

SURVEY REPORT
of the
City Of Santa Barbara
2008 SECOND ORDER LEVELING NETWORK SURVEY
prepared by
McGee Surveying Consulting
Santa Barbara, California

PROJECT OVERVIEW: The City of Santa Barbara, Department of Public Works, Engineering (the City) performed a Height Modernization Survey Project between May 2007 and June 2008. The purpose was to upgrade the City from the superseded National Geodetic Vertical Datum of 1929 (NGVD 29) to the North American Vertical Datum of 1988 (NAVD 88), to establish a vertical reference network known as the 2008 Second Order Leveling Network and to support the utilization of GPS technology for establishing elevations within the City. Previously, the City and the public have relied on estimates of the relationship between the old and new datum. This survey provides an assessment of the National Geodetic Survey (NGS) NAVD 88 benchmarks in the City and their relationship to the old NGVD 29 City Benchmarks.

New elevations resulting from this leveling survey supersede the NGVD 29 Datum elevations. New elevations of specific points in the City's GPS network known as the Santa Barbara Control Network (SBCN) also supersede those shown on the 1995 Record of Survey recorded in Book 147 of Records of Surveys at Page 70-74 and Book 149 of Records of Surveys at Page 16-17. A leveling network was established across the City connected to NGS Benchmarks (permanent monuments with published elevations). Points in the SBCN were included for the purpose of determining the conversion from ellipsoid heights measured with GPS to NAVD 88 elevations. See the 2008 Height Modernization GPS Survey Report for additional information.

PROJECT DATUMS, REFERENCE SYSTEMS and HISTORY: Orthometric heights (elevations) published by this survey are based on the North American Vertical Datum of 1988 (NAVD 88) established by the National Geodetic Survey (NGS) as referenced to monuments in the National Spatial Reference System. NGVD 29 was established by the NGS, formerly the United States Coast & Geodetic Survey about 1930. In years past, the NGS and its predecessor have established benchmarks within the Railroad Right-of-Way and along the waterfront. The results of national leveling surveys through these benchmarks in the late seventies were published as the last Adjustment of NGVD 29. The City of Santa Barbara under the direction of Archie Macomber, a former surveyor for the City, conducted leveling surveys in 1978 establishing benchmarks throughout much of the City based on the NGVD 29 Datum. In 1989, the NGS benchmarks were re-leveled as part of a national leveling survey to upgrade to the new NAVD 88 Datum. In 1991, the NGVD 29 Datum was superseded when the NGS published the new NAVD 88 elevations. Since 1991, NAVD 88 elevations within the City were usually approximated by shifting NGVD 29 benchmark elevations +2.65 feet. The actual difference from NGVD 29 to NAVD 88 varies throughout the City between +2.5 and +2.7 feet.

EQUIPMENT, DATA COLLECTION & POST PROCESSING OF DATA: The measurements were collected and recorded with second order electronic digital levels and bar code rods. A Topcon DL-102C was used during Phase One and Two, and a Leica DNA10 was used during Phase Three. The FGCS Specifications and Procedures (ver. 4.0) for Second Order Class I Geodetic Leveling were followed. The instrument was calibrated before commencing each field day of leveling and the rods were calibrated periodically. The field survey procedures follow: the instrument was set up at locations intended to balance the backsights (BS) and foresights (FS), three measurements were averaged for each sighting and were taken in the sequence BS-FS-FS-BS, with two rods moving in a leap frog manner. McGee Surveying Consulting processed the measurements, analyzed network closures and residuals using Starplus Starnet Software v6.0, computed final adjustments and reported the results.

SURVEY NETWORK: The Leveling Network was planned and surveyed in three phases described below. Thirty-four miles of inter-connected loops were measured to form a backbone network for the City. All points were connected with independent measurements and closed loops. The naming convention for the points follows: the NGS benchmark names were used and cross referenced to their PID as shown below; new benchmarks are preceded by "BM" and begin with 801 (i.e BM801); control points established with GPS are preceded by "GPS" and begin with 9001 (i.e GPS9035) and are consistent with the horizontal accuracy of the primary Santa Barbara Control Network; points preceded by PM are Caltrans control points utilized in this survey; Santa Barbara Control Network (SBCN) point numbers are preceded by SBCN with 10000 added to the numbers shown on the Book 147 of Records of Surveys at Page 70-74 (i.e SBCN10001); and the old City benchmarks take their original names (i.e MOD3601). In a few cases old City benchmarks were used for GPS control and the names are combined (i.e GPS9035MOD3601).

