Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS32-01 Room:201A Time:May 20 10:45-11:00

How precise is continuous observation of stress-strain in deep borehole? Examination by invariants of elastic theory.

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Though seismic precursors surely exist, it is considered that they are very small in comparison with coseismic signal caused by the earthquake. However,observations are mostly performed on the surface of the earth where precursory signals are disturbed by the artificial noise and so on ,and may not be able to be detected. One possibility to solve these problems is to make observations in deep underground of bedrock where earthquakes occur.

Being based on this idea we have developed multi-component borehole instrument including multi-component strain meters and stress meters with high sensitivity , tilt meters, seismometers, accelerometers , a thermometer and magnetometers for earthquake prediction study. The sizes of the instrument are about 10 cm of diameter and about 8 m of length depending on purposes and combinations of sensors.

Multi-component borehole instruments have been installed in some boreholes of our observation area. The deepest borehole is 1030m deep. Data obtained by the instruments are send to our institution by online. Our strain meters and stress meters have recorded well strain and stress variations.

In this presentation we report how precise our instruments record stress and strain variations. Our instruments recorded strain and stress seismograms caused by 2011 Tohoku earthquake. By analyzing the records we derived elastic invariants of elastic theory. The invariants derived by several components coincides very well for both one station and different stations. We present the obtained results and discuss goodness of our observation.

Keywords: deep boborehole observation, continuous observation of stress and strain, invariants of elastic theory, observation accuracy, stress seismogram of 3.11 earthquake, multi-component borehole instrument

Japan Geoscience Union Meeting 2012
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SSS32-02 Room:201A Time:May 20 11:00-11:15

Results of continuous crustal strain observation in vicinity of Mozumi-sukenobe fault

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The Active Fault Research Group of the Earthquake Frontier Project (Ando, 2007) excavated a 480 m long tunnel across the Mozumi-sukenobe fault. Two major fault zones appeared across the tunnel (e.g. Tanaka et al, 2007). Two strain meters were installed on both sides of the fault zone (Ishii et al, 2007).

The observation as a Eqrthquake Frontier Project were ended in 2000. Tono Research Institute of Earthquake Science, ADEP has carried out continuous observation of strain since July 2006.

We will present the results of continuous strain observation.

Keywords: Ishii-type borehole strainmeter, in-situ stress measurements, continuous strain observation, Mozumi-Sukenobe fault, Observation in vicinity of active fault

SSS32-03 Room:201A Time:May 20 11:15-11:30

A strain behavior before and after the 2009 Suruga-Bay earthquake (M6.5)

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On 11 August 2009 the intraslab earthquake (M6.5) struck the Tokai area. The largest seismic intensity observed was VI- in JMA scale, and it was a felt earthquake in a wide area including the Kanto and Koshin'estu Regions. Tsunamis were observed at and around the Suruga Bay. In the Tokai area, the Japan Meteorological Agency (JMA) continuously monitors strain data by the real time automated processing in the Tokai network. According to JMA, it is unconnected to the anticipated Tokai Earthquake (M8) judging from the acceptable reasons. For instance, it is an intraslab earthquake in the Philippine Sea plate, while the anticipated earthquake is a plate boundary earthquake on the upper side of the Philippine Sea plate. We consider it as an appropriate earthquake for validation of the Tokai network, though the feature of earthquake is different from one of the anticipated earthquake. We here tried to investigate the strain behavior before and after the 2009 Suruga Bay earthquake occurred in the fault zone of the anticipated Tokai earthquake. In actual, the Tokai network of strainmeters has been monitoring the short-term slow slip events (SSE) synchronized with nearby low frequency earthquakes or tremors since 2005 (Kobayashi et al., 2006). However, the earth's surface is always under the continuous influence of a variety of natural forces such as earthquakes, wave, wind, tide, air pressure, precipitation and a variety of human induced sources, which create noise when monitoring geodetic strain. Eliminating these noise inputs from the raw strain data requires proper statistical modeling, for automatic processing of geodetic strain data. It is desirable to apply the state space method to noisy Tokai strain data in order to detect precursors of the anticipated Tokai earthquake. The method is based on the general state space method, recursive filtering and smoothing algorithms (Kitagawa and Matsumoto, 1996). The first attempt to apply this method to actual strain data was made using data from the 2003 Tokachi-oki earthquake (M8.0) recorded by the Sacks-Evertson strainmeter, which has been operating since 1982 at Urakawa Seismological Observatory (KMU) of Hokkaido University in the southern part of the Hidaka Mountains (Takanami et al., 2009). KMU is far 105 km NW of the epicenter of the 2003 Tokachi-oki earthquake. After the earthquake, the data showed a clear episode of contraction for 4 days followed by expansion for 23 days. These signals correlate with increased aftershock seismicity for events greater than M4. The strain changes, together with surface displacements detected by the GPS network, are indicative of propagation of slow slip at depth (e.g. Geographical Survey Institute, 2004). We here review the computational approach to state space method and the results of its application to the strain data from the 2009 earthquakes (M6.5) occurred off Sagami in the Tokai area. Interestingly, for the 2011 Tohoku Earthquake off the Pacific coast no pre-slip was detected by land-based observations even though its magnitude was M9. In order to detect the nucleation of such an earthquake occurring far offshore, high-precision strain data is necessary but was not available.

