Arkadiusz Kampczyk
dr inż.
AGH Akademia Górniczo-Hutnicza,
Wydział Geodezji Górniczej i Inżynierii Środowiska,
Katedra Geodezji Inżynieryjnej i Budownictwa
kampczyk@agh.edu.pl

Ewelina Skoczylas
mgr inż.
absolwentka AGH Akademia Górniczo-Hutnicza,
Wydział Geodezji Górniczej i Inżynierii Środowiska,
Katedra Geodezji Inżynieryjnej i Budownictwa
ewelinaskoczy@wp.pl

DOI: 10.35117/A_ENG_17_04_03

Geometrical layouts of railroad switches applying single turnouts

Abstract: In the article there were included issues of geometrical layouts of railroad switches "in design" by applying single turnouts which are components of technical research of turnouts. During rebuilding railroad switches it is required to project a new geometry by a correct selection of kinematic and geometrical parameters. Research referred to geometrical layouts of railroad switches applying single turnouts described in the article were supported by computer program POŁĄCZENIA TORÓW developed for this purpose and by the practical example. The article includes results of confrontation Polish regulations with Directive 2008/57/EC of 17 June 2008 on the interoperability of the rail system within the Community and with TSI regulations. The paper presents conclusions and observations copyright. This work was done within the framework of the statutory research No AGH 11.11.150.005.

Keywords: Railroad switches; Railroad switches; Crossover; Single turnout; Single point; Geometry of turnout; Measurement of layout; Examination
of turnouts; Straight railway segment; TSI

Introduction

The topic of designing geometrical systems of railway track connections appears by the issue of so called railway "bottlenecks". The term is defined as the sections of railway lines where the track system does not provide adequate capacity, thus limiting the number of trains to be operated by the station. An example of railway "bottlenecks" are stations in the Łódź Railway Node - Łódź Fabryczna and Łódź Widzew. The only solution is to redesign the geometry by selecting the appropriate parameters and rebuilding the existing track connections [7].

Rail switch is a construction that allows rolling stock passage from one track to another. An important element within which the direction of rolling stock can be changed is the railroad crossing. In the industry manual Id-4 (D-6) [5] stand out types of switches used on PKP PLK S.A. There are:

- Single turnout (Rz),
- double turnout: unilateral (Rpj), bilateral (Rpd) the symmetric (Rps),
- arc turnout: unilateral (Rłj), bilateral (Rłd), the symmetric (Rłs),
- transverse turnover with needles inside or outside the quadrilateral: single (Rkp), double (Rkpd).

Information obtained from one of the PKP PLK S.A., in the śląskie province, the most common turnoutr is the straight turnout, with a percentage of over 80% (Table **1**). Frequent use of ordinary crossovers is justified by their uncomplicated design, as well as the smallest maintenance and operating costs of all used turnouts. Another advantage is that they can be installed in both main and side tracks.

Table 1. Statistics of the number of individual types of turnouts in one of the PKP PLK S.A. in the province of Silesia

Type of the turnout	Quantity	Percentage [%]
straight	1549	83,3
double one-sided	3	0,2
double two-sided	12	0,6
double symmetrical	4	0,2
arched one-sided	2	0,1
arched symmetrical	6	0,3
single cross	36	1,9
double cross	248	13,3

The geometry of railway track connection

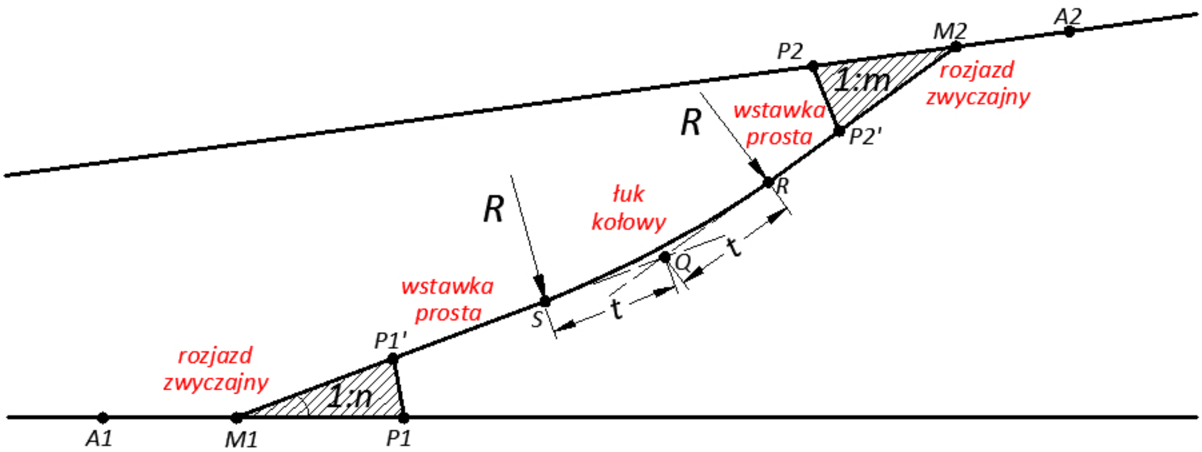
The combination of tracks with the turnouts can be made up of three components (fig. 1):

- set of straight turnouts of certain types,
- rail link so called junction rail line,
- The circular arc track alignment in non-parallel or arcuate portion extending from the arc frog (optional).

