ICUS/INCEDE NEWSLETTER

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

VOLUME 2 NUMBER 4
JANUARY-MARCH 2003

Creation of DEMs for Urban Areas from Airborne Laser Scanner Data and Their Applications

By

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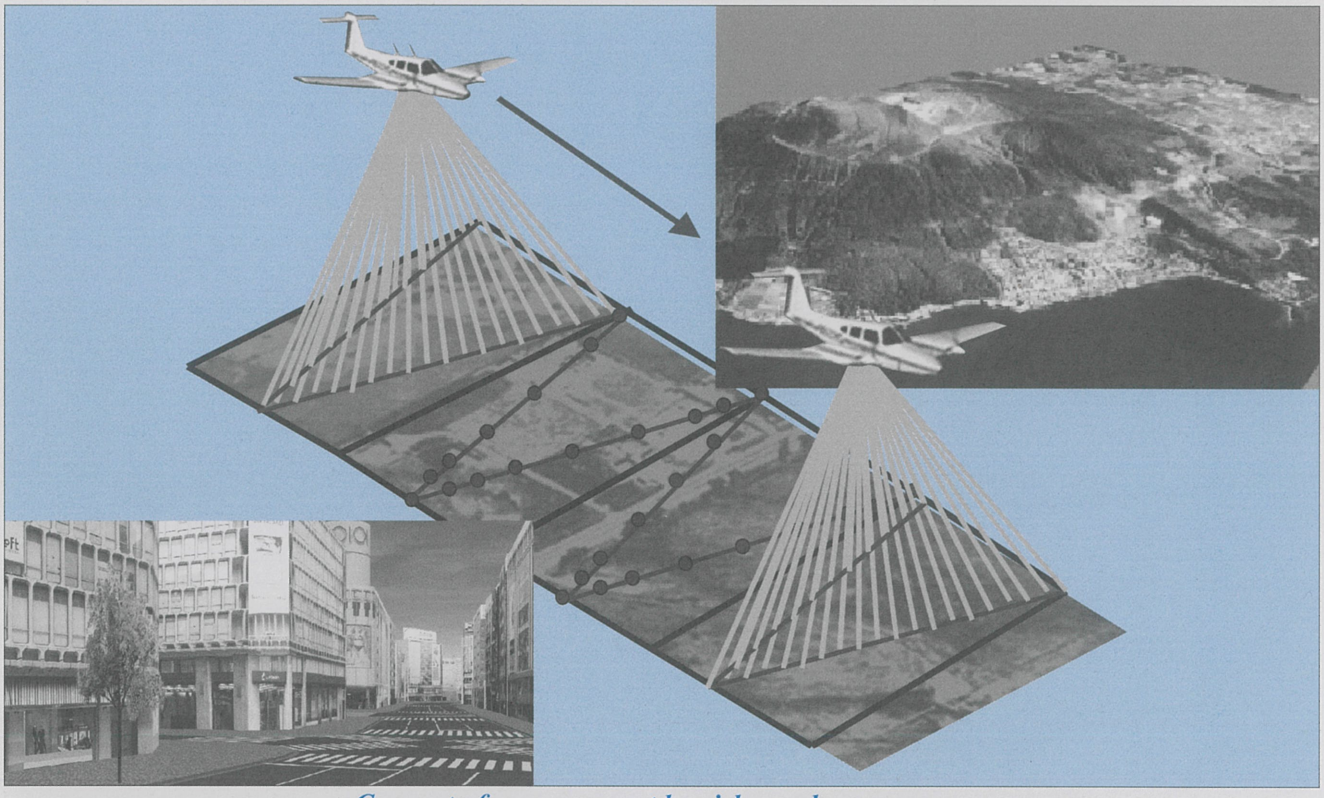
In recent years, many cities and their surrounding areas in Japan have faced difficult problems associated with natural disasters and global environmental changes. It is only eight years since the Kobe Earthquake (January 17, 1995) killed over 6,400 people, and the fear of the urban disaster is still vivid in our memory. Moreover, there is an apprehension about a big earthquake in the Tokai region. Besides large-scale disasters such as large magnitude earthquakes, a number of river floods, especially urban floods due to drainage overflow caused by intense rainfall are increasing in the cities and their surroundings.

