README file for the USGS/NEHRP/GTSM borehole strainmeters

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Provided below is information and comments with respect to the eight, borehole tensor strainmeters installed in California for the USGS by Michael Gladwin and colleagues. The data in this archive cover the period between the time of installation of each instruments to the present; this archive will be updated periodically (with periods < 1 year).

- Brief history – an introduction
- Organization of the ftp directories
- Description of the format of the data files
- Differences between the GTSM archive and this archive
- Notes on calibration of these instruments
- Miscellaneous information for each site including site location and known problems with the site

Brief History:

Eight Gladwin tensor strainmeters were installed in California between the early 1980s and the mid-1990s. Data in this archive are results of this effort. Gladwin, through his association with U. Queensland, CSIRO, and GTSM Technologies built, installed and maintained these instruments for the USGS. In addition, he processed these data for others to use. Now that he has retired, USGS continues to maintain these instruments and provided data from these instruments to other users. More information on these instruments is found at the GTSM Technologies web site, http://gtsmtechnologies.com including a data archive for observations up to 30 September 2008. The archive described here is a continuation of the GTSM archive with some differences to be described below.

Organization of ftp directory:

All of the data from each site is downloaded as a single tar gzipped file. Included in the tar-file are the linearized strain changes from each gauge (between 3 and 4 gauges per site) and another set of three files of the tensor strain components labeled with ***ea***, areal dilatation, ***gam1***, gamma 1 or Eee – Enn, and ***gam2***, gamma 2 or 2Een. The unit of strain change in each file is nano-strain or 0.001 parts-per-million. The term "linearizing" means that the raw output of each gauge is formally the position on a ratio transformer. Linearization transfers that "position" into a unit of strain by using the ratio to determine the position of the "central plate" a capacitor transducer that senses the extensional strain on each gauge.

One of the problems working with the raw strain data from the telemetry has been the limited bandwidth of the GOES telemetry system used by USGS. Consequently, most of the data that we record are the least significant digits with periodic updates, depending upon the instrument, of the most significant digits. Consequently, in periods with high strain rates, it is possible to loose count of the MSD.. The total count eventually does get reconciled, but there is still some ambiguity during periods of high strain rates. (Think of this in terms of cycle-slips in GPS). Much of the resolution of the ambiguity can be done automatically, but, importantly, it needs to be "human" checked and adjusted, which does take time. This important step has been done for the data in this archive.

For the linearized strain data derived from the raw telemetry, these files are identified with the leading letter, ***l***, as in ***ledt1***. I**MPORTANTLY, these data do represent the basic data for these strainmeters**.

In addition, I provide an additional set of linearized strain data for which I have removed some known, spurious strain changes. These file are identified with the leading letters, ***cl***, as in ***cledt1***. For instance, for both SJT and DLT, these have reset pulses every 10 days which I have removed. This refinement only operates for data after 30 September 2008. Using the transformation matrix derived from the tidal calibration, these "cleaned" data are converted to tensor quantities; the files are labeled ***eaxx_cl***, ***gam1xx_cl***, and ***gam2xx_cl***.

Data formats:

I provide data in two different formats; binary and ASCII. The binary are formatted as USGS bottles which can be read, plotted, and manipulated with the appropriate software; most of which can be found: ftp://ehzftp.wr.usgs.gov/langbein/CLEANST/LOWFREQ_LINUX/ or, ftp://ehzftp.wr.usgs.gov/silver/LINUX or ftp://ehzftp.wr.usgs.gov/silver/MAC, ftp://ehzftp.wr.usgs.gov/silver/INTELMAC/binary/ or ftp://ehzftp.wr.usgs.gov/silver/SUN/. Commercial software can be obtained through GTSM Technologies. (This does not imply any USGS endorsement of this product)

The format of the ASCII data, identified with a suffix of ***jl***, have four columns with each row representing a single observation. The first two columns represent the time in years and the day of the year. The third column is the observation of strain in nano-strain. The fourth column should be ignored. Normally, the sampling interval is 18-minutes (DLT and SJT) or 30-minutes. If there are missing observations, the corresponding record is skipped.

Differences between data in this archive and previous archives

There are two difference between the data archive here and that from GTSM Technologies. The GTSM Technologies offers an additional version of the linearized strain data which are derived from the same linearized strain data provide here. The added feature from GTSM Technologies is that a temporal function has been fit to the original data and the residuals from that fit are provided. The function is typically a combination of an exponential and linear curve used to model the relaxation of the borehole and the grout to the installation of the instrument.

For the tensor strain components, I use a different "calibration" matrix than used by GTSM Technologies. The "calibration" matrix is used to transform the linearized strain gauge data (extensometer measurements at prescribe azimuths) to tensor strain. Typically the elements of the matrix are obtained by least square regression between the observed O1 and M2 tidal constituents from the gauge data with the theoretical O1 and M2 tidal strains. Additional constraints are frequently employed.

