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Deformations of the surface and trackbed beside the bridge objects - tests and diagnostics

Abstract: In the paper the results of research into dynamic rail deflections and rail accelerations under passing trains are presented. The research was carried out on five railway bridges within the precinct of Krakow Railway Management. The objects varied as to their construction (ballasted, ballastless structures) and tonnage borne. The measurements were carried out in the period of 18 months. As a result, special algorithms for predicting the geometrical deformations and the changes in the dynamic stiffness of the railway structure (track, subgrade, bridge) were worked out. These algorithms were implemented in the diagnostic data base DIAGTOR. Some examples of the algorithms and calculations are presented in the paper.

Keywords: transition zone; track and subgrade stiffness; transition effect; track and subgrade deformation; maintenance

Introduction

The paper presents the results of synthetically approximately 3-year research project carried out by the Cracow University of Technology, represented by one of the authors of the paper and the company NeoStrain sp. z.o.o., represented by the other co-author of the paper. The project consisted of two phases: research and implementation.

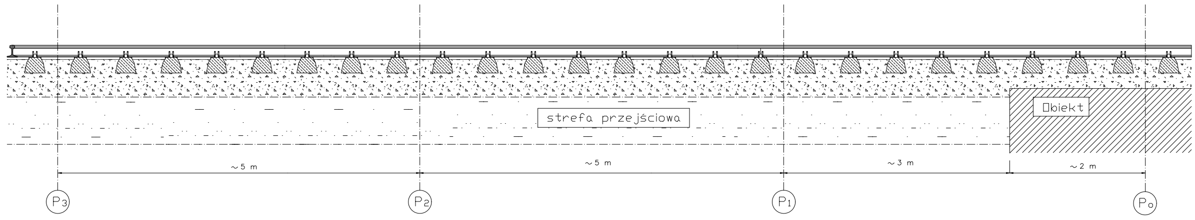
The first one analyzed existing literature on the issue of impacts of dynamic vehicle-railway road and the formation of inequalities track geometry and surface subsidence and the substructure - for example, [2,3,4,5,7,12,16]. Introduced own algorithms for determining the dynamic stiffness of the road train and predict the degradation geometric [9,10,11].

As part of the implementation done tens of measurements of dynamic interactions vehicle-track as the measurement of dynamic deflection rail, vertical rail acceleration while measuring the speed of trains on six bridges with different structures and different load-year (volume of traffic).

As a result of the research was a system and a computer program DIAGTOR for diagnostics and forecasting changes in road train during operation.

Description of the research on the research sections

The studies of dynamic deflections and accelerations of vertical rails in the transition zones was carried out on 6 sections of research during the period from June 2014. December 2015 several series of measurement. Research sections were located at 3 railway lines, on the railway line No. 8 Warszawa Wschodnia-Krakow, on the railway line 91 Krakow-Medic, and on the railway line No. 100 Mydlniki-Gaj.



1. Outline of arranging measuring sections

On each of research segments 4 measuring diameters were covered according to the scheme presented in the picture with No. 1. Points, in which measurements of dynamic diffractions and accelerations were being conducted (pic. 2) they located on both tracks of the track.

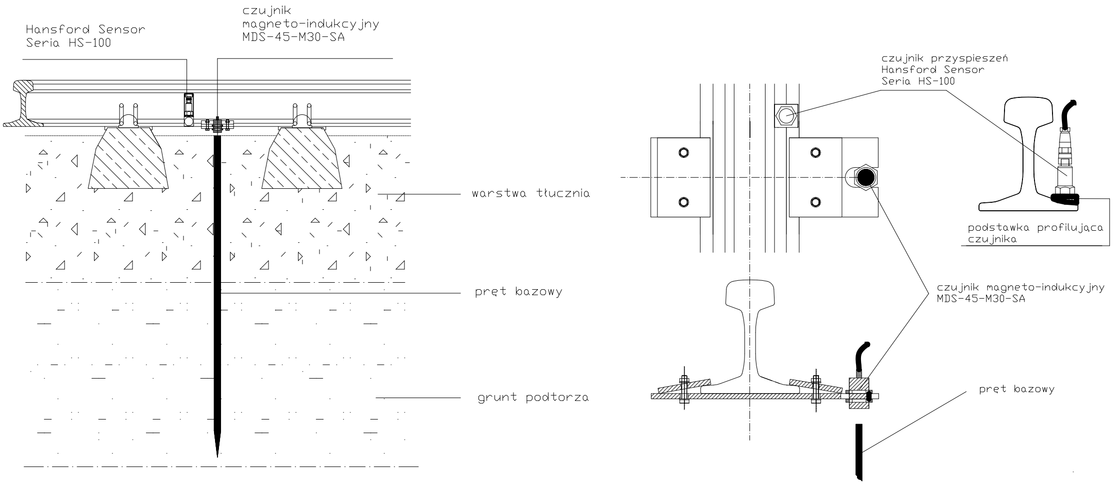
Measuring instrumentation of research segments

Measurements of vertical transfers of the track in first series of measurements, they carried with noncontact method with sensors magnet-inductive of type MDS-45-M30-SA.

Team of the measurement of transfers of vertical tracks (pic. 2) constitute:

- handle of the device fastened to the foot of the track;
- sensor magnet-inductive MDS-45-M30-SA, fastened in the handle of the device;
- steel rod stuck in the roadbed (measuring base) at the window between undercoats.

The measurement of vertical accelerations of the track was being measured with HS 100 accelerometers of the Hansford Sensors company, screwed to metal cubes stuck to the foot tracks (pic. 2).



