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Accuracy of Determining the Volume of Road Salt Storage Based on Surveying with Reflectorless Total Stations**

1. Introduction

In surveying practice, inventory works associated with the storage volume of loose materials are carried out quite often. Today, when the option of reflecorless surveying becomes a standard accessory of popular total stations which are available on the market, making use of their potential in carrying out this type of works seems to be a natural process. Many publications prove that the ranges of distance survey with the use of reflectorless distancemeters, as presented by the manufacturers, tend to be limited by nature of the reflecting surface and its physical properties and are not adequate for the data contained in the technical specifications of the equipment.

Therefore, the articles which present the results of the range of distance survey carried out directly towards the typical materials which may exist at such storage sites or represent surfaces of engineering objects which are subject to reflectorless surveys are becoming increasingly important. These issues were broadly discussed by Lenda [2] and Strach [1]. Lenda conducted surveys for seven types of materials representing the most common surfaces in surveying practice, exploring the possibilities of TCRA1102plus and TCR303. Strach conducted range tests for TCR407Power for 19 raw materials, which included rock materials.

This article enlarges the base of the instruments tested for the range of reflectorless surveying in surveys for the road salt. This type of salt is used in winter to manage traffic on main roads and motorways. Surveying and determining the volume of a storage involves the inventory of salt mass, which was used during the winter season and left the warehouse (the survey is carried out before and after the season to compare the recording status with the actual numbers). It is the

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base for financial settlements between the road manager and the companies which are responsible for conducting road winter maintenance process.

The results of test and practice surveys presented in this article can provide support to the land surveyors who will be designated to carry out such works and who have doubts about the reliability of the results obtained using reflectorless total stations. This is all the more justified as reflectorless total stations are widely in use and the number of road salt storage facilities in Poland amounts to 125.

2. Characteristics and Distribution of Loose Material Storage Facilities in Poland

DOME INTERNATIONAL Sp. z o.o. is a company preoccupied with construction of warehouses for storing loose materials, and in particular those which are strongly hygroscopic and corrosive, such as salt or artificial fertilizers, in Central and Eastern Europe. During its over 40 years of business activity the company has built more than 6,000 facilities around the world, mainly in the U.S. and Canada.

DOME INTERNATIONAL offers a wide variety of types of warehouses [4]. They are divided into objects having the following shapes:

- round (with diameter up to 50 m) (Fig. 1a),
- elliptical (with axis dimensions of 29 m × 35 m) (Fig. 1b),
- barrel-shaped (with width from 12.5 m to 45 m and of any length) (Fig. 1c).

a) b) c)

Fig. 1. Types and shapes of warehouses for the storage of loose materials: a) round; b) elliptical; c) barrel-shaped (http://www.dome-international.com)

Recently, the construction system of two-gate elliptical warehouses has been introduced throughout Europe in countries like the Czech Republic, Slovakia, Ukraine, Russia and Poland. Warehouses which are elliptical in shape are more and more frequently used due to the possibility of their location on elongated plots as well as easier way to plan the site.

In Poland, since 1996, 125 warehouses have been built, whose distribution has been presented in figure 2. The main user of this type of object is the General Directorate for National Roads and Motorways.

Fig. 2. Distribution of road salt storage facilities in Poland (http://www.dome-international.com)

3. Test Surveys of Reflectorless Distancemeters

Prior to proceeding with the proper survey of the volume of a specific storage, the range and the accuracy of a distance survey with the instruments applied to an object such as road salt was examined. For this purpose, the test of three Leica reflectorless distancemeters (TCR407Power, TCRA1102plus and TCRP1205) was carried out. Distancemeters for reflectorless surveys have this same class of the laser emitting beam, and although for the first two of them the manufacturer claims the maximum range of 300 m, for TCRP1205 this range is 500 m [6–8].

