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Stake - Out of Curves with the Polar Method: Application in Trumpet Type Intersections

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Abstract

The sustainability and efficiency of modern infrastructure are directly related to effective highway design. The increasing demands of industrialization, tourism, and trade have highlighted the need for fast and safe transportation. Trumpet-type interchanges provide a significant solution for these transportation needs. This study examines how the intermediate points of curves used in the connecting roads of trumpet-type interchanges can be staked out using the polar method. The research provides a detailed explanation of how to determine intermediate points of curve elements both at project and land level, supported by simulated data. The results offer a practical approach to enhancing accuracy and efficiency in engineering projects.

Keywords: Interchange with different levels, inverted curve, Curve stake out with polar method, Trumpet type intersection

1. Introduction

Industrialization, tourism activities, and the marketing of commercial products domestically and internationally have increased the mobility of highways today. Bridged interchanges and connecting routes are designed for quick transportation between cities and nearby areas. The connection paths can be in various forms; they may be in the form of a trumpet or in the form of two successive inverse curves (Figs. 1-4) [1-3]. There is usually a certain level of difference in the trumpet-shaped connection path between the entrance and exit points of the main highways. The shape of the connecting highway on the outside of the trumpet interchange is in the form of an inverted curve in general appearance. The shape of the connecting path in the interior is a circular arc with a divergence angle greater than 200 grad (Figs. 1-2).

The general stake-out of curves in engineering is widely found in the literature [3-9]. Stake-out is one of the most crucial tasks for a surveying engineer since it allows them to meet the project's required accuracy standards while preserving the engineering structure's planned geometries [10-15]. Inverse curves are often used on urban and mountain roads where there is no high-speed limit. They are also used for longitudinal and transverse scrolling of a road leading to a line in highway projects from a certain point to a desired amount [5, 7]. Total stations are used to conduct construction surveys and layouts, even though modern GNSS systems have the potential to stake out points with an accuracy of 2 cm under better conditions. The polar coordinates approach, which involves calculating and estimating the position of a horizontal angle and a distance from two control points (or geodetic points), forms the basis of a total station stake-out [10].

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Fig. 1. Trumpet interchange and connecting highways [16]

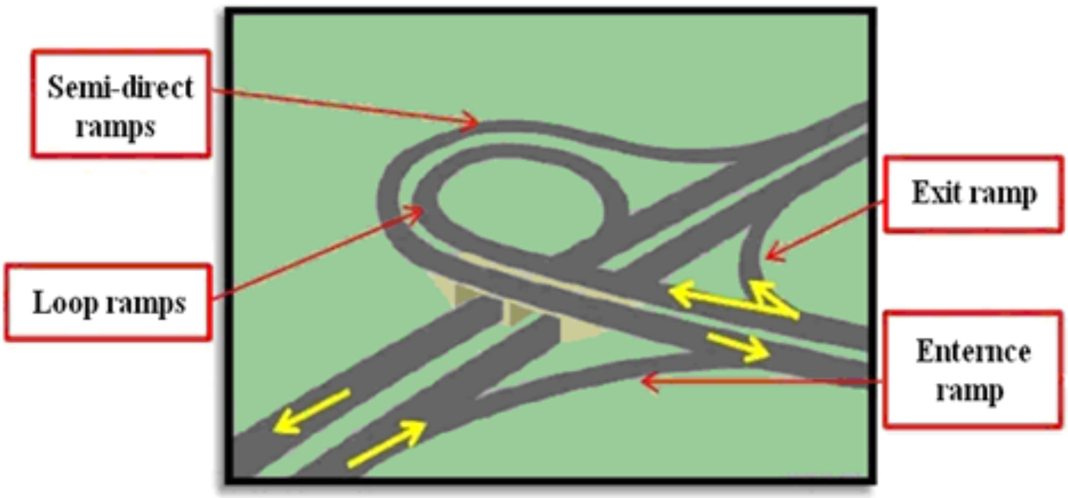

Fig. 2. Graphic illustration of trumpet interchange

Fig. 3. The Cloverleaf interchange [16]

