Chapter 10
Terrestrial 3D Laser Scanners

10-1. Purpose

This chapter provides an overview of 3D laser scanners used for detailed mapping of facilities, structures, utilities, and ground planes. High-precision/high-definition tripod mounted laser scanners are covered. Examples of recent applications where these instruments have been used to map Corps facilities or structures are provided.

Figure 10-1. Optech ILRIS 3D laser scanner--detailed mapping of structures and facilities at St. Lucie Lock and Dam, Jacksonville District (Arc Surveying & Mapping, Inc.)

10-2. Background

Laser scanners operate similarly to reflectorless total stations. However, instead of a single shot point being observed, a full field-of-view scan is performed--at a speed upwards of 500,000 points per second. Unlike a total station, the location of the scanner is not usually a required input--resulting in points that are spatially referenced to the instrument and not real-world coordinates. This is somewhat analogous to an uncontrolled photogrammetric model. (Newer models allow input of the scanner coordinates from which all observed pixels may be directly georeferenced). The resultant imagery from a scan (termed a "point cloud") provides a full 3D model of the facility, utility, or terrain that was scanned. Objects can be scanned at a high density--with output pixels smaller than 5 mm. Relative 3D accuracies approaching the millimeter level are claimed, based on redundant observations over a surface. However, 5 to 10 mm accuracy is more realistic in practice. Scans can be rapidly made--a full field-of-view scan of a site or structure can be performed in 5 to 15 minutes per setup (multiple setups generally are required to fully detail a given site or structure). Unlike a total station, however, laser scanners have no means of assigning feature codes or attributes to the measured points--this must be done in post-processing, and is often a tedious and time-consuming process. Laser scanners have increasing application to many Corps civil and military missions. They can be used to perform traditional topographic surveys (detailed planimetry and elevations) of project sites and facilities--providing ground elevations at a high density. These scanners are especially useful in detailed mapping of exposed (and hard to access) utility systems, such as those inside a hydroelectric power plant. They also have application in mapping archeological sites, HTRW sites, dams, rock faces, hazardous traffic areas, unexploded ordinance sites, or any other inaccessible location.

Figure 10-2. Laser scanned image (upper left) and rendered image (lower right) of Corps Mississippi River Division headquarters building, Vicksburg, MS (ARC Surveying & Mapping, Inc.)

a. Manufacturers. Laser scanners have been on the market for only a few years--since the late 1990s. As of 2005, there were about 12 manufacturers of laser scanners listed in trade publications.

b. Cost. A complete laser scanning system (including a high-end modeling software package and training) can cost between $150,000 and $200,000. Thus, few, if any Corps Districts would have a sufficient number of applications to justify this level of expense. In time, it is possible these prices will decrease to a level where 3D scanners may be cost-effective if the workload warrants. Data processing and modeling software is typically expensive; however, it is essential in order to export scanned images to CADD platforms. At present, Corps Districts contract for periodic 3D scanning services--many AE surveying contractors performing Corps work have acquired (or are acquiring) 3D scanners. Given the limited amount of work, the hourly/daily rate is understandably high for these scanners (and data processing)--daily operating costs of $2,000 to $5,000 or more (including processing) are not uncommon, and can vary widely depending on the amount of processing required. Most often, a project cost would be negotiated on a lump sum basis, factoring in the basic daily rental cost of the scanner plus the operator and CADD processor time estimates.

c. Accuracy. The accuracy of a scanned object can be relative or absolute. Relative accuracies are very good (5 mm or better at close ranges). Absolute accuracies depend on the accuracy of the control network developed for the site, how accurately the instrument is aligned to this network, and how well overlapping images (i.e., picture points or targets) are transferred and adjusted (best fit). In general, absolute accuracies can be kept within 1 or 2 centimeters over a small project/structure site. In many cases, relative accuracies are far more important than absolute geospatial accuracies. For example, measurement of a crack in a wall requires a high relative accuracy; however, the absolute geospatial coordinates of the crack are not significant. Overall accuracy is a function of range, scan density, spot/footprint size, and single point accuracy (Jacobs 2004).