In the surrounding areas of cities, on the other hand, there are many occurrences of landslide disasters due to the degradation of



Concept of measurement by airborne laser scanner

the natural environment and the devastation of suburban forests resulting from ongoing urbanization. In addition, we had experienced serial volcanic eruptions in the past decade, beginning with the eruption of Mt. Unzen-Fugen (Nagasaki) in 1990 followed by the eruptions of Mt. Usu (Hokkaido) and Miyake Island (Tokyo).

As for the global environment, the heat island phenomena occurring in the cities have drawn people's attention in recent years, and urgent countermeasures need to be taken immediately. In addition, urgent reduction of the greenhouse gases, such as carbon dioxide, causing global warming, is needed.

To solve these problems related to natural disasters and environmental issues occurring in cities and their surrounding areas, it is indispensable to construct and utilize geographical information databases storing a wide variety of geographical information associated with those areas. Among various types of geographical information, Digital Elevation Models (DEMs) are the most fundamental geographic information.

This article describes the basics of airborne laser scanners (hereinafter, abridged as airborne LS), which have recently drawn attention as a means to speedily generate DEMs at high accuracy, and their applications.

Method to rapidly generate DEMs with high accuracy

Traditionally, aerial photogrammetry has been widely used to generate DEMs. It uses a pair of aerial photographs to measure topography, and is useful in preparing DEMs with relatively high accuracy. But, photogrammetric processes are usually time and labor consuming. It is also possible to create DEMs using a pair of images taken by remote sensing satellites. However, DEMs created from satellite remote sensing data are usually less accurate than those generated from aerial photographs. Besides, radar interferometry, which uses radar data captured by the radars mounted on artificial satellites or aircrafts, can be used to create DEMs. But, radar interferometry has some problems in terms of the available wavelength range and operability.

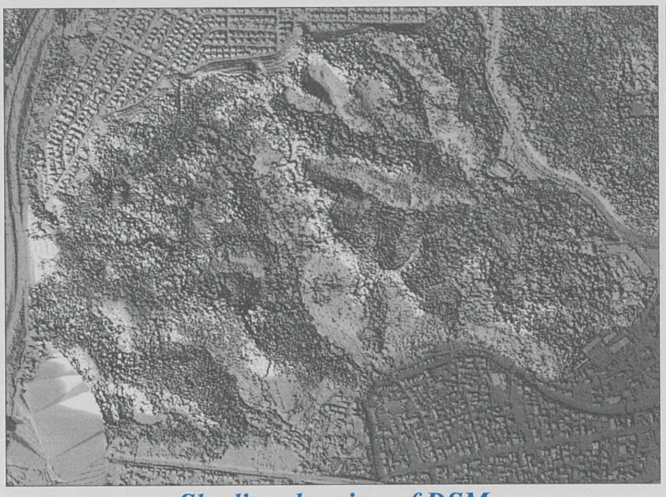
The use of airborne LS has been increasing as a method to rapidly generate DEMs at high spatial accuracy. Its great advantage is that it can acquire data through relatively easy operation.

Airborne LS is mounted on an aircraft or helicopter, and emits laser pulses towards the ground orthogonal to the flying direction (while scanning leftward and rightward); it receives the reflection of the pulses from the ground with a light receptor panel. The distance between the scanner and the target on the ground can be calculated from the time necessary for the laser pulses to make a return trip between the sensor and the target. At the same time, aerial images are taken with a high-resolution digital camera synchronously with the laser measurements. In this case, the aircraft is equipped with a Global Positioning System (GPS) and an Inertial Measurement Unit (IMU), so that the position and inclination of the fuselage at the moment of each laser measurement can be obtained by analyzing the data recorded with those equipments together with the measurement data of another GPS installed on the ground.

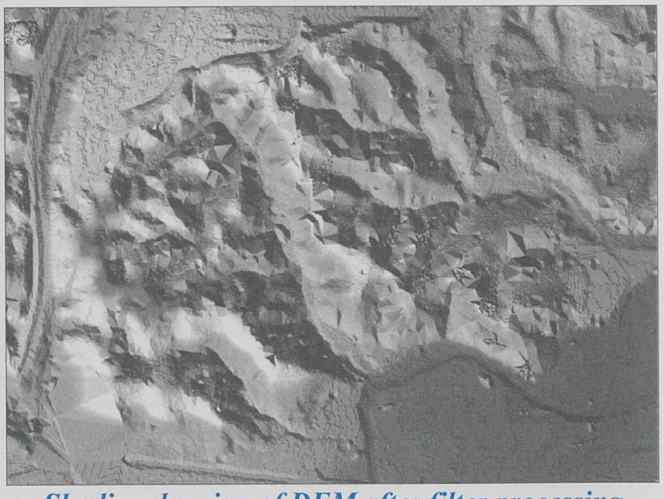
In general, the measurement altitude of airborne LS is 300 to 3,000 m, the scanning angle of airborne LS ranges between 5 and 45 degrees, and the scanning width is within 80 to 2,000 m. The measuring accuracy is ±30 cm in horizontal direction and ±15 cm in vertical direction.

