Is Reflectorless EDM Technology Reliable for Building Construction Layout Tolerances?

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Compared to its civil and land tract counterparts, surveying for building construction layout typically requires more stringent tolerances in measurement. Various methods of measurements are available for building layout, many having been used historically for decades, while other are relatively new. The advancement of technology over the past 15 plus years has created new widely used ways of measuring with increased accuracy and reduced time necessary to complete layout tasks, namely Electronic Distance Measuring (EDM.) More recently, commercially available technology in the form of reflectorless EDM (which requires no prism) proposes improvements to surveying processes, but may not have the same accuracy of instruments in prism mode. This paper proposes to explore whether the accuracy of reflectorless technology is suitable for building construction layout by quantitatively testing in quasi-controlled field conditions for accuracy and reliability, and will compare the results with the qualitative outlook of professionals within the construction industry.

Keywords: surveying, building layout, electronic distance measuring, reflectorless

Introduction and Literature Review

The history of surveying dates back to biblical times in the measuring and mapping of the land. However, it wasn't until after the Civil War that the most extensive and precise use of nineteenth-century construction surveying practices began. The transcontinental railroad, the Brooklyn Bridge, Panama Canal, the Empire State Building and the Hoover Dam projects brought the science of surveying and building layout into the twentieth century. (Roberts, 1995) Today, the complexity of buildings and the dimensional accuracy required have made it extremely important in building layout.

There are many different types of surveys, each with a particular purpose. Construction surveys are for the purpose of locating and laying out building components associated with the site, structure, skin, and interiors. (Roberts, 1995) Other types of surveying include property boundaries, land tracts, and other large scale civil efforts, however this paper will focus on vertical building construction survey methods and tolerances.

Building construction layout is a vital function of the construction process, and its accuracy and reliability must be precise. Today, construction professionals rely on time-tested measurement techniques as well as modern technologies to facilitate this process. Whichever technique is used, it must be accurate, and the user must have total confidence in the reliability of the measurement. In the construction industry, building layout accuracy is based on a range of tolerances, given the nature of the task or component being installed. Generally, primary control lines and planes are established with zero tolerance. This is important given the nature of how inevitable human errors tend to exponentially grow. Beginning with a tolerance of zero helps to minimize the amplification of errors as the project progresses. Other components have more liberal tolerances, although as compared to civil or property surveying, are still relatively constrained. The American Concrete Institute (ACI) recommends a tolerance of ¼" within 10 feet of flat concrete work. (ACI 117-06, 2006) Other components such as structural steel, glazing, and architectural precast operate with similar or more demanding tolerances. Therefore, the accuracy of how measurements are established in the field is of major importance. The reliability of each measurement technique must be controlled and constant.

The long term historic use of metal tapes and chains is a fairly reliable method of establishing dimensions. A metal tape's accuracy can easily be compared to other known measurements within a specific site, other measuring tapes, or other electronic methods. However, there are certain human or environmental factors which can impact its accuracy. Mathematic errors can occur, and dimensions can be overstated if the tape is not taught or is not parallel to the plane in which the measurement is desired. Further, measuring typically requires two people, compounded by the fact that either individual can make an error in the process of marking points or making the right calculation. Temperature can also affect a metal tape's reliability in extreme cold or extreme heat, either of which can create potential errors in measuring distance. Therefore, knowledge and experience are valuable when performing the layout process with a metal tape or chain.

Electronic Distance Measuring devices (EDM) have now been regularly used in the field for over fifteen years, and its accuracy has proven itself acceptable. Additionally, improvements in technology continue to enhance EDM's function in a total station's accuracy. However, even with this improved technology, the reliability of the measurements can still have a propensity for human error and environmental changes. Human error can be seen in two primary ways. For prism-based EDM measurement, the process also takes two people to conduct, similar to the use of a tape or chain (robotic gear notwithstanding.) The individual operating the total station and/or the rodman with the prism pole can make errors. The prism pole must be held completely still and plumb for the total station's EDM device to take an accurate and reliable measurement. Environmental factors such as wind, rain and poor lines of sight can also affect the reliability of a total station using prism-based EDM.

