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MEASURING DEVICES SET FOR DETERMINING HEIGHT DIFFERENCES IN CONSTRUCTION WORKS

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Summary

During construction and maintenance of buildings it is necessary to transfer the height from the ground level to each floor. The transfer is realized by various methods, e.g. by geometric levelling, geometric levelling with the use of geodetic measuring tape, or by trigonometric levelling.
The authors developed and made a set of measuring devices consisting of a benchmark table and plane mirrors enabling the transfer of height with the use of an electronic total station equipped with an option of measuring distance without using reflector prisms.
The paper presents the results of experimental studies carried out within the building of The Faculty of Environmental Engineering and Geodesy of the Wrocław University of Environmental and Life Sciences, with the use of the proposed measuring devices set.
The research work was based on functional and accuracy analysis and the analysis of the time of height transfer made by means of the studied measuring devices and was compared with the measurement results obtained by a precision level Leica DNA03.

Keywords

buildings • height transfer • geodetic equipment

1. The transfer of height by traditional methods

During construction and assembly or maintenance works in various kinds of buildings it is often necessary to transfer the heights between various levels. The transfer or measurement of a height difference can be realized by geodetic methods, while using specialist equipment and methods such as: geometric levelling, trigonometric levelling and length measurements of vertical segments with the use of geodetic measuring tape or a rangefinder (e.g. DISTO) [Boryś and Przewłocki 1998, Pelzer 1988].

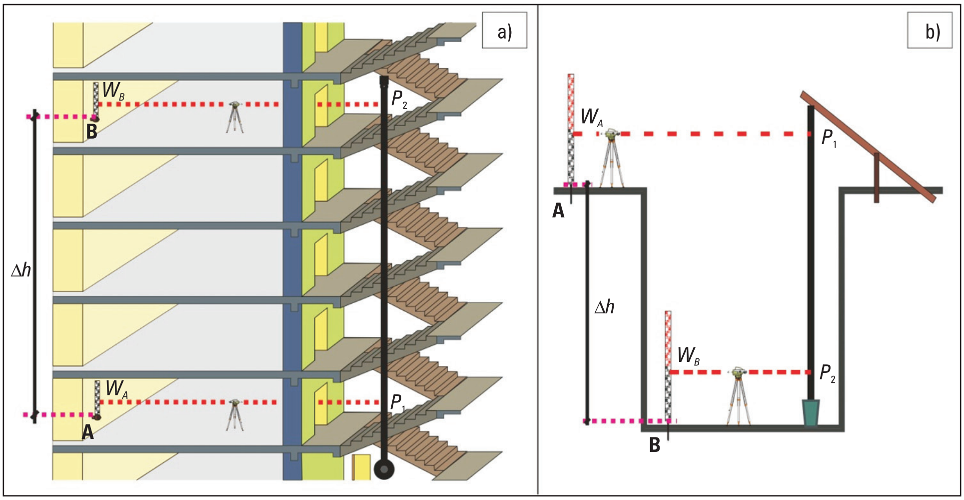
1.1. The measurement with the use of geodetic measuring tape

Whenever the height between points in a shaft, excavation or a staircase has to be transferred one can use a geodetic measuring tape hanging vertically, levelling rod or a surveyor's level (Figure 1). The measurement procedure is very simple. The ribbon gauge plays a role of an elongated levelling rod. The rods should be placed at points for which heights differences are determined, and measuring tape supplied with a weight and with millimetre scale is hanging between the levels. On the basis of readings obtained at scales of the two levelling rods and at millimetres scales of measuring tapes one calculates the difference of heights according to the formula (1): [Popek and Wapińska 2009].

$$\Delta h = W_A - W_B - (P_1 - P_2) \tag{1}$$

where:

Δh – the transferred height difference between points A and B,
W_A – reading form a levelling rod at point A,
W_B – reading from a levelling rod at point B,
P_1, P_2 – reading from a millimetre scale of a measuring tape.