Measurement of airborne LS data and DEM generation

Data collected with an airborne LS are three-dimensional (3D) point clouds corresponding to the surfaces of spatial objects on the ground such as the ground surface, buildings, bridges, roads, trees, vehicles, etc. They are called Digital



Shading drawing of DSM



Shading drawing of DEM after filter processing

Surface Model (DSM) and distinguished from DEMs.

Data filtering is needed to create a desired DEM from a DSM. Data filtering consists of two major processes: i) elimination of noises and ii) elimination of ground objects such as trees and buildings. To remove noise from DSMs, the points reflected from dusts in the air, clouds, etc. are eliminated first. Then, the noise due to mirror surface reflections from building walls covered with glasses, etc. are removed. To eliminate trees and buildings from DSMs, the search size and threshold are determined respectively for tall, middle height and low height buildings, trees and small areas first. Next, the points come under these thresholds are sequentially removed. A DEM is generated through such processes.

Creation of 3D city model

3D city models constructed using airborne LS data can be utilized as the essential information for predicting the damages of urban disasters such as earthquakes and floods. In addition, it can be used as the basic information for the maintenance and management of urban facilities. Frequent updates of the geometrical information of ground objects are needed in these applications. Airborne LS, which allow us to conduct measurements of the shapes of ground objects rapidly, may be an optimal means for 3D city modeling.

The two figures of this page show 3D city models created by extracting point clouds corresponding to buildings and trees on the ground through high-pass filtering with Fast Fourier Transform applied to an airborne LS data, and by applying a polygon processing technique to the aerial image data taken with a CCD camera simultaneously with the acquisition of the airborne LS data to reconstruct spatial objects such as buildings and trees.

Three-dimensional expression of close-range view of a city made by laser scanner

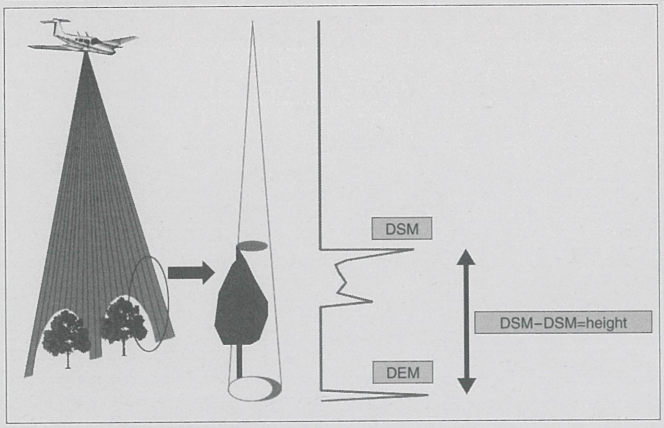
Use of DEMs for topographic analyses of slope lands

Debris flows, slope failures and landslides often occur in the outskirts of many cities in Japan. For those areas, detailed geomorphologic studies of the slope lands should be carried out for planning countermeasures against slope disasters. Ground surveys are not optimal for the purpose, because the high labor-cost due to the heavy vegetation cover in those areas. The use of airborne LS, on the contrary, appears to be a good alternative for surveying terrain features of the slope lands.

