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The Impact of Vibration on the Accuracy of Digital Surveying Instruments

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Abstract

A digital surveying instrument has a crucial and effective role in civil engineering. These digital surveying instruments have contributed to providing quick and simplified solutions to solve many surveying problems: particularly accuracy, saving time, and effort .Therefore, the main objective of this research is the study of the vibrations effect on digital devices efficiency during the observation process, which occur frequently especially when the devices occupy the bridges during observation or when the occupation of the device is set nearby the railways, as well as in construction sites with heavy equipment movement. Although most digital surveying instruments contain a compensator device, this research find out through the experimental test that the effect of vibration on the accuracy of observation results and the noticed errors may extend to many centimeters. In case of using the digital level devices (SOKKIA SDL-30) under exposure to vibration (up to 20 KHZ/Sec), the average error of elevation was 36.9 mm in 80 m distance and the maximum standard deviation elevation error was 18.26 mm. But in the case of using the reflector-less total station (SOKKIA SET330RK) under exposure to vibration (from 7.5 to 15 KHZ/Sec), the average error of positioning was 79.95 mm in 85 m distance and the maximum standard deviation positioning error was 43.41 mm.

Keywords: Accuracy; Digital Instruments; Vibration; Collimation Error; Arduino.

1. Introduction

The advancement of surveying instruments and the contrivance of digital electronic instruments lead to exceptional progress in the surveying field and avert many errors in optical instruments such as inaccuracy due to the manual method that takes a long time to write down the observation process results which, in turn leads to more fallible outputs of the surveying process. However, these digital devices are not efficient in reducing errors significantly because they are affected by the conditions surrounding the observation process. As a general rule, a civil structure is exposed to shifting ecological and operational conditions, for example, traffic, moisture, wind, sun oriented radiation and temperature [1]

The last decade witnesses a lot of researches conducted to the Digital Level, and Total station's accuracy. The effect of Sun, and battery capacity have been measured and estimated by Ashraf A.A. Beshr, and Islam M. Abo Elnaga [2]. The authors concluded that the leveling process has been enhanced by (10-15) %. Moreover, Reda el al [3] studied the effects of angle incidence and targets with different colors on distance measurement about the total station refrectorless, and The accuracy of reflectorless distance measurement is also investigated, In addition to that, comparison was made for manual and automatic target recognition measurement. The results showed that the error in the distance increased as the incident angle in the target increases.

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Regarding to previous mentioned studies, there is no research investigates the effect of the vibration on the performance of the Digital level and Total station which caused by observing nearby railway, observing on bridges or in construction sites having heavy equipment causing high vibrations. In this research, the vibration was measured by SW-420 vibration sensor. The experiment carried out by examining some digital level devices (SOKKIA SDL- 30) and total station (SOKKIA SET330RK) which contain an automatic compensators device that can maintain the device's horizontal plane. This compensator works to correct the optical path depending on the gravitational property and the optical pathway to its horizontal plane but this compensator works within a very small field (a few minutes of the arc). Therefore, some errors remain even after correction. Although it helps reduce the impact of vibration effect but it does not completely eliminate it.

A simulation test was carried out to measure these vibrations, using connecting 3 DC motors (24 volt) on leg of the tripod which acted as a generator of vibrations for three stages (0.0 to 7500 Hz/Sec., 7500 to 15000 Hz/Sec. and 15000 to 20000 Hz/Sec.). This research investigates the accuracy of observation from digital level and total station devices under exposed to vibration. It investigates also the ability and distance limitation to using these digital devices under exposed to vibration. Precision comparison for the observation before and after exposed to vibration is also presented. The results of the practical measurements, calculations and analysis of results are presented.

However, it is important to begin by presenting the technical specifications of the digital level devices (SOKKIA SDL- 30), the total station (SOKKIA SET330RK) and defining vibration and how to measure it before explaining the experimental as follows:

2. The Technical Specifications of the Digital Level Devices (SOKKIA SDL-30) and the Total Station (SOKKIA SET330RK)

Digital automatic levels are a precise instruments used for precise leveling. Operation of digital levels is based on the digital processing of video indications of a coded staff [4]. Operation of digital levels is based on the digital processing of video indications of a coded staff [5]. To determine the height difference, it is necessary to bring the line of sight to the horizontal position. Horizontality of the line of sight is achieved by the compensator [6]. This device virtually eliminates reading errors and automates the collection of data. Also, fieldwork is conducted more quickly with digital reading than with conventional methods [7]. The geometric leveling was conducted with a SOKKIA power level SDL 30, which provides data acquisition (by estimation) up to 2 decimals when measuring mode is tracking. The Sokkia power level SDL 30 was used as shown in Figure 1. The "Power Level SDL 30" makes measurement quick, easy, and accurate. Moreover, it makes the function of measuring the height and distance in all types of environments. This device also gives satisfying measurements in tunnels and high levels of temperature [8].

General specification of the SDL30:

- Accurate under contrary illumination and environmental changes.
- 4 main measuring types: single-fine, repeat-fine, average, and tracking.
- Water proof and resist to shock.

The technical specifications of the digital level devices (electronic SOKKIA SDL-30) are mentioned in Table 1 [8, 9].

Table 1. Technical Specifications of the Digital Level Devices [8]

Accuracy of Height	1 mm
Accuracy of Distance	[<10m = +/-10mm] [10m to 50m = +/-.1%xD] [>50m = .2%xD]
Resolution of Display	.0001 / .001m
observing Range	1.6 to 100m
Zoom in	32 time
Compensator	Pendulum compensator with magnetic damping system
Operation limit	no less than 8.5 h.

