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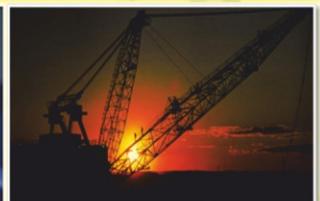
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Slope Monitoring using Total Station – a look at the effect of glass shapes on distance measurements with total station

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A B S T R A C T

Keywords:

Total station, shelter, glass shapes, distance measurements and impact.

Continuous monitoring (be it slope or structural monitoring) with total station required the instrument to be stationed in the field, both day and night. This necessitates housing the total station in a shelter, which isdesigned to have wide-windowcover withglass materials, and carryout the monitoring survey through the shelter glass. This study examines the likely effect of the shapesof the glass medium on distance measures with total station during slope or structural monitoring through such shelter glass. In this study, three glass shapes were examined, namely; 2.0mm clear float plane, concave and convex glass panes. The result revealed that the shape of the glass matters when using total station to measure distances through a glass medium. However, the effect of the 2.0mm plane glass was within the accuracy specification limit, which is 1mm + 1.5 ppm, when using Infrared mode(IR mode) of the total station – Leica TCR + 1201, used for this research,while the concave and convex glass pane impact exceeded the accuracy limit.However it is recommended that further detail work should be carried out to quantify the impact of shelter glass shape ontotal station observations (taking through convex glass or concave glass) and develop a systematic error correction formula(e)/nomogram or model to cater for the impact.

1.   Introduction

The use of Robotic Total Station(RTS), also known as Automated Total Station (ATS), for monitoring work is a common practice at most open-pit mines, construction sites and dams, because it provides continuous 24-hours remote data collection, analysis and warning to immediately alert the personnel with regard to stability problems. Conventional total station observations are time consuming, labour intensive and have the potential for human error when used for monitoring work. All the problems that are associated with the conventional total station are catered for in a RTS. Although conventional system are very accurate and adequate for ad hoc monitoring, continuous monitoring requires a more advanced system to cope with the intensity of the program (JoosteandCawood, 2006).

The utilisation of RTS surveying instruments for monitoring structures movement with good results were reported by many authors, such as Radovanovic and Teskey(2001), Hill and Sippel(2002),Kuhlmann and Glaser (2002),Zahariadis and Tsakiri(2006), as well as Lange and Kippelen(2008). Continuous monitoring as an important operation in an open-pit mine to ensure the safety and stability of the mine wall was described by Palazzo *et al.,* (2006).

Rueger *et al.,* (1994) highlighted that when measuring angles through windows, the glass sheet acts as a plain parallel plate.

The effects of parallel plates on line-of-sights are known from precise levelling. The parallel shift q caused by a parallel plate of thickness t can be computed from:

$$q = \left(\frac{n_G - 1}{n_G}\right) \times t_i \tan \varphi \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 1$$

where

$\varphi$is the angle of incidence of the rays (measured from the normal to the glass surface).$n_G$is the refractive index of the window material (n_G=1.5 for glass and acrylic glass e.g. Perspex).

However, real windows differ from parallel plates in so far as the glass is not perfectly flat and does not have parallel faces. The effects of window glass imperfections can only be established through experiment (Rueger *et al.,* 1994).

The effect of the shelter glass on the beam generated by the total station during monitoring with RTS from transfer beacon shelter is called refractive effects and it is based on Snell's law. This law expresses the relationship between the angles of incidence and refraction, when a lightray passes through a boundary between two different isotropic media, namely air and glass, as regards to this study. Ostdiek and Bord (2008) simplified the whole process by saying,"a light ray is bent toward the normal when it enters a transparent medium (e.g. glass or water) in which light travels more slowly. It is bent away from the normal when it enters a medium in

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which light travels faster". Based on Snell's theory, the beam from the RTS passes through the air inside the total station shelter (transfer beacon shelter)and strikes the shelter glass window at an angle of incidence θ with respect to the surface normal. It refracted and passed through the glass at angle θ_g with respect to the surface normal. The beam is slowed down when passing through the glass, because the refractive index of the glass, n_g, is greater than the refractive index of the air n_a. When the beam emerges from the glass, it refracted once more so that its angle with respect to the surface normal is again θ and also resumes its original speed. Figure 1 demonstrates the whole scenario (Lutes, 2002):

