Visual Quality Studies in Highway Design

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Modern conditions require increasingly higher standards in highway design. Faults can no longer be tolerated. In particular, studies in highway perspective are necessary at the design stage. Traditional techniques are inadequate for the volume of drawings and calculation needed.

This report describes a highway design computer program, TE. GI (imposed geometry automatic alignment calculations), which carries out all numerical calculations for a project, and produces a full set of drawings including accurate perspective views. The program uses an original representation of the ground, the numerical ground image, which allows the interpolation of any ground level within the defined zone to a precision of about 5 in., at a rate of 900 points interpolated per minute. The necessary interpolation programs form part of a program package composed of seven sections, treating the various design aspects, with automatic data transfer between sections. The package can be used section by section to keep pace with design phases, and is well adapted to the study of several different alternatives.

Particular emphasis is placed on the use of the perspective drawings to correct faulty designs. The most common errors are illustrated, with comments on how corrections could have been made; before and after examples are given for an access point where the design was changed when perspective drawings showed that the new design would be inherently less likely to cause accidents.

The use of the program to obtain the perspective views is explained, and the available types of view are given with their approximate costs. An independent program based on the perspectives phase of the TE. GI package is also explained, along with its use for studying interchanges and other aspects of design that cannot be handled directly by TE. GI. Both of these programs can be used to obtain a large number of closely spaced perspective drawings that can be photographed using cartoon film techniques to obtain animated views of the project as seen by a driver following any trajectory at any speed. The cost of these cartoon films will be reduced by modifications to the program, adapting it to new equipment coming onto the market, such as a small high-performance computer coupled to a cathode-ray tube and an automatic camera.

•THE basic aim of a projected highway is to provide the most comfortable and safest conditions for the flow of automobile traffic. Traditional design methods based on horizontal and vertical alignments are no longer adapted to such modern traffic conditions

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as high vehicle densities, relatively higher speeds, and numerous interchanges. The designer must now be able to study directly the visual appearance of his project, putting himself in the driver's seat and simulating driver reactions. He must be aware of all defects in his design and of the dangers which they bring, and he must know what improvements can be made to insure optimum safety, notably through improved signposting.

TE. GI PROGRAM IN HIGHWAY DESIGN AUTOMATIZATION

Development of the TE. GI (imposed geometry automatic alignment calculations) program was started at the end of 1962. The first version was brought into service progressively from 1963 to 1965, and an improved and enlarged version was available in March 1967. From 1965 on, the TE. GI program has been used to calculate and draw nearly 700 miles of highway projects yearly.

General Description

TE. GI, an integrated computer program for highway design, automates most of the numerical and graphical work involved in preparing an alignment project for a long-distance throughway.

The geometry of the project is "imposed": the project is conceived by the designer, and not by the computer. The designer must make all of the basic choices fixing the project's geometrical parameters, and must take into account all factors bearing on his research: geometrical, geological, orographic, technical, safety, climatic, economic, political, human, etc.

For these reasons studies of perspective views represent one of the major phases in highway design. Through the use of "perspectographs," perspective drawings have been prepared in various countries since 1960. These machines, which use optical methods to provide a perspective projection from horizontal and vertical alignments, have been invaluable in eliminating alignment errors and, consequently, in avoiding a large number of accidents which otherwise would have occurred.

However, a systematic perspective drawing of all projects would require a large stock of perspectographs, as well as the availability of large numbers of operators, who are not easy to find and train. Simulation of the reactions of the highway driver, through the use of cartoon techniques, would be impossible with these costly, slow, manual methods. Fortunately, computer techniques have taken over and provide a high volume of output at fairly low costs, and industrial output of perspective views has now been achieved thanks to TE. GI.

Besides, the machine carries out for the designer all of the repetitive work which does not require intelligence, but which is still essential to the preparation of the project, such as numerical calculations (earthwork volumes, for example), and automatic drawings (such as perspective views of the throughway).

The use of the "numerical ground image" as a terrain model and the simplicity with which the computer produces drawings and calculations, opens the way for comparative studies of several variations, which are entirely calculated and easily visualized; the chief designer can select the best solution at his leisure, using whichever criteria seem to apply.

