# AMBAG, California
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## GPS Survey
## Final Report
## Volume 2

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## EXECUTIVE SUMMARY

Sanborn established three survey networks in the Monterey, Santa Cruz, and Soledad areas using differential Global Positioning System (GPS) surveying techniques. The network includes new points and existing National Geodetic Survey (NGS) monuments.

The control points are designed to provide control for high accuracy analytical aero-triangulation solutions in support of mapping and ortho-photo products for AMBAG.

The internal accuracy of the geodetic network in the Soledad area achieved *first order* standards in all station pairings. The relative horizontal positional accuracy between stations in the network does not exceed 10 mm + 10 parts per million (ppm) of the station separation. The Monterey and Santa Cruz networks also achieved first order standards in all station pairings with the exception of 2 baselines each. These baselines were 210-256 and 211-256 in the Monterey network and 168-172 and 172-176 in the Santa Cruz network. All relative station confidence regions did not exceed specifications by more than 5mm.

Final horizontal coordinates are provided in California Zone 3 (State Plane 403) for the Santa Cruz region and California Zone 4 (State Plane 404) for the Monterey and Soledad regions. Coordinates for the Monterey area are provided in the North American Datum of 1983 (epoch of 1998) and for the Santa Cruz and Soledad areas, in North American Datum of 1983 (epoch of 1992). All coordinates are found in Appendix A.

Furthermore, orthometric elevations were estimated for all points in the network using sophisticated geoidal modeling techniques and are provided on the North American Vertical Datum of 1988 (NAVD88), also in Appendix A.

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# 1. INTRODUCTION

This report contains the technical write-up of the differential GPS survey performed for the ground control in support of high accuracy, analytical aero-triangulation solutions for AMBAG.

Sanborn was responsible for the fieldwork, including reconnaissance of existing control points, establishment of additional control points, GPS survey, all GPS data processing and reductions, and the preparation of the final report.

## 1.1 Purpose of the Survey

The GPS survey network was based on existing National Geodetic Reference System (NGRS) control.

The GPS survey was designed to provide ground control for high accuracy analytical aerial triangulation solutions to support mapping and orthometric photography for AMBAG. The network also serves to densify existing control and support subsequent surveying and mapping activities in the area enabling future surveys to be integrated on a unified system. The network in Monterey consists of a total of 56 stations, of which 5 are existing NGRS monuments. The Santa Cruz network totaled 95 stations, of which 9 are existing NGRS monuments. The Soledad network comprised 14 stations, 4 being existing NGRS monuments. The horizontal and vertical datum of the GPS network is based on these control points.

## 1.2 Duration/Time Period

The acquisition of the aerial photography and the survey campaign was completed in a single mobilization. Sanborn crews supported the AGPS (Airborne GPS) by establishing multiple GPS receivers on control points to serve as base stations during the photography missions. The static GPS control surveys were performed during the period June 26 to July 9 (Julian Day 177 to 190).

## 1.3 Contact

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## 1.4 Accuracy requirements

The GPS network meets the current Federal Geodetic Control Subcommittee (FGCS) accuracy standard for *first order* GPS surveys. All but four baselines meet the required relative horizontal positional accuracy of 10 mm + 10 ppm, at the 95% level of confidence. Two baselines in each of the Monterey and Santa Cruz areas did not meet first order standards primarily due to the short baseline lengths.

# 2. PROJECT LOCATION AND SCOPE

The project area is situated in the areas of Monterey, Santa Cruz and Soledad, California. The total GPS network spans the following ranges of latitude and longitude:

| | | | |
|---|---|---|---|
| $\phi$: | N 36° 00’ | $\Rightarrow$ | N 37° 20’ |
| $\lambda$: | W 121° 00’ | $\Rightarrow$ | W 122° 20’ |

The GPS network diagrams for Monterey, Santa Cruz and Soledad are presented in figures 1, 2 and 3 respectively.