Where:

TS is the RTS position inside the shelter;

RB is the reference beacon (control point) for orientation;

θ is the angle of incidence of the RTS with respect to the surface normal of the glass;

sd_i is the slope distance between the RTS and the glass;

hd_i is the horizontal distance between the RTS and the glass;

n_{ai} is the refractive index of air inside the shelter;

θ_g is the angle of refraction within the glass;

sd_g is the slope distance within the glass or distance travelled by the RTS beam through the glass;

t is the thickness of the glass;

n_g is the refractive index of the glass;

n_{ao} is the refractive index of air outside the shelter;

sd_o is the slope distance between the glass and the target, the prism, that is being monitored,

while hd_o is the corresponding horizontal distance; and

Prism$_m$ is the measured prism position, while Prism$_a$ is the actual prism position.

Mathematically, the total slope distance would be:

$$sd_{total} = sd_i + sd_g + sd_o \ \dots\dots\dots\dots 2$$

where $sd_g = \dfrac{t}{\cos(\theta_g)}$; and $\theta_g = \sin^{-1}\left[\sin\theta \times \dfrac{n_a}{n_g}\right]$

i.e. by using trigonometry:

$$\frac{t}{sd_g} = \frac{adj}{hyp} = \cos\theta_g$$

$$\therefore \ sd_g = \frac{t}{\cos(\theta_g)}$$

$$\frac{\sin\theta}{\sin\theta_g} = \frac{n_a}{n_g}$$

$$\sin\theta_g = \sin\theta \times \frac{n_a}{n_g}$$

$$\therefore \ \theta_g = \sin^{-1}\left[\sin\theta \times \frac{n_a}{n_g}\right]$$

Where $n_a = n_{ai} = n_{ao}$

It is assumed that the refractive index of air n_a is the same inside, n_{ai} and outside, n_{ao} the total station shelter.

While the total horizontal distance would be:

$$hd_{total} = hd_i + t + hd_o \ \dots\dots\dots\dots\dots\dots\dots 3$$

Consequently, the actual coordinate of the prism would be:

Prism$_a$ $(Y_a) = (sd_i + sd_o).\sin(\theta) + sd_g.\sin(\theta_g)$; and Prism$_a$ (X_a)

$= (sd_i + sd_o).\cos(\theta) + sd_g.\cos(\theta_g).................................4$

However, all the above quantities are hardly taken into account, nor are their values known when computing the position of the prism relative to the RTS position. The measured coordinate values that are displayed on the RTS screen are usually computed from:

Prism$_m$ (Y_m)
$= (sd_i + sd_g + sd_o).\sin(\theta)$; and Prism$_m$ (X_a) $= (sd_i + sd_g + sd_o).\cos(\theta)$
i.e.
Prism$_m$ (Y_m) $= sd_{total}.\sin(\theta)$ and Prism$_m$ (X_m) $= sd_{total}.\cos(\theta)$ $\Big\}\,5$
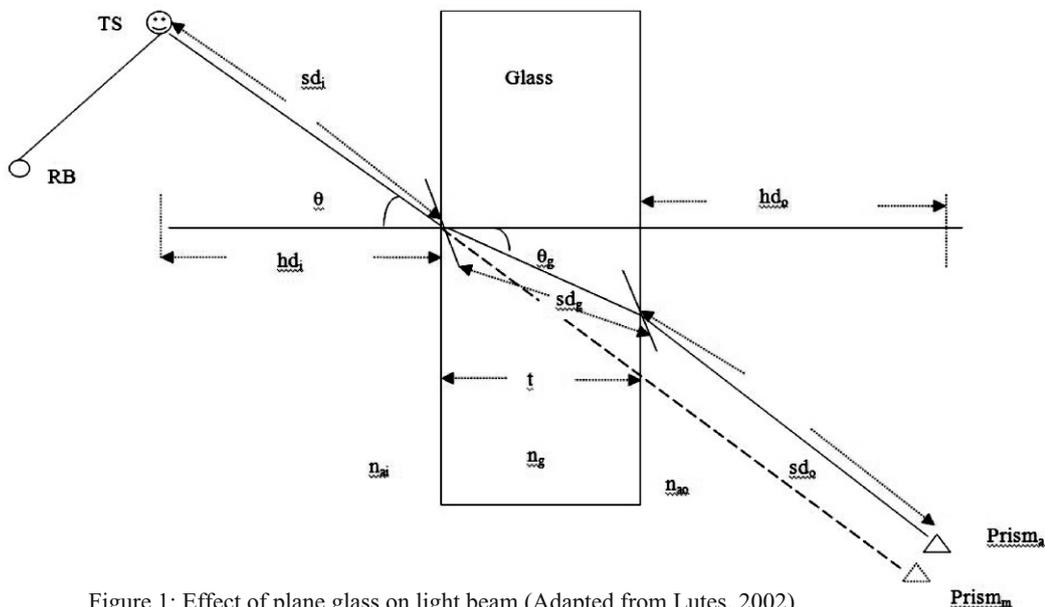