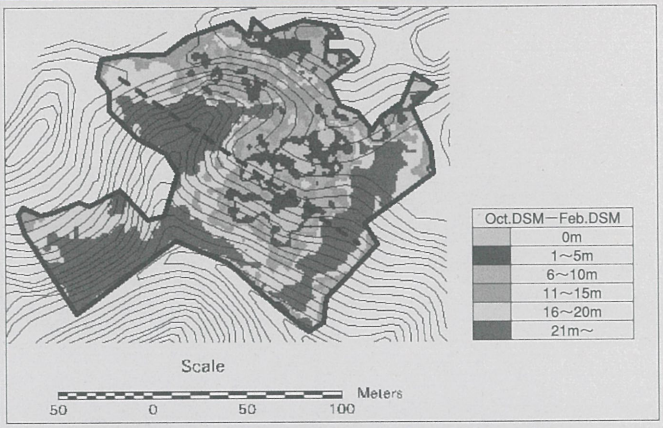
Tree height measurements and forest structure analyses

Measurement of the tree heights of a forest, as well as the identification of the forest structure, provides important information for estimating the amount of carbon dioxide absorbed or fixed by the forest. Tree heights can be obtained by subtracting the height values at root positions of trees recorded in a DEM from

Three-dimensional expression of bird's-eye view of a city made by laser scanner



Concept of tree height measurement by DSM and DEM



Amount of change in vertical direction of DSM before and after defoliation

those at treetops recorded in a DSM.

In case of a deciduous forest, the vertical tree structure of the forest can be identified by comparing multi-temporal DSMs generated from airborne LS data taken before and after defoliation. Furthermore, with the technique mentioned above, the horizontal distribution pattern of the vegetation, such as shrubs and grasses, covering the lowest layer of a deciduous forest can be identified.

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ICUS Signs MOU with BES and NCEE of Bangladesh

On February 21, 2003 ICUS signed a Memorandum of Understanding (MOU) with Bangladesh Earthquake Society (BES) to work together to achieve common objectives towards urban safety. BES was founded in 2002. The aims and objectives of BES are mainly directed towards promoting research, development and awareness in the field of earthquake engineering.

On the same day, ICUS also signed an Agreement for Collaboration in Research, Education and Training Programs with the National Center for Earthquake Engineering (NCEE) of the Bangladesh University of Engineering and Technology (BUET). Through this agreement both the parties agreed to cooperate in the fields of mutual interest. Dr. Mehedi Ahmed Ansary, Associate Professor, Department of Civil Engineering, BUET, represented both the organizations in the signing ceremony, which took place at ICUS. Several staff members of ICUS attended the ceremony.

Signing cermony was held at ICUS

Through these MOU and Agreement, ICUS hopes to strengthen its working relationships with the researchers from Bangladesh for future collaborative activities.

WWF3 and First International Symposium of APHW held in Kyoto

The 3rd World Water Forum (WWF3) was held from March 16-23, 2003 in the three neighboring Japanese Prefectures of Kyoto, Shiga and Osaka holding 351 separate sessions on 38 interlocking themes dealing with water, especially on how to bring safe water and sanitation to the entire world. Some 24,000 participants from 182 countries, more than triple the number of participants expected, attended the sessions.

The Asia Pacific Hydrology and Water Resources Association, which was established in September 2002, organized its first international conference on "Hydrology and Water Resources in Asia Pacific Region" during March 13-15, 2003 in Kyoto. More than 350 people from over 30 countries participated in the conference.

Eight Years after the Kobe Earthquake

- Its impact on Earthquake Disaster Reduction Strategies in Japan -

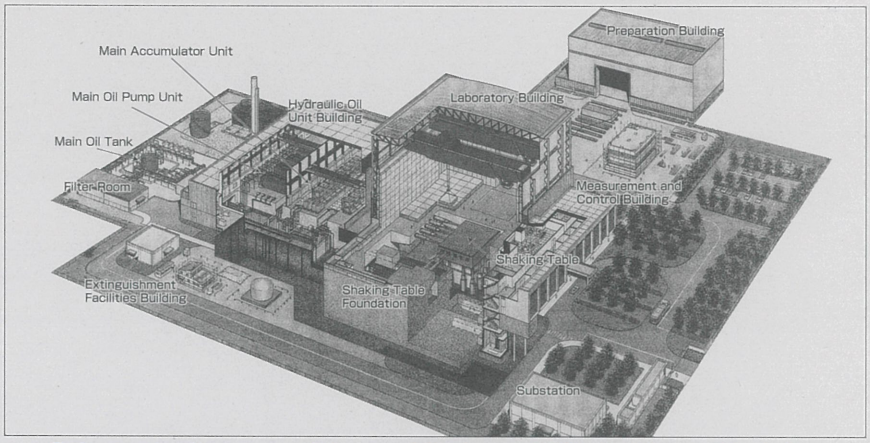
January 17, 2003 marks the eight anniversary of the Hyogo-ken Nanbu (Kobe) Earthquake, which killed about 5,500 people just after the event and eventually 6,433 people as of Jan. 2003. This devastating earthquake shattered the beliefs of Japanese engineers and researchers regarding building and infrastructure protection against earthquakes. During this eight-year period, many changes have taken place in earthquake disaster mitigation strategies in Japan.