In order to conduct the test, a sample collected on 20 February 2009 from the warehouse belonging to STALEXPORT Transroute Autostrada S.A. was used. The subject warehouse is located at the town of Rudno near Krakow at the A4 motorway in the direction of Katowice. This is an elliptical warehouse of DE 22x28-16S type, with the capacity of up to 3620 t of collected material [4]. Salt accumulated in the warehouse comes from the Kłodawa Salt Mine SA. It occurs in the loose form and exhibits the following physichemical parameters: the content of NaCl is minimum of 95%, grain of less than 1 mm – maximum of 50%, grain exceeding 1 mm – maximum % does not apply, grain exceeding 3.5 mm – maximum % does not apply, grain exceeding 6 mm – maximum of 5%, insoluble content – maximum of 3%, water content – maximum of 1%, anti-lumping substance ($K_4Fe(CN)_6$) – 40 ppm.

Due to the loose nature of the material, the salt did not allow for the vertical plane to be heaped up, for which, in turn, the rotation in the horizontal plane would be possible, which constituted an important condition of the test. Therefore, a special surveying sample consisting of wooden plates joined together at the right angle was prepared. On one of the plates a 1 mm thick layer of silicone was applied, and this plane was sunk in a sample of salt and left there for 24 hours. The resulting sample could be then set on a special tripod, both vertically and at the right angle to the sight line axis. It enabled to change the angle of incidence of the laser beam from 100g to 190g in the horizontal plane (Fig. 3).

Fig. 3. The sample used for the test

In order to determine the maximum length of the bases for which the ultimate test was to be carried out, the maximum range of distance survey to the test material for all tested reflectorless distancemeters was verified. The verification was carried out on Krakow's Błonie Meadows on 3 April 2009 with an average insolation, the temperature of 12°C and the pressure of 991 hPa. Atmospheric data were input into the instruments prior to conducted surveys. Each instrument was set on a tripod and levelled. The distancemeters were set in the "tracking" survey mode and only the previously prepared sample of salt was moved. During the survey, the perpendicularity of the sight line axis to the surveying plane was retained.

As a result of the test the following maximum distances for each of the distancemeters (TCR407Power – 112 m, TCRA1102plus – 124 m, TCRP1205 – 137 m) were observed.

In the case of the tests carried out by Strach, the maximum observed distance to the rock-salt was 200 m. In the case of road salt the observed distance was 112 m for the same instrument (TCR407Power). The reduction of the maximum observed distance in this case was influenced by the fact that the survey was carried out for the irregular surface, which consisted of salt crystals of dimensions even up to 6 mm. In Strach's tests the surveys were performed for flat surfaces of sufficiently large dimensions. Scattering of the signal, which was the case with road salt, resulted in a decrease of distance survey range by 44% compared to a uniform and flat surface. It is not surprising, however, it demonstrates the scale of the impact of this factor, and the obtained result may assist in the planning of surveying positions in relation to the observed object.

Having determined the maximum range of individual distancemeters to a sample of road salt, it was decided that the length of the bases used to assess the relative accuracy of survey distances taking into account the angle of incidence of the beam, would be 15 m, 50 m, 100 m. The first distance reflects the conditions of the salt storage survey in the warehouse in Rudno, which is of DE 22x28-16S type [4], i.e. it has an elliptical shape of the axis values of 22 m and 28 m, respectively. The length of the sight line in the surveys conducted in this warehouse from a free station selected in the middle of this a warehouse should not exceed approximately 15 m. In the largest elliptical and round warehouses radii are a maximum of 50 m. Therefore, the second base where the test will be carried out is 50 m, representing the most unfavourable case of instrument setting on the largest of the possible facilities intended for the storage of materials, which are strongly hygroscopic and corrosive. The 100 m base enabled the assessment of the distancemeter operation within the limits of the maximum range. The obtained results may prove to be helpful in surveys conducted in the barrel-shaped warehouses, which are characterised by a width of up to 45 m and any length. The test involved carrying out a series of distance surveys with all distancemeters in a reflectorless mode for a previously prepared samples of salt for 10 angles of incidence of the laser beam. The change of the incidence was obtained via the rotation of the sample on a plane table with applied angular distribution (Fig. 3). The distance survey for each angle of incidence was repeated 30 times. For each length of the base, a model distance was specified, which was designated in a reflectorless manner on a target plate with an accuracy of 3 mm + 2 ppm. This length represented a model value towards which distance surveys for different angles of incidence of the laser beam on the sample was compared. For 3 instruments, 3 lengths of bases, 10 angles of incidence, 30 repetitions for each angle and 3 model distance surveys, more than 2,700 observations were obtained. The values of the temperature, changing during the test, were being altered in the instruments on a current basis.