Figure 1: Effect of plane glass on light beam (Adapted from Lutes, 2002).

If the join between the TS and RB is calculated, and the direction from TS to the prism is known by using RB for orientation, for instance α_{ts-p}, the above equation, 5, can be re-written as:

$$
\left.\begin{array}{l}
\text{Prism}_m(Y_m) = [(hd_i + t + hd_o).\sin(\alpha_{ts-p})] + Y_{TS}; \text{ and Prism}_m(X_m) \\
\qquad\qquad = [(hd_i + t + hd_o).\cos(\alpha_{ts-p})] + X_{TS} \\
\text{i.e. Prism}_m(Y_m) = [hd_{total}.\sin(\alpha_{ts-p})] + Y_{TS}; \text{ and Prism}_m(X_m) \\
\qquad\qquad = [hd_{total}.\cos(\alpha_{ts-p})] + X_{TS}.
\end{array}\right\} 6
$$

Where:

α_{ts-p} is the direction of prism from the instrument station TS; and

Y_{TS} and X_{TS} are the coordinates of instrument station TS.

The displayed coordinate on the screen of the RTS are based on equations 4 and 5. According to Lutes (2002), this is based on the assumptions that:

a. the glass is perfectly flat on both sides;
b. the inside and outside surfaces of the glass are parallel;
c. the glass molecules are pure, i.e. without bubbles in the inner structure of the glass
d. the glass refractive index is uniform;
e. the refractive index of air inside the shelter is identical to that outside of the shelter; and
f. the refractive index of the air is uniform.

Practically, the above assumptions are not attainable. Notwithstanding, the above Figure 1 and the mathematical analysis

that followed clearly revealed that the properties of the shelter window glass matters when using RTS to monitor deformation/stability from transfer beacon shelter. Therefore, this study was carried out to examine the effect of the shelter glass shapes on the distances measure with a RTS setup in a transfer beacon shelter.

2. Materials and Method

This case study examines the likely impacts of total station shelter glass shapes, whether plane, concave or convex, on distance measurements for an efficient and reliable monitoring program. A high precision and efficient total station TR 1201 was used for this research work. Three 2.0mm clear float glass of different shapes (plane, concave and convex) were procured. The total station was mounted on a beacon located beside an office window wall and levelled.

The instrument was orientated using an established reference point. Distances, both Horizontal distance (HD) and vertical distance (VD) were measured to the target; a Leica Circular prism hung on a wall of a building located directly opposite the office window taking a reading per minute for 20 minutes. Figure 2 shows the experimental setup. After the 20 readings, a 2.0mm plane glass was placed 42 m two, the total station and the target. The glass was placed close to the total station telescope. 20 readings were also taken through the glass to the target. Later, the 2.0mm plane glass was replaced with concave glass, followed by convex glass, and the HD and VD readings during each measurement were recorded. The experimental setups are shown in Figure 3:
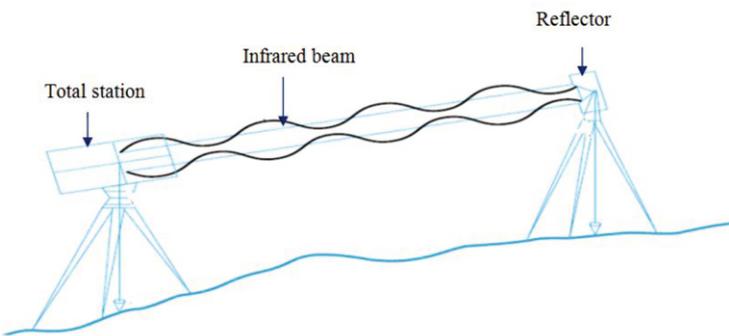

