Concrete Grade-Separation Structures

Portland Cement Association • 33 West Grand Avenue • Chicago 10, Illinois

Contents

The activities of the Portland Cement Association, a national organization, are limited to scientific research, the development of new or improved products and methods, technical service, promotion and educational effort (including safey work), and are primarily designed to improve and extend the uses of portland cement and concrete. The manifold program of the Association and its varied services to cement users are made possible by the financial support of over 65 member companies in the United States and Canada, engaged in the manufacture and sale of a very large proportion of all portland cement used in these two countries. A current list of member companies will be furnished on request.

Introduction

The expanded highway program now under way is aimed at improving the safety and capacity of our major highway systems. An important part of this program is the National System of Interstate and Defense Highways, which is being designed to handle the traffic of 1975.* This system will connect nearly every city in the United States with a population of more than 50,000. A major feature of the program is the construction of grade-separation structures, which are designed to provide safe access and egress at intersecting highways without traffic disruption.

Highways are built on all types of terrain and must meet various urban and rural requirements. As a result, grade-separation structures must be designed to fit various conditions. They must not only satisfy requirements of their

*See "Geometric Design Standards for the National System of Interstate and Defense Highways" (abstracted in Appendix A, pages 17-18), adopted July 12, 1956, by the Committee on Planning and Design Policies of the American Association of State Highway Officials.

particular sites but also fit into the overall engineering and architectural plan of the highway system. A bridge designed for one site will seldom be usable at another location without some modification. In this respect, using concrete is particularly advantageous. Because of its plasticity and adaptability, changes in structural type or architectural form can easily be made. Variety in appearance can be obtained and, as shown in the photographs included in this booklet, pleasing architectural effects can be achieved for all parts, from massive abutments to fine decorative details.

Concrete is not only adaptable; it is also ruggedly durable, capable of withstanding the destructive action of weather with almost no maintenance. Sturdy, rigid construction results from the stiffness of the concrete members and from the structural continuity that is easily and economically attained. Bridge decks can be designed in concrete to carry heavy loads without annoying vibration.

Exhaustive studies of site conditions, costs and materials led to the selection of concrete bridges for the Fort Worth Expressway, Pennsylvania Turnpike, Merritt Parkway, Hollywood Freeway and the Alaskan Way. These structures and others throughout the country are giving excellent service and are adding to the safety and appearance of our entire highway network.

Progress in bridge construction calls for continual review of established procedures to obtain the best possible solution to both old and new problems. In this booklet, current methods of selecting a bridge for a given site and important factors to be considered in the layout of any grade-separation structure are discussed.

In Section 1, general types of highway interchanges in common use today are briefly illustrated and described. These interchanges involve grade-separation structures that permit traffic on each road to maintain an almost uninterrupted rate of flow regardless of direction of turn. Various types of bridges suitable for interchanges are illustrated and described in Section 2, and the conditions for which each is best adapted are discussed. Bridge types considered are the deck girder, box girder, slab, rigid frame, arch and prestressed girder. In Section 3, important design considerations are summarized, and in Section 4 the procedure for selecting a suitable grade-separation structure is illustrated for three typical situations.

SECTION 1. *Highway Interchanges*

Normal, open-road flow of traffic will not be interrupted at the intersection of two highways if the roadways are separated by means of grade-separation structures. Continuous and full capacity of both highways can be assured by adequate interchange roads and properly designed entryways to allow turning vehicles to join through traffic without interference.

The selection of interchange type depends on a variety of conditions, including volume, type and speed of traffic, right-of-way restrictions, and topography at the interchange site (see Fig. 1). A discussion of the selection and design of interchanges of several kinds is given in *A Policy on Geometric Design of Rural Highways,* published by the American Association of State Highway Officials 1954.*

Most effective of the various patterns are directional interchanges of the kind shown in Fig. 2, designed with long ramps having large curvatures. On these, vehicles can move from one road to the other with little or no reduction in speed.

*Also see *A Policy on Grade Separations for Intersecting Highways,* American Association of State Highway Officials, National Press Building, Washington, D.C., 1944.

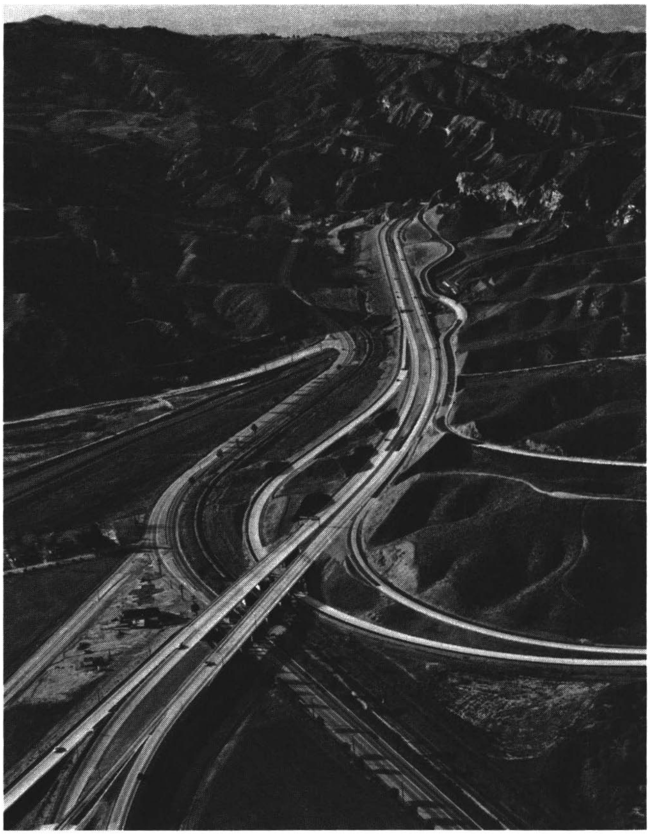

Fig. 1. This view, looking northerly along the Golden State Freeway just west of San Fernando, Calif., dramatically illustrates the effect of topography on highway interchanges.

Courtesy of California State Department of Public Works, Division of Highways.

Fig. 2. This directional interchange at the intersection of U.S. 80 and the Cabrillo Freeway, San Diego, Calif., allows vehicles to change direction with little reduction in speed and without obstruction to through traffic.

Fig. 3. Service roads for local traffic both flank and pass over the Los Angeles Harbor Freeway through busy industrial and residential areas. Interchange is by means of one-way ramps. Courtesy of California State Department of Public Works, Division of Highways.

Expressways passing through congested residential or industrial areas, where right-of-way is restricted, are frequently depressed. Local traffic is routed on overpass bridges and on service roads parallel to the main highway. Access to the expressway is usually infrequent and by means of interchanges like those shown in Fig. 3.

Interchanges discussed in AASHO publications represent types in general use, but many variations are possible. An outstanding example is the four-level Los Angeles interchange shown in the cover photograph and Fig. 10 (page 7), with its complex arrangement of freeways and connecting ramps.

Whatever form is chosen, the interchange can help to maintain a constant flow of traffic and to eliminate accidents due to crosstraffic.

Fig. 4. This aerial view shows the interchange on the Penn-Lincoln Parkway at the entrance to the Squirrel Hill Tunnel near Pittsburgh, Pa. Courtesy of Pittsburgh Post-Gazette.

SECTION 2. *Types of Grade-Separation Structures*

DECK GIRDER

In St. Clair County, Ill., a three-span continuous deck or T-girder bridge (see Fig. 5) was selected for its architectural beauty, suitability to the terrain and economic feasibility. Open end spans with spill-through abutments give the motorist a feeling of unrestricted vision and result in an efficient, economical design.

Span lengths were chosen so that maximum positive design moments are approximately equal in all spans. An interior span of 62½ ft., which allows for future widening of the underpass highway, is balanced against end spans of 48 ft. The bridge has four 13-ft. lanes, a 4-ft. wide median strip and a 2-ft. wide safety curb on each side of the roadway. Slab depth is 7 in. and girders are spaced at about 7 ft. on centers.

The superstructure is divided into two parts by a sealed joint running the full length of the bridge at the roadway centerline; each half of the structure was cast in one continuous operation. Open piers between abutments reduce objectionable noise under the structure and provide good distribution of light.

Reactions from the superstructure are transmitted to the piers through conventional bearings. In some structures it is possible to extend continuity by eliminating the intermediate bearings and making the deck integral with the piers. Elimination of continuity between the deck and abutments may be desirable if some movement of the abutments under lateral forces is expected, but integration of the deck with some of the interior supports is usually advantageous.*

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*Information on this type of design is found in *Continuous Concrete Bridges*, available from the Portland Cement Association in the United States and Canada.

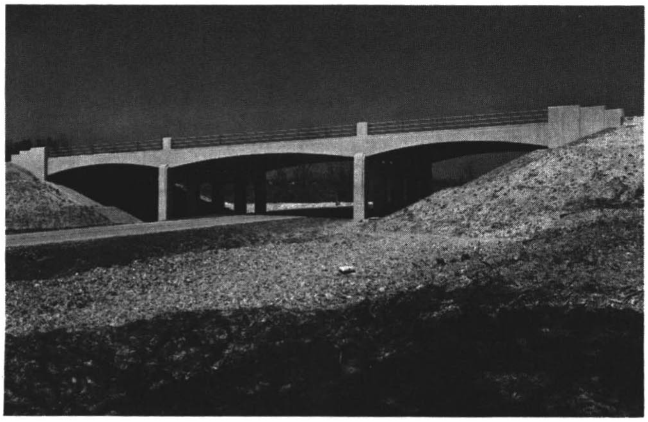

Fig. 5. Maximum visibility is provided by this bridge in St. Clair County, Ill., which has open piers and open end spans with spill-through abutments. Design: Illinois Division of Highways. Construction: Maurice Hoeffken Co., Belleville, Ill.

