Assessing available sight distance: an indirect tool to evaluate geometric design consistency

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ABSTRACT

Any highway should be able to offer driving safety. In this sense, it is especially valued that roadways satisfy drivers' needs of riding with safety and render an adequate workload.
Available sight distance along a road alters drivers' expectancies and the way in which they perceive the driving environment, influencing their ability to adjust speed when driving.
Roadway design should offer the driver enough visibility to perform driving manoeuvers such as braking and overtaking, among others.
This paper describes a tool for assessing the availability of sight distance as an aid to improve road geometric layout consistency. This tool was entirely developed at the San Juan National University, in San Juan, Argentina. At any station along the road alignment it estimates the distance between driver's eyes and the point in which the road becomes hidden and its angle with respect to the road axis. In addition, it estimates the availability of passing distance and the sectors of the road where passing is restricted. Also, the software evaluates if the stopping sight distance at any station is available.
This system is a relevant aid for assessing geometric consistency, because it identifies adjacent segments of the road layout that offer considerably different sight distances.
Nowadays, this tool is used for teaching road geometric design both in under graduate and graduate engineering programs at the San Juan National University. Some universities of Chile and Argentina use this tool as well. Argentinean Highways Agencies and Consultant firms also use this software as well.

INTRODUCTION

The geometric design of any highway should warrant safe alignment conditions, for driving safety is a value of growing importance to societies. It is particularly appreciated that highway geometric design should satisfy drivers´ expectancies of traveling safely and with a fairly constant, low mental workload.

Driving a vehicle is a continuous process of acquiring and processing information, and making decisions in accordance with what the driver is exposed to: alignment of the road he is presently seeing and his anticipation of geometric conditions to come; environment; traffic control systems present and the purpose of his trip, among other factors.

The results of these analyses are the actual driving manoeuvers he performs along the road. These driving decisions can be evaluated in terms of operating speed, clearance to lane edge, vehicle trajectory, etc.

Of utmost importance in highway design is the sequence of geometric elements so that there is adequate sight distance for safe and efficient traffic operation, assuming adequate light conditions, and drivers' visual acuity.

THE EICG06 SYSTEM

This paper describes a tool for assessing the availability of sight distance as an aid to improve road alignment consistency. The EICG06 System is a geometric design software – entirely developed at the San Juan National University – that shows remarkable versatility to perform all the task of highway geometric design, such as: digital terrain modelling; full definition of horizontal and vertical geometry with many interactive options to improve the project axis in a friendly trial and error process; graphical analysis of terrain overall drainage; optimization of earth work; simultaneous display of horizontal and vertical alignment along with cross sections of the examined stations so as introduce any needed adjustments.

On of the most useful features of this system is the possibility of observing the final design in continuous perspective views, seen from the driver's position or from any point of the space selected by the operator. In that way, the whole length of the project can be "travelled" at any speed chosen by the designer. This special feature of the system was the one used to develop the assessment of available sight distance presented in this report. Figure 1 shows some of the graphical capabilities of the EICG06 System.

ANALYSIS OF ALIGNMENT CONSISTENCY

The geometric design of a road is said to be consistent when its alignment is in agreement with the drivers´ expectations, so that no unexpected driving manoeuvres are needed. Drivers' expectations related to the actual geometry of the road sections to come influence their level of driving attention and behaviour. The amount of information drivers have to process in relation to the time available for such analysis in know as mental workload. Naturally, mental workload is heavier as the geometry of the road is more complex or less predictable. *(1)*

High speed and/or shorter sight distances also intensify mental workload. The drivers who do not have time to adapt their behavior to poor and inconsistent alignment conditions certainly increase their chances of being involved in accidents. Consequently, sudden changes in operating speeds or vehicle trajectories are usual signs of intense mental workload forced by alignment inconsistencies. *(1)*

Operating Speed

Sudden operating speed changes explain many accidents in rural roads environments. Particularly, rural roads with low design speeds may have alignment configurations that promote large variations of operating speed, consequently increasing the possibilities accidents. The evaluation of alignment consistency through the criteria of drivers´ expectations seeks that geometric design satisfies drivers' wishes and appraisals. But the most commonly used method to judge alignment consistency is the operating speed profile, where attention is focused on the differences of operating speed and design speed, and also on the differences in operating speed of the adjacent geometric elements of the alignment. *(1)*

Operating speed variations along a road are caused by geometric alignment, environment and particular personal features of drivers. Some studies have pinpointed factors that determine or influence operating speed, as show in Table 1, to accordingly develop methods of alignment consistency evaluation. Assessment of available sight distance as a mean to judge alignment consistency is proposed *(2)*.

Available sight distance along a road is a factor that affects drivers' expectations and consequently their operating speeds. It influences the way drivers judge the stretch of the road they are exposed to and their ability to adjust operating speeds to present and oncoming geometry.

EICG06 perspective views

At any station along the road axis, the EICG06 perspective views display a color segment on the road pavement located at the end of the stopping sight distance. Obviously, there shouldn't be any station along the road length where this color segment is not seen. The software also displays the front image of a vehicle traveling in the opposite direction, located at the passing sight distance from the driver's point of view. This tool simulates driver's vision as the virtual vehicle travels along the designed road. The system operator may "travel" in both directions and move his point of view any where in the space around the station under consideration. At any station, the system also determines the distance from his position to the point where the road axis no longer visible. Both the overtaken vehicle and the one traveling in the opposite direction are displayed in the perspective view of the road. Passing sight distance – where the opposing vehicle is located and displayed – and the distance to the vehicle to be overtaken are calculated by the system through the equations of the passing sight distance model, based on the design speed of the project.

For the station under analysis, on the lower part of the 3D representation, these sight distances are displayed. The angle between the tangents to the road axis at the driver's position and the line of farthest vision is also displayed, as seen in Figure 2. When the process of the geometric design is completed, the system generates these sight distances files. To do so, the system inspects the road in both travel directions. *(4)*.

Diagram of available sight distance

The EICG06 sight distances module also calculates and displays a diagram of available sight distance, or visibility profile. Both horizontal and vertical alignments are jointly considered to calculate the different sight distances mentioned above. The calculations process is repeated at any desired interval along the project axis, in both directions of travel. The diagram displayed in Figure 3 is the result of such process. *(5, 6)*.

Generally speaking, the diagram is composed of three parts. The upper part shows available sight distance along the road, for the direction of travel being considered. The white line indicates stopping sight distance (or DVF for its initials in Spanish). This distance is calculated in the traditional way, using the friction model *(7)*:

$$DVF = \frac{V * t}{3.6} + \frac{V^2}{254 * (f + i)} \tag{1}$$

Where:

f: longitudinal friction coefficient
i: longitudinal grade
t: perception and reaction time (sec)
V: design speed (km/h)

Note how this distance is influenced by longitudinal grade. The magenta line indicates passing sight distance (or DVS), calculated as mentioned previously. The gray line is related to available sight distance (or DVD), that is, the distance from the driver's location to the farthest point where the road axis is still visible. The horizontal axis of the diagram represents stations along the road, in the directions of travel under consideration. The distance from the starting point of the project to the station being considered is shown on the upper part the profile, just on top of the pointer movable vertical line. The different sight distances mentioned above are measured on the vertical axis.

