14. TERRESTRIAL AND MOBILE LASER SCANNING FOR STRUCTURES AND THE COLLECTION OF DIGITAL TERRAIN DATA AND ROAD SURFACE MARKINGS

This chapter deals with the survey of Bridge Structures, the survey to create a Digital Terrain Model (DTM) and the survey of Road Surface Markers. In the case of a Bridge Structure, a Stationary Terrestrial Laser Scanner is used. In the case of a DTM and the survey of the Road Surface Markings both a stationary terrestrial and a mobile scanner can be used. Such survey (3D model) may be utilised by a Consulting Engineer for actual detail design work.

14.1. General terrestrial Laser Scanning requirements

14.1.1 Phases of the survey

a) The following is generally recognised as separate phases with respect to a 'scanned' survey:

i) **Mission planning:** This being the planning of the survey in order to ensure that the required results are obtained;

ii) **Data collection:** This being the actual 'scanning' of the terrain/structure i.e. collection of the raw scanned information; and

iii) **Data processing:** This being the processing of the raw 'scanned' data, the referencing and calibration of such data onto the control points, the line work for structures, Road Surface markings, the determination of break lines and the creation of a Digital Terrain Model (DTM). The DTM must then be matched with the conventional surveyed data outside of the Road Surface in order to generate a combined dataset for the entire project.

14.1.2 Stationary Terrestrial Laser Scanning (STLS)

Stationary Terrestrial Laser Scanning (STLS) technology incorporates a tripod mounted laser scanner which captures high density readings which create a Point Cloud from which a drawing and a DTM model may be created and which accurately represents the area scanned in 3D.

Point Clouds must be absolutely orientated to a specified Survey System using geo-referenced control points.

STLS must comply with the requirements as prescribed in Chapter 6 "TOPOGRAPHICAL SURVEYS".

14.1.3 Mobile Terrestrial Laser Scanning (MTLS)

Mobile Terrestrial Laser Scanning (MTLS) technology that incorporates a laser scanner(s), a Global Navigation Satellite Systems (GNSS), an Inertial Measurement Unit (IMU) and in some instances a digital imaging mobile platform which produces accurate and precise geospatial data in colour. This data is initially adjusted via post-processing using kinematic Global Navigation Satellite Systems (GNSS) procedures and which are referenced to separate GNSS base stations which are positioned over the entire project area. This GNSS output is then combined with information from the Inertial Measurement Unit (IMU) resulting in geospatial data in the form of a Point Cloud. The Point Cloud is adjusted by a local transformation using control points positioned over the entire project area and which then produces final geospatial data. This data must then be verified by establishing a comparison model from independently surveyed 'check' points.

MTLS must comply with the requirements as prescribed in Chapter 6 "TOPOGRAPHICAL SURVEYS".

Note: Standards of accuracy as prescribed in Chapter 3 "SURVEY REGULATIONS AND STANDARDS OF ACCURACY" must be complied with when employing MTLS and STLS technology.

14.1.4 A Registered Surveyor in terms of paragraph 1.18 "Registration in terms of the Professional and Technical Surveyors' Act, Act 40 of 1984" shall supervise the scanning work.

14.1.5 Project Selection

a) The following factors must be considered when determining whether STLS or MTLS is suitable for a project:

   i) Safety;

   ii) Project time constraints;

   iii) GPS data collection environment; and

   iv) Project size.

b) Typical cases where the use of STLS/MTLS for topographical type surveys may be employed are:

   i) Surveys from which engineering designs will be created;

   ii) As-Built – of a Road Surface;

   iii) As-Built – of a structure (at present the use of STLS is the preferred method);

   iv) Surveys to determine clearances with respect to Bridges;

   v) Surveys for the determination of lines of sight; and

vi) Surveys to determine earthwork quantities.

14.1.6 Equipment

- The STLS and MTLS equipment must produce data to the specified accuracy for a project.

- MTLS comprises two primary type systems currently supplied by manufactures, namely the survey grade systems and the mapping grade systems. The mapping grade system is mainly used for GIS mapping applications and **may not** be used for topographical survey work. The survey grade system **may be** used for topographical survey work provided the specifications for the registration and geo-referencing of the data are fully complied with.