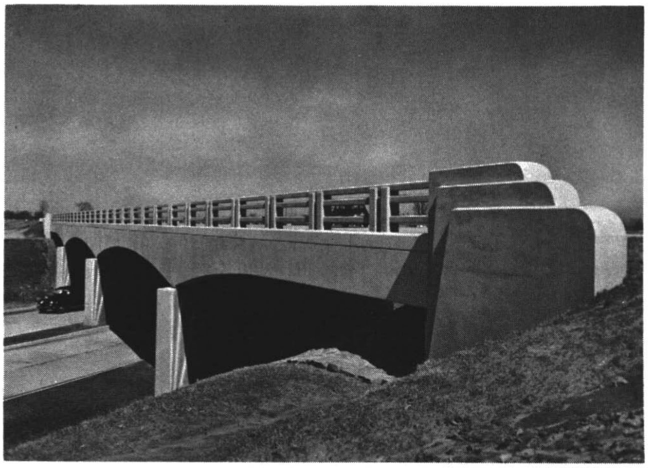

Fig. 6. Use of concrete for all parts, including the handrails, is typical of grade-separation structures on the Detroit Industrial Expressway. Design: Michigan State Highway Department. Construction: L. A. Davidson, Lansing, Mich.

The continuous T-girder shown in Fig. 6 carries eastbound traffic of the Detroit Industrial Expressway over Ecorse Road in Detroit, Mich. The soffits of the ends of the girders are straight rather than curved like those of the bridge shown in Fig. 5. Either design is pleasing. The use of concrete for all parts of the Detroit bridge, including the handrails, resulted in a harmonious appearance and low maintenance costs.

The bridge has two 65-ft. spans and two 53½-ft. spans and carries a roadway 36 ft. wide. Girders cast integrally with a 7¾-in. thick deck slab are spaced at 6 ft. on centers and vary in depth from 2 ft. 7 in. at midspan to 5 ft. 8 in. at interior piers.

This bridge is typical of grade-separation structures used on the Detroit Industrial Expressway as well as on the Detroit-Toledo Expressway and the Ann Arbor Belt Line.

BOX GIRDER

The concrete box-girder bridge, frequently used at grade separations when a low depth-to-span ratio is required, may be supported by one- or two-column bents as shown in the cutaway view in Fig. 7 and usually consists of one or more boxlike cells with transverse diaphragms. The box-girder section is efficient for resisting moments and enables a designer to use concrete for spans longer than those generally considered economical for T-girders.

Box-girder bridges are particularly suitable for skewed sites and curved superelevated roadways requiring extra torsional strength. There is generally enough space in both top and bottom slabs for reinforcement to be placed in a single layer. This simplifies construction and permits maximum effectiveness of all bars. Conduits can be carried in the cells.

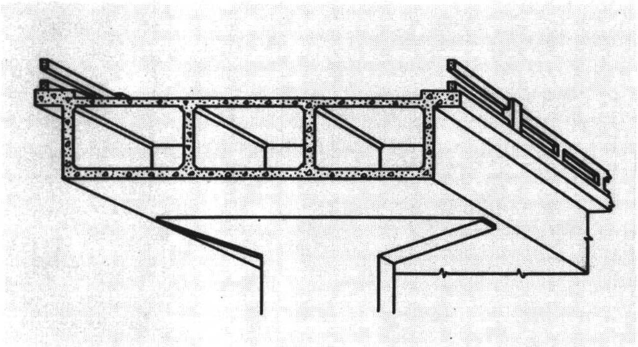

Fig. 7. Box-girder superstructures—a typical one is shown here in a cutaway view—are well suited for both vertical loads and torsional effects.

The two-span bridge in the foreground of Fig. 8 is a box girder functioning as part of a rigid frame. The design, typical of the other bridges shown in the photograph, was selected on the basis of a comparative cost analysis and because it harmonized with the surroundings. This bridge, carrying North Broadway over the Hollywood Freeway, is one of many similar structures in the Los Angeles area.

Closed abutments and a shallow superstructure were used because of the width of the depressed six-lane divided highway and its limited right-of-way. To secure shallow depth, advantage was taken of continuity by making the superstructure integral with abutments and center pier. The bridge is designed for H20-S16 loading of the AASHO *Standard Specifications for Highway Bridges* (1953) plus a special loading for vehicles of the Los Angeles Transit Authority. Girders vary in depth from 3 ft. 3 in. at midspan to 5 ft. at supports. The two equal spans are 62 ft. long and carry a roadway 60 ft. wide.

Another example of rigid-frame box-girder construction is the Highland Creek Underpass (see Fig. 9), which is located east of Toronto, Ont., Canada, and carries local traffic over Highway 2A on a 115-ft. span. Formwork for the structure was designed to create a rough-board texture.

The bridges in Fig. 10 are typical of multilevel grade-separation structures used by the California State Department of Public Works, Division of Highways. The top two levels are continuous hollow box girders while the third level is continuous-slab construction. This four-level interchange in Los Angeles provides nonstop traffic for the Hollywood Freeway (top level) and the Harbor Freeway (third level), with interchange ramps between the two expressways. The adaptability of concrete to structural,

Fig. 9. This long-span rigid-frame box-girder bridge near Toronto, Ont., Canada, provides safety through maximum visibility and unrestricted passage. Design: Department of Highways, Ont., Canada. Construction: Bailey Construction Co., Toronto, Ont., Canada.

Fig. 8. Vertical clearance and right-of-way limitations were easily satisfied by the use of rigid-frame box-girder construction for these bridges in Los Angeles, Calif. Design: City of Los Angeles. Construction: Guy F. Atkinson Co., San Francisco, Calif.

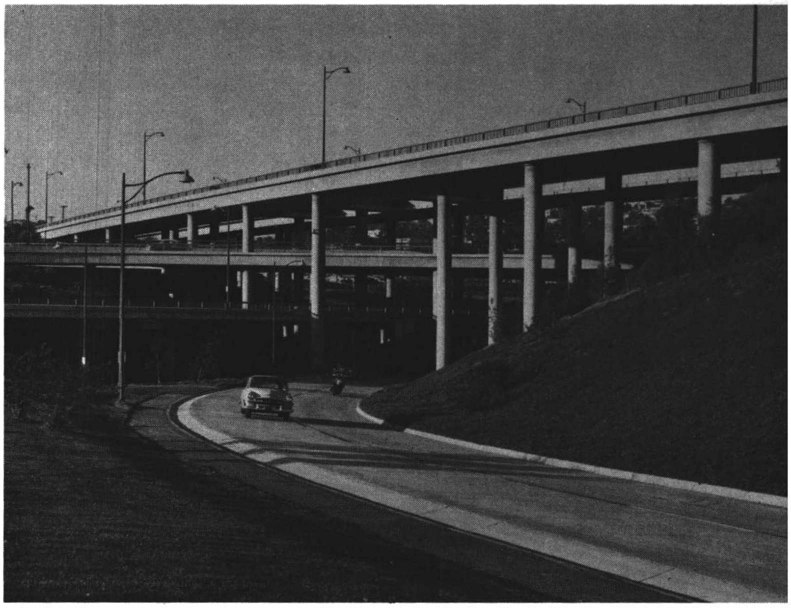

Fig. 10. Long spans and shallow superstructures are provided by box-girder construction in the top two levels of this multilevel grade separation in Los Angeles. Design: California State Department of Public Works, Division of Highways. Construction: James I. Barnes Construction Co., Santa Monica, Calif.

visual and architectural requirements of interwoven structures is well illustrated here.

SLAB

Concrete slab bridges are popular and economical structures for short-span grade separations. Although slab bridges are sometimes composed of one or more simple spans, structural continuity is desirable where good foundation conditions exist or can be provided, because concrete is ideally suited to integral construction. With continuity, the cost of joint construction and maintenance is greatly reduced. Also, a smoother riding surface is secured because deflections are decreased and there are fewer joints.

Continuous slabs are usually suitable for bridges with end spans up to approximately 35 ft. and interior spans proportionately longer (see page 11). The shallow superstructure inherent in slab construction helps solve the common problem of vertical clearance. A minimum grade differential between the two roadways generally results in overall economy because the height of embankments is reduced.

The four-span continuous concrete slab bridge in Coshocton, Ohio, shown in Fig. 11, is typical of structures used by the Ohio Department of Highways for a series of short spans. The 18½-in. slab is designed for S-20-46 live load, as specified by the State of Ohio, equivalent to AASHO H20-S16 loading. Interior span lengths of 40 ft. are balanced by end spans of 32 ft. The bridge carries four 13-ft. traffic lanes, a 4-ft. raised median and two 6-ft. sidewalks.

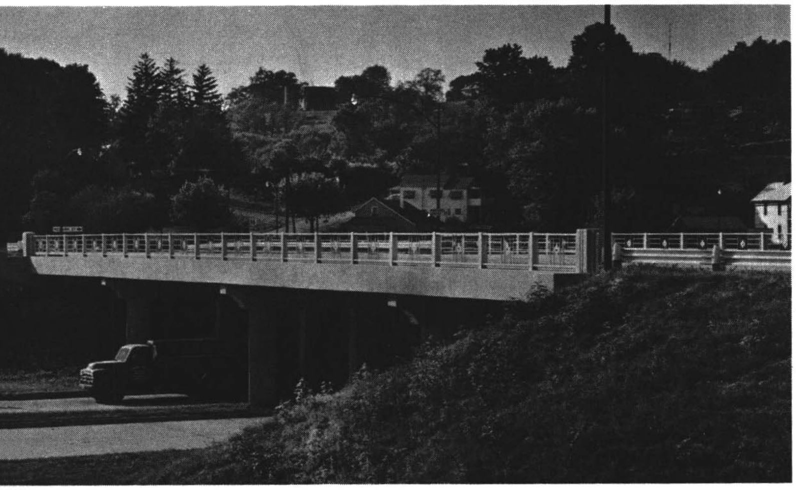

Fig. 11. Economical short-span bridges are obtained with a continuous concrete slab, such as this one in Coshocton, Ohio. Design: Ohio Department of Highways, Bridge Bureau. Construction: V. N. Holderman & Sons, Inc., Columbus, Ohio.

