Michał Strach*, Arkadiusz Kampczyk**

Surveys of Creep-Susceptible Locations Using the Method of Fixed Points in Jointless Rail Track***

1. Introduction

A railway track consists of two rail courses arranged at a fixed distance. The manner of joining the rails determines whether it is a classical or jointless rail track. A track with the standard length of the rails,connected with rail joint bars and fixed to a sleeper, or with welded rails of lengths greater than standard but shorter than 180 metres is the classical rail track. A track with permanently interconnected rails by means of electric resistance welding, thermite welding or joint bar welding of lengths exceeding 180 metres is a jointless rail track [3, 4]. Currently, a jointless rail track is the most commonly applied structure, which is used for the basic system railway lines, tram and underground lines. Many of the railway Boards of Directors (including the Polish Railways) uses a jointless rail track on bridges. Also the welded variety is being used increasingly for railway turnouts. This sort of solution has currently become a standard for high-speed railway lines (200 km/h and more) [1].

The diagnosis of a track surfacing, is used, inter alia, to predict changes in the track due to the operating conditions at different time intervals. The continuous monitoring of a jointless rail track condition plays an important role in determining the size of the rail course creep in relation to the fixed points. These are grounds for conducting an analysis of changes in the stress and for verification of neutral temperature. A jointless rail track whose sections have a neutral temperature of less than +5°C, poses a threat to the safety of train traffic due to a possibility of buckling of the track during the period of increased temperatures. A neutral

* Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow
** Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow; Diagnostic Team of PKP PLK S.A. (PKP Polish Railway Lines Company)
*** The paper was prepared within the scope of the AGH statutory research no. 11.11.150.005 in 2010

temperature higher than +40°C poses a threat of increased probability of rail cracking during the period of reduced temperatures. The stability of the neutral temperature should be reviewed at least once a year, before the period of daytime temperatures exceeding 15°C. To verify the stability of the neutral temperature, the following methods are applied: fixed points method, direct survey method, visual method, and others which have been authorized by the infrastructure manager.

The article deals with the problems as well as principles of conducting surveys and observations of creep-susceptible locations of rail courses in a jointless rail track using the method of fixed points. The paper presents and discusses the results of authors' surveys of rail courses creep of the No. 1 jointless rail track of the railway line No. 161 Katowice Szopienice Północne – Chorzów Stary, which were carried out in the spring of 2008 and 2009. The total length of the jointless rail track covered by the monitoring was 5.227 km. The distribution velocity at this section equaled to 80 km/h. In addition, photographs and own observations on the relevant issues were presented.

Due to the limitations in size, the article sets out the most important aspects of conducting surveying works, which are to determine the occurring shifts as well as to mark the fixed points and reference points. It also presents the manner of carrying out the analysis and final assessment of the jointless rail track operation.

2. Technical Documentation Regarding the Diagnosis of the Jointless Rail Track Condition

Documentation on conducting diagnostic tests referring to monitoring of the jointless rail track includes:

- a jointless rail track metrics,
- a survey record book of the rail shifts at fixed points,
- a diagram of rail course creeps of a jointless rail track,
- a sheet of thermal analysis of a jointless rail track.

All the documentation is stored and archived in the operation section (ISE). During the surveys, the results are recorded in the survey book of the rail shifts. On this basis the diagrams of rail course creeps are compiled. The conclusions and recommendations arising from the analysis of the jointless rail track are presented in a sheet of thermal analysis.

The elementary document enabling decision-making in the field of maintenance and operation of the jointless rail track is the jointless rail track metrics. It contains two basic groups of information. The first group includes data on the structure and condition of the track, the second one includes data on the cracks in the rails and track repairs which were carried out. The metrics is set upon the completion of all the works relating to the laying of the jointless rail track throughout its whole section, i.e. between the joints.

3. Conditions of Use and Maintenance of the Jointless Rail Track and Observations of Creep-Susceptible Locations with the Use of Fixed Points

At the length of the jointless rail track there are three main zones: expansion zone, central zone, the next expansion zone [4]. At the expansion zones, starting from the joint, there is balancing of the thermal forces generated in the rails and the longitudinal resistance of the track. An unbalanced part of the thermal force results in the movement of the rail terminal in the joint. The length of the expansion zone depends upon the track longitudinal resistance as well as temperature changes.