2. Team of the measurement of vertical transfers and accelerations of the track

3. Measurement of dynamic deflections and accelerations of vertical rails

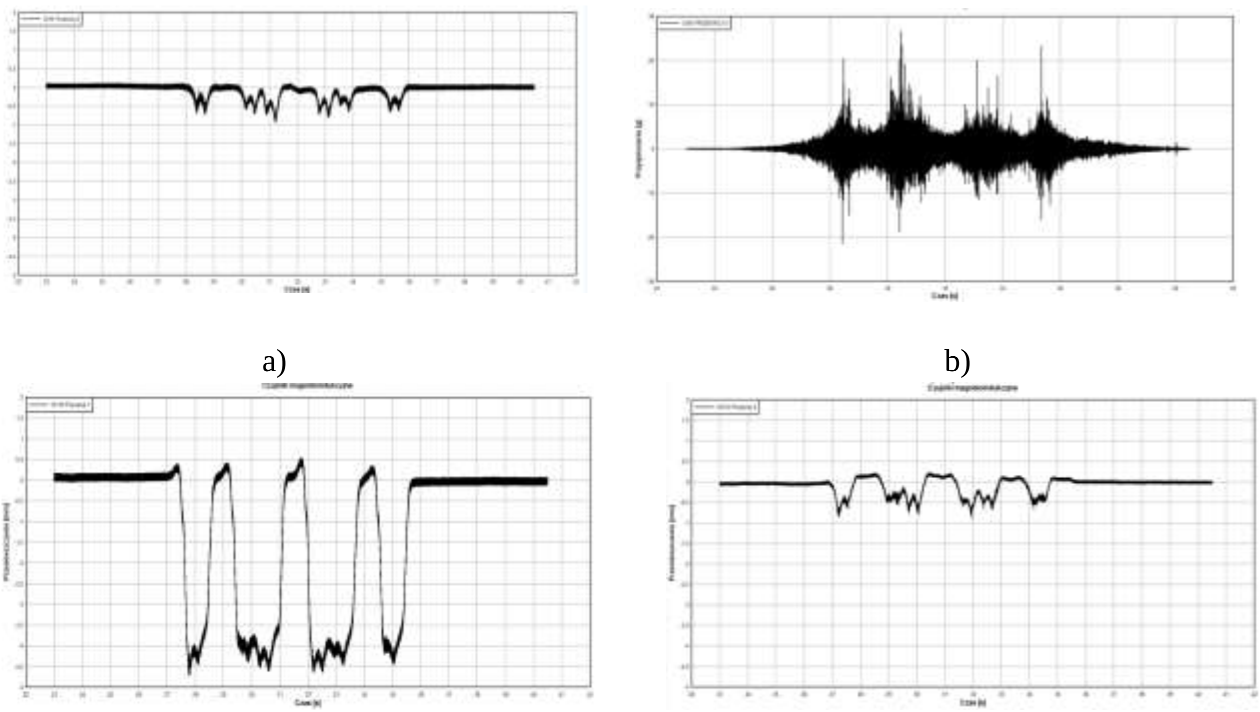
Conducted in the first period measurements were designed to refine the methodology for measuring the acceleration to use the results of the measurement for the calculation of the amplitude of the vertical deflections and wavelength diffraction and finding the correlation between the values of effective accelerations, and deflections of the rail, so in this studies tested different types of sensors at an angle the range and the frequency of the measured vertical accelerations of the rail.

Also tested an alternative method of measuring the vertical deflection of the rail loaded dynamically (contact measurements) using a potentiometric sensor Burster type 8713 and the measurement of the amplitude of the maximum dynamic deflection of the rail using a electronic ruler (Fig. 4).

4. Measurements testing acceleration sensors and sensors of the deflection of dynamic surface

The results of the tests

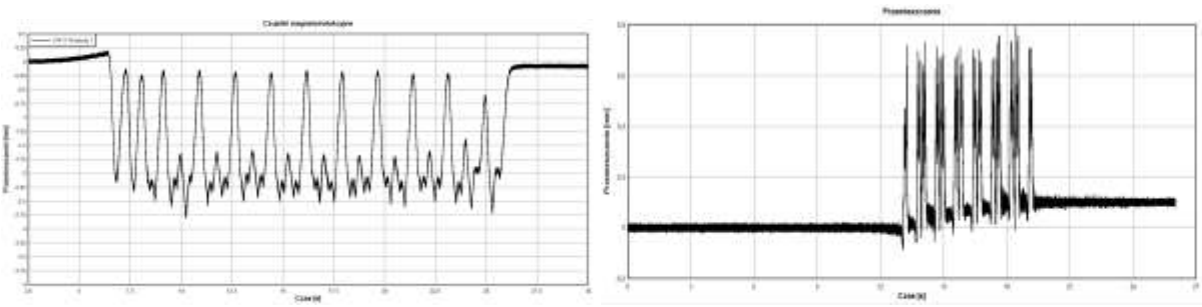
Measurements of dynamic deflections and accelerations of vertical rails (Fig. 3), was carried out during normal movement of rail vehicles (locomotives, trains , personnel units, and freight trains) conducted at different speeds (from 10 km/h to 110km/h). The following pictures show the process of dynamic deflections of the rail measured in sections of research for different dynamic loads.



a) b)

b) d)

5. Surface RHEDA2000, drive unit EN 64 at a speed of 40 km / h:
a) diffraction diagram -intersection P0, b) acceleration diagram-intersection P0,
c) diffraction diagram -intersection P1, d) diffraction diagram -intersection P2



a) b)