RIGID FRAME

The concrete rigid-frame bridge, economical for spans ranging from about 35 ft. to 100 ft. or more, provides maximum structural continuity. Integral construction of both horizontal and vertical members permits a shallow deck and reduces material used in the bridge approaches. As is evident in the accompanying photographs, the rigid-frame bridge integral with closed abutments and intermediate piers is more massive in appearance than the T-girder bridge, such as those shown in Figs. 5 and 6. This is only one type of rigid frame. A bridge integral with two intermediate piers and free at the abutments is also a rigid frame. Because of its monumental appearance, a rigid frame is particularly suitable for parkways and boulevards.

Fig. 12 shows the impressive two-span rigid-frame bridge that carries McCutcheon Road over U.S. 40 in St. Louis County, Mo. This structure was selected for the site because of its economy, appearance and general usefulness. Although the wingwalls create a feeling of massiveness, the curved intrados carried from one embankment to the other gives the bridge a graceful appearance.

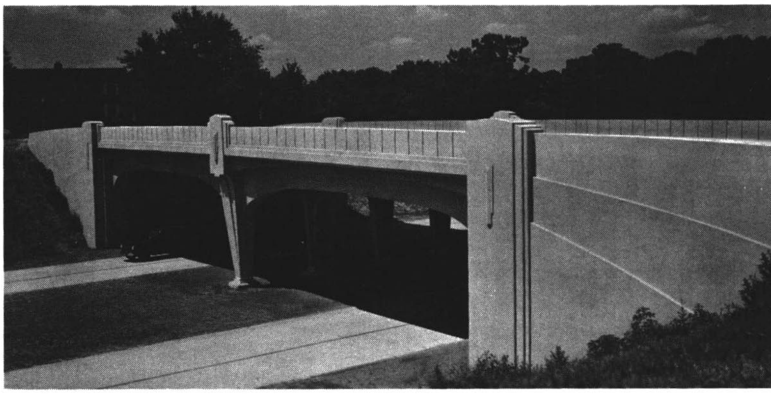

Fig. 12. Special architectural effects can be developed economically with the rigid-frame bridge. This all-concrete structure is in St. Louis County, Mo. Design: Sverdrup & Parcel, Inc., St. Louis, Mo. Construction: Israel Bros., Clayton, Ohio.

Horizontal clearance for each span is approximately 62 ft., with a minimum vertical clearance of 14 ft. The superstructure carries a roadway 44 ft. wide with an additional 7 ft. 9 in. at each side for curb, sidewalk and handrail. The five reinforced concrete frames vary in depth from about 4 ft. at midspan to a little more than 9 ft. at abutments and center columns. The deck slab is 10½ in. thick.

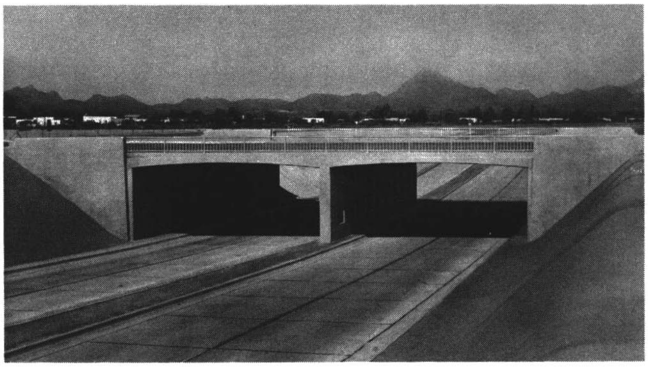

Fig. 13. The shallow superstructure of the solid-slab rigid frame minimizes earthwork in bridge approaches. Side slopes at this structure in Tucson, Ariz., have been given a protective surfacing of pneumatically applied mortar. Design: Bridge Division, Arizona State Highway Department. Construction: San Xavier Rock & Sand Co., Tucson, Ariz.

A solid slab without girders serves as the deck of the bridge in Fig. 13. This structure carries U.S. 89 over U.S. 80 in Tucson, Ariz., and accommodates a 72-ft. roadway and two 6-ft. sidewalks. Preference was given to this design because past experience proved it to be economical and because of its general suitability to the terrain. Each span provides a horizontal clearance of 34½ ft. from the breastwall to the face of the 2-ft. thick center pier. The breastwalls and pier are supported by spread footings. Earth slopes adjacent to the wingwalls were given a surface of pneumatically applied mortar to prevent erosion.

Another solid-slab rigid-frame bridge is illustrated in Fig. 14. This bridge, which carries Route 638 over the Henry G. Shirley Memorial Highway in Fairfax County, Va., adds beauty to the parkway. The slab varies in thickness from 2 ft. 2½ in. at midspan to 6 ft. 1½ in. at abutments. It spans 81 ft. to carry a 26-ft. roadway designed for AASHO H-20 loading. The curved intrados of the bridge is in harmony with the rolling countryside.

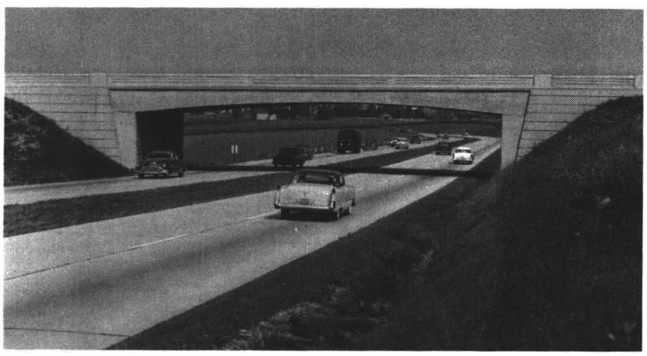

Fig. 14. Concrete lends itself to many attractive variations in architectural form, as shown in this rigid-frame bridge on the Henry G. Shirley Memorial Highway in Fairfax County, Va. Design: Virginia Department of Highways. Construction: Guy H. Lewis & Son, McLean, Va.

Fig. 15. Maximum driving safety is provided by carrying the full roadway width, including shoulders, under structures on the Dallas Central Expressway. Design: Texas State Highway Department. Construction: Austin Bridge Co., Dallas, Texas.

Typical of grade-separation structures on the Dallas Central Expressway is the two-span rigid-frame bridge shown in Fig. 15, which carries the 48-ft. wide roadway of Monticello St. over U.S. 75 on two 54-ft. 9-in. spans. The slab varies in depth from 1 ft. 4 in. at the center of each span to 3 ft. 1¼ in. at abutments and piers. Comparative cost analyses showed this design to be equal to any other in first-cost economy. Concrete was chosen for its durability, architectural versatility and low maintenance cost.

ARCH

The arch, one of the oldest and most graceful of architectural forms, is suitable when there is sufficient difference between the elevations of intersecting roadways. The concrete arch bridge shown in Fig. 16 carries Brinton Road approximately 40 ft. above the Penn-Lincoln Parkway at Pittsburgh, Pa. The ribs span 164 ft. and are 6 ft. wide, with depth varying from 4 ft. 7½ in. at the springing to 2 ft. 6 in. at the crown. Spandrel columns 3 by 1½ ft. in cross-section support floor beams that in turn carry a deck slab 10 in. thick. The deck accommodates two 12-ft. traffic lanes and two 5-ft. sidewalks. An arch was chosen for this site because of its beauty and its suitability to the conditions.

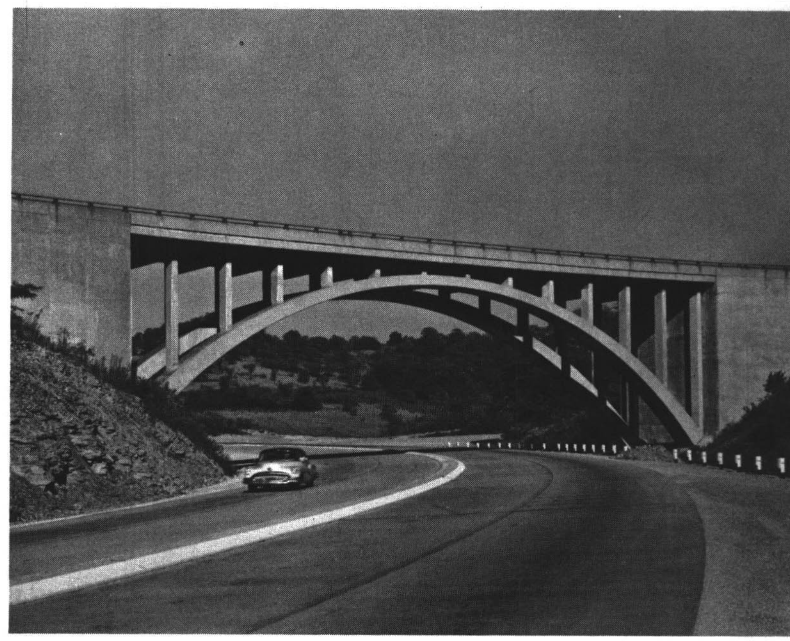

Fig. 16. The graceful lines of this concrete arch bridge add beauty to the scenic Penn-Lincoln Parkway at Pittsburgh, Pa. Design: George S. Richardson, Pittsburgh, Pa. Construction: Sanctis Construction, Inc., Pittsburgh, Pa.

PRESTRESSED GIRDER

Prestressed concrete, a modification of reinforced concrete, takes advantage of high-strength concrete and steel and results in members that are graceful in appearance and often shallow enough to reduce the cost of retaining walls and bridge approaches. Prestressed concrete members are comparatively light and easily handled.

Twelve bridges on the Garden State Parkway, a north-south toll route near the New Jersey coast, consist of precast-prestressed concrete girders supporting cast-in-place deck slabs. Contractors bid only on prestressed concrete for these structures although alternate construction was allowed.

Spans vary from about 39 ft. to 60 ft. However, interior girders for all bridges are of the same I-shaped cross-section and have a 33-in. depth, 6-in. web, 12-in. wide top flange and 19-in. bottom flange. Fascia beams are also 33 in. deep but have a rectangular section to provide a smooth, exposed vertical surface. Stress variations in the girders due to different span lengths are compensated for by variations in the girder spacing and the number of steel strands per girder.

