

Engineering Applications of Computer Aided Design for Spatial Transition Curve

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Abstract - In this paper 3D model of railway with transition curves with nonlinear change of curvature is represented. Main goal of this paper is a straightforward application of complex spatial geometry, so that engineers can apply with ease technical conditions of European standard EN 13803-1:2010 on Serbian Railways. European standard installs a modern approach in railway design that implies the selection of geometric form of transition curve and cant transition as a unique spatial element. An engineering choice of spatial form of cant transition is required by type of superstructure or maintenance conditions of track geometry during exploitation. In Serbia and in some countries of European Union, civil engineers use GavranCivilModeller® (GCM®) for railways and roads designing. This paper shows how to create AutoLISP routines which will be used along with GCM® in order to design model of railway with transition curve with nonlinear change of curvature.

I. INTRODUCTION

Transition curve is an element of alignment that connects straight line and circular curve or two circular curves with same or different radius, which can have same or opposite direction of curvature.

Transition curve and cant transition form complex spatial geometric shape with simultaneous change of curvature of both track rails and change of cant of the outer rail [1]. Additionally, both track rails follow designed grade level in longitudinal profile.

In order to secure ride comfort, function of rail curvature change in the zone of the transition curve must coincide with function of cant change in the zone of the defined cant transition.

According to European standard EN 13803-1:2010 six forms of transition curves can be used: clothoid, cubic parabola, Bloss curve, cosine curve, Schramm curve and Klein curve (sine curve) [2].

From denominated transition curves only clothoid and cubic parabola have linear function of curvature and cant change (Fig. 1). Other transition curves require appropriate nonlinear function, namely [2]:

- third-order parabola for Bloss curve,
- second-order parabola for Schramm curve,
- cosine function for cosine curve and
- sine function for Klein curve.

Following symbols are used in Fig. 1:

- D – cant,
- $1/r$ – curvature,
- R - radius of circular curve,
- l – distance from the random point to the beginning of transition curve,
- BT – beginning of transition curve and
- ET – end of transition curve.

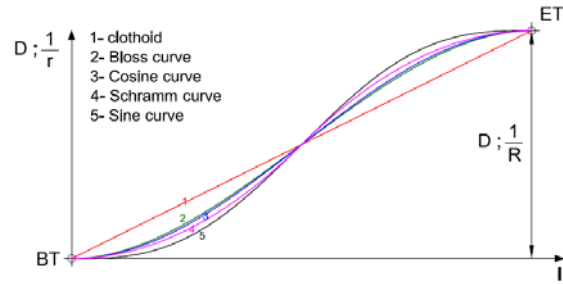


Figure 1. Parallel review of different cant transition geometry [4]

Nonlinear cant transitions are designed in the way to reduce dynamic influences on a vehicle and vertical acceleration that affects the passengers. The main problem that occurs in these cant transitions during exploitation is deterioration of geometry of the track laid on ballast bed due to uneven bed settlement [3].

In general, for curvature equation in random point of the transition curve applies:

$$\frac{1}{r} = f(l) \text{ boundary conditions: } \begin{cases} l=0 \Rightarrow \frac{1}{r} = 0 \\ l=L \Rightarrow \frac{1}{r} = \frac{1}{R} \end{cases} \quad (1)$$

where:

l - distance from the random point to the beginning of transition curve,

L - length of transition curve,

R - radius of circular curve.

If θ represents an angle between tangent line and tangent in random point of transition curve, then it applies [3]:

$$\frac{d\theta}{dl} = \frac{1}{r} = f(l) \Rightarrow \theta = \int f(l) \cdot dl \quad (2)$$

$$\text{boundary conditions: } \begin{cases} l = 0 \Rightarrow \theta = 0 \\ l = L \Rightarrow \theta = \tau \end{cases}$$

Calculation of x and y coordinates is done relatively to local coordinate system whose origin is in the beginning of transition curve and with one axis parallel to tangent line and another perpendicular to it [3, 5, 6].

