RESEARCH

UDOT CONNECTING COMMUNITIES

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CONSTRUCTION MACHINE CONTROL GUIDANCE IMPLEMENTATION STRATEGY

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Research Division

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16. Abstract

Machine Controlled Guidance (MCG) technology may be used in roadway and bridge construction to improve construction efficiencies, potentially resulting in reduced project costs and accelerated schedules. The technology utilizes a Global Positioning System (GPS) in conjunction with 3-D computer models to determine the precise location and elevation of construction materials. This technology is currently being used on dozers, graders, scrapers, and excavators. UDOT must develop procedures and specifications to address the potential issues associated with the use of this technology.

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EXECUTIVE SUMMARY

The objective of this research is to provide an understanding of and to outline the advantages, disadvantages, and department procedures for using Machine Controlled Guidance technology. The research objectives are to describe contract negotiations, define the design survey requirements, analyze the design process, examine advertising requirements, recommend pre-construction formats, and describe the construction process.

1.0 INTRODUCTION

1.1 Technology Description

Machine Controlled Guidance (MCG) technology has been developed to improve construction efficiencies resulting in reduced cost and accelerated schedule, by enabling contractors to reduce construction survey stakeout, as well as improve construction quality by ensuring uniform and consistent surfaces. MCG technology utilizes a Global Positioning System (GPS) and a three-dimensional computer model of the road design to guide equipment used to place, level, and compact materials used in road construction. Although MCG has proven to be advantageous to the construction of roadway projects, issues remain in the establishment of project survey control, preparation of design files, and verification of the specified construction tolerances.

Use of GPS to guide earth moving equipment such as dozers, graders, scrapers, and excavators is quickly becoming common place in private sector and DOT construction because of its ability to speed project delivery and cut costs. As more state highway projects are constructed using MCG technology it is necessary that UDOT develop procedures and controlling specifications to address potential issues associated with use of this technology, including questions about vertical accuracy (i.e., error margins in vertical control) and liability issues (i.e., digital design file accuracy).

1.2 Project Approach

The background information for this research comes from through literature reviews and site visits to construction projects where MCG was being used for earth moving, grading, utility installation, and concrete paving operations. Advice and suggestions for project implementation were provided by a Technical Advisory Committee (TAC) formed by UDOT employees, representatives of WW Clyde and Geneva Rock (contractors who currently work with MCG), and engineers from Horrocks. In several meetings, participants were asked to address issues and provide input. In addition, guidance for both design and construction were developed to address issues not included in the specification and to assist field and office personnel in meeting the requirements of the specifications. Horrocks Engineers gained additional information from pilot projects. This experience provided knowledge that helped refine the current specification and guidance of the implementation of GPS machine guidance.

2.0 DESIGN AND CONSTRUCTION CONSIDERATIONS

2.1 Design and Models

Engineers designing for road construction projects have traditionally developed CAD files and partial three-dimensional (3-D) models representing the desired construction activities. These design files are then incorporated into plans, specifications, and estimates as the primary means of communicating the construction activities. The 3-D models, which may vary in terms of completeness and accuracy, are typically not provided to the contractor.

When utilizing MCG technology the designer(s) should prepare complete and accurate 3-D models for the contractor's MCG system. These 3-D models are then provided to the contractor to be used for information and comparison as they prepare their own 3-D model. The models may be checked against each other to ensure accuracy. Ultimately the contractor is responsible for the 3-D model(s) used for MCG on the project. Utilizing a computer, the contractor's equipment can then be positioned within the 3-D model by registering its x, y, & z coordinates for the machine to the local coordinates of the model. Currently MCG is used with excavators, graders, scrapers, and dozers.

The group involved in the research has been evaluating software products and formats that support three-dimensional engineering design. The design files, which are typically MicroStation and InRoads files, must be converted into a format that the equipment can read. Based on industry standards the preferred format is LandXML files, because the majority of MCG software packages will accept this format. The LandXML files are then translated by the MCG software packages into their own proprietary format. The design linework files should also be exported out to a .dxf file format to be used in background maps and linework for the 3-D models. The .dxf file is nearly as important as the LandXML file to ensure the accuracy and completeness of the 3-D model.

