
TECHNICAL REVIEW
City & County of San Francisco
2013 Leveling Network
and
2013 High Precision Network Surveys
CCSF, F3 & Assoc., Inc. & McGee Surveying Consulting
11/13/2014 NOAA Web
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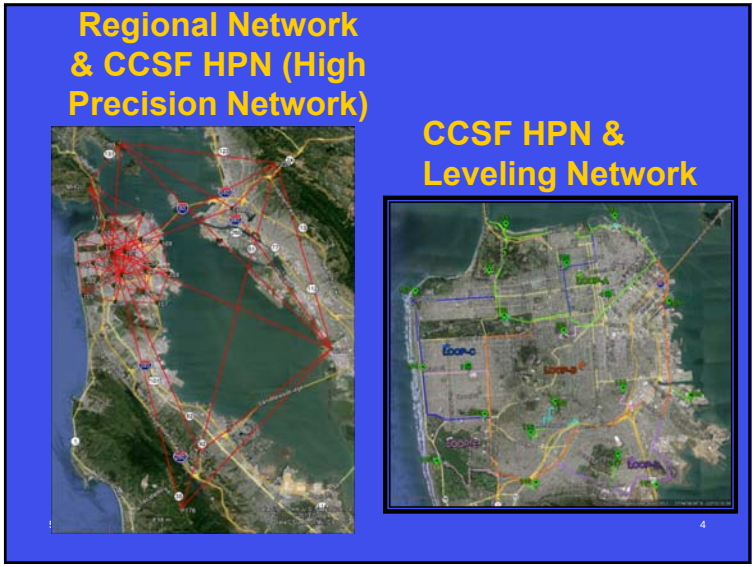
Regional Network & CCSF HPN (High Precision Network)
CCSF HPN & Leveling Network
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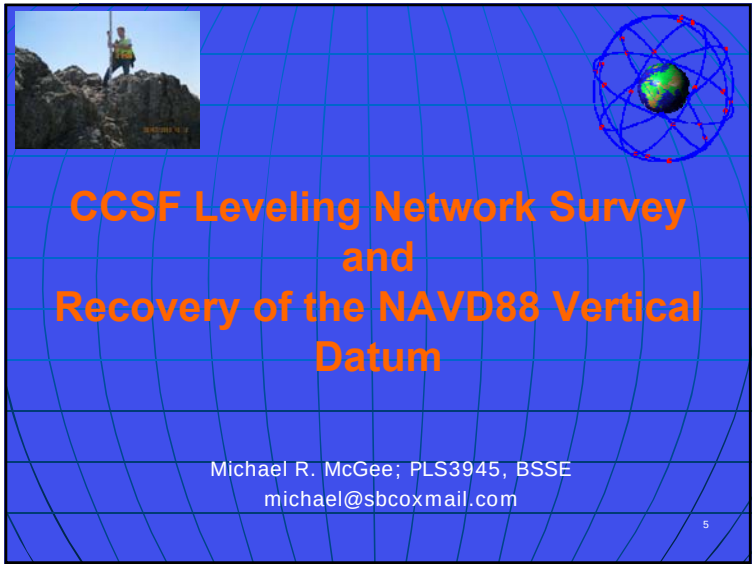
CCSF Leveling Network Survey
and
Recovery of the NAVD88 Vertical Datum
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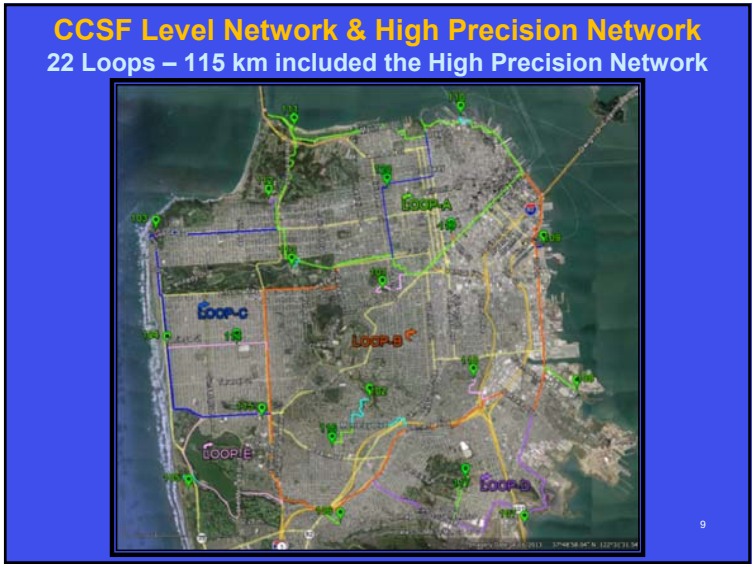
CCSF Level Network & High Precision Network
22 Loops – 115 km included the High Precision Network
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Leveling Included 670 New and 35 Existing Benchmarks (see kmz File)

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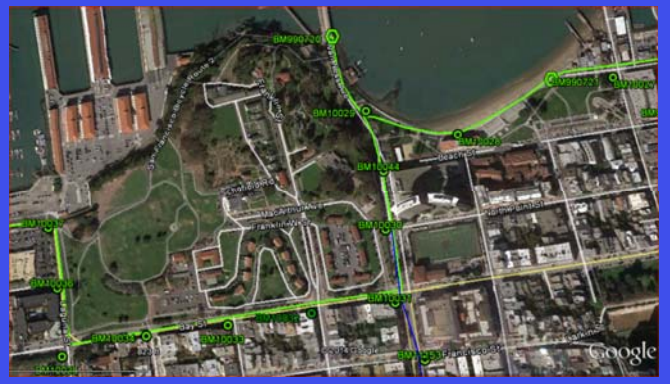
CCSF NAVD88 (2013) Vertical Datum

Benchmarks, Routes & Photos available on CCSF Website (kmz files)



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Benchmark Routes, Photos, KMZ's & Descriptions available on CCSF Website

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2013 BM Monument - 2014 BM Monument

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Detailed BM Descriptions available in a Spreadsheet on the CCSF Website

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Specification and Procedures
Second Order Class I

- The "Federal Geodetic Control Subcommittee (FGCS) Specifications and Procedures to Incorporate Electronic Digital/Bar-Code Leveling" (ver. 4.1) for Geodetic Leveling -
- Combined with best practices, experience and "Murphy" in a document titled "2013 Second Order Leveling Network Specification and Procedures"

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DATA COLLECTION & EQUIPMENT

- Field Surveys: Three person crew committed about 1/3 time from January-October 2013
- Instrument: Leica DNA10 electronic digital level and a pair of 4.05 meter Leica GKNL4 fiberglass bar code rods
- The DNA10 level was calibrated by Leica prior to the survey and a level collimation test (peg test) was performed prior to each field day of operation

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DNA 10 Digital Level & Bar Code Rod

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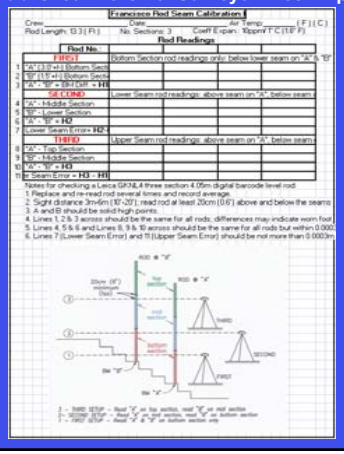
The Rods & Rod Seams Calibrated

Rod & Seam Calibration Form
Published in the Cal Surveyor "Tech Tips"