Keywords: 2009 Suruga-Bay earthqauke(M6.5), Strain, Anticipated Tokai earthquake, State-space model

Japan Geoscience Union Meeting 2012
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SSS32-04 Room:201A Time:May 20 11:30-11:45

Vertical Crustal Movements in the vicinity of Hanaori fault nearby the campus of Kyoto University(Subsequent Report)

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Precise leveling (spirit leveling) has been carried out in and around the campus of Kyoto University as a part of a basic practical course on earth sciences in Kyoto University. Hanaori Fault, one of the active faults in the Kinki region, runs along the east edge of the campus and the west foot of the Yoshidayama hill. To lead students to an interest in earth sciences including geodesy, monitoring the vertical crustal movements across the active fault by precise leveling was adopted as a subject of the course.

Although some cases resulted in failure, the precise measurements on the accuracy of the first order leveling have been carried out annually for 30 years since 1982. Therefore the changes of height difference in millimeter can be detected.

In this report, the results of the precise leveling along the bench mark net crossing the Hanaori Fault will be shown. The bench mark located halfway up the Yoshidayama hill was rising relative to the ground of the campus of Kyoto University at the rate of 0.001 cm/year before 2000. The rising rate has changed between 2000 and 2004; the bench mark at Yoshidayama has been rising at the rate of 0.05 cm/year since 2000. For the moment, it is not clear what has caused this change of the rising rate of Yoshidayama.

Whether the crustal movements at Yoshidayama were affected by the big earthquake "The 2011 off the Pacific coast of Tohoku Earthquake (M9.0)" or not was of interest. As a result, no effect of the earthquake on the Hanaori Fault was detected by the measurements in 2011. The bench mark at Yoshidayama is rising at the same rate before the earthquake.

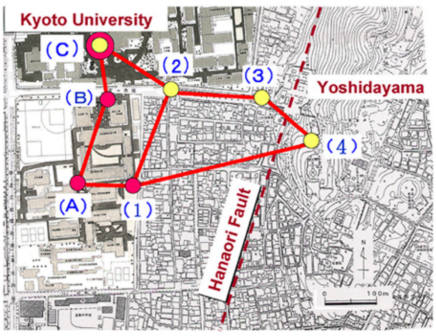

Fig. 1 Leveling net in and around the campus of Kyoto University and Yoshidayama.

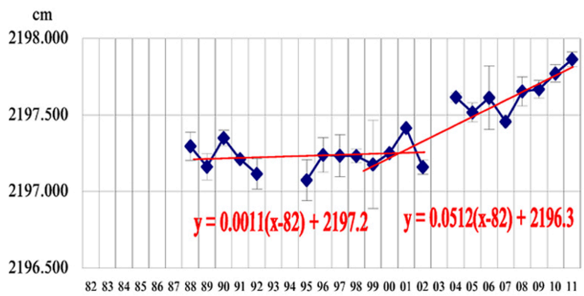

Fig. 2 Height difference change between the bench marks (1) and (4).

