Calculation of a Standard Single Turnout with a Crosscutting Curved Switch Rail

Student

University

Calculation of a Standard Single Turnout with a Crosscutting Curved Switch Rail

Main Principles

All turnouts must correspond to the operating conditions they are intended for. To this end, the turnout parameters must be determined and justified, and basic (molded lead and total lead) and axial (layout) dimensions must be established in order to set out and lay the turnout. For educational purposes, the values used herein are applied exclusively within the project and are not precise. They set an example by showing the general principle of calculations. For educational purposes, all variables in this project are based on actual and fictitious values to be used for training of engineers. All random data was chosen by the professor for calculation and graphical development of a turnout realistic to the highest degree possible.

Various possible objectives of a turnout calculation determine the varying sets of basic design data. This course project provides calculations of the curved switch rail basic parameters, stock rail dimensions, frog and tangential path dimensions, basic and axial dimensions, and dimensions determining a fouling point position. All calculations are carried out based on the angle size accurate to 1 sec and on the linear size accurate to 1 mm, which requires the application of trigonometric functions with a mantissa of at least 6 digits and a constant π value accurate to the sixth digit - 3.141593.

A turnout diagram shall be drawn on the basis of calculation results. It will serve as the main document establishing the way the turnout will be set out and laid. This diagram is a turnout plan consisting of two parts - a layout diagram for the point sleepers with indication of their dimensions and quantity, and a turnout breakdown diagram with indication of all angles as well as specified and design dimensions.

Type of the turnout rails: 65 kg/m (131 lb/yd);

Curved switch rail length: ; $l_{SR} = 12m$

Frog marking plate: 1/12;

Permissible speed of travel onto $V_s = 13 m/s$

a side track: .

Switch Rail Design Diagram

The switch rail design diagram (Figure 1) shows the dimensions calculated in the course project and given by the design assignment.