No graphic sales for stations and sight distances are provided because the system automatically displays both the station and corresponding sight distance as coordinates of the location of pointer. In Figure 3, available sight distance (DVD) for station 9204 is 412 m. Both values are automatically displayed on the upper and left part of the diagram.

The middle part of the diagram shows the longitudinal terrain profile and the corresponding vertical alignment, vertical curves included. Horizontal geometry is also displayed along a horizontal axis, where horizontal curves – and their lengths – are shown in different colors whether they are left or right hand turns. This part of the diagram is useful to identify the origin of reduced sight distances.

The lower part of the diagram provides written information: the angles of vision from the driver's position, with the meaning to be explained below, in coincidence with the colors of the shaded areas shown on the visibility profile.

Stopping sight distance (DVF) *(7)*

As previously mentioned, the profile of the stopping distance is shown with a white line. The vertical alignment influences this distance. At any point of the project available sight distance should not be shorter than stopping sight distance. In Figure 4 there are three locations where stopping sight distance is not available. Made on purpose for this presentation, the geometry of such places ought to be modified for a real case. The intermediate part of the diagram should help to understand the terrain constraints and alignment reasons of these irregularities. The designer can also evaluate such situations in 3D perspectives.

Passing sight distance (DVS) *(7)*

This distance is shown on the diagram with a magenta line. Its value is constant for the entire length of the project. In the examples shown, its value is 680 m.

Available sight distance (DVD)

It is displayed with a grey line on the upper part of diagram. In the example of Figure 4, its value is 412 m for station 9204. The road axis farther away (from the driver's position) than 412 m cannot be seen by the road user.

Note that the line of vision at any station is restricted by the surfaces of the project's digital model, such as the natural terrain cross sections, or the excavation planes in cuts. That is way it can be stated that available sight distance (DVD) fully considers the spatial layout of the road: horizontal and vertical alignment and the corresponding design cross sections.

Any other object – a building, for instance – that restricts the line of vision will correspondingly affect the available sight distance. In such case, the object must be particularly incorporated to the related cross sections by the system operator.

Visibility angles

Drivers usually aim their line of vision to the point where the parallel edges of the roadway seen to meet. In relaxed driving, this vision of the road perspective is approximately limited to a solid angle of 10º, its vertex being the driver's eyes. Satisfactory vision can still be possible under angles up to 20º. Above that limit vision may be become diffuse. If additional or sharper vision outside those cones is required, drivers will probably turn their heads to aim their line of vision accordingly. *(8, 9, 10)*

To evaluate these needs, the system calculates, at any station considered, the corresponding angles of vision of stopping, passing and available sight distances. These angles are grouped in intervals selected by user in α1, α2 and α3 for clear, satisfactory and borderline vision. Each interval is displayed with a specific color: green, yellow and orange, respectively. Red colour is used to represent angles larger than borderline values. See Figure 5 *(5, 6).*

These colors are used on the visibility profile of upper part of the diagram. The different angle intervals, i.e. colors, are useful to know at any station under what angles the different sight distances are observed. Such information is useful to learn if oncoming stretches of road are fairly straight, slightly curved or very curvy.

DIAGRAM APPLICATION

DVF, DVS and DVD comparisons

The following examples are set to illustrate the applications of the visibility diagram. In Figure 6, evaluation of sight distances is required for station 2080. When the pointer is set at station 2080, points ➀, ➁ and ➂ on corresponding vertical line give the following information:

➀ DVF: 157 m, the angle of vision is 5º or less (green zone)
➁ DVS: 678 m, the angle of vision is 5º or less (green zone)
➂ DVD: 860 m, the angle of vision is 5º or less (green zone)

It may be concluded on station 2080 the driver has a line of uninterrupted vision 860 m long. As DVF is shorter than DVD, the driver can safely stop if necessary. Also, as DVS is shorter than DVD, on that station the driver may perform an overtaking manoeuvre. To clearly know if the road above station 2080 is straight or curved, the central part often diagram shows the horizontal and vertical alignment, where that information is available. Figure 7 shows the perspective view from station 2080.

In that figure, stopping sight distance is shown by a horizontal light blue segment located DVF in front of the vehicle (position ➀); on the opposite lane, a pink segment and a cross denote the passing sight distance, or DVS, on location ➁. Finally, a white square on the road axis indicates the available sight distance or DVD, in location ➂. The corresponding sight distances are also displayed on the lower part of the perspective view, under the title "VISIBILIDAD" with the following designations: "Obstáculo" (obstacle), or DVF; "Vehículo" (vehicle), or DVS, and "Eje" (axis), or DVD.

Figure 8 illustrates the visibility diagram at station 5135. The corresponding sight distances are: DVF = 160 m (angle < 5º, green zone); DVS = 680 m (angle 10º < α < 30º, orange zone) and DVD = 756 m (10º < α < 30º, orange zone). The qualitative meanings of these distances are:

a) The road axis disappears from the driver's line of vision 756 m in front of his position, and as such distance is connected to an angle of vision larger than 10º, this distance is located on the grey zone of the diagram. Point ③ in Figure 8.
b) As DVD is many times longer than DVF, the vehicle can be easily be stopped if necessary.
c) There is enough sight distance to perform an overtaking manoeuvre (DVD > DVS), but this may not be allowed by traffic rules as most of the DVS is on a left hand curve.

Availability of passing sight distance

Figure 9 indicates that on the segment of road displayed (stations 0-7,000) the visibility diagram shows that there are 6 locations where the available sight distance is longer than the passing sight distance (DVD > DVS). In order to verify if these potential passing operations are practically and legally possible, the designer must check if those segments are longer than the minimum distance required by regulations to initiate an overtaking operation, and also verify if the segments are located on straight or curved (horizontal and vertical) parts of the road axis *(6).* The available passing sight distance is obtained through the difference of initial and final stations of the analyzed segment. If this length is longer than the minimum distance required by regulations to initiate a passing operation, overtaking is potentially possible. Additionally, passing operations will be legally possible if the segment under consideration is located along a straight part of the road.

Qualitative evaluation of alignment consistency

The visibility diagram can be used to evaluate the alignment consistency of a road project.

In Figure 10, diagram a) illustrates the case of a non consistent design (Project # 1), where the available sight distance shows dramatic drops from values well above passing sight distances to almost stopping sight distances with almost no longitudinal transitions.

