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Galina L. Kozinets, professor, Head of Civil Engineering Institute,
Peter the Great St.Petersburg Polytechnic University, Civil Engineering Institute, St.Petersburg, Russia,
kozinets_gl@spbstu.ru

Petr V. Chernov, tutor, Peter the Great St.Petersburg Polytechnic University,
Civil Engineering Institute, St.Petersburg, Russia,
chernov_pv@spbstu.ru

Natalia S. Kolotvina, leading specialist,
Peter the Great St.Petersburg Polytechnic University, Civil Engineering Institute, St.Petersburg, Russia,
muromtseva_ns@spbstu.ru

CONTINUED MONITORING OF TIMBER STRUCTURES

Abstract. This study is devoted to the monitoring of strongly deformable wooden structures located in hard-to-reach places, without the possibility of precise binding to the reference points. The binding to stable objects in the surrounding landscape, such as large rocks, was tested. We investigated the deformations that occurred during the winter period from November 2020 to May 2021, which were caused by soil settlement under the base of the bridge. The relative deformations of the bridge structure were investigated, taking into account the soil settlement. The results are compared with the results of finite element modeling.

Key words: wood-composite structures, laser scanning, point cloud registration, finite element modeling, monitoring of wood structures.

Галина Леонидовна Козинец, доктор технических наук, профессор, директор Инженерно-строительного института, Санкт-Петербургский политехнический университет Петра Великого,
Инженерно-строительный институт, Санкт-Петербург, Россия,
kozinets_gl@spbstu.ru

Петр Владимирович Чернов, тьютор, Санкт-Петербургский политехнический университет Петра Великого,
Инженерно-строительный институт, Санкт-Петербург, Россия,
chernov_pv@spbstu.ru

Наталия Сергеевна Колотвина, ведущий специалист,
Санкт-Петербургский политехнический университет Петра Великого,
Инженерно-строительный институт, Санкт-Петербург, Россия,
muromtseva_ns@spbstu.ru

МОНИТОРИНГ ДЕРЕВЯННЫХ КОНСТРУКЦИЙ

Аннотация. Настоящая работа посвящена мониторингу деревянных сильнодеформируемых конструкций, находящихся в труднодоступных местах, без возможности точной привязки к реперным точкам. Была апробирована привязка к стабильным объектам окружающего ландшафта, таким как большие камни. Были исследованы деформации, возникшие за зимний период с ноября 2020 по май 2021 г., которые были вызваны осадкой грунта под основанием моста. Были исследованы относительные деформации конструкции моста без учёта осадки грунта. Результаты сопоставлены с результатами конечно-элементного моделирования.

Ключевые слова: дерево-композитные конструкции, лазерное сканирование, регистрация облаков точек, конечно-элементное моделирование, мониторинг деревянных конструкций.

1. Introduction

There is a problem of control over wooden structures and their base on which these structures are installed, namely wooden bridges on concrete blocks in remote areas where there are no geodetic marks (benchmarks) regarding which to monitor the object. There are also no marks on the site to control this structure. In connection with the above, a Leica BLK360 3d scanner and Leica Cyclone and CloudCompare post-processing software complexes were used to monitor the state of this structure. This technology makes it possible to obtain data in the form of clouds of points of geometric samples on the surface of an object, from which, using the software package, these points can be extrapolated to recreate the shape of the object, i.e. to obtain a 3d model of the object itself, as well as trees, bushes and other surrounding surfaces. Having made several surveys of this object, it is possible to carry out a comparative analysis of the obtained models in order to identify the differences between them, i.e. changes in the design of the investigated object. The bridge, which was under control, is located in the «Vepsskiy Les» (Veps forest) Nature Park.

