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Earthquake Safety of Existing Dams for Irrigation and Water Supply in Rural Areas

By
Dr. Martin Wieland*

Up to now no incidents have been reported in the literature, where people have been killed due to the failure of a well-engineered dam during an earthquake. This is very encouraging, indeed. However, this favourable performance of dams does not necessarily mean that dams are inherently safe against earthquakes. For example, during the Bhuj earthquake of January 26, 2001 in Gujarat Province in India, about 200 earth dams were damaged and need repair and/or strengthening. Because the reservoir levels were extremely low during the time of the earthquake, no catastrophic release of water took place from the reservoirs of the severely damaged dams.

Despite the fact that these earth dams with a height of less than 30 m, which are often built by local communities, are different from the well-engineered dams for hydropower projects, we have to

Cracks along the crest and vertical settlement of the Suvi dam damaged during the January 26, 2001 Bhuj earthquake (Mw 7.7) in Gujarat, India (courtesy: JSCE, Japan)

recognize that plenty of similar dams exist all over the world. The water stored behind these earth dams is mainly for irrigation and water supply.

Moreover, there are very few large dams, which have been exposed to ground motions that may be expected during the maximum credible earthquake (MCE), an event which a dam must be able to resist successfully according to the current International Commission on Large Dams (ICOLD) guidelines prepared by the Committee on Seismic Aspects of Dam Design (CSADD), which is chaired by the author of this paper.

The Bhuj earthquake has also shown that in countries with inadequate earthquake preparedness, strong earthquakes can cause large number of casualties and huge economic losses. The problem is the largely unknown and often insufficient earthquake safety of the existing buildings and infrastructure projects as earthquake actions may not have been taken into account properly in the design. Earthquake regulations exist in most countries. If they are followed properly, they apply to new structures only and the earthquake safety of the many old structures is essentially ignored. Unfortunately, the same applies to the existing irrigation dams in most parts of the world. Although it may be known that these relatively small dams do not comply with today's rigorous design criteria, the owners and dam safety authorities are still reluctant to look into the safety of these dams as long as no catastrophic incident has occurred.

In the subsequent part, the reasons and justification for a program of earthquake safety evaluation and seismic upgrading of existing irrigation dams are given, which we hope, will encourage the dam owners and dam safety agencies to address this issue.

If we ignore the call for increased safety of the existing infrastructure projects with large damage potential - dams belong to this category of projects - the many groups, who are already opposing new dams, will use the earthquake safety as one of their arguments. This is already true for quite a number of large dam projects.

Background

The majority of the older dams were built using methods of seismic analysis and seismic design criteria, which, today, are considered as obsolete or outdated. Therefore, in many cases, it is not known if an old dam complies with the current seismic safety guidelines published by ICOLD (1989). Therefore, at the Annual ICOLD Meeting in Antalya, Turkey in September 1999, CSADD was given the task to address the issue of the earthquake safety of existing dams. This is also one of the subjects, which will be discussed during the forthcoming ICOLD Congress in Montreal, Canada in 2003.

According to the current ICOLD guidelines, large dams have to be able to withstand the effects of the so-called MCE. This is the strongest ground motion that could occur at a dam site. In practice, the MCE is considered to have a return period of several thousand years (typically 10,000 years in countries of moderate to low seismicity).

Because of the very long return period of destructive earthquakes in many parts of the world and because relatively few dams have been severely damaged by strong earthquakes, it is rather difficult to convince the dam owners and decision makers of the benefits of a seismic reassessment and upgrading of deficient dams.

Risk analyses, carried out for several dams in industrialized countries, have shown that the failure of a large dam and the resulting flood wave may cause a large number of casualties and huge economic and environmental damages exceeding billions of US$. Earthquakes may cause failure of dams, with inherent weaknesses. These weaknesses are often not known. But the statistics on dam incidents show that quite a number of deficient dams fail during the first few years after construction.