6. Ride passenger train:
a) Line No. 91 train speed of 80 km/h, intersection P1
b) railway line No. 8 speed train (Pendolino) of 110 km/h, intersection P1

Methods of measurement for diagnostic purposes The system diagnosis of transitional zones is based on measurement the dynamic deflection rails to the simultaneous measurement of the speed of the train. Based on the deflections and dynamic speed trains are determined interactions of dynamic wheel-rail and strain in the surface (eg. under the bed), and is determined the dynamic stiffness of the surface and the bed. Based on the strain and internal forces in the surface are determined subsidences in those points, unevenness of the rail and track twist- it is possible to diagnose the stirring holes under the beds. Knowing the initial state of the track geometry (eg. The state after renovation) can make a assessment his condition (collection diagnostics), at the current time (current diagnosis) and predict changes in the course of further operation based on of empirical formulas. Measurements of deflection

of dynamic surface for diagnostic purposes is performed while passing train with the spreaded speed and reduced to:
– measuring the dynamic deflection surface in two cross sections normal P0 and P1(look Fig.1) located one in front and one on the object;
– measuring the speed of a passing train during the measurement deflection.
These measurements are carried out with the test set (pic. 7) consisting of displacement sensors, radar speed meter, programming tablet.

7. Set-up for diagnosing transition zones

Measuring element of the amplitude of the deflection of the rail loaded dynamically is ruler electronic on the boom (pic. 8) attached to the foot of the rail and freely based on the measurement tip face measuring pins embedded in rubble.

8. Electronic ruler to measure the deflection of dynamic of the rail

To accomplish diagnostic measurements associated with assessment of the size of dynamic deflection of rails should:
a) determine intersections of the measuring section of the transition zone,
b) in the windows of the measurement intersections embedded in rubble measuring pins (filling the space between particles rubble assembly foam) such that the flat surface of the pin was in the axis of the intersection at a distance from 10 to 20 cm from the foot of the rail, and about 5 cm below of the rail foot, c) to the foot of the rail attach booms with measuring

sensors, d) the tip of sensors lean on a flat surface of pins embedded in rubble, so that the tip of the vertically set sensor was hanging on a distance of about 10 mm e) before starting the measurement switch on the tablet and run the program DIAGTOR and reset the readings on the measuring sensors. f) measuring session includes a series of several measurements. During each measurement perform measurement of the amplitude of the dynamic deflection rail in 4 points and measure the speed of the vehicle passing through the test transition zone.

The measurement of the amplitude of the dynamic deflection rail is implemented by electronic gauge attached to the foot of the rail, by measuring the size of movement of the measuring tip gauge from the top surface of the measuring pin embedded in a pile rubble between two adjacent beds. Measurement of the speed of the vehicle passing through a section of the transition zone, carried out with the instrument Yukon Extend RLS-100. Measurement of the speed of the vehicle perform directing the axis purposeful on the face of the an approaching train or the face of the last carriage of the deflecting train.

Description of changes deformation of the surface and subgrade

Condition of the surface and subgrade within the bridge structure at the time (period) exploitation is defined as:

$S(t_0) = \{K_{naw}(t_0), G_{naw}(t_0), K_{pdt}(t_0), G_{pdt}(t_0)\}$ (1)

Where:

K_{naw}Stiffness of the surface (static and dynamic) G_{naw}Geometry of the surface (unevenness vertical rails in the form of a trough or a ramp and warping)

K_{pdt}Stiffness of the subgrade, G_{pdt}Geometry of the subgrade (subsidences and transverse deformations). Dynamic load depends on the state of parameters of mechanical surfaces and the current state of the geometry of the surface, because the unevenness of rails significantly impact on the dynamic load. At a given period of exploitation t_0 is expressed as:

$P(t_0) = \{S(t_0), Q(t_0), V(t_0)\}$ (2)

Where:

$S(t_0)$ Is defined by the formula (1), $Q(t_0)$ Static axle loads of rolling stock $V(t_0)$ Is exploitation speed in a given period t_0. The evolution of the state of the surface and subgrade is defined as:

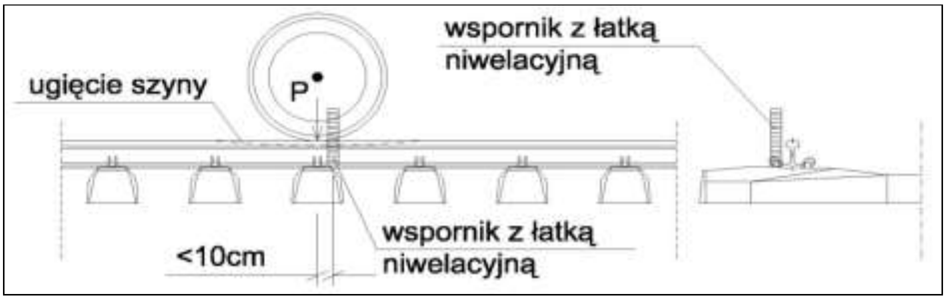
$E = S(t)$ (3)

and dynamic load at the given time exploitation is defined as.

Geometric measures of degradation are:

a) unevenness rails in the form of so called "Trough" or "ramp" and track warping, b) settlement of the subgrade.

Measurement of geometric deformation under load is carried out with the use of eg. precise leveling. Are needed leveling patches mounted on the foot rails - Fig. 9.



