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Appraising Reflectorless Total Station Instruments

Abdullah S. Alsalman, Abdullah Elsadig Ali, Fahad A. Abanmy and Emad Eddin Abdou Ibrahim
Civil Engineering Department., College of Engineering ,
King Saud University,
Box 800, Riyadh 11421, Saudi Arabia.

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Abstract. A number of retroreflectors of various types were used to appraise the performance of reflectorless total stations as exemplified by a Leica TCR-1102 total station. For this purpose, a carefully-established geodetic test line was measured using these retroreflectors. Grand-pooled root-mean-square errors were then computed and converted to accuracy values. The results show that smooth white ceramic and porcelain tiles gave accuracy values of the order of 7mm in 100m with linear fractional errors better than 1/13000 . These were followed by smooth and rough wooden white surfaces where grand-pooled r.m.s.e. values of around 9.5mm were obtained (corresponding to fractional errors better than 1/8000). Next come the smooth black surfaces (ceramic and porcelain tiles and the wooden reflector) and the white-painted steel reflector with corresponding accuracy figures of around 10 mm and fractional error of around 1/7500. Intermediate accuracy figures (1/3000 – 1/5000) were obtained with the concrete block, the white zinc sheet and the unpainted steel bracket. Markedly lower accuracy was obtained with the rest of the reflectors, namely, the rough black wooden surface and the brown mud sheet. It is clear then that the first two groups gave results better than or similar to those quoted by the manufacturer i.e. around ± 10 mm in 80 m. This range of accuracy is commensurate with a number of civil engineering and architectural surveys. Other retroreflectors gave markedly lower accuracy figures. However, even those low figures could serve the purpose of some applications where stringent measuring precision levels are not sought or are not of paramount importance.

1.0. Introduction

Electromagnetic distance measurement (EDM) is a general term embracing the measurement of distance using electronic methods. Despite the widespread use of global positioning systems (GPS) nowadays for distance computation, EDM is still ubiquitous and often offers a more economical alternative to GPS surveys. A number of EDM instruments of various types, characteristics, abilities and capabilities have been manufactured since the inception of this technology in the early 1950's. Depending on instrument type, EDM equipment can be used in the field with either (i) active remote reflectors (electronic reflectors) (Fig. 1) (ii) passive glass cube reflectors (Fig. 2) or (iii) retroreflective (mostly polished plastic) reflectors (Fig. 3).

In recent years, instrument manufacturers have produced a fourth type of short-range EDM instruments that do not need any type of reflector in order to measure a distance. Most of these are time-pulsed electronic devices which measure the time

Fig. 1. Active remote reflector.

Fig. 2. Passive glass cube reflectors.

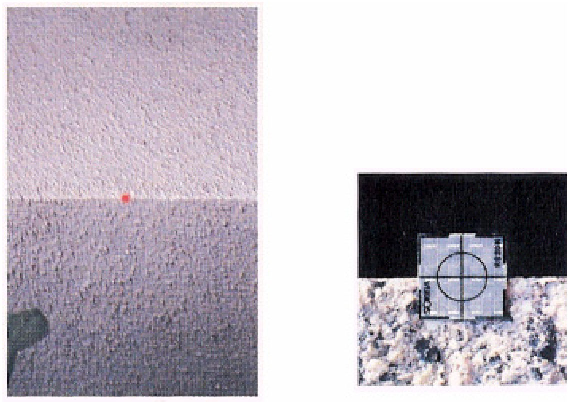

Fig. 3. Retro-reflective plastic reflector.

Fig. 4. DIOR 3002 reflectorless EDM instrument.

needed for a pulse of infra-red light to travel from the instrument to the target and back. As with other types of EDM instruments, the displayed result is the mean of hundreds or even thousands of such measurements. The first of this category to be put to the surveying market was the Leica (Wild) DIOR 3002 manufactured in 1986 (Fig. 4).

Depending on target type, surface roughness and ambient light, objects up to 200 m from instrument station could be measured with an accuracy ranging from ± 5 mm to ± 10 mm (Wild Heerbrugg (now Leica) (1986),.. In 1998, Leica replaced the DIOR 3002 with the newly-produced Leica TCR-1102 electro optical distancer (Fig. 5). The claimed accuracy of this new device is reported to be within ± 10 mm in 100 m with "good-reflecting" surfaces and favorable weather conditions.

hat being said, it remains to be seen whether this claimed accuracy always holds. The aim of this paper is therefore to report results of a pilot study concerned with attesting the viability of the accuracy of reflectorless EDM instruments as exemplified by a Leica TCR-1102, by carrying out a number of measurements with it on a carefully established geodetic line set-out on a well-protected survey site. The results of the study will give an insight as to the extent with which this type of EDM is to be used in everyday surveying work and in circumstances involving the use of locally-available non-conventional EDM reflectors .

