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FUNCTIONALIZATION OF HIGHWAY ALIGNMENT FOR COMPUTER-BASED DESIGN

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Abstract

Under the present highway design method, highway alignment is treated as the sequence of segments prescribed by the design speed. However this method is not useful for the advanced computer-based design. This paper shows the functionalization of highway alignment for computer-based design. Curvature and gradient functions are defined for a highway alignment. By functionalization of highway alignments, cross fall and widening are calculated, thus 3 dimensional highway geometric models can be defined automatically.

Introduction

The horizontal trajectory of a traveling automobile is determined by variations of velocity with time and variations of curvature by maneuvering. The vertical trajectory depends on variations of velocity and gradient with time. Time, velocity, curvature and gradient, therefore, need to be represented by coordinates in the design space at a certain point in the design process. Conventional design methods avoid conversion to space coordinates in the design process. They position instead elements of a two-dimensional alignment that are suitable to a time-velocity-curvature or time-velocity-gradient system on a plan or profile in advance (Lorenz, 1971; AASHTO, 1994).

The method proposed in this study is aimed at computerizing highway geometric design by defining a highway alignment based on functionalization of curvature and gradient that use distance as a parameter.

Functionalization of highway alignment

On the assumption of an automobile traveling at a constant velocity, a time-velocity-curvature system can be expressed by distance. Time-velocity-curvature and time-velocity-gradient systems can be regarded to be equivalent to distance-curvature and distance-gradient systems, respectively. Here, functions with the horizontal distance along a highway alignment as a parameter in each system are defined as the curvature and gradient functions. The curves on the curvature and gradient diagrams drawn as a result of horizontal and vertical design by existing design methods.

The method proposed in this study handles these curves as functions that determine highway alignments and thereby tries to design highway alignments in a process reverse to conventional methods. Horizontal and curvature functions can be represented by continuous piecewise linear functions and can be specified by the list of turning points of curvature and gradient with the distance.

A driver traveling along a continuous highway alignment turns the steering wheel continuously. Then curvature function $\Theta(l)$ is becomes also continuous. $\Theta(l)$ may thus be regarded as a continuous piecewise linear function. $\Theta(l)$ at distance l in section n (n = 1, 2, 3…) is expressed as shown in Eq.(1). Curvature function $\Theta(l)$ can be defined by given (l_n, θ_n) as a boundary condition.

$$\begin{cases} \Theta(l) = \Delta\theta_n(l - l_{n-1}) + \Theta(l_{n-1}) \\ \Delta\theta_n = \dfrac{\theta_n - \theta_{n-1}}{l_n - l_{n-1}} \end{cases} \tag{1}$$

where,

l_n : distance at the end of section n (where $l_0 = 0$)

θ_n : curvature at the end of section n (θ_0 is the initial curvature)

$\Delta\theta_n$: rate of change in curvature in section n

For existing design methods, elements of a vertical alignment consist of straight lines and vertical curves. For vertical curves, parabolic curves are generally used. Gradient, which is a differential of vertical alignment, is then represented by a linear expression. Since vertical gradient is continuous as well as horizontal alignment, gradient function $J(l)$ at distance l in section n (n = 1, 2,3…) is represented by equation shown in Eq.(2). Thus, gradient function $J(l)$ can be defined by boundary condition (l_n, j_n)

$$\begin{cases} J(l) = \Delta j_n(l - l_{n-1}) + J(l_{n-1}) \\ \Delta j_n = \dfrac{j_n - j_{n-1}}{l_n - l_{n-1}} \end{cases} \tag{2}$$

where,

j_n : gradient at the end of section n (j_0 is the initial gradient)

Δj_n :rate of change in gradient in section n

Schema of Geometric Design Model

This study uses an undivided two-lane highway without a sidewalk as a basic model. Here, design speed, width of the traffic lane and shoulder, and standard value of crossfall are defined as the initial values.