Acting as a real assembly line for road alignments, the TE. GI program lowers design costs while improving technical quality, overcomes difficulties due to the scarcity of qualified personnel, optimizes personnel, requires no displacement of manpower, and frees the designer from trifling jobs that prevent him from looking full-time for the best solution.

The Numerical Ground Image

Since a computer can process only numerical information, ground information must be transformed into numerical figures. The problem is how to transform the ground into a discrete numerical image. The most widely used solution has been that of defining the ground after and along the project alignment. An air or ground survey used to be carried out along the proposed alignment, using more or less equally spaced cross-sections as survey lines. Obviously, this method covers the whole project, but it does not allow the study of any important variations without carrying out further surveys.

A much more rational solution is provided by the numerical ground image. All survey work is carried out before starting the project design, using a study strip that is large enough to allow for alternative solutions. Thus the same ground model is used for all calculations, major alignment modifications can be handled without going back to new surveys, and the designer is no longer tied to an a priori alignment which is sometimes a disastrous choice.

The numerical ground image is a set of points on the ground, suitably distributed along the project study strip, and represented by their orthogonal coordinates X, Y, Z in the chosen reference system. The points are held in memory through their cartesian coordinates X, Y, Z and the computer will work directly in a three-dimensional geometry.

To calculate a particular alignment, the computer places points along the cross-sections using X, Y plane coordinates, and then interpolates the gound elevation Z at each point. This is done by first picking up all image points close to the interpolated point, and weighting them according to the exact distance; next, the computer bases a second-degree surface on these points, using a weighted least-squares method. This surface hugs the ground around the interpolation point; its value at this point is taken as the ground elevation.

The interpolation speed is about 900 points per minute. Accuracy is good: the standard deviation of error is usually less than 5 in. —hardly significant in projects of this nature.

Computer Calcuations and Automatic Drawings

The general TE. GI program consists of seven sections linked together, although some of them can be used separately.

Section 1 (horizontal alignment) calculates basic element characteristics for a horizontal alignment, working from the geometric parameters of the circular and straight sections. If required, progressive spirals (clothoids) can be tabulated, and a machine drawing of the alignment can be produced.

Section 2 (structural zones) is used to define and record for the following sections numerical values for certain geometric, geological and economic parameters (such as tabulation distance, cross-section templates, ground types, and earth-works costs), which vary along the project but which can be considered constant within zones, called "structural zones." The program also calculates and produces drawings of the superelevation diagrams.

Section 3 (ground interpolation) applies the numerical ground image to the calculation; it is used with Sections 1 and 2 to calculate and draw the ground section along an alignment calculated by Section 1 and along the cross-sections prepared by Section 2.

Section 3b (staking-out) converts general coordinates to local polar, semipolar or orthogonal coordinates based on a polygonal or on a local triangulation. The results are supplied to the surveyors responsible for marking the alignment on the ground to be used such as they come out of the computer.

In the same way that Section 1 handles the horizontal alignment, Section 4 (grade line), prepares detailed drawings and the exact calcuation of a project grade line. The vertical alignment automatic drawing can be superimposed on the ground alignment section drawing prepared by Section 3.

Section 5 (earthworks) provides three series of results: (a) calculation and automatic drawings of cross-sections of the ground, project and subgrade level; (b) earthworks volume calculations, with costs for fill, pavement, topsoil, and three layers of cut; and (c) toeline and earthworks surface area, used for land acquisition.

Section 6 (perspective views) prepares two types of drawings: (a) an automatic plan drawing of the complete alignment showing the center-line, pavement edges, platform edges and toelines; and (b) automatically prepared perspective views at requested points.

If the user wishes, this section can be used to make a cartoon film of a driver's view of the road while advancing at a given speed.

PERSPECTIVE VIEWS AND VISUAL QUALITY

Rural Highways

It is customary to carry out separate studies for horizontal and vertical alignments. As a result the road, once constructed, is often a let-down although both alignments are, considered separately, prepared according to design standards and correctly integrated with the ground relief. This is because the alignment is, in fact, a three-dimensional curve whose perspective appearance depends not only on the vertical and horizontal projections, but also on the combination of both.