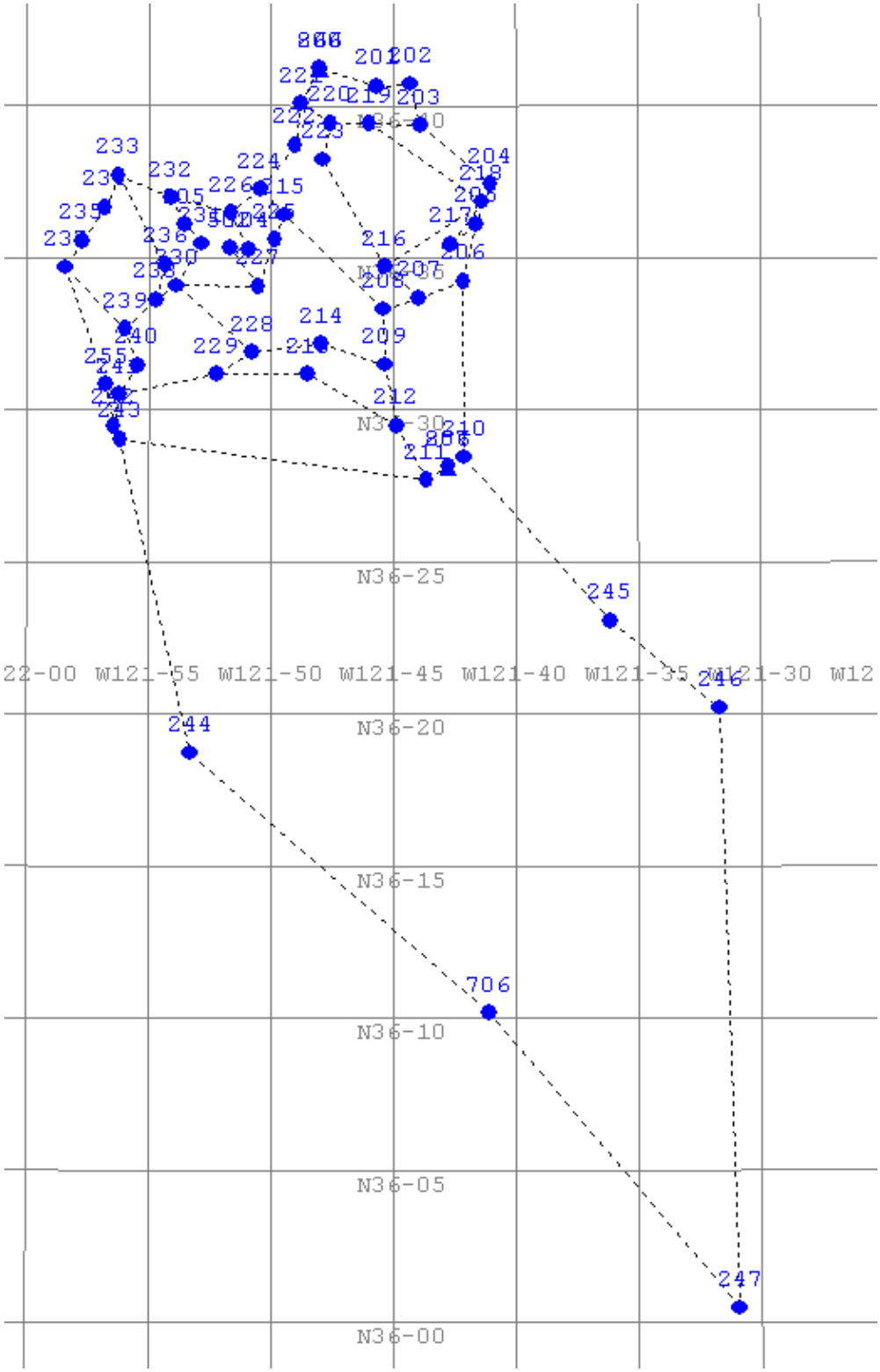


**FIGURE 1. GPS NETWORK - MONTEREY**

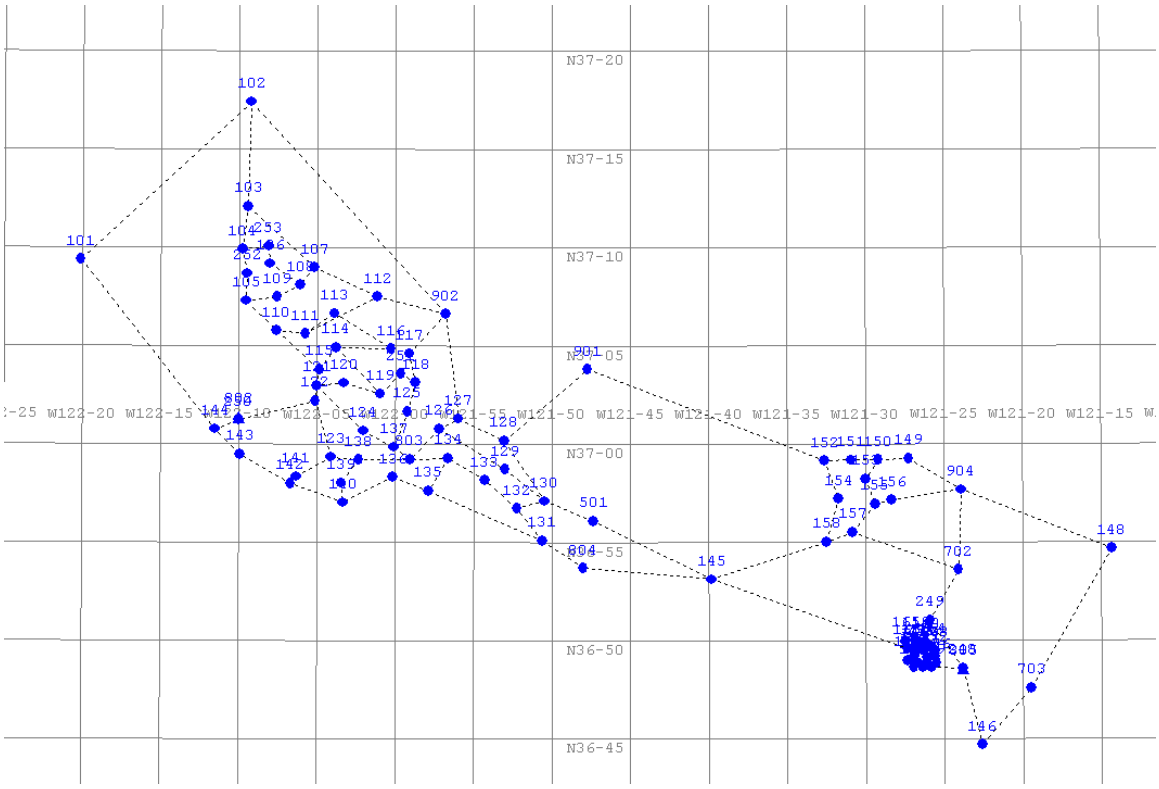


**FIGURE 2. GPS NETWORK – SANTA CRUZ**

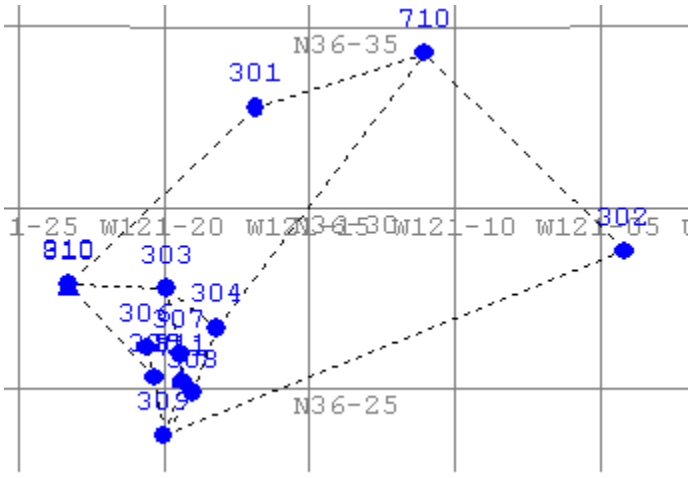


**FIGURE 3. GPS NETWORK – SOLEDAD**

## 2.1 Monuments and Station Naming

The three networks contain a total of 165 stations and 210 quasi-independent baseline vectors. Numeric abbreviations were used as a substitute for the station names for simplicity in file naming and post–processing. Points in the 700, 800, and 900 series were used to represent National Geodetic Survey (NGS) monuments. The 100-500 series points represent new control.

