Transportation Research Board, 82th Annual Meeting, January 12-16, 2003, Washington, D.C.

Digital Imaging for Screening and Making Measurement of Features on Highway Rock Cuts

Norbert H. Maerz, University of Missouri-Rolla, 1006 Kingshighway, Rolla, MO, 65409-0660, Tel: (573) 341-6714, Fax: 573 341-4368, Email: norbert@umr.edu

Ahmed Youssef, University of Missouri-Rolla, 1006 Kingshighway, Rolla, MO, 65409-0660, Tel: (573) 341-6714, Fax: 573 341-4368, Fax: 573 341-4729, Email: youssef@umr.edu

Qinfang Xiang, University of Missouri-Rolla, 1006 Kingshighway, Rolla, MO, 65409-0660, Tel: (573) 341-6714, Fax: 573 341-4368, Email: xiang@umr.edu

Highway rock cuts must be maintained for the safety of the motoring public. Since highways cover vast areas through differing geological terrains, it is not cost effective to remediate all rock cuts; remediation efforts have to be prioritized. Even doing traditional geological engineering evaluations on all the rock cuts is prohibitive.

Most jurisdictions now use a rock mass classification such as the Oregon Rock Hazard Rating System (RHRS) to streamline the process by quickly classifying rock cuts, rather than evaluating each in detail. The cuts that have the worst score in the classification can then be further evaluated in the traditional way.

This paper demonstrates how further efficiencies can be realized, by using computer scaled video images. Digital video image of entire highways can be acquired at highway speeds. Later using a computer, engineers can review the video, select areas that look like they may be problematic, and plan further investigations at those sites. Additionally, some of the parameters required in the classification systems, such as slope heights and slope angles can be measured directly on the digital images.

A low cost, state-of-the-art system developed to perform these tasks is described here. Typical measurement can be made with errors of less than 10%, which is more than adequate for the purposes of rock mass classification, and estimating rock quantities.

SUBMISSION DATE: JULY 26

WORD COUNT: 3707 + 12*250 = 6707

INTRODUCTION

Identifying and Remediating Problematic Rock Cuts

The safety and convenience of the motoring public demands that highway rock cuts be made as safe as possible, while expenditures on remediation are always limited by available budgets and sometimes shrinking budgets. Catastrophic failures of rock cuts can result in property damage, injury, and even death. Highways impeded by even small spills of rock material are in addition an inconvenience for motorists. Yet simply inspecting all of the rock cuts along a highway system may be prohibitive, let alone remediating all possible problem areas.

Ensuring the stability of highway rock cuts, whether new or old, requires an evaluation of the structure and condition of the rock, to determine the risk of failure as well as identifying the consequence of such failures. The most satisfactory approach to evaluating the condition of large numbers of rock cuts, in a limited time and with limited budgets, is to use a classification system designed for such a purpose (1).

Classification Systems

Classification systems are best for screening rock cuts because they provide the ability to rapidly screen rock cuts and separate out the ones that are fundamentally sound, and identify the ones that have potential problems. Examples of classification systems that are common in the mining and tunneling industries, and described in Singh and Goel (2), and include examples such as Deere's RQD (rock quality designation) system (3), Franklin's Size-Strength system (4), Franklin's Shale Rating System (5), Bieniawski's RMR (rock mass rating) system (6), and Barton Q system (7).

In addition there are several schemes specifically for slopes. An example is Romana's SMR system for rock slopes, based on Bieniawski's RMR system (8). All these examples consider geological factors only, and are essentially classifying risk only. Another system that considers rainfall as well as geological factors is the Rock Engineering System (RES) (9).

The RHRS (Rock Hazard Rating System) is designed specifically for highway cuts in Oregon (10). This system also considers the consequence of failures, classifying such parameters as ditch effectiveness, average vehicle risk, sight distance, and roadway width. This system is however not universally applicable, as it was developed for the rugged mountainous terrain of Oregon with its inherent high cuts, and consequently is insensitive in evaluating hazards from relatively lower rock cuts.

The Ontario RHRON (Rock Hazard Rating ONtario) system is a modification of the Oregon system (11), designed for less mountainous terrains.

Factors to Improve the Efficiency of Classification Systems

While the use of a classification system significantly improves the efficiency of evaluating rock cuts, there are two areas where efficiency improvements can be made, first by identifying which rock cuts need to be assessed using classification systems, and secondly by measuring some of the parameters needed for the system, such as slope height, and angle, ditch width and capacity, etc. The efficiency improvement can be made using digital video imaging of rock cuts and scaled measurements of features on the images.

COMPUTER SCALED VIDEO IMAGES

Introduction

Video images of highway right-of-ways are routinely done for inventorying of highway assets and measurements of such attributes as sign placement (12). These systems are usually complex and expensive requiring complicated vehicle instrumentation, but may have very precise measurements.

For this project a system was developed using state of the art but inexpensive off the shelf hardware and purpose designed software. The goal was to make a cost effective system that can be used to preview road cuts, and to make simple measurements, where extreme accuracy and precision are not required.

Video Preview

The concept of using video images is simple. Video images can be taken at highway speeds by technicians, digitally recorded, and evaluated back in the office by the engineer or geologist. The engineer or geologist can quickly select the areas where stability may be an issue, and pick locations for site evaluations, preparing hard copies of images to take to the field to facilitate the identification of problem areas. Figure 1 shows the hardware setup, which consists of a digital camera mounted on the dash of a vehicle. Figure 2 shows and example of a video image, with GPS coordinated generated by a simple hand-held GPS device.

The digital video is recorded on mini-DV tapes, and transformed to avi files using commercially available software such as Adobe Premiere®. The avi files are then loaded into the AVI viewer, and individual rock cuts can be viewed (Figure 3). Areas that appear problematic can be identified for later detailed analysis. Hardcopies of images of problematic areas can be printed to be used as references in the field.

Video Measurements

Measurements can be made on single images without extensive vehicle instrumentation and modifications. Although not as accurate as manual measurements in the field, the measurements are more than accurate enough for the purposes of providing input data for rock hazard rating system.