Fig. 17, one of the Garden State Parkway bridges, illustrates the ease with which precast-prestressed girders are handled during erection. The completed structure carries the Parkway over U.S. 322 and U.S. 40 near Atlantic City, N.J., on two 58-ft. simple spans. Girders are spaced at 3-ft. 4-in. centers across the 90-ft. roadway width. The superstructure is prestressed transversely by cables that pass through diaphragms at the third-points of each span.

The Wisner Blvd. Overpass, shown in Fig. 18, is a 1,420-ft. grade-separation structure in New Orleans, La. Use of precast-prestressed members not only reduced construction time but also permitted uninterrupted traffic on the 42-ft. span over two railroad tracks. Each of the other 23 spans is 60 ft. long. Eight posttensioned, T-shaped girders were used for each span.

Fig. 18. Site-casting the 192 posttensioned 60-ft. girders needed for the Wisner Blvd. Overpass, New Orleans, La., reduced handling to a minimum. Precast diaphragms were used between the beams, which were set 6 ft. 8 in. apart. Design: George A. Heft & Co. Construction: Keller Construction Corp. Both are of New Orleans.

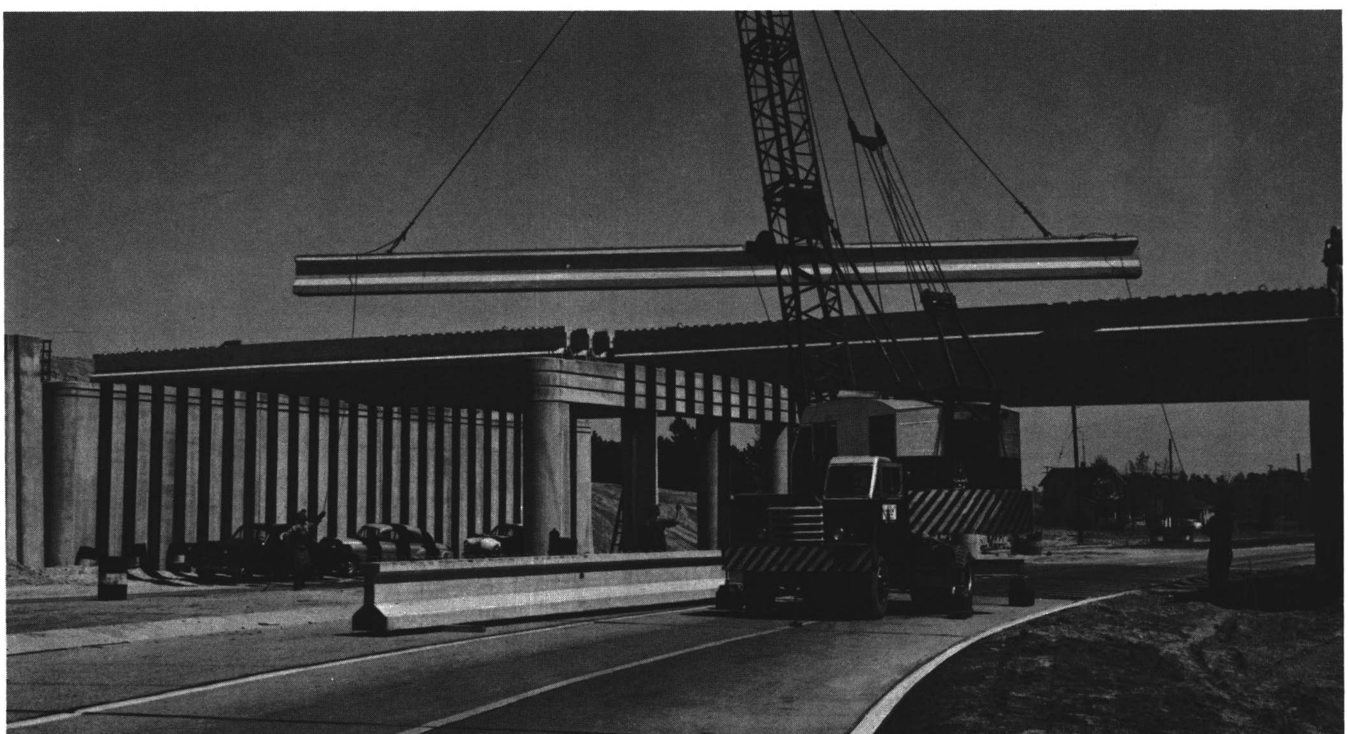

Fig. 17. Using precast-prestressed concrete girders facilitates construction and minimizes interference with traffic. This photograph shows precast-prestressed girders being erected to carry the Garden State Parkway in New Jersey over U.S. 322 and U.S. 40. Design: Gannett, Fleming, Corddry & Carpenter, Inc., Harrisburg, Pa. Gonstruction: S. J. Groves & Sons Co., Woodbridge, N.J.

SECTION 3. *Design Considerations*

To develop any new bridge project successfully, designers must know the requirements to be met. Consideration must be given to bridge types, span lengths, deck widths, clearances, alignment, and sight distances. The completed structure must not only provide necessary functional features but should also add to the overall appearance, usefulness and safety of the highway system.

Established standards are helpful as a guide in the determination of minimum requirements. For highways that are part of the National System of Interstate and Defense Highways, Tables 1 and 2 (Appendix B, pages 19-20) give the minimums recommended by AASHO. For highways that are not part of the National System of Interstate and Defense Highways, Tables 3 and 4 (Appendix C, pages 21-22) give the minimums recommended by AASHO.

SAFETY

It is difficult to show a direct relationship between the cost of a grade-separation structure and the safety it affords. However, there are many valuable safety features inherent in good layout practices and, therefore, they are obtained without the expenditure of additional money. The most functional layout can be, and often is, the safest and most economical one.

The safe structure is one that least restricts motorists. A good example is the deck bridge with open end spans, similar to the one shown in Fig. 4, page 5. In contrast, bridges that have massive, solid abutments are likely to give the motorist a feeling of constriction, especially if the abutment is close to the edge of the pavement. Generally, open end spans are also economical. However, in cases where the right-of-way is limited, closed abutments with wingwalls may provide the only practical solution.

SPAN LENGTHS

The determination of minimum span lengths is controlled by clearance requirements, grades, and fill slopes.

In continuous bridges the ratio of interior-span length to end-span length has a direct effect on cost. For this reason the optimum ratio should be used whenever possible. On the basis of (1) AASHO loadings; (2) concrete design stress of $f_c = 0.40\,f'_c$; and (3) use of 3,000-psi concrete, the following ratios of interior to end spans are recommended:

For slab bridges with end spans up to 35 ft.: 1.26:1
For slab bridges with end spans 35 to 50 ft.: 1.31:1
For girder bridges with end spans 35 ft. and more: 1.37:1 to 1.40:1

In general, if end spans exceed 35 ft., it is more economical to use girder construction than a solid slab.

The span ratios given are for continuous decks that are not integral with supports. If superstructures and supports are integral or if allowable working stresses or loads are changed, some deviations are to be expected. However, the values given are usually satisfactory for planning and for preliminary cost estimates.

VERTICAL CLEARANCE AND DECK WIDTHS

For bridges not on the National System of Interstate and Defense Highways, AASHO *Standard Specifications for Highway Bridges* (1953) recommends a minimum vertical clearance of 14 ft., plus an allowance for future paving. The ideal deck width allows space for both the approach pavement and shoulders. AASHO recommends that the roadway be at least 6 ft.* wider than the pavement and not less than 26 ft. for two traffic lanes. For each additional lane the roadway should be widened 10 to 12 ft.

Bridges on the Interstate System must have a clear height of not less than 14 ft. over the entire roadway, including the usable width of shoulders. The width of bridges with a length of 150 ft. or less between abutments or end supporting piers is to equal the full approach roadway width, including the usable width of shoulders. Barrier curbs on bridges longer than 150 ft. are to be offset at least 2 ft. from the edge of the through-traffic lane. Also, offsets to the face of the parapet or handrail should be at least 3½ ft. at both the right and the left.

Although it is desirable to carry the full median strip across any bridge, this becomes economically impractical when the median is very wide. It is satisfactory in this situation to decrease the width of the strip gradually as the bridge is approached. Two separate structures, one for each direction of traffic, are desirable if it is economically feasible.

In practice there is no general rule governing the transition point from a single to a double structure. As one example, the Illinois Department of Public Works and Buildings, Division of Highways, changes to a double bridge at a median width of about 20 ft.

ARCHITECTURAL DESIGN

At the outset of the planning stage a grade-separation structure should be studied from the architectural as well as the structural viewpoint. Although there is no easy rule to follow that will ensure the proper aesthetic use of a building material, experience has shown that close cooperation between engineer and architect leads to the most satisfactory result.

In the case of a bridge, it is important for the designer to recognize that his structure will probably outlast many aspects of its surroundings and that foresight is necessary to assure lasting beauty. To help achieve this goal, concrete offers the advantage of versatility. The choice of bridge type as well as of its shape and lines is completely unrestricted by the building material, and a design may be developed that is in complete harmony with the surroundings.

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*But 4 ft. when safety curbs or contiguous sidewalks are used, or if traffic lane widths exceed 12 ft.

SECTION 4. *Planning a Grade-Separation Structure*

Three typical situations have been selected to illustrate the principles of layout of a highway grade-separation structure: (1) highway over highway, unrestricted site; (2) highway over railroad, restricted site; (3) highway over highway, restricted site.

HIGHWAY OVER HIGHWAY, UNRESTRICTED SITE

A two-lane, east-west secondary highway 24 ft. wide intersects a six-lane, north-south Interstate expressway at right angles in open, level country. It is desired to separate the intersecting roads by carrying the east-west highway over the expressway. The median between north- and south-bound expressway traffic lanes is 36 ft. Each 36-ft. roadway has 10-ft. shoulders, as shown in Fig. 19. Design live load is AASHO H20-S16.

Determination of Bridge Type

The selection of a structure to separate traffic at this intersection is simplified because there are no space restrictions. As a result, in the layout full attention can be given to function and appearance.

Safest driving conditions for expressway traffic would be obtained if the entire roadway, including shoulders, were spanned by the secondary highway bridge without the use of a center pier. However, the gain in safety would not be great enough to justify the increased cost of the long span, especially since the pier would occupy only about one-tenth of the 36-ft. median width.

