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Recent Activities in CRL

CRUSTAL DEFORMATION MONITORING IN TOKYO METROPOLITAN AREA BY SPACE GEODETIC OBSERVATION

By
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ABSTRACT

In the Key Stone Project (KSP), crustal deformation monitoring system using VLBI and SLR technology, is being built at four sites in the Tokyo Metropolitan area to detect the precursors of big earthquakes larger than M7. These systems use K4 VLBI techniques and will use advanced SLR systems to obtain high precision. After the completion of this system, changes in baseline length will be monitored daily with a precision of a few mm. According to test VLBI experiments conducted between Koganei and Kashima since 1988, the baseline length has changed by –5 mm/yr.

Keywords: crustal deformation, KSP (Key Stone Project), VLBI (Very Long Baseline Interferometry), SLR (Satellite Laser Ranging), earthquake prediction

1. Introduction

Since the Great Kanto Earthquake of 1923, there has been relatively little seismic activity in Tokyo. However, seismologists are suggesting that seismic activity in Tokyo will once again become high in 10 to 20 years from now(1), and there is likely to be another big earthquake in the Tokyo metropolitan area.

Crustal deformation monitoring is one of the most important ways of detecting precursors of big earthquakes. Over the past decade, great improvements have been made in the precision of positioning and baseline vector measurements using space technology such as VLBI (Very Long Baseline Interferometry), SLR (Satellite Laser Ranging) and GPS (Global Positioning System). These technologies allow the earth's shape to be measured to within a few cm or mm depending on baseline length. In the first stage of the technical development of VLBI and SLR, NASA has played a key role in building up these systems. CRL has also begun global baseline measurements using our own NASA-compatible system. This system is used to measure the motion of the Pacific plate(2).

Earthquakes are geodetic phenomena which result in the dislocations of the Earth's crust. It is believed that several percent of dislocations happen as pre-seismic activity. CRL started constructing collocated VLBI and SLR stations at four points in the Tokyo metropolitan area in order to apply space technology to the monitoring of crustal deformation. This project is named the Key Stone Project (hereafter, KSP) after a Japanese legend in which a key stone in Kashima shrine holds down the head of a catfish that is believed to cause earthquakes (figure 1). As of April 1994, VLBI systems were installed in both Koganei and Kashima. KSP monitors crustal deformation in the Tokyo metropolitan area to detect the precursors of earthquakes larger than M7 in active faults or the upper

Fig. 1 A picture of the legendary Key Stone holding down the head of a catfish that was believed to cause earthquakes

surface of the Philippine Sea plate. The earthquakes occurring in Tokyo were classified into five types by Okada as shown in figure 2(3). We focused our attention on earthquakes of types 1 and 2.

2. Space Geodetic Observation in KSP

Since the KSP was approved in 1993, four KSP stations are being deployed in Koganei, Kashima, Hatsuse (Boso Peninsula) and Inuishi (Miura Peninsula), as shown in figure 3. The longest baseline length is 135 km, and the shortest is 33 km.

As is known, a great many people and business are concentrated in Tokyo. Hence, there is a great need for an earthquake prediction system. However, predictions are hampered by man-made noise, a thick layer of sediment and the existence of diverse earthquake mechanisms due to the complexity of the crust in this area. Observation of baseline vectors by space geodetic instruments overcomes the first two difficulties because the baseline length is measured directly in spite of the long distance. Compared with conventional ground surveying by short distance measurement, this change is significant, and observations can be made daily. Modern techniques are more precise than conventional techniques and they are also cheaper and require less manpower. To enable the prediction of diverse types of earthquake, the KSP network is connected to the dense GPS network controlled by the Geographical Survey Institute (GSI) at two points, Koganei and Kashima, to provide reference points.

