Suggested Specifications For 3D Seismic Surveys

General

It is important to investigate, and if necessary, specify the procedures by which real-time GPS operations will be conducted in order to ensure a quality 3D survey, however it is also important not to overlook any other activity which affects the real-time results. For example, GPS in either the real-time code phase differential or the real-time carrier phase kinematic mode provides position information relative to the coordinates used at a nearby reference station. The origin of these coordinates, typically the result of a static GPS control survey, is therefore a vitally important real-time survey component, and must also undergo close scrutiny in order to evaluate the overall accuracy and quality of the operation.

Furthermore, since the precision of a three dimensional GPS survey is maintained only if the static or real-time measurements are processed within the geodetic framework in which they are acquired, suitable transformations must be used which allow local coordinates to be converted to WGS84 and vice versa. Again, the origin and suitability of the transformations are both vitally important and require investigation.

This section presents suggested specifications and procedures for real-time GPS surveys including the initial control survey and derivation of the local/WGS84 datum transformation. The rationale for the specification is given and discussions of the topic are presented as required.

Control Survey

Number of horizontal and vertical control points

Specification - There should be a minimum of two each horizontal and vertical control points. It is acceptable for the same control point to serve as both a horizontal and vertical control point if the documented accuracy standards meet the criteria specified in the section entitled 'Order of points'.

Commentary - The primary purpose of a GPS control survey (static, rapid static, or post-processed kinematic) for real-time operations is to establish coordinates for the base stations and checkpoints relative to the local control network.

It should be noted that our specification for two each horizontal and vertical control points does not imply holding these stations fixed in the adjustment (see Adjustment Methods), but rather, using the redundant control points as protection against blunders in data processing. The reasoning used here is that if a known point is processed in an identical manner as the points which are unknown, and the computed coordinates compare within expected tolerances to the published coordinates, then the unknown points should be free of any significant error as well. Note, that if a significant misclosure does occur, then a third control point will need to be included in the network to isolate the suspect point.

Order of control points

Specification -The relative distance accuracy for at least one horizontal control point should be 1:50,000 or better while the elevation accuracy of the vertical control points should be 2.0 or better. The distance and elevation accuracies quoted are defined in identical fashion to FGCC specifications. For horizontal control, this will be the ratio of the relative positional error of a pair of control points to their separation distance. For vertical control, this will be the ratio of the relative elevation error in millimeters of a pair of points to the square root of the distance in kilometers between them as measured along level routes.

Commentary - The 'order' of the points used in a control survey refers to the distance and elevation accuracy standards of those points in relative terms. With the specified horizontal and vertical accuracies, comparisons to other similar or higher order control points would be at the 20 and 1 centimeter levels respectively for control survey baselines of approximately 10 kilometers. Since it is in our specification to use a minimum of two horizontal and vertical control points, there would be sufficient evidence that blunders have been avoided in processing.

Note that the elevation accuracy is more than an order of magnitude better than the horizontal accuracy. In large respect, this is because the product of the typical conventional level (vertical) survey is much more precise than a horizontal control survey, therefore, we have the 'luxury' of specifying similar orders (the accuracies specified here are classified in the U.S. as third order vertical and second order, class 1 horizontal) for each yet realizing the inherent precision of the former.

Control survey baseline precision -

Specification - All control survey baselines must be fixed integer solutions. Baselines greater than 30 kilometers will require dual frequency receivers and should be fixed integer solutions in which ionospheric refraction has been compensated for. All baselines should exhibit 2ppm precision or better as demonstrated through loop closures and/or a minimally constrained network adjustment. All relevant baseline processing statistics including aposteriori values and confidence levels of the fixed integer solution should be reported.

Commentary - The baselines of a GPS control survey should easily exhibit precisions of 2ppm or better. This is approximately twice the amount achievable for differenced carrier phase measurements. Loop closures accurately indicate baseline precision levels although errors such as HI busts can go undetected. Minimally constrained adjustments are also good indicators of precision and do reflect the effects of HIs (see next section). Since each baseline reflects a least squares solution, various aposteriori (observation) statistics involving the residuals can also be reported to reflect the baseline precision.

