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A Comparative Analysis of Slope Height Using Simple Methods

Basit Yöntemlerle Şev Yüksekliğinin Karşılaştırmalı Analizi

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Abstract
Analysis of slope stability is crucial for the design of many engineering processes such as open pit mine and highway. Slope stability is generally evaluated by limit equilibrium and numerical analyses, and rock mass classification systems. The slope height is used as the input parameter in many of these methods. Advanced methods such as LiDAR and TLS are expensive and time consuming and they require professional use. Therefore, researchers generally need to use simple methods for the measurement of slope height because of their cheapness, rapidity and portability. In this study, height of the rock slopes was determined with tape line, laser meter, altimeter, clinometer and geological compass. Measurements were taken from steep (90°) and inclined slopes (75°). Further, various models were developed in the laboratory for understanding the mechanism of methods in inclined slopes (45°–90°). The findings of methods used compared with each other and the reliability of the methods was discussed. Strengths and weakness of the methods were highlighted. This study indicated that some factors (measurement distance, slope width, the inclination of the ground, rugged surface in toe of the slope, etc.) can negatively affect the estimations of slope height.

Keywords: Altimeter, Clinometer and compass, Height of slope, Laser meter, Tape line

Öz
Şev duraylılık analizi açık işletme ve karayolu gibi birçok mühendislik işlemlerinin tasarımı için çok önemlidir. Şev duraylılığı genellikle limit denge ve sayısal analizler ile kaya kütlesi sınıflama sistemleri kullanılarak değerlendirilmektedir. Şev yüksekliği bu yöntemlerin çoğunda girdi parametresi olarak kullanılmaktadır. LiDAR ve TLS gibi ileri yöntemler pahalı ve zaman alıcıdır ve profesyonel kullanım gerektirirler. Bu nedenle, araştırmacılar taşınabilirlikleri, ucuzlukları ve hızlılıkları nedeniyle genellikle şev yüksekliğinin belirlenmesinde basit yöntemlere ihtiyaç duyarlar. Bu çalışmada kaya şevlerinin yüksekliği şerit metre, altimetre, lazer metre, klinometre ve jeolog pusulası ile belirlenmiştir. Ölçümler dik (90°) ve eğimli şevlerden (75°) alınmıştır. Ayrıca, eğimli şevlerde (45°–90°) yöntemlerin mekanizmasını anlamak için laboratuvarda çeşitli modeller geliştirilmiştir. Kullanılan yöntemlerin bulguları birbiriyle kıyaslanmış ve yöntemlerin güvenilirliği tartışılmıştır. Yöntemlerin güçlü ve zayıf yanları vurgulanmıştır. Bu çalışma bazı etkenlerin (ölçüm mesafesi, şev genişliği, zeminin eğimi, şev topuğu önünde engebeli yüzey, vb.) şev yüksekliği tahminlerini olumsuz etkilediğini göstermiştir.

***Anahtar kelimeler**: Altimetre, Klinometre ve Pusula, Şev Yüksekliği, Lazer metre, Şerit metre*

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1. Introduction

Analysis of slope stability is vital for safety design in geotechnical engineering and open-pit mining (Gürocak et al., 2008; Kaya et al., 2015). It can also reduce costs, extend the mine life and decrease the stripping ratio (Bye and Bell, 2001; Karaman et al., 2013). Various methods are performed for the evaluation of the slope stability. Kinematic, limit equilibrium, numerical analyses and rock mass classification systems are widely used by engineers for assessment of slope stability (Barton, 1976; Hoek and Bray, 1981; Bieniawski, 1989; Laubscher, 1990; Alejano et al., 2011; Kanik and Ersoy, 2019). Each method requires different parameters such as internal friction angle, cohesion, seismic force, water pressure, slope dip/dip direction, and slope height, etc.

Slope height is a significant parameter used in the limit equilibrium (Kesimal et al., 2008), numerical analyses (Kadakçı Koca and Koca, 2014), some rock mass classification systems (Karaman et al., 2013; Karaman, 2013) and fuzzy logic system (Mohamed et al., 2012). Kadakcı Koca and Koca (2014) mentioned that slope angle, water saturation, seismic force and slope height are the important parameters that affect the stability of the slopes. Karaman (2013) and Karaman et al. (2013) utilized the Slope Stability Probability Classification (SSPC) system (Hack, 1998) and determined the maximum slope height for design of safe slopes using current height of slopes as an input parameter. Mohamed et al. (2012) performed the fuzzy logic method for the investigation of slope stability and pointed out that the slope height is one of the most significant input parameters.