The leveling loops are shown on an attached map and are described as follows: Phase One, completed in April 2007, began 1/2 mile west of Highway 154 and proceeded easterly adjacent to Highway 101 along the Union Pacific Railroad, Castillo Street, Cabrillo Boulevard to Hot Springs Road and east along the Railroad for a total of 9 miles. Phase One connected eleven NGS NAVD 88 Benchmarks used to recover the NAVD 88 Datum. Phase Two, completed in January 2008, began on Phase One at Santa Barbara Control Network (SBCN) 10026 and proceeded northerly along Milpas Street, Carpinteria Street and Sycamore Canyon Road to Stanwood Drive, then westerly along Stanwood Drive, Mission Ridge Road, Mountain Drive, Foothill Road to Mission Canyon Road, then southerly to and along Mission Street to Highway 101, connecting to Phase One at the Railroad for a total of 9 miles. Phase Three, completed in July 2008, consisted of several loops for a total of 16 miles. The first loop began at Mission Canyon Road and Foothill Road (at Phase Two) and ran westerly along Foothill Road to San Roque Road and southerly along San Roque Road and Las Positas Road to Highway 101 connecting to Phase One at the Railroad. The second loop began at Las Positas Road and Highway 101 and ran southerly along Las Positas Road to Cliff Drive, then easterly to and along Shoreline Drive to Cabrillo Boulevard connecting to Phase One. Several smaller loops were run as shown on the attached diagram.

PROJECT ADJUSTMENTS: A Minimally Constrained Adjustment was processed first to analyze the record elevations of eleven recovered NGS benchmarks, compute loop closures and validate the integrity of the survey measurements.

The adjustment contained 351 measured vertical differences after removing measurements that did not meet the Second Order Class I tolerance of (6mm* $\sqrt{\text{kilometers}}$). The average absolute value of the residuals is 0.002' with a standard deviation of 0.003'. The range is -0.014 to +0.014' with nine residuals equal to or greater than 0.010'. There are five large loops and multiple smaller loops. The loop closures are generally 0.01' with the exception of 0.06' on the largest loop from Mission Street and Highway 101, easterly to Cabrillo Boulevard and to Milpas Street, then northerly to Stanwood Drive and westerly over Mountain Drive and Foothill Road back to Highway 101 at Mission Street. All loop closures meet First Order tolerances except the last which met Second Order Class I.

NGS benchmark C658 was fixed for this analysis at its published NAVD 88 elevation of 154.173 feet. The differences in feet from the NGS record elevations of the benchmarks to the calculated elevations, determined in this minimally constrained adjustment, are listed below and arranged from west to east.

<u>NGS Benchmarks</u>		
ID	Diff.	Comment
W1042	0.057	
C658	0.000	Fixed
S1441	-0.000	
T1441	0.025	
K1215	0.041	aka GPS9027
TIDAL2	-0.035	
TIDAL3	0.014	
TIDAL1	0.017	
A609	-0.064	
T28	-0.075	
A1044	-0.098	

Fixing C658 finds three benchmarks to the southeast in good agreement at First Order vertical tolerances as listed below.

- S1441 1.1 miles southeasterly of C658 at 0.000'
- TIDAL3 1.9 miles southeasterly of S1441 at -0.014'
- TIDAL1 0.3 miles northeasterly of TIDAL3 at -0.017'
- Note, the relative accuracy of TIDAL3 and TIDAL1 is 0.003'.

In the final Constrained Adjustment, the above 4 benchmarks were fixed at their NGS published NAVD 88 elevations. The final elevations and differences from record to computed are listed below in alphabetical order in feet.

ID	NGS Designation	NGS Benchmarks		Final Elev.	Diff.	Comments
		NGS PID				
A1044	A 1044	EW3734		36.142	-0.114	
A609	A 609	EW3736		29.946	-0.080	
C658	C 658	EW3758		154.173	0.000	Fixed
K1215	K 1215	EW3749		31.343	0.031	
S1441	S 1441	EW9489		113.392	0.000	Fixed
T1441	T 1441	EW9490		60.810	0.019	
T28	T 28	EW3735		39.224	-0.090	
TIDAL1	941 1340 TIDAL 1	EW3742		16.145	0.000	Fixed
TIDAL2	941 1340 TIDAL 2	EW3741		12.838	-0.049	
TIDAL3	941 1340 TIDAL 3	EW7026		10.433	0.000	Fixed
W1042	W 1042	EW3766		126.393	0.057	

NGS Data Sheets for the above benchmarks are attached for reference and are listed in order of their NGS PID. One additional NGS benchmark J324 did not have an NAVD 88 elevation and is listed below with the summary of old City benchmarks included in this survey.