From observed, infinitely small element from Fig. 2, it follows:

$$\begin{aligned} \cos \theta &= \frac{dx}{dl} & \sin \theta &= \frac{dy}{dl} \\ dx &= \cos \theta \cdot dl & dy &= \sin \theta \cdot dl \\ x &= \int \cos \theta \cdot dl & y &= \int \sin \theta \cdot dl \end{aligned} \quad (3)$$

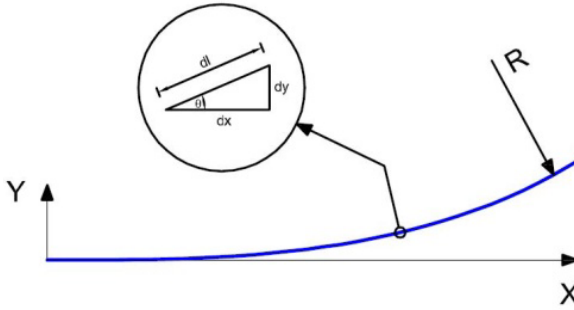


Figure 2. Local XOY coordinate system and transition curve

First of all, coordinates x and y are calculated relatively to local coordinate system, and then these coordinates should be defined in global coordinate system.

Cant is usually applied by raising the outer rail, while keeping the inner rail at the same level. It is also possible to simultaneously raise the outer and lower the inner rail for one half of cant value. But these types of track alignment are more difficult and more expensive to maintain, so they are rarely applied.

Railway centre line in the zone of transition curve is a complex trilinear curved line. From the aspect of mathematics, it represents smooth spatial curve defined with following parameter relation:

$$F(l) = (x(l), y(l), z(l)) \quad , \quad l \in [0, L] \quad (4)$$

By raising the outer rail for constant value D in the zone of circular curve, railway centre line will be raised for value $D/2$ above the inner rail, so in general it follows:

$$z(l) = z_{ir} + \frac{D(l)}{2} \quad (5)$$

where z_{ir} is level of the inner rail.

II. MAIN PRINCIPLES OF 3D RAILWAY MODEL DESIGN IN GCM® ENVIRONMENT

Software products for road design, which are used in Republic of Serbia, support the use of clothoid as a transition curve, while software products for railway design support the use of cubic parabola. Most frequently used software GCM® supports the use of clothoid and offers big opportunities in railway and road design [7] (Fig. 3).

In order to create 3D model of the transition curve in GCM® environment, it is necessary that railway centre line in a horizontal plane and in a longitudinal profile was previously defined. This means creating *.hcl and *.vcl files, which contain necessary data about spatial centre line in both mentioned projections.

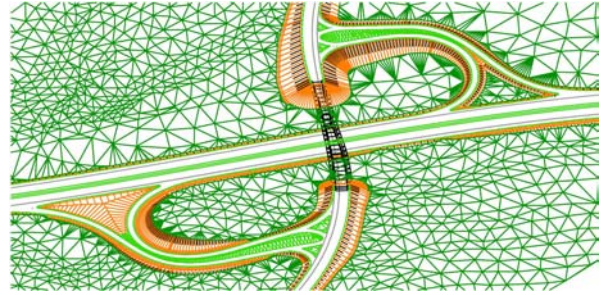


Figure 3. Possible application of software GCM®

Next step is to define the so-called templates. Generally, template represents a set of lines that 3D model should have in its every cross section. For example, it can be only outer contour of ballast bed, or completely defined cross section with all the details. It is necessary to define templates for straight line and for every circular curve, and also for the specific places such as inflection points or for other characteristic places where cant is not applied in the usual manner.

