

A three-component plan of drilling and monitoring around a subduction zone for seismic hazard

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Abstract:

In subduction zones, slow slip events have recently been detected at the same depth as asperities (where great earthquakes occur). The areas where slow slip and earthquake occur are not overlapped to each other. Such partitioning may be caused by spatial change of frictional properties on plate boundary controlled by materials, fluids, mechanics, or surface roughness other than pressure and temperature. Slow slip events around asperities may play an important role in stress accumulation in interseismic phases. For seismic hazard, we should know what is different in areas of great earthquakes (asperities) and the surrounding areas (non-asperities). We propose a three-component plan of drilling and monitoring a subduction zone. The first one is shallow drilling at several sites in wide area for combined purposes of geological characterization, tectonic reconstruction, accretion, earthquake history inferred from sediments, and in situ stress measurements. The second one is long-term geophysical monitoring by using wide area network covering asperities and non-asperities and consisting of borehole sites ocean floor cable network. This monitoring program is focused on understanding geometry of plate boundaries and present geophysical characterization of asperities and non-asperities. The third one is drilling into plate boundaries in asperity and slow slip regions, which will be well investigated by site surveys and geophysical monitoring. Coring and logging in and around plate boundaries can provide us with physical properties. Information obtained in this plan may be effective to modify simulations of earthquake cycles, strong motion, and tsunamis for seismic hazard assessment.

Asperity model

In the last decade, seismological and geodetical studies have brought a large amount of knowledge of behaviors in subduction zones, and have developed an asperity model. Large slip regions associated with great earthquakes are not changed spatially (Tokachi and Miyagi), where coupling between the slab and continental plate is strong during interseismic phase (Kanto, Tokai, Nankai, and Cascadia). In non-asperity region, aseismic slips (slow slip events or steady slip) are dominant. If this model is correct, future earthquake occurrence and the associated strong ground motions can be forecasted, resulting in hazard mitigation. Recurrence times of most great earthquakes in subduction zones are $\sim 10^2$ years. Several times in repeating history have been documented by human or been able to be recorded in sediment layers. It is effective to verify the physical models of earthquakes cycles and strong ground motions.

Asperity and slow slip event region at the same depth level

In the cases of Nankai and Cascadia, slow slip events occur at deeper levels than the asperities, in a transition zone between the asperity and a region of steady slip. The location of the transition zone is considered to be controlled by conditions of temperature and pressure.

In the cases of subduction zones around the southern Kanto region in Japan (Figure 1), North Island of New Zealand, and Mexico, in contrast, slow slip events occur at relatively shallow depths, at the same level as the asperity, raising the possibility of different conditions (materials, fluids, mechanics, or surface roughness) to those encountered at Nankai and Cascadia.

Some of slow slip events have much shorter recurrence time (< 10 years) than great earthquakes. If slow slip events and ordinary great earthquakes are characterized only by frictional properties in asperity or slip regions, the physical model of slow slip cycles may be able to be replaced by that of great earthquakes except for coseismic slip phase (Toshinori Sato's white paper). We can repeatedly verify the cycle model in a couple of decades because of the short recurrence time of slow slip events.

A three-component plan

A drilling project focusing both asperity and slow slip event region at shallower depths can reveal conditions controlling frictional properties because it is possible to penetrate plate boundary in both regions. We should also carefully investigate

geometry and geophysical specifications of asperity and non-asperity regions by other ways than penetrating plate boundary, we propose a plan consisting of three components of drilling and monitoring.

The first component is shallow drilling, coring, and logging at several sites distributed in wide area for the combined purposes of geological characterization (sediments, basements, and faults), tectonic reconstruction (collision, accretion, and rotation), earthquake history inferred from sediments, and in situ stress measurements. In particular, core samples and logging records recovered from the boreholes may advance insights of paleoseismological records (described in white paper #1 by Japanese planning group for Geohazard science). The distribution of a turbidites can indicate area affected by strong seismic motions, enabling us to recognize the earthquake as a multiple-asperity or a single-asperity one.

The second component is long-term geophysical monitoring with wide area network covering multiple asperities and slow slip event regions (white paper #2 by Japanese planning group for Geohazard science). This monitoring program is focused on understanding the geometrical and geophysical situation of the system of asperities and non-asperities. Since present networks have been developed in inland region, it is difficult to investigate objects in coastal and oceanic regions. Important regions of subduction zones places in coastal and oceanic regions, and monitoring in oceanic regions together with those in inland regions is necessary to understand seismicity, slow slip activities, couplings, and structure in subduction zone.

The oceanic network should consist of borehole sites and ocean floor cable network. Observation in boreholes is better in signal-to-noise ratio, distance from faults and installation of strain meters than that on seafloor. However observation on seafloor is also necessary to measure ocean bottom crustal deformation using GPS-acoustic system and to deploy a large number of stations, which can depict slip deficit distributions.

Several times of repeating slow slip events can be detected in during period of ~10 years. Physical model of slow slip cycle can be verified repeatedly, and may be useful to construct that of great earthquake cycle.