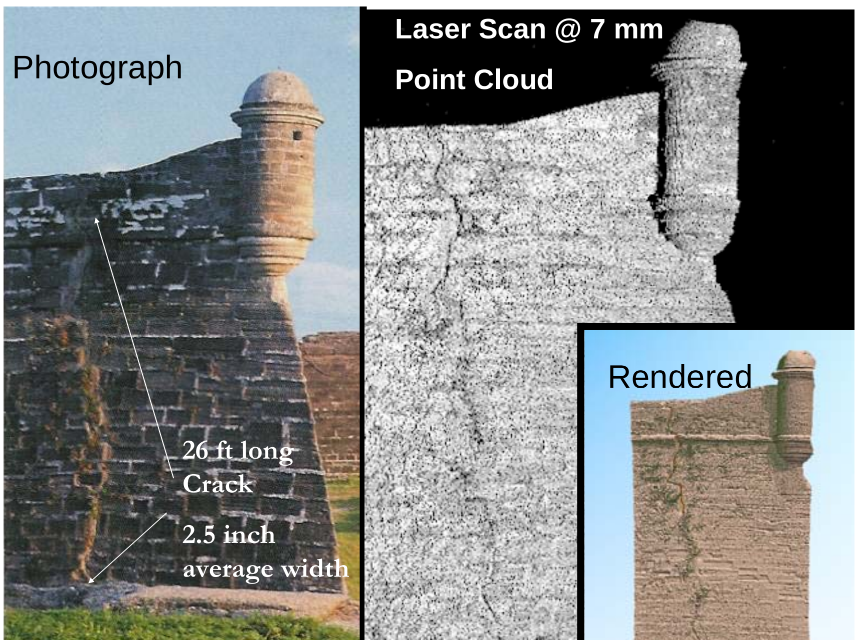

Figure 10-3. Crack measurements with a 3D laser scanner. Castillo de San Marcos, Saint Augustine, FL (Arc Surveying & Mapping, Inc. for National Park Service)

d. Density of scanned points. Laser scanners can be set to any desired scan density, e.g., 5 mm to 1 meter, usually based on some short nominal distance. The higher the density the larger the resulting dataset--and more time-consuming data editing and processing. The purpose of the project determines the required density. For general 3D planimetry or buildings or ground elevations, a low density can be set. For detailed maps of structural members or concrete cracks, a high density is set.

e. Field-of-View. Depending on the model and project requirements, scanners can be set to scan a full 360 deg field or zoomed (windowed) into a narrowly set field-of-view. The Leica HDS4500 scanner has a field-of-view of 360 deg horizontal by 310 deg vertical. The reality of scanning means that even a 360º field of view does not guarantee full area coverage; in fact, it rarely does. Laser shadowing forces data to be collected from multiple angles for complete data coverage. A large field of view does not alleviate this requirement. Also, the angle of incidence of a measurement will have a profound impact on its accuracy and the resolution of the data in general. Keeping this fact in mind, imagine surveying a long, flat wall. If the scanner has a 180º horizontal field of view it will be able to survey the wall in a single scan. Depending on the length of the wall, measurements may be collected from angles that approach 90º, but the reliability of these measurements will be very poor.

f. Range. Range of scans is a function of the laser intensity and reflectivity of the object scanned. Some scanners are designed for only close up scans--i.e. 200 meters. Others claim ranges of upwards of 1,000 meters--or more. Obviously, the longer the range, the larger the footprint and less accurate the resultant measurement becomes. In general, most detailed scans of facilities, buildings, and structures are kept at close range--usually less than 500 ft and not much beyond 1,000 ft. The laser eye safety classification may also be a factor in longer-range scanners--a Class 3 type laser may not be desirable for surveying a populated beach but would be acceptable at a remote HTRW site. (A Class 1 laser device "denotes exempt lasers or laser systems that cannot produce a hazard under normal operating conditions" and a Class 3a laser device "denotes visible lasers or laser systems that normally would not produce a hazard if viewed for only momentary periods with the unaided eye. They may present a hazard if viewed using collecting optics."). The ranging capability of a laser scanner is more important than it first seems. In some cases, the lack of ranging ability will completely eliminate the ability to do certain projects. For example, let's examine the case of a bridge that crosses a body of water. A lack of certain characteristics (such as a 360º field of view) may force you to collect more scans but it doesn't prevent the project from being completed. The inability to range to the structure, with no provisional means of getting closer, will eliminate the potential of the scanner being used on the project. It is also true that a survey will rarely be conducted at a range greater then a few hundred meters (except in cases similar to the above example). However, long-ranging capability has other benefits that are not immediately identifiable. At the extreme limit of a scanners specified range, the accuracy of the measurements will begin to decrease in a non-linear fashion. As such, let's consider the example of scanning a structure from 150 m away. The scanner whose maximum range is 150-200 m will struggle to collect the data. It may succeed, but the measurement quality will suffer and the dataset will contain a large number of "drop out" points (instances where no measurement was collected). Alternatively, the scanner that provides 1,000 m range will be collecting data from the ideal area of its total dynamic range. The data collected will be of optimum accuracy.

g. Beam footprint size. The footprint size will vary (increase) with the distance from the scanner to the object. Typically, on close-range applications (less than 100 ft ranges), a 5 mm footprint is observed.