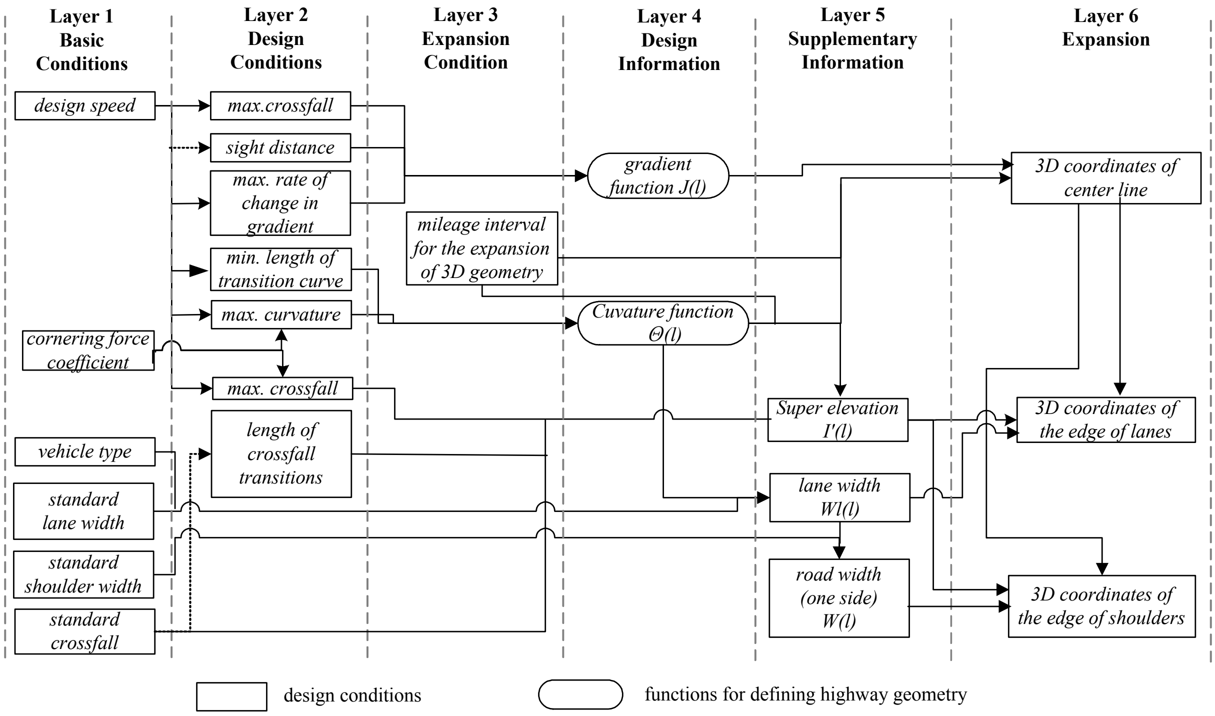

Fig. 1 : Schema of geometric design model

Based on the boundary conditions for curvature and gradient function, 3D coordinates of the highway alignment can be defined. Crossfall and widths of the lane can be determined by the curvature functions automatically. Thus, a 3D highway geometric design model can be built in the design space.

Restrictions are placed on curvature and gradient functions in view of the comfort and safety of the occupants of the traveling vehicle. The restrictions considered in this study are shown below:

- Maximum curvature
- Minimum length of transition curve
- Vertical gradient
- Length of vertical circular curve

The modeling process of the 3D highway geometry can be classified into 6 layers schematically (Fig. 1).

-Layer 1 provides the most basic information on the highway to be designed, and defines such elements as the design velocity, design vehicle, basic lane width, basic shoulder width and basic cross slope.

- -Layer 2 provides conditions for defining the curvature and gradient functions that define the alignment.
- -Layer 3 shows conditions that define the conditions for expanding curvature and gradient functions.
- -Layer 4 provides data that define curvature and gradient functions, backbone of the geometric design defined by the design engineer, which are the boundary conditions of the functions.
- -Layer 5 provides preliminary data for defining a geometric design based on the highway alignment defined in Layer 4. The data are obtained automatically.
- -Layer 6 shows the results of expansion to the design space of the highway geometric design built based on the data defined in Layers 4 and 5.

Development of Geometric Design System Prototype

A prototype of a highway geometric design system was developed. Under the system, the design engineer sets curvature and gradient functions while constantly monitoring the geometric design expanded on the design space, by repeating a procedure at a high speed for setting the functions temporarily, expanding them to the design space and drawing an alignment. For following the procedure, interactive response by GUI and high-speed computing are essential.

In order to speed up drawing and computing, an array is defined for each increment in distance to store all the information required for the expansion in the design space. At the same time as when the curvature and gradient functions are set, re-calculation is carried out for the information in the array, and an alignment is drawn accordingly.

Fig.2 shows the prototype's GUI. Curvature and gradient functions are set in two windows at the bottom of the screen by a mouse. Then, a three-dimensional design model is automatically expanded based on the predetermined basic design conditions. Graphics showing the horizontal alignment, perspectives (showing driver's view and bird's-eye view), vertical alignment, crossfall and width increase are updated and drawn simultaneously. In design, the engineer determines boundary conditions for curvature and gradient functions one by one while constantly monitoring information that is updated with the movement of a cursor by a mouse.

The boundary conditions for respective functions are set so as not to deviate from the range specified by the restrictions. The design engineer can, therefore, carry out design without being aware of parameters for elements of the alignment such as the radius of a circular curve and clothoid. Also shown as required is the area required for securing combined gradient and sight distance that have not been given as conditions controlling curvature and gradient functions.