During the last decades, significant progress in the assessment of the seismic hazard at a dam site and the dynamic analysis of dams has been achieved. The trend goes towards higher intensities of the earthquake ground motion at dam sites, which is usually characterized by the peak ground acceleration (PGA). To illustrate this problem: most dams were designed against earthquakes using a so-called pseudo-static approach and a PGA of 0.1 g (g: acceleration due to gravity). An MCE with a magnitude of larger than 6 can generate (locally) a PGA of more than 0.5 g, i.e. a value, which is five times larger than the design value. Because of this large discrepancy between the design acceleration and the PGA values to be expected during the MCE, it is often not possible to make a reliable statement about the earthquake safety of an existing dam.

The main conclusion that can be made is that the earthquake safety of most existing dams is unknown and some may even be unsafe. If a dam should turn to be unsafe, then the easiest way to comply with safety standards would be to lower the reservoir level or decommission a dam. Because there are very few viable alternatives to dams in many developing countries, decommissioning of dams or lowering the reservoir level would be the last resort.

Based on our experience with the seismic safety evaluation of dams in countries of high and moderate seismicity like Iran and Switzerland respectively, we can state that well-designed dams will also satisfy to-

day's seismic safety criteria. We feel that it would be appropriate to address this important subject and take adequate action as structural safety stands in the first place of any dam project, i.e. way ahead of economic, environmental, ecological and socio-political concerns. This fact may have been overlooked in the recent debate on benefits and concerns of dams.

It is also in the interest of the dam community to have a clean record, as the failure of a single large dam may increase opposition against any new dam projects worldwide.

Proposed plan for action

Investments in the seismic safety of dams generally receive low priority as there is no visible immediate return on the investment. This has been a problem with all projects related to natural disasters with a very low probability of occurrence.

These investments into the future do seldom reap benefits for those, who have taken the decisions, as the horizon of politicians may be a few years and that of managers is often even much shorter. A long-term view in such programs is a prerequisite for sustainable safety improvements of the existing dams.

As there is a steadily increasing demand for water, flood protection and clean energy, safe operation and dam safety are prerequisites. Unfortunately, seismic safety of dams (and other infrastructure projects) has been an area, which has been neglected despite the fact that the decade 1990 to 2000 was declared by the UN as the International Decade for Natural Disaster Reduction, in which earthquake hazard played an important role. Earthquake safety of a dam is a must, as it seems that strong earthquakes cannot be predicted in the near future. By means of water alarm systems for critical dams, a large number of people could be saved from a flood wave but economic and environmental losses cannot be avoided in the case of a dam breach.

Shi-Kang water supply weir damaged during the Chi-Chi earthquake (Mw 7.5) of September 21, 1999 in Taiwan (courtesy: K. Meguro)

The main benefits of a seismic safety evaluation program for large dams are as follows:

i) Compliance with current safety requirements: all parties responsible for the safety of a dam can be ensured about its safety during very strong earthquakes (legal protection of owners against claims of negligence).
ii) Socio-economic and political acceptance of dam: the safety of the people living in the downstream area of the dam and their property can be guaranteed.
iii) Sustainable economic benefits: the dam and the reservoir can be used as initially planned.

Awareness is the first step towards improved earthquake safety. Seminars would be a cost-effective means to raise awareness in this problem and a first step towards a comprehensive program for the seismic upgrading of existing dams. Such a program has, for example, already been implemented successfully in California in the 1990s. During these seminars, the optimum methods for the reduction of the seismic risk posed by deficient dams could be discussed as well.

As the first step, this issue shall be put on the agenda of dam safety agencies and dam owners. Next, seismic re-evaluations of the older dams, especially those located in seismically active regions shall be performed and finally measures shall be taken to improve the safety of any deficient dams.

Finally, we have to realize that we have not yet solved all seismic problems completely. Every time there is another strong earthquake, we have to improve the earthquake standards and guidelines.

