

International Center for Urban Safety Engineering



Institute of Industrial Science The University of Tokyo

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HIDDEN CAVITIES UNDER THE GROUND - THEIR CAUSES AND CONSEQUENCES -

By

HIDDEN CAVITIES UNDER THE GROUND

You may think that the ground is firm and solid, unless some natural disasters like earthquake or landslide occur. But this is not always the case. Sometimes, you may be standing on an underground pitfall covered with solely a layer of pavement, which may collapse without a clear sign of warning. The photos below show a sinkhole that appeared on a road, caused by failure of a sewer pipe lying underneath, on the left, and a much larger cave-in, about 30 m wide and 3

Reiko KUWANO

m deep, which occurred in Tsu-city, Mie Prefecture in July 2006, on the right. The cause of this huge hole has not yet been clarified, although it is suspected that numerous old small pits and tunnels for mining sands in this area, an activity that stopped more than 20 years ago, are the most likely responsible.

In most cases, a cavity in soil precedes such a sudden collapse of ground surface. The origin of the cavity could be natural or artificial. When the stability of the cavity is lost for any reason, soil above the cavity falls causing loosening of



A cave-in due to failure of a corroded sewer pipe

surrounding soil. The loosened area spreads up until the surface collapse eventually occurs.

POTENTIAL SOURCES OF UNDERGROUND CAVITY

We have laid various infrastructures, such as tunnels, trenches, water pipes, sewer pipes, gas pipes and others, deeply underground. In order to catch up with the growth of urban population and functions, construction of those lifelines has rapidly progressed in the recent decades. The current underground situation is congested and complicated. All the underground lifelines are potential sources of cavities when they are too deteriorated to support the surrounding soil. Old abandoned mines and tunnels and air-



A cave-in of 30 m wide and 3 m deep affected road and residents. (Photo courtesy of the Tsu Municipal Government)



Relationship between the average age of sewer pipes in 23 wards in Tokyo and the number of cave-in incidents (after "Prospects of Sewerage 2001" Tokyo Metropolitan)

raid shelters are the most dangerous sources of underground cavities as they are likely to be poorly supported and their locations are not well recorded.

CAVE-IN DUE TO FAILURE OF SEWER PIPES

Recently, approximately 1000 cave-ins on roads occur every year due to the failure of sewer pipes in the urban area of Tokyo, within the 23 wards. Especially areas, where the urbanization started early and the existing sewer pipes are old, are suffering from frequent cave-ins, as shown in the figure on the upper left corner of this page.

Damage to old deteriorated sewer pipes appears to be the major source of soil cavities leading to cave-ins in earlier developed cities. Looking at the history of sewer pipe construction in Tokyo depicted on top right corner of this page, we note that the situation will soon become more serious.

Tokyo metropolitan government as well as other local governments are well aware of this problem and carrying out various actions for the efficient maintenance of existing sewer pipes. Their efforts include systematic reconstruction of old pipes and early detection of damage to pipes or cavities in soil, both of which apparently contribute to prevent further increase in the number of cave-in.

In fact, the reasons for the damage to sewer pipes are not only age. It was reported that around 15% of sewer pipe failures in Tokyo were caused by "other" construction works. The photos on the right show sewer pipes broken by water pipes. Such sewer pipe failures are not always noticed immediately, and



History of sewer pipe construction in 23 wards of Tokyo (after the website of the Ministry of Land and Infrastructure)

could be discovered even years later. Developing underground mapping information seems to be necessary to fundamentally sort this out.

RESEARCH ON THE MECHANISM OF GROWTH OF CAVITY AND SOIL LOOSENING

Whatever the reason is, once a buried pipe is broken, surrounding soil will be disturbed. This will loosen the ground and when the disturbance reaches the ground surface, local settlements will appear. Rainfalls seem to accelerate the process, judging from the fact that larger number of cave-ins occur in rainy seasons, from spring to autumn. The difficulty is to answer more specific questions. How fast does the initial disturbance reach the surface? How can we identify the dangerous void/cavity which will grow bigger? If we find a small defect in a pipe like a thin crack, do we need to worry?