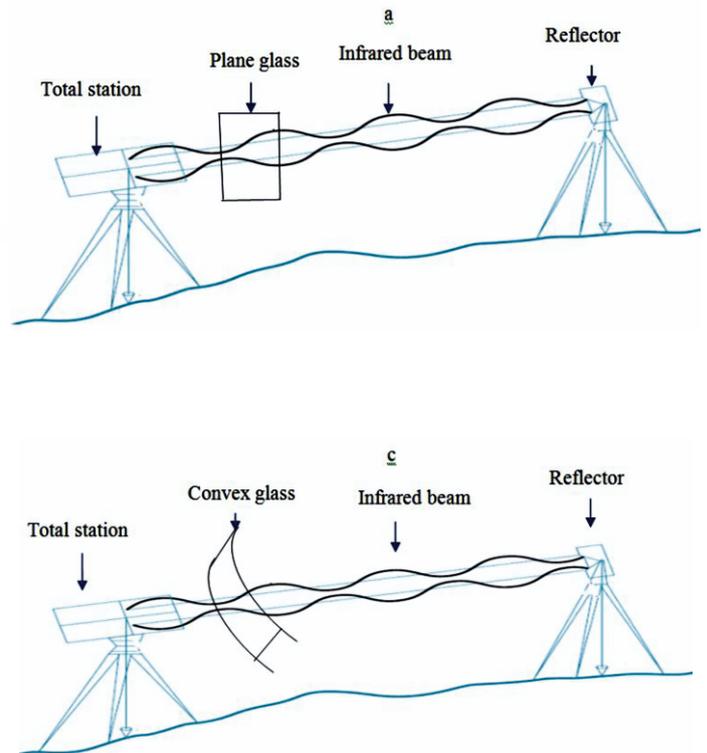Figure 2: Typical sketch of setup for direct observation between the total station and the target.

Figure 3: Typical sketch of setup for the determination of impact of glass shapes on distance measurements with total station through shelter glass (a – plane glass; b – concave glass and c – convex glass).

Throughout the exercise, a temperature variation of 0.5°C, a pressure variation of 0.1 mb and a humidity variation of 1 % were observed. It must be noted that the total station was programmed to correct all the readings for prism constant and scale factor before embarking on any distance measurement. The recorded HD and VD readings per measurement were corrected for atmospheric variations using the formula given by Leica Geo-systems for atmospheric corrections in the instrument manual, as shown in equation 7(Leica Geo-systems, 2008):

For infra-red EDM:

$$\Delta D_1 = 283.05 - \left[\frac{0.29196P}{(1+\alpha t)} - \frac{4.126 \times 10^{-4} h}{(1+\alpha t)} .10^x . \right] \quad \text{...................7}$$

where:

ΔD_1 is atmospheric correction, ppm

P is air pressure, mb

t is air temperature, °C

h is relative humidity, %

$$\alpha = \frac{1}{273.15}$$

$$x = \left[\left(\frac{7.5t}{237.3 + t} \right) + 0.7858 \right]$$

y expansion of second term with 273.15 (1/0.003661), equation 7 can be expressed as follow:

For infra-red EDM

$$\Delta D_1 = 283.05 - \left[\frac{79.7489P}{(273.15 + t)} - \frac{11.27e}{(273.15 + t)} \right] \quad \text{......} 8$$

Where:

$$e = \frac{10^x h}{100}$$

The acquired distance readings were subjected to statistical analysis before and after atmospheric corrections. The accuracy specification limit [(i.e. ± (1mm + 1.5 ppm)] stated in the TCR 1201 total station manual was used as an indicator to detect the impact of the glass shapes on the measured distances.