9. Schematic layout of leveling patches on the foot rails

As a result of measurements is obtained the form of deformations in transition zone on the basis of which is calculated:

• gradients of vertical uneveness for each rail as:

$$g_{i,i-1}^{lewa} = \frac{\left| w_{i\ \text{lewa}}^{P} - w_{i-1\ \text{lewa}}^{P} \right|}{\Delta_{i,i-1}} \; [{}^{0}/_{00}] \text{ oraz } g_{i,i-1}^{prawa} = \frac{\left| w_{i\ \text{prawa}}^{P} - w_{i-1\ \text{prawa}}^{P} \right|}{\Delta_{i,i-1}} \; [{}^{0}/_{00}] \quad (4)$$

Where: $w_i^P[mm]$ - the height of the rail head under load in intersection $i-tym$ for left and right rail, $w_{i-1}^P[mm]$ - the height of the rail head under load in intersection $i-1$ for left and right rail,for $i=1,2,3,4$, $\Delta_{i,i-1}\,[m]$ - distance between points.

• tarck warping under static load in case 4 pairs of points based on 5 m, defined as:

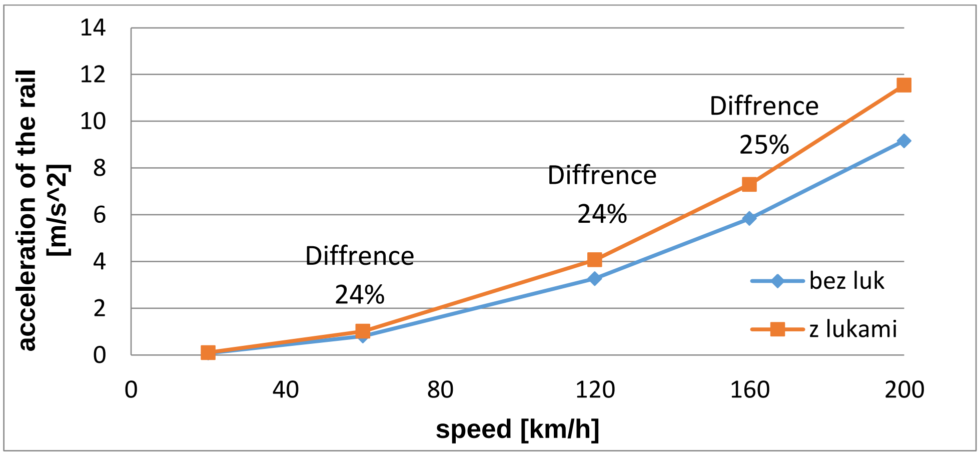
$$w_{i,i-1} = \frac{\left(w_{i\ lewa}^{P} - w_{i\ prawa}^{P}\right) - \left(w_{i-1\ lewa}^{P} - w_{i-1\ prawa}^{P}\right)}{b} \; [{}^{0}/_{00}] \quad (5)$$

Where:

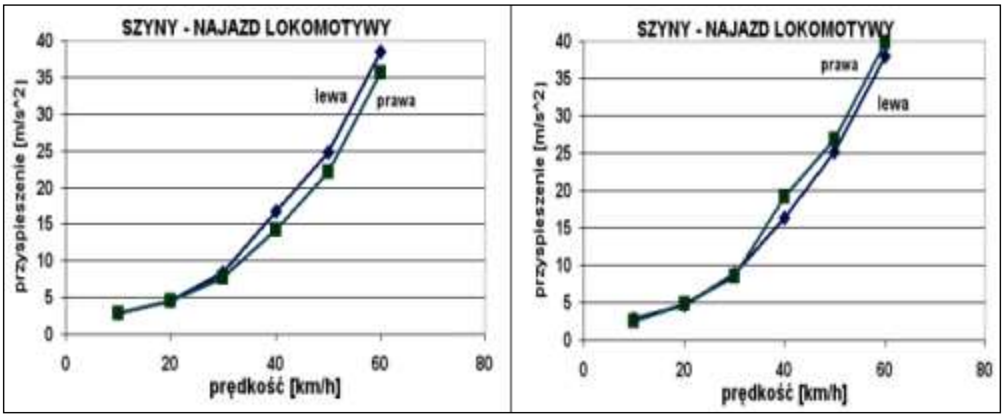
$i=1,2,3$ and $w_{0\ lewa}^{P}$[mm] - the height the left rail head measured under load on the engineering building (relatively on the surface of another type) $w_{i\ lewa}^{P}$[mm] -the height of the rail head on the left in the i -tym intersection of the track, $w_{0\ prawa}^{P}$[mm] – the height of the right rail head measured under load on the engineering building(relatively on the surface of another type) $w_{i\ prawa}^{P}$[mm] –the height of the right rail head in i-tym intersection of the track b [m] – measuring base amount to 5m.

In connection in the creation of uneveness the dynamic load is rising,which causes the acceleration of settlement pavement and subgrade. Measures of degradation of the surface are mechanically:

a) reducing the stiffness of the surface-track bed - a significant reduction in stiffness is observed when the deflection under axes of rolling stock around. 200kN reach values higher than 3.0mm, b) increasing the heterogeneity of the surface - the stiffness (relatively deflection dynamic) in the individual intersections are different from each other by more than 30%. c) the effective values of the accelerations in the individual intersections are different from each other by more than 20%.



10. calculated dependence the maximum acceleration of the rail of the vehicle speed. The point x = 17m,v=200 km/h, c = 100 kNs/m/m, U = 40 MPa, P = 3x100KN



11. Measured dependence accelerations effective rails on the speed of the locomotive [9]

In the research phase heterogeneity of the surface and substructure were taken into account in the four intersections of measurement.

• the relative differences between the maximum deflection (dynamic)of the rail along a longitudinal axis of the track.