If a center pier is assumed, the expressway will be accommodated either by a structure with closed abutments, of the type shown in Fig. 19(a), or by one with open end spans, as sketched in Fig. 19(b). In either case the superstructure can consist of slab or slab-and-girder construction designed either as a rigid frame, a series of continuous spans, or a series of simple spans.

In open country, the confinement of earth fill is unnecessary. In addition, solid abutments at each side and a pier in the middle give the motorist a feeling of constriction, causing him to focus his attention on the bridge and to "aim" for the center of the passageway. As a result, the vehicle usually moves toward the center of the road.

Open end spans with spill-through abutments provide a structure that does not distract the driver's attention and is usually economical. Therefore, closed abutments are eliminated in favor of the type shown in Fig. 19(b). Structural continuity is adopted to take advantage of the integral action of all spans.

Span Lengths

The choice of either slab or slab-and-girder construction is made by comparing relative costs of each type for the indicated span lengths. Each interior span will be about 65½ ft. long if 3-ft. piers are assumed. Tentative end spans may be determined by ratios given on page 11.

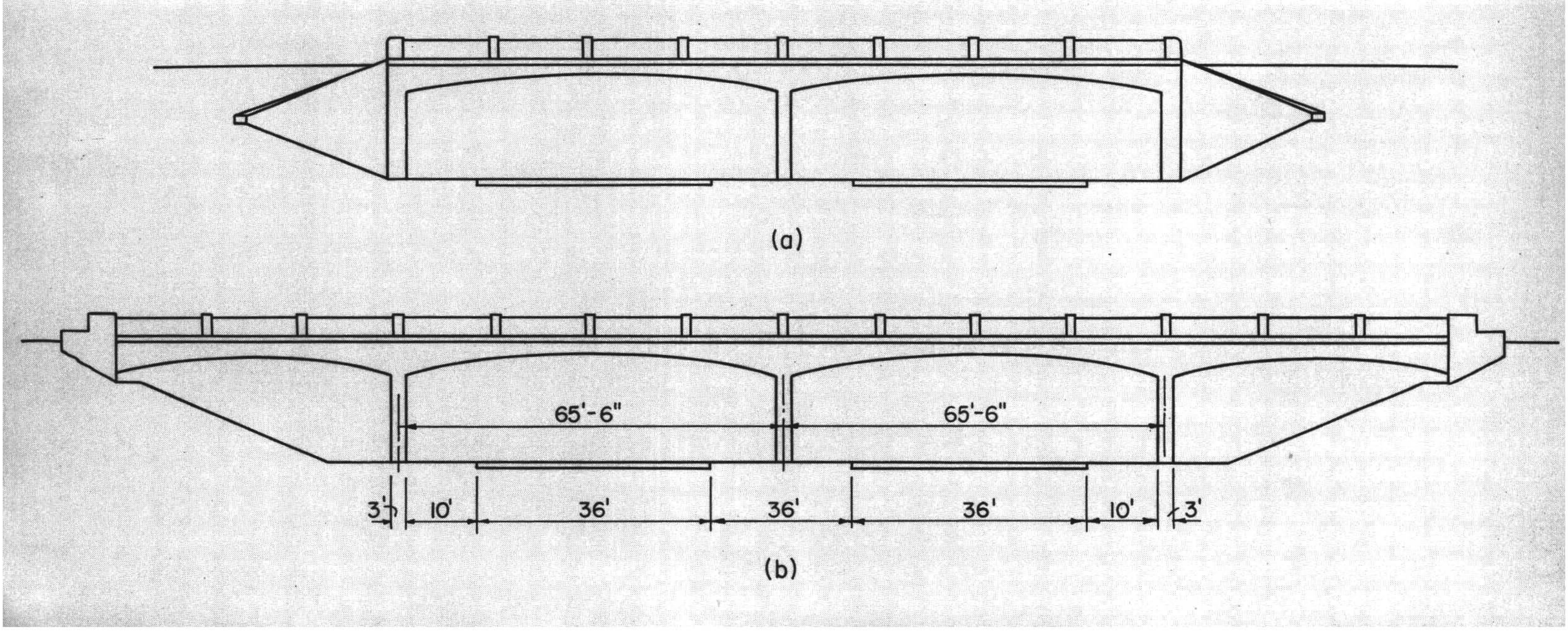
If slab construction is used, the ratio 1.31:1 indicates end spans of about 50 ft. (65½ ÷ 1.31 = 50 ft.). This end-span length eliminates the slab from further consideration since girder construction is usually more economical when end spans exceed 35 ft. With girders, the value 1.37 gives end spans of about 48 ft.

Superstructure Dimensions

Deck width may be determined by following AASHO recommendations. Width of the roadway will be equal to the pavement width of 24 ft. plus 4 ft., or 28 ft., between safety curbs. When 3 ft. is allowed on either side for safety curbs and handrails, the overall superstructure will be 34 ft. wide.

A 7-in. deck slab is common for H20-S16 loading. For this thickness, economical girder spacing varies from 7 ft. to 10 ft., as discussed in *Continuous Concrete Bridges*, page 60. If five girders are assumed, spacing can be 7 ft. 3 in., which leaves a distance of 2 ft. 6 in. from centerline

Fig. 19. A comparison of bridges with (a) closed abutments and (b) open end spans.



of outside girder to the exterior bridge face. If desired, however, spacing can be altered so that exterior girders are flush with the edges of the deck.

Although the stem width of a T-girder depends on several variables, approximate width may be taken to be $b' = 0.0025 \sqrt{b} \times L$ (also shown in *Continuous Concrete Bridges* on page 60), where b is the center-to-center spacing of girders and L is the length of the end span. When dimensions already established are used,

$$b' = 0.0025 \sqrt{7.25 \times 12} \times 48 \times 12 = 13.4 \text{ in.}$$

Experience has shown that a minimum stem width of 17 in. is necessary to allow sufficient space for placing reinforcement; therefore, a width of 17 in. is assumed in this case.

When girder spacing and stem width have been tentatively determined, girder depth over interior supports is found to be 70 in. (*Continuous Concrete Bridges*, Fig. 47, page 63). If the girders are assumed to have a parabolic soffit, approximate midspan depth may be determined by dividing support depth by 2.3, an average value for the ratio of support to centerline depths for girders of this shape. This gives a midspan depth of approximately 31 in.

HIGHWAY OVER RAILROAD, RESTRICTED SITE

A four-lane divided Interstate highway is to pass at right angles over an existing double-track railroad on which traffic must be maintained at all times. Tracks are 14 ft. on centers. The two 24-ft. roadways of the highway are paralleled by 10-ft. wide shoulders but are separated by only a 4-ft. median strip because of confining topography nearby. Sufficient right-of-way is available to allow construction of approach fills with 2-to-1 side slopes.

Determination of Bridge Type

The main consideration is to provide a bridge that will perform its functional requirements efficiently and that can be constructed with a minimum of inconvenience to the railroad. Units that are both precast and prestressed are ideally suited to this situation because of the speed with which they can be erected.

Since the railroad right-of-way at this site does not require confinement of fill, closed abutments are not considered. Instead a multiple-span bridge that has spill-through abutments and a precast-prestressed concrete superstructure appears most desirable. Features that promote good driving conditions on the roadway carried over the tracks should, of course, be included in the design.

Span Lengths

Well-defined clearance requirements for proper operation of railroad equipment determine span lengths and vertical height. The *Manual for Railway Engineering** establishes a minimum horizontal clearance of 8 ft. from track centerline to the faces of bridge piers and a minimum vertical clearance of 22 ft. from top of rail to soffit of the overhead bridge. During construction, minor encroachments on these minimum clearances may be allowed if permission is secured from the railroad.

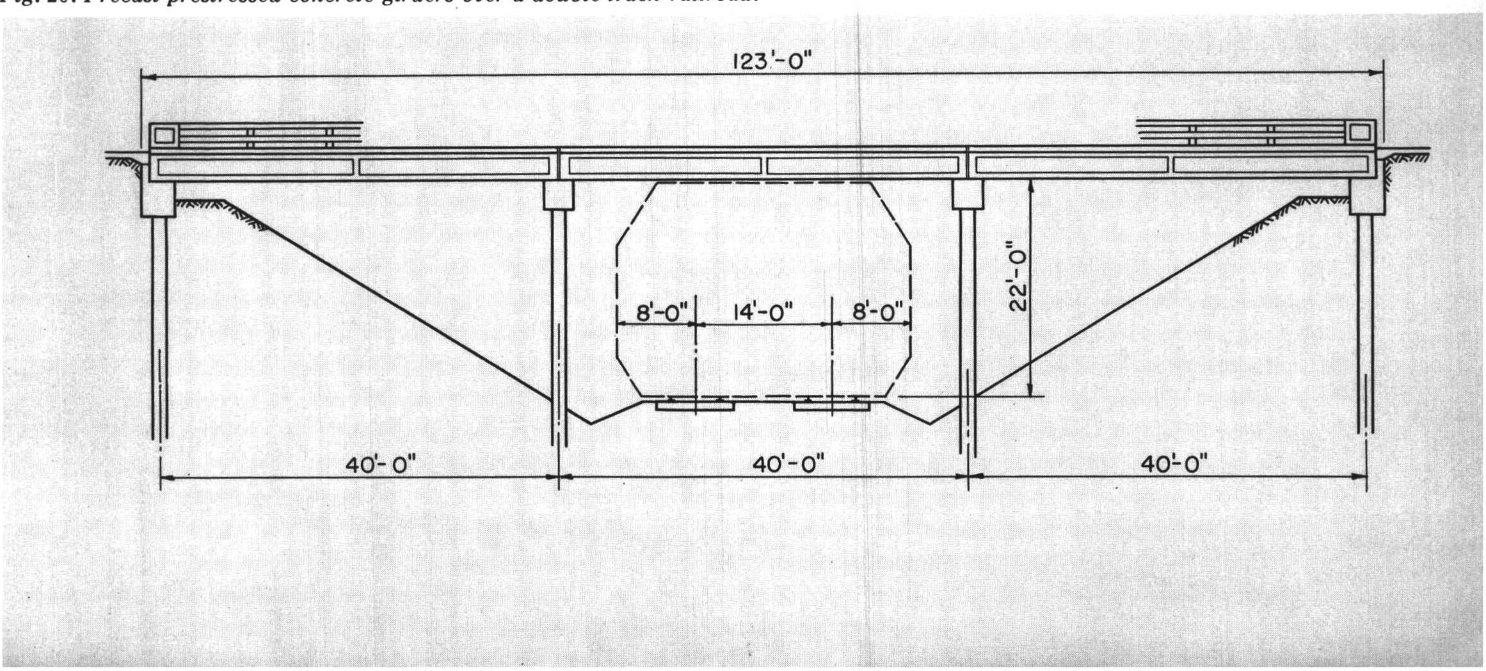
According to these specifications, minimum clear span over the tracks should be $14 + (2 \times 8) = 30$ ft. If 2 ft. is allowed for depth of superstructure and 22 ft. is added for required vertical clearance, grade differential between road surface and top of rail is 24 ft. If a 2-to-1 slope for fill at the abutments is assumed, the bridge length, including abutments, is approximately 120 ft.