The type of travel is determined by many parameters. In the process of designing the track geometry, it is important:

- type of turnout (Rz, Rpj, Rpd, Rps, Rłj, Rłd, Rłs, Rkp, Rkpd),
- type of rails from which the crossover was made (60E1 (S60), 49E1 (S49), S42, 8, 6),
- the size of the back path arc radius [m] (190, 300, 500, 760, 1200 and others),
- slope of turnout (1:9, 1:12, 1:14, 1:18,5 and others).

According to the provisions of Regulation [11], a straight track insert should be used between two arched elements in track joints. If its length is up to 30 m and is located between railroad turnouts, the insert is classified as interstate. The interstitial is not a station track marked by a number, nor is it a travel route [5]. In case the length of the straight insert exceeds 30 m, this section is treated as a new track with a given number. Then a separate Track Condition Monitoring Book (D972) is set up, which records the results of diagnostic measurements.



1. The geometric design of the track connection elements

In the case of a combination of non-parallel tracks, the geometry of the system requires the addition of a circular alignment circular arc. It is separated from the crossings with straight inserts. The circular arc is also used as an extension of the cross-sectional arch.

Exemplary railroad connections using conventional turnouts are joints in parallel tracks with:

- a straight turnout,
- two straight turnouts with equal bevels,
- two common turnouts with different bevels,
- four turnouts (the so called trapezoid combination).

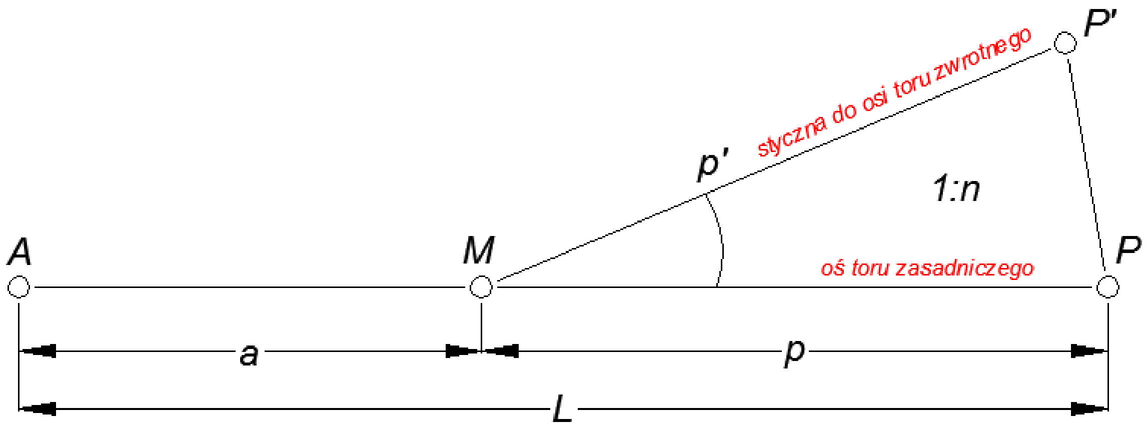
In unequal tracks, exemplary track connections using ordinary switches are connected to:

- two straight turnouts with equal bevels,
- two straight turnouts with different bevels.

Geometric-structural characteristics of the straight turnout

Turnout as a technical-railway device consists of three units meeting specific tasks. The turnout unit enables the steering of the rolling stock set from the main track to the reverse track. The turnout design consists of two fixed rails (straight rudder, arch counter) and two movable rails (straight spine, arch spike). The changeover of the railway track in the steering area is done by means of a switchgear, which by means of the adjustment closure controls the change of the position of the needles. The busbar assembly is a central component of the normal travel connecting the steering unit to the crossing unit. On the other hand, the task of the turnout unit is to allow the free passage of rolling stock wheels through the crossing point of the rails. Due to the design of crossing are divided into fixed and mobile (moving from the bow or wing rails). The design of the mobile crosshairs eliminates the beating of the beak of the beak and flattening of the beak of the crossbrecher while taking over the load from the wing rails [9]. In addition, they wear slower. The exception is the moving parts, whose consumption due to operation is 2-3 times faster than in monoblock crossings [1]. Because of the geometry, the crosses are simple and arched.

