MINE ACCESS ROAD DESIGN AND MODELLING WITH IROAD

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ABSTRACT: The design of a mine access road is in general terms not very different from the design of any other road in civil engineering. In most cases mine access roads have a short life span and are build using material from the area near the mine. This paper presents the design and modelling of a mine access road using computer software and in particular a package called IROAD. In the example presented in this paper, IROAD was used to design an 8km long access road from a set of given stations and according to some case specific design parameters. The module produced all the necessary alignments and cross-sections including cut and fill batters. The design was triangulated and a model was produced that in conjunction with the topographic surface model allowed the calculation of cut and fill volumes. The triangulated model of the road design together with the modified model of the topography can then be used for virtual driving and fly-over giving a clear understanding of how the road will look like from any view point.

1 INTRODUCTION

The IROAD module is part of the VULCAN 3D Software suite from Maptek Pty Ltd. It is used for designing roads in rural and urban environments. This module combines powerful graphics hardware with a sophisticated general purpose three dimensional graphics editor to provide the designer with a flexible tool to assist in the planning, design and construction of a roadway system.

The IROAD module allows the designer, given a suitable model of the terrain upon which the road will lie, to generate a roadway. The designer can quickly produce the road alignment, then design a typical road cross section or select a section from a library, apply this to the alignment and instantly get a report of earthworks needed. The designer can then pass through this design cycle again and again until the optimal design is reached. From this reports and plots can be generated. Civil engineers can use the module for the detailed design of road sections. This module is suitable for mining engineers who can use the module for the design of roads in mining environments.

In this paper, IROAD is used for the design of an 8km long mine access road. The design is based on a number of stations controlling various aspects of the road's geometry.

2 DATA REQUIREMENTS

The process of designing and modelling a road begins with the collection of data in the computer. Some of that can already be in digital format and other might need digitising. The control station data,

for example, should be transferred easily through an ASCII file from any spreadsheet program.

The terrain on which the road is to be designed, if not in digital format, needs to be scanned from a contour map and vectorised using one of the many freeware and commercial packages for raster to vector conversion. These packages have many facilities that enable very accurate vectorising of images. The resulting strings can be scaled and brought to the appropriate co-ordinate system before being exported to a data transfer format file such as DXF. Scaling and positioning can also take place within the modelling software (Figure 1).
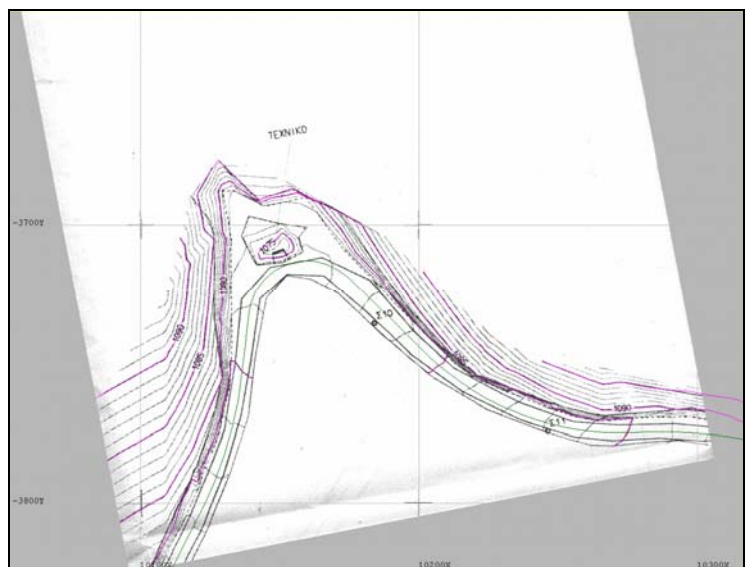

Figure 1. Digitising, scaling, and positioning part of a contour map in VULCAN.

The road section or sections need to be designed according to specifications, or be transferred from a CAD package using

a file format such as DXF. It is better to design them in the road design package as in this case all the section points will get the appropriate code names and be easier to identify later.

Other information, such as aerial photographs of the area, economical data for the road construction, or super elevation angles can be provided to make the design more complete.

3 METHODOLOGY

Once the necessary data is in the appropriate digital form, the road design process can commence. The road design data is accessed on a design by design basis. Each design comprises all the data necessary for the road (i.e. intersection points, alignment, typical cross sections and road cross sections as well as design parameters, such as grade limits and batter slopes). The data is stored in different layers, but the IROAD module will access them in an organised fashion.