The reserve is located in the southern part of the Podporozhsky district, the northeastern part of the Tikhvin and Lodeynopolsky districts, and the northern part of the Boksitogorsky district. The natural park «Vepsskiy Les» is a specially protected natural complex with typical landscape tracts; high-age indigenous spruce forests, practically not affected by economic activity, high-age forests of other species; rejection of coal rocks, which are geological and geomorphological anomalies; massifs of raised sphagnum bogs of the Western Russian type; oligotrophic and dystrophic lakes; lakes in the zone of faults in bedrock; sources and upper reaches of rivers and streams belonging to the basin of the Oyat and Kapsha rivers; the valleys of the Urya and Kanzhai rivers, especially in the lower reaches, their tributaries; types of soils listed in the Red Book of Soils of the Leningrad Region.

2. Methods

To identify changes in the design of the object under study, the following algorithm will be applied as the most optimal for comparing two point clouds, the ICP (or Cloud-to-Cloud) algorithm was chosen.

(ICP) is an algorithm used to minimize the difference between two point clouds. The algorithm is conceptually simple and is often used in real time. It reapplies the transforms (displacement, rotation) necessary to minimize the distance between points from two raw scans. Inputs: points from two raw scans, initial evaluation of transformation, criteria for stopping iteration.

Previously, all merged point clouds were cleaned using the SOR algorithm. Laser scanning typically generates point cloud datasets with varying point densities. In addition, measurement errors lead to sparse emissions, which further distort the results. This makes it difficult to evaluate the local characteristics of the point cloud, such as surface normals or curvature changes, leading to erroneous values, which in turn can lead to point cloud registration failures. Some of these irregularities can be eliminated by performing a statistical analysis of the vicinity of each point and trimming those that do not meet a certain criterion. Sparse outlier removal is based on calculating the distribution of distances between points and neighbors in the input dataset. For each point, the average distance from it to all its neighbors is calculated. Assuming that the resulting distribution is Gaussian with mean and standard deviation, all points whose mean distances are outside the range defined by the global mean distance and standard deviation can be considered outliers.

The merged and registered point clouds are provided in Figures 1, 2. Figure 1 shows the merged point cloud made in November 2020, which consists of 21 million points, and the point cloud in Figure 2, made in May 2021, which consists of 19 million points. Each merged point cloud consists of 7 registered point clouds. The figures are presented below.