Source: a) Gocał 2009, b) based on Popek and Wapińska 2009

Fig. 1. The transfer of height by means of a steel measuring tape: a) between many floors, b) downwards

By this method one can, in a relatively short time, determine the height difference with high accuracy. When using a measuring tape the following corrections in calculating an elevation should be taken into consideration:

- thermal – resulting from the differences between the temperature of a measuring tape during measurement and comparison,
- comparative – resulting from a scale of a tape,

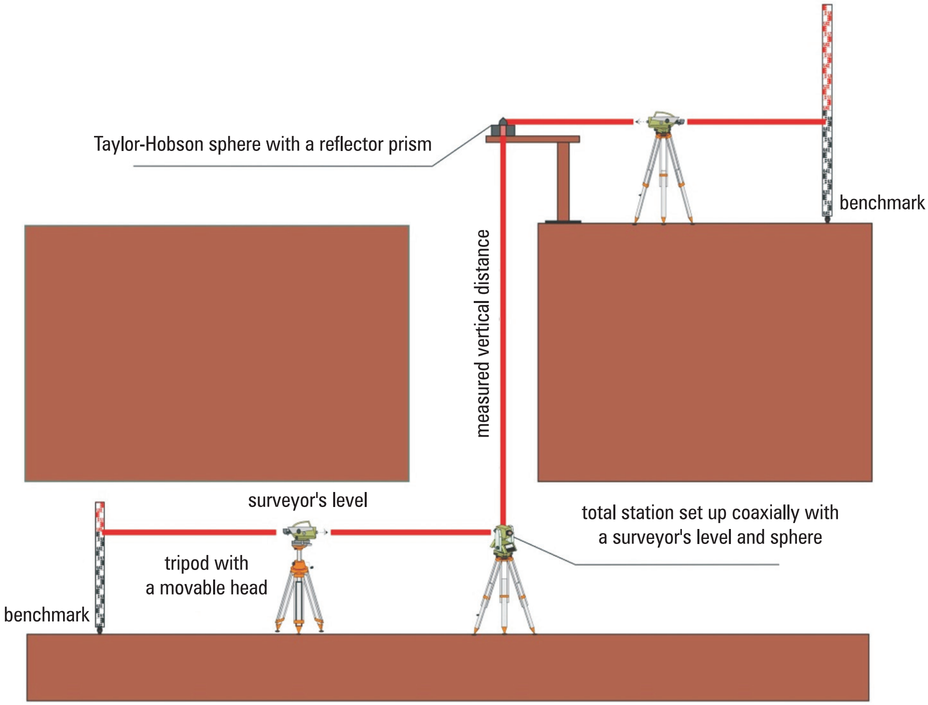
- with regard to the specific weight of a measuring tape,
- with regard to the difference in tape's tension during measurement and comparison.

In order to increase the accuracy of the measurement one need to move the tape vertically by a certain value and take a reading again.

1.2. The measurement taken with the use of Taylor-Hobson sphere and electro-optical rangefinder

Another method of height transfer, used during the construction of cyclotron Superconducting Super Collider in Texas, involves using Taylor-Hobson sphere (Figure 2). The device has a double function: measuring point for a surveyor's level and a reflector prism for an electro-optic rangefinder, by which vertical distance measurement is taken [Greening et al. 1995].

The accuracy of the transfer was ±0.7 mm, while the shaft's depth was around 250 m [DeKrom 1995].



Source: authors' study based on DeKrom 1995

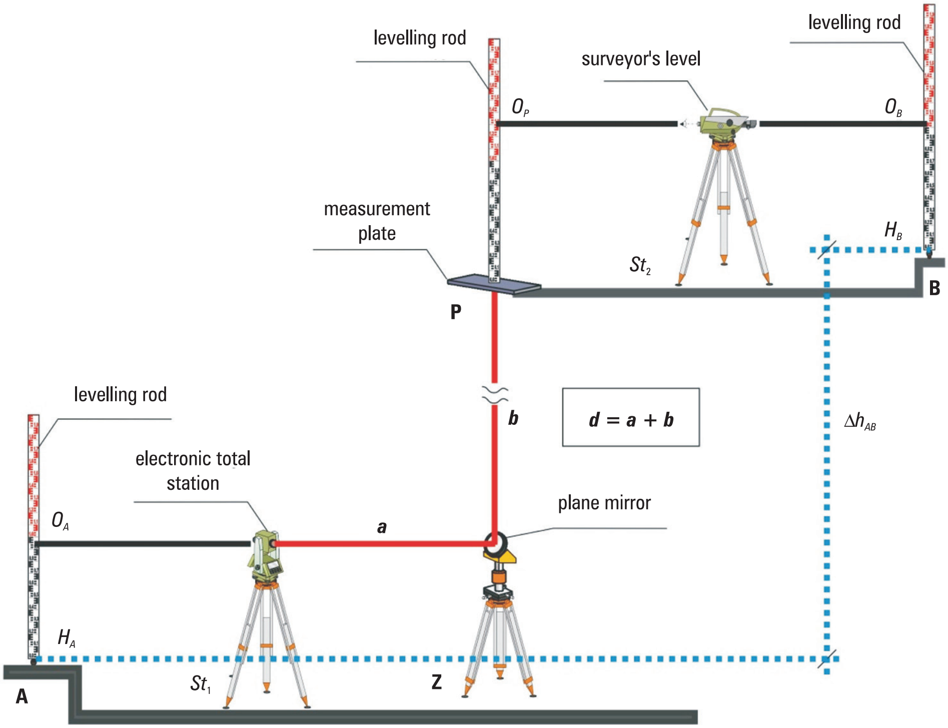
Fig. 2. Height transfer from a ground level to underground