Of the 165 stations included in the network, a total of 147 are new monuments set by members of a Sanborn field crew. The monuments consist of 12" spikes. Station sketches for the 'newly-established' semi-permanent monuments are contained in Appendix E.

## 2.2 Existing Control

Eighteen existing NGS survey monuments were recovered for use as control in the surveys. In total, 11 of these monuments were used as horizontal control in the networks, and 13 were used as vertical control.

# 3. CONDITIONS AFFECTING PROGRESS

A careful reconnaissance was undertaken prior to the monumentation and subsequent GPS survey. All of the points in the network are directly accessible by vehicle and have good satellite visibility. The satellite window provided 24–hour coverage, and GPS observation sessions were typically scheduled between 7:00 am and 7:00 PM, local time, each day. No difficulties were experienced with solar storm activity. All baseline processing, loop misclosure analyses, and preliminary least squares adjustments were performed on a daily basis, thus allowing for continuous quality control.

# 4. FIELD WORK

The GPS observations for the survey campaign was conducted between June 26 and July 9, 2003. There were no serious problems or delays in the ground GPS survey.

Six Trimble Navigation 4000SSi dual–frequency geodetic GPS receivers were used for the fieldwork. Conventional static surveying techniques were used for measuring all of the baseline vectors.

Instrument heights were measured twice, once in meters and once in feet. These values were reduced and compared in the field prior to leaving a station. In the cases where a single station was occupied consecutively for more than one session, the antenna was removed and re–centered over the station mark at the start of each new session, thus fulfilling the condition for an independent setup.

# 5. POST PROCESSING

## 5.1 Baseline Processing and Preliminary Analysis

All static baseline vectors (210) were processed using Trimble Navigation's GPSurvey™ (Ver. 2.35a) software. Fixed bias solutions were adopted for all baselines. The broadcast ephemeris was used, since the accuracy and extent of the network does not warrant the use of the precise ephemeris.

The loop misclosures are summarized in Table 1. The misclosures in each component (X, Y and Z) are given in millimeters and parts per million (ppm) in the WGS84 coordinate system. The spatial misclosure in ppm is also provided. All loops comprise quasi–independent baselines from at least two sessions. Every station in the network appears at least once in a loop. All loops, in fact, satisfy the guidelines for *first order* work, namely:

- in any component (X, Y, Z), the maximum misclosure does not exceed 250 mm (the worst case is 138.4 mm),
- in any component (X, Y, Z), the maximum misclosure in terms of the loop length does not exceed 12.5 ppm (the worst case is 6.1 ppm), and
- in any component (X, Y, Z), the average misclosure in terms of the loop length does not exceed 8 ppm (the worst case is 1.0 ppm).