• relative differences acceleration of vertical rails (the value of effective acceleration). In connection with heterogeneities appears locally increased responses to beds (which are associated with increased strain on ballast) and increased vibration imparted to the beds on ballast and on the track bed in the transition zone.

Increased influences in given intersection will cause increased settling in this intersection. Additional deflection of the rail, which arises as a result of mechanical heterogeneity is defined of a intersection located at a distance of about 2-3 meters from a connecting location of the surface or by a bridge structure (for example a point P_1, other similarly). This deflection will be determined as:

$w_{P_1} = w_{szt} + w_m + w_c + w_{wiezy}$ (6)

Where:

w_{szt} - dynamic deflection of the rail in cause of change the stiffness of the surface, w_m - dynamic deflection of the rail in cause of change of the surface mass, w_c - dynamic deflection of the rail in cause of change the suppression of the surface, w_{wiezy} - dynamic deflection of the rail as a result of a change fix the rail to the substrate (eg. changing the type of fastenings, changing the type of beds or changing the type of of surface on unballast). The reasons for the increased deflection given above will be absent at the same time, because each object has its own specifics. Average strain under the bed as a result of the deflection defined by the formula (5) is defined as follows:

$$p = \frac{U \cdot w_{P_1} \cdot b}{F_{ps}} \quad (7)$$

Where:

p - The average strain under the bed, U - the coefficient of the rail substrate at a given point, b - spacing beds, F_{ps} - the surface of the bed corresponding to the pressure of one rail. Deflection referred to above will be used to calculate settlements in the model adopted in the system DIAGTOR. It is based on the Munich model [6] and the model Kassel [8]. **In the Munich model** adopted three values to assess the settlement of ballast [mm] (S_{opt} - positive variant, S_{pes} - pesimistic variant, S_{sred} - medium variant):

$$S_{opt} = 1.57 \cdot p \cdot \Delta N + 3.04 \cdot p^{1.21} \ln N$$

$$S_{pes} = 2.33 \cdot p \cdot \Delta N + 15.20 \cdot p^{1.21} \ln N \quad (8)$$

$$S_{sred} = 1.89 \cdot p \cdot \Delta N + 5.15 \cdot p^{1.21} \ln N$$

Where:

p - the strain under the bed,

ΔN - the number of axes in the first stage of settlement,

N - the numer of axes passing throught given section (calculated based on the number of trains, which are monitoring).

In Kassel model adopted the subgrade settlement as

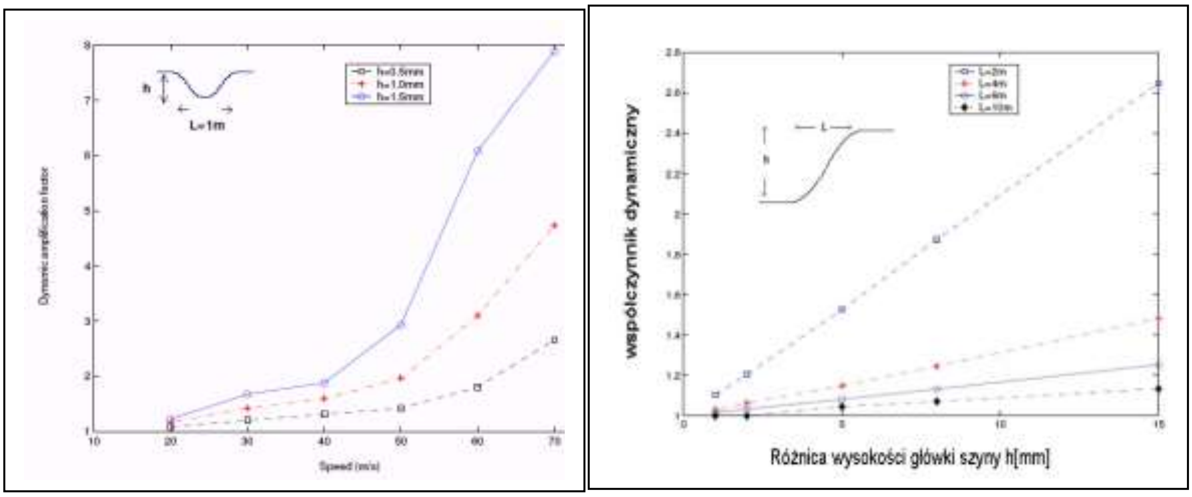
$$s_N = s_1 + \frac{c \cdot \ln N}{(1 - 0.047 \cdot \ln N)} (\varphi_{dyn} \cdot P)^{0.6} \cdot EI_{naw}^{-0.2} \left(\frac{0.5 \cdot h}{1 + 0.34 \cdot h} \right) \cdot f(D) \text{ [mm]} \quad (9)$$

$$s_1 = \frac{\sigma_{pdt} \cdot \varphi_{dyn} \cdot b_p}{E_{v2}} f_s \quad \text{[mm]} \quad (10)$$

Where:

