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Testing and evaluation of railway pavement construction stiffness based on a new testing method

Abstract: This project is based on search for the method of measuring and evaluation the railway pavement construction. The authors note some analogies between road and railway, both in terms of construction and the dynamic load. Already in the 1960s a method for measuring road pavement deflections under dynamic load was developed using Falling Weight Deflectometer. During years the device and the results analysis method were developed and currently commonly used. The FWD device was adapted for use on railway pavement construction. The first tests were done in the field and have brought reliable results. The device and measuring and pavement evaluation methods are under development.

Keywords: Railway pavement; Measurements; Pavement diagnostics; FWD; Stiffness

Introduction

The surface of a railway road as a linear object is a difficult structure in terms of maintaining uniform stiffness/elasticity. Mainly in the areas of engineering objects, where the effect of transition zones is particularly visible [4]. On the other hand, continuous dynamic influences from moving vehicles change the rigidity of the pavement structure in time, thus lowering its load capacity. This is where the question arises: what and how to test the stiffness of the surface.

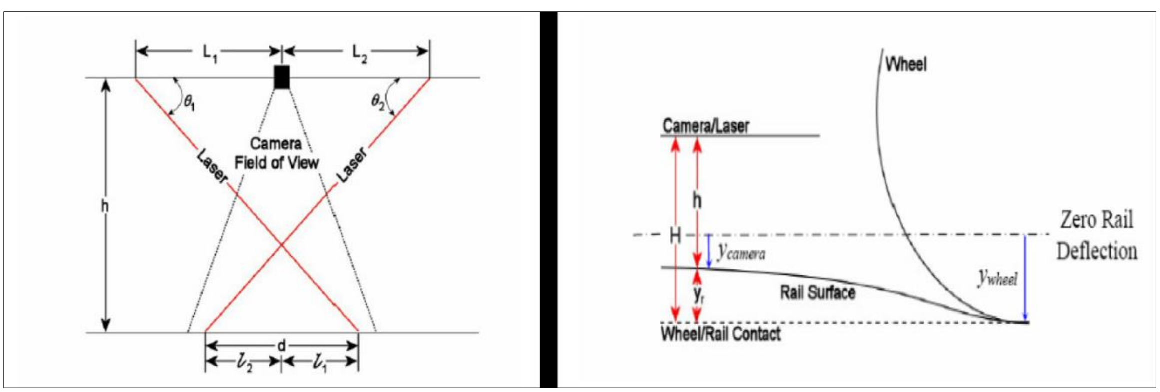
Knowledge about the condition of the track is extremely important in the proper assessment and planning of reinforcements and renovations. Unfortunately, increased rail traffic limits, and in some cases, prevents the track from being taken longer. This is caused by the necessity to temporarily close the section and shut off from traffic for the duration of tests and measurements. Therefore, the search for automated, non-destructive and fast-tracking measuring methods becomes one of the objectives. The subject of consideration is the development of such a method of research and interpretation, which will bring us closer to the answers to, among others, what is the load-bearing capacity of the surface, its stiffness and, consequently, durability. At the same time, the measurement should take place in conditions similar to the work conditions of the surface. As it turns out, a similar solution has been used in road engineering since the 1960s. In this way, the idea of adapting to railway surfaces was born.

Current methods for assessing the technical condition of the track in Poland

The obligation to properly maintain the railway infrastructure rests with the Owner or the Manager. This is due in particular to the provisions of the construction law. What tests and measurements should be carried out to properly diagnose the state of the object, which is the surface? In the case of motorways, the methods of research and interpretation of the results were elaborated in detail by the General Directorate for National Roads and Motorways as part of the DSN [2] document. This study is also based on the managers of other roads. In the case of railway surface, we are talking about the Technical Conditions and Instructions from the "Id" series introduced for use through the orders of the Management Board of PKP Polskie Linie Kolejowe S.A. The condition of the track is assessed on the basis of the measurement [7]: track gauge, track rail height differences, track twist, horizontal and vertical rail tracts, synthetic track gauge "J" values and additional measurements as track position in the plane, values of rail course shifts and the clearance values on the contacts. The individual elements of the surface are also subjected to diagnostics. The rails are analyzed, in particular, visually for external defects and damages, railhead wears measurement, defectoscopy, measurements of rolling surface wear, determination of the number of cracks. In the case of foundations, we mainly talk about the visual detection of defects and the measurement of the spacing and mowing size. The bedding is analyzed based on its thickness determination, the measurement of the width of the prism, the assessment of the filling of the windows between the undergrowths, the assessment of weed infestation, compaction status, an occurrence of traps and the degree of contamination of the ballast. In addition, couplings are assessed, and a non-contact track, turnouts, railway crossings and pedestrian crossings are separately diagnosed. The load-bearing capacity, a durability of the surface and its damping properties are not assessed as part of periodic inspections or are determined indirectly, e.g. by deterioration of track geometry parameters or other visual defects of the surface.