3.1 Terrain Selection

The first step is to acquire terrain upon which to design the road. The terrain must consist of a triangulated surface. This surface can be generated from survey data, photogrammetry or by digitising maps (Figure 2) using the Delaunay algorithm.
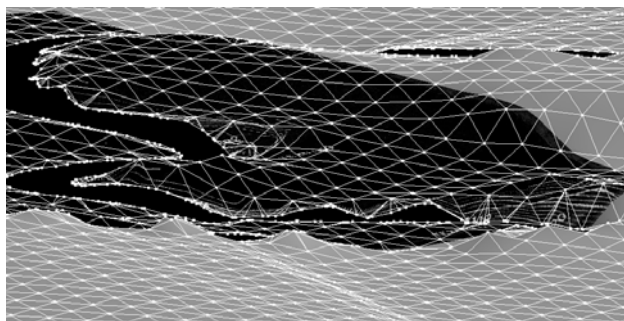

Figure 2. Triangulated digital terrain model for road design.

The triangulation must be dense enough to provide the necessary detail for the calculation of the cut and fill batters.

3.2 Road Design Default Parameters

The default road design parameters can be provided at the beginning of the process. These parameters relate to aspects of the road design such as:

- alignment
- intersection points
- super elevation values
- slope of batters

More specifically, the user has to select the start and increment of chainage, the minimum allowable radius (i.e. the smallest radius curve that the current design can have), the maximum allowable grade (i.e.

the steepest grade, either going up or down, that the current design can have), the default super elevation values to use when no designed super elevation diagram is used for the generation of cross sections, left/right crossfalls, and cut and fill slopes. Additional parameters can be provided related to topography, subsurfaces, label size (for plotting), bulking factor and haulage costs.

3.3 Horizontal Intersection Points (IPs) and Alignment

These are, in essence, the control stations of the road design. The intersection points (IPs) control the overall shape of the road alignment in the horizontal (XY) plane (Figure 3).
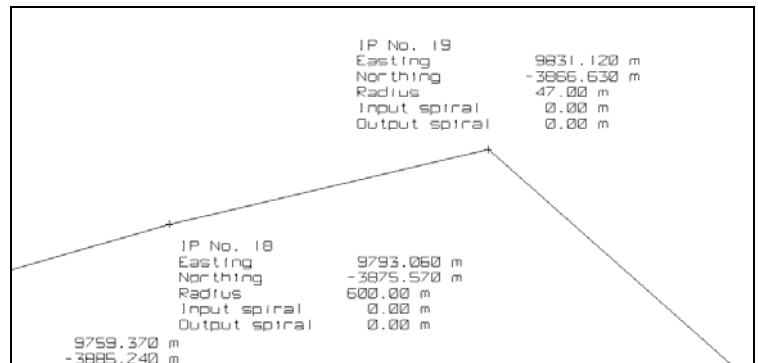

Figure 3. Horizontal intersection points and related information.

The IPs contain not only the X, Y co-ordinates but other information such as the minimum allowable radius and input/output spiral lengths. The spiral lengths define the length of a curve that will be fitted between, the tangent and circular part of the alignment. The spirals allow a smooth transition from a straight to circular curve.

The alignment is then fitted on the IPs. It is the line that the road follows, which is not necessarily the centre line. In the IROAD module it is a line in 3D space consisting of points with the easting, northing, elevation and chainage value of the points (Figure 4).
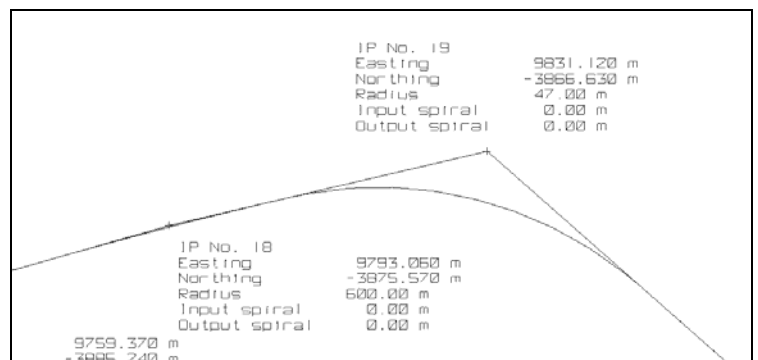

Figure 4. Road alignment fitted on horizontal IPs.

When the alignment is created, the points on it are given chainage values. Each point on the alignment is given a value that is a linear distance along the curve, from a given starting point. If the alignment cannot be created because the radius at a point is too large, then an error message is given referring to the problem point.

3.4 Long Section and Vertical Intersection Points

So far the design process produced a curve (alignment) that contains the correct X, Y co-ordinates of the road according to the horizontal intersection points, the minimum allowable radius, and the input/output spiral lengths.

