

Recent Developments in Close Range Photogrammetry (CRP) for Mining and Reclamation

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Preface

- This talk is a follow-on to my paper in this Conference's Proceedings. For that paper, the photos used for CRP were collected randomly and only to document a large project. Regardless, results were impressive.
- For this talk, the photos were taken with CRP in mind. Lacking experience and climbing the “learning curve” resulted in LOTS of photos - mostly worthless – but results continue to impress.
- I am NOT an expert in CRP and look forward to collaborating with true experts like Matthews (2009) to refine techniques to make CRP practical for mining and reclamation, especially SMCRA workers.
- This prototyping work is an effort sponsored by the OSM TIPS program under the TIPS Remote Sensing initiative.
- Use of trademarks and brand names are to identify the tools used and do not imply endorsement by OSM; they are included as examples of current technology.

Introduction

- The mining/reclamation community depends on accurate mapping for almost all activities. Traditional ground surveys are totally adequate for small, uncomplicated jobs but at some point, the size and/or complexity of a project makes it more economical to have a site “flown” (mapped using photogrammetry.)
- Aerial photography is best known; it is mature, accurate, and trusted, but expensive. Newer forms like photography/LiDAR hybrids and pure LiDAR provide more detail but are often more expensive.
- Because of cost, most projects are only “flown” at the start and less often when completed. Changes during the project may be surveyed but in many cases aren’t worth it – negative cost/benefit, too dangerous, or inaccessible.
- AML complaint investigators can face similar issues. For example, monitoring a nuisance landslip to decide whether it is a true emergency.
- Close Range Photogrammetry (CRP) offers much potential for measuring features that can’t or aren’t being measured otherwise.

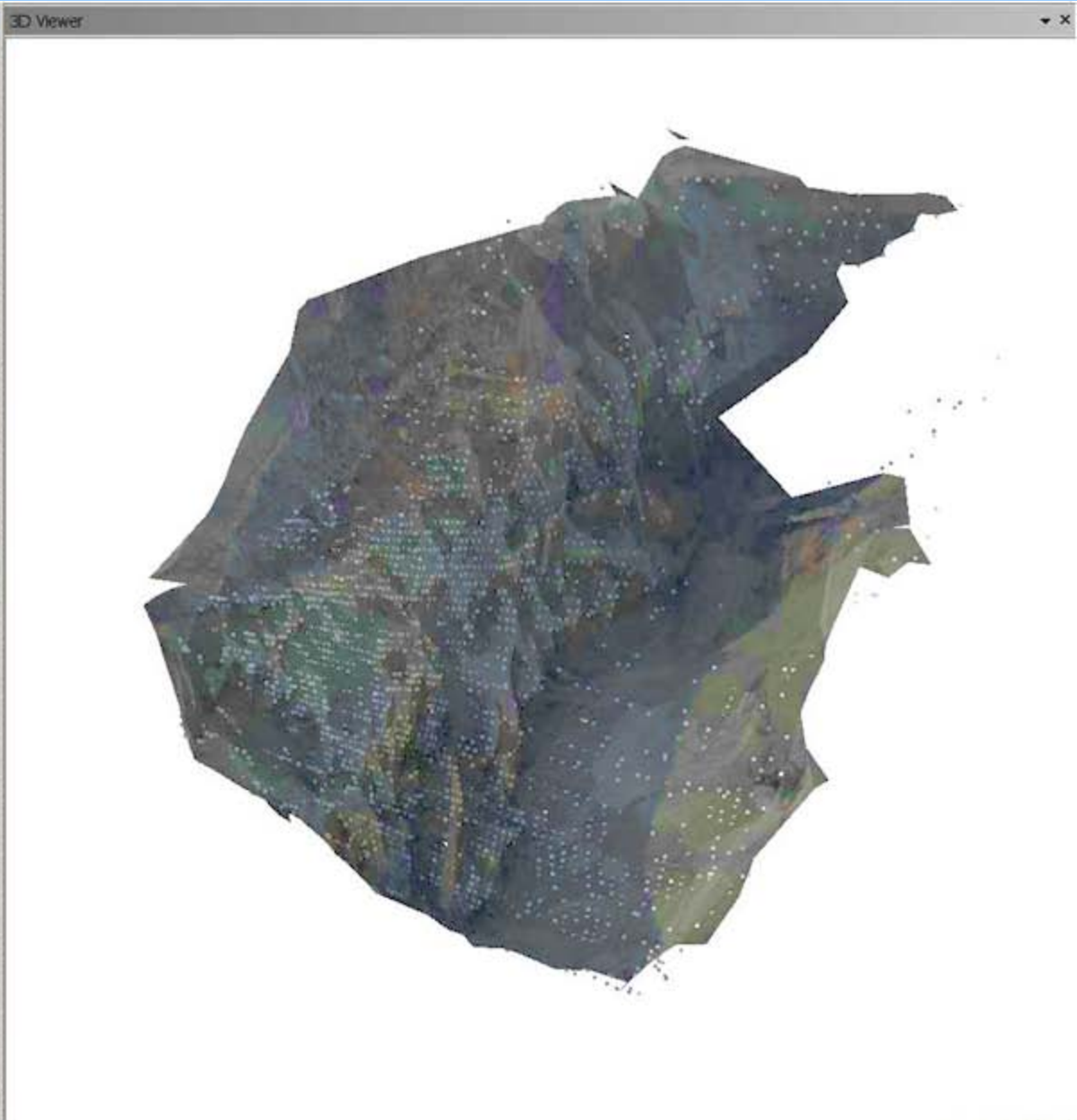
CRP

- Using non-metric photography to accurately measure objects at distances less than 1,000 feet.
- Types (my interpretation):
 - Perspective (regular geometric objects)
 - Stereo (random, irregular objects)
- Perspective is well suited for and widely used in accident investigations and architectural studies; it doesn't work well on mine sites.
- Stereo is potentially ideal for mines but for a number of reasons, few practical solutions have ever been readily available. One of these, PhotoModeler Scanner, was selected to test CRP for mining and reclamation applications.
- Because hand-held, "consumer grade" digital cameras are part of most field workers equipment, photos from these non-metric cameras are used exclusively in this study.
- An overview of the CRP process and techniques is presented in the Paper.