- All equipment utilised to produce MTLS and STLS data, the control for such data and the undertaking of quality control check readings must comply with the accuracy specifications for a project.

a) Scanners - General

i) Eye Safety

The Surveyor must ensure that written approval from the Department of Health in accordance with their Radiation Control Program is obtained where the use and operating procedures for Laser Scanning are defined. The field Surveyors must successfully conclude a laser safety course as specified by the Department of Health. Proof hereof must be submitted to the Client.

Surveyors must comply with the Occupational Safety and Health Administration (OSHA) – United States Department of Labour Guidelines and Regulation 1926.54 during the period where the written approvals from the Department of Health is awaited. Reference must also be made to OSHA STD 01-05-001 - PUB 8-1.

Generally, the Surveyor must ensure that the 'eye safety' of all concerned, including the general public, is achieved by operating the 'laser' equipment in an appropriate and safe manner.

ii) Scan density (MTLS)

The scan density is determined by the speed at which the MTLS is undertaken. Accordingly this speed must be set so that the required scan density as specified is achieved.

iii) Useful range of scanner

Whilst laser scanners are capable of performing and capturing scanned data over long distances, the scanning work must be planned in such a way as to ensure that the scanned data is always within the working range of the scanner

i.e. the Point Cloud created must comply with the specified accuracy. It is noted that the working range of a scanner is determined by:

- The range and technical specification of the particular type of scanner to be used; and
- The accuracy specifications for the project.

The above is generally achieved by using techniques such as range and/or intensity filtering during the scanning process and/or by the removal of 'out of working range' data during the post-processing phase.

Unlike with total stations, where the use of specialised targets reduces observation errors over long distances, Laser Scanning targets are designed for a specific distance. Further, most laser scanners do not incorporate a telescope and thus orientation of the equipment must follow a particular procedure. This is achieved by the scanning of targets placed on the control beacons and where sufficient data density must be achieved to model their centre points. Generally, cylindrical, spherical or Planar Targets are used where Planar Targets are preferred as they tend to yield the best results.

The target size, its distance from the scanner and the 'laser spot' size will determine how precise the target centre may be modelled. The distance referred to above is critical in the context of the equipment manufacturers' technical specifications and errors increase, in magnitude, exponentially if this distance is exceeded. In this regard the equipment supplier's targets are recommended as these targets are specifically designed for the scanner frequency.

b) Global Navigation Satellite System (GNSS) for MTLS projects

The GNSS equipment may be used provided the requirements for the fixing of Permanent Survey Control as defined in paragraphs 5.1.1(f) "Construction of the Permanent Survey Control beacons", 5.1.1(g) "Vertical fixing of Permanent Survey Control beacons" and 5.1.1(h) "Horizontal fixing of Permanent Survey Control" are fully complied with).

Additional GNSS equipment requirements are:

i) The use of a dual frequency GNSS receiver which is capable of receiving data at 1 epoch per second or faster.

14.1.7 Local transformation – geo referencing (Applicable to both STLS and MTLS)

a) Description

In order to ensure that accuracy specifications are complied with, the Point Cloud must be processed via a local transformation. Whilst there are well-known transformations, the preferred transformation is one where, using a "least squares

adjustment" which incorporates the horizontal and vertical residuals where these are determined by the correlation of pre-established local transformation points with their corresponding points in the Point Cloud and which then result in the relevant transformation parameters known as 'translation', 'rotation' and scale applicable to the horizontal values and an 'inclined plane' for the vertical values being determined. The above named transformation parameters are then applied to the Point Cloud to produce an acceptable and accurate final geospatial dataset.

Due to specific technical limitations, GNSS is not sufficiently accurate for the determination of Road Surface levels. Additional control points (known as local transformation points) must be established within the area to be scanned using MTLS, thus enabling the Point Cloud elevation to be further enhanced in level determination. Again, this is achieved using local transformation techniques where this is based on the independently established validation points (control).

b) Placement of local transformation points – control points

i) The placement of control as described below is applicable only when Point Cloud to Point Cloud registration is used. Refer to paragraph 14.2.1 "Field planning procedures" for control configuration for scanners without a compensator.

ii) For the establishment of survey control for structural surveys refer to paragraph 14.4.1 "Stationary Terrestrial Laser Scanning (STLS)".

