Freeway and Interchange Design: A Historical Perspective

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Controlled-access facilities for vehicular traffic first came into being during the 1920s. Since that time, their design has continually evolved as transportation professionals have gained increased experience in their operation, direction from research, and expanded knowledge of human factors related to driver characteristics and expectations. The need for such facilities was much as it is today—capacity and safety for highways to move people efficiently. Early controlled-access facilities, however, were predominantly isolated grade separations with roadways connecting the two grade-separated highways or streets. It was not until the 1930s that freeway or expressway facilities were constructed with grade separations and interchanges. By the late 1930s and early 1940s, freeways of significant length were constructed as part of a planned system of controlled-access facilities. A variety of different interchange forms came into being as well; the cloverleaf, diamond, and trumpet were the predominant types. By the late 1950s, every basic interchange form had been constructed. Although those basic types have not changed, geometric variations have been developed, constructed, and operationally tested. Discussed are the development and evolution of freeway and interchange design and the safety, operational, and human factors research over the last 30 years that has contributed to recognition of the interchange forms and design elements that produce safe and efficient operations consistent with driver characteristics and expectations.

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EARLY FREEWAY AND INTERCHANGE DEVELOPMENT

Early controlled-access facilities were predominantly isolated grade separations with roadways connecting the two grade-separated highways or streets. The first interchange was constructed in Woodbridge, New Jersey, in 1928 as a cloverleaf (see Figure 1). This was unique at the time because all through and turning movements were uninterrupted.

It was not until the 1930s that freeway or expressway facilities were constructed with grade separations and interchanges. The earliest of these were relatively short in length and were generally not conceived as part of a system or network of controlled-access facilities. Interchanges were predominantly of the cloverleaf type. Horizontal and vertical geometry and cross-sectional features were generally not distinguishable from other lower-type facilities. Some of these early facilities include the Merritt Parkway in Connecticut (Figure 2), the Henry Hudson Parkway in New York City, and Lake Shore Drive in Chicago (Figure 3).

By the late 1930s and early 1940s, freeways of significant length were constructed as part of a planned system of controlled-access facilities. A variety of different interchange forms came into being as well; the cloverleaf, diamond, and trumpet were the predominant types. During this period, several other countries built freeways. In Ontario, Canada, the Queen Elizabeth Way was constructed, and in Germany, the first of the Autobahns was built. In the United States, a long section of the Pennsylvania Turnpike was opened to traffic (Figure 4) and a section of the Davison Expressway with frontage roads was constructed in Detroit (Figure 5).

The Pentagon Road Network (Figure 6) was completed and opened as the first freeway network. This was a system of 10 mi of freeway with 21 grade separations and 11 interchanges. Commonly referred to as the Mixing Bowl, it later became a laboratory of operational experience and research that influenced changes in geometric design criteria for freeway facilities of the future.

The first freeway constructed in the western part of th United States was appropriately in Los Angeles-Arroyo Sec Parkway (Figure 7). It not only connected Los Angeles wit Pasadena, but also channelized the Arroyo Seco (Dry Creek as part of a flood control project. Several diamond inter changes were constructed (Figure 8) as an effort to conserv right-of-way.

POST–WORLD WAR II FREEWAY DEVELOPMENT

After World War II, considerable effort was directed towar planning, design, and construction of freeways and freewa networks in metropolitan areas. In 1944, the Interregiona Highway Commission, which was appointed by Presiden Roosevelt, released recommendations for construction of ap proximately 34,000 mi of freeways to connect all cities wit populations of 300,000 or more and 80 percent of cities o 50,000 or more. This later became the basis for the Interstat system of 1956. The 1944 Highway Act incorporated the com mission's recommendations with expansion to 40,000 mi bu failed to authorize special funding. Portions of this syste were built, however, using primary highway funding, with th