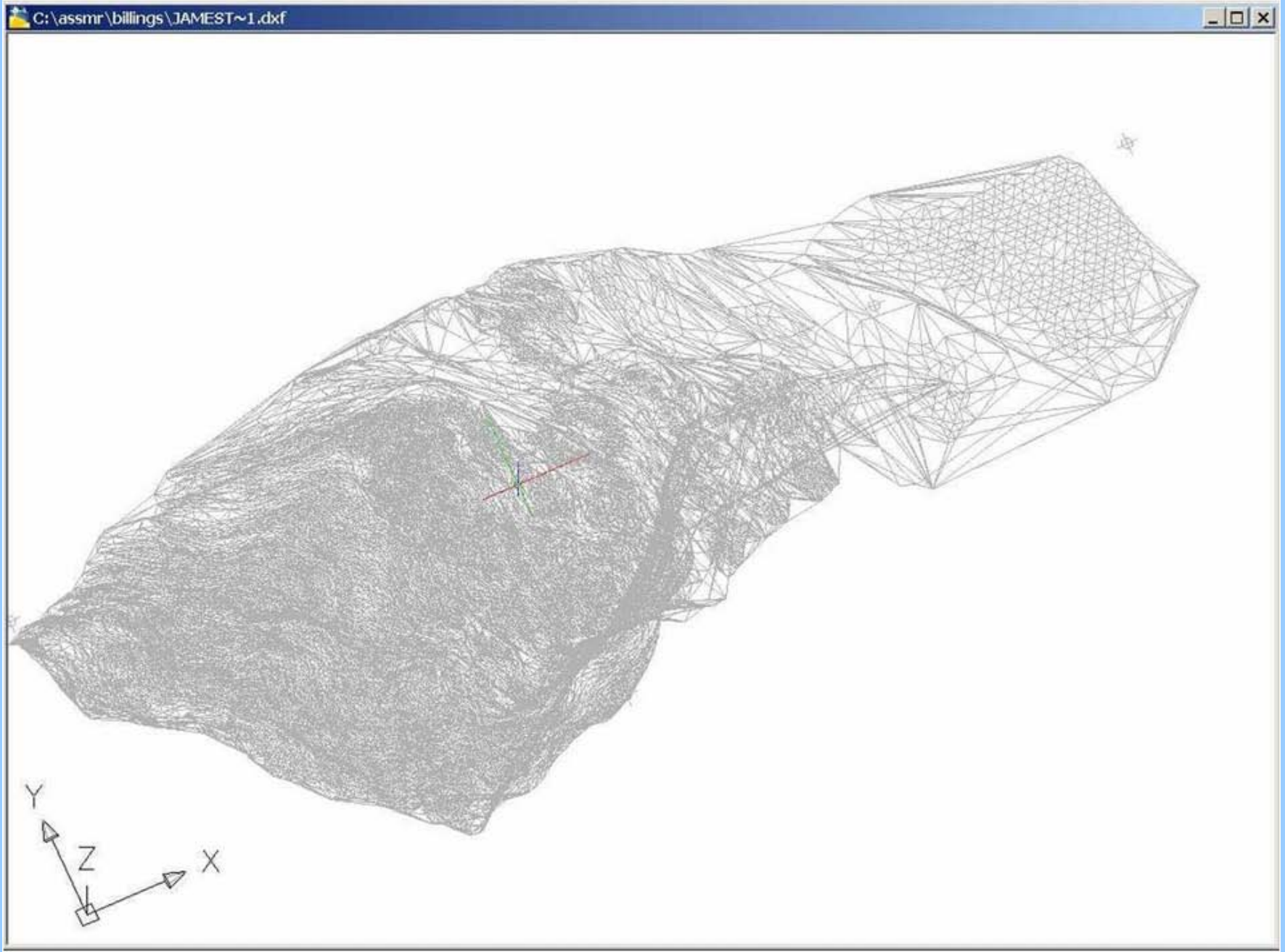
First Tests

- Several thousand pictures of the Dolph Fire Project were taken on the ground and from a small plane.
- The site was flown before and after construction and detailed topography and surface features were generated and supplied as digital drawings.
- On ground surveys were done to keep to design and locate new boreholes.
- An detailed unreferenced stereo mesh model of the trench was created from random photos.
- The digital topography and surveys provided enough ground control to generate referenced stereo models using random photos from a small plane.

Unreferenced Trench Model



Trench Model – 3D Mesh in CAD



Trench Model Analysis

- The photos were taken with a camera that was later calibrated to remove lens and other distortions.
- The stereo coverage was not optimum yet the mesh was truly proportioned in XYZ.
- After scaling, rotation, and repositioning in CAD, the mesh matched closely to the aerial topography.

Small Plane Photo– March (left) Aerial Survey Photo – April (right)



Small Plane Photos, Ground Control Points, Calculated Camera Positions

The screenshot displays a photogrammetry software interface with four photo windows and a 3D view window.

Photo Windows [Floating]:

- Photo3 : DSC00025 : oriented : 15%** (top-left): Shows aerial photo with ground control points (GCPs) labeled: 1 (cpm:"E-43"), 71 (cpm:"betweennorth"), 6 (cpm:"E-24"), 49 (cpm:"oldgully"), 28 (cpm:"int1"), 11 (cpm:"E-39"), 16 (cpm:"roadint"), 33 (cpm:"sepile"), 24 (cpm:"notc"), 20 (cpm:"swtop"), and 42 (cpm:"southben").
- Photo2 : DSC00024 : oriented : 15%** (top-right): Shows aerial photo with GCPs labeled: 6 (cpm:"E-24"), 11 (cpm:"E-39"), 1 (cpm:"E-43"), 16 (cpm:"roadint"), 53 (cpm:"pointc"), 47 (cpm:"GAI-1"), 20 (cpm:"swtop"), 38 (cpm:"bend"), 49 (cpm:"int1"), 71 (cpm:"betweennorth"), 33 (cpm:"sepile"), and 49 (cpm:"oldgully").
- Photo6 : DSC00026 : oriented : 15%** (bottom-left): Shows aerial photo with GCPs labeled: 49 (cpm:"oldgully"), 71 (cpm:"betweennorth"), 53 (cpm:"pointc"), 28 (cpm:"int1"), 42 (cpm:"southben"), 1 (cpm:"E-43"), 38 (cpm:"bend"), 33 (cpm:"sepile"), 20 (cpm:"swtop"), and 47 (cpm:"int1").
- Photo5 : DSC00029 : oriented : 15%** (bottom-right): Shows aerial photo with GCPs labeled: 53 (cpm:"pointc"), 71 (cpm:"betweennorth"), 49 (cpm:"oldgully"), 1 (cpm:"E-43"), 28 (cpm:"int1"), 42 (cpm:"southben"), 38 (cpm:"bend"), 33 (cpm:"sepile"), 42 (cpm:"southben"), 6 (cpm:"E-24"), and 11 (cpm:"E-39").