The total Station is an electronic surveying instrument that combines Electronic Distance Measuring Equipment (EDM) with an electronic theodelite and a computer. The EDM measures the distance (slope distance) to a directed prism to which it is pointed, while set on-board [10]. The electronic theodelite simply measures obliquity episodes within two planes, the X-Y plane (horizontal plane) the X-Z plane (vertical plane). The computer stores and manipulates a large number of values resulting from these three measurements [11]. The used total station device is SOKKIA SET330RK as illustrated in Figure 2. The technical specifications of the SOKKIA SET330RK total station are given in Table 2 [12].

Table 2. Technical Specifications of the SOKKIA SET330RK Total Station [12]

Minimal Display			1 sec
Accuracy			3 sec
with Prism			Up to 5 km
Sheet prism			1.3 up to 300 m
Reflector-less	**White colour**		0.3 up to 200m
With Prism	**Fine-Measurement**		2 mm ± 2 mm/km
Sheet prism	**Fine-Measurement**		3 mm ± 2 mm/km
Reflector-less	**White colour**	**Fine-Measurement**	3 mm ± 2 mm/km (0.3 to 100m)
			5 mm ± 10 mm/km (over 100 to 200m)

Figure 1. The SOKKIA Power Level SDL30

Figure 2. SOKKIA SET330RK Total Station

3. Vibration

As for vibration, it is defined as a direct physical effect that appears frequently in our daily lives. These vibrations result from different sources such as noise, wind, and mechanical vibrations, which are formed nearby bridges and trains, as regular movements around a certain place for several times. It is known as frequency in Hz unit [13]. Evaluating and measuring the vibration has a lot of variations and possible technologies. Piezoelectric, resonance, and magnetic can be used to measure the vibration values [14]. It is now easy to measure these vibrations through a remarkable development in technology that produces, digital devices, including vibration sensors. For instance, SW-420 is a vibration sensor as shown in Figure 3 [15].

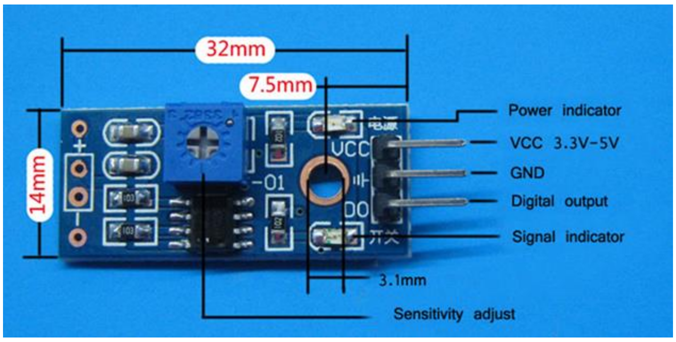

Figure 3. SW-420 Sensor

The SW-420 vibration sensor uses Arduino program-software to measure Vibration. It is a cheap device that does not require great effort or a large number of electronics. It can also detect slight vibrations and re-record them on a digital image with the help of the specified software. Arduino is an electronics company that develops software and electronic devices which are easy to handle. We adopt Arduino as the base of the Middle-Device since the difficulty of operating the hardware is abstracted, programming is easy for a beginner, and the Arduino has more extensibility[16, 17]. All researchers and students use Arduino programs because its cost is reasonable and one can apply tests using this program easily. In this research, Arduino products have been used to carry out the suggested experiment. Arduino Uno is a microcontroller board which can be connected to a computer a Universal Serial Bus (USB) as indicated in Figure 4. Uno dimensions are (68.61 x 53.40) mm, weighs (25) gram. It has (ATmega328 8-bit) microcontroller [16]. The Arduino Uno ("Uno" means one in Italian) is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP (In circuit serial programming) header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with AC-to-DC adapter or battery to get started. Also an advantage of using the Uno is that the chip used in it can be replaced for relatively cheap cost. UNO board is the very first of the Arduino boards and even though there are some advanced boards available; for this project, the UNO board will be enough [18, 19].

Figure 4. Arduino Uno Board

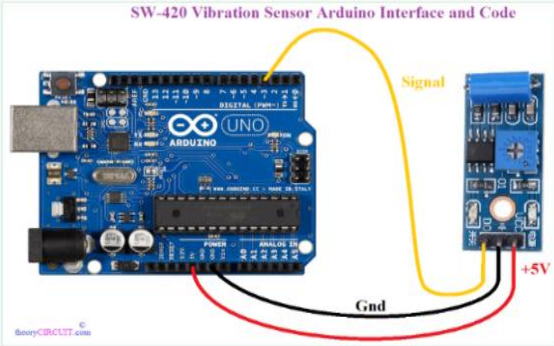

Figure 5. Arduino Uno Board Connected to SW-420 Vibration Sensor

Then, the Uno board is connected to a USB to a computer USB to display the results on the Arduino program using the vibration sensor and wires to measure vibration using the code shown in Figure 6. Then, the result of vibration in Hertz unit is shown in Figure 7.

```
code
int LED_Pin = 13;
int vibr_Pin =3;

void setup(){
  pinMode(LED_Pin, OUTPUT);
  pinMode(vibr_Pin, INPUT); //set vibr_Pin input for measurment
  Serial.begin(9600); //init serial 9600
 // Serial.println("----------------------Vibration demo------------------------");
}
void loop(){
  long measurement =TP_init();
  delay(1000);
 // Serial.print("measurment = ");
  Serial.println(measurement);
  if (measurement > 1000){
    digitalWrite(LED_Pin, HIGH);
  }
  else{
    digitalWrite(LED_Pin, LOW);
```

Figure 6. Vibration Code in Arduino Program

```
Send
10219
31159
11087
11445
11318
131663
11223
11309
11711
0
0
10695
0
0
11254
13707
10644
10789
10661
10082
8402
9910
10412
270953
0
0
```

