

## **MEASUREMENT OF STRAIGHTNESS AND VERTICALITY OF SHEET PILING**

Wanda KOKOSZKA<sup>1</sup>, Piotr OCHAB, Anna GARDZINSKA  
Rzeszow University of Technology, Rzeszów, Poland

### **Abstract**

Sheet piling is commonly used in various areas of special construction. Embedded in the ground before carrying out excavation works, sheet piling constitutes an enclosure and protection for the designed excavation. It is a temporary enclosure and protection for excavations made for communication structures, launch shafts built for microtunnel construction, etc. In order to assess the quality of the engineering works related to the construction of sheet piling, measurements were made of straightness and verticality of the sheet piling used for the technological chambers. The measurements concerned two technological chambers of 7.2 and 6.4 m height. Inventory measurements were made using a total station of 1" accuracy and a leveling staff with the appliance of the so-called projection method. The two technological chambers were built in the investment area called "Infrastructure construction for rainwater drainage, water supply and sanitary sewage collection from the John Paul II International Airport Kraków-Balice."

**Keywords:** sheet piling, straightness and verticality measurement, accuracy analysis

### **1. INTRODUCTION**

Sheet piling is commonly used in various areas of special construction. Embedded in the ground before carrying out excavation works, sheet piling constitutes an enclosure and protection for the designed excavation. It is a

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<sup>1</sup> Corresponding author: Rzeszow University of Technology, Faculty of Civil and Environmental Engineering and Architecture, Powstancow Warszawy av. 12, 35-959 Rzeszow, tel.+48178651013, e-mail: wandak@prz.edu.pl

temporary enclosure and protection for excavations made for communication structures, launch shafts built for microtunnel construction, etc. This type of protection limits the area needed to carry out excavation works and allows for engineering works to be performed in close proximity to existing infrastructure facilities such as buildings, roads, etc. Sheet piling is successfully used in investments that require temporary protection of the excavation area, and as a permanent structural element or formwork. This implies high quality, straightness and verticality of sheet piling [1–5].

Sheet pile walls consist of continuously interlocked pile segments embedded in the ground to resist horizontal pressures. Classified as a flexible retaining system, sheet piling can tolerate relatively large deformations [6,7].

Sheet piles have been used as retaining systems for many years. They are widely used for several purposes such as [6]:

- waterfront structure construction;
- erosion protection;
- ground slope stabilisation;
- excavation and cofferdam shoring.

In general, sheet piles used for retaining walls are classified into two types: anchored sheet piles and cantilevered sheet piles. Sheet piles are made of different kinds of materials such as wood, concrete, steel or aluminium, and these different materials cause different applications.

Sheet pile wall is constructed by [6]:

- laying out a sequence of sheet pile sections and ensuring that sheet piles will interlock,
- driving (or vibrating) individual sheet piles to the desired depth;
- connecting adjacent sheet piles;
- repeating steps 2 and 3 until the perimeter wall is completed;
- for complex-shaped excavations, connecting elements are used.

Sheet pile walls have the following disadvantages:

- sections can rarely be used as part of the permanent structure;
- installation of sheet piles is difficult in soils with boulders or cobbles, in such cases, the desired wall depths may not be reached;
- excavation shape is dictated by the sheet pile section and connecting elements;
- sheet pile driving may cause neighbourhood disturbance;
- settlements in adjacent properties may occur due to installation vibrations.

## 2. TOLERANCES REGARDING PLAN POSITION AND VERTICALITY

The plan position and the verticality of the sheet piles after installation should be in accordance with the typical recommended values given in Table 1. Values given in Table 1 are for normal cases [9].