Proposed Layouts

A suggested layout involving three 40-ft. simply supported spans with precast-prestressed members is shown in Fig. 20. Although earth slopes are increased slightly and the center span is 7 ft. longer than the required minimum of 30 ft. clear plus 3-ft. pier width, this plan results in maximum duplication of parts because all girders are of equal length. However, the cost of a bridge that utilizes equal-length girders should be compared with the cost of one that has a shorter, shallower center span since a shallow superstructure will reduce the earthwork in bridge approaches. Also, if precast members of reinforced rather than prestressed concrete are used, shorter spans are needed

*Published by the American Railway Engineering Association, Chicago, Ill.

Fig. 20. Precast-prestressed concrete girders over a double-track railroad.



to minimize the weight of individual units.

As an alternate layout, the center span may be reduced to 33 ft. with the remaining 87 ft. divided to form a five-span structure.

HIGHWAY OVER HIGHWAY, RESTRICTED SITE

A non-Interstate freeway to be built within city limits is to have four 12-ft. traffic lanes separated by a 4-ft. median strip. The freeway will be constructed in a cut and the finished grade will be dependent on vertical clearances required at several other grade-separation structures. The bridge considered in this example is to carry an existing roadway 48 ft. wide with a 6-ft. sidewalk at each side across the freeway. The location limits the freeway right-of-way to 110 ft.

Determination of Bridge Type

The most economical bridge is not always the best from the functional point of view. For example, a bridge with an intermediate pier at the center of the 4-ft. median strip would probably be the most economical for this site, but to maintain clearances recommended by the AASHO it is necessary to span the entire roadway without intermediate support. A clear span of 64 ft. complies with AASHO recommendations by providing a 6-ft. clearance from edge of roadway to face of pier or abutment.

If a three-span continuous bridge is used, end spans will be about 51 ft. long as determined by applying the approximate balanced-span ratio of 1.30:1. However, right-of-way limitations at the site provide a length of only 22 ft. for end spans. As a result, the multiple-span bridge is eliminated in favor of a single 64-ft. span with closed abutments. The rigid-frame bridge is appropriate because of its shallow deck and relative economy. For spans up to about 70 ft. the rigid frame with a solid deck is usually economical and is recommended in this case.

Experience shows that right rigid frames (those without skew) of the solid-deck type designed for heavy highway loadings have a superstructure depth of about $L/35$ at midspan and L 15 at abutment faces, where L is the clear distance between abutments. If the slab soffit is assumed to be parabolic, depth of the superstructure directly above the outside edge of pavement will be about 3 ft. 5 in. for a span of 64 ft. In contrast, the depth required for a simply supported T-girder of the same length is about 4 ft. 3 in. for girders spaced at 6 ft. or about 5 ft. 9 in. for girders spaced at 9 ft. This comparison indicates one of the advantages of structural continuity.

Preliminary Layout

A quick, simple method of estimating frame dimensions is valuable in preparing architectural studies and preliminary cost estimates. Referring to Fig. 21, the following empirical procedure is applicable to right rigid frames carrying heavy highway loading:

1. Lay out the deck ABA according to roadway requirements.
2. Determine clear span, L.
3. Lay out BC equal to about $L/35$. This value may be reduced to $L/40$ when the foundation is practically unyielding; it should be increased when footings rest on highly compressible soils.
4. Lay out AD and DE equal to about $L/15$.
5. Draw the soffit curve DCD' (usually a parabola).
6. Determine the elevation of F and G from clearance requirements and foundation conditions.
7. Lay out FG equal to about $1\frac{1}{2}$ ft. for 30-ft. spans, about $2\frac{1}{2}$ ft. for 60-ft. spans, and about $3\frac{1}{2}$ ft. for 90-ft. spans.
8. Connect E and F with a straight line.

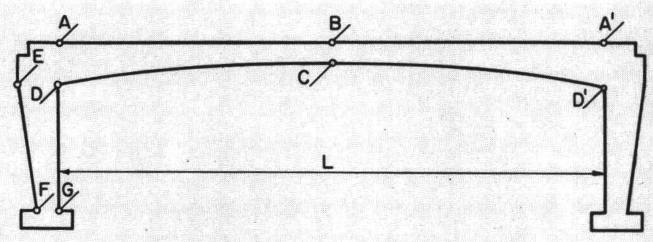


Fig. 21. Outline of a typical single-span, solid-deck, rigid-frame bridge.

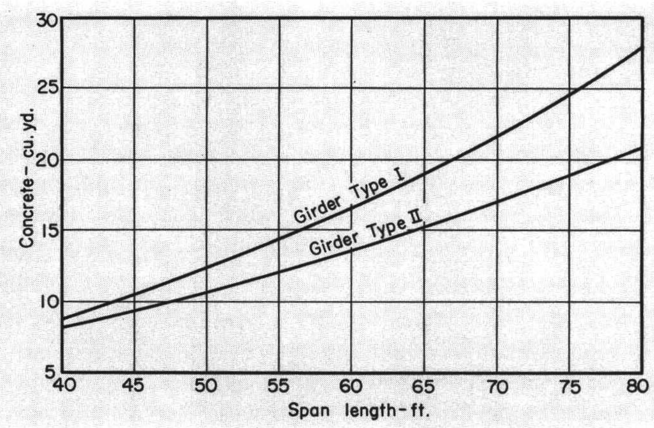


Fig. 22. Concrete quantities required per 6-ft. deck width for prestressed concrete girder spans shown in Fig. 23.

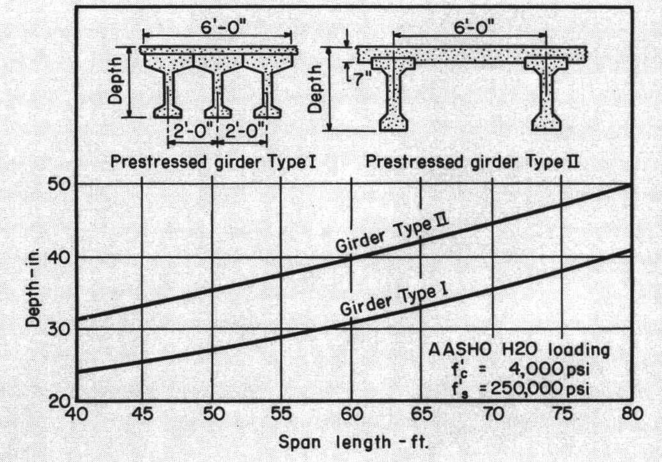


Fig. 23. Depth-to-span relationship for simply supported prestressed concrete girder bridges.

9. Determine roadway and curb widths according to AASHO specifications, adding about 2½ ft. for hand-rail construction.

With the exception of wingwalls, which are controlled by site conditions, essential frame dimensions are now determined and quantities for preliminary estimates may be computed.

Alternate Solution

A shallow superstructure can also be achieved by use of prestressed concrete girders simply supported on closed abutments. Fig. 23 shows depths required by spans varying from 40 ft. to 80 ft. for two girder arrangements, Types I and II, with spacings of 2 ft. and 6 ft. respectively. Fig. 24 illustrates in cross-section the superstructure of the same bridge with the deck slab supported on either of the two types of girders and also indicates appropriate overall depths. Fig. 22 gives concrete quantities involved in each design. Quantities are given for the 6-ft. wide sections shown in the sketches in Fig. 23.

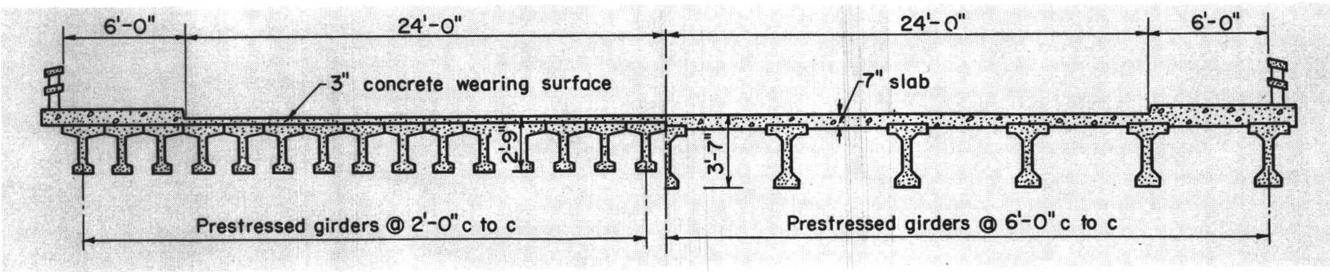


Fig. 24. Alternate layouts of prestressed concrete girders in a bridge superstructure.