Figure 7. Result in Arduino Program by Hertz Per Second

4. Experimental Test Field

It was so difficult for the researchers to carry out the observation nearby a railway or a bridge because of overcrowding, passing vehicles and surrounding circumstances. In general, the magnitude of a vibration acceleration signal in a structure can be represented by its peak value [20]. We found that the vibration was up to 12000 Hz per second. Consequently, a simulation test was conducted to measure these vibrations, using connecting 3 DC motors (24 volt) on each leg of the tripod of the electronic instruments which acted as a generator of vibrations for three stages until we reached a certain value of vibrations 20000 Hz. These values were measured by the SW-420 vibration sensor that was connected to an Arduino program. Therefore, the research project passed through three levels of vibration values: (1) generating vibration in a domain of 0.0 to 7500 Hz per second; (2) vibration from 7500 to 15000 Hz per second; and (3) Vibration from 15000 to 20000 Hz per second. Figure 8 shows the research methodology.

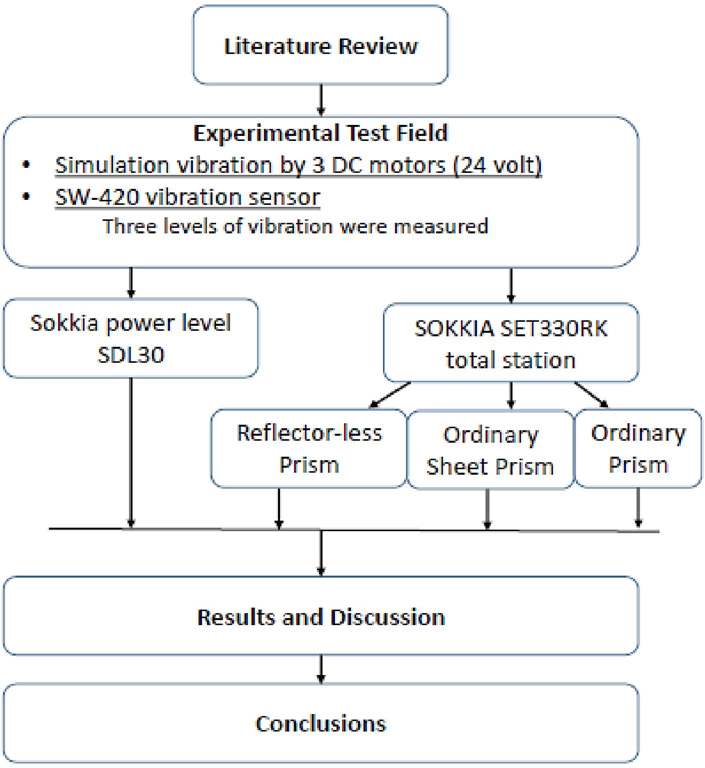

Figure 8. the research methodology

The first test was run using Sokkia power level SDL30. The test was carried out with fully charged battery during daytime under natural light and temperature of 20º C. It was adjusted horizontally and recorded the average of 25 staff reading without vibration at equal divided distances every 5 meters up to 100 meters, then the level device was exposed to three stages of vibrations as was mentioned before. In each interval, the 25 staff readings were recorded. The absolute maximum error, absolute minimum error, absolute average error and standard deviation error of elevation observations were calculated using the following equations [21, 22]:

$$V_{i\ (i=1,2,\ldots\ldots,n)} = \left|X_i - X^{\backslash}\right|$$

$$max.\,(elev.)_{error} = Maximum(V_i),\ \ min.\,(elev.)_{error} = Minimum(V_i) \qquad (1)$$

$$avg.(elev.)_{error} = \frac{\sum_{i=1}^{n} V_i}{n},\ \ \sigma_x = \pm\sqrt{\frac{\sum_{i=1}^{n} v_i^2}{n-1}}$$

Where:

$V_{i\ (i=1,2,\ldots\ldots,n)}$= the absolute error of elevation on staff reading after exposure to vibrations

n = the number of staff readings (25 times).

X_i= the staff reading after exposure to vibrations

$X^{\backslash}$= the average staff reading (before exposure to vibrations)

$max.\,(elev.)_{error}$ = The absolute maximum error of elevation.

$min.\,(elev.)_{error}$ = The absolute minimum error of elevation.

$avg.(elev.)_{error}$ = The absolute average error of elevation.

σ_x = the standard deviation error of elevation observations.

The second test was run using SOKKIA SET330RK total station. The test was carried out with fully charged battery during daytime under natural light and temperature of 20º C. It was adjusted horizontally and recorded the positioning (positioning without vibration). The total station was used in several tests:

a. Observing the coordinates of an ordinary prism with vertical angle equal to zero, with equal distances (50 m) of reach to 1000 meters. In each interval, the 25 observations were recorded once without vibration and were recorded a second time with three levels of vibrations.

b. Observing the coordinates of an ordinary sheet prism with vertical angle equal to zero, with equal distances (10 m) of reach to 200 meters. In each interval, the 25 observations were recorded once without vibration and were recorded a second time with three levels of vibrations.

c. Observing the coordinates with reflector-less prism using white paper as a target with vertical angle equal to zero, with equal distances (5 m) of reach to 100 meters. In each interval, the 25 observations were recorded once without vibration and were recorded a second time with three levels of vibrations.

