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Evaluation of tramway overhead line system in city of Osijek

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Abstract. Overhead line system is a vital element of any electrified railway infrastructure. Its performance reflects to all vital parameters such as traction, reliability, availability and safety of railway infrastructure. Operator GPP Osijek runs a 27.5 km long tramway network which plays a key role in transit system of the city of Osijek, Croatia. In 2016 GPP Osijek applied to a tender for acquisition of new rolling stock with 85% EU investment. Mayor requirement prior to rolling stock acquisition was to document, analyse and upgrade current infrastructure (including track structure, electric substations and catenary) to an optimal level. Task of measurement and evaluation of tram track structure and catenary has been appointed to University of Zagreb Faculty of Civil Engineering. Overhead line analysis comprised from several measuring procedures, including supporting columns evaluation, catenary stagger, height, shocks and wear. Such extensive analysis included GPS positioning and on-site evaluation of 1214 supporting columns of overhead line, as well as overhead line measurements using an instrumented tram vehicle on 18 km of track. For conducting overhead catenary wire measurements, a tram pantograph has been fitted with equipment for measuring catenary height, accelerometers for shock measurement, camera, ruler and GPS for stagger measurement. Catenary wire wear was checked manually from catenary inspection vehicle. To conduct measurements, power had to be switched off on all electric substation along the route and tram vehicle had to be towed by a catenary inspection vehicle. All the data has been analysed and presented to end user in a user-friendly and intuitive GIS environment capable of further updates and detailed analyses. Evaluation of overhead line based on direct measurement results pointed out all the defects and weak spots on the system. It resulted in a series of recommendations for reconstruction and upgrade of the catenary system to fit the need of existing state and further development of tramway network.

1 Introduction

Urban transit systems, such as one in Osijek, Croatia often rely on tramway networks as a backbone for delivering quality service to its passengers. Electric energy for powering the rolling stock is delivered from electric substations through the overhead line system. In Osijek, such a system delivers DC 660 V to the rolling stock. Maintenance of such a system is crucial for safe and reliable running of tramway rolling stock. The overhead wire is attached to hangers which are mounted on supporting columns or supporting anchors on building facades.

In 2016, tramway operator GPP Osijek has appointed a task of evaluation of current overhead line system to University of Zagreb Faculty of Civil Engineering, to prepare the documentation for future tenders for reconstruction of tramway infrastructure. This task was a part of integral evaluation of tramway infrastructure in the city of Osijek which also included evaluation of tramway tracks, electrical substations and a feasibility study on 27.5 km of tramway track [1, 2].

The analysis of overhead line consisted of several measurement procedures including supporting columns evaluation, catenary stagger, height, shocks and wear, with a goal of determining the structural health of the system.

2 Measurements and analysis of overhead line

Measurement of the data required to evaluate the state of the overhead line required substantial effort. Measurements were divided into discrete mapping and visual inspection of supporting columns and anchors, and continuous measurement of overhead wire parameters (height, shocks, stagger) using an instrumented T3 tram towed by a catenary inspection vehicle at ~10 km/h. The whole tram pass by over 18 km of track has been divided into 11 subsections.

2.1 Supporting columns and anchors evaluation

Supporting structure of overhead wire plays a significant role in the electrification system. Its stability and position ensure correct position of overhead wire and the contact with vehicle pantograph. Deteriorated supports can have different stiffness, foundation conditions, shape,

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inclination, and structural damage, which leads to difficulties in ensuring the correct position of overhead wire. In this evaluation all supporting columns and anchoring points have been examined. Total of 1214 measuring points have been acquired and recorded to a GIS application for further analysis. The data set comprises of 1072 columns, 112 anchoring points on building façade and 30 anchor points to other structures such as viaducts. For each measurement, a set of visual inspection data variables (such as overall state, coating state, general comment, column diameter) have been acquired and stored to the GIS database, along with photos and anchoring point position.