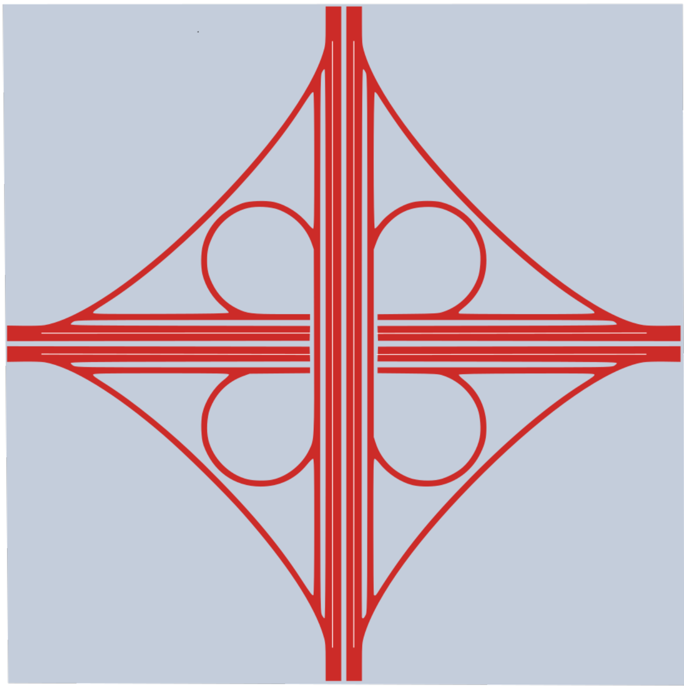

Fig. 4. Graphic illustration of the cloverleaf interchange

Inverse curve that forms the outer part of a trumpet interchange and the circular arc forming the inner part from points where curves are tangential to the main path how the inverse curve that forms the outer part of a trumpet interchange and the circular arc forming the inner part from points where curves are tangential to the main path can be applied by the polar method was deemed necessary to investigate the matter as it was not explained in detail in the literature [3-9]. This study explains in detail the stake-out process for connection and tangential points of inner and outer connection paths to the upper and lower main highways at both land and project levels. It also covers the stake-out of intermediate points of related curves from tangent points at these levels. The numerical stake-out was applied, and the results are presented within the study [17]. Thus, it has contributed to filling the gap in the literature regarding the stake-out of trumpet type intersections.

2. Overview of the Trumpet Interchange

2.1. Stake-out of Top and Bottom Tilting Points of Inner and Outer Connection Highways at Trumpet Interchange

On a highway plan with a trumpet interchange (Fig. 5), the inner link path is between points A, B, G, E, and B' between circular arcs of radius R_1 and R_2 with center O_1, and the external link path is located between points C, E', F, H, E, and B' between the circle springs R_2 and R_3 with center O_1 and circle springs R_4 and R_5 with center O_2. The deviation angle seen from the center of the inner connecting path is 1>200, and the divergence angles of the inverse curve forming the external connection path are Δ_2 and Δ_3.

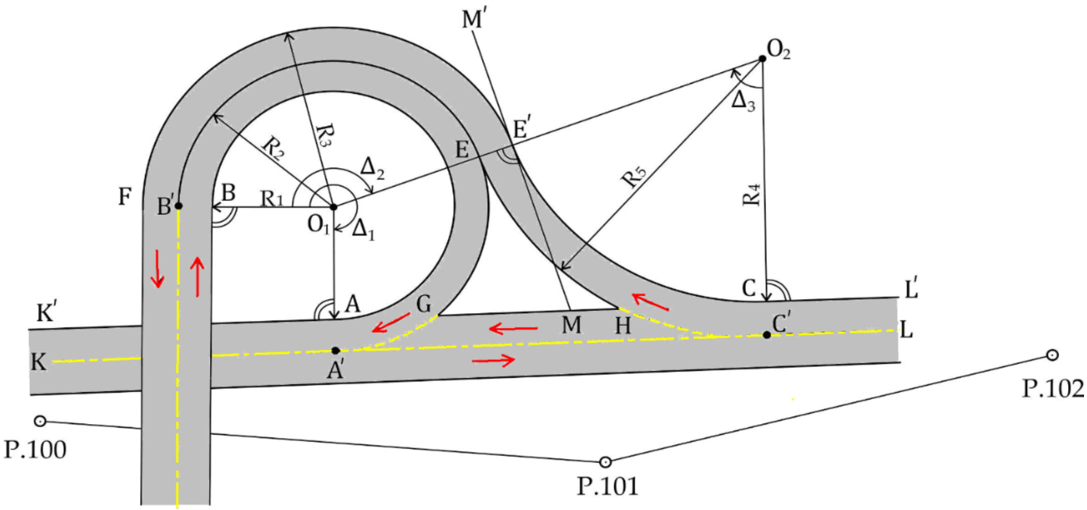

Fig. 5. At the trumpet interchange, the inner curve provides the reverse curve, and the inner connection forms the outer connection path.