On the contrary, diagram b) exemplifies (Project # 2) a generous and quite consistent alignment, for available sight distances are consistently above the passing distance, and show small changes all along the road axis. Project # 3 is also a consistent design, even though available sight distances are quite reduced. It is the case of a consistently winding road. *(11,12).*

Statistical evaluation

An output file containing the existing DVF, DVS and DVD for each station can be printed, if necessary. With that data an statistical analysis to obtain a quantitative interpretation of the availability of the sight distance can be performed.

In Figure 11 the horizontal axis indicates available sight distance; the vertical axis shows the cumulative frequency of sight distances shorter than the distance under evaluation. Thus, sight distances shorter than passing sight distances or DVS, are present on 35% percent of the station checked. Figure 11 also shows that these are no sight distances shorter than stopping sight distance, or DVF, and that all the available sight distances at the stations examined are shorter than 1100 m.

CONCLUSIONS

The perspective views of the EICG06 system are valuable tools to evaluate the spatial design of a road project. Visual continuity of the road perspectives, alignment consistency, coordination of horizontal and vertical alignment and visual guidance can be thoroughly examined and improved with this 3D module.

The assessment of available sight distances along the road axis performed by the EICG06 software as described in this report can also be used to evaluate alignment consistency just by identifying where along the visibility diagram the available sight distance suddenly drops from large values to minimum ones, equal or almost equal to the stopping sight distance.

Many of the existing softwares calculate passing sight distances after processing the horizontal and the vertical alignment of the road axis, each at time. EICG06 does that in one simultaneous operation, based on its capacity of working with and displaying the spatial model of the road designed. It is of utmost importance its ability to model the terrain around the road, including the planes of cuts and fills that sometime interrupt the driver's line of vision.

The driver's mental workload can also be inferred through the colors of the visibility diagram, for those colors are linked to the angles of DVD, DVS and DVD lines of vision as described here. Large angles increase the driver's mental workload, as the driver will often have to turn his head sideways to focus his vision on the point of the available sight distance.

The authors are working to establishing an alignment consistency qualifier, resembling the existing criteria where alignment consistency is rated according to the Curvature Change Rate over a specified segment of the road (º/km), or through operating speed profiles. The qualifier should be based on the available sight distance, and its variations along the road axis.

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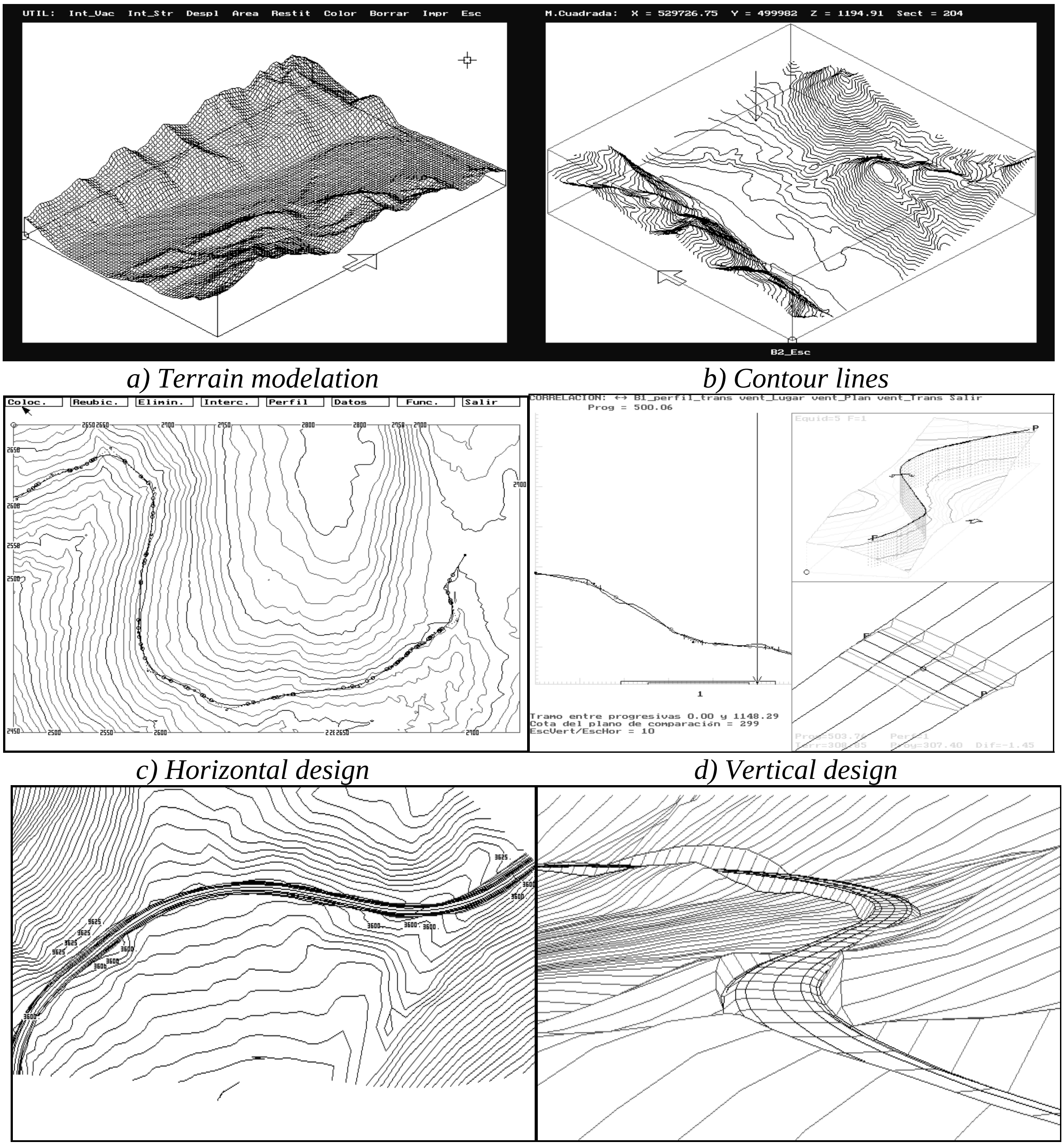
LIST OF TABLES AND FIGURES

TABLE 1 Factors that influence operating speed *(3)*

	Conditions	**Variable**
Operating Speed	Alignment	Geometric design Cross section **Available sight distance** Stability
	Environment	Lateral clear zones Traffic Weather Day/night
	Driver	Concentration Mental workload Other

TABLE 2 Availability of segments where passing operations can be performed (Stations 0,00 – 7,000.00). *(6)*

Segment	Stations		Zone	Length of segment	Comments
	From	To			
1	0	268	Green	268 m	Verify if this is a straight segment
2	373	980	Green	607 m	Verify if this is a straight segment
3	1353	2252	Green	899 m	Verify if this is a straight segment
4	4550	4590	Yellow	40 m	Located on a curved section
5	5110	5215	Orange	105 m	Located on a curved section
6	5647	6340	Green	693 m	Verify if this is a straight segment



a) Terrain modelation *b) Contour lines*

c) Horizontal design *d) Vertical design*

e) Final design – Horizontal geometry *f) 3D Perspective view*

FIGURE 1 EICG06 System.