10-3. Scanner Operation and Data Processing

Scanners are normally mounted on a tripod, directly onto the plate or in a standard tribrach. The scanner is set up at any arbitrary location that affords the best view of the area or object to be mapped. No absolute geospatial orientation of the scanner is required (unless the scanner model is designed to incorporate geospatial references). Most structures require multiple scans in order to develop a complete 3D model, as illustrated in Figure 10-4 below. In addition, multiple scans are required to cover hidden, shadowed, or obstructed areas in a single scan. Thus, a rectangular building will require scans from four setups offset from each of the corners--each scan providing data covering two faces of the building, which will overlap with adjacent scan locations. These overlapping scans allow a full 3D model of the building to be generated using imagery correlation (optical recognition) software (similar to soft-copy photogrammetry). The scanned "point clouds" are saved on flash memory devices in the scanner, which can be later downloaded to a field or office computer. The overlapping "point clouds" from each scan are edited for data spikes--often a lengthy process. They are then merged to form the full 3D model. This merging is done in proprietary software that is usually sold separately with the laser scanner. This resultant 3D model is referenced only to a relative/internal coordinate system. If real-world geographic X-Y-Z coordinates are required (and they are not always needed for many project applications), then targeted points need to be set in the scanned area/structure in order to perform a standard coordinate transformation. Once the model is generated, a variety of computer graphic enhancements can be performed. These include coloring, wire meshing, rendering, and smoothing objects. Rough point cloud images of solid objects can be smoothed using various software-fitting routines--e.g., items such as wall faces, cylindrical pipes, etc. If the resultant model is going to be exported to a CADD or GIS platform, then additional descriptor, attribute, or layer/level assignments may be required. Final data processing can represent a significant effort on some projects--a structure that is scanned in 4 hours may take as much as 40 hours or longer to process the data to a CADD compatible format. The software used for processing scanned datasets is a critical component in the overall efficiency and economy of the process.

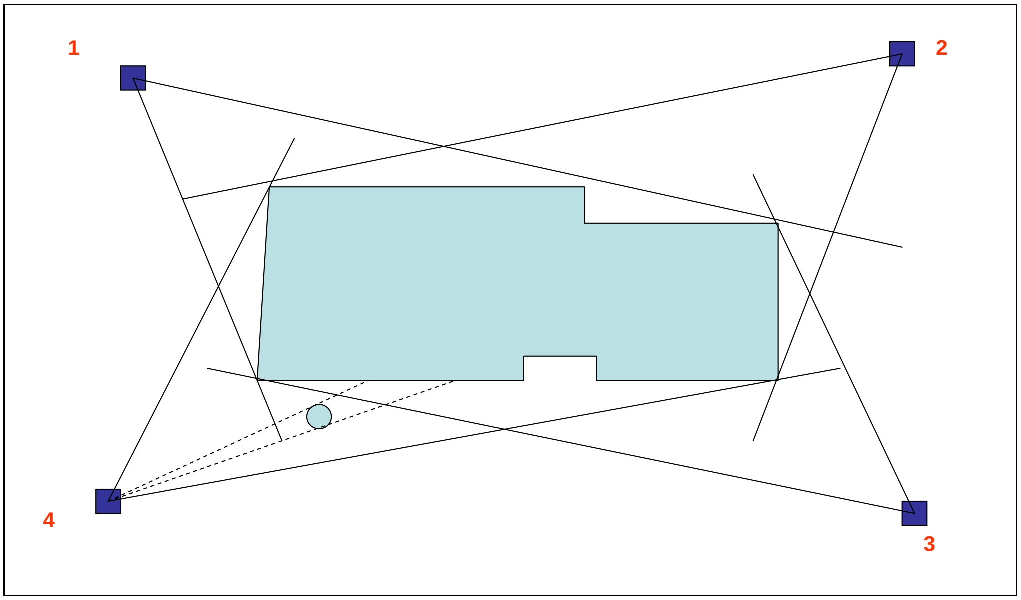

Figure 10-4. Typical four scan locations needed to fully model a building and cover obscured areas. In practice, additional scan points may be needed.