In Fig. 5, point A is the point where the inner radius of the radius R_1 is tangential to the right side of the subway platform. Point A' is the point at which the circular extension of the radially inner connection path R_2 is tangential to the main axis (line KL).

- B point: the point O_1 is tangent to the left side of the upper main highway platform of the radiused circle arc of radius R_1.
- Point B' is the point where O_1 center R_2 is radially tangent to the outer major axis of the outer and inner link paths.

- Point C is the point where the O_2 center external link path R_4 is tangent to the right side (K'L' line) of the lower highway platform.
- Point C' is the point at which the circular extension of the outer radius of the radius connection R_5 is tangential to the axis of the subway (line KL).
- Point E' is the point at which the outer radius of radius R_5 is tangential to the inner radius of radius R_2.
- Point E is the point at which R_4 is tangent to the radius of the outer connecting path and R_2 is tangent to the radius of the inner connecting path.
- Point F is the point where the arc of radius R_3 is tangent to the right side of the upper highway platform.
- Point G is the point of intersection on the right-hand side of the lower highway platform of the radiused circle arc.
- Point H is the intersection point of the right-hand side of the lower highway platform of the circle with R_5.
- Point M intersects the tangential GH line segment passing through the common tangent point R_3 with O_1 center R_3 and O_2 center R_4 radiused edges E'.

In a highway plan (Fig. 5) where the trumpet interchange is located, these points (A, A', B, B', C, C', E, E', F, G, H, O1, O_2, K, L) are digitized and their coordinates are obtained.

The polar Stake-out components are calculated using the coordinates of the points where taking advantage of the two polygons (P.100, P.101) previously set up around the Trumpet interchange and the coordinates of the specified points (β_A , β_A', β_B, β_B' β_C, β_C', β_E, β_E' β_F, β_G, β_H, β_K, β_K', β_L, β_L', P_{101}A, P_{101}A', P_{101}B, P_{101}B', P_{101}C, P_{101}C', P_{101}E, P_{101}E', P_{101}F, P_{101}G, P_{101}H, P_{101}K, P_{101}K', P_{101}L, P_{101}L'). For example, stake-out elements for points A, B and C are calculated with the help of the following equations [6], (Fig. 6):

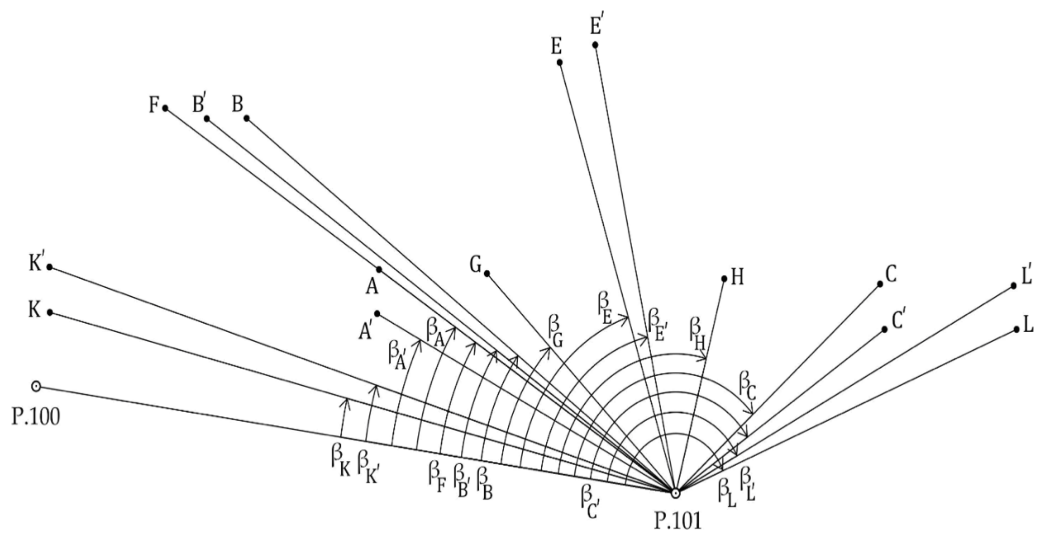

Fig. 6. Stake-out by using the polar method of fundamental points of trumpet interchange from P.101 point to P.100 point