The geometrical layout of turnout is defined by four main points in the plan. At the intersection of the central axis of the track with the tangent to the axis of the return path, the so called " Mathematical point M. At the junction of the travel point, the starting point of the travel is point A. The other two points are the points of travel P, P 'which are taken in the main and branch paths in the rail contacts behind the cross. In order to obtain geodetic coverage, the geodetic team views the main points based on the coordinates of the points given in the land development plan or on the basis of the technical data for the construction or modernization of the railway [6][3]. Figure 2 shows the diagram of the travel geometry along with the main points.



2. Scheme of normal traffic geometry with main points of crossover

In addition to the main points, the travel geometry is characterized by its length L, the travel slope 1: n, and the radius of the travel crossover R. The length of travel L is defined as the distance along the main track between the start point A and the travel point P. The tangent of the angle and tangent to the axis of the return path at point P ', whose vertex is at the mathematical point M is called the travel slope. In addition, the crossing angle is equal to the value of the crossing angle. This is not the case with arc crosses, where the angles are not equal [8].

TSI and national regulations on railways connection

Directive 2008/57 / EC of 17 June 2008 on the interoperability of the rail system in the Community [2] requires the subsystem components to meet the requirements of the technical specifications for interoperability (TSIs). Railway turnouts are components of the infrastructure subsystem. In the Regulation of 13 May 2014 on the entry into service of certain types of buildings, facilities and vehicles [13], there is a requirement to obtain a type approval certificate for the type of turnouts. According to the Regulation of 25 February 2016 on the interoperability of the rail system [14], the geometry of railroad turnouts should be checked for compliance with the essential requirements for interoperability of the rail system. The assessment is made by a notified body.

The consequence of the introduction of the TSI was the need to change Polish regulations to comply with the requirements of European legislation. In the regulation of 5 June 2014 amending the Regulation on technical conditions to be met by railway structures and their location [12], the EN 13803 standard for design calculations and limit values was invoked for rail geometry. Part 2 [10] concerns geometrical arrangements of track connections. Includes records of calculations and limit values for the cant deficiency method and a sudden change in the cant deficiency which was not required prior to the TSI input when designing the track link. Another method for performing calculations for geometric arrangements of track connections is the rigid wagon base method. In the regulation of 10 September 1998 on the technical conditions to be met by railway structures and their location [11], limit values are presented and only the rigid wagon base method is characterized. Regulation [12] amended the limit values for kinematic parameters for this calculation method.

The changes were also introduced in the Technical Conditions for Surface Maintenance on Id-1 (D-1) railway lines [4]. In the current version of the Technical Terms, which was released in 2015, a chapter on the geometry of the track was removed. It is replaced by module A3, which allows you to choose the calculation method for the parameters of the geometric layout of the track, from the two methods mentioned above. In module A3, the permissible acceleration values appearing during the fastest train journey (centrifugal acceleration), the slowest train (centripetal acceleration), and the cant deficiency and surplus values included in the maintenance plan.

The topic of geometrical systems of track connections was also discussed in Volume I of PKP PLK S.A. [15]. They include speed limits only for the cant deficiency method and sudden change in cant deficiency. In contrast, in Annex ST-T1-A9 [16], which is to enter into force on 01.01.2017, there are provisions for the selection of turnouts when designing a rail link. The type of turnout should be adjusted to the maximum speed in the lines of the given line type and the required travel speed on the branch and to the local conditions. Another classification is the selection of the type of turnout for the connections between the main tracks and the other for the main track connection with additional main tracks.

Method of rigid wagon base

In the rigid wagon base method, a motion model of the material point moving along the trajectory of the track axis [12] should be adopted. The following kinematic parameters are determined:

- unbalanced centrifugal acceleration a [m/s^2],
- unbalanced centrifugal acceleration at [m/s^2],
- increase of unbalanced acceleration ψ [m/s^3],
- lifting speed of the wheels on the cant transition type f [mm].

For crossovers, the value of only unbalanced acceleration (centrifuge for passenger or freight trains) and the increase of unbalanced acceleration are calculated and analyzed.

The lateral acceleration occurs when driving a railway vehicle on curved sections. In the case of ordinary crossover, this is a turnout curve.

The vector of unbalanced centrifugal acceleration in a cant path is the result of the difference of the vector of sums from the centripetal acceleration and the acceleration of the earth, and the vector perpendicular to the path. The value of unbalanced centrifugal acceleration can be determined using the formula (1):

$$a_{nzr} = \frac{V^2}{12{,}96 \cdot R} - \frac{g_z}{s} \cdot D \tag{1}$$

where:

a_{nzr} – unbalanced acceleration [m/s^2],
V – speed of rolling stock passage [km/h],
R – radius of the track arc [m],
g_z – earth acceleration [m/s^2],
s – gauge [m],
D – cant track [mm].

In turn-offs, the value of unbalanced lateral acceleration depends on the applied cant in the reverse path. The greater the value of the cant, the lower the value of unbalanced acceleration. For turnouts where the cant is zero the form of the formula (1) is reduced to the first member.