iii) The Local Transformation Points must be evenly spaced computations throughout the project area so as to avoid extrapolation during the mathematical computations. The maximum spacing between such points shall not exceed 300m for MTLS and 120m for STLS surveys, reckoned in both sides on a road type survey.

iv) With respect to other types of surveys, control must be 300m and 120m square blocks for MTLS and STLS respectively and be over the entire terrain. Control must always be established so as to avoid any extrapolation.

v) The Local Transformation Points must be surveyed to the same standard or better as for Permanent Survey Control prescribed in Chapter 3 "SURVEY REGULATIONS AND STANDARDS OF ACCURACY". Existing Permanent Survey Control must be utilised to determine the values of the transformation points.

vi) Permanent Survey Control must, in addition to the control required for laser surveys, be established so as to fully comply with the specifications relating to topographical survey projects.

c) Quality assessment plan (QAP) (MTLS and STLS)

i) The Surveyor must submit a Quality Assessment Plan (QAP) to the Client, which plan must also comply with all requirements as prescribed in Chapter 13

"QUALITY CONTROL". This QAP must clearly outline the proposed quality control measures that are to be employed that will achieve the required quality assurance results.

The following check list is a guide for quality assurance:

i) Quality Control (QC) Report

The QC report must have regard to the following:

- Statistical system reports (MTLS and STLS);
- PDOP values during the survey (MTLS);
- Comparison of elevation data from different runs/Overlaps (MTLS);
- Comparison of elevation data from Overlapping (side lap) runs (MTLS);
- Comparison of points at the area of Overlap (end lap) where more than one base is used (MTLS);
- Statistical comparison of Point Cloud data and check points (MTLS and STLS);
- Statistical comparison of adjusted Point Cloud data and redundant check points(MTLS and STLS);
- GNSS Accuracy Report which must include the following (MTLS):
  - Forward/reverse or combined separation plot;
  - Number of satellites bar plot;
  - PDOP, HDOP, VDOP plots;
  - L1 satellite lock/elevation plot; and
  - Estimated position accuracy plot.
- **IMU Accuracy Report which must include the following (MTLS):**
  - IMU position RMS plot; and
  - GNSS/IMU position differences plot.
- **Control Report which must include the following (MTLS):**
  - Table showing the dB between GCPs and known points;
  - Average, minimum and maximum dB; and
  - Average magnitude, RMS and standard deviation
- **Control survey report (MTLS and STLS);**
- Scan seam comparison of elevation data from Overlapping scans **(STLS);**

- **Statistical comparison of Point Cloud data and control points (MTLS and STLS);**

- **Check cross section data and results (MTLS and STLS).**

- **Point Cloud**

- **The Point Cloud must be filtered to one layer of points which represents the mean value of all scans; and**

- **The "noise" must be removed.**

ii) Check Points Measurements

- The 30m road edge quality control points, if so instructed by the Client, and the 300m cross-sections points in Chapter 13 "QUALITY CONTROL" must also serve as the check points for the laser survey. The results must then be submitted as prescribed in Chapter 13 "QUALITY CONTROL".

- Quality control for structural surveys must be undertaken strictly in terms of Chapter 8 "ENGINEERING AND CONSTRUCTION SURVEYS" paragraph 8.7.3(e) "Quality control".

- Check point elevations must be surveyed using techniques that are capable of achieving a higher accuracy than a MTLS system can achieve. These checks must be undertaken within a maximum spacing of 300m and as prescribed in Chapter 13 "QUALITY CONTROL". The check points must not be used in the transformation.

Note: In addition to the prescribed quality control survey, suitable additional quality checks must be undertaken; and

- Where STLS of structures is undertaken then ten random check points must be surveyed using a total station. The coordinates and heights thereof must then be compared with the final scanned model.

iii) Accuracy Achieved

- The accuracy which is claimed to have been achieved for the final STLS and MTLS geospatial data must comply with those prescribed in Chapter 3 "SURVEY REGULATIONS AND STANDARDS OF ACCURACY"; and

- The Client must conduct check surveys and an Independent Quality Assurance (IQA) review of the QAP.

