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Research paper

Introducing a new method for assessing short railway bridge conditions using vehicle onboard systems

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Abstract: Railway bridges are critical in the transportation network and vital to the profitability of the industry. Maintaining the bridge condition to safety standards is a priority for all railroad owners. However, the accumulation of damage that is not visible during regular inspections may cause catastrophic failures. The recent railroad bridge collapse over the Yellowstone River caused a train carrying toxic materials to fall into the river. The question arises "Could we predict and prevent this bridge collapse?". The railroad bridge's dynamic response under the train traversed can enable the assessment of structural conditions and may reveal structural issues that are not visible during the visual inspection itself. The onboard vehicle-based system is a novel concept that allows an autonomous evaluation of the existing railway bridge structures and substructures. An onboard system provides observations for multiple bridges, as opposed to a structural health monitoring system that is capable of monitoring only a single bridge. In 2016 the potential use of existing onboard systems to detect weak bridge stringers and changes in pier elevations was proved by a set of tests performed in the Transportation Technology Center (TTC) in Colorado, USA under controlled conditions. Recently, the research expanded to evaluate bridges in service. Several short, open-deck, railway bridges on the Polish Railway were examined using track geometry cars. The data were analyzed to compare and observe the changes in bridge response. This paper provides a summary of the findings of the analyzed data and future steps for research implementation.

Keywords: condition of bridge approaches, dynamic bridge response, field test, onboard vehicle system, railway bridges, vertical displacements

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1. Introduction

A bridge in service is subjected to varying environmental and operational conditions such as traffic, temperature, humidity, wind, and solar radiation. These external conditions cause the deformation of the structure. Elements in tension elongate and bars in compression shorten, beams bend, and cable stretch. As deformation occurs, the structure changes shape and the points of the structure displace. To ensure the safe operation of bridges usually, the visual inspection is performed along with structural health monitoring (SHM) which may include strain, vibrations, and displacement measurements. Many case studies are performed to evaluate bridge response under dynamic loading using traditional measurements technologies [1, 2].

Deflections are one of the most important physical quantities characterizing the change of a bridge that provides information about the global behavior of the structure while the other measurements are usually local. In addition, according to a survey conducted in 2010, displacement measurement under dynamic loading provides objective information about the performance of the bridges and it should be a priority for the assessment of railroad bridges [3].

The traditional method for bridge displacement measurement utilizes contact sensors such as linear variable differential transducers (LVDTs) and accelerometers installed on the structure [4, 5]. Most of these sensors require access to measurement locations under the bridge and the installation of these transducers is expensive, time-consuming, and very often requires special equipment (Fig. 1). A more recent method is to use Global Positioning System (GPS) contact sensors for displacement measurements [6]. However, the reading from a GPS unit is not accurate enough for detecting smaller displacements. To enhance accuracy some researchers fused GPS data along with data from accelerometers and inertial measurement units (IMU) [7]. Lately, a measuring system, that uses inertial sensors: inclinometers, and accelerometers, was developed and implemented to assess the structural condition of railway bridges and viaducts under dynamic loading [8]. The system does not need any referential points. However, all contact sensor methods need manual installation of their systems and regular monitoring. Therefore, it requires the interruption of traffic during the instrumentation setup.

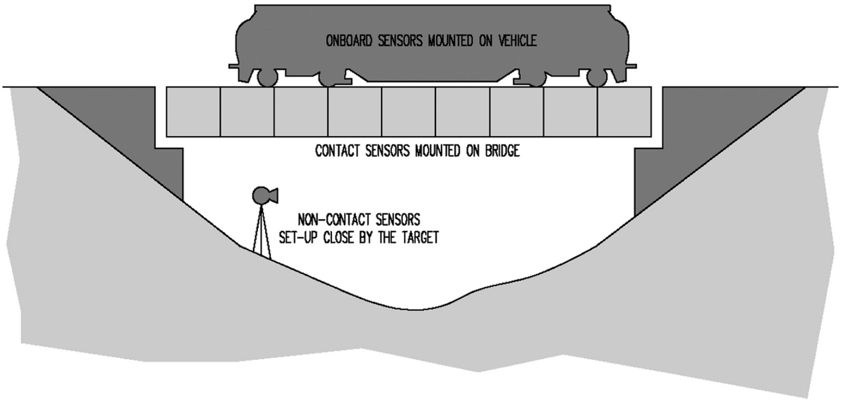

Fig. 1. Schematic examples of bridge displacement measurement sensors

In recent years, non-contact sensors such as robotic total station (RTS), image processing, unmanned aerial system (UAS), and the Laser Doppler Vibrometer (LDV) have been proposed for measuring bridge displacement [9, 10]. Often, the accuracy of the system is sensitive to atmospheric conditions, needs to be set up close to the target, and requires complex post-processing algorithms.

The objective of this paper is to demonstrate a novel concept of detecting railroad bridge conditions using onboard vehicle-based systems. The onboard detecting system collects real-time data under the dynamic load of the railcar. The railroad bridge's dynamic response under the train traversing the bridge can enable the assessment of structural conditions. Onboard systems are commonly used to collect geometry properties of the track, such as the alignment, gauge, vertical and lateral perturbation, cross-level, rail conditions, and other factors that affect the stability and safety of the railroads [11, 12]. The feasibility of using vehicle-based (onboard) systems to detect railroad bridge impairments was proven in controlled conditions by a set of tests performed in the Transportation Technology Center (TTC), USA [13, 14]. The results from the initial investigation indicated that the onboard systems can be used successfully for detecting changes in bridge superstructure and substructure conditions. Therefore, there was a strong motivation to take the next steps toward using onboard systems for bridge conditioning monitoring in revenue service. A research team at the Warsaw University of Technology is currently analyzing track geometry data collected from several Deck Plate Girder (DPG) and Through Plate Girder (TPG) bridges on the Polish Railway (PKP PLK). Using the knowledge discovery in databases (KDD) process, the research team examined the vertical rail irregularities extracted from the onboard track geometry data to identify bridge structural response and its changes in time. In addition, the types of bridge structural configurations, span length, and inventory information were considered. Fig. 2 presents a flowchart of the implemented KDD procedure to find changes in bridge structural response using onboard data.