$$P_{101}A = \sqrt{(Y_A - Y_{101})^2 + (X_A - X_{101})^2} \quad (1)$$

$$P_{101}B = \sqrt{(Y_B - Y_{101})^2 + (X_B - X_{101})^2} \quad (2)$$

$$P_{101}C = \sqrt{(Y_C - Y_{101})^2 + (X_C - X_{101})^2} \quad (3)$$

$$(P_{101}P_{100}) = arctan\left(\frac{Y_{100} - Y_{101}}{X_{100} - X_{101}}\right) \quad (4)$$

$$(P_{101}A) = arctan\left(\frac{Y_A - Y_{101}}{X_A - X_{101}}\right) \quad (5)$$

$$(P_{101}B) = arctan\left(\frac{Y_B - Y_{101}}{X_B - X_{101}}\right) \quad (6)$$

$$(P_{101}C) = arctan\left(\frac{Y_C - Y_{101}}{X_C - X_{101}}\right) \quad (7)$$

$$\beta_A = (P_{101}P_{100}) - (P_{101}A) \quad (8)$$

$$\beta_B = (P_{101}P_{100}) - (P_{101}B) \quad (9)$$

$$\beta_C = (P_{101}P_{100}) - (P_{101}C) \quad (10)$$

The above-mentioned stake-out elements are applied by observing at the P.100 control point with a total station set up at point P.101, and these points are evident at the land level.

2.2. Computation of the Inner Connection Pathway Curve, Inverted Parietal Deviation Angle, and Development Tail

The deviation angle Δ_1 of the O_1 center curve and the deviation angle Δ_2 and the deviation angle Δ_3 of the O_2 center curve are obtained from the following geodetic equations, taking the coordinates of the points A, O_1, B, B', C, E, E, and O_2 into account in Fig. 7.

$$\Delta_1 = (O_1A) - (O_1B) \quad (11)$$

$$\Delta_2 = (O_1E) - (O_1B^I) \quad (12)$$

$$\Delta_3 = (O_2E^I) - (O_2C) \quad (13)$$

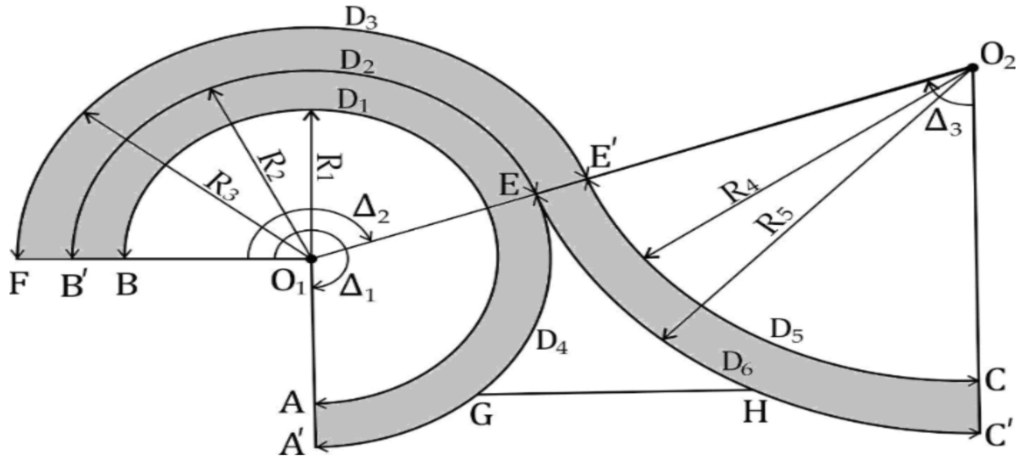

Fig. 7. Geometry of connection paths in the trumpet interchange (inverse curve and inner curve)

D_1, D_2, D_3, D_4, D_5, and D_6 of each curve are computed from the following relation, taking into account the radiuses of the respective curves (R_1) and the angles of deviation (Δ_1, Δ_2, and Δ_3) computed by these equations (11), (12), and (13) [7].