The absolute average positioning error and standard deviation error of positioning were calculated for each case using the following equations [21, 22]:

$$V_{i\ (i=1,2,\ldots,n)} = \sqrt{(X_i - X^{\backslash})^2 + (Y_i - Y^{\backslash})^2 + (Z_i - Z^{\backslash})^2}$$
$$avg.(Pos.)_{error} = \frac{\sum_{i=1}^{n} V_i}{n}, \ \ \sigma_{Pos.} = \pm\sqrt{\frac{\sum_{i=1}^{n} v_i^2}{n-1}} \qquad (2)$$

Where:

$V_{i\ (i=1,2,\ldots\ldots,n)}$= the error of positioning on observation after exposure to vibrations

n = the number of observation (25 times).

X_i, Y_i & Z_i= the Easting, Northing and Elevation of observation after exposure to vibrations

$X^{\backslash}$, $Y^{\backslash}$ & $Z^{\backslash}$= the average Easting, Northing and Elevation of observation (before exposure to vibrations)

$avg.(Pos.)_{error}$ = The absolute average error of positioning.

$\sigma_{Pos.}$= the standard deviation error of positioning observations.

5. Results and Discussion

The absolute maximum error of elevation, the absolute minimum error of elevation, the absolute average error of elevation and the standard deviation error of elevation observations were calculated using the Equation 1. It was calculated for Digital Level Devices (Electronic Sokkia SDL- 30). The average error in positioning and the standard deviation in positioning were calculated using the Equation 2. It was calculated for total station (SOKKIA SET330RK).

5.1. Digital Level Devices

The absolute maximum/minimum error, the absolute average error and the standard deviation error of elevation observations were calculated as given in Table 3. The average error in elevation was presented for the three domains of vibration levels mentioned earlier in Figure 9. The standard deviation in elevation was also displayed for the same three domains of vibration shown in Figure 10. In the second domain of vibration (from 7500 to 15000 Hz/sec.), the Digital Level Devices (Electronic Sokkia SDL- 30) observation is limited with 90 m and in the third domain of vibration (from 15000 to 20000 Hz/sec.) 80 m is the limit.

As shown in Figures 9 and 10, the relationship between both the average and standard deviation elevation error against the distance are almost linear. As the levels of vibrations accumulate, the average and standard deviation errors increased rabidly, especially at far distances.

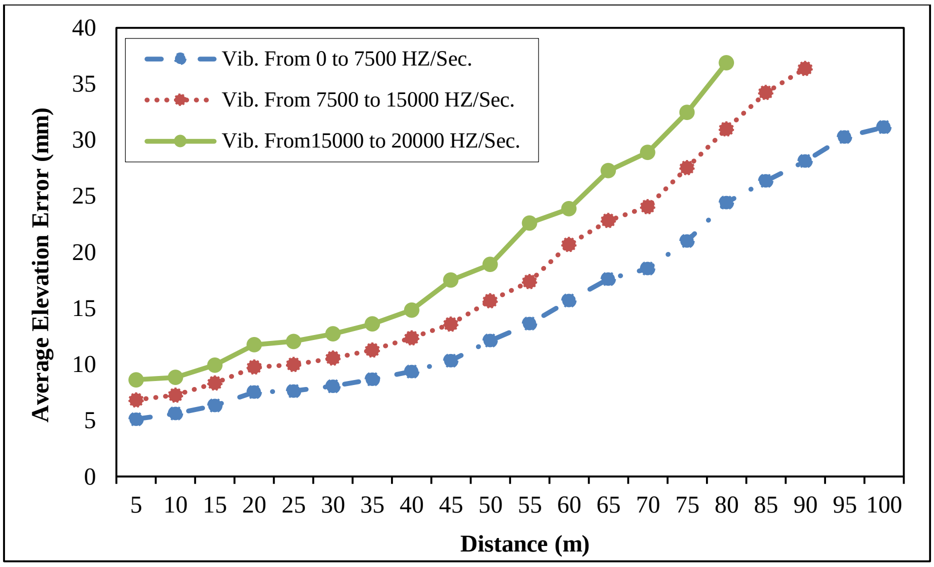

Figure 9. Average Error in Elevation (mm) Using Digital Level Devices (Electronic Sokkia SDL- 30)

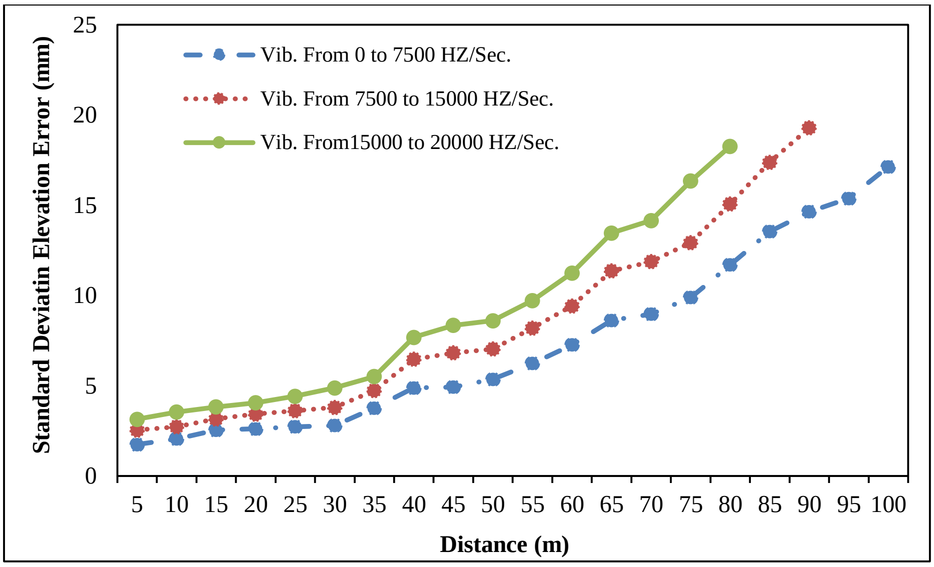

Figure 10. Standard Deviation in Elevation (mm) Using Digital Level Devices (Electronic Sokkia SDL- 30)

Table 3 illustrates the accurate values of the experimental tests conducted to Digital Level Device, in which the trend of the values refers to an obvious increase in errors. The reasons of the errors can be referred to the hesitation of the sight line that can read more than one point on the barcode staff.