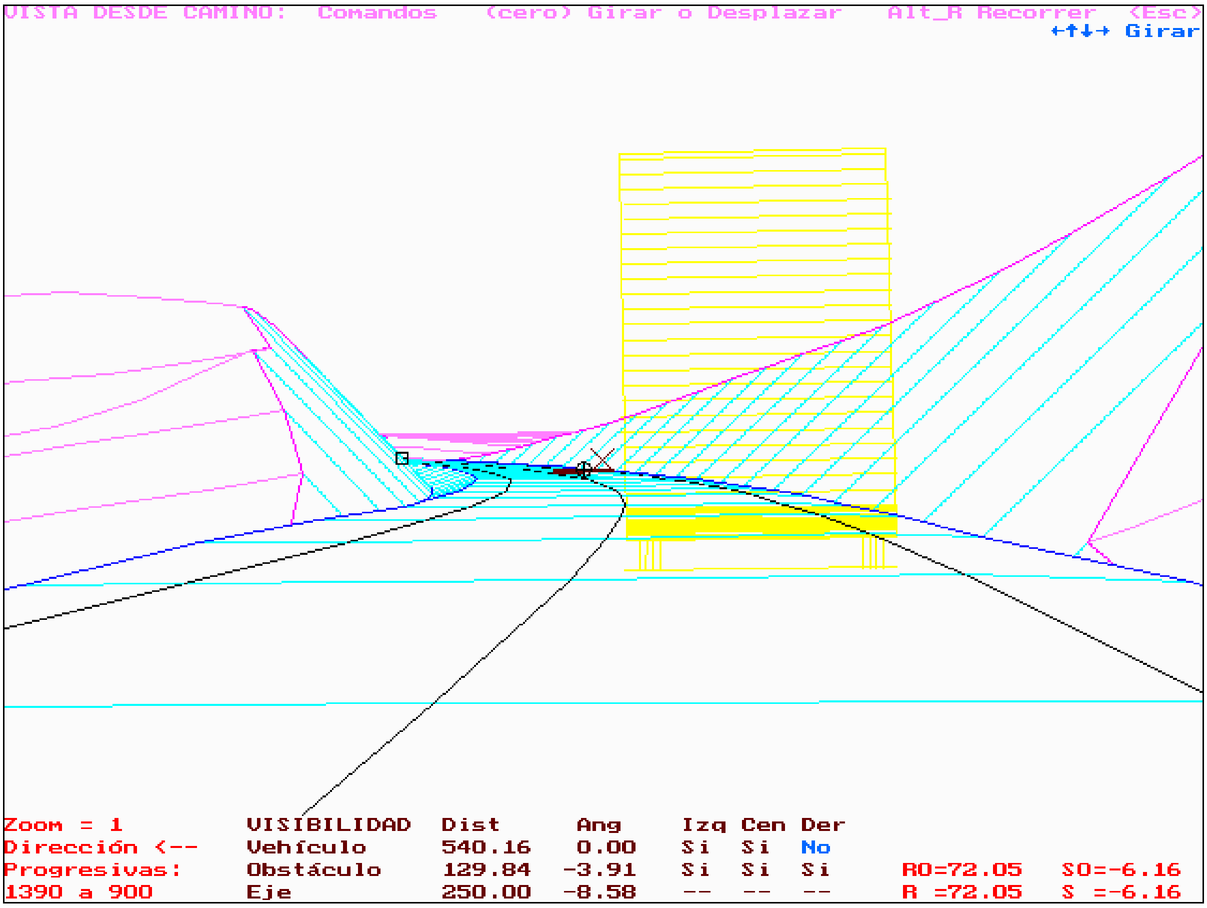


FIGURE 2 Perspective view of completed road design, as seen from the driver's position.

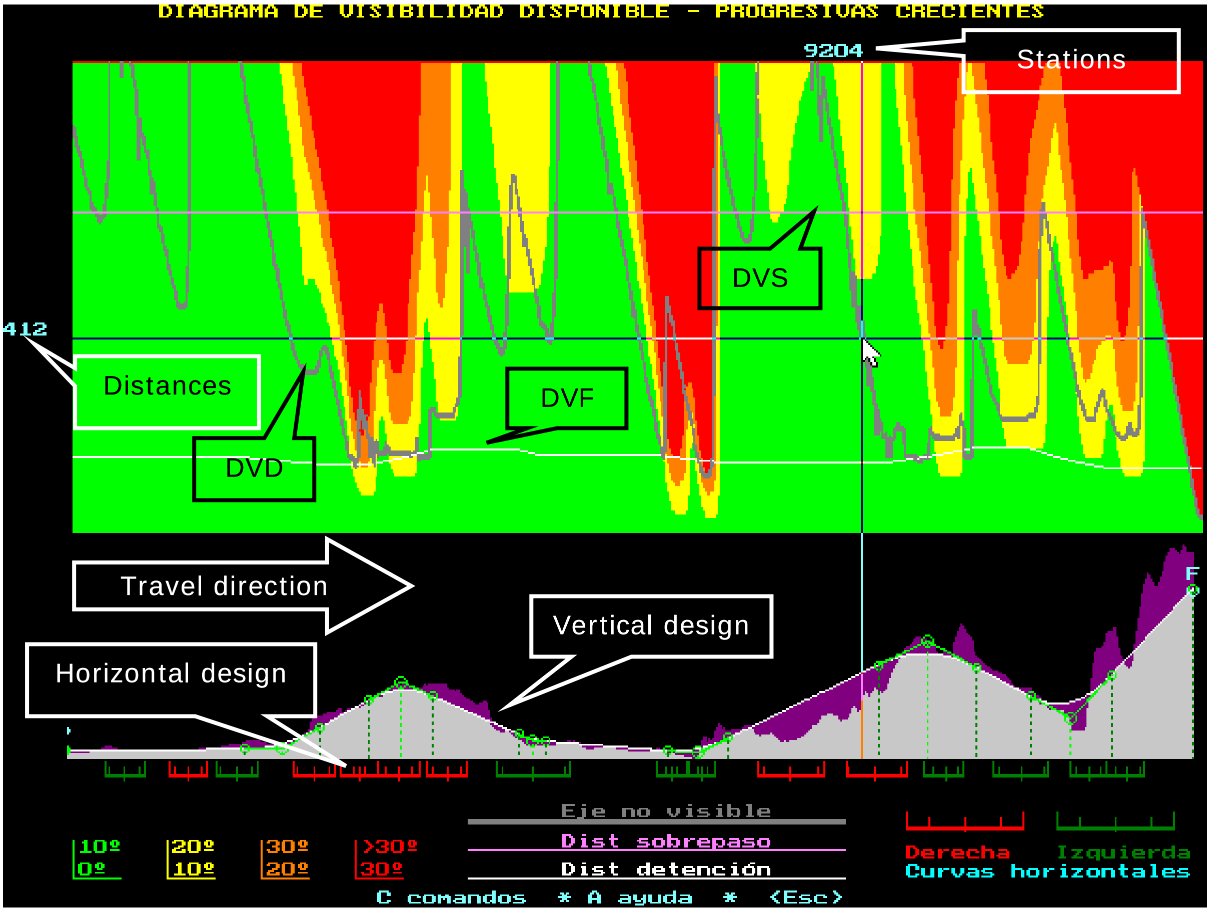


FIGURE 3 Available sight distance, EICG06 System.