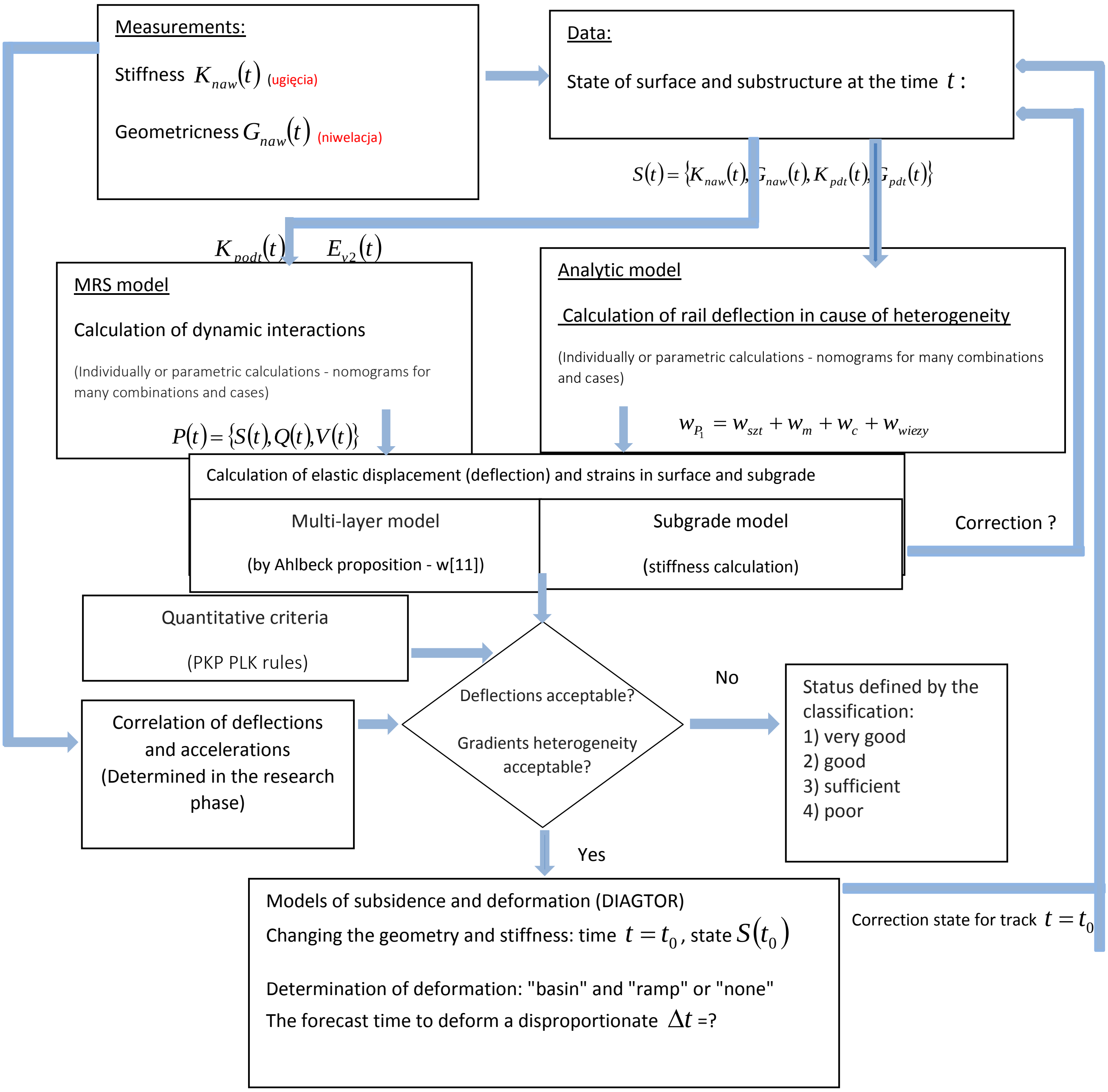
s_1 - settlement after passing the first axis, c - coefficient depending on the structure of the transition zone(the shape of a technical wedge), $N = Q_{brutto}/20$ - axles, which depends on the load of the cumulative gross Q_{brutto} [t] and the adopted average axle load of 20 tons, P - the dynamic pressure of the axis according to the adopted dynamic coefficient - eg. the formula (17) EI_{naw} - the stiffness of the carrier surface system to bending, h - the height of a technical wedge, $f(D)$ - the function of the width of a technical wedge, for $D \geq 1$, $f(D) = 1$ [4], σ_{pdt} - the average pressure on the track bed, φ_{dyn} - dynamic coefficient, b_p - the width of interaction belt of the surface on track bed, f_s - coefficient taking into account the relative settlement the surface and substructure (in [6] taken $f_s = 0.57$), E_{v2} - modulus of subgrade deformation

Dynamic coefficient (a function of the dynamic load depending on the speed) is determined from a suitable nomogram after completing the parameter calculation for vehicles existing railway on lines PKP PLK and for different sizes of "basin" and "ramp", or in the absence of the existing deformation, knowing the characteristics of the track -eg. attaching [1].



12. Exemplary dependence of dynamic coefficient (labeled as φ_{dyn}) of train speed and size of unevenness in a "ramp" or "basin" [3]

Model degradation of surface and substructure consists of the following components: 1) a model for dynamic calculations MRS (in the Finite Difference Method) which is used to check nomograms for determining the dynamic coefficient of deformation as a "basin" and "ramp" and to verification the deflection and acceleration of the rail, 2) the model of subgrade to determine the stiffness of the surface and substructure based on structural details of transition zone and bridges, 3) model of subsidence in two versions: Munich and Kassel, they are subject to calibration on the given object (ie. are determined coefficients presents in the equation of subsidence) 4) based on the determined subsidence in accordance with above formulas will be defined a new form of deformation ("basin" and "ramp" or "no deformation") and based on nomograms will be calculated a new dynamic coefficient, which is used again to estimate the settlement 5) after these point again will be calculated settlement and - in this way - in the feedback - will be determined evolution of the state of the track $E = S(t)$ - Fig. 13.