2. The design and operation of the prototype measuring set

The developed measuring devices set consist of: a measurement plate, plane mirror station, electronic total station, a surveyor's level and levelling rods (Figure 3). Before making the measurement the levelling rods should be placed vertically at points *A* and *B*, a measurement plate should be put horizontally at point *P*, and a plane mirror – at point *Z*, and on the measuring levels the electronic total station and the surveyor's level respectively. The plane mirror should be placed so that one could measure the distance *a* (up to the obscured reflecting surface of a plane mirror) with the use of a total station, and then the distance *d* (formula 2) by means of reflecting surface of a mirror (up to a horizontal surface of the measurement plate). Depending on the structure of the measurement plate, the way it is fixed and the position of the levelling rod at the top measuring level (station *P*), it may be necessary, in the results of the determined elevation Δh_{AB}, to take into account the thickness of the measurement plate *g* (formula 3).

$$b = d - a \tag{2}$$

$$\Delta h_{AB} = H_B - H_A = O_A + b + (g) + Op - O_B \tag{3}$$

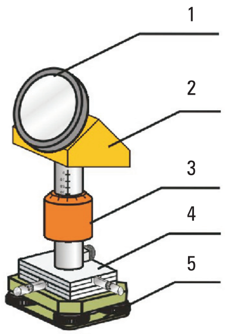


Explanations to Figure 3 and Formulae 2 and 3:
A, B – points for which the height difference is determined,
St_1 – total station
St_2 – surveyor's level station
P – measurement plate station
Z – plane mirror station
Δh_{AB} – the transferred height difference between points A and B,
O_A – reading taken at the levelling rod placed at point A,
O_B – reading taken at the levelling rod placed at point B,
O_p – reading taken at the levelling rod placed on a measurement plate,
b – the vertical distance between the reflecting surface of the plane mirror and horizontal surface of the measurement plate,
g – thickness of a measurement plate,
d – the distance measured by a total station with the use of mirror up to the surface of a measurement plate,
a – the distance between a total station and a reflecting surface of plane mirror.

Source: authors' study

Fig. 3. The characteristics of height transfer by means of the developed measuring set

The basic element of this measuring set is a plane mirror station (Figure 4), which enables the correct setting of a mirror's surface in a measured space. The correct setting of a mirror's surface during measuring procedure is ensured by: a prism with polished sides set at an angle of 45°, a screw jack (it moves the mirror vertically), a micrometric table (it move the mirror horizontally), and a tribrach with bubble level (it enables setting the mirror level at an angle of 45° with a vertical line).



Explanations:
1 – plane mirror
2 – a prism with polished sides set at an angle of 45°
3 – screw jack,
4 – micrometric table
5 – tribrach with adjustment screws

Source: authors' study

Fig. 4. Model of a plane mirror station

3. Empirical research

The empirical research was carried out in stages with the aim to verify the structural and functional assumptions about how the proposed measuring set can transfers heights.

At the first stage the geodesic instruments have been tested: a surveyor's level and a total station. The following possible errors have been checked and eliminated: the error of non-parallelism of target axis of and the vertical circle index error.

At the second stage the thickness of a measurement plate has been determined by means of a calliper (Figures 3 and 5) and the accuracy of the plane mirror station has been checked (Figures 4 and 6). The basic function of a mirror's station is moving the surface of the mirror vertically and making little horizontal adjustments of the mirror's position so as the geometrical centre of its surface was at the height of horizontal target axis of a total station (Fig. 3). After completing the settings of a mirror at the station its surface should be at an angle of 45° to a vertical line.

At the next stage the height has been transfer along the staircase of the building of The Faculty of Environmental Engineering and Geodesy of the Wrocław University of the Environmental and Life Sciences. The height was transferred from a benchmark *A*, situated at the ground floor level of a building to a benchmark B placed at the wall of the fourth floor of the building. Both benchmarks are stabilized at the load-bearing wall of the building, and the height difference between them was around 17 m.