TABLE 1. ABSOLUTE LOOP MISCLOSURES

| LOOP | δX [mm] | δX [ppm] | δY [mm] | δY [ppm] | δZ [mm] | δZ [ppm] | LENGTH [m] | δS [ppm] |
|---|---|---|---|---|---|---|---|---|
| 144-101-102-103-104-252-105-110-115-122-250-144 | 40.0 | 0.48 | 72.4 | 0.87 | 81.3 | 0.97 | 83530 | 1.39 |
| 102-902-112-107-103-102 | 23.1 | 0.39 | 25.4 | 0.43 | 12.2 | 0.21 | 58717 | 0.62 |
| 103-107-108-106-253-104-103 | 46.5 | 2.08 | 65.2 | 2.92 | 51.8 | 2.32 | 22318 | 4.27 |
| 108-106-253-104-252-105-109-108 | 20.2 | 1.12 | 85.3 | 4.73 | 43.3 | 2.40 | 18042 | 5.42 |
| 107-112-111-110-105-109-108-107 | 40.4 | 1.41 | 29.6 | 1.04 | 32.6 | 1.14 | 28589 | 2.09 |
| 115-110-111-113-116-114-115 | 0.3 | 0.01 | 8.2 | 0.32 | 23.8 | 0.92 | 25748 | 0.98 |
| 112-902-117-116-114-115-110-111-112 | 9.6 | 0.26 | 17.5 | 0.47 | 8.0 | 0.21 | 37249 | 0.58 |
| 902-127-126-803-137-125-118-117-902 | 138.4 | 4.31 | 100.4 | 3.12 | 94.8 | 2.95 | 32137 | 6.08 |
| 116-114-119-251-118-117-116 | 18.8 | 0.93 | 0.7 | 0.03 | 9.9 | 0.49 | 20165 | 1.05 |
| 119-251-118-125-137-124-121-120-119 | 103.6 | 3.94 | 93.9 | 3.57 | 118.5 | 4.51 | 26289 | 6.97 |
| 122-123-141-142-143-144-250-122 | 2.6 | 0.09 | 35.7 | 1.24 | 28.8 | 1.00 | 28896 | 1.59 |
| 142-140-139-138-123-141-142 | 3.3 | 0.19 | 24.4 | 1.43 | 35.6 | 2.08 | 17099 | 2.53 |
| 122-115-114-119-120-121-124-137-803-138-123-122 | 72.5 | 1.72 | 12.1 | 0.29 | 17.8 | 0.42 | 42060 | 1.80 |
| 140-136-135-134-803-138-139-140 | 10.0 | 0.39 | 14.5 | 0.57 | 19.0 | 0.74 | 25543 | 1.02 |
| 134-803-126-129-130-132-133-134 | 13.8 | 0.45 | 11.6 | 0.38 | 11.8 | 0.39 | 30506 | 0.70 |
| 135-131-132-133-134-135 | 9.7 | 0.36 | 15.7 | 0.57 | 4.6 | 0.17 | 27311 | 0.70 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 127-128-130-129-126-127 | 12.8 | 0.50 | 13.1 | 0.51 | 17.8 | 0.69 | 25826 | 0.99 |
| 901-128-130-501-145-158-154-152-901 | 28.8 | 0.37 | 36.0 | 0.46 | 14.8 | 0.19 | 78190 | 0.62 |
| 501-130-132-131-804-145-501 | 9.2 | 0.22 | 12.1 | 0.30 | 6.1 | 0.15 | 40948 | 0.40 |
| 152-151-150-153-155-157-158-154-152 | 2.4 | 0.10 | 5.9 | 0.25 | 16.0 | 0.67 | 23808 | 0.73 |
| 158-145-165-161-159-160-249-702-157-158 | 8.0 | 0.15 | 0.6 | 0.01 | 22.3 | 0.41 | 54375 | 0.44 |
| 149-150-153-155-156-904-149 | 13.5 | 0.63 | 16.5 | 0.77 | 9.6 | 0.45 | 21509 | 1.09 |
| 904-156-155-157-702-904 | 13.4 | 0.45 | 11.0 | 0.37 | 15.8 | 0.53 | 29798 | 0.79 |
| 904-148-703-146-248-249-702-904 | 7.7 | 0.12 | 31.7 | 0.50 | 33.4 | 0.53 | 63504 | 0.74 |
| 161-159-162-166-173-169-165-161 | 1.1 | 0.21 | 0.2 | 0.04 | 2.9 | 0.54 | 5336 | 0.59 |