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From Editor's Desk

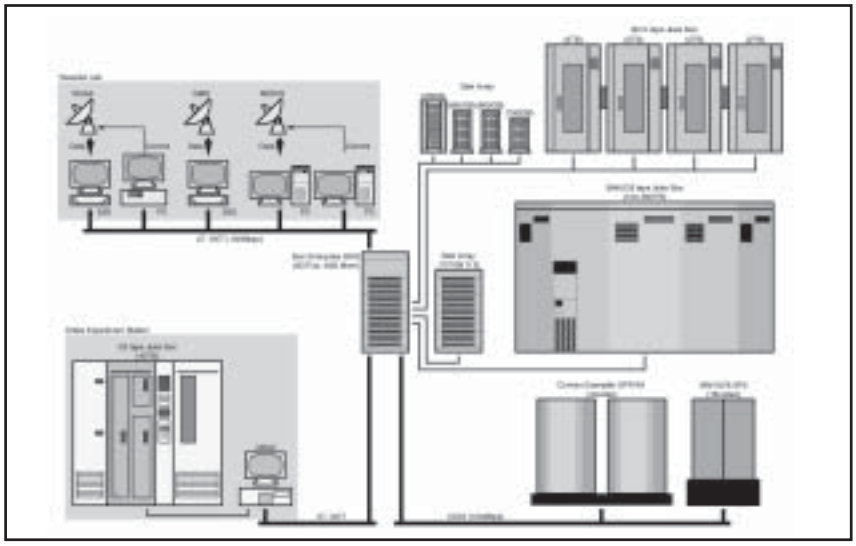
Half a year has past since the starting of ICUS/INCEDE. With the time, the center is expanding its activities to cover broad aspects of urban safety engineering. We are pleased to see that our network is expanding as well, which gives us a broad platform to share our views and outcomes with the members around the world. In this newsletter, we include the articles on our expanded activities regularly along with the research outcomes. We welcome the articles on various activities of network members on urban safety in this newsletter so that other members can share your views. Please feel free to send us your articles on your activities, your achievements anytime by e-mail or mail. We shall put effort to include it in newsletter in time. Let us share our activities among our network members for our common goal.

Analyzing "Heat Island" from Space

By
Yoshifumi Yasuoka

Prof. Yoshifumi Yasuoka, a professor at the Division of Information Dynamics of ICUS/INCEDE, has the research specialization in the field of remote sensing. As a part of the research of his team, a MODIS receiving station was installed at IIS last year. In this article, Prof. Yasuoka introduces the expanded research activities of his team on heat island phenomenon using data from MODIS receiving station.

In December 18, 1999, NASA launched the Terra satellite, which is the first Earth Observing System (EOS) platform and provides global data on the state of the atmosphere, land, and oceans, as well as their interactions with solar radiation and with one another. MODIS (Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths.