The system simply requires a simple camera setup, scale calibration, and appropriate identification of measurement object endpoints.

Camera Setup

The camera setup consists simply of vertical and horizontal alignment of the camera, and setting the zoom factor on the lens.

Vertical alignment and zoom factors are set in tandem, to ensure that the picture encompasses the top of typical road cuts as well as the plane of the highway. Typically the alignment is near horizontal, or pointing slightly up, with the zoom set to a fairly wide angle, but not so wide as to include the hood of the vehicle in the image.

Horizontal alignment should be set to about 10º to the left of the direction of travel. This is best accomplished by stretching a tape measure 100' in the direction of travel, stretching a second tape measure 17.6' at 90º and to the left, placing a vertical object, and centering the camera on that object (Figure 4).

Calibration

Scale calibration is required. This can be done by taking an image such as in Figure 5, with a scaling object in the image. The portion of the image that the scaling is valid for is defined by a vertical plane, perpendicular to the camera vector, and that passes through the point defined by the painted white road edge line and the vertical dotted line that is arbitrarily placed 1/3 of the way into the image from the left hand side. This scale remains constant for that position in all images, but makes the assumption that the roadway is straight between the vehicle and the plane of measurement.

Alternatively, the road width if constant can be used as a scaling object. This allows measurements to be made in a vertical plane perpendicular to the camera vector, anywhere in the image.

Measurements

Measurements that can be made include slope heights, lengths, and angles; ditch widths, depths, and volumes; mass volumes; and other linear measures. Measurements all need to be made within a "measurement plane" as described below.

Guide and Reference Lines

When an image is loaded, the yellow vertical line 1/3 of the way across the image is automatically drawn in (Figure 5). The user selects the "HOT LINE" option and clicks on the intersection of the vertical yellow line and the painted white road edge line. This puts in place a horizontal dashed line that with the vertical dashed line defines the measurement plane (Figure 5). Figure 6 defines the measuring concept.

At any time the user can select the "VER. LINE" option and put an additional vertical line in the measurement plane, for instance to define the edge of a rock face. If the ditch measurements or slope heights are required, a ditch reference line to define the outside edge of the ditch.

Scale Calibration

Scale calibration is done in one of two ways. If a scale is entered in the measurement plane as anchored by the intersection of the vertical yellow dashed line and the painted white road edge line, this scale is valid in all images as long as the plane measurement in each case is anchored on the white edge line, and the camera tilt, pan, and zoom is not changed since the calibration was entered.

The scale can also be determined at different points on an image (Figure 7). It is important to note, only the scale anchored on the painted white road edge line can be carried forward to another frame.

Slope Measurements

Slope measurements (in the measurement plane) consist of measuring the height and slope face length (if not vertical) and using a trigonometric relationship to calculate the slope angle (Figure 6).

Ditch Measurements

Ditch measurements (in the measurement plane) consist of measuring the width and the depth of the ditch (Figure 6). Ditch volumes per linear foot are calculated by using one of three models for calculating the cross sectional area of the ditch: Rectangle, triangle, or terrace (trapezoid).

Rock Volume Measurements

Measurements of rock volumes, for instance volumes of loose rock, can be estimated by measuring, on a vertical slope (in the measurement plane), the height of loose blocks, and the width of loose blocks close to the proximity of the measurement plane. The depth of loose rock must be estimated, and with that the volume of loose rock can be predicted.

Other Linear Measurements

Any other linear measurements (in the measurement plane) can be made at any time. This includes lane and shoulder widths, and heights of objects at the side of the road, such as retaining walls.

RESULTS OF TEST MEASUREMENTS

A series of test measurements were conducted to evaluate the effectiveness of the measuring system.

Manual Measurements

To test the measuring system, 17 locations were selected along state highways, and manual measurements of measurements of road widths, ditch widths and depths, and slope heights and angles were conducted using tape measures, measuring rods, and a range-finding clinometer (Figure 8).

Image Measurement Results

Results of imaging measurements are shown in Figures 9-12. Errors, defined as the percentage difference between manual and image measurements, on average were found to be less than 10%.

The following is the average error for each type of measurement:

Ditch Width	6.0%
Ditch Depth	8.6%
Slope Length	4.2%
Slope Angle	2.7%
Cliff Height	3.9%
Shoulder Width	7.6%
Road Width	2.7%

Measurements do have a high variability, with a few errors above 10%, and occasional errors of up to 30-40% when for instance miss-locating the edge or the bottom of a ditch due to the obscuring effect of vegetation.

CONCLUSIONS

Digital imaging can be use to screen highway rock cuts to identify which cuts need further attention. Furthermore, measurements needed for classifying rock cuts can be made using scaled video images.

Research has shown that the measurements can be made with sufficient accuracy for the purposes of rock mass classification and for estimating loose rock quantities or ditch capacities.

ACKNOWLEGEMENTS

The authors would like to acknowledge the University of Missouri System Research Board for funding of this research. We would also like thank Ray Purvis, Mike Fritz, and Rob Lauer of the Missouri Department of Transportation (MODOT) for their help in providing guidance for this project.