| 170-166-162-159-160-163-167-254-170 | 7.4 | 1.62 | 1.3 | 0.28 | 9.7 | 2.12 | 4567 | 2.69 |
| 177-173-169-165-161-159-162-166-170-174-178-177 | 2.0 | 0.27 | 9.8 | 1.31 | 17.4 | 2.33 | 7478 | 2.69 |
| 171-167-254-170-174-178-179-175-171 | 11.3 | 2.19 | 23.3 | 4.51 | 14.5 | 2.81 | 5167 | 5.74 |
| 160-164-168-171-167-163-160 | 22.9 | 6.14 | 17.2 | 4.61 | 2.1 | 0.56 | 3733 | 7.70 |
| 171-168-172-176-179-175-171 | 0.3 | 0.08 | 3.4 | 0.87 | 10.1 | 2.60 | 3888 | 2.74 |
| 249-248-179-176-172-168-164-160-249 | 4.6 | 0.34 | 2.6 | 0.19 | 15.3 | 1.13 | 13550 | 1.19 |
| 301-710-304-303-810-301 | 2.7 | 0.06 | 77.1 | 1.60 | 15.3 | 0.32 | 48186 | 1.63 |
| 710-302-309-308-304-710 | 26.1 | 0.41 | 0.5 | 0.01 | 6.4 | 0.10 | 63677 | 0.42 |
| 307-303-304-308-309-711-307 | 9.1 | 0.53 | 1.8 | 0.10 | 10.4 | 0.61 | 17161 | 0.81 |
| 309-305-306-307-711-309 | 1.9 | 0.18 | 2.6 | 0.24 | 6.6 | 0.62 | 10693 | 0.68 |
| 305-810-303-307-306-305 | 28.4 | 1.56 | 67.8 | 3.71 | 56.9 | 3.12 | 18250 | 5.09 |
| 806-201-202-203-219-220-221-806 | 3.2 | 0.17 | 3.9 | 0.21 | 0.9 | 0.05 | 18339 | 0.28 |
| 203-204-205-217-218-219-203 | 21.0 | 0.85 | 30.7 | 1.24 | 34.5 | 1.39 | 24822 | 2.04 |
| 206-205-217-218-216-207-206 | 2.6 | 0.12 | 17.2 | 0.80 | 11.7 | 0.54 | 21582 | 0.97 |
| 220-219-218-216-223-220 | 7.6 | 0.28 | 14.2 | 0.51 | 20.0 | 0.72 | 27626 | 0.93 |
| 221-220-223-216-207-208-215-224-222-221 | 9.1 | 0.27 | 14.0 | 0.42 | 10.7 | 0.32 | 33502 | 0.59 |
| 224-215-225-227-502-704-226-224 | 11.7 | 0.76 | 27.3 | 1.77 | 3.1 | 0.20 | 15431 | 1.94 |
| 232-226-704-502-227-230-231-905-232 | 10.2 | 0.47 | 8.2 | 0.38 | 8.0 | 0.37 | 21513 | 0.71 |
| 232-233-236-238-230-231-905-232 | 9.6 | 0.49 | 32.7 | 1.66 | 18.6 | 0.94 | 19746 | 1.96 |
| 233-234-235-237-239-238-236-233 | 21.7 | 0.96 | 24.5 | 1.08 | 70.0 | 3.09 | 22649 | 3.41 |
| 255-237-239-240-241-242-255 | 0.3 | 0.01 | 6.4 | 0.30 | 2.6 | 0.12 | 21664 | 0.32 |
| 230-227-225-215-208-209-214-228-230 | 0.2 | 0.01 | 48.5 | 1.35 | 27.4 | 0.76 | 35820 | 1.55 |
| 241-240-239-238-230-228-229-241 | 0.6 | 0.03 | 4.1 | 0.18 | 18.4 | 0.79 | 23349 | 0.81 |
| 229-228-214-209-212-213-229 | 0.3 | 0.01 | 7.3 | 0.28 | 13.9 | 0.52 | 26536 | 0.59 |
| 208-207-206-210-256-211-212-209-208 | 4.4 | 0.15 | 5.3 | 0.18 | 25.4 | 0.86 | 29515 | 0.89 |
| 211-243-242-241-229-213-212-211 | 9.9 | 0.23 | 52.9 | 1.22 | 24.6 | 0.57 | 43428 | 1.36 |
| 244-243-211-256-210-245-246-247-706-244 | 49.1 | 0.33 | 18.3 | 0.12 | 15.1 | 0.10 | 147274 | 0.37 |