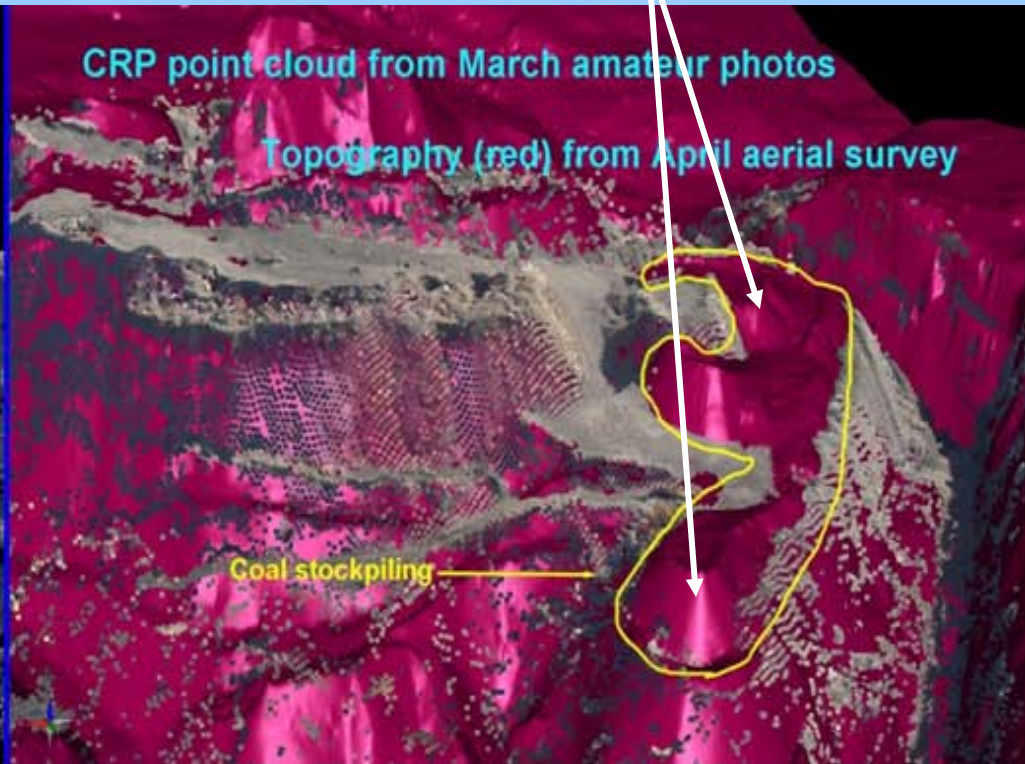
3D View Windows [Floating]:

The 3D view window shows a 3D reconstruction of the terrain. The terrain is represented by a textured surface. Several camera positions are shown as blue rectangular blocks with red and green markers. The terrain features are labeled with GCP names: "pointc", "betweennorth", "oldgully", "southbench", "little southpond", "GAI-1", "GAI-2", "GAI-3", "GAI-4", "GAI-10", "GAI-15", "GAI-16", "GAI-21", "GAI-16", "int1", "BH2", "BH_C2", "BH_C1", "BH_P", "BH_P7", "BH_P8", "BH_P9", "BH_P10", "BH_P11", "BH_P12", "BH_P13", "BH_P14", "BH_P15", "BH_P16", "BH_P17", "BH_P18", "BH_P19", "BH_P20", "BH_P21", "BH_P22", "BH_P23", "BH_P24", "BH_P25", "BH_P26", "BH_P27", "BH_P28", "BH_P29", "BH_P30", "BH_P31", "BH_P32", "BH_P33", "BH_P34", "BH_P35", "BH_P36", "BH_P37", "BH_P38", "BH_P39", "BH_P40", "BH_P41", "BH_P42", "BH_P43", "BH_P44", "BH_P45", "BH_P46", "BH_P47", "BH_P48", "BH_P49", "BH_P50", "BH_P51", "BH_P52", "BH_P53", "BH_P54", "BH_P55", "BH_P56", "BH_P57", "BH_P58", "BH_P59", "BH_P60", "BH_P61", "BH_P62", "BH_P63", "BH_P64", "BH_P65", "BH_P66", "BH_P67", "BH_P68", "BH_P69", "BH_P70", "BH_P71", "BH_P72", "BH_P73", "BH_P74", "BH_P75", "BH_P76", "BH_P77", "BH_P78", "BH_P79", "BH_P80", "BH_P81", "BH_P82", "BH_P83", "BH_P84", "BH_P85", "BH_P86", "BH_P87", "BH_P88", "BH_P89", "BH_P90", "BH_P91", "BH_P92", "BH_P93", "BH_P94", "BH_P95", "BH_P96", "BH_P97", "BH_P98", "BH_P99", "BH_P100".

Referenced Stereo Model from Small Plane Photos (left); Overlain with Aerial Survey (right)

Stockpiling Pad

Stockpiles



Stereo Model Analysis

- The photos were taken with an unknown camera.
- Only ground control points were used to correct distortions and scale/reference stereo model.
- The stereo model is only accurate and stable near the model center (the stockpile pad); away from the center, the model is worthless.
- At center, model XYZ positions are within inches of the aerial survey.
- Stockpile volume estimates agree well with on-the-ground measurements.

First Tests Findings

- Random photographs from calibrated and uncalibrated cameras can yield realistic and accurate models.
- Additional testing with more technique and control is worthwhile.
- The Kentucky program has a helicopter with belly-mounted non-metric camera; but past attempts at photogrammetry have all failed. They believe this is a solution and are “gearing up” to test.

Second Tests

- Experiment on picture-taking techniques under controlled, realistic conditions:
 - Ideally, a mine site, but a natural rock face or construction project would suffice.
 - No shadows in mid day and good lighting.
 - Ground control.
- Create surface model to compare against surroundings, or better, against undisturbed ground.

Site

- In 2006, LiDAR and digital color imagery was collected for Western Pennsylvania. The imagery and DEMs and sometimes the raw data are publicly available.
- Ground control is therefore likely for any test site within the covered area.
- Best case would be a disturbance after 2006 with undisturbed features visible on the 2006 aerials AND that could be included in test photos.
- *I found one!*