The second kinematic parameter calculated in railroad crossings using the wagon's rigid wagon base method is the increase in the unsustainable acceleration ψ calculated from the formula (2):

$$\psi = \frac{V \cdot (a_1 \pm a_2)}{3{,}6 \cdot (b + w)} \tag{2}$$

where:
ψ – increment of unsustainable acceleration [m/s^3],
V – train speed in the reverse direction [km/h],
a_1, a_2 – unbalanced acceleration in crossbars [m/s^2],
w – length of straight insertion [m],
b – rigid wagon base [m] (accepted for calculation 20 m).

The increase in unbalanced lateral acceleration for railroad crossings may not exceed the limit value specified in Regulation [12] and is 1 m/s^3.

Method of changing cant deficiency and sudden change of cant deficiency
The second method is to calculate the cant deficiency parameter and the sudden change in the cant deficiency. The definition of these parameters is in the aforementioned standard PN-EN 13803-2 [10]. Cantilever deviation occurs when the value of cant is too small to compensate for lateral acceleration while driving the train. Excess cant occurs when the value of cant to compensate for lateral acceleration is too high. The formula for calculating the underweight or surplus cant figure is a formula (3):

$$l = 11{,}8 \cdot \frac{V^2}{R} - D \tag{3}$$

where:
l – cant deficiency or cant excess [mm],
V – travel speed on the reverse direction of travel [km/h],
R – radius of crossover arc [m],
D – cant (negative value when the outer rail is lower than the inner) [mm].

On the other hand, the magnitude of the sudden change in cant deficiency depends on the driving speed and the arc radius - calculation (4):

$$\Delta l = 11{,}8 \cdot \frac{V^2}{R} \tag{4}$$

where:
Δl – sudden change of cant deficiency [mm],
V – travel speed on the reverse direction of travel [km/h],
R – radius of crossover arc [m].

In the case of ordinary crossovers, the cant deficiency values and the sudden change in cant deficiency are equal, since the value of D in the formula (3) for the cant deficiency is zero, which reduces it to the form of the same as formula (4) for a sudden change in cant deficiency.

POŁĄCZENIE TORÓW program
The work carried out during the design calls geodetic track, aimed at choosing the right kinds and types of turnouts to the existing ground conditions and the speed of trains. The geometry of the track joint systems is optimized. Design work may be supported by expert

computer systems. For the purposes of research on geometric railways connection systems using turnouts, the computer program POŁĄCZENIE TORÓW was developed and tested by the author. It enables the calculation of the kinematic parameters for the rigid wagon base method and the method of changing the cant deficiency and the sudden change of cant deficiency. In addition, the geometry parameters are calculated according to the type of the analyzed track connection, i.e. the length of the straight insert, tangential to the leveling arc and other dimensions useful for geodetic positioning and control of the elevation of the track connection to the ground. Moreover, the program algorithm calculates the coordinates of the main points of the switches, other connection points and the indicator W17, the so called period.

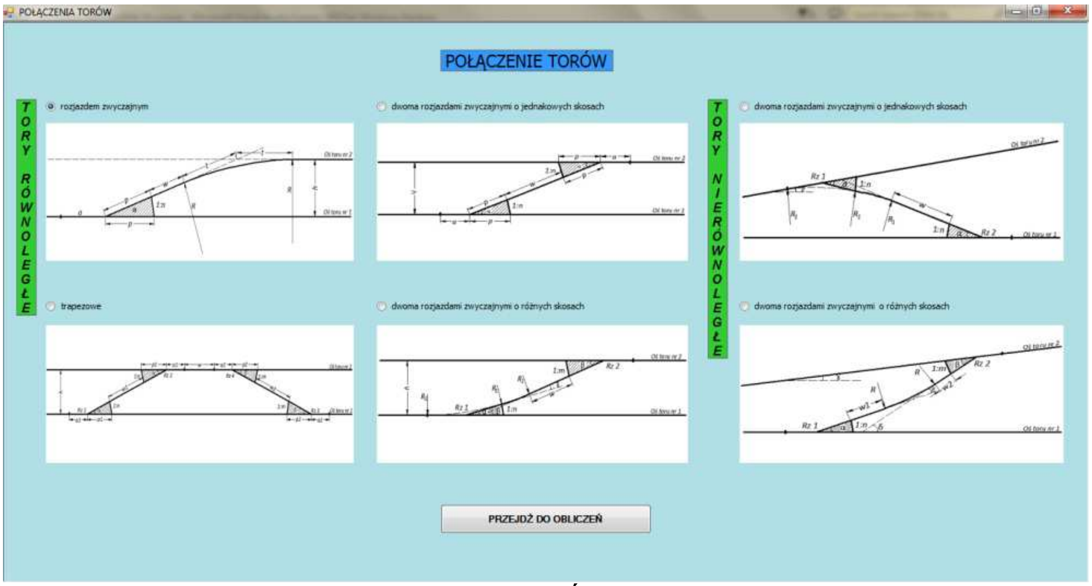
If the axes of the coordinate system are not parallel to the axis of the rectangular coordinate system, the angle of rotation of the coupling system relative to the axis of the rectangular coordinate system should be specified. In case the coordinates of the starting point of the connection system are not equal to (0,000; 0,000), then the coordinates of this point must be given in order to calculate the offset of the coupling system in relation to the rectangular coordinate system used in the program. The program algorithm calculates the coordinates transformed by rotation and offset on the basis of the formulas (5) and (6).