NATIONAL AUTOMOTIVE FIBRES INC

Appendix A Geometric Design Standards for the National System of Interstate and Defense Highways*

AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS

ADOPTED JULY 12, 1956

GENERAL

The National System of Interstate and Defense Highways is the most important in the United States. It carries more traffic per mile than any other comparable national system and includes the roads of greatest significance to the economic welfare and defense of the Nation. The highways of this system must be designed in keeping with their importance as the backbone of the Nation's highway systems. To this end they must be designed with control of access to insure their safety, permanence and utility and with flexibility to provide for possible future expansion. Two-lane highways should be designed so that passing of slower moving vehicles can be accomplished with ease and safety at practically all times. Divided highways should be designed as two separate one-way roads to take advantage of terrain and other conditions for safe and relaxed driving, economy and pleasing appearance. All known features of safety and utility should be incorporated in each design to result in a National System of Interstate and Defense Highways which will be a credit to the Nation.

These objectives can be realized by conscious attention in design to their attainment. All Interstate highways shall meet the following minimum standards. Higher values which represent desirable minimum values, a device used in previous Interstate standards, are not shown because it is expected that designs will generally be made to values as high as are commensurate with conditions, and values near the minimums herein will be used in design only where the use of higher values will result in excessive cost. In determination of all geometric features, including right of way, a generous factor of safety should be employed and unquestioned adequacy should be the criterion. All design features required to accommodate the traffic of the year 1975 shall be provided in the initial design; however, where justifiable, the construction may be accomplished in stages.

The Association Policy on Geometric Design of Rural Highways, the Policy on Arterial Highways in Urban Areas, when adopted, and the Standard Specifications for Highway Bridges shall be used as design guides where they do not conflict with these Standards.

TRAFFIC BASIS

Interstate highways shall be designed to serve safely and efficiently the volumes of passenger vehicles, buses and trucks, including tractor-trailer and semi-trailer combinations and corresponding military equipment, estimated to be that which will exist in 1975, including attracted, generated and development traffic on the basis that the entire system is completed.

The peak-hour traffic used as a basis for design shall be as high as the 30th highest hourly volume of the year 1975, hereafter referred to as the design hourly volume, "DHV (1975)." Unless otherwise specified, DHV is the total, two-direction volume of mixed traffic.

RAILROAD CROSSINGS

Railroad grade crossings shall be eliminated for all through traffic lanes.

INTERSECTIONS

All at-grade intersections of public highways and private driveways shall be eliminated, or the connecting road terminated, rerouted, or intercepted by frontage roads, except as otherwise provided under Control of Access.

MEDIANS

Medians in rural areas in flat and rolling topography shall be at least 36 feet wide. Medians in urban and mountainous areas shall be at least 16 feet wide. Narrower medians may be provided in urban areas of high right-of-way cost, on long and costly bridges, and in rugged mountainous terrain, but no median shall be less than four feet wide.

Curbs or other devices may be used where necessary to prevent traffic from crossing the median.

Where continuous barrier curbs are used on narrow medians, such curbs shall be offset at least one foot from the edge of the through-traffic lane. Where vertical elements more than 12 inches high, other than abutments, piers, or walls, are located in a median, there shall be a lateral clearance of at least three and one-half feet from the edge of through traffic lane to the face of such element.

BRIDGES AND OTHER STRUCTURES

The following standards apply to Interstate highway bridges, overpasses and underpasses. Standards for crossroad overpasses and underpasses are to be those for the crossroad.

Bridges and overpasses, preferably of deck construction, should be located to fit the overall alinement and profile of the highway.

The clear height of structures shall be not less than

*To supersede the Design Standards for the National System of Interstate Highways, adopted August 1, 1945.

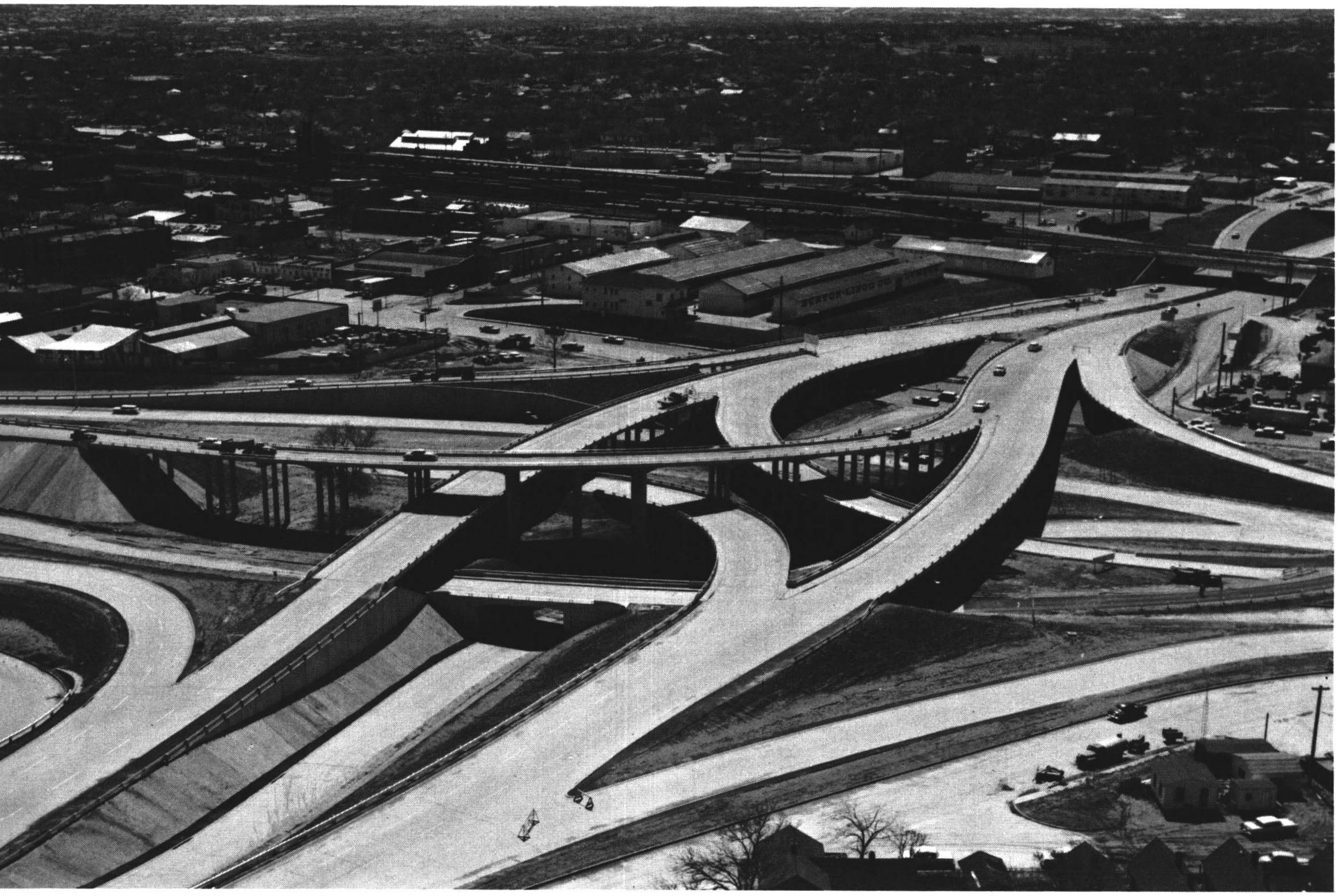
14 feet over the entire roadway width, including the usable width of shoulders. Allowance should be made for any contemplated resurfacing.

The width of all bridges, including grade separation structures, of a length of 150 feet or less between abutments or end supporting piers shall equal the full roadway width on the approaches, including the usable width of shoulders.

Barrier curbs on bridges longer than 150 feet between abutments or end supporting piers and curbs on approach highways if used shall be offset at least two feet. Offsets to face of parapet or rail shall be at least three and one-half feet measured from edge of through-traffic lane and apply on right and left.

The lateral clearance from the edge of through-traffic lanes to the face of walls or abutments and piers at underpasses shall be the usable shoulder width but not less than eight feet on the right and four and one-half feet on the left.

A safety walk shall be provided in tunnels and on long-span structures on which the full approach roadway width, including shoulders, is not continued.



Appendix B Notes for Underpasses and Overpasses on the Interstate System

Tables 1 and 2 show the minimum dimensional requirements for roadway shoulders, medians, and side clearances for bridges and underpasses as defined by the "Geometric Design Standards for the National System of Interstate and Defense Highways." Where definition is not specifically given in the Design Standards, the details presented here are the interpretation by the Bureau of Public Roads of the minimum acceptable dimensions. Vertical clearance in underpasses is 14 ft. plus paving allowance.

Normally, the approach roadway dimensions are carried unchanged over short bridges and through underpasses, unless modification is required by the Design Standards, making desirable the continuation through structures of curbs, guardrails, and similar features of the approaches.

Since safety walks are required on long bridges, this construction is shown with barrier curbs in Table 2, figures A2, B2, and D2. The median width in figure A2 may be 4 ft. with a mountable curb, or 6 ft. with a barrier curb continued from approaches. Where the barrier curb is introduced at the structure, the median width should be 8 ft.

Figure E1 covers the left clearance requirement for vertical construction more than 1 ft. high in the median.

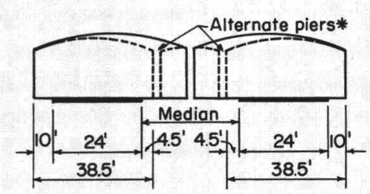
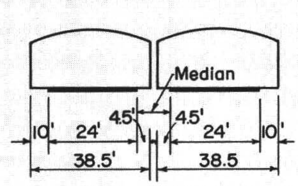
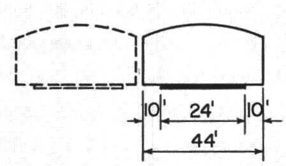
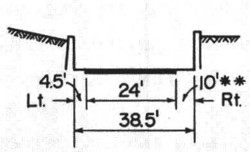
Figure E2 shows the side clearance requirements for elevated structures with adjacent vertical construction.

Left shoulders, W_S, in figure B1 may be carried on short bridges to continue approach shoulders, ranging in width from 2 ft. to 6 ft. Where the 6-ft. width is used, a barrier curb is not required on the structure if approaches have no median curb. For widths less than 6 ft., a barrier curb should be used on the structure.