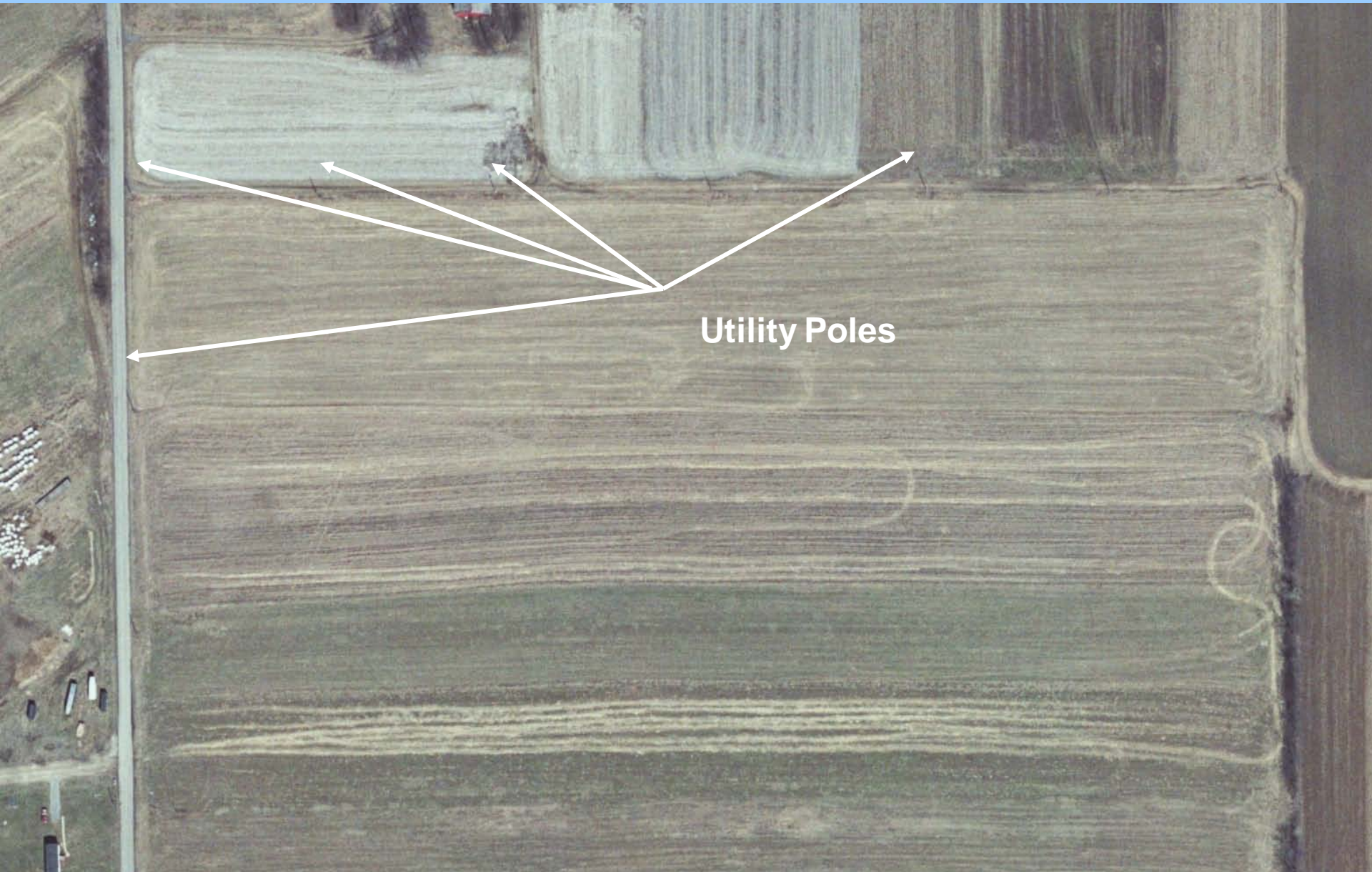
Sand and Gravel Pit, May 17, 2009



Utility Poles

Digital Imagery, Spring 2006

No Mine



Utility Poles

Virtual Earth Imagery, Spring 2008

Disturbed Area ~ 200' by 500'



Mt. Union Rd

Mt. Union Rd

Sand and Gravel Pit, May 17, 2009

Disturbed Area ~ 400' by 1000'

- Extraction and segregation, topsoil stockpiling.
- Many features visible on 2006 digital imagery unchanged.
- Strong light, sun near nadir.
- Pit walls steep, near vertical.

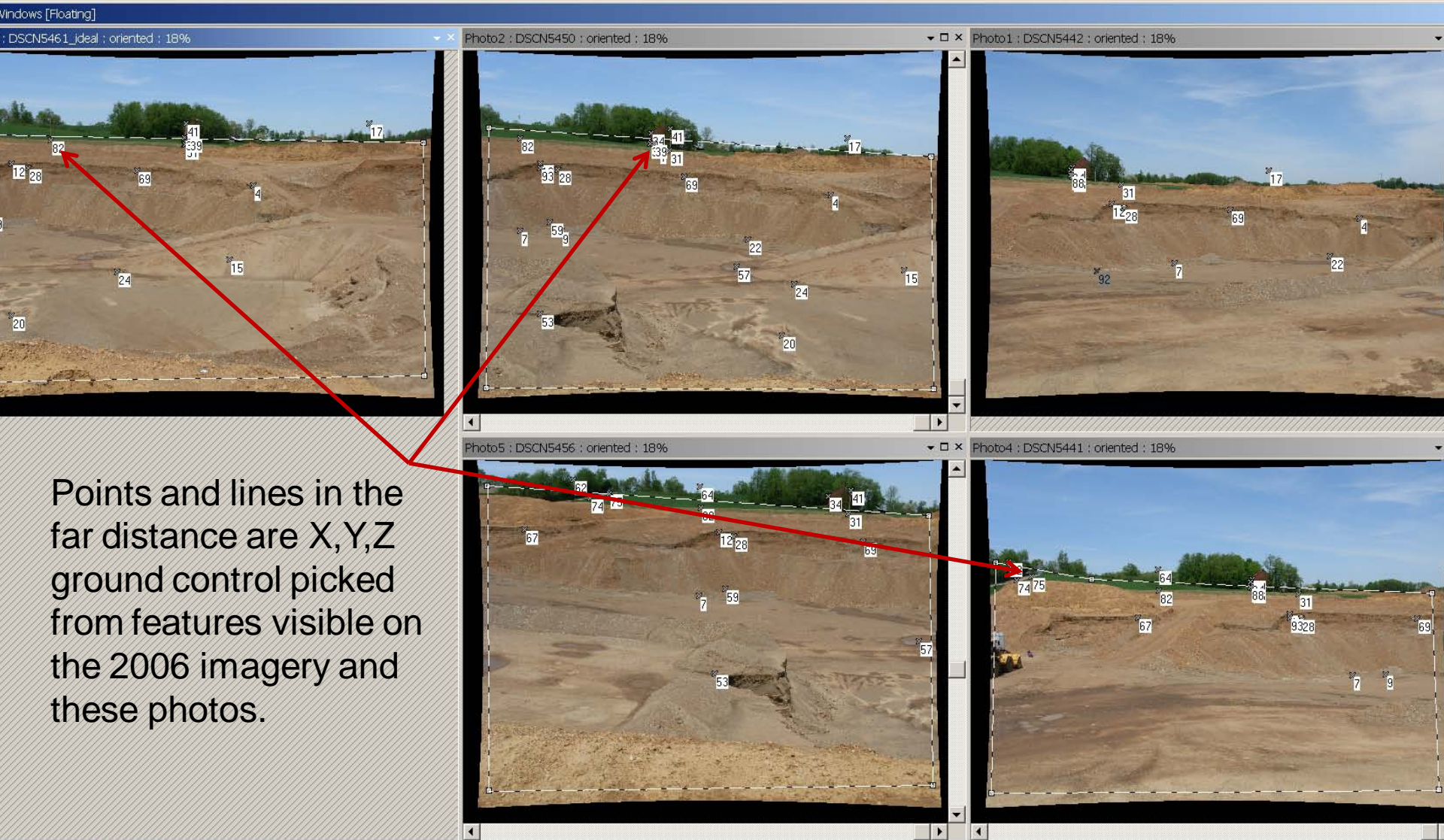


Technique

(Old habits are hard to break!)