In order to produce a curve that also contains the correct elevations (Z co-ordinate) we need to work on the long section of the road. The IROAD module produces a section following the horizontal alignment produced. This section is not a flat plane but more of a curved surface, stretched to look flat on the computer screen. The long section allows you to view the natural surface along the alignment, i.e. a long section view of the terrain. The X-axis of the long section is actually the chainage along the alignment and the Y-axis is the Z co-ordinate. This is used for looking at the terrain under a horizontal alignment and for designing vertical intersection points (IPs) and alignments (Figure 5).
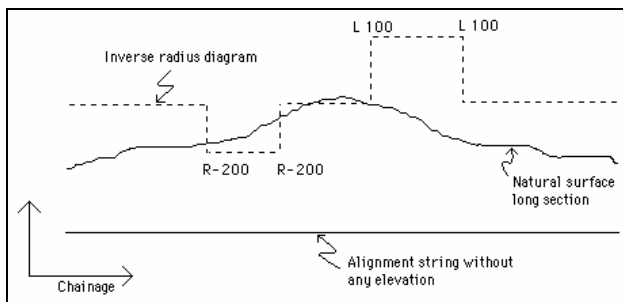

Figure 5. Long section showing natural surface, horizontal alignment and inverse radius diagram.

The process of selecting IPs is repeated in the long section window, this time the IPs are getting the correct Z value as well as the X and Y. The maximum allowable gradient is used by the module to check each new point in relation to the previous so that the gradient is kept below the default maximum value. The new vertical IPs are combined with the already existing horizontal alignment to produce a new alignment in 3D.

Another useful feature of the Long Section view is the inverse radius diagram. This diagram shows deviations from a zero level, in inverse proportion to the radius of curvature of horizontal alignment. The diagram is used to design a superelevation diagram that is used to superelevate the left and/or right hand sections of a roadway. This may be necessary for roadways with a sharp turn, small radius of curvature, as a vehicle entering the turn is propelled out by the centrifugal forces, at a tangent to the curvature. To counteract centrifugal forces, the vehicle may either decrease its travelling speed or the road surface may be cambered as it is at a velodrome or racetrack.

If the alignment is curving to the left, then the right hand section of the roadway will be elevated and the left hand section of the roadway will be depressed, and vice versa if the alignment curves to the right (Figure 6).
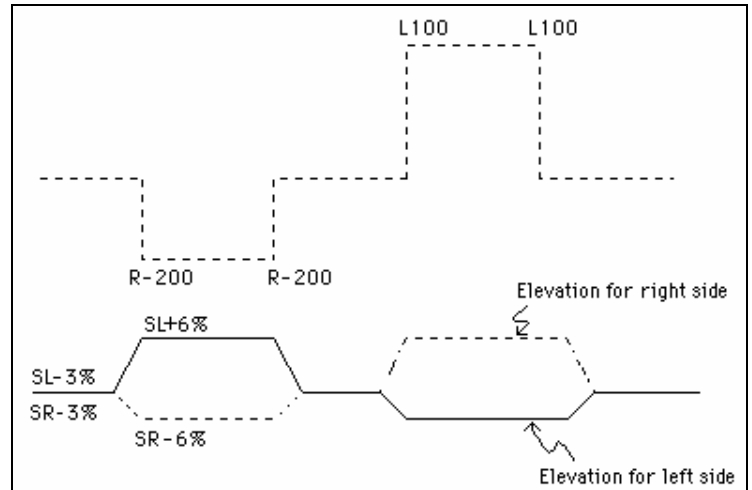

Figure 6. Use the inverse radius diagram as a guide to applying superelevation.

3.5 Balancing Earth Works

IROAD includes a Balance option that allows you to balance out the height differences between the long section terrain and the alignment. This is useful for preliminary balancing of earth works. The balance is based only on height differences (effectively the area calculated from height by chainage as shown in the view) between the alignment and the terrain. At this stage the road cross section is not taken into account. It is, however, useful as a guide to how the actual volumes will balance.

3.6 Cross Section Design

When the final alignment is produced, a road surface cross section can be designed, along with the super elevation diagram. These sections are applied to the alignment to produce a set of cross sections along the alignment that has been modified according to the super elevation and the natural terrain.
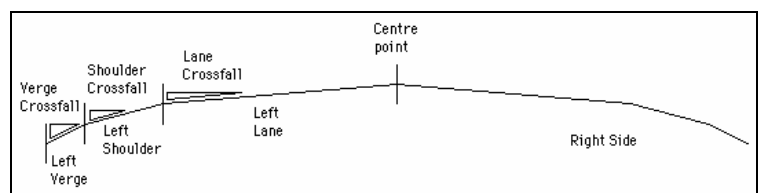

Figure 7. Road section diagram showing parts of the road surface and their slopes.

