OPTICAL, LASER AND DIGITAL LEVELLING: 
A COMPARISON OF ACCURACY IN HEIGHT MEASUREMENT

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ABSTRACT

Three levelling instruments of different designs, an NA2 optical level from Leica, an LP3A laser level from Sokkia and an SDL30 digital level, also from Sokkia, were compared for accuracy of height measurements. A base line was first established using geodetic means. This was then remeasured with the three test levels using two distinct approaches. In the first, several loops were run from a starting point, and back to it and misclosures were computed and converted into accuracy values. In the second, elevations of all steel hub pegs were established several times from one end of the line and root-mean-square errors were computed and converted to pooled values. In both cases, the results showed that while the NA2 generally satisfied second order class I standards, and the LP3A third order standards commensurate with most civil engineering surveys, the SDL30 achieved accuracy far better than those normally required for first order class I surveys while saving time and effort. Taking into account its many other features, the authors suggest surveyors consider digital levels for their levelling work.

Keywords: Adindan-Sudan, Doppler and GPS datums (WGS72, WGS84).

1. INTRODUCTION

Levelling, a basic discipline in geomatic engineering, is the process of measuring vertical distances between two or more points either directly or indirectly for the purpose of determining their elevations. The classic spirit level has a line of sight that is set horizontal by a spirit level tube. Generally, surveying levels are classified into three
main types according to the method of reading the levelling rod. These are optical levels, laser levels, and digital levels

1.1 Optical levels

Optical levels are divided into many types in accordance with the technique of obtaining coincidence between the line of collimation and the horizontal plane through the instrument. Three main types of the optical level can be distinguished. In the dumpy level, the sighting telescope is rigidly fixed to the standing axis of the instrument and can be rotated in just one direction, which is about the standing axis. A system of three (ideally located) levelling screws and a spirit level are used to establish a vertical standing axis and, in consequence a horizontal line of sight to enable staff readings to be taken.

In tilting levels, the telescope is not rigidly fixed to the standing axis, but can be tilted a small amount in the vertical plane about a pivot situated below the eyepiece of the telescope. A circular (spot) level mounted on the tripod is usually levelled independent of the main bubble. Many designs and models of tilting levels exist. Some feature coincidence bubble readers in order to increase the accuracy of setting the main bubble (Figure 1).

In automatic levels, however, the horizontal line of sight is established by means of a combination of optical prisms and mirrors, supported by wires as in a pendulum, the arrangement being referred to as “compensator system” (Figure 2). The instrument needs to be levelled only approximately (with ± 15’) to allow the compensators set the line of sight horizontal. A damping device brings the compensator system to rest quite rapidly. The automatic level has therefore the advantage of offering fast instrument set-ups and of reducing random errors in centring the tubular level bubble, a common nuisance to surveyors in dumpy and tilting levels.

Line levelling accuracy obtained with optical levels range from third order levelling standards (i.e. misclosure $e = \pm 25 \sqrt{K}$ mm where K is level circuit length in km) with some dumpy designs to $e \pm 0.2 \sqrt{K}$ mm for first order class I levelling standards with high precision geodetic (spirit) levels such as the Leica N3.

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**Figure 1: Tilting level coincidence reading bubble**

(a) Bubble not centred

(b) Bubble centred
1.2 Laser levels
These are devices that emit monochromatic, intense, coherent and directional radiation in the form of a rotating beam. Basically, a laser level consists of:

(i) a laser generating and leveling mechanism which projects a horizontal laser beam, and

(ii) A photo-electric laser detector. This device can be moved up and down an ordinary levelling staff to give rod readings relative to the horizontal laser plane (Figure 3).

Since all height measurements are related to the rotating laser beam, it is mandatory to ensure that the plane created by this beam is horizontal. In practice, this is achieved by one of three methods: either by manually using tubular bubbles and instrument foot screws as in dumpy and tilting levels, by utilizing optical compensator system as in automatic optical levels or by using some sort of an electronically-controlled self-levelling servomotors.

Most of the laser levels recently introduced in the surveying market have either optical compensators or servomotors to achieve a horizontal laser beam. This made many
surveyors, who initially bore a conservative, and sometimes wary, look towards such devices, more comfortable and lead to their acceptance as a modern and efficient measuring device for suitable surveying tasks.