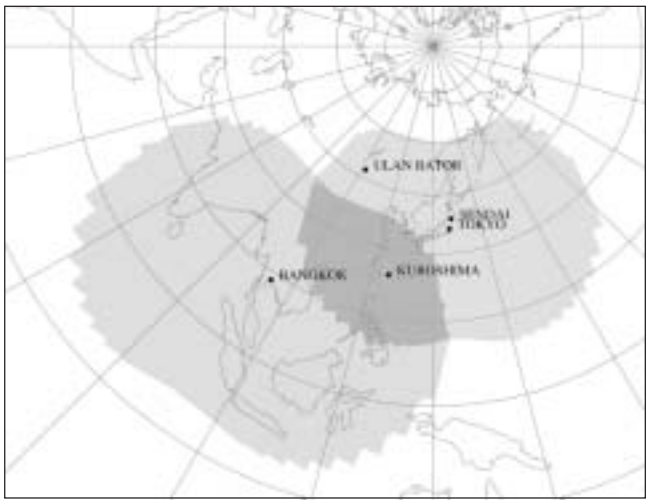


The Tape Archiving System for Satellite Data at IIS

To monitor the environment and disaster parameters around the East Asia as a part of our research, two MODIS receiving stations were installed by our research team, one at the Institute of Industrial Science (IIS) of the University of Tokyo and another at the Asian Institute of Technology (AIT), Thailand, from which we started receiving data since May, 2001. In addition to our existing satellite receiving systems of NOAA HRPT and GMS S-VISSR, a new X-band satellite reception facility was installed in IIS, University of Tokyo, which has been initially used to collect data from MODIS. The dish has been placed on the roof of the 8-storey IIS building. In order to acquire Terra data for expanded continental-scale change researches into the Southeast Asian sub-region, the IIS has provided Asian Center for Research on Remote Sensing (ACRoRS), AIT one identical MODIS receiving facility. That station is managed by the Joint Management Committee composing of ACRoRS, Geo-Informatics and Space Technology Development Agency (Thailand) and IIS. The MODIS raw data from AIT receiving facility is transferred to the IIS archiving system as well through Internet in real time.

MODIS has 3 different modes of spatial resolutions - 250m, 500m and 1000m - with 36 spectral bands