Acquisition and evaluation of the state of columns and anchors has been processed using GIS software specifically designed for this purpose [3]. The software allows data acquisition via Android or iOS mobile devices by building custom acquisition forms including with GPS positioning, photos, reports in PDF and different textual and numerical attributes assigned to each point. Such approach allowed a sophisticated and easy to preform analysis of the overhead line supports on such a large dataset. This approach also allows interactive reporting, updating of the database used for maintenance planning. Based on state of the columns, different parameters can be graphically represented for further maintenance planning, such as overall columns state represented in Figure 1.

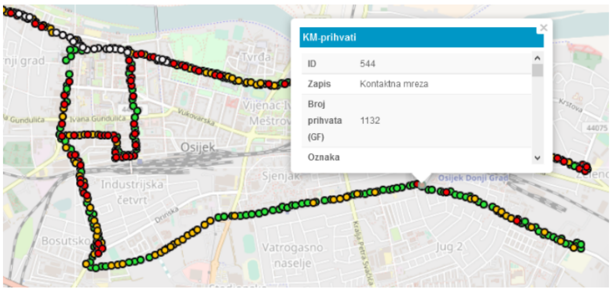

Fig. 1. Acquired GIS dataset of 1214 analysed supports.

According to analysis, 20 % of columns were characterized as substantially damaged (bent out of vertical axis, corrosion damage, shrapnel damage etc.), as presented in Figure 2; 32 % endangered (minor corrosion or dents); 48 % in good state (not bent, no corrosion or dents).

Fig. 2. Example of substantially damaged columns.

2.2 Overhead wire measurements

Overhead wire had to be checked along 18 km of track. On these sections, a tram T3 has been instrumented with measurement equipment and towed by a towing truck to conduct measurements off the power grid with a speed of around 10 km/h, Figure 3. Towing truck has also been used as an inspection vehicle for overhead wire wear assessment.

Fig. 3. Towing truck and tram T3 during overhead line measurements.

All measurements described in subsections have been synced with GPS data acquired from a GPS receiver mounted on a tram roof to assign position data to all records and further analyse the data using GIS software. HD video recording of the tram pass by has also been synced to all the recorded data. In this way all the continuous measurements can be simultaneously displayed and analysed, and certain events and defects properly located, described and documented.

2.2.1 Overhead wire height

The overhead wire height has been measured using a digital measuring strip attached to pantograph base and pantograph top, recording the height variation, Figure 4. By adding the fixed value of top of rail to pantograph base height, total overhead wire height is calculated. Measurements are recorded continuously at 100 Hz. Such procedure allowed recording of overhead wire along the whole 18 km of tram track.

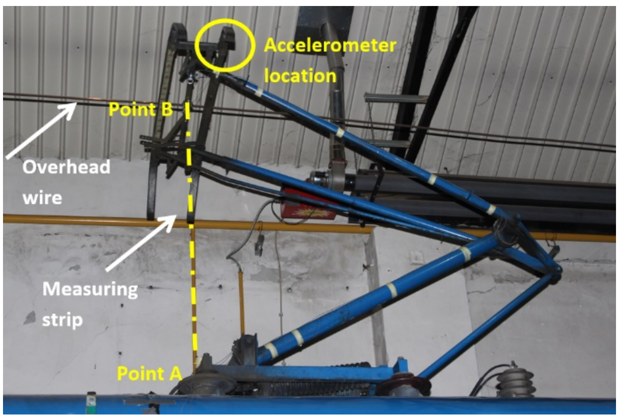

Fig. 4. Overhead wire height and shock measurement setup.

The height of overhead wire has been displayed in a histogram form to analyse the height distribution and occurrence along each of 11 subsections. A minimum height of overhead wire has been carefully examined and documented due to a requirement of free cross section of road vehicles that require 460 mm of height of overhead wire [4], Table 1. Lower level of overhead wire can endanger road users and pedestrians on sections of tram line where road vehicles share the same lane or in an intersection. In such case road vehicles can come in contact with the overhead wire that can result in wire damage, power outage, costly repairs and casualties.