$$X = X_0 + X_p \cdot \cos\beta - Y_p \cdot \sin\beta \tag{5}$$

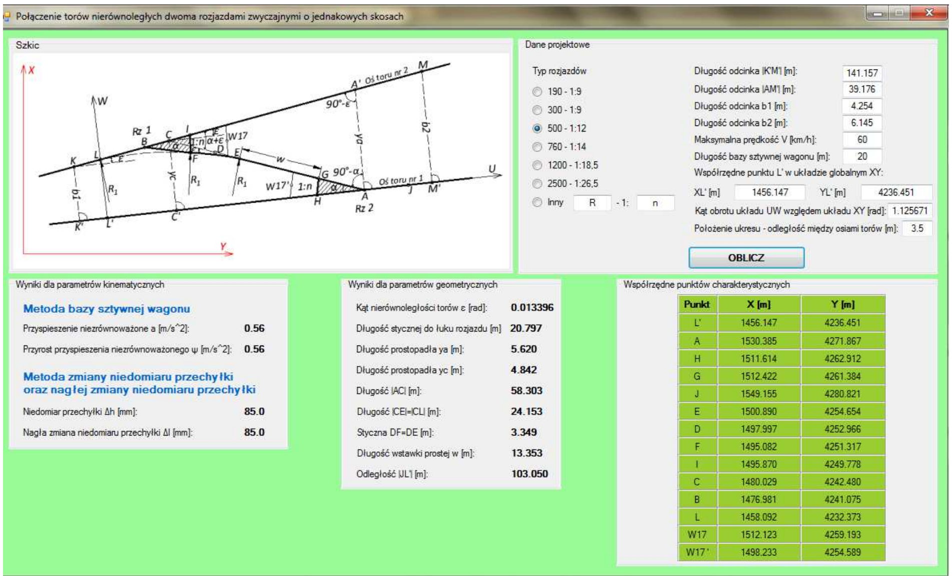
$$Y = Y_0 + X_p \cdot \sin\beta + Y_p \cdot \cos\beta \tag{6}$$

where:
X_o, Y_o – coordinates in a secondary starting point of the original system,
X_p, Y_p – point coordinates in the primary system,
X, Y – point coordinates in the secondary system,
β – angle of rotation of the secondary system relative to the primary system.

The work in the program starts with the selection of the track connection type, out of six, which were previously mentioned in the chapter "Track geometry" (Figure **3**). In the calculation window in the design data section, the user enters the values needed to calculate the geometric parameters characterizing the track and kinematic parameters. The parameters to be introduced are, among others. track gauge, maximum speed for the direction of travel, the length of the rigid wagon base and other sizes depending on the type of track connection. You should also choose the types of ordinary turnouts. In the calculation window there is also an attached sketch suitable for the type of connection being analyzed. The calculations show the values of the kinematic parameters, the geometric values and the coordinates of the main points of the turnouts, the characteristic connections, as well as the period (fig. 4).



