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Point clouds to evaluate geometric quality control of road constructions

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Abstract

The use of point cloud technology has become a valuable tool in the field of civil engineering for its extraordinary resolution in recording three-dimensional data for numerous applications, which include surveying, construction, and quality control. Continued use of point clouds help civil engineers to carry out accurate measurements of geometric features, helping them to reduce errors and which leads to more efficient construction processes.

The Standard Highway Specifications entitled „Geodesic specifications and Geometrical Requirements of Roads” has been operative since January 2019 and being updated in 2024. One of the key points of its update is to setup the rules of using point cloud techniques in road planning and construction.

This paper presents the methods in general to use point clouds to evaluate geometric errors of asphalt layers under construction and describes the flow to visualize and document the results. These findings aim to offer great contributions to developing the geometric precision of road construction projects.

Kivonat

Pontfelhőket ma már általánosan használunk a mérnöki gyakorlatban, hiszen a pontfelhőket alkotó technikákkal alakzatok felmérése három dimenzióban rendkívüli hatékonyan valósítható meg. A pontfelhők számos alkalmazása ismert a mérnökgeodéziában, azon belül is az építőiparban, illetve a geometriai minősítésben. A Közutak geodéziai előírásai és geometriai követelményei című Útügyi Műszaki Előírás 2019. januárban vált hatályossá, az előírás megújításán jelenleg is dolgoznak. A megújítás egyik kulcseleme a pontfelhők készítésének és alkalmazásainak szabályozása. A dolgozatban bemutatjuk, hogyan lehet burkolatok geometriai minősítését pontfelhők alapján végezni, illetve az eredmények hogyan dokumentálhatók.

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1. INTRODUCTION

Engineers can improve different aspects of their workflow by integrating point cloud technology into their work, allowing them to be more efficient, improve their accuracy and decision-making processes. The need for using point cloud technology in the field of road construction (like many other fields of engineering) can be found in the limitations of traditional methods and in the advantages created by point clouds, such as:

- Given the development of modern road construction projects, traditional road survey methods face some limitations when it comes to the required level of detail in these projects, as they are generally slow and require a lot of manual labour processes, unlike back in the day when they were enough for simple tasks such as earthworks calculations. Trying to detect complex details of the road surface like vehicle dynamics simulations, accurate progress monitoring, or pavement failure detection might be difficult using traditional methods [1].

This means that high resolution data is required to help identify any minor pavement failures, such as small cracks or slight crossfall changes. Point clouds can be applicable in road construction because they are capable of capturing road surface data with sub centimetre-level accuracy.

- With the increasing shift towards digitisation, just as with building construction, digital twins of road infrastructure are increasingly required to support different use cases like design, construction, maintenance, and simulation. With point clouds as the foundation of these digital twins, they give a complete and accurate 3D model of the road.

The main objective of this study is to test and apply the new version of Geodesic regulations and geometric requirements developed in the Hungarian highway standards, to a project 500 m long section of the M4 highway, between stations 93+700 and 94+200.

2. LITERATURE REVIEW

2.1. Traditional engineering survey methods

Total stations are used in a lot of construction projects for their ability to measure both the vertical and horizontal angles, including the slope distance between an object and the instrument. This method of surveying is still favoured for its accuracy in measuring points within 1 cm precision, which is essential for detailed surfaces on geodetic layers like concrete and asphalt surfaces [2].

Another method that was developed for surveying is the GPS (Global Positioning System), but the caveat of this method in the 1990's was that data can only be processed afterwards. The method was further developed in the late 1990s which made centimetre-level positioning obtainable even in real-time using RTK (Real-Time Kinematic) techniques, thus making the method of GPS more efficient. Quite a lot of development have been carried out over the recent two decades, such as involving further satellite constellations in addition to the American one, like the Russian GLONASS, the European Galileo, the Chinese BeiDou and developing GNSS infrastructure to support the users by a network of permanent stations to make the observations more affordable and efficient. Despite all the advancements, the main limitation of GNSS technique in engineering geodesy remained the same: its accuracy in vertical sense, a couple of centimetres, is far from the requirements in quality assessment of asphalt layers in road construction [2].

2.2. Application of point clouds in road construction

Point clouds can be used to create highly accurate 3D models of roads surfaces, which can be used to support a variety of road construction activities including planning, design, construction, maintenance, and rehabilitation [1, 3]. These can be expanded upon a bit further:

- **Road surface assessment and maintenance:** pavement failures such as cracks and potholes can be easily detected using point clouds [1]. Information on pavement failures can be used by engineers to schedule repairs and improve road safety for users. An example of how this can be done is through image processing algorithms that are able to analyse captured by Unmanned Aerial Vehicle (UAVs) to generate 3D models and orthophotos which make it possible to measure road surface distresses [3].
- **Road design and construction:** Point clouds can be used to create digital twins of road surfaces, which can be used for a variety of purposes, such as vehicle dynamics simulations. This information can be used to improve the design of new roads and ensure that they meet the required safety standards. For example, the paper "Point Cloud Based Road Surface Modelling and Assessment" explains that while traditional geodetic surveying methods are sufficient for general construction requirements, they do not provide the detail needed for applications like vehicle dynamics simulations or detection of minor pavement failures [1].

- **Construction progress monitoring:** Point clouds can be used to track the progress of road construction projects. This information can be used to identify delays and ensure that projects are completed on time and within budget [1].

2.3. Accuracy and efficiency of point clouds

The use of point clouds in road construction is becoming increasingly common as technology becomes more affordable and easier to use.

- **Accuracy in road surface modelling:** point clouds from terrestrial laser scanner (TLS) based road surface models are highly accurate, enabling detailed assessment of road surfaces. This accuracy comes from the specified high-resolution scanning capabilities of the TLS systems, such as the *Surphaser 400* that was used, which is capable of 1 mm ranging accuracy and 0.1 mm ranging noise [1].
- **Relative Accuracy:** different use case specifications show that TLS surveys can achieve relative positional accuracy (as well as absolute accuracy), more especially in measurement and plane generation of the plane from point cloud data. A case study of this is presented in [4] which shows evaluation, control and report on how good TLS survey can be on the application of the Ariza Bridge.

Accuracy assessment was also investigated as seen on **Table 1** of [5]. Point clouds collected with different techniques (TLS, MMS {Mobile Mapping Systems}, drone photo) were compared to traditional surveying results and found that the mean differences and standard deviations are a few millimetres, and the maximum difference is less than 2 centimetres. The method of comparison of the point cloud to the planned geometry ([5] – 4. ábra) is also shown. RANSAC is the robust method to applied to estimate the cross slope of actual surface as represented by the point cloud ([5] – 5. & 6. ábra).

There are several factors that can influence point cloud accuracy, including obscured areas during construction. Other factors include the texture of the surface, lighting conditions, amount and resolution of images captured, and the feature detection from different viewpoints [6]. Depending on the size of the construction site, multiple observation points for the point cloud may be needed to capture the entire site, which can take up a lot of time. When compared to laser scanning, photogrammetric data acquisition methods give a less accurate point cloud and still requires a lot of computing power to recreate the site. However, because of its ease of application and flexibility, this method is still used because camera equipment is inexpensive, standard and used a lot on UAVs [6].

There are advantages and disadvantages when choosing either TLS or photogrammetry, and the best method to use depends on the requirements and the specific use case. If high accuracy is needed, the best method may be TLS, whereas, if an efficient method is needed, photogrammetry might be better especially for big scale projects where time constraints need to be adhered to [6].

3. METHODOLOGY

The flowchart as illustrated in **Fig. 1** helps to visualise the process of the work carried out. The process is presented in the Hungarian regulation [11], in this chapter we apply and test it to an actual project. There are three main sections:

- I. Modelling the planned road.
- II. Processing the result of surveying, which is the point cloud data.
- III. Documenting the geometric quality, such as the vertical deviations and actual cross slopes.