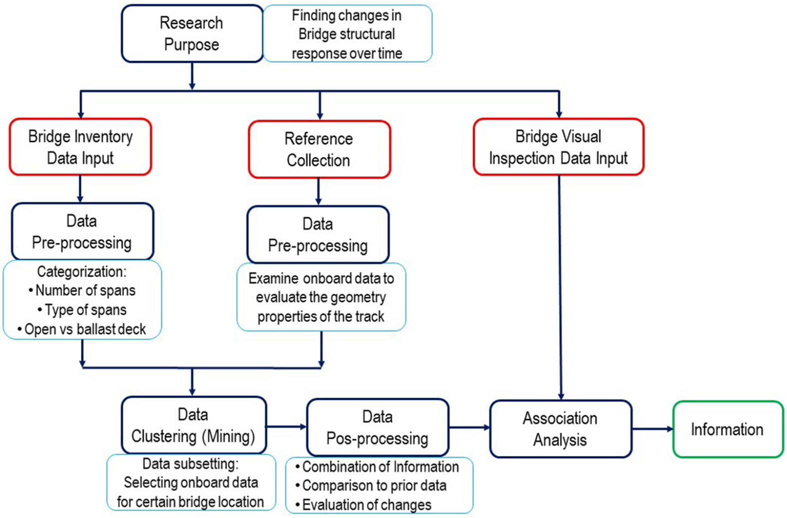

Fig. 2. Flowchart for railway bridges evaluation using vehicle onboard systems

The existing onboard systems do not measure the absolute deflections of the bridge but only their changes. Therefore, the trending of historical readings is needed to track changes and predict when action might be required. Along with the input from visual inspection and associated analysis, the evaluation of the bridge's technical condition is performed. The goal is to detect bridge condition impairments using existing onboard systems. If the system detects any unusual bridge response the bridge inspector can be sent for a detailed evaluation [15].

This paper presents the results of the current research to investigate responses of open deck railway steel bridges in service. Track geometry data collected on the track-geometry car are utilized to develop characteristic signatures for various types of bridges of different lengths and with different track properties. The focus is on detecting bridge impairment in between scheduled inspections. Trending of historical readings will be needed to track changes and predict when action might be required. Therefore, if the system detects any changes to the bridge response the bridge inspector can be sent for an additional visual inspection.

2. Methodology of onboard technologies

2.1. Literature review

Over the past decade, many researchers have presented new methods based on indirect bridge monitoring. One of the most popular SHM approaches is the use of structural vibration data for nondestructive damage assessment. The underlying principle is that if damage occurs in a structure, it leads to changes in its physical properties, for example, a loss of stiffness, and consequently causes measurable changes in its dynamic properties. Based on which dynamic properties or damage features are considered, such damage identification methods can generally be categorized into the following four groups [16]: natural frequency-based methods; mode shape-based methods; curvature/strain mode shape-based methods; and other methods based on modal parameters. A comprehensive survey of the most commonly used Vehicle-Bridge Interaction (VBI) models is given by Gonzalez [17]. A particularly promising development is the concept of using vehicle-mounted laser vibrometers to obtain highly accurate measurements of the relative velocity (and hence displacement) between a moving vehicle and a bridge. OBrien and Keenahan [18] have developed a damage indicator from such measurements that appears to be highly damage-sensitive.

In railway transportation, onboard systems are widely used to collect track geometry properties such as vertical and lateral perturbation, cross-level, and rail conditions [11, 12]. A theoretical investigation of train and railway bridge interaction was presented by Quirke et al. [19] to detect damage through a comparison of the Apparent Profile (AP), sensed by the passing vehicle. The APs are calculated using the Cross-Entropy (CE) optimization method that generates a vehicle dynamic response most similar to the measured input. APs for several damage scenarios are inferred and compared over time to detect damage. Fitzgerald et al. [20] developed a method to detect the presence of railway bridge scour using bogie acceleration measurements from a passing train. A scour indicator is defined as the difference in average Continuous Wavelet Transform coefficients between healthy and scoured batches of train crossings. The result shows that this indicator is quite effective at detecting the presence of scour and its location. Train-track-bridge system was considered in the study by Cantero [21] where the modeling parameters were reviewed. A novel method to determine the apparent profile of the track and detect railway bridge conditions using sensors on in-service trains was further investigated in a recent study [22]. The method uses a type of Inverse Newmark-β integration scheme on data from a batch of trains.