There are advanced methods such as LiDAR (Light Detection And Ranging) and TLS (Terrestrial Laser Scanning) for the evaluation of slope stability (Bellian et al., 2005, Rosser et al., 2005; Nguyen et al., 2011). However, it is mostly impossible to use the advanced methods which necessitate professional use especially for the preliminary studies of geotechnical works. Further, they are not suitable for daily use in open pit mines and exploration of slopes in the field. Therefore, researchers and appliers generally need to use simple methods for the measurement of slope height because of their simplicity, rapidity and portability. The objective of this study is to conduct a comparative study between various simple methods for obtaining slope height measurements in steep and inclined slopes.

2. Experimental Studies

Height measurements were performed in the Black Sea Region (Ordu and Trabzon Cities), North of Turkey. In this study, measurements were taken from heights of steep slopes (90º) and an inclined slope (75º). While tape line was utilized as a direct method of measurement, laser meter, altimeter, clinometer and geological compass were used as indirect method of measurement (Fig. 1).

Figure 1. Measurement tools used in this study

Tape line is commonly used in discontinuity surveys of rock masses (Jennings, 1970; Priest and Hudson, 1981; ISRM, 1978; Ulusay and Sonmez, 2007). In this study, for the measurements of tape line, one person stands on top edge of slope and other stands by toe of the slope in order to measure height of the slope. As for altimeter method, slope height is calculated from the differences between slope top and toe of the slope readings. Laser meter calculates the slope height based on the geometric relations using the points targeted from top and toe of the slope. Clinometer and geological compass are based on the angular measure (Fig. 2). Measurements were performed for clinometer and compass using the Eqs. 1, 2, respectively. Fig. 3 shows some field studies.

Slope height (H) = (A% + B%) x distance (1)
A% and B% are inclinations in percentage.

Slope height (H) = Tan (B) x distance + observer’s eye height (h) (2)

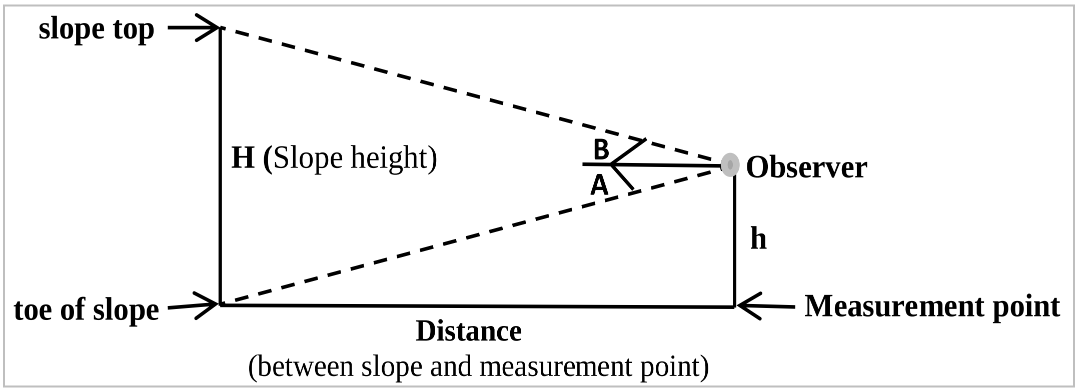

Figure 2. Parameters used in the measurements of clinometer and compass

Measurements were performed from different distances (10, 15 and 20 meters) for more accurate determination of slope height in proper distance. Measurements related to slope 1 were given in Table 1. Laser meter readings were not taken from these distances due to the clear day. Therefore, short distances (2 and 5 meters) were evaluated in order to use laser meter in the measurements of other slopes studied.

Same distances (2 and 5 meters) were taken into account for the slopes given in Table 2. Because measurements of tape line and altimeter were carried out on slope top and toe of the slope, they are independence of distance. Slope heights changes between 2.4 meters to 21.3 meters with tape for steep and inclined slopes.