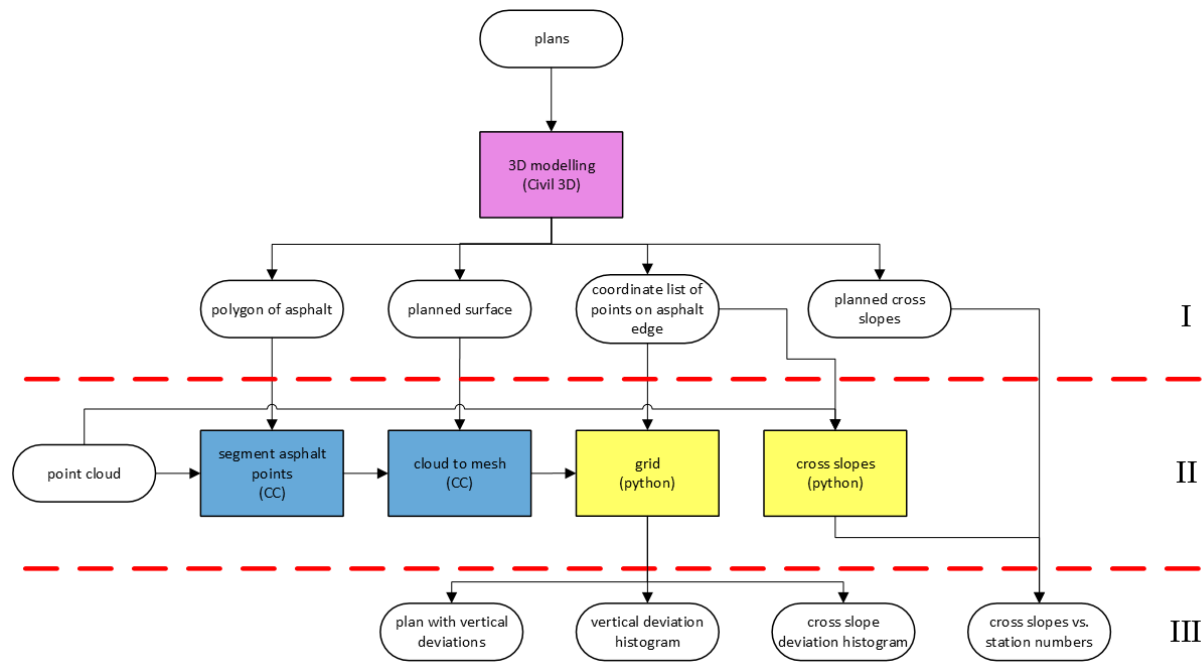


Figure 1: Flowchart

The following software were used to carry out the work and give outputs:

- AutoCAD Civil3D (for modelling)
- CloudCompare (for processing)
- Python (for processing and documenting)
- QGIS (for documenting)

AutoCAD Civil3D is widely used in civil engineering road design because of its parametric tools that improve drafting, design, and construction documentation. Civil 3D's corridor modelling capabilities allow for detailed 3D models of roads, including intersections and multi-lane highways. It also integrates with survey and GIS data, ensuring designs align with real-world topography and planning data. Finally, its compatibility with industry standards enables efficient documentation and reporting, reducing manual work and enhancing accuracy [7].

The original purpose of CloudCompare [8] is to compare two-point clouds, but in our case, we compare a point cloud to a mesh (surface). CloudCompare is an open-source software designed primarily for handling and processing 3D point cloud data. It's widely used in fields like surveying, civil engineering, and GIS for analysing and visualizing point clouds, which are dense sets of points representing surfaces or objects in 3D. The software supports various data formats, such as *stl*, *ply*, and *dxf* (from the files I used), making it compatible with data captured by different devices like LIDAR scanners, drones, and photogrammetry software.

Python is a versatile programming language which is often used in data analysis, automation, and scripting.

QGIS [9] is an open-source Geographic Information System (GIS) software widely used for spatial data analysis and mapping. It allows for managing, analysing, and visualizing geospatial data like shapefiles, satellite images, and more. QGIS has robust plugins for different analyses and can connect with databases, making it adaptable for various GIS needs.

3.1. Modelling designed road geometry

All the planners use some kind of 3D model but most of the cases they do not give them to general workers. In preparation, the 3D models are developed again using the paper based or digital conventional 2D plans.

Table 1 shows the setting out data of horizontal alignment from our actual project (M4), with units in meters [m]. In case the whole circle bearing measurement is given, the element is a straight-line, in case the “R” (the radius) is given it shows that that’s a circular curve, and the “A” is the parameter of the transition curve.

Station	Easting	Northing	length	whole circle bearing [degree]	R	A	chord length
90+800,000	725347,397	208442,800					
90+950,000	725493,442	208408,582	150,000	103,186288			
91+037,158	725578,326	208388,806	87,158		-35000		87,158
91+110,319	725649,583	208372,219	73,161		35000		73,161
91+452,535	725982,807	208294,287	342,216	103,163375			
92+103,577	726608,883	208117,675	651,042			1250	
92+463,251	726933,947	207964,519	359,674		2400		359,337
92+613,251	727062,899	207887,907	150,000			600	
93+087,840	727468,366	207641,266	474,590	121,311689			
93+375,840	727719,835	207501,232	288,000			600	
94+360,237	728678,315	207465,240	984,396		-1250		959,155
94+560,237	728861,722	207544,859	200,000			500	
94+760,237	729045,129	207624,477	200,000			500	
95+092,533	729368,221	207697,849	332,296		1250		331,319
95+292,533	729568,027	207705,256	200,000			500	
96+166,427	730439,869	207759,199	873,895		-8500		873,510
			5366,427				

Table 1. Setting out data

Fig. 2 shows our horizontal alignment for a 500 m long section between stations 93+700 and 94+200.

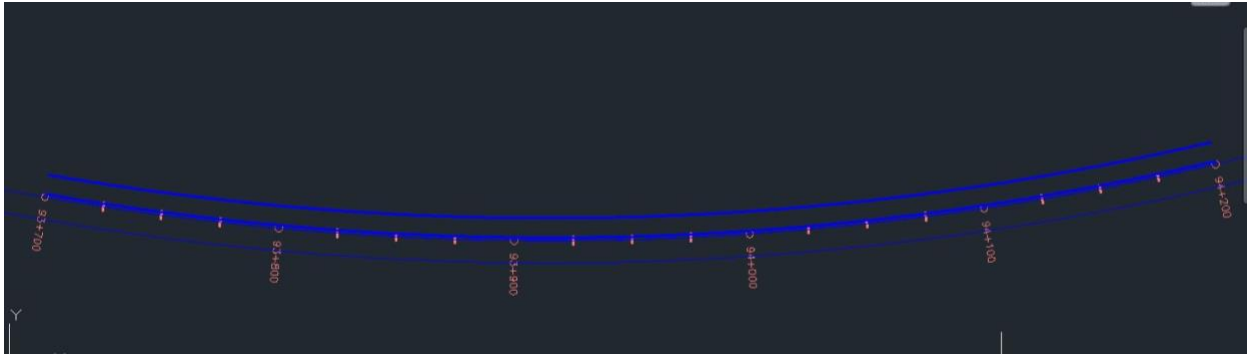


Figure 2: Road horizontal alignment

The assembly of our road as shown in **Fig. 3** has a width of 8.25 m, and a cross slope of $\pm 3.5\%$.