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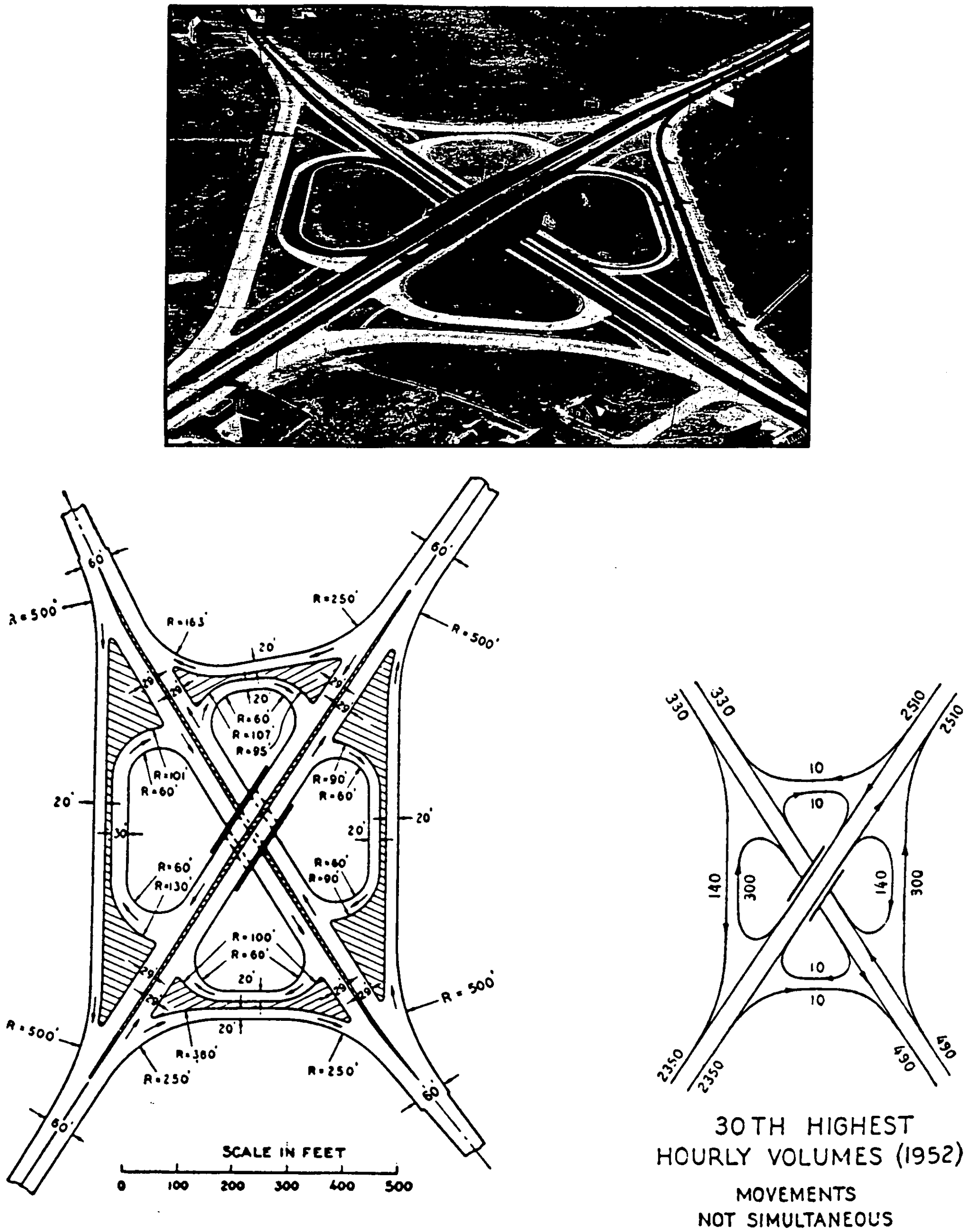

FIGURE 1 Cloverleaf interchange in Woodbridge, New Jersey (1928) (*1*).

ederal government and the states sharing the cost. Many of he facilities constructed during this period were conversions f 2-lane primary highways to 4-lane divided facilities. Many f these were the first to be reconstructed in the late 1970s nd 1980s because they were physically, operationally, and eometrically deficient. They had been designed using criteria f the 1940s, which was based on limited experience.

In 1956 the Federal Highway Act authorized funding at a 0/10 federal/state proportion, and the 42,500-mi system of nterstate highways was born. Finally, the financial resources ere in place to implement the greatest single public works roject of all time.

Although the funding resources were in place, the engi- eering resources to plan, design, and implement the system ere not. Few engineers had experience in freeway and interchange design in 1956. To accomplish the implementation of such a massive system in 20 years required extensive mobilization and training. As with mobilization for the second World War, public agencies and private enterprise responded in exemplary fashion. By 1965, some 27,000 mi of the system was constructed or was under construction—a monumental effort. By the early 1970s, more than 90 percent of the system was completed and opened to traffic.

By the mid-1960s, enough experience had been gained in operating the Interstate highway system and research conducted relating geometrics, operations, and safety that the design criteria of the 1940s and 1950s was being rethought. This naturally is part of the planning, design, and implementation process. The freeways of the 1940s, 1950s, and early 1960s also became a laboratory of observation and a research