Table 1. Tolerances of plan position and verticality of the sheet piles after installation [9]

Type of wall	Situation during execution	Plan position of pile top [mm]	Verticality <sup>2)</sup> measured over the top 1 m [%]
			all directions
Sheet pile <sup>4)</sup>	on land over water	$\leq 75$ <sup>1)</sup> $\leq 100$ <sup>1)</sup>	$\leq 1$ <sup>3)</sup> $\leq 1,5$ <sup>3)</sup>
Primary element of combined wall		depending on soil conditions and on length, shape, size and number of secondary elements, these values should be established in each case in order to ensure that declutching is not likely to occur	
<sup>1)</sup> Perpendicular to the wall <sup>2)</sup> Where the design requires piles to be driven at an inclination, the tolerances specified in the table are with respect to that direction <sup>3)</sup> May amount to 2 % in difficult soils, provided that no strict criteria (e.g. regarding weathertightness) are specified and declutching is not considered to become a problem after excavation. <sup>4)</sup> Excluding straight web piles NOTE The tolerances regarding the position and the verticality may be additive.			

For combined walls, the requirements with respect to the plan position and verticality of the primary elements are generally very strict and, consequently, special measures such as rigid and stable guide frames should be applied.

If the toe levels of the sheet piles and of the primary and secondary elements of a combined wall after driving differ more than 250 mm from the levels specified in the design, it shall be demonstrated that the performance requirements of the design are still satisfied.

If the head levels of sheet piles and of primary and secondary elements after driving differ more than 50 mm from the levels specified in the design, it should be demonstrated that the performance requirements (e.g. connections with other elements) are still satisfied. If this is not the case, the sheet piles should be made good in accordance with the execution demands [9-11]. It should be

remembered that depending on the type of structure and its subsequent operating conditions, we select the method of measurement [12-17].

### **2.1. Corrections of sheet piling position during driving**

When driving in very hard soil layers, the stiffness and stability of the guide frame should receive special attention in order to keep transverse and longitudinal leaning and horizontal displacements of the driven sheet piles within the tolerances given in Table 1.

Chamfering or partial cutting of the toe of a steel sheet pile to prevent longitudinal leaning should not be carried out because of the risk of declutching. If transverse leaning and rotation of a sheet pile occurs during driving, it should be extracted and re-driven unless other measures are sufficient. If longitudinal leaning of the sheet piles occurs during driving, immediate action to counteract this should be taken, for example by pushing or pulling.

## **3. TESTING AND MONITORING OF SHEET PILING**

In order to assess the quality of the engineering works related to the construction of sheet piling, measurements were made of verticality and straightness of the sheet piling used for the technological chambers. Measurements concerned two technological chambers of 7.2 and 6.4 m height (chambers no.1 and no.2). These technological chambers were built in the investment area called "Infrastructure construction for rainwater drainage, water supply and sanitary sewage collection from the John Paul II International Airport Kraków-Balice."

Figures 1 and 2 are the photographic documentation of inventoried technological chambers.

Inventory measurements were made using a total station of 1" accuracy and a leveling staff with the appliance of the so-called projection method.

The obtained measurement results as well as calculation and analysis results regarding straightness and verticality of the sheet piling are presented in Fig. 3 to 8 below.



Fig. 1. Technological chamber no.1



Fig. 2. Technological chamber no.2

Diagrams of deflection from the vertical of individual sheet piles at the height of the profile measured for technological chamber no.1 are shown in Fig. 3 to 6.

Fig. 3 and 8 present the sketches of sheet pile deflection (shown in cm) for the airtight/technological chambers measured.

On the basis of the calculations performed, graphs were made of the deflection from the vertical of individual sheet piles at the height of the profile measured for technological chambers no.1 and no.2.