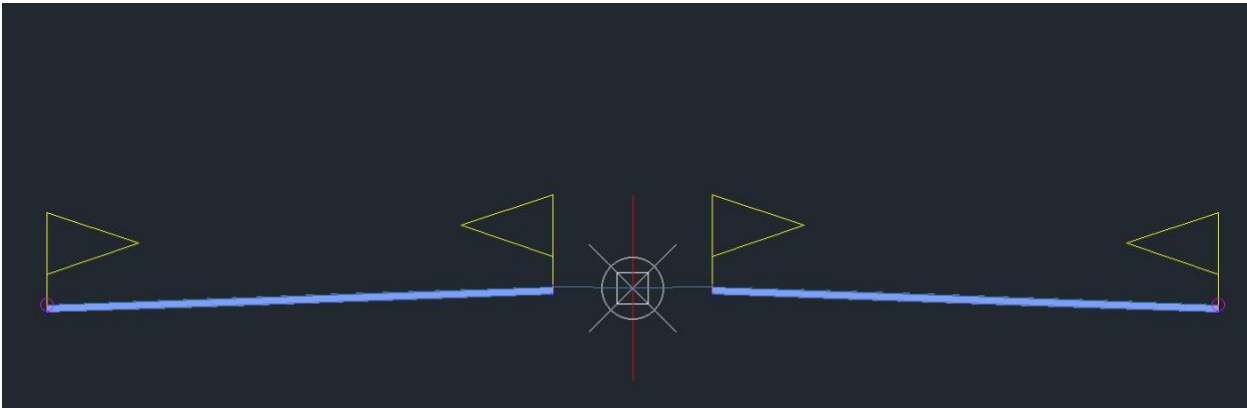


Figure 3: Road assembly

Table 2 shows the elevations of M4 at different stations and their radii.

Station	Elevation	R
90+800,000	90,795	
91+425,000	90,733	1000000,000
91+475,000	90,733	
91+796,318	90,729	-50000,000
91+884,025	90,713	50000,000
91+974,232	90,631	
92+775,000	90,550	50000,000
93+025,000	90,550	
93+150,000	91,175	
93+434,796	91,800	-35000,000
94+389,550	92,065	250000,000
94+497,500	90,893	25000,000
94+652,500	91,200	
95+175,000	91,975	-52250,000
95+300,000	91,350	
95+760,000	90,200	92000,000
96+166,427	90,200	

Table 2. Profile elevation data of M4

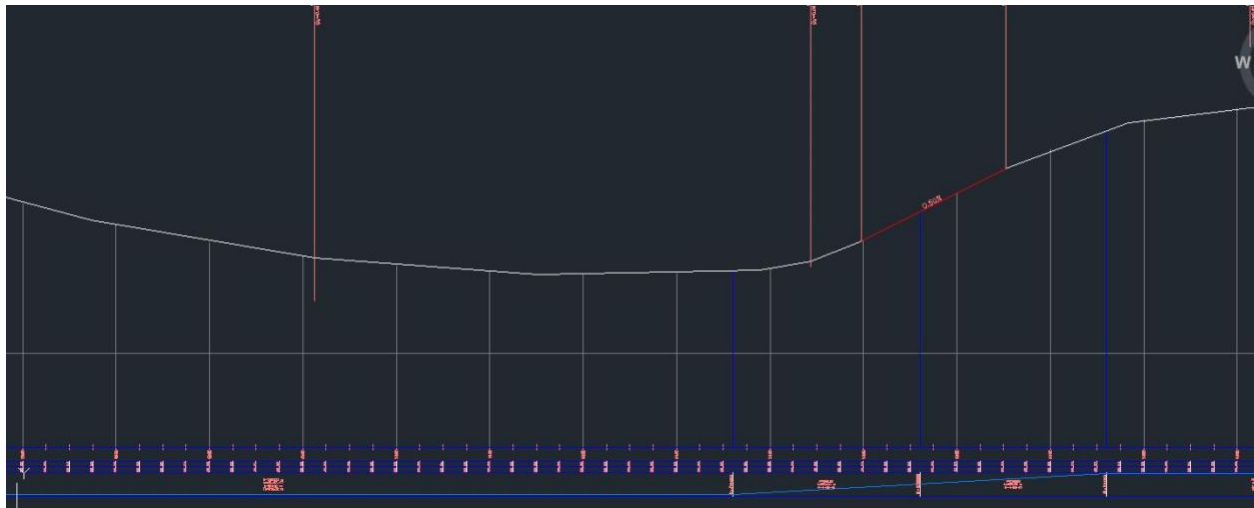


Figure 4: Road profile

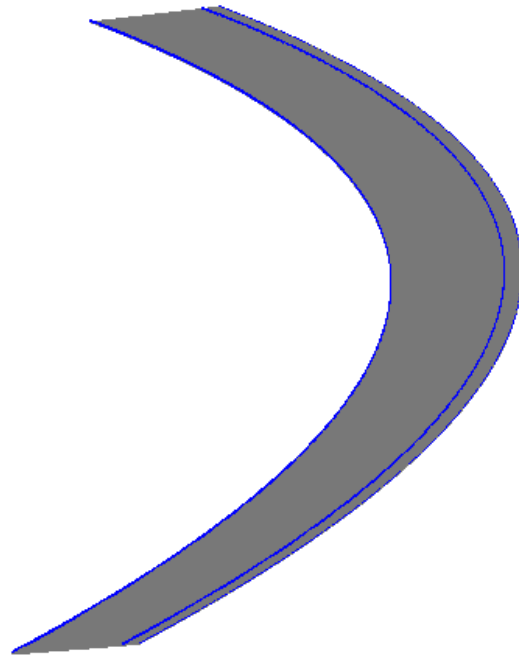


Figure 5: Corridor in Autodesk Civil3D

The outputs of Civil3D model are

1. the polygon of the asphalt (from the edge of asphalt layer),
2. the coordinate list of points on asphalt edge,
3. the planned surface and
4. planned cross slopes in function of station numbers.

Station	Offset	Northing	Easting	Elevation	Description
93+700.00	-9.55	207414.611	728030.128	90.907	ETW_SubBase
93+700.00	-9.55	207414.611	728030.128	90.947	ETW
93+700.00	-1.3	207406.483	728028.716	91.361	ETW_SubBase
93+700.00	-1.3	207406.483	728028.716	91.401	ETW
93+701.00	-9.55	207414.442	728031.106	90.905	ETW_SubBase
93+701.00	-9.55	207414.442	728031.106	90.945	ETW
93+701.00	-1.3	207406.312	728029.7	91.359	ETW_SubBase
93+701.00	-1.3	207406.312	728029.7	91.399	ETW
93+702.00	-9.55	207414.273	728032.084	90.903	ETW_SubBase
93+702.00	-9.55	207414.273	728032.084	90.943	ETW
93+702.00	-1.3	207406.143	728030.685	91.357	ETW_SubBase
93+702.00	-1.3	207406.143	728030.685	91.397	ETW

Table 3. *Part of the left-side point cloud report*

The Civil3D surface file that can be generated by exporting your surface as a *stl* (industry standard file format for 3D modelling and 3D printing) file. The export is done by going to the Civil3D main menu, export, and selecting other formats. From here you can save the file as a stereolithography (*stl*) file. You then select the section of the road that you want the surface for as can be seen in **Fig. 6**, which can be viewed on CloudCompare or any other 3D viewing platform.