14.2 Specific requirements for Stationary Terrestrial Laser Scanning (STLS) on Road Surfaces

14.2.1 Field planning procedures

a) Scanning setups shall not exceed a spacing of 120m;

b) Scanning distances shall not exceed 70m where a 5% to 15% Overlap is maintained;

c) "Grazing ray" observations must be generally avoided where oblique angles must be catered for by overlapping scans;

d) Shadow areas (areas behind obstructions) must be observed by moving the scanner so that these areas are scanned such that the Point Cloud is complete;

e) Where the scanner's instrument height exceeds 1.5m – 1.7m then a heavy duty tripod must be used so as to stabilize the scanner;

f) Scanning shall not be undertaken onto a wet surface;

g) In determining the scanning density, regard must be had to the possible need to extract specific detail, such 'Road Surface markings', directly from the Point Cloud. Where a DTM (grid spacing of 2m x 2m) must be finally produced (refer to paragraph 14.2.3 "Deliverables") then a minimum scan density of 500mm must be used which may require further adjustment for steeper gradients;

h) A suitable number of control points must be observed during the scan so as to achieve the accuracy specified. These must then be used for the geo-referencing of the scanned data. Where the scanner used does not have a compensator then a minimum of 4 (four) points must be observed from each setup. For scanners with a compensator then a Point Cloud to Point Cloud correlation may be used as prescribed in paragraph 14.1.7 "Local transformation – geo referencing (Applicable to both STLS and MTLS)"; and

i) The 'edge of the road' shall be surveyed at 30m spacings and using conventional survey techniques (using a total station) and which points must then be utilised for the quality control on the scanned data if instructed by the Client.

14.2.2 Office procedures and reporting

It is noted that there are two methods for referencing the scans, namely, Point Cloud scan to Point Cloud scan or by way of the utilisation of the Permanent Survey Control.

In both of the above instances a report must be compiled. Where the former method is preferred by the Surveyor then the procedures as defined in paragraphs14.1.7(b) "Placement of local transformation points – control points" and 14.1.7(c) "Quality assessment plan (QAP)" must be used.

14.2.3 Deliverables

a) Deliverables as defined and described in Chapter 12 read together with Chapter 6 “TOPOGRAPHICAL SURVEYS” must be submitted.

b) In addition to the above, the following must be extracted from the geo-referenced scanned data and submitted:

i) Crown point of the road where applicable;

ii) Coded detail and line data utilising standard codes as per **Annexure 15**;

iii) Surface data for modelling based on a grid spacing of 2m x 2m (DTM);

iv) Surface changes (break lines) and any depressions etc. on the Road Surface;

v) Drainage and other visible structure detail which was possible using the laser scanner;

vi) Where more than one survey technique is utilised (e.g. use of GPS and Total Station) then the data extracted must comply as prescribed in paragraph 14.1.1 “Phases of the Survey”; and

vii) Quality control (QC) report for STLS projects.

14.3 Specific requirements for Mobile Terrestrial Laser Scanning (MTLS) on roads

14.3.1 Establishment of global navigation satellite system (GNSS) Control Stations

a) The ‘dual redundant’ GNSS Control Stations (utilised to control the post-processed kinematic adjustment of the MTLS dataset) must be established at a maximum spacing of 15km so as to ensure that the processed baselines do not exceed 7.5km in length. At least two Control Stations must be established at the start and end of a project respectively. With respect to large projects, additional Control Stations may require to be established so as to comply with the constraints imposed on the baseline distance; and

b) The horizontal and vertical accuracy standards as prescribed for Permanent Survey Control in Chapter 3 “SURVEY REGULATIONS AND STANDARDS OF ACCURACY” will apply to GNSS Control Stations. The Client may however specify more stringent accuracy requirements. It is further noted that the elevations of the GNSS Control Stations must be established only by the use of spirit levelling (double-run).