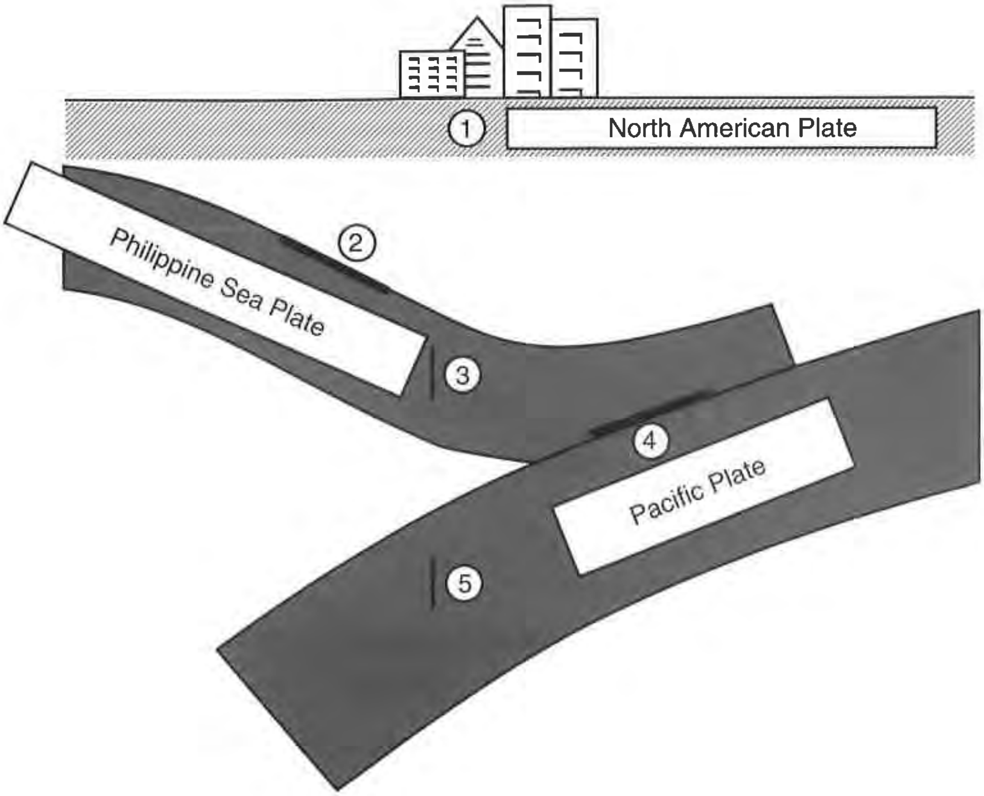


Fig. 2 Types of earthquakes in the Tokyo Metropolitan area

At CRL, we are also studying VLBI systems from a technical point of view since we have been nominated as the VLBI technical development center of IERS (International Earth Rotation Service). The systems deployed in KSP use state-of-the-art for precise monitoring of crustal deformation with high reliability in daily service.

VLBI and SLR systems will be installed together in each station to produce reliable and complementary results in the coordinates. VLBI uses the position of celestial radio sources to determine the baseline vector between the stations. SLR systems determine their position by bouncing laser pulses of geodetic satellites and measuring the round trip time. Both techniques use independent electromagnetic waves and independent sources for references, and both have advantages and disadvantages. VLBI can operate in any weather conditions, while SLR needs a clear sky, and the reference coordinates of VLBI are free from the mass center of the Earth, while SLR coordinates are connected to the mass center of the Earth.

3. Observing System

The KSP system will measure baseline lengths between four stations every day with a few mm precision. For practical purposes, the system was designed to have high reliability. A VLBI system is shown in figure 4 and an SLR system is shown in figure 5.