Nowadays, laser levels are being used on construction sites, off-shore channel dredging, dam deflection surveys, tunnel guidance works, underground surveys, architectural designs (e.g. interior height control of buildings, decorations, setting out partition walls etc) to determine heights (or elevations) to an accuracy ranging from ±3 mm to ±9 mm in 100 m [1]. This accuracy range is acceptable for most of these types of surveys. As a result, the laser levels enjoy a good deal of popularity in these areas.

1.3 Digital levels

The development of this level became possible due to advances in microchip technology and image processing. The attributes of self-levelling instrumentation coupled with digital array photography and electronic image processing have generated a digital level, that is very much close to being truly automatic. The instrument is operated in conjunction with a special bar-coded staff (Figure 4). This type of level has the same features as automatic levels, namely, the eyepiece, the focusing knob, the compensator, the circular level bubble, tangent motion, the levelling screws and objective. This is in addition to the special features pertinent to it i.e., a built-in solid-state “camera”, a storage module, a microprocessor, a display register and a control panel.

Although the operation of digital levels varies slightly in accordance with instrument type, model and make, the procedure is to set up and level the instrument and focus it on the bar-coded staff. The operator then presses the on-off switch on the control panel to receive instructions on the display screen directing him/her or asking for information. If the “measurement without recording” mode is selected, the operator presses the “measure” button and the staff reading will start. The solid-state “camera” then records a digital image of the staff. This image is then compared to a “master” image of the whole staff resident in the memory of the instrument microprocessor and the rod reading is then determined to five decimal places by the process of digital image correlation. This rod
reading can either be displayed or else stored in the storage module. The distance to the rod can also be determined and displayed by pressing the appropriate key on the control panel. When this “measurement without recording” mode is selected, the resulting readings could be recorded manually in a field book as in dumpy, tilting and automatic optical levels.

The other mode i.e. “measuring and recording” is however, preferable in everyday survey practice. Here, by appropriate manipulation of the keys of the control panel, the operator enters the number and elevation of the initial benchmark on which a backsight is to be taken. The software incorporated in the instrument will display, compute and store rod readings, heights of the instrument, elevations and distances to all or some of the turning points on the line of levels. At the end of the levelling job, the memory module can be removed and interfaced to a computer where the data is downloaded and processed to give hardcopy versions of the data and the least-squares-adjusted elevations of the points occupied by the rod.

As is the case with all survey instrumentation, the digital level is also prone to a number of errors that have adverse effects on the measuring process. Like automatic levels, instrumental errors (e.g. collimation, bubble off center, pendulum instability, etc.), natural errors (e.g. earth curvature, refraction, etc), and personal errors (e.g. parallax) also affect the digital level. However, human reading error is eliminated with this level. The software of the instrument is capable of correcting for most natural errors. Efficient handling of the instrument and adoption of appropriate observational techniques, will assist in reducing instrumental and personal errors.

2.0 PURPOSE OF THE STUDY

Having outlined the main characteristics of present day levelling instruments, a keen surveyor or civil engineer will want to know the extent to which these various instruments compare as far as the accuracy of derived heights is concerned. Also what are their other relative merits and demerits and what range of applications is actually possible with each type?

The aim of this experiment is, therefore, to appraise the accuracy values with which differences in elevation can be measured using some selected levelling instruments of the types mentioned above. However, it is to be mentioned from the outset that it is not the intention of the authors of this work to endorse or recommend these or any other instruments for a certain group of applications. The authors merely attempt to evaluate, in limited and confined circumstances the levels used in the experiment by comparing the results obtained with them with known levelling standards. This will give an insight into the “relative” measuring capabilities of the instruments for various application fields and may well suggest the prospects of future levelling operations as regards the type of level that will dominate.

3.0 INSTRUMENTS USED IN THE TEST

Instruments used in the present experiment were one each of the following makes:

(i) A Leica NA2 automatic level with a Leica (10mm) GPM3 parallel plate micrometer attachment and a GPLE3 geodetic invar staff with 10 mm graduations.

(ii) A Sokkia LP3A automatic laser level used with a laser detector unit (the LPR3A) and Sokkia AE55 telescopic aluminium staff.
(iii) A Sokkia SDL30 digital level used with a Sokkia BGS40 staff. The level was used in the electronic measurement mode. The rod readings were recorded manually in a fieldbook. No attempt was made to make use of the automatic recording and reduction module of the instrument.