A typical road section in IROAD consists of a number of segments as shown in Figure 7. All segment lengths and slopes can be defined according to specifications. The centre point is the default centre of the road, where the section will follow the alignment string. The following diagram (Figure 8) shows how a typical road section is coded in IROAD. The codes assigned to the various points linking the segments of the section are used for identifying them and for connecting the sections together to a final road design (Table 1).
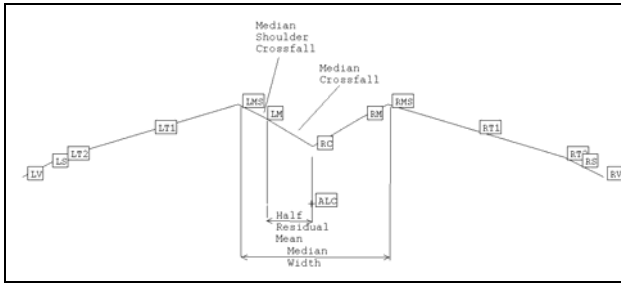
Figure 8. Road section coding in IROAD.

Table 1. Valid point names in IROAD.

Left Lane	Right Lane
LBP (Left batter point)	RBP (Right batter point)
LV (Left Verge)	RV (Right Verge)
LS (Left Shoulder)	RS (Right Shoulder)
LT1 (Left Traffic Lane #1)	RT1 (Right Traffic Lane #1)
LT2 (Left Traffic Lane #2)	RT2 (Right Traffic Lane #2)
LM (Left Median)	RM (Right Median)
LMS (Left Median Shoulder)	RMS (Right Median Shoulder)
LC (Left Centre)	RC (Right Centre)

IROAD also allows generation of conditional sections. A conditional section is a section that is appended to the typical road section on either side, and can be selectively applied in cut or fill conditions. This includes drains in cuttings and berms, or embankments in fill conditions.

3.7 Applying and Connecting Road Sections

In order to produce the final and complete road surface design, the designed road sections and 3D alignment need to be combined. This is done by applying the appropriate road sections to parts of the alignment (i.e. start and end chainage) (Figure 9).
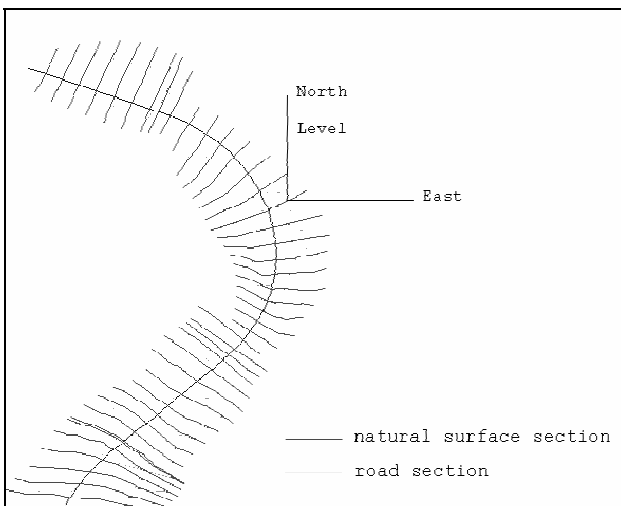

Figure 9. Application of road sections to 3D alignment.

IROAD produces not only the road surface section on the alignment and with the right orientation, but also the section of the natural surface and cut and fill batters. The next step is to join cross sections generated, to create a more appealing road design. The sections are joined together by a set of lines. Each line connects similar named points on the road, or on the natural surface section (Figure 10).
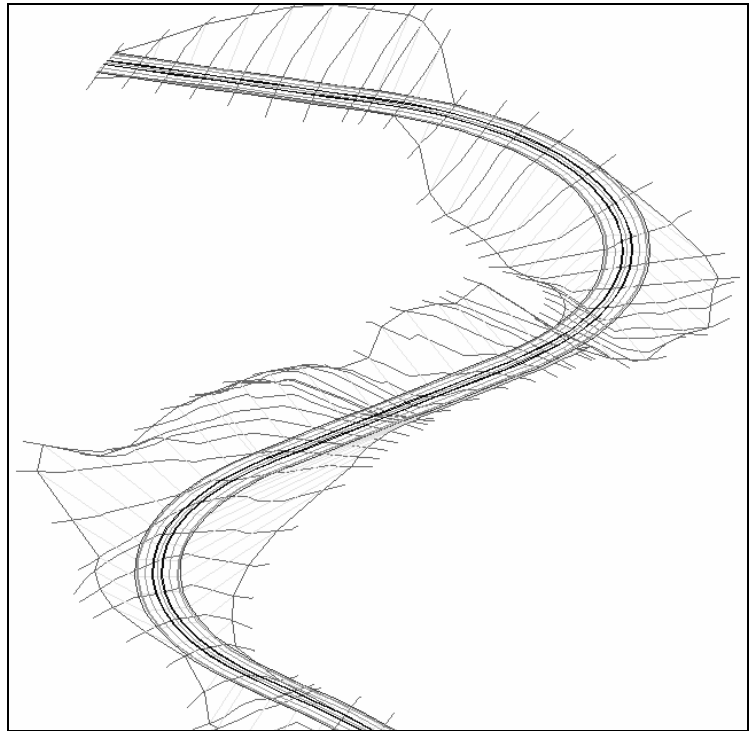