The feasibility of using vehicle-based (onboard) systems to detect railroad bridge impairments was proved in controlled conditions by a set of tests performed in the Transportation Technology Center (TTC), USA [13, 14]. Pilot testing using the Association of American Railroads's (AAR's) Track Loading Vehicle's (TLV) loading system and track geometry system was performed in 2012, which demonstrated the feasibility of the concept [23]. In 2014 several onboard systems were examined on the Bridge Deflection Test Facility (BDTF), including the track modulus measuring system (MRail) and track geometry on the Federal Railroad Administration's (FRA's) DOTX218 car, track geometry on a lightweight passenger car, an accelerometer-equipped instrumented freight car, and a track modulus system (MRail) on a hopper car [13, 14]. Testing performed at TTC indicated that all three types of systems (geometry, deflection, acceleration-based) have the potential to detect changes in bridge conditions. Track geometry as well as deflection data from DOTX218 detected changes in bridge span conditions and pier geometry. In 2015, results obtained at TTC from the track geometry systems on DOTX218 and other railway geometry cars were again examined. Track geometry data from DOTX218 once more accurately detect changes in span conditions [13].

Most recently, Micu et al. [24] introduced a field study of drive-by bridge monitoring using acceleration measurements on an instrumented train. The dynamic responses of the train signals are used to detect the existence and location of a stiffer part of the viaduct where two spans were replaced. The results show that instrumented trains can be successfully used to monitor bridge conditions and to identify the need for repair or rehabilitation.

2.2. Vehicle onboard technologies

The typical track geometry car used in Europe and the USA is equipped with a track geometry measurement system to measure gauge, alignment, and track surface. Track geometry cars typically use a variety of sensors, some of the most common sensors include:

- Gyroscopes: These sensors measure the rate of rotation and orientation of the car to determine the lateral and longitudinal alignment of the track.
- Accelerometers: These sensors measure the acceleration of the car to detect track irregularities such as bumps, dips, and curves.
- Laser detectors: These sensors scan the track to measure gauge, cross-level, alignment, and other key parameters.
- Ultrasonic sensors: These sensors are commonly use to check for the rail defects or damage.
- Cameras: Cameras capture images of the track to help visualize the condition of the rails, sleepers, and other components, as well as, help assess the correctness of the calibration of the localization system.
- GPS receivers: These sensors use satellites to acquire precise location information, which can help track operators map defects, and prioritize repairs.

- Inclinometers: These sensors measure the angle of the incline of the track to detect any irregularities or imperfections.

In addition, the car may be equipped with a track deflection measuring system to measure vertical rail deflection under the wheel loads. It is possible, that the track geometry measurement system uses also automatic location detectors (placed at each end of the tested span) in addition to GPS. Track geometry data collects the rail surface space curve for the left and right rails that can be processed further to find bridge deterioration. In theory, the surface space curve represents the actual position of the rail surface in space [25]; in practice, gradients and long-wavelength components are removed, and filtering is applied to establish a zero level. Then, the surface data can be used to determine the location of the test bridge and the bridge approaches. In Europe and the world, various measurement systems are used, which differ in the way they represent the actual irregularities of the track. In Poland, track geometry cars EM-120 and DP-560 among other methods are currently used for track geometry measurements (Fig. 3).

EM-120
6-axle
Length 14940 mm
Height 4070 mm; Width 3060 mm
Weight 48760 kg / 478.4 kN / 79.7 kN per axle
Pivot spacing (outer bogies) 10,000 mm
Bogie wheelbase 1 800 mm
Maximum driving/measuring speed 20 km/h

DP-560
4-axle
Length 25160 mm
Height 4280 mm; Width 2800 mm
Weight 64000 kg / 627,8 kN/ 157 kN per axle
Pivot spacing (outer bogies) 16 000 mm
Bogie wheelbase 2 600 mm
Maximum driving/measuring speed 120 km/h

Fig. 3. Track geometry cars in Poland, which were used to collect the analyzed data

Chord-based measurement systems and inertial-based measurement systems are the dominant techniques for efficient and fast detection of track geometry irregularities. In the case of the chord-based measurement system, a reference chord is formed between two points on the rails, and the distance between this reference chord and a third position of the rail is measured [26]. This reference chord, generally with a length of about 1 m, moves along the rail propelled by a trolley or vehicle to achieve a continuous measurement of rail geometry. During the chord measurement process, the data is always changing along the rail, leading to an amplitude variation (ranging from 0 to 2) of the amplitude transfer function [26]. The inertial-based measurement systems are used due to the existence of an inertial reference frame of accelerometers: the data does not change during the measurement [26]. The displacement is then determined by double integration of the acceleration signal that is measured along the rail surface. These are especially suitable for higher speed measurement because they can reduce the measurement uncertainty.

In Europe, track irregularities in the vertical plane are most often classified according to the deformation wavelength, which can be associated with the cause of track deformation. Three ranges of wavelengths are taken into account in the analysis of vertical irregularities (Table 1). The basic and required range is D1, which is related to driving safety. The other wave ranges (D2 and D3) are used at higher speeds and take into account the smoothness of driving and enable the assessment of the shape of the arches rounding the bends of the longitudinal profile.

Table 1. Wavelength ranges of vertical irregularities

	Wavelength range [m]	**Speed range [km/h]**
D1	$3 < \lambda \leq 25$	the entire range
D2	$25 < \lambda \leq 70$	$V > 160$
D3	$70 < \lambda \leq 150$	$V > 250$

The wavelength range of 70–150 m is used only on lines with a speed higher than 250 km/h [27–30]. The minimum requirements for the characteristics of the basic parameters and methods for their measurement and analysis are contained in the technical specifications for interoperability relating to the ‘infrastructure’ subsystem of the rail system in the European Union [27].