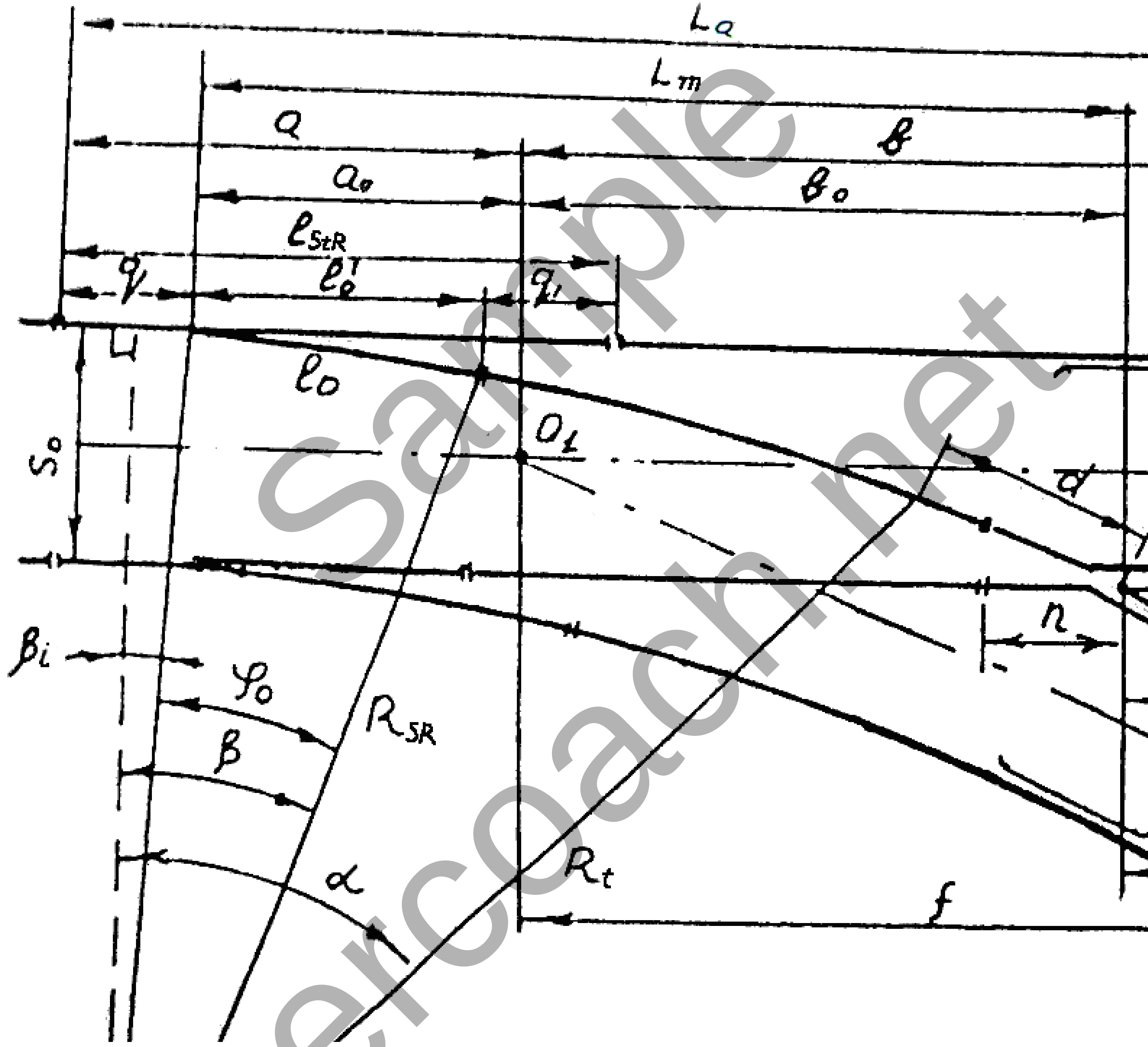

Figure 1. Switch rail design diagram.

Legend for Figure 1:

α: the frog angle;

β_i: the switch rail initial angle;

β: the total switch angle;

φ: the central angle (degree of switch rail curvature);

R_{SR}: the switch rail radius;

R_t: the turnout curve radius;

p: the rear end length;

n: the front end length;

d: the tangential path (distance between the turnout curve end and the theoretical frog point);

q: the stock rail front offset length;

q_1: the stock rail rear offset length;

l_0: the curved switch rail length;

l_0': the curved switch rail projection on the stock rail direction;

S_0: the turnout gauge;

L_m: the turnout molded lead;

L_a: the turnout actual or total lead;

a_0, b_0, a, b: the distance between the turnout center 0_1 to, respectively, switch rails front, theoretical frog point, stock rail front joint, and frog rear end joint;

f_0, f: the distance between the fouling point and theoretical frog point and the turnout center 0_1 respectively.

Calculation of Point Elements

Determination of the Curved Switch Rail Basic Parameters

Calculations determine numerical values of the basic parameters of the curved switch rail and the stock rail length.

The purpose of calculation is to determine numerical values for R_t, $β_i$, β, and l_0 (see Figure 2). The calculations are performed via a force balance method.

Upon entering the point, the wheel hits the switch rail leading to the side track. This creates excessive kinetic energy (an impact effect).

Permissible value of the switch $W_0 = 0.225 m/s$

rail impact effect is set at .

Following hitting the switch rail, the movement along the curved switch rail and then along the turnout curve occurs. This facilitates centrifugal accelerations (j_0 and γ_0 respectively) which can be defined as $j_0 = \gamma_0 = 0.3...0.4$ m/s^2, where $R_{SR} = R_t$.

Where the speed of travel onto the side track is known, the switch rail radius can be calculated as follows:

;

$$R_{SR} = \frac{V_S^2}{j_0} \quad (1)$$

$$R_{SR} = \frac{13^2}{0.4}$$

= 422.5 *m* = 422,500 *mm*.