3. POŁĄCZENIE TORÓW Window startup

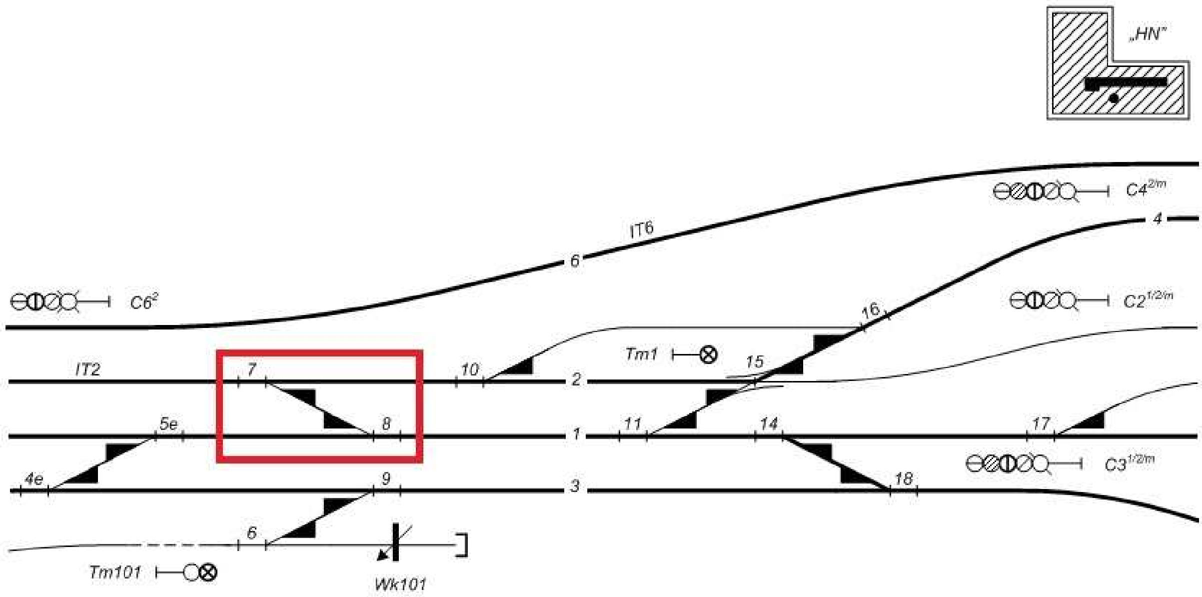


4. Sample calculation window of the POŁĄCZENIE TORÓW

Dodatkowymi funkcjami programu jest ostrzeganie użytkownika odpowiednim komunikatem o niewprowadzeniu wszystkich wymaganych danych, o niespełnieniu wymogu minimalnej długości wstawki prostej wynoszącej według rozporządzenia [12] 6 m oraz w przypadku ujemnej wartości łuku wyrównującego.

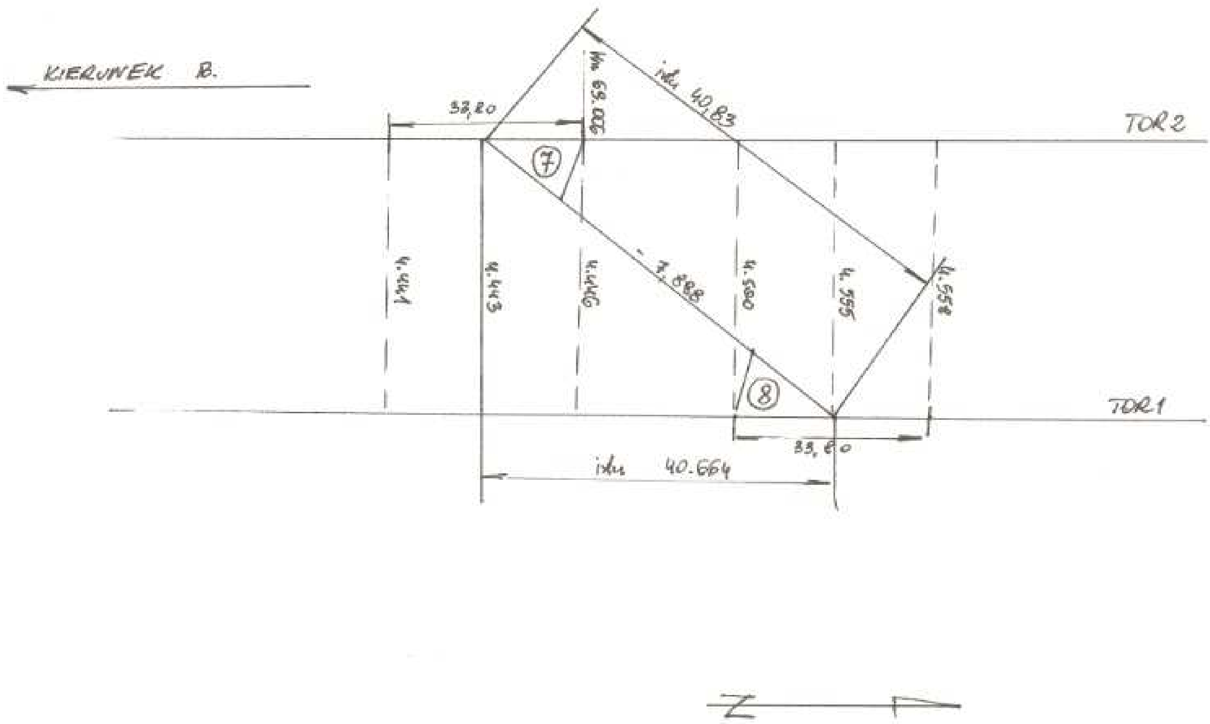
The combination of the two parallel tracks by ordinary junctions with equal bevels

In the adjustment area HN - railway line 131 measurements were taken to check the geometrical connection of railway tracks 1 and 2 "in plan". Both switches are type S60-1: 9-300, right, slider closure, year of manufacture and incorporation 1987, wooden trunks, operated (figs **5** and **8**).

