

Implementation of Automated Machine Guidance (AMG)

Guidelines for Surveys Implementation of Automated Machine Guidance

Department of Transportation
Division of Right of Way and Land Surveys
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Guidelines for the Implementing Automated Machine Guidance

Background

Automated Machine Guidance (AMG) technology applied to highway construction projects provides the opportunity for an integrated and efficient construction process. A trained equipment operator using AMG can perform grading or paving operations with increased safety, efficiency, and accuracy along with less dependency on grade checkers, fewer reference stakes, and other types of surface control points. Use of AMG workflows has the potential to improve design, survey, and construction operations resulting in improved quality and decreased project duration and cost.

Implementation of AMG as a standard practice of constructing highways requires Caltrans to update its processes, standards, and practices. Caltrans project delivery staff, including Surveys, will need to change and adapt current procedures and practices to fully realize the benefits from designing and constructing projects based on a 3D engineered models versus 2D plan sheets.

Project Selection Criteria

Every effort should be made to identify an AMG project at the earliest phase, including project initiation PID (WBS 150). Not every project will be suitable for AMG. In general, projects with the following characteristics will be the best candidates for this technology:

- Projects with greater than 5,000 cubic yards of earthwork or paving.
- New alignments.
- A good Global Navigation Satellite System (GNSS) environment for receiving satellite signals or enough line of sight for successfully using total station controlled systems.
- A 3D Digital Design Model (DDM) based on an accurate original ground Digital Terrain Model (DTM)

Some project conditions that limit or exclude the use of AMG are:

- Widening by addition of narrow strips.
- Designs, such as overlays, which are not based on an existing DTM.
- Structures.
- Projects that are under tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals. (*This limitation only applies when GNSS is used to position equipment.*)

Preliminary Engineering and Design Phase (PA&ED, PS&E) WBS 160, 185

The determination that a project is suitable for AMG should be made early on in the project development process. It is imperative that Surveys become actively engaged in the project development team (PDT). As a member of the PDT, District Surveys will provide guidance to the team on subjects such as GNSS coverage, control densification, required staking.

Surveys

Engineering surveys¹ gather data for use by planners and engineers. The products resulting from engineering surveys are generally topographic base maps, and/or an original ground DTM. Different methods, including conventional (total station and GNSS), terrestrial and aerial LiDAR, and photogrammetric surveys, are used to gather data for engineering surveys. Project Engineers provide District Surveys with a Survey Request during PA&ED (WBS 160) and/or the PS&E (WBS 185) phase of the project to gather this data.

During the process of collecting topographic data for design, Surveys can determine the suitability of the project site for GNSS controlled AMG. Although there is no set procedure or a professional requirement to verify GNSS coverage, the Survey Crew can identify areas within the project limits where GNSS coverage is questionable.

Design

Project Engineers (PE) have historically produced a variety of 2D bid documents. Cross-section delivery was made mandatory in 2004, and the Project Development Procedures Manual (PDPM), Appendix QQ Survey File requirements, was updated in 2008.

Designers are now required to develop a complete 3D DDM for the bid package. The project design should include all the 3D elements needed to build a complete DDM of the project.

Small details such as gore areas, side roads, curb returns, etc., should be done in 3D. Edits done to the design on slope stake notes should be eliminated. Complicated at-grade intersections may require more detailed design information to adequately create a surface. HQ's CADD has developed procedures and workflows for designing difficult intersections.

Electronic design data² required by the contractors are horizontal alignments, profiles, cross-sections, target geometry, 2D Microstation .dgn files and Civil3D DDM, original ground DTM, and contour grading areas. In some instances, the use of AMG may require conversion of electronic design data to another format. Design will only convert data into those available format options currently within the roadway design software. The PE should work with the District, and/or HQ Surveys and CADD staff to assist in the conversion of data.

On past projects, contractors have had to prepare their own earthwork grading and/or paving models by hand entering data from 2D bid plans and slope stake notes. This created extra work

¹ See Chapter 11 "Engineering Surveys" of the Caltrans Surveys Manual for detailed information

² Per Project Delivery Directive PD-06

for contractors and increased the risk of mistakes. Contractors can now build their own Digital Construction Model (DCM) based on available 3D design data.

Project Delivery Directive PD-06 (“Sharing of Electronic Files”) provides guidance on sharing certain design files with internal and external forces throughout the project delivery process. PD-06 is a vital component in the implementation of AMG. <http://www.dot.ca.gov/pd/directive/PD-06-Final-2016.pdf>

During the preliminary engineering and design phases, the role of District Surveys includes:

- Actively participate on the PDT and communicate AMG related project issues to the team.
- Evaluate the project site for GNSS signal suitability for AMG.
- Assist Design with data format conversion as expertise permits.
- Review 3D DDM with Design as part of the 30%, 60% and 95% PS&E/constructability review process.
- Establish project control for Project Control sheet in the project plans.
- Update project work plans to address any anticipated AMG workload impacts.