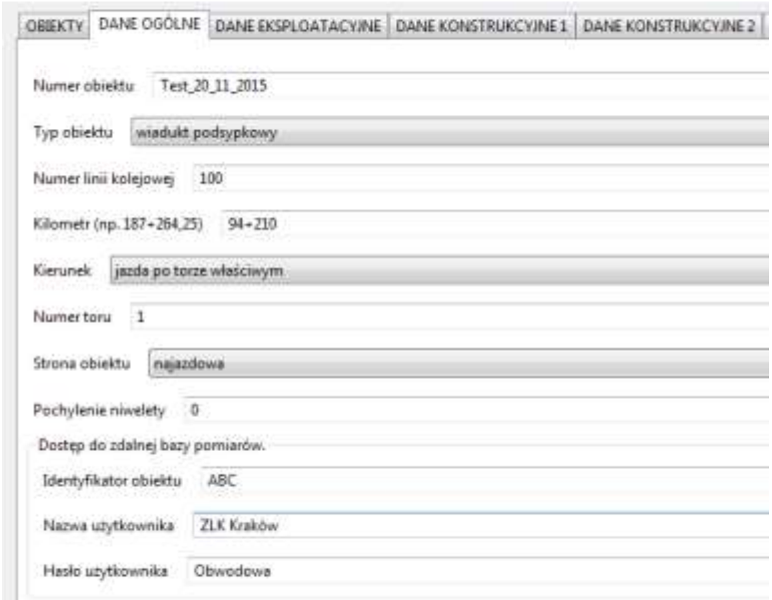


13. Model of degradation the surface and substructure

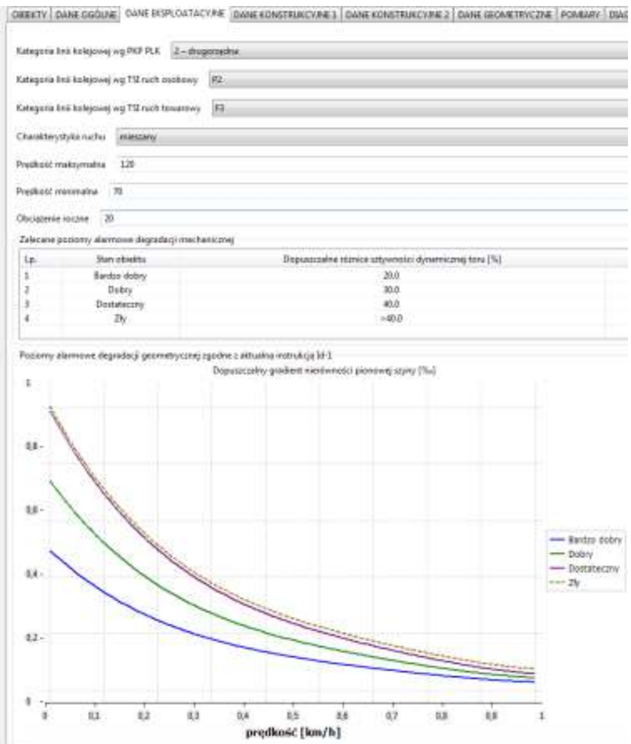
Acceptable values of heterogeneity are determined on the basis of:
• applicable regulations (Regulation MTiGM, 1998, Dz. U. 151) [14], according to which the difference in stiffness between the joined surfaces should not exceed 30% (condition abolished by the Decree of the MIR 2014. (Dz. U. 867) [15] . • regulations Id-1 [13]
• precise dynamic analysis with the use a computer program, which implements the model MRS,
• taking into account the process of settlement and deformation,
• with the use of deflection and acceleration data received from the measurements.

The program DIAGTOR and examples of calculations

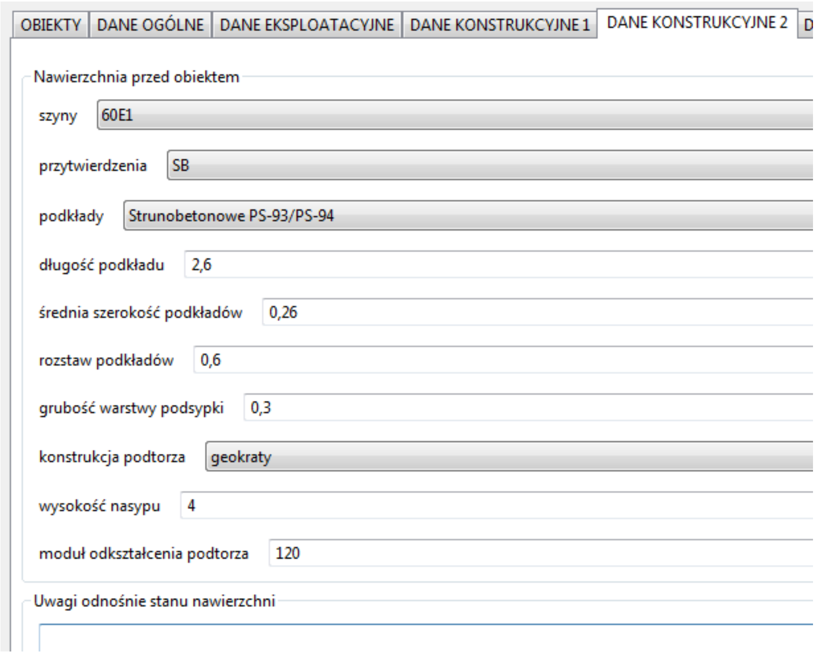
The program DIAGTOR is also a database of bridge structures (containing elements such as line number, km, track number, type of object, etc.) and is a tool to assist in the diagnosis of bridges and transition zones. Examples of screen shots shown in Figs14,15,16,17. Examples of diagnosing the state of the surface and substructure shown in Fig.18, while the predicted deformation during exploitation (ie. Time to take maintenance treatments) is shown in Fig.19.