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DNA 10 Digital Level & Bar Code Rod

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Leveling Demonstration & Validation Survey

Required all personnel to *demonstrate* their proficiency in the instrument operation, their understanding of the "Leveling Specification & Procedures" and that the equipment was operating correctly

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ADJUSTMENTS: 22 Loops / 115 km

- **Average Closure for 22 Loops = 3 mm (0.01')**

Loop	Length Km	Closure mm	1stOrd/I mm= 3√km	2ndOrd/I mm= 6√km	Loop	Length Km	Closure mm	1stOrd/I mm= 3√km	2ndOrd/I mm= 6√km
A	24.3	0	15	30	L	1.1	1	3	6
B	25.7	9	15	30	M	0.6	1	2	5
C	11.4	-3	10	20	N	0.5	2	2	4
D	10.1	-4	10	19	O	0.5	2	2	4
E	5.8	-3	7	14	P	0.8	0	3	5
F	6.8	1	8	16	Q	0.8	0	3	5
G	3.1	1	5	10	R	2.4	0	5	9
H	2.6	1	5	10	S	3.5	-16	6	11
I	1.8	-1	4	8	T	2.4	0	5	9
J	1.6	1	4	8	U	3.5	1	6	11
K	0.6	1	2	5	V	4.8	9	7	13

- 20 loops closed <= 1st Order Class I (3mm*√km)
- Loop "V" closed 9 mm = 1st Order Class II (4mm*√km)
- Loop "S" closed -16 mm = 2nd Order Class II (8mm*√km)

Level Network & High Precision Network

22 Loops – 115 km included the High Precision Network

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FINAL NETWORK ADJUSTMENT

- All loops were combined in a Minimally Constrained Adjustment fixing one BM to develop final heights
- Adjustment Residuals less than +/-1 mm
- The combined network adjustment statistically resulted in 2mm*√km
  (First Order Class I = 3mm*√km)

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NAVD88 DATUM RECOVERY:

- NAVD88 is realized by NGS benchmarks leveled circa 1977 and 1989 and published in the original 1991 national adjustment
- As a result of the 2013 leveling, the realization of NAVD88 in San Francisco is based on an extensive recovery of "First Order" NGS benchmarks in the City.

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NAVD88 DATUM RECOVERY:

All NGS Published Benchmarks in San Francisco

NGS BM's: Green=1st Order Class I - stability A/B,
Yellow=1st Order Class I - stability C/D, Brown=VertCon

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Datum Recovery:
Criteria for Benchmarks deemed the best candidates for recovering the NAVD88 Datum

- Height derived from the 1991 national adjustment of NAVD88
- Accuracy classification of "First Order"
- Stability Classification of A or B (on a scale of A-D)
- All such candidates were searched for and 14 recovered in the County

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Datum Recovery: 35 NGS Benchmarks were recovered and included in the Leveling Network

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NAVD88 DATUM RECOVERY:
Selecting a reference point for the adjustment that best fit all the candidate BM's

- The record height at NGS Benchmark HT2255 located east of the Golden Gate Bridge was found to agree with a best fit of all candidate Benchmarks.

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NAVD88 DATUM RECOVERY:
Selecting a reference point that best fits all the candidate BM's

- HT2255 has the following attributes:
- First Order Class I classified as a stability "A" benchmark set in a bedrock formation and expected to remain stable,
- Agreed 1-2 mm with two nearby stability "B" benchmarks (HT0698 and HT0700) a further indication of long term stability,

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Analysis of NGS Benchmarks

Fixed HT2255: The differences from record heights to adjusted heights in meters are listed in the right three columns

			Record	Record to Computed Height		
Name	NGS PID	Status-Stability	NAVD88 Ht	All BM's	All Adj'd	AB Adj'd
BM990515	HT0515	VertCon	91.520	0.007		
BM990516	HT0516	VertCon	92.710	0.013		
BM990517	HT0517	VertCon	90.070	0.008		
BM990604	HT0604	VertCon	4.690	0.001		
BM990687	HT0687	Adjusted-CD	3.779	0.001	0.001	
BM990692 *	HT0692	Adjusted-AB	4.754	-0.021	-0.021	
BM990697	HT0697	Adjusted-CD	5.029	-0.006	-0.006	
BM990698	HT0698	Adjusted-AB	4.249	-0.001	-0.001	-0.001
BM990700	HT0700	Adjusted-AB	4.237	-0.002	-0.002	-0.002
BM990701=111	HT0701	Adjusted-AB	4.008	-0.008	-0.008	-0.008
BM990702	HT0702	Adjusted-AB	3.996	-0.012	-0.012	-0.012
BM990705	HT0705	Adjusted-CD	4.833	-0.002	-0.002	
BM990713 *	HT0713	Adjusted-AB	3.409	-0.045		
BM990720	HT0720	Adjusted-AB	3.800	0.014	0.014	0.014
BM990721	HT0721	Adjusted-CD	3.563	-0.007	-0.007	
BM990724	HT0724	Adjusted-AB	6.221	0.005	0.005	0.005
BM990726	HT0726	Adjusted-AB	6.990	0.004	0.004	0.004
BM990728	HT0728	Adjusted-AB	4.385	-0.009	-0.009	-0.009
BM990759	HT0759	Adjusted-CD	3.505	-0.010	-0.010	
BM990781	HT0781	VertCon	7.150	0.008		
BM991843=104	HT1843	VertCon	7.560	-0.010		
BM992254	HT2254	VertCon	4.370	-0.003		
BM992255	HT2255	Adjusted-AB	5.844	0.000	0.000	0.000
BM992259	HT2259	Adjusted-CD	51.430	-0.003	-0.003	
BM992261	HT2261	Adjusted-AB	46.912	0.013	0.013	0.013
BM992262	HT2262	Adjusted-CD	52.738	0.008	0.008	
BM992263	HT2263	Adjusted-CD	69.619	0.014	0.014	
BM992267	HT2267	Adjusted-CD	67.480	0.012	0.012	
BM992268	HT2268	Adjusted-CD	102.431	0.021	0.021	
BM992273	HT2273	Adjusted-CD	58.189	0.009	0.009	
BM993538	HT3538	Adjusted-CD	3.734	-0.023	-0.023	
BM993541	HT3541	Adjusted-AB	5.601	0.004	0.004	0.004
BM995209=201	AE5209	Adjusted-AB	3.669	-0.010	-0.010	-0.010
BM997677=202	AB7677	3rd Order	23.690	0.071		
BM997679=107	AB7679	GPS Observation	3.700	-0.003		
			Number =	35	25	12
			Mean =	0.001	0.000	0.000
* = outlier			Std.Dev.=	0.017	0.011	0.008

HISTORICAL CCSF LEVELING
FOUND CONSISTENT WITH THIS SURVEY

- CCSF conducted extensive precise leveling surveys between 1999-2002 using a first order NA3003 Digital Level and invar rod with struts
- 37 BM's were recovered. The average difference from the 2002 Record Ht's to this survey is +1 mm with a Std. Dev. of 9 mm.

