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首都圏広域地殻変動観測システム

1. 緒　　言

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CRUSTAL DEFORMATION MONITORING SYSTEM FOR THE TOKYO METROPOLITAN AREA

1. INTRODUCTION

By

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At 5:46 AM on January 17, 1995 the Hanshin-Awaji area centering around the city of Kobe was rocked by a major earthquake of magnitude 7.2 that claimed more than 6,000 lives, destroyed some 30,000 buildings, and ignited fires that scorched over a 100 square hectares. The people who lived through it were left with a profound fear of earthquakes, and many are still suffering psychological aftereffects more than a year later. Reconstruction of the devastated area will take a long time.

Turning to Tokyo, an strange silence grips the people in their awareness that 73 years have now gone by since the devastating Great Kanto Earthquake of 1923. Particularly in light of the common historical observation that earthquakes tend to occur at intervals of around 70 years, the local residents live with the knowledge that it would not be strange at all for another major quake to hit the area at any time. To dispel this awful psychological anxiety of knowing that a major temblor is overdue yet not knowing when it will strike, what is needed is a reliable method of predicting earthquakes. However, at present, such a capability is not available.

Earthquakes are attributed to a mechanism in which deformations due to movements of the earth's crust accumulate until eventually the deforming forces are released in a destructive display of energy. The ability to predict earthquakes thus hinges on obtaining detailed knowledge of such crustal movements. Here we are fortunate because the Communications Research Laboratory has already developed a number of sophisticated space geodetic technologies including very-long-baseline interferometry (VLBI) and satellite laser ranging (SLR). These technologies can be systematically harnessed to continuously measure crustal movements, and we would be very pleased if this contributes in some measure to the development of a viable earthquake prediction capability. Our goal in deploying this system is to record statistical and constant measurements of crustal movement in the critically important capital region, and to supply this data to the Meteorological Agency, the Liaison Committee of Earthquake Forecast, and other interested agencies in the hopes of enhancing our ability to predict earthquakes.

With its record of achievement in VLBI and SLR technologies and thanks to a promotional grant from the Science and Technology Agency, the Communications Research Laboratory took part in the Metropolitan Diamond Cross (MDX) project, which evolved a much more sophisticated approach to the measurement of crustal distortion in the Tokyo area. This led to a plan to deploy a network of observation stations around Tokyo to make highly accurate measurements of crustal movement across the wide expanse between observation stations on a daily bases by exploiting the Laboratory's space geodesic

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technologies. The Key Stone Project (KSP) was launched in 1993 with the aim of using these observations to detect precursors of earthquakes in the Tokyo area. The name of the project alludes to a famous keystone located at Kashima Shrine that purportedly has the magical power to quell mythical catfish that stir up earthquakes. A project that involves ultra modern, state-of-the-art technologies has thus taken its name from an ancient legend.

Crustal movements cause deformation of the lithosphere which rebound with destructive force as an earthquake when the strain exceeds a certain point. The aim of the Key Stone Project is to detect the indications or signals that are produced by these crustal movements and strain before an earthquake occurs. More specifically, the project will provide detailed observations of crustal movements above the Philippine Sea plate and along active faults that are generally assumed will trigger the next major quake in Tokyo.

In VLBI, electromagnetic waves are received at different points located far apart, and from the difference in arrival time, the distance between the two points can be measured to an accuracy of less than one-ten billionth of a second. The distance between the two observation points is measured in millimeter units. Although VLBI is a powerful technology for measuring the distance between two points, one drawback of the technique is that it is insensitive to the earth's gravity.

SLR has the ability to determine a satellite's obit with a very high degree of precision. Tremendous progress has been achieved in realizing greater degrees of accuracy thanks to recent advances in laser technology and analytical software. Unlike the quantitative VLBI observations, SLR sensitivity is greatest in a direct line of sight with a satellite, and the technique is extremely sensitive to vertical fluctuations of the station when a satellite is directly overhead in the sky. In short, VLBI affects the range precision in the horizontal direction while SLR affects the range precision in the vertical direction, so the two techniques complement each other and both are needed. Meanwhile, the Geographical Survey Institute is promoting a plan to measure crustal movement using the Global Positioning System (GPS) network. GPS observation points have been established in Koganei city (the main observation station) on the outskirts of Tokyo and in the town of Kashima in Ibaraki Prefecture (the branch observation station). By combining the precise data obtained by KSP at these observation points, accurate control point data can be provided to the GPS network. Realization of this extremely high level geodetic observation network represents an immense challenge and does not have an analog anywhere else in the world.