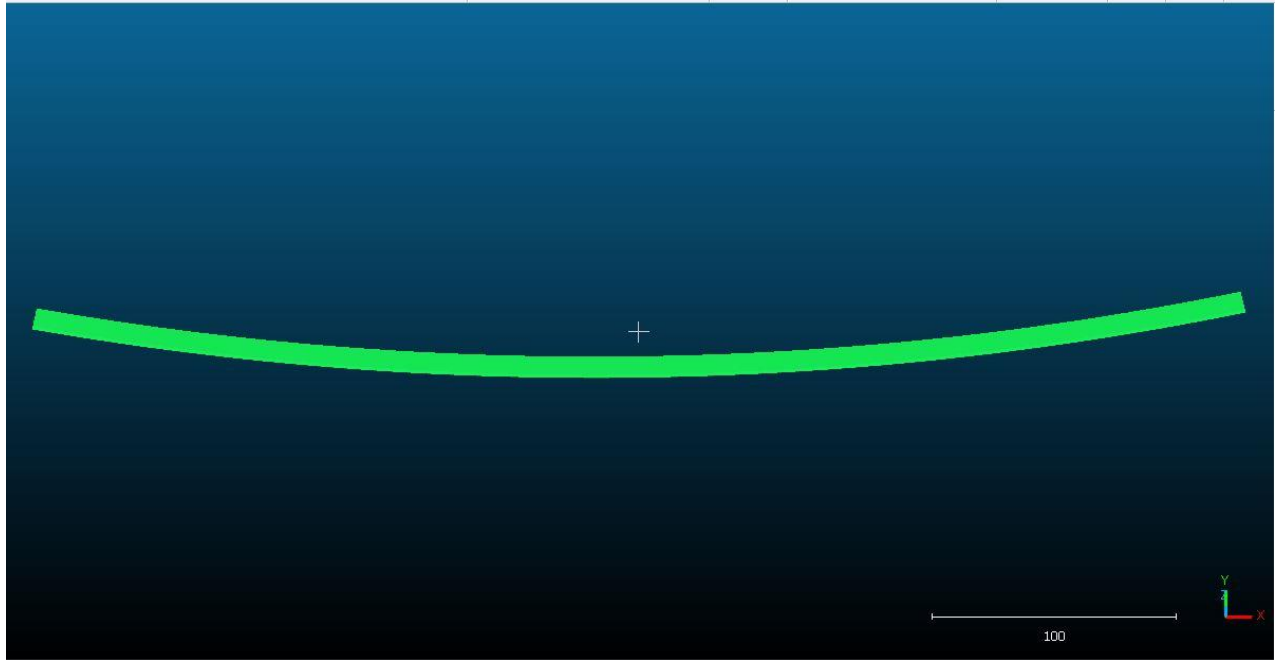


Figure 6: Surface of road

3.2. Point cloud processing and evaluation

3.2.1. *Segmenting the point cloud*

The point cloud that I used comes from a drone photogrammetry survey, which is available in *ply* format, made up of **82 198 326** points (as shown in **Fig. 7**), for an approximately 500 m long road segment.



Figure 7: Original point cloud.

Importing the *dxf* file gives the closed polygon as shown in **Fig. 8** and it's important to note that only points on the asphalt layer (that I will later try to segment) are relevant.

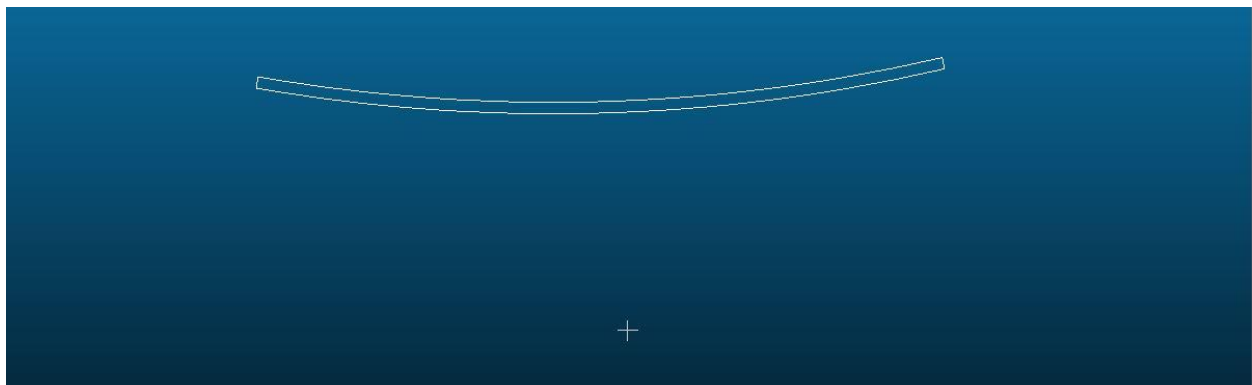


Figure 8: Polygon for segmentation

The segmentation is done between the points inside and outside the polygon, thus cutting up the point cloud into two parts. I just turned off the part that is not relevant for this, as shown by **Fig. 9**.

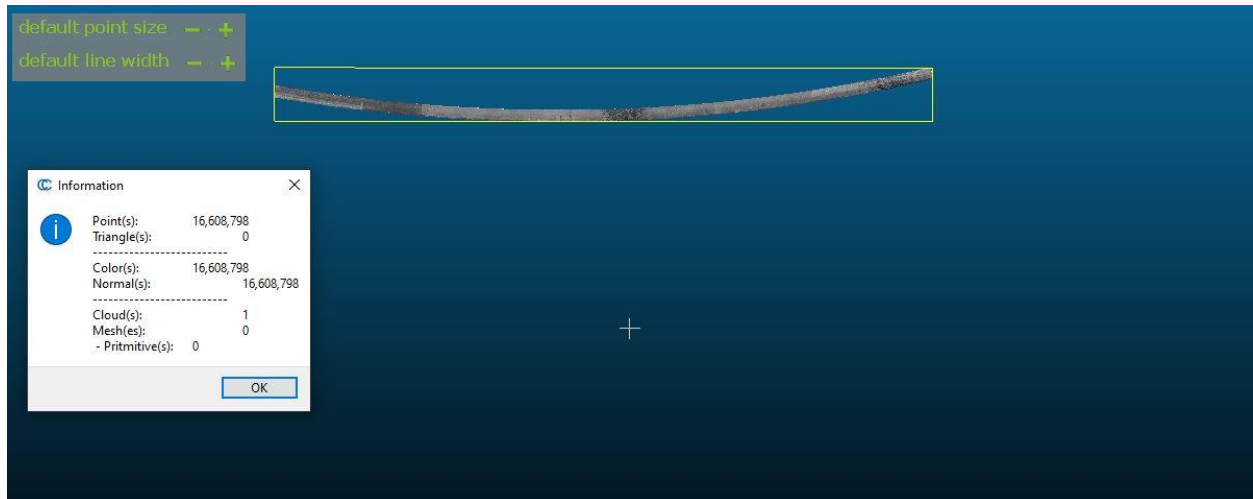


Figure 9: Segmented point cloud.

3.2.2. Cloud to mesh

Turning off the other point cloud helps in focusing on the segmented point cloud and checking the quality of the asphalt layer within the polygon. This segmented point cloud is made up of **16 608 798** points, lot less than the original. From the segmented point cloud and mesh, I computed the cloud mesh distances (distance from each point cloud to the mesh), which outputs the **histogram** as shown in **Fig. 10**.