In the central zone of the jointless rail track the creeping of rails or track results in changes in the value of longitudinal thermal forces in the rails.

The main causes of the occurrence of the rail creeping may be as follows:
- changes in the rail temperature,
- local changes of surface longitudinal resistance caused by variable ballast condition or fixing of rails to sleepers,
- discontinuity of the rail course,
- impact of train wheels.

Based on an updated neutral temperature, an authorized employee of the diagnostic team shall identify and provide the manager of the executive organizational unit with:
- range of secure thermal conditions of the jointless rail track,
- locations and types of repairs to be carried out in order to prevent the train velocity limitations during high temperatures.

The surveys carried out using the fixed points method, conducted to verify the stability of the neutral temperature, are aimed at, inter alia, making a decision to carry out the adjustment of longitudinal forces. It is conducted if:
- at the used section of the track the specified values of the neutral temperature exceed the required range, which is from +15°C to +30°C;
- the differential in the values of neutral temperatures in neighbouring rail courses in the cross section of the rail track exceeds 10°C;
- at the used section of the track the specified values of the neutral temperature differ by more than 10°C;

– while determining the neutral temperature, it was found that at the same sections the differences between successive annual findings were more than:
  • 15°C with good ballast condition and full ballast profile,
  • 10°C with average ballast condition and full ballast profile,
  • 7°C in the remaining ballast condition or deficiencies in ballast profile.

A neutral temperature is the temperature of the jointless track rail at which longitudinal forces do not occur at a particular section of the track, which is without any movement loads. In the central zone, if there were no local movements of the track or rails, the neutral temperature would be equal to the temperature of fixing the rails to the sleepers. There are, however, phenomena causing sectional balance disorders. There are cases of micro-shifts of the rails, which may take the form of he rail creep. They lead to changes in the value of longitudinal forces at the section length, at which the displacement has occurred (which can be considered a change of the neutral temperature). The effect of the increase in the compressive forces at the track section will be analogical to the reduction of the neutral temperature on this section by the following value:

$$\Delta t_n = \frac{\delta}{500\alpha l} \text{ [°C]} \tag{1}$$

where:

δ – the maximum survey value of the track creep [mm]
α – the coefficient of linear expansion of steel rail [$1.12 \cdot 10^{-5}$ 1/1°],
l – the surveyed length of track section where creeping has occurred [m].

4. Observation of Creep-Susceptible Locations with the Method of Fixed Points; Analysis and Evaluation

In order to carry out a detailed survey of possible shifts of the rails, while fixing long rails to the sleepers, the fixed points must be directly installed (Fig. 1). These points must be installed in the same sections at both courses of the jointless rail track, in the central zone exclusively (i.e. no closer than circa 100 metres from the joint) according to the following principles:
– with the rail track section of the length of more than one kilometre being subject to observation, two points on one long rail, before it getting welded, at approximately 50 metres from the ends of the rail;
– with the rail track section of the length of less than one kilometre being subject to observation, the fixed points at distances from 50 to 200 metres apart, depending on local conditions.

The fixed points should enable to conduct a reference line in relation to which the survey of the distance will be conduced to the base point on the rail (this is a control point incised on the outer side plane of the rail head made during the first survey). The authors' surveys show that reference points are incised or studded with a centre punch on the outer side plane of the rail head during the first survey (Fig. 1). Attention should be drawn to the explicit reproducibility of the line in the consecutive surveys, even at large time intervals. Reference line may be a simple measuring (fishing) line stretched between the objects. Surveying of these distances is recommended. Then, a base for surveying instrument should be attached to the fixed point. Surveying with the use of fixed points is measuring with the accuracy of 1 mm the distance from the line of reference (stretched measuring line or instrument sight line) to the base point on the rail head. The measurement is conducted using a triangle prepared in such a way that the "0" on the reading scale coincides with the point of application of the triangle to the measuring line (at the time of the measurement it is not allowed to push the measuring line with the triangle) or with the instrument sight line.