AB arc length $$D_1 = \frac{2\ .\ \pi\ .\ R_1}{400}\ .\ \Delta_1 \tag{14}$$

EB' arc length $$D_2 = \frac{2\ .\ \pi\ .\ R_2}{400}\ .\ \Delta_2 \tag{15}$$

A'E arc length $$D_4 = \frac{2\ .\ \pi\ .\ R_2}{400}\ .\ (\Delta_1 - \Delta_2) \tag{16}$$

CE' arc length $$D_5 = \frac{2\ .\ \pi\ .\ R_4}{400}\ .\ \Delta_3 \tag{17}$$

C'E arc length $$D_6 = \frac{2\ .\ \pi\ .\ R_5}{400}\ .\ \Delta_3 \tag{18}$$

C'E arc length $$D_6 = \frac{2\ .\ \pi\ .\ R_5}{400}\ .\ \Delta_3 \tag{19}$$

Fig. 5 also shows that the O_2 center point and radius R4, MC = ME' tangent length, are computed by using the following equation 20:

$$MC = ME^I = R_4\ .\ tan\left(\frac{\Delta_3}{2}\right) \tag{20}$$

The stake-out (with the polar method) elements of the highway were computed by using the formulas [6].

3. Polar Method Stake-out Of Curve Interval Points From Tangential Points

3.1. Land-elevation Stake-out of Curve Interval Points

In general, when the number of intermediate points to be formed in the Stake-out of the spots belonging to the curve is determined, it is desirable that the difference between the spring length determined between the intermediate points of the curtain and the length of the beam length of that spring is not more than 1 cm. For this, for curves with a radius of up to 300 m, the arc length ℓ^I between the two intermediate points can be taken as equation 21:

$$\ell^I \cong \frac{R}{10} \tag{21}$$

Approximate number of intermediate points (n'), taking into account the approximate arc height (ℓ^I) and the curve D development height

$$n^I = \frac{D}{\ell^I} - 1 \tag{22}$$

is obtained from the relation. The number of intermediate points is an integer. n' is rounded by looking at the number after the counting of the fractional number obtained as n', n is the number of intermediate points. The exact spring length (l) considering n and D

$$\ell = \frac{D}{n+1} \tag{23}$$

is obtained from the relation. ε angle in the center of the circle of arc

$$\varepsilon = \frac{\ell}{R} \cdot \rho \tag{24}$$

In Fig. 7, in the Stake-out of the interconnection points AB, FE', E'C, and EC'; the exact arc lengths between the intermediate points and the ε arcs that see this arc length from the center are calculated by operating in the manner described above. In the Stake-out of the intermediate points of the radius A'B' arc of radius R2, the exact arc length between the intermediate points, and the ε angle that sees this arc length from the center must be calculated considering the GB's arc size (gathering D2 and D4 development).

In polar Stake-out of curve points and land and project elevations, usually the tangential point of the curve is taken as the station point, while the connection point is taken as the marked point on the tangent line of the curve.

In Fig. 5,

- For the Stake-out of curve points of the AB spring, A point is taken to the station, G, H, or L' point connection point,
- For the Stake-out of the curve anchor points of A'B', the A point station, C', or L point connection point is taken, and the Stake-out is started from point G,

- For the Stake-out of the curve points of the CE', C point station, H or G point connection point,

- For the Stake-out of the curve points of the C'E arc,

- C point station, A' or K point connection is taken, and Stake-out starts from H point,

- For stake-out of intermediate points of the E'F arc, the Stake-out is initiated by accepting the M' point marked in the extension of the E' point station, E'M.

The Stake-out to be done by the polar coordinate method; for the Stake-out elements ε_1, ε_2, ε_3, AP_1, AP_2, and AP_3 of intermediate points such as a curve P_1, P_2, P_3:

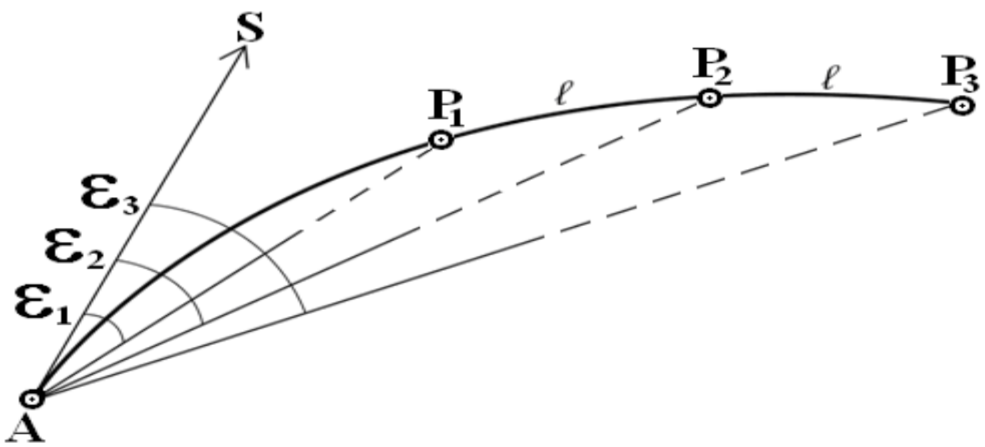

Fig. 8. The polar Stake-out of the intermediate points according to AS tangential direction from point A