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2002 era benchmarks recovered in this survey with the differences in meters from the 2002 to 2013 heights

2013	2002 Survey		2002-2013	2013	2002 Survey		2002-2013
Name	Name	Ht(m)	Difference	Name	Name	Ht(m)	Difference
BM10249	T-0089	3.479	0.005	BM10299	BM-0005	3.471	-0.006
BM10251	T-0087	3.467	-0.007	BM10300	T-0179	3.565	-0.005
BM10252	T-0086	3.485	-0.014	BM10303	BM-0004	3.441	0.000
BM10254	T-0085	3.369	-0.007	BM10310	T-0181	3.469	-0.006
BM10255	T-0017	4.721	0.000	BM10427	T-0169	56.460	0.016
BM10256	T-0016	4.716	-0.001	BM10450	T-0144	11.401	0.004
BM10258	T-0083	4.506	-0.013	BM10468	T-0121	8.516	0.044
BM10261	T-0080	4.392	-0.017	BM10469	T-0120	7.066	-0.004
BM10263	T-0078	5.323	-0.014	BM10522	T-0109	22.196	0.001
BM10264	T-0077	5.509	-0.016	BM990604	HT0604	4.691	0.000
BM10265	T-0076	5.677	-0.012	BM990726	HT0726	6.990	0.004
BM10271	T-0069	12.953	0.005	BM990728	HT0728	4.378	-0.002
BM10272	T-0068	13.305	0.003	BM990781	HT0781	7.158	0.000
BM10273	T-0067	13.010	0.003	BM992267	HT2267	67.480	0.012
BM10276	T-0065	8.136	-0.005	BM992268	HT2268	102.431	0.021
BM10278	T-0064	5.853	0.028	BM993541	HT3541	5.601	0.004
BM10293	T-0176	4.715	-0.001	BM997677	AB7677	23.757	0.004
BM10294	T-0177	4.266	-0.004	BM99999	SM No.1	59.213	0.010
BM10295	T-0161	6.590	0.001				

SAN FRANCISCO VERTICAL DATUMS

- The new "SFVD13" realization of the NAVD88 Datum supersedes previous NGS Benchmark Heights, and the old "SF Datum"
- The City and County Surveyor has determined that the conversion from the CCSF 2013 NAVD88 Datum to the old City Datum, henceforth shall be the following:
  - Conversion Constant (Feet)
  - 2013 NAVD88 Datum - 11.35 feet = City Datum

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GPS SURVEYS

- In July 2013 a high precision GNSS survey observed all CCSF-HPN points (101-120)
- The ellipsoid heights were combined with a refined Geoid 2012A Model to compute NAVD88 Heights and found to agree with the leveling survey, averaging 4 mm (0.01') and a range of +/- 7mm (0.02')
- CCSF intends to utilize GNSS and a local RTN to replace conventional differential leveling for determining heights in the future at the sub-centimeter level

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ACCURACY

- Relative accuracy of adjacent monuments is expected to be less than 0.001 meters (0.003')
- 95% Error of the heights range 1 to 12 mm relative to fixed constraint HT2255 (average 9 mm)
- Absolute accuracy of the heights is dependent on the recovery of the NAVD88 Datum which was based on a best fit of 12 BM's with a Std. Dev. of 8 mm

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ACCURACY

- This survey is classified as Second Order Class I;
- however, the average actual loop closures of 3 mm (0.01 feet),
- the agreement with 2002 precise leveling
- and the results of the GNSS survey indicate results consistent with First Order specifications were obtained .

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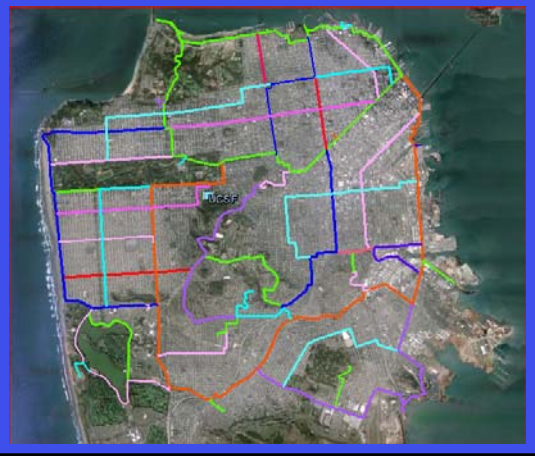
2014 Densification (112 km) of the Leveling Network (227 km total)



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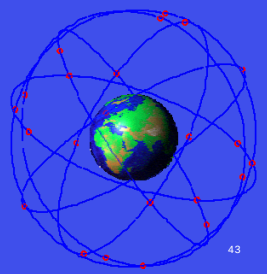
EQUIPMENT, DATA COLLECTION

ADJUSTMENTS

NAVD88 DATUM RECOVERY

HISTORICAL LEVELING &
SAN FRANCISCO CITY DATUM



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Leveling Survey Report

of the

CCSF 2013 Second Order Leveling Survey (pdf)

Available At

http://www.sfdpw.org/index.aspx?page=1781

(Google "HPN Survey")

Report Attachments

- NAVD88 (2013) Orthometric Height List
- Benchmark Descriptions, Photos & KMZ Files
- "CCSF 2013 2nd Order Leveling Network Specification and Procedures"

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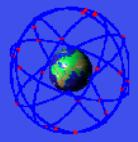

City & County of San Francisco

2013 High Precision Network Survey (HPN)

CCSF, McGee Surveying Consulting & F3 & Assoc., Inc.

10/13/2014

Michael R. McGee; PLS3945, BSSE

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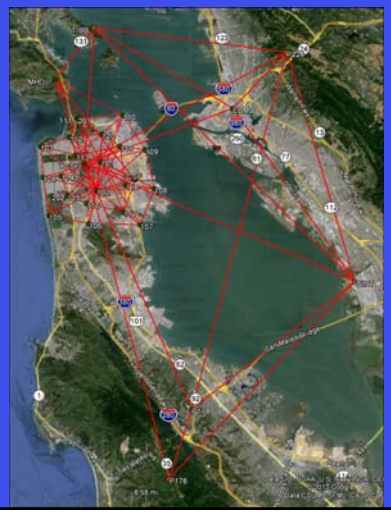
Regional & CCSF High Precision Network



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PROJECT OVERVIEW

- The Survey established 20 high precision control points in July 2013 utilizing GNSS technology
- The Network is referred to as the "City & County of San Francisco High Precision Network" (CCSF-HPN)
- Purpose: Provide a framework for densification, support the City's GIS, and provide a Deformation Network to measure secular and episodic ground movements
- Under the old classification system, the network is classified as a "B" Order Survey 1:1,000,000

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Planning/Preparation

5/1/2014

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Planning/Preparation

HPN Monument

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Planning/Preparation

HPN-101 North Central Radial Base

HPN-102 South Central Radial Base

Planning/Preparation

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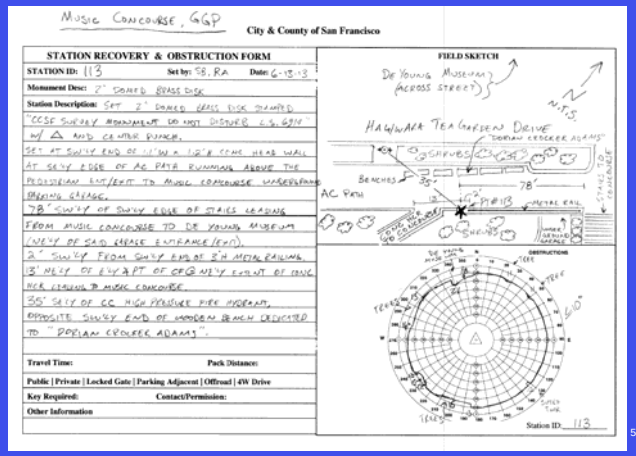
Station Recovery & Obstruction Diagram, Photos and KMZ Files are available on the Website



Music Concourse, GGP

City & County of San Francisco

STATION RECOVERY & OBSTRUCTION FORM

STATION ID: 113 Set by: SS, RA Date: 6-13-13

Monument Desc: 2" DOMED BRASS DISC

Station Description: SET 2" DOMED BRASS DISC STAMPED "CCSF SURVEY MONUMENT DO NOT DISTURB C.S. 6/14" W/ Δ AND CENTER PUNCH.