3.   Result and Discussion

The results of the analysis of the distance measurements before atmospheric corrections are presented in Figures 4 and 5. The corresponding results after atmospheric correction are presented in Figures 6 and 7.
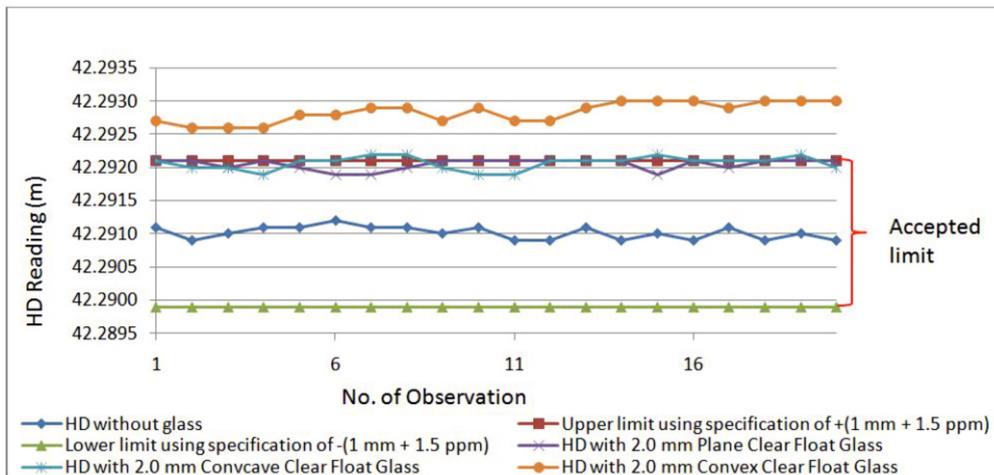

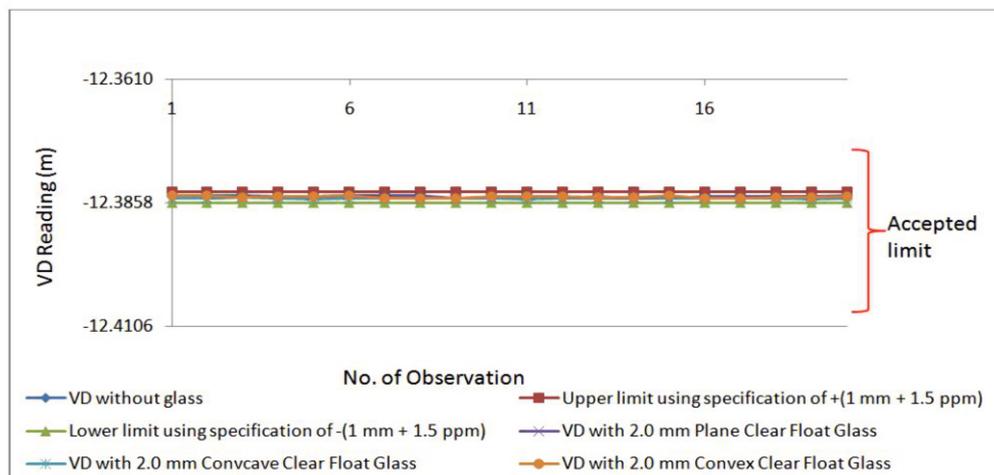Figure 4: HD Readings before Atmospheric Corrections.

Figure 5: VD Readings before Atmospheric Corrections.

Figure 4 shows the results of HD measurements before atmospheric corrections. The graph revealed that the entire glass barriers had an impact on the HD readings when compared to HD readings without glass. However, the impact of plane glass was within the accuracy specification of the instrument and this is in agreement with Afeni&Cawood(2010). All other glass shapes were outside the limit. The impact of the concave glass was not much when compared with the impact of convex glass.

In the result of VD analysis before atmospheric corrections, as shown in Figure 5, all the readings were within the accuracy limit. In fact, there were no differences between the VD readings without glass and VD readings with glass. This clearly revealed that the glass barrier has no impact on VD measurements, as established in Afeni (2011).

`Figure 6 shows the result of HD readings after atmospheric corrections. The graph is similar to the graph on HD readings before atmospheric corrections, as shown in Figure 4. The only difference is that the atmospheric impact has been removed. The differences are not noticeable because throughout the exercise, a temperature variation of 0.5°C, a pressure variation of 0.1 mb and a humidity variation of 1 % were observed

Figure 7 shows the result of VD readings after atmospheric corrections.It is also similar to the result of VD readings before atmospheric corrections, as shown in Figure 5. The glass barrier has no impact on VD readings.The differences are not also noticeable because throughout the exercise, a temperature variation of 0.5°C, a pressure variation of 0.1 mb and a humidity variation of 1 % were observed.