$$\varepsilon_1 = \varepsilon/2 \tag{25}$$

$$\varepsilon_2 = 2\ .\ \varepsilon/2 \tag{26}$$

$$\varepsilon_3 = 3\ .\ \varepsilon/2 \tag{27}$$

$$AP_1 = 2\ .\ R\ .\ sin\,\varepsilon_1 \tag{28}$$

$$AP_2 = 2\ .\ R\ .\ sin\,\varepsilon_2 \tag{29}$$

$$AP_3 = 2\ .\ R\ .\ sin\,\varepsilon_3 \tag{30}$$

are used in these relations (Fig. 8), [6, 7].

The Stake-out elements of the curve intermediate points are calculated and applied according to the above-mentioned principles to each curve in connection paths so that the points that make up the connecting roads become apparent at the land level.

4. Results

Numerical data for a highway project related to the subject were generated, including the reverse curve forming the outer part of a trumpet interchange and the project data of the connection path in the form of a circular arc. Since there was no plan for the route on a coordinate map, numerical stake-out was performed. Fig. 5 is taken as an example of a numerical stake-out in relation to the related stake-out, [1]. The radiuses of O_1 center curves are R_1 = 40 m, R_2 = 45 m, and R_3 = 50 m, and the radiuses of O_2 center curves are R_4 = 55 m and R_5 = 60 m.

The road design subject to the stake-out is transferred to a computer environment with computer hardware. The marked points (A, A', B, B', C, C', E, E', F, G, H, K, L, K', L', O_1, O_2) in the highway map are digitized, and P.101 is the station point and P.100 is the connection point. Stake-out elements are calculated and applied at the heights of B, B', E, E', F, and G points. It has been applied that the A, A', C, C', H, K, L, K, and L points are applied at project height.

Using the coordinates of the digitized A, O_1, B, B', C, E, E, and O_2 points in Fig. 5, the divergence angle of Δ_1 was 300g.0120, the divergence angle of divergence was 181g.0220, the divergence angle was 76g.2250 were obtained from (11), (12), and (13) equations. From the data received from the project of the trumpet interchange, It is assumed to be ΔH_{AB}=8.50 m, $\Delta H_{A'B'}$=8.60 m, $\Delta_{HE'F}$ =8.50 m, $\Delta_{HCE'}$=2.72 m, $\Delta_{HC'E}$=2.82 m.

Table 1. The data on the development of the curves, the approximate and precise number of points, the exact arc length, and the angles that see these springs from the center

Centre of the curve	The divergence angle Δ_i	R Radius (m)	Development length (m)	Approximate number of waypoints (n')	The exact number of waypoints (n)	Definite intermediate spring length (ℓ)	ℓ angle seen from the centre (ε)
O_1	$300^g.0120$	40	D_1=188.503	46.12	46	4.0110	6.3832
O_1	$181^g.0220$	45	D_2=127.957	46.12	46	4.5120	6.3832
O_1	$118^g.9900$	45	D_4= 84.109	-	-	-	-
O_1	$181^g.0220$	50	D_3=142.174	27.44	27	5.0770	6.4650
O_2	$76^g.2250$	55	D_5= 65.854	10.97	11	5.4878	6.3521
O_2	$76^g.2250$	60	D_6= 71.840	10.97	11	5.9867	6.3521

Using project data and the relevant relativity, the development tiles of the curves forming the external and internal connection at the trumpet interchange, the approximate and precise number of points, the exact arc lengths (ℓ), and the angles (ε) are calculated and shown in Table 1.