One of the major impacts of the Kobe earthquake has been the changes taken place in the Japanese government organizations, from national to local levels, in order to efficiently implement countermeasures before and after a disaster event. Many local governments have established high positions to implement and manage proper disaster countermeasures.

Another effect has been the increased support of Japanese government to research on earthquake disaster reduction. Several new research centers, such as the Earthquake Disaster Mitigation Research Center, Disaster Reduction and the Human Renovation Institution, have been established in Kobe city.

Seismic monitoring and testing facilities have also improved. 1,000 seismometers (K-net) have been installed by the National Institute of Earth Science and Disaster Prevention (NIED). Now around 4,000 strong motion stations including K-net together with 1,200 GPS stations are regularly monitoring ground motion and seismic activity throughout Japan. A large 3D earthquake simulator (shown in the figure) is also being constructed by NIED. Once completed, it will allow experiments of total failure using full-scale structures.

Although these developments have contributed a lot towards improving the resistance of Japanese society against earthquakes, there are still several important and urgent issues to be addressed. The most important is retrofitting of old structures. In the Kobe disaster, over 80% of the victims were killed within 15 minutes after the earthquake due to collapse of structures, mainly residential houses. Furthermore, the main cause of firebreak and spread was structural collapse. Also, around 15% victims, who were killed by fires, could not escape from fires as they were trapped under damaged houses. Over 60% of the monetary loss was due to damage to residential houses. If structural damage were limited, the various problems generated after the event, such as community disruption, temporary shelter and refuge camps, construction demolition among others might not have been so severe. This is the most important lesson learnt from the Kobe event.



Schematic diagram of the world's largest 3D shaking table being constructed in Japan (Max. capacity: 1,200tf, 200kine, ±100cm)

The Kobe experience showed us that the structures constructed following the latest seismic code revised in 1981 performed well even in case of a severe ground motion. However, nearly 60% of the existing structure stock in Japan were constructed before 1981. These structures need urgent retrofitting to avoid a catastrophic disaster. To overcome this situation, a good environment is needed under which house owners are encouraged to retrofit their houses. The key issues are development of efficient low cost technologies and a new social system/law for retrofitting promotion. Role of the government in the latter issue is very important.

A government system that supports house owners to retrofit before an earthquake is not realistic as it needs a huge budget considering the number of vulnerable houses, while a government system that supports house owners in reconstruction of their collapsed houses after an earthquake is not a proper approach as it reduces the motivation of house owners for retrofitting and that leads to increased damage in the next disaster event. Japanese government should rather encourage the owners to retrofit their houses on their own. People can be motivated to retrofit if the government guaranties financial support to damaged houses only if they are retrofitted. Various simulations have clearly shown that this system with low cost retrofitting technology would give larger benefit to both citizen and government and definitely help reducing casualties and large-scale damage.

Within coming 30 to 40 years, Japan is going to be rocked by a series of M8 class earthquakes. At the present conditions, it is estimated that these earthquakes may cause an economic damage equivalent to 20 to 60% of the Japanese GDP. As natural hazards cannot be prevented, all the governments, local communities and individuals must make every possible effort before the events to reduce the vulnerability of buildings and infrastructure and avoid huge unbearable losses.

(K. Meguro)

Announcement: International Symposium on Oct. 30-31, 2003
- New Technologies for Urban Safety of Mega Cities in Asia -

Over half of the world's population is concentrated in urban areas covering just 4% of the world's surface. Mega cities are in particular characterized by a high population density. Rapid urbanization is a distinctive feature of Asia with a tremendous rate of population growth. It is estimated that by 2015, over 50% of the mega cities in the world are going to be in Asia. Due to rapid economic development, there has been a phenomenal growth of high-rise buildings and other infrastructure in the Mega Cities of Asia. However, this growth of infrastructure is not adequately balanced by the appropriate measures for their maintenance and management and that has led to a deterioration of urban infrastructures and resulted in urban disasters in many cities. Moreover, dense concentrations of populations are leading to high rates of water-related illnesses from lack of safe drinking water or adequate sanitation or environmental problems.

