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Evaluating the Accuracy of Laser Levels for Engineering Surveying

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Abstract. A Sokkia LP,3A automatic laser level was tested for the purpose of judging its capability for differential heighting as practiced in engineering surveying works. A test line was first established on flat ground using precise levelling. This was re-measured using the laser level. Two approaches were followed.

In the first, several closed loops were levelled and the corresponding misclosures calculated and compared with known levelling standards. In the second, the elevations of the pegs on the test line were re-established several times from instrument station at the start of the test line. The r.m.s.e. values of height measurement were then calculated for each peg. These were also compared with known levelling standards. The results showed that in the first approach, the test instrument was able to give misclosure values better than ±7 mm for level circuits up to 340 m in length. This is commensurate with the requirements for third order optical levelling. In the second approach, the r.m.s.e. of height measurement of pegs up to 150 m from instrument station is better than ±2 mm. This is within the order of requirements for third order optical levelling. Taking into account the fact that with the laser level observations can be carried out by one person only, it is concluded that the laser level could be effectively used in place of conventional optical levels in localized surveys concerned with preparation of construction sites, drainage works, inner-city road surveys etc. where only lower order accuracy is required.

Introduction

The word laser is an acronym for the phrase Light Amplification by Stimulated Emission of Radiation. Nowadays, the term is used to describe a device that emits radiation which is more intense, monochromatic, coherent and directional than the light emitted by an ordinary source such as an incandescent lamp. These unique characteristics make the laser useful for many applications.

In civil engineering, the laser has found extensive use in most forms of construction work (e.g. earth excavation, grading and alignment tasks [1], off-shore channel dredging, dam deflection measurement [2], tunnel guidance, underground surveys, etc. [2-5]). The laser has also found use in mechanical engineering and manufacture for automatic scale measurement [6], laser plumbing [7] and in monitoring measurement dimensions [8].

The architect has also benefited from the use of laser-based instruments. In this respect, laser planers have been extensively used in monitoring interior height control of buildings, decorations, setting out of individual walls and suspended ceilings and control of elevator guide rails [9].

In the field of surveying, the laser has long been recognized as a carrier wave in electro-optical distance measurement (e.g. in the AGA-6 distance meter). However, in the last ten years or so, laser levels have been frequently used for levelling operations concerned with construction, earthmoving, drainage etc. However, there is still some sort of conservative look from the part of the surveyors towards this new device. Therefore, the purpose of this paper is to report results of a pilot experiment concerned with the evaluation of laser levels for surveying work. It is not, however, the intention of the authors to recommend or endorse this or any other instrument for a certain application. Rather, the aim is to evaluate, in a limited manner, the present test instrument by attempting to compare the results obtained with it with those established using conventional optical levelling. The results are believed to answer some of the questions often being raised by surveyors as regards the suitability of this device for routine surveying work.

The Laser Level

A laser level system consists of:

i) a laser source which can be levelled. The generated laser beam is projected by a rotating prism to form a horizontal reference plane; and

ii) a photo-electric laser sensor (or detector) which can be moved up and down a levelling rod in order to measure height differences relative to the laser-defined horizontal plane.

Since the continuous rotation of the laser beam about its vertical axis determines the projection of the beam, it is very important that the instrument be kept accurately level while in action. Thus, one of three methods is used to accomplish this task. Either manually using tubular bubbles in conjunction with foot screws, by use of an optical compensator (as in the automatic optical level) or by incorporating some kind of electronically-controlled self-levelling device (e.g. using electro-levels and servo-motors).

Over the last six to eight years, the majority of laser levels sold in the market have employed optical compensators or electro-levels and servo-motors which points to the possibility of improved performance of these levels. In fact, although the laser level is becoming more popular, many surveyors still feel wory about it. The main criticism from the part of the surveyor regarding the use of this device relates to the uncertainty of defining a horizontal plane by the continuously rotating laser beam, and the accuracy on the staff by which the photo-electric detector picks up the laser beam. This seems specially critical at distances longer than 100 m.

The first source of error is believed to yield a probable cumulative error in the order of 5-15 seconds of arc i.e. anywhere between ±2.4 mm to ±7.2 mm at a range of 100 m [10]. The limitations of the sensitivity of the detector arise from the size and sensitivity of individual cells, configuration of cell matrix and the definition of the laser beam when it impinges the cell matrix. It is believed that these facts, combined together, can result in an error value ranging from ±0.75 mm to ±3 mm depending on make and model of detector and distance from laser beam source. A further source of error is contributed by earth curvature and refraction (i.e. about ±0.7 mm/100 m).