Table 1. Height of overhead wire analysis.

Sub-section	Max / Min [cm]	Height difference [cm]	Below 460 cm [%]
1	523 / 442	81	14.2
2	525 / 441	84	5.1
3	519 / 438	81	17.0
4	523 / 451	73	0.2
5	523 / 430	93	6.7
6	539 / 438	101	9.6
7	527 / 400	127	19.3
8	542 / 438	104	10.4
9	526 / 448	78	4.8
10	543 / 409	133	12.2
11	517 / 402	116	17.1

Height difference in respect to travelled distance has also been analysed because it can lead to loss of contact between the pantograph and the wire, Figure 5.

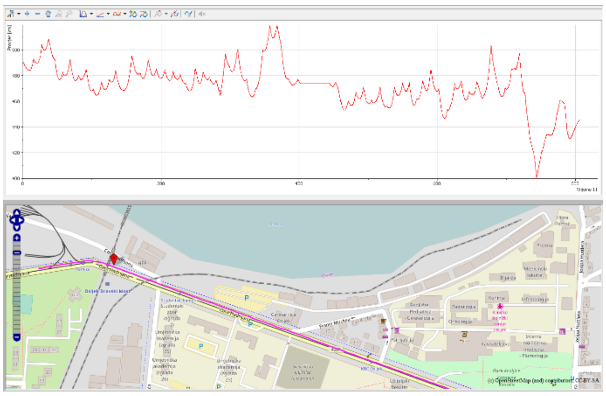

Fig. 5. Substantial height difference of overhead wire (right).

2.2.2 Pantograph shocks and vibrations

Shocks on the pantograph are usually caused by irregularities of contact surface between the pantograph and overhead wire. The discontinuities that result in pantograph vibrations are often caused by joints due to wire break. They can also be caused by cracks in the contact wire that could result in wire breakage. It is therefore important to measure and evaluate shocks and vibrations on the pantograph. To measure vibrations of the pantograph, accelerometers were attached to pantograph head and support rod (Figure 4) in vertical direction. Vibrations were recorded with a frequency of 100 Hz.

Through vibration analysis different average level of vibrations have been recorded on different track segments as well as individual shock events on the catenary, Figure 6. Such data is important for evaluation of overhead line wear, joints, overlaps and potential weak spots.

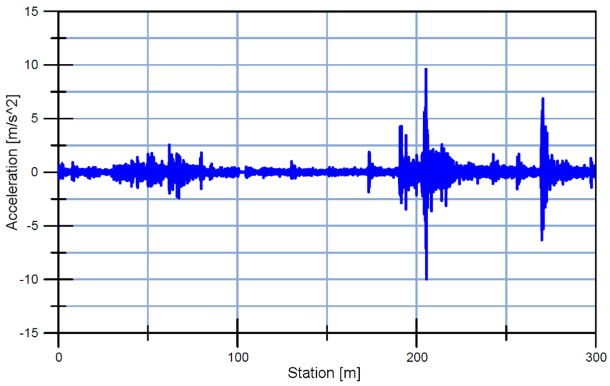

Fig. 6. Overhead wire shock time signal sample.

2.2.3 Overhead wire stagger

During a tram pass by over 18 km of track, a video camera was used to record the pantograph head with a measuring strip attached to it, to record the stagger of the overhead wire in lateral direction, Figure 7.

Fig. 7. Overhead wire stagger measurements using camera and measuring strip on the head and camera in the base.

This data has further been processed to create a polygonal curve base on the maximum values the wire has reached in lateral direction, traveling over the pantograph head, Figure 8. Using a GPS signal recorded simultaneously, such data could be geolocated to the tram network and track station.