Control survey adjustment methods -

Specification - A minimally constrained adjustment should be made and the magnitude of the coordinate misclosures at the non-fixed control should be reported. One horizontal and one vertical control point should be held fixed in the final adjustment.

Commentary - A minimally constrained adjustment attempts to create a group of baseline vectors that are geometrically consistent by translating the coordinates which resulted from the initial baseline processing. If the baselines exhibited the typical 1ppm or better GPS static control precisions before this adjustment, then the coordinate adjustments using minimal constraints will reflect similar values (i.e., 1 cm over a 10km baseline).

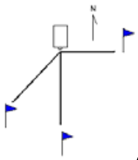
Holding two or more horizontal or vertical control points fixed in an adjustment will embed the respective relative distance and elevation accuracies for those points in the network. Unless those relative accuracies exceed those expected from the control survey (again better than 1ppm for the typical GPS static survey), the use of additional points will simply degrade the precision of the network.

Geodesy

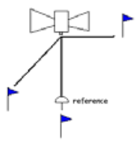
Use of WGS84 coordinates

Specification - WGS84 (or NAD83 in the U.S. and Canada) coordinates and ellipsoidal heights should be used at any real-time reference station, or for the primary control point in any static baseline processing. Local datum coordinates and/or orthometric heights are not acceptable.

Commentary - Errors of 1ppm in the horizontal and 2 ppm in the vertical can result in the baseline computation (real-time or static) for every 10 meters of difference between the actual WGS84 coordinates and those that are used.



As an analogy, consider the use of a total station in placing several points at predetermined locations. We are given a setup point and a range and bearing for each point. A last minute change requires shifting all points 5 meters south so a decision is made to add 5 meters to the observed ranges. This would prove a correct solution only for the points south of the total station and increasing error would result as the bearing deviated from this.



Now, substitute a GPS satellite for the total station. Whenever we alter the true WGS84 coordinates of a GPS reference station, we artificially alter both the observed satellite ranges, and subsequently, the computed range corrections that are transmitted to the rovers. We thereby make the same mistake that was made in the analogy. In this case, real-time (or static) surveying results will only be correct at the reference station and degrade in accuracy as we move away from it. One correct solution would be to move the satellite from its WGS84 position to the corresponding position in the local datum system. Another solution would be for the satellite to broadcast its local datum position rather than its WGS84 position. Since either solution is impossible for mere commercial entities, we are compelled to use the geodetic framework within which the system operates,namely **WGS84**.

Horizontal datum transformations

Specification - A three parameter Molodensky type datum shift consisting of geocentric offsets of the respective ellipsoid centers should be developed from the local and WGS84 datum horizontal coordinates (NAD83 in the U.S. and Canada) available for the control point held fixed in the network adjustment. This datum shift should then be used for all required local datum/WGS84horizontal conversions. Note that since this shift is used only for the horizontal datum shift, the ellipsoid heights of the WGS84 and local datum coordinates should be set to zero when computing the geocentric offsets.

Commentary - Since a seven parameter shift is derived from several (a minimum of three) horizontal and vertical points, the relative precisions of those points become embedded in it. It is therefore not acceptable to use a seven parameter shift unless the relative accuracies of the points used in its derivation exceed 1ppm, the approximate relative precision of coordinates resulting from static GPS surveys. Datum shifts based on interpolation (e.g., NADCON) should also be avoided since they force coordinates to realize local datum geodetic tensions and warps.

The derived shift should be used to convert the local coordinates of the second horizontal control point to WGS84 coordinates. The difference between the datum shifted and published WGS84 (or NAD83) coordinates should be investigated. While the datum shift will be exact only at the primary control point at which it was derived, the results of this comparison will serve as protection against blunders in this step. It is also useful for revealing the relative accuracy of the horizontal control.