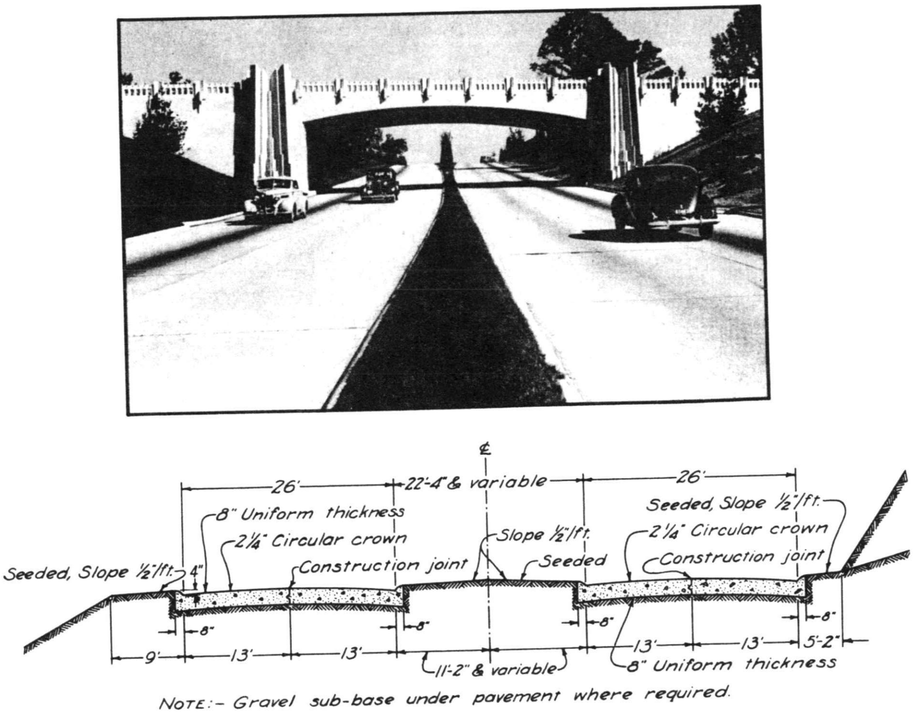

FIGURE 2 Photograph and typical cross section of Merritt Parkway, Connecticut.

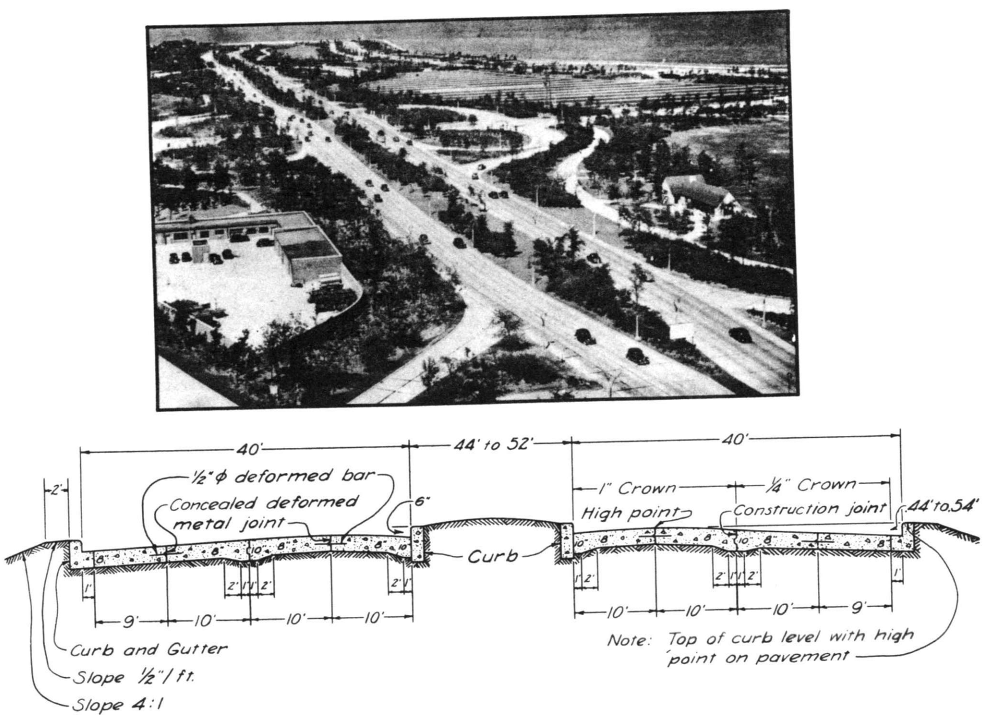

FIGURE 3 Photograph and typical cross section of Lake Shore Drive, Chicago.

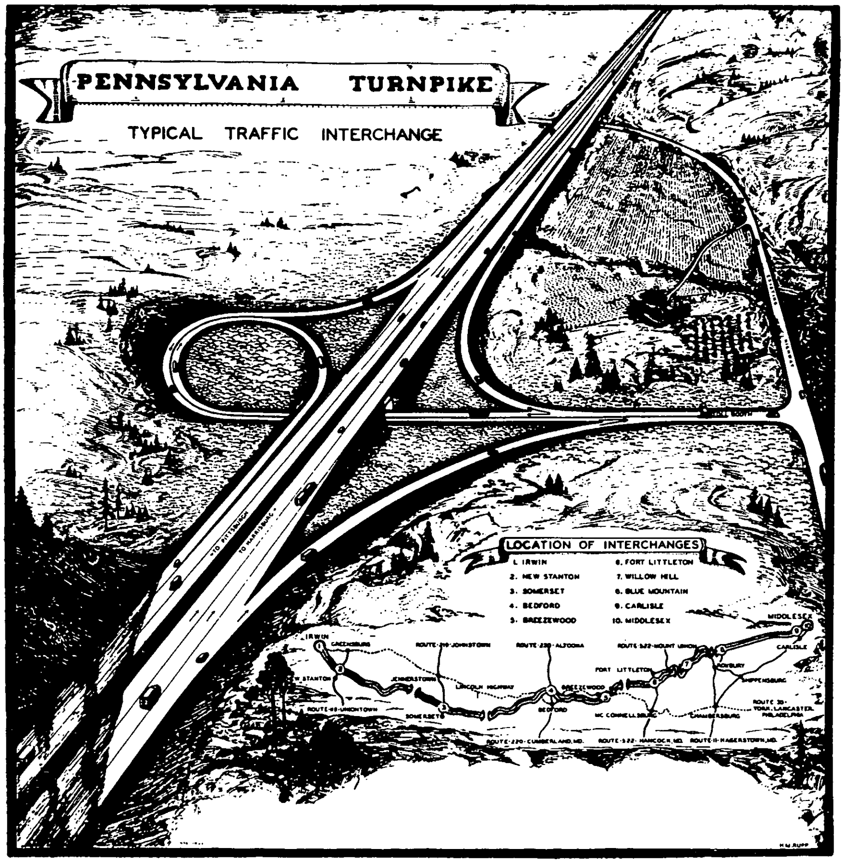

FIGURE 4 Pennsylvania Turnpike.