Unfortunately, the basic mechanism of the formation of initial voids in soil and the growth of cavity resulting in the eventual ground surface cave-in has not been well understood yet. The author



A water pipe passing through an existing sewer pipe, found under a cave-in

and her colleagues investigated this phenomenon by small scale model experiments, results of which are shown in the figure on the top left corner of the next page. The main findings from the study were:

- Even a small crack or gap (5 mm wide) is sufficient to cause a cave-in.
- In sandy soils, an initial small void can quickly grow, especially when the ground is saturated. Above a cavity in sand, a loosened part largely develops where the dry density decreases by approximately 10 to 20 %.
- For sands with fines, which are commonly used for backfilling sewer pipes in practice, the rate of cavity growth seems to be slower. A loosened part, where almost half of the soil is lost, develops above a cavity, but it is not considerably large. A schematic diagram is displayed in the next page.
- In order to prevent soils from being washed away and form a cavity even in case a sewer pipe is broken, it is ultimately necessary for soil particles to be bonded to each other. Even, weak bond is enough for the purpose.



A water pipe broke an existing sewer pipe, found under a cave-in



Typical patterns of cavity and loosened area developed in sandy ground

Sand is the least resistible material. The content of fine fraction improves the situation although not for a long time. Soil around a cavity loses confinement and when it is saturated, soil particles would yield to water. Thus, a heavy rainfall significantly affects the process of cavity growing. The figure on the top-center of this page is an X-ray CT scanning image, showing a cavity and loosened area formed in a small model sand chamber. Above a cavity of only 5mm in size, the loosened area vertically spreads and reaches the surface. When this happens in the actual ground, the loosened area masks the small cavity underneath and its detection by radar exploration may become difficult.

CAVE-IN WITHOUT AN APPARENT CAVITY

A cave-in sometimes occurs without a preceding cavity formation. The photo on the right shows a hole that appeared in a flood plain along a river. Due to heavy rain brought by a typhoon, the level of river water rose and inundated the plain for a day. After the water level



X-ray CT image of cavity and loosened area in sand obtained from a small scale model test

lowered, local people found the hole approximately 2 to 4m wide and 1m deep.

Under the hole, at a depth of 15m, a water pipe of 2m diameter had been constructed by shield tunneling method. The front of the tunnel had passed the location of the cave-in more than 6 months before. Yet, there was no indication that the tunneling work excavated too much soil, equivalent to the hole size. Because the profile of the ground was sand/gravel with cobbles, conventional sounding techniques, like standard penetration test (SPT) or cone penetration test (CPT) could not be successfully applied. In fact, the SPT, that had been carried out before the tunnel construction, recorded an N-value over 50 by simply hitting large cobbles. A radar exploration was performed to search for cavities and loosened parts in relatively shallow ground, up to a depth of 3m. A new sounding technique measuring the resistance

with drilling was also carried out to explore deeper sectors up to a depth of 15m. Although there was no apparent cavity, the ground above the tunnel was found to be noticeably loosened all along. The loosened area was constrained to only above the tunnel, which is not usually expected in tunneling works. All the holes, cavities, and loosened areas were filled/grouted securely, not to affect the safety of the river bank which was adjacent.

TOWARDS FUNDAMENTAL SOLUTIONS

Thus, a cave-in is mostly a manmade disaster. Once we open a space in the ground, it should be properly maintained. When we decide to abandon the man-made space, it should not be left unfilled. A cavity in the ground grows and creeps upward in silence, then with some trigger, which in many cases is a rainfall, it suddenly appears on the surface. Currently, the problem of cave-ins is not prevented but mainly addressed once it occurs by temporarily filling up the holes. Several aspects should be considered to fundamentally sort this out, including developing techniques for early detection of dangerous underground cavity/looseness, proper and efficient maintenance of underground pipes, and developing filling materials and burying techniques which are not washed away in case a pipe is deteriorated.



A hole appeared in a flood plain along a river (after the website of the Ministry of Land and Infrastructure)

UTITU Workshop was held in Istanbul

UTITU Ordinary / Emergency Workshop 2006 was held in Istanbul Technical University (ITU), Istanbul, *Turkey during the week of September* 10-16. Both Istanbul and Tokyo are seismic prone areas. This workshop was one of the activities among the joint study project together with ITU and the University of Tokyo (UT). The objectives of the workshop were enhancing the strategic approach for the regeneration of Galata region, the historical site in the central business district of Istanbul. It was organized to be an educational seminar for 17 students from ITU and 12 students from UT. The

students were divided into three groups. After having a field excursion, they discussed new image of public space in their target area during both ordinary and postearthquake emergency situations. They surveyed current problems and future possibility in the area during the field excursion. Finally, regeneration plans were proposed integrating four research interests: urban design, urban history, water engineering and earthquake disaster mitigation engineering. This workshop was a valuable opportunity not only for the integration of different researches but also for





exploring new educational strategies for urban regeneration.