Pre-Construction WBS 255, 270

At the time the project is ready to list (RTL), the Survey File is delivered to the District Surveys office by the Project Engineer. The checklist for the files to be delivered can be found in Appendix QQ of the PDPM. <http://www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm>

The Project Surveyor, along with Surveys office staff, checks the Survey File deliverables for accuracy and completion. As part of the pre-construction process, Surveys should check the original ground DTM for changes that may have occurred during the project development process and transmit any changes to the Project Engineer.

Typically, Surveys office staff check the plans, cross sections and slope stake notes for constructability. Data such as alignments would be checked and converted to field surveys appropriate file format. As part of the implementation of AMG, Design will be delivering a DDM to include in the OE submittal. The Survey File deliverables checklist has a box for Surveys to request the DDM from Design. If the DDM is available, Surveys should request a copy and review it for accuracy and completeness. Once the Survey File has been received and approved, the Surveys office staff generates a field book for the Survey field crews containing the information required to successfully stake the project.

The following section provides step-by-step procedural guidance on the implementation of the Caltrans AMG contract specifications.

Automated Machine Guidance Standard Special Provisions

Background

The following provides background information on the new AMG standard special provision (SSP) to help prepare District Surveys for the rollout of AMG on eligible projects. As of January 1, 2017, the use of AMG became an option on Caltrans construction projects with greater than 5,000 cubic yards of earthwork. Mandatory implementation of AMG will occur on select qualifying pilot projects in 2018. It is important for District Surveys to study these guidelines and prepare to actively participate in AMG implementation.

The Division of Design, Office of Construction Contract Standards (OCCS), develops and revises construction contract standards. OCCS also provides resources to help technical owners develop their standards and guide district staff to properly use the standards on projects. These standards are the culmination of extensive development by Caltrans subject matter experts. Concurrence has been obtained from stakeholders including the Construction Division, Legal Division, and FHWA. When applicable, concurrence has also been obtained from industry and other agencies.

Caltrans Construction Contract Standards include the *Standard Special Provisions, Notice to Bidders, Standard Specifications, Standard Plans, Standard Bid Items, and Bid Book*.

The use of standards is required to ensure that contracts are clear, concise, correct, complete, and in compliance with FHWA guidelines.

Do not edit an SSP beyond the instructions in that SSP. The Department requires substantial justification and approval for deviation from the standards. Deviation should be rare and will not be approved for minor or preferential changes.

There is a hierarchy to the construction contract components. If a discrepancy exists:

1. Governing ranking of Contract parts in descending order is:
 - 1.1. *Special provisions*
 - 1.2. Project plans
 - 1.3. Revised standard specifications
 - 1.4. Standard specifications
 - 1.5. Revised standard plans
 - 1.6. Standard plans
 - 1.7. Supplemental project information
2. Written numbers and notes on a drawing govern over graphics
3. Detail drawing governs over a general drawing
4. Specific specification governs over a general specification
5. Specification in a section governs over a specification referenced by that section

OCCS, in conjunction with the Division of Construction and the Office of Land Surveys, has developed a new SSP that provides AMG guidance for contractors working on Caltrans projects. The contractor can choose to use AMG or not. If the contractor chooses to not use AMG, the Department will provide construction staking per Chapter 12 (Construction Surveys) of the Caltrans Surveys Manual.

Prior to the implementation of the new SSP, Surveys set stakes for transportation projects per Chapter 12 of the Caltrans Survey Manual. Chapter 12 is currently included in every project requiring construction surveys per the 2015 Standard Specifications Section 5-1.26.

The Surveys owned portion of the new SSP is in Section 5-1.24B. Sections 5-1.25 and 5-1.26 are now Division of Construction owned SSP's. If the contractor will be using AMG on a project, then the special provisions 5-1.24, 5-1.25, and 5-1.26 will replace the 2015 Standard Specification 5-1.26³ in the project Standard Special Provisions.

The following *guidance* (italics) is intended to help Surveys implement the AMG SSPs (underlined).

5-1.24 Construction Surveys

5-1.24A General

The Department places stakes and marks under Chapter 12, "Construction Surveys," of the Department's Surveys Manual.

Submit your request for Department-furnished stakes:

1. Once staking area is ready for stakes
2. On a Request for Construction Staking form

After your submittal, the Department starts staking within 2 business days.

Preserve stakes and marks placed by the Department. If the stakes or marks are destroyed, the Department replaces them at the Department's earliest convenience and deducts the cost.