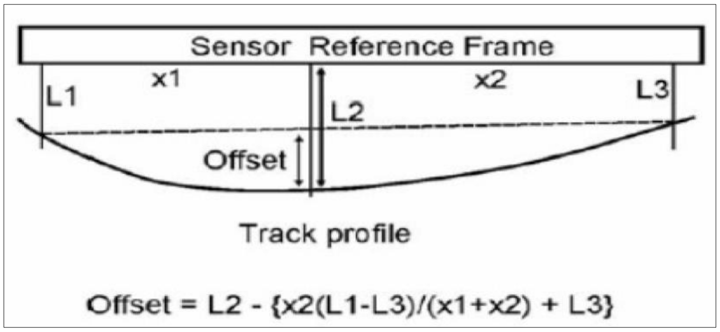
Current methods for assessing track stiffness

There are currently different methods for measuring this size. Works [3, 9] describe the measurement of rail deflection based on data from cameras and lasers whose radius falls on a rail at a known angle. Depending on the size of the rail deflection, the distance "d" between the spots of the beams, is variable and recorded continuously by the camera while driving.



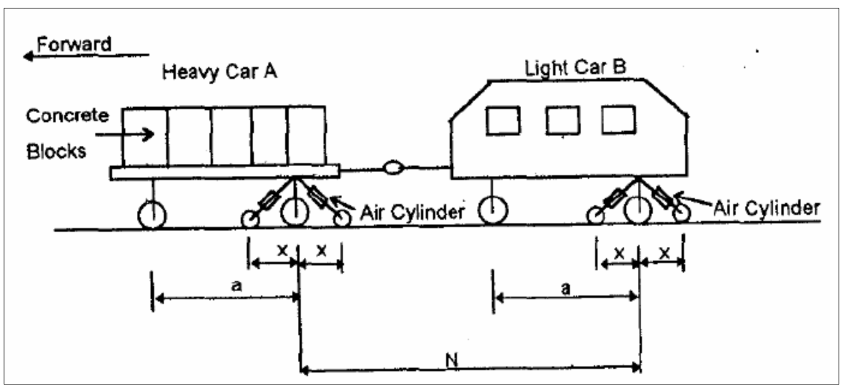
1. Measurement of rail deflection based on the camera and the laser system [9]

Measuring lasers the distance from the emitter to the measured element can also be used in a different way. In work [5], a wagon equipped with an additional axle placed in the middle of the wagon length is used, which is lowered and lifted by a hydraulic cylinder causing a static load of 4 to 267kN. Based on the difference in deflections caused by the maximum and minimum pressure, the track rigidity is determined. The deflection is determined by the arrangement of three lasers placed on the reference frame.



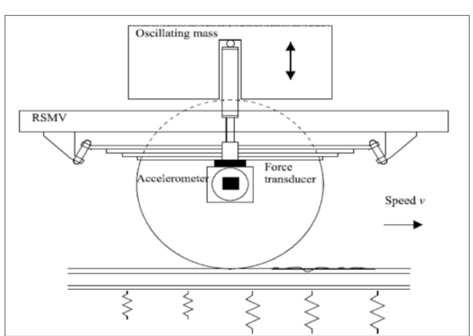
2. Measurement of rail deflection based on the laser system at a given static load [5]

An interesting method is described in [10] (China). Here the rail stiffness is determined based on the difference in rail deflections under the light and heavy wagon.