Table 1 shows some of the characteristics of the three instruments believed to be of interest to the circumstances of the present experiment. Before the test commenced, all instruments were subjected to the usual series of adjustments e.g. the two-peg test, bubble adjustment, etc. following the instructions provided by the respective manufacturers. Adjustments were carried out when deemed necessary.

4.0 PROCEDURE OF THE TEST

Basically, a procedure similar to that followed by Ali and Algarni [1] and Algarni and Ali [2] was followed. A 170-m long baseline consisting of seventeen sections was first established on flat firm ground. The lengths of these sections were approximately 10 m each.

Table 1: Some characteristics of the test instruments

<table>
<thead>
<tr>
<th>Instrument Characteristics</th>
<th>Leica NA2 (optical)</th>
<th>Sokkia LP3A (laser)</th>
<th>Sokkia SDL30 (digital)</th>
<th>Leica N3 optical tilting (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring range</td>
<td>up to 150 m</td>
<td>100 m</td>
<td>1.6 – 100 m</td>
<td>up to 150 m</td>
</tr>
<tr>
<td>Measuring time</td>
<td>operator-dependent</td>
<td>0.5” (on detector)</td>
<td>4 seconds</td>
<td>operator-dependent</td>
</tr>
<tr>
<td>Accuracy (st. deviation)*</td>
<td>±0.3 mm/km **</td>
<td>±1.5 mm/100m</td>
<td>±0.4 mm/km</td>
<td>±0.2 mm/km</td>
</tr>
<tr>
<td>Display</td>
<td>optical</td>
<td>LCD</td>
<td>LCD</td>
<td>optical</td>
</tr>
<tr>
<td>Bull’s eye sensitivity</td>
<td>8'/2mm</td>
<td>10'/2 mm</td>
<td>8'/2 mm</td>
<td>8'/2 mm</td>
</tr>
<tr>
<td>Means of levelling</td>
<td>automatic</td>
<td>automatic</td>
<td>automatic</td>
<td>split bubble</td>
</tr>
<tr>
<td>Accuracy of compensator (or bubble)</td>
<td>±0.3&quot;</td>
<td>±0.5&quot;</td>
<td>±0.4&quot;</td>
<td>±0.2&quot;</td>
</tr>
<tr>
<td>Display resolution</td>
<td>0.01 mm (on micrometer)</td>
<td>0.1 mm/0.01 mm (select)</td>
<td>0.01 mm</td>
<td></td>
</tr>
<tr>
<td>Telescope magnification</td>
<td>32X</td>
<td>***</td>
<td>24X</td>
<td>40X</td>
</tr>
<tr>
<td>Distance measurement accuracy</td>
<td>± 18 – 28 mm/100 m [5]</td>
<td>***</td>
<td>2 – 5 mm/10 m</td>
<td>± 18-28 mm/100 m [5]</td>
</tr>
<tr>
<td>Detector level sensitivity</td>
<td>***</td>
<td>1'/2mm</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Detector accuracy range</td>
<td>***</td>
<td>± 0.8mm (high)</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Detector display</td>
<td>***</td>
<td>± 2.5 mm (low) LCD</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

*with invar staff and parallel plate micrometer and after.
**after DIN 18723 or equivalent ISO standard double run.
*** not applicable or available.
Steel hubs driven flush with the ground were used as benchmarks on the line and a small tack marked the exact point on each steel hub. The elevations of these benchmarks were measured using precise levelling techniques to first order class I levelling standards using a recently-adjusted Leica N3 geodetic tilting level in conjunction with a Leica GPLE3 invar levelling rod. In establishing the elevations of the points, some precaution measures were taken during observations. For example, the observer placed the level midway (to within ± 0.1 m) between backsights and foresights in an attempt to reduce the effects of residual collimation errors and the small errors contributed by curvature and refraction. The line of sight was always kept at least 1 m from the ground in order to avoid grazing rays. Also from experiences gained by the authors in earlier experiments ([3], [4],[5]), all observations were conducted in early mornings or late afternoons in order to make use of the less turbulent atmosphere at these times.

The rise-and-fall method of reduction was used and the usual arithmetic checks were made. The computed misclosure of this part of the test satisfied the requirements of first order class I levelling standards published by the Federal Geodetic Control Committee (FGCC) of the U.S.A. i.e. better than ±4\( \sqrt{K} \) mm [6]. The misclosure was then distributed in the normal way to give the “true” or “most probable” elevations of the points with which the elevations derived using the test instruments are to be compared.