Tables 1, 2 and 3 contain the mean values of deviation from the model distance (mean) where the minus (–) by the specific value refers to the observed distance longer than the model one, as well as standard deviations (standard deviations) from each of the tests. All values are presented in millimetres.

Table 1. Summary of results for the base of 15 metres in length

Angle [g]	Base 15 m						Angle [g]
	TCR407Power		TCRA1102+		TCRP1205		
	mean [mm]	standard deviation [mm]	mean [mm]	standard deviation [mm]	mean [mm]	standard deviation [mm]	
100	0	0	–1	1	0	1	100
110	0	0	0	0	0	0	110
120	0	0	0	0	0	0	120
130	0	0	0	0	0	1	130
140	–1	1	0	0	–1	1	140
150	–1	1	–1	1	–1	1	150
160	–1	1	–1	1	–1	1	160
170	–3	3	–1	2	–2	2	170
180	–3	4	–3	3	–2	2	180
190	–3	3	0	1	–4	4	190

Table 2. Summary of results for the base of 50 metres in length

Angle [g]	Base 50 m						Angle [g]
	TCR407Power		TCRA1102+		TCRP1205		
	mean [mm]	standard deviation [mm]	mean [mm]	standard deviation [mm]	mean [mm]	standard deviation [mm]	
100	–3	4	–4	4	0	0	100
110	–3	3	–4	4	1	1	110
120	–3	3	–3	3	0	1	120
130	–3	4	–4	4	0	0	130
140	–2	2	–5	5	2	2	140
150	–2	2	–1	2	0	1	150
160	–1	2	1	2	–1	1	160
170	–1	2	2	2	–2	2	170
180	0	1	3	4	–4	4	180
190	4	4	17	18	–15	16	190

Table 3. Summary of results for the base of 100 metres in length

Angle [g]	Base 100 m						Angle [g]
	TCR407Power		TCRA1102+		TCRP1205		
	mean [mm]	standard deviation [mm]	mean [mm]	standard deviation [mm]	mean [mm]	standard deviation [mm]	
100	–7	7	–9	9	–6	6	100
110	–8	8	–8	9	–7	7	110
120	–9	9	–9	9	–7	7	120
130	–9	9	–9	9	–8	8	130
140	–8	8	–9	9	–9	9	140
150	–8	8	–10	10	–9	10	150
160	–8	9	–9	10	–10	10	160
170	–10	10	–6	6	–9	10	170
180	–15	16	–3	4	–9	9	180
190	–9	9	20	21	–25	26	190

Based on the results compiled in the table the following conclusions were formulated:

- For the base with the length of 15 m, the obtained standard deviations for distancemeters are within the error limits provided by the manufacturer and only in two cases they reached 4 mm. The duration of a single distance survey did not exceed 2 seconds.
- For the base with the length of 50 m, the obtained standard deviations only in one case reached the value of 5 mm. Others remained within the measurement error of the distencemeter. Only for the instruments TCRA1102 + and TCRP1205 with the angle of incidence on the sample equal to 190^g, the deviation was 16 mm and 18 mm, respectively. Very sharp angles of incidence should be avoided for these distancemeters. The duration of a single distance survey was 3–4 seconds.
- For the base with the length of 100 m, the standard deviation ranged within the limits from 6 mm to 10 mm. Only for the TCR407Power distancemeter the maximum deviation was equal to 16 mm for the angle of incidence equal to 180^g, for the TCRA1102 + distancemeter the standard deviation reached the value of 21mm for the angle of 190^g, and for the TCRP1205 distancemeter the deviation was 26 mm for the angle equal to 190^g. Also, when carrying out surveys for this distance, very sharp angles of incidence of the laser on the salt should be avoided. The duration of a single distance survey was 4–6 seconds.