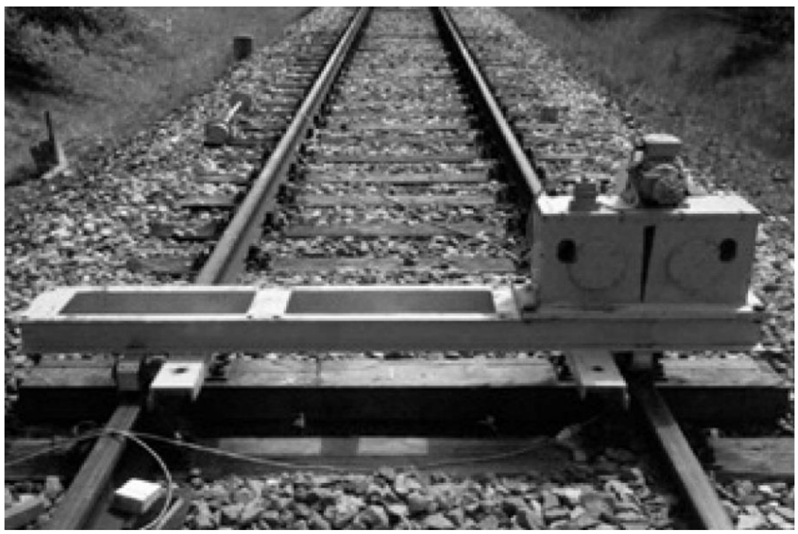
3. Measurement of rail deflection using two wagons [10]

Another method of measurement is presented in [8]. In this case, the stiffness is determined by measuring the accelerations of the wagon axle, taking into account the pressure force, additionally equipped with an oscillating mass system.



4. Assessment of track and ground rigidity from dynamic quantities under the vertical oscillating mass [8]

A similar measurement method was used as part of the dynamic path study [6]. However, in this case, a small mass inducing high frequency vibrations was used.



5. A rotational inertial rotary inductor with boom cylinders [6]

The new concept

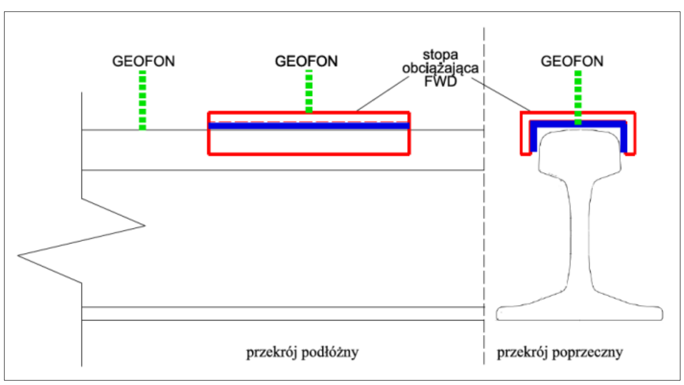
The assessment of the stiffness/elasticity of the road surface is mainly carried out by two methods: measurement of surface deflections by the Benkelman beam method and using the FWD dynamic fall deflectometer. The device is widely used in road engineering to assess the load-bearing capacity and durability of a road surface. The first application of the FWD for load capacity determination was applied in 1964 by two students of the Danish Technical University. The main idea was to introduce a device that generates a dynamic load that simulates the actual movement of vehicles. In 1965, engineer J. B. Villadsen founded the A / S PHONIX company, which constructed the first FWD model transported on a truck. Another model was FWD on the trailer.

A/S PHONIX (currently Sweco Pavement Consultants) became the first to commercialize FWD. In the years 1968-1969, 65 FWD machines were produced and sold. In 1979 Dynatest A/S started production of FWD and discontinued cooperation with A / S PHONIX, but until then FWD was "know-how" of A/S PHONIX and Dynatest A/ S. However, the beginning was in DTU in cooperation with A / S PHONIX in 1965. and until some of the FWD team members created Dynatest A/ S. In 1979, Dynatest introduced the first FWD, and in 1981 A/S PHONIX introduced FWD with one load plate and 6 geophones. Currently, there are many manufacturers of devices with different features and equipment, but with similar performance, enabling the use of loads up to 350kN.

