On Digital Levelling Technique Applied in Water Crossing

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Key words: Levelling, digital levelling system, sight distance, water crossing.

SUMMARY

The digital levelling technique is commonly applied in precise levelling today. In Finland the longest sighting distances in precise levelling are 50 m, but sometimes the longer sightings are needed, e.g., in water crossings over the lakes, valleys or rivers. The Zeiss DiNi12 digital levelling system is capable to operate until to 100 m, but in water crossings we need longer sightings. Basically, the bar code scale of the rod can be copied with a certain magnification and thus be enabled to use longer sighting distances. According to the tests the Zeiss DiNi12 was able to process rod readings at the distances even to 400 m.

- A new rod pair, in which the bar code scale was magnified 4 times, was constructed. To study the operational terms and accuracy of the Zeiss DiNi12 in the water crossing circumstances, a special test field with 250 m, 350 m and 400 m sighting distances was constructed. Results obtained verified that the developed digital water crossing method fulfills the requirements of the precise levelling.
- A trigonometric levelling method applied in water crossing was also studied. The results were promising.

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1. INTRODUCTION

At the beginning of the 90th the digital levelling technique came to market as a very effective tool for the line levelling. It was almost automated, accurate and very quick technique when we use short, ie., less than 50 m sighting distances (Ingensand 1990). To apply it directly in the water crossing was problematic, because the optical characters, the size of the CCD-array and especially the size of the code element limits its maximum sighting distance to100 (Feist et al.1999) or in good weather conditions even 120 m. In the water crossing we need often several hundreds meters, some times even kilometers long sighting distances. For normal digital levelling equipment that is not possible. Application of the digital leveling technique in the water crossing has been studied in Japan, Germany (Schauerte et al. 1999) and in Finland since 2003 (Takalo and Rouhiainen 2004a). The solution has been the magnifying the bar code scale.

In Finland we have earlier studied the behavior of the Zeiss DiNi12 digital levelling system (Takalo and Rouhiainen 2001) and since 2003 its applicability to the water crossing. The remarkable advantage of the Zeiss Dini is that the program of the instrument uses only a limited sector, according to the manufacturer 30 cm, of the observed bar code scale to compute the rod reading. This minimizes the effect of the disturbing, extra code lines, shadows etz. To magnifying the size of the bar code element (20 mm) 2-10 times larger, the Dini-level can read the rod scale from the distance of even 1000 m.

In this study will be described the tests to apply the DiNi12 digital levelling system in water crossing in Finland. By the side of the digital technique tests we have also tested use of the trigonometric leveling in the water crossing.

2. ZEISS DINI12

According to study by Schauerte et al. (1999) the magnifying the bar code scale influences linearly to the height and distance readings of the digital level, but does not change the magnifying ratio between the bar code and its projection on the CCD-array. Several magnification testes of the DiNi-code were done in 2003-2004 in Finland. First we produced a 4 times magnified bar code scale on a copy paper with a copy machine. The scale was 1 m long and fixed on a panel. Later we used black and white plastic tape to built up 4 times magnified bar code rod. The scale was fixed on the backside of a 3 m long aluminum rod. To determine the accurate position of the each code element we used two steel precise measuring pieces and a sharp knife (Figure 1).

Figure 1. Producing of a magnified bar code using precise measuring pieces.

The accurate scale factors of the 4 times magnified bar code rods Nos. 8617 and 8618 were determined by calibrating them in the system calibration comparator (Takalo and Rouhiainen 2004b). The calibrations were made at three different temperatures (Figure 2) in order to obtain the thermal expansion coefficients. According to the results they were quit near to that of aluminum (+24 ppm/°C). The scale factors, which in fact include the constant length correction of the scale and the thermal corrections are:

Instrument / Rod	**Scale factor**
320015 / 8617	$3.99990 + 21.6 \times 10^{-6}$ (t-20°)
320015 / 8618	$3.99982 + 22.2 \times 10^{-6}$ (t-20°)