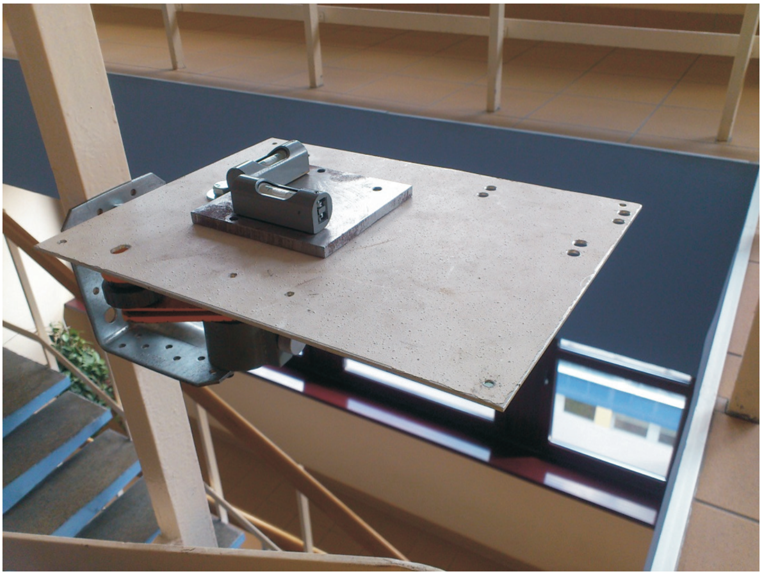


Photo by K. Ćmielewski

Fig. 5. The measurement plate station on the fourth floor of the studied building

Photo by K. Ćmielewski

Fig. 6. The plane mirror station on a geodetic tripod set at the ground floor of the studied building

In the first place a precision geometric levelling of a draught by means of a level Leica DNA03. The averaged result of this measurement (Dh_{niw} = 16.88648 m) was a reference value for the measurements carried out with the author's measuring set. The height measurements were taken in six series, and their results are gathered in Table 1.

Table 1. The results of height differences between benchmarks measured with the proposed measuring set

Series no.	Distances			Levelling rods readings			The thickness of the measurement plate	Elevation		
								measured	Averaged from the position I and II	Final
	a	d	$b = d - a$	O_A	O_P	$O_{B'}$	g	Dh_{ABpom}	$Dh_{AB\acute{s}r}$	Dh_{AB}
	[m]			[m]			[m]	[m]	[m]	[m]
	The total station's telescope position I			Level's horizon I			$2.35 \cdot 10^{-3}$	Position I		
I	6.430	22.543	16.113	0.864	1.1028	1.1952		16.8870	16.8870	16.8869
II	6.429	22.543	16.114	0.864	1.1029	1.1952		16.8881	16.8875	
III	6.446	22.560	16.114	0.862	1.1028	1.1952		16.8860	16.8865	
IV	6.445	22.561	16.116	0.862	1.1029	1.1952		16.8881	16.8875	
V	6.415	22.531	16.116	0.861	1.1028	1.1952		16.8870	16.8865	
VI	6.415	22.531	16.116	0.861	1.1028	1.1952		16.8870	16.8865	
	The total station's telescope position II			Level's horizon II				Position II		
I	6.430	22.543	16.113	0.864	1.0748	1.1672		16.8870		
II	6.430	22.543	16.113	0.864	1.0748	1.1672		16.8870		
III	6.446	22.561	16.115	0.862	1.0748	1.1672		16.8870		
IV	6.446	22.561	16.115	0.862	1.0748	1.1672		16.8870		
V	6.416	22.531	16.115	0.861	1.0748	1.1672		16.8860		
VI	6.416	22.531	16.115	0.861	1.0748	1.1672		16.8860		

4. Conclusions

The presented research was carried out to assess the accuracy of height transfer realized with the author's device set and to compare the results obtained by this method with the results of traditional geometric precision levelling. The proposed method and the measuring device set enable the transfer of height (around 17 m) between a building's floors with accuracy of ±0.4 mm. The developed measuring set considerably accelerates the measurement works in buildings with limited space for observations. The set uses mainly standard geodetic equipment, which is its additional advantage. When using precision total stations, e.g. Trimble S8 or Leica TCR2003, one can increase the accuracy of the elevation measurement, but the precision of the measurement could be limited by the working conditions in a measured object.

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