Figure 10. Final road design – connected road sections.

Once the sections are joined, the user has the option to create a mask. A mask is a polygon that totally includes all the created joining lines. The mask represents in reality the area that has been changed by the road design. The mask is useful when triangulating the road surface so that the triangulation does not extend beyond the roadway. It can also be used to remove any topography points inside the roadway so that the natural surface can be modelled (Uecker 2001).

3.8 Calculating Cut and Fill Volumes

Volumes can be calculated using two different methods: End Area and Triangle. The latter is more accurate as it deals with volumes between the newly created road triangulations and the existing topography.

The End Area option allows you to produce cut and fill volumes for the road areas, based on the cross sectional end areas method. Although this method is comparably faster than the method used with the Triangle method option, it only produces approximate volumes. The difference between the two methods is usually very small. However, the End Area method reports volumes calculated by the road sections at each chainage, which can be very useful for determining, for example, which chainage will have the largest cut or fill.

A mass haul diagram can be produced using the Mass Haul option showing both sectional cut and fill, and cumulated volumes (Figure 11). This diagram is useful for balancing

earthworks and calculating haul distances. This is achieved using the Balance Line option, which allows you to modify graphically the cut and fill volumes, useful for balancing earthworks and calculating haul distances. The way it works is that the chainage between any horizontal line connecting two points on the mass haul diagram, represents an area of equal cut and fill (i.e. the earthworks are balanced). The area between the balance line and the mass haul line is proportional to the cost of the earthworks, i.e. the haul distance by volume. This area can also be divided into free haul and overhaul area. This is defined by the free haul distance.
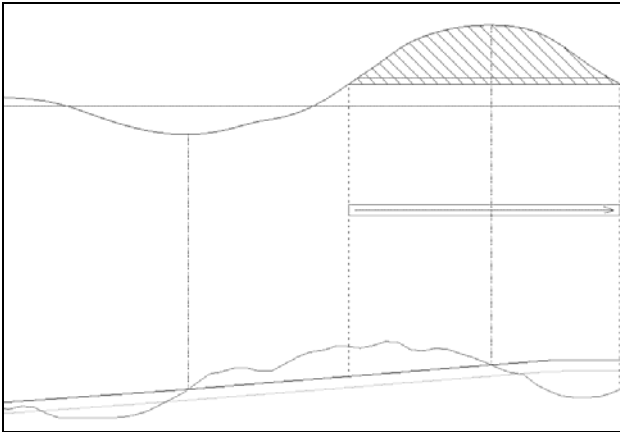

Figure 11. Mass haul diagram and balance line. The shaded area represents the total cost of the haulage. The area above the straight horizontal line is the free haul cost, the area below is the overhaul cost. The arrow indicates the general haulage direction.

A default bulking/compaction factor can be set to be used in the cut and fill volume calculations. It can be a fixed value or a grid model. When a model is used, a factor for each end area or exact volume calculation between sections is taken from the surface at that point in the alignment. The model can be used to take into account different material types and hence their bulking properties along the length of the road.

The Haul Costs option allows you to set the free haul cost and over haul cost. These costs are used in the mass haul diagram. The Haul Costs option also allows you to set a default free haul distance that is used to draw the balance line when modifying the haul diagram via the Balance Line option as described above.