If the local control is of poor quality as to be unusable, or if local control is nonexistent, it would be necessary to establish WGS84 control from which to operate, bypassing a local system altogether. The procedure to do this has gradually moved toward differential processing of the collected data from a GPS receiver with the precise ephemeris and clock available from one of several agencies maintaining satellite tracking networks. This method typically produces positions accurate to approximately a meter within the WGS84 geodetic framework. Should coordinates for two sites be derived in this manner, it would then be possible, using the control survey results, to determine in relative terms if this level of accuracy has been achieved. However, as is the case with a more 'traditional' operation, only the one control point would be held fixed in the network adjustment.

Vertical transformations

Specification - WGS84 ellipsoid heights are to be converted to orthometric heights using the most accurate geoid model available for the area. Heights are to be adjusted in this manner based on the point's coordinates and are not to be adjusted using an average geoid/ellipsoid separation value for the area.

Commentary - Since the geoid is an undulating surface, the difference between it and the smooth mathematically definable ellipsoid is coordinate specific, i.e., the difference changes with location. This difference can be quite pronounced in some areas and gradients can approach one meter per five kilometer in mountainous areas. With this in mind, using a 'fixed' height adjustment approach could lead to significant elevation errors.

Several regional and global geoid models have been created and are available from governmental and university agencies. Worldwide, the OSU91A and DMA models may be used. The more recent DMA model appears to more accurately represent the geoid in many areas than does OSU91A. In the U.S., GEOID93, and in Canada, NGSD95 geoid models may be used in order to achieve highly accurate orthometric heights from GPS vectors (delta WGS84 ellipsoid heights).

Projection

Specification - Local grid coordinates should utilize a projection suitable or accepted for the area. All projection parameters should be reported and should include the scale factor and grid convergence for the prospect center.

Commentary - This specification is vaguely written since there are several projection types which might be suitable for an area.In the United States, each state has one or more adopted systems. Elsewhere, local systems which utilize a common projection type might prevail. In any case, since it is the projection surface coordinates with which the client ultimately works with, it is important to try to approach a one to one relationship between the distance on the projection surface and the actual distance it represents. The ratio of grid distance to true distance along the ellipsoid is called scale factor and is dictated by the type of projection and defining parameters. A one to one relationship occurs only where the grid and ellipsoid surfaces are coincident. The projection and defining parameters also dictate the grid convergence, which can be viewed as the difference between true north and grid north (direction defined by increasing Y values). Grid convergence increases away from the projection's central meridian.

Both scale factor and grid convergence are point dependent so there is a need to request these values at a specific point (in our case, at prospect center). As an example of their importance, consider the planning of a new pipeline in which required length and layout direction must be calculated, or an estimate of possible oil reserves by determining the size of a geologic structure. Unless parameters such as map scale factor and grid convergence are well documented and utilized in the measurements, significant errors can result.

Real-time Survey

Kinematic or Differential

Specification (Land) - The survey will be conducted in the fixed integer kinematic mode. Every effort will be made to survey all points in the fixed integer mode, realizing that the prospect tree cover and culture will require a certain percentage of uninitialized float (code phase) shots. A maximum allowable percentage of float points should be specified.

Specification (Transition Zone) - The survey will be conducted in the differential GPS mode utilizing narrow code correlator receivers.

Commentary - There is every reason to specify that all land seismic surveys be conducted in the fixed integer kinematic mode since real-time kinematic with automatic initialization is now widely available. The vast majority of survey companies now possess systems which resolve integer cycle ambiguities when the rover is stationary (static initialization) or as it is moving (On-The-Fly, or simply OTF). The question now becomes what percentage of points should be surveyed in the fixed mode. This is largely determined by the environment, however, in the absence of any significant blockage and interference, it is perfectly reasonable to expect that the greater percentage of all points will be surveyed in the fixed integer mode.