The move towards 3-D Modeling however involves more than just exporting design files. It requires a new way of thinking about how the world is represented and how the work is done. Recommendations for implementing this technology include: modifying the design and construction survey standards and procedures, and creating complete and accurate 3-D models. MCG requires designers to prepare an accurate and complete model with the CADD software. This model is a three dimensional representation of all the construction phases of all the roadway features being built with MCG as they would be placed on the ground. Additional attention must be given to details at more complex locations, such as road intersections, where slope transitions, curb returns, and pavement warping should also be accurately modeled.

2.2 Time Savings

The contractor can accelerate some construction activities with MCG because of reduced construction staking. Survey and design elevation conflicts can be spotted before construction begins. MCG requires less survey field work than the conventional design, survey, build process, with fewer machines and applications, no waiting for surveys, and no re-surveys. The survey preparation work is roughly equivalent to non-MCG project survey preparation.

2.3 Risk

There are always some risks and issues when implementing a new technology such as MCG. These risks include:

1. Vertical accuracy requirements. The use of GPS has the potential to introduce errors in vertical accuracy. In order to minimize this risk the UDOT survey specification should be modified (see section 2.6 Design Survey).
2. Liability issues. UDOT has concerns over the responsibility of discrepancies between the 3-D model and the project plans. In order to minimize this risk all 3-D models should receive a full QC/QA audit.
3. Construction inspection and Documentation Requirements. MCG will require UDOT to change their inspection process due to the reduction in survey staking. This has the potential to reduce UDOT's ability to check grades for accuracy. In order to minimize this risk the contractor should be required to submit additional documentation to verify the accuracy of the 3-D models and of the work performed using MCG equipment (see section 5.3 Inspection Method).

UDOT should develop policies identifying areas of responsibility between contractor and owner.

2.4 Project Scoping

The decision to use MCG Technology for construction should be made during the project scoping and design phase and requires the decision to develop a 3-D model. The decision to use this technology on a specific project should be based on, but not limited to, the following project characteristics, recognizing time and money:

1. New roadway construction
2. Total roadway reconstruction
3. Significant changes to the terrain surface
4. Large cut/fill slopes
5.

Careful consideration should be given when considering using MCG on widenings, extremely flat grades, and flat pipe installations, due to the vertical limitations of GPS technology.

The owner considering using MCG should at least provide 3-D models of the proposed finished surface for all of the project's work areas. All elements of the roadway, including intersections, curb returns, slope transitions, etc. should be modeled in 3-D.

2.5 Design Deliverables

The designer must produce and furnish the contractor with the following information and files:

1. 3-D model of finished roadway surface(s)
2. LandXML files for pertinent ALG and DTM files
3. .dxf background file
4. Elements to include:
    - Roadway features such as profile grade line, axis of rotation, edge of pavement, curb and gutter features, sidewalks, walls, slope break lines, toe of slope, etc
    - Drainage features such as cut ditches, ponds, swells, etc
    - Other features such as large pipes and major utilities may be included, depending on project needs and characteristics

This information will assist the contractor is producing and verifying their 3-D model(s) for MCG. These files will be provided to the contractor "for information only", with the contractor responsible for producing the final 3-D model(s).

2.6 Design Survey

The current UDOT Survey Specification, number 01721, should be modified for MCG. The following are proposed changes to the current survey specification:

1. Control points must fully encompass project limits
2. Control points must not all be in a straight line (may result in project tilt)
3. Control points must be set a maximum spacing of 1000', with a minimum of 6 points
4. Control points must include a minimum of 4 wing points which encompass the project limits and are a minimum of ¼ mile off centerline
5. Establish bench mark controls in 4 quadrants of the survey area
6. Require differential leveling for vertical control procedures on all projects
7. Specify the control points to use for calibration in the project plans (only include points to be used)
8. Require all surveys performed on the project to use the same calibration

Any additional control points needed by the contractor will be the contractor's responsibility. These additional points will follow the same standards.