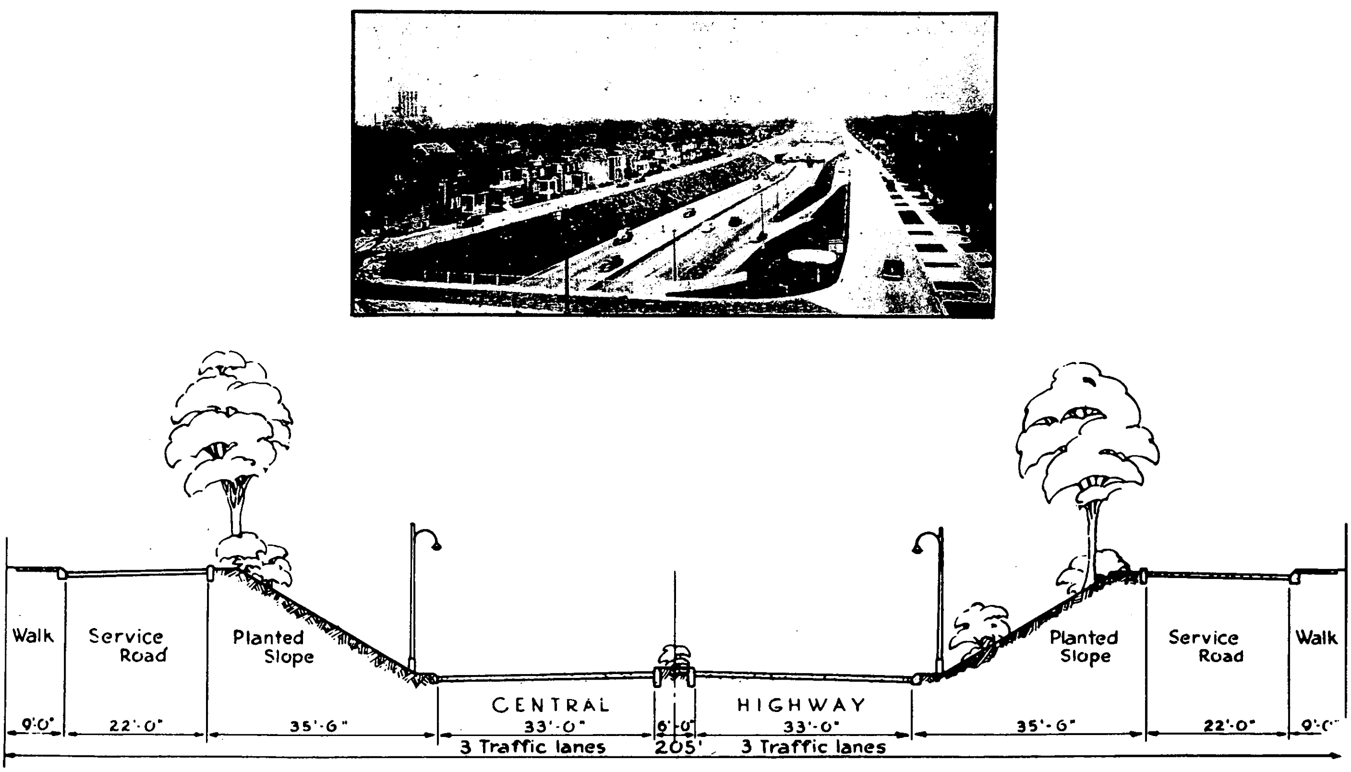

FIGURE 5 Photograph and typical cross section of Davison Limited Freeway, Detroit, Michigan.

