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GEOMETRIC DESIGN OF HIGHWAYS IN USA

SUMMARY

This paper describes the criteria, standards, and engineering procedures used to design principal elements of the highway alignment, highway cross sections, and adjacent roadside environment. Development of a comprehensive highway design focuses on the establishment of travel lane configuration, alignment location, and all dimensions related to the highway cross section. A three-dimensional physical location is determined through calculation of a horizontal and vertical alignment of the highway centerline, based on a variety of operational considerations. The results of these activities are referred to as the geometric design and represent all the visible features of a highway or street. The first and major portion of the paper deals with the design of motor-vehicle facilities. Specific design elements are described and discussed with respect to design methodology.

1. INTRODUCTION

Geometric design practices of the state highway and other designing agencies are not entirely uniform on a national basis. A considerable variation exists in the laws of various states, which serves to limit the size and weight of motor vehicles. Differences also exist in the financing ability of various governmental agencies, and these among other policy issues significantly influence the designer's decisions and modify the implementation of wholly uniform design standards. Differences in experience and the interpretation of research also contribute to variation in design practices. Furthermore, differences in local conditions among regional factors such as terrain, weather conditions, and available construction materials affect standards and design practices on a state-by-state basis.

The differences are allowed and tolerated by the Federal Highway Administration as unavoidable and are accepted when approval is requested on plans developed by various states for federally funded highway improvements. The strongest force tending to standardize these differences lies in the numerous and diverse technical committees of the American Association of State Highway and Transportation Officials (AASHTO). All state highway agencies and the Federal Highway Administration hold membership in this association and join in the deliberations of its technical committees. Upon approval by a required majority, a standard is declared adopted and becomes, in effect, a guide for all members of the association.

2. THE ELEMENTS OF DESIGN CONTROLS

The elements of design are influenced by a wide variety of design controls, engineering criteria, and project-specific objectives. Such factors include the following:

- functional classification of the roadway
- projected traffic volume and composition
- required design speed
- topography of the surrounding land
- capital costs for construction
- agency funding mechanisms
- human sensory capacities of roadway users
- vehicle size and performance characteristics
- traffic safety considerations
- public involvement, review, and comment
- environmental considerations
- right-of-way impacts and costs

These considerations are not, of course, completely independent of one another. The functional class of a proposed facility is largely determined by the volume and composition of the traffic to be served. It is also related to the type of service that a highway will accommodate and the travelling speed of a vehicle along a highway. For a given class of highway, the choice of design speed is governed primarily by the surrounding topography, regional importance within the larger highway network, magnitude of related construction impacts, and capital costs associated construction of the highway project.

The design features of a highway influence all visible features and directly affect its capacity and traffic operations, its safety performance, and its social acceptability to highway users, owners of abutting land, and the general public.

Of all the factors that are considered in the design of a highway, the principal design criteria are traffic volume, design speed, vehicle size, and vehicle mix. Each of these criteria is discussed in more detail along with other related design considerations in the following paragraphs.

The major traffic elements that influence highway design are

- average daily traffic (ADT)
- design hour volume (DHV)
- directional distribution (D)
- percentage of trucks (T)
- design speed (V)

Average daily traffic is a fundamental measure of traffic flow. To the designer, the most significant measure of traffic volume is the design hour volume, a two-way value, which may be determined by multiplying the ADT by as percentage representative of the amount of traffic occurring during the peak hour during an average weekday. This percentage, K, is typically 8 to 12 percent for urban facilities and 12 to 18 percent for rural facilities. The directional distribution (D) is the one-way volume in the predominant direction of travel, expressed a percentage of the volume in the two-way design hour volume. For rural roads, D ranges from 55 to 80 percent and is typically about 67 percent.