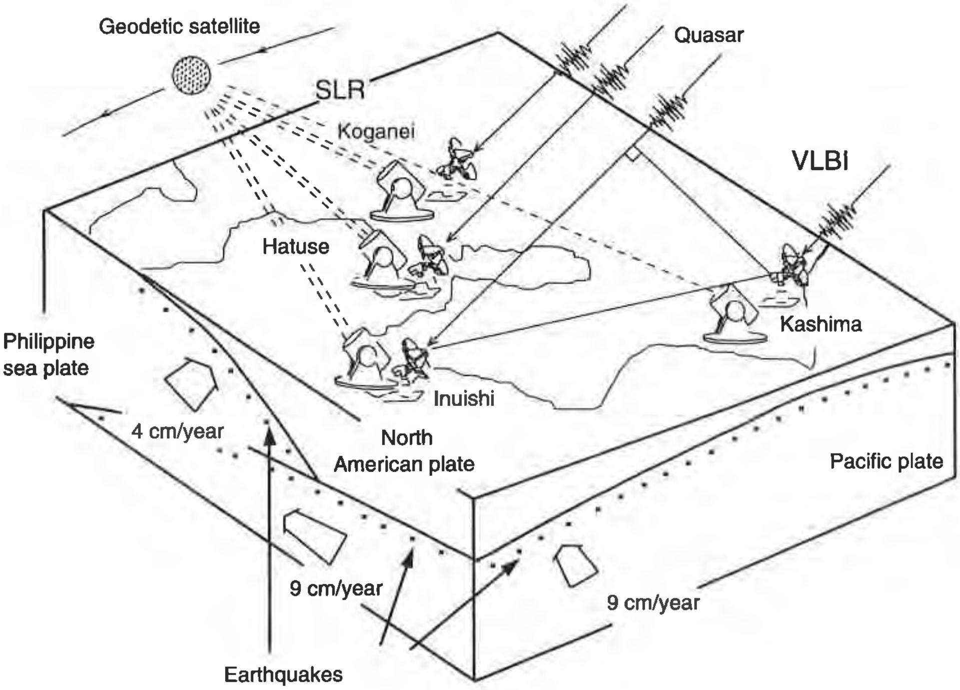


Fig. 3 The four VLBI/SLR stations in the Key Stone Project

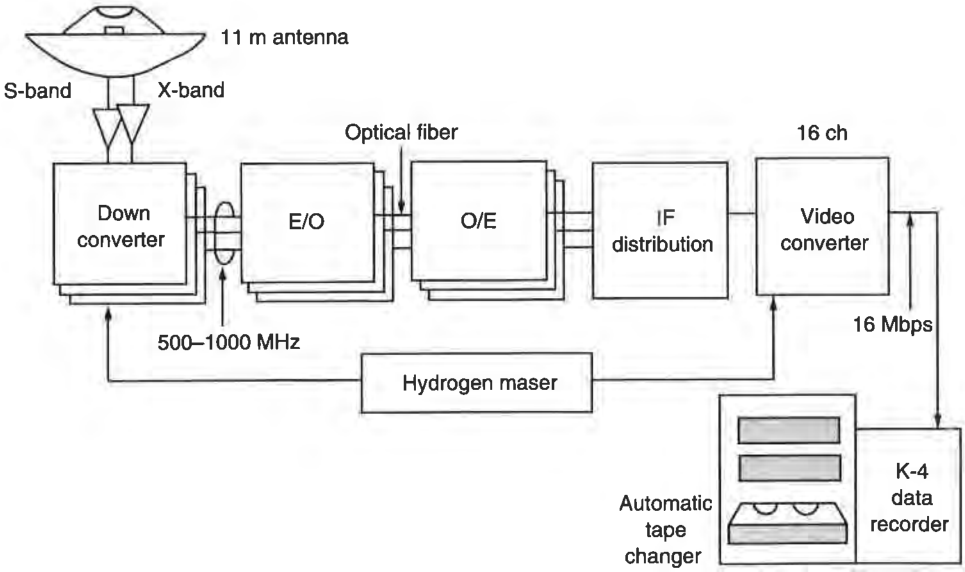


Fig. 4 VLBI system for KSP

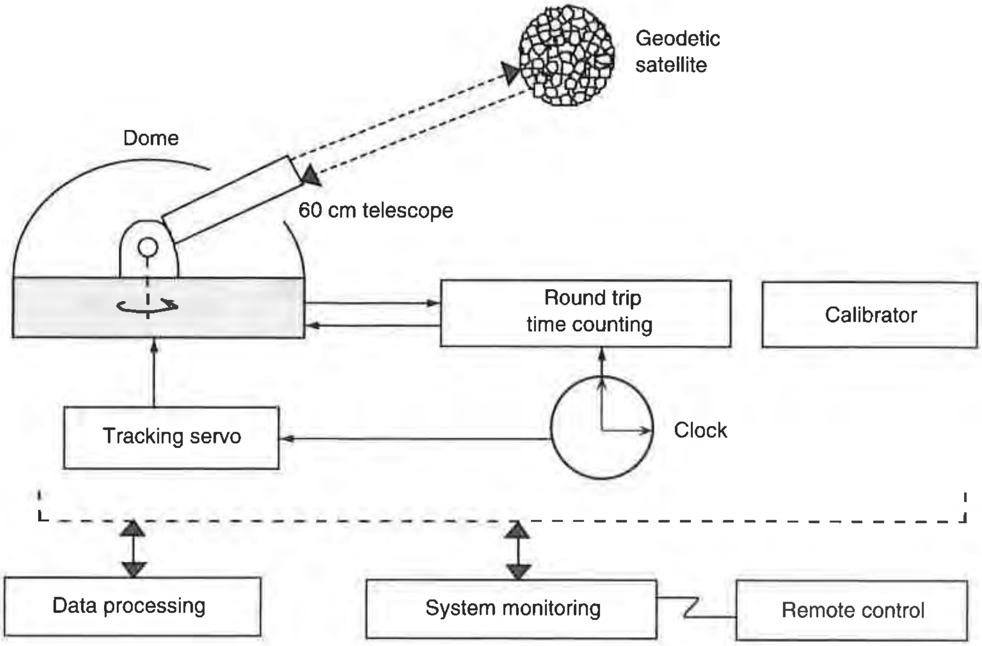


Fig. 5 SLR system for KSP

The VLBI systems were designed along the following guidelines:

a) Baseline measurement with a precision of a few mm in four hours.
b) Data processing and analysis should be finished within 1.5 days, including tape shipment time.
c) System operation should be fully automated.
d) The overall system should be highly reliable.
e) The system should be easy to operate and maintain.

In item a), the duration of daily observations is determined from the graph of figure 6 at the point where the vertical component is measured with a precision of better than 1 cm. Items c) through e) are also applied to the SLR design.

In VLBI, K4 type data acquisition terminals are used(4) to satisfy the above requirements. For the data recording/processing systems, a 256 Mbps wide band system has been developed with higher sensitivity than the conventional MarkIII/K3 whose recording speed is 64 Mbps. The bandwidth of each channel is 8 MHz. In the software design, the man-machine interface was improved to satisfy item e). The 11-m antennas used for VLBI at the Koganei and Kashima stations are shown in figure 7. The data acquisition terminal at the Koganei station is shown in figure 8.

SLR technology is improving due to advances in both laser technology and analysis software. In the case of a Lageos satellite (6,000 km), the ranging precision would be 10 mm (2 min rms.). Assuming this precision, a simulation gives 4 mm precision in three components with 6 passes as shown in figure 9. Synchronous ranging(5) and two-color ranging systems will be introduced in the KSP system to acquire mm precision. Since daily SLR observation is required, unmanned operation with automatic satellite tracking and a sophisticated ranging system is planned.