Procedure of Test and Instrument

Initially, a line of levels 170 m long was established on flat ground of a reasonably protected site. Steel pegs were then firmly driven flush with the ground every 10 m along the line. The precise elevations of the pegs were then established using a Wild NAK2 automatic level in conjunction with a parallel plate micrometer and a GPLE2 precise levelling rod. The level was placed midway between successive pegs (to within approximately ±0.1 m) in an attempt to minimize collimation error as well as curvature and refraction effects by setting foresights and backsights approximately equal.

Further, in order to minimize the effects of refraction caused by heat waves, the line of sight was always kept at least 1 m above the surface of the ground. During the time span of the test (about ten days), all measurements were carried out in early morning (06-08 hr) or late afternoon (16–17 hr). This is believed to be advantageous because at these hours the atmosphere is rather homogeneous.

The misclosure value obtained in establishing the test line satisfies the requirements of first order class I standards as set out by the U.S.A. based Federal Geodetic Control Committee (FGCC) (i.e. better than $\pm 4\sqrt{K}$ mm) [10]).

The instrument used in the test is Sokkia LP3A automatic level (i.e. with a compensator). The laser detector unit is the Sokkia LPR3A (with a bond level) used in conjunction with a Sokkia AE55 telescopic metal rod and an LPC2 bracket. The LP3A was operated on a Sokkia LPT2 flat head tripod. Table 1 shows some of the characteristics of the LP3A and the LPR3A units.

Table 1. Some characteristics of test instrument

The LP3A Laser Level	Measuring range	100 m
	Horizontal accuracy	10″
	Light Source	Infrared laser diode
	Means of levelling	Automatic compensator
The LPR3A Detector	Measuring time	0.5 second
	Display	LCD
	Sensitivity of level	1 degree/2 mm
	Accuracy range	High ±0.8 mm Low ∓2.5 mm

Before being used in the test, the instrument was subjected to a series of adjustments. These are (i) adjustment of the circular level (ii) calibration of the XY axes and (iii) checking of the conical beam error. Adjustments were made when found necessary.

Two approaches were followed in this experiment. In the first, closed loops were run from one end of the test line (denoted as station 0 in Fig. 1), through intermittent pegs to each of pegs 2, 32, 4,... 17 and back to station 0 in an out-and-back manner. Each loop was observed independently and misclosures were then computed and compared with known levelling standards.

In the second approach, the test instrument was set over station 0. The rod-and-detector assembly was then made to occupy positions of pegs 1,2,3,..., 17 thus deriving heights of the pegs using the height of plane of collimation method. In order to

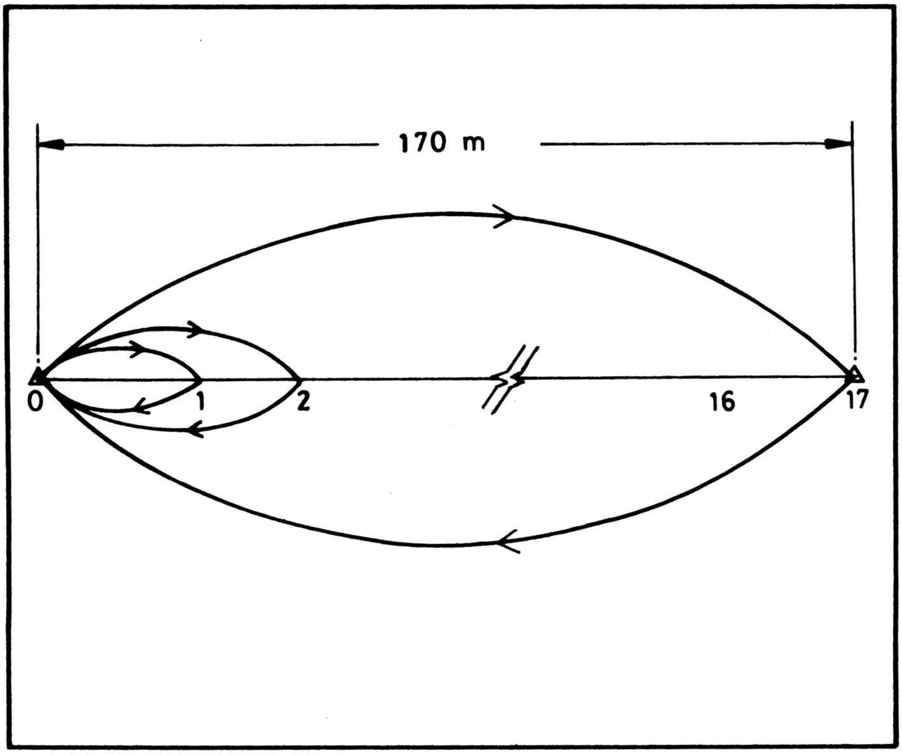

Fig. 1. Configuration of the test (Approach 1).

have a range of values, observations were made in four different days. Four sets of measurement were made in each day, two in the morning and two in the afternoon. This means that the height of each peg was derived sixteen times. Comparison of the derived heights of each peg with the corresponding height obtained from precise levelling, which was considered as the "true" or "most probable" height value, allowed computation of r.m.s.e. of height measurement σ_j for each peg j. These are compared with known levelling standards.