In recent years, technology has evolved and attempted to solve some of these issues in the creation of reflectorless modes of operation which do not require a prism to return the signal to the instrument, doing so by 'bouncing' the signal off of whatever is within the cross hairs of the optical scope. For some operations, this results in requiring only one operator, reducing labor costs of the process. For layout tasks, a second person in the party is still required, although the use and propensity for error in using a prism is eliminated. If accurate, the use of reflectorless technology seems to be the natural progression of improving vertical building layout. However - human, technical and environmental factors can also cause problems for reflectorless technology as well. Factors include: the ability to properly focus the cross hairs on the desired object off of which the signal will be returned, the geometric orientation of the surface relative to the line of sight, the color and shade of the target, as well as traditional hindrances such as wind and rain. While the technology is very advanced, the aforementioned factors are threats as to whether reflectorless technology is a legitimate option for vertical building construction layout.

While many manufacturers provide their own self-generated technical data for their respective instruments, there is little other scholarly literature that addresses this topic.

Methodology and Results

The research of this paper utilized a mixed method approach. First, a series of interviews was conducted with field practitioners to qualitatively gauge their perspective and/or experience with reflectorless technology. Results from these responses were used as a pilot to establish the controls for the two sets of quantitative tests conducted. Afterwards, the practitioners were interviewed a second time during which the quantitative results were shared, to see if their perspective might be altered. Key to the quantitative testing was the theory that it should be done with quasi-controlled variables to specifically not eliminate human error or weather/lighting conditions, which are realities with which practitioners must deal.

For the quantitative testing, a Topcon 3000W was used. The specifications and internal operational data from the manufacturer's website state that the measuring range in prism mode is up to 9,900 feet. In non-prism mode using reflectorless technology, the range is reduced to 820 feet. The manufacturer's specifications note that in establishing this limit, a "Kodak white" target was used in the range specification for non prism mode. The specifications claim the accuracy in prism mode is within plus or minus three millimeters. The accuracy for non-prism mode is broken up into two ranges: five to eighty two feet is plus or minus ten millimeters, greater than eighty two feet is plus or minus five millimeters. This suggests the accuracy of the non prism mode, i.e. reflectorless, actually improves as the distance increases. In all cases, the accuracy results were likely generated in a highly controlled environment

that did not consider field conditions or human error.
(http://www.topconpositioning.com/index.html/session_id/f91755f15dea2bc103a1aaf970f27c74/screen/model/category_id/id43305d4fbd85b4.36440921/category_ids/73, retrieved 2006).

Preliminary Qualitative Perspective

Industry professionals from seven firms were interviewed prior to the quantitative testing to gather opinions on the relatively new reflectorless technology. Company sizes as defined by annual revenue ranged from $1MM to $2BB. The titles of the professionals interviewed ranged from Field Engineer, to Project Superintendent, and to Professional Land Surveyor. The first interviews consisted of basic questions about building layout and the use of reflectorless technology. The interviews were unstructured and open ended as general opinions were desired, as well as any other thoughts, ideas, or rumors that the industry professionals had on the use of this gear. The two basic questions asked in each interview were: "Have you ever used reflectorless technology in construction layout, and if not, why?" Their opinion of the technology was also sought; categorically the general response was that they knew of the technology, but none of them had used it. One interviewee had access to a reflectorless total station within his firm, but had not had a chance to use it. Another interviewee has used a reflectorless instrument before, but because it still required a second person to set a hub, they did not perceive a benefit in using it. In general, all other responses to the questions stated that the prism based method has worked fine in the past; therefore there is no need to change. This skepticism became the basis for testing whether not having to use a prism (and relying on whether or not it is plumb) could be beneficial in building construction layout.

Quantitative Data – Geometry in a Controlled Environment

In the first testing effort, reflectorless technology compared the use of a metal chain and a traditional prism-based EDM instrument in an interior environment. To study the geometry of the target relative to the line of sight (whether perpendicular or angular) as well as the color and shade of the target, six different types of backdrops were tested to see which one was best for both the user and the total station's technology.

The first field tests were conducted to measure the accuracy and reliability of the three measurement methods. The different methods were tested using pencil marks, as well as cut tacks installed in a hub as a target to measure the accuracy of each measurement tool. This was important to maintain the type of actual materials used in conducting layout on a construction site. The first field test was conducted in a large industrial manufacturing plant with regulated temperatures and adequate lighting. Five targets were set up every fifty feet from 100 feet to 300 feet across the concrete floor of the plant. At each point, measurements were taken with six different targets or hubs with cut tacks. (Figures 1, 2) This process was repeated three times to develop three independent data sets for comparison. The survey equipment was repositioned each time to simulate an actual building layout process. Data in Table 1 shows the results of using the prism-based EDM as well as the range of targets in reflectorless mode, all of which are compared to the chained distance established by the metal tape, which was presumed correct on a flat surface in a controlled temperature environment.