Table 1. Measurements for slope 1

Slope 1 --- dip angle 90°		
methods		***height, H (m)***
Tape line		**6.3**
Altimeter		8
10 meters	Clinometer	5.7
	Compass	6
15 meters	Clinometer	5.4
	Compass	5.6
20 meters	Clinometer	5.1
	Compass	5.2

Figure 3. Images from different methods used in the field

Table 2. Measurements of slope height taken from standard distances

Dip angle: 90°		**S – 2**	**S – 3**	**S – 4**	**S – 5**	**S – 6**	**S – 7**	**S – 8**	**S – 9**
Distance from the slope	***Methods***	***H (m)***	***H (m)***	***H (m)***	***H (m)***	***H (m)***	***H (m)***	***H (m)***	***H (m)***
	Tape line	**2.4**	**3**	**3.83**	**4.39**	**6.05**	**7.6**	**7.7**	**8.4**
	Altimeter	3	3	4	4	5	8	7	7
2 meters	Laser meter	2.42	3.2	3.98	4.58	5.96	7.67	6.97	7.48
	Clinometer	2.19	2.34	2.72	3.4	3.34	3.44	4.60	4.24
	Compass	2.23	2.81	3.13	4.05	3.43	3.7	5.0	4.73
5 meters	Laser meter	2.95	3.6	4.05	5.23	6.47	7.38	7.39	8.32
	Clinometer	2.15	2.9	3.30	3.8	4.0	4.7	5.80	6.30
	Compass	2.32	2.98	3.50	4.33	4.1	4.8	6.54	5.4

3. Results and Discussion

3.1. Evaluation of Steep Slopes

Measurement of slope heights by different methods for slope-1 is shown in Fig. 4. Slope height value obtained from altimeter tool was higher than that of tape line measurement. Tape line, clinometer and compass measurements were close each other when the distance was 10 meters. As shown in Fig. 4, measurement of slope height may be influenced by distance from measurement point because slope height values derived from the clinometer and compass decreased as distance from measurement point increased.

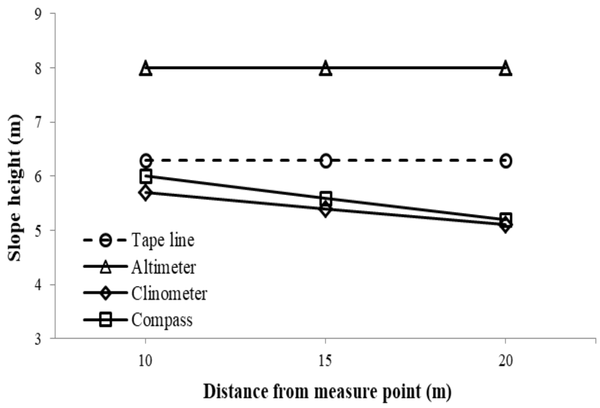

Figure 4. Slope height predicted by different methods (slope 1)

Different methods in the estimation of slope height and distance effects of measuring point (for slopes 2–9) are depicted in Fig. 5. As shown in the figures, compass and clinometer measures give lower values in the estimation of slope height. Altimeter readings are generally consisted with the tape line measures. Different height values were obtained from the laser meter, clinometer and compass tools when distance is changed between the slope and measurement point. This study indicated that the predictions of slope height are affected by distance between measurement point and the slope studied.

The measured (from tape line) versus predicted plots were constructed for tape line and other methods in the estimation of slope height. The error in the estimated height value is represented by the distance that each data point plots from the 1:1 diagonal line (Fig. 6). A point falling on the line in Fig. 6, indicates an exact estimation. Fig. 6 shows the measured and estimated slope heights obtained from different methods. For the altimeter method, the data points fall close to the line at all height values. The laser meter results indicated that the points fall closer to the line for a distance of 2 meters but become a little bit more scattered for a distance of 5 meters from the slopes (Fig. 6b). Two different situations are observed based on the data points for clinometer and compass methods in terms of the current slope heights (< 5 meters and > 5 meters) (Figs. 6c-d). The data points fall closer to the line for the heights of slope less than 5 meters. This shows that the ability to estimate the slope height using the clinometer and the compass methods are the best for the slopes having height less than 5 meters. Further, the points fall closer to the line for a distance of 5 meters for both methods.