## 5.2 Minimally Constrained Network Adjustment

A minimally constrained least squares adjustment was performed for each of the three areas using Geolab™ (Ver. 3.65) 3-dimensional adjustment software.

### 5.2.1 Monterey Minimally Constrained Network Adjustment

The horizontal geodetic coordinates and the orthometric elevation of control point 905 were held fixed in the minimally constrained adjustment. The adjustment comprises 56 stations and 69 baseline vector components. *A priori* weights for the observations were based on the (scaled) variance-covariance sub-matrices from the GPSurvey™ solutions.

None of the standardized residuals were flagged for possible rejection under the Tau$_{max}$–test ($\tau_{MAX}$–test), at the 0.05 level of significance. The histogram of standardized residuals indicates that the observations are well distributed. The *a posteriori* variance factor ($\sigma_0^2$= 1.0707) indicates that the scaled *a priori* standard deviations of the vector components are realistic. The absolute and relative confidence regions were not scaled by the *a posteriori* variance factor.

The relative confidence regions and the associated relative horizontal and vertical precision were computed for all pairs of points that were directly connected by vectors. All station pairings, except two, meet the horizontal positioning standard for *first order* surveys, i.e., the relative horizontal precision between each pair of points does not exceed 10 mm + 10 ppm of their horizontal separation, at the 95 percent level of confidence. The baselines between points 210-256 and 211-256 did not meet first order standards because of short baseline lengths.

### 5.2.2 Santa Cruz Minimally Constrained Network Adjustment

The horizontal geodetic coordinates and the orthometric elevation of control point 901 were held fixed in the minimally constrained adjustment. The adjustment comprises 95 stations and 125 baseline vector components.

None of the standardized residuals were flagged for possible rejection under the Tau$_{max}$–test ($\tau_{MAX}$–test), at the 0.05 level of significance. The histogram of standardized residuals indicates that the observations are well distributed. The *a posteriori* variance factor ($\sigma_0^2$= 0.9618) indicates that the scaled *a priori* standard deviations of the vector components are realistic.

All station pairings, except two, meet the horizontal positioning standard for *first order* surveys, i.e., the relative horizontal precision between each pair of points does not exceed 10 mm + 10 ppm of their horizontal separation, at the 95 percent level of confidence. The baselines between points 168-172 and 172-176 did not meet first order standards because of short baseline lengths.

### 5.2.3 Soledad Minimally Constrained Network Adjustment

For horizontal control the geodetic latitude and longitude of the existing NGS control point 711 were held fixed and for vertical control the orthometric elevation of the existing NGS control point 810 was held fixed. The adjustment comprises 14 stations and 16 baseline vector components.

None of the standardized residuals were flagged for possible rejection under the Tau$_{max}$–test ($\tau_{MAX}$–test), at the 0.05 level of significance. The histogram of standardized residuals indicates that the observations are well distributed. The *a posteriori* variance factor ($\sigma_o^2$= 1.0074) indicates that the scaled *a priori* standard deviations of the vector components are realistic.

All station pairings meet the horizontal positioning standard for *first order* surveys, i.e., the relative horizontal precision between each pair of points does not exceed 10 mm + 10 ppm of their horizontal separation, at the 95 percent level of confidence. The network is therefore classified as *first order* in terms of its *internal* accuracy.

## 5.3 Constrained Network Adjustment

A suitable subset of the recovered existing NGRS horizontal control provide a sound basis for the constrained network adjustments. Position quality and distribution were the main selection criteria.

Since the networks have a high internal accuracy, and since the fit of the networks to the existing control is relatively good, a strategy was devised in which the networks would be constrained tightly to the existing control stations. This would further ensure a smooth integration between the newly established control and the existing framework.

The constraints assigned for the final network adjustments are shown in Tables 2-4 (page 11-12) for Monterey, Santa Cruz and Soledad respectively, and lists the standard deviations used in the adjustment. In the Monterey area, three control points were used to constrain the network horizontally, and three control points were used to constrain the network vertically. In the Santa Cruz and Soledad areas, six and two control points respectively were used to constrain the network horizontally, and eight and two control points respectively were used to constrain the network vertically. GEOID99 was incorporated into the adjustment, thereby allowing rigorous interpolation of the geoidal undulation values (*N*) at each point in the network. This provides a useful method of estimating the elevations at all points in the network.

The adjustment for the Monterey area was constrained to the NAD83 (epoch of 1998) NGS control values and to the NAD83 (epoch of 1992) for the Santa Cruz and Soledad areas to ensure the mapping datum for AMBAG agrees with the previous control framework established within the are on previous projects.