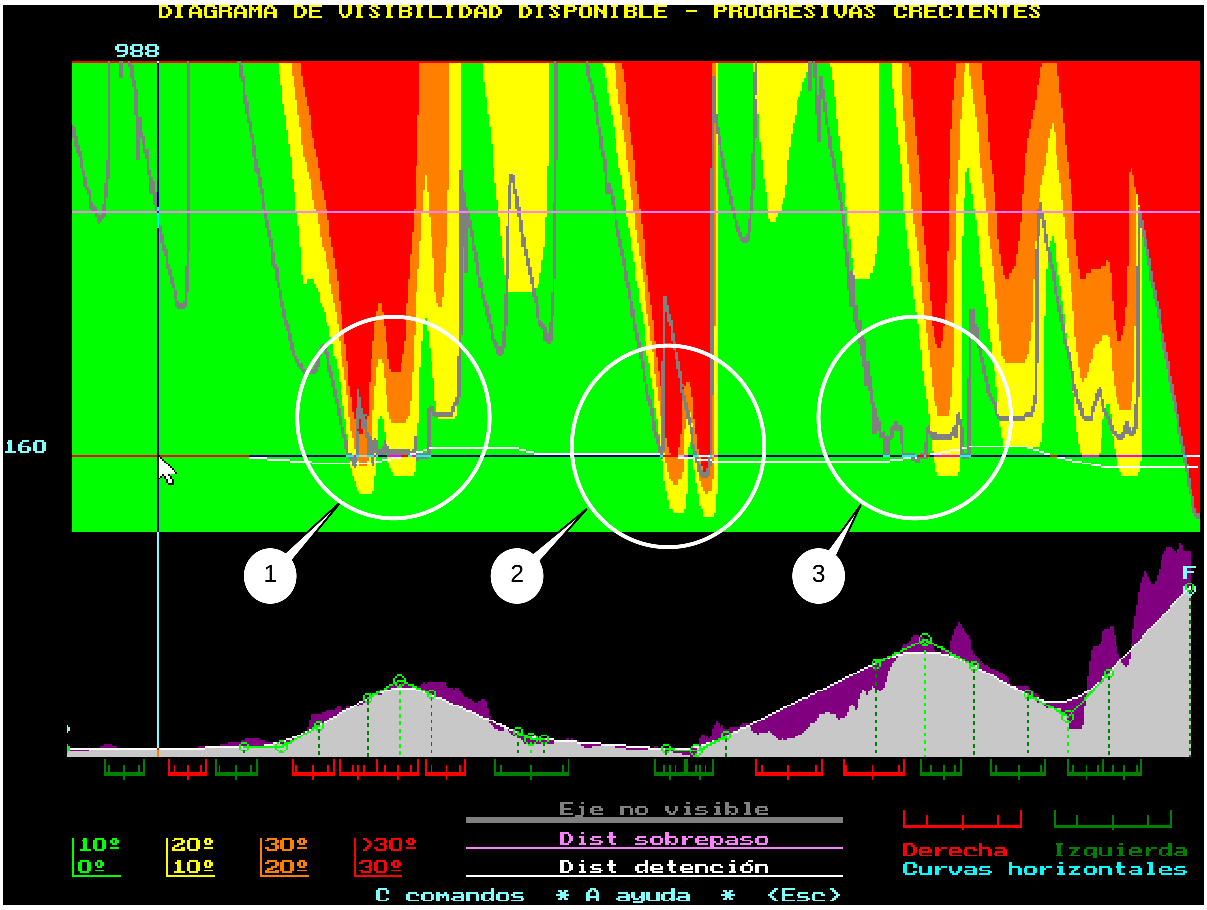


FIGURE 4 Stopping sight distance, EICG06 System.

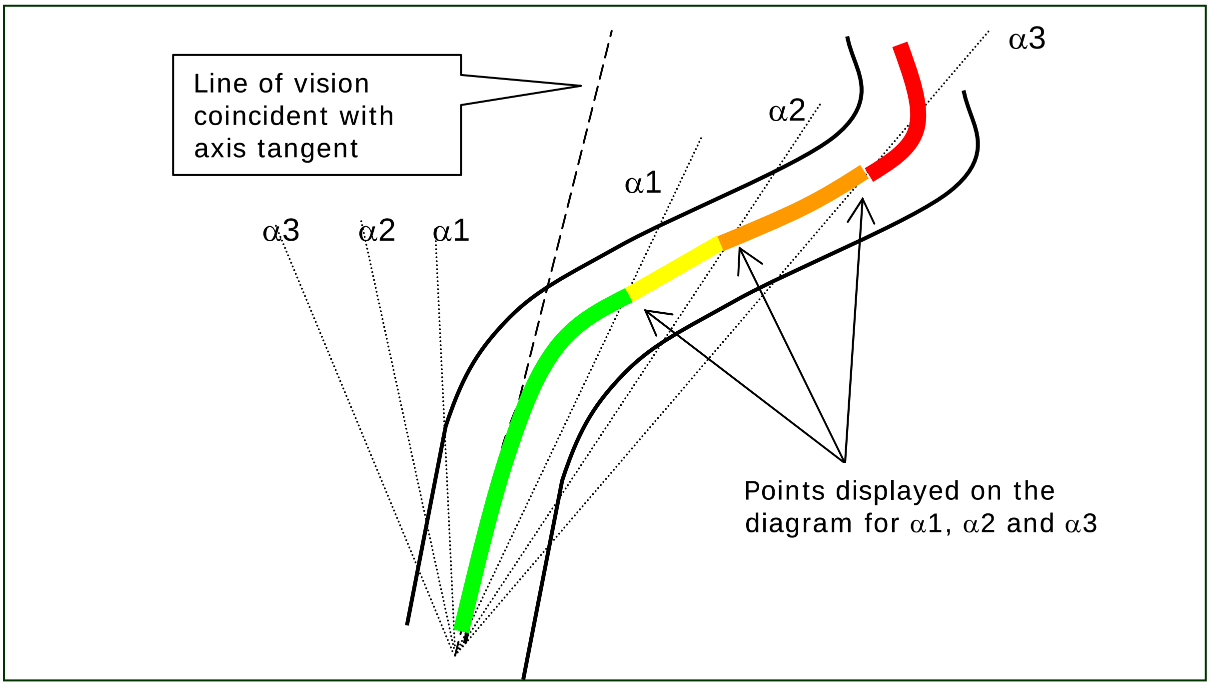


FIGURE 5 Visibility angles and corresponding colors on the visibility diagram. *(5, 6)*