The mean absolute percentage error (MAPE) analyses were also performed between measured and the estimated values. Lewis (1982) indicated that the MAPE is the most useful measure to compare the accuracy of the forecasts between different items because it measures relative performance. Based on the MAPE analysis, the lower the percentage errors, and more accurate the forecasts. If the MAPE calculated value is less than 10 %; it is interpreted as “highly accurate forecasting”, between 10–20 % “good forecasting”, between 20–50 % “reasonable forecasting” and over 50 % “inaccurate forecasting”. MAPE analyses indicated that the best estimation capacity was obtained from laser meter method especially for measurement distance of 2 meters (Table 3).

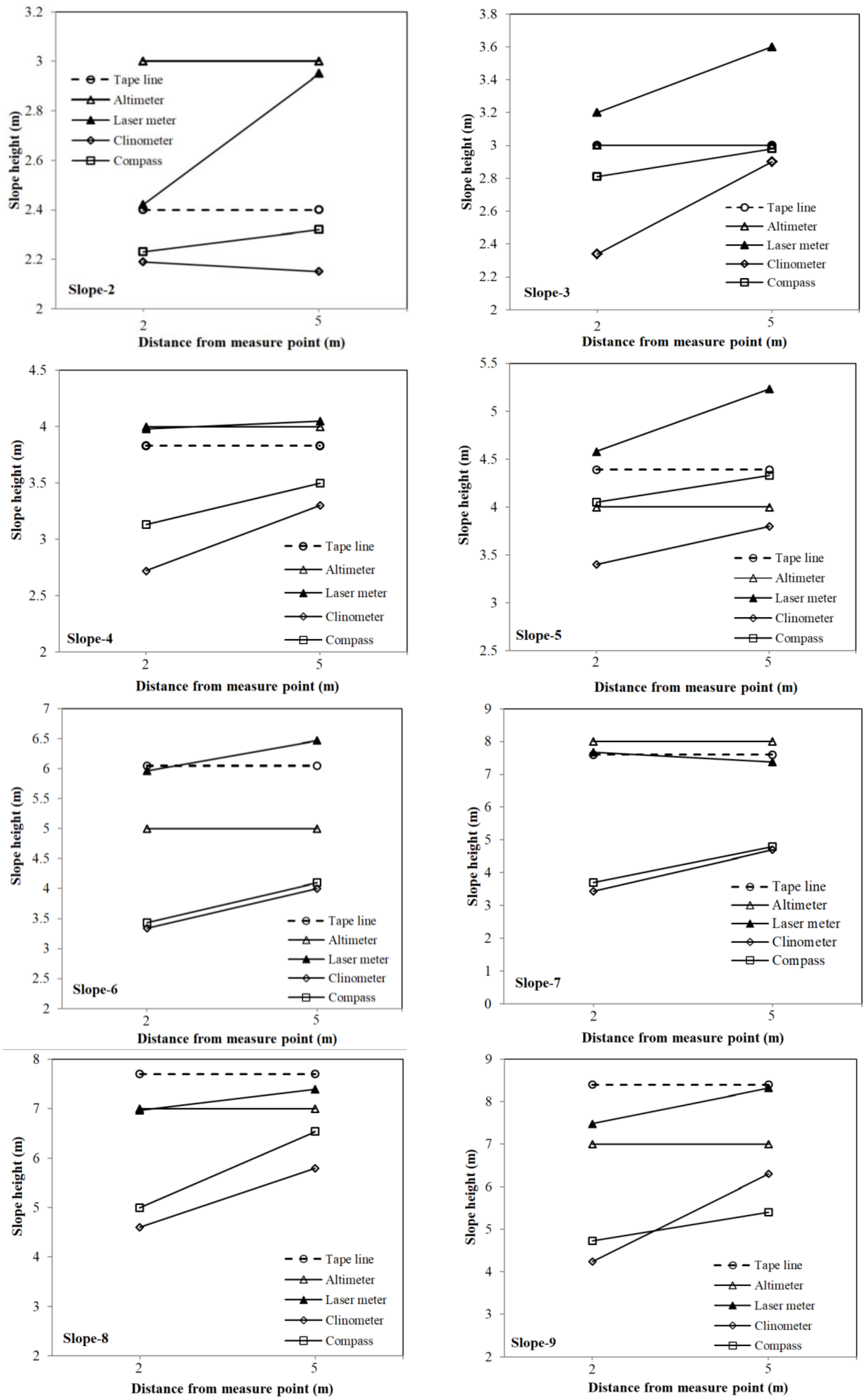

Figure 5. Different methods in the estimation of slope height and distance effect