MODIS receiving antenna on the roof of IIS

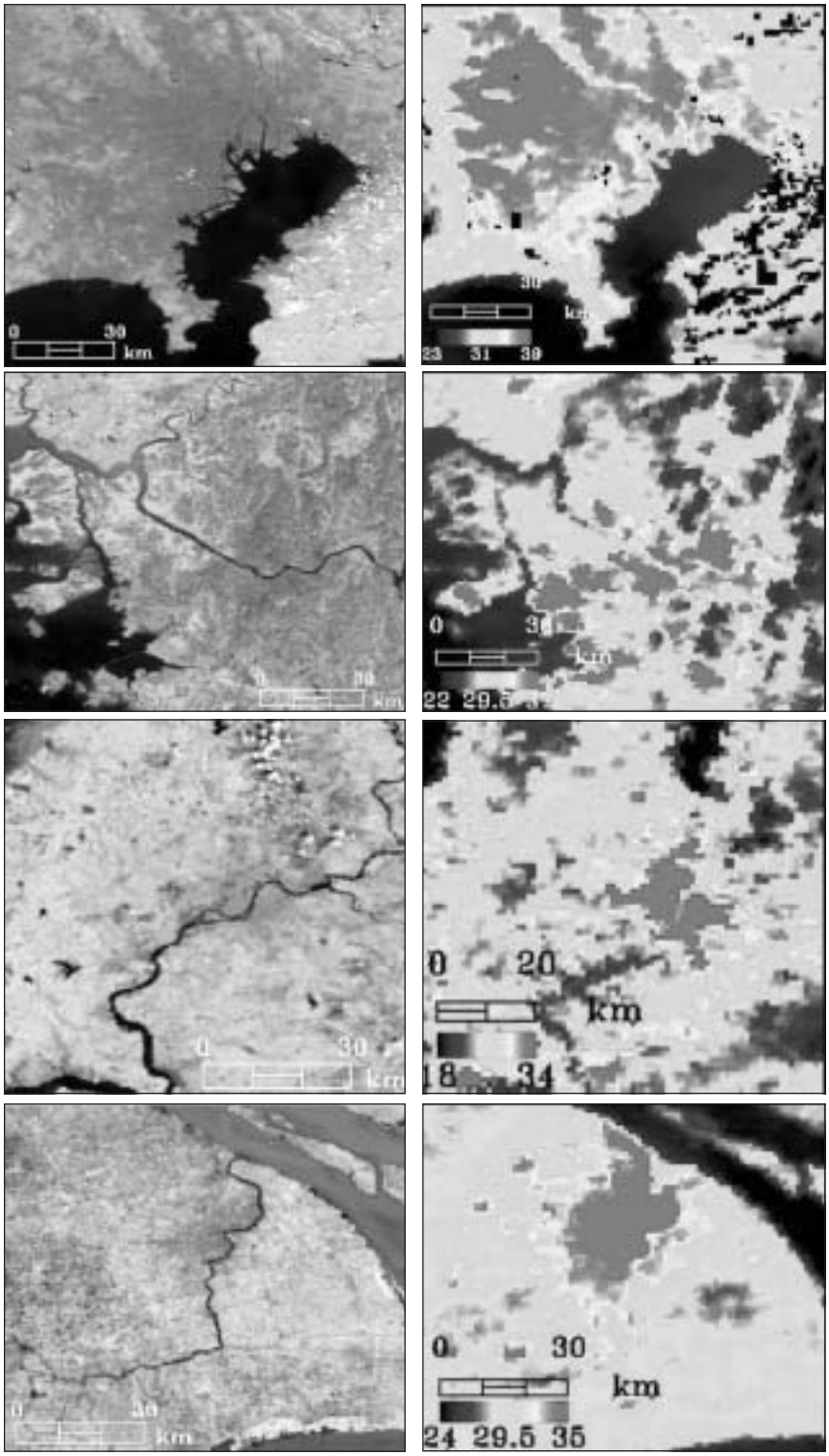


Satellite coverage by IIS and AIT receiving stations

in total. The IIS Station covers the east part of Asia including the east Siberia, and the AIT Station covers the southeast Asia including India, a part of Pakistan and Tibet Plateau. At present, our research group is preparing satellite data products relating to the global and regional environmental studies.

As a part of our research activities using the MODIS data, we have carried out a research project to monitor "Heat Island" by analyzing the land use/land cover characterization and heat parameters around cities. For conducting the research study, we have selected five cities in the East Asia region, those are: Tokyo (Japan), Seoul (South Korea), Pyongyang (North Korea), Beijing and Shanghai (China), which are within the range of IIS receiving station coverage.

In the study, the land cover characterization and the "Heat Island" intensity are analyzed by comparing the images of summer versus winter, and day versus night time for the cities. The first step of the study is to make the land cover classification of the areas using 250m resolution optical images. Build up, forest, grass, water body and bare soil are classified in order to give the emissivities of the land cover categories. The emissivity is then used to estimate the land surface temperature from the brightness temperature value in the thermal band image with 500m resolution data. Finally the "Heat Island" impact is analyzed. The land surface temperature is of course influenced by the geographic condition such as the climate and whether at the time of the area. In order to compare the "Heat Island" impact among the cities, the standardized surface temperature images are prepared by equalizing the temperature values of forested region in suburbs where the "Heat Island" effect is supposed to be unrelated. As the intermediate report, the study concludes that



MODIS 250m optical and 500m thermal images covering Tokyo, Seoul, Pyongyang and Shanghai (from top)

the intensive of the heat island impact is ordered by Tokyo, Seoul, Pyongyang, Beijing and Shanghai.

Continuous observation will be made for more quantitative analysis using more stable satellite information which avoid the temporal error such as whether condition and sensor anomalies. Our group expect that the study can define the vegetation function to the "Heat Island". Furthermore, some more cities from South East Asia such as Bangkok, Hanoi, Ho Chi Minh City, Jakarta, Kuala Lumpur, Singapore, covered by AIT broadcasting station will be added for the study.

For further information on this particular research topic or on any of our research activities, the author can be contacted by e-mail at yyauoka@iis.u-tokyo.ac.jp.

Bridging between Policy and Research

By
Takefumi Takahashi

ICUS welcomes Mr. Takefumi Takahashi, the Director General for Disaster Management at the Cabinet Office of the Government of Japan, as a Visiting Professor to the Urban Safety and Disaster Mitigation Division. In this article, Prof. Takahashi introduces his new activities at ICUS.