Computations, Results and Analysis

The LPR3A laser detector works in two modes, the high sensitivity and the low sensitivity modes. The high sensitivity mode was used for height measurement while the low sensitivity mode was used to show the rough position of the beam on the staff. Every effort was made to use both the LP3A level and the LPR3A laser beam detector very carefully during observations. Some observational difficulties were experienced. These include instability of the high sensitivity display at distances longer than 150 m, clamping the LPC2 bracket along joints of sections of the telescopic staff, setting the rod exactly vertical (using detector bubble) while at the same time sliding the detector up and down to pick up the beam, holding the staff on exactly the same point of the peg, estimating millimeters on the staff, attempting to avoid looking directly at the invisible beam from close proximity while reading the rod and occasional interruptions of the beam caused by the observer attempting to read the staff. Every effort was made to minimize the effects of these difficulties on the measuring process.

The r.m.s.e. was computed in the form of standard deviation σ_j using the formula:

$$\sigma_j = \pm \left[\frac{\sum_{i=1}^{n} v_i^2}{n} \right]^{1/2} \quad (1)$$

where

υ_i is the discrepancy between measured elevation h_i of peg j and its equivalent as derived from precise levelling; and

n is the number of acceptable observations of peg j.

When computing σ, a rejection criteria was adopted in which observations showing discrepancies greater than 3σ were rejected. Tables 2 and 3 show the results of the experiment. The two tables look largely self-explanatory. However, it is possible to augment them with some comments. The best accuracy was obtained with the first two loops (i.e. misclosure e better than or equal to $\pm 7\sqrt{K}$ mm. Thereafter the accuracy of the laser level deteriorates gradually as length of loops increase. However, it is noted that (with only two exceptions) even for the maximum double-run distance of 340 m, the accuracy obtained with the LP3A is still within that specified for third order optical levelling (i.e. $e = \pm 12\sqrt{K}$ mm).

The results on Table 3 which were obtained with the second approach show that r.m.s.e. values also increase gradually with increasing distance from instrument station. For distances up to 150 m (normal sighting range on engineering sites), the standard deviation in elevation difference is better than ±2 mm. This is in the order of figures specified for third order optical levelling. Figure 2 shows a quadratic relationship between the two parameters distance "d" from starting point and σ of height measurement using the test instrument. The relationship is in general agreement with those obtained using standard levelling operations as conducted with conventional levels.