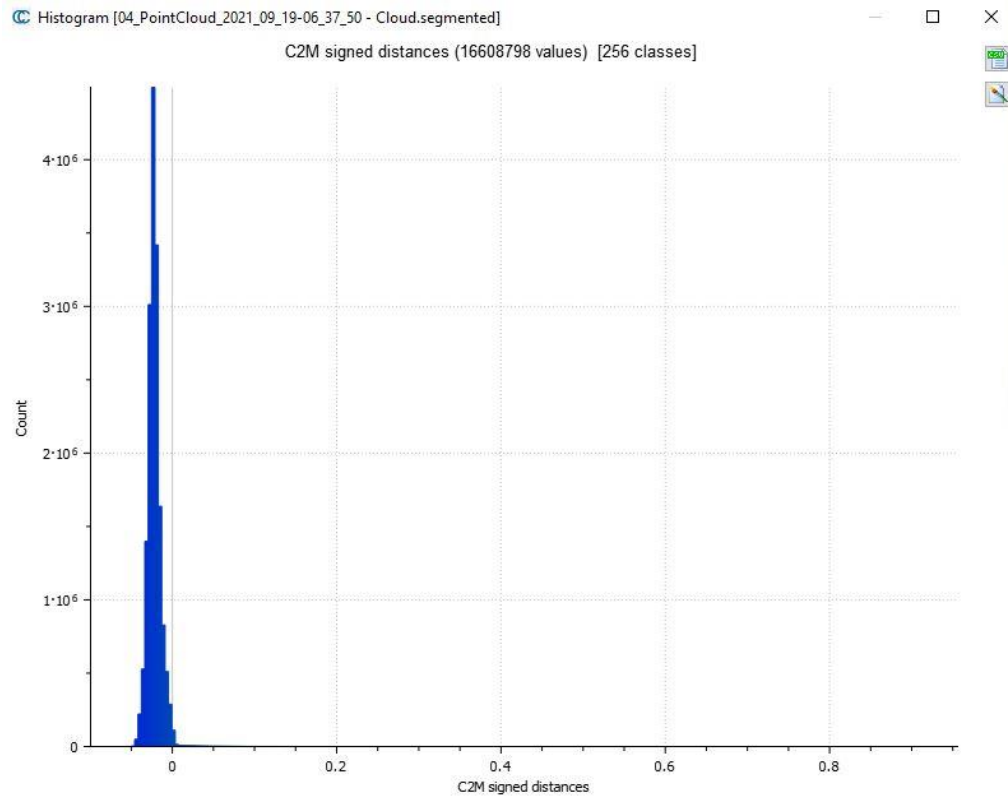


Figure 10: Histogram of vertical deviations

Distances on the histogram can be read as 5 cm readings, and majority of the points have a vertical deviation between 0 and +5 cm. In an ideal situation where the construction is perfect, the distances/deviations would be zero. What we want to investigate is the distribution of these distances, and cloud compare shows a minimum value of the distance as **-0.096 m**, maximum value of the distance as **+0.996 m**, mean distance of **+0.018 m** and standard deviation of **0.008 m**, giving a more detailed surface of the road with the vertical deviations as can be seen in **Fig. 11** and **Fig. 12**.

It means that we have a few vertical deviations around +1 meter, they can be considered as outliers. To have relevant vertical deviations we set the maximum value to **0.100 m**.

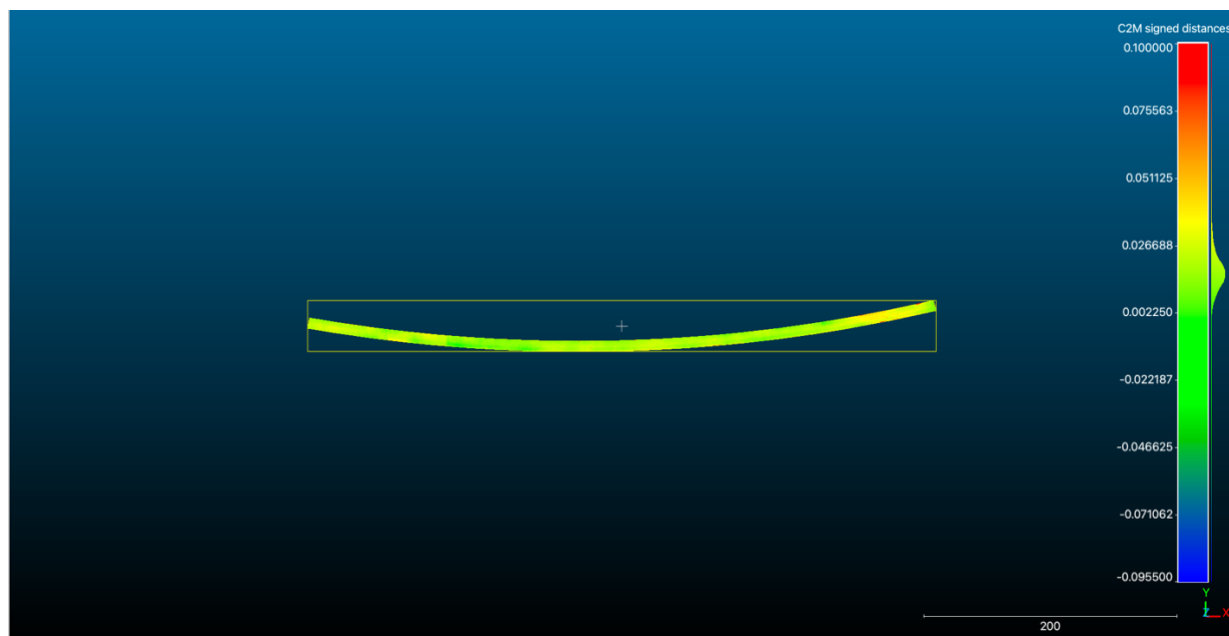


Figure 11: Surface of road with vertical deviations.

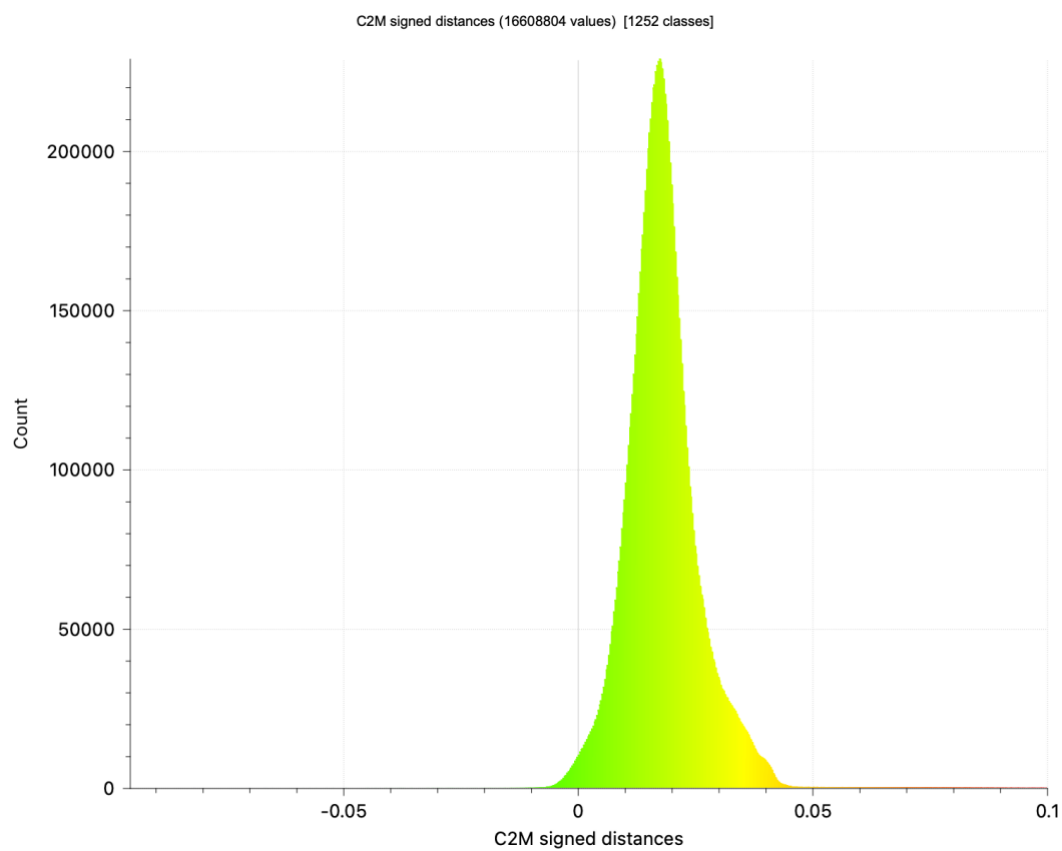


Figure 12: Updated histogram at 1m deviation

3.2.3. Setup grid along centre line

The quality assessment of road pavement layers can be carried out by conventional engineering surveying measurements in discrete points or over the entire surface using point clouds. The locations of discrete points are given in the Hungarian specification [10]; they are in the cross sections of the final construction drawing, hence every 20 or 25 metres along the centreline and in cross-sections at the edges of layers, in the border and the middle of traffic lanes, as seen in **Fig. 13**.