The vertical irregularities marked as z are deviations from and in the direction of the z-axis of successive levels of the running surface of the rail head relative to the average vertical position (reference line), covering the specified wavelength ranges and calculated from successive measurements. The average vertical position (reference line) is obtained by filtering the measured irregularities with a low-pass filter and with a specific cut-off wavelength, separately for each rail in track. Vertical deviations $f(x)$ are measured from the running surface of the rail head to the reference line, which is a chord with an asymmetric or symmetrical division (Fig. 4).

In the case of the contact system, the reference line (chord) is determined by two wheels of the measuring vehicle spaced apart on the length of the measurement base (e.g. EM120 trolley – symmetrical chord with a base length of 10 m), and in non-contact systems, a rigid vehicle frame to which the measuring devices are suspended (e.g. UPS-80 vehicle – asymmetric chord with a base length of 10.3 m).

The vertical irregularities should be measured using the inertial or chord method (asymmetric is recommended) or a combination of both methods. The inertial method consists of measuring the accelerations and displacements of a specific point of the railcar (wagon). The inertial reference line is obtained by integrating the acceleration signals twice, separately for the left and right rail, and then subtracting the obtained values from the measured displacements (Fig. 5). Initially, this method was used in measuring railcars of Dutch railways and British ones and enabled the mapping of vertical irregularities in the wavelength range of 0.5–25 m (1.6–82 ft.) and 0.5–70 m (1.6–230 ft.) [30, 31].

Currently, non-contact inertial systems are more often used (Fig. 5 on the right) which are characterized by a separate structure and the possibility of attaching to the vehicle chassis frame. These systems enable the measurement of track irregularities at high speeds, even up to 400 km/h [33].

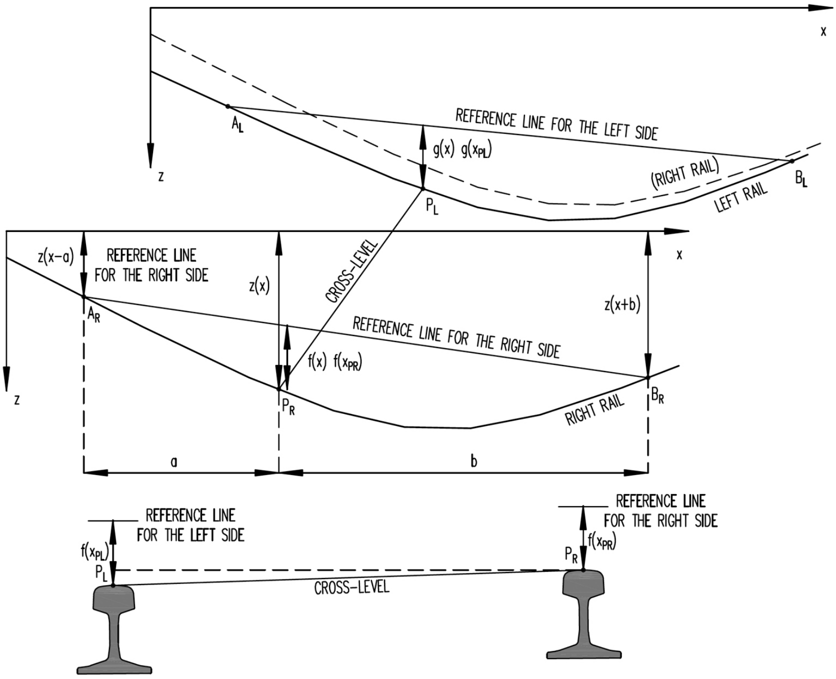

Fig. 4. Scheme of determining the vertical deviation

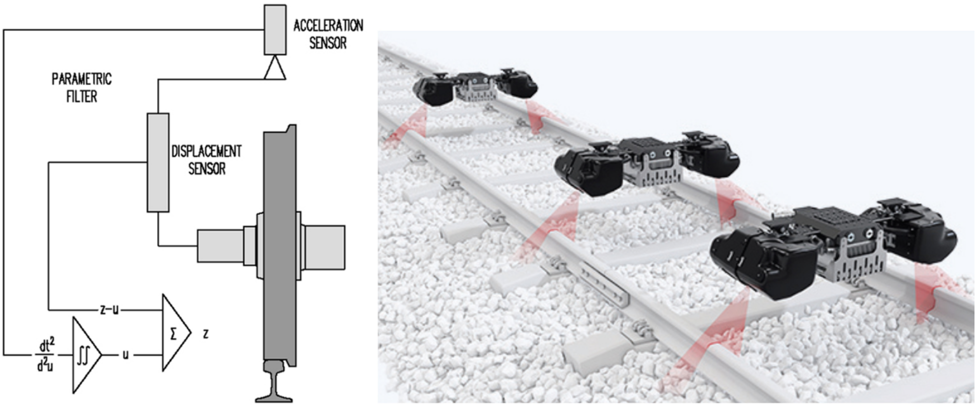

Fig. 5. Scheme of the contact system for measuring vertical irregularities (on the left) and non-contact Inertial track irregularities measurement system (on the right) [31–33]

In chord systems, the values of the vertical deviations $f(x)$ are calculated based on the measured distances between the optical sensors and the running surface of the rail head at three points that form an asymmetrical measuring chord (Fig. 4). The vertical deviations $f(x)$

of the chord (asymmetric) measurement system can be calculated from the Eq. (2.1):

$$f(x) = z(x) - \left[\frac{b}{a+b} z(x-a) + \frac{a}{a+b} z(x+b) \right] \tag{2.1}$$

where: $f(x)$ – vertical deviation [mm], z(-) – ordinate value in the vertical plane [mm]; a, b – chord division (for a symmetrical chord $a = b$) [m].