The points, or hubs, are described as follows:

1. Metal tape/chain measurement with pencil mark upon floor
2. EDM with prism pole measurement from pencil mark
3. Hub surface is perpendicular to the gun, wood surface, light in color
4. Hub surface is perpendicular to the gun, wood surface, black in color
5. Hub surface is flat to the gun, wood surface, light in color
6. Hub surface is flat to the gun, wood surface, black in color
7. Hub surface is flat to the gun, wood surface, light in color, pink backdrop
8. Hub surface is flat to the gun, wood surface, black in color, pink backdrop

Table 1

All Units in Feet											
Station 1 Prism	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Prism mgn. of error**
Targets	99.980	.020	149.980	.020	199.970	.030	249.950	.050	299.990	.010	0.026
Station 1 Reflector-less	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Avg. Margin of Error**
Targets											
Perpendicular/light	100.020	-.020	149.995	.005	200.000	.000	250.000	.000	300.010	-.010	.007
Perpendicular/dark	100.010	-.010	150.010	-.010	200.010	-.010	250.055	-.055	300.060	-.060	.029
Flat/light	100.060	-.060	150.205	-.205	200.095	-.095	250.115	-.115	299.990	.010	.097
Flat/dark	100.245	-.245	150.455	-.455	200.420	-.420	250.310	-.310	300.070	-.070	.300
With backdrop/light	100.000	.000	149.990	.010	199.970	.030	249.970	.030	299.980	.020	.018
With backdrop/dark	100.005	-.005	149.995	.005	200.000	.000	249.975	.025	299.985	.015	.010

Station 2 Prism	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Prism mgn. of error**
Targets	99.985	.015	149.960	.040	199.970	.030	249.965	.035	299.965	.035	0.031
Station 2 Reflector-less	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Avg. Margin of Error**
Targets											
Perpendicular/light	100.005	-.005	149.975	.025	199.985	.015	250.000	.000	299.980	.020	.013
Perpendicular/dark	99.995	.005	149.985	.015	199.990	.010	250.035	-.035	300.020	-.020	.017
Flat/light	100.160	-.160	150.105	-.105	200.040	-.040	250.000	.000	300.000	.000	.061
Flat/dark	100.255	-.255	150.240	-.240	200.165	-.165	250.100	-.100	300.055	-.055	.163
With backdrop/light	99.990	.010	150.005	-.005	199.990	.010	249.985	.015	299.980	.020	.012
With backdrop/dark	99.995	.005	149.995	.005	200.000	.000	249.995	.005	299.990	.010	.005

Station 3 Prism	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Prism mgn. of error**
Targets	99.990	.010	150.005	-.005	199.970	.030	249.960	.040	299.980	.020	0.021
Station 3 Reflector-less	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Avg. Margin of Error**
Targets											
Perpendicular/light	100.025	-.025	150.020	-.020	200.095	-.095	250.050	-.050	300.015	-.015	.041
Perpendicular/dark	99.990	.010	150.015	-.015	200.280	-.280	250.025	-.025	300.060	-.060	.078
Flat/light	100.120	-.120	150.075	-.075	200.020	-.020	249.990	.010	299.980	.020	.049
Flat/dark	100.210	-.210	150.250	-.250	200.140	-.140	250.045	-.045	300.040	-.040	.137
With backdrop/light	99.995	.005	149.995	.005	199.995	.005	249.990	.010	299.985	.015	.008
With backdrop/dark	100.015	-.015	150.005	-.005	200.005	-.005	250.005	-.005	299.995	.005	.007

