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Design of Railway Track for Speed and High-Speed Train

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***ABSTRACT*—Railway transportation has become an important aspect of public transportation system because of the increasing traffic demand on the road pavement structures, due to this problem, we decided to map out a critical area along the north-central Nigerian corridor, where railway can be introduced to ease the problem of high congestion of traffic congestion, high cost of transportation on the public street system. The design of railway line involves designing with AutoCAD civil3D software and comparing the results with that of manual calculation. Designing of minimum radius values of horizontal and vertical alignment radii, for speeds of *V* = 150 km/h, and a radius of 1500m and a high speed of 250km/h for a road length of 2.125km. The survey data were for Shiroro road in Minna linking Tunga-Chanchaga area in Niger State, Nigeria. The cut and fill volumes calculated by AutoCAD Civil3D were 31562.98m^3 and 501.32m^2, Civil CAD were 32088.35m^3 and 646.42m^3, that of manual calculation were 38575.00m^3 and 800.00m^3 respectively, the rail cant p= 150mm,180mm,the radii of 1500m and 3750m for speed and high-speed railway lines of speed, v = 150km/h and 250km/h.**

Keywords— rail track design; Civil 3D; Civil CAD; rail alignment

I. INTRODUCTION

The design of railway tracks must consider the 3D design of digital design documentation and design parameters of the currently valid standards. In the European countries there are valid railway track design standards for the CEN members, such as EN 13803-1, adopted by the EU Member States as STN EN 13803-1(2010) [1]. Besides this, some countries have adopted regional standards that regulate design parameters with regard to the conditions of a particular country, while respecting the basic framework criteria of the European standards. The higher the speed, the more stringent design criteria of the track geometry and also of the deformation resistance of the railway subgrade body are required.

The final project documentation for the construction of railway track must be elaborated in a very high quality of processing, not only graphics but also software solutions utilized for its creation.

The design parameters of the railway line project and the optimized location of this track body are closely related. The more difficult conditions of complicated terrain or dense area (population, objects and industrial parks), the more difficult is to satisfy the criteria of parameters for designing the railway line and there is also a reduction in driving comfort (especially in the case of passenger transport).

If the railway line is only used by passenger trains, for example in the speed limit RP6 (230 < *V* < 300 km/h), it is possible to use maximum longitudinal gradients of vertical alignment of the lines and maximum cant of rails in curves. The passenger trains are light, short, have a low center of gravity of wagons, and on these tracks freight trains and heavy trains would not be able to run. In the case of mixed traffic, the line is also used by slower trains (e.g. freight trains) and these trackage parameter values would not be suitable for them.

II. LITERATURE REVIEW

Horizontal Alignments

Nearly any alignment can be physically defined with variances of two components: tangents and curves. Horizontal alignments of existing and proposed railway tracks generally are given the highest interest as their location seem to be the easiest to grasp when reviewing the location of facilities relative to one another. A tangent is simply a straight line between two points. Tangents are usually denoted with bearings. However, it must be noted that without an accompanying starting point and length associated with that bearing (and thus establishing the location of the second point), there is no way to definitively establish the tangent's location in space. Other points along a given tangent can be defined in this manner.

Vertical Alignments

Vertical alignments are generally less complex than horizontal alignments. As such, it would seem that they are often overlooked during the early part of many design processes resulting in unnecessary re-design of horizontal alignments late in the design phase or settling for less than optimal vertical designs. The grades, which must be traversed by rail vehicles, are generally much more limiting than highway vehicles, due to both the limited amount of friction available at the interface of the steel wheel and the steel rail, as well as the substantially smaller power to weight ratio of rail vehicles.

Vertical alignments are comprised of the same two components as horizontal alignments (tangents and curves) Vertical tangents, commonly referred to as grades, are straight lines effectively plotted in the Z-plane or vertically. These tangents are classified by the grade or incline. The grade is measured in the amount of rise or fall over a distance and is expressed in terms of percent. For example, a grade, which rises 0.45m in 30m travelled, is referred to as 1.5%. If the grade drops 0.3m over 60m, the grade is termed .0.5%. Note that the relative positive or negative is determined by the net gain or loss of elevation in the direction of increasing station. The concepts pertaining to two points defining a line, three points for establishing an existing tangent and two tangents meeting at a PI are identical in concept. Only the terminology is different [2].