REFERENCES

1. Maerz, N. H. Highway Rock Cut Stability Assessment In Rock Masses Not Conducive to Stability Calculations. Proceedings of the 51st Annual Highway Geology Symposium, Aug. 29-Sept. 1, Seattle, Washington, 2000, pp. 249-259.
2. Singh, B. And Goel, R. K. Rock Mass Classification. A Practical Approach in Civil Engineering: Elsevier, 1999, 267 pp.
3. Deere, D. U., Merritt, A. H., And Coon, R. F. Engineering Classification of In Situ Rock: Air Force Systems Command, Kirtland Air Force Base, Report AFWL-64-144, 1969.
4. Franklin, J. A. Size-Strength System for Rock Characterization: Proceedings of the Symposium of Rock Characterization to Mine Design, American Society of Mining Engineers Annual Meeting, 1986, pp. 11-16.
5. Franklin, J. A. Evaluation of Shale's For Construction Projects – An Ontario Shale Rating System: Research Report RR229, Ontario Ministry of Transport and Communication, 1983, 99 pp.
6. Bieniawski, Z. T. Rock Mechanics Design in Mining and Tunneling: A. A. Balkema, 1984.
7. Barton, N. M., Lien, R., and Lunde, J. Engineering Classification of Rock Masses for the Design of Tunnel Support: Rock Mechanics 6, 1974, pp. 189-236.
8. Romana, M. New Adjustment Ratings for Application of Bieniawski Classification to Slopes: International Symposium on the Role of Rock Mechanics, Zacatecas, 1985 pp. 49-53.
9. Ali, K. M, and Hasan, K. Rock Mass Characterization to Indicate Slope Instability at Bandarban, Balgladesh: A Rock Engineering Systems Approach. Environmental & engineering Geoscience, vol. VIII, No. 2, 2002, pp. 105-119.
10. Pierson, L. A., and Van Vickle, R. Rockfall Hazard Rating System – Participants' Manual: FHWA Report – FHWA-SA-93-057, 1993, 102 pp.
11. Franklin, J. A., And Senior, S. A. Outline of RHRON, the Ontario Rockfall Hazard Rating System: Proceedings International Symposium on Engineering Geology and the Environment, Athens, Greece, 1987, pp. 647-656.
12. Maerz, N. H., and McKenna, S. Mobile Highway Inventory and Measurement System. Transportation Research Record No. 1690, 1999, pp. 135-142.

LIST OF TABLES AND FIGURES

FIGURE 1 Digital camcorder mounted on vehicle dashboard.

FIGURE 2 Video frame with overlain GPS coordinates, heading, speed, time, and date.

FIGURE 3 AVI player interface.

FIGURE 4 Aiming the camera at an angle of 10º to the left of the direction of travel vector.

FIGURE 5 Calibration of scale using a vertical scaling device. (This calibration is valid only in the vertical plane defined by the horizon dotted yellow line.) This calibration is valid in any image, in the plane anchored by the yellow vertical line and the white edge line of the road.

FIGURE 6 Plane of measurement concept.

FIGURE 7 Multiple planes of measurement on a single image.

FIGURE 8 Manual measurements of road widths, ditch widths and depths, and slope heights and angles.

FIGURE 9 Test results for test #1

FIGURE 10 Error results for test #1

FIGURE 11 Test results for test #2

FIGURE 12 Error results for test #2

FIGURE 1 Digital camcorder mounted on vehicle dashboard.

FIGURE 2 Video frame with overlain GPS coordinates, heading, speed, time, and date.

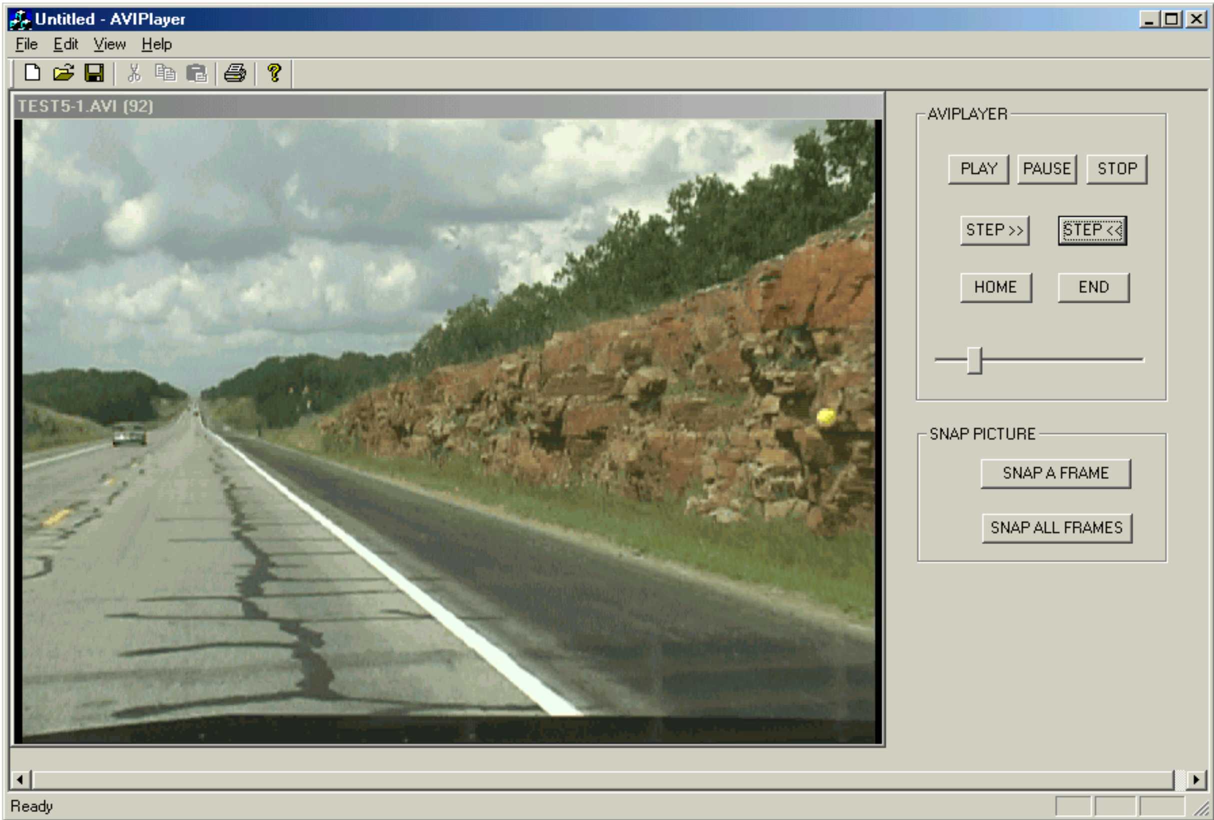
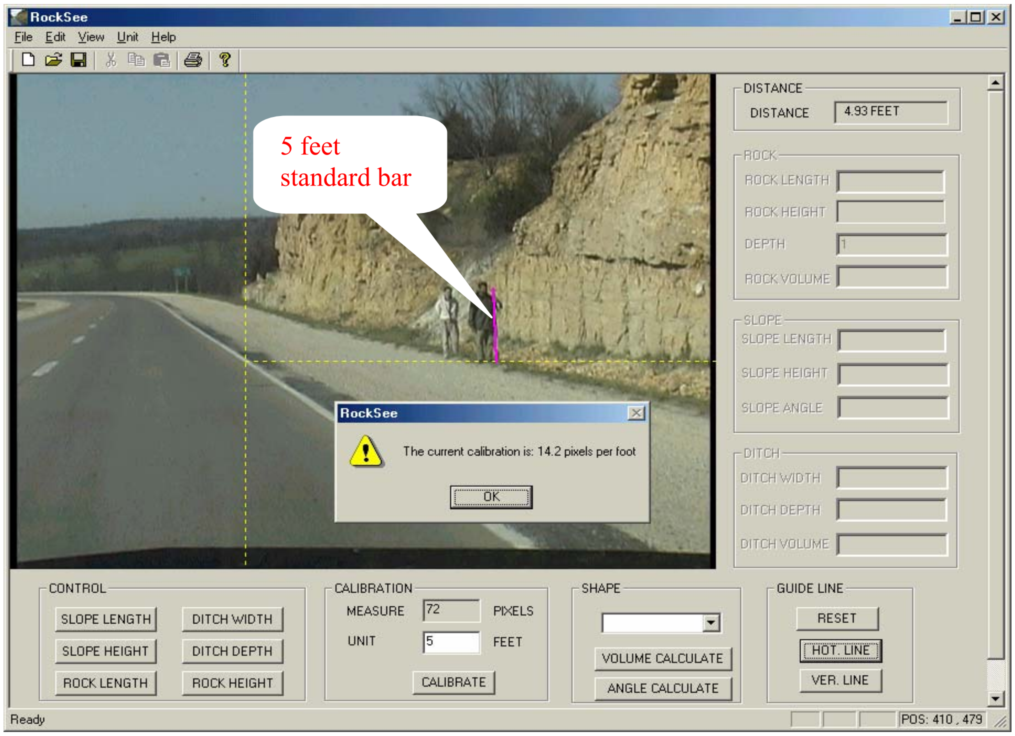