These requirements should be established for all GPS surveys, not just surveys for MCG projects. We recommend UDOT create a GPS survey user's manual similar to the Texas

Dept of Transportation's "TxDOT GPS User's Manual" (available at http://onlinemanuals.txdot.gov/txdotmanuals/gps/index.htm).

We also recommend that additional changes be made to the 01721 specification to establish construction survey control and construction staking tolerances that are realistic and achievable. The changes would include:

1. Requiring reference/location stakes be placed every 100 ft for each alignment
2. Modifying the tolerances in Table 1, and adding a column for which type of survey equipment is acceptable for the different staking elements
3. Requiring a minimum of 3 control points be established for bridge construction. The established points would be required to meet the tolerances specified relative to each other and to the nearest survey benchmark.

These changes would apply to all projects, not just those utilizing MCG.

These changes will address the survey issues in construction. However, changes also need to be made to standard practices and procedures to establish adequate survey control during the pre-construction phase. The accuracy of the control established during design should meet the same requirements required of the contractor established control during construction. We recommend UDOT establish a procedural manual for setting project control, update the UDOT Mapping and Aerial Photogrammetry manual, update the Manual of Instruction, and revise the Design Network in order to create these survey control standards.

2.7 Survey Stakeout Revisions

The revised survey specification should require the surveyor to verify the positional tolerance of the DTM surface elevation by comparing the original collected point data with recollect point data which are measured at the same horizontal locations. No feature positional tolerance verification using field comparisons to interpolated DTM surfaces or recreated surface information (from paper drawings) should be allowed. Comparisons of re-measured point data should be made with the original collected point data only, not to interpolated positions. The surveyor should be required to verify DTM points from the contract control network, using instruments with equal or greater precision than those used to set those points.

3.0 DESIGN PROCESS AND PROCEDURES

3.1 Specifications

We recommend that when planning to allow MCG on a project a special provision be written during the preconstruction phase with specific information and direction to use MCG for that project.

3.2 QC/QA

The 3-D model and all other elements required for MCG should be independently reviewed before bid. A third party (someone other than the designer) should check the model for completeness and accuracy.

- Design: require the designer to provide documentation that a full quality control and quality assurance check of the 3-D models (and LandXML and .dxf files) is completed prior to advertising the project. This includes verifying the horizontal and vertical accuracy of the points and lines contained in the models.
- Construction: require the contractor is responsible to perform a full quality control and quality assurance check of the 3-D models to be used for MCG. Documentation of the QC/QA process must be provided to the UDOT Engineer prior to using the models in construction.

3.3 Quantity

The quantities for all items associated with MCG shall be calculated using the Measurement and Payment document for Earthwork, Plan Quantities, or Lump Sum.

4.0 PROJECT ADVERTISING (Contractor Vs. Engineer's Perspective)

4.1 Contractor

Difficulties in development of the three-dimensional models can arise from inconsistencies in the original plans and in the content and the format of the electronic files.

The contractor using MCG needs 500 feet spacing on control points to minimize geoid tilt. For this reason, the contractor prefers using single source of all control information, single source for all electronic data, conducting their own quality control checks in the field, and having quality assurance checks made by their source.

4.2 Engineer

When planning to allow the use of MCG the contractor should be involved in setting the project controls, GPS calibration, and coordinate system transformations. Problems can arise within a project if the control is not well-distributed for calibration, or between adjacent projects if they have independent control networks. These problems may include a tilt or rotation in the survey and/or differences in vertical elevations, thus resulting in potential construction errors such as grade issues, subgrade or pavement section thicknesses, and drainage problems. UDOT is also concerned about the responsibility for an error in the 3-D model.

