DOI: https://doi.org/10.37434/tpwj2023.08.08

# REMOTE ASSESSMENT OF DAMAGES OF THE KYIV TV TOWER BASED ON THE USE OF AERIAL PHOTOGRAPHY AND THE METHOD OF PHOTOGRAMMETRY

**L.M. Lobanov[1], D.I. Stelmakh[1], V.V. Savitsky[1], V.P. Diadin[1], O.P. Shutkevych[1], A.G. Kozachek[2]**

[1]E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine
[2]Broadcasting, Radiocommunications & Television Concern
10 Dorogozhytska Str., 04112, Kyiv, Ukraine

**ABSTRACT**

The article is devoted to the use of non-destructive testing and visual inspection methods using UAVs (drones) to assess damages of the TV tower structure. The methodology is described including the use of aerial photography and photogrammetry method to create a 3D TV tower model and localization of damages. With the use of 3DF Zephyr software, a 3D model was built, which allowed setting the sizes of defects and classifying them. On the basis of the carried out examination, recommendations for prompt repair and restoration of the TV tower were developed to provide the safety of its operation. The presented results confirm the high potential of combining traditional methods of non-destructive testing with remote diagnostics based on the use of drones and photogrammetry for inspection of large-sized structures.

**KEYWORDS:** UAV (drone), photogrammetry, non-destructive testing, 3D model, visualization, TV tower

## INTRODUCTION

Prevention of emergency situations and providing reliable operation of large-sized structures involves regular preventive measures to maintain their technical condition. The aim of examination of large-sized structures is to reveal possible drawbacks, defects or potentially problematic zones that require maintenance. In the case of large-sized structures, for effective detection of defects, specialized additional equipment should be used, which complicates the process, makes it long-term, labour-consuming and dangerous for performers [1]. In addition, for successful examination, professional climbers should be involved and it is necessary to obtain permits for their work. In many cases, there are also places with a limited view and a difficult access, which reduces the effectiveness of damage detection.

One of the possible methods to overcome the abovementioned limitations is the use of unmanned aerial vehicles (UAVs). However, the presence of qualified engineers on site continues to play a fundamental role in performing the examination task (for example, a pilot, a second pilot, an expert in the field of material diagnostics). In addition, to obtain objective results, it is important to eliminate the dependence of their checking on experience, physical aspects and skill set of UAV operator. The results cannot be achieved in real time and some defective places must be confirmed and examined repeatedly. Therefore, experienced professional specialists in the field of non-destructive quality testing are required.

The article describes the procedure for examination of the Kyiv TV tower, which was damaged by an enemy missile strike on March 1, 2022 as a result of Russia's military aggression. The Kyiv TV tower, an all-welded metal spatial lattice high-rise 380 m tall erection, built in 1968–1973, was the highest lattice freely located erection in the world at the time of construction [2, 3]. Taking into account that PWI of the NAS of Ukraine and LLC "V.M. Shimanovskyi Ukrainian Institute of Steel Construction" were the authors of the project of this unique engineering structure, examination and assessment of the technical condition of the tower metal structures was performed by these organizations.

The visual and instrumental inspection of the tower metal structures in the missile strike area from the mark +0.000 to + 80.000 was performed in four stages using the following methods of non-destructive testing:

- visual-measuring;
- magnetic flaw detection;
- ultrasonic testing of the base metal and welded joints of the tower elements;
- visual examination with the use of UAVs.

## METHODS OF INSPECTION OF LARGE-SIZED METAL STRUCTURES

Visual-measuring inspection consisted in external inspection of the tower pipe elements, assembly welded joints, facets and other elements of its metal structures. An inspection of the tower metal elements was performed from the marks 0; +5; +40; +72 and +80 m.

The main task of the visual-measuring method of testing was to detect and record all visually observed damages of the elements of the tower metal structures for their further assessment. Thus, depending on the exposure energy of fragments on the pipe walls, several types of damages of the elements of the structure can be distinguished:

- complete penetration of a fragment through a one wall of the pipe without influence on the other wall;
- complete penetration of a fragment through a one wall of the pipe with plastic deformation of the other wall;
- full penetration of a fragment through both walls of the pipe (shot through);
- partial penetration of a fragment into a one wall of the pipe to different depth (crater);
- presence of a dent in the pipe wall without penetration of a fragment;
- deformation of the element under the influence of debris and a shock wave;
- destruction of an element or an assembly of its fastening;
- presence of cracks in the places of exposure of fragments and in the assemblies of elements connection;
- destruction of shock absorbers between the elements.