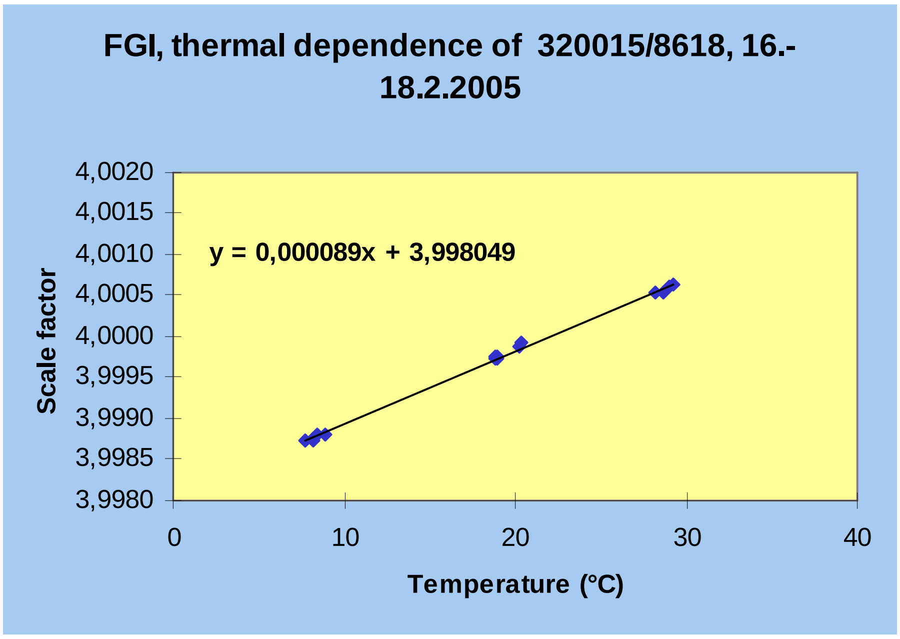

Figure 2. Thermal dependence of scale factor.

According to the calibration a single correction of rod readings varied from +0.1 mm to –0.2 mm, which show the quality of the self made rod scales.

3. TRIGONOMETRIC LEVELLING

The trigonometric levelling was studied as a second method or a reference method for the digital method in the water crossing tests. The method was developed in Finland (Takalo 2000) and basis on the use of two thacheometers and is partly automated. The measurement consists two basic operations: Bench mark connection and Height transfer (Figure 3). In the former the difference in height between bench mark and the theodolite is determined by observing the vertical angels to the marks on the rod set up on the bench mark bolt. In the latter the difference in height between theodolites are derived from simultaneous and reciprocal observations of the vertical angles and slope distances to the targets and prisms of the theodolites, respectively.

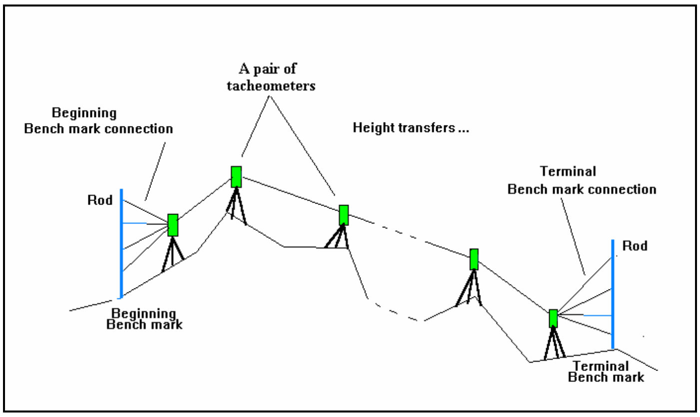

Figure 3. Principle of trigonometric levelling

The measuring equipment consists of two electronic theodolites, a precise EDM instrument, an automated weather station, two radio modems and a field computer. In the water crossing method an enlarged signal target was used (Figure 4).

Figure 4. Enlarged target used in water crossing tests in Otsolahti.

The maximum sighting distances in the precise trigonometric levelling method have been 300 m and the achieved accuracy has been 0.8-2.1 mm/√km (Takalo 1998), but its applicability to the longer sightings had not any experiences in Finland.