SSS32-05 Room:201A Time:May 20 11:45-12:00

3D Analysis of crustal motions of Japan

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The GPS observation made it much easier to understand the crustal motions. The Geographical Survey Institute of Japan(GSI) has about 1400 GPS stations(GEONET) over Japan for observing Japanese crustal deformations, and the GEONET enabled us to understand how Japan continuously deforming. However, time series plotting or vector arrow figures of the GPS data are sometimes not easy to understand the three dimensional deformation with time.

In this study, we created 3D animations for Japanese crustal deformation using GPS data obtained by GSI, and make it easier to understand the Japanese crustal motions. The GSI already had created animation of Japan for horizontal motion of only limited time and area, whereas we can make animations for three dimensional deformation of any given time and area if the GPS data are available. The newly created animations revealed the detailed crustal deformation in Japan.

We compared our results to a 100 years leveling data of Japan and the geological data for about two million years. In spite of time differences, a lot of similarities can be seen on the pattern of deformation of Japan, and amount of crustal motions were comparable between GPS data and leveling data.

Keywords: GPS, crustal deformation, 3D Analysis

SSS32-06 Room:201A Time:May 20 13:45-14:00

Spatial variations in Fault Coupling on the northern portion of the Great Sumatran Fault

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The Great Sumatran Fault system in Indonesia is a major right-lateral strike-slip trench-parallel system that can be divided into several segments, most of which have ruptured within the last century. This study focuses on the northern portion of the fault system which contains a 200-km-long segment that has not experienced a major earthquake in at least 170 years. In 2005, we established the Aceh GPS Network for the Sumatran Fault System (AGNeSS) across this segment. AGNeSS observes large displacements which include significant postseismic deformation from recent large megathrust earthquakes as well as interseismic deformation due to continued elastic loading of both the megathrust and the strike slip system. We parameterize the displacements due to afterslip using a model based on a rate- and state-dependent friction formalism. Using this approach, we are able to separate post-seismic and inter-seismic contributions. From the interseismic component, we infer the depth of shallow aseismic creep and deeper locked segments for the Great Sumatran Fault. In the northern portion of this fault segment, we infer aseismic creep down to 7.3+-4.8 km depth at a rate of 2.0+-0.6 cm/year. In the southwestern portion of the segment, we estimate a locking depth of 14.8+-3.4 km with a downdip slip rate of 1.6+-0.6 cm/year. This portion of the fault is capable of producing a magnitude 7.0 earthquake.

Keywords: Sumatran fault, fault coupling, Monte Carlo method

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SSS32-07 Room:201A Time:May 20 14:00-14:15

Surface motions prior to mega earthquakes by using GPS data

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Measurements of surface deformation can be used to understand complex stress changes underground. Stress gradually accumulates on strata until it exceeds thresholds that strata can withstand, at which point abrupt tectonic motions occur, causing earthquakes, rupture and intense vibration. The elastic deformation caused by force accumulation in strata during seismogenic processes may also be observable. In this study, we try to find out any unusual behaviors of surface motion prior to mega earthquakes by using GPS data provided by The Geospatial Information Authority of Japan (GSI).

First, we have investigated short-term deformations prior to the 2003 M8.0 Hokkaido earthquake and the 2011 M9.0 Tohoku earthquake. GPS data near the epicenters has been checked. It is found that one day before the M8.0 Hokkaido earthquake, some pre-slip may have occurred at the stations near the epicenter. As for the M9.0 mega event, two days before there have been significant deformation in the region close to the focal area. However, because of the M7.3 foreshock two days before, the deformation results may possible affect by the co-seismic slip and the afterslip.