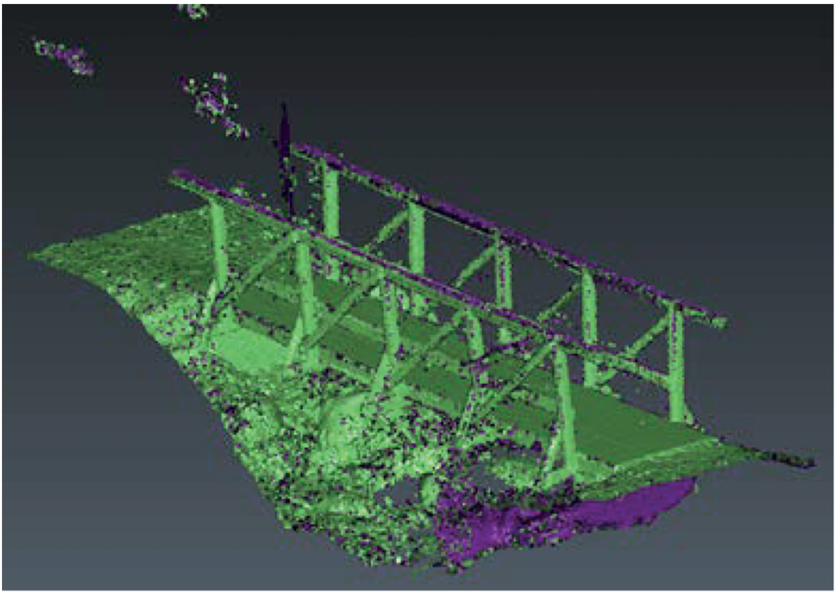

Figure 1. Point Clouds - November

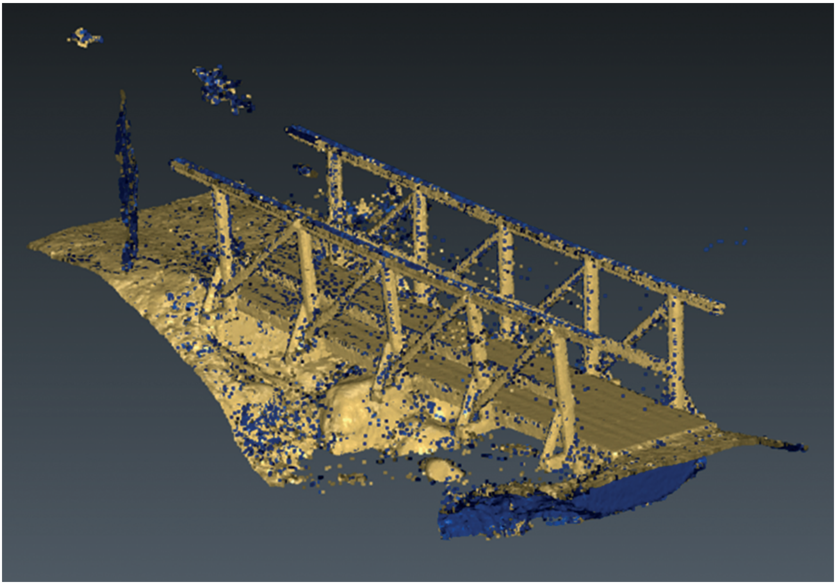

Figure 2. Point Clouds - May 2021

When comparing the registered merged clouds of points 3 and 4 using the ICP method, we get the attraction of all objects to all objects, which in this case is not acceptable. On the cloud of points 3, we see noise from the grass on the left side, whereas on the cloud of points 4, we see clean land, respectively, when registering, the earth will be attracted to the middle plane of the surface of the grass, which will give unacceptable distortions. In order to prevent this, segmentation is necessary. And the selection of the most stable areas, which can be snapped. The boulders in the riverbed in Figures 3, 4 were chosen as such a stable site.

These boulders have a smooth surface and a pronounced relief, making them ideal for registration and use of ICP. After registration, we will be able to compare both objects in the same coordinate system.