Table 3. The values of MAPE, and definitions for all slopes

Methods	Distance between slope and measurement point	MAPE %	Definition
Altimeter		10.8	Good forecasting
Laser meter	2 meters	4.8	Highly accurate forecasting
	5 meters	10.3	Good forecasting
Clinometer	2 meters	33.9	Reasonable forecasting
	5 meters	20.3	Reasonable forecasting
Compass	2 meters	26.6	Reasonable forecasting
	5 meters	16.7	Good forecasting

According to the Fig. 6, the plotted points lie close to the 1:1 line implying a good prediction capacity for the slope height < 5 meters when clinometer and compass are used. However, as it is shown in Figs. 6c-d, clinometer and compass were less reliable in the estimation of slope height for > 5 meters. Therefore, MAPE values related to clinometer and compass were calculated again for the slopes < 5 meters height and > 5 meters height (Table 4). Compass became the best tool in terms of the estimation capacity (highly accurate forecasting) for the slopes < 5 meters height based on the Table 4. Methods were evaluated in this study for generally small slopes (< 10 meters height). Therefore, evaluation of slope height for > 5 meters is valid for the slopes < 10 meters height, not all heights.

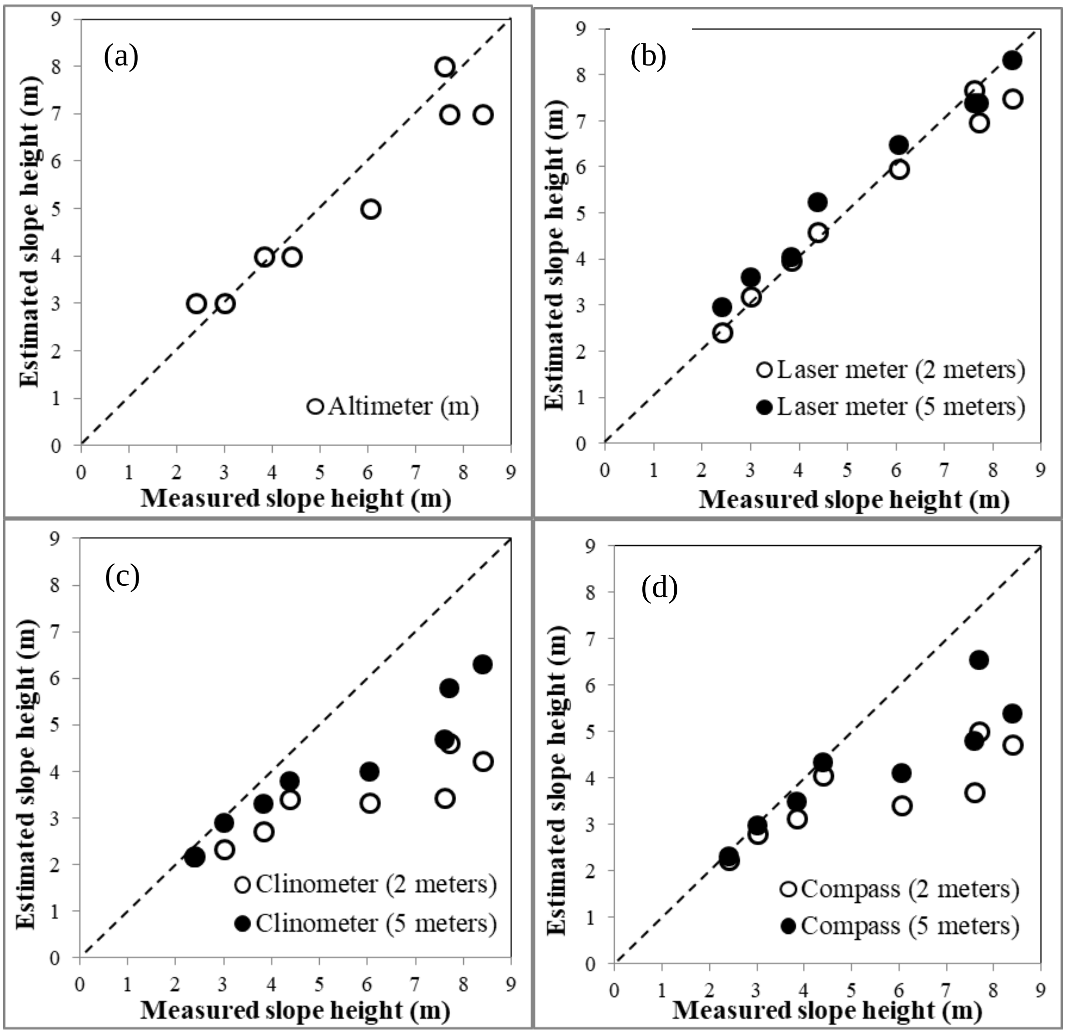

Figure 6. Measured (tape line) and the estimated values obtained from the methods

Table 4. The values of MAPE, and definitions for the slopes < 5 m, and > 5 m

Methods	Distance between slope and measurement point	Slope heights	MAPE %	Definition
Clinometer	2 meters	< 5 meters	20.6	Reasonable forecasting
		> 5 meters	47.3	Reasonable forecasting