Table 3. Average Error in Elevation (mm) and Standard Deviation in Elevation (mm) Using Digital Level Devices (Electronic Sokkia SDL- 30)

Distance (m)	Elevation observation error											
	Vibration from 0.0 to 7500 Hz per second				Vibration from 7500 to 15000 Hz per second				Vibration from 15000 to 20000 Hz per second			
	max	min	avg	Std	max	min	avg	Std	max	min	Avg	Std
5	9	3	5.13	1.74	12	4	6.83	2.54	14	5	8.63	3.14
10	10	4	5.63	2.05	12	5	7.27	2.72	15	6	8.84	3.54
15	10	4	6.34	2.54	13	5	8.34	3.16	15	6	9.94	3.82
20	11	4	7.54	2.61	14	5	9.76	3.42	16	7	11.76	4.05
25	11	5	7.63	2.72	15	6	9.98	3.61	18	7	12.06	4.42
30	12	5	8.06	2.79	16	7	10.56	3.80	19	8	12.72	4.88
35	14	6	8.67	3.76	18	8	11.29	4.73	21	9	13.61	5.51

40	14	7	9.38	4.88	18	9	12.37	6.46	22	11	14.84	7.68
45	15	8	10.35	4.92	19	11	13.59	6.82	23	13	17.51	8.34
50	16	9	12.12	5.36	22	11	15.67	7.03	26	14	18.91	8.60
55	19	10	13.64	6.23	24	13	17.38	8.19	28	16	22.60	9.72
60	19	13	15.69	7.26	25	16	20.69	9.42	30	20	23.87	11.24
65	20	14	17.61	8.62	27	17	22.82	11.36	32	21	27.27	13.46
70	22	15	18.54	8.96	29	19	24.06	11.87	35	22	28.91	14.15
75	25	17	21.01	9.89	32	23	27.54	12.93	38	27	32.47	16.34
80	29	19	24.43	11.69	37	25	30.99	15.06	44	30	36.89	18.26
85	31	23	26.35	13.54	40	30	34.23	17.38	-----	-----	-----	-----
90	34	26	28.13	14.64	43	34	36.38	19.28	-----	-----	-----	-----
95	36	27	30.27	15.37	-----	-----	-----	-----	-----	-----	-----	-----
100	39	28	31.15	17.13	-----	-----	-----	-----	-----	-----	-----	-----

5.2. Total Station Devices

Figure 11 shows the average positioning errors against observed distances using total station with ordinary prism when exposed to three domains of vibration levels (from 0.0 to 7500, from 7500 to 15000, and from 15000 to 20000) Hz/sec, while Figure 12 illustrates the effect of previous mentioned domains on the standard deviation positioning error. As is observed, the increase in vibration levels effect the accuracy of observation besides the observed distances.

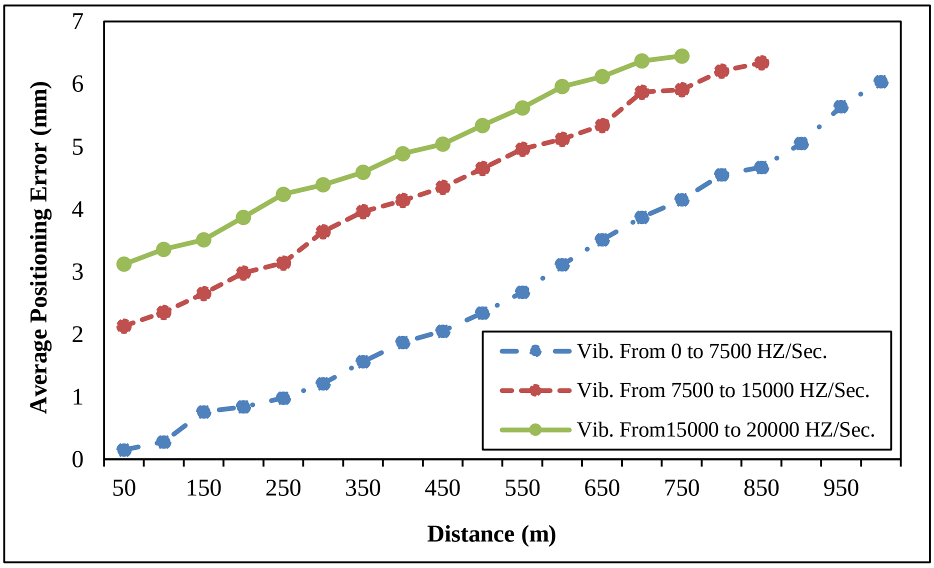

Figure 11. Average Error in Positioning (mm) Using Ordinary Prism Total Station (SOKKIA SET330RK)