For an expressway, the perspective appearance of the alignment, as seen from every point along the road, must let the user:

1. See clearly the pavement and all obstructions which could be on it, over a long enough distance for him to take avoiding action or to stop (classic visibility conditions);
2. Distinguish clearly particular points such as forks and interchanges;
3. Foresee direction of the road ahead; and
4. Enjoy the alignment as forming part of the countryside without his being abused by artificial devices or annoyed by elbow bends, breaks and discontinuities which destroy the driver's psychological comfort.

Let us look at some of the most common errors caused by a poor combination of horizontal and vertical curvature. A horizontal curve is deformed in perspective if a high point lies on it. A short, low hump can completely transform the alignment's appearance, and the horizontal curve can even be completely hidden if it starts at about the position of the hump.

An alignment which has no point of inflexion in its horizontal or vertical components may have a point of inflexion in the two considered together. This happens when the ocular plane at an alignment point passes through the observer's eye. These artificial inflexion points are extremely common, produced either by combining horizontal and vertical curves with radically different radii or, worse, by putting vertical and horizontal curves in sequence or with a slight overlap. Artificial inflexion points are disagreeable and misleading when marked, as they will make people think that there is a real point of inflexion on the alignment.

The road may also disappear behind a vertical hump only to reappear further on in line with the original platform. The difference in platform widths and alignment directions makes such a loss of view of the road ahead disagreeable and often dangerous because it modifies the driver's appreciation of distances and can give him the impression that vehicles coming toward him from far away are in the same lane as he is.

The accompanying photographs show some of the most important well-known alignment errors, and certain extremely dangerous errors in horizontal and vertical coordination near interchanges and forks.

Urban Freeways, Multilevel Interchanges and Underpasses

On urban and suburban freeways or on interchanges, perspective studies are even more useful, despite the lower design speed. Not only can visibility be correctly studied, together with landscape integration and the location and correction of optical errors, but also advance studies can be made of overhead and conventional signposting, acceleration and deceleration ramps, and crossing zones.

The alignment errors already discussed for alignments in open country are now even more serious: alignment losses, inflexions, and curvature changes on humps often produce an anxiety reflex in the driver who, consciously or unconsciously, slows down, and starts a wave of decelerations in the dense traffic behind him—thus, during peak hours, jams and multiple accidents.

Poor signposting—badly studied, badly placed or badly written—coupled sometimes with defective visibility at forks and interchanges, is bound to slow down the traffic flow and prompt dangerous lane changes and a breakdown in the regularity of the flow, leading to a reduction in capacity.

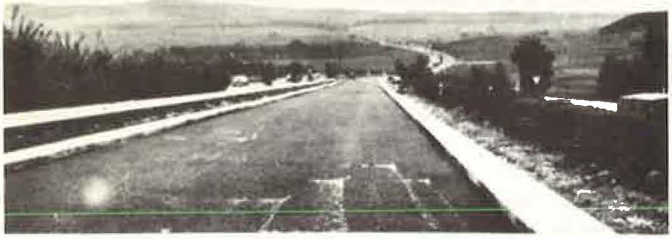

Figure 1. A winding alignment visible over a considerable length appears artificial unless the natural features responsible for the curvature are visible.

Figure 2. An example of sight loss and a poor combination of vertical curvature.

Figure 3. An example of a bayonet in a vertical alignment.

Figure 4. Sight loss near a fork: the driver cannot see the decision point shown by the signposting; this visual defect gives him a feeling of insecurity.

Figure 5. The same fork (farther on): the exit ramp aligned with the previous roadway seems to be the main road, while the main road is hidden by an inflexion on the left and is nearly invisible—the driver can be misled by the appearance of the exit into making dangerous maneuvers.

Figure 6. Poor visibility at a fork: in this case, the minor fork is on the left (this disposition should never be adopted); the straight, horizontal alignment hides the fork, which only appears at the last moment for a driver who is not concentrating.