14.3.2 Field survey planning

a) Prior to the commencement of a MTLS project, an appropriate ‘mission planning’ session must be conducted so as to ensure that, during the scanning operation,

sufficient and suitably located satellites are continuously available and that the Position Dilution of Precision (PDOP) specifications are adhered to;

b) A minimum of five (5) suitably located satellites must remain in view at any point in the scanning exercise from the GNSS Control Stations and the GNSS unit within the MTLS system. Further, the maximum PDOP must not exceed five (5);

c) A reconnaissance of the project area must be conducted so as to minimise the "noise" created from traffic and other factors during the scanning operation;

d) Scanning shall not be undertaken onto a wet surface;

e) In determining the scanning density, the possible need to extract specific detail, such as 'Road Surface markings', directly from the Point Cloud must be considered. Where a DTM (grid spacing of 2m x 2m) must finally be produced (refer to paragraph 14.2.3 "Deliverables") then a minimum scan density of 500mm must be used which may require further adjustment for steeper gradients;

f) If instructed by the Client, the 'edge of the road' shall be surveyed at 30m spacings and using conventional survey techniques (using a total station) and which points must then be utilised for the quality control on the scanned data;

g) "Grazing ray" observations must be generally avoided where oblique angles must be catered for by Overlapping scans;

h) Shadow areas (areas behind obstructions) must be observed using a Stationary Terrestrial Scanner or Total Station so as to complete the Point Cloud;

i) The careful monitoring of the various aspects of the scanning operation is imperative and will determine the adequacy of the QA process. Accordingly, the Surveyor must take appropriate and timeous actions where the operation incurs adverse conditions which could have a materially negative impact on the final results; and

j) The MTLS equipment must be continuously monitored throughout the data collection operation in order to manage the following aspects:

   i) Degraded or loss of GNSS reception;

   ii) Distance travelled during and the time duration of degraded or loss of GNSS reception (resulting in IMU drift which cannot be corrected for);

   iii) Correct functioning of the laser scanner; and

   iv) Vehicle speed determined by the required point density.

14.3.3 Calibration of equipment

Prior to and after collecting of MTLS data all equipment in the MTLS system must be calibrated in accordance with the manufacturer's specifications. Calibration results must be submitted together with the project survey data.

14.3.4 Test run

a) In order to ensure the accurate collection of MTLS data, a ‘test run’ must be conducted. The test run must be of a sufficient length and duration so as to ensure that the system is functioning and collecting data correctly; and

b) Such test data must be submitted on completion of the survey project.

14.3.5 MTLS under structures

Due to the fact that the GPS system will experience loss of satellite coverage when proceeding under structures, the Inertial Measurement Unit (IMU) readings must be closely monitored. Where a separation is evident then STLS data must be observed and later combined with the MTLS dataset so as to enhance the quality of the MTLS data under the structure. Such events may also be experienced in built up and mountainous areas together with high vegetation such as forests which could result in loss of satellite coverage.

14.3.6 Redundancy

a) The collection of MTLS data must be undertaken to achieve a given redundancy with respect to such data collected;

b) The above effectively means that an ‘Overlap’ of scanned data must be provided for which ‘Overlap’ may be achieved by:

   a. Two or more passes in the same direction; or

   b. Overlapping passes in opposite directions; or

   c. A combination of the above.

c) With respect to the ‘side’ Overlap of passes in opposite directions, the redundancy shall be determined by a minimum of 20% of the ‘pass width’; and

d) The time period between passes must be determined so as to ensure that the satellite constellation has materially altered (minimum 1 hour).

14.3.7 Check list for documentation to be submitted on completion (where such information must be confirmed prior to the field operations):

a) Who is the project manager;

b) Purpose of project mapping;

c) Map units;

d) Project coordinate system;

e) Scanner calibration data;

f) Proposed driving plan;

g) GNSS visibility report;

h) Suitable driving speed to obtain required point density;

i) Proposed base station locations;

j) Proposed Ground Control Points (GCPs);

k) Proposed check points; and

l) Driving Plan.

14.3.8 Deliverables

a) Deliverables as defined and described in Chapter 12 “DELIVERABLES” read together with Chapter 6 “TOPOGRAPHICAL SURVEYS” must be submitted.

b) In addition to the above, the following must be extracted from the geo-referenced scanned data and submitted:

i) All data as specified in paragraph 14.3.7 “Check list for documentation to be submitted on completion (where such information must be confirmed prior to the field operations):” ;

ii) Crown point of the road where applicable;

iii) Coded detail and line data utilising standard codes as per **Annexure 15**;

iv) Surface data for modelling based on a grid spacing of 2m x 2m (DTM);

v) Surface changes (break lines) and any depressions etc. on the Road Surface;

vi) Drainage and other visible structure detail which was possible using the laser scanner;

vii) Calibration data; and

viii) Test run data.