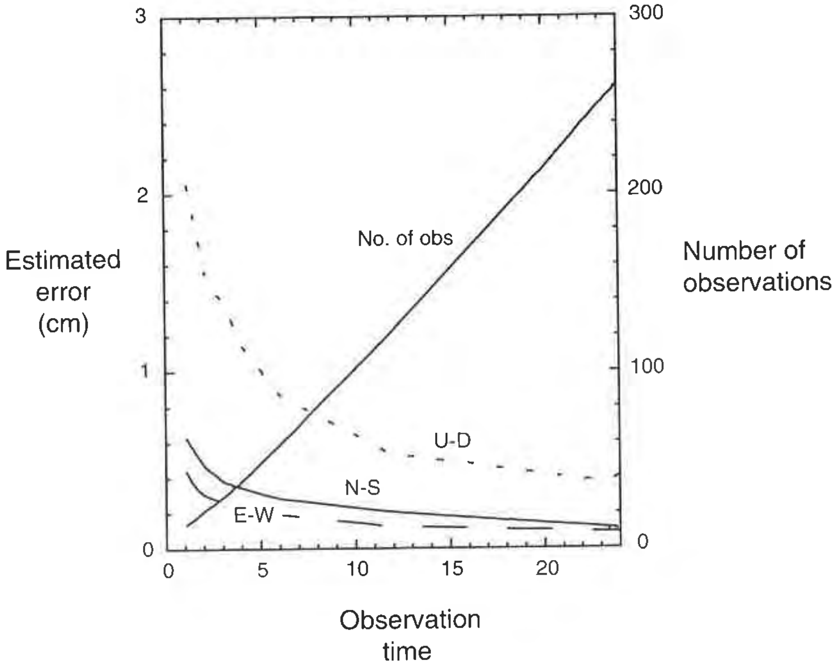
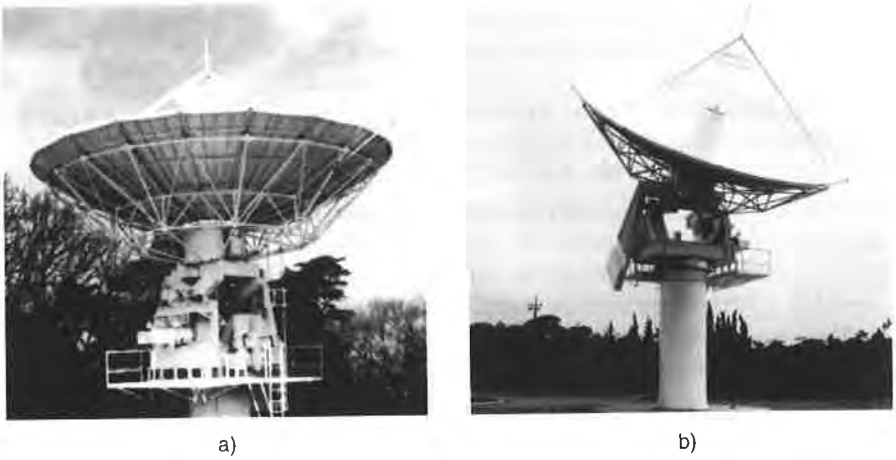


Fig. 6 Estimated precision in KSP VLBI system


a)

b)

Fig. 7 11-m antenna for VLBI at a) Koganei and b) Kashima stations

Fig. 8 VLBI data acquisition system at Koganei (The systems used at all four sites are identical)

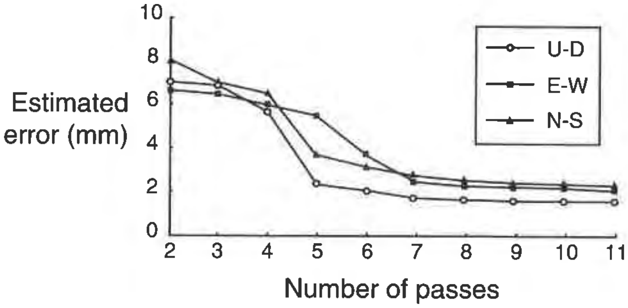


Fig. 9 Estimated precision in KSP SLR system

4. Previous Test VLBI Observation between Koganei and Kashima

Before starting KSP, a geodetic VLBI observation was made in 1988 using 3-m (Koganei) and 26-m (Kashima) antennas. In 1992, observations started again to study the possibility of monitoring crustal deformation in Tokyo. According to the data analysis, the baseline length changed by –5 mm/yr (figure 10). This is interpreted as intraplate deformation, considering the pressure applied from the east by the Pacific plate. Since the VLBI system at Koganei only has an X-band receiver, ionospheric correction cannot be performed. Hence the precision of the observation is worse than it would be with correction. Moreover, the observation was made almost every two months. To achieve good time resolution, daily KSP observation is necessary.