When templates are completely defined, *.tmp files for each one of them are created. Then, these files are "attached" to the centre line on appropriate positions and command for 3D model generation is called. This command generates triangulated 3D model of railway (road or tunnel) by interpolation between the key points on previously chosen, constant distance. Key points are centre line points in which change of template occurs and these points can be stored in created *.tmc file, but also there is a command that can recognize these points by itself. Generation of 3D model between the beginning and the end of the transition curve is based on calculation of a cant value (cross grade) in every pair of consecutive points. Then, between those pair of points, according to created templates, triangulated model of surface that shall be represented in space is created.

In order to create a model of transition curve with nonlinear change of curvature in GCM®, it is necessary

first to develop AutoLISP routines for their construction in horizontal plane.

Next step is final model generation using AutoLISP routine that will, by combining horizontal and vertical geometry, define the set of characteristic points in space on constant distance along the railway centre line. It is best that these points define outer contour of ballast bed, but they also can define upper edges of right and left rail, platform level, i.e. everything that would make completely defined model.

To invoke standard GCM[®] command for generation of triangulated model from chosen points, it is necessary to create *.pts file that will contain handles and coordinates of these points. This file can be created using the already existing GCM[®] command, or it can be one of the results of routine invoking. For the purpose of further adjustment of the railway model in the terrain model, it would be useful that routine also creates a couple of *.str files, above all two of them, which will define right and left edge of ballast bed, and if it is necessary those with the data about right and left rail and/or railway centre line. These files will enable further construction of railway cut and fill slopes, right and left rail, platform surface, drainage details etc. This is the way to create fully defined and detail model, which will represent the stage after railway construction.

III. AUTOLISP ROUTINES FOR 3D MODEL DEVELOPMENT

Algorithm for construction of transition curves in horizontal plane is shown on Fig. 4.

First step is to adjust by need proper system variables and control variable *cv*. Selection of two tangent lines is done using two while loops. Both of these loops repeat until user selects line entity, and only then variable *cv* takes value nil, which terminates a loop. Selection point's coordinates and entity lists are read from both line entities and they are assigned to certain variables. Then user needs to input values of the circular curve radius and the transition curve length, and according to these values geometric elements for construction are calculated, as well as coordinates of all significant points.

Before invoking the command that draws polyline, variable *i* is assigned to a value 2. It means that points for transition curve construction are calculated in successive distances each of 2 m. After leaving the loop, it is checked if the last calculated point is also the end of the transition curve, and if not so the last segment of polyline is drawn and command is stopped. The same procedure is used for other transition curve. Next, command that draws arc using beginning point, ending point and radius is invoked. Hence, transition curve is actually polyline entity, whose vertices are calculated detail points.

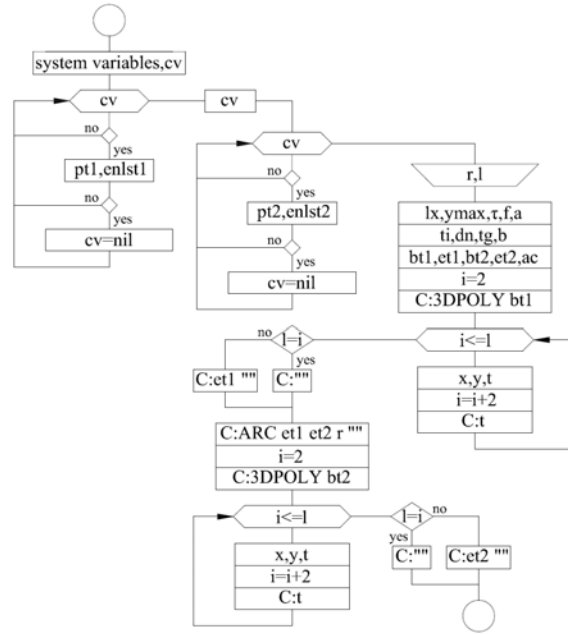


Figure 4. Algorithm example for construction of transition curves in horizontal plane

In order to allow further work with model, every drawn transition curve has additional information that describes its geometry (extended data) attached with entity list. These pieces of information are: form of transition curve, its length, radius of the circular curve and direction angle along the tangent line gainst polygon vertex.