The test line was then remeasured using each of the instruments. Two distinct approaches were followed. In Approach I, several closed loops were run starting from the known benchmark “Point 0 on the beginning of the line” to each of the other points in forward-and-return manner (Figure 5). One instrument set-up was used in observing each section. This means backsight and foresight distances were only five metres each. The misclosure of each loop was computed and converted to accuracy specification.

![Figure 5: Configuration of the test (Approach 1). (After [1])](image-url)
In Approach II (Figure 6), a test level was set over station “0” to plumb bob setting accuracy. The height of the instrument was then measured several times using a precise steel tape; and the average value added to station elevation to give height of collimation to which all elevations to be measured were referred. The levelling rod was then placed on pegs 1, 2,…, n thus determining their elevations using the method of plane of collimation. In order to have a range of values, each peg height was determined four times on four different days. By comparing the derived heights of each peg with the “true” height obtained from precise levelling, a root-mean-square error value of height measurement \( \sigma_j \) for each peg \( j \) was obtained using the formula:

\[
\sigma_j = \pm \sqrt{\frac{\sum_{i=1}^{n} u_i^2}{n}} \tag{1}
\]

where \( u_i \) = discrepancy between elevation \( h_0 \) of peg \( j \) as obtained using the N3 and its equivalent \( h_i \) \( (i = 1,\ldots, 4) \) as obtained using the test instrument; and \( n \) = number of measurements.

In order to make interpretation of the results more meaningful, the standard error values were combined to form what is termed “pooled standard error” (or pooled standard deviation) \( \sigma_g \) using the formula:

\[
\sigma_g = \pm \sqrt{\frac{\sum_{j=1}^{m} w_j n_j \sigma_j^2}{\sum_{j=1}^{m} w_j n_j}} \tag{2}
\]

In using equations (1) and (2) a rejection criterion suggested by Logan (see Schofield [7]) was adopted in which observations having discrepancies from the mean more than \( \pm 1.5 \sigma \) (for a sample of size 4) were rejected. In fact, no observation was rejected on this basis.

Figure 6: Configuration of the test (Approach II) (after (2))
5.0 COMPUTATION, RESULTS AND ANALYSIS

Despite the precautions adopted during observations, some measurement difficulties were experienced. These included holding the staff exactly plumb, placing the staff on exactly the same point in forward and backward loop readings, some windy and dusty times of observation, weather heating up quickly in the morning thus causing heat shimmer, bull’s eye bubble moving slightly off-centre during the measurement, difficulties in taking rod readings beyond certain distances, estimating millimetres on the staff for the laser level, difficulties in communication between the instrument operator and the rod man at longer distances and, of course, tiredness and fatigue on the part of the levelling crew (instrument and rod men and booker) because of lengthy and repetitive measurements.

The observational difficulties were pertinent to the laser level, e.g. instability of the detector high sensitivity display at distances approaching 90 m from the instrument, moving the detector bracket across the various joints of the metal staff, setting the rod plumb with the bubble while at the same time sliding the detector up and down to take readings, trying to avoid looking into the laser beam at shorter distances while taking readings and accidental interruptions of the beam by the observer while reading the staff.

These difficulties proved to be frustrating and a nuisance. The survey team members endeavoured to make every effort to mitigate the effects of these difficulties on the results.

For Approach I, the misclosure “e” of each loop was used to compute the value of the constant “m” in the following well-known formula:

\[ e = \pm m \sqrt{K} \text{ mm} \]  \hspace{1cm} (3)

where \( m \) = a constant (in mm) indicating the class and/or order of the levelling process;

and \( K \) = loop length in km.

Equation (3) was then rearranged to give the pooled (overall loops) accuracy specification obtained with that particular loop and test instrument. Table 2 shows the results obtained with the three instruments using approach I.

For approach II, the maximum distance at which rod readings were conveniently and unambiguously taken were also noted. Table 3 presents the results of this approach.

To fortify the results shown on Tables 2 and 3, Figure 7 has been compiled to denote the relationship between loop length and value of misclosure for the three test instruments.