At the right shoulder of short bridges, see figures E3 and E4, the approach curbs at outer edge of shoulder and the guardrails should be carried on the structure without break in alignment. If the curb is introduced at the bridge, it may encroach 1 ft. 6 in. maximum on the shoulder width in order to continue the approach guardrail alignment.

In those cases where no barrier curbs are provided,

TABLE 1. WIDTHS AT UNDERPASSES ON INTERSTATE HIGHWAYS

	TYPE OF UNDERPASSING HIGHWAY	ROADWAY ELEMENTS THROUGH STRUCTURES
A	FOUR-LANE DIVIDED HIGHWAY Wide median	
B	FOUR-LANE DIVIDED HIGHWAY Narrow median	
C	TWO-LANE DIVIDED as first stage Ultimate four-lane divided highway	
D	TWO-LANE ONE-WAY HIGHWAY	

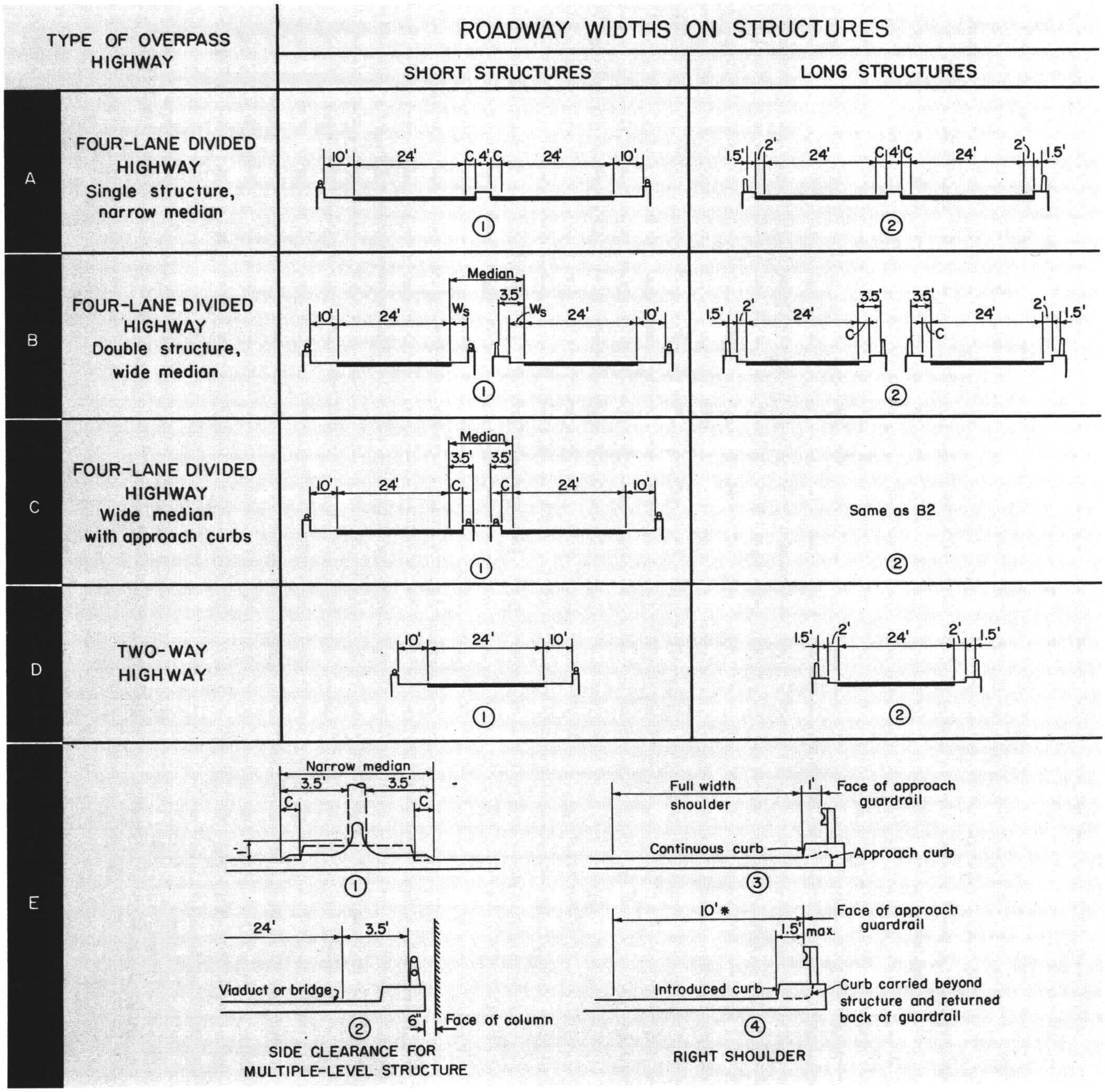
*Alternate for cases where single pier in median is not practicable.

**The 10-ft. right shoulder is the normal minimum, which may be reduced to 8-ft. side clearance where approach shoulders are less than 10 ft., as in rugged mountain terrain. The left or median clearance dimension, 4.5 ft., may not be reduced.

bridge rails shall be designed to resist a lateral force of not less than 500 lb. per lin.ft. applied to the lower rail. Where a single beam-type rail is provided, it shall be designed to resist the force of 500 lb. per lin.ft. applied to the center of the rail.

Where auxiliary lanes come on bridges, a curb will be used with railing offset 1 ft. 6 in. on right and left. In the length of auxiliary lane where the width is less than 12 ft., the curb is offset 2 ft. when introduced at the bridge. On short bridges where the tapered auxiliary lanes come into the right shoulder width, normal shoulder dimensions govern as shown in figure E4.

TABLE 2. WIDTHS AT OVERPASSES ON INTERSTATE HIGHWAYS



*The 10-ft. right shoulder is the normal minimum, which may be reduced to 6 ft. to suit approach shoulders in rugged mountain terrain.

Note: C is the left curb offset in the median: $C=0$ for mountable curbs; $C=1$ ft. for continuous barrier curbs; $C=2$ ft. for introduced barrier curbs.

W_s is the left shoulder width, used only on short bridges. The maximum width recommended for four-lane bridges is 6 ft. Wider shoulders may be considered for six- and eight-lane bridges.

Appendix C **Widths at Underpasses and Overpasses Not on the Interstate System***

TABLE 3. WIDTHS AT UNDERPASSES ON NON-INTERSTATE HIGHWAYS

	TYPE OF UNDERPASSING HIGHWAY	ROADWAY ELEMENTS THROUGH STRUCTURES**		S-WIDTH OF UNDERPASS, IN FT.			
		SINGLE OPENINGS	DOUBLE OPENINGS	SINGLE OPENING		DOUBLE † OPENING	
				Min.	Des.	Min.	Des.
A	FOUR-LANE DIVIDED HIGHWAY	S; 6' 22' 4' 22' 6'; 12' 24' 14' 24' 12'	S; 4.5' 22' 6'; 6' 24' 12'	60	86	32 (68)	42 (88)
B	MAJOR TWO-LANE HIGHWAY as first stage Ultimate divided highway	6' 22' 4' 22' 6'; 8' 24' 6' 24' 8'	4.5' 22' 6'; 4.5' 24' 8'	60	70	32 (63)	36 (76)
C	MAJOR TWO- OR THREE-LANE HIGHWAY Widened through structure and interchange area	6' 22' 4' 22' 6'; 8' 24' 6' 24' 8'		60	70		
D	MAJOR TWO-LANE HIGHWAY Provision for possible future improvement	4' 42' 4'; 6' 48' 6'		50	60		
E	TWO-LANE HIGHWAY No foreseeable improvement in type	6' 22' 6'; 8' 24' 8'		34	40		
F	LOCAL ROAD Narrow two-lane or one-lane width	4' 20' 4'; 6' 22' 6'		28	34		

*From *A Policy on Geometric Design of Rural Highways*, American Association of State Highway Officials, 1954.
**Upper set of dimensions, minimum; lower set of dimensions, desirable. Exclusive of auxiliary lanes and sidewalks.
†Value in parentheses is total width of underpass for two spans.

TABLE 4. WIDTHS AT OVERPASSES ON NON-INTERSTATE HIGHWAYS

	TYPE OF OVERPASS HIGHWAY	ROADWAY WIDTHS ON STRUCTURES*	
		SHORT STRUCTURES	LONG STRUCTURES
A	FOUR-LANE DIVIDED HIGHWAY Single structure	64' / 86' 8' / 12' — 22' / 24' — 4' / 14' — 22' / 24' — 8' / 12' (1)	52' / 58' 2' / 3' — 22' / 24' — 4' — 22' / 24' — 2' / 3' (2)
B	FOUR-LANE DIVIDED HIGHWAY Double structure	32' / 39' 8' / 12' — 22' / 24' — 2' / 3' 32' / 39' 2' / 3' — 22' / 24' — 8' / 12' (1)	26' / 30' 2' / 3' — 22' / 24' — 2' / 3' 26' / 30' 2' / 3' — 22' / 24' — 2' / 3' (2)
C	MAJOR TWO- OR THREE-LANE HIGHWAY Widened over structure and interchange area	52' / 58' 24' / 27' — 4' — 24' / 27'	
D	MAJOR TWO-LANE HIGHWAY	38' / 48' 8' / 12' — 22' / 24' — 8' / 12' (1)	26' / 30' 2' / 3' — 22' / 24' — 2' / 3' (2)
E	TWO-LANE HIGHWAY (Local character)	28' / 38' 4' / 8' — 20' / 22' — 4' / 8' (1)	24' / 26' (2)
F	LOCAL ROAD Narrow two-lane or one-lane width	Pvt.+ 4'	

*Exclusive of auxiliary lanes and sidewalks.
Overall width, face of rail to face of rail: add 3 ft. minimum to roadway widths.
Upper set of dimensions, minimum; lower set of dimensions, desirable.

Back Cover—This attractive bridge at the junction of Routes 90 and 35, near Des Moines, Iowa, was one of the first to be built on the Interstate System. The use of precast-prestressed beams ensured speed of construction.

Printed in U.S.A.