Use of fixed integer real-time kinematic in the transition zone requires special equipment and procedures. For example, it would first be necessary to use an OTF system, and yet some manufacturer's equipment still require the rover antenna to be absolutely stationary when logging a position. Even this limitation can be overcome if we utilize precise timing marks from the GPS receiver to synchronize logging in an attached PC. However, the entire system complementbecomes too cumbersome for installation on some of the vessels used for such operations (e.g., airboats). Since differential GPS using narrow code correlator receivers provides sub-meter horizontal positioning, and the orthometric heights for coastal zone surveys are not in question, the additional expense and effort of kinematic for these types of surveys does not appear to be justified.

Checkpoints

Checkpoints are points which are established within the project area during the GPS control survey, and are used to periodically confirm the accuracy and precision of the real-time solutions. All rover units should have the three dimensional coordinates of all available checkpoints in their data collectors at all times.

Number of checkpoints

Specification - The survey company should establish sufficient checkpoints so as to allow repeated daily visits for each rover unit without significantly affecting operations.

Commentary - A minimum number of checkpoints and their general location within the prospect area should be established for each project and become part of this specification. Kinematic and code-phase differential real-time surveys should provide specific relative accuracies based on the rover distance from the reference station, so the insistence for a minimum number of widely separated checkpoints would allow the survey company to demonstrate the system is performing normally in all areas of the prospect.

Checkpoints both ensure that a certain precision is being achieved and normally ensure that no blunders are made. The term 'normally' is used here since it is possible for the coordinates or height held fixed in the control survey network adjustment to be in error in which case all network points, including the reference station coordinates, contain the error. (It is for this reason that our control survey specifications insist on a second control point so that this possibility is eliminated in the network adjustment.) Recall that real-time GPS surveys are effectively radial surveys from the reference station. Therefore any errors in the reference coordinates including the GPS antenna height will be transmitted to all surveyed locations and checkpoints. If the checkpoint coordinates contained the same error, it would appear to tie correctly

Frequency of checkpoint ties

Specification - Checkpoints should be visited at least twice daily; once prior to, and once after the conclusion of daily real-time survey activities. A previously surveyed point will be visited prior to stakeout activities. The survey company is encouraged to make additional visits to checkpoints and previously staked points during the course of daily survey activities when possible.

Commentary - Twice daily checks provide confidence in the reference station and rover operating parameters used for real-time survey activities. On many projects, the kinematic or differential reference station is installed each morning, and if we remember that the real-time survey results are relative to the entered WGS84 coordinates and ellipsoid height, it is in our best interest to verify entries each time they are made. Additionally, they also confirm HIs, both at the base and at the rover. Finally, visiting staked points provide a means of confirming previously used survey parameters.

Checkpoint misclosures

Specification - For both kinematic and differential surveys, comparisons to checkpoints are to be made in real-time and the results logged for subsequent reporting. For kinematic surveys, horizontal or vertical observed differences in excess of 10 centimeters when in the fixed integer mode will be considered unacceptable and must be investigated. This figure will be relaxed to 1 meter in the horizontal and 2 meters in the vertical for differential mode comparisons.

Commentary - The relative precision of fixed integer real-time kinematic solutions is approximately 2cm plus 1ppm, and the GPS control survey is at least this precise. Therefore, a 10cm difference at a checkpoint is easily discernable as an error and should be resolved. The relative precision of code phase GPS utilizing narrow code correlator technology is typically ten to twenty five times worse than fixed integer solutions, however 1 and 2 meter differences in horizontal and vertical components should still be discernable with favorable geometry.

Checkpoint report

Specification - A separate report should be provided for all checkpoint observations during the entire prospect. The report should specify the checkpoint name, date and time of observation, offset north, offset east, vertical offset, and radial offset and bearing. The report should be ordered by radial offset and averages and standard deviations for offsets should be reported.

Commentary - In many ways, this report is analogous to a list of conventional ties and thereby provides the quality assurance we desire. It supplies critical evidence that the overall accuracy tolerance we specify is being achieved, which itself, is a reflection of both the quality of the control survey and the precision of the GPS equipment being used.

Maximum PDOP during real-time survey

Specification - The maximum allowable PDOP for real time differential or kinematic float mode survey positions will be 5. For positions surveyed in the fixed integer mode, this value will be relaxed to 8.