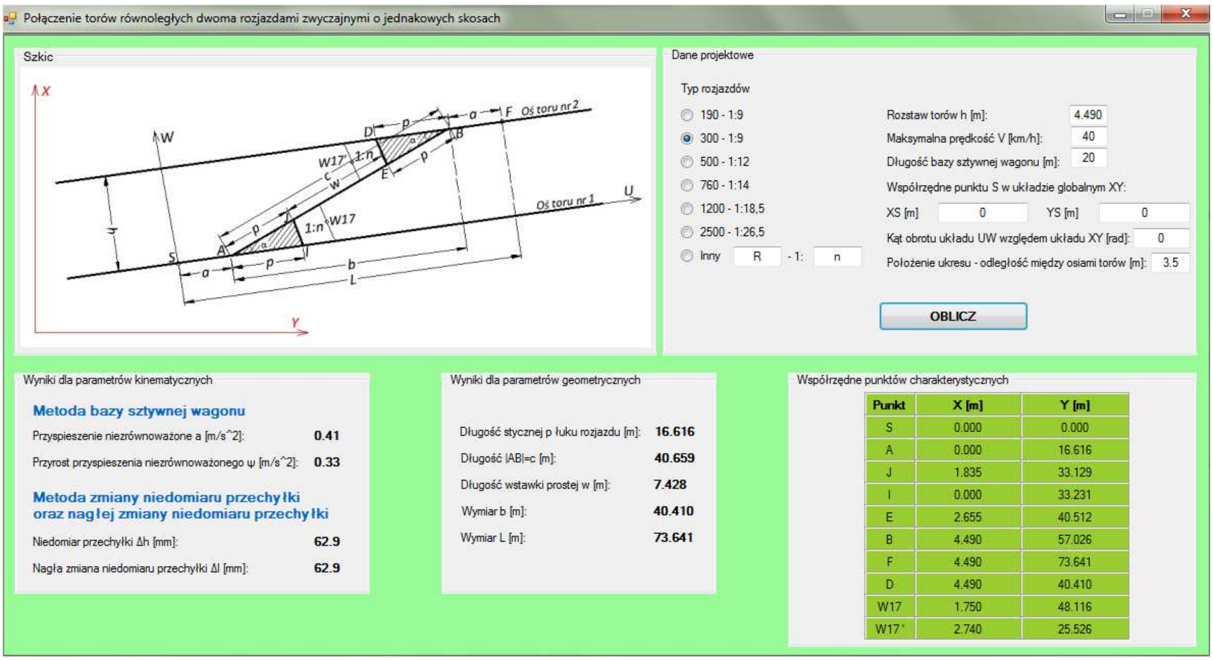


5. Location of turnouts No. 7 and 8 (red frame) in the adjustment area HN

This type of combination of two tracks, theoretically parallel, by means of two turnouts with the same pitches 1: 9, is a single combination of tracks. Inventory measurement "in plan" showed the differences in the value of the width of the existing intersection. Figure **6** shows a sketch of the measured values in the analyzed track combination.



6. Sketch of stocktaking measurements of turnouts No. 7 and 8 in the adjustment area of HN



7. Calculations of the parallel tracks No. 1 and 2 with two turnouts No. 7 and 8 with equal slants in the program

In order to perform a comparative analysis of the obtained values "in plan" with theoretical values, calculations were made in the POŁĄCZENIE TORÓW program. The resultant values obtained are designed values for the geometric parameters of the tested track connection, assuming the average cross-section calculated on the basis of the measurement results of the existing condition. For the calculation, the median width of 4,490 m (using the Krylov-Bradis rounding rules) was assumed, assuming that the axis of track 1 and 2 should be brought into parallel. In practice, the value of the projected intersection can be assumed from the project of alignment of the track axis or the take-off protocol. Execution of design calculations is necessary in the case of work on the alignment of track axis 1 and track 2 for parallelism. Table **2** summarizes the results of the analysis compared with the existing state.

Tab. 2. Summary of design parameters with the existing condition for the analyzed track connection using turnouts No. 7 and 8 in the adjustment area HN within line 131

Geometric parameter	Design value [m]	Existing value [m]
Length of junction No. 7	33,232	33,800
Length of junction No. 8	33,232	33,800
Distance between mathematical points of switches	40,659	40,830
The distance between the mathematical points of switches turned on the axle of the track	40,410	40,664
Lenght of the single turnout	7,428	7,888

8. The combination of the parallel tracks 1 and 2, two ordinary switches 7 and 8 (Rz S60-1: 9-300) in the region of the adjusting HN