Listed below are the computed shifts from NGVD 29 to NAVD 88 at 51 City Benchmarks and the NGS Benchmark J324. The shifts vary between 2.52' and 2.71' and average 2.61'. The shifts at CAR953W of -0.42' and at CLI2346 of 2.38' are outliers and indicate the original NGVD 29 elevation is incorrect.

City Benchmarks

ID	Diff.	ID	Diff.
(1)ANA00	2.529	LAS3061	2.653
BAT1900	2.614	LOS340	2.631
BAT1935	2.626	LOS505	2.664
CAB13	2.557	MEI500	2.536
CAB23	2.523	MEI606	2.575
CAL4010	2.521	MEI630	2.585
CAN00	2.631	MEI800	2.611
CAR1005W	2.576	MOD2000	2.589
CAR1030W	2.637	MOD2109	2.621
CAR400W	2.647	MOD2220	2.678
CAR606W	2.620	MOD2303	2.658
CAR953W	-0.423	-MOD2414	2.650
CARP1133	2.593	MOD2505	2.643
CLI1900	2.574	MOD2541	2.668
CLI2109	2.566	MOD3523	2.630
CLI2309	2.562	MOD3558	2.683
CLI2346	2.384	MOD3601	2.663
GAR1900	2.663	MOD3659	2.675
GAR2000	2.671	MOD3721	2.655
GPS9022CAB17	2.571	MOD3831	2.658
GPS9023CAB14	2.552	PED100W	2.621
J324	2.541	PED130	2.677
LAS1102	2.546	SAL2S	2.713
LAS1402	2.652	SAN1000	2.558
LAS2400	2.647	STA1300	2.642
LAS2900	2.638	STA3800	2.547

(1)ANA00 was destroyed after the survey and because it is a City block corner it was replaced but not used for elevation.

Listed below are the computed shifts from the NAVD 88 elevations published in 1995 on 22 of the 36 Santa Barbara Control Network (SBCN) points.

<u>Santa Barbara Control Network</u>			
ID	Diff.	ID	Diff.
SBCN10002	-0.050	SBCN10023	-0.039
SBCN10003	0.125	SBCN10025	-0.100
SBCN10005	0.130	SBCN10026	0.015
SBCN10006R	0.090	SBCN10027	0.034
SBCN10007	0.032	SBCN10029	-0.096
SBCN10009	0.028	SBCN10030	-0.113
SBCN10012	0.007	SBCN10031	0.022
SBCN10015	0.094	SBCN10033	-0.009
SBCN10020	-0.184	SBCN10034	-0.053
SBCN10021	0.007	SBCN10035	-0.051
SBCN10022	-0.012	SBCN10036	0.039

Note: SBNC10025 was destroyed in 2004 and was included by a tie to a reference point set before construction. The elevation of SBNC10025 is computed to have been 119.657 feet.

OTHER CITY LEVELING SURVEYS: The City performed leveling surveys in 2000 to connect SBCN10002 to control points #9006 to 9010 at the Cater Plant. This survey found SBCN10002 to differ 0.05' from the record; however, GPS9009 at the Plant was found to be at 526.419' verses 526.41 in June 2000. The 2000 survey results are compatible with this survey; however, SBCN10002 located north of the Plant appears to have settled 0.05'. In 2001, the City performed leveling surveys to connect NGS Benchmark TIDAL-1 to SBCN10033, GPS9015, GPS9025 (destroyed)and TIDAL-2. TIDAL-1 was fixed and SBCN10033 was found in good agreement. TIDAL-2 was found 0.044 feet lower than the published elevation at 12.843 feet in 2001. This survey finds TIDAL-2 at 12.838 feet (final). The 2001 survey results are compatible with this survey.

GPS SURVEYS: At completion of the leveling, a precision GPS survey observed a select set of SBCN points and new control points that were included in the Leveling Network Survey. These measurements provide a basis for using GPS technology to model orthometric heights (elevations) at the level of one centimeter (0.03') across the City. Combining the leveled elevations of SBCN points with GPS measurements provides the means to utilize GPS as a replacement tool for conventional leveling to establish NAVD 88 elevations. The benefit will result in costs savings and improved accuracy for City projects and the private sector when relying on City elevations for project control. See the 2008 Height Modernization GPS Survey Report for additional information.

ACCURACY: The relative accuracy of the leveled heights are expected to be better than 0.01 feet. The absolute accuracy of these heights is dependent on the values provided for the NGS benchmarks.

Attachments: Elevation List, NGS Reference Data

SURVEYOR'S STATEMENT: This report on the criteria and procedures used on the Differential Leveling Survey was prepared by me on November 11, 2008 at the request of the City of Santa Barbara.

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