Diagrams of deflection from the vertical of individual sheet piles at the height of the profile measured for technological chamber no.2 are shown in Fig. 7 and 8



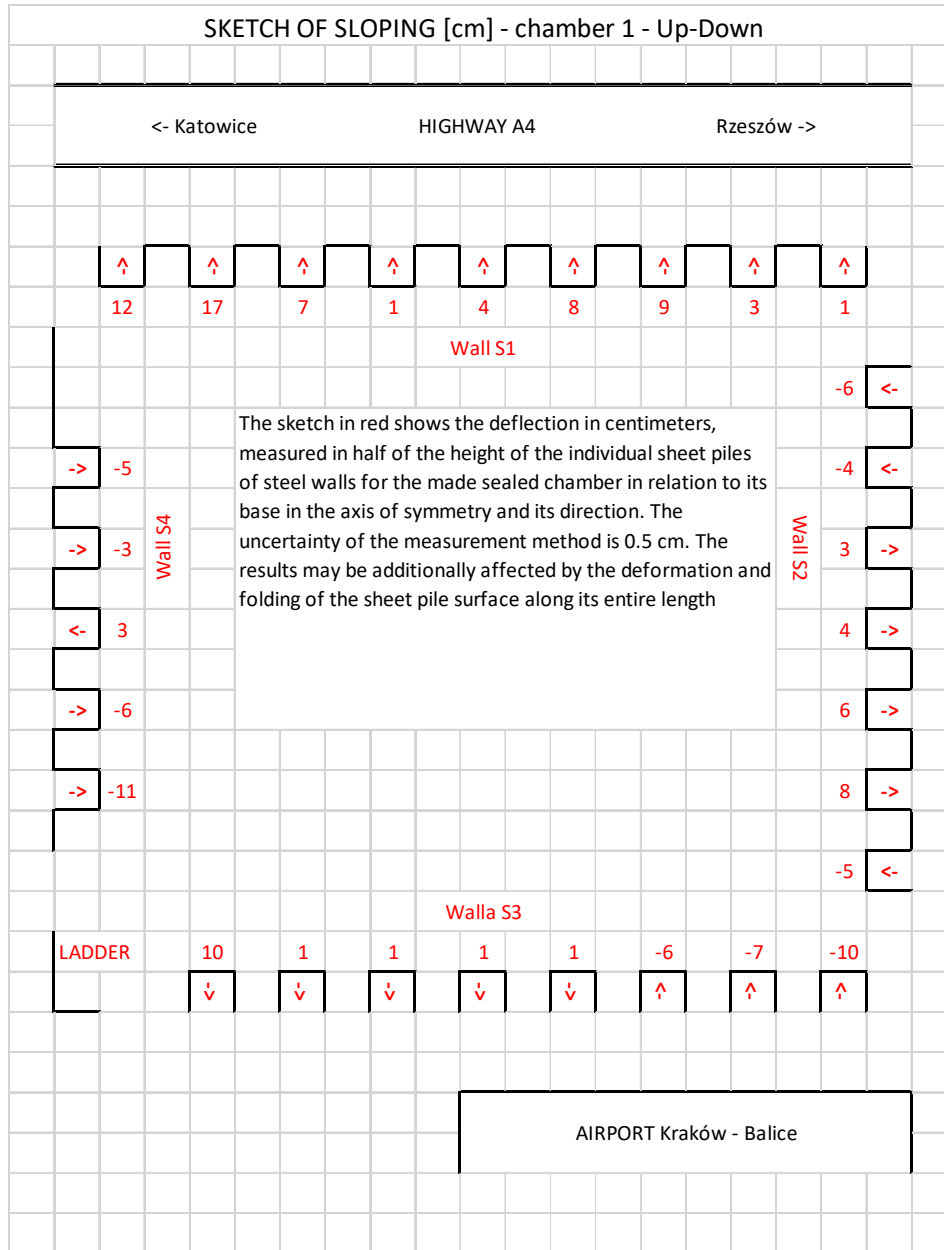


Fig. 3. Sheet pile deflection for technological chamber no.1

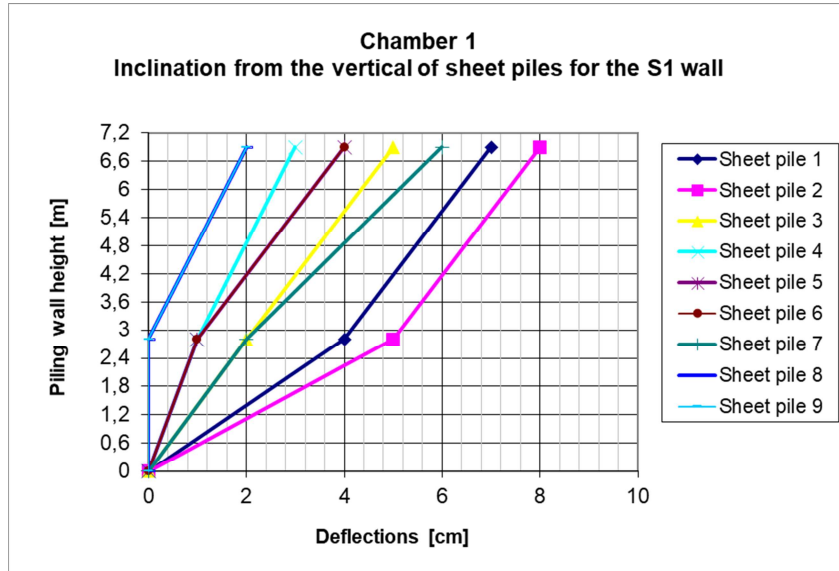


Fig. 4. Graph of sheet pile deflection for wall S1 of chamber no.1