6. FWD dynamic deflection meter from SWECO - Denmark A/S

Noting the needs of the railway market and using the current experience in road engineering, the concept of adaptation of a road FWD dynamic deflectometer to railway solutions and conducting field tests appeared. The project is of great importance for the development of railway (rail) surface models, with particular emphasis on dynamic stiffness and non-linearity of the surface response to extortion. The device's properties allow for creating a surface load, which will simulate a vehicle with different speed and pressure moving on the rail. In addition, the device has the ability to register the deflection value thanks to geophones, placed at different distances along the length of the rail. In this way, we obtain the rail deflection bowl both at the point of application of the load and at a certain distance. In addition, thanks to the "Time history" function, the device registers an increase in the value of force and deflection in time. In this way, the obtained results can be more accurately analyzed.

The first test measurements were preceded by the adaptation of the deflectometer to railway solutions. For this purpose, design changes of the device were necessary. The most important was the redesign of the foot of the device so that the load would be applied directly to the rail. The schematic solution is shown in Figure **7**.



7. Scheme of the loading foot

Test measurements

Thanks to close cooperation with the Danish manufacturer of this type of devices, it was possible to develop a prototype of the device for railway solutions. The first tests done in Denmark have brought promising results.

8. FWD measuring device during measurements

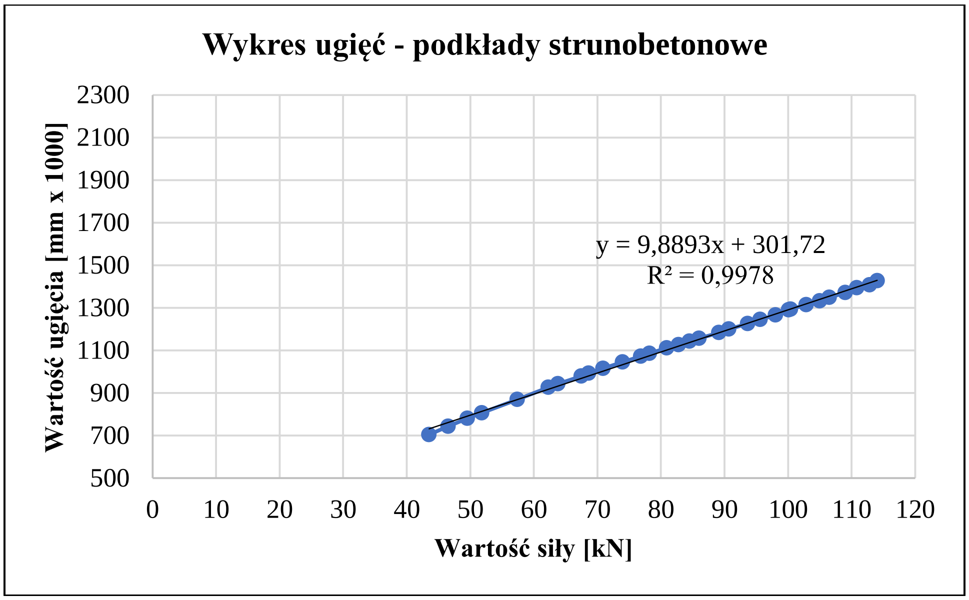
9. Arrangement of sensors (geophones) for measuring deflections

Thanks to the experience gained, some adjustments were made to the design of the device. The next step was to perform test measurements in Poland.