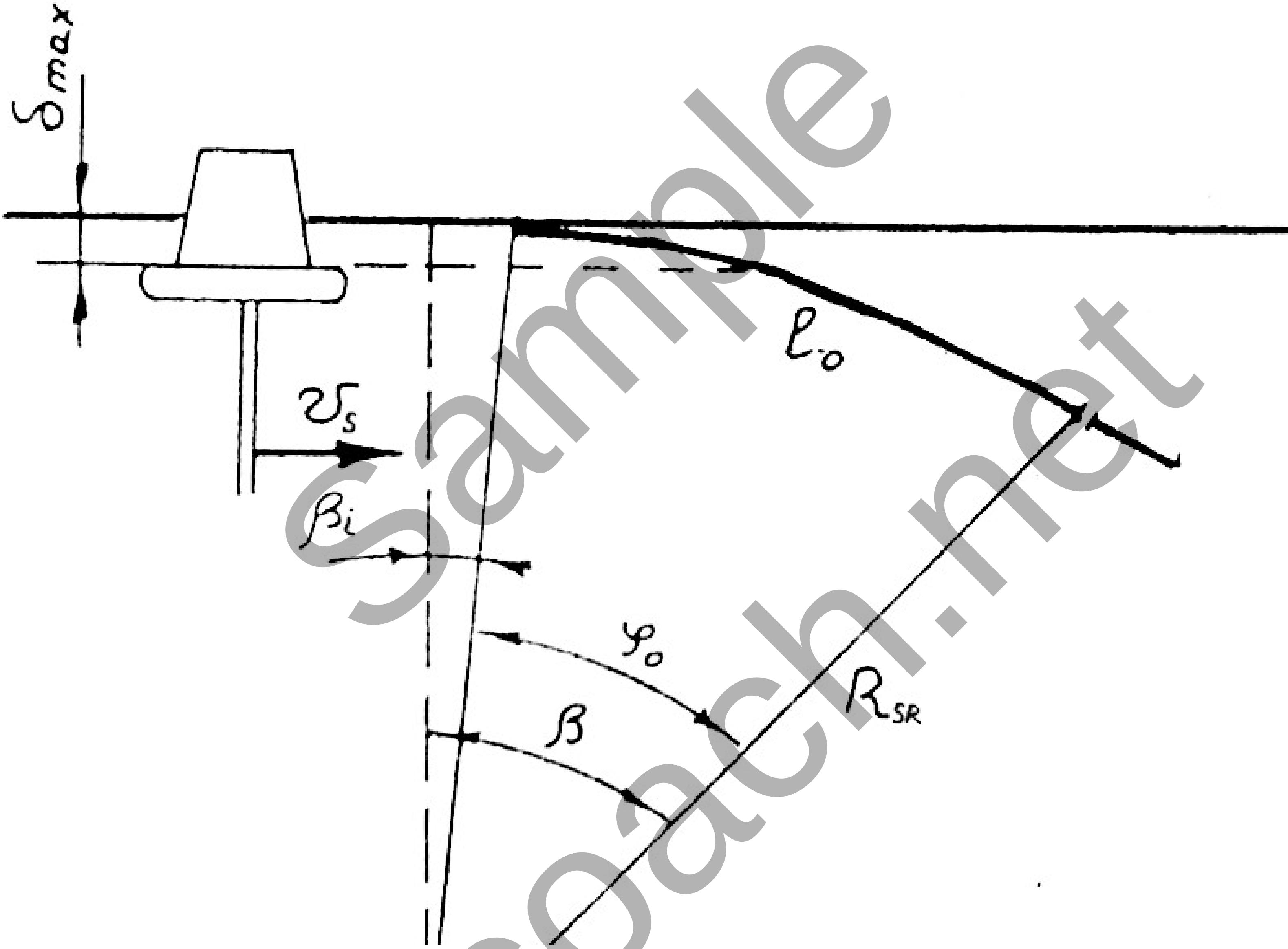

Figure 2. Design diagram for the curved switch rail parameters calculation.

Initial angle is calculated on the basis of the following trigonometric function:

,

$$\sin\beta_i = \frac{1}{V_S}\sqrt{W_0^2 - (2\delta_{max}\cdot j_0)} \quad (2)$$

where $2\delta_{max}$ is a maximum gap between the wheel and the stock rail (= 36 mm).

$$\sin\beta_i = \frac{1}{13}\sqrt{0.225^2 - (2\cdot 0.036\cdot 0.4)}$$ = 0.011364;

β_i = 0.651127.

Next, on the basis of design data and the formula below, the switch rail length l_0 or the central angle φ_0 can be determined:

$$l_{SR} = \frac{\pi R_{SR}\varphi_0}{180^0} \quad (3)$$

,

$$\varphi_0 = \frac{l_{SR}180^0}{\pi R_{SR}}$$

$$\varphi_0 = \frac{12\cdot 180^0}{3.141592\cdot 422{,}500}$$ = 1.627336.

With the values β_i and φ_0 known, a total switch angle β can be calculated:

$\beta = \beta_i + \varphi_0$ = 0.651127 + 1.627336 = 2.278463.