10-4. Corps of Engineers Project Application: St. Lucie Lock and Dam, Jacksonville District

The following figures illustrate an application of 3D laser scanning on a Corps civil works project--mapping lock and dam structures and related grounds and facilities. This project (in 2001) involved both topographic and hydrographic surveying of the lock and dam site. An Optech laser scanner was used to capture images around the project. Given the complexity of the site, numerous instrument setups were required to fully cover the site. The individual point clouds were merged and a continuous 3D model of the lock and dam was created. Additional color rendering was also performed. The above ground Optech laser data set was subsequently merged with 3D hydrographic data obtained with a multibeam echo sounder. (This project was performed by Arc Surveying & Mapping, Inc. for the Jacksonville District).

Figure 10-5. Typical scan location to cover downstream gate structures--instrument set up between 6th and 7th gates

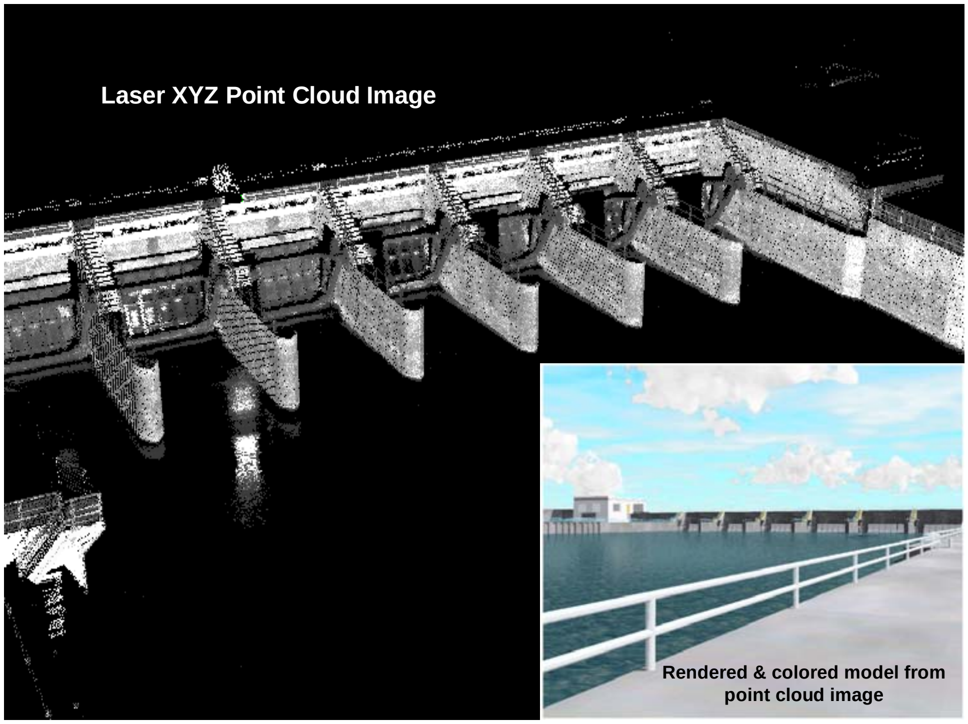

Figure 10-6. Merged point cloud images of gate structures, from multiple scanning locations