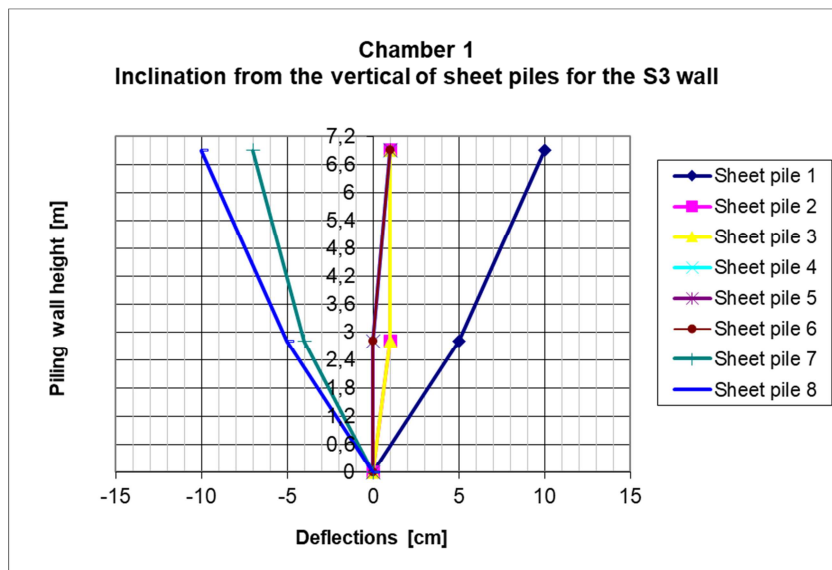


Fig. 5. Graph of sheet pile deflection for wall S3 of chamber no.1



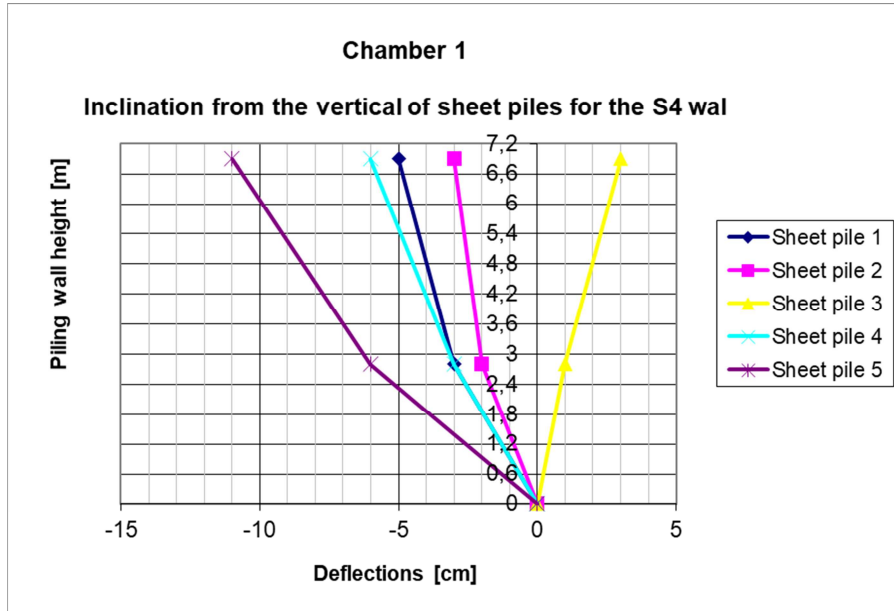


Fig. 6. Graph of sheet pile deflection for wall S4 of chamber no.1

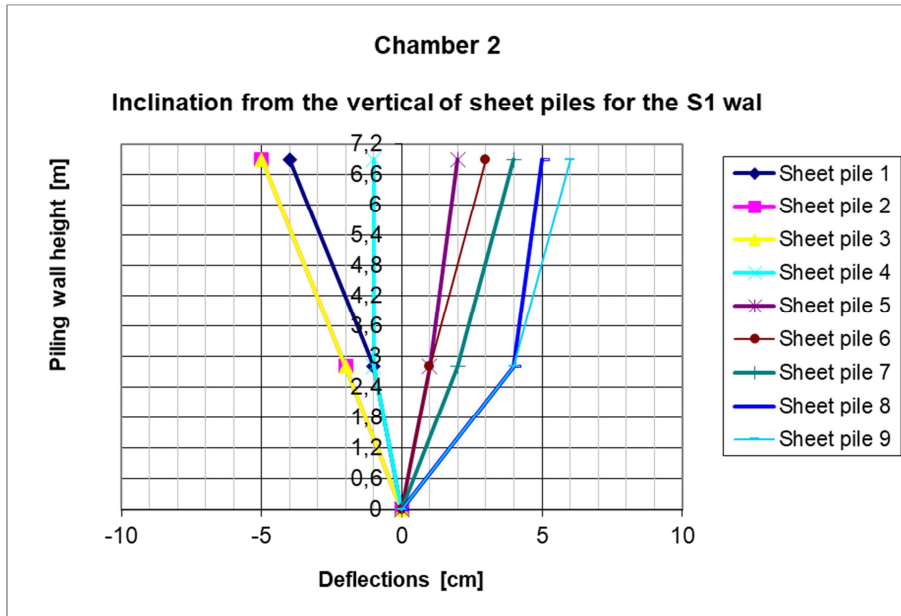


Fig. 7. Graph of sheet pile deflection for wall S1 of chamber no.2

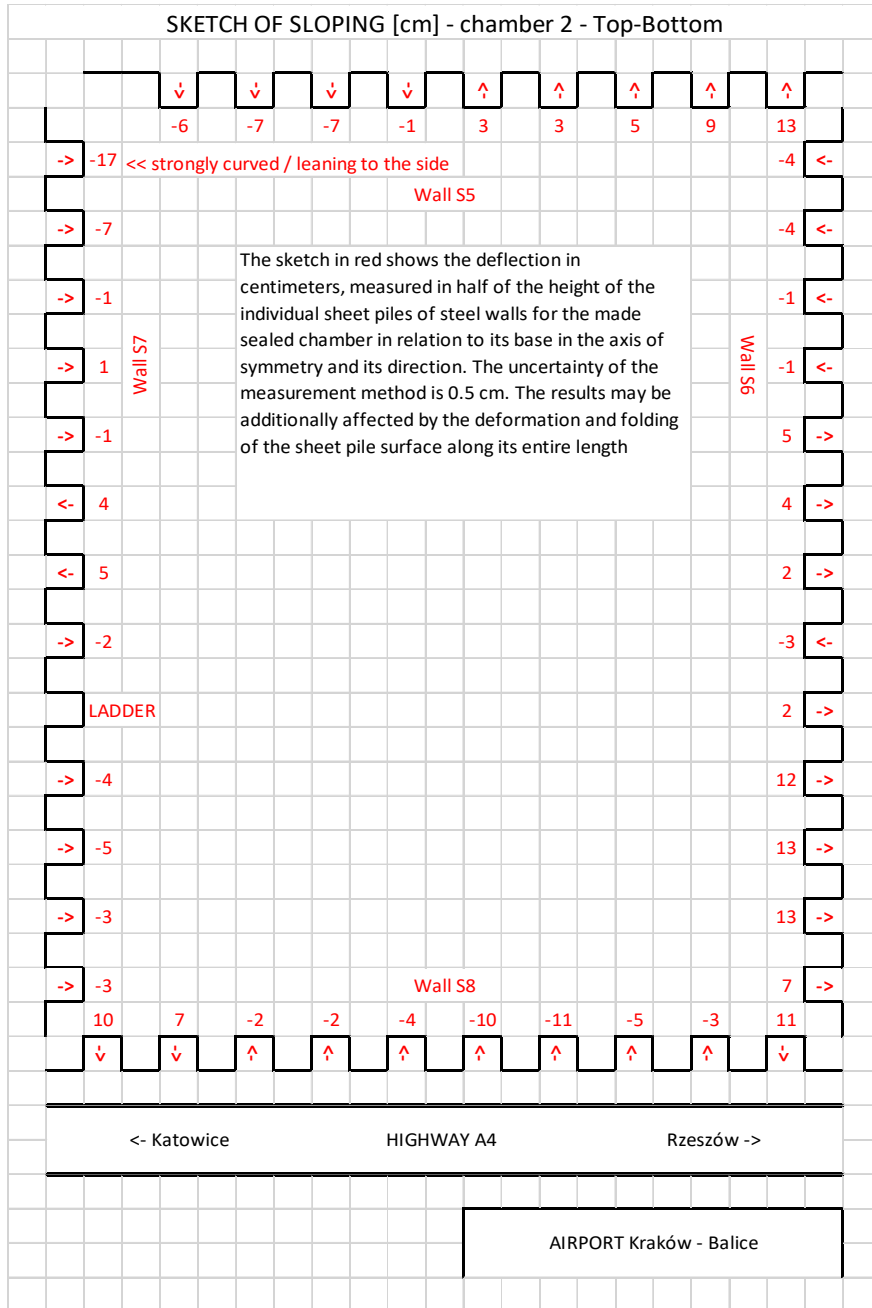


Fig. 8. Sheet pile deflection for technological chamber no.2

#### 4. DISCUSSION

On the basis of the inventory measurements performed, descriptive statistics were calculated concerning the values of position parameters and dispersion for the deflections of the top edges of steel sheet pile walls (top-bottom) of the two technological chambers. The standard deviation value obtained (scatter of results) for deflections was equal to 7 cm, whereas the average value for deflection from the vertical was equal to 6 cm. The relative differentiation measured by the coefficient of variation for the verticality of the sheet pile walls of technological chambers amounted to 86%. The typical sheet pile deflection value ranged from -1 cm to 13 cm. The value range for sheet pile deflection was 34 cm (Table 2 and Fig. 9).