Then, we have monitored long term motion of GPS stations associated with the M9.0 event. GPS data of three stations on the Pacific coast and three stations on Japan Sea coast in the Tohoku region have been selected to analyze. It is found that about one year before the mega earthquake, the direction of motions of Japan Sea region began to change from east to west. And around 40 days before, the whole Tohoku region began to move to east. The details of the phenomena and possible mechanism will be discussed in our presentation.

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SSS32-08 Room:201A Time:May 20 14:15-14:30

Effects to the crustal movements of the Tokai region by 2011 Tohoku Earthquake

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On March 11, 2011, a massive earthquake of Mw9.0 occurred along the plate boundary off the Tohoku region, Eastern Japan. This was the largest earthquake in the recent Japanese history. Its co-seismic and after-seismic crustal deformation affected the crust of all over Japan and also triggered active seismicities.

Tokai region, central Japan, is located at the plate boundary zone between subducting Philippines Sea Plate and Amurian Plate. In this region, Tokai Earthquake has been expected to occur in the near future along the plate boundary. Some of the induced earthquakes of the Tohoku Earthquake occurred in the Tokai region. Therefore, this massive earthquake might change the conditions of the crust in this area. We estimated the effects of the Tohoku Earthquake which was appeared in the crustal deformation in the Tokai region.

Very dense observation network has been expanded in the Tokai region. We obtained GPS station coordinates by analyzing observation data of 84 stations in Shizuoka, Aichi, Nagano and Yamanashi Prefectures. These GPS stations included GEONET (GPS Earth Observation Network System) and JUNCO (Japanese University Consortium for GPS Research). We processed their data during the period of 200 days from February to September 2011. We used GAMIT ver.10.4 software for analyzing observation data. Reference frame was ITRF2008. At first, we estimated co-seismic displacements of each stations from the obtained coordinates. Then, we calculated after-seismic velocity field and dilatation velocities, and compared them with the ones calculated in the previous study (Hashimoto et al., 2011) from GPS observation during the period before the Tohoku Earthquake, August 2005 to December 2006.

Our results showed clear dilatation velocity distribution change before and after the Tohoku Earthquake on March 11, 2011. The effect of the afterslip was quite significant, and also the coupling condition between Philippine Sea plate and Amurian Plate may be changed, although the Tohoku Earthquake was the event which occurred in subducting zone of the different pair of plates from the Tokai region.

Keywords: GPS, crustal movements, Tokai region, Tohoku Earthquake, strain velocity, temporal change

SSS32-09 Room:201A Time:May 20 14:30-14:45

Plate Coupling and Deformation of Forearc Sliver in Southwest Japan

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The Philippine Sea plate has subducted beneath southwest Japan at the Nankai Trough. Oblique subduction of the plate and strong coupling on the plate interface have deformed the overriding plate in two different modes: crustal shortening in the direction of plate convergence and long-term lateral movement of the forearc sliver along the Median Tectonic Line (MTL). In this study, we decompose crustal deformation field into these two modes using three-component GPS displacement rates (velocities) from nationwide continuous GEONET and supplementary campaign networks across the MTL.

Horizontal and vertical velocities are obtained from final coordinate (F3) time series at 333 sites of GEONET from Kinki to Kyushu regions during 2004-2009. The original velocity data contain both of the elastic compressional deformation and lateral forearc movement. At first we correct the original velocity data to remove the latter. We assume that the forearc slides at a constant rate along the MTL but its fault plane is fully locked from surface to a depth of 15 km. Next, using the corrected velocity data, we estimate interseismic slip deficit distribution on the plate interface reproduced by more than 500 triangular elements. Then site velocities calculated from the above plate coupling distribution are compared with the original GEONET and campaign velocities. Residuals between the original and calculated velocities illustrate forearc lateral motion and locking effect of the MTL fault plane. Now we can use the residual velocity field to estimate slip-locking distribution on the MTL fault plane. At last we check the first-assumed constant rate of the forearc block motion by comparing it with the estimated slip deficit rate on the MTL. Since no clear evidence of creep motion has been obtained from the surface observation across the MTL, the two rates should agree with one another. In this analysis the optimal rate of the forearc block motion is 5 mm/yr. In the eastern Shikoku the slip pattern is nearly pure strike-slip at a rate of 2-4 mm/yr. In contrast significant normal component is recognized together with strike-slip component of about 5 mm/yr in the western Shikoku.

