeditiously.

SOME UNUSUAL PRECAST CONCRETE USES

In Louisiana, at the town of New Roads on the Mississippi River, a 12 000-ft^2 (1 100-m^2) cargo dock is being built using standard precast, prestressed concrete highway bridge girders as supporting members (*23, 24*). The dock is supported on precast, prestressed concrete piles, and the connecting caps are cast-in-place concrete. There was probably substantial savings because a local supplier had the forms for the highway girders. As the structure was to have a 40 × 300-ft (12 ×91-m) cast-in-place concrete deck, it would seem using precast deck form panels could have saved the forming costs.

Another interesting combination of precast and cast-in-place concrete is a bridge in Southhampton, England with several 410-ft (125-m) spans (*25*). The cantilevers were cast in place 150 ft (38 m) out from the piers. The 108-ft-long (27.5-m) suspended section was then precast and the 270-ton (240-Mg) girders moved out over the gap and lowered into place. Working 80 ft (20 m) above the navigable channel of the river, this partially precast procedure offered a quick method of closing the gap.

A segmented concrete box girder parallel bridge is to be completed in 1979 near Rockford, Illinois (*26*). Twin structures 1 090 ft (332 m) long, each with three 250-ft (76-m) spans, are to be built using precast segmental construction. Single-stage stressing is to be used rather than the usual two-stage, for an estimated saving of 25 percent. The plan to use precast rather than cast-in-place segments is claimed to save $1.1 million. The sections are 7 ft (2.1 m) long and weigh 40 to 49 tons (36 to 44 Mg) each. They are to be erected from an overhead truss that

spans the 250 ft (76 m) between piers and enables the work to be carried on entirely in the air without disruption of the ground cover underneath.

Another interesting segmentally constructed bridge crosses the Wabash River at Covington, Indiana (*27*). The bridge is straight and level, 935 ft (285 m) long, with end spans of 93.5 ft (28.5 m) and interior spans of 187 ft (57 m). The superstructure is an 8-ft (2.4-m), two-cell box girder. Using a midspan temporary bent and a steel truss launching nose as support, 46-ft (14-m) segments are cast near one abutment and then slid into place on Teflon skids.