The peculiarities of using magnetic and ultrasonic methods of testing consisted in the probable detection of hairline through, surface and subsurface cracks in the places of shock impact and penetration of missile fragments through the wall of the tower metal structure elements. In the places of detected damages, photographing with the record of their location place was made.

As a result of the performed inspection of different sections of the TV tower metal structures, it was found that:

1. In the places prone to significant force effect, there were no elongated hidden cracks, i.e., cracks extending on the inner surface or cracks inside the metal, which cannot be visually detected. Almost all of the detected and investigated cracks are a through thickness rupture of the metal. There are few deformed areas where traces of cracking are detected on the inner surface. The assessment of sizes of such cracking is only a few mm.

2. In instrumental inspection of metal in places with obvious plastics and ruptures, the quantitative estimates of cracking sizes are almost equal to visual-measuring estimates, the difference is not more than 2–3 mm.

3. No defects (including cracks) were detected in places distant from the zones of plastic deformation and traces of shock action.

Over the last decade, the widespread use of UAV (drones) has begun to perform a large range of tasks, including for non-destructive quality testing.

While studying damages of the TV tower, the use of this method of diagnostics was predetermined by several reasons. First, the accessible places for visual inspection of damaged structures did not allow inspecting the entire surface of spatial structures because of the restriction of the viewing angles from the places of observation. As a consequence, this significantly complicated the task of the overall assessment of the volumes of destruction of an object as a whole. Secondly, mapping of damages of the elements without their spatial review required considerable time and attracting a large number of climbers for their implementation. In addition to the mentioned reasons, it is also necessary to note the problem of defects identification on the results of visual inspection.

Examination of metal and reinforced concrete structures with the use of unmanned and robotic systems significantly reduces the cost and time of checking, simultaneously increasing the reliability and consistency of the obtained data. In addition, shortening the downtime helps to continue the work for a long period that leads to improving serviceability of critical objects. It should also be noted that in the case of examination of dangerous or difficult-to-access zones, the most effective method to diagnose structures in terms of operating risk, cost and capabilities is the use of drones [1, 4].

However, drones have some restrictions that need to be taken into account. One of the problems during the operation of a drone is vibration. UAVs are often exposed to various sources of vibration that may affect the reliability of the obtained data [5]:

- vibrations caused by external sources, for example, strong wind gust;
- vibrations caused by drone manoeuvres;
- vibrations caused by aerodynamic sources, for example, headwind;
- vibrations caused by the stabilization system itself;
- vibrations caused by engines and propellers.

In the process of examination of the TV tower, some influences of external factors were observed, namely:

- formation of shadows on pipe structures as a result of cloudy weather;
- violation of stabilization because of variable wind flows;
- changing the angle of object illumination;
- attraction to metal structures as a result of effect of electromagnetic equipment.

The specific time when the flight covering structures takes place, may significantly affect the accuracy of the result. For example, shadows, daylight, weather conditions and solar radiation may have a negative impact that leads to inaccurate results [1].

## APPLICATION OF PHOTOGRAMMETRY METHOD FOR FINDING DAMAGES OF THE TV TOWER

Photogrammetry is a technology for obtaining reliable information about physical objects and the environment through the processes of recording, measuring and interpretation of photographic images. As the name of the technology implies, the methodology initially consisted of photo analysis, but the use of film cameras decreased significantly in favour of digital sensors. Photogrammetry was expanded to include an analysis of other records such as digital images, emitted acoustic energy, laser measurements and magnetic phenomena [6].