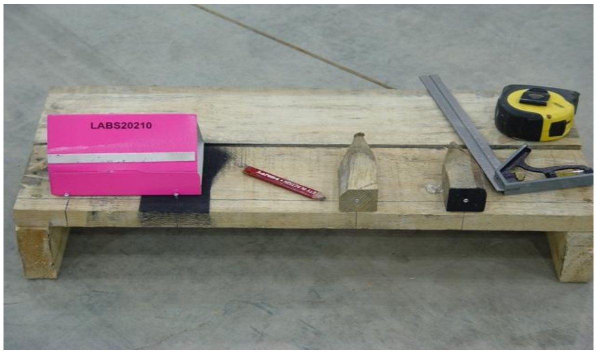

Figure 1

Figure 2

After the first round of field tests, data suggested that there was a clear accuracy advantage in the reflectorless results in which either the surface was perpendicular to the line of sight or if a backdrop was used. Compared to industry standards, results from data collected in which the surface was "angular" (labeled 'flat') indicate that distances measured in this fashion would not be within industry standards. In some cases, data figures utilizing the prism-mode were also inaccurate per industry standards. The authors speculate this could be due to the inexperience of academic subjects recruited to use the equipment, nonetheless demonstrating the propensity for human error.

The results of the first phase of the quantitative pilot study helped to develop a theory that the use of a simple backdrop or a target would greatly increase the accuracy of a reflectorless measurement, and would also eliminate potential errors associated with maintaining a plumb prism pole. Prototype devices were created for use in the second field tests.

Quantitative Data –Outside Conditions

After analysis of the first field tests, it was necessary to acknowledge the discrepancy in the reliability of the reflectorless technology. The data suggests the need for a perpendicular target to the device to increase reliability by enhancing the known location of the point. A prototype target was developed, with four different faces, to determine the best face of the target. (Figures 3) The prototype needed to be durable, small, light weight and portable to be compelling for use in the field. The white plastic target had four different colors on the face of the target as follows:

1. White plastic target with an orange face similar to a Gammon Reel®.
2. White plastic target with small black crosshairs for alignment.
3. White plastic target with large black crosshairs for alignment.
4. White plastic target with red crosshairs for alignment.

A second set of data, shown in Table 2, was collected with the new targets; all by the same individuals, for appropriate control of related variables. The data was taken in an open field in a quasi-controlled environment to simulate the actual light and weather working conditions in which an instrument would be used, but by using a relatively flat surface, so that the researchers could minimize errors associated with chaining on a slope. (Figure 4) The prototype shots were compared to another group of shots using the prism pole, all of which were based off of hubs set at distances established by the use of a chain as a presumed accurate baseline.


Figure 3


Figure 4

All Units in Feet												
Station 4	**Prism**	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Prism mgn. of error**
Targets		100.005	-.005	149.995	.005	200.010	-.010	249.995	.005	300.005	.065	0.018
Station 4	**Reflector-less**	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Avg. Margin of Error**
Targets												
Orange-Tack		100.020	-.020	150.005	-.005	199.960	.040	249.985	.015	299.935	.065	.029
Orange-Target		100.030	-.030	150.005	-.005	199.990	.010	250.000	.000	300.000	.000	.009
Gammon Reel-Tack		100.010	-.010	149.995	.005	199.985	.015	249.985	.015	299.935	.065	.022
Gammon Reel-Target		100.020	-.020	149.995	.005	200.000	.000	250.000	.000	299.980	.020	.009
Black-small-Tack		100.020	-.020	150.005	-.005	199.960	.040	249.985	.015	299.915	.085	.033
Black-small-Target		100.030	-.030	150.025	-.025	199.985	.015	250.025	-.025	299.965	.035	.026
Red-Tack		100.000	.000	150.005	-.005	199.970	.030	249.995	.005	299.945	.055	.019
Red-Target		100.005	-.005	150.030	-.030	199.995	.005	250.015	-.015	299.965	.035	.018
Black-Large-Tack		100.000	.000	150.005	-.005	199.960	.040	249.995	.005	299.960	.040	.018
Black-Large-Target		100.020	-.020	150.015	-.015	199.975	.025	250.030	-.030	300.000	.000	.018