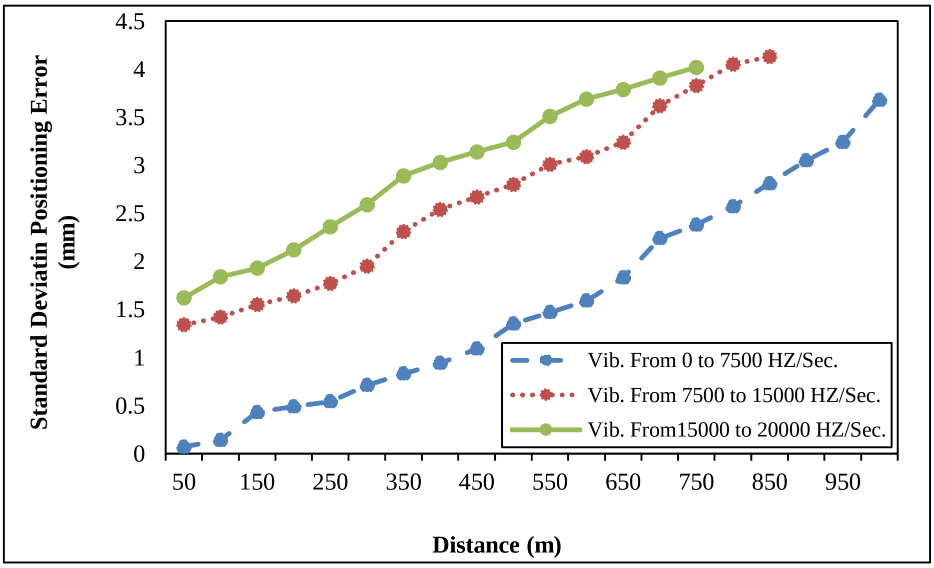

Figure 12. Standard Deviation Error in Positioning (mm) Using Ordinary Prism Total Station (SOKKIA SET330RK)

Positioning average error and positioning Standard Deviation for total station with ordinary prism when goes under variable domains of vibrations at different distances from (50 to 1000) m with step 50 m is tabulated in Table 4. The maximum observed distance in case of (from 0.0 to 7500, from 7500 to 15000, and from 15000 to 20000) HZ/sec. signified (1000, 850, and 750) m with standard deviation (3.68, 4.13, and 4.02) mm, respectively.

Table 4. Average Error in Positioning (mm) and Standard Deviation in Positioning (mm) Using Ordinary Prism Total Station (SOKKIA SET330RK)

Distance from Instrument to Target (m)	Positioning Observation Error Using Ordinary Prism (Mm)					
	Vibration from 0.0 to 7500 Hz per second		Vibration from 7500 to 15000 Hz per second		Vibration from 15000 to 20000 Hz per second	
	avg.	Std.	avg.	Std.	avg.	Std.
50	0.15	0.07	2.13	1.34	3.12	1.62
100	0.28	0.14	2.35	1.42	3.36	1.84
150	0.76	0.43	2.65	1.55	3.51	1.93
200	0.84	0.49	2.98	1.64	3.87	2.12
250	0.98	0.54	3.14	1.77	4.24	2.36
300	1.21	0.71	3.64	1.95	4.39	2.59
350	1.56	0.83	3.96	2.31	4.59	2.89
400	1.87	0.94	4.14	2.54	4.89	3.03
450	2.05	1.09	4.35	2.67	5.04	3.14
500	2.34	1.35	4.65	2.8	5.34	3.24
550	2.67	1.47	4.96	3.01	5.62	3.51
600	3.11	1.59	5.12	3.09	5.96	3.69
650	3.51	1.83	5.34	3.24	6.12	3.79
700	3.87	2.24	5.87	3.62	6.37	3.91
750	4.15	2.38	5.91	3.83	6.45	4.02
800	4.55	2.57	6.21	4.05	------	------
850	4.67	2.81	6.34	4.13	------	------
900	5.05	3.05	------	------	------	------
950	5.64	3.24	------	------	------	------
1000	6.04	3.68	------	------	------	------

Table 5 illustrates the average error in Positioning and standard deviation in Positioning in the case of total station with sheet prism. In case of applying total station with sheet prism (the average error and standard deviation) in positioning increased although the observed distance decreased when compared to the total station with ordinary prism at the same domains of vibration levels (from 0.0 to 7500, from 7500 to 15000, and from 15000 to 20000) in which the maximum distances were (200, 180, and 140) m with standard deviation (4.87, 5.87, and 5.16) mm, respectively.

Table 5. Average Error in Positioning (mm) and Standard Deviation in Positioning (mm) Using Sheet Prism Total Station (SOKKIA SET330RK)

Distance from Instrument to Target (m)	Positioning Observation Error Using Sheet Prism (mm)					
	Vibration from 0.0 to 7500 Hz per second		Vibration from 7500 to 15000 Hz per second		Vibration from 15000 to 20000 Hz per second	
	avg.	Std.	avg.	Std.	avg.	Std.
10	0.48	0.26	1.31	0.75	2.34	1.11
20	0.69	0.47	1.84	0.98	2.86	1.87
30	1.23	0.66	2.12	1.14	3.27	1.99
40	1.51	0.84	2.67	1.65	3.89	2.17
50	1.67	1.05	2.99	1.84	4.12	2.55
60	1.97	1.09	3.61	2.01	4.68	2.91
70	2.35	1.27	3.92	2.27	5.01	3.51
80	2.87	1.34	4.36	2.57	5.58	3.78
90	3.46	1.71	4.57	2.85	5.83	3.84
100	3.78	1.87	5.12	3.14	6.31	4.04
110	3.91	2.03	5.62	3.64	6.87	4.28

120	4.15	2.31	5.89	3.89	7.12	4.61
130	4.63	2.64	6.13	4.11	7.54	4.92
140	5.31	2.95	6.87	4.5	7.96	5.16
150	5.67	3.24	7.32	4.83	------	------
160	6.02	3.64	7.75	5.08	------	------
170	6.47	3.79	8.21	5.61	------	------
180	7.05	4.08	8.73	5.87	------	------
190	7.76	4.51	------	------	------	------
200	8.35	4.87	------	------	------	------

Figures 13 and 14 show the average positioning error and standard deviation error with respect to observed distances in case of applying the mentioned domains of vibration levels on the total station with sheet prism, from which we can deduce that the observed distance decreases rapidly when applying the vibrations.