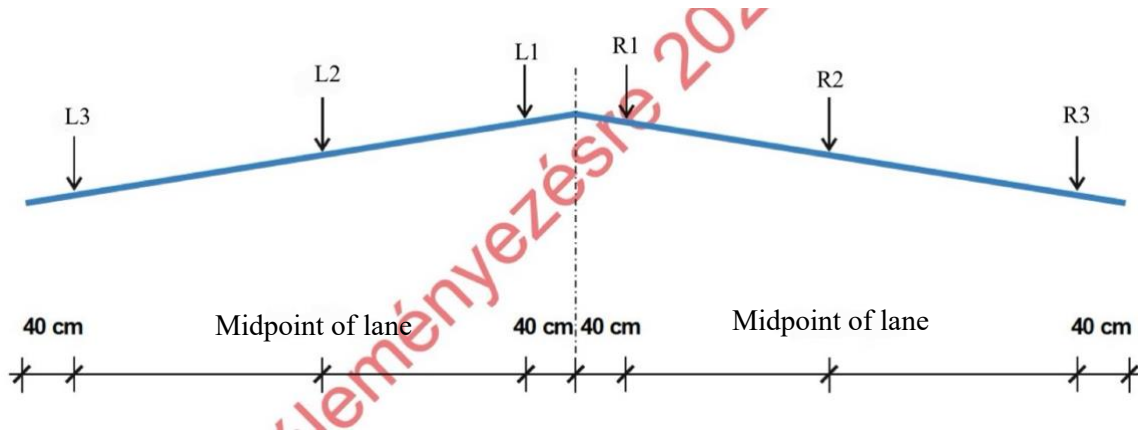


Figure 13: 2X1 traffic lane: pavement rating points [10]

The point cloud shall be used to produce a grid model in which the distance between adjacent points (grid cell size) shall not exceed 1 m. The grid shall be set up along the centreline of the road. Hence, the longitudinal distance between the grid points in transition curves and arcs may increase or decrease due to the curvature of the curves. The distance between the adjacent points of the grid in cross-sections is typically slightly less than 1 metre; the width of the current pavement layer shall be divided into equal parts. In our example, the width of the asphalt layer is 8.25 m; it shall be divided by 9 to get a cross-sectional distance of 92 cm.

The point cloud shall be segmented upon the grid cells, and vertical deviations in every grid cell shall be statistically analysed. A robust and efficient approximation is to get the median of vertical deviations in every grid cell. Other statistical figures such as standard deviations, ranges, mean, histograms, Q-Q plots, and rug plots can also be applied to describe the distribution of vertical deviations and keep the relevant and characteristic features. The median-based method automatically removes outliers, decreases the noise of the point cloud and makes the data size affordable. In our example, the original point cloud consists of 16608804 (16.6M) points, and the grid has 4500 (4.5k) elements. This section of the road could have been surveyed using a traditional engineering surveying method at 100 discrete points.

Developing a grid with 1 metre grid cell size was done by a python scripts, developed by Bence Takács. The main idea of the grid is to reduce noise on the point cloud, as well as reducing the points to a more manageable number. It's important to note that the grid is developed from the vertical deviations, in a grid cell the median of vertical deviations is kept. The python script reads the segmented point cloud having the vertical deviation as a scalar field.

```

PointCloud with 16608804 points.
2004 points read
728030.539 207414.075 0.019 0.019 3494 0.013 0 0 93+700.500 0.458
728030.382 207413.172 0.018 0.018 3616 0.014 0 1 93+700.500 1.375
728030.225 207412.268 0.020 0.019 3711 0.021 0 2 93+700.500 2.292
728030.069 207411.365 0.020 0.020 3751 0.017 0 3 93+700.500 3.208
728029.913 207410.462 0.021 0.021 3752 0.028 0 4 93+700.500 4.125
728029.756 207409.559 0.022 0.022 3777 0.013 0 5 93+700.500 5.042
728029.599 207408.656 0.020 0.020 3764 0.013 0 6 93+700.500 5.959
728029.443 207407.752 0.019 0.019 3835 0.012 0 7 93+700.500 6.875
728029.286 207406.849 0.021 0.021 3852 0.011 0 8 93+700.500 7.792
728031.517 207413.906 0.015 0.014 3440 0.013 1 0 93+701.500 0.458
728031.361 207413.003 0.016 0.016 3458 0.015 1 1 93+701.500 1.375
728031.205 207412.099 0.016 0.017 3616 0.013 1 2 93+701.500 2.292
728031.049 207411.196 0.018 0.018 3763 0.011 1 3 93+701.500 3.208
728030.894 207410.293 0.021 0.021 3885 0.018 1 4 93+701.500 4.125
728030.738 207409.389 0.022 0.022 3863 0.016 1 5 93+701.500 5.042
728030.582 207408.486 0.022 0.022 3820 0.011 1 6 93+701.500 5.958
728030.426 207407.583 0.021 0.021 3930 0.012 1 7 93+701.500 6.875

```

Figure 14: First few lines of the grid data

The grid (**Fig. 14**) helps to decrease the total number of points that need to be analysed, which is good for us because the grid is visualized by colour codes. The colours categories can be interpreted as: green is prescribed, yellow is convenient, and red is failed. In the Hungarian regulation we have these three categories. Convenient needs to be explained, its tolerance is higher than the prescribed one. However, convenient deviation does not affect the proper use of the road. In case having deviations in convenient category, the original undertaking price can be decreased, the details are also described in the Hungarian regulation [11]. Regarding our example, the different tolerances are presented in **Table 4**. Their values depend on design speed, are of evaluation. There are different tolerances to individual values and to the mean of all deviations.

Name of the threshold level	Design speed, km/h					
	≥90			<90		
	Evaluation section area, m ²					
	<15000	15000-30000	30000<	<15000	15000-30000	30000<
Individual prescribed limits, mm	Required level ±30			Required level ±35		
Individual compliance limits, mm	Required level ±40			Required level ±50		
Average deviation from prescribed limits, mm	-	±20	±15	-	±25	±20
Average deviation compliance limits, mm	-	±27	±20	-	±35	±27

Table 4. Height requirements for asphalt pavement classification points for development work.

4. RESULTS AND DOCUMENTATION

4.1. Vertical deviations

Now that we have the grid from the point cloud, the next task is to present individual vertical deviations in a plan. This can be done easily in QGIS. Points are categorized upon the following tolerances: green (< 30 mm), orange (< 40mm) and red (> 40mm). **Fig. 15** shows the entire section, while **Fig. 16** shows a closer look at those sections that are mixed deviations and **Fig. 17** shows a closer look of those sections that are “prescribed” deviations.