If the contractor will be using AMG, the following specification 5-1.24B will be added to 5-1.24A in the project's Standard Special Provisions. The added SSP details the density of survey control and stakes.

5-1.24B Department Construction Surveys for Automated Machine Guidance

The Department sets control points to a minimum of 0.07 foot local horizontal accuracy and third order vertical accuracy standards.

See sections 5.3-1(d) of the Caltrans Surveys Manual

For slope stakes and rough grade stakes, Department sets 6 survey control points or 2 per mi, whichever is greater.

³ 5-1.26 will be renumbered 5-1.24 as a Revised Standard Specification (RSS) in the July 2018 posting. Attachment to Surveys Information Bulletin (SIB) 18-02
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The Department sets slope stakes and rough grade stakes at:

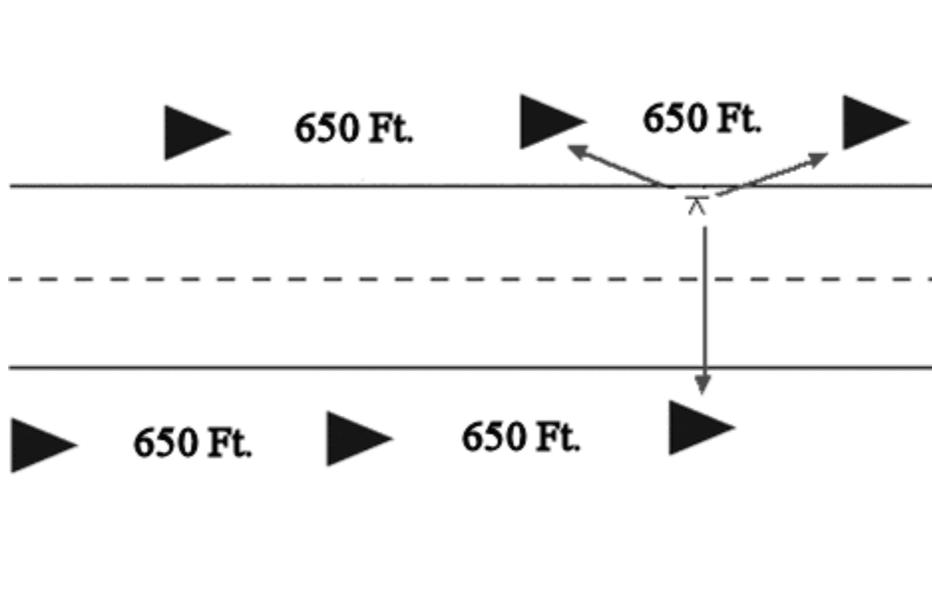
1. Conform stations
2. Beginning and end of each alignment (*These are roadway and ramp alignments only. As stated in the last paragraph of this specification, surveys will still provide staking for intersections, clearing, fencing, drainage, curbs, structures, abutment fill, wall, and miscellaneous areas*)
3. Midpoint or every 200 feet, whichever results in the greater number of stakes, on a curve
4. Every 500 feet on tangents

For final grade, the Department sets stakes per Chapter 12 section 12.5-6 of the Department's *Surveys Manual*, or, at your request, the Department sets survey control points under chapter 12, "Construction Surveys," section 12.1-6, "Automated Machine Guidance (AMG)," and figure 12-2 of the Department's *Surveys Manual* and final grade stakes at:

1. Conform stations
2. Beginning and end of each alignment (*See explanation above for rough grade*)
3. Midpoint or every 100 feet, whichever results in the greater number of stakes, on a curve with a radius of 1,200 feet or less
4. Midpoint or every 200 feet, whichever results in the greater number of stakes, on a curve with a radius of more than 1,200 feet
5. Every 200 feet on a tangent

At your request and under Chapter 12, "Construction Surveys," of the Department's *Surveys Manual*, the Department provides (1) staking for intersections, clearing, fencing, drainage, curbs, structures, abutment fill, wall, and miscellaneous areas and (2) additional survey control or staking for earthwork in areas where GNSS coverage is inadequate for automated machine guidance.

The new standard specification gives the contractor the option of traditional final grade stakes or requesting control for total station machine guidance. If the latter is chosen, then the Department supplies final grade stakes only as listed in lines 1 – 5 above. Control spacing will be set per the diagram below.



Although the Division of Construction owns AMG specifications 5-1.25 and 5-1.26, there are portions of those standard special provisions which may require equipment, training and technical support from District Surveys (see below).

Replace reserved section 5-1.25 with:

5-1.25 Automated Machine Guidance (Construction Owned)

5-1.25A General

You may use automated machine guidance (AMG) if the AMG meets or exceeds the staking tolerances described in section 12.5, "Typical Department-Furnished Construction Stakes," of the Department's Surveys Manual.