A full listing of the constrained adjustments for Monterey, Santa Cruz and Soledad are in Appendices B, C, and D respectively. The residuals and the standardized residuals are listed in pages 11-19 for Monterey, pages 19-34 for

Santa Cruz and pages 6-8 for Soledad of their respective appendix. None of the vector components in any of the three areas were flagged for possible rejection under the $\tau_{MAX}$ - test at the 0.05 level of significance. None of the horizontal or vertical constraints for any of the three areas were flagged. The *a posteriori* variance factor for the Monterey, Santa Cruz and Soledad areas are 1.1007, 1.2252 and 0.9111 respectively. These values indicate that each network is not being unduly distorted by the imposition of its constraints. The absolute and relative confidence regions were not scaled by the *a posteriori* variance factor. The absolute horizontal confidence ellipses appear on page 22 for Monterey, pages 37-38 for Santa Cruz and page 11 for Soledad in their respective appendix. Examination of the relative precisions for each area reveal that all three networks have maintained their high internal accuracy.

TABLE 2. ADJUSTMENT CONSTRAINTS - MONTEREY
**(standard deviations in meters)**

**Horizontal**

| Code | Station Name | Order | $\phi$ | $\lambda$ |
|---|---|---|---|---|
| 704 | AE6682 | B | 0.02 | 0.02 |
| 706 | GU4326 | A | 0.04 | 0.04 |
| 905 | GU4116 | A | 0.02 | 0.02 |

**Vertical**

| Code | Station Name | Order | H |
|---|---|---|---|
| 806 | GU4107 | 1 – II | 0.01 |
| 807 | GU2842 | 2 – 0 | 0.01 |
| 901 | EV1120 | 1 - II | 0.01 |

TABLE 3. ADJUSTMENT CONSTRAINTS – SANTA CRUZ
**(standard deviations in meters)**

**Horizontal**

| Code | Station Name | Order | $\phi$ | $\lambda$ |
|---|---|---|---|---|
| 702 | GU3630 | A | 0.04 | 0.04 |
| 703 | GU4323 | A | 0.04 | 0.04 |
| 803 | AB7668 | A | 0.04 | 0.04 |
| 901 | HS5267 | A | 0.03 | 0.03 |
| 902 | HS4896 | B | 0.04 | 0.04 |
| 904 | GU2656 | A | 0.03 | 0.03 |

**Vertical**

| Code | Station Name | Order | H |
|---|---|---|---|
| 702 | GU3630 | 3 | 0.05 |
| 703 | GU4323 | 3 | 0.05 |
| 802 | HT3641 | 1 – II | 0.01 |
| 804 | GU4161 | 1 – II | 0.01 |
| 805 | GU2594 | 1 – I | 0.02 |
| 901 | HS5267 | 1 – II | 0.01 |
| 902 | HS4896 | 1 – II | 0.01 |
| 904 | GU2656 | 1 – I | 0.01 |

TABLE 4. ADJUSTMENT CONSTRAINTS - SOLEDAD
**(standard deviations in meters)**

**Horizontal**

| Code | Station Name | Order | $\phi$ | $\lambda$ |
|---|---|---|---|---|
| 710 | GU4332 | A | 0.02 | 0.02 |
| 711 | GU4262 | B | 0.02 | 0.02 |

**Vertical**

| Code | Station Name | Order | H |
|---|---|---|---|
| 810 | GU4125 | 1 – II | 0.01 |
| 811 | GU4126 | I – II | 0.01 |

## 5.4 Final Coordinates and Elevations

The final NAD83 State Plane Coordinates, California Zone 3 for Santa Cruz and Zone 4 for Monterey and Soledad, are presented in US survey feet and meters in Appendix A. Final orthometric elevations, referenced to the North American Vertical Datum of 1988 (NAVD88), are also presented in Appendix A. All final coordinates (including NGS control points) are derived from the constrained adjustment shown in Appendix B, C and D for Monterey, Santa Cruz and Soledad respectively.

# APPENDIX A
# FINAL COORDINATES AND ELEVATIONS

# APPENDIX B
# CONSTRAINED LEAST SQUARES ADJUSTMENT - MONTEREY

# APPENDIX C
# CONSTRAINED LEAST SQUARES ADJUSTMENT – SANTA CRUZ

# APPENDIX D
# CONSTRAINED LEAST SQUARES ADJUSTMENT - SOLEDAD

# APPENDIX E
# NEW STATION DIAGRAMS