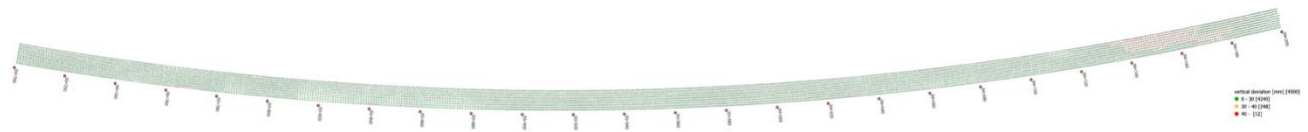


Figure 15: Grid in plan

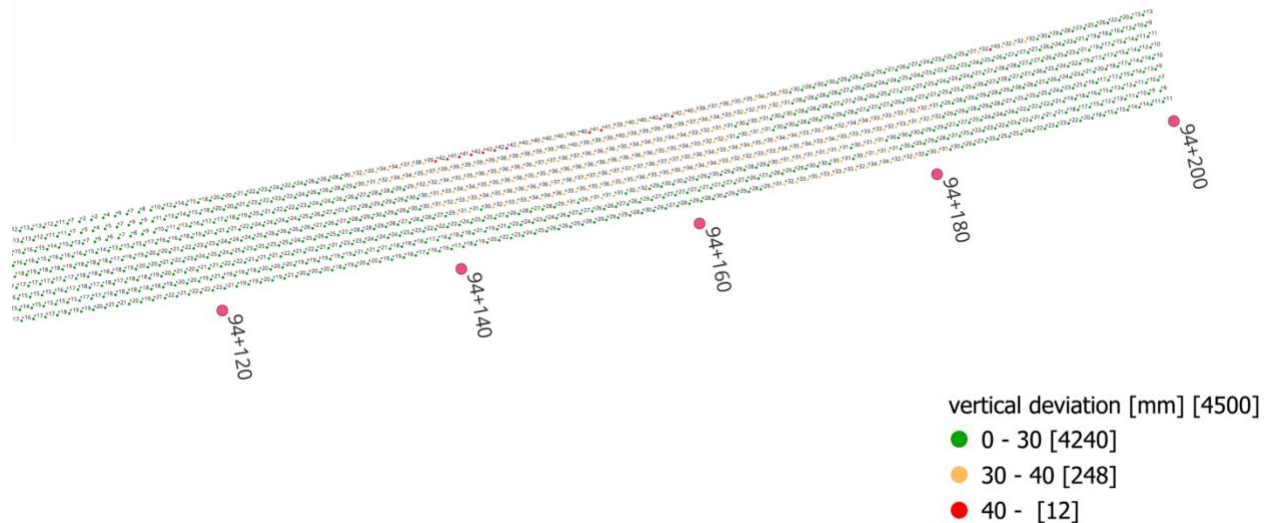


Figure 16: Grid in plan of mixed deviations

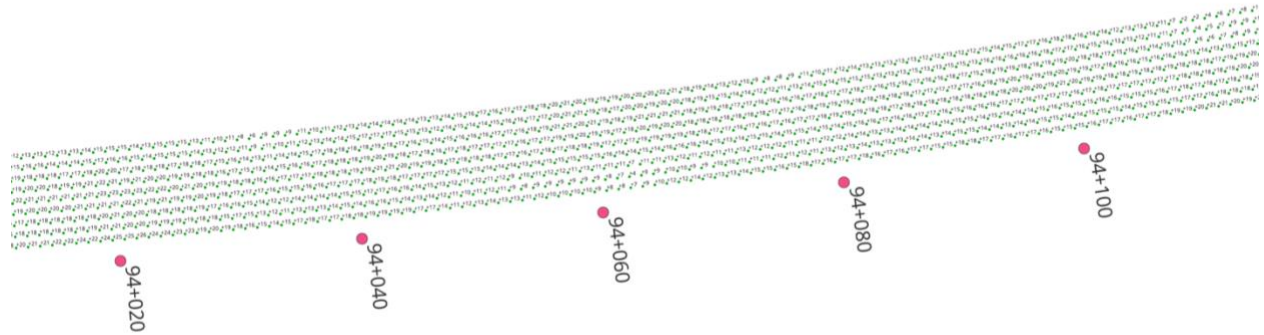


Figure 17: Grid in plan of prescribed deviations

The next task in the documentation is to present how many vertical deviations of grid points are in the prescribed, convenient and failed category. This can be done in histogram **Fig. 18**.

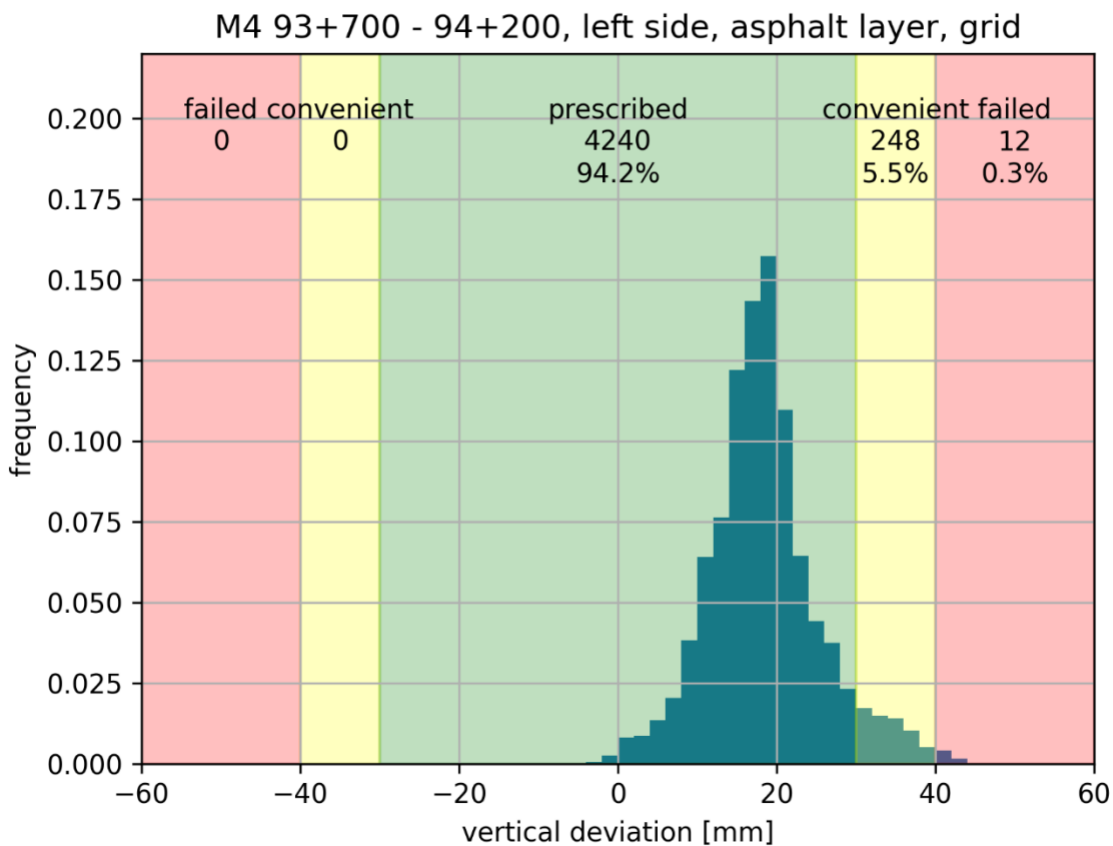


Figure 18: Empirical density function of height deviations versus individual threshold levels

The peak of the histogram is 18 mm, which meets the limit value (20 mm) as stated in the Hungarian regulations. From the histogram, 94,2% of the points are with prescribed quality meaning that they fall within the limit of 30 mm, 5.5% of the points are convenient meaning that their vertical deviations are between 30 and 40 mm, and only 0,3% of the points are outside the convenient limit but the maximum value is 43 mm. According to the Hungarian regulation [11], the whole project has prescribed quality, since the mean value is prescribed, less than 10% of the deviations are convenient and those are failed are less than 1% of the whole data and none of them is higher than 1.5 x convenient limit.

4.2. Cross slope values

Another task is to analyse cross slope values. This can be done in a figure presenting either the actual or the planned cross slope values with respect to station numbers (**Fig. 19**). The figure shows the prescribed (0.45) and convenient (0.60) tolerances, as well as **Table 5**. All the cross-slope values can be characterized with prescribed quality, which can be seen in the histogram plot of cross-slope deviations as shown in **Fig. 20**.

Name of threshold level	Design width of the wear layer surface with the same lateral inclination, m								
	>10			>5 – 10			2,5 – 5		
	Evaluation section area, m ²								
	<1500 0	15000 - 30000	30000 <	<1500 0	15000 - 30000	30000 <	<1500 0	15000 - 30000	30000 <
Specific prescribed limits, mm	Required level ±0,40			Required level ±0,45			Required level ±0,70		
Individual compliance limits, mm	Required level ±0,55			Required level ±0,60			Required level ±0,90		
Average deviation prescribed limit, mm	-	0,25	0,20	-	0,30	0,25	-	0,45	0,35
Average deviation compliance limit, mm	-	0,35	0,27	-	0,40	0,35	-	0,60	0,45

Table 5. Side slope requirements for development work on roads with a design speed of 90 km/h or more

The cross slopes are computed as follows: the algorithm takes the first and last grid points in one section, computes their height difference and distance, their rate is the cross slope. Having the grid with vertical deviations, this yields the difference between planned and measured cross slope. Another algorithm is filter out points in the point cloud in the actual cross-section with a specific width, filter out outliers with a robust algorithm, fit a line to the points using regression, and the cross slope can be considered as the gradient of the regression line.