FIGURE 3 AVIPlayer interface.


FIGURE 4 Aiming the camera at an angle of 10º to the left of the direction of travel vector.



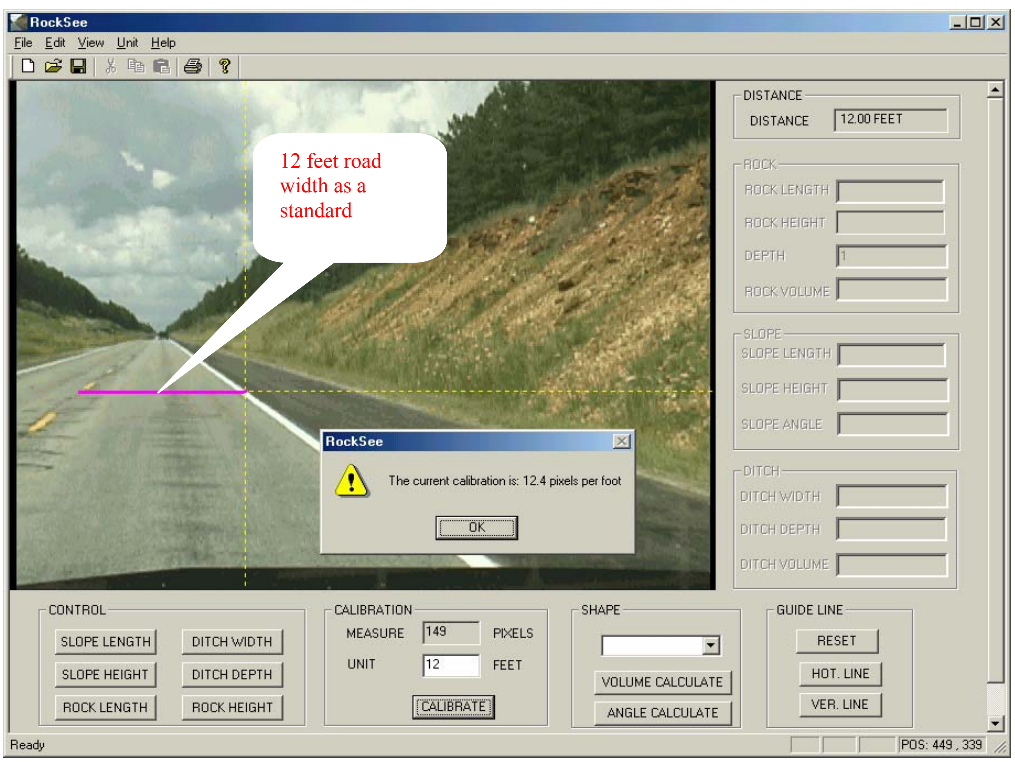


FIGURE 5 Calibration of scale using a vertical scaling device (top). (This calibration is valid only in the vertical plane defined by the horizon dotted yellow line.) This calibration is valid in any image, in the plane anchored by the yellow vertical line and the white edge line of the road. Bottom: Calibration of scale using road width.