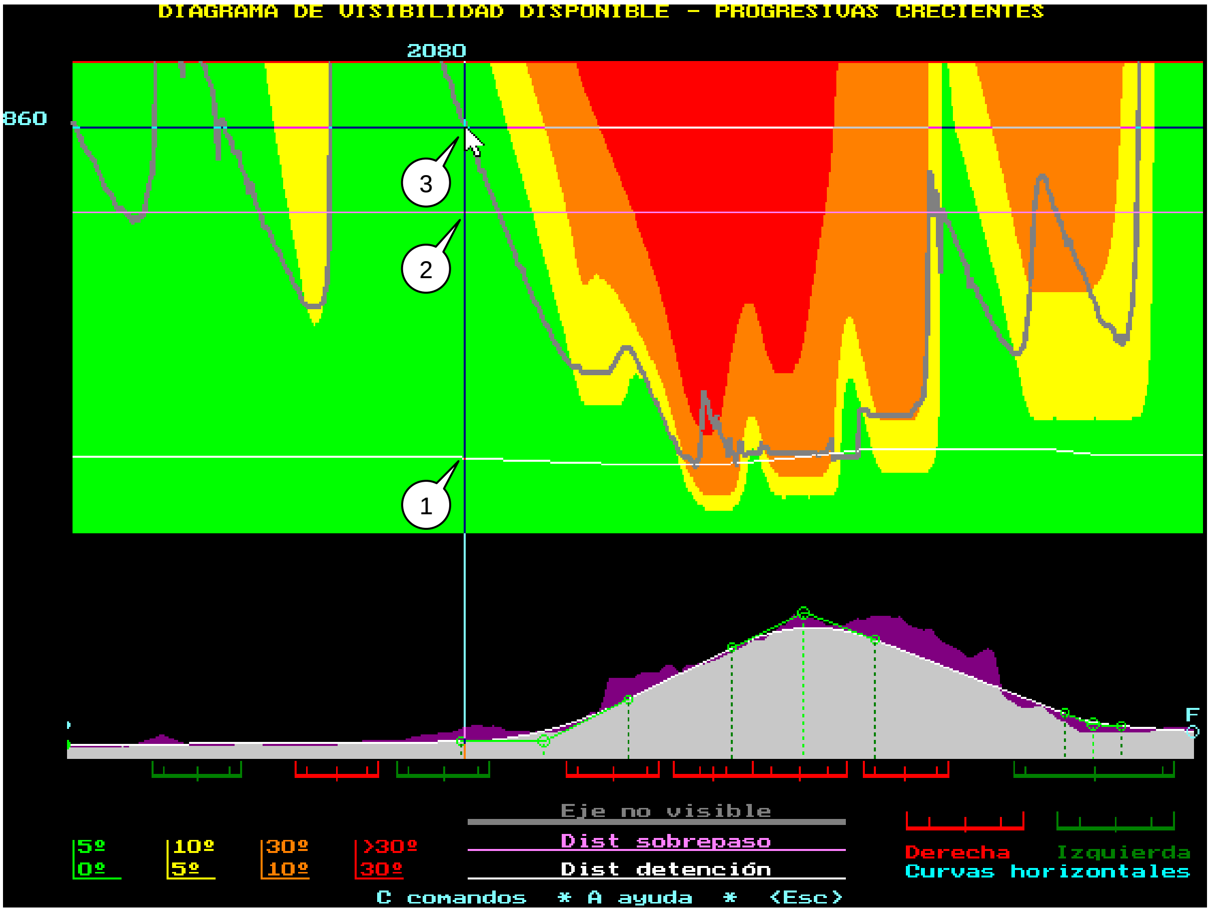


FIGURE 6 Visibility Diagram at station 2080.

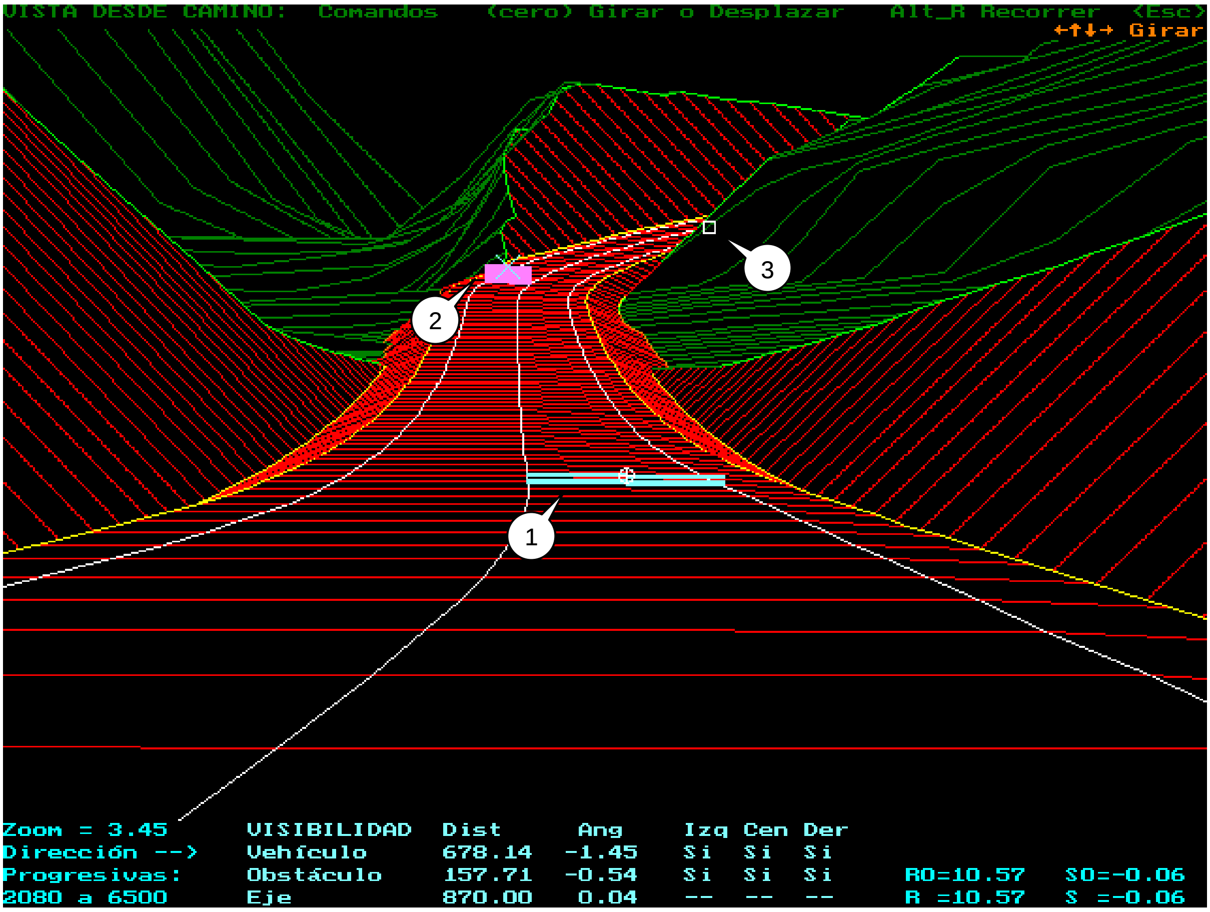


FIGURE 7 3D Perspective at station 2080.