All the plots were created by python scripts developed by Bence Takács.

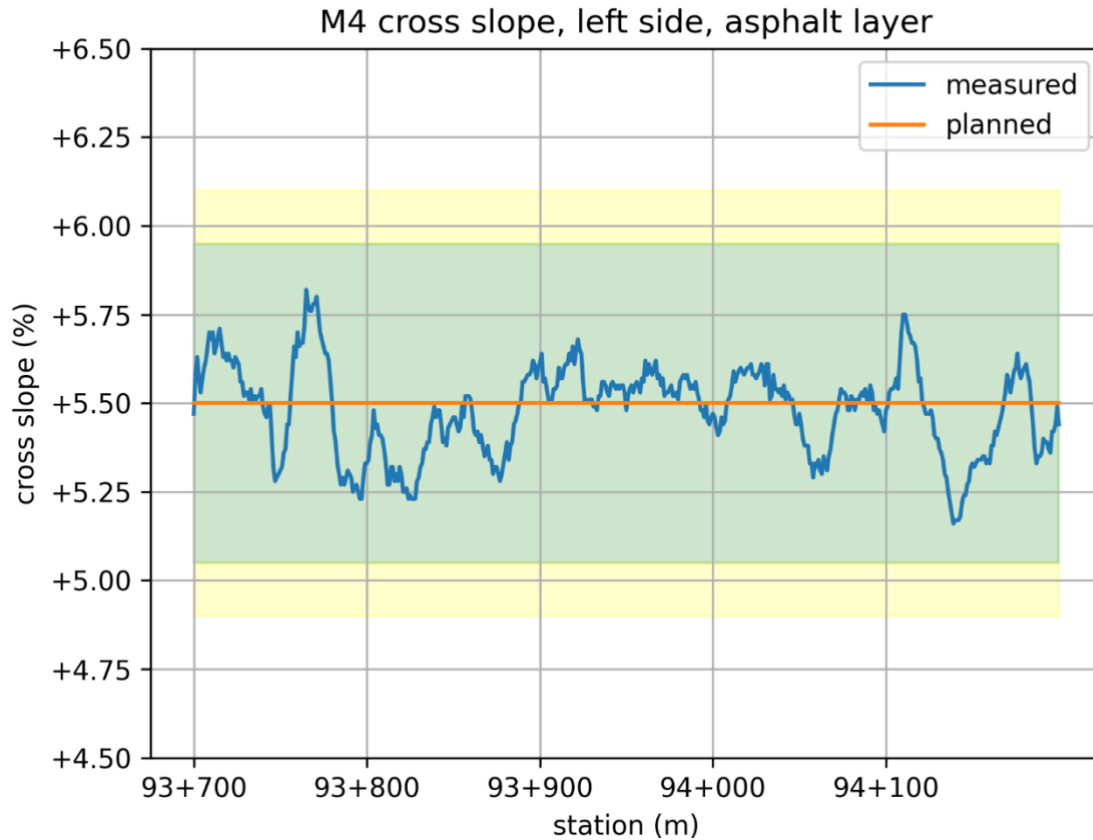


Figure 19: Cross slope versus station number plot.

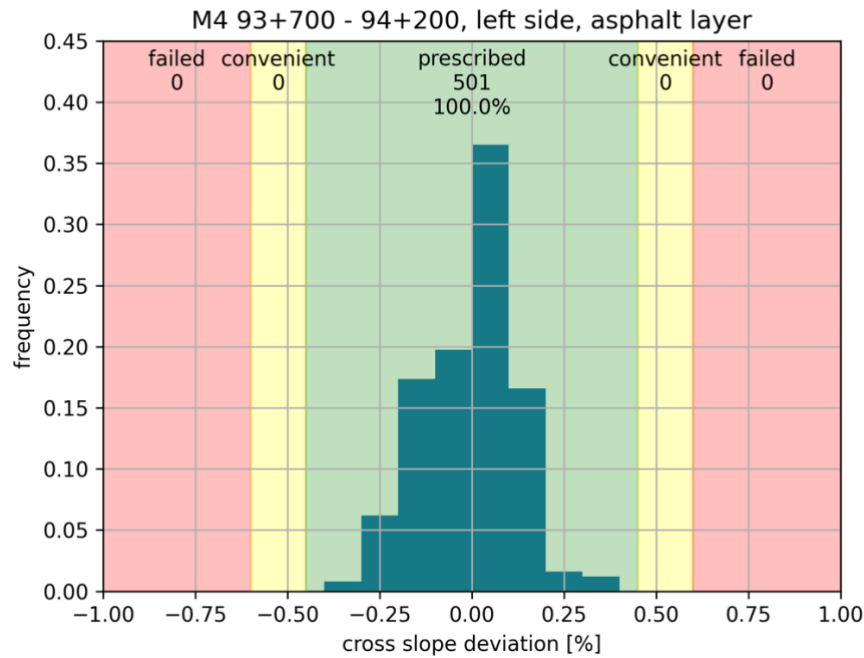


Figure 20: Empirical density function of cross slope slopes versus individual threshold levels. Green for prescribed, yellow for convenient, and red for failed.

One more python script is used that inputs the point cloud data in txt, the cross-section points in MS Excel and generates the cross section as shown in **Fig. 21**. The figure only shows one of the sections out of many.

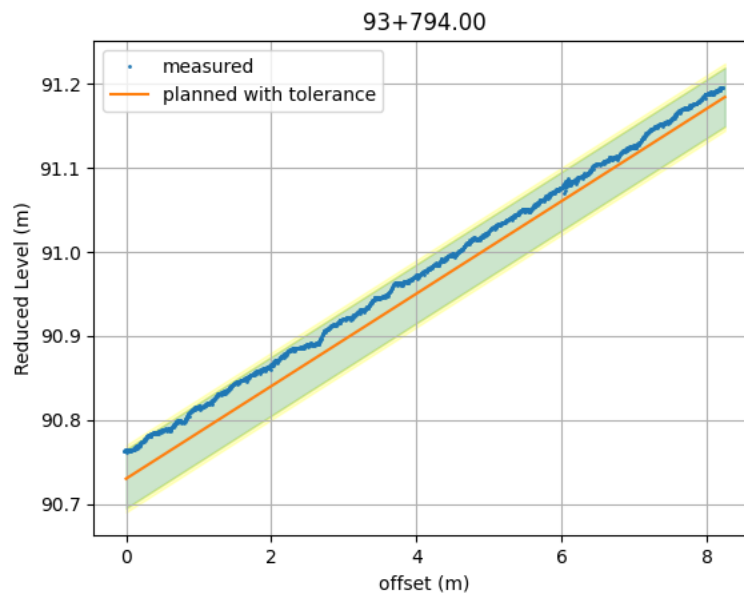


Figure 21 : Cross section plot versus station number

5. CONCLUSION

With the ability to create very detailed and comprehensive road surface models, point clouds are helpful data for road construction. The use cases of these models vary, and can include identification of pavement problems, assessing deviations from design plans, and make simulations with high degree of accuracy requirement possible.

Despite its promising applications in road construction, it still carries some challenges and considerations that need to be investigated, such as:

- There are several factors that can prevent the accurate detection of road elements for the point cloud, such as obstructions from temporary structures, construction equipment, as well as limited locations where points can be obtained. All in all, the accuracy of the analysis of point clouds is dependent on the quality of the point cloud and its density.
- Processing of large point cloud datasets can be time consuming and computationally intensive, especially for things like crack detection.

In the thesis we presented the method described in the new Hungarian regulation [11] which is being introduced. The method talks about the quality assessment of the whole surface not just discrete sections and points as is the case in conventional engineering surveying methods. The results conform with the guidelines outlined in the regulations, which shows that they can be used to assess point cloud data to check the quality of a road project.

There remain some issues with the technology as outlined previously. Further research on the application of point clouds in road construction is required, and the development in point cloud processing algorithms and their integration with other technologies such as BIM will enhance its applications, resulting in more efficient, safe and economical projects.

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