To calculate the vertical irregularities for a specific wavelength range (D1, D2, or D3 per Table 1), the measured signal values are filtered. It is recommended to use a fourth-order Butterworth filter with a specific cut-off wavelength, e.g. lower 3 m and upper 25 m, i.e. over the full measurement range of D1 irregularities. To detect short waves, the lower limit of the D1 range should be reduced to 1 m [30]. Assuming a sinusoidal shape of the track irregularities, a single wave of length λ, amplitude A and phase shift φ can be described by the Eq. (2.2):

$$z(x) = A \sin\left(\frac{2\pi x}{\lambda} + \varphi \right) \tag{2.2}$$

where: A – wave amplitude [mm], λ – wavelength [m], φ phase shift [rad].

Then the relationship between the vertical inequality and the vertical deviation can be written as presented in Eq. (2.3):

$$f(x) = A \left| H(\lambda) \right| \sin\left(\frac{2\pi x}{\lambda} + \varphi \right) \tag{2.3}$$

where: $|H(\lambda)|$– chord system transition function module [29].

The use of the chord method requires filtering the measured deviations to eliminate the influence of the transition function, i.e. transforming the measured vertical deviations into vertical irregularities. For this purpose, it is necessary to calculate the Fourier transform in the adopted measurement window and approximate the measured deviations with a finite Fourier series. The received signals shall be filtered with a fourth-order Butterworth filter with a defined cut-off wavelength in the range of D1 and D2, respectively [30].

3. Case study

3.1. Description of the test side

The track geometry data is usually collected a couple of times a year or after a special request e.g. when the new ballast is placed. Section of the railway line was selected for a case study and the historical track geometry data was analyzed. The superelevation of the 10 km long track is presented in Fig. 6. The track geometry car DP-560 was used until July 2021, and EM-120 was used after that time. Therefore, the data from both systems are analyzed and compared.

First, the track geometry data were analyzed to check if the selected bridges were included in the collected data. The considered line has three single-span structures that are marked with vertical dash-dot lines in Fig. 6. Pictures of the spans with additional details are presented in Fig. 7.

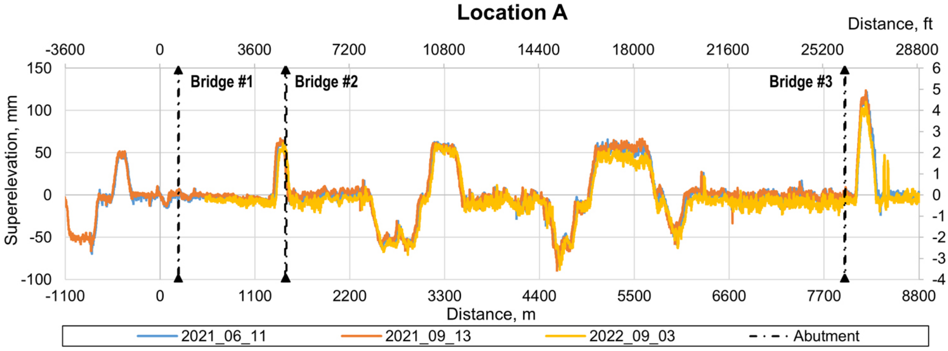

Fig. 6. Superelevation of the track at the considered railway line

Bridge Type: DPG from 1960
Total length = 9.6 m
Theoretical Span Length = 8.8 m

Bridge Type: TPG from 1960
Total length = 13.35 m
Theoretical Span Length = 12.9 m

Bridge Type: TPG from 1956
Total length = 13.63 m
Theoretical Span Length = 12.72 m

Fig. 7. General view of the tested bridges at the considered railway line

The track geometry data collected on all bridges were analyzed and the results of the vertical irregularities in the wavelength range D1 and D2 are presented in the subsections 3.2 and 3.3. However, the track geometry data collected on the Bridge #2 were not satisfactory. The Bridge #2 is located on the curve and the signal from the track geometry car was disturbed. Further research will be performed to see if the vertical irregularities of other bridges on the curve are also not possible to interpret.

3.2. Results of Bridge #1

Bridge #1 is a DPG span of approximately 9.6 m (32 feet) span length, Bridge #2 is 13.35 m (44 feet) long and the third span is 13.63 m (45 feet) long. The data from the track geometry cars was analyzed and the results of the vertical irregularities of Bridge #1 in the wavelength range D1 are presented in Fig. 8, while the vertical irregularities in the wavelength range D2 are presented in Fig. 9. The vertical dash-dot lines lines show the abutment location, while the vertical solid red lines show the bearing location (Fig. 8). The signature of the bridge approach as well as the span deflection is very clear. The span's response measured by the track geometry car varies between June and September of 2021.