Compass	2 meters	< 5 meters	9.9	Highly accurate forecasting
		> 5 meters	43.3	Reasonable forecasting
Clinometer	5 meters	< 5 meters	10.3	Good forecasting
		> 5 meters	30.4	Reasonable forecasting
Compass	5 meters	< 5 meters	3.5	Highly accurate forecasting
		> 5 meters	30.0	Reasonable forecasting

3.2. Understanding the Mechanism of Inclined Slopes

An inclined slope (75°) with the height of 21.3 m was evaluated. Altimeter and laser meter measurements were similar with the tape line survey. However, findings obtained from clinometer and compass methods were quite different from tape line (Table 5). Therefore, different models were developed in the laboratory in order to understand which factors affect the height measurements in inclined slopes (Fig. 7). Different angles (90°, 75°, 60° and 45°) and constant distance (5 m) between the slope bottom and measurement point were used. The results of slope height calculations indicated that all methods were consistent with the results of tape line for the slope dip is 90°. However, predicted slope height decreased with decreasing slope dip from 90° to 45° which was presumably due to the slope width affecting the distance between slope bottom and the measure point. Therefore, lower angle values were obtained from top of slope which is measured by clinometer and compass. Slope width was zero in case of the slope dip is 90°. However, slope width/slope height ratio increased from 0 to 100 % when the slope dip decreased from 90° to 45° (Figure 8a).

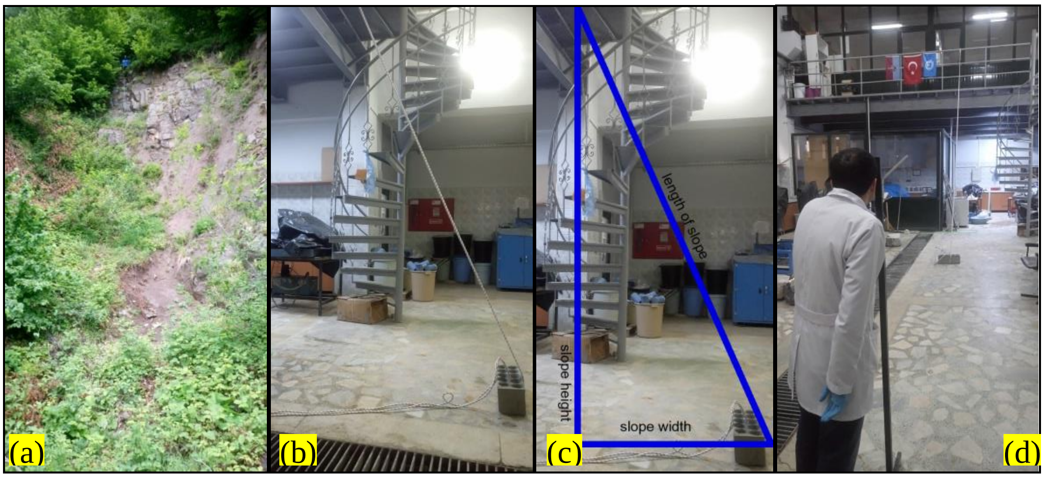

Figure 7. Measurement of inclined surfaces, field (a) and laboratory (b-d)