2.0. Some Main Features of the Leica TCR-1102 Instrument

Generally, reflectorless EDM instruments can be fitted on any optical or digital theodolite, but ideally it constitutes part of a total station system. The latter is actually the case with the Leica TCR-1102 as shown in Fig. 5.

Fig. 5. Leica TCR-1102 reflectorless instrument.

Actual measuring range of such type of instruments depends on target reflectance, the angle it makes with the impinging beam and ambient light. Generally, dry, smooth and light-coloured surfaces reflect particularly well. The manufacturer quotes a maximum measuring range in the order of 100 m in good and favorable measuring conditions. With a very flat surface perpendicular to the measuring beam, an accuracy of ± 5 mm to ± 10 mm in 100m is believed to be achievable. To corners, edges, inclined and rough surfaces, the accuracy is, expectedly, lower. The displayed distance is actually the mean of longer and shorter distance components.

3.0. Errors In Short-range Electro-Optical Distance Measurement

Systematic instrumental errors occurring in short-range electro-optical distance measurement systems include uncertainties in the position of the electrical centre of the instrument, uncertainties in the effective centre of the reflector, drift of the frequency of the beam and nonlinearity of instrument performance (the so-called cyclic error). The first two of these must carefully be catered for in all EDM surveys. The third error needs continuous monitoring while the last one is significant only when high precision is required.

In EDM systems properly adjusted at the factory, the errors noted above will be small and in a practical sense may be considered insignificant for many applications. However, periodic calibration of EDM instruments against a known distance is absolutely necessary to ensure consistent results.

Physical or natural errors include atmospheric corrections and refractive index errors. Geometric errors include slope effects, height difference and scale factor errors. For the first group, an essential feature of modern infra-red instruments is an atmospheric correction switch which can be set according to weather conditions. The distances displayed on such instruments are automatically corrected, and thus atmospheric corrections need not be applied. Further, geometric error corrections can automatically be applied using the microprocessor of the instrument by keying in the appropriate information.

4.0. Procedure of the Test

Essentially, the method of approach is to establish a 100 m long geodetic test line on which to base the measurement using very accurate geodetic means. The line was then divided into approximately 10 m intervals using steel hubs driven flush with the ground, the exact distances between these hubs being derived using a Leica TCR-1102 total station in conjunction with a Leica corner cube reflector. The total station was carefully erected on one end of the line, centered and leveled. The corner cube reflector was then firmly attached through bolts , rivets and stirrups to a specially-prepared holding-bracket and placed on top of a tripod which had to be carefully erected and centred on the point (hub) in question using the plumb bob . This is carried out for all pegs on the test line .The test site was very flat and every effort was made to set the measuring beam perpendicular to the reflector surface in order to maximize the amount of radiation being sent back to the instrument .

This distance (d_i) was then measured six times independently, the mean taken and the root-mean-square error of measuring this distance was computed as standard deviation from the mean. The discrepancy value "v_i" from the mean of observations was then compared with the 99.6% confidence level i.e. 3σ. If $v_i > 3\sigma$, then that measurement is rejected and consequently the distance remeasured. This is repeated for all pegs resulting in a series of root-mean-square errors (i.e. $\sigma_1, \sigma_2, \sigma_3, \ldots\ldots.\sigma_{10}$).

To make the results more meaningful; a grand-pooled root-mean-square error (σ_g) was then computed for the whole line. The accuracy figure obtained in this stage of the experiment showed that the test line had been established to an accuracy of 1/50000 which was viewed as satisfactory for the purpose of the experiment.