Calculation of the Stock Rail Length

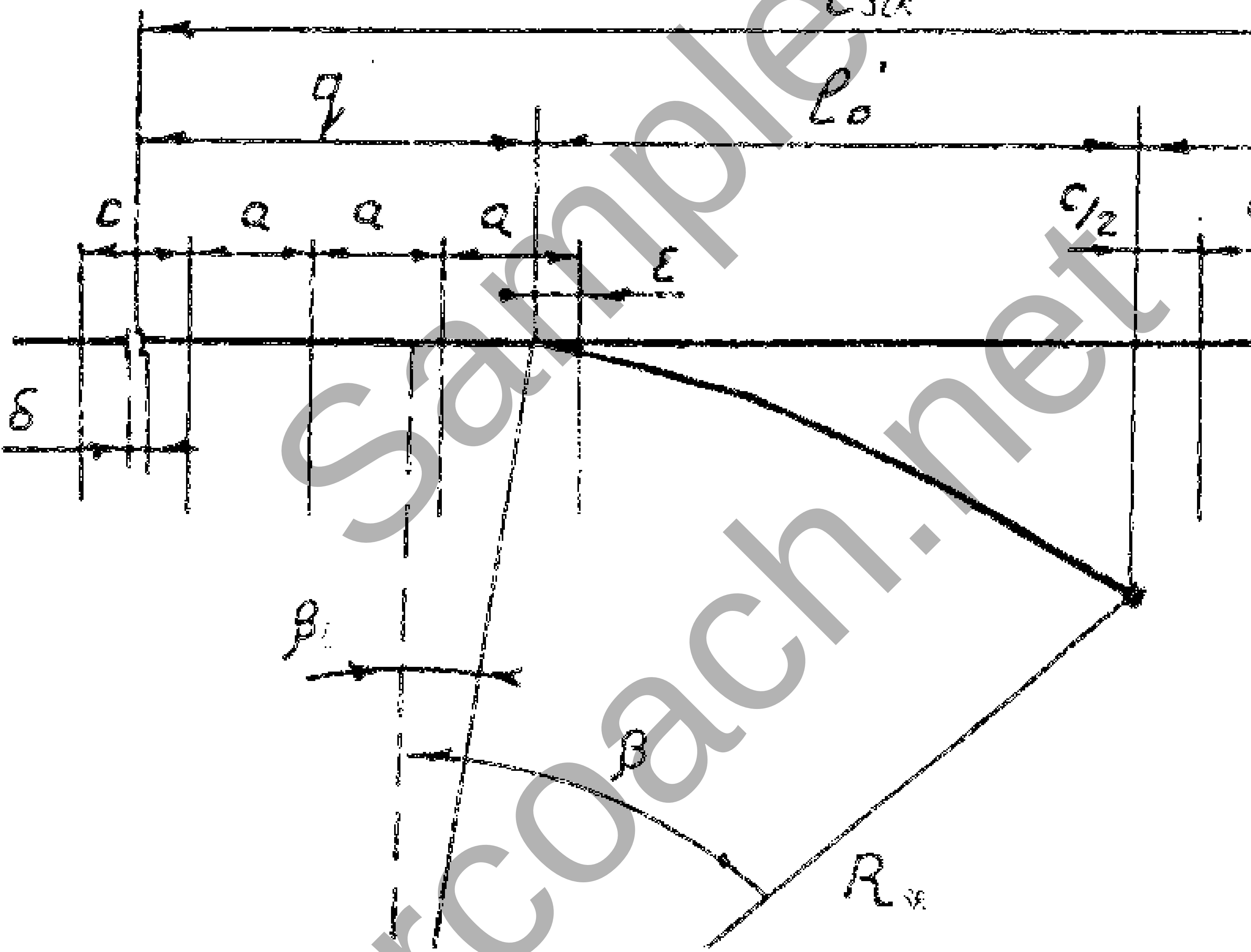

Figure 3. Design diagram for the stock rail length calculation.

The stock rail length is determined in accordance with Figure 3 as a sum of its three sections: front offset q (from the point rail to the stock rail front joint), switch rail projection on the stock rail direction l_0', and the rear offset q_1 (from the switch rail projection end to the stock rail rear joint):

$$l_{StR} = q + 1_0^{'} + q_1 \qquad (4)$$

Stock rail front offset is calculated on the basis of rational combination of front sleepers:

,

$$q = n_1 a + \frac{j - \delta}{2} - \varepsilon \qquad (5)$$

Where:

n_1: the number of spans between the point sleepers' axes, $n_1 = 6$;

a: the intermediate span, a = 500 mm;

j: the joint span for the 65 kg/m (131 lb/yd) rails, j = 420 mm;

δ: the joint gap, δ = 8 mm;

ε: the point rail advance behind the first switch sleeper axis, ε = 41 mm.

$$q = 6 \cdot 500 + \frac{420 - 8}{2} - 41$$

= 3,165 *mm*.

Switch rail l_0 projection is calculated as follows:

$$l_0^{'} = R_{SR}(\sin\beta - \sin\beta_i) \qquad (6)$$

$= 422500 \cdot (0.039756 - 0.011364) = \; l_0' \qquad 11{,}995\ mm.$

Rear offset is calculated based on the following assumption:

$$q_1 = an_2 + c \qquad (7)$$

where n_2 = 1...5 spans, n = 5.

$$q_1 = 500 \cdot 5 + 420 = 2{,}920\ mm$$

$$l_{StR} = 3{,}165 + 2{,}920 + 11{,}995 = 18{,}080\ mm.$$

The lengths of stock rails of the straight and side tracks are taken to be equal.