The recent developments of various advanced technologies including Remote sensing, GIS, GPS and other computational tools have generated scopes and motivation to focus on devising appropriate methodologies for management and maintenance of urban buildings, infrastructures, mitigation of urban disasters and environmental problems for sustainable development of the Asian Mega Cities with adequate safety and security.

As a large number of population is under potential risk, safety and security of Asian Mega Cities deserve increased attention of various concerned groups including the researchers and decision makers. With this realization and recognition of the importance of advanced tools in urban safety, ICUS is organizing a 2-day international symposium during October 30-31, 2003 on the use of advanced technologies towards development of methodologies for safety and security of Mega Cities in Asia. This is the second symposium organized by ICUS on this particular topic.

The prime objective of the symposium is to bring together decision makers, practitioners and researchers involved in these fields to share their expertise, knowledge and experience for tackling the critical issues of urban safety with advanced technologies.

The topics of the symposium include various issues related to advanced technologies for urban safety and security covering the following broad areas:

- Urban Disaster Mitigation
- Safety and Security Assessment of Urban Infrastructure
- Environmental Impact Assessment of Urbanization
- Space Technologies and GIS for Monitoring and Assessment of Urban Safety

For further details about the symposium, please visit the symposium home page at ICUS(http://icus.iis.u-tokyo.ac.jp/isus03/). The Symposium Secretariat can be contacted by telephone (+81-3-5452-6472), fax (+81-3-5452-6476) or, e-mail (icus@iis.u-tokyo.ac.jp).

ICUS Staff Activity Records

Some of the international activities carried out by ICUS faculty members during the period of January-March 2003.

- *Dr. D. Dutta carried out a field survey in the Pak-Mun River Basin in Thailand during February 16-20 for gathering data and information for hydrologic modeling.*
- *Dr. Shiro Ochi participated in the Regional Conference on Digital GMS held at AIT, Thailand during February 26-28.*
- *Dr. Yoshitaka Kato visited Bangkok, Thailand during March 11-14 for a field experiment and demonstration related to urban infrastructure health monitoring.*
- *Prof. Y. Yasuoka attended the Second EU-Japan Symposium on Climate Research held in Brussels, Belgium during March 13-14.*
- *Dr. Kimiro Meguro visited Maui, Hawaii, USA from March 23-26 to attend the 7th US-Japan workshop on Urban Earthquake Disaster Mitigation.*

Visitors to ICUS

Some of the international visitors to ICUS during the period of January-March 2003 are listed below:

- Prof. Ehrhard Raschke, Institute of Meteorological University, Hamburg and Visiting Professor, CCSR, The University of Tokyo (Feb. 5).
- A delegation of academicians working in Urban Environment fields from several regional universities of China (Feb. 10).
- Dr.Mehedi A. Ansary, Department of Civil Engineering Banladesh University of Engineering and Technology (BUET) (Feb. 21)
- Prof. Ashim Das Gupta and Prof. Tawatchai Tingsanchali, School of Civil Engineering, Asian Institute of Technology, Thailand (Mar. 11).
- Prof. A. W. Jayawardena, Hong Kong University, Hong Kong (Mar. 11).

ICUS held 4th Open Lecture on Water Related Issues in Mega Cities of Asia

As a large number of population is under potential risk, solving urban water issues in mega cities deserves increased public attention. With this realization, ICUS held its 4th Open Lecture on "Water Related Issues in Mega Cities of Asia in the 21st Century" in Tokyo on March 11, 2003. In this forum, five internationally renowned academicians and experts in the field of water from Asia Pacific region delivered talk on important water related issues in Mega Cities of Asia.

A snapshot from the Lecture Hall

The first speaker of the forum was Prof. Ashim Das Gupta of the Asian Institute of Technology (AIT), Thailand, who delivered a talk on "Emerging Challenges in the 21st Century to Meet the Demand of Water Supply in the Fast Growing Mega Cities of Asian Developing Countries". In his talk, Prof. Das Gupta covered a wide range of issues on new challenges facing by the developing countries of Asia to provide clean water to the residence of its growing mega cities. He has pointed out the need of coordinated efforts by all the concerned authorities to institute a framework to solve these problems, so that the future generation will not suffer adversely due to water crisis.