4. Verification of the Method on an Experimental Object

The real object test survey was conducted on 9 June 2009 in the warehouse which the sample for the tests of range and accuracy came from. The work was carried out during the seasonal inventory of the warehouse. The essence of the presented survey was to test the applicability of the reflectorless method as an alternative to measure to prism, which would shorten the surveying time itself, and reduce the number of people involved in such a procedure. The following total stations were used for this purpose: Elta R55 – measure to prism Leica; TCR407Power – reflectorless measure. Total stations used in the test have similar accuracy parameters for angle and distance surveys [9].

The warehouse in which the salt is stored consists of a horizontal concrete floor, vertical retaining walls of the height of 2.89 m, and a wooden roof to protect the stored material from flooding. Salt in such warehouses is not stored in the form of a cone in the middle of the building, but mostly by the wall of some part of a warehouse. In such a case, there is a problem with surveying the lump outline of that storage from the side which is adjoining to the retaining walls, as access to the outline refractions of the object may be sometimes difficult, or even impossible. To avoid such a situation, the overall outline of the warehouse, i.e. all the refraction points of the retaining walls should have been measured during the first survey. The outline points at the same time created control network in the local system, which during subsequent inventory surveys was used to determine the position of the instrument using the free station method. In the warehouse where the test was performed, the control network consisted of 18 points numbered 501 to 518, evenly spaced on the circumference of the warehouse (Fig. 4).

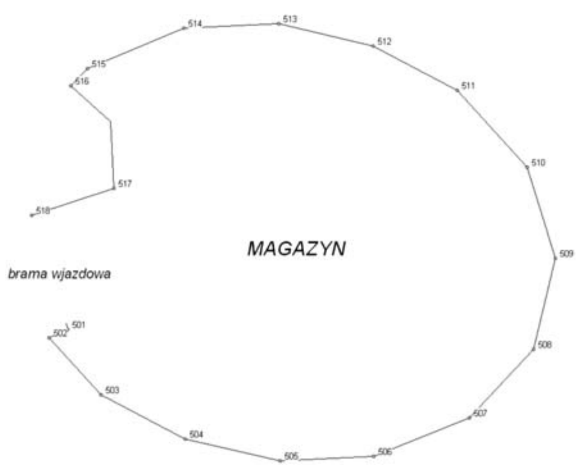

Fig. 4. Surveying control network, simultaneously constituting warehouse outline

At the first survey, the height of the floor was measured at several points in order to later determine a benchmark level from which the volume of the storage was calculated.

Prior to each survey, the company STALEXPORT Transroute Autostrada A-4 levels off the storage of salt in such a way, so as to create a compact and relatively regular lump. This operation facilitates the surveying itself, as well as reduces the likelihood of faulty determination of the volume of salt in the warehouse. During the test, storage surface observations were made independently, i.e. with different distribution of station poles for both instruments. The outline of the storage was attempted to be preserved the same for both methods, while the remaining points reflecting the lump were determined in different places [5]. The survey was carried out using the 3D polar method, with reference carried out with the free station procedure.

The Elta R55 total station was set in the middle of the storage of salt. The prism was placed on adjustable levelling staff. The use of the staff as a "medium" for the prism allowed the adjustment of the signal within the range of 0 m to 5 m and prevented the subsidence of a signal in salt, as it would take place in a sharply ended pole.

The TCR407Power total station was set close to the main slope, next to a small refraction, as the survey was carried out directly to the storage of salt, and this ensured correct surveying of station poles on a slope. During the survey itself no problems with the survey of the distance to road salt stored in the warehouse were observed. Both the surveying time was equal and it did not exceed two seconds and in the observed distances during the subsequent analysis no blunders were detected, which would refer to determining the position and height.

The volumes were determined from both conducted independently sets of surveys with the use of three computer programs: Winkalk, C-Geo and Surfer. The aforementioned results were used to conduct assessment which included the comparison of (tab. 4):

- two independent surveys carried out with various instruments,
- computational algorithms applied in used programs.

The volume was determined using the method of generating the surface of the salt solid based on a mesh of triangles and squares. In the case of a mesh of squares the following grid densities were adopted: 1.00 m, 0.50 m, 0.25 m, 0.10 m, 0.01 m. The height of the nodes were determined based on the spline functions.