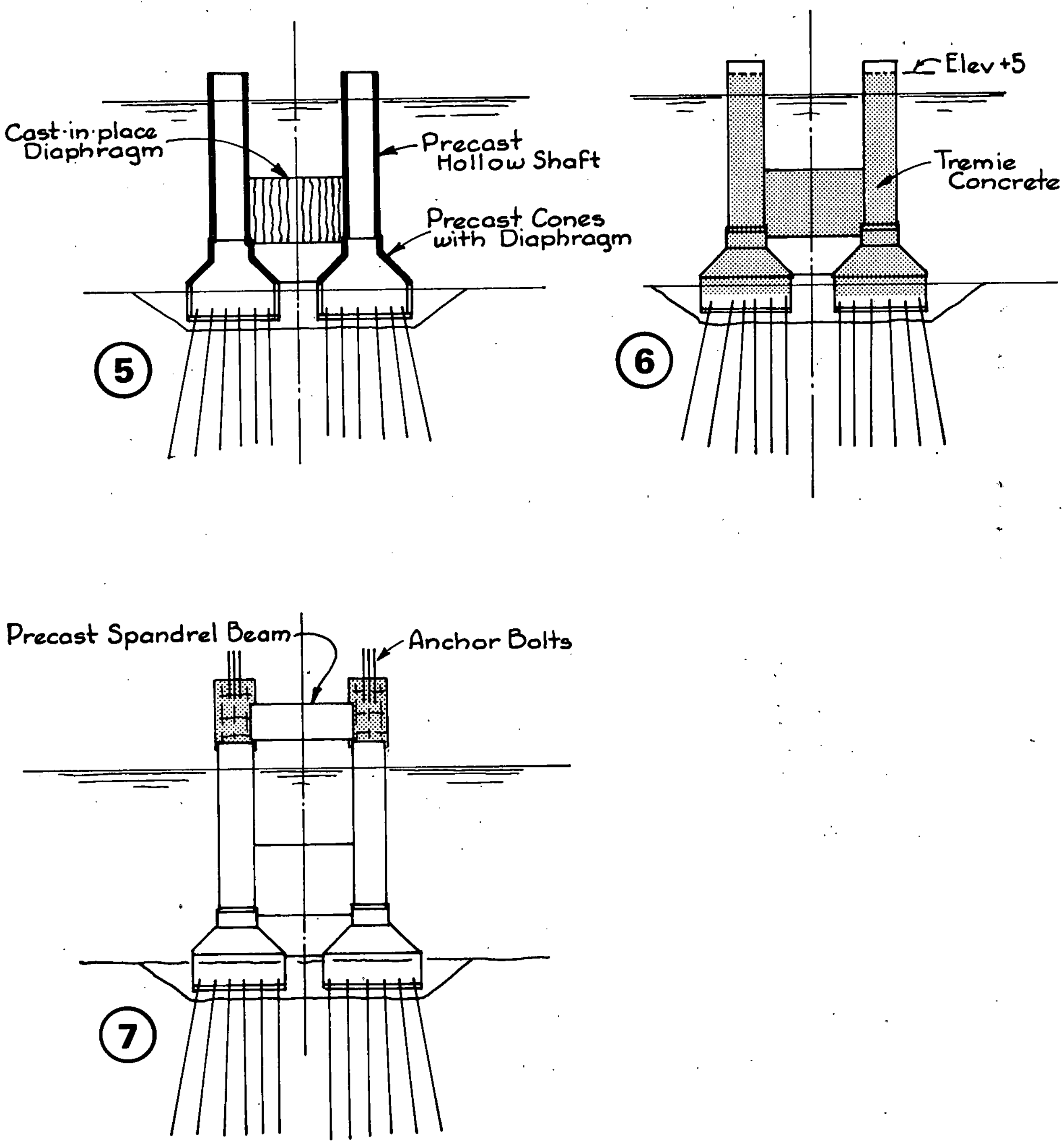


Figure B-3. San Rafael Bridge. Pier construction sequence 1–4.