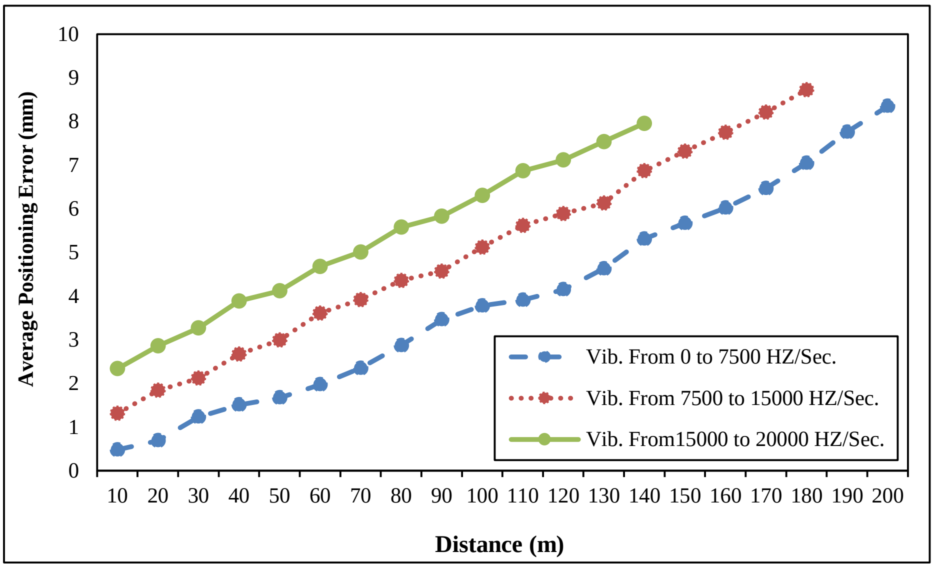

Figure 13. Average Error in Positioning (mm) Using Sheet Prism Total Station (SOKKIA SET330RK)

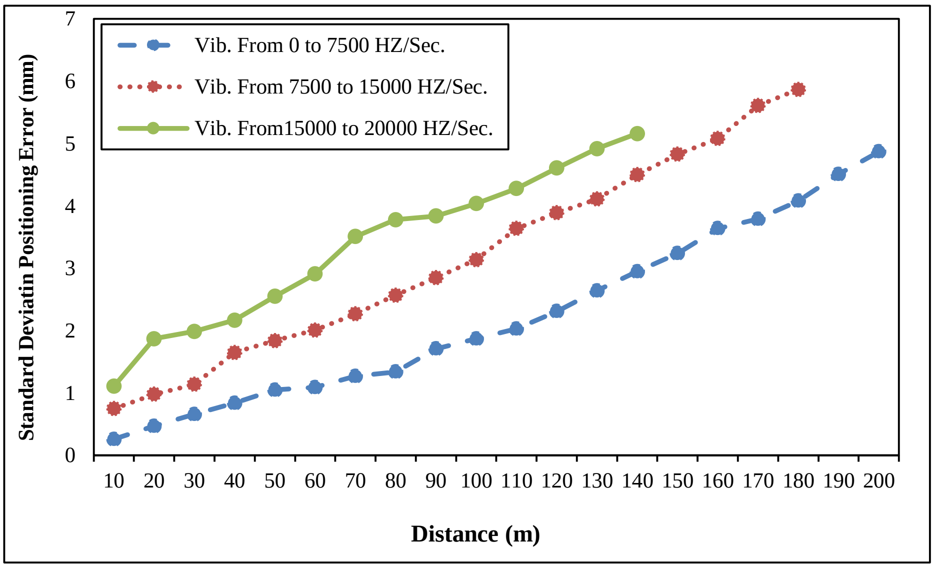

Figure 14. Standard Deviation Error in Positioning (mm) Using Sheet Prism Total Station (SOKKIA SET330RK)

Table 6 shows the values of (average error standard deviation) in Positioning in cased of Total Station with reflector-less prism, which record maximum values (79.95, and 43.41) mm at observed distance 85 m at vibration domain (from7500 to 15000) Hz/sec. when the maximum observed distances (100, 85, and 60) m at the same domains of vibration levels (from 0.0 to 7500, from 7500 to 15000, and from 15000 to 20000), respectively.

Table 6. Average Error in Positioning (mm) and Standard Deviation in Positioning (mm) Using Reflector-less Total Station (SOKKIA SET330RK)

Distance from Instrument to Target (m)	Positioning Observation Error Using Reflector-less Prism (mm)					
	Vibration from 0.0 to 7500 Hz per second		Vibration from 7500 to 15000 Hz per second		Vibration from 15000 to 20000 Hz per second	
	avg.	Std.	avg.	Std.	avg.	Std.
5	2.35	1.16	6.37	3.69	9.36	5.31
10	7.38	3.12	12.67	7.12	14.89	8.34
15	12.87	7.36	16.87	9.31	19.67	11.21
20	18.64	11.39	21.35	12.35	26.34	14.87
25	22.54	13.61	28.67	16.53	37.64	19.87
30	27.89	15.64	33.54	18.04	41.27	22.54
35	28.67	17.35	39.24	21.64	46.71	24.57
40	33.57	20.31	44.87	23.61	53.87	28.61
45	38.62	23.61	49.69	28.12	60.46	32.54
50	40.36	27.34	53.48	30.05	64.97	36.54
55	44.38	29.38	58.6	32.51	70.05	38.57
60	48.75	31.08	60.37	34.38	77.98	41.54
65	51.68	34.02	66.51	36.04	------	------
70	54.89	36.35	70.01	38.62	------	------
75	57.89	38.27	74.39	39.25	------	------
80	60.57	40.05	77.62	41.06	------	------
85	63.54	43.64	79.95	43.41	------	------
90	66.87	45.05	------	------	------	------
95	69.34	46.37	------	------	------	------
100	70.87	48.08	------	------	------	------

Figures 15 and 16 show the variation of (average error standard deviation) in Positioning in cased of Total Station with reflector-less prism in which the changes in both average error and standard deviations in observed distances from 5 to 35 m are approx. close. while the average error standard deviation recorded their highest levels in case of applying vibration domain (from7500 to 15000) Hz/sec.