4. THE OTSOLAHTI TEST FIELD

To test the water crossing levelling methods a test field was established around the Otsolahti bay in the city of Espoo in 2003-2004. The basic field consists of three bedrock bench marks T1, T2 and T3 and their reserve bench marks T11, T21 and T31 also in bedrock (Figure 5).

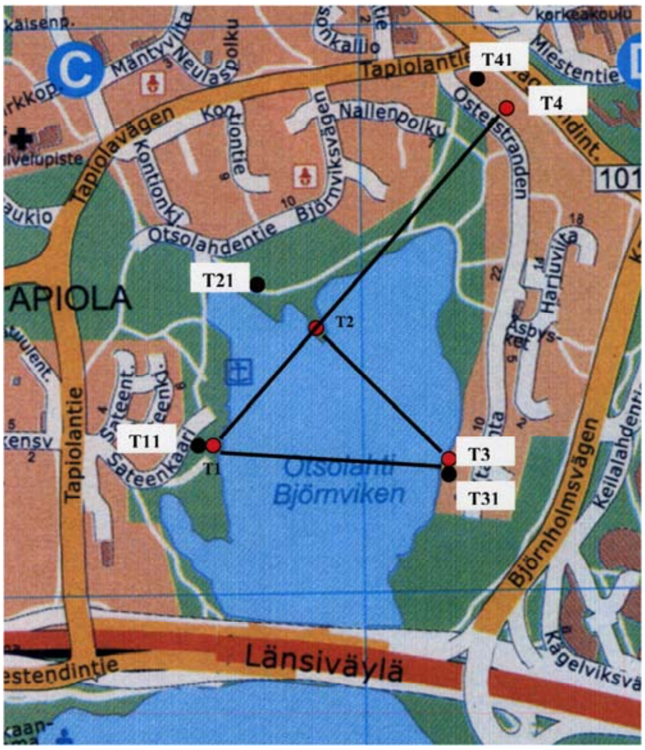

Figure 5. The Otsolahti test field for water crossing. The copy right of the map © by the city of Espoo.

The point T4 was established in 2005 only to test the trigonometric water crossing method. The point is on a big boulder, but its reserve point T41 is on bedrock. The distances as the crow flies and the height differences of the bench mark intervals in the Otsolahti test field are:

Interval	Distance	Height difference
T1 – T2	260 m	+0.29 m
T2 – T3	370 m	-0.11 m
T3 – T1	405 m	+0.18 m
T1 – T4	730 m	+3.83 m

The length of the loop T1-T2-T3 is 1035 m and from each point is the open view to another, except the point T4 can not seen from the point T3. All reserve points are near (<100 m) to the main points and are used only to control the stability of the main points.

5. MEASUREMENTS

In order to create an accurate and real reference, true heights, the height differences between all bench marks of the Otsolahti test field were measured using the precise leveling, i.e., the normal format by the Zeiss DiNi12. The levellings were done along the coastal walking paths of the Otsolahti bay (Figure 5) and they were carried out twice between points Ti, T2 and T3 in autumn 2004-2005 and once to the point T4 in autumn 2005. The standard error computed from the fore and back levellings was ±0.18 mm/√km.

The digital water crossing method Zeiss DiNi12 was tested in Otsolahti between August and October 2004 and second time between October and November 2005. In total, 50 test measurements were carried out. The observation procedure was as follows: The observer at the beach 1 measures the nearest rod with a short, usually less than 10 m sighting distance and then across the sea to the rod at the beach 2 using 250-400 m sighting distances. Next, the observer moves the instrument to the beach 2 and interchanges the positions of the rods and carries out the observations similarly as at the beach 1. The interchange of the rods eliminates the effect of the zero point errors of rods and the change of the position of the instrument from one beach to another the effect of the collimation from the mean of the observed height differences. Of course, the latter presupposes that the collimation of the instrument does not change during the transportation and the observations.