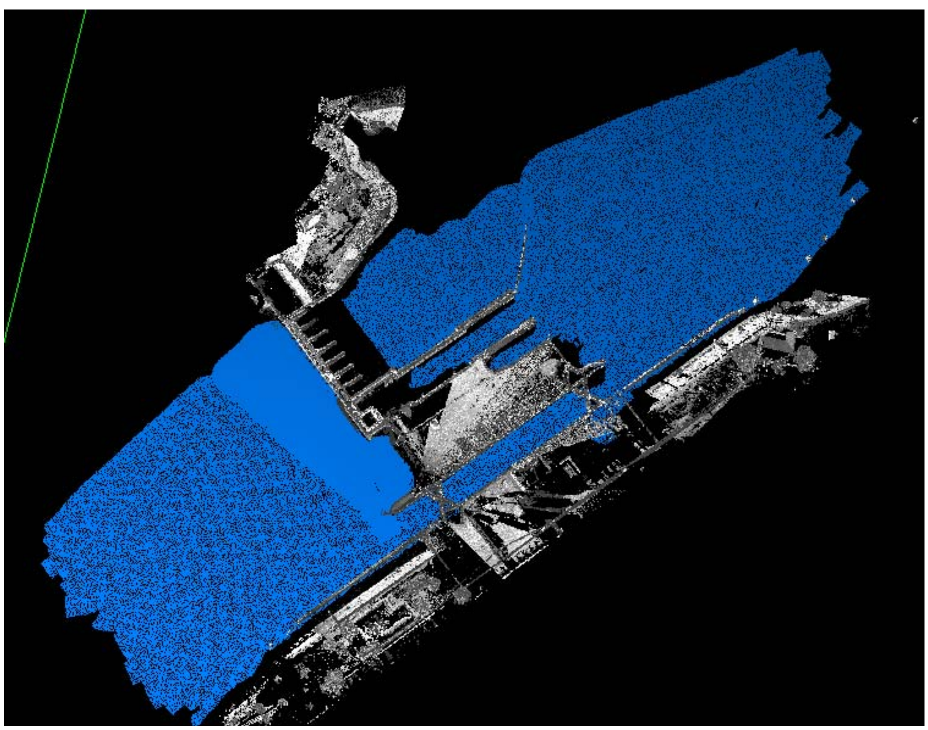

Figure 10-7. Merged Optech laser scanned imagery with subsurface multibeam imagery--resultant 3D imagery model of entire lock and dam project

10-5. Corps of Engineers Project Application: Portuguese Dam Foundation Construction, Ponce, PR, Jacksonville District

The following figures depict a topographic survey of the foundation for the Portuguese Dam north of Ponce, Puerto Rico. These scans were made during grouting operations at the foundation. The entire area surrounding the foundation was scanned, and georeferenced to the local coordinate system using targeted reference points in the scans. A conventional total station survey on a 10 ft x 10 ft grid was performed over the same area and compared with the far denser matrix generated from the laser scan. Rappelling techniques had to be employed to reach many of the total station shot points in this rugged mountainous terrain--these same points were easily and safely tied in with a Cyrax 3D laser scanning system (Cyra Technologies--now Leica). These surveys were performed in 2000 by Arc Surveying & Mapping for the Jacksonville District.

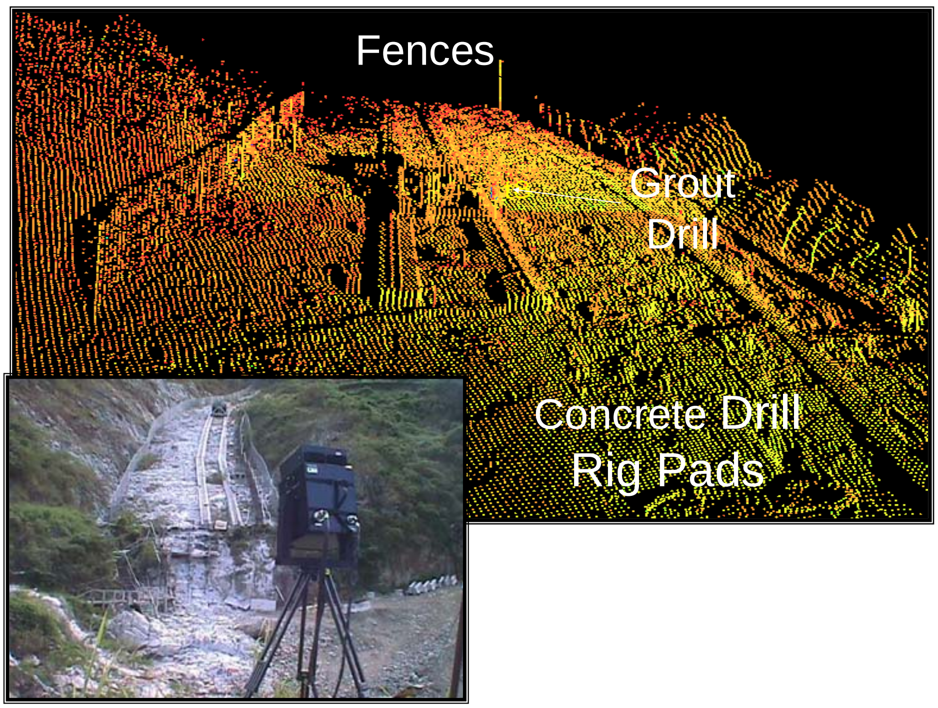

Figure 10-8. Portion of Portuguese Dam foundation scanned by Cyrax laser (Arc Surveying & Mapping, Inc.)