When planning to allow the use of MCG on a project a 3-D model should be prepared for the bid package and be made available for the contractors in a usable digital format. This will allow for time saving and accurate bidding and should eliminate some risks. The advertisement package shall include type of survey information, such as aerial mapping, or field survey. It shall also explain in the Measurement and Payment document how the quantities were developed.

4.3 Pre-Construction Conference

All projects that are scoped to include MCG technology should hold a pre-construction conference to inform the Contractors of the process and deliverables. The preconstruction conference shall include the following items:

- Agree on model to be used
- Agreement of the control to be used
- How the quantities are to be calculated or lump sum
- The amount of survey control

5.0 CONSTRUCTION PROCESS AND PROCEDURES

5.1 Survey Method

The rewrite of the 01721 survey specification shall define the construction survey requirements and procedures. This specification will outline the required contractor submittals, QC/QA process for the contractor's 3-D model(s), and survey stakeout requirements.

5.2 Survey Tolerances

All MCG machines must to equipped to shut off when the survey tolerances defined in the specifications are exceeded.

5.3 Inspection Method

Changes are required to the construction inspection process to accommodate the use of MCG. The contractor should be required to submit documentation of QC/QA for all 3-D models used on the project. The 01721 specification rewrite should identify the frequency of location stakes, cross section survey locations, and grade stakes for survey inspection. The contractor should be required to submit Electronic and/or hand written stakeout/cut-fill report(s) for cross section stakes. The contractor should perform the QC/QA for these points and submit to the Engineer for approval. The contractor should also be required to set project bench marks that the MCG equipment will be required to check in to at least once per day to ensure setup and tolerances are within requirements. In addition, the contractor should be required to provide an equipment rover for UDOT to inspect as desired.

5.4 Inspection Training

UDOT should develop a training process for inspectors that will be used on the MCG project. The contractors could assist in the training of these inspectors by getting them familiar with the equipment and how it works.

6.0 CONCLUSIONS

MCG could reduce the project cost and time of construction projects by improving construction efficiencies. MCG technology utilizes GPS in combination with 3-D computer models to determine the exact location of construction materials being placed on a project and to control robotic construction machinery. The use of MCG requires less survey staking and reduces survey and design errors to provide smoother, more consistent finished surfaces. The following issues should be addressed when considering MCG: the establishment of project survey control, preparation of the required design files, and verification of construction tolerances.

In order to effectively implement this technology changes need to be made to the design process, design survey process, construction survey process, and construction inspection process. The use of MCG technology on a project should be made early on in the design process. Designers of these projects need to develop complete and accurate 3-D models of the entire roadway(s). These surfaces will be converted to LandXML and .dxf files and provided to the contractor. Special Provisions will also need to be included in the project plans to address the construction tolerances and documentation and inspection process. The design survey process must also be revised to ensure that the control points and bench marks used are adequate for the MCG system.

The contractor will use the Special Provisions, LandXML files, and .dxf files to create a 3-D model of their own. This model must be thoroughly and independently checked by the contractor for accuracy, as it will be used by the MCG equipment on the project. The contractor will be required to submit stake out reports to the UDOT Engineer to ensure the accuracy of the MCG equipped machines.

Before this technology can be fully implemented UDOT will need to complete the rewrite of the 01721 specification, develop the documentation requirements, and train project inspectors in MCG. The specification rewrite should also address tolerance requirements for construction survey control and construction staking. The tolerances should be realistic, achievable, and enforceable. The contracting community will need to continue to be highly involved in these activities.

Standards and criteria also need to be created and adhered to for establishing survey control during the pre-construction phase. The survey control established during this phase should meet the same tolerance requirements as those required during construction. Creating these standards will help to resolve the current survey control issues that are present on many projects.