3.9 Modelling

After completion of the road design, the triangulation model of the road surface including the cut and fill batters can be created using VULCAN's advanced modelling options. This model will be limited within the mask created during the road sections connection. The same mask can be used to remove the part of the terrain that has been changed due to the new road surface (Figure 12).
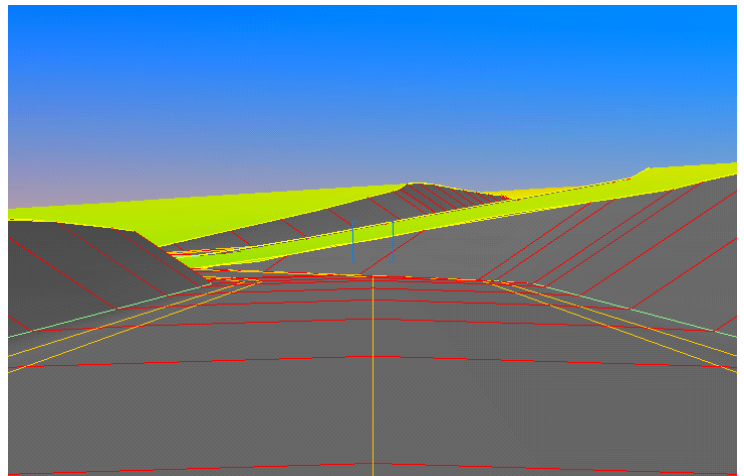

Figure 12. Perspective view of road surface model and surrounding terrain.

4 MINE ACCESS ROAD DESIGN EXAMPLE

The design example presented in this paper was part of a final year project at the Department of Geotechnology & Environmental Engineering of the Technological Education Institute of West Macedonia, Greece (Tavoularis 2002). The primary data come from a real mine access road that was built for a pit at the north-west of Greece. The terrain close to the path of the access road and the control stations (horizontal IPs) were included in this information.

4.1 Primary Data

The terrain information came in the form of plotted maps that had to be digitised, scaled, and located in real world co-ordinates within VULCAN (see Figure 1). This process resulted to a design database with two layers, one for the contours and one for the horizontal intersection points. The latter contained all the necessary information (i.e. minimum allowable radius and input/output spiral lengths). A plan view of these objects is shown in Figure 13.
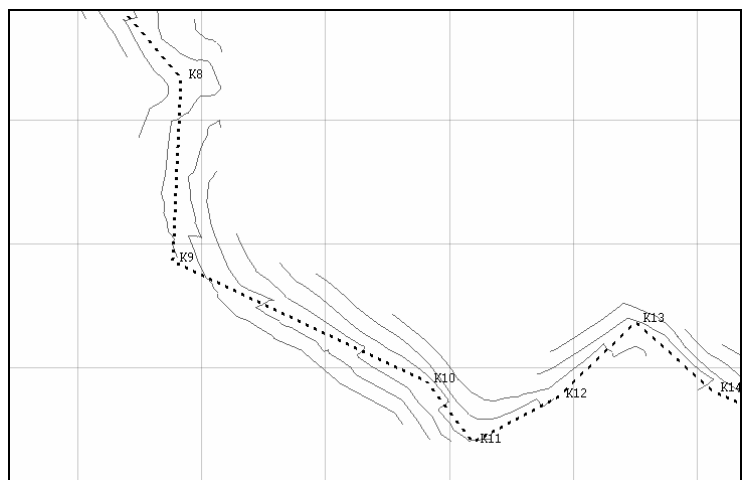

Figure 13. Initial data for road design (terrain contours and horizontal IPs).

4.2 Alignment Design

The horizontal IPs were used for designing the horizontal alignment of the road. This alignment followed the minimum allowable radius stored in the IPs as well as the input/output spiral lengths (Figure 14).

Figure 14. Horizontal alignment of the mine access road.

The next step was to produce the long section in order to design the vertical IPs and produce the final road alignment in 3D. The main aim of this process was to maximize fill and minimize cut as the idea was to use the available waste material from the mine. The long section for the first part of the road is shown in the Figure 15. A vertical exaggeration is also used to make the terrain features more visible.
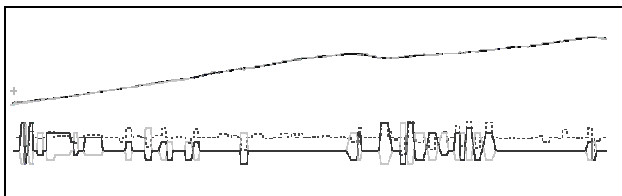

Figure 15. Long section of terrain showing inverse radius diagram and left/right superelevation designs.

Combining the horizontal alignment and the vertical IPs produced the final 3D alignment. The next step was to design the road section.