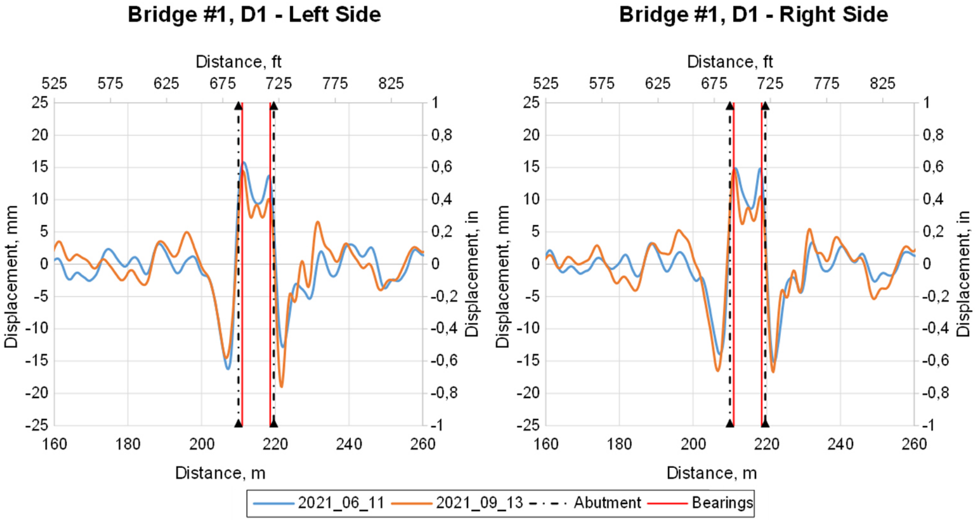

Fig. 8. Bridge #1 response measured by track geometry car – the vertical irregularities in the D1 wavelength range

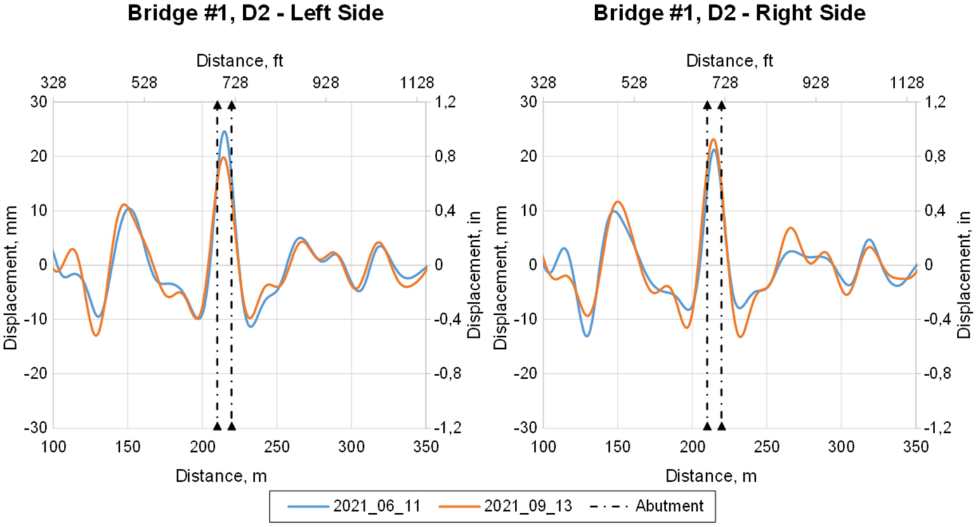

Fig. 9. Bridge #1 response measured by track geometry car – the vertical irregularities in the D2 wavelength range

The difference between the data collected can be related to the ballast condition on the approach Fig. 10, which was noticed during the visual inspection. The deflection of the rail on the approach lifted the rail on the span during the passage of the track geometry car. Also, the two measurements were performed by two different track geometry cars; therefore, further analysis will need to be performed to evaluate if both cars can equally evaluate the bridge approach issues.

Fig. 10. Loss of ballast on the bridge approach

3.3. Results of Bridge #3

The track geometry data collected on Bridge #3 were analyzed and the results of the vertical irregularities in the wavelength range D1 are presented in Fig. 11, while the vertical irregularities in the wavelength range D2 are presented in Fig. 12.

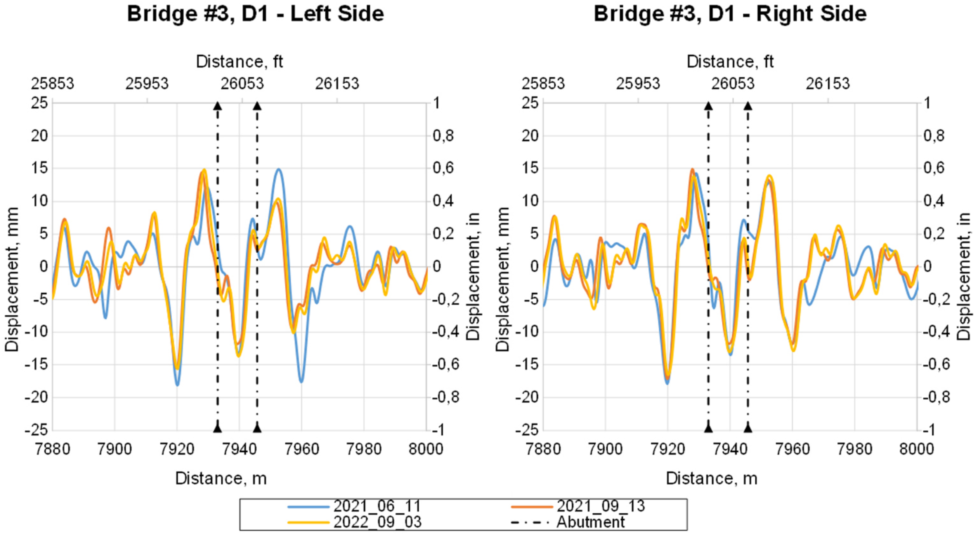

Fig. 11. Bridge #3 response measured by track geometry car – D1 wavelength

The track geometry data was collected three times in several-month intervals. The Bridge #3 response is very consistent for both measurements in the wavelength range D1 and D2. However, the vertical irregularities in the wavelength range D1 are more precise and they are more sensitive to the changes in the bridge response when the vertical irregularities in the wavelength range D2 are overlapping each other (Fig. 12).