Table 2. Calculation slopes, slope angles, and vertical angles of the curves forming the connecting path

Curve	Relevant arc	D (m)	Height difference	Slope	Slope angle α	Vertical angle Z
O_1 center R_1 radius	AB	188.503	8.50	0.04509212	2.8687	97.1313
O_1 center R_2 radius	A'B'	212.066	8.60	0.04055340	2.5803	97.4197
O_1 center R_3 radius	E'F	142.174	6.41	0.04508560	2.8649	97.1351
O_2 center R_4 radius	CE'	65.854	2.72	0.04130350	2.6280	97.3720
O_2 center R_5 radius	C'E	71.840	2.82	0.03925390	2.4977	97.5023

Considering the height differences between the points where the connecting roads are tangent to the upper and lower main ties and the development tile, the calculated slope angles (α) and vertical angles (Z) are shown in Table 2.

Table 3. The stake-out elements for the stake-out of the intermediate points at the land height and the project height with center O1R1 = 40 m and radius Δ1 = 300 g.0120

Station Point	Point of	Horizontal angle (ε_i)	Horizontal distance (Aİ)	Length of spring Ai (ℓ_i)	The slope of the road	Project Height	Vertical angle	Height of reflector
A	H	0.0000				H_A=0.00		1.52
a=1.52	1	3.1916	4.009	4.011	0.0450921	0.181	97.1313	"
	2	6.3832	8.008	8.022	"	0.362	"	"
	3	9.5748	11.987	12.033	"	0.542	"	"
	4	12.7664	15.935	16.044	"	0.723	"	"
	5	15.9580	19.844	20.055	"	0.904	"	"
	6	19.1496	23.703	24.066	"	1.085	"	"
	7	22.3412	27.502	28.077	"	1.266	"	"
	8	25.5328	32.232	32.088	"	1.447	"	"
	9	28.7244	34.884	36.099	"	1.628	"	"
	10	31.9160	38.448	40.110	"	1.808	"	"
	11	35.1076	41.915	44.121	"	1.989	"	"
	46	146.8144	78.120	184.503	"	8.320	"	"

Using the data in Table 1 and Table 2, the stake-out elements calculated both at the grade level and the project level are shown in Tables 3, 4, 5, 6, and 7. Since the deviation angle of the curve with center O_1 and radius R_1 is 300g.0120, the number of curve intermediate points located between the tangent points A, B, and A', B' is too high (46), the application elements of the first 11 and the last intermediate point are calculated in Table 3 and are shown in Table 4.

On the other hand, the first 11 of the 27 intermediate points belonging to the curve with a center of O_1 and a radius of R_3 with a declination angle of 181g.0220 are calculated and shown in Table 5.

$$E^I M = MC = R_4 \ . \ tan\frac{\Delta_3}{2} = 40.931 \ m \tag{31}$$

Table 4. The Stake-out elements required for the Stake-out of the intermediate points at the land height and the project height with center O1R1 = 45 m and radius Δ1 = 300g.0120

Station Point	Point of	Horizontal angle (ε_i)	Horizontal distance (Aİ)	Length of spring Ai (ℓ_i)	The slope of the road	Project height	Vertical angle	Height of reflector
A'	C'	0.0000				$H_{A'}$=0.00		1.54
a=1.54	1	3.1916	4.510	4.512	0.040553	0.183	97.4197	"
	2	6.3832	9.008	9.024	"	0.366	"	"
	3	9.5748	13.485	13.536	"	0.549	"	"
	4	12.7664	17.927	18.048	"	0.732	"	"
	5	15.9580	22.324	22.560	"	0.915	"	"
	6	19.1496	26.666	27.072	"	1.097	"	"
	7	22.3412	30.940	31.584	"	1.281	"	"
	8	25.5328	35.136	36.096	"	1.464	"	"
	9	28.7244	39.244	40.608	"	1.647	"	"
	10	31.9160	43.254	45.120	"	1.830	"	"
	11	35.1076	47.154	49.632	"	2.013	"	"
	46	146.8140	87.886	207.552	"	8.417	"	"

The point M, which has a horizontal length of E'M=MC=40,931 m from C, is marked in the direction of CH in the field. With the electronic tachometer installed at the E' point, the M point is looked at, the binoculars are rolled up, and the M' point is marked in the direction in which the binoculars are directed. E'M' direction is taken as the tangent direction of the stake-out of the intermediate points of the E'F circle arc.