4.3 Road Section Design

The road section design was fairly straightforward as there were not many aspects to consider. All the necessary parameters were entered in the road section panel (Figure 16) and the section was designed on a separate 2D window (Figure 17). Multiple sections could be designed here but there was no need in this example.
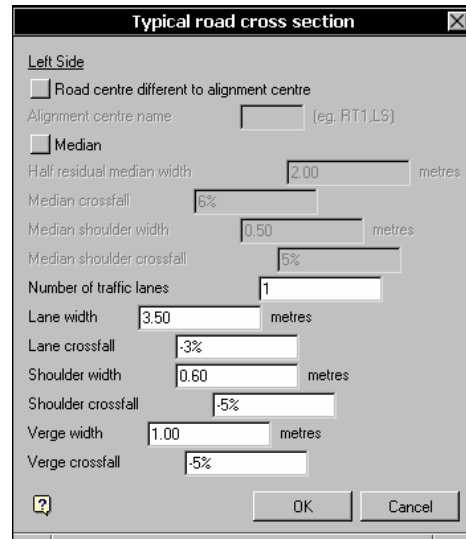

Figure 16. Road section parameters input panel for the left side. Same parameters were applied to the right side. *Screenshot from VULCAN V4-IROAD.*
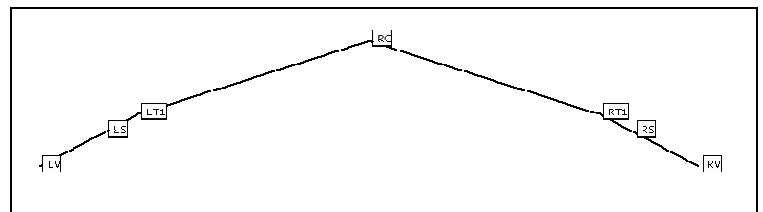

Figure 17. Road section design showing individual point names.

4.4 Finalizing the Road Design

Connecting the road sections and creating the mask polygon is the final stage of the road design. It's a process that takes very few moments and in this example produced very impressive results as can be seen in the following figures (Figure 18 and 19). All different objects of the design were saved in layers starting with the name of the design and having a code added at the end that identifies the role of the object.
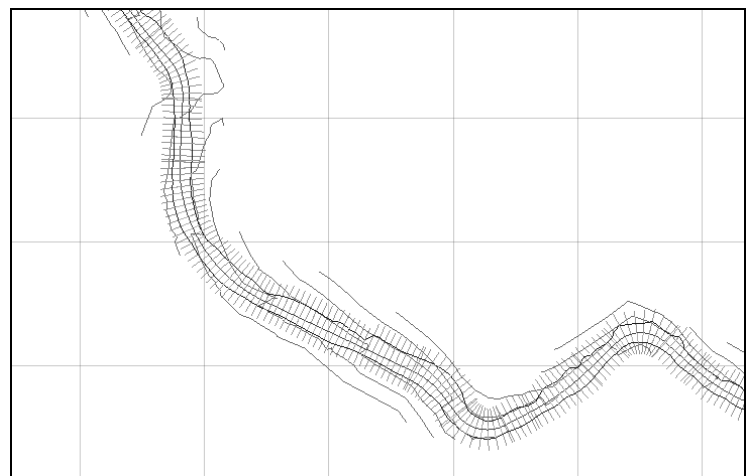

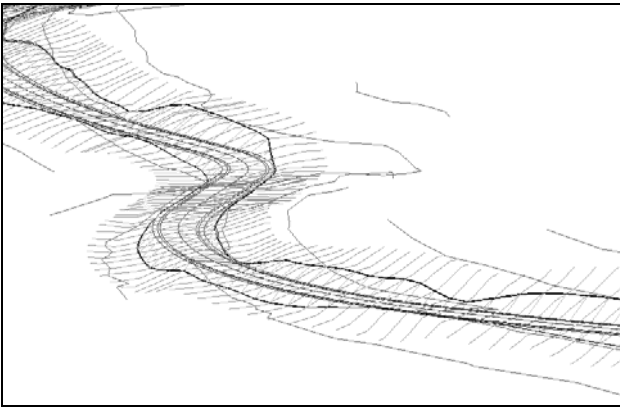Figure 18. Final road design showing multiple road sections linked with strings defining the road surface.

Figure 19. 3D view of final road design. The individual road sections and respective natural surface sections are shown.