SET AT SWLY END OF NW 1-1/2" STONE HEAD WALL AT SELY EDGE OF AC PATH RUNNING ABOVE THE PEDESTRIAN ENT/EXIT TO MUSIC CONCOURSE UNDERGROUND PARKING GARAGE.

78' SW'LY OF SW'LY EDGE OF STAIRS LEADING FROM MUSIC CONCOURSE TO DE YOUNG MUSEUM (NE'LY OF SAID LEASE ENTRANCE (EXIT).

2' SW'LY FROM SW'LY END OF EH METAL RAILING

13' NE'LY OF ELV ΔPT OF CB @ NE'LY ENDT OF CONC. RET. LEADING TO MUSIC CONCOURSE

35' SE'LY OF CC HIGH PRESSURE FIRE HYDRANT, OPPOSITE SW'LY END OF MODERN BENCH DEDICATED TO "DORIAN CROCKER ADAMS".

Travel Time: Pack Distance:

Public | Private | Locked Gate | Parking Adjacent | Offroad | 4W Drive

Key Required: Contact/Permission:

Other Information

FIELD SKETCH

DE YOUNG MUSEUM (ACROSS STREET)

HAWTHORN TERRACE DRIVE

DORIAN CROCKER ADAMS

N.T.S.

BENCHES

AC PATH

78'

#113

METAL RAIL

OBSTRUCTIONS

Station ID: 113

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EQUIPMENT

- Four Leica GS15 geodetic GNSS receivers mounted on fixed height poles (5th Recvr on Secondary Pts)

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EQUIPMENT CALIBRATION

- Fixed Height Poles calibrated for height and plumb

- Receiver PCV's calibrated for eccentricity

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CREW CALIBRATION

- Validation Survey: Verify the crews understand their assignments, procedures, receiver operation, filling out the paperwork, communication protocols and verify the equipment was operating properly before starting the field campaign.

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OBSERVATIOIN & DATA COLLECTION

- GNSS Survey:
- Constellation: 32 US Navstar GPS satellites and 24 Russian GLONASS satellites
- Satellite Observed: 12-21 satellites observed with a minimum of 6 GPS and 6 GLONASS; GDOP< 2;
- Elevation Mask set at 10° and post-processed at 15°
- Observables: GPS L1 & L2, GLONASS L1 & L2

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OBSERVATIOIN & DATA COLLECTION

- GNSS Survey:
- Space Weather: Planetary K Index = 1-3 (gauges ionospheric activity on a scale of 0-9, <5 preferred)

Weather: Generally overcast marine layer and mild temperatures throughout the five day campaign

5/1/2014

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DATA PROCESS

- Absolute Antenna Models used in processing baselines; imported from the NGS and listed in the Survey Report
- Vectors (baselines) were processed in IGS08 (WGS84) with the Precise Ephemeris imported from the NGS (GPS) and IGS (GLONASS)
- Post-Processing: Leica Geomatics Office (LGO) v8.1
- Network Adjustments: Starnet v7.2.

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REGIONAL NETWORK

Four nearest NGS CORS stations (TIBB, P224, WINT & P176) were included and are the basis for recovering the IGS08(2005) and NAD83(2011) Datums

Four CGPS stations (EBMD, P178, UCSF and MHDL) were included to add strength and redundancy to the Network.

NGS CORS

5/1/2014

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REGIONAL NETWORK STATISTICS

The network contained 57 vectors averaging 20 km (12 mi.) in length, max. 38 km

Each vector represents three 24 hour observations staggered every other day

Min. Constrained Adjustment 2D Residuals Av. 2 mm, Std. Dev. 2 mm, Max. 10 mm; Vertical Residuals Av. 2 mm, Std. Dev. 2 mm, Range -7 to +8 mm

HIGH PRECISION NETWORK (HPN) SURVEY

Field campaign took 5 days during the week of July 15-19, 2013 (average epoch 2013.54)

Four crews operated Four Leica GS15 GNSS Receivers on FHP's

HPN points were occupied for 45 minutes at 15 sec. epoch rate

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Field Campaign: Day-1 - Radial Network
A Base Receiver occupied #101 while three crews occupied 19 remaining points at will

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Field Campaign: Day-2 - Radial Network
A Base Receiver occupied #102 and three crews occupied 19 remaining points

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Field Campaign: End of Day-2

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Day-3: Tandem Operation - Four Crews working in unison at assigned points; completed surveyed in nine sessions

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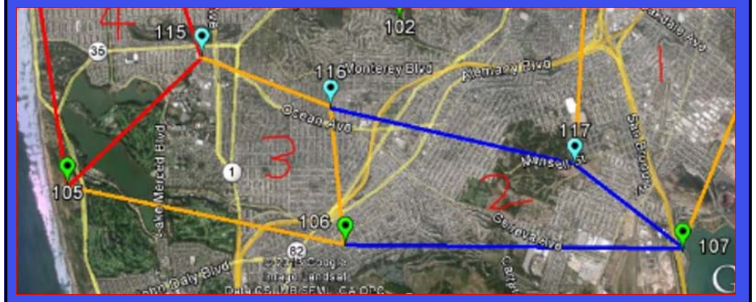
Session Occupations & Processing Non-Trivial Lines



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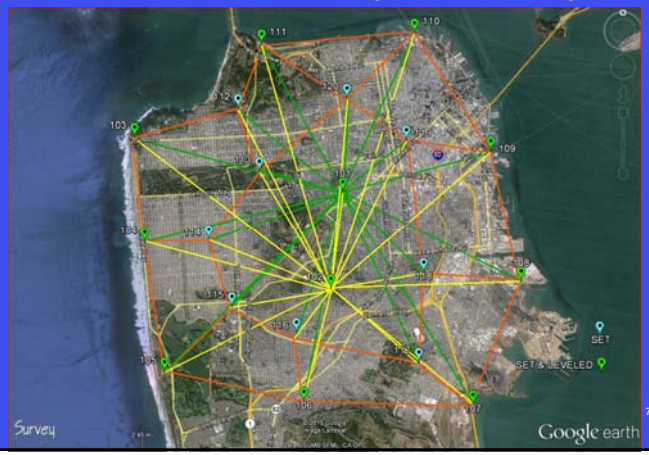
Completed Field Campaign

HPN points were occupied 3-5 times
at different times of the day on different days



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HPN STATISTICS

The network contained 83 non-trivial vectors averaging 4 km (2 1/2 mi.) in length, maximum 8 km

Min. Constrained Adj. Vector Residuals:

2D Av. 3 mm, Std. Dev. 2 mm, Max. 10 mm;

Vertical Av. 3 mm, Std. Dev. 3 mm, Range -9 to +16 mm

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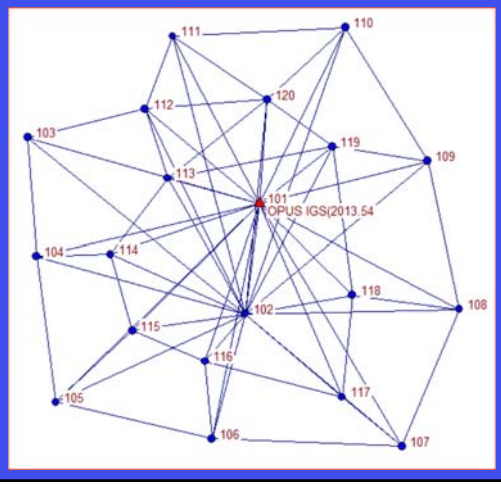
Network Solution: Fix 101