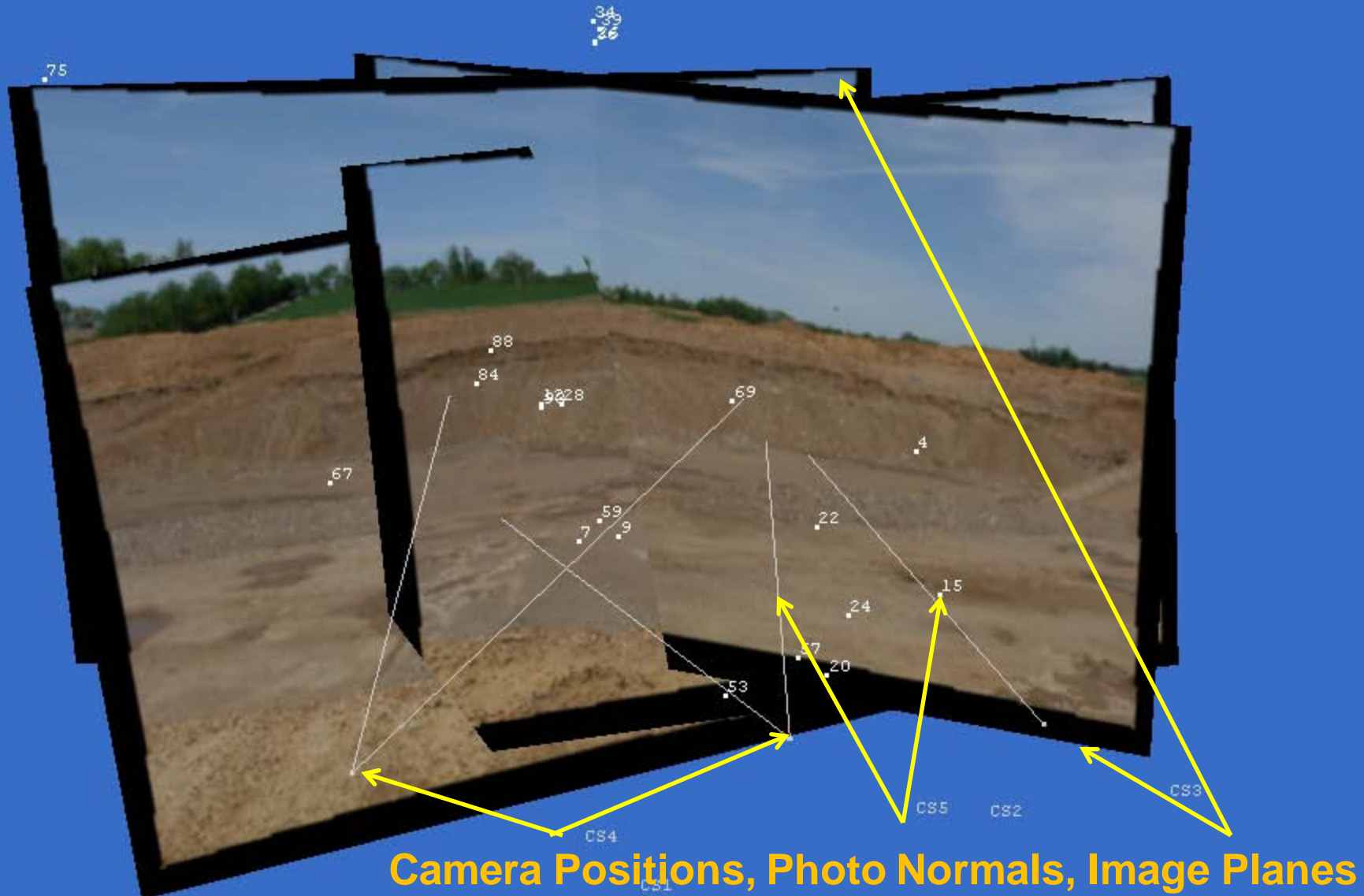
- Tended to take panorama photos instead of stereo photos.
- Average photo only had about 40% pit, rest was background (landscape and sky).
- Perpendicular to surface, parallel image axes and good overlaps were rare.
- However, enough photos were taken to compensate for mistakes.

High Quality Photo Pairs with Points for Orientation and Ground Control

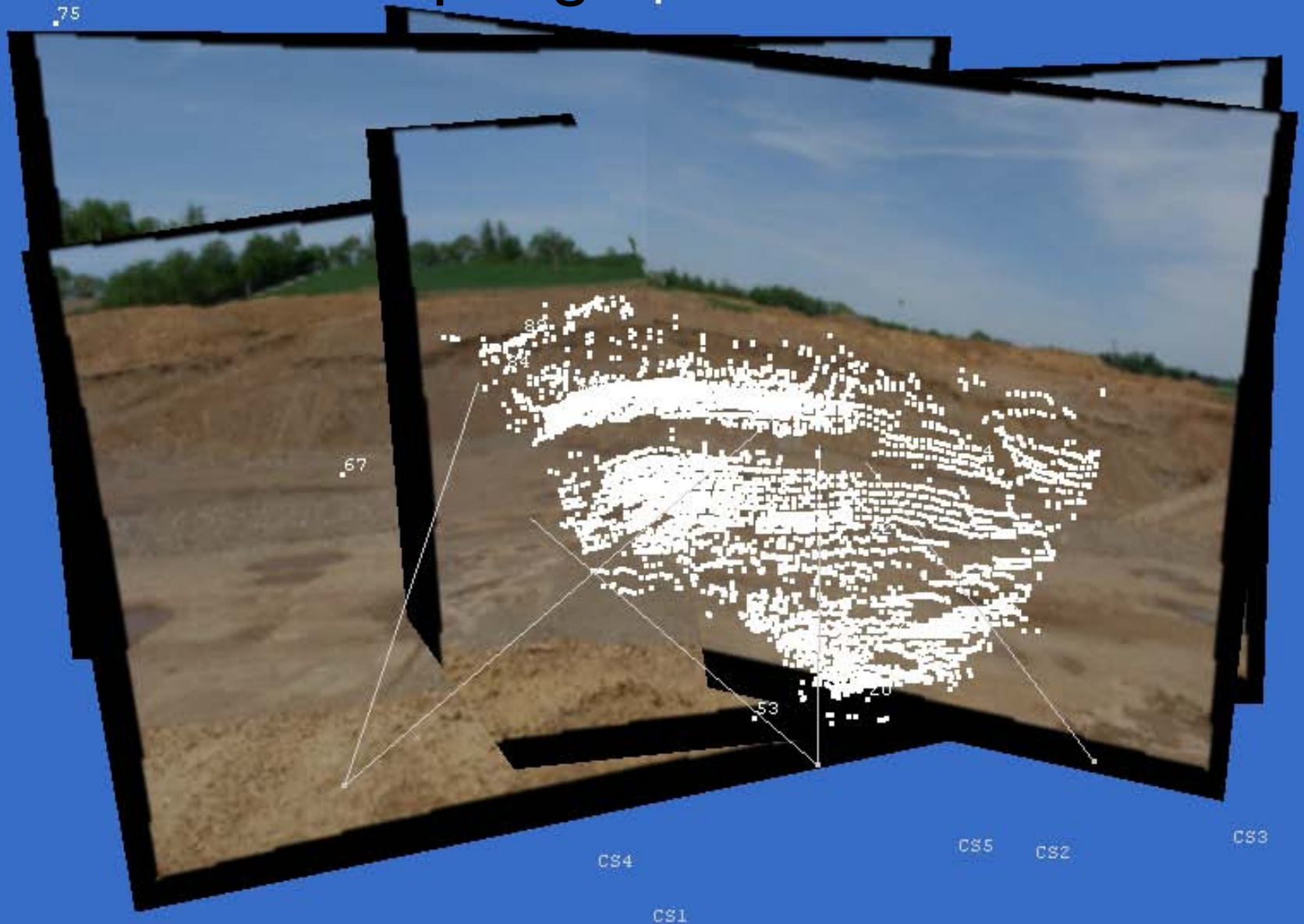


Points and lines in the far distance are X,Y,Z ground control picked from features visible on the 2006 imagery and these photos.