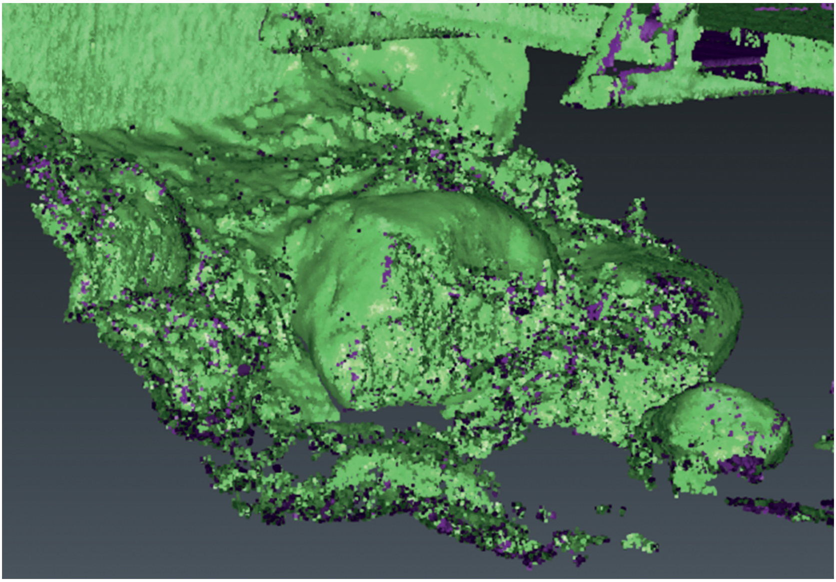

Figure 3. Point clouds (cobblestones in the riverbed) - November

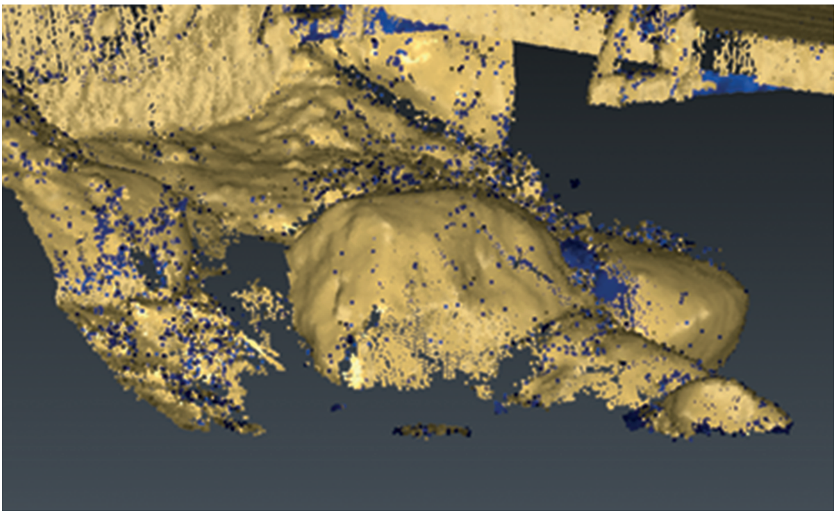

Figure 4. Point clouds (cobblestones in the riverbed) - May 2021

3. Results and discussion

Boulders were registered on a segmented point cloud. Over 80% Final Overlap was chosen as conditions. The final RMS was 0.0058. Figure 5 shows the registered cobblestones.

After obtaining the transformation matrix for the segmented point cloud, this transformation matrix was applied to the base point cloud, as a result, both steel point clouds are in the same coordinate system. Other objects that could be used as stable objects included trees, but the use of trees was rejected due to their high flexibility. The concrete base of the bridge could not be chosen as a stable object due to the fact that it is part of the object under study. After applying the transformation matrix to the main point cloud, and merging them into one coordinate system, the point clouds were compared. For comparison, the method of finding the nearest points and the same normals was used. The result is shown in Figure 6.

Figure 6 shows that part of the bridge on the right bank of the river has deviations of about 18 mm. In the picture above, deviations of more than 24 mm are also visible. These deviations are caused by vegetation in the first point cloud and are not taken into account. Upon further analysis, it was revealed that the deformations were caused by the movement of the concrete base of the bridge (Fig. 7).