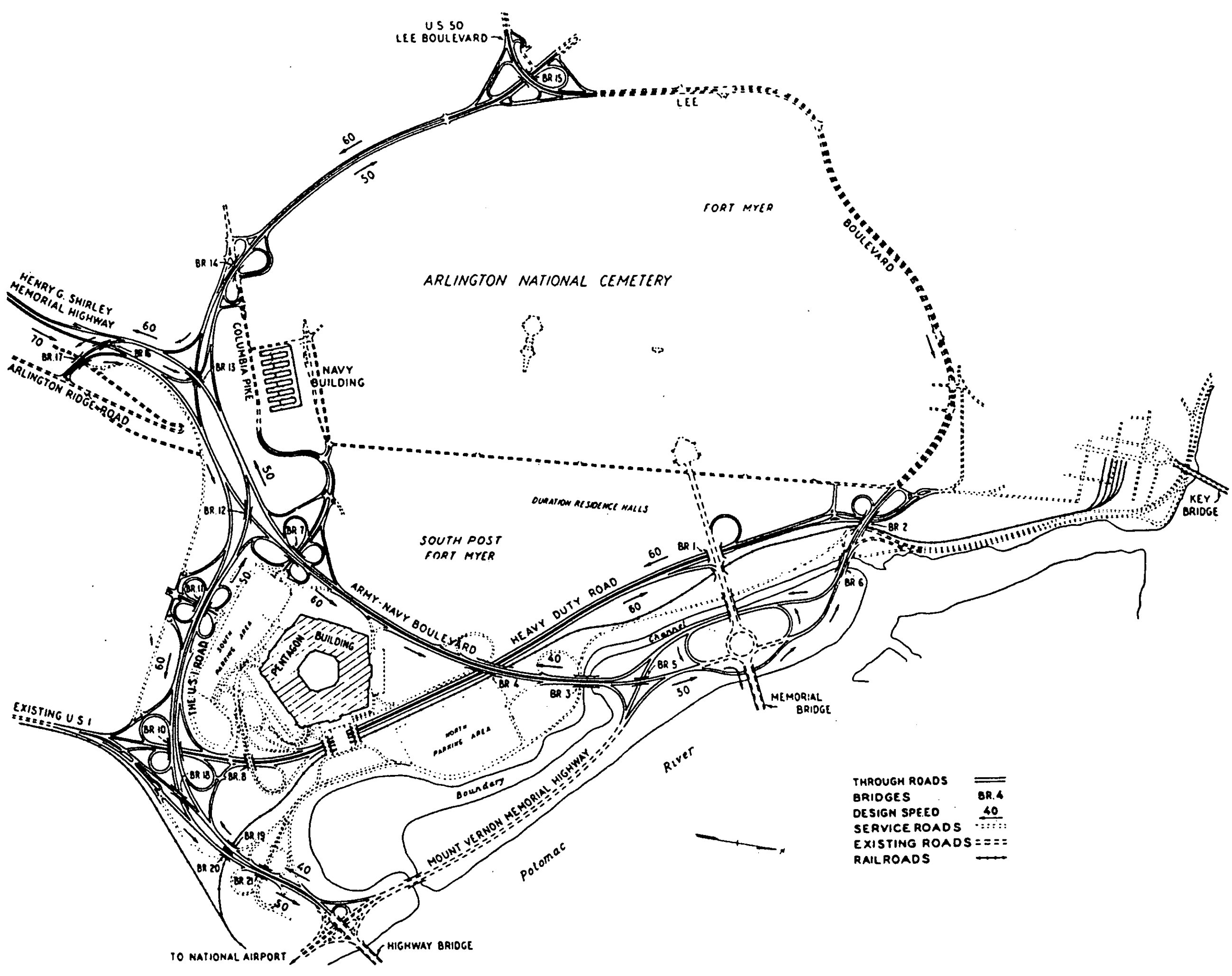

FIGURE 6 Pentagon road network.

resource. The consequences of the operational experience and the research was the foundation for changes in the future AASHO and AASHTO design policies, the *Highway Capacity Manual*, and the *Manual on Uniform Traffic Control Devices*. Countless other publications have been developed or modified since the mid-1960s; they reflect the experience gained and the research accomplished.

The remainder of this paper will discuss freeways and interchanges and the evolution of their design and operation and give some direction for the future.

EVOLUTION OF GEOMETRIC DESIGN OF FREEWAYS AND INTERCHANGES

In general terms, a freeway has always been a high-speed highway accommodating large volumes of traffic. According to the AASHTO definition, a freeway is an expressway with full control of access (i.e., a divided arterial highway with all intersecting roads grade separated and all entrances and exits accomplished by high-speed merging and diverging maneuvers). To achieve both high vehicular volumes and high speed we have learned that the standards of the freeway must be of superior caliber. The freeway is also characterized by efficiency and safety, a by-product of control of access and high design criteria.

The aspects of freeway design covered here are those that relate primarily to geometric features. The discussion, therefore, is oriented toward geometric design and planning considerations. Geometric design is the dimensional design of a highway; it may also be defined as the design of the visible dimensions of a highway with the objective of forming (shaping) the facility to the characteristics and behavior of drivers, vehicles, and traffic. Geometric design is a dynamic area of highway and traffic engineering which, in its true sense and broad application, translates research and operational experience into a physical highway plant.

Geometric design of freeways involves features of location, alinement, profile, cross section, and interchanges. The form and dimensions of the freeway, made up of these elements, should properly reflect driver safety, desire, comfort, and convenience. Closely related and considered in geometric design are aesthetic qualities and roadside, community, and environmental effects.