The contents of Tables 2 and 3 and Figure 7 explain clearly the relative performance of the test levels used in this experiment. Table 2 shows that in the worst cases, the conventional optical level Leica NA2 was able to give height accuracy values within second order class I standards according to FGCC specifications. It is also noted that for most loops this level gave accuracy specification better than or equal to first order class I standards (i.e. better than \( \pm 4 \sqrt{K} \text{ mm} \)). These findings are in line with specifications mentioned by the manufacturer for this level. It is rather strange to note that the best accuracy standards were obtained with the two extreme-case loops, the first and the last (loop lengths 40 m and 340 m) i.e. \( \pm 1.8 \sqrt{K} \text{ mm} \) and \( \pm 2.2 \sqrt{K} \text{ mm} \) respectively. The special circumstances that made this happen are not clear to the authors.

The Sokkia LP3A laser level gave accuracy specification ranging from \( \pm \)
new digital technology over its predecessors. Except for one unimportant exception, accuracy specifications obtained with this level were always better than $\pm 1.0 \sqrt{K}$ mm. Also accuracy standards better than $\pm 0.5 \sqrt{K}$ were obtained for most loops.

The results obtained with the Sokkia SDL30 compare favorably with those reported by Algarni and Ali (2007) using a Leica NA 3000 digital electronic level. To the best knowledge of the authors, the results of these two digital levels are far better than those reported by other investigators for their optical counterparts (7, 8). This suggests that digital electronic levels are indeed Embarras de richesses and can therefore be used at all times for carrying out precision geodetic surveys commensurate with first order class I levelling standards, for example, establishing primary control networks, crystal deformation studies, monitoring movement of structures etc., and in this respect might completely replace traditional optical instruments in the near future.

Table 2: Results obtained with the three test instruments (Approach I)

<table>
<thead>
<tr>
<th>Loop No.</th>
<th>Double-Run Distance (m)</th>
<th>Misclosure (mm)</th>
<th>Accuracy achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Leica NA2(mm)</td>
<td>Sokkia LP3A</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>0.35</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>1.62</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>1.99</td>
<td>-3</td>
</tr>
<tr>
<td>4</td>
<td>160</td>
<td>1.13</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>2.09</td>
<td>-5</td>
</tr>
<tr>
<td>6</td>
<td>240</td>
<td>-1.5</td>
<td>-6</td>
</tr>
<tr>
<td>7</td>
<td>280</td>
<td>-3.1</td>
<td>-3</td>
</tr>
<tr>
<td>8</td>
<td>340</td>
<td>1.27</td>
<td>-3</td>
</tr>
</tbody>
</table>
Table 3: Results obtained with the test instruments (Approach II)

<table>
<thead>
<tr>
<th>Test Instrument</th>
<th>Grand-pooled root-mean-square error (mm)</th>
<th>Max. Range (unambiguous staff reading) (m)</th>
<th>Max. Range quoted by (manufacturer) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leica NA2 optical level</td>
<td>±0.67</td>
<td>110</td>
<td>120-150 (excellent weather conditions)</td>
</tr>
<tr>
<td>Sokkia LP3A laser level</td>
<td>±1.8</td>
<td>122</td>
<td>100 m (good weather conditions)</td>
</tr>
<tr>
<td>Sokkia SDL30 digital level</td>
<td>±0.11</td>
<td>90</td>
<td>100 m (good weather conditions)</td>
</tr>
</tbody>
</table>

The contents of Table 3, which were obtained following approach II, confirm the findings derived from Table 2. The SDL30 gave the best ground-pooled error value (i.e. $\sigma_g = \pm0.11$ mm), followed by the NA2 ($\sigma_g = \pm0.67$ mm) and then, expectedly, the LP3A laser level ($\sigma_g = \pm1.8$ mm). When converted to accuracy specifications, these refer to first order class I, second order class I and third order levelling standards, respectively. These are, practically, the findings obtained from Table 2. What is curious on this Table is the maximum distance after which no staff readings could be taken due to obliteration of staff graduations, fading of laser beam or staff too far away to form an image of it. For the laser level that was 122 m.

The manufacturer states 100 m maximum. The only explanation to this unexpected upshot is that the levelling operation was carried out in much favourable site and weather conditions. During the time span of testing this instrument (from 25th to 28th of January), the surveyors reported cold refreshing and calm weather with temperatures ranging from 13°C to 16°C in early mornings. This may be one reason for getting this result.