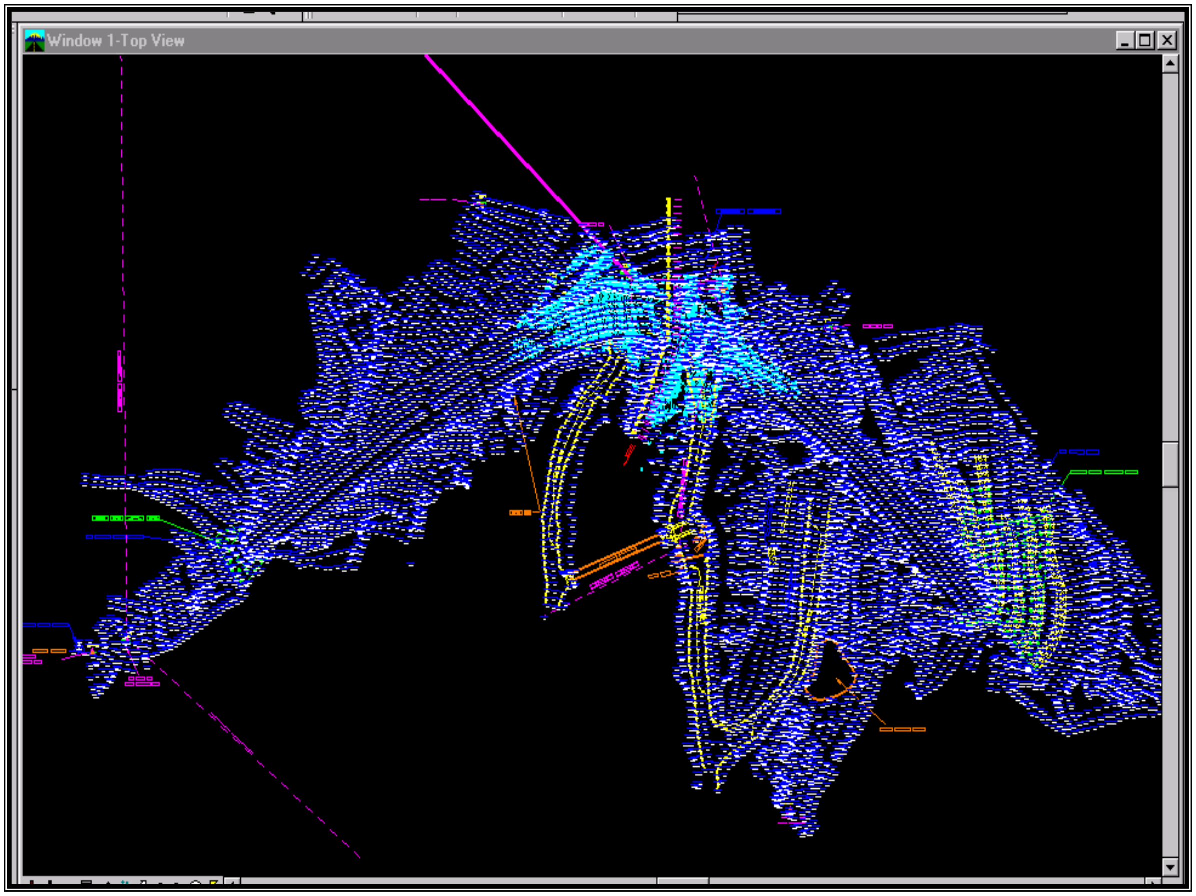

Figure 10-9. Merged datasets: Conventional total station topography and 3D laser scanned model (Portuguese Dam foundation--Jacksonville District)

10-6. Corps of Engineers Application: Steel Bayou Levee Surveys, Vicksburg District

The following figures depict a topographic survey of a levee using a 3D laser scanner. This was a demonstration project performed for the Vicksburg District; to assess the capabilities of terrestrial laser scanners for levee surveys. Comparisons were made between the scanned surveys and conventional topographic surveys performed by the Vicksburg District. A major problem with scanning flat terrain is the limited range when the scanner is set on a standard tripod. To be effective, an elevated platform is needed to obtain a more effective working range. Establishing georeferencing on the scanned images is also problematic in a linear scan over a flat area. Targeted control along the top of the levee is needed to reference each scan and may not be a cost-effective process. In addition, this demonstration project was conducted with 2-ft height grass on the levee. Since the laser picks up the top of grass, any practical use of 3D laser scanners must be performed immediately after vegetation is cleared--or in sites without vegetation. Effective use of laser scanners on flat terrain is marginal unless an elevated view site can be obtained.