Basic design parameters of curves of railway tracks

The design parameters of the railway line project and the optimized location of this track body are closely related. If the railway line is only used by passenger trains, say speed limit RP6 ($230 < V = 300$ km/h), it is possible to use maximum longitudinal gradients of vertical alignment of the lines and maximum cant of rails in curves. The passenger trains are light, short, have a low center of gravity of wagons, aerodynamic shape etc. On these tracks, freight trains and heavy trains would not be able to run. In the case of mixed traffic, the line is also used by slower trains (e.g. freight trains) and these trackage parameter values would not be suitable for them. Therefore it is necessary to make a compromise between the assumed fastest and slowest trains of the particular designed rail line, and this implies the proposed radius r between r_{min} and r_{max}, also the cant p [mm] of the track can be calculated from STN 73 6360 the cant deficiency Imax [mm] or cant excess E_{max} [mm] and other parameters such as longitudinal gradient [‰], etc.

$(11.8 / p + I_{max})V^2_{max} \leq r \leq (11.8/p – E_{max})$ V2min

In the case of reconstruction, the railway track follows the original body and only improves certain elements of the track, but in the case of modernization, e.g. for V = 160 km/h, the track route usually leaves the original body in some sections of the new railway track, as there is the axis alignment of the route under ŽSR Z10. The speed and high-speed tracks have their own specified criteria of design parameters [3] and are typically designed on a new body or with certain completely redesigned sections of the original route (according to SK, (2014). - large values of radii $r$min = C.Vmax 2/(D + Ilim), where C = 11.8 mm.m.h2/km2, cant D = 160 mm, possibly limit of D = 180 mm, cant deficiency Ilim = 100; 130 mm for Vmax = 300 km/h, but for tilting railway cars running at V = 260 km/h the values are Ilim = 275; 306 mm).

If the terrain is mountainous, it is appropriate to consider the optimal location of the route in the terrain. In a mountain area the route requires a lot of bridges, tunnels, supporting and retaining walls and other objects. It is not necessary to circumvent mountains and valleys, as it was in the past.

A possible development of the railway route can be consider that the original track for V = 140; 100 km/h was rebuilt to a track of higher quality, in this case to a high-speed track for V = 300 km/h.

Also the route is built for V = 140 km/h as a hillside route and circumvents transverse mountain ridge or mountain range. For the above mentioned speed according to the minimum radius r_{min} is proposed for mixed traffic as

$R_{min} = (6.5 / P_{d2max})V^2_{max} = (6.5/150)150^2 = 980$m

The proposed radii are greater r1 = 2500 m, r2 = 1250 m and r3 = 900 m, thus the particular cants will be in the new curves smaller than the ones considered in the calculation for $r$min. The high-speed tracks require $r$min as

$R_{min} = (C / P + I)V^2_{max} = (11.8 / 160 + 100)250^2 =$ 4500m.

$R_{min} = (C / P - E_{max})V^2_{min} = (11.8 / 150 - 100)160^2 =$ 6041.60m

If the track is going to be used by slower trains such as freight trains running at Vmin = 160 km/h, it is necessary to consider the design of the radius with respect to the cant excess Emax of the slowest train in for rmax , where cant p = 160 mm, and p = 150 mm. These values are valid for the recommended limits which secure the driving comfort of passengers and also the safety of goods transport. Maximum permissible limit values are also acceptable by the standard, but in this way the driving comfort is reduced. The route requires the tunnel advancement through the rock mass.

On construction of railway project, it is often necessary to modify the existing ground levels to create platforms to build on. Accurately calculating the volumes of soil that must be removed (cut) or added (fill) to create the final ground levels is an essential part of the planning process.

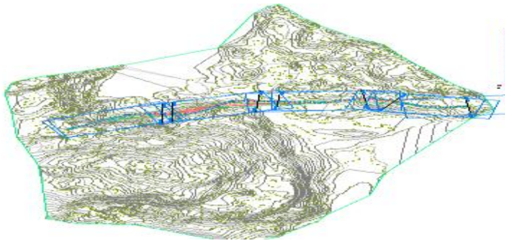

Fig 1: Complete profile surface with corridor

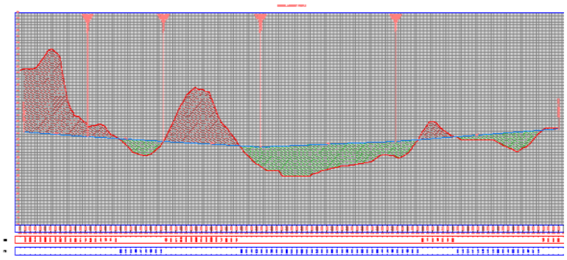

Fig 2: Profile view for Civil3D

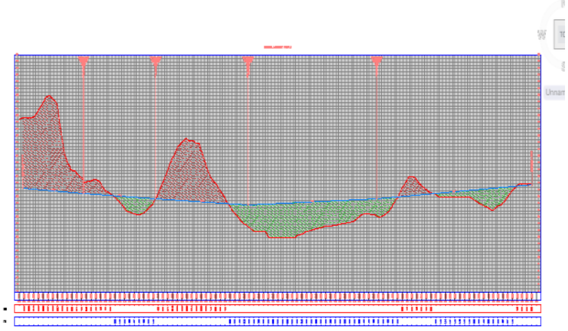

Fig 3: Profile view for Civil CAD

III. METHODOLOGY

This study estimates cut and fill volumes using three methods out of which two involves the use of software (with pictures of their interface shown in Fig. 1 – 3). The three methods are:

- The cross-section method
- The use of Civil CAD
- The use of Civil3D

IV. RESULTS

The cut and fill volume generated by the software for the rail track design are shown in Table 1 – 2.

Table I: Section cut and fill volume generated from Civil 3D

Chainage	Cum.Fill Vol. (m^3)	Cum. Cut Vol.
0+00	0	0
0+025	304.97	0
0+050	608.16	0
0+075	878.49	0.04
0+100	1137.07	0.08
0+125	1420.62	0.08
0+150	1766.77	0.08
0+175	2169.07	39.28
0+200	2529.93	79.04
0+225	2860.29	80.18
0+250	2860.29	80.78
0+275	3232.77	81.56
0+300	3589.22	84.19
0+325	3903.93	89.24
0+350	4233.56	95.25
0+375	4557.09	98.1
0+400	4862.19	118.49
0+425	5167.53	164.92

Table 2: Section cut and fill volume generated from Civil CAD

Chainage	Fill volume Cum. Fill vol (m^3)	Cut volume Cum. Cut Vol. (m^3)
0+00	0	0
0+025	0	325.08
0+050	0.68	638.12
0+075	0.92	923.25
0+100	0.92	1145.08
0+125	0.92	1575.3
0+150	43.05	1809.66
0+175	82.04	2235.04
0+200	84.18	2765.35
0+225	84.78	2998.07
0+250	86.19	3567.06
0+275	86.19	3895.66
0+300	93.25	4051.88
0+325	98.1	4335.9
0+350	100.5	4763.8
0+375	135.67	4930.5
0+400	157.59	5311.67
0+425	187.02	5567.9

Cross-Section Method (Manually Calculated)

The cross section method involves plotting cross sections of the existing and proposed levels at regular intervals across the project site. For each of the cross sections, the cut area and the fill area is determined. The volume between each pair of sections is estimated by multiplying the average cut or fill area of the two sections by the distance between them. Once these volumes have been calculated for each pair of sections the total cut and fill volumes are obtained by adding them all together.

Sections are drawn at equal intervals through the project. For each section line the cut area and the fill area is determined. The volume between two sections is determined as the average area of the two sections multiplied by the distance between them. By adding together the area between all of the sections shown in Table 3, the total cut and fill volumes are computed afterwards.

Table III: Cut and Fill Volume for manual calculation

SECTION NO	CUT AREA (m^2)	FILL AREA (m^2)
1	1295.00	20.15
2	1059.00	21.68
3	507.00	17.15
4	225.00	5.01
Total	3086.00	63.99

Average cut area =
(1295.00+1059.00+507.00+225.00)/4
= 771.50 m^2

Average fill area = (20.15 + 21.68 + 17.15 + 5.01) /4
= 16.00 m^2

Distance between sections = 50m

Cut volume = 50 * 771.50 = 38575.00m^3
Fill volume = 50 * 16 = 800.00m^3

V. SUMMARY

There is a number of methods available for estimating cut and fill quantities, three of which are described here. The best method for a particular organization will depend on a number of factors, including:

- The number and complexity of the projects
- The presentational requirements for the estimation
- The level of accuracy required
- The available design period
- Availability of software license.

VI. CONCLUSION

- In this study, the design of railway track was carried out along the north-central corridor region of Nigeria, using a computer based application and manual design procedure.
- The results of this study can be drawn as follows
- The cut and fill volumes calculated by AutoCAD Civil3D were 31562.98m^3 and 501.32m^3.
- The cut and fill volumes calculated by Civil CAD were 32088.35m^3 and 646.42m^3.
- The cut and fill volumes of manual calculation were 38575.00m^3 and 800.00m^3.

The design works include complicated procedures, while the railway track components must comply with all design criteria of the currently applicable standards and regulations.

Nowadays the development of quality and precise design documentation is not possible without computer technology using 3D variant solutions. The project design documentation contains many complex structural objects required for the railway operation and crossing with other modes of transport (bridges, tunnels, railway stations, terminals, intermodal terminals, humps and others and all of them must have an exact spatial position given by the coordinate and height system and thus the use of computer technology is encouraged.

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