14.4 Specific requirements for Stationary Terrestrial Laser Scanning (STLS) of Bridge structures (Also refer to paragraph 8.7 "Structural Surveys – Bridges and Culverts")

14.4.1 Stationary Terrestrial Laser Scanning (STLS)

a) Field Planning Procedures:

i) All scanned models must be geo-referenced to the Permanent Bridge Control points established at each structure;

ii) Additional control points must be established around the structure where the accuracy of such control must comply with the specified accuracies for Permanent Survey Control;

iii) Scanning observations from control points shall not exceed 70m;

iv) Scanning must be undertaken where the maximum scanned distance shall not exceed 70m from the Bridge structure and where a 30% Overlap is achieved between adjacent scans. In the event that the 70m distance constraint must be exceeded due to circumstances beyond the Surveyor's control, then additional control points must be established on the Bridge structure itself. In such event additional scans shall be observed so as to increase the density of the final geo-referenced Point Cloud. This is generally encountered with extremely high Bridges;

v) In determining the scanning density, regard must be had to the possible need to extract specific detail directly from the Point Cloud. The following minimum scanning densities apply:

- Bridge abutments - 5mm;
- Top of Bridge piers and bearings - 5mm; and
- Remainder of the Bridge – shall not exceed 10mm.

vi) A suitable number of control points must be observed during the scan so as to achieve the accuracy specified. These must be used for the geo-referencing of the scanned data. Where the scanner used does not have a compensator then a minimum of four points must be observed from each setup. For scanner with a compensator a minimum of two control points must be observed together with additional observations taken onto an additional control point (redundancy point to serve as a check point); and

vii) All control points must be positioned so that all surfaces of the Bridge are scanned in such a manner to enable and guarantee the correct modelling of the Bridge from the final Point Cloud.

14.4.2 Equipment

Phase based laser scanners have specific limitations and are accordingly not suitable for the scanning of Bridges/structures.

14.4.3 Point Cloud

a) The final Point Cloud must be filtered down to a single layer of points which must represent the mean value of all the scans;

b) The Point Cloud database shall be created using only licensed and registered software;

c) The “noise” must be removed as far as is possible; and

d) The Point Cloud database must be supplied in an ASCII format for importing into other software packages.

ASCII format:

SYMBOL	DESCRIPTION
Y	Y-coordinate value of a point
X	X-coordinate value of a point
Z	Z-coordinate value of a point
I	Laser return intensity value of a point (integer, 0 to 255)
R	Digital image Pixel overlay red component value of a point (integer, 0 to 255)
G	Digital image Pixel overlay green component value of a point (integer 0 to 255)
B	Digital image Pixel overlay blue component value of a point (integer 0 to 255)

Note: The R, G and B component above applies only where the scanner has an on-board camera or a mountable camera system and used at the setup position. Having regard to the use of Point Clouds such as an engineering design tool, it is preferable that the archived database is in ‘full colour’ and where the imagery gathered at each setup is supplied (preferably stitched into a viewable panoramic format of a high resolution for zooming purposes).

14.4.4 ‘Wire frame model’ (Line Mapping)

a) ‘Wire frame models’ should have sections taken at predetermined intervals provided that abutment faces, centres of piers and joint locations are specifically included;

b) Where Bridges are located on a curve then the interval between sections will be determined by the radius of the curve i.e. the tighter the curve the shorter the distance between wire frame sections;

c) The long section should follow the Bridge soffit;

d) The wire frame model must accordingly represent the Bridge accurately; and

e) The following features must at the very least be specifically sectioned:

i) Piers – showing the top of the pier;

ii) Abutment – including the bearing seat;

iii) Wing walls;

iv) Bearings;

v) Soffit;

vi) Balustrade detail; and

vii) Deck.

14.4.5 Additional deliverables

All deliverables as prescribed in Chapter 12 “DELIVERABLES” must be supplied and all data must comply with the specification prescribed in paragraph 8.7 “Structural surveys – Bridges and Culverts”.

Acknowledgement: The Majority of these specifications were obtained from the Californian Department of Transportation Survey Manual: Terrestrial Laser Scanning Specifications: CULTRANS