Table 5. Results of height according to different methods

Methods		**S-10 75°**	**S-10 (corrected) 75°**	**M-1 90°**	**M-2 75°**	**M-3 60°**	**M-4 45°**
Slope width (m)				0	1.3	2.8	4.9
		H (m)	***H (m)***	***H (m)***	***H (m)***	***H (m)***	***H (m)***
Tape line		**21.3**	-	**4.9**	**4.9**	**4.9**	**4.9**
Altimeter		20	-	5	5	5	5
Distance from slope bottom: 5 meters	Laser meter	21.5	23.8	4.8	4.6	3.7	3.4
	Clinometer	13.3	14.6	4.8	4.3	3.9	3.5
	Compass	13.20	14.7	4.8	4.2	3.9	3.5

S-10: Slope-10, M-1, 2, 3 and 4: Models developed in the laboratory

Percentage error (differences) (%) between predicted and measured height values were determined and plotted against slope dip (Figure 8b-d). High correlation coefficients (R^2=between 0.94 and 0.99) between data pairs were obtained for clinometer, compass and laser meter. Similar differences (max: 28–30) were shown for three methods mentioned. In this regard, it is possible to measure the height of slope with the percentage error of about 30 % when the slope dip is 45̊. Therefore, slope height value must be corrected using the percentage error values derived from the equations in Figure 8. Values of slope-10 were corrected based on the percentage error but low height values were obtained compared with those of tape line. This study has shown that there are some factors (slope width, rugged surface, weathered soil/rock at the base of slope-10) affecting the measurements for inclined slopes.