The geodetic line thus established was then remeasured using the Leica TRC-1102 and each of a number of reflectors representing materials often used on construction, architectural, archeological , industrial , agricultural , forest and archeological sites in Saudi Arabia where distances often need to be measured . These reflectors are:

(i) A rough surface concrete block of 10cm x 10 cm x 30 cm size;
(ii) A rough black wooden surface (10 cm x 15 cm);
(iii) A smooth black wooden surface (10 cm x 15 cm);
(iv) A rough white wooden surface (10 cm x 15 cm);
(v) A smooth white wooden surface (10 cm x 15 cm)
(vi) A smooth white ceramic tile(10cmx15cm).
(vii) A smooth black ceramic tile(10 cm x15 cm).
(viii) A smooth white porcelain surface (10cm x 15cm).
(ix) A smooth black porcelain surface (10 cm x 15 cm).
(x) A steel bracket painted white .
(xi) An unpainted steel bracket .
(xii) A white zinc sheet (40 cm x 20 cm); and
(xiii) A piece of brown mud sheet (20cm x20 cm) .

These retroreflectors are shown in Figs. 6 to 18 respectively.

Every effort was made to erect the reflector plumb on the hub. All observations were manually recorded in a conventional field book i.e. no attempt was made to use the electronic field book supplied with the instrument. For each distance “d_i”, the standard deviation “σ_i” was computed using the standard formula:

Fig. 6. The rough concrete block reflector.

Fig. 7. The rough black wooden surface reflector.

Fig. 8. The smooth black wooden surface reflector.

Fig. 9. The rough white wooden reflector.

Fig. 10. The smooth white wooden surface reflector.

Fig. 11. The smooth white ceramic tile reflector.

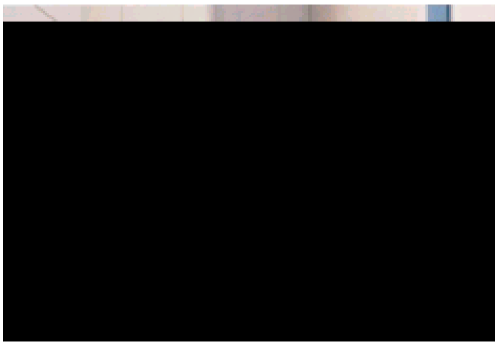

Fig. 12. The smooth black ceramic tile reflector.

Fig. 13. The smooth white porcelain tile reflector.

Fig. 14. The smooth black porcelain tile reflector.

Fig. 15. The steel bracket painted white.

Fig. 16. The Unpainted Steel Bracket Reflector.

Fig. 17. The white zinc reflector.

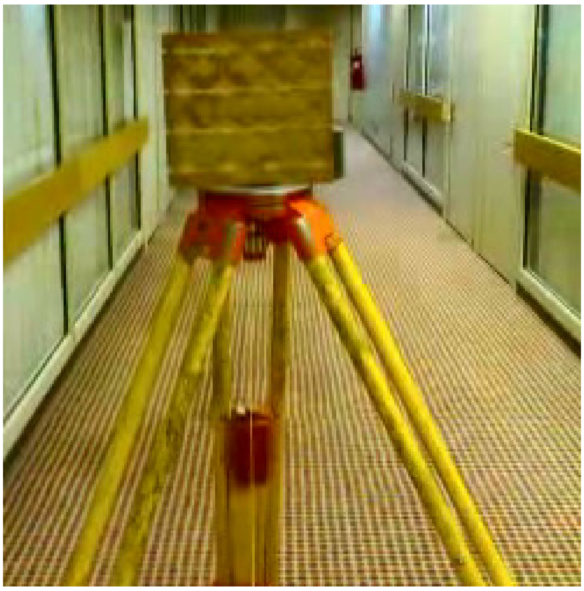

Fig. 18. The brown mud sheet reflector.

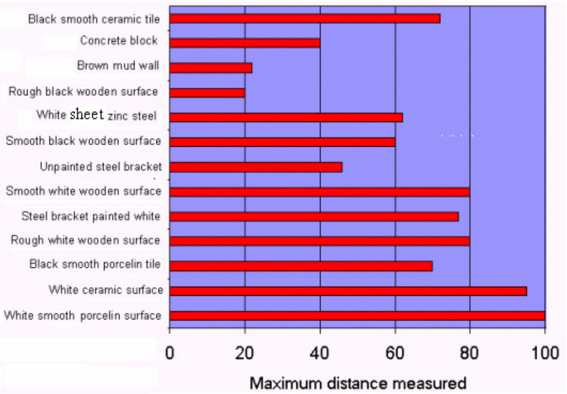

Fig. 19. Maximum range measured by the test surfaces (reflectors).

$$\sigma_i = \pm\sqrt{\frac{\sum v_i^2}{n}} \qquad (1)$$

Where

v_i = discrepancy between "true" distance as measured using geodetic means and its equivalent as measured using a retroreflector;

n = number of acceptable measurements (i.e. number of points showing discrepancy values $v_i < 3\ \sigma_i$).