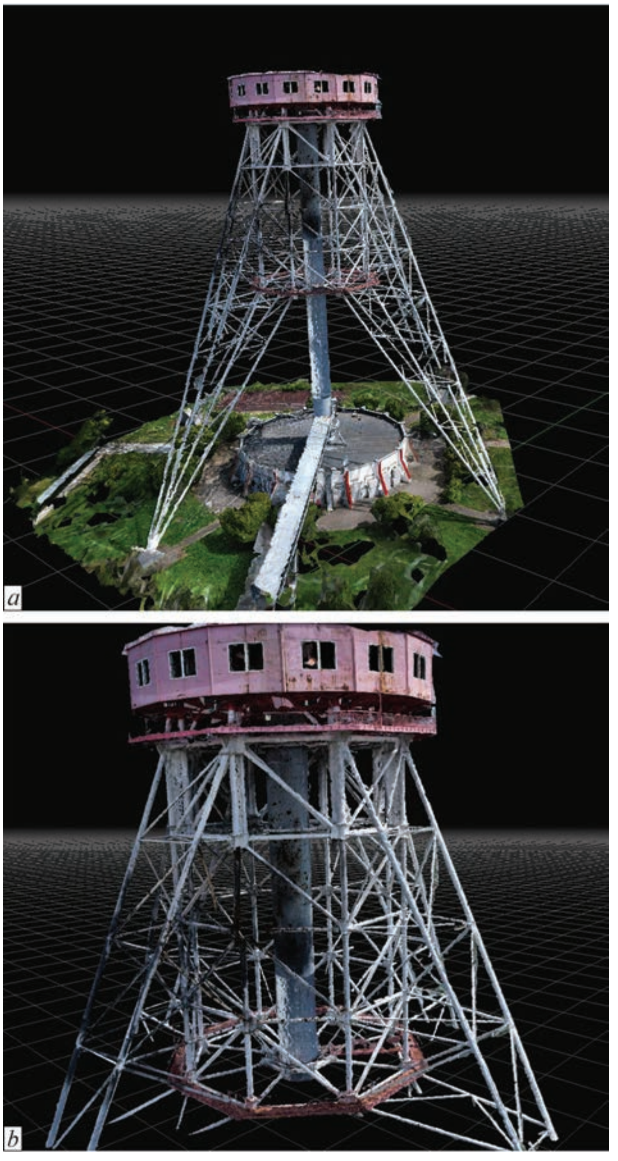


**Figure 1.** Models of the lower tier of the Kyiv TV tower: *a* — full-scale model; *b* — place of explosion

In recent years, photogrammetry with its capabilities of computer processing and attracting new data collection tools has opened many new areas of application: remote visualization, robotics, virtual reality, 3D animation, etc. [7]. In industrial inspection and quality testing, photogrammetric methods and systems have found their purpose in such areas as highways, bridges, pipelines, wind turbines, power lines.

There are two main types of photogrammetry: aerial (with a camera in the air) and terrestrial (camera handheld or on a tripod). Terrestrial photogrammetry dealing with object distances up to ca. 200 m is also termed close-range photogrammetry. Small-format aerial photogrammetry in a way takes place between these two types, combining the aerial vantage point with close object distances and high image detail [9].

The method of photogrammetry is based on geometrical–mathematical reconstruction of the paths of rays from the object to the sensor of a digital camera at the moment of exposure, which allows remotely determining defective areas, obtaining accurate geometric dimensions of damages and their location on the structure. In order to do that, first, orientation algorithms for determination of the inner and outer parameters of each image are used, such as focal length, point of the focus center, position and orientation of the camera and point of shooting. At the next stage, joint image processing is performed, they are aligned to provide a correct mutual position and the correspondence of the points in the photo. After alignment of the images, it is possible to determine 3D coordinates of the object's surface points using the methods based on their relative positions on the images. Based on 3D coordinates of the point cloud, a 3D model of the object is created. After receiving a 3D model based on photogrammetry, it is scaled.

To find the sizes of defects, a 3D model of the Kyiv TV tower was built using 3DF Zephyr software. A base from 2351th photography was used to build the model, 1292 photos were involved for the final result (Figure 1).

Before building the model, all available modes were analyzed in the 3DF Zephyr software and the best one among 6 variants was experimentally selected [9]:

- General;
- Aerial–Nadiral images;
- Urban;
- Human body;
- Surface scan;
- Vertical structure.

Urban and Human body modes were immediately rejected because they need to be used if there is a task of building a 3D model of city with its landscape and different facades of buildings or if 3D model of human with accurate sizes of its body is required.


**Figure 2.** Photo of support element obtained with an unmanned aerial vehicle at aerial photography of the TV tower

General mode is universal and it can be used to complete the set task, but there is a problem with determination of sizes of defects. This mode does not provide a sufficient accuracy of sizes of the structural elements and makes it impossible to measure distance with the accuracy to mm.

