Geodetic Measurement System on the Seafloor

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1 Introduction

Global Positioning System (GPS) has revolutionized geodetic measurements on land in the resolution in space and time. One of the important results is that crustal deformation at a plate boundary is episodic while plates move continuously as a whole. Another example is large deformations observed on a steep slope such as observed near the southeast coast of Hawaii Island. In both cases the rate of crustal movement increases toward the coast indicating that the center of deformation is located under the sea. Observation of crustal deformation on the seafloor is critical to understand the mechanism of dynamics of plate motions and large-scale landslides.

While it is usually not so difficult to deploy GPS receivers for long-term or re-visiting observation on land, it is quite difficult on the seafloor. Because any kind of electromagnetic wave is highly attenuated in the seawater, power supply and data acquisition is general problems against submarine observations. Deployment of an instrument on a benchmark with cm-resolution is a specific problem against cm-geodesy on the seafloor. We will briefly review geodetic measurement systems being developed under these limitations with a focus on the systems developed under the OHP Program.

2 Monitoring horizontal movements

Horizontal crustal movements on land are monitored with GPS and laser/optical ranging with sub-cm resolution. Unfortunately seawater prevents us from using these methods on the seafloor. It has been proposed instead to monitor submarine crustal movements with similar method using acoustic waves, which can travel in the seawater.

Scripps Institution of Oceanography (SIO) was the first to develop precision acoustic transponders with sub-cm resolution in the ranging of 4-5 km and combined them with kinematic GPS positioning. Their results of GPS/Acoustic (GPS/A) experiments about 100 km off from Oregon agree with the plate motion in the geological time scale.

Hydrographic Department of Japan (JHD) has developed similar acoustic systems for shorter ranges. Two instruments for horizontal acoustic ranging were deployed across the southern East Pacific Rise for 14 months. The resolution of ranging after correction for temperature variation in the seawater was sub-centimeter at a baseline length of about 700 m. JHD also developed three sets of acoustic system for GPS/A and deployed them on landward slope of subduction zones around Japan at about 2500 m depth. A preliminary result observed by one of the sets shows positioning errors of about 5 cm (r.m.s.).

We have developed two acoustic systems for GPS/A positioning under the OHP Program. One is the most up-to-date system for positioning on the deep ocean (6 km) developed jointly with SIO. Encouraged with the results of its sea trials SIO produced 10 units of similar transponders and deployed them on the southeastern slope of Hawaii Island. Preliminary results show that the transponders can measure precise slant ranges over 13 km, which is more than enough for GPS/A experiment we plan on the seaward slope of the Japan Trench (slant range of about 8 km) in 2001. We have also developed another system for shallower water and plan to deploy it on the landward slope of the Japan Trench in 2001.

3 Monitoring vertical movements

Continuous GPS observation and re-visiting leveling give us information of vertical crustal movements on land with sub-cm resolution. Precise gravimetry with a resolution of 10 micro gals is important to understand the mechanism of the deformation. Because GPS and leveling are not available on the ocean bottom, we have utilized water pressure as a measure of vertical movement. Combined with sea bottom gravimetry, pressure monitoring can distinguish crustal movements from ocean dynamics.

Precise quartz pressure gauge combined with a quartz thermometer developed by Paroscientific Inc. is widely used for precise pressure monitoring. We developed 4 sets of ocean bottom pressure gauges (OBPs) during the OHP Program. Each set is composed of a Paroscientific quartz pressure sensor, a data logger in a glass sphere, and acoustic release mechanism. These OBPs were deployed on a few sites around Japan for several months. Results of these observations show that relative vertical movements can be monitored with an array of pressure gauges with a resolution of about 5 cm. The drift of a gauge is constant on the seafloor, and the rate is estimated to be around 10 cm/yr. How to accurately estimate the drift rate remains to be solved.

We developed an ocean bottom gravimeter with a Scintrex gravity sensor funded by Earthquake Research Institute, University of Tokyo, and modified it to be a pop-up type with a fund of the OHP Program. Observations on a shallow seafloor for one or two days show much the same performance with a field gravimeter on land: resolution of about 10 micrognals and repeatability of a few tens of microgals.