Frog Dimensions Calculation

This course project identifies the dimensions of the front (n) and end (p) sections of the frog (see Figure 4), the value of which depends on the frog angle, rail type, and the frog structure.

Dimensions of n and p are calculated by the formulas below:

a) for the mold core bolted frog:

$$(8)\; n = \frac{l_f}{2} + d_1 \cdot N - x$$

$$p = d_2 \cdot N \tag{9}$$

$$n = 800/2 + 250 \cdot 12 - 80 = 3{,}320\ mm$$

$$p = 230 \cdot 12 = 2{,}530\ mm$$

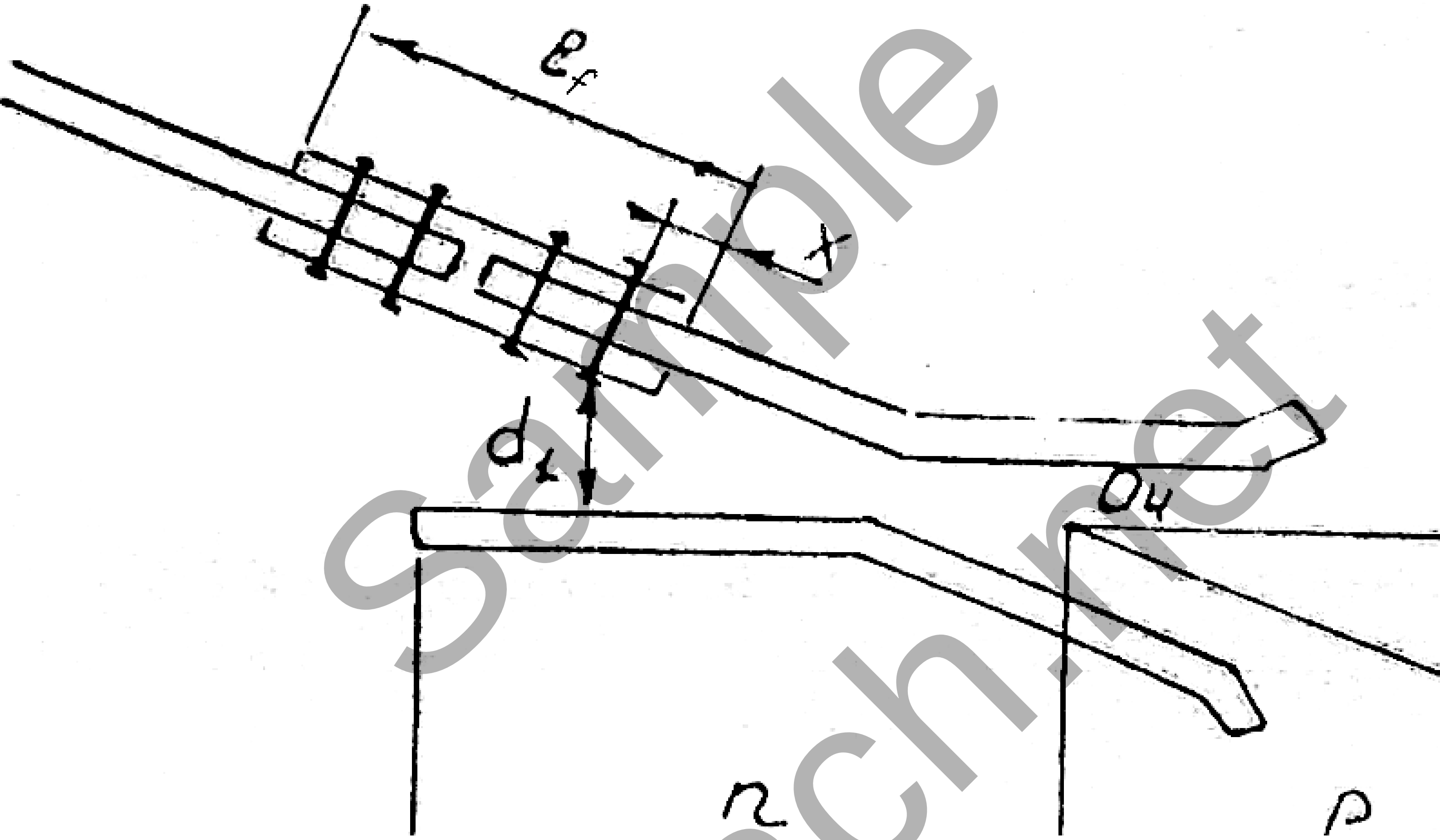

Figure 4. Design diagram for the frog dimensions calculation.