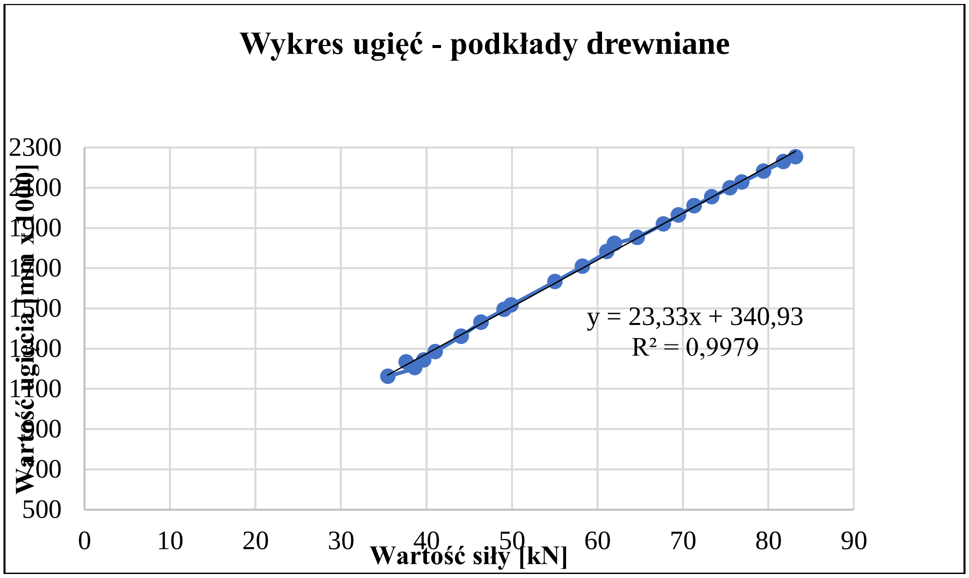
Obtained results

Measurements were made on the railway tracks of one of the stations in Cracow. There were selected two locations for the surface with wooden and prestressed sleepers.

Figures **10** and **11** show the values of the deflection depending on the applied force. As can be seen, the increase in deflection is directly proportional to the increase in strength. In the case of paving with wooden sleepers, with a force of about 85 kN a deflection of more than 2.2 mm was recorded, while for prestressed concrete sleepers with the same force, the value of deflection is almost by half lower. This is understandable due to the higher stiffness of the string than the wood. In addition, a linear relationship between the value of force and deflection is visible, which allows determining the rigidity of the surface.

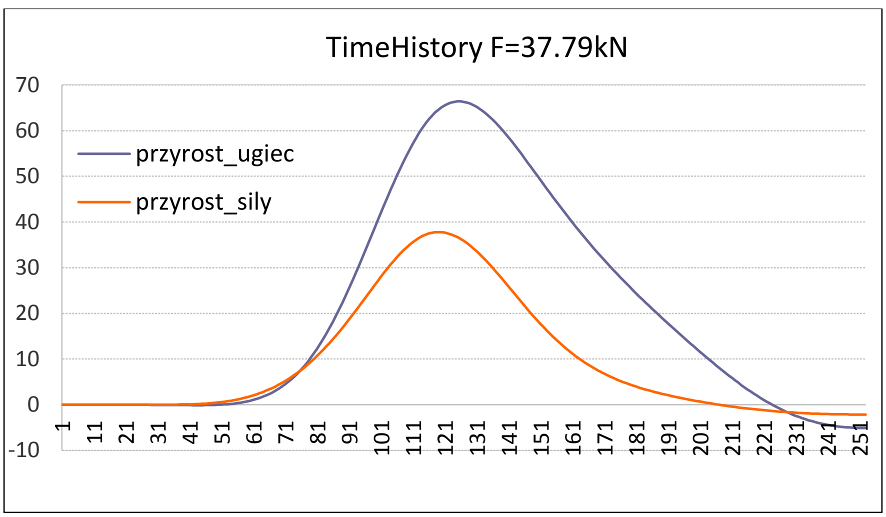


10. Diagram of rail deflections depending on the value of applied force - surface with wooden undercoat. The stiffness of the pavement is 97.63 kN / mm