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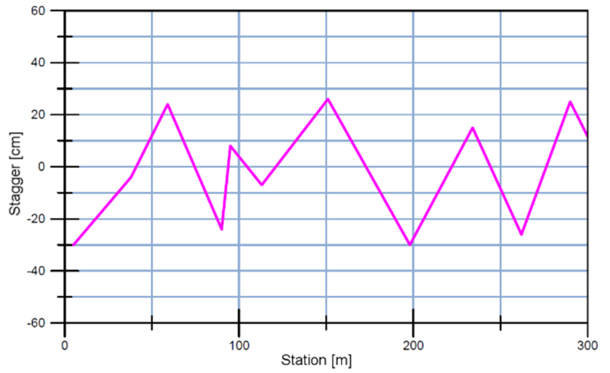

Fig. 8. Pantograph stagger recording.

Depending on pantograph specifications there is an optimal stagger width that leads to even wear of the photograph contact surface. In case of Osijek tram network, it is +/- 30 cm from pantograph centre line [4]. According to that, by histogram analysis, conclusions can be made on wear of pantograph contact surface. Analysis can also pinpoint locations of undesired wire placement (outside of +/- 30 cm range).

2.2.4 Overhead wire wear inspection

Using an overhead line inspection vehicle, the overhead wire has been checked for wear on different cross-section (Figure 9) as well as for wire defects and joints (Figure 10). Such measurements were conducted to asses the overall state of the contact wire on different subsections of the network.

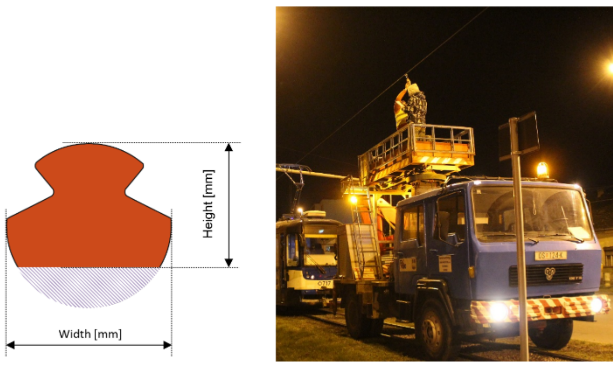

Fig. 9. Measurement of overhead wire wear.

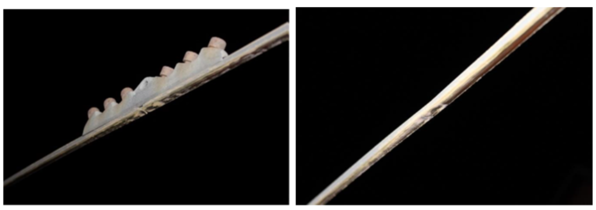

Fig. 10. Inspection of wire joints and potential weak spots.

Such inspection, together with historic data of GPP Osijek maintenance division, revealed 79 joints due to wire breakage, 46 substantially worn spots and other potentially critical points, Figure 10.

3 Conclusions

Overhead wire on tram networks needs to meet high standards of safety and reliability for proper functioning of a transit system. This is can be a challenge in densely populated and narrow urban landscape, with overhead line often anchored to building facades, complex alignment of a tram centreline. Additionally, since tram and road vehicles often intersect or share the same running surface, substantial clearance for road vehicles must be ensured to avoid potential line breakage.

To evaluate the state of overhead line network in whole, different measurement and analysis approaches need to be implemented, as often used on conventional railway tracks [5]. Only the collective knowledge of all components of the overhead line system can lead to correct conclusions.

Overhead line measurements have been divided into discrete mapping and evaluation of supporting columns and anchoring points, discrete measurements of wire wear along the track and continuous recording of wire height, stagger and shocks. To integrate all the measured components, GPS location of each dataset has been stored in a GIS database for further analysis [3].

Conducted measurements and further analysis revealed weak spots and sections in overhead line system that are to be replaced or reconstructed due to weakened or damaged support columns (around 20%), worn overhead wire and elevated level of vibrations and shocks on vehicle pantograph. Furthermore recommendations for correction of overhead line alignment in terms of height and stagger have been given for more than 2000 m of track. Priority levels for reconstruction have also been determined.

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