The time span of the test was about eight weeks beginning from early December and extending to late January during which period the weather was mostly mild with occasional light rains and some cold refreshing light winds. This allowed the author to assume favorable weather conditions during the time span of the test.

Table 1. Initial results of the test

Reflector Type	Computed reflector/inst. Constant (mm)	Maximum distance measured (m)
Concrete block	11.2	40
Unpainted steel bracket	9.8	46
Rough black wooden	10.7	20
A brown mud surface	14.3	22
Smooth black wooden	13.1	60
A white zinc sheet	9.4	62
Rough white wooden	9.3	80
Smooth white wooden	9.1	80
White smooth porcelain tile	9.0	100
White smooth ceramic tile	6.9	95
Steel bracket painted white	7.1	77
Black smooth porcelain	9.7	70
Black smooth ceramic tile	9.8	72

The test was not, however, without problems. As examples, despite utmost care being taken, it proved to be extremely difficult to centre the retroreflectors vertical and on exactly the same point on a hub. Also some observation times were somewhat windy which slightly affected the orientation of the reflectors.

The instrument itself (the TCR-1102) was believed to be in good adjustment since it had just been purchased. Subsequent tests on it proved that was right.

Before being used in the test, each reflector was made to undergo a calibration test to determine the combined instrument-reflector constant. In this respect, standard techniques were followed using the established geodetic test line (Benton, A.R. and Taetz, P.J., 1991; Anderson, J.M. and Mikhail E., 1985; Bannister, A., Raymond, S. and Baker, R., 1992). The computed constants were then applied to the various distances measured in the test. (See Table (1)).

5.0. Results of the Test, Discussion and Analysis

Initially, the range of each retroreflector (i.e. the distance beyond which there is no signal returning to the instrument because of the physical and/or chemical characteristics and the general nature of the reflector) was determined. Table (1) and Fig. 19 show the maximum measurement ranges achievable with each retroreflector together with values obtained for the various combined reflector/instrument constants.

A grand-pooled root-mean-square error (σ_g) was then computed using all standard deviation values for each reflector along all measured distances, using the standard formula:

$$\sigma_g = \pm \sqrt{\frac{\sum_{i=1}^{n} \frac{1}{\ell_i} \sigma_i^2}{\sum_{i=1}^{n} \frac{1}{\ell_i}}} \qquad (2)$$

where σ_i is as computed from Eq. (1); and ℓ_i is the distance (i = 10 m, 20 m,……..)

Table (2) and Fig. 20 show the results obtained.

Table 2. Results of the test

Reflecting surface	σ_g(mm)	Fractional accuracy
Concrete block	10.1	1/3800
Unpainted steel bracket	10.4	1/4400
Rough wooden black	12.3	1/1630
Brown mud surface	15.2	1/1450
Smooth wooden black	8.0	1/7500
White zinc sheet	12.8	1/4800
Rough wooden white	9.7	1/8250
Smooth wooden white	9.6	1/8330
White smooth porcelain tile	6.8	1/14500
White smooth ceramic tile	7.2	1/13200
Steel bracket painted white	10.1	1/7600
black smooth porcelain tile	9.8	1/7350
Black smooth ceramic tile	9.7	1/7400

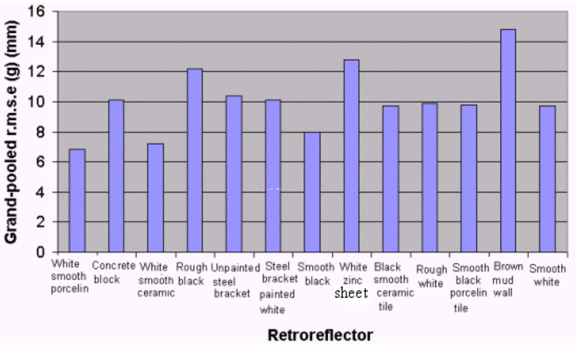

Fig. 20. Grand-pooled r.m.s.e values obtained in the test.

Fractional accuracy values on Table(2) were computed from the equation :

$$\text{Fractional accuracy} = 1/(L_j/\sigma_{gj}) \qquad (3)$$

where L_j = maximum distance measured with reflector j ,

σ_{gj} = grand-pooled r.m.s.e obtained with reflector j.