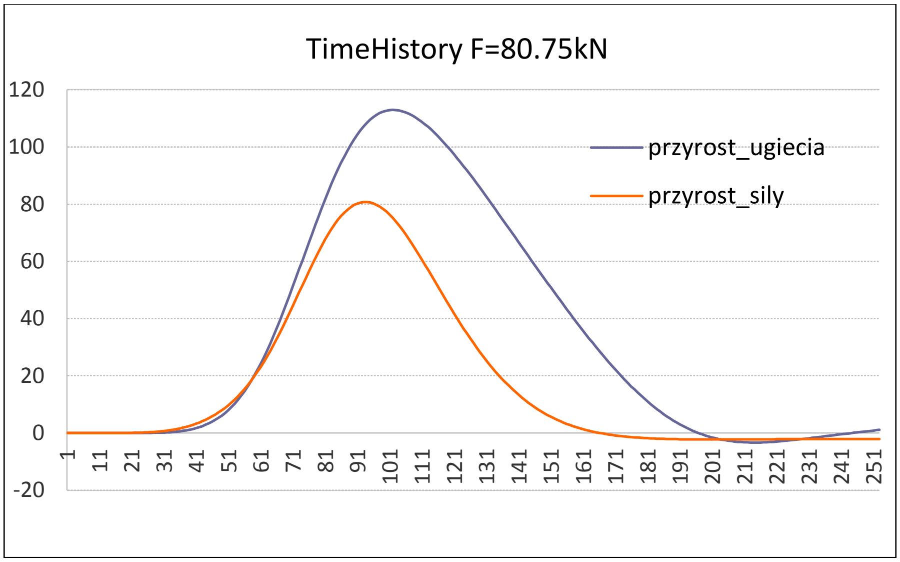


11. Diagram of rail deflections depending on the value of applied force - surface with prestressed concrete foundation. The stiffness of the surface is 43.7 kN / mm

Figures **12** and **13**, thanks to the „Time history" device function, show values of forces and deflections in time for two maximum values of forces: 37,79 kN and 80,75 kN.