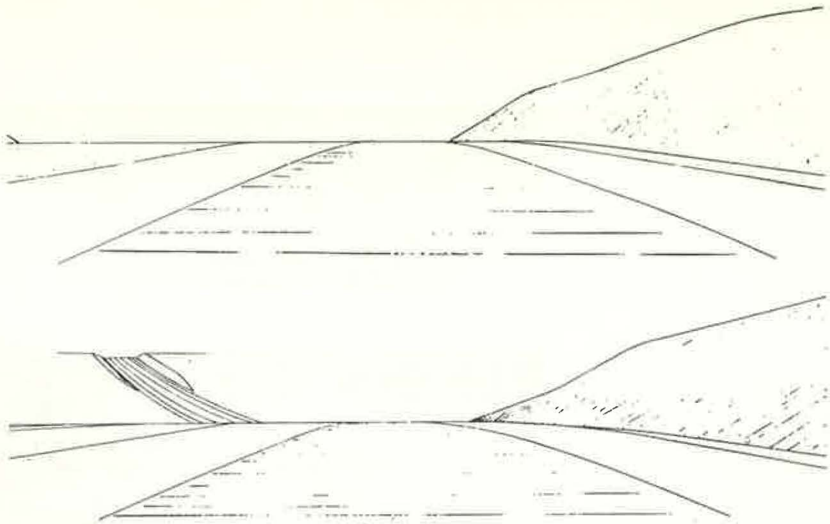

Figure 7. Poor visibility at a fork at the design stage: the fork is invisible at 500 yd (top), and still invisible at 300 yd (bottom), although the left arm can now be seen behind the masking hump.

Figure 8. The same after correction by offsetting the alignment: both arms can be seen at 500 yd (top), and the division itself is clearly visible at 300 yds (bottom).

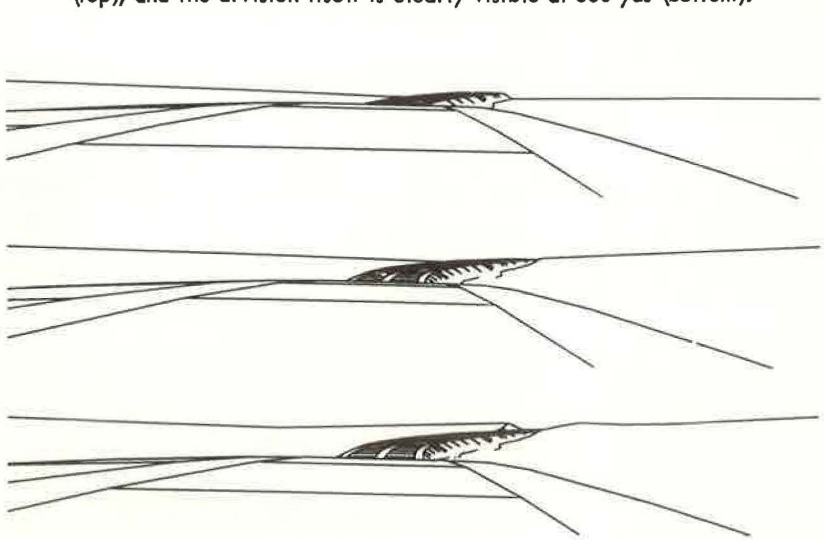

Figure 9. Automatic perspective example—characteristic sight losses.

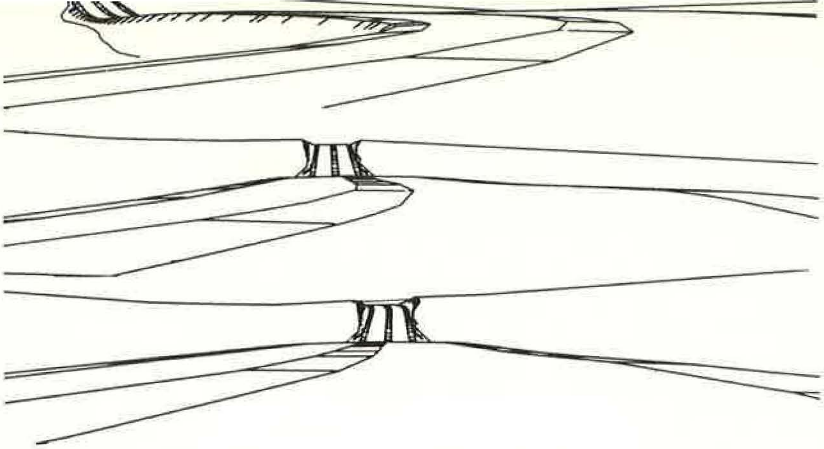

Figure 10. Automatic perspective examples—characteristic sight losses.

