Geophysical Research Abstracts
Vol. 13, EGU2011-1496, 2011
EGU General Assembly 2011
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The observation of 4-gage borehole strainmeters in China

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The first 4-gage borehole strainmeter (FGBS) was reportedly invented in China in late 1970s by a group of scientists lead by Ouyang Zuxi. The instrument is designed to measure the temporal changes in horizontal strain in the crust for the purpose of earthquake forecasting. While there are only three independent variables in plane strain, a FGBS uses four gages to measure the changes of borehole diameter in orientations 45 degrees apart. With one more measurement, FGBS can self-check how credible the measurements are, gaining an advantage over the 3-component borehole strainmeter.

There are now several types and about 40 observatories of FGBS in China. Most of the sites use an YRY-4 type of FGBS fabricated by Chi Shunliang and his partners, whose probes are usually placed at the depth of about 40m. Observations of the network are sampled every minute.

The theoretical relation of the recording Si (differences) of the gage in azimuth θi (i=1, 2, 3, 4, clockwise) with the strain (ε1, ε2, Φ) is

Si=A(ε1+ε2)+B(ε1-ε2)cos(θ1-Φ) (1)

Accordingly, the Self-Checking Function can be obtained

S1+S3=S2+S4 (2)

The credibility of the measurements is defined as

C=1-sum(abs(S1+S3-S2-S4))/sum(abs(S1+S2+S3+S4)/2) (3)

Credibilities of most of the YRY-4 FGBS are quite satisfying.

Since the probe of a FGBS must be put into intact rocks, it is assumed that the self-check function should always be satisfied so that an operation called Relative In-situ Calibration is conducted, calculating a unified correction factor for every gage. Corrected data with these factors come with even higher credibilities.

The following set of denotation are used in order to derive a symmetrical comprehensive form for the expression of strain with the corrected measurements

s13=S1-S3

s24=S2-S4

s1234=(S1+S2+S3+S4)/2 (4)

The presently practical means to determine the parameters A and B, which is termed as Absolute In-situ Calibration, is related to the theoretical Earth Tide of strain. A scanning method to pick the best fit of the recordings to the theory is adopted, which gives relatively acceptable results of A and B, as well as the corresponding time delays. The two parameters are calculated separately with the following equations

s1234=2A(ε1+ε2) (5)

sqrt(ε12+ε22)=2B(ε1-ε2) (6)

Equation (5) corresponds to the areal strain and (6) to the maximum shear strain.

The methodology has been applied to the data of all the CEA's observatories. Major conclusions are: 1, The correlation coefficients of S1+S3 and S2+S4 for most of the YRY-4 type FGBS are satisfyingly high, with the highest of over 0.99. 2, Effect of Relative In-situ Calibration is evident and the correction factors can either be very steady or vary significantly with time. 3, Values of A and B for most of the sites are comparable. The former is uniformly smaller than the latter, in agreement with the property of the steel cylinder, i. e., harder to change in area than in shape.