(By M. Yoshimura)



Evacuation plan proposed using 3D-GIS data



Field excursion in Galata area by students

Japanese and Turkish students discussing plans

Final presentation

Disaster-preparedness drill held at the University of Tokyo Hospital

As informed in Newsletter Vol.5, No.4, 2006, a project team was formed to consider the role of The University of Tokyo Hospital at a time of a disaster. ICUS members are now investigating the social demands of a disaster base hospital such as the number of patients after large-scale disaster.

The University of Tokyo Hospital conducted a comprehensive disaster-preparedness drill on September 8, 2006. ICUS members and students of Meguro laboratory joined and supported the drill.

The disaster scenario was conceived by Dr. Yoshimura to



Disaster command center

simulate an actual large earthquake disaster; the drill was planed in order to adapt the scenario. Dr. Kanada designed a central administration tool for disaster headquarter. This enabled to display important information such as damage to facilities or triage results on a large screen.

Confirmation of the safety of hospital inpatients and facilities was carried out just after earthquake. Nurses permanently reported the situation to the disaster command



Simulated patient



Triage training

center. The hospital headquarter director decided to accept outside disaster victims after judging the facility capability from the collected information.

Simulated patients were transported in ambulances and triage training was carried out in front of the hospital main entrance.

A simulated press interview meeting was held after the drill and the director commented on the exercise outcome. All processes were filmed with video cameras and a documentary DVD will be completed in the near future.

11th Open Lecture was held

The 11th ICUS Open Lecture was held at IIS in the afternoon of September 25, 2006. The title of the lecture was "Risk Management of Building Sanitation" and reported the achievements of the research project under the same name which is supported by the Japanese Ministry of Health, Labour and Welfare. About 80 people attended the lecture.

Four speakers delivered the following presentations:

- Dr. Koichi Ikeda, Director of the Department of Architectural Hygiene and Housing, National Institute of Public Health of Japan, and Project Leader, explained the project outline and "Risk management of hygiene for architectural equipments".
- Prof. Shinsuke Kato, Director of the Center for Development of Instrumentation Technology, IIS, the University of Tokyo, delivered the talk: "Diffusion of hazardous agents in buildings".
- Dr. Masaki Itoh, Chief of the Water

Supply Planning Section, Department of Water Supply Engineering, National Institute of Public Health of Japan, gave the speech: "Ensuring drinking water safety in buildings".

Dr. U Yanagi, Chief of the Health Housing Section, Department of Architectural Hygiene and Housing,



Lecture by Dr. K. Ikeda



Lecture by Prof. S. Kato

RNUS Activities

measurement method using remote sensing technology.

After the seminar, guests from Kanazawa Institute of Technology visited the RNUS office as well as the laboratory of the Structural Engineering Department and discussed RNUS activities.

Special Presentation on the Utilization of Expansive Concrete for Higher Cracking Resistance of Structure

On September 26, 2006, Dr. Sahamitmongkol held a seminar on "The Utilization of Expansive Concrete to Prevent Cracking in



Group photo of presenters, students and staffs of Structural Engineering after RNUS Seminar

National Institute of Public Health of Japan delivered the lecture: "Countermeasures for bio and chemical terrorism in buildings".

Finally Professor Kimiro Meguro of ICUS made concluding remarks and expressed gratitude to the participants.

(By R. Ooka)



Lecture by Dr. M. Itoh



Lecture by Dr. U Yanagi

Concrete Structures." The audience included undergraduate and graduate students of the Department of Civil Engineering and Technology, Sirindhorn International Institute of Technology.

RNUS Staff Served as Local Organizing Committee of EASEC-10

Dr. Kato and Dr. Sahamitmongkol were assigned by Prof. Worsak Kanok-Nukulchai as part of the local organizing committee of the 10th East Asia-Pacific Conference of Structural Engineering & Construction (EASEC-10).

Initiated 30 years ago, EASEC-10 is the biggest conference related to structural engineering and construction in the Asia-Pacific region. There were more than 700 presentations and more than 850 participants.

(By R. Sahamitmongkol)

RNUS Seminar

On August 9, 2006, RNUS organized a seminar on "Analysis and Treatment for Corrosion of Reinforced Concrete Structures."

A group of researchers from Kanazawa Institute of Technology led by Associate Professor Shinichi Miyazato and Associate Professor Mitsuharu Tokunaga kindly delivered lectures to AIT students and staffs.