It has become apparent through operational experience and research that to successfully plan and design freeways and

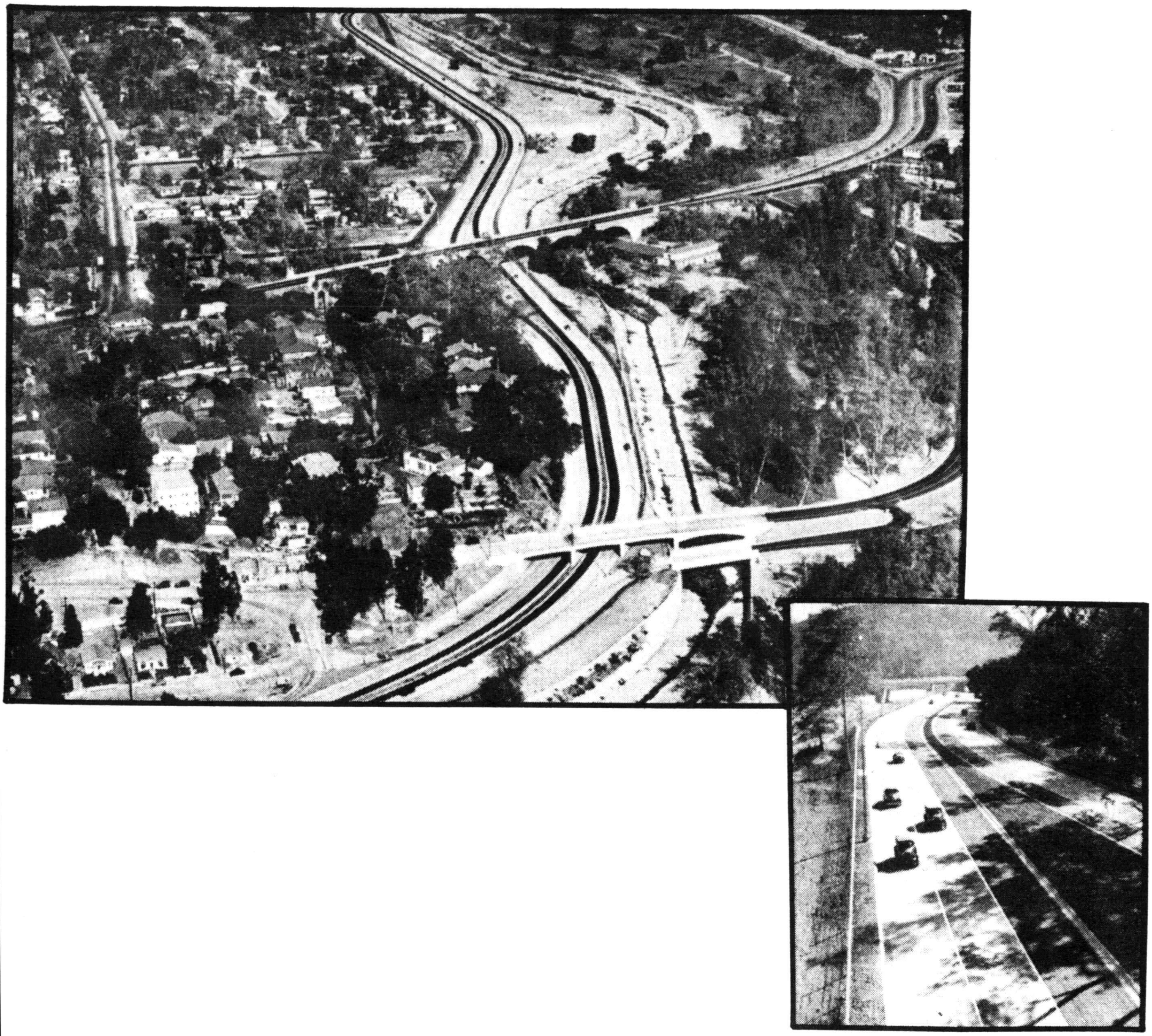

FIGURE 7 Arroyo Seco Parkway, Los Angeles.

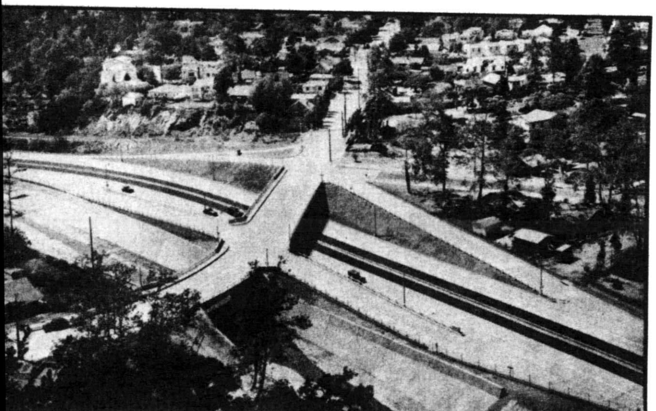

FIGURE 8 Diamond interchange of Arroyo Seco Parkway.

related facilities, certain basic concepts of design must be recognized and adhered to in practice. These same concepts apply in planning and design for freeway reconstruction. Consequently, this paper, after addressing the evolution of design concepts, will also present philosophical considerations in geometric design and the application of human factors in the planning and design process.

Freeway Design

Early freeways in urban areas were usually designed and constructed with design speeds of 50 to 60 mph. Today, 60 mph is the basic design speed considered. Many urban freeway reconstruction projects include upgrading a present design to 60 mph or greater as well as increasing capacity, modifying interchanges, and enhancing safety. In rural areas, 70 and 80 mph design speeds have become well accepted. In mountainous areas, a design speed of 60 mph has evolved as a basic criteria.