Finally, the Northern California Data Center (ncedc.org) provides data from these strainmeters too. However, the data from ncedc are simply the raw telemetry values and with **NO** linearization and resolving the ambiguities described above, these data are not useful to most applications.

Calibration:

Briefly, the calibration of a tensor strainmeter is set-up as the following observation equation:

$$g_i = 0.5*C_i*\varepsilon_a + 0.5*D_{1i}*\gamma_1*\cos(2\theta_i) + 0.5*D_{2i}*\gamma_2*\sin(2\theta_i)$$

where g_i is the observation on the i^{th} extensometer oriented 2θ, the C and D represent the areal and shear coupling coefficients, and ε_a, γ_1, and γ_2 are the areal and shear components of tensor strain. Calibration is typically accomplished by matching the observed O_1 and M_2 tidal constituents for each extensometer at the strainmeter to the predicted strain tides produced by one of the available models (SPOTL by Agnew is used here) which incorporates deformation caused by ocean loading and the local tides in any nearby body of water (SF Bay and Sea of Cortez for the California instruments). In the theoretical model, the value of C should be 1.5 and the value of D should be 3.0 for each gauge. For the calibration exercise used here, I will restrict $D_{1i} = D_{2i,}$ but the value of Ds (and Cs) can vary with the different gauges. In addition, the instrument azimuth, θ, is estimated from the tidal data and model. It is assumed that gauge 2 is oriented 60˚ from gauge 1, gauge 3 is 120˚ from gauge 1, and, if gauge 4 exists, it is oriented 150˚ from gauge 1. Examination of the set of parameters provided by Gladwin reveals that he used the same approach with the possible exception is that the instrument azimuth is taken as measured in the field (which might be in error).

The following tables show my estimates of instrument azimuth (typically for gauge 1) and the Cs and Ds for each gauge. Azimuth is reckoned from east with positive as the angle counter-clockwise from east.

SJT			
Gauge #	Azimuth	C	D
1	123.10	0.97	1.44
2		0.52	0.76
3		0.81	1.18

DLT			
Gauge #	Azimuth	C	D
1	188.20	0.67	1.31
2		0.66	1.18
3		1.21	1.83

EDT			
Gauge #	Azimuth	C	D
1	261.4	1.34	1.48
2		0.82	1.16
3		0.93	0.7

PFT			
Gauge #	Azimuth	C	D
1	210.4	1.11	2.01
2		1.85	3.03
3		1.41	2.05

FLT			
Gauge #	Azimuth	C	D
1	219.30	0.21	1.36
2		1.27	1.83
3		0.50	2.04

GAT			
Gauge #	Azimuth	C	D
1	86.3	0.32	0.60
2		1.15	1.10
3		0.18	0.80

GAT does have four gauges but I only use three gauges to construct the "calibration" matrix. See below for the four gauge estimates

CHT			
Gauge #	Azimuth	C	D
2	146.80	0.50	0.63
3	206.80	0.05	1.91
4	236.80	0.21	0.88

Note: CHT has four extensometers, but gauge 1 does not work. Note weak areal coupling for gaug3

CLT			
Gauge #	Azimuth	C	D
1	53.20	0.74	2.04
2		0.80	2.36
3		1.05	1.37

CLT does have four gauges but I only use three gauges to construct the "calibration" matrix. See below for the four gauge estimates.

GAT-using 4 gages			
Gauge #	Azimuth	C	D
1	86.3	0.27	0.51
2		1.18	1.13
3		0.2	0.64
4		0.04	0.98

CLT-using all 4 gages			
Gauge #	Azimuth	C	D
1	55.70	0.74	2.25
2		0.79	2.37
3		1.04	1.12
4		1.04	1.83

Site Locations:

Locations		
Site	Latitude	Longitude
SJT	36.84	-121.55
DLT	35.94	-120.42
EDT	35.89	-120.42
FLT	35.91	-120.49
CLT	34.29	-117.84
PFT	33.62	-116.45
CHT	37.75	-122.1
GAT	37.63	-122.03

Site notes:

FLT Gauge 2 started to deteriorate in 2006. For the data after 2006, I have stopped creating tensor data files. And, for data after 30 September 2008, I have stopped providing linearized gauge 2 data (l***flt2***). Starting in late 2011, flt3 appears to be failing.

DLT PBO installed a new GTSM strainmeter adjacent to the existing GTSM strainmeter. There has been a persistent problem of a leaky seal with the new strainmeter installation. Consequently, there will be periods of high strain rate on the older instrument. At times, I found it difficult to resolve the 'cycle-slips' during the event; however, the total strain change is correct. DLT failed in early 2011

GAT failed in 1998
EDT failed in 2002
PFT gauge 1 and 2 failed in late 2002; gauge 3 failed in mid-2005