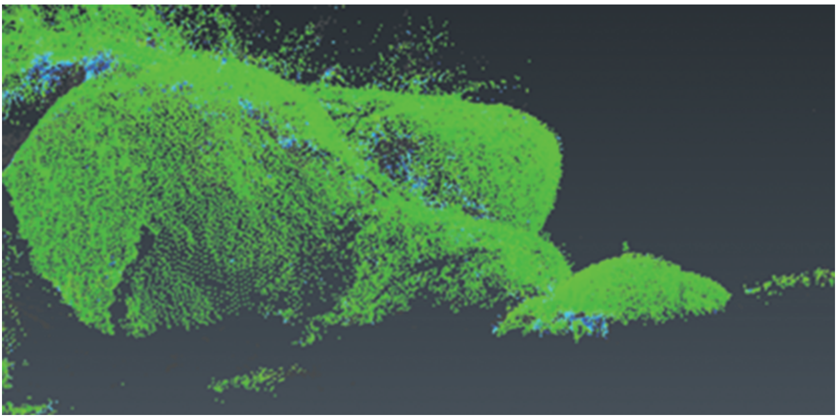

Figure 5. Cobblestones

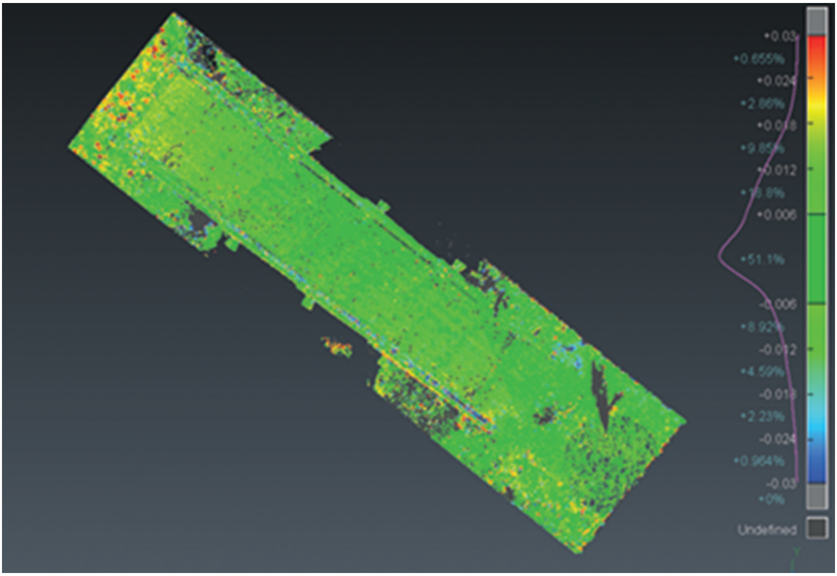

Figure 6. The result of comparing two point clouds

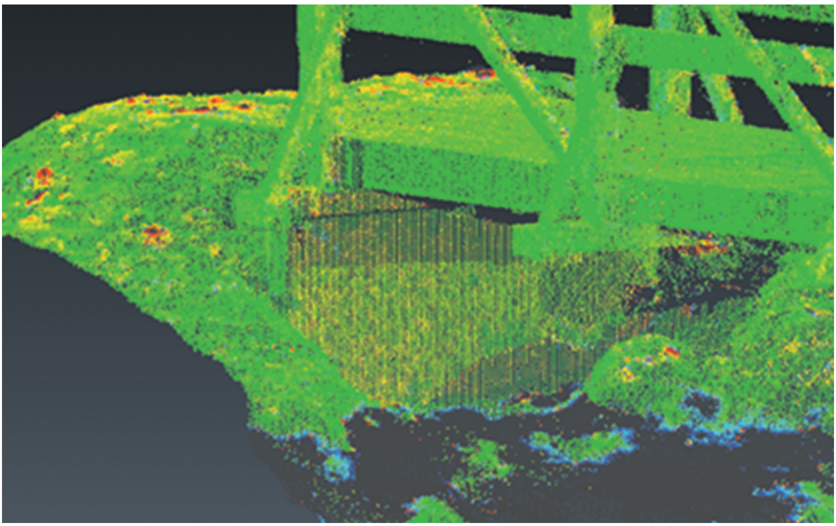

Figure 7. Moving the concrete base

It can be seen that the movements are caused by the movement of the concrete base. Deformations are uneven due to the slump of the concrete block occurring at an angle. The bridge is twisted in a spiral shape, probably 2 or 3, it can be seen in the picture that one half (along the axis of the bridge!) turns. The movements of the concrete base have a minimal effect on the reliability of the wooden structure.

The second stage was the study of the plane of the surface of the working part of the bridge. For this, the middle plane was built (with the normal z = 1). The distance from the plane to the surface of the bridge is shown in Figures 8, 9.

According to the results of the analysis of the constructed plane, the deflections were found to be a maximum of 20 mm, which is 20/6000, or 1/300 of the deflection, which is a good result even for the metal structure (deflections up to 1/200 span), taking into account that in previous studies [] , it was noted that the ultimate deflections for a given cellular construction are 1/25 of the span for the reinforced one and 1/40 for the non-reinforced one.