It is important to adopt a marking of the survey direction. If the survey is carried out in the direction of the mileage (expressed in kilometres), the reading is marked as "+", and in the opposite direction as "–".

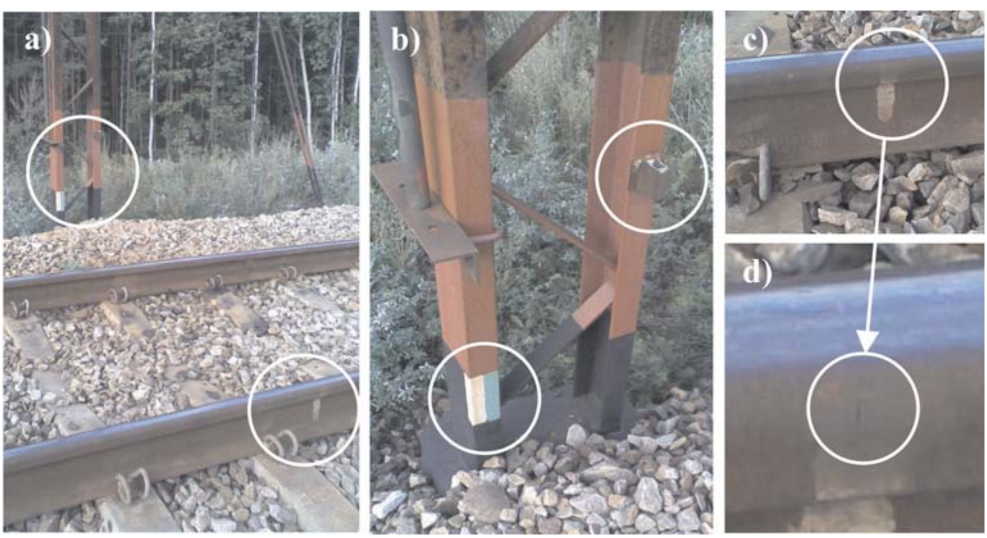

Fig. 1. Points: fixed point (reference point), installed on the traction pole together with the base point on the rail: a) general view of the fixed point, base point and geodetic railway network point; b) steel traction pole with the installed fixed point, and geodetic railway network point (above); c) base point; d) its magnification

The first survey has to be carried out during the laying of a jointless rail track immediately upon laying a long rail on sleepers and fixing it to the sleepers. It provides a reference for the conducted calculations of the forces in successive surveys, and that is why it is necessary to record it in a survey record book of the rail shifts at fixed points. Upon completion of all track works, a control survey should be carried out. The following surveys shall be conducted at least once a year.

The terms of installing fixed points and conducting surveys have been shown in figure 2

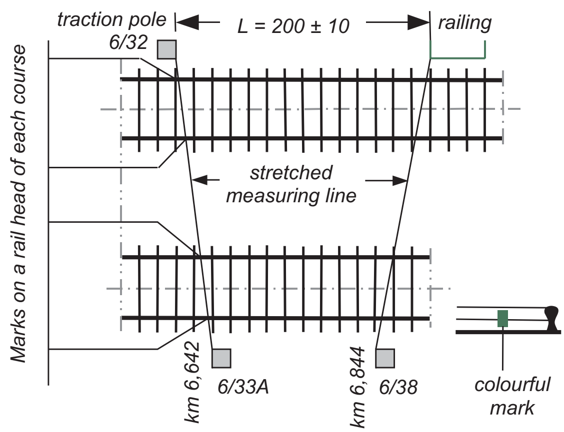

Fig. 2. Terms of installing fixed points and surveying (in horizontal projection)

5. Verification of Neutral Temperature on the Basis of Diagnostic Tests

The calculations of current neutral temperature between fixed points shall be based upon the survey results as follows:

- Determining the value of the base point shift (i) that has occurred in the period from the first survey to the current one:

$$\Delta d^{(i)} = d^{(i)} - d_0^{(i)} \tag{2}$$

where:

$d^{(i)}$ – current survey of shift taking into account the sign (direction of shift),

$d_0^{(i)}$ – the first survey of the base point position immediately after fixing the rail to the sleeper.