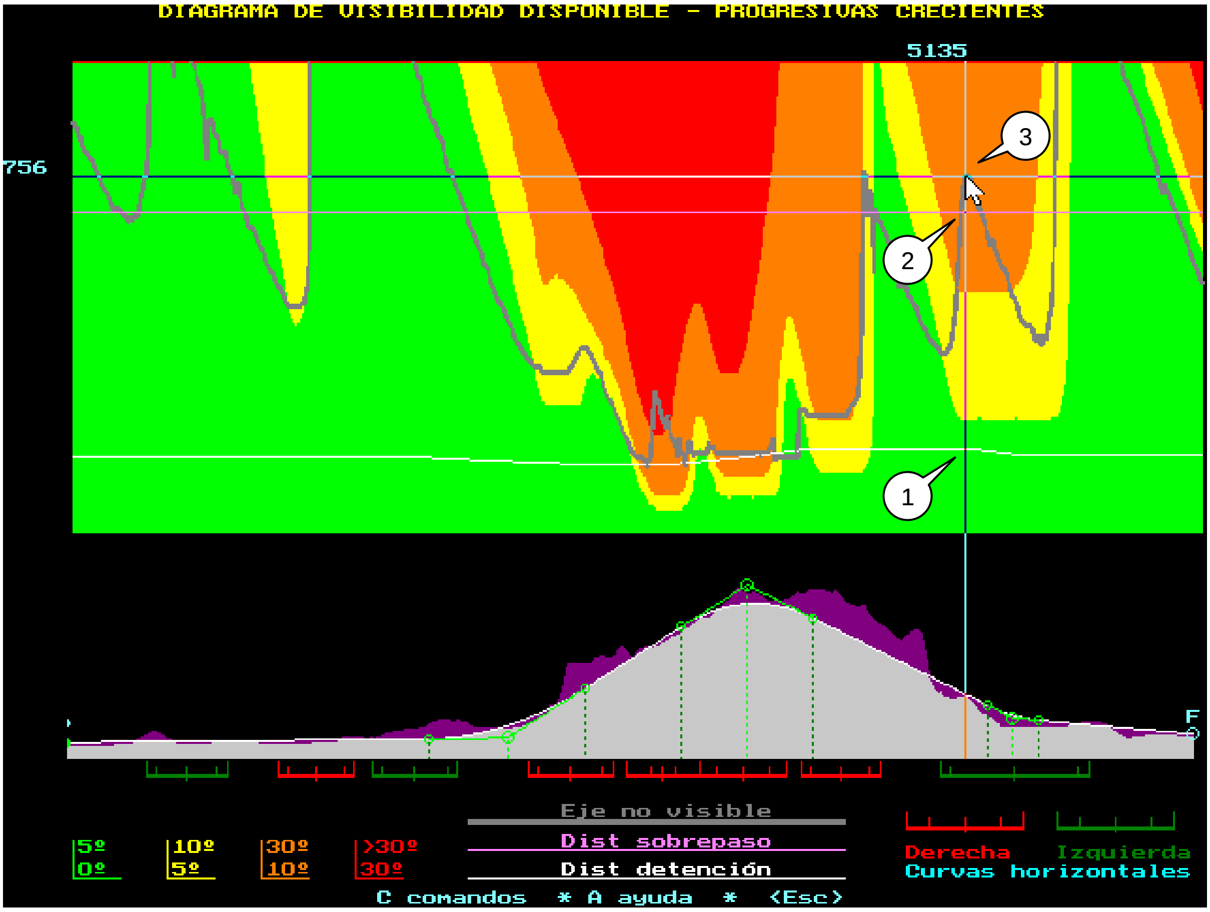


FIGURE 8 Visibility Diagram at station 5135.