Cross Sections

The cross sections of freeways have changed rather dramatically since the 1930s. Although lane width criteria have changed little, the use of full and continuous shoulders, introduced in the 1950s, has become standard practice. This feature is particularly important on facilities with high-occupancy vehicle (HOV) treatments, to effect maintenance, and to efficiently and safely manage incidents. Such safety features as clear roadsides and flatter cut-and-fill slopes have evolved based on extensive research in the 1950s and 1960s. Safety appurtenances including the concrete barrier, safer guardrail and guardrail end design, crash attenuation devices, and frangible sign and lighting supports also were developed, making the highway environment a safer one.

Initially, freeways were constructed with two lanes in each direction of travel. The Arroyo Seco Parkway in Los Angeles, opened in 1941, was the first six-lane freeway. It was initially believed that six lanes (three in each direction) was the maximum that could be operated safely and efficiently. By the late 1950s, however, 8- and 10-lane freeways were being planned, designed, and built. Today, there are short sections (2 mi or less) of seven contiguous lanes on a number of freeways. Most of these in operation are basic 10-lane freeways (5 lanes in each direction) with 2 auxiliary lanes to accommodate entering, exiting, and weaving traffic between interchanges. In expanding a freeway beyond 10 basic lanes, consideration should be given to continuous collector-distributor roads. If frontage roads already exist, increasing the capacity of the corridor can be achieved through ramp metering, frontage road expansion, and frontage road and cross street signal coordination.

Medians

The separation of opposing lanes has progressively increased over the years. On early freeways, medians as narrow as 4 ft were prevalent. The 1945 Design Standards for the National System of Interstate Highways called for minimum medians of 4 ft in urban areas and 15 ft in rural areas; the 1956 Geometric Design Standards for the National System of Interstate and Defense Highways indicated minimum medians of 16 ft in urban areas and 36 ft in rural areas; the 1967 AASHTO publication *Highway Design and Operational Practices Related to Highway Safety* recommends a minimum median width of 60 to 80 ft. The latter dimensions are now being applied in rural areas. In some states, medians of 80 to 100 ft in open country are common on 70- and 80-mph freeways. In and near downtown areas, median widths of 24 to 30 ft, with inside shoulders and median barrier, are prevalent on new designs. Wider medians should be used on radial freeways in the intermediate and outlying areas of cities. Some metropolitan transportation studies recommend medians upwards of 70 ft in those locations to allow for future expansion—for added lanes, reversible roadway, HOV and exclusive bus lanes, or rail transit.

Sight Distance

Sight distance considerations along freeways and highways have changed and evolved over time. Although there have been some modifications in stopping sight distance, the new concept of decision sight distance (originally referred to as anticipatory sight distance) first surfaced in the late 1960s. It was initially quantified in 1970, recognized by AASHTO in 1984, and refined by AASHTO in 1990.

During many freeway and interchange reconstruction projects it was realized that horizontal stopping sight distance around curves was never provided. The location of concrete barriers, the construction of retaining walls in conjunction with lane additions, and more extensive use of directional or semidirectional ramps with tight geometry are just some situations in which the designer must be cognizant of potential horizontal stopping sight distance deficiencies.

Interchange Design

By the 1960s, it was realized that freeways and interchanges should be planned and designed as integrated systems because their geometric and operational characteristics are interrelated. If considered as such in the planning and design process a higher capacity, more operationally efficient and safer facility could be achieved. Much of this was realized through human factors research resulting in a greater understanding of the capabilities and requirements of drivers.

Interchange forms increased significantly in number between 1928 and the late 1950s—from the cloverleaf in Woodbridge, New Jersey, to the diamond in Los Angeles, to a broad array as depicted in the early AASHTO design policies of 1954 and 1957. By the advent of the Interstate system, interchanges were categorized into several basic types, including

- 3-leg (trumpet, directional T or Y),
- Diamond,
- Cloverleaf,
- Partial cloverleaf,
- Directional with loops, and
- All directional.

These types have not changed over the years; however, different geometric forms of these basic types have been developed and implemented and are part of the engineer's arsenal in providing freeway access. Two broad categories of interchanges related to the two interchanging facilities are prevalent—service and system. Service refers to an interchange of the freeway with a surface street (i.e., arterial or collector street), and system refers to one between two freeways.

Not only has there been a change in design approach in the specific geometrics of interchanges during the 1970s and 1980s but there has been a rethinking of the interchange selection process. Much of this change has occurred as a result of a better understanding of human factors and the realization that consistency in operational characteristics along the freeway is more important than designing each individual interchange to precisely fit a future traffic forecast. The concepts of basic lanes, lane balance, single exit design in advance of the crossroad, all right-hand exits and entrances, minimum 1-mi spacing between interchanges, and no weaving within an interchange are now generally accepted practice. Interchange forms that are consistent with these operational guidelines are presently those that are considered for new locations or in modifying existing interchanges. Consequently, the diamond forms and some of the partial cloverleaf forms are prime candidates for service interchanges.