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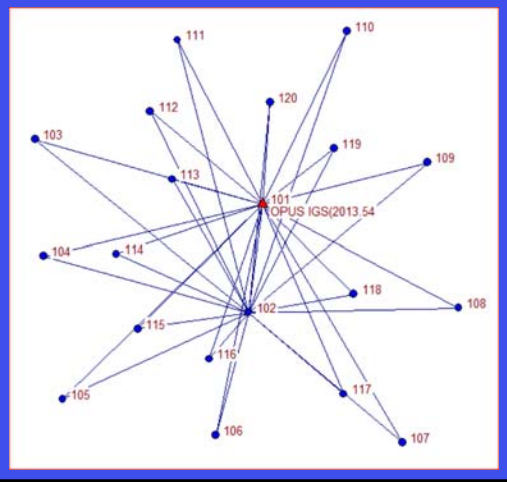
Hub Solution: Fix 101



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Stat	dN	dE	dZ
101	-0.000	-0.000	-0.000
102	-0.000	0.000	0.000
103	0.002	0.001	0.001
104	0.001	-0.001	-0.002
105	-0.003	-0.001	0.002
106	-0.004	-0.000	0.000
107	0.001	0.001	0.003
108	0.004	-0.002	0.001
109	-0.003	-0.001	0.003
110	-0.001	-0.000	0.003
111	-0.002	0.001	-0.002
112	0.001	-0.002	-0.001
113	0.002	0.000	-0.001
114	0.001	0.001	-0.001
115	0.002	-0.000	-0.001
116	-0.000	0.002	0.002
117	0.000	-0.000	-0.002
118	0.001	0.002	-0.002
119	-0.002	-0.000	0.004
120	-0.000	-0.001	-0.005

Coordinate Changes from Network to a Radial or "Hub" Solution (meters)

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DATUMS - REFERENCE SYSTEMS

- Geometric Datums (3D) and Reference Frame
- NAD83 (2011) Epoch 2010.00 & Epoch 2013.54
- IGS08 (2005) Epoch 2013.54 (July 17, 2013)
- Reference Network
- NGS CORS (Continuously Operating Reference Stations)

- Vertical Datum
- CCSF NAVD88 2013 Vertical Datum (SFVD13)
- Reference Network
- Reference by the HPN

80

DATUM RECOVERY

Four nearest operating CORS were the basis for recovery of the IGS08 & NAD83 Datums

- IGS08 and NAD83 positions and velocities were obtained from the NGS CORS website
- HTDP model v3.2.3 was used to move positions between epochs for CORS operating <2.5 years
- Six network adjustments were processed to develop geodetic and plane coordinates in two reference frames at two different epochs

81

HTDP = Horizontal Time Dependant Program

- Why HTDP? Why Change Epochs?
- SF Bay Area is crossed with multiple faults and the CORS are each moving in a different direction and speeds.
- The CORS do not have the same relationship today as in 2010.00; therefore, must process in real time by moving the 2010.00 positions to 2013.54 (date of field survey).

82

REGIONAL NETWORK

Four NGS CORS:
TIBB
P224
WINT
P176

Four CGPS stations:
EBMD
P178
UCSF
MHDL

CCSF (Private RTN Sta.)

OVERVIEW of the ADJUSTMENTS

- #1 MA and #2 CA: Developed positions in IGS08(2005) 2013.54 Epoch for referencing future secular and episodic movements
- #3 MC and #4 CA: Developed positions in NAD83(2011) 2013.54 Epoch on the Regional Network for the purpose of establishing NAD83(2011) in the City
- #5: Developed positions in NAD83(2011) 2010.00 Epoch for the HPN in the City
- #6: Analyzed the Geoid 2012A Model for accuracy and consistency with the 2013 Leveling Network

84

System Test: Compute a 3D 7-Parameter Transformation of the Measured Network to Best Fit the IGS08 Positions of the CORS Stations

- Verify the consistency of the network computed with the precise ephemeris and the NGS IGS08 positions of the CORS Stations. The expectation is no change.
- Datum Transformation
  - Scale Factor = 1.0000000685 (1:15m)
  - Rotation Around North Axis = -0.07 Sec
  - Rotation Around East Axis = -0.06 Sec
  - Rotation Around Vert. Axis = -0.01 Sec

Station	dN	dE	dZ
P176	0.003	-0.001	0.002
P224	0.006	0.002	0.006
TIBB	-0.005	-0.001	-0.003
WINT	-0.004	0.000	-0.005

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IGS08(2005) Epoch 2013.54
Adjustment #1

Steps:

1- IGS08(2005) positions of the CORS obtained from NGS

|

2- IGS08(2005) positions moved to 2013.54 with HTDP

|

3- WINT was fixed in a Minimally Constrained Adjustment (includes four CORS, four CGPS stations, RTN CCSF and the HPN

|

4- Coordinate differences (closures) reviewed at other three CORS

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IGS08(2005) Epoch 2013.54
Adjustment 1: 3D Minimally Constrained

- Coordinate Differences: IGS08 to Computed

Station	dN (m)	dE (m)	dZ (m)	
P176	0.007	-0.004	0.006	
P224	0.012	0.003	0.002	
TIBB	0.003	-0.001	-0.015	
WINT	0.000	0.000	0.000	FIXED

- Diff. N 3 to 12 mm, E -4 to 3 mm, Up -15 to 6 mm

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IGS08(2005) Epoch 2013.54
Adjustment 2: 3D Constrained Adjustment

- All four CORS were constrained to develop IGS08(2005) 2013.54 Epoch positions on the CGPS and the HPN Stations

---

- UCSF position obtained from OPUS used as a check (mean of three 24 hours observations)

- Coordinate Difference: UCSF/OPUS to Computed (m)

Station	dN	dE	dZ	
UCSF	-0.001	0.001	-0.014	CA/free

- Difference of 1mm at UCSF indicates the compatibility with the NGS process

88

NAD83(2011) Epoch 2013.54
Adjustment #3

Steps:

1- NAD83(2011) 2010.00 Epoch positions of the CORS obtained from NGS Data Sheets

|

2- NAD83(2011) 2010.00 Epoch positions moved to 2013.54 with HTDP

|

3- WINT was fixed in a Minimally Constrained Adjustment (includes four CORS, four CGPS stations, and CCSF)

|

4- Coordinate differences (closures) reviewed at other three CORS

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NAD83(2011) Epoch 2013.54
Adjustment 3: 3D Minimally Constrained

- Coordinate Differences: NAD83(2011) to Computed

Station	dN	dE	dZ	
P176	0.006	-0.004	0.005	
P224	0.012	0.004	0.006	
TIBB	0.004	-0.001	-0.010	
WINT	0.000	0.000	0.000	FIXED

Max. Closures N 12mm, E 4mm, Up 10mm

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NAD83(2011) Epoch 2013.54
Adjustment 4: 3D Constrained

- All 4 CORS were constrained to develop NAD83(2011) 2013.54 Epoch positions on the CGPS