Algorithm for defining points for model generation is shown on Fig. 5.

First step in defining points for model generation is adjusting proper system variables. Then selection of *.hcl and *.vcl file is made, and also user should choose a distance *d* for calculation of previously mentioned points. Calculation begins at station *s*=0, but it would be more practical that user chooses this value. Loop repeats until current station becomes bigger than ending station *es*. In this loop it is first checked to what element of horizontal geometry current station belongs and this will dictate the way of calculation of all necessary points from cross section. After leaving the loop, it is checked if last calculated points belong to the ending cross section.

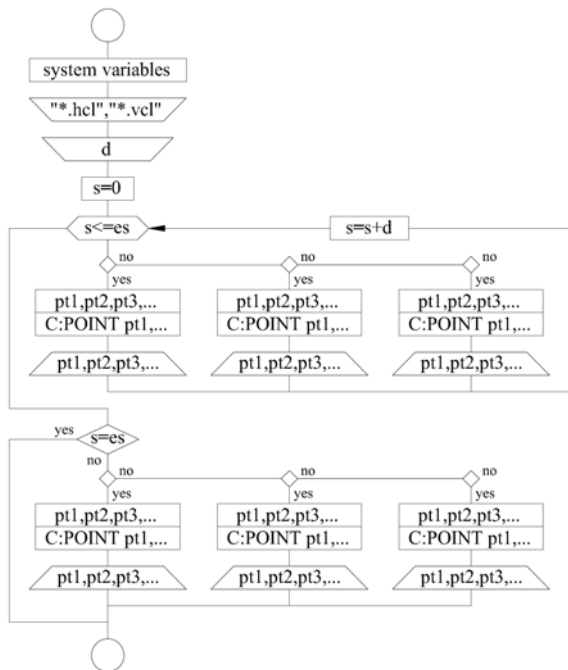


Figure 5. Algorithm example for defining points for model generation

Since this algorithm makes *.pts file, as well as couple of certain *.str files [8], it is only left to invoke commands for calculation and drawing of triangulated model of railway. Now, it is possible to use all GCM[®] commands that work with strings in order to nest the railway model into the terrain model.

Complex 3D surfaces of transition curves with cant transitions are shown on Fig. 6-10.

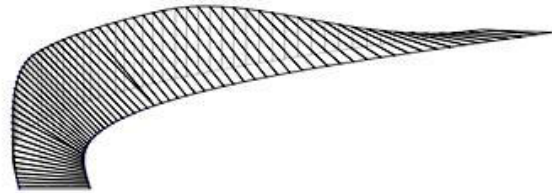
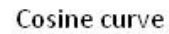


Figure 8. Complex 3D surfaces of cosine transition curves with cant

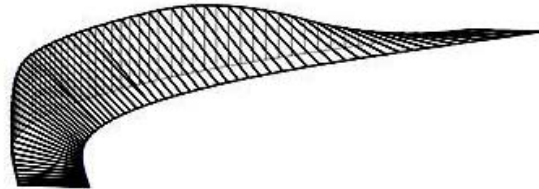
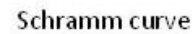


Figure 9. Complex 3D surfaces of Schramm transition curves with cant

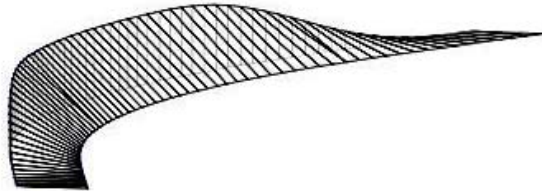
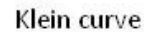