Table 5. The stake-out elements for the stake-out of the intermediate points at the land height and the project height with center O_1R_1 = 50 m and radius Δ_1 = 181g.0220

Station Point	Point of	Horizontal angle ($\mathcal{E}_i$)	Horizontal distance (A_i)	Length of spring A_i (ℓ_i)	The slope of the road	Project height	Vertical angle	Height of reflector
E’	M’	0.0000				$H_{E'}$=0.0		1.55
a=1.55	1	3.2325	5.075	5.077	0.0450856	0.229	97.1351	“
	2	6.4650	10.138	10.154	“	0.458	“	“
	3	9.6975	15.174	15.231	“	0.687	“	“
	4	12.9300	20.171	20.308	“	0.916	“	“
	5	16.1625	25.116	25.385	“	1.144	“	“
	6	19.3950	29.996	30.462	“	1.373	“	“
	7	22.6275	34.800	35.539	“	1.602	“	“
	8	25.8600	39.513	40.616	“	1.831	“	“
	9	29.0925	44.124	45.693	“	2.060	“	“
	10	32.3250	48.622	50.770	“	2.289	“	“
	11	35.5575	52.994	55.847	“	2.518	“	“

Table 6. The Stake-out elements required for the Stake-out of the intermediate points at the land height and the project height with center O_1R_1 = 55 m and radius Δ_1 = 76g.2250

Station Point	Point of	Horizontal angle ($\mathcal{E}_i$)	Horizontal distance (A_i)	Length of spring A_i (ℓ_i)	The slope of the road	Project height	Vertical angle	Height of reflector
C	H	0.0000				H_C=0.00		1.51
a=1.51	1	3.1760	5.486	5.4878	0.0413035	0.227	97.3720	“
	2	6.3521	10.957	10.976	“	0.453	“	“
	3	9.5282	16.402	16.463	“	0.680	“	“
	4	12.7042	21.806	21.951	“	0.907	“	“
	5	15.8802	27.155	27.439	“	1.133	“	“
	6	19.0563	32.437	32.927	“	1.360	“	“
	7	22.2323	37.639	38.415	“	1.587	“	“
	8	25.4084	42.746	43.903	“	1.813	“	“
	9	28.5844	47.747	49.390	“	2.040	“	“
	10	31.7605	52.630	54.878	“	2.267	“	“
	11	34.9366	57.381	60.366	“	2.493	“	“

Table 7. The Stake-out elements required for the Stake-out of the intermediate points at the land height and the project height with center O_1R_1 = 60 m and radius Δ_1 = 76g.2250

Station Point	Point of	Horizontal angle (ε_i)	Horizontal distance (A_i)	Length of spring A_i (ℓ_i)	The slope of the road	Project Height	Vertical angle	Height of reflector
C'	A'	0.0000				$H_{C'}$=0.00		1.52
a=1.52	1	3.1760	5.984	5.9867	0.0392539	0.235	97.5023	"
	2	6.3521	11.953	11.973	"	0.470	"	"
	3	9.5281	17.893	17.960	"	0.705	"	"
	4	12.7041	23.788	23.947	"	0.940	"	"
	5	15.8801	29.624	29.933	"	1.175	"	"
	6	19.0562	35.386	35.920	"	1.410	"	"
	7	22.2322	41.060	41.907	"	1.645	"	"
	8	25.4082	46.632	47.893	"	1.880	"	"
	9	28.5842	52.087	53.880	"	2.115	"	"
	10	31.7602	57.414	59.867	"	2.350	"	"
	11	34.9363	62.597	65.853	"	2.585	"	"

5. Conclusions

This study examined the polar stake-out of the curves in the trumpet intersection's connection road.

First of all, the entry and exit points and tangent points of the connection roads to the main roads should be stake-out according to the criteria specified in the article.

Internal and external connection roads: Since there are roads where vehicle speed is generally reduced, slope application is not needed. If slope is required in the intersection project, the stake-out of the points on the right and left of the connection road axis should be made according to the height values calculated according to the project slope.

In order to prevent the vehicle from crossing into the opposite lane in case of a traffic accident, metal guardrails are placed on both sides of the connection road. The guardrail points to be built on the right and left borders of the road should also be staked out.

Before the connecting road at different level crossings, after the connection highway has been made roughly by filling the curved intermediate points marked temporarily at the land level, the stake-out should be made at the project level of the intermediate points by installing tools again at the relevant tangent points.

Trumpet interchange is used in road applications in urban and non-residential areas. In this study, how to stake-out these intersections is explained in detail.

Author Contribution

Mehmet Eren: Conseptualization, Software, Writing, Investigation.
Aziz Uğur Tona: Methodology, Review & Editing, Writing, Supervision.

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