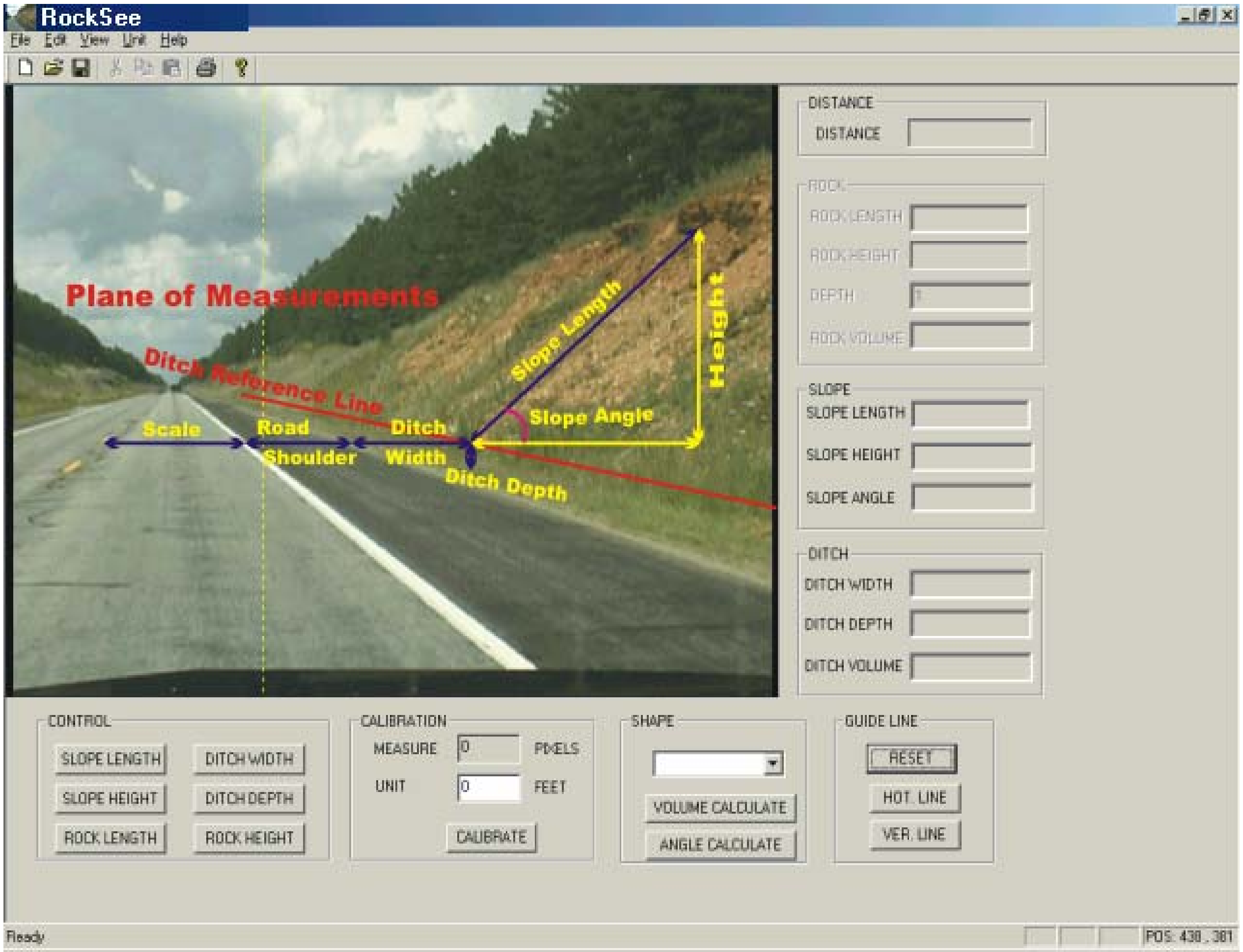


FIGURE 6 Plane of measurement concept.