Aerial–Nadiral images is the mode created to work with data provided by UAVs. When using this mode, there was a problem with doubling of elements and their indefinite orientation in space. Since the tower examination was conducted at different altitudes and at different angles, it was a major problem for the given mode, because for optimal construction of models in Aerial-Nadiral Images, the photos are required taken at the same altitude in a top-down direction to the object under examination.

Surface scan would fit if analysis of a small area of the structure was required. This also requires images from the closest distance to the object. A drone cannot fly closer than 1 m to the object, because protective built-in sensors are activated blocking its control. The problem with incorrect orientation of elements in space in this mode is also present.

It was determined, that Vertical structure is optimal for building a model of the Kyiv TV tower. With its help, it was managed to solve the set tasks.

To create a 3D model, a graphic station Dell Precision 3650 Tower was used with the following characteristics: Processor (11th Gen Intel(R) Core(TM) i7-11700 @ 2.50GHz), Memory (32 GB (4·8 GB)), Disc (512 SSD), Video card (Nvidia T1000 4 GB), Operating System (Windows 10 Pro).


**Figure 4.** Area of the TV tower at the epicentre of the explosion: *a* — photo; *b* — 3D model

The work with a large amount of data is labour-consuming, because the processes of creating models can take several days or even weeks. In our case, the final result required a continuous operation of the graphic station for about 36 h.

After building the rough version of the 3D model, the next stage of work began, namely its processing. Unnecessary graphic elements are filtered; optimal parameters are selected for the best inspection of the model and detecting defects. After that, the final 3D model (Figure 1) is obtained.

Figure 2 shows defects formed from a missile explosion. Defect 0 represents a destruction of the protective coating of the structural element and is not dangerous for the tower in the short term. Defects 1 and 2 are the holes formed as a result of penetration of a fragment through the wall of the pipe and through them water and moisture gets into the middle of the pipe elements, which leads to their corrosion and a significant decrease in strength characteristics.

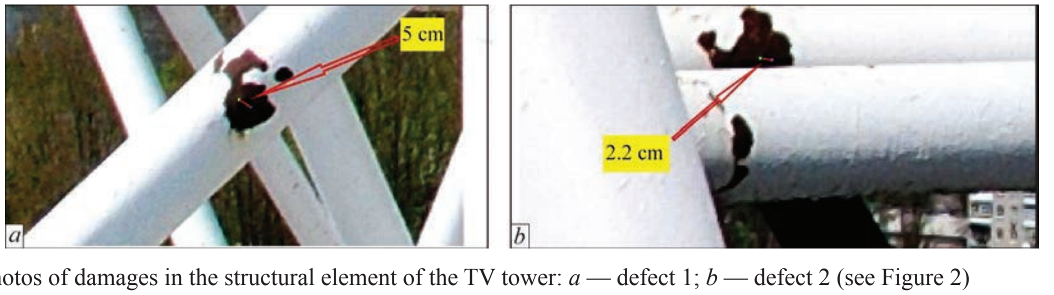


**Figure 3.** Photos of damages in the structural element of the TV tower: *a* — defect 1; *b* — defect 2 (see Figure 2)

Based on the analysis of photographs and their projections on a digital 3D model obtained by the method of photogrammetry, the typical sizes of these defects were measured. Thus, for example, with the help of the Measures tool it was found that the diameter of the first defect is approximately 5 cm (Figure 3, *a*), and the second one is 2.2 cm (Figure 3, *b*). It is worth noting that these defects were found on the least damaged support of the TV tower.

The 3D model allowed successfully visualizing large damages with their real appearance and sizes (Figure 4).

The conducted works on examination of the Kyiv TV tower helped to assess defects and develop recommendations for repair.