Station 5	**Prism**	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Prism mgn. of error**
Targets		100.010	-.010	150.010	-.010	199.980	.020	249.985	.015	299.985	.015	0.014
Station 5	**Reflector-less**	**100**	**Diff.**	**150**	**Diff.**	**200**	**Diff.**	**250**	**Diff.**	**300**	**Diff.**	**Avg. Margin of Error**
Targets												
Orange-Tack		100.000	.000	150.005	-.005	199.970	.030	250.000	.000	299.920	.080	.023
Orange-Target		100.020	-.020	150.015	-.015	199.990	.010	250.025	-.025	299.940	.060	.026
Gammon Reel-Tack		100.010	-.010	149.985	.015	199.950	.050	249.985	.015	299.935	.065	.031
Gammon Reel-Target		100.010	-.010	150.005	-.005	199.980	.020	250.010	-.010	299.965	.035	.016
Black-small-Tack		99.995	.005	150.010	-.010	199.960	.040	249.990	.010	299.915	.085	.030
Black-small-Target		100.010	-.010	150.015	-.015	199.995	.005	250.015	-.015	299.935	.065	.022
Red-Tack		100.000	.000	150.010	-.010	199.960	.040	249.995	.005	299.935	.065	.024
Red-Target		100.000	.000	150.015	-.015	200.000	.000	250.005	-.005	299.980	.020	.008
Black-Large-Tack		99.995	.005	150.005	-.005	199.965	.035	249.975	.025	299.910	.090	.032
Black-Large-Target		100.015	-.015	150.020	-.020	199.985	.015	250.020	-.020	299.965	.035	.021

Table 2

The data taken from the new targets resulted in much greater accuracy when compared to the first data set. The instrument was set up two different times to get two data sets. Two shots were taken of each target with each instrument set up. One shot was aimed directly at the tack, and the other shot was aimed just above the tack, at the prototype target. The second shot on the red prototype target proved to be the most accurate during both tests. This shot was aimed just above the tack. The next target closest in accuracy shooting just above the tack was the Gammon Reel®. The other prototype targets had a considerably smaller margin of error than the shots taken in the controlled environment.

Accuracy of the use of the prism-based mode also improved, suggesting that the student subjects' facility improved from the pilot study. The largest average margin of error outside in the more uncontrolled environment was .033 feet. In comparison, the largest average margin of error with the first shots inside the more controlled environment was .163 feet.

Qualitative Perspective – Post Testing

After field tests were complete and collated, the same industry professionals from the initial qualitative study were interviewed a second time to get their opinions on the data that was gathered. The purpose of the second interview was not necessarily to be compelling, rather it was intended to be an informative interview welcoming any change of opinion. Since conducting the first interviews, one person had used a reflectorless total station, but it was used in an as-built situation. The interviewee said it was convenient to be able to switch over to reflectorless, but did not see it being more beneficial than prism-based building layout. Generally, the accuracy of the reflectorless technology shown by the data impressed almost all of those interviewed. However, none of the industry professionals could see using reflectorless technology over prism based, since the data showed that a target was needed to accurately use the total station, even considering that rodmen would likely be carrying a Gammon Reel® regardless. Additional issues of concern still remained, specifically the cost of the equipment and the need for two people to effectively operate it. Another concern was not having a clear line of sight for every shot, for which a prism pole could compensate. Therefore, the general opinion of potential efficacy by the professionals did not change.

Authors' Conclusions

The industry professionals were impressed with the results from the second data set, however the results did not seem to be compelling for them to welcome an immediate change to reflectorless technology, even though the data suggested that reflectorless results are just as accurate as those taken by utilizing a prism. If a target is still required, then a second person is still needed, although the potential for error associated with the prism's pole not being plumb is all but eliminated. Anecdotally, the feedback from one interviewee suggested that in an as-built situation, reflectorless gear could be quite useful.

While it could be extremely useful for civil, land tract and other types of surveying with more liberal tolerances, reflectorless technology is only accurate and reliable for use in building layout if a known target perpendicular to the line of sight is used. Ultimately for a change in user preferences for building construction layout, the authors believe their perspective would be changed only after significant advances are made in how instruments respond to the geometry of the shot and the reliability of whether what is actually in the cross hairs is being returned to the EDM device.

References

ACI 117-06 (2006) *Specifications for Tolerances for Concrete Construction and Materials and Commentary,* American Concrete Institute, Farmington Hills, MI, 2006

Roberts, Jack (1995) *Construction Surveying, Layout, and Dimension Control,* Delmar Publishers, Inc., Albany, NY, 1995

http://www.topconpositioning.com/index.html/session_id/f91755f15dea2bc103a1aaf970f27c74/screen/model/category_id/id43305d4fbd85b4.36440921/category_ids/73, retrieved May, 2006