The corresponding values for the NA2 and the SDL30 are 110 m and 90 m, respectively i.e. less than the figures quoted by the manufacturers. Again, this discrepancy may be attributed to the unfavourable weather conditions prevalent during observations that is...

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**Figure 7: Graphical Representation of the Results (Approach I)**
late April to mid May where outside air temperature in Riyadh City reached 46°C with occasional dusty times.

Figure 7 shows the relationship between loop length and misclosure for the three test instruments. As expected, the SDL30 clearly outclassed the other two levels. The figure also shows that the distance/misclosure relation is generally quadratic in nature. This is in general agreement with common levelling experience [6].

It is possible to compare the results of this test with those reported by other investigators e.g. Hussain and Hemman [10] and Algarni and Ali [2]. Hussain and Hemman [10] used a Spectra Physics Model 944 laser level while Algarni and Ali [2] used a Leica NA3000 electronic digital level. In both cases, the investigators used a Wild N3 precise level and a precise invar rod to test their instruments. First, a number of monuments were established in open ground and observed with the N3 as a reference level. Then, the test instruments (the Spectra Physics 944 and the Leica NA3000) were used to remeasure the elevations of the monuments. For distances up to 150 m, the Spectra Physics 944 gave accuracy specification within $\pm 12.2\sqrt{K}$ mm i.e. third order levelling. The Leica NA3000 gave accuracy results ranging from $\pm 0.21\sqrt{K}$ mm to $\pm 1.59\sqrt{K}$ mm for loop lengths up to 340 m. These figures are in general agreement with the results of the present experiment.

6.0 CONCLUSION

This experiment was carried out in order to evaluate the relative measurement capabilities of three different levels in height measurement, a Leica NA2 optical level, a Sokkia LP3A laser level and a modern Sokkia SDL30 electronic digital level. For this purpose, a geodetic test line was first established on firm flat ground of a well-protected site using a Leica N3 geodetic level. The line was then remeasured using the three test instruments in turn. Two approaches were followed. In the first, closed loops were run from an initial point at one end of the line through all hubs at multiple of forty metre distances from the starting point (i.e. hubs at 40 m, 80 m, 320 m, 337 m) and back to the initial point in an out-and-back manner. Loop misclosures were then computed and converted to accuracy specification.

In the second approach, the instrument was erected plumb over the starting point and carefully levelled. The height of the line of collimation was determined by adding instrument height to the elevation of the point. The staff was then made to occupy all steel hubs on the line and elevations of the points derived several times in different days. The discrepancies between the known and measured heights were computed and converted to root-mean-square errors. These were then combined to form a grand-pooled value for the whole line using each test instrument.

The results obtained with approach I showed that, for most loops, the Leica NA2 optical level was able to achieve first order class I levelling standards i.e. within $\pm 4.0\sqrt{K}$ mm and that, in general, second order class I standards could easily be achieved with this level. This is in general agreement with specifications quoted by the manufacturer. The Sokkia LP3A laser level gave accuracy values commensurate with third order levelling standards i.e. within $\pm 12\sqrt{K}$ mm. Again this agrees with manufacturer quotations.

The results obtained with the Sokkia SDL30 digital level were exceptionally good. Thus, this instrument was able to obtain accuracy values exceeding normal requirements for first order class I standards, namely $\pm 1.0\sqrt{K}$ mm. So, taking into account the many...
capabilities of this level and its readiness for automation and direct integration with other equipment for online data processing, it is likely that digital levels such as the SDL30, will soon replace conventional I levels in most precision geodetic or engineering surveys. The results obtained with Approach II virtually confirmed those obtained with Approach I.

The issue of the maximum distance from the instrument beyond which staff readings could not be taken with certainty is another worthwhile finding of this test. The laser level outdistanced the figure quoted by the manufacturer by more than 20%, while the optical and the digital levels underrated manufacturer’s figures. The authors attribute these findings to prevailing weather conditions during the respective use of the test levels.

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The Civil Engineering Department of the College of Engineering, King Saud University allowed the use of their Leica NA2 and Sokkia LP3A levelling instruments. Messrs Saudi Survey Systems., agents of Sokkia, Riyadh, Saudi Arabia, supplied the SDL30 digital level and some other valuable information which made the testing and analysis of this instrument possible. Engineers Faisal Algamdi, Fahd Al-Shehri and Naser Al-Shehri carried out most of the field observations of this experiment. Our sincere thanks are due to all of them.

References