Oriented Photos in 3D



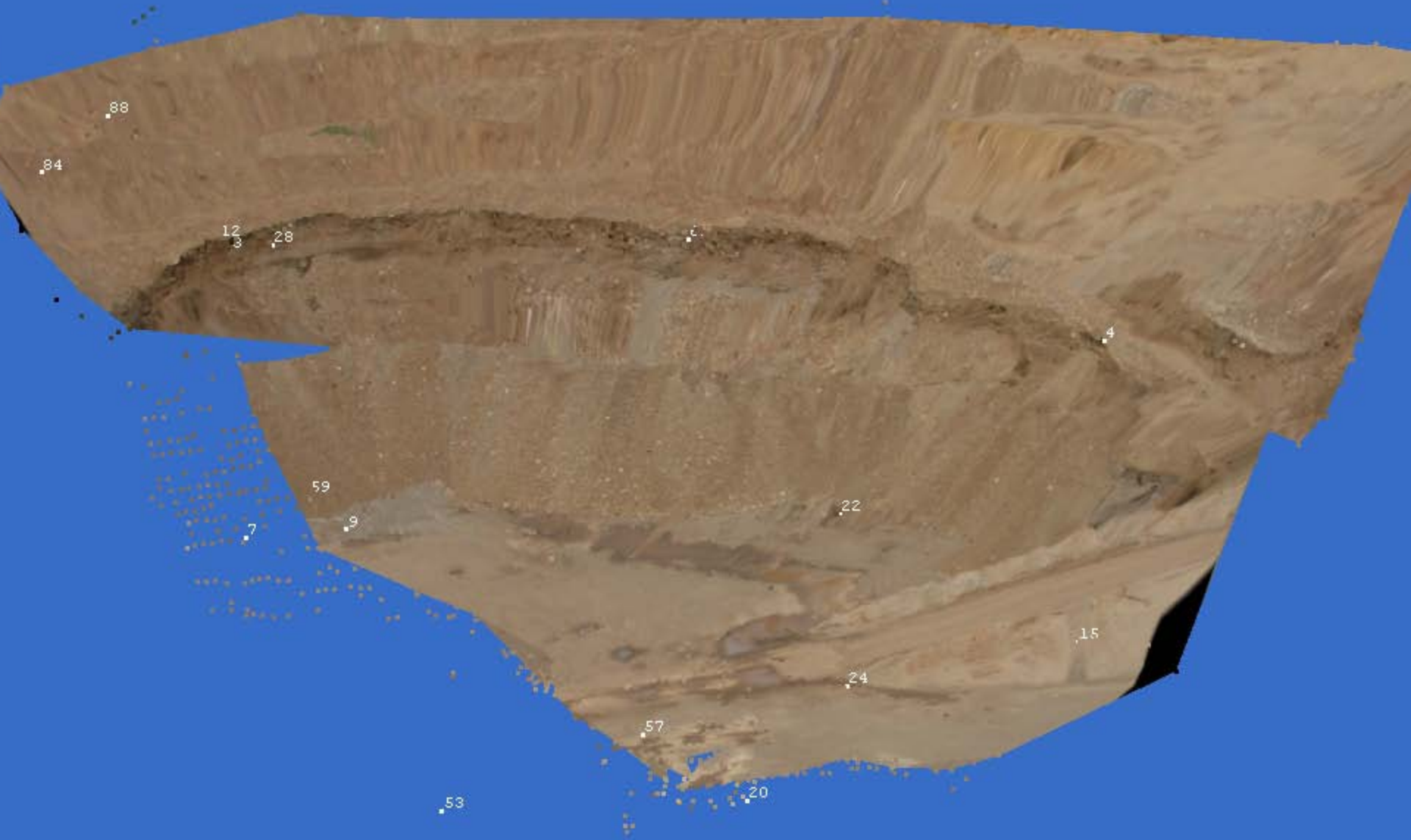
Point Cloud Extracted by Sub-pixel Sampling of Photos



Point Cloud “Painted” in Image Colors



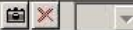
Point Cloud “Painted” in Image Colors



Point Cloud with 2008 Image on Topo - Something's Wrong!

on 3D Viewer (pid = 2764, ipc = 8381)

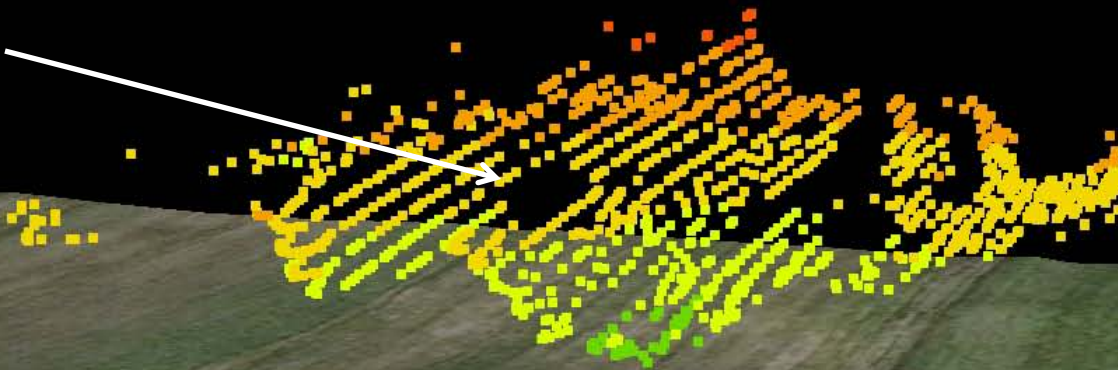
File Window Display Query Analysis Help



Z contour: s



Points are 30'
Too high.



File Query

File: topo.2grd

Query Info

Edit table: 1/1

Query Table

Attribute	Value	Unit
x	1324658.851	USft
y	614209.72	USft
z	1295.734	USft
dip	0.54949	
dipazm	312.598	



Other Problems

- Although, the XY coordinates appear accurate:
- The Z values are 20 to 50 feet too high.
- The point cloud is tilted in 2 directions with a northwestward resultant.

Diagnosis

- The control points used were well-spaced in the XY plane but not in Z .
- The Z points were at the edge of model space and disproportionately impacted the low-angle geometry causing rotation upward.
- A line of known length was not level and caused westward tilt.