REFERENCES

TxDOT GPS User's Manual, Texas Department of Transportation, 2005 (available at http://onlinemanuals.txdot.gov/txdotmanuals/gps/index.htm)

The Bottom Line: Machine Control and American Transportation Agencies, Machine Control Online, Paul F. Hahn, September 2009 (available at http://machinecontrolonline.com)

APPENDIX A

SPECIAL PROVISION

SECTION 01721M

SURVEY

Add the following to Article 1.1 SECTION INCLUDES:

1.1 SECTION INCLUDES

C. Processes and procedures for implementing Machine Control Guidance (MCG) technology. MCG utilizes Global Positioning System (GPS) and/or Robotic Total Station (RTS) in conjunction with three-dimensional computer models to determine the precise location and elevation of the materials being moved.

Delete Article 1.5 and replace with the following:

1.5 SUBMITTALS

A. The Department requires that all submittals be signed and sealed by a Professional Engineer or Professional Land Surveyor licensed in the State of Utah.

B. Resubmittals may be required depending on completeness and correctness of the work.

C. Submit a statement five (5) days prior to beginning work indicating all Department-provided horizontal and vertical control have been field checked and the control has been determined to be sufficient to stake the construction within the tolerances specified in this section.
   1. Attach field survey information used to verify control.
   2. Notify the Engineer verbally and in writing if discrepancies are found.
   3. Include any additional survey points required to implement the MCG/RTS technology.

D. Provide a written description of the equipment prior to beginning work including calibration certifications (or published equipment accuracy standard), manpower, methods, and data storage format proposed for use to complete all survey activities.

E. Record keeping: Keep all field notes, diaries, and books according to standard surveying practice.

1. Loose leaf books are not acceptable.
2. Make available at any time all survey records including field notebooks and forms used for the work to the Engineer upon verbal or written request.

F. Submit all surveying and design data requirements:
1. Return all surveying and design data to the Engineer after project completion.
2. Provide a red-lined hard copy plan set showing as-constructed features denoting changes from the original design.
3. Provide an electronic copy of the red-lined 11 x 17 as-constructed plan, containing the "As-Built" stamp dated and signed by the Engineer, in a colored PDF format as follows:
   a. Resolution of not less than 400 dpi
   b. Individual file sizes not greater than 10 megabytes\
   c. Group similar sheet types together into individual PDF files. For example: Summary Sheets grouped together in a single PDF file or Summary Sheets and Plan and Profile Sheets grouped together in a single PDF file.
   d. Provide electronic files on CD.

G. Survey Monuments:
1. Refer to this Section, article 3.12, and paragraph C3 for submittal of drawings and notes.

H. Machine Control Guidance technology implementation: Provide the following:
1. Written notification to the Engineer that MCG will be used on the project.
2. Electronic and/or hand written stakeout/cut-fill report(s) for cross section stakes, in accordance with Section 3.5. Reports are not required when measurement of work is by "Plan Quantity" or Weight.

Add the following to Article 1.7 PAYMENT PROCEDURES

D. Include the costs of all machine control equipment in equipment cost. Include all survey equipment and labor in the bid item for survey.

Delete Articles 1.8 and 1.9 and replace with the following:

1.8 QUALITY ASSURANCE

A. Contractor is responsible for survey and control of the work and for correcting Contractor errors whether the errors are discovered during the actual survey work or in subsequent phases of the project and bears any cost overruns resulting from errors.

B. Perform all work in accordance with the plans and specifications and standard Engineering and Surveying practices under the responsible charge of a Professional Engineer or Professional Land Surveyor licensed in the State of Utah.

C. The Engineer may spot check the work for accuracy or conduct verification surveys. Unacceptable portions of work will be rejected. Resurvey rejected work and correct work that is not within the specified tolerances at no additional expense to the Department.

D. The contractor is responsible for creating and verifying, under the responsible charge of a Professional Engineer or Professional Land Surveyor licensed in the State of Utah, any 3-D model(s) that will be used in conjunction with Machine Control Guidance. The contractor is also responsible for correcting any construction errors that result from errors in the 3-D model(s). Obtain written acceptance of the model from the Engineer prior to beginning work.