## CONCLUSIONS

Damages of pipe structures of the Kyiv TV tower were examined using the methods of non-destructive testing and visual inspection with a drone with the subsequent use of the photogrammetry method. The built 3D model helps to detect locally the location of defects on the elements of the structure and visualize the results of diagnostics, determine the sizes of defects and classify them. Using a remote visual inspection with UAVs, it was possible to find damages that were not identified by non-destructive testing methods and critical defects that may pose a danger to safe operation of the object or lead to serious problems with its functioning and require urgent repair in order to reduce the risk of an emergency and provide the safety of the object operation. A built 3D model can be used for numerical calculations of the stressed-strain state of the Kyiv TV tower for the analysis of spatial stress distribution in assemblies and elements of its structure. The obtained data allowed developing recommendations for prompt repair and restoration of the TV tower. The presented results demonstrate the high potential of combining traditional methods of non-destructive quality testing with remote diagnostics technology based on the use of UAVs and photogrammetry for examination of large-sized structures of critical purpose.

## *ACKNOWLEDGMENTS*

*The authors express gratitude to 3Dflow Corporation for the 3DF Zephyr digital support and technical support within the framework of the program 3D flow for the Ukrainian Crisis [10]. The authors are grateful for the opportunity to use this powerful tool in their research works and believe it helped to succeed with their work.*

*This research was conducted with the support of the project 022.01/0095 "Development of technology for remote diagnosis of damaged large-scale objects based on the use of unmanned aerial vehicles (UAVs) and photogrammetry" funded by the National Research Foundation of Ukraine in the framework of the competition "Science for the Recovery of Ukraine in the War and Post-War Periods".*

## REFERENCES

1. Parham Nooralishahi, Clemente Ibarra-Castanedo, Shakeb Deane et al. (2021) Drone-based non-destructive inspection of industrial sites: A review and case studies. *Drones*, 5(**4**), 106. DOI: https://doi.org/10.3390/drones5040106.
2. Lobanov, L.M., Garf, E.F., Kopylov, L.N., Sineok, A.G. (2013) Welding at erection of Kyiv TV tower. *Promyslove Budivnytstvo ta Inzhenerni Sporudy,* **3**, 16–20 [in Russian].
3. Demyanov, I.A., Murashov, A.P., Borisov, Yu.S. et al. (2005) Application of electric arc metallizing for anticorrosive protection of Kyiv TV tower. *Svarshchik,* **3**, 19–21 [in Russian].
4. Nenad Gucunski, Hung Manh La, Kien Dinh, Mustafa Khudhair (2023) Advancing condition assessment of reinforced concrete bridge elements through automation, visualization, and improved interpretation of multi-NDE technology data. *Materials Evaluation*, 81(**1**); 56–66. DOI: https://doi.org/10.32548/2023.me-04289
5. Rok Cajzek, Uroš Klanšek (2016) An unmanned aerial vehicle for multi-purpose tasks in construction industry. *J. of Applied Engin. Sci.*, 14(**2**), 314–327. DOI: https://doi.org/10.5937/jaes14-10918.
6. Paul, R. Wolf, Bon A. Dewitt, Benjamin E. Wilkinson (2014) *Elements of Photogrammetry with Applications in GIS.* 4th Ed.
7. Zhilin Li, Jun Chen, Emmanuel Baltsavias (2008) *Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences.* ISPRS Congress Book.
8. James, S. Aber, Johannes, B. Ries (2010) *Small-Format Aerial Photography*.
9. https://www.3dflow.net/technology/documents/3df-zephyr-documentation/Copyright © 2023 by 3Dflow srl.
10. https://www.3dflow.net/3dflow-for-the-ukrainian-crisis/(3 March 2022)

## ORCID

L.M. Lobanov: 0000-0001-9296-2335,
D.I. Stelmakh: 0000-0002-0412-9747,
V.V. Savitsky: 0000-0002-2615-1793,
V.P. Diadin: 0000-0002-2061-8436,
O.P. Shutkevych: 0000-0001-5758-2396

## CONFLICT OF INTEREST

The Authors declare no conflict of interest

## CORRESPONDING AUTHOR

V.V. Savitsky
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.
E-mail: viktor.savitsky@gmail.com

## SUGGESTED CITATION

L.M. Lobanov, D.I. Stelmakh, V.V. Savitsky, V.P. Diadin, O.P. Shutkevych, A.G. Kozachek (2023) Remote assessment of damages of the Kyiv TV tower based on the use of aerial photography and the method of photogrammetry. *The Paton Welding J.*, **8**, 60–64.

## JOURNAL HOME PAGE

https://patonpublishinghouse.com/eng/journals/tpwj

Received: 31.05.2023
Accepted: 07.08.2023