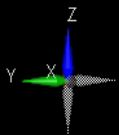
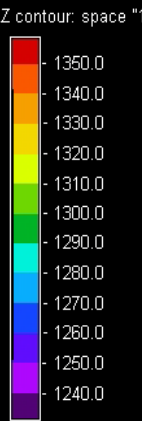
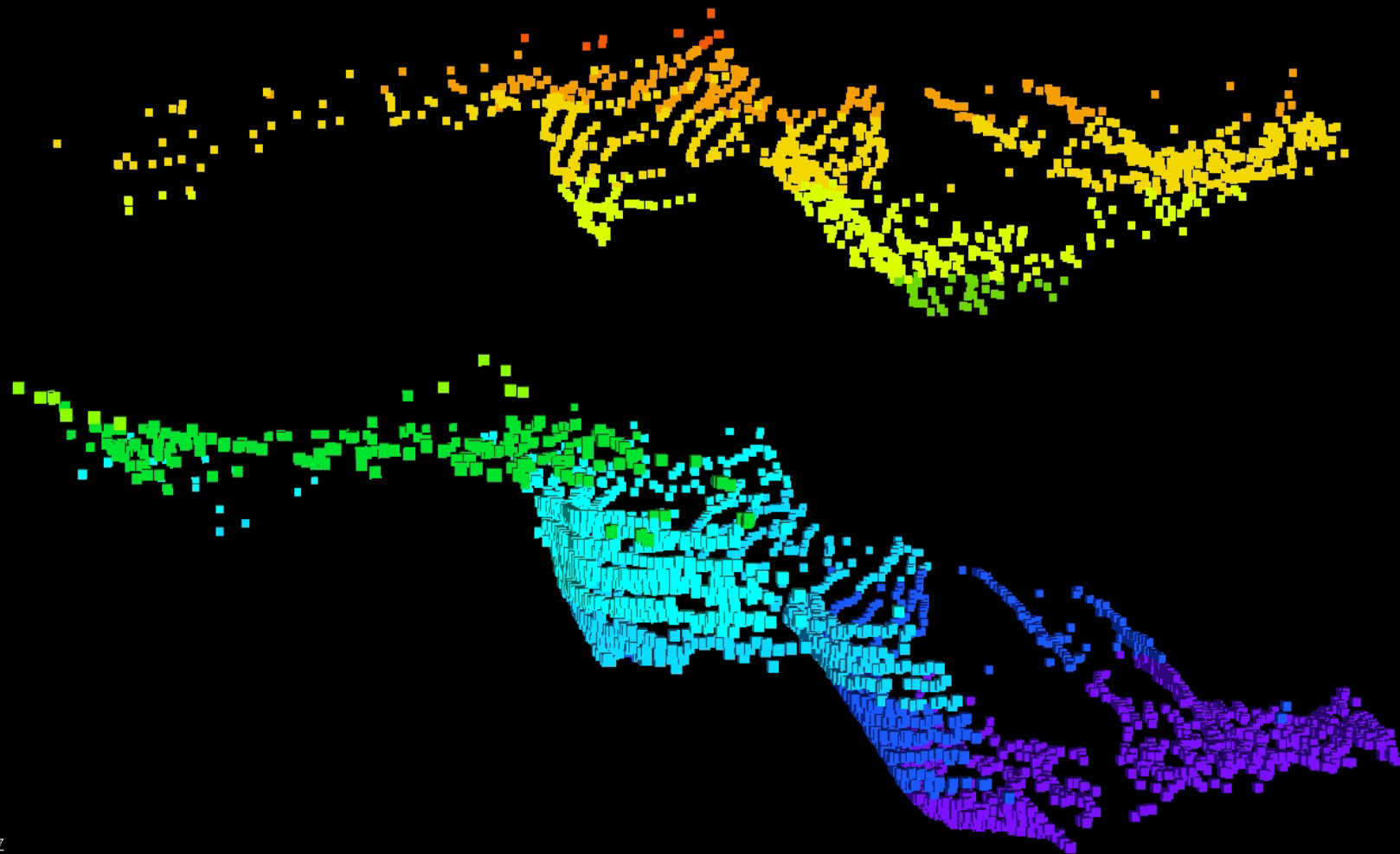
Correction was Trivial



The entire model, including point cloud, was corrected by adding 2 more tie points at the top and bottom of a vertical face on the pit wall.

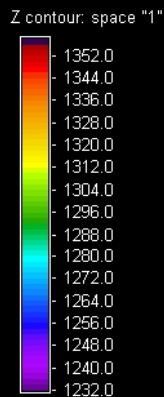
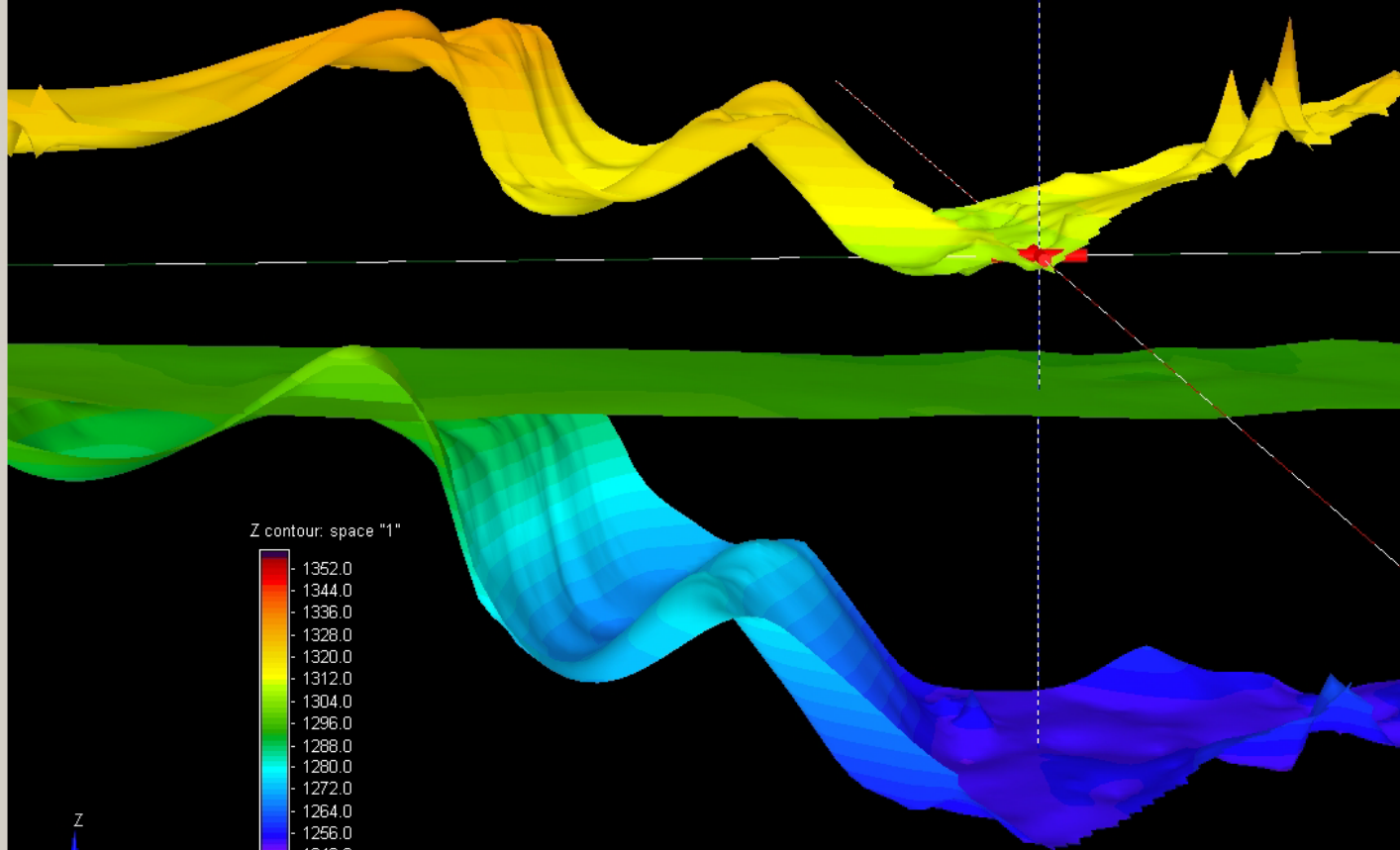
When assigned Z dominance, these points forced full and accurate correction of the model in XYZ.