5. Structure of the Japanese System for Earthquake Prediction

Since 1964, earthquake prediction plans have been executed at many institutions using many observing instruments. The latest plan was compiled in 1993, in which space geodetic observation is emphasized. The structure of the Japanese system for earthquake prediction is shown in figure 11. The results are exchanged at the Coordinating Committee for Earthquake Prediction. Observation

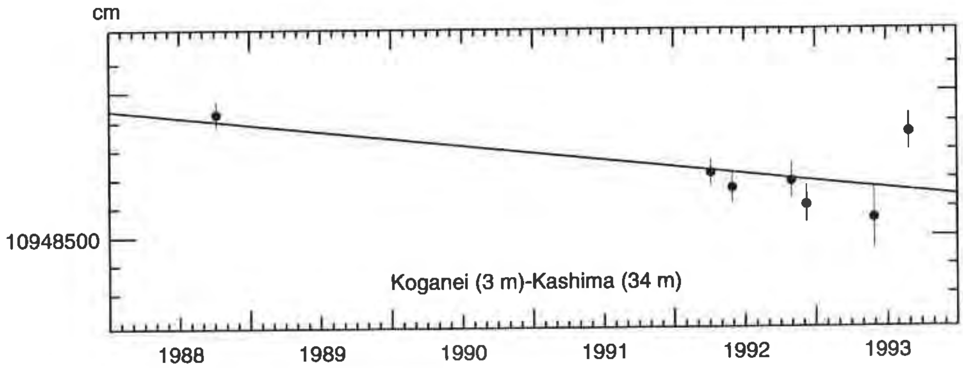


Fig. 10 Baseline length change between 3-m (Koganei) and 34-m (Kashima) antennas (Since observations were made either by the 26-m or 34-m antenna at Kashima, the results obtained using the 26-m antenna have been converted to correspond to those obtained using the 34-m antenna. Note that this data was taken not by the KSP system but by the test system.)

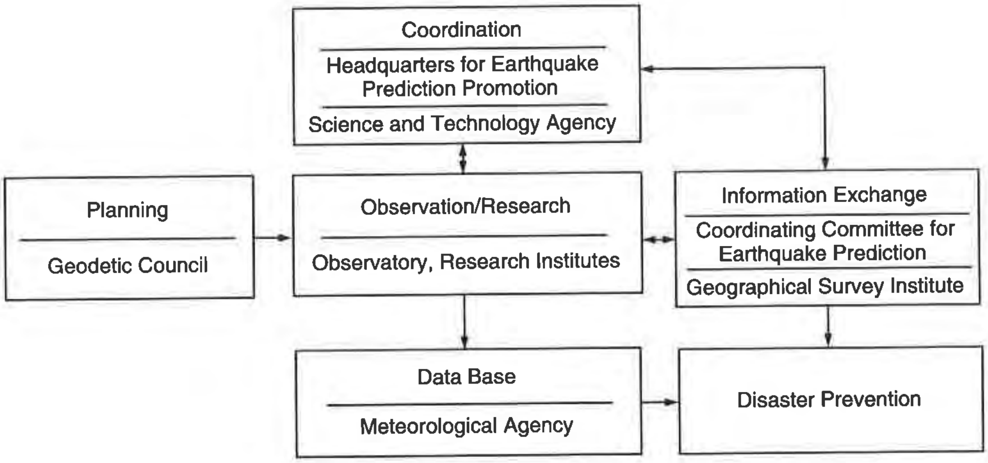


Fig. 11 Organization of earthquake prediction in Japan

data is accumulated at the Meteorological Agency. KSP data will be transferred to the Meteorological Agency and will be discussed regularly at the Coordinating Committee for Earthquake Prediction.

6. Conclusion

We will begin daily crustal motion monitoring in the Tokyo metropolitan area using modern geodetic tools, VLBI and SLR systems, with a precision of a few mm. The results will be transferred to the relevant institutions in the Japanese earthquake prediction system.

The VLBI systems are designed with recording systems because real-time data processing is too expensive due to the enormous amount of data transmission involved. However, a high-speed data channel is now being constructed, and its cost is expected to be comparable to that of the recording systems. In the near future, the KSP will use this high-speed network to create a real-time VLBI system, the results of which will be available much earlier than in the case of tape transfer.

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