In the above modeling we assume a constant block rate of the forearc sliver. To investigate internal deformation of the sliver we calculate strain distribution after removing the effect of the plate convergence. We recognize small E-W compression in the eastern Shikoku but the compression is altered by E-W extension in the western Shikoku and the principal axis of the extension rotates counter-clockwise gradually toward a N-S trending in the central Kyushu. This means that the forearc sliver is not absolutely rigid and its driving force is not only the oblique subduction of the plate. Further detailed modeling is needed to better understand deformation mechanism of the forearc sliver.

Keywords: Philippine Sea plate, the Median Tectonic Line, GPS, Nankai Trough

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SSS32-10 Room:201A Time:May 20 14:45-15:00

A new interpretation of the slow slip event in the Tokai region

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In the Tokai region, central Japan, anomalous displacements had been detected by GEONET during the period from mid-2000 to mid-2005 and they seem to have been caused by a slow slip event (SSE) beneath the Lake Hamana and have been called as "Tokai SSE". Previous studies introduced the Tokai SSE by the inversion of data which is the difference between the observed displacements and the displacements due to the continuous plate coupling. However, this model has no physical meaning. The present study claims that the combined effects of the slow slip events (or forward slip) and the plate coupling (or so-called back slip) should represent the state of the plate interface. In addition, the temporal change of the plate coupling has not been taken into account in the previous studies. In this study, we estimated the state of the plate interface by the geodetic inversion method without the assumption of the steady state coupling in order to estimate the temporal change of the coupling and slip process on the plate interface.

The data used in this study are the GPS data taken from the GEONET and the leveling data published by GSI for the period from July 1996 to June 2009. In order to examine the temporal change, we divided the entire period into 12 epochs. The duration of each epoch is two years and the neighboring two epochs overlap one year. The two-year averaged rate of crustal deformation are derived from the GPS data and the leveling data separately and are taken into the geodetic inversion simultaneously.

The estimated distributions of the strain accumulating and releasing areas, by which "strain accumulating area" indicates a area of slip deficit and accumulates in the continental wedge and vice versa, suggested that the whole period was able to be divided into three sub-periods depending on the emergence of the strain releasing area. The strain releasing area emerged in the period from 2000 to 2005, which is consistent with the duration of the Tokai SSE in the previous studies. The maximum value of the strain releasing was about 20 mm/yr and the depth was around 30-40 km, while the maximum value of the Tokai SSE was about 35-50 mm/yr in the previous studies. Compared with the previous studies, the present study showed that only the deeper portion of the Tokai SSE really released the strain. The total amount of the released strain was equivalent to the seismic moment of Mw ˜ 6.6, while the Tokai SSE was equivalent to Mw ˜ 7.0 to 7.1. Therefore the previous studies overestimated the released strain.

The spatial distribution of the interplate coupling also changed temporally, whereas the coupling of the area had been assumed to be time invariant in the previous studies. It had extended along the plate interface to a point beneath the Lake Hamana before the emergence of the strain releasing area, and then became narrower with the emergence of the strain releasing area, and then had not recover the original distribution after the end of strain releasing process. Although the distribution of coupling changed with time, the maximum value of the interplate coupling did not change; 35 mm/yr through the entire period from July 1996 to June 2009. The maximum value estimated in this study were almost the same as the maximum coupling estimated by the previous studies.

The results also revealed that the distribution of the strain releasing area well coincide with the hypocenters of the low frequency events which occurred repeatedly near the plate boundary. The previous studies inferred that the distribution of the Tokai SSE is shallower than that of the strain releasing area in the present study.

Therefore the Tokai slow slip and the low frequency events were thought to be spatially segregated. The results of present study may require a change of the view about the relationship between these two sorts of strain releasing processes, which may be important for the study of background physics.