Add the following to PART 2 PRODUCTS:

2.2 EQUIPMENT FOR DEPARTMENT USE

A. Provide and maintain the following equipment when MCG is to be used on the project:
   1. GPS Capable Rover compatible with the other GPS equipment being used on the project.
   2. Other hardware and software associated with the equipment so that Department personnel can operate the equipment for quality assurance purposes.
   3. Provide adequate training so that Department personnel can operate the survey equipment.
   4. Contractor will make available GPS rover immediately upon request from Department.
   5. Jointly develop a process with the Department for Department to check-in and check-out equipment from contractor.

Add the following to Article 3.1, paragraph E:

6. For projects implementing Machine Control Guidance, the Department furnishes 3-D data consisting of:
   a. LandXML files for the Design Digital Terrain Model(s) (including features).
   b. LandXML files for the Design Alignment(s)

Replace Article 3.3, paragraph B with the following:

B. Engineer may approve alternate methods of calculating quantities. Submit proposed alternate method of quantity calculation prior to beginning item of work.

Replace Article 3.4, paragraph B with the following:

B. Provide and maintain reference/location stakes that identify stationing at least every 100 ft until all work has been completed and accepted by the Engineer for each alignment. Provide reference/location stakes at whole station intervals (i.e. 1032+00) for each alignment.

Delete Table 1 and replace with the following:

Table 1

Survey Control For Construction Staking			
Description	Horizontal	Vertical	Equipment Selection
Contractor provided construction control	± 0.01’	1:100,000	Total Station (H only), Robotic Total Station (H only), GPS (H Only), Differential Level (V Only)
Reference/Location points	± 0.03’	-----	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only)
Cross sections and slope stakes	± 0.10’	± 0.10’	Total Station (H,V), Robotic Total Station (H,V), GPS (H,V)
Slope stake references	± 0.10’	± 0.10’	Total Station (H,V), Robotic Total Station (H,V), GPS (H,V)

Table 1 (Cont.)

Culverts and Ditches	± 0.10’	± 0.05’	Total Station (H,V), Robotic Total Station (H,V), GPS (H,V)
Minor drainage structures	± 0.10’	± 0.03’	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only), Differential Level (V Only)
Curb and gutter	± 0.05’	± 0.02’	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only), Differential Level (V Only)
Guardrail and concrete barrier	± 0.05’	± 0.05’	Total Station (H,V), Robotic Total Station (H,V), GPS (H,V)
Retaining walls	± 0.05’	± 0.03’	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only), Differential Level (V Only)
Bridge substructure and overall	± 0.01’	± 0.01’	Total Station (H Only), Robotic Total Station (H Only), Differential Level (V Only)
Bridge superstructure and overall	± 0.01’	± 0.01’	Total Station (H Only), Robotic Total Station (H Only), Differential Level (V Only)
Environmental Control Limits	± 1’	-----	Total Station (H), Robotic Total Station (H), GPS (H)
Clearing and grubbing limits	± 1’	-----	Total Station (H), Robotic Total Station (H), GPS (H)
Right of Way Limits (fencing)	± 0.03’	-----	Total Station (H), Robotic Total Station (H), GPS (H)
Roadway sub grade finish stakes	± 0.10’	meet tolerance of succeeding layer	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only), Differential Level (V Only)
Roadway finish grade stakes	± 0.04’	meet tolerance of succeeding layer	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only), Differential Level (V Only)
Signals and electrical	± 0.05’	± 0.05’	Total Station (H,V), Robotic Total Station (H,V), GPS (H,V)

Table 1 (Cont.)

Striping	± 0.08’	-----	Total Station (H), Robotic Total Station (H), GPS (H)
Paving reference line: Rigid Pavement	± 0.04’	± 0.02’	Total Station (H only), Robotic Total Station (H only), GPS (H Only), Differential Level (V Only)
Paving reference line: Flexible Pavement	± 0.10’	± 0.05’	Total Station (H,V), Robotic Total Station (H,V), GPS (H Only), Differential Level (V Only)
Milepost Sign	± 1’	-----	Total Station (H), Robotic Total Station (H), GPS (H)

Coordinate the survey tolerances of any items not listed above with the Engineer.
Tolerances given above are subordinate to any tolerances listed in other specifications.