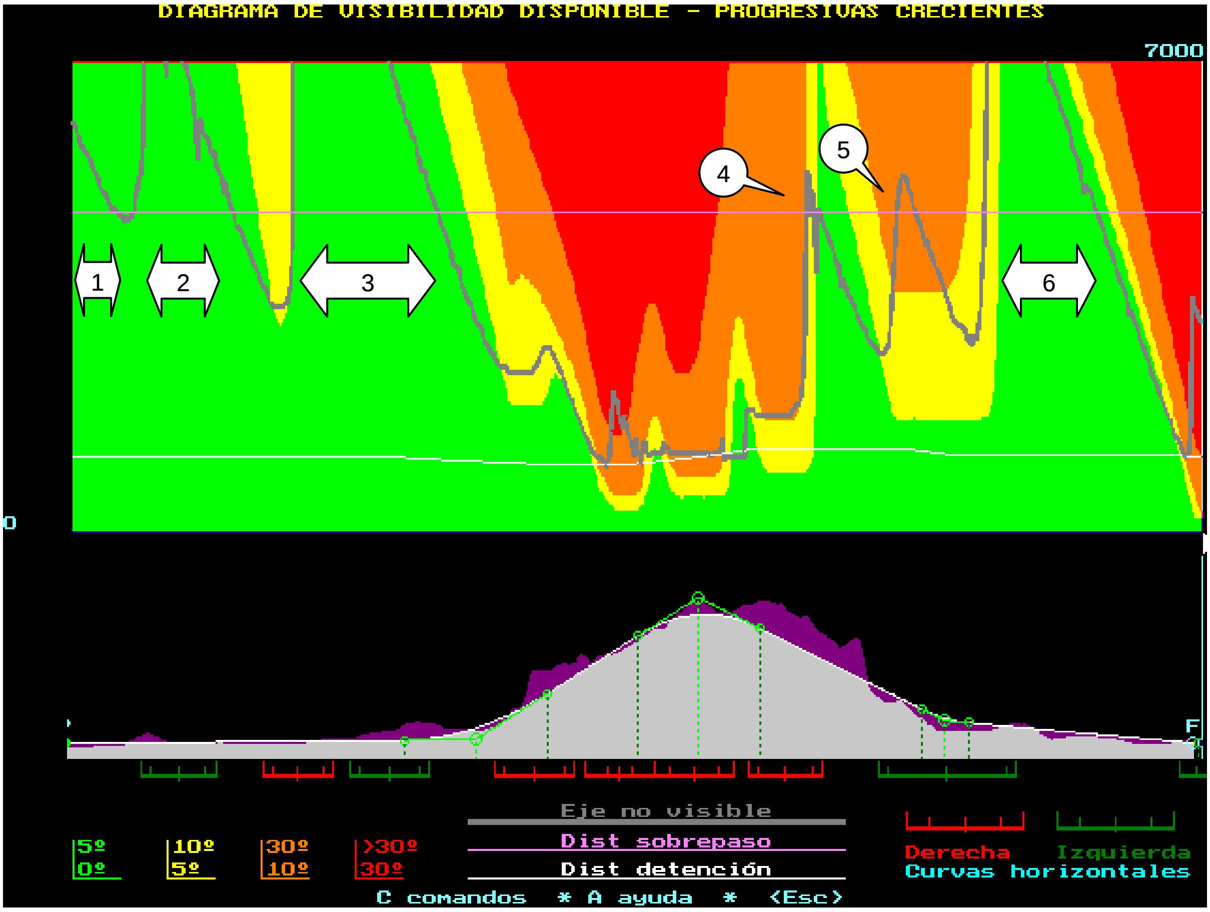


FIGURE 9 Visibility diagram, stations 0,00 – 7,000.00.

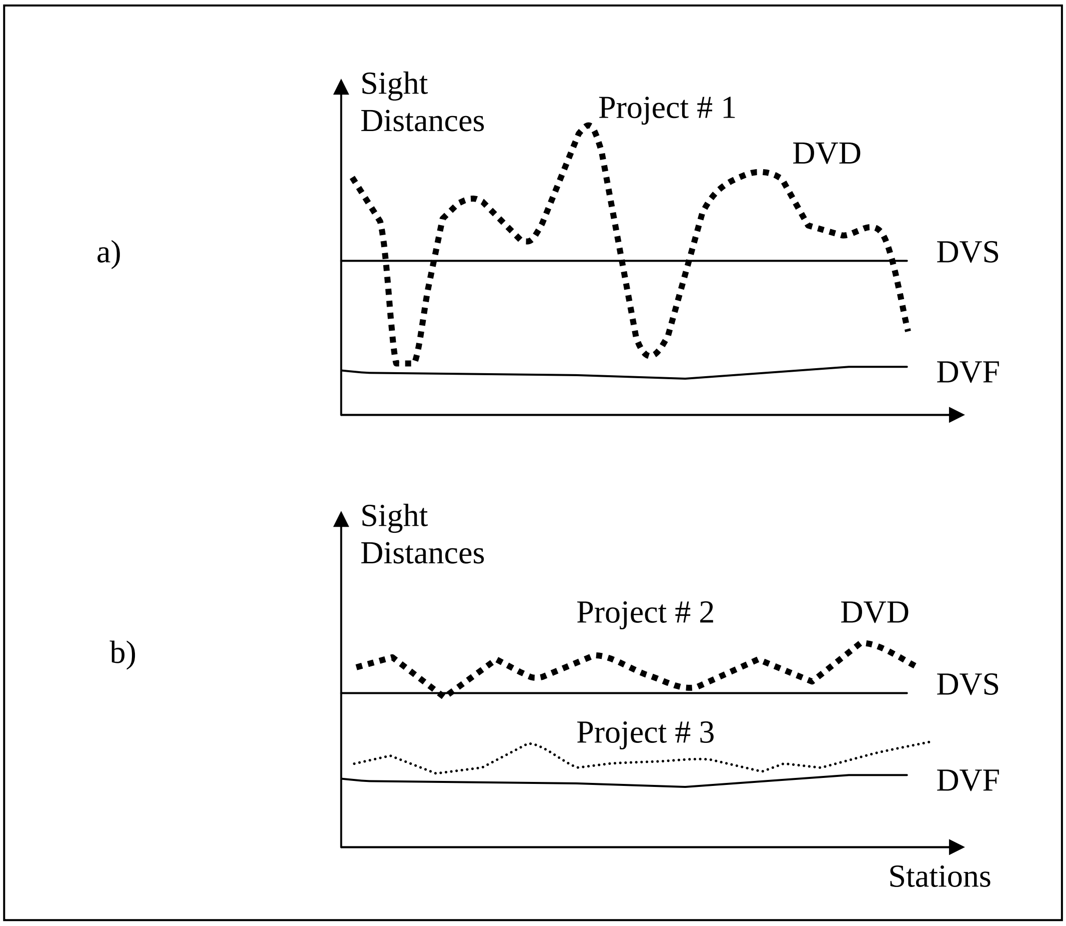


FIGURE 10 Examples of consistent and unconsistent design.

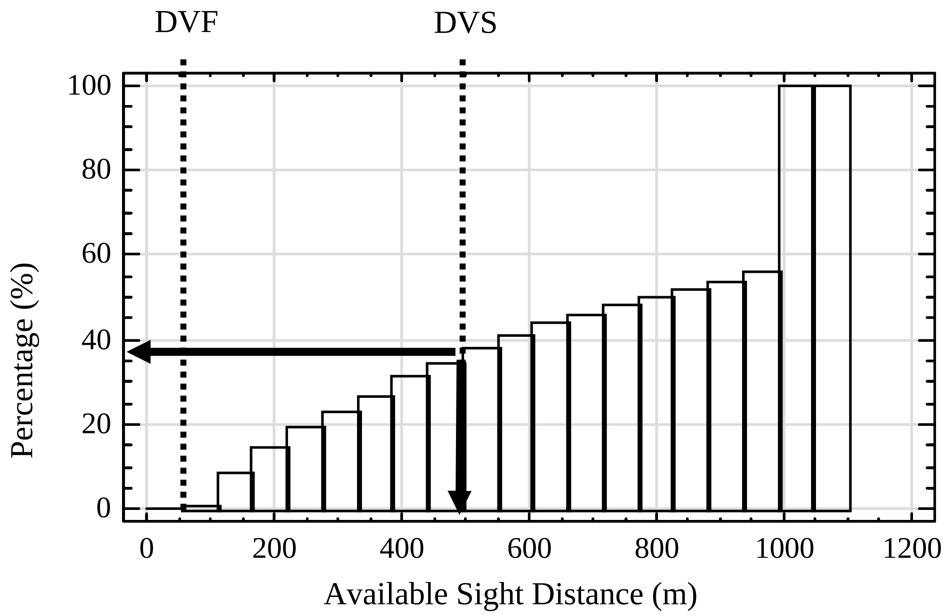


FIGURE 11 Statistical evaluation of existing DVF, DVS and DVD.