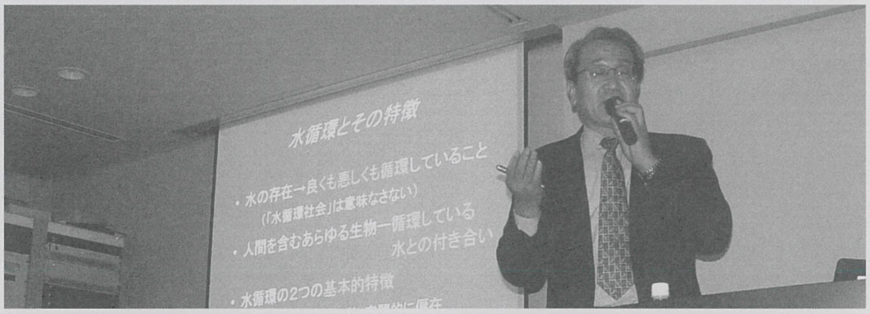
Prof. Katumi Musiake of the University of Tokyo talked on ìIntegrated Urban River Basin Management: Experiences from Past and Future Directions in Japan . In his lecture, Prof. Musiake gave the audience much insight of the Japanese experiences of managing water and the future directions with several examples and case studies.

Prof. Tawatchai Tingsanchali of AIT delivered a talk on "Strategic Framework and Institutional Arrangement for Flood Disaster Management in Large Cities in Thailand". In his talk, he elaborated the present strategy of the Government of Thailand for flood disaster mitigation in Thailand. He strongly emphasized the need of adopting a pro-active flood disaster management strategy of development instead of the existing reactive strategy to overcome the challenges of flood disaster reduction under changing socio-economic and climatic conditions.

Prof. Jayawardena from the Hong Kong University talked on issues "Towards Sustainable Development and Management of the Water Supply of Hong Kong". Through his presentation, he explained in depth how Hong Kong has been managing the increasing water demand. Hong Kong can be a model example for many Mega cities of Asia, especially in developing nations, in their efforts to manage the increasing water demand.

Prof. Kuniyoshi Takeuchi of the Yamanashi University, Japan talked on "Importance of Hydrological Forecasting for Integrated Urban Water Management". With the emphasis on need of hydrological forecasting and limitation of hydro-meteorological ground observation, he stressed on developing new initiatives to come out with alternatives for hydrologic predictions. He introduced the recent initiative of International Association of Hydrological Sciences (IAHS) on that direction about prediction in ungauged basins (PUB). It is envisioned that success of PUB will help the scientific community to come closer to the common public with better predictions.

Dr. Dushmanta Dutta of ICUS coordinated the forum. For any further information on the forum proceedings, please contact ICUS.



Prof. Musiake of IIS, the University of Tokyo, during his talk

Editor's Note

Advancement in technologies in the recent years has made it possible to undertake many new research activities in the fields of urban safety engineering. The main article of this Newsletter elaborates the generation of high precision DSM and 3D city model using airborne laser scanners. Such high precision data are very useful for advanced and fine scale mathematical modeling of urban environments and behaviors. ICUS is going to hold an international symposium on New Technology Tools for Urban Safety of Mega Cities in Asia in October this year. This is a very important and timely topic and through this symposium, ICUS wishes to bring together the concerned people of the Asian region to share the knowledge on new technologies and their uses towards making our mega cities safer and securer. I am very sure that the symposium will provide an opportunity to establish strong connections among the decision makers, practitioners and researchers of the region for future collaboration.

While we talk on advanced technologies, I would also like to emphasize that the advanced technologies alone are not enough to achieve our objectives of safety and security for all urban dwellings without proper use of basic technologies, e.g., retrofitting of existing housing is essential to ensure safety against a strong earthquake. After the devastating Kobe earthquake disaster, Japanese earthquake engineers and researchers have been focusing on development of advanced technologies for design and construction of earthquake resistant structures and for quick damage estimation and monitoring. We must also continue our focus on how to reduce damage to the existing old structures, especially, residential houses in various parts of Japan with low cost basic technologies. House owners of such structures cannot afford to reconstruct their structures with advanced technologies. These low earthquake resistant structures are highly likely to be collapsed by a strong earthquake causing large casualties and huge economical loss. To overcome such situations, we should prepare a good environment under which house owners can easily retrofit their own structures. The key issues are development of basic low cost retrofitting technologies and a new social system/law having driving force function. These issues are important for all the Asian countries to reduce the vulnerability of urban infrastructure.

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