Replace Article 3.5, paragraph D with the following:

D. Staking limits – Reference / Location stakes can serve the purpose of the following staking requirements as long as all required information for both purposes can be written on the stake.

1. Stake clearing limits on both sides of centerline at each established station. Locate the clearing limit on the ground as shown by the cut and fill limits on the plans.
2. Where ROW is not delineated by existing fence lines or other obvious boundaries stake right of way limits, or TCE if one exists, every 500 ft maximum on tangents, every 250 ft maximum on curves. Stake Right of Way limits at all right of way break/angle points along the right of way lines. If staking distance is affected by line of sight, reduce the distance.
3. Stake environmental control limits on both sides of centerline at each established station. Locate the environmental control limits on the ground as shown by the slope rounding contours and environmental and silt fence locations as shown on the Plans. Stake environmental control limits every 25 ft in environmentally sensitive areas. In standard silt fence installations where stations/locations are not called out on the environmental control plan sheets, provide staking as needed to ensure silt fence is located inside of right of way.

Replace Article 3.5, Paragraph E, with the following:

E. Furnish reference stakes for all slope stakes and stakes used for setting items for work.

1. For projects using Conventional Survey Methods furnish the following:
   a. Maintain the reference stakes for the duration of the project until the Engineer approves removal.
   b. Establish and set slope stakes and references on both sides of centerline at cross section locations.

1) Place slope stakes at a maximum centerline spacing of 25 ft when the centerline curve radius is less than or equal to 500 ft.
2) Place slope stakes at a maximum spacing of 50 ft when the centerline curve radius is greater than 500 ft.

c. Establish slope stakes in the field as the actual point of intersections of the design slope with the natural ground line.
d. Set slope stake references outside the clearing limits.
e. Include all reference point and slope stake information on the reference stakes.

2. For projects using Machine Control Guidance Methods furnish the following:
   a. Maintain the reference stakes for the duration of the project until the Engineer approves removal.
   b. Establish and set location stakes and references on both sides of centerline at cross section locations.
      1) Place reference/location stakes at a maximum spacing of 100 ft.
      2) Place cross section stakes at a maximum spacing of 300 ft. Cross section stakes reference physical points in the proposed cross-section, such as centerline and profile grade line, edge of pavement, top back of curb, etc.)
   c. Place slope stakes at a maximum spacing of 300 ft.
   d. Establish slope stakes in the field as the actual point of intersections of the design slope with the natural ground line.
   e. Set slope stake references outside the clearing limits.
   f. Include all reference point information on the reference stakes.
   g. Provide adequate bench marks throughout the project for for construction equipment equipped with MCG to check setup and tolerances. Perform equipment checks at least once per day. Record equipment checks in a log for verification by the Engineer.

Replace Article 3.5, paragraph G with the following:

G. Setting grade finishing stakes (For Conventional Survey or RTS):
1. For grade elevations and horizontal alignment:
   a. On centerline.
   b. On each shoulder at roadway cross section locations and between centerline and shoulder with a maximum spacing of 25 ft.
   c. At the top of sub grade and the top of each aggregate course.
2. Locations:
   a. Set stakes on centerline, on each normal shoulder, and on the shoulder of the turnout where turnouts are constructed.
   b. Set hubs at the center and along the edges of parking areas.
   c. Set stakes in all ditches to be paved.
3. Maximum spacing between stakes along the alignment:
   a. Conventional surveying methods: 50 ft.

b. Machine Control Guidance: 300 ft

4. Use brushes or guard stakes at each grade finishing stake.
5. Reset grade finishing stakes as many times as necessary to construct the sub grade and each aggregate course.