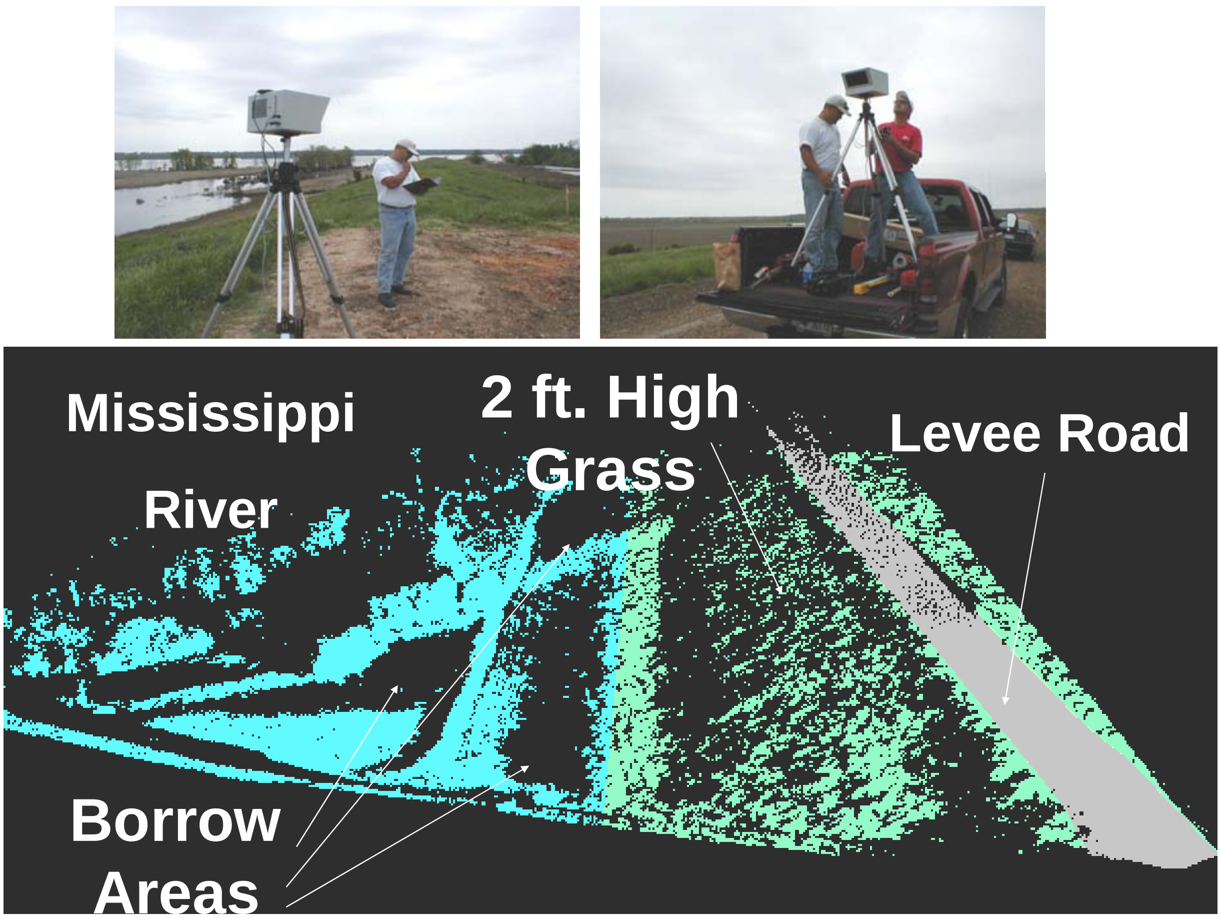

Figure 10-10. Scanned images of Steel Bayou levee in Vicksburg District. Scanner elevated to maximum height in order to extend distance.