The third one is coring and logging plate boundaries in asperity and slow slip regions. The results from the second component together with site surveys will be used to finalize the design of a deep riser borehole, intended to penetrate the plate boundary zone in the area currently understood to host a significant locked asperity or slow slip regions. Materials and logging records in and around plate boundaries can bring us true values of physical properties, which can verify structure models and frictional

properties of earthquake cycle models (white paper #2 by Japanese planning group for Geohazard science). Long-term monitoring in deep borehole may detect activities of microearthquakes and temporal changes of fluid behavior in an interseismic phase (or preseismic, coseismic, and postseismic phases in some cases).

Ultra-deep riser drilling (>6000 m) is necessary to reach plate boundaries in asperity and slow slip regions. In order to know difference of materials in asperity and slow slip region, it is ideal to penetrate both regions. However, it is practical to penetrate either one. We should calibrate physical properties obtained site surveys and tomographic studies by using results of coring and logging, and infer spatial variations from maps of reflectivity strength and Poisson's ratio.

Outcomes of three components are important for simulations of earthquake cycles, strong motions, and tsunamis. By comparison with the *past* earthquake cycles and *present* geophysical situations, the simulations can validate (or tune) parameters in physical model, and can assess seismic hazards of *future* earthquakes. Seismic hazard map in Japan has been published and been updated every year. The simulations with outcomes from drilling and monitoring can improve seismic hazard maps.

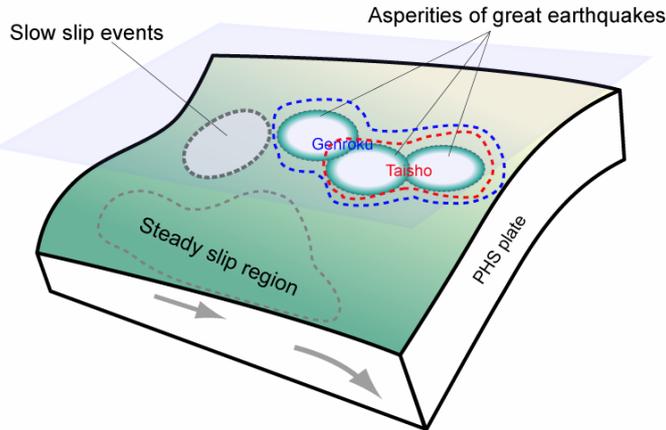


Figure 1. Schematic image of asperities, slow slip event, and steady slip regions on the subducting Philippine Sea plate beneath the southern Kanto region. Taisho (red) and Genroku (blue) mean asperities of the 1923 (Taisho) Kanto and 1703 Genroku earthquakes respectively.

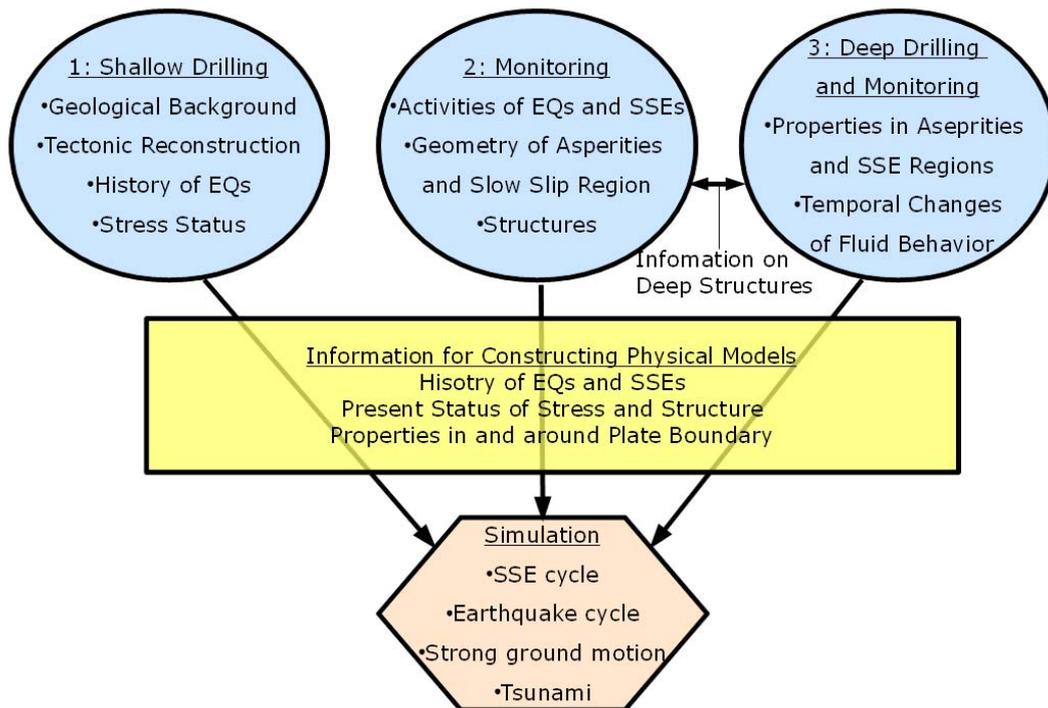


Figure 2. Three-component plan (ellipses) of drilling and monitoring for seismic hazard. EQ and SSE mean earthquake and slow slip event. Yellow rectangular and orange hexagon denotes outcomes from the plan and simulations studies for seismic hazard.