- A 2013.54 position of UCSF (in SF) was obtained from SOPAC/SECTOR as a check.
- Coord. Differences: From UCSF to Computed

Station	dN	dE	dZ	
UCSF	0.004	-0.001	-0.004	CA/free

Note, SECTOR is referenced to NAD83(2007), whereas this adjustment is referenced to NAD83(2011)

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NAD83(2011) Epoch 2010.00
Adjustment #5 (getting back to 2010)

Steps:

1- NAD83(2011) 2013.54 Epoch positions of UCSF, MHDL & CCSF were obtained from Adjustment #4

|

2- NAD83(2011) 2013.54 Epoch positions moved to the NAD83(2011) 2010.00 Epoch with HTDP

|

3- UCSF fixed in a Minimally Constrained Adjustment (included the HPN, MHDL & CCSF)

|

4- Coordinate differences (closures) reviewed

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NAD83(2011) Epoch 2010.00
Adjustment 5: 3D Minimally Constrained

- Coordinate Differences: NAD83(2011) to Computed

Stat.	dN(m)	dE	dZ	Epoch	
UCSF	-0.000	-0.000	-0.000	2010.00	FIXD
MHDL	-0.003	0.003	-0.006	2010.00	
CCSF	-0.005	0.002	0.007	2010.00	

- A 2010.00 Epoch position of UCSF was obtained from OPUS as a check base on three 24 hour observations.
- Coord. Differences: From UCSF/OPUS to Computed

Station	dN	dE	dZ	
UCSF	-0.004	0.001	-0.013	CA/free

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NAD83(2011) Epoch 2010.00
Coordinate Differences from HTDP to Computed

- The closures on the HTDP positions of MHDL and CCSF are less than the noise level of the HTDP model.
- Therefore, the results of this adjustment were held to established NAD83(2011) 2010.00 Epoch positions on MHDL, CCSF and the City's HPN.

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NAD83(2011) Epoch 2010.00
Adjustment 5: HPGN in the City

- Coordinate Differences at the HPGN stations: NGS NAD83(2011) 2010.00 Epoch to Computed

Stat.	dN(m)	dE	dZ(EH)	Epoch	Source
107	-0.034	0.007	-0.040	2010.00	NGS Candlstck
201	-0.029	0.002	-0.045	2010.00	NGS Tidal
202	-0.053	0.017	-0.031	2010.00	NGS Sloat

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Adjustment 6: Geoid Model Analysis

- Two Methods for incorporating Ellipsoid Heights and Geoid Heights to Determine NAVD88 Orthometric Heights are discussed here.
- Method One: Approximates NAVD88 Heights by applying the hybrid Geoid 2012A heights to the measured NAD83 Ellipsoid Heights using the equation H=h-N
- (H= Orthometric Ht, h=Ellipsoid Ht, N=Geoid Ht).
- The accuracy of this method in San Francisco is about 0.06 meters (Note, Geoid 12A is a hybrid model, compatible with NAD83(2011) Ellipsoid Hts)

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Geoid Model Analysis
Adjustment #6

- Method Two: Takes advantage of the relative precision of geoid heights. The Geoid 2012A Model was incorporated in a seven parameter transformation to best fit the leveled NAVD88 2013 Heights on the 20 HPN points
- Transformation Explained:
- Two horizontal constraints, scale fixed to 1.0 and heights loosely weighted
- Least Squares solution allows the geoid to float and rotate around the north and east axis to best fit the vertical constraints.

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Geoid Model Analysis
Adjustment #6

- Method Two: Takes advantage of the relative precision of the geoid model heights.
- The Geoid 2012A Model was incorporated in a seven parameter transformation to best fit the leveled NAVD88 2013 Heights on the 20 HPN points
- Least Squares solution allows the geoid to float and rotate around the north and east axis to best fit the vertical constraints.
- The rotations represent the tilts applied to the Geoid 2012A surface model to best fit the leveled NAVD88 2013 Heights

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Geoid Model Analysis
Adjustment #6

- The rotations represent the tilts applied to the Geoid 2012A surface model to best fit the leveled NAVD88 2013 Heights

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Column "A" are Differences from Leveled Ht to Modeled

Column 'A': Mean = zero, Range = -7 to +7 mm, Std Dev = 4mm, Solved rotations = +0.21" around the N and +0.24" around the E axis

	A	B	C	D=C-B	E	F=E-D
Point	Diff's	NAVD88 Hts	NAD83 EH	Meas'd GH	2012A GH	Diff.
101	-0.003	150.799	118.188	-32.611	-32.548	0.063
102	0.004	170.991	138.344	-32.647	-32.587	0.060
103	0.004	46.352	13.592	-32.760	-32.712	0.048
104	0.000	7.550	-25.278	-32.828	-32.771	0.057
105	-0.004	56.489	23.607	-32.882	-32.817	0.065
106	-0.007	110.302	77.575	-32.727	-32.653	0.074
107	0.006	3.698	-28.944	-32.642	-32.574	0.068
108	0.000	4.484	-28.109	-32.593	-32.523	0.070
109	-0.004	3.461	-29.098	-32.559	-32.491	0.068
110	0.003	3.279	-29.261	-32.540	-32.486	0.054
111	0.003	4.000	-28.605	-32.605	-32.555	0.050
112	-0.004	54.344	21.692	-32.652	-32.593	0.059
113	-0.001	74.816	42.159	-32.657	-32.598	0.059
114	-0.001	99.656	66.915	-32.741	-32.681	0.060
115	0.003	61.448	28.692	-32.756	-32.697	0.059
116	0.007	89.985	57.292	-32.693	-32.635	0.058
117	-0.004	117.172	84.526	-32.646	-32.572	0.074
118	0.003	78.553	45.947	-32.606	-32.543	0.063
119	-0.003	18.941	-13.634	-32.575	-32.511	0.064
120	-0.002	85.887	53.304	-32.583	-32.524	0.059
Mean=	0.000	63.188	30.513	-32.675	-32.613	0.062

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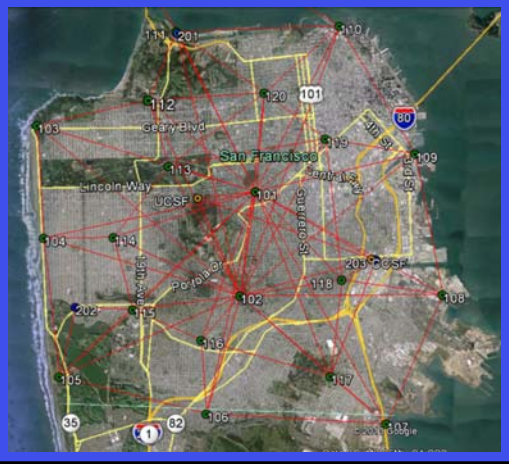
Leveled Hts & GNSS Modeled Hts at HPN 101 & 102 Agree 6 mm (0.02')



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Determine Orthometric Hts

- The accuracy will be the combined accuracy of the NAVD88 height of the HPN points, the accuracy of the measured ellipsoid height differences, the relative accuracy of the geoid heights and the residual tilt between the geoid modeled surface and the actual geoid surface. The effect of the tilt listed above (rotations of +0.213 and +0.243 seconds around the north and east axis) is 1.6 mm per kilometer (0.008' per mile) or less and would be absorbed in a constrained adjustment. The largest source of error is usually in the measured ellipsoid heights.