b) for the solid frog, p is calculated by formula (9), and n is calculated as follows:

$$n = \frac{l_f}{2} + \frac{t_2}{2tg\alpha/2} \quad (10)$$

Where:

l_f: the fishplate length;

d_1: the distance between the active faces of counter-rails which conditions the positioning of the first fish bolt;

x: the distance between the fishplate butt end and the first bolt hole axis;

N: the frog marking plate denominator;

d_2: the distance between the frog core active faces which conditions the rails adjunction to the core;

t_2: the frog throat width, t_2 = 64 mm.

$$n = 800/2 + 64/(2\cdot 0.041078) = 1{,}179\ mm.$$

Table 1

Design values of parameters

Rail type	Parameter value, *mm*			
	l_f	d_1	x	d_2
65 kg/m (131 lb/yd)	800	240	50	205
50 kg/m (101 lb/yd)	800	250	80	230

After calculation of n and p values, the frog molded length can be determined as follows:

$$l_{fr} = n + p \qquad (11)$$

For the mold core bolted frog, n = 3,320 mm:

$$l_{fr} = 3{,}320 + 2{,}530 = 5{,}850\ mm.$$

Tangential Path Length Calculation

Tangential path (from the turnout curve end to the theoretical frog point) is designed to facilitate the linear motion of the sets of wheels up to the entry into the frog throat.

The tangential path length d (see Figure 1) is calculated on the basis of positioning conditions of the curved switch rail, turnout curve (where $R_{SR} = R_t$), and tangential path projections on the vertical axis in track S_0:

, (12) $$S_0 = R_{SR}(\cos\beta_i - \cos\alpha) + d\sin\alpha$$

Whence it follows that:

(13) $$d = \frac{1}{\sin\alpha}(S_0 - R_{SR}(\cos\beta_i - \cos\alpha))$$

When sin *α* = 0.082019 and cos *α* = 0.99663,

d = 1/0.082019 · (1,520 – 422,500 · (0.999935 – 0.99663) = 1,507 *mm*.

The value of d must not be less than that of d_{min}, which is calculated as follows:

(14) $$d_{\min} = n + \frac{l_f}{2}$$

d_{min} = 3,320 + 800/2 = 3,720 *mm*.

If following calculations by formula (13) the value of d is lower than d_{min} ($d < d_{min}$), then d must be taken as equal to d_{min} ($d = d_{min}$), and the new turnout curve radius value must be calculated. In this case, the R_{SR} radius will not be equal to the turnout curve radius R_t, as it was set at the beginning of calculations.

The radius changes from R_0 to R_{SR} in the frog heel. The new turnout curve value is calculated as follows:

$$(15)\ R_t = \frac{S_0 - R_{SR}(\cos\beta_i - \cos\beta) - d_{\min}\sin\alpha}{\cos\beta - \cos\alpha}$$

R_t = (1,520 – 422,500 · (0.999935 – 0.999209) – 3,720 · 0.082019)/(0.999209 –

– 0.99663) = 35,2134 *mm*.

In this case, all further calculations must be performed with consideration of radii R_{SR} and R_t.

Calculation of Basic Axial Dimensions of a Turnout

Basic dimensions include molded lead L_m and actual (total) lead L_a of a turnout.

Molded lead L_m (the distance from the switch rail front to the theoretical frog point) is determined by the projection of the curved switch rail, the tangential path, and the turnout curve on the horizontal axis (see Figure 1).

When R_{SR} R_t: =

$$(16)\ L_m = R_{SR}(\sin\alpha - \sin\beta) + d\cos\alpha$$

$$L_m = 352{,}134 \cdot (0.082019 - 0.03975) + 3720 \cdot 0.99663 = 14{,}884\ mm$$

When R_{SR} R_t: ≠

$$(17)\ L_m = R_{SR}(\sin\beta - \sin\beta_i) + R_t(\sin\alpha - \sin\beta) + d_{\min}\cos\alpha$$

L_m = 422,500·(0.039756 – 0.011364) + 352,134·(0.082019 – 0.039756) +

+ 3,720·0.99663 = 30,285 *mm*.