4.5 Road Surface Modelling

The two lanes of the road surface were triangulated to a single model. The sides of the road were triangulated separately as well as the cut and fill batters. Creating separate models allowed for different colours and textures for each part of the design. The natural surface model was altered so that it will not include the part that has now changed due to the road. The result was a realistic model of the complete design including the surrounding topography (Figure 20).
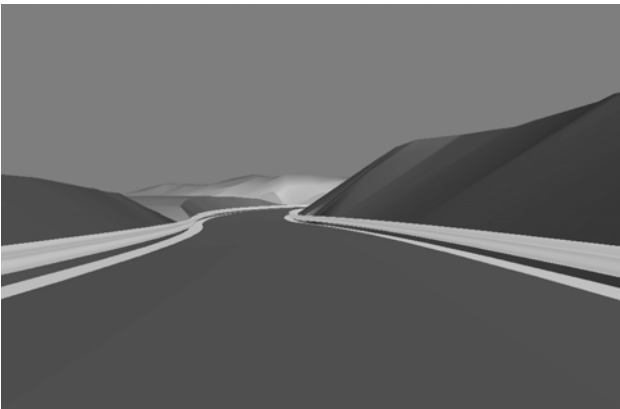

Figure 20. Perspective view of the road design and topography models in VULCAN.

Additional features such as side bars, traffic signs, trees, and ponds can be added easily to the model within VULCAN (Figure 21). Aerial photographs as well as other images can be draped on the triangulation models. IROAD also allows plotting individual sections, or a range of sections, or all of the sections into a group plot. These plots provide a valuable reference for identifying where alterations in the design may achieve better results (Cumplido 2001).
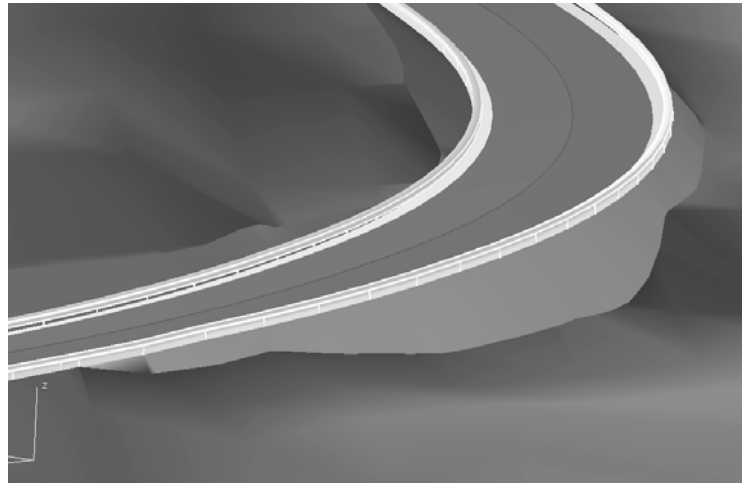

Figure 21. 3D view of the road design model with protective side bars and posts added.

4.6 Real-Time Animation

IROAD enables the user to do a lot more than just static perspective views of the road design model. A real-time drive through the model allows you to view the designed road from a vehicle's point of view. The user can select the lane and then control the speed as well as the viewing height during the animation using the mouse (Figure 22).
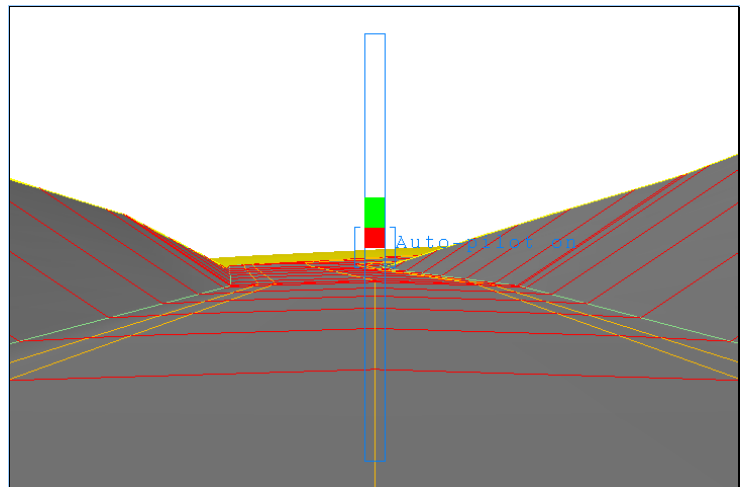

Figure 22. Virtual driving in IROAD. The travel speed is controlled by the mouse and the bar shown in the middle of the screen.

5 CONCLUSIONS

This paper presented the methodology of road design and modelling using a road design module (IROAD) of a complete earth resource modelling package (VULCAN). The main steps of the design process were explained and the results were illustrated. An example was given of a mine access road design using real data. In this example, the advanced visualisation capabilities of IROAD and their benefits were demonstrated. The combination of IROAD and the graphical environment of VULCAN gives a powerful solution to road design needs for earth resource management specialists.

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