Composition of traffic (T) is usually expressed as the percentage of trucks (excluding light delivery trucks) present in the traffic flow during the design hour. That percentage typically varies from about 5 to 10 percent. In urban areas, the percentage of trucks traveling within the overall flow of traffic during peak hours tends to be considerably less than percentages on a daily basis.[1]

The traffic volumes that can be served at each level of service are referred to as "service volumes."[2] Once a level of service has been chosen for a particular project design, the corresponding service volume logically becomes the design service volume. This implies that if the traffic volume using this facility exceeds that value, the operating conditions will be inferior to the level of service for which the roadway was designed. The level of service appropriate for the design of various types of highways located within representative surrounding terrain conditions is shown in Table 1.

The assumed design speed for a highway may be considered as "the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features govern". The choice of design speed will depend primarily on the surrounding terrain and the functional class of the highway. Other factors determining the selection of design speed include traffic volume and composition, costs of right-of-way and construction, and aesthetic considerations.

Table 1: Guide for Selection of Design Levels of Service

Highway Type	Type of Area and Appropriate Level of Service			
	Rural Level	Rural Rolling	Rural Mountainous	Urban and Suburban
Freeway	B	B	C	C
Arterial	B	B	C	C
Collector	C	C	D	D
Local	D	D	D	D

Note: General operating conditions for levels of service (A, B, ..., E)

Source: From A Policy on Geometric Design of Highways and Streets, copyright 1990. American Association of State Highway and Transportation Officials, Washington, DC.

Design speeds typically range from 30 to 120 km/hr (20 to 75 mph), and intermediate values are chosen in increments of 10 km/hr; 40, 50, 60 km/hr, and so forth. Where feasible, a constant design speed should be used in the design of a highway of substantial length. Where changes in terrain or other conditions dictate a change in design speed, such change should be made over a sufficient distance to permit drivers to change speed gradually. The changes in design speed should, of course, be indicated by appropriate traffic control devices.

A tabulation of the major traffic controls used for the design of a highway are collectively referred to as the design designation.[3] Examples of such designations are shown below. The tabulation on the left is for a two-lane highway; the traffic data on the right for a multilane highway (Table 2).

Table 2: Design Designation

	Control of access = full
ADT (1995) = 2,500	ADT (1995) = 10,200
ADT (2015) = 5,200	ADT (2015) = 21,200
DHV = 720	DHV = 2,950
D = 65%	D = 60%
T = 12%	T = 8%
V = 100 km/h	V = 110 km/h

The highway design designation is normally placed on the cover sheet of the plan set for proposed improvements in order to indicate to all those handling and reviewing the plans the traffic values used in establishing the basis for the project design. Because of functional differences, a wide array of design standards must be used for the many types of facilities comprising a highway system. Design standards vary widely for different functional classes. For example, freeways are designed predominantly for traffic movement, and freeway standards are characterized by high design speeds, wide lanes, and straight horizontal and vertical alignments.[4]

Within a functional class, design standards may vary with the type of terrain, anticipated traffic to be served, and whether the highway is to be in an urban or rural area. (Table 3)

Table 3: Minimum Design Speeds for Rural Roads

Traffic Volume	Type of Terrain, km/hr (mph)		
	Level	Rolling	Moun-tainous
Current ADT < 50	64 (40)	48 (30)	32 (20)
Current ADT 50-250	64 (40)	48 (30)	32 (20)
Current ADT 250-400	80 (50)	64 (40)	32 (40)
Current ADT 400-750 and DHV 100-200	80 (50)	64 (40)	48 (30)
DHV 200-400	80 (50)	64 (40)	48 (30)
DHV > 400	80 (50)	64 (40)	48 (30)

Source: Design Manual, Vol. I, Roadway, North Carolina Department of Transportation, Raleigh.

3. COMPUTER APPLICATIONS

The use of computers and computer networks is continuing to revolutionize the field of highway design. Digital data formats have allowed engineers to automate many of the design tasks, translating design criteria through the design process, directly reflecting the information in the project constructing drawings. This is accomplished through integrated design environment that links design activities, such as horizontal alignment, cross sections, profiles, and quantities, with the final production of drawings that are created through the use of multifaceted software programs. An example flow chart of a typical software design package is presented in Figure 1.