I have been serving as a Visiting Professor in the Urban Safety and Disaster Mitigation Division of the International Center for Urban Safety Engineering since 1st December, 2001. In my official capacity as the Director General for Disaster Management of the Cabinet Office, I am responsible for coordinating disaster-related administrative activities in the national government of Japan.

As you may know, Japan is very susceptible to natural hazards because of its geographic location, topography, climate and other conditions. Thus, it is subject to frequent earthquakes, volcanic eruptions, floods, typhoons, etc. Furthermore, 50% of population and 75% of the property are accumulated on alluvium plains which cover 10% of the countryís total area and are at a very high risk of suffering floods. Due to such land use patterns, Japan is very vulnerable to natural disasters. Although we can not avoid such natural hazards, we should have countermeasures in place in order to mitigate potential damages.

Two years ago, Mt. Usu in Hokkaido and Mt. Oyama in the Miyake Island near Tokyo erupted. They brought economic losses, but no one was killed or injured. The absence of human casualties can be attributed to the coordinated efforts made by researchers, administrative organizations and citizens. In particular, three factors are worth mentioning. First, an accurate prediction prepared by continuous observation made a great contribution. Second, an effective network among research organizations and national and local governments enabled proper information dissemination and timely evacuation orders. Third, a good response on the part of local residents facilitated swift evacuation. With these three factors in a good combination, the whole system proved to be functional and negative impacts were minimized.

It would be possible to further reduce negative impacts caused by natural hazards if we prepare proper countermeasures based on a good understanding of potential disaster risks. Towards this goal, many hazard maps for earthquakes, volcanoes, floods, geo-hazards, etc. have been developed in recent years. They have been disseminated to citizens and related organizations who understand their importance.

Prof. T. Takahashi

I would like to investigate how to disseminate disaster-related information, such as observated information and research outcomes, so as to implement effective disaster countermeasures. I would also like to examine how to prepare proper disaster manual to be distributed among administrative offices, representative persons and citizens. Being in charge of disaster management, I will do my utmost to improve coordination between the research organizations and administration.

I would like to have many opportunities to exchange ideas. Therefore, it is my strong wish that everyone works together for disaster management in Japan as well as other countries.

ICUS ACTIVITY RECORDS

* *Prof. Y. Yasuoka attended the 22nd Asian Conference on Remote Sensing held in Singapore from November 5-9, 2001.*
* *Prof. T. Takahashi joined ICUS as Visiting Professor on December 1, 2001.*
* *Profs. T. Uomoto and S. Misra attended the International Commission on Concrete Model Code for Asia (ICCMC) held in Kuala Lumpur, Malaysia during December 3-4, 2001.*
* *Dr. S. Ochi attended the 1st Asian Eco-Seminar held in Kathmandu, Nepal from December 3-5 , 2001.*
* *Dr. D. Dutta attended International Hydrological Programme (IHP-5) regional meeting at Hanoi during November 18-20, 2001. After the meeting, he carried out a field survey in the lower Mekong basin together with his colleagues from IIS.*
* *ICUS held the Civil Engineering Seminar on Urban Safety at the Komaba Campus of IIS on 11 December, 2001.*

ICUS held Civil Engineering Seminar on Urban Safety

The 8th Civil Engineering Seminar, organized by the Comprehensive Research Foundation and the School of Civil Engineering of the University of Tokyo, was held on December 11, 2001 at IIS with about 60 audiences. The theme of the seminar was "Urban Safety Engineering" and the speakers were the five faculty members of ICUS, who presented on the following themes.

Prof. Y. Yasuoka presented a lecture on "The Assessment of Safety and Amenity of Urban Infrastructure using Information Technology" in which he explained that Remote Sensing technology and Image Processing can be a powerful tool to describe the quality of the urban environments.

Assoc. Prof. R. Ooka presented on "Urban Climate Simulation Model for Urban Planning" in which the mechanism of Hear Island phenomenon was explained and a simulation model for urban climate analysis was introduced.