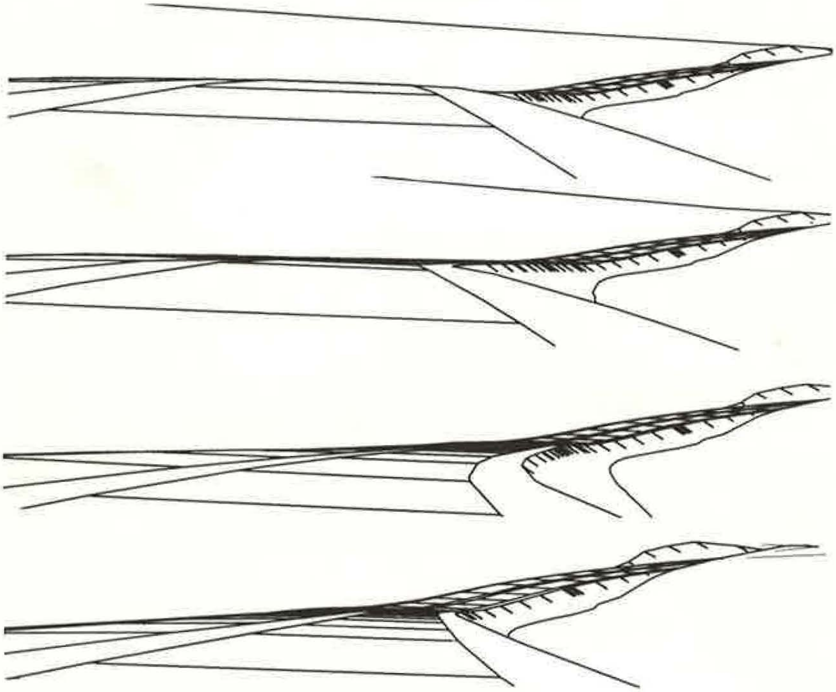

Figure 11. Automatic perspective examples—sight losses and inflexions.

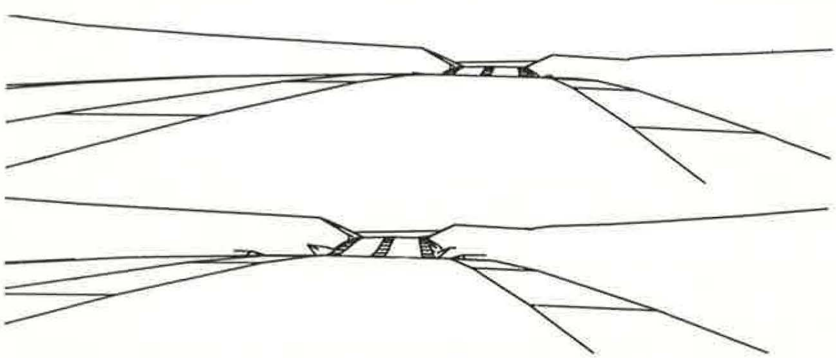

Figure 12. Automatic perspective examples—bayonet on the vertical alignment.

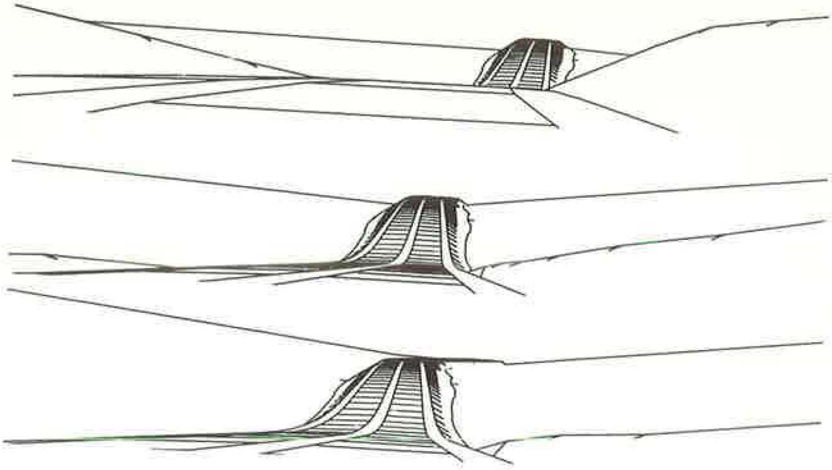

Figure 13. Automatic perspective examples—bayonet on the vertical alignment; the left carriageway seems to be a continuation of the right.