One of the primary benefits of using a computer design program is to enhance the ability of an engineer to conduct numerous design iterations for the purpose of improving and refining the design without expending a large amount of time or effort. Another valuable feature is the ability to view the resulting effect of the design modification on the construction plans without the need to conduct the numerous intermediate steps that have been associated with the more traditional manual design methods of the past. It is important to note that the design engineer must have a firm understanding of all the criteria, standards, and design methods necessary to design a safe and efficient highway as described in the preceding sections of this chapter in order to utilize the computer programs correctly.

A full discussion of computer applications in highway design is beyond the scope of this text. The many companies that develop, distribute, and support computer aided design and drafting (CADD) software programs have numerous manuals describing programming commands and techniques for efficiently using their respective software products. The focus of the following paragraphs will be to present an overview of the most important features that this computer technology has contributed to an enhancement of the highway design process.

The utilization of this feature within an automated computer design process involves creating a digital database for the project limits and in areas immediately surrounding the proposed construction. Survey and topographic information describing the project area can be collected through conventional field survey techniques or through controlled aerial photography. These spatially oriented data are located within the context of a three-dimensional grid, which is referenced in the traditional variables x, y, and z. Coordinates for x and y represent the horizontal location of the data points, and the variable z serves to provide an elevation of each point, typically measured with respect to sea level.

Field-collected survey points at consistently spaced intervals, perpendicular to the centerline at approximately 20 m (50 ft) extending to the outer limits of the project area, and at all surface-evident breaks in the terrain, such as ditches and ridge lines, are located in a digital format with respect to x, y, and z dimensions. A data collector is utilized that allows easy transfer of survey information into a consistent format that can be read by a DOS-based desktop computer. The fieldcollected information is utilized by one of the numerous computer aided design and drafting (CADD) programs, and an analytical method referred to as triangulated irregular network (TIN) is created through an interpolation between the various data points that were collected within the project limits. The results of the TIN is a digital terrain model (DTM) for the project area, which serves to create a computer surface model that represents the project topography.[5]

4. CONCLUSION

The results of this modeling procedure can be used to efficiently evaluate construction requirements of a new highway design. Once a similar three-dimensional model of the proposed highway improvements is designed, these models, which are commonly referred to as surfaces, can be merged and further utilized in the design process. This merging of data allows determination of earthwork quantities and a number of other volume-based calculations, such as amount