The results of individual volume calculations have been summarized in table 4. In addition, the table contains discrepancies obtained from the carried out calculations. They were determined from the difference between the first and second survey.

Table 4. Summary of differences in volumes obtained from two surveys for different programs

Software	Method	Survey I 09.06.2009 Elta R55	Survey II 09.06.2009 TCR407Power	Difference in surveys I i II	
		[m³]	[m³]	[m³]	[%]
Winkalk	△	766.35	767.72	1.37	0.2
C-Geo	△	768.10	768.29	0.19	0.0
	□ 1.00 × 1.00	794.72	789.34	5.38	0.7
	□ 0.50 × 0.50	795.65	789.96	5.69	0.7
	□ 0.25 × 0.25	796.87	791.24	5.63	0.7
	□ 0.10 × 0.10	796.80	791.14	5.66	0.7
	□ 0.01 × 0.01	796.82	791.15	5.67	0.7
Surfer	□ 1.00 × 1.00	786.44	788.71	2.27	0.3
	□ 0.50 × 0.50	807.79	794.19	13.60	1.7
	□ 0.25 × 0.25	803.82	793.76	10.06	1.3
	□ 0.10 × 0.10	801.12	792.80	8.32	1.0
	□ 0.01 × 0.01	808.37	794.57	13.80	1.7

The obtained results indicate that the smallest differences were obtained by the method of triangle mesh used for both of the applied programs. They respectively amount to 1.37 m^3 for the Winkalk program (which is 0.2%) and 0.19 m^3 for the C-Geo program, which is an almost faultless result. In the method, a mesh of squares, we can see a constant difference of about 5.5 m^3 accounting for just 0.7% for the program C-Geo. However, the results obtained using the Surfer program range from 0.3% to 1.7% depending on the grid density. Moreover, the calculated 1.7%, which represents 13.80 m^3 is the largest difference obtained in our analysis.

The comparison of the obtained results in terms of computational algorithms used in specific programs indicate that for the triangle mesh the obtained differences are minor and for the first survey they amount to a mere 1.75 m^3 (corresponding to 0.2%), and for the second survey 0.57 m^3 (corresponding to 0,1%). For the square mesh method we can observe more clearly a greater divergence of the results obtained from the first survey than from the second one. The maximum value equals to 12.14 m^3 which represents 1.5%. The smallest difference was obtained from the second survey which was only 0.63 m^3 which represents 0.1% of the total volume of salt. At the same time, for the results obtained from the second survey, smaller differences were observed in the calculated volume with respect to the applied programs, regardless of the method used. This may be due to the fact that more points representing the surface of salt were surveyed with the TCR4077Power total station. In all cases described above, regardless of the applied surveying and calculation method as well as of the model used, the differences in volume did not exceed 2%. Taking into account the maximum observed discrepancy, which amounted to 1.7%, it was found that the surveys fall within the limits laid down by the *Ministry of Heavy Industry's Survey Manual*. In annex No. 8 to this manual, *Guidelines for implementation of surveys of industrial plants*, it is stipulated that the accuracy of determining the volume should be less than ±2% ±3% for raw materials and ±5% for industrial waste [3].

5. Determining the Density and the Mass of the Stored Road Salt

Within the scope of the commissioned inventory of the storage, the total mass of the accumulated material was to be determined. For this reason it was necessary to determine the density of salt. For that purpose, samples were collected and weighed in two scaled containers of the capacity of 5.500 dm^3 (Fig. 5). The electronic scales RADWAG WPT/R, with the permissible mass ranging from 200 g to 30 kg and the reading accuracy of 10 g, was used for weighing the samples. Prior to proceeding to the weighing of the salt mass, the scales was levelled and tared using the containers intended for weighing. The samples were collected from 60 pits distributed evenly over the entire surface of the storage, with depths of 10 cm to 120 cm. The depth of the pit was dependent upon the hardness of the salt storage.

The distribution of the quantity of the collected samples in relation to the place of their collection was as follows:

- 15 pits were made in the embankment of the slope,
- 15 pits were made at the top of the dump of salt,
- 15 pits were made at the top of the dump of salt at a depth of up to 50 cm below the surface of salt,
- 15 pits were made at the top of the dump of salt at a depth of up to 120 cm below the surface of salt.