A quick glance at Tables (1) and (2) and Fig. 20 reveals the following:-

(i) The rough-black wooden surface and the brown mud sheet were able to measure distances to around only 20 m away from the instrument, while with the concrete block and the unpainted steel bracket, distances up to around 40 m could be measured.

(ii) With the smooth black wooden surface and the white zinc sheet, distances up to 60 m could be measured, while up to 70 m could be observed with the black smooth porcelain tile and the black smooth ceramic tile.

(iii) The smooth and rough white wooden surface and the white-painted steel bracket could be observed to distances up to around 80 m from the instrument station , while distances up to about 100m could be measured with the white ceramic and the white porcelain surfaces.

(iv) Generally speaking, reflector/instrument constants determined in this test range from 9 mm to just above 14 mm. These figures are generally two to five times higher than values obtained with corner cube reflectors (see e.g. Anderson, J.M. and Mikhail E., 1985; Bannister, A., Raymond, S. and Baker, R., 1992). This is understandable, however, since the latter ones are usually manufactured to much higher standards in order to perform the reflection process.

(v) The best accuracy figures (grand-pooled r.m.s.e. values) were obtained with the white porcelain and the white ceramic tiles. Thus grand-pooled standard deviation values of ± 6.9mm and ± 7.1 mm were obtained corresponding to fractional equivalents of 1/14500 and 1/13200 respectively. These are followed by the smooth and rough wooden white surfaces where grand-pooled values of ± 9.6mm and ± 9.7 mm were obtained corresponding to fractional errors of about 1/8300. The smooth black surfaces (wooden, ceramic and porcelain) and the white-painted steel bracket gave grand-pooled values approximately equal to or better than ± 10 mm with fractional errors around 1/7500.

(vi) The white zinc sheet and the unpainted steel bracket yielded medium accuracy figures, i.e. ±10 m to ± 13mm with fractional accuracy less than 1/5000.

(vii) The concrete, the brown mud surface and the rough black surfaces gave markedly lower accuracy figures, i.e. 1/3800, 1/1450 and 1/1630 respectively with $\sigma g = \pm 12.3$ mm, ± 15.2 mm and $\sigma g = \pm 10.1$ mm respectively.

(viii) It is clear that the white porcelain and ceramic surfaces and the smooth black one gave accuracy values far exceeding those normally obtainable with optical tacheometry (see Ali, A.E., 1993).

(ix) The concrete and the unpainted steel bracket surfaces gave accuracy figures in the order of magnitude of those attainable with modern optical tacheometry i.e. 1/2500 – 1/4000 (see e.g. Ali, A.E., 1993).

(x) The rough black wooden surface and the brown mud sheet obtained accuracy values of only 1/1630 and 1/1450 respectively That is roughly in the order of the accuracy of the steel tape and the electronic digital level when used as a tacheometer i.e. approaching 1/2000 (see e.g. Algarni, D. and Ali, A.E. 1998) .

(xi) It is noted that the smooth white surface reflectors (e.g. porcelain and ceramic) and the smooth black reflector gave accuracy values better than those quoted by the manufacturer i.e. around ±10 mm in 100 m. The smooth reflectors of black colour and other white-colour reflectors gave accuracy figures slightly less than ± 10mm in 100m. Both accuracy levels are commensurate with the requirements of a number of localized surveying works in civil engineering, cadastral surveys, industrial works etc. On the other hand, although fairly lower accuracy figures were obtained with the other test reflectors i.e. less than 1/5000, it is clear that even these low figures serve useful purposes for some low order surveying works where stringent accuracy figures are not of paramount importance e.g. inner city road maintenance surveys, land demarcation for multiple agriculture, open-pit mining, forestry surveys, geologic reclamation activities etc. This means that reflectorless EDM instruments could be viable tools in everyday surveying works. Taking into account simplicity of operation, speed of the surveying process and reasonable cost, the author appeals to surveyors to consider these devices for accomplishing their respective surveying tasks.

6.0. Conclusion

Reflectorless total stations instruments, as exemplified by the Leica TCR-1102, can favorably be used for localized-type surveys where accuracy figures in the order of up to ±10 mm in 80 m – 100 m are required, the accuracy figures obtained being mainly dependent on type of reflecting surface and distance of observation. Generally, smooth surfaces, especially white, measure longer and yield results in the vicinity of ± 9 mm in 100m. Smooth black reflectors and rough white surfaces come next with accuracy figures of around ± 10mm in 80m. Other surfaces (rough wooden black, the concrete block, the zinc sheet and the brown mud surface) measure much shorter and yield markedly low accuracy values. So, while the first and second groups are commensurate with the requirements of many on-site surveying tasks in civil engineering , industry , archeology , forestry , agriculture and architecture, the third group may also be useful in application areas where stringent accuracy figures are not sought e.g. in land demarcation in multiple agriculture, localized geological surveys, surveys for dredging operations and other applications requiring an accuracy level of only a few centimeters in several hundreds of meters.