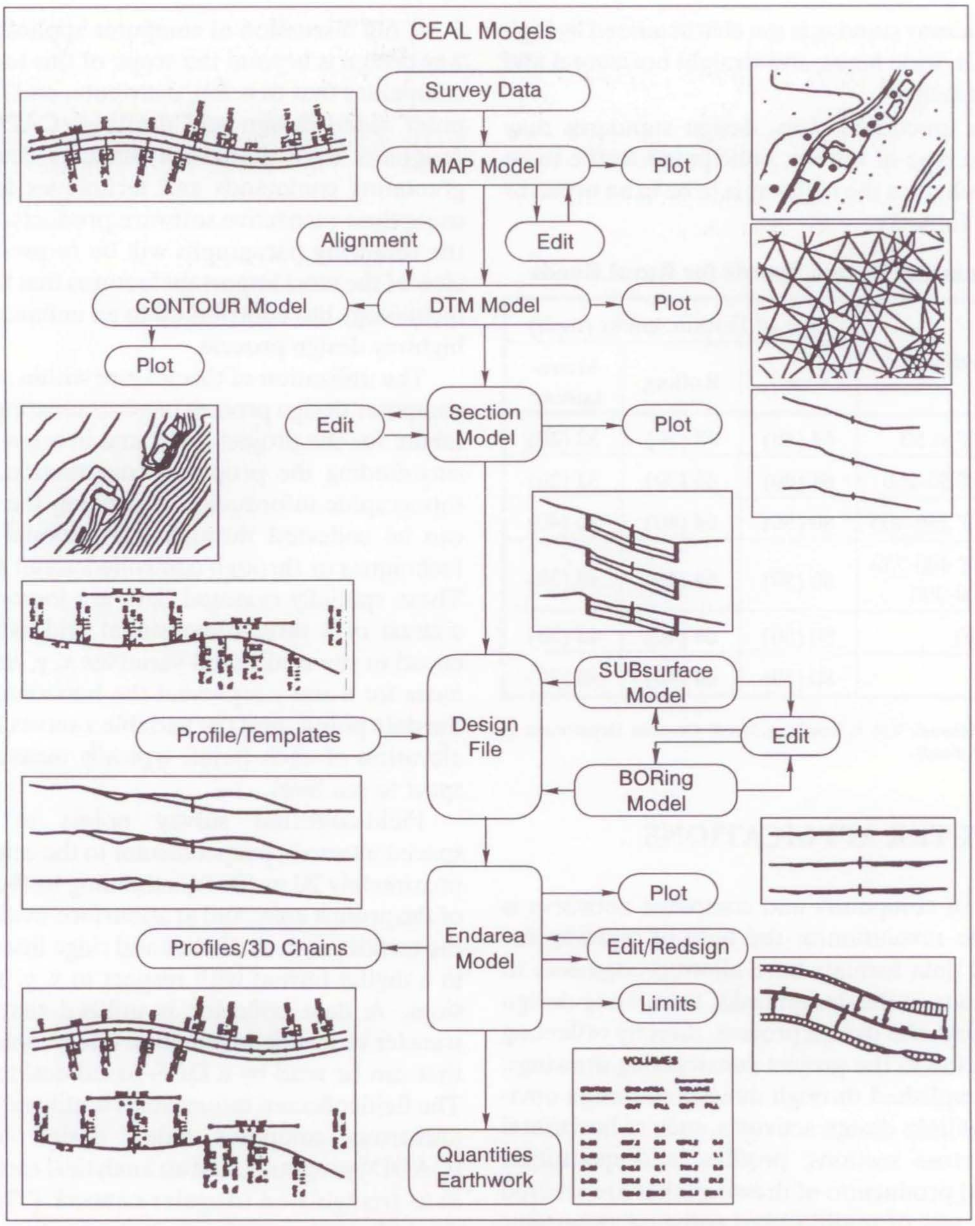

Figure 1 - Desing flow chart of a computer-aided design and drawing preparation software program entitled Civil Engineering Automation Library (CEAL). (Courtesy CLM/Systems, Inc.)

of rock excavation, limits of de-mucking in low-lying areas, and asphalt pavement quantities, given that the initial database can support such evaluations.

SAŽETAK

GEOMETRIJSKO OBLIKOVANJE AUTOCESTA U SAD-U

U ovom radu objašnjeni su kriteriji i standardi inženjerske procedure, koji su uporabljivi kao najvažniji elementi u oblikovanju trasa autocesta, sektora križanja i parametara tehničkog ozračja. Razumijevanje razvitka autocestovnog dizajna treba staviti u kontekst ustanovljenja konfiguracije linija putovanja, determiniranja osovine prometnice, kao i dimenzioniranja svih ostalih relevantnih veličina. Trodimenzionalno lociranje i određivanje fizičkih parametara u funkciji je definiranja osovine i nivelete autoceste, a sve uz respektiranje dopunskih varijabli. Rezultati ovih razmatranja referirani su na tragu relevantnih čimbenika geometrijskog oblikovanja autocesta uvažavajući i performanse motornih vozila. U radu se opisuje i potiče na diskusiju specifična metodologija dizajniranja primjenjena u Sjedinjenim Američkim Državama.

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