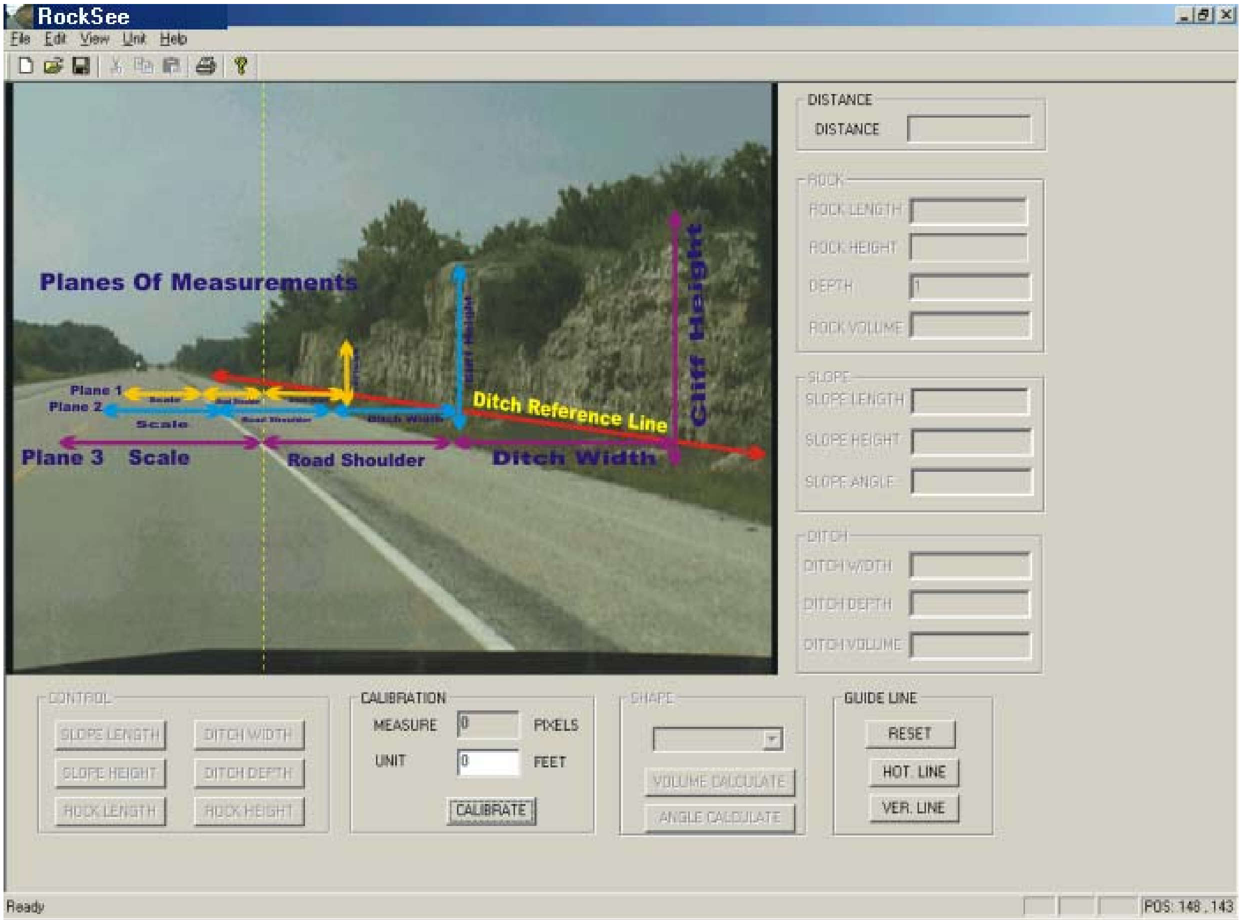


FIGURE 7 Multiple planes of measurement on a single image.

FIGURE 8 Manual measurements of road widths, ditch widths and depths, and slope heights and angles.

Location		Ditch Width (m)	Ditch Depth (m)	Cliff Height (m)	Road Shoulder (m)	Road Width (m)	Comments
Location 1	Actual	4.26	0.61	3.65	4.26	3.65	// Image 15, Calibration 14.2 pixel/foot
	Pass 1	4.15	0.61	3.51	4.18	3.81	
	Pass 2	4.02	0.58	3.54	4.11	3.69	
	Pass 3	4.20	0.60	3.60	4.21	3.70	
	Ave.	4.12	0.60	3.55	4.17	3.73	
	Error %	3.28	1.64	2.74	2.11	2.19	
Location 2	Actual	4.78	0.52	5.79	4.87	3.65	//Image 75
	Pass 1	4.84	0.58	5.88	3.69	3.35	
	Pass 2	4.90	0.51	5.85	3.60	3.51	
	Pass 3	4.78	0.53	6.10	3.81	3.60	
	Ave.	4.84	0.54	5.94	3.70	3.49	
	Error %	1.25	3.84	2.59	24.02	4.38	
Location 3	Actual	4.87	0.67	3.65	3.65	3.65	// Image 119
	Pass 1	5.24	0.64	3.44	3.29	3.75	
	Pass 2	4.87	0.64	3.35	3.50	3.65	
	Pass 3	5.15	0.64	3.44	3.63	3.51	
	Ave.	5.08	0.64	3.41	3.47	3.64	
	Error %	4.31	4.47	6.57	4.93	0.27	
Location 4	Actual	4.57	0.46	6.10	4.42	3.65	// Image 159
	Pass 1	5.04	0.61	5.24	3.35	3.41	
	Pass 2	4.87	0.64	5.73	3.65	3.51	
	Pass 3	4.75	0.65	5.42	3.75	3.47	
	Ave.	4.89	0.63	5.46	3.58	3.46	
	Error %	7.00	36.95	10.49	19.00	5.20	
Location 5	Actual	4.26	0.55	5.49	4.42	3.65	//Image 214
	Pass 1	4.18	0.54	5.52	4.81	3.69	
	Pass 2	4.08	0.49	5.73	4.24	3.78	
	Pass 3	4.14	0.58	5.61	4.51	3.65	
	Ave.	4.26	0.54	5.62	4.52	3.71	
	Error %	0.00	1.81	2.36	2.26	1.64	