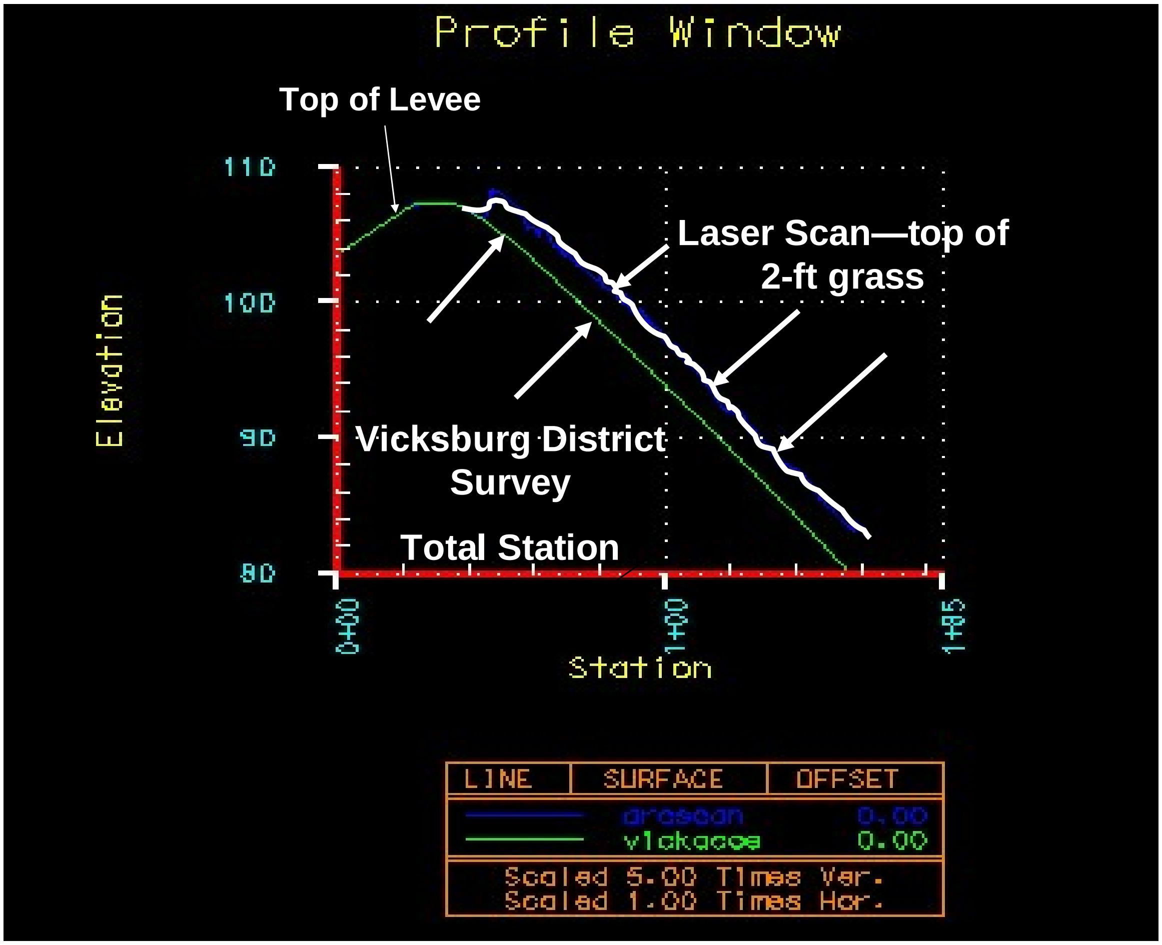

Figure 10-11. Levee cross-section: comparison between conventional total station survey and 3D laser scanner

10-7. Corps of Engineers Application: Structure Subsidence Survey, Philadelphia District

The following figures illustrate another application of 3D laser scanning on a Corps civil works project--monitoring subsidence for lock and dam structures. This was a demonstration project performed by TVGA Consultants for the Philadelphia District, to assess the capabilities of terrestrial scanners for subsidence monitoring. The location of dam outfall structure for the Francis E. Walter Dam makes access extremely difficult, time consuming and requires a detailed safety plan be prepared and followed. Given the complexity of the site conditions and instrument setup distance from the structure an Optech Ilris laser scanner was used. GPS observations on the local control monumentation was collected and tied in to independent offsite control. Using conventional reflectorless total stations, targeted control points were geo-referenced to the project control network. The individual point clouds were merged and a continuous 3D model of the outfall structure was created. Additional color rendering was also performed.

Figure 10-12. Francis E. Walter Dam located in Whitehaven, Pennsylvania. Concrete outfall structure located on the downstream side of the dam is shown at bottom right.

Figure 10-13. Optech Iris Unit positioned in center of river bed at the Francis E. Walter Dam site located in Whitehaven, Pennsylvania.

Figure 10-14. Reflectorless Total Station was utilized to georeference scanner data to project control network