The system interchanges have evolved in a similar manner and for similar reasons as the service interchanges. In the 1950s the philosophy appeared to be to minimize the number of bridges in a system interchange. This produced some rather interesting designs with left- and right-hand exits and entrances, transposed mainline traveled ways, and weaving within the interchange between major turning and through traffic movements. One is shown in Figure 9. Fortunately, this interchange has been partially reconstructed and the operational and safety deficiencies eliminated. The basic forms of system interchanges usually considered today are the all-directional (Figure 10) or directional with one loop or two loops in opposite quadrants. The full cloverleaf should never be considered for a system interchange because of its excessive right-of-way requirement, potential weaving problems, and high accident experience.

There has been a continuing evolution in geometric design of freeways and interchanges since the 1920s. Much has been

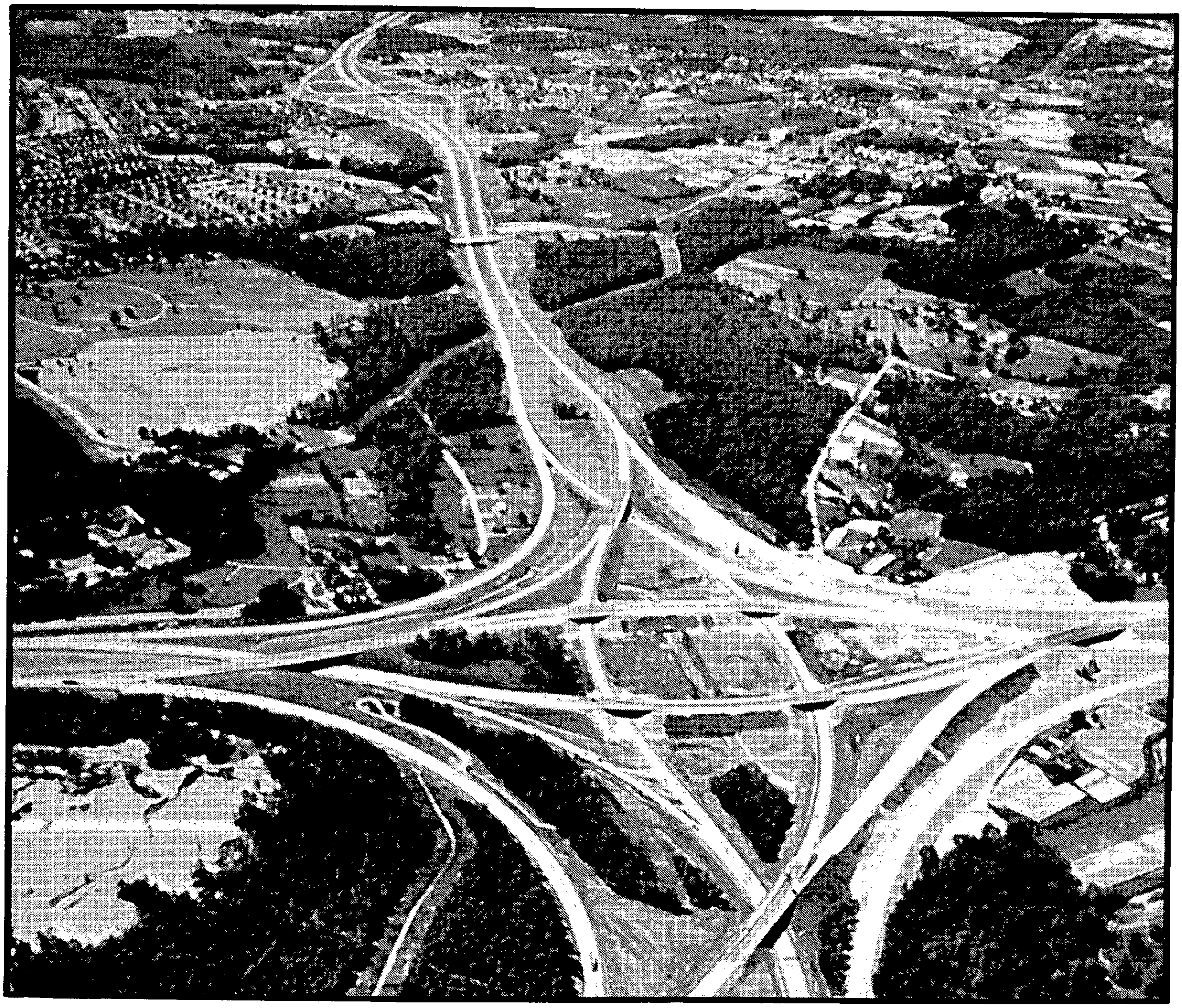

FIGURE 9 System interchange in Baltimore, Maryland (1950s).

FIGURE 10 All-directional interchange in California.

learned, yet there is still more to learn, to research, and to observe that can continue to assist in the design of safer and more operationally efficient freeway facilities. As we move forward into an era of greater use of freeway corridors for transit and HOV facilities, attention should be directed toward better integration of the modes. Also, with future implementation of intelligent vehicle highway systems, freeway facilities will continue to change and evolve to respond to different physical and human requirements.

REFERENCE

1. *A Policy on Geometric Design of Rural Highways.* AASHO Washington, D.C., 1954.

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