Figure 10. Complex 3D surfaces of Klein transition curves with cant

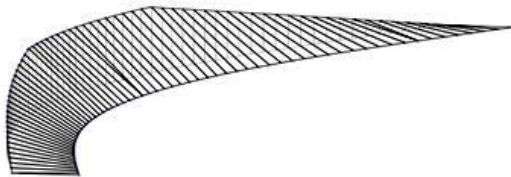
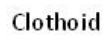


Figure 6. Complex 3D surfaces of clothoid transition curves with cant

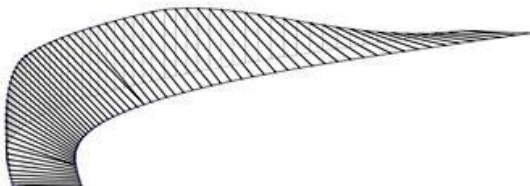
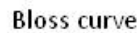


Figure 7. Complex 3D surfaces of Bloss transition curves with cant

Final result of 3D modeling is shown on Fig. 11.

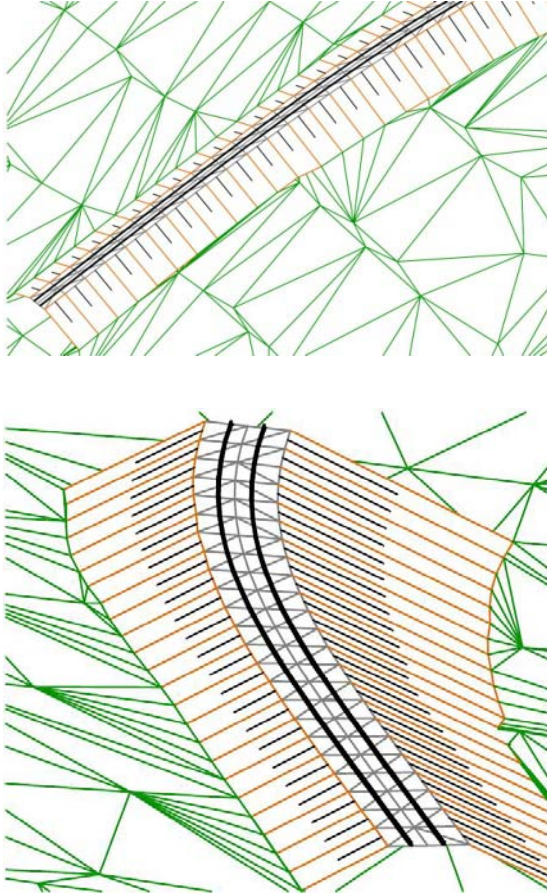


Figure 11. 3D wireframe model

IV. CHOOSING THE DISTANCE FOR MODEL GENERATION

At the end, there is a question about the value of distance that should be used for model generation along the railway centre line in order to achieve its adequate precision. In fact, all needed values for model, first of all a value of cant, will be calculated in every cross section on chosen distance. It means that model will be made of linear segments between calculated cross sections, so it will cause a certain model fault. Diagrams on Fig. 12 show correlation between distance for model calculation and difference between calculated cant value and cant value on linear segments of model ($V_R=80\text{km/h}$).