At the present time, data received at the observation stations is recorded on magnetic tape and delivered by truck to Kashima and Koganei. There the data is correlated to calculate the amount of crustal movement. Obviously, crustal movements measurements cannot be obtained in real time with this arrangement, considering the substantial delay for delivery. Now there is a plan to set up a fiber-optic link between the observation stations to transmit the data electronically instead of delivering the data by truck. Although the point is covered in detail in the pages of this special issue, here I would only observe that these large quantities of data will not just benefit specialized technical institutions. Autonomous regional organizations and the mass media will also be able to make good use of the data. This is because, through visualization techniques, it is very easy for anyone to appreciate the implications of crustal movement. For example, one can easily imagine a crustal movement report on the evening news right after the weather forecast. With a relief map displayed in the background, an announcer might inform the public that "...today such-and-such an area experienced a 0.3-millimeter crustal shift, adding to the overall deformation in this area. This increases the likelihood of an earthquake to 30 percent. All residents of the area should maintain a constant state of readiness in case a natural disaster strikes." We shouldn't be at all surprised to see the appearance in the near future of an exam to qualify for the new position of "certified earthquake forecaster."

The primary purpose of this special issue is increase public awareness of the Key Stone Project and inform the public of the direction it is heading. As a public research institution, the Communications Research Laboratory is supported by public tax revenues, and therefore has an obligation to publicly disclose all plans and research achievements. The Laboratory's research results are reported in detail at academic conferences, but we are also making an effort cultivate wider appreciation of the Laboratory's work through news coverage by the media whenever appropriate. The Laboratory also holds press conferences to publicize its research. However, we still haven't done enough to inform the public of the details and full scope of the Key Stone Project, and this special issue was prepared to provide a fuller explanation. Besides furthering public awareness of the project, we are also open to criticism and will make every effort to address any legitimate shortcomings. If we succeed in advancing our ability to predict earthquake even slightly through this project, then everyone associated with the venture will certainly feel that the all the time and effort has been well worthwhile.

平成7年1月17日午前5時46分頃、神戸を中心とする阪神淡路地区にマグニチュード7.2の大地震が発生し，死者六千人以上，倒壊焼失家屋三万棟以上，焼失面積100ヘクタール以上の大変な被害が生じた．地元住民の地震に対する恐怖は大変なもので，1年以上を経た今日でも未だ精神的に不安定な状態にある人もいると聞く．更に，復興には長期間を要する．

振り返って首都圏に目を転じると，関東大震災から72年を経過した今日，未だ首都圏は異例な静けさに包まれている．「70年周期説」から判断しても，もはや首都圏は何時大地震が発生してもおかしく無い状況下にある．来るべきものが，来ないで，何時来るのか分からない——という精神衛生上まことに好ましくない状況を解消するには，「地震予知の確立」を実現することにある．しかし，現在このことは不可能とのことである．

地震発生のメカニズムは，地殻変動による歪みエネルギーの開放にある．そのため，「地震予知の確立」には地殻変動を詳細に知ることが必要である．幸い，通信総合研究所では，既にVLBI（超長基線電波干渉計）やSLR（衛星レーザ測距）等の高度な宇宙測地技術は開発済みである．この技術を用いて地殻変動を継続的に計測し，少しでも地震予知技術の確立に貢献することが出来れば，こんな嬉しいことはない．本システムの整備は，首都圏の重要な地点における地殻変動を系統的・定常的に計測し，そのデータを気象庁及び地震予知連絡会等に提供して，地震予知の高度化に寄与することを目的としている．