Prof. Uomoto, ICUS Director, presenting his views on urban safety

Assoc. Prof. K. Meguro presented on "Towards Tokai Earthquake -Balancing Structural and Non-structural Measures for Minimizing Earthquake Damage" in which he stressed the importance to retrofit existing weaker houses and to have proper disaster manuals for implementing good countermeasures.

Prof. T. Takahashi presented on "National Policy and Countermeasures of Japan for Urban Safety and Disaster Reduction" in which the strategic idea of Government of Japan was introduced.

Prof. T. Uomoto presented on "Current Status and Future of Non-destructive Inspections for Concrete Structures" in which several advanced technologies to assess the safety of the concrete structures were introduced.

Further details of this seminar are available at the home page of ICUS.

(By Ochi)

International Symposium on Geoinformatics in September 2002

An International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences (GISIDEAS' 2002) is going to be held in Hanoi, Vietnam during September 25-28, 2002. It is organized by the Japan-Vietnam Geoinformatics Consortium.

The Symposium will focus on integration of Information Technology tools for the development of spatial databases and the utilization of spatial data for mathematical modeling and computer simulation of processes related to our natural and social environment. It aims not only to serve as a forum for scientific exchanges but also as a conduit for technology transfer through short courses that will be organized within the framework of the symposium. In order to promote a better understanding of specific needs, field excursions and visits are also being planned.

The further details of the Symposium information are available in web site http://gisws. media.osaka-cu.ac.jp/gisideas, which provides on-line registration facilities for participating in the Symposium.

Visitors to ICUS

During the period of October-December, 2001, ICUS received the following visitors.

- *Mr. Raffaele Raja, Regione Lambardia Unita Organizzativa Protezione Civile, Italy (Oct. 24).*
- *Mr. Jia Kunji, Chinese Embassy, Tokyo, Japan (Nov. 15).*
- *Dr. Bui Ta Long, Director of Institute of Applied Mechanics, Vietnam (Nov. 19).*
- *Dr. Jorge F. Meneses-Loja, Assistant Scientist, University of California, San Diego, USA (Nov. 21).*
- *Prof. Tso-Chin Pan, Director of the Protective Technology Research Centre, Nanyang Technological University, Singapore (Nov. 27).*

Four students from ICUS won the prize at JSCE conference

This year, the annual conference of Japan Society of Civil Engineers (JSCE) was held at the Kumamoto University, Kyushu during October 2-4, 2001. In the conference, about 4,000 technical papers were presented in seven sessions and over 7,000 research engineers and university students participated. From ICUS/INCEDE, the faculty members and students attended the conference and made their presentations. Our center's research outcomes got good impression from the participants as the result of that four students listed below won the prize of best presentation by young researcher. Comparing the average ratio of the prize winners with that of our center, our center's winner ratio was very high. It showed the high quality of ICUS/INCEDE's researches and high performance of the center.

Names of the winners are: Ms. Ema Tsukahara (supervised by Prof. Uomoto), Mr. Ms. Misaki Enomoto, Mr. Muneyoshi Numada and Mr. Suguru Fujita (supervised by Prof. Meguro).

Editor's Note

Not only researchers for urban safety, but also the most citizens are conscious of comprehensive safety of our society and its functions, after the September 11 terrorist attacks in New York, USA. The affair awoke us that it is actually impossible to go on without risks in this complex and international society. We, Japanese also remember our experience of the sarin gas attack on Tokyo subway system in 1995.

ICUS does not directly target on the researches for the counter-terrorism at this moment, however, it aims to develop systems to prevent social emergency and the countermeasures for them from engineering aspects. ICUS has timely welcomed Prof. Takefumi Takahashi as an expert of disaster politics from the Cabinet Office of the Governmentent of Japan on December 1, 2001. By his joining to ICUS, we expect ICUS can contribute more effectively to the strategy preparation of domestic as well as international disaster policies lead by the Japanese Government.

(S. Ochi)

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