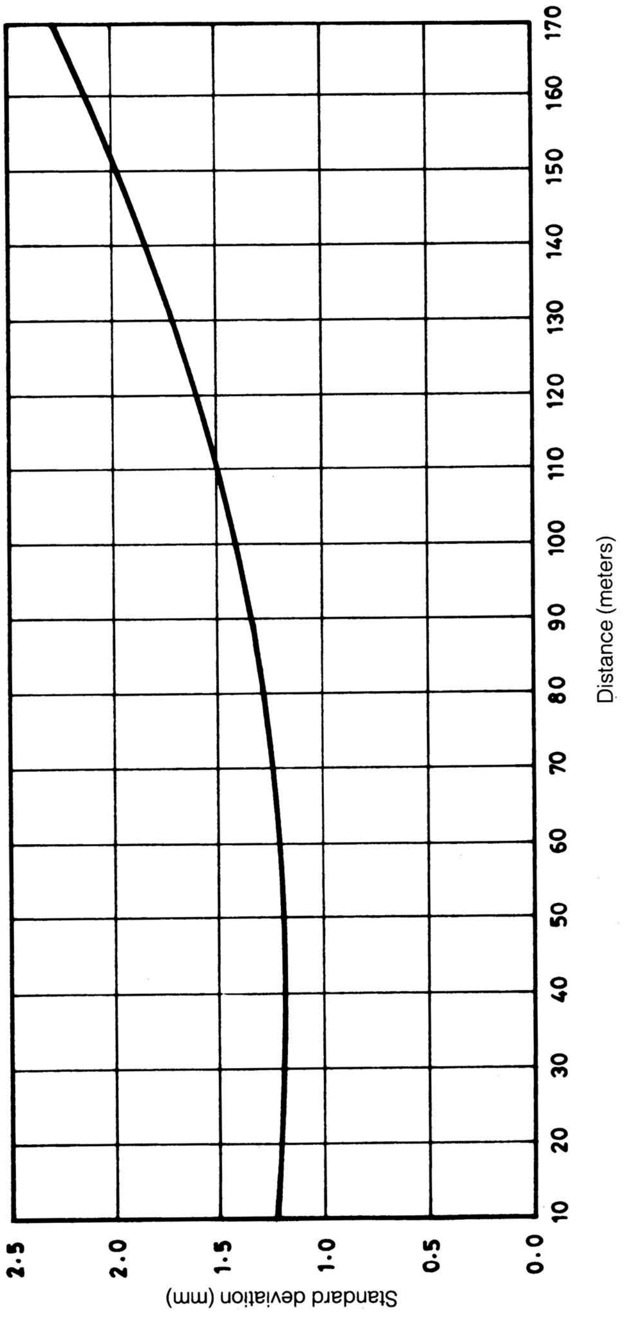

Fig. 2. Results obtained with Approach 2.

Table 2. Results obtained with Approach 1

Loop No.	Double-run distance (m)	Misclosure (mm)	Accuracy specification
1	20	–1	± 7.0√K
2	40	1	± 5.0√K
3	60	2	± 8.1√K
4	80	–2	± 7.1√K
5	100	–3	± 9.5√K
6	120	4	±11.5√K
7	140	–4	±10.7√K
8	160	–4	±10.7√K
9	180	–5	±11.8√K
10	200	–5	±11.2√K
11	220	–5	±10.7√K
12	240	–5	±10.2√K
13	260	–6	±11.8√K
14	280	–6	±11.3√K
15	300	–7	±12.8√K
16	320	–8	±14.1√K
17	340	–7	±12.0√K

Table 3. Results obtained with Approach 2

Peg No.	Distance (m)	Stand. deviation (mm)	Peg No.	Distance (m)	Stand deviation (mm)
1	10	±1.1	9	90	±1.4
2	20	±1.1	10	100	±1.4
3	30	±1.2	11	110	±1.4
4	40	±1.2	12	120	±1.5
5	50	±1.3	13	130	±1.5
6	60	±1.3	14	140	±1.6
7	70	±1.3	15	150	±1.9
8	80	±1.4	16	160	±2.2
			17	170	±2.5

Thus, in both approaches, it was found that at normal sighting distances (i.e. 150 m and less), the LP3A laser level is capable of achieving height measurement accuracy values commensurate with the requirements for third order optical levelling while considerably saving time and effort required for observation since with the laser level, only one person can carry out the field measurements. Also, it is noted that in this particular experiment, the LP3A performed well within specifications set out by the manufacturer. The range of accuracy values obtained in this experiment may be adequate for a number of levelling works of local nature e.g. site preparations in construction, drainage works, setting out and maintenance of inner-city roads etc.

It is possible to compare the results of this experiment with those reported by Hussain and Hemman [11] using a Spectra Physics Model 944 laser level. The accuracy of this level was tested against data acquired from a Wild N3 precise level used in conjunction with a precise levelling rod. First, a number of monuments were established in open ground and measured with both the reference instrument (the N3) and the test instrument (the Spectra Physics 944). For distances up to 500 ft (152.5 m), the results obtained were within a precision of $\pm 12\sqrt{K}$ mm. This is in general agreement with the results of this experiment.

Conclusion

The experiment was carried out in order to investigate the accuracy of laser levels in height measurement. A line of levels was first established using precise levelling. Two approaches were followed. In the first, several loops were levelled starting from one end of the line through all intermediate pegs to peg i and back to the starting point. The misclosures were computed and converted to accuracy specifications.

In the second approach, the instrument was set over one end of the line and the levels of all pegs were derived several times using the height of plane of collimation method. The discrepancies between the known elevation of a peg and each of its observed equivalents were used to compute standard deviation of height measurement of the peg.

The results showed that in the first approach, with only few exceptions, the test instrument was able to give misclosure values in the order of ±7 mm for circuit lengths (round-trip distance) up to 340 m. This is compatible with the requirements of third order optical levelling ($e = \pm 12\sqrt{K}$ mm). In the second approach, the standard deviations of height measurement of pegs up to 150 m from instrument station are better than ±2 mm. Again, this is commensurate with the requirements for third order optical levelling operations. This means that for normal sighting distances in engineering surveys, i.e. up to around 150 m, the accuracy with which differences in height are measured using laser levels satisfy the requirements for third order optical levelling. Taking this into consideration and noting that only one person can carry out the field measurements, the laser level can be effectively used in place of conventional optical levels to meet accuracy requirements for third order levelling as practiced in some localized engineering surveys e.g. preparation of construction sites, drainage studies, surveys of inner-city roads, etc.

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