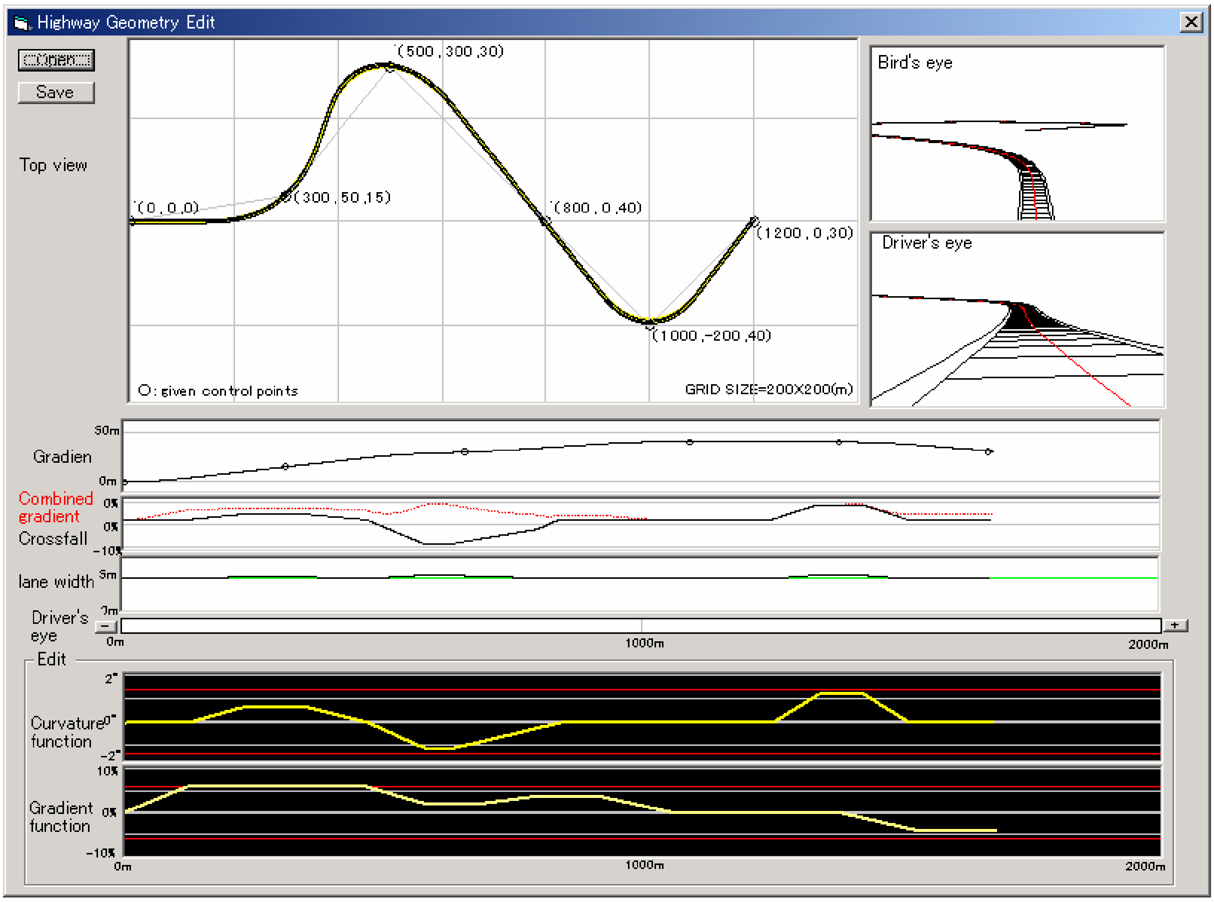

Fig.2: GUI of the geometric design system

Benefits of Geometric Design System

The geometric design system using curvature and gradient functions produces the following benefits.

- -Setting only of curvature and gradient functions enables automatic definition of geometric design and immediately provides three-dimensional data.
- -Curvature and gradient functions are simple piecewise linear functions, and enable the design engineer to carry out design without considering parameters of clothoids or circular curves.
- -Curvature and gradient functions are always continuous and guarantee the continuity of the highway alignment.
- -Three-dimensional data for geometric design may be used to easily display two-dimensional drawings and three-dimensional prospects. Thus, design and evaluation can be performed simultaneously.
- -Transmission of precise design information is possible only with a few data. Data processing is also easy.

Conclusion

This study has illustrated that highway geometric design can be determined basically by curvature and gradient functions with distance l as a variable. It has also been indicated that building a geometric design model by these functions can increase the efficiency of computer-based design.

By the method shown in this paper, conditions concerning design standards are provided to a computer as numerical functions with the design velocity, and curvature and gradient as variables. The design method is totally different from existing methods based on drawing (Beilfuss and Guess, 1990). The design engineer can now obtain an alignment that meets design standards without being aware of alignment parameters. Wasteful drawing work is reduced, and design efficiency is increased. Since alignment design becomes possible while monitoring a three-dimensional highway alignment, visual evaluation, or verification of how the alignment looks to driver's eyes, is now possible. Thus, the quality of design is expected to increase.

In the field of highway engineering as well as in other fields, product models are now being developed (OKSTRA, landXML etc.). For defining highway alignments, however, existing methods based on alignment parameters are still being used. The geometric design model built by the method proposed in this paper can be expanded in the three-dimensional design space with fewer data more precisely with the object format being maintained. Complicated models such as intersection models that are made based on the geometric design model can be used as product models.

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