FIGURE 9 Test results for test #1

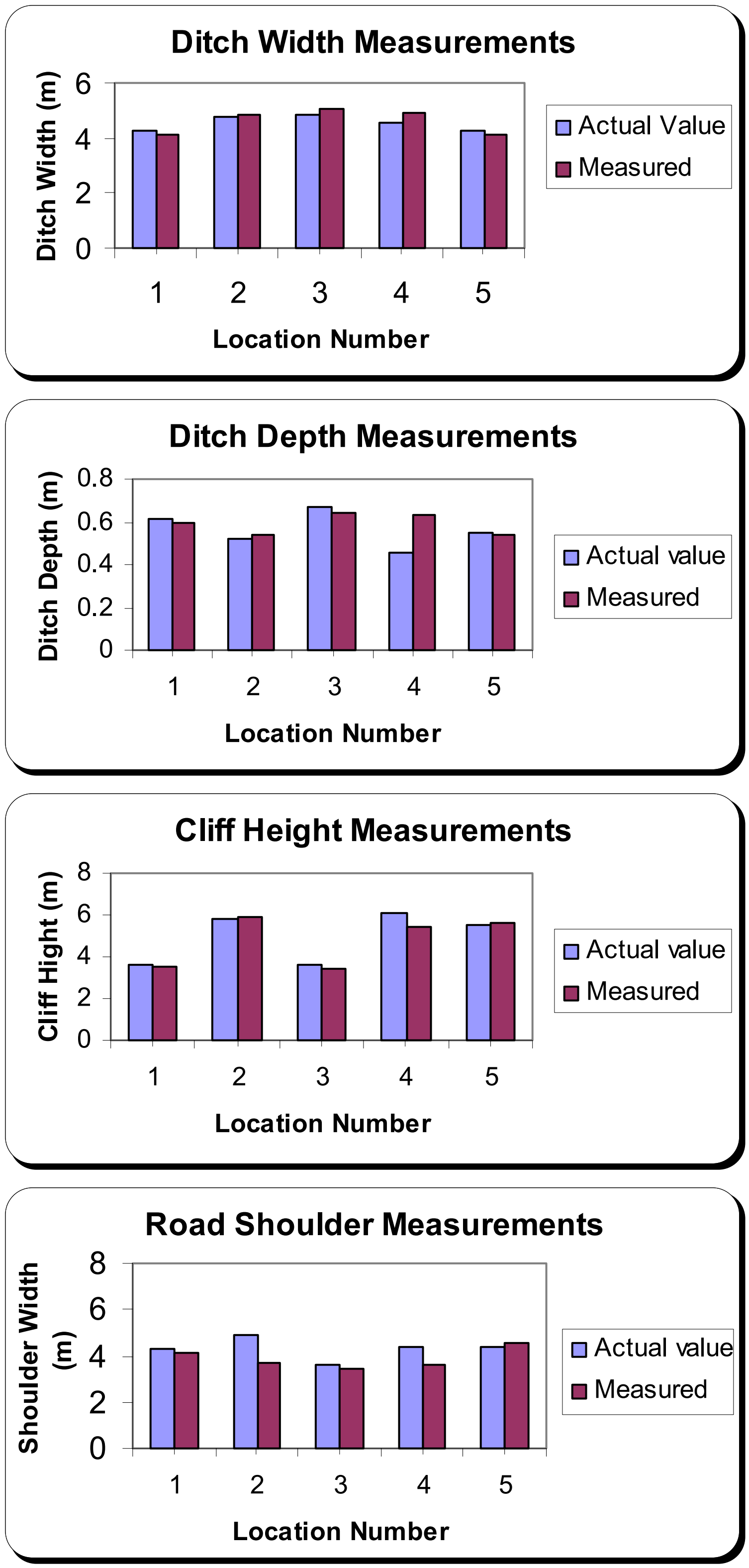


FIGURE 10 Error results for test #1

Location		Ditch Width (m)	Ditch Depth (m)	Slope Length (m)	Slope Angle (Degree)	Cliff Height (m)	Shoulder (m)	Commentes
Location 1	Actual	3.96	0.49	7.01	65	N/A	3.05	//Image 18
	Pass 1	3.94	0.67	6.82	67.5	N/A	3.38	
	Pass 2	3.60	0.55	6.54	65.7	N/A	3.21	
	Pass 3	4.00	0.58	7.00	65.8	N/A	3.60	
	Ave.	3.85	0.60	6.79	66.3	N/A	3.40	
	Error %	2.77	22.44	3.13	2	-	11.47	
Location 2	Actual	1.98	0.46	N/A	N/A	6.40	3.05	//Image 57, 14pixels/foot
	Pass 1	2.04	0.44	N/A	N/A	6.51	2.90	
	Pass 2	2.12	0.48	N/A	N/A	6.39	2.97	
	Pass 3	2.00	0.52	N/A	N/A	6.61	3.02	
	Ave.	2.05	0.48	N/A	N/A	6.50	2.96	
	Error %	3.53	4.34	-	-	1.56	2.95	
Location 3	Actual	2.29	0.46	N/A	N/A	3.96	3.14	// Image 92 17.2 pixels/foot
	Pass 1	2.40	0.48	N/A	N/A	4.13	3.02	
	Pass 2	2.43	0.44	N/A	N/A	4.21	3.03	
	Pass 3	2.28	0.46	N/A	N/A	4.15	3.00	
	Ave.	2.37	0.46	N/A	N/A	4.16	3.02	
	Error %	3.49	0.00	-	-	5.05	3.82	
Location 4	Actual	2.59	0.30	8.84	42.0	N/A	3.35	// Image 129 10.8 pixels/foot
	Pass 1	2.66	0.34	8.79	44.7	N/A	2.95	
	Pass 2	2.58	0.36	9.60	45.0	N/A	2.98	
	Pass 3	2.62	0.31	9.12	44.3	N/A	3.01	
	Ave.	2.62	0.34	9.17	44.6	N/A	2.98	
	Error %	1.15	13.33	3.73	6.19	-	11.04	
Location 5	Actual	2.74	0.30	6.40	40	N/A	3.20	//Image 181 11.8 pixels/foot
	Pass 1	2.67	0.36	6.34	39.3	N/A	3.09	
	Pass 2	2.46	0.35	6.45	39.7	N/A	3.09	
	Pass 3	2.64	0.32	6.37	39.4	N/A	3.13	
	Ave.	2.59	0.34	6.39	39.4	N/A	3.10	
	Error %	5.47	13.33	0.15	1.5	-	3.12	
Location 6	Actual	3.35	0.37	7.62	41.0	N/A	3.20	//Image 231 11.0 pixels/foot
	Pass 1	2.97	0.39	7.37	40.3	N/A	2.72	
	Pass 2	3.12	0.41	7.45	41.3	N/A	2.98	
	Pass 3	3.02	0.37	7.39	40.7	N/A	3.13	
	Ave.	3.04	0.39	7.40	40.8	N/A	2.94	
	Error %	9.25	5.40	2.88	0.48	-	8.12	