These atmospheric variations are so minute to give clear or noticeable graphical change.

4.   Conclusion and Recommendation.

The study discussed the effect of glass shapes on distances measured with total station through a total station shelter glass. The findings revealed that the shape of the glass matters when carrying out observations with total stationthrough a shelter window glass. The plane glass has the least impact on HD measurements, followed by the concave glass, while the convex glass has the highest impact. However, the impact of the plane glass was within the accuracy specification limit of the total station. The findings also showed that the glass shapes has no effect on the VD measurements.

Therefore, slope, dam orstructural deformation monitoring with total station must be carried out without glass barrier. Otherwise, plane glass should be used for the total station shelter window cover during construction of the total station shelter at mines and construction sites.If concave or convex glass must be used, there is a need to quantify the impact of the glass shape and develop a systematic error correction formula(e)/nomogram or model to compensate for the impact of the glass shape on HD readings through detail experiment.
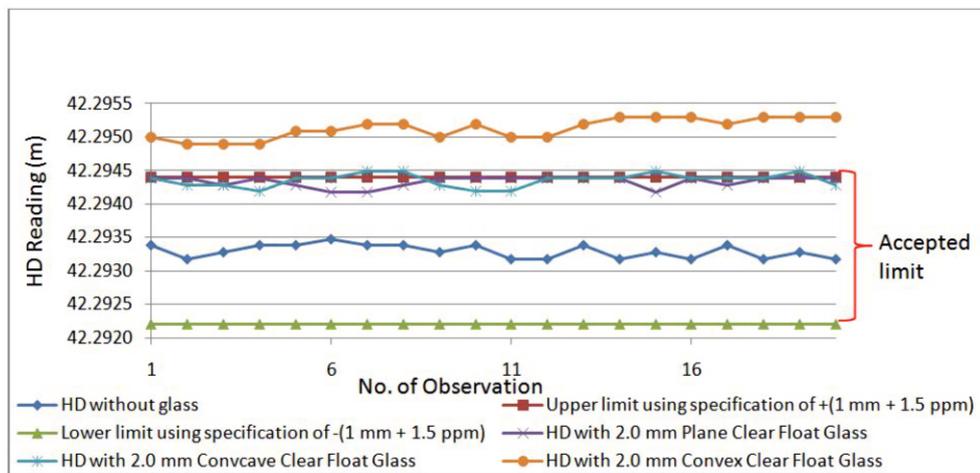
Acknowledgement

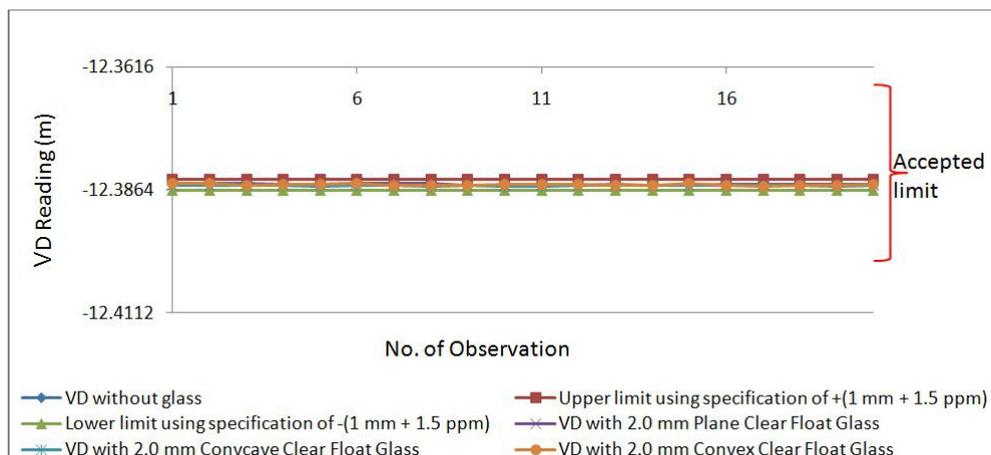Figure 6: HD Readings after Atmospheric Corrections.

Figure 7: VD Readings after Atmospheric Corrections.

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