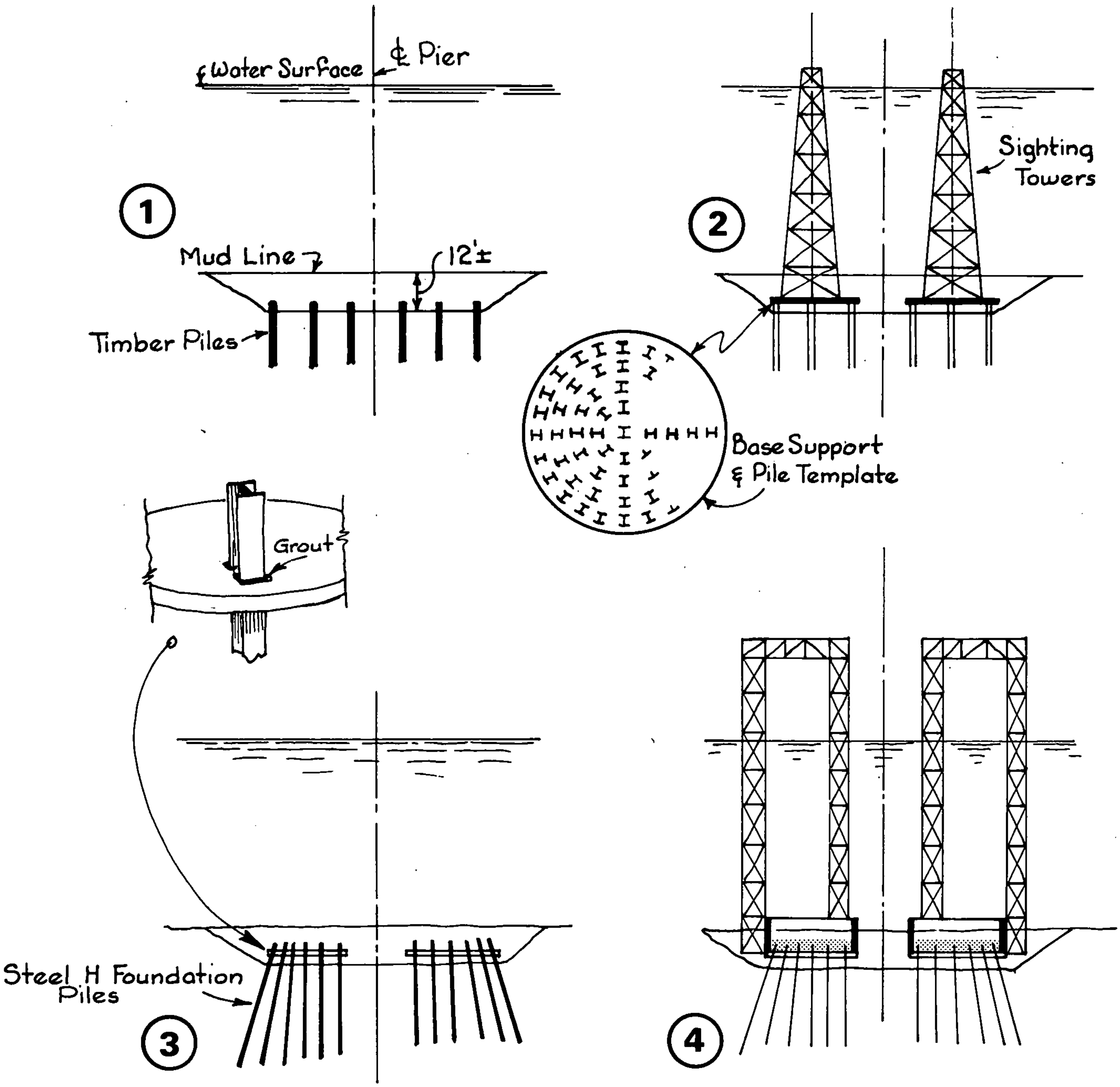


Figure B-4. San Rafael Bridge. Pier Construction sequence 5–7.

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 150 committees and task forces composed of more than 1,800 administrators, engineers, social scientists, and educators who serve without compensation. The program is supported by state transportation and highway departments, the U.S. Department of Transportation, and other organizations interested in the development of transportation.

The Transportation Research Board operates within the Commission on Sociotechnical Systems of the National Research Council. The Council was organized in 1916 at the request of President Woodrow Wilson as an agency of the National Academy of Sciences to enable the broad community of scientists and engineers to associate their efforts with those of the Academy membership. Members of the Council are appointed by the president of the Academy and are drawn from academic, industrial, and governmental organizations throughout the United States.

The National Academy of Sciences was established by a congressional act of incorporation signed by President Abraham Lincoln on March 3, 1863, to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance. It is a private, honorary organization of more than 1,000 scientists elected on the basis of outstanding contributions to knowledge and is supported by private and public funds. Under the terms of its congressional charter, the Academy is called upon to act as an official—yet independent—advisor to the federal government in any matter of science and technology, although it is not a government agency and its activities are not limited to those on behalf of the government.

To share in the tasks of furthering science and engineering and of advising the federal government, the National Academy of Engineering was established on December 5, 1964, under the authority of the act of incorporation of the National Academy of Sciences. Its advisory activities are closely coordinated with those of the National Academy of Sciences, but it is independent and autonomous in its organization and election of members.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 42970

000015MC03
MATERIALS ENGR
IDAHO TRANS DEPT DIV OF HWYS
P O BOX 7129
BOISE ID 83707