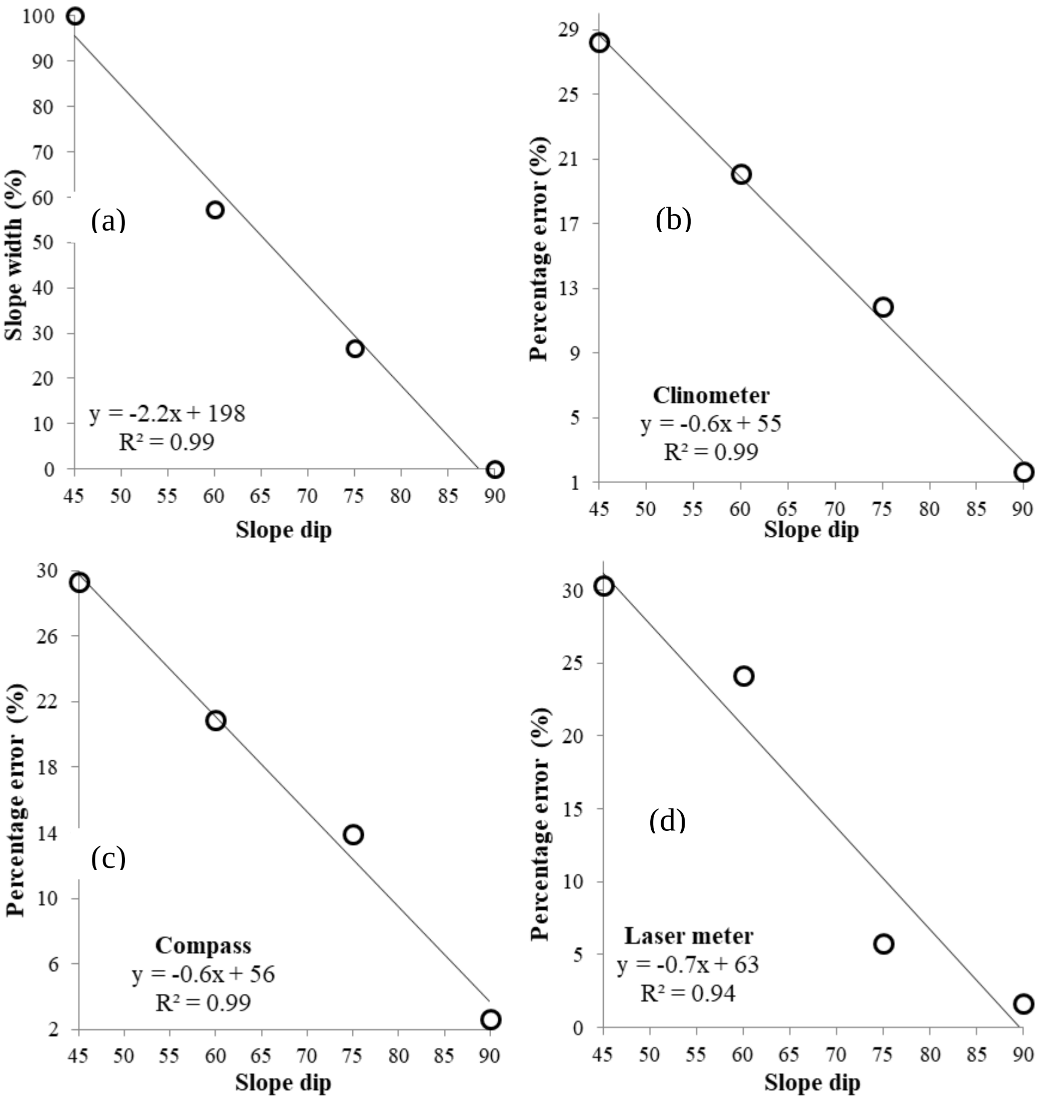

Figure 8. Relationships between slope dip and slope width (a) and percentage error (b – d)

3.3. The Advantage and Disadvantage of the Methods Used

Slope face can be directly measured by the tape line. This method is more suitable for small slopes (< 8 – 10 meters) which haven't risks (failure and rock fall). However, there are some disadvantages of this method; two people are required for the measurements of top and toe of slope. It is dangerous to stand in the bottom of risky slopes. Further, a person may fail to reach top slopes due to the rugged terrain.

One person can perform the altimeter, laser meter, clinometer and compass readings alone. There is no complicated geometric calculation in altimeter method. Measurements are independent of slope dip angle. However, it contains some risks as in the method of tape line because of the topographic conditions.

The laser meter method gives rapid evaluation in the measurements provided that measurement point is near the slope studied (distance less than 10 meters). However, it is not possible to measure from long distance on a clear day.

Clinometer and compass are based on geometric calculations. Because horizontal distance should be calculated between slope and measurement point, second tool is required for measuring such as tape line or laser meter. Measurements are affected by inclined surface and rugged terrain in toe of the slope. Also, the inclination of the ground affects the measurement of distances that is important input parameter used in calculations of height. The results obtained from the laser meter, clinometer and compass methods should be corrected based on the different slope dip.

4. Conclusions and Recommendations

In this study, slope heights were calculated by using different simple methods such as tape line, laser meter, altimeter, clinometer and geological compass. Effect of distance between slope and measurement point on the slope height estimation was also investigated. Although, different findings were obtained from the methods used, altimeter and laser meter methods provided a more accurate estimate of slope height according to the 1:1 line graphs and MAPE analyses in steep slopes. This study revealed that the predictions of slope height are affected by distance between measurement point and the slope studied. While laser meter provided more reliable estimates of slope height at a short distance (2 meters), clinometer and compass methods gives lower MAPE values (more reliable) for the distance of 5 meters. More reliable estimates of slope heights were also obtained using clinometer and compass for the slopes less than 5 meters based on the 1:1 line graphs and MAPE.

If there are some risks that the slopes contain such as rock fall and failures, it can be dangerous measuring with tape line and altimeter methods for a researcher. It may not be possible to measure with laser meter from long distance (> 10 meters) on a clear day. Clinometer and compass measurements are affected by inclined surface and rugged surface in toe of the slope especially for inclined slopes which have slope width. However, a person can perform easily measurements of altimeter, laser meter, clinometer and compass. Laser meter provides rapid evaluation at a short distance. When it comes to short steep slopes that have a smooth surface in front of it, slope height can be determined by using clinometer and compass tools. Further, equations developed in this study can be used for the estimation of slope height in inclined slopes having dip angles from 45° to 90°.

Consequently, this study indicated that the simple methods can utilize for assessing the height of slopes especially for the preliminary geotechnical investigations. However, two simple methods (compass–laser meter, clinometer–altimeter, compass–altimeter, etc.) may be used in order to obtain more accurate evaluation. Further, keep in mind that some factors (measurement distance, slope width, rugged surface in toe of the slope, etc.) can negatively affect the estimations of slope height. Therefore, proper method should be selected considering these factors. It may be remarked that measuring error can be reduced through meticulous attention in the field.

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