Before and After Correction



Before and After Correction

Original Ground Shown



3D Cursor Dialog

Location | Options

3D Cursor Location

1324048.04 X-axis Location 1326658.04

612563.86 Y-axis Location 615603.86

1237.368 Z-axis Location 1351.947

1324828.63 USft

614283.0 USft

1308.469 USft

3D Cursor Marks

Add Delete Mode: History

Cursor 1

X (USft)	Y (USft)	Z (USft)
1324828.6...	614283.0	1253.831
1324828.6...	614283.0	1294.703
1324828.6...	614283.0	1308.469

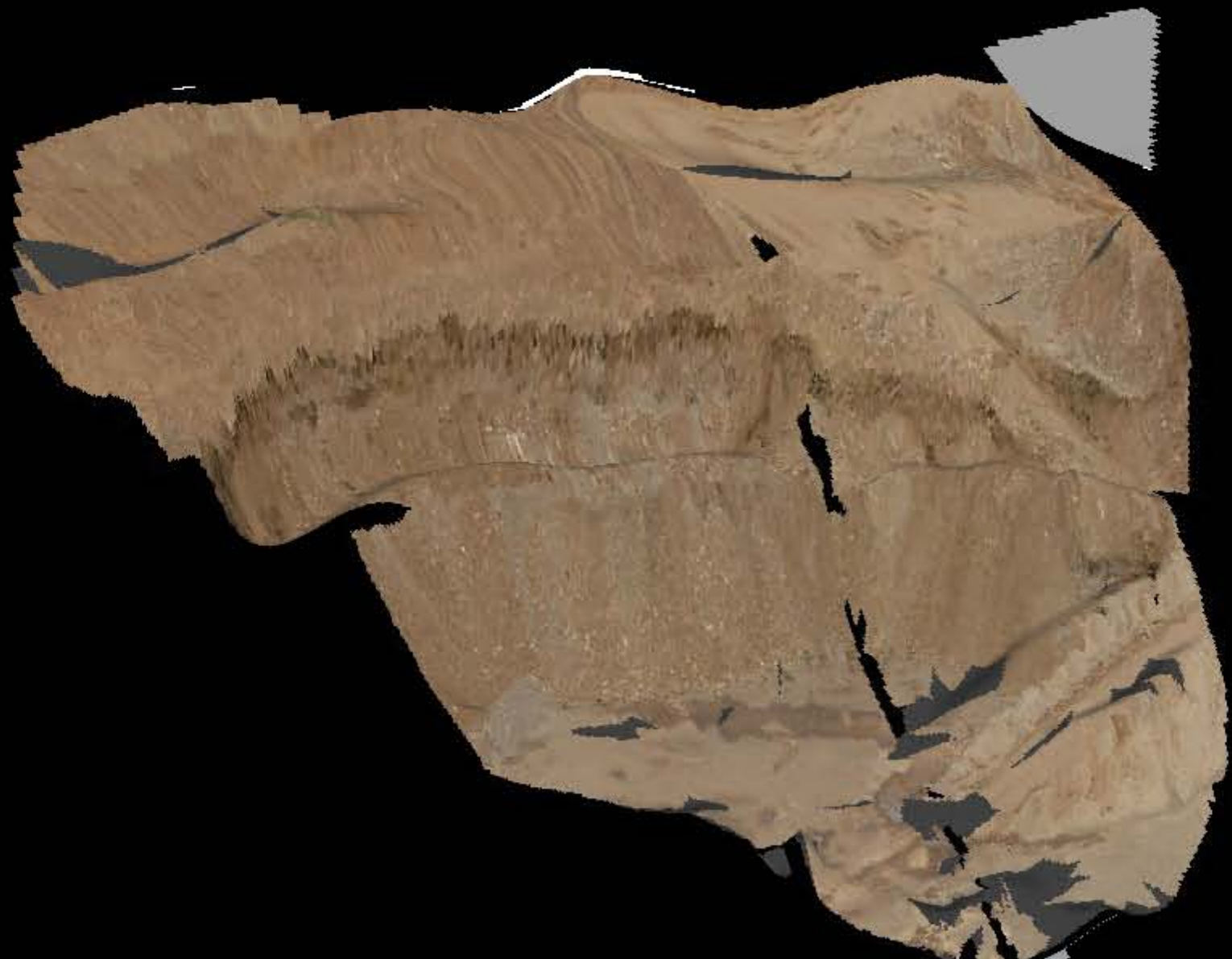
OK Cancel

Putting the Pieces Together

- 2006 topography
- 2008 image showing start of pit
- 2009 partial pit model







Second Test Findings

- Close Range Photogrammetry with consumer-grade and better cameras is capable of very accurate surface modeling.
- Careful planning and guidelines for photography are crucial.
- Technique is everything.

Next Steps

- Kentucky Regulatory and AML will be conducting new user testing on landslip monitoring, attempting aerial photogrammetry with the State helicopter, and working on adding rangefinder and GPS components in highwall/pit situations.
- In August, we plan to begin discussions with the REAL experts in the Bureau of Land Management.

(Parting Shot)

CRP Techniques Perfected!

(BLM gets “on top” of
things)



References

- Burtch, Robert. 2008(?). Short History of Photogrammetry. <http://www.ferris.edu/htmls/academics/course.offerings/burtchr/sure340.html>
- Doneus, Michael. 1996(?) Introduction to Photogrammetry. <http://www.univie.ac.at/Luftbildarchiv/wgv/intro.htm>
- [Fritsch](#), Dieter. 2005. The Photogrammetric Week Series – A Centennial Success Story. <http://www.ifp.uni-stuttgart.de/publications/phowo05/phowo05.en.htm>
- Matthews, Neffra A. 2009 (in preparation). Resource Documentation, Preservation, and Interpretation: Aerial and Close-Range Photogrammetric Technology in the Bureau of Land Management. Bureau of Land Management Technical Note 428, Bureau of Land Management National Operations Center, Denver, Colorado 80225.

Discussion