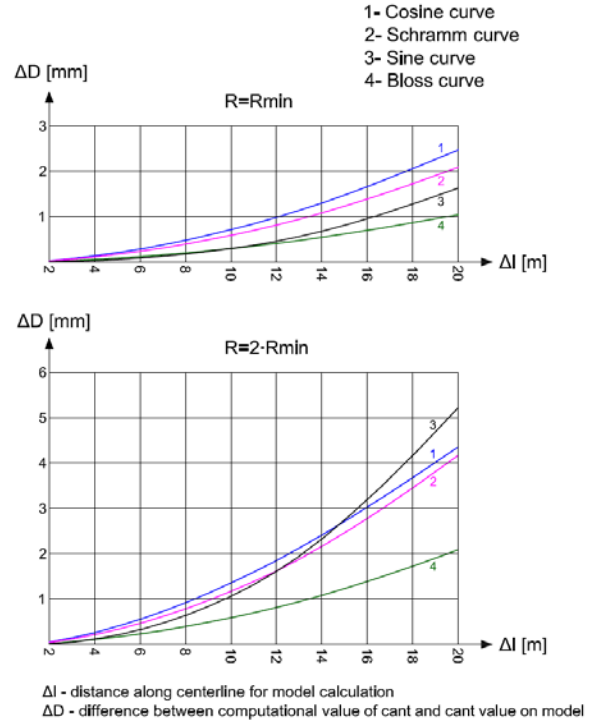


Figure 12. Correlation between distance for model calculation and cant defect

From diagrams follow that in case of maximum length of transition curve, cant defect can be between 1-3 mm. By raising radius of the circular curve, i.e. by reducing length of the transition curve, cant defect raises. Also, from diagram follows that sine curve has fastest cant defect flow.

General recommendation is that distance for model generation should be at most 5-10 m, not only because of mentioned cant defect, but also because of length defect of nonlinear elements.

V. CONCLUSION

The European Union has enacted various legislative measures aimed at achieving the opening up, integration and harmonization of national railways to form a European railway network. Harmonization of the national railway legislation with the aquis communautaire on safety and interoperability is of a special importance for integration of the Serbian railway systems [9].

Modern approach in railway design implies the selection of geometric form of transition curve and cant transition as a unique spatial element. Selection of spatial form of cant transition is required by type of superstructure or maintenance conditions of track geometry during exploitation.

In this paper 3D models of railway with transition curves with nonlinear change of curvature (Bloss, cosine, Schramm and Klein transition curve) are represented.

Main goal is a straightforward application of complex spatial geometry, so that engineers can apply with ease

technical conditions of European standard EN 13803-1:2010 on Serbian Railways.

In Serbia and in some countries of European Union, civil engineers use GavranCivilModeller® (GCM®) for railways and roads designing. This paper shows how to create AutoLISP routines which will be used along with GCM® in order to design model of railway with transition curve with nonlinear change of curvature.

ACKNOWLEDGMENT

This work was supported by the Ministry of Science and Technological Development of Republic of Serbia through the research project No. 36012: "Research of technical-technological, staff and organizational capacity of Serbian Railways, from the viewpoint of current and future European Union requirements"..

REFERENCES

- [1] M. Weigend, Linienführung und Gleisplangestaltung, Eurailpress, S. 120, Hamburg, 2004.
- [2] CEN: EN 13803-1:2010 Railway applications - Track alignment design parameters –Track gauges 1435 mm and wider - Part 1: Plain line
- [3] L. Lazarević, Cant transition as spatial element of railway, MSc Thesis, University of Belgrade, Faculty of Civil Engineering, Belgrade, Republic of Serbia, 2010.
- [4] Z. Popović, L. Puzavac and L. Lazarević, "The Shape of Superelevation Ramps According to European Standards", XIV Scientific-Expert Conference on Railways with International Participation RAILCON '10, Conference Proceedings, pp. 151-154, Niš, Republic of Serbia, October 2006.
- [5] L. Puzavac, Z. Popović and L. Lazarević, "Transition Curve Design According to European Standards", XIV Scientific-Expert Conference on Railways with International Participation RAILCON '10, Conference Proceedings, pp. 147-150, Niš, Republic of Serbia, October 2006.
- [6] Z. Popović, L. Lazarević and L. Puzavac, "Superelevation Ramp Design", Izgradnja, No. 11-12, November-December, pp. 621-636, 2010.
- [7] D. Gavran, GCM®2010 manual, 2010.
- [8] AUTODESK, AutoCAD® R14, Visual LISP Guide, 1998.
- [9] Z. Popović, "Interoperability and standardization of railway infrastructure of Serbian railways", Railway Technical Review, Hamburg, ISSUE 4/2007, Volume 47, pp. 6-9, 2007.