Commentary - Kinematic precision is typically quoted at 2cm plus 1ppm. At this level, we can allow the Position Dilution of Precision (PDOP) to be fairly high, yet still achieve excellent positioning results. For example, since the users position error is roughly equivalent to the product of DOP and the average range error, a DOP of 8 still equates to 16cm level positioning.

Code phase accuracy, however, is approximately ten to twenty five times worse than kinematic, equating to 50-100 cm positioning near the reference station and degrading in accuracy at a rate of between 10-25 ppm. With precisions at these levels, we cannot afford to let the DOP to be too great without sacrificing the positioning accuracy we desire.

The Position Dilution of Precision (PDOP) is the square root of the sum of the squares of Horizontal Dilution of Position (HDOP) and Vertical Dilution of Precision (VDOP). Because of the orbital characteristics of the satellites, the vertical geometry is on average, 2-3 times worse than the horizontal. If we assume respective values of approximately 1.7 and 4.7 for HDOP and VDOP, we obtain a PDOP near 5. In essence, by making 5 the maximum allowable PDOP for differential and float mode GPS survey points, we hope to achieve submeter horizontal positioning levels and vertical positioning levels ranging from slightly less than one meter to slightly worse than two.

Minimum satellites for code phase positions

Specification - There should be a minimum of five satellites for any survey point when in the code phase differential or kinematic float mode. For a kinematic survey, if initialization is retained when the number of satellites drops to four, surveying may continue.

Commentary - We can ensure that the precision for points surveyed in the code phase differential mode is not diluted by specifying maximum DOP values, however DOP is a position domain quality control statistic which only guarantees a favorable geometrical arrangement of satellites. The ranges to the satellites may very well exhibit gross errors, yet the DOP will remain unaffected. It is therefore necessary to move into the observation (range) domain by examining the differences between the observed satellite ranges and ranges that would result from computing the actual distances between the satellites and the users GPS antenna. These differences are called residuals and exist only if there are more ranges than unknowns to solve for. Since there are four user unknowns (X,Y,Z, and time), residuals are only computed if there are five or more satellites in the fix.

We allow surveying to continue in the fixed integer kinematic mode when the number of satellites drops to four since, in order to first initialize, the system must have examined and discounted solutions exhibiting large residuals. This means that a fixed integer solution must, out of necessity, exhibit the desired precision. In the case of extreme multipath, the system simply fails to initialize.

Unit variance limits for code phase positions

Specification - The unit variance for any survey point in the code phase differential or kinematic float mode should not exceed the expected values for the system in the given operating mode.

Commentary - The unit variance is the sum of the weighted squares of the residuals divided by the number of redundant observations. If range noises are being estimated properly, the square root of the unit variance will fluctuate around a value of one. If it is much less than one, either the estimates of range noise are too high, the precision of the actual measurements very small, or both conditions exist. If it is much greater than one, then the reverse is true, i.e., the estimates of range noise are too low, or the precision of the actual measurements are high. The latter case can be caused by multipath.

Since different manufacturers may compute this value differently (perhaps reporting the square root of unit variance) , this specification is written in relative terms. However, lets examine the case where a true unit variance is reported, and for simplicity, let's assume all residuals and their estimated range noise values are identical. The weight is the squared reciprocal of the estimated range noise so the weighted square of the residual is one. With five satellites, there is one redundant range, so the unit variance is 5/1, with six satellites, 6/2, with seven satellites, 7/3, etc. By imposing a unit variance of five, we would in effect be saying that we will tolerate five satellites, however, the residuals of the solution must be no worse than the estimates of noise for each range. We would then rely on the weighted least squares solution to provide an accurate position. For fixes utilizing more satellites, the residuals could be greater but we would assume that the extra observations would provide as accurate a position.

Maximum age for pseudorange corrections

Specification - The maximum age for pseudorange corrections will be five seconds.