As a result of weighing, five samples were obtained the mass of which deviated far from the average. These samples were excluded from further calculations. During the weighing procedure, no differences in shape or colour of salt were observed. The average mass of the sample was 6940 ±141 g and the average density was 1.261884298 g/cm^3. Each inventory survey carried out by a surveyor shall be accompanied by an audit, which requires the value of the density to be checked, and controls the inventory process and methodology.

Fig. 5. Checking the mass of the collected samples of salt

To calculate the total mass of the storage, the previously determined volume of salt and the density calculated on the basis of the collected samples were used. The initial volume was determined as the mean from the method of triangle and square mesh, separately for each survey. The following values of the storage volume were obtained: 783.78 m^3 (Elta R55) and 780.09 m^3 (Leica TCR407Power). The square mesh models with dimensions of 1.00 m × 1.00 m and 0.01 m × 0,01 m were excluded from the calculations, as in the first case the interpolation accuracy for such a varied surface was too small. By contrast, the smallest mesh sizes were too dense for such a rare survey of points representing the surveyed storage. The results of determining the storage mass were 989.04 t (Elta R55) and 984.39 t (Leica TCR407Power). By comparing the above values of road salt mass accumulated in the warehouse, we can note that the difference obtained from two independent surveys amounts to just 4.66 t which represents 0.5% of the total mass of salt. On the basis of the conducted test, and all the related analysis it might be concluded that both of the methods for surveying the volume of the storage, which were used in this case, may be treated as equally accurate and the differences obtained in this way are minimal with this kind of materials. The value of mass obtained in the survey inventory process was compared with the records. The value compliance was obtained at the level not exceeding 2% (tab. 5).

Table 5. Summary of salt masses obtained from the conducted inventory with record status

Date of measurement	Inventory	Record Status	Difference between the masses	
	[t]	[t]	[t]	[%]
2008.01.11	1 115.49	1 127.39	11.90	1.1
2008.06.27	1 162.28	1 195.41	33.13	2.8
2008.11.06	1 191.30	1 195.41	4.11	0.3
2009.06.09 Elta R55	989.04	1 002.45	13.41	1.3
2009.06.09 Leica TCR407Power	984.39	1 002.45	18.06	1.8

6. Conclusions

The carried out experimental works permit the formulation of the following conclusions:

– The range of distance survey for the reflectorless instruments involved in the test survey conducted towards a properly prepared road salt samples was respectively:
  • TCR407Power – 112 m,
  • TCRA1102plus – 124 m,
  • TCRP1205 – 137m.
– For the measured lengths up to 50 m, standard deviations in the case of all the total stations were within the instrument measurement error. Only in the case of very acute angles of incidence of the sight line axis on the salt, this error increased to 5 mm. However, for longer sight lines of up to 100 m, standard deviation for total stations ranged from 6 mm to 16 mm.
– Based on the results presented above, it was found that both the surveying and calculation methodologies which were for the total stations ELTA R55 (measure to prism method) and Leica TCR407Power with reflectorless survey mode, give comparable results. Therefore, the instruments having the same type of a distancemeter may be, or even should be used for inventory of road salt storage in closed warehouses, because they provided equally satisfactory results as the survey using the measure to prism method, and they shorten the time and reduce the number of people involved in the surveying process.
– To calculate the total mass of road salt stored in a warehouse it is necessary to calculate the volumetric weight of the raw material. The applied and presented method as well as the obtained results of determining the density carried by a surveyor were confirmed by a survey conducted by an independent company CBiDGP. The discrepancy between the determined weights reached 1.6%. Hence, we can state that the ultimately determined total mass of salt storage will not be subject to a blunder due to the determination of the density. The surveying test set out in the article is the fourth inventory survey conducted for this facility in order to compare the actual numbers with the recording status. In our case, this discrepancy amounted to 13.41 t which corresponds to 1.3% (Elta R55) and 18.06 t 1.8% (Leica TCR407Power) of the total mass of road salt. During the previous inspections, these differences fell within 0.3% during the survey on 6 November 2008, to 2.8% obtained on 27 June 2008.

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