Actual (total) lead L_a (the distance from the stock rail front joint to the frog rear end joint) is calculated as follows:

$$(18)\ L_a = q + L_m + p$$

When $R_{SR} = R_t$:

L_a = 3,165 + 2,530 + 14,884 = 20,579 *mm*

When $R_{SR} \neq R_t$:

L_a = 3,165 + 2,530 + 30,285 = 35,980 *mm*.

Axial (layout) dimensions include the distances from the turnout center to:

a) the beginning of switch rails (a_{SR});

b) the beginning of stock rails (a);

c) the theoretical frog point (b_0);

d) the frog rear end joints (b) as well as distances f_0 and f determining the fouling point position (the fouling point is positioned where the distance between the straight and side track axes reaches 4,100 mm).

Axial dimensions are calculated as follows:

$$b_0 = \frac{S_0}{2tg\alpha/2} \approx S_0 N \quad ;$$

$$a_0 = L_m - b_0 \quad ;$$

$$b = b_0 + p \quad ;$$

$$a = a_0 + q \quad ;$$

$$f = \frac{4{,}100}{2tg\alpha/2} \approx 4{,}100N$$

$$f_0 = f - b_0 \qquad (19)$$

Whence it follows that:

; $b_0 = \frac{S_0}{2tg\alpha/2} \approx S_0 N$

b_0 = 1,520/(2·0.041078) = 16,754.48 ≈ 1,520·12 ≈ 18,502 *mm*;

; $a_0 = L_m - b_0$

a_0 = 30,285 – 18,502 = 11,783 *mm*;

; $b = b_0 + p$

b = 18,502 + 2,530 = 21,032 *mm*;

; $a = a_0 + q$

a = 11,783 + 3,165 = 14,948 *mm*;

; $f = \frac{4{,}100}{2tg\alpha/2} \approx 4{,}100N$

f = 4,100/(2·0.041078) = 49,905 *mm*;

; $f_0 = f - b_0$

$$f_0 = 49{,}905 – 18{,}502 = 31{,}403\ mm.$$

Length Calculation for the Rails of Adjoining Tracks

A standard single turnout can be assembled either with standard length l_{st} rails (12.5 and 25 m) or with shorter ones, the length of which cannot be less than 4.5 m (see Figure 5). If the length of short rails is less than 4.5 m, the length of standard rails is reduced by half.

Rails that do not adjoin the stock rails and frog heels are taken as being of standard length:

$$l_1 = l_3 = l_5 = l_7 = l_{st}$$

The length of the rail positioned against the frog on the straight track:

$$l_2 = L_a - l_{StR} - l_1 - 2\delta \quad (20)$$

$$l_2 = 35{,}980 – 18{,}080 – 12{,}500 – 2\cdot 8 = 5{,}384\ mm.$$

The length of the rail adjoining the frog on the straight track:

$$l_6 = L_m - l_0 - l_5 - n - 3\delta \quad (21)$$

$$l_6 = 30{,}285 – 12{,}000 – 12{,}500 – 3\cdot 8 - 3{,}320 = 2{,}441\ mm.$$

The following is assumed for the purpose of this project:

$l_4 \approx l_2$, $l_8 \approx l_6$

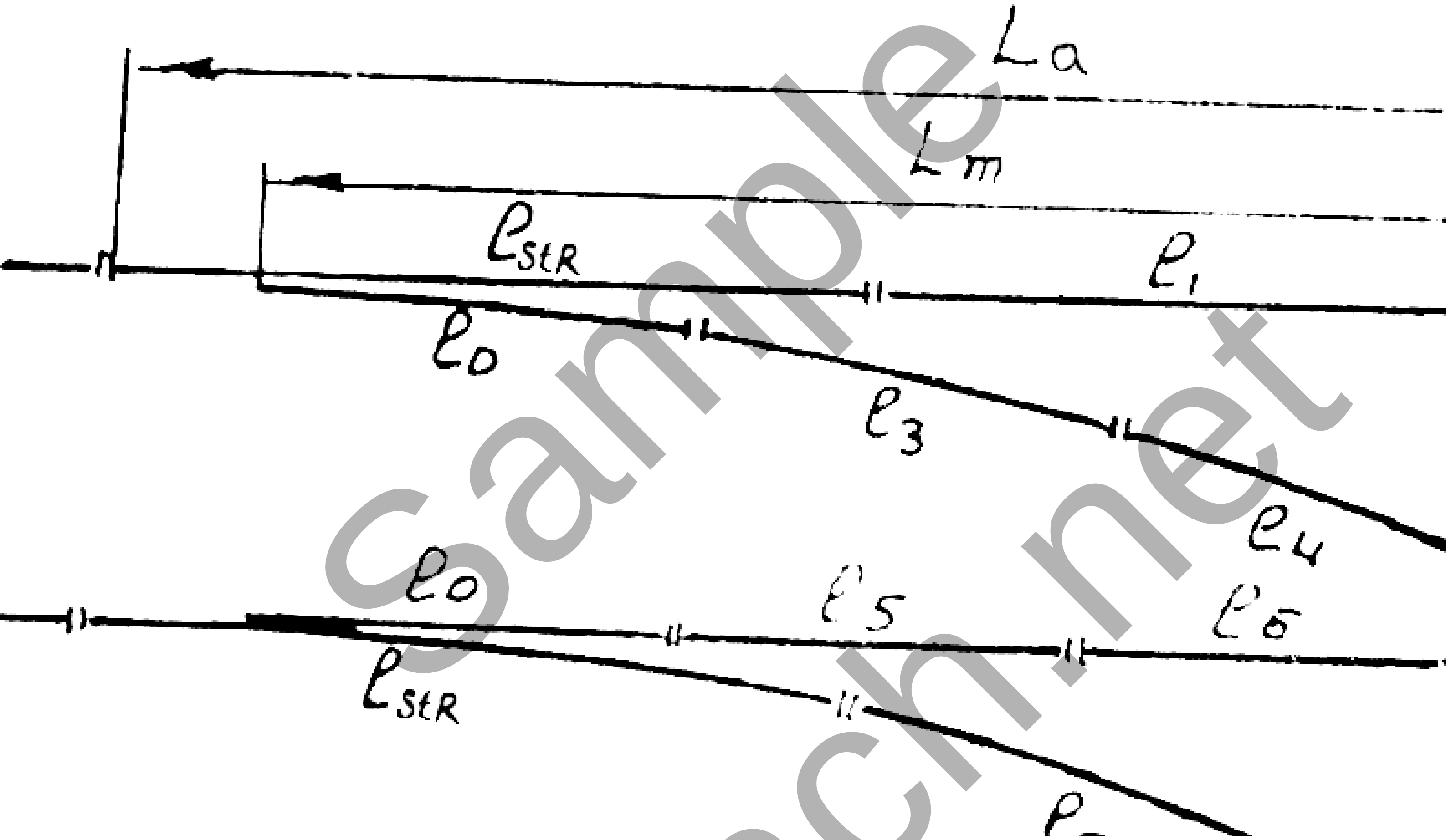

Figure 5. Design diagram for the length calculation of rails for adjoining tracks .

Guidelines for the Turnout Diagram

The turnout diagram consisting of the point sleepers layout diagram and the turnout breakdown diagram must be drawn on graph paper on a scale of 1:100 or 1:50.

Both diagrams are drawn based on the values obtained through calculations. Both diagrams must have the turnout straight track axis drawn with the turnout center indicated; axial dimensions a_0, b_0, a, and b must be laid out from the turnout center, and, finally, the theoretical frog point position must be established, such position being characterized by values b_0 and $S_0/2$.

An arc with an $S_0/2$ radius is then drawn from the theoretical frog point, and by drawing a tangent from the turnout center, a side track axis direction is determined. The turnout is then plotted with joints indicated.

The rails are shown in gauge corners on the diagram, and the sleepers are shown in axes. All joints and distances between all sleeper axes must be indicated. The sleepers are laid out as follows: first, the sleepers are positioned under the joints at the distance of the joint span “C”, whereupon the sleepers are laid under the entire turnout with a 500-550 mm distance between the axes. Two switch sleepers with up to 4.5 *m* in length and axle spacing of 600 mm must be laid at the beginning of switch rails for the purpose of the switch box installation.

Standard ties with the length of 2.75 m are laid under the stock rail front offset (to the point of the first switch sleeper) and point sleepers with the length of 3.0-5.5 m (divisible by 0.25 m) are laid further. The number of sleepers of particular length is calculated graphically with consideration of the minimum sleeper overhang over the rail head active face being 613 mm. When the sleeper overhang is lower than this value, the layout of a new group of sleepers (that are 250 mm longer) must be performed.

Under the turnout point and towards its center, the sleepers are laid perpendicular to the straight track axis. Gradual arrangement of the sleepers into a position perpendicular to the frog angle bisector is performed within the section from the turnout center to the frog front joint. The sleepers are laid under the frog in this manner until it is possible to lay the ties.

All dimensions and angles calculated, along with rail joints of adjoining tracks and short rail lengths, must be specified on the diagram.

All graphs are presented in A1 format on a scale of 1:75.