Summary

The research carried out on the connection of railway tracks shows that the most commonly used in Poland are ordinary crossovers. It was therefore justified to carry out research on the geometrical arrangements of railroad crossings with the use of turnouts. The analysis of legal regulations shows that the introduction of technical specifications of interoperability required the introduction of changes in Polish legislation. In the area of geometric design of railroad connections, in addition to the rigid wagon base method, the cant deficiency and sudden change in cant deficiency have been introduced, which is defined in detail in the PN-EN 13803-2 standard [10]. During design work, the permissible kinematic parameters specified for both methods can not be exceeded. These values are included in [11], [12], [4], [5], [10]. In terms of geometry of railway track connection systems, the minimum length of the interstitial insert of 6 m is to be maintained. In addition, the role of geodetic and diagnostic units for pavement and railroad tracks is to prepare the design documentation for the connection and operation of assembly of turnouts in the field, main points of switches and other points of characteristic connections. In addition to the tasks of these units it is necessary to carry out measurement work in the scope of technical tests of turnouts, by checking the geometrical arrangements of the railway track connections in the plan. This documentation is a data material that should be obtained not only during operational measurements performed during technical tests of turnouts, but also during construction work. These works can be automated by making calculations in a computer program, such as the program POŁĄCZENIE TORÓW. A comparative analysis of the design parameters with the existing condition for the analyzed connection of tracks with the use of turnouts No. 7 and 8 in the adjustment area HN in line 131 shows that there are significant differences between these values. Such large differences justify and raise the importance of performing theoretical calculations using the described computer program. It is also advisable to carry out permanent and frequent diagnostic measurements in the field, and in some extreme cases to make the adjustment of the axes. Presented research results are included in the subject of contemporary research in the disciplines of engineering geodesy - industrial and diagnostics of communication construction.

Source materials

[1] Bogdaniuk B., Towpik K. Budowa, modernizacja i naprawy dróg kolejowych. Wyd. PKP Polskie Linie Kolejowe, 2010.

[2] Dyrektywa Parlamentu Europejskiego i Rady nr 2008/57/WE z dnia 28 czerwca 2008 r. w sprawie interoperacyjności systemu kolei we Wspólnocie (przekształcenie) (Dz.U. L 191, 18.7.2008, p.1).

[3] Gocał J. Geodezja inżynieryjno – przemysłowa. Część II. Uczelniane Wydawnictwo Naukowo – Dydaktyczne AGH, 2005.

[4] Id-1 (D-1) Warunki techniczne utrzymania nawierzchni na liniach kolejowych, 2015.

[5] Id-4 (D-6) Instrukcja o oględzinach, badaniach technicznych i utrzymaniu rozjazdów, 2015.

[6] Kampczyk A. Geodezyjno - analityczne opracowanie projektów połączeń torowych. Przegląd Geodezyjny, Cz. 1.(Geodetic-and-analytical design of track connections. Part 1),2010, R.82, nr 4, s. 3-8.

[7] Klemba Sz. Łódzki Węzeł Kolejowy. Problemy i rozwiązania. Seminarium Instytutu Kolejnictwa. 03.06.2014 r., s. 92-105.

[8] Łączyński J. Rozjazdy kolejowe. Wydawnictwo Komunikacji i Łączności, 1976.

[9] Paś J., Dyduch J. Współpraca rozjazdu z napędem dla kolei dużych prędkości. Czasopismo Logistyka, 6/2014.

[10] PN-EN 13803-2+A1:2010 Kolejnictwo - Tor - Parametry projektowania toru w planie - Tor o szerokości 1435 mm i większej - Część 2: Rozjazdy, skrzyżowania i inne porównywalne przypadki z nagłymi zmianami krzywizny.

[11] Rozporządzenie Ministra Transportu i Gospodarki Morskiej z dnia 10 września 1998 r. w sprawie warunków technicznych, jakim powinny odpowiadać budowle kolejowe i ich usytuowanie (Dz.U. 1998 nr 151 poz. 987).

[12] Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 5 czerwca 2014 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budowle kolejowe i ich usytuowanie (Dz.U. 2014 poz. 867).

[13] Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 13 maja 2014 r. w sprawie dopuszczania do eksploatacji określonych rodzajów budowli, urządzeń i pojazdów kolejowych (Dz.U. 2014 poz. 720).

[14] Rozporządzenie Ministra Infrastruktury i Budownictwa z dnia 25 lutego 2016 r. w sprawie interoperacyjności systemu kolei (Dz.U. 2016 poz. 254).

[15] Standardy techniczne - szczegółowe warunki techniczne dla modernizacji lub budowy linii kolejowych do prędkości Vmax ≤ 200 km/h (dla taboru konwencjonalnego) / 250 km/h (dla taboru z wychylnym pudłem). Tom I. Droga szynowa, 2009.
[16] Załącznik ST-T1-A9 ROZJAZDY do standardów technicznych - szczegółowe warunki techniczne dla modernizacji lub budowy linii kolejowych do prędkości Vmax ≤ 200 km/h (dla taboru konwencjonalnego) / 250 km/h (dla taboru z wychylnym pudłem). Tom I. Droga szynowa, 2016.