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Determine Orthometric Hts

- **Following the specifications and procedures used in this survey, an orthometric height accuracy of 0.007 meters (0.02 feet) was achieved at the HPN Stations utilizing GNSS.**
- **CCSF is in the process of developing procedures to utilize the local RTN Network to establish centimeter level orthometric heights.**

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NGS Gravimetric Geoid Model

- **USGG2012 Model used in a trial transformation to best fit the NAVD88 heights of the HPN points**
- **Returned results similar to the hybrid model; however, the rotations were +0.138 and +0.120 seconds around the north and east axis (negligible improvement as expected)**

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Accuracy

- **Vector Residuals: Resulting from the minimally constrained adjustment in meters.**

	Two Dimensional Residuals				Vertical Residuals (absolute values)		
	No.	Average	Std.Dev.	Max.	Average	Std.Dev.	Range
CCSF HPN	83	0.003	0.002	0.010	0.003	0.003	-0.009 to +0.016
Regional CORS	57	0.002	0.002	0.010	0.002	0.002	-0.007 to +0.008

- **Local Accuracies: Resulting from the minimally constrained adjustment at the 95% Level of Confidence in meters**

	Vector Lengths(m)		Relative Dist. Error			Rel.Vert. Error	
Network	Vary	Average	Average	Max.	Precision	Average	Max.
CCSF HPN	1675-8291	4267	0.004	0.005	1:1,070,000	0.003	0.004
Regional	5322-37896	20224	0.003	0.003	1:6,740,000	0.003	0.004

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Local Accuracy

- Local Accuracies: Resulting from the minimally constrained adjustment at the 95% Level of Confidence in meters

	Relative Dist. Error			Rel.Vert. Error	
Network	Average	Max.	Precision	Average	Max.
CCSF HPN	0.004	0.005	1:1,070,000	0.003	0.004
Regional	0.003	0.003	1:6,740,000	0.003	0.004

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Computing Network Accuracy

- RMS's for the Latitude, Longitude & Ellipsoid Heights of the CORS stations were obtained from the "Short Term Time Series" at the NGS CORS website,
- and used to in a weighted constrained adjustment to develop the Network Accuracies on each point (Public Resources Code requirement)

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Computing Network Accuracy

- Standard Deviations for three of the four CORS were not available (less than 2.5 years of data),
- therefore the "Short Term Time Series" were used for all CORS for consistency

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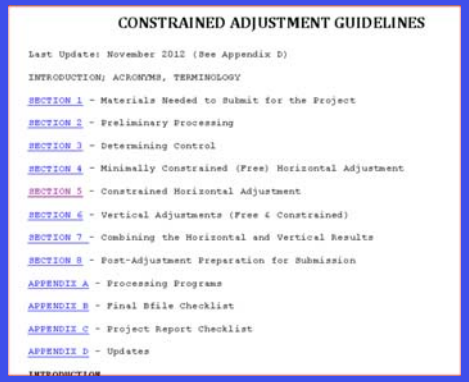
NGS Reference Document



CONSTRAINED ADJUSTMENT GUIDELINES

Last Update: November 2012 (See Appendix D)

INTRODUCTION; ACRONYMS, TERMINOLOGY

SECTION 1 - Materials Needed to Submit for the Project

SECTION 2 - Preliminary Processing

SECTION 3 - Determining Control

SECTION 4 - Minimally Constrained (Free) Horizontal Adjustment

SECTION 5 - Constrained Horizontal Adjustment

SECTION 6 - Vertical Adjustments (Free & Constrained)

SECTION 7 - Combining the Horizontal and Vertical Results

SECTION 8 - Post-Adjustment Preparation for Submission

APPENDIX A - Processing Programs

APPENDIX B - Final Bfile Checklist

APPENDIX C - Project Report Checklist

APPENDIX D - Updates

INTRODUCTION

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Network Accuracy

This table allows users to calculate the propagated network error for future surveys based on the HPN positions

NETWORK ACCURACY in Meters

Station	Coordinate Std. Deviations			Network Accy.	95% Confidence
	Latitude	Longitude	Ellipsoid Ht	Horizontal	Ellipsoid Ht
101	0.002	0.002	0.004	0.005	0.008
102	0.002	0.002	0.004	0.005	0.008
103	0.003	0.003	0.004	0.006	0.009
104	0.003	0.003	0.004	0.006	0.009
105	0.002	0.002	0.004	0.006	0.009
106	0.003	0.003	0.004	0.006	0.009
107	0.003	0.003	0.004	0.006	0.009
108	0.002	0.002	0.004	0.006	0.009
109	0.003	0.002	0.004	0.006	0.009
110	0.002	0.002	0.004	0.006	0.008
111	0.002	0.002	0.004	0.006	0.008
112	0.002	0.002	0.004	0.006	0.008
113	0.002	0.002	0.004	0.006	0.008
114	0.003	0.002	0.004	0.006	0.009
115	0.002	0.002	0.004	0.006	0.008
116	0.003	0.002	0.004	0.006	0.009
117	0.002	0.002	0.004	0.006	0.009
118	0.002	0.002	0.004	0.006	0.008
119	0.002	0.002	0.004	0.006	0.008
120	0.002	0.002	0.004	0.006	0.008
CCSF	0.002	0.002	0.004	0.005	0.008
EBMD	0.002	0.002	0.004	0.004	0.008
MHDL	0.002	0.002	0.004	0.004	0.008
P176	0.001	0.001	0.004	0.004	0.008
P178	0.002	0.002	0.004	0.004	0.008
P224	0.001	0.001	0.004	0.003	0.008
TIBB	0.001	0.001	0.004	0.004	0.008
UCSF	0.001	0.001	0.004	0.003	0.008
WINT	0.001	0.001	0.004	0.003	0.008

CORS >
P176
P224
TIBB
WINT

Accuracy Classification per FGDC-Std-007, 2-1998

- Following the FGDC "Geospatial Positioning Accuracy Standard, Part 2, Geodetic Control Networks" (FGDC-Std-007, 2-1998), at the 95% Level of Confidence this survey is classified as……
- Local Horizontal Accuracy Classification is 5 mm
- Local Ellipsoid Height Acc. Classification is 5 mm
- Network Horizontal Accuracy Classification is 1 cm
- Network Ellipsoid Height Acc. Classification is 1 cm
- This Survey conforms to the requirements of Public Resources Code Section 8801 through 8819 and 8850 through 8880.

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Transformation: 1999 NAD83 (1991.35 Epoch) SPC > 2013 NAD83 (2011) 2010.00 Epoch SPC

INPUT COORDINATES (Feet)

	1999 NAD83(1991) 1991.35 SPC			2013 NAD83(2011)2010.00 SPC	
PT#	North(1)	East(1)	PT#	North(2)	East(2)
CANDLESTICK	2085128.546	6013911.480	107	2085130.260	6013910.280
TIDAL	2121772.462	5993470.060	201	2121774.233	5993468.889
SLOAT	2095678.561	5984226.406	202	2095680.395	5984225.175
ARMY	2100667.364	6012652.104	203	2100669.127	6012650.919

TRANSFORMATION SOLUTION RESIDUALS (Feet)

1999	2013	North	East	N.Azim & Dist
CANDLESTICK	107	-0.019	+0.018	138° 0.026
TIDAL	201	-0.031	-0.009	197° 0.032
SLOAT	202	+0.034	-0.011	342° 0.036
ARMY	203	+0.015	+0.003	11° 0.016