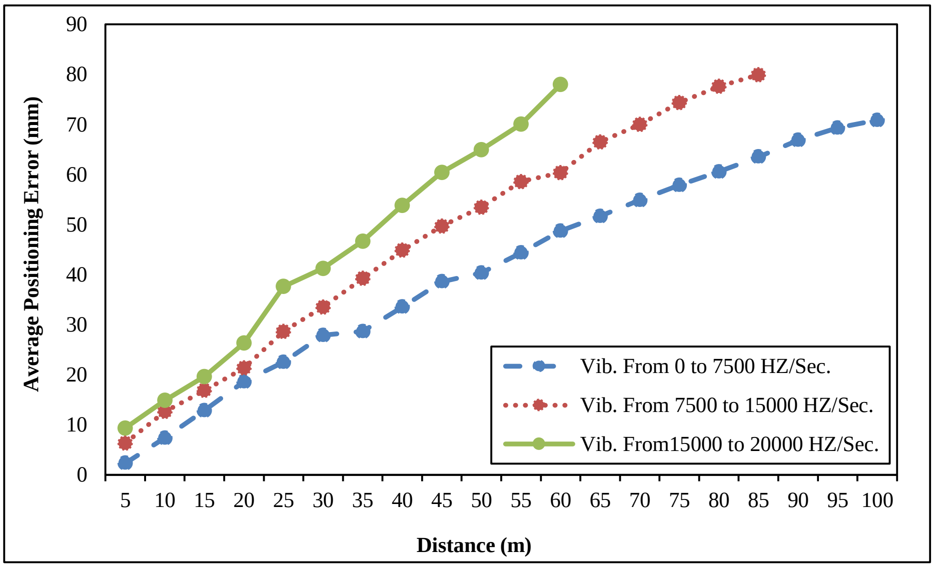

Figure 15. Average Error in Positioning (mm) Using Reflector-less Total Station (SOKKIA SET330RK)

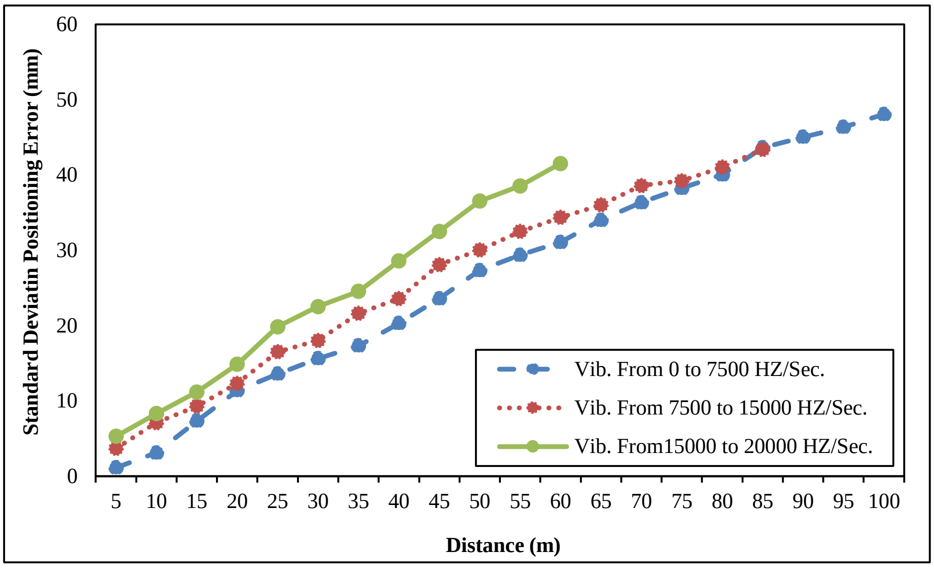

Figure 16. Standard Deviation Error in Positioning (mm) Using Reflector-less Total Station (SOKKIA SET330RK)

6. Conclusions

- The higher the vibration levels the higher average errors and standard deviation of observations of both Digital level and Total Station.
- The maximum distances from Digital level to bar code staff with applying (i.e. from 0.0 to 7500, from 7500 to 15000, and from 15000 to 20000) Hz/sec levels of vibrations were (100,90, and 80) m, respectively.
- The maximum, average, and standard deviation error in elevation signified (44, 36.89, and 18.26) mm with 80 m between the instrument and bar code staff when applying the Digital level at vibration levels (from 15000 to 20000) Hz/sec of vibration all at distance 80 m.
- The influences of vibration on the Total Station in case of reflector-less is more than the ordinary prism or sheet prism.
- The maximum distances measured by the Total station with ordinary reflector prism, sheet prism, and reflector-less prism were (i.e. 750, 140, and 60) m with standard deviation (i.e. 4.02, 5.16, and 41.51) mm when applying vibrations (from 15000 to 20000) Hz/sec, respectively.

7. Conflicts of Interest

The authors declare no conflict of interest.

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