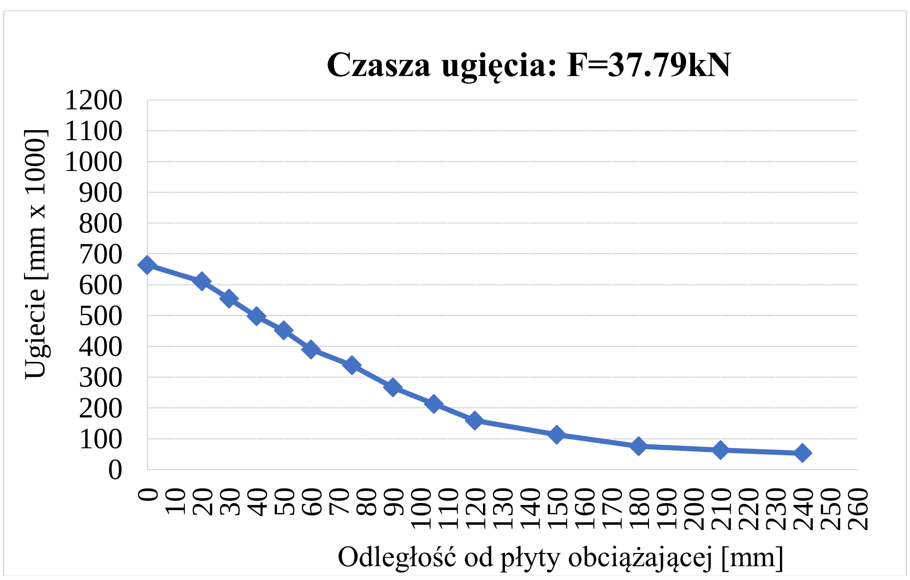


12. Diagram of load growth and deflection in time for the force of 37.79kN

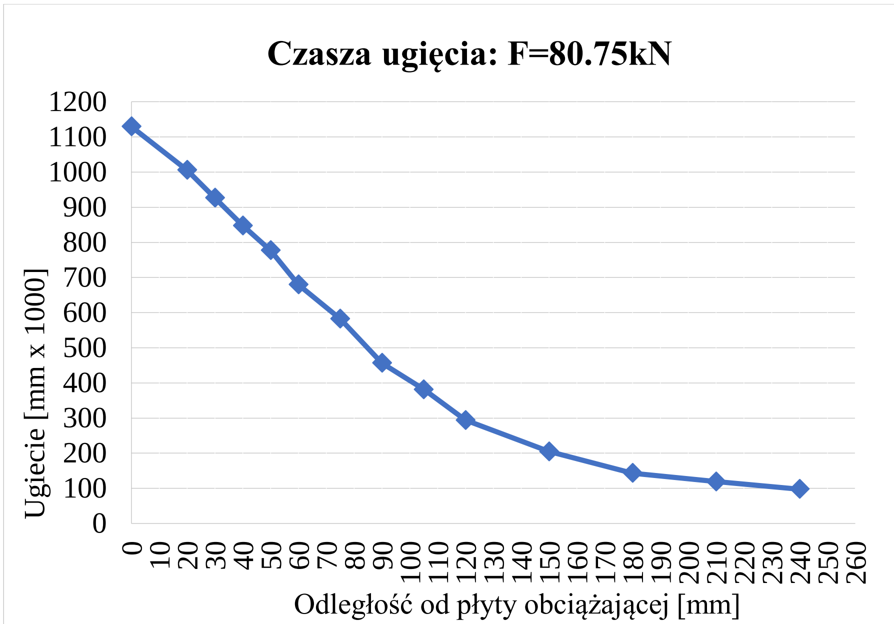


13. Diagram of load growth and deflection in time for a force of 80.75kN

The FWD device has a minimum of 9 displacement sensors as a standard. In our case, 14 geophones were used. In this way, we obtain information about how the rail bends over a certain distance, and not only directly under the load, thus obtaining a so-called deflection bowl. Such data obtained in the measurements performed on the road surface are used to assess the bearing capacity of the ground and the surface as a whole. For this purpose, the so-called "back calculation" method is used. It consists in simulating in the computer program deflections under load and iterative method, the program selects the stiffness/elasticity moduli of the pavement structure layers until the value of deflections equal or close to those obtained during the measurement.



14. Deflection bowl (deflection values) measured on 14 sensors (geophones) for a force of 37.79kN



15. Deflection bowl (deflection values) measured on 14 sensors (geophones) for a force of 80.75kN

Summary
Test measurements carried out so far confirm that FWD can also be used for measurements on a rail surface. Obtained results are realistic, both the work of sensors and the registration of values proceed without major disturbances. Certain analyzes of the results obtained have already been carried out, however, they require further field tests, in particular on different types of surface. It is necessary to obtain repeatability of results and to obtain a numerical/mathematical model of the surface that maps the obtained results of field measurements.

Further work on the device and the measurement/interpretation method are being carried out, but today we can say that the obtained results are promising.

Source materials

[1] Aspekty modelowania numerycznego oddziaływania pojazdnawierzchnia-

[2] Diagnostyka stanu nawierzchni i jej elementów, Załącznik do Zarządzenia nr 34 Generalnego Dyrektora Dróg Krajowych i Autostrad z dnia 30.04.2015 roku

[3] FRA report RR04-03, A Preliminary Design of a System to Measure Vertical Track Modulus from a Moving Railcar, January 2004, http://www.fra.dot.gov/downloads/-Research/-rr0403.pdf

[4] J. Sołkowski, D. Kudła, Wykonawstwo stref przejściowych do obiektów mostowych i

[5] Li D., R. Thompson, S. Kalay, Development of Continuous Lateral and Vertical Track Stiffness Measurement Techniques, Proceedings Railway Engineering, London 2002.

[6] M. Krużyński, E. Kwiatkowska, J. Zwolski, Badania dynamiczne toru kolejowego, Przegląd komunikacyjny 11/2012.

[7] Podtorze, Zeszyty Naukowo-Techniczne Stowarzyszenia Inżynierów i Techników Komunikacji w Krakowie. Seria: Materiały Konferencyjne; Drogi Kolejowe 2013 (23-25.10.2013) ; Krynica Zdrój, Polska

[8] Sussmann T.R. „Track Geometry and Deflection from Unsprung Mass Acceleration Data” Proceedings from Railway Engineering Conference, London 2007
[9] US Department of Transportation (Shane Farritor) „Real-time measurement of truck modulus from a moving car” DOT/FRA/ORD-05/2005
[10] Wangqing, Z. Geming, Z. Kaiming, L. Lin, Development of Inspection Car from Measuring Railway Track Elasticity, Proceedings from 6th International Heavy Haul Conference, Cape Town 1997
[11] Warunki techniczne utrzymania nawierzchni na liniach kolejowych Id-1 (D-1), załącznik do zarządzenia nr 14/2008 Zarządu PKP Polskie Linie Kolejowe s.a. z dnia 18 maja 2005r.