– Determining the value of base point shift $(i+1)$ which has occurred in the period from the first survey to the current one:

$$\Delta d^{(i+1)} = d^{(i+1)} - d_0^{(i+1)} \tag{3}$$

where:

$d^{(i+1)}$ – current survey of shift taking into account the sign (direction of shift),

$d_0^{(i+1)}$ – the first survey of the base point position immediately after fixing the rail to the sleeper.

– On the basis of the above-mentioned data, compiling diagrams of creeps for both rail courses (Fig. 3).

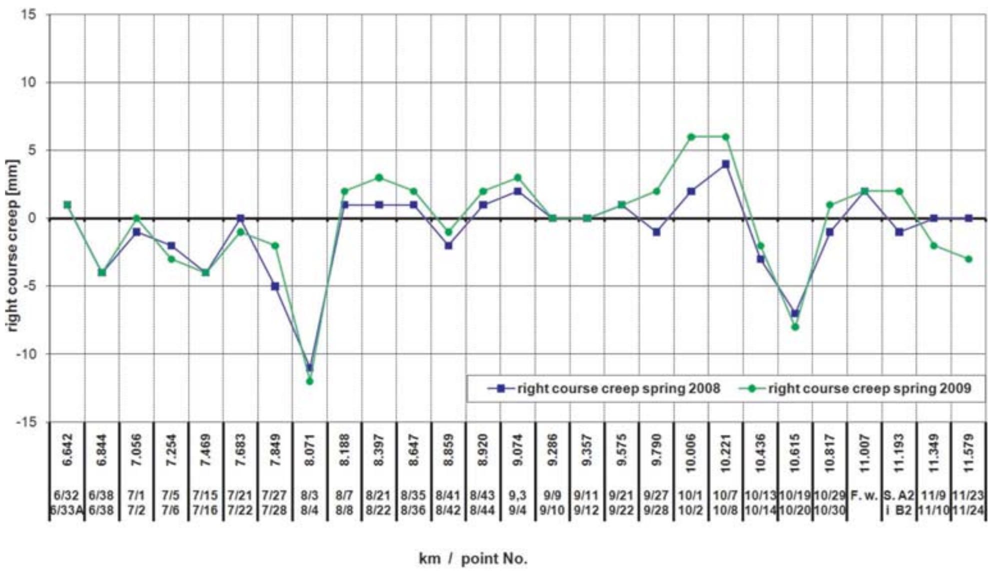

Fig. 3. Diagrams of rail course creeps for jointless rail track No. 1, right course, line No. 161, km 6.642–11.579

– Determining the change in the length of the section between the base points $(i, i+1)$:

$$\Delta L = \Delta d^{(i)} - \Delta d^{(i+1)} \tag{4}$$

– Calculating the value of temperature change corresponding to the change of longitudinal forces caused by shifts considering the signs, which in reference to the assumptions adopted above mean: compressive force, as a "+" sign, tensile force, as a "–" sign:

$$\Delta t = \frac{\Delta L}{\alpha L} \tag{5}$$

where:

L – length of track section between adjacent fixed points [m]
α – coefficient of linear expansion of rail steel [$1.12 \cdot 10^{-5}$ 1/1°],
ΔL – value of the change in the length of the section [m].

– Current neutral temperature, at the section between the fixed points is:

$$t_n = t_0 - \Delta t \tag{6}$$

where:

t_n – current neutral temperature,
t_0 – rail fixing temperature.

Following the recommendations of the technical conditions Id-1 (D1) [4] the adjustment of longitudinal forces should be carried out when the neutral temperature differential between successive annual surveys is greater than:

– with good ballast condition and full ballast profile: 15°C,
– with average ballast condition and full ballast profile: 10°C,
– with other ballast conditions or deficiencies in ballast profile: 7°C.

Figure 4 presents a graphic interpretation of the neutral temperature differentials between successive annual surveys from 2008 to 2009 for the left and right courses.

It can be noticed that at kilometre 8.920 the neutral temperature differential between successive annual surveys in the years 2008 to 2009 for the left track comes to a value of –7.32°C. The value of this differential falls within the limits specified in the instruction manual and there is no need to exercise the adjustment of longitudinal forces.