Root Mean Square of the North and East Residuals = 0.02
Scale Factor = 1.00000077 Standard Deviation = 0.00000078
Rotation = +0° 00' 00.4" Standard Deviation = 0° 00' 00.2"
TRANSFORMATION EQUATIONS: N2=A1*N1-A2*E1+A4 E2=A2*N1+A1*E1+A3
A1= 1.0000007745 A2= 0.0000019602 A3= -9.96251 A4= 11.90684

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New CCSF Coordinate System

City & County of San Francisco
Coordinate System 2013 (CCSF-CS13)

- CCSF-CS13: A low distortion grid projection designed for and centered on the County

Minimizes grid-ground differences in distances

- CCSF-CS13 provides a grid scale distortion of less than 1:100,000 (10 ppm) in most parts of CCSF
- For the average combined factors of the 20 HPN points, a ground distance of 1000 foot equals
- 1000.003 feet in the CCSF-CS13 and
- 999.925 feet in SPC Zone 3

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City & County of San Francisco
Low Distortion Projection

- Projection surface was positioned at the most common ground height so that the combined scale factor is 1.0 and the distortion is zero

- Projection Surface Height
- Ellipsoid Height = 44.50 meters (146.0 feet);
- NAVD88 Height = 77 meters (253 feet)
- (see Purple Contour on next Slide)

- Note, Changes in height increases/decreases the scale 4.8 ppm for every 30.5 meters (100 foot)

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CCSF-CS13: PPM (Distortion) Contours
Purple= 0, Yellow= -10, Green= +10 (Bill Hurdle)

5/1/2014

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City & County of San Francisco
Low Distortion Projection

- CCSF-CS13 system is referenced to the GRS80 ellipsoid, centered in the NAD83(2011) 2010.00 Epoch reference frame (same as SPC)

- Therefore: Coordinates are referred to as NAD83 (2011) Epoch 2010.00 CCSF-CS13

- North coincides with NAD83 Geodetic North at the Central Meridian near the center of the City

- Convergence Angle varies +/- two minutes east-west across the City

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City & County of San Francisco
Low Distortion Projection

- *Projection specifications for input in user's software:*
  Projection: Transverse Mercator
  Ellipsoid: GRS-80
  Scale: 1.000007
  Latitude of Origin: 37º45'00" (37.75)
  Central Meridian: -122º27'00" (-122.45)
  False Northing: 24,000 meters (78,740 feet)
  False Easting: 48,000 meters (157,480 feet)

(same idea as SPC Projections only less local distortion)

5/1/2014

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SUMMARY

- CCSF sits between two major faults, the San Andreas & Hayward. Future re-surveys of the HPN will be conducted to determine secular and episodic movements in the City
- If future surveys of the HPN follow the specifications and procedures adopted for this survey, the relative accuracy of measured movements is expected to approach 5 mm at the 95% level of confidence
- Statistically, this means the probability at the 95% level of confidence is that movement (signal) has occurred if the movement between two epochs is greater than the relative error (noise)

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RECOMMENDATION - SUMMARY

- The differences in successive coordinates on a point can be used to estimate ground movements but they do not provide statistical information about the relative accuracies of movements; therefore the signal cannot be distinguished from noise.
- Measurements of temporal movements must be based on a rigorous simultaneous least squares adjustment of multiple independent observations at two different epochs for each point to compute the relative accuracy and thus the actual movement

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Report Contents

Survey Report

of the

City & County of San Francisco
2013 High Precision Network Survey

Prepared by
McGee Surveying Consulting and F3 & Associates, Inc.
February 20, 2014

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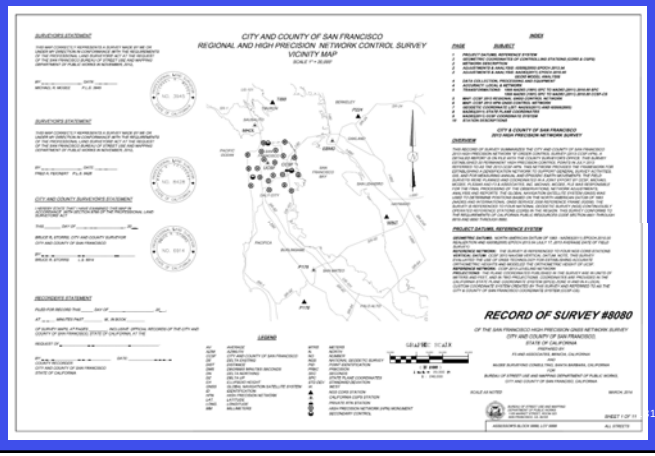
RECORD of SURVEY #8080
Posted on the CCSF Website



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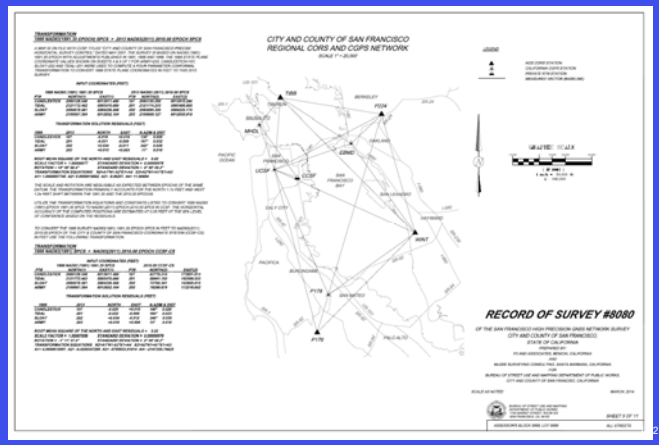

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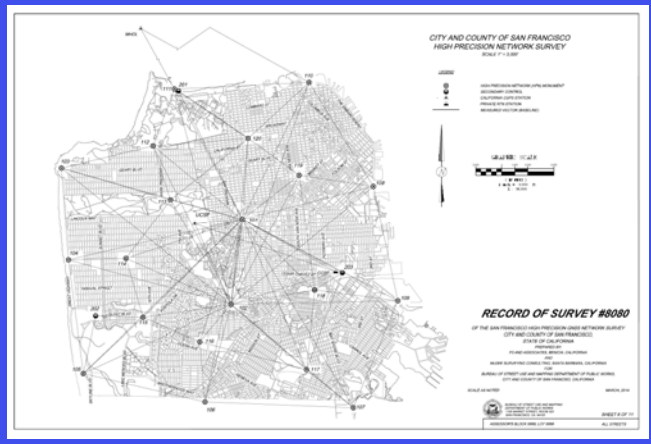

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Survey Report

of the

2013 CCSF High Precision Network Survey(pdf)

Available At

http://www.sfdpw.org/index.aspx?page=1781

(Google "HPN Survey)

Attachments

Record of Survey

HPN Point Description/Obstruction Diagrams

HPN KMZ Files

Transformation Spreadsheets

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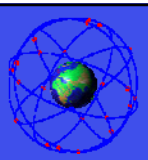
Report Appendix



Glossary

Geodetic Coordinate List
NAD83(2011) & IGS08(2005)

Plane Coordinate List
NAD83 SPC & CCSF-CS13 (LDP)

Maps: CCSF 2013 Regional & HPN GNSS Network

CORS Reference Data:
CORS Coordinates, HTDP Solutions, NGS Data Sheets & Short Term Time Series

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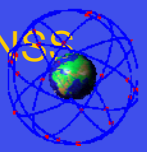
Final Thoughts About GNSS



- "..... it is far more important to have a somewhat faulty measurement of the spot where the line truly exists than to have an extremely accurate measurement of the place where the line does not exist at all"
- By A.C. Mulford, from "Boundaries and Landmarks", 1912

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