Commentary - In order to defeat the effects of Selective Availability, differential pseudorange corrections must be applied on a timely basis to the satellite ranges observed by the rover equipment. Many studies have been made which demonstrate the deterioration in the accuracy of a differential position as the age of corrections increase. A five second age of correction mask for differential code phase operations is quite sufficient for maintaining sub-meter horizontal positioning.

Number of epochs for each position

Specification - One epoch per point is sufficient for both differential and kinematic operations.

Commentary - The epoch to epoch stability of fixed integer kinematic solutions and modern narrow correlator code phase solutions is sufficient so as not to warrant averaging or accumulating multiple epochs per position. This is not to say the solution will be correct, only that the solutions from a wide range of "survey grade" real-time systems have been demonstrated to be quite stable.

Real-time survey quality control report

Specification - A report which indicates station number, number of satellites used in fix, DOP, horizontal and vertical precision, unit variance, and operating mode should be provided for each surveyed point.

Commentary - This summary report represents a significant portion of the normal complement of quality control figures available from real-time GPS surveying systems. Traditionally, the precision values are scaled to the 95% confidence levels.

The 95% precision values are scaled elements of the trace elements of what is called the variance-covariance matrix. These figures are a function of geometry and estimated range noise and are attempt to specify the precision of the positioning at the 2 sigma level. The only caveat here is that there is always some subjectivity in estimating range noise (e.g., basing current noise levels on past noise levels, or basing noise levels on the elevation of a satellite), so the 95% precisions are considered to be a 'priori' values, i.e., based or theory rather than observation.

An average of the actual residuals might be available for some systems. Typically, this average is in the form of an RMS which is the square root of the mean of the squared residuals.

Tolerances

Accuracy tolerance

Specification - The accuracy tolerance will be demonstrated through adherence to all other specifications listed in this document.

Commentary - A 10cm accuracy tolerance for fixed integer kinematic shots is easily achievable considering the fundamental 2cm plus 1ppm relative accuracy of kinematic surveying, and our specifications concerning the control survey, checkpoints, and real-time quality control criteria. Sub-meter horizontal and 1-2 meter vertical accuracy tolerances for code phase shots are also achievable assuming the use of the narrow code correlator technology and adherence to the relevant specifications.

Layout tolerance

Specification - The layout tolerance (maximum radial horizontal distance between the preplot location and the survey evidence) for survey points should be ____ (but certainly not less than one meter.) The survey company should provide a brief description of the procedure for the placement of pinflag or stake.

Commentary - The layout tolerance pertains to the maximum allowable distance the survey point may be placed from the design or preplot point. Both this specification and those listed below will differ from company to company, however this one is elaborated upon since the simple placement of pinflags (and subsequent placement of source and receiver equipment) can erase the efforts of a high quality survey if it is done poorly. Therefore, the survey company must give some assurance that the pinflag is indeed being placed under the GPS antenna when the coordinates for that point are recorded. Excessively small layout tolerances (sub-meter) are counter productive considering that survey accuracy is far more important than minor perturbations to the design geometry, and that sub-meter guidance for pinflag placement can significantly increase the time to establish the lines.

Summary of Required GPS related deliverables

1) Report of GPS static control survey which includes all information specified in this document
2) Report which includes all relevant geodetic parameters and their derivation where necessary
3) File (and/or hardcopy listing) of preplot points in desired format (SEG P1, UKOOA, etc.)
4) File of postplot points
5) File of preplot/postplot offsets
6) File/Listing of all of checkpoint comparisons as specified
7) File/Listing of quality control values for each surveyed station as specified
8) File/Listing of all offsets (magnitude and direction) exceeding the layout tolerance

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The items below are listed here for completeness since for each job, they need to be addressed. However, they are typically determined by the contracting company.

Offsets

1) When should source offsets be made
2) How should source offsets be made; what are the priorities
3) When should source points be skipped
4) What if any rules exist for receiver offsets

Existing Wells

1) Should area wells be surveyed
2) What documentation for the wells is required

Other Possible Deliverables

1) Maps (with preplot and postplot points, access features, wells, control, etc.)
2) Offset station listing and reasons for offsets

3) Chaining notes