Every year in early spring before the period of high temperatures, using the Id-1 [4] instruction manual, the allowable operating temperature of the rail $t_{\exp}$ can be determined as follows:

$$t_{\exp} = t_n + \Delta t_{\max} \tag{7}$$

where:

t_n – is the neutral temperature value,
$\Delta t_{\max}$ – is the value of allowable rail temperature increase over the neutral temperature due to the condition of the track – read from the manual.

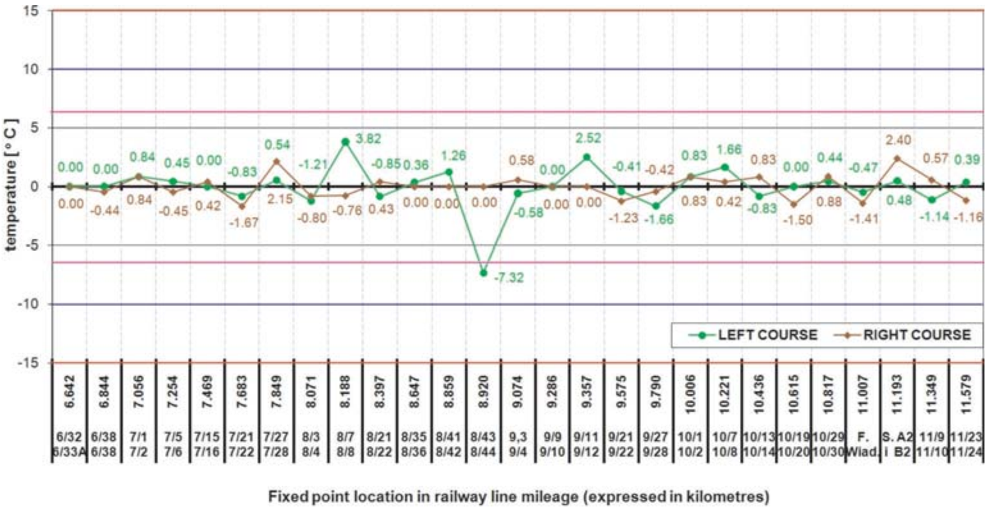

Fig. 4. Diagram of neutral temperature differentials between successive annual surveys in 2008–2009 of left and right courses, track number 1, line 161

On 2 June 2009 at the analysed track, a survey of its geometry was carried out with the use of an electronic track recording trolley TEC-1435. It revealed that at kilometres 7.469 and 7.683 occur horizontal inequalities of the maximum values of 9 mm. According to the values of acceptable deviations of fundamental parameters of the track position (Annex 13 Table 1, Id-1) for V = 80 km/h, horizontal inequalities should not be larger than 17 mm. Therefore, this condition was fulfilled. Then, using the Id-1 instructions, appropriate values of rail temperature increases, which are above the neutral temperature, for the locations with maximum inequalities was read. Therefore, in the analysed jointless rail track there is no need for velocity reduction for Δt_{max} = 55°C. For temperatures higher than 55°C the velocity should be prophylactically reduced to V = 60 km/h.

At the track sections where the estimated operating temperature t_{exp} is below 60°C, in the period preceding the occurrence of high temperatures, safety works preventing the joinless rail track from buckling should be carried out, and after their execution, re-check the value of the permissible operating temperature. In the event of failure of the execution of these works, or where, despite their execution, the estimated operating temperature was still lower than 60°C, reductions to the use and maintenance conditions should be introduced gradually in the period when the rail temperature is higher than the operating temperature.

If the scope of works exceeds their capability to be carried out before the period of high temperatures, it is necessary to adjust longitudinal forces in such a way that even the occurrence of the maximum temperature would not result in exceeding the limit values of the temperature increase. If, however, the upper limit of the neutral temperatures is exceeded, it is necessary to re-adjust the longitudinal forces before the winter period.

6. Summary

The subject of surveying creep-susceptible locations using the method of fixed points in a jointless rail track allowed to draw a number of conclusions, which have been compiled below. The conducted analysis indicated that the jointless rail track metrics are not updated on a regular basis and unfortunately, this negligence refers to the most of railway lines.