通信総合研究所では，VLBIやSLRの実績があるため，科学技術庁の振興調整費によるMDX（Metropolitan Diamond Cross）実験に参加し，首都圏の地殻歪みの観測技術の高度化を実施してきた．これらを背景に，首都圏を包囲する観測局を整備し，宇宙測地技術を活用して局間の広域地殻変動を連日高精度に観測する計画を立案した．この観測で，首都圏の直下型地震の前兆を捕らえようとするもので，KSP（Key Stone Project）と命名し，平成5年度に開始した．このKSPの名称は，「地震を起こすナマズを押さえている」との古くからの伝説である鹿島神宮の要石（かなめいし）にちなんだもので，超現代的な技術に古代の伝説を頭に頂いてのプロジェクトである．

地震は，地殻の変動で歪みが生じ，それが集積し限度を越えたとき，その歪みを是正する復元運動で発生する．KSPでは，この地殻変動を通して出されるシグナルを地震発生前に捕らえるのがねらいである．特に，首都圏に地震をもたらすと予想されるフィリピン海プレート上面または活断層での地殻変動を詳細に観測するのが目的である．

VLBIは，何億光年もの離れた宇宙からの電波を離れた地点で同時に受信し，到達時間の違いから，2地点間の距離を百億分の一秒以下の精度で測定する．観測地点間の距離に換算すると，ミリメートルの単位になる．VLBIは，2地点間の距離を計測するのに強力な計測技術であるが，地球の重心を感知しえないのが欠点である．

SLRは，衛星軌道を高精度に決定する能力を持つ．その精度はレーザ技術の進歩と解析ソフトウェアの向上により，長足の進歩を遂げている．VLBIの観測量と異なり，衛星の視線方向の感度が最も高く，天頂方向では，局の垂直変動に感度を持つ．そのため，VLBIは水平方向，そして，SLRは垂直方向の測距精度に影響を及ぼし，両者相まって相補的な役割を果たす．国土地理院では，GPS（Global Positioning System）網による，地殻変動計画を推進している．そして，東京都小金井市の本所と茨城県鹿島町の関東支所構内にはGPS観測点があり，これらの観測点にKSPで得た高精度のデータを結合することで，GPS網への正確な基準点情報を与えることが出来る．こうした最高水準の測地観測網は世界でも類を見ない挑戦的なものである．

現在は，観測局で得たデータを磁気テープに記録し，鹿島（あるいは小金井）に輸送し，そこで相関処理を行って地殻変動量を算出している．しかし，この方法では実時間での地殻変動を得ることは出来ず，遅延が生じる．そこで，観測局間を光ファイバ網で結合し，データの搬送をテープ輸送から電子的なデータ伝送に変更する計画がある．詳しくは，本特集号の中で紹介するが，このような大量データ伝送が可能になると，データの利用は専門機関に止まらず地方自治体やマスコミでの利用も意味を持ってくる．理由は，地殻変動の可視化により，だれもが理解しやすくなるからである．例えば，毎日行われるTVでの天気予報の時間に，地殻変動の立体模型を表示して「本日は，××地域で0.3ミリメートルの地殻変動があり，全体でこのように歪みが増幅されて来ています．地震発生の確率は，30％に上昇しています．——地方の皆様は，ぜひ火災発生には常に注意が必要です．」などの予報も珍しくなくなると予想される．地震予知報道官の資格試験も，将来誕生するかもしれない．

本特集号では，KSP計画を詳細に公表し，皆様のご理解を得ることを主眼にしている．通信総合研究所は公立の研究機関で，研究費は税金で賄われており，全ての計画や成果は公表の業務がある．研究成果は，学会で逐一報告し，一部はマスコミによる報道を通して周知する努力を行っている．また，所の研究発表会などでも報告を行ってきた．しかし，全体計画や経緯を公表するには，不十分なので，今回の特集号発行の企画となったものである．計画に対して，ご理解を賜り，また，ご批判などを頂ければ謙虚に耳を傾け，至らない所は改める覚悟でいる．本計画が成功裏に推移し，地震予知に少しでも貢献できれば，関係者一同望外の喜びとするところである．