Delete Article 3.5, paragraph H and replace with the following:

H. Grade Verification (for Machine Control Guidance)

1. The following procedure will only be applicable for verification of roadway layers for grade elevations and horizontal alignment the Department will utilize the contractor provided survey equipment listed above. The Department will verify elevations at the following locations:
   a. On centerline.
   b. On each shoulder at roadway cross section locations and between centerline and shoulder with a maximum spacing of 25 ft.
   c. At the top of sub grade and the top of each aggregate course.
2. Locations:
   a. On centerline, on each normal shoulder, and on the shoulder of the turnout where turnouts are constructed.
   b. A the center and along the edges of parking areas.
   c. At the top of subgrade and the top of each aggregate course.
   d. In all ditches to be paved.
3. Department will verify and document elevations at a 300 ft maximum spacing between locations along the alignment.
   a. The Department reserves the right to increase the spacing between grade verification locations up to, but not to exceed, 1000 feet if a level of confidence can be attained by the Engineer.

Replace Article 3.8, paragraph A with the following:

A. Set a minimum of 3 horizontal and vertical control reference points to be used for surveying all bridge substructure and superstructure components, including but not limited to pile locations and cutoffs, line and grade for abutments and bents, beam seats, anchor bolts, and screed grades. The established control points must meet the tolerances specified relative to each other and to the nearest survey benchmark.

Replace Article 3.14, paragraph A with the following:

B. Layout all temporary and permanent pavement markings per Section 02765.

1. Place references for traffic striping a minimum of 150 ft apart on tangents and a minimum of 50 ft on curves.

Replace Article 3.15, paragraph A with the following:

A. Remove and dispose of all flagging, lath, stakes and other staking material after the project is complete.

Add Article 3.17

3.17 EXISTING MILEPOST SIGNS

A. Locate station of all existing milepost signs within project limits.
   1. Contact the Engineer to determine, in coordination with Highway Referencing Specialist of the Asset Management Division, any locations where milepost sign was placed at a point other than the actual mile point due to prior physical limitations such as driveways, intersections or bridge parapets.

B. Reestablish location of milepost signs prior to project completion if construction activities required removal of any existing milepost signs.
   1. Reset sign location at original station of existing sign.
      a. Exceptions:
         1) Any prior physical limitations listed in this Section, article 3.17, paragraph A were removed during construction and no longer prevent installation of a sign at the actual mile point.
         2) Roadside conditions or newly constructed physical limitations would prevent reestablishment of any milepost sign within 3 ft of its original station.
      b. Contact the Engineer to determine, in consultation with the Highway Referencing Specialist, how to proceed in either of these special cases listed in this Section, article 3.17, paragraph B1a.
   2. Establish an appropriate offset for each milepost sign to meet installation and clear zone requirements.

C. Contact the Highway Referencing Specialist through the Engineer to determine the preferred action for reestablishing the milepost signs where the alignment of the roadway was modified during construction to the extent that the new measured mile point locations of any milepost signs were shifted more than 10 ft from their original location.

END OF SECTION

APPENDIX B

MACHINE CONTROL GUIDANCE AND PROJECT SURVEY RECOMMENDATIONS

- Survey Control
  - Accuracy of Control
    - EIS/EA Phase
    - Design Phase
  - Resolve/Establish Control during Preconstruction phase
    - During Design Process (UDOT or Consultant)
    - During RFP Process (Program Manager)
    - Deliverable is survey control sheet (Task in Design Network)
  - Establish criteria for setting design control
    - Same requirements of Contractor established control (H = ±.01', V = 1:100,000)
- Manuals and Documents revisions
  - Establish Procedure Manual for setting control
    - Similar TxDOT manual "TxDOT GPS User's Manual"
    - Update regularly
  - UDOT Mapping and Aerial Photogrammetry
    - Update regularly
  - Design Network
  - Manual of Instruction
  - MS&T and A&D
- 01721M Spec revisions (see attached draft spec)