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8.0. References

Algarni, D. and Ali, A.E.. “Heighting and distance Accuracy of Digital Electronic Levels”, Journal of King Saud University (Engineering Sciences), Vol. 10, No. 2, (1998), pp. 229-240.

Ali, A.E. “Accuracy of Modern Optical Theodolites in Tacheometric Surveys”. The Surveying Technician, Vol. 21, No. 1, (1993), pp. 9-10 (London).

Anderson, J.M. and Mikhail E.."Introduction to Surveying". McGraw-Hill Book Company, N.Y.,, 1st Edition (703 pages) , (1985).

Bannister, A., Raymond, S. and Baker, R., "Surveying". 6th Edition, Harlow (U.K.), Longman Scientific and Technical (482 pages).(1992).

Benton, A.R. and Taetz, P.J. "Elements of Plane Surveying". McGraw-Hill International Editions, First Edition, Singapore (429 pages)(1991).

Wild Heerbrugg (now Leica),".Distomat Wild DIOR 3002": "Measurement Without Reflectors". Wild Brochure (1986).

تقييم أداء المحطات الشاملة في قياس المسافات من دون استعمال عاكسات بصرية

عبدالله بن سلمان السلمان، عبدالله الصادق علي، فهد بن عبدالعزيز أبانمي، و عماد الدين عبده ابراهيم
قسم الهندسة المدنية ، كلية الهندسة ، جامعة الملك سعود
ص ب ٨٠٠، الرياض ١١٤٢١ ، المملكة العربية السعودية

(قدم في٢٧/٠٥/٢٠٠٧م ؛ وقبل للنشر في ١٦/٠٣/٢٠٠٨م)

الكلمات المفتاحية: عاكسات ، دقة.

ملخص البحث. استعملت أنواع مختلفة من المواد العاكسة للأشعة تحت الحمراء لتقييم أداء المحطات الشاملة التي يمكنها العمل علي هذا النوع من العاكسات مثل جهاز TCR 1120 من شركة لايكا. انشيء لهذا الغرض خط جيوديسي ثم قيس هذا الخط باستعمال المحطة الشاملة وعدد من هذه العاكسات. حسبت بعد ذلك قيم الانحراف المعياري لهذه القياسات ومن ثم حولت إلي قيم تبين دقة المسح . وقد أوضحت النتائج أن أسطح السيراميك والبورسيلين الأبيض يمكن أن تعطي دقة تصل ٧ ملم في كل ١٠٠ متر. يرادف هذا الرقم القيمة النسبية ١/١٣٠٠٠ . تأتيء بعد ذلك الأسطح الخشبية الناعمة والخشنة حيث كانت قيم الانحراف المعياري في حدود ٩,٥ ملم (أي ما يساوي خطأ نسبياً مقداره ١/٨٠٠٠) . تأتي بعد ذلك الأسطح السوداء الناعمة من السيراميك والبورسيلين والخشب والعاكس الحديدي الأبيض بخطأ قدره ١٠ ملم (أي ١/٧٥٠٠ خطأ نسبي). أما العاكسات التي أعطت دقة متوسطة (١/٣٠٠٠ – ١/٥٠٠٠) فكانت الكتلة الخرسانية ولوحة الزنك البيضاء و القطعة الحديدية غير المطلية. أما بقية العاكسات فقد أعطت دقة قياس متواضعة وهي السطح الخشبي الخشن واللوحة الطينية البنية الخشنة. ومن الواضح أن النوعين الأول والثاني أعطت نتائج أحسن من أو مساوية لأرقام الدقة التي ذكرها المصنع (حوالي ١٠ ملم في كل ٨٠ متر). وتصلح هذه الدقة لتنفيذ الكثير من أعمال الهندسة المدنية والعمارة. أعطت بقية العاكسات دقة متواضعة ولكن حتى هذه قد تكون مناسبة للكثير من الأعمال والمشاريع التي لا تتطلب دقة عالية.