Location		Ditch Width (m)	Ditch Depth (m)	Slope Length (m)	Slope Angle (Degree)	Cliff Height (m)	Shoulder (m)	Comments
Location 7	Actual	3.05	0.46	4.88	45.0	N/A	3.05	// Image 274 14.2 pixels/foot
	Pass 1	2.25	0.50	4.22	43.4	N/A	2.98	
	Pass 2	2.35	0.47	4.43	44.2	N/A	3.04	
	Pass 3	2.46	0.52	4.54	43.7	N/A	3.11	
	Ave.	2.35	0.49	4.40	43.8	N/A	3.04	
	Error %	22.9	6.52	9.83	2.66	-	0.32	
Location 8	Actual	2.13	0.61	N/A	N/A	3.65	3.35	//Image 308 16.9 pixels/ foot
	Pass 1	2.39	0.63	N/A	N/A	3.92	3.10	
	Pass 2	2.42	0.66	N/A	N/A	3.82	3.05	
	Pass 3	2.36	0.64	N/A	N/A	3.76	3.14	
	Ave.	2.39	0.64	N/A	N/A	3.83	3.10	
	Error %	12.20	4.91	-	-	4.93	7.46	
Location 9	Actual	2.13	0.52	N/A	N/A	7.01	3.35	// Image 360 13.5 pixels/foot
	Pass 1	2.35	0.52	N/A	N/A	6.39	3.05	
	Pass 2	2.29	0.52	N/A	N/A	6.33	3.15	
	Pass 3	2.27	0.51	N/A	N/A	6.41	3.12	
	Ave.	2.30	0.52	N/A	N/A	6.38	3.11	
	Error %	7.98	0.00	-	-	8.98	7.16	
Location 10	Actual	1.98	0.61	N/A	N/A	6.25	3.50	// Image 408 14.5 pixels/foot
	Pass 1	2.02	0.63	N/A	N/A	6.24	3.00	
	Pass 2	2.12	0.66	N/A	N/A	6.20	3.12	
	Pass 3	2.00	0.61	N/A	N/A	6.21	3.07	
	Ave.	2.05	0.63	N/A	N/A	6.22	3.06	
	Error %	3.53	3.27	-	-	0.48	12.5	
Location 11	Actual	2.44	0.61	N/A	N/A	5.64	3.05	//Image 452 14.9 pixels/foot
	Pass 1	2.65	0.63	N/A	N/A	5.29	2.96	
	Pass 2	2.61	0.63	N/A	N/A	5.64	3.05	
	Pass 3	2.41	0.60	N/A	N/A	5.42	2.94	
	Ave.	2.56	0.62	N/A	N/A	5.45	2.98	
	Error %	4.91	1.63	-	-	3.36	2.29	
Location 12	Actual	2.29	0.76	N/A	N/A	9.15	3.35	// Image 483 11.0 pixels/foot
	Pass 1	2.12	0.64	N/A	N/A	8.64	3.21	
	Pass 2	2.17	0.66	N/A	N/A	8.68	3.09	
	Pass 3	2.21	0.71	N/A	N/A	8.58	3.14	
	Ave.	2.17	0.67	N/A	N/A	8.63	3.15	
	Error %	5.24	11.84	-	-	5.68	5.97	

FIGURE 11 Test results for test #2

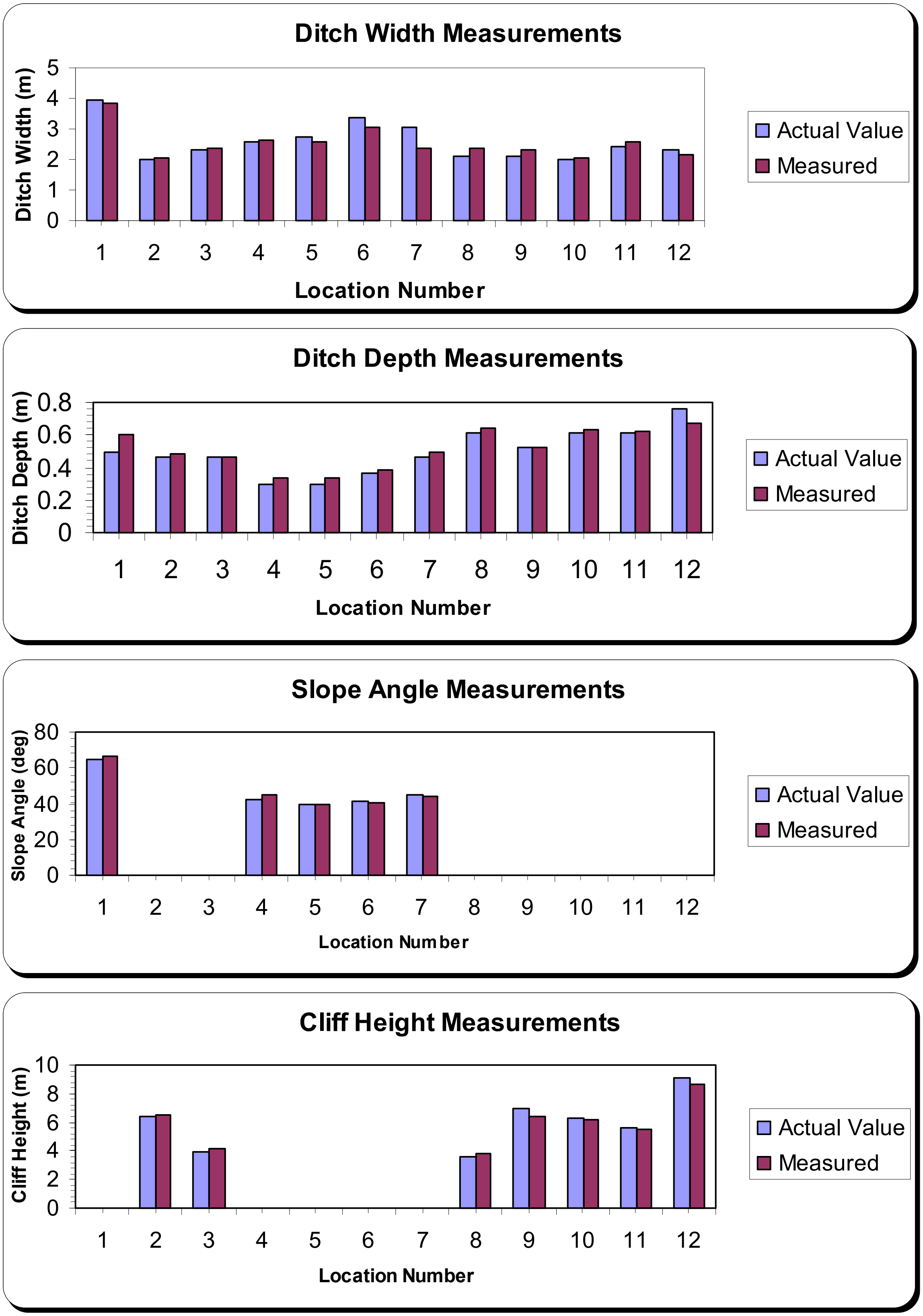


FIGURE 12 Error results for test #2.