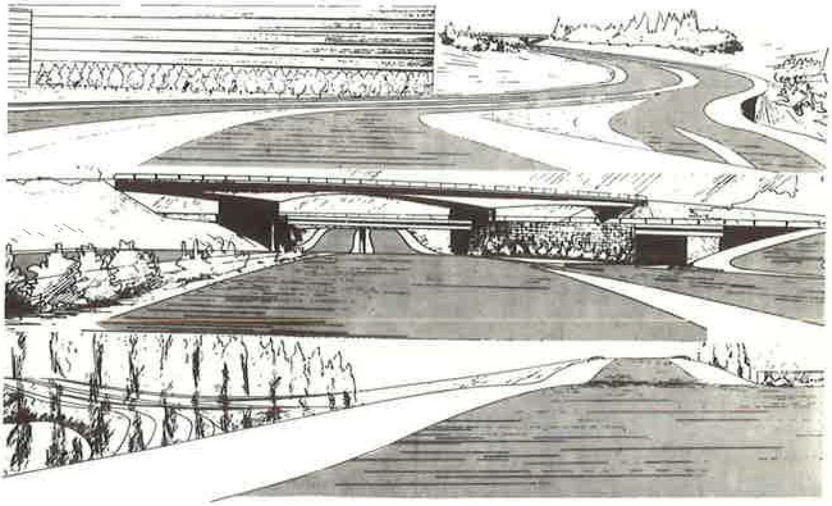

Figure 14. Perspectives in suburban zones: (top) inflexion; (middle) bayonet on the vertical alignment; (bottom) sight loss which could be corrected by masking the reappearance behind a curtain of trees.

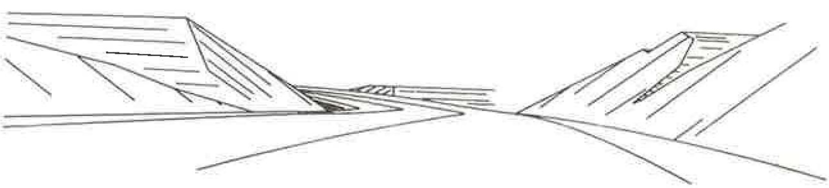

Figure 15. Alignment adaption studies in rough ground in southern France.

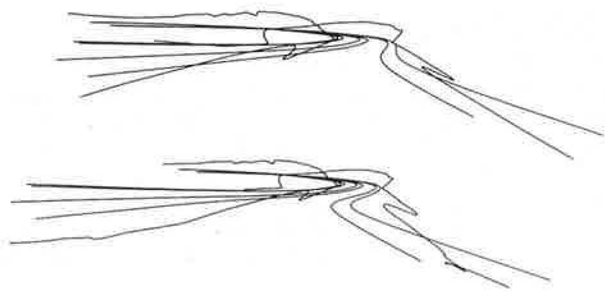

Figure 16. Extracts from an animated perspective film (rural expressway).

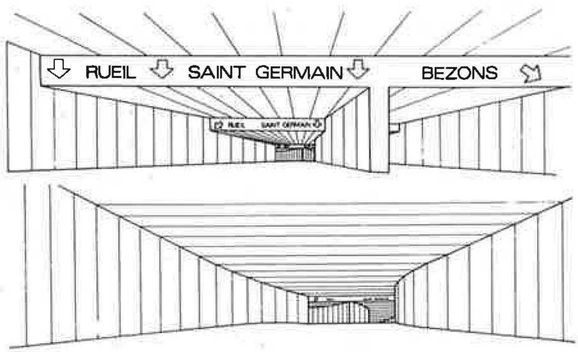

Figure 17. Extracts from an animated perspective film (underpass).

In the same way, crossing zones that have not been correctly studied in perspective may give reduced capacities and lead to incidents in the circulation and to accidents.

Underpasses are particularly delicate from the point of view of traffic flow; steady-flow conditions, lane guidance and fluid merging control the hourly capacities of these points. All this implies a very careful study of the geometrical dimensioning, the spatial coordination and the signposting, which can only be made by studying perspective views. Studies of crossing zones may even require the preparation of animated cartoons from the perspectives to simulate merging traffic.