The statement above is included in the Standard Special Provision (SSP) 5-1.25A to allow contractors the option of using AMG or request conventional stakes.

2. Do not use if the Survey office for the district is able to provide a GNSS rover and training to construction staff. (Instructions)

Furnish a GNSS rover compatible with your GNSS base station or the GNSS correction service you subscribe to. The Department returns the GNSS rover upon work completion. This is change order work.

The statement above and the SSP instructions (above in bold) are of particular concern to District Surveys. The special provision calls for the contractor to provide the engineer with a rover for checking grade. When the Office Engineer (OE) reviews the SSP, they look at the instructions imbedded in the SSP. Either the PE or the OE will contact Surveys and inquire if Surveys will be providing construction staff with the GNSS rover, base station and just-in-time (JIT) training. If Surveys has GNSS equipment available, District OE will delete the above paragraph from the SSP. If not, the contractor will provide all of the above as a change order.

At the preconstruction conference, be prepared to discuss survey control points, site and equipment calibration, inspection methods, conflict resolution, and staking.

This statement is for the contractor. However, on any project that will be using AMG, Surveys should be represented at the pre-construction meeting.

5-1.25C Electronic Files

Electronic design files include:

1. Digital terrain model in 3D DGN or LandXML format (This is the original ground DTM delivered to design from surveys. The district surveys may wish to deliver the DTM in both civil 3D and LandXML format to design as well as archive the XML formatted surface in the project folder).
2. Roadway design alignments and profiles in LandXML format
3. Cross sections in 2D DGN and PDF
4. Digital design model in LandXML format
5. 2D layout lines and target geometry in DWG format

Digital design model information may not exist for contour grading and some drainage areas. The Department places stakes for these areas.

The Department provides you with updated electronic data whenever the Engineer determines a plan change materially affects the finished grade. For minor grade changes, the Department places stakes and marks. Surveys should review the DDM as part of the overall survey file review. Areas not covered by the model will require survey stakes.

5-1.25H Construction

5-1.25H(1) General

If you find a discrepancy in any survey control point, survey stake, or in the electronic data provided, immediately, submit an RFI.

Surveys should be notified by the engineer of any discrepancies in control points or stakes set by surveys. Field surveys should monitor project control periodically, especially in areas where there is significant subsidence, tectonic movement or freeze/thaw conditions.

5-1.25H(2) GNSS Site Calibration or Localization

Perform GNSS site calibration or localization to the survey control points at least 5 business days before starting work requiring AMG.

Check each survey control point for accuracy. Submit the GNSS site calibration or localization results within 1 business day of the calibration or localization testing. Allow 3 business days for the review of the results.

Per Surveys Manual Chapter 12 section 12.1-6(h) “Provide the Contractor with the latest control points. Provide the RE and contractor with the coordinates and elevation for the local survey control calibration control points to ensure project consistency”

12.1-6(i) “Review the Contractor’s calibration report and compare with the Departments calibration”

5-1.25H(3) GNSS Check Testing

Before starting daily work requiring AMG, conduct check testing for the proper setup of the GNSS or robotic total station equipment. Ensure the GNSS or robotic total station equipment achieves accuracies within:

1. 0.10 foot in both horizontal and vertical directions for rough grading - GNSS
2. 0.05 foot in horizontal directions and 0.02 foot in vertical directions for final grades – Total Station

Using GNSS for final grade does not meet the horizontal and vertical accuracies required. Contractors will need to use Total Stations or request final grade stakes for paving.

Conclusion

Automated Machine Guidance (AMG) has been used by industry for almost two decades. Contractors have been developing their own Digital Construction Model and using GNSS technology to control their equipment, Caltrans is modernizing processes to encourage the use of AMG to improve accuracy and efficiency.

Chapter 12 of the Caltrans Surveys Manual provides guidance to District Surveys as well as contractors working on state transportation improvement projects on the accuracies, as well as the type of stakes, which the contractor is entitled to for Caltrans involved projects. Caltrans commitment to implement AMG on transportation projects will not substantially change the way District Surveys sets stakes, only the density of the stakes.

Key points for Surveys implementation:

- Early and active participation on the Project Development Team (PDT).
- Provide guidance to the PDT on project site GNSS suitability.
- Review Digital Design Model for completion and constructability.
- Attendance at pre-construction meetings. Fully discuss AMG requirements.
- Provide support and guidance to Construction staff during the project construction phase.

Additional Resources

<http://www.dot.ca.gov/hq/construc/amg/>

http://www.dot.ca.gov/landsurveys/docs/surveys-manual/12_Surveys.pdf