Table 2. Descriptive statistics for sheet pile deflection

Descriptive statistics	Value in [cm]
Average value	6
Median	1
Modal value	5
Standard deviation	7
Variance	47
Range	34
Minimum	-17
Maximum	17

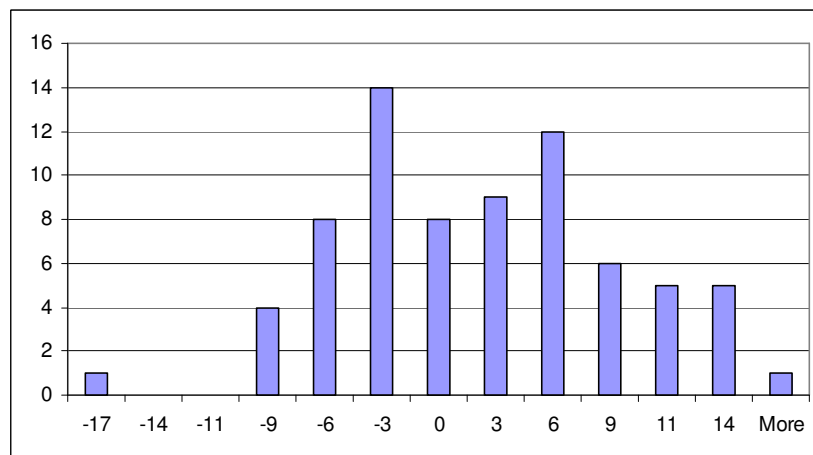


Fig. 9. Histogram of test results for sheet pile deflection (in cm)

The results obtained (Table 1) confirm that conventional methods of carrying out engineering works related to the construction of sheet piling and airtight/technological chambers do not ensure satisfactory quality, which may result in chamber leakage, failure to meet dimensional tolerances and increased material consumption.

The  $\chi^2$  test was used to verify whether the angle measurement accuracy is less than or equal to the value declared by the manufacturer at the significance level of 0.05. The  $\chi^2$  test is the most common test and can be used to examine the compatibility of both measurable and immeasurable characteristics [5, 6]. If the measurement results are normally distributed and the number of results is less than 50, the  $\chi^2$  test can be applied (1):

$$\chi^2 = \frac{\sqrt{v} \cdot s}{\sigma} \quad (4.1)$$

where:  $\chi^2$  – value of the  $\chi^2$  statistic ,  
 $s$  – an estimate of the standard deviation,  
 $\sigma$  – standard deviation,  
 $v$  – degrees of freedom.

The value of the  $\chi^2_{1-\alpha}(v)$  statistic is read from the  $\chi^2$  test tables. The rejection area is  $P(\chi^2 < \chi^2_{\alpha}) = \alpha$ . If the determined  $\chi^2$  statistic belongs to the  $(0, \chi^2_{\alpha}]$  interval, there is a reason to reject the hypothesis that the estimate of the standard deviation obtained in simplified method of total station testing is equal to the measurement accuracy declared by the manufacturer.

Table 3.  $\chi^2$  test results

Observations	Calculated value of the $\chi^2$ statistic	$(0; \chi^2_{\alpha})$	Compliance with the declared measurement accuracy
Horizontal	3.951	(0; 1.635)	+
Vertical	3.951	(0; 1.635)	+

On the basis of the analyses (Table 3), it may be stated that the sheet piling tested meets the declared accuracy of horizontal and vertical measurement requirements.

## 5. CONCLUSIONS

Based on the tests and measurements conducted, the following conclusions can be formulated:

- the test showed that the sheet piling meets the declared accuracy of horizontal and vertical measurement and that the method is suitable for the purposes of geodetic measurement;
- it is important to take into consideration that the actual accuracy achieved can be worse due to unfavourable conditions of the engineering works;
- position and orientation of the sheet piling should be indicated in the driving plan; deviations from this theoretical layout may occur due to rolling tolerances, soil conditions, setting and driving procedures;
- in some cases – and for certain circumstances – tighter tolerances may be specified, as in the case of king post piling, where accuracy is especially important.

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