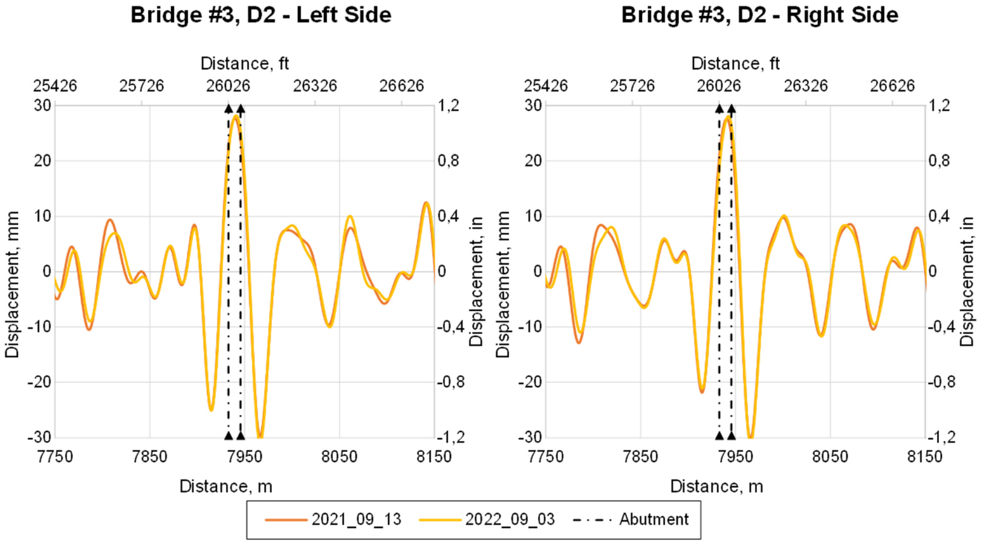

Fig. 12. Bridge #3 response measured by track geometry car – D2 wavelength

The vertical irregularities in the wavelength range D1 from June 2021 compared to September 2021 may suggest changes in the bridge approach. The verification of the photographic documentation confirms a slight loss of ballast on one side that was repaired during the summer of 2021. The span's response measured by the track geometry car in September 2021 and September 2022 aligns nicely which confirms the repeatability of measurements.

4. Discussion and conclusions

Bridges are particularly vulnerable elements of transport infrastructures. Therefore, frequent bridge inspections can provide essential source of information about their technical conditions and potential damages that may influence their safe performance [34]. The onboard vehicle-based systems is a novel concept that allows an autonomous evaluation tool for existing railway bridge structures and substructure. The bridge's dynamic response under the train traversing the bridge can enable the assessment of structural conditions. Several existing railroad bridges located on Polish Railways were examined using the onboard track geometry system installed on the EM-120 and DP-560. The results show that track geometry cars can be used successfully for detecting changes in bridge conditions. The findings from the initial investigation are as follows:

- The vertical irregularities in the wavelength range D1 – clearly and correctly identified the location of the bridge span on the tangent track. The signal of the DPG spans is unique and provides a good basis for evaluating changes in bridge conditions.
- The vertical irregularities in the wavelength range D2 – clearly and correctly identified the location of the bridge span on the tangent track. The signal of the DPG spans is unique; however, the changes in the bridge conditions are not visible since the signal is based on a longer wavelength and only bigger track irregularities are visible.
- The vertical irregularities in the wavelength range D1 and D2 did not provide a strong signal for the bridge span located on a curved track.
- The condition of the revenue service bridges did not change dramatically between the dates the track geometry car collected the data. However, more distinct changes can be noticed in the ballast condition on bridge approaches. The changes in this matter are visible in the vertical irregularities in the wavelength range D1.
- Trending of historical readings is needed to track changes and predict when action might be required.

The existing onboard systems used by PKP PLK S.A. do not measure the absolute deflections of the bridge but only their changes; however, if the raw data of the sensors installed on the track geometry car are properly processed, the deflection of the bridge is possible to obtain. This paper presents the analysis of data that is commonly used to inspect the track; however, further research is ongoing to propose a more accurate evaluation of a bridge displacement/deflection. The goal of this research is to establish the procedures for using existing onboard systems for bridge condition assessment.

This initial research study of revenue service bridges confirmed that the onboard system is capable of detecting characteristic bridge signatures and tracing the changes based on the initial track geometry measurements. The traditional methods for bridge inspection focus on the superstructure and usually omit the underwater substructure that has limited access. The onboard systems can be used on rail vehicles with the regular speed of operation and evaluate changes in the bridge response under dynamic load, as well as evaluate changes in bridge approaches and piers. In addition, the onboard system affects the economic aspect of the inspection, the visual inspection and the labor involved are more expensive than processing the data from the onboard detecting system that is currently in use for track geometry. This can revolutionize the assessment of railway bridges' condition and their fitness for service.

It is recommended that future work should be focused on developing reliable procedures for processing the raw data from the track geometry measurement system dedicated to bridge inspection. For successful implementation, railroad companies would need to establish databases for their bridges and then begin establishing baselines for the onboard data. New data would be compared to historical data to look for changes in the track geometry to infer trends in bridge condition. Appropriate trending software would need to be developed. Accurate location of bridge ends is essential, possibly including on-the-ground location indicators in addition to GPS.

Future work will include the evaluation of additional bridges in various locations with an open and ballasted deck. Evaluation of longer spans may require modifications or different algorithms in trending software. Processing of raw data may allow investigation of the bridge's natural frequency along with the deflection of the bridge. This may help to investigate defective conditions such as cracks in steel girders that do not manifest themselves in significant changes in deflection [15].