In the traditional water crossing levelling (Kneissel 1956), the observations were always carried out with two instruments simultaneously and reciprocally from both beaches of the crossed interval, in order to eliminate the effect of refraction. There was also presupposed that the distribution of the refraction is symmetrical for the whole interval. In Otsolahti, we used one instrument at a time and kept the time difference between the reciprocal observations as short as possible, in practice less than one hour. Then we selected the weather conditions so that the effect of the refraction was minimal.

We had three Zeiss DiNi12 digital levels in Otsolahti and one 3 m long 4 times magnified bar code rod pair. During the measurements the temperature of the water, the temperature of the rods and the vertical air temperature gradient were observed near the instrument. During the observations the weather was mainly cloudy or semi-cloudy. The final height differences were obtained by multiplying the observed height readings in the units given by the program of the instrument with the corresponding scale factors. The mean of the height differences observed by the same observer and using the same instrument from the both beaches was the final height difference for each water crossing.

Measurements with the trigonometric leveling were carried out in Otsolahti two times in July and in November 2005 between the points T1-T4 and the interval T1-T3 in July and T1-T2 and T2-T3 in November 2005. In each water crossing measurements from the theodolite to the theodolite were taken five series of observations instead of two. The weather conditions were meanly good.

6. RESULTS

In Table 1 are given the results of the loop T1-T2-T3 measured by the precise levelling (true values), the digital water crossing method and the trigonometric water crossing method. The errors (Figure 6) of the digital as well as the trigonometric levelling were derived by comparing the observed height differences with the true values.

Critically said, we can achieve with the digital method in the water crossing approximately the same accuracy as achieved in the precise leveling (±1 mm/√km), if the sighting distances are shorter than 400 m. According to our tests the trigonometric water crossing method is able to achieve better than ±4 mm/√km accuracy while the sighting distances are shorter than 1 km.

Table 1. Results of the Otsolahti testfield measurements

Measurement method	Year	T1-T3	T3-T2	T2-T1	Closure
Precise levelling (as reference)	2004	175,76	114,86	-290,62	—
Precise levelling	2005	175,60	114,87	-290,47	—
Digital water crossing	2004	175,1	114,5	-290,1	-0,5
Digital water crossing	2005	175.0	114.5	-290.6	-1.1
Trigonometric water crossing	2005	175,6	116,7	-291,2	+1,1

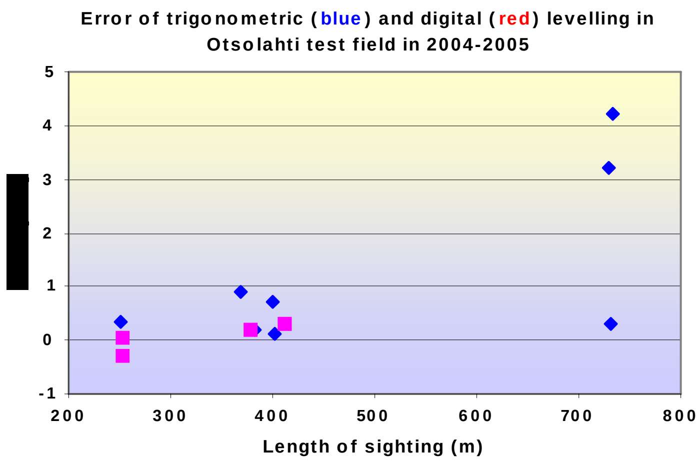

Figure 6. The accuracy of the water crossing test measurements

CONCLUSIONS

- The digital levelling technique Zeiss DiNi12 can be applied in the water crossing by magnifying the size of bar code element
- A special test field was established around the Otsolahti bay enabled the sightings of 250 m, 370 m, 400 m and 750 m
- A rod pair with the 4 times magnified bar code scales were constructed
- The achieved accuracy using the digital technique was the same quality as the precise levelling has
- The reflection of the sun shining from the surface of water disturbed seriously the operation of the digital level
- The achieved accuracy with the trigonometric water crossing method was better than half cm until to 1.3 km distances
- In next future the bar code scale will be and is possible to magnify 8-10 times in order to measure even one km water crossings using the Zeiss DiNi12 digital levelling technique.

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