In designing airport runways, architectural and urban projects, the perspectives also have many applications.

These examples of the uses that can be made of perspective views for project designs are certainly not the only ones that can be imagined; no doubt, in the future the visual aspect of human achievement will take on, in the design stage, the importance that it merits.

SOME APPLICATIONS OF THE TE. GI PROGRAM TO VISUAL QUALITY CONTROL

The key role of perspectives for improving roads was seen some years ago and one of the declared aims of the TE. GI program was the production of perspective drawings for the designer.

For this purpose, TE. GI Section 6 links onto the output of preceding sections, while leaving viewpoints and distances between views open to the designer's choice, to produce a perspective drawing where readability is increased by computer-added shading on the center reserve and berms, and by marks on the high side of the side slopes.

Awareness of the Visually Disturbing Elements

A design engineer usually asks for perspectives spaced every 200 yd along the alignment in both directions. Marked perspectives are immediately readable, while the complete perspectives with all lines are used to detect alignment faults. This systematic use of perspectives allows the engineer to track down all alignment errors, however small, showing him exactly what the results of his design will be.

The independent version of Section 6 lets the designer study all problems which are not covered by the rural expressway possibilities of TE. GI. It is being used more and more for urban expressways, with their multiple accesses, interchanges, and complex signposting.

Other uses that have been made of the program, outside of its normal applications, include views of a runway as seen from the aircraft and views of a bobsled run.

Improvement of Visual Quality

What can be done for this? The simple answer is to increase vertical radii of curvature; this, however, leads to enormous embankments, deep cuttings, and the highway becomes a slash across the countryside destroying the landscape. Therefore, the designer has an aesthetic and monetary interest in modifying the horizontal alignment as well, fitting it as best as he can to the countryside. In general, he should replace straight sections by fluid curves following the lines of the ground and integrated with the landscape to give a harmonious overall effect. It must be emphasized that this is not only advisable from an aesthetic viewpoint, but also from a hard economic standpoint, since accident risk plays an important part in the user's cost function. For roads as elsewhere, a well thought out product with a harmonious design is, in the end, a source of economy.

The adaptation to the environment must be designed by the engineer, but the TE. GI program will help him by cheaply and rapidly showing the finished effect, and allowing comparative studies of a number of different projects.

Simulated Driving Through the Use of Animated Cartoons

The best way of checking visibility and visual guidance is obviously to simulate the behavior of a driver traveling along the highway at a given, though not necessarily constant, speed. This requires the preparation of a large number of closely spaced perspectives, which are then used to prepare an animated film cartoon. Two such projects have already been run in two different fields. The first was prepared on a rural expressway to find out the effect on the driver of completely separating the dual carriageways. The second was for an urban expressway running underground. Each roadway had six lanes, and the film checked on the behavior of a driver leaving on the extreme left lane after traversing three successive merge areas. The main objective of the film was to control overhead signposting limited, obviously, by the height of the tunnel roof.

This design technique, because of its efficiency and its appeal for nonspecialists, will certainly be considerably developed. For this, it will be necessary to reduce the cost, made up of computer cost and the cost of refining the perspectives and preparing the film views.

The cost of refining can best be reduced by making the process automatic, as has already been done for rural perspective drawings in TE. GI. Research is going on for the introduction of bridges, trees and other objects in these perspectives, so as to give maximum possibilities of automatic completion. This technique, coupled with the use of an electro-optical plotter "drawing" on a cathode ray tube, will be able to give us directly, without other manipulation, a movie film.

These are the aims toward which we are working, and we hope that, before long, all the major road projects will include a film simulating driver's reactions on the highway.

CONCLUSIONS

These examples show the enormous changes in our way of thinking which have been forced on us by computer techniques, particularly by the generalization of spatial visualization by perspective views. General appearance, access points, signposting—all can be foreseen and verified as though the designer were in the driving seat of an automobile driving along the road two or three years later. Moreover, the road can be tried out at a series of different speeds.

These amazing design tools need a greater degree of thought and reflection from the engineer if they are to be of the greatest use, but the tools themselves free the engineer from rote tasks. Safer, less expensive, more beautiful highways are now possible and, because they are possible, they are necessary.

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