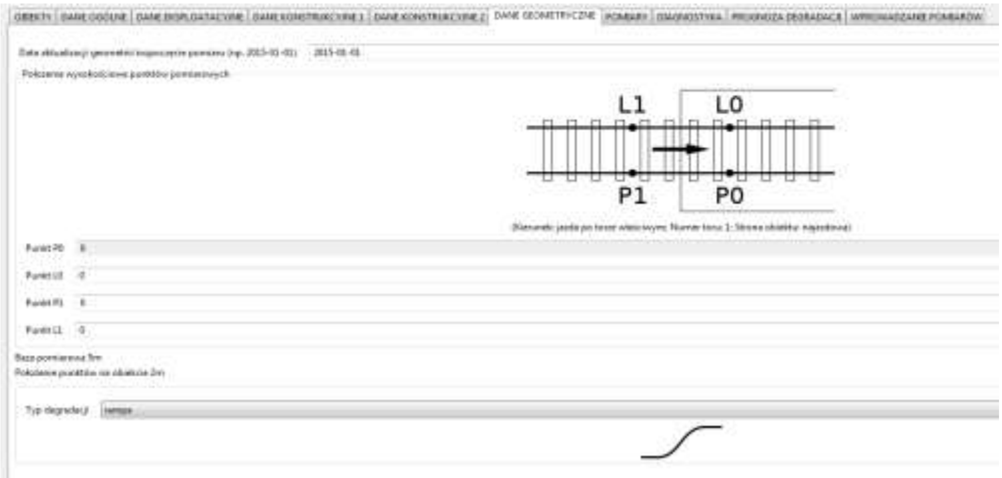
14. Window with details about the general object and the transition zone



15. Window with operational details and acceptable geometric deformations by Id-1

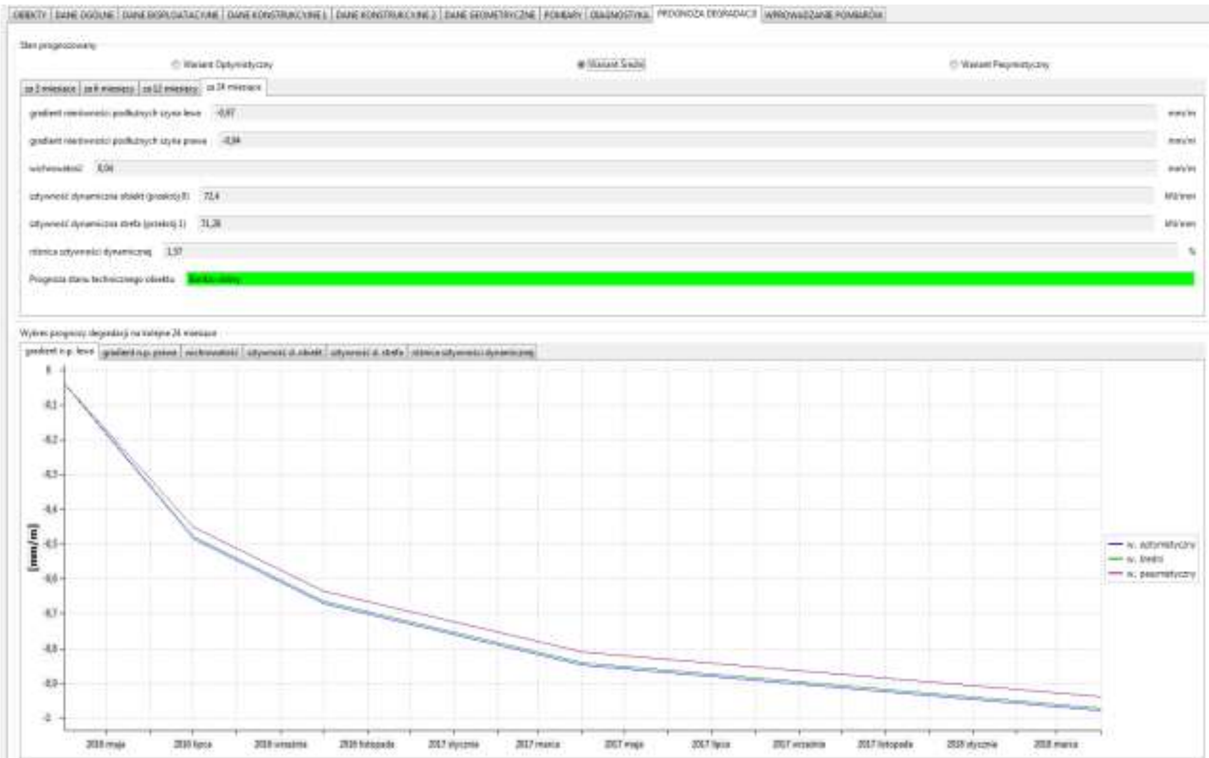


16. Window with construction details of a railway



17. Window with geometric details in transition zone

18. Window with exemplary results of measurements



19. Window with the forecast of geometric degradation (deformation) and mechanical degradation (dynamic stiffness)

Summary

The paper presents the results of the research phase and implementation support system diagnostics bridges DIAGTOR, which was developed in cooperation with the Technical University of Cracow and companies NeoStrain sp. z o.o in Krakow in the last three years. This is on the one hand database of bridges, and on the other side the measuring system with the software used for the current diagnosis of surface and subgrade, and to predict the rise speed of deformation of a railway during the exploitation.

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