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Ocena krótkich mostów kolejowych z wykorzystaniem systemów pomiarowych na diagnostycznych pojazdach kolejowych

Słowa kluczowe: diagnostyka obiektów mostowych, mosty kolejowe, obciążenia dynamiczne, pionowe przemieszczenia, pojazdy do diagnostyki geometrii toru, strefy dojazdowe/przejściowe

Streszczenie:

Zmiany geometryczne konstrukcji mostowych, takie jak przemieszczenia i ugięcia, są jedną z najważniejszych wielkości fizycznych charakteryzujących pracę całego ustroju. W przypadku obiektów kolejowych, gdzie dopuszczalne odchyłki niwelety toru od założonych wartości są stosunkowo niewielkie, mają one istotne znaczenie przy ocenie stanu technicznego eksploatowanych konstrukcji. Tradycyjnie stosowane w tym celu metody pomiaru oparte są o czujniki kontaktowe, przemieszczeń, przyśpieszeń zainstalowanych na konstrukcji, nowszą metodą jest wykorzystanie czujników kontaktowych GPS. Niestety metody te ze względu na czasochłonność, duże koszty instalacji czujników i utrudnienia związane z brakiem swobodnego dostępu do konstrukcji są stosowane indywidualnie do wybranych obiektów, przeważnie o dużych rozpiętościach. Stąd w ostatnich latach do pomiaru przemieszczeń elementów mostu coraz częściej próbuje się wykorzystywać metody bezdotykowe, oparte na czujnikach bezkontaktowych, takich jak tachimetry, przetwarzanie obrazu, laserowe wibrometry dopplerowskie, zainstalowane w pewnej podległości od obiektu lub, coraz częściej, na dronach. Niniejsza praca przedstawia nową metodę monitorowania stanu technicznego konstrukcji i detekcji stanów awaryjnych w oparciu o pokładowe systemy pomiarowe geometrii toru zainstalowane na pojazdach diagnostycznych zwanych drezynami pomiarowymi. Metoda ta nie wymaga instalowania czujników na obiektach oraz może być stosowana powszechnie do wielu obiektów. Pokładowy system pomiarowy zbiera dane w czasie rzeczywistym pod dynamicznym obciążeniem drezyny pomiarowej. Uzyskana odpowiedź dynamiczna konstrukcji nośnej obiektu pod wpływem przejeżdżającego pojazdu może umożliwić ocenę globalnych warunków pracy ustroju. Jako, że dane zbierane przez pokładowe systemy pomiarowe służą do oceny poszczególnych charakterystyk toru (wichrowatość toru, nierówności pionowe i poziome, zużycie faliste itp.) oraz stanu technicznego układów torowych znacznych odcinków linii kolejowych, daje to równoczesną możliwość monitoringu wszystkich obiektów inżynieryjnych położonych na odcinkach objętych pomiarami. Możliwość wykorzystania systemów pokładowych do wykrywania uszkodzeń mostów kolejowych jest stosunkowo nowym zagadnieniem i została zapoczątkowana badaniami w kontrolowanych warunkach zrealizowanymi w Transportation Technology Center (TTC) w USA. Wyniki pomiarów wykazały, że metodę można z powodzeniem stosować do wykrywania zmian sztywności przęseł oraz przemieszczeń podpór obiektów mostowych. W ramach prac badawczych prowadzonych na Politechnice Warszawskiej analizowane są dane pomiarowe geometrii torów na liniach eksploatowanych będących pod zarządem PKP Polskie Linie Kolejowe S.A., zebranych dla kilkunastu obiektów inżynieryjnych o przedziale rozpiętości do 15,0 m i schemacie statycznym belki swobodnie podpartej. Do analizy wykorzystano dane pomiarowe z drezyn pomiarowych EM-120 i DP-560 zbierane cyklicznie i zgromadzone w bazach danych. Zespół-badawczy przeanalizował nierówności pionowe toków szynowych celem zidentyfikowania odpowiedzi konstrukcyjnej mostu i jej zmian w czasie, porównując zmiany przemieszczeń konstrukcji nośnych. Biorąc pod uwagę, że analizowane wartości nierówności pionowych nie odpowiadają wartościom bezwzględnym ugięć konstrukcji nośnej, przewidywania w zakresie stanu technicznego obiektu i ewentualnych działań utrzymaniowych wymagają śledzenia trendów diagnostycznych powiązanych z tradycyjnymi metodami oceny stanu technicznego. Ostatecznym efektem jest informacja o wszelkich nietypowych reakcjach konstrukcji, które przy wykorzystaniu dostępnych zespołom diagnostycznym zarządcy infrastruktury narzędzi, byłyby niemożliwe do wykrycia przy okazji przeprowadzanych standardowo oględzinach czy przeglądach okresowych. Stan techniczny przykładowych analizowanych w niniejszym artykule konstrukcji nie zmienił się znacząco w czasie prowadzenia badań, natomiast zauważono zmiany w obrębie stref przejściowych i podsypki na dojazdach do obiektów. Podczas analizy zebranych danych wykryto również pewne ograniczenia stosowanych algorytmów i procedur. Planowana kontynuacja prac pozwoli na opracowanie bardziej precyzyjnych procedur monitoringu konstrukcji nośnych obiektów inżynieryjnych, dzięki czemu możliwe będzie objęcie monitoringiem obiektów o bardziej skomplikowanych schematach statycznych, większych rozpiętościach czy innych typach konstrukcji nawierzchni torowej.

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