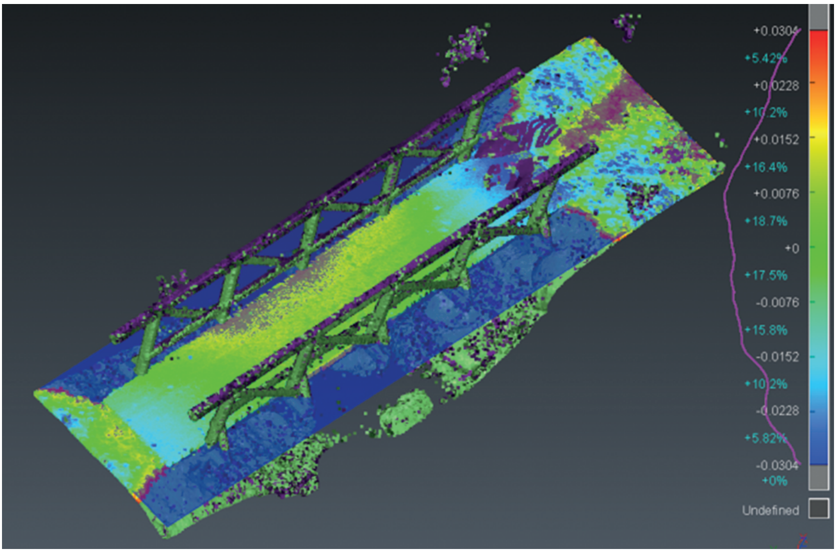

Figure 8. Bridge Cover Plane - November 2020

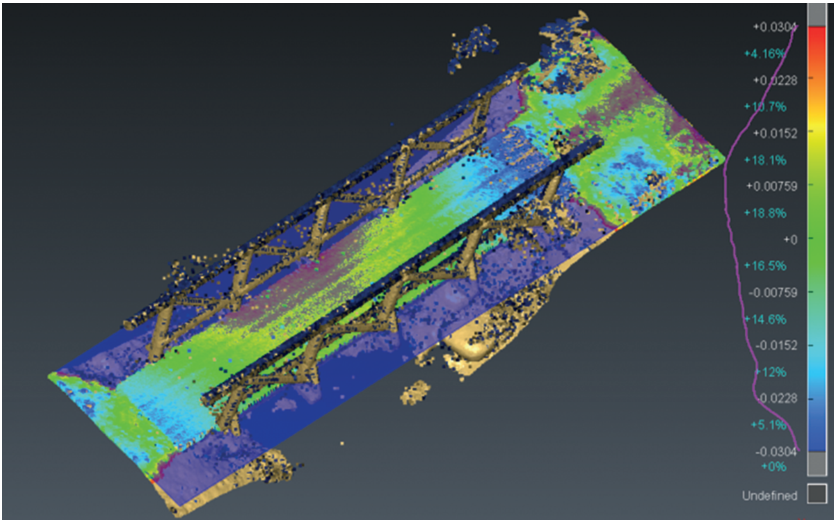

Figure 9. Bridge Cover Plane - May 2021

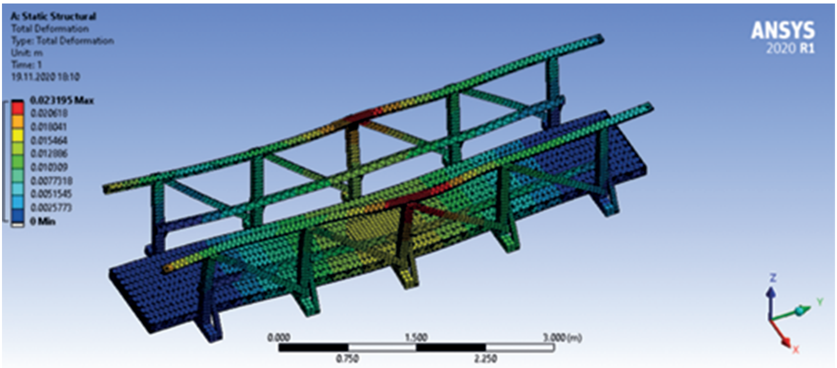

Figure 10. FEM model

The results agree with the FEM results. Based on the solid model of the bridge, the FEM model was built, shown in Figure 10.

4. Conclusions

Ground-based laser scanning with subsequent registration using ICP is the best method for monitoring wooden structures in conditions where reference points are not feasible.

Cellular timber structures are the optimal solutions for creating solid timber structures.

The accuracy of the terrestrial laser scanning is sufficient to monitor the deflections of the structure.

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