There are numerous locations where the phenomenon of a creep of a rail or track may occur, causing changes in the distribution of longitudinal forces. Most often, however, they should be expected in the following locations [4]:

- at the distance of about 50 m to 100 m before and after the locations which are changing the surface structure, such as crossings, single junctions welded into the jointless track, places of the change of the sleeper type;
- at straight sections at the beginning of and at the end of a curve with a radius <600 metres;
- at the locations of significant differences in the thermal impacts on the track, for example: a transition from an embankment into a trench, passing through forests, before and after tunnels, etc.;
- at the sections of trains braking and starting, e.g. before semaphores;
- at inclinations greater than 5‰ with the lengths greater than the length of freight trains;
- at sections, where there was a history of the rails or track creep.

Power engineering services when replacing traction posts fail to inform the surveying units, diagnostic units or directly the infrastructure manager about their intention to do so. As a result, both the adjustment signs of the track axis as well as fixed points are permanently removed.

It has been repeatedly confirmed that the power engineering services during maintenance works on traction poles paint over the markings of fixed points. There are also cases of changing the locations (position, numbering) of the posts. Unfortunately, the staff of power engineering services do not realize that this very position sets grounds not only for fixed points surveys but also signs of adjustment of the track axis.

From a practical point of view, atmospheric conditions during surveys are an essential factor. The necessity of conducting surveys in relation to the reference line, which is a stretched line, requires works to be carried out on a windless day.

The adoption of uniform rules referring to the marking of readings which depend on the direction of the surveys is significant. If the survey is carried out in the direction of the mileage (expressed in kilometres), the reading is marked as "+", and in the opposite direction as "–". Unfortunately, numerous errors have been found in the readings in relation to this principle.

During the surveys with the use of a measuring line as a reference line, the control of its condition and location is essential. At each survey, the measuring line has to be hooked at the same points, must have equal tension and position. The fixed points (reference points) are generally installed at traction poles. These in turn have a different structure and are made of reinforced concrete or steel.

Depending on the shape of the pole, the following solutions were assumed, exemplified by the railway line 143 (Kalety – Wrocław):

- survey straight lines were installed on the traction poles on the surface from the side of the declining mileage;
- survey straight lines were installed at the minimum height above the rail head, ensuring lack of contact with any obstacle (always traction pole, never its foundation; in the case of platforms, high gate foundations or other obstacles, the point was given full measure with a plumb bob);
- due to the variety of types and structures of traction poles, different but the most optimal application points ought to have been selected;
- the points were stamped on the side, on the rail head, while below. On the neck, they were labelled with white paint;
- the reading signs of the fixed point shifts in relation to the survey line were adopted according to the principle of "+" in the direction of increasing mileage; "–" – declining mileage.

References

[1] Czyczuła W.: *Tor bezstykowy* [Jointless rail track]. Wydawnictwo Politechniki Krakowskiej, Kraków 2002.

[2] Gołaszewski A., Sancewicz S.: *Tor bezstykowy* [Jointless rail track]. Wydawnictwo Komunikacji i Łączności, Warszawa 1986.

[3] Towpik K.: *Infrastruktura transportu kolejowego* [Infrastructure of the railway transport]. Wydawnictwo Politechniki Warszawskiej, Warszawa 2004.

[4] Instrukcja Id-1 (D-1): *Warunki techniczne utrzymania nawierzchni na liniach kolejowych* [Technical conditions for the maintenance of railway line]. Warszawa 2005.

[5] *Ustawa z dnia 7 lipca 1994 r. Prawo budowlane* [Building Law of 7 July 1994 and subsequent amendments]. Tekst jednolity Dz. U. z 2006 r. Nr 156, poz. 1118.

[6] *Ustawa z dnia 17 maja 1989 r. Prawo geodezyjne i kartograficzne* [Geodesic and Cartographic Law of 17 May 1989 and subsequent amendments]. Tekst jednolity Dz. U. z 2005 r. Nr 240, poz. 2027.

[7] Instrukcja Id-8: *Instrukcja diagnostyki nawierzchni kolejowej* [Instruction of the diagnostics of the railway permanent way]. Warszawa 2005.