The seminar was composed of four presentations, three were about the corrosion of reinforcement in concrete structures and one was about a three-dimensional



Dr. Kato gives a memorial gift to Dr. Shinichi Miyazato for his kind presentation

THEOS: An eye in the sky for development of Thailand

Since the introduction of remote sensing technology to Thailand in the early years of 1970's, the world has witnessed tremendous advance in both the technology itself and also the applications. As a developing country, Thailand has been following such development with great interest and has committed resources to tap on the benefit of this technology. In November 2000, a new public organization was set up by the Royal Thai Government (RTG) to engage in remote sensing and geographic information system. Geoinformatics and Space Technology Development Agency (GISTDA) is thus a specialized organization with the objectives of maximizing the benefit of 3S, namely, remote sensing, GIS and GPS for national development.

In July 2004, GISTDA signed the contract agreement with EADS Astrium of France in Bangkok to build and launch Thailand's first earth observation satellite: Thai Earth Observation System (THEOS). The project will take 30 months to complete at a cost of 128 million euros to the Thai Government. It is scheduled to be launched in the second half of 2007. Although this is a commercial undertaking, nevertheless, THEOS was initiated under the umbrella of the Thai-French Government Agreement on Space Technology Development. As such, several projects are being implemented to support the long term exploitation of space technology. For example, the training and hands-on experience of 20 Thai engineers at the company factory in Toulouse, France and a series of joint cooperative application are being implemented with satisfactory results.

THEOS is a sun synchronous, polar orbiting satellite with a designed life time of 5 years. The main characteristics are as follows.

Altitude	832 kilometers
Sensors	Panchromatic with 2.0 m resolution. Multispectral with 4 bands from blue to near IR and 15.0 m resolution
Swath	22 km for panchromatic 90 km for multispectral
Viewing	±35 degree with 3-5 day revisit
On board memory	50 GB
Weight	750 kg

Several countries have expressed their interest to access to THEOS within their footprints. Therefore, THEOS will not only contribute to the development of Thailand, but also to other regions of the world. The Thai government has also expressed its



THEOS spacecraft (image credit: EADS Astrium)

intention to offer THEOS data to the disaster mitigation efforts under the International Charter. It has always been the RTG's policy to abide by the Principles of the Exploitation of Outer Space for the benefit of mankind. Since admitted as a full member of the Committee on the Peaceful Users of Outer Space (COPUOS) in 2005, Thailand has been participating actively in two subcommittees (Scientific and Technical Subcom and Legal Subcom) as well as in the main COPUOS.

Besides applications in agriculture, land use planning, forestry and environmental assessment, etc. THEOS will be used in the integrated urban river basin management, urban flood disaster prevention and mitigation and urban sprawl planning.

> (By Dr. Suvit Vibulsresth Executive Board Member and Former Director, GISTDA)

Establishment of BNUS at BUET and it's Activities

A contract has been signed to establish the Bangladesh Network Office for Urban Safety (BNUS) at BUET, Bangladesh between Prof. Dr. Md. Mazharul Hoque, The Head, Department of Civil Engineering, BUET and Prof. Dr. Taketo Uemoto, The Director, International Center for Urban Safety Engineering, Institute of Industrial Science, the University of Tokyo in June 14, 2006. The main objective of this office will be to promote and enhance high quality cooperative research in areas related to urban safety.

BNUS office comprise of four rooms at the fifth floor of Civil Building, BUET. The current BNUS

members are Prof. Dr. Mehedi -Ahmed Ansary, Dr. Munaz Ahmed Noor, Ms. Israt Jahan, Mr. Md. -Yasin, Mr. Qumruzzaman and Mr. Qurban Ali. BUET has already provided a space for BNUS in its webpage.

The current and future activities will be as follows:

- Evaluation of concrete structures of Bangladesh (already done for BUET buildings in June 2006)
- School earthquake safety program (Launched in September 2006)
- Seismic evaluation of lifeline infrastructures
- Evacuation plans for different wards of Dhaka city

- Evaluation of concrete bridges and flyovers of Dhaka
- Development of indigenous instruments for reinforcement detection
- *Please visit BNUS website at http://www.buet.ac.bd/BNUS/*

(By M. A. Ansary Professor, BUET)



BNUS office at the 5th floor, Civil Building, BUET

Dr. Sanae Miyazaki joined ICUS

Dr. Miyazaki got her undergraduate degree from the Tokyo Institute of Technology (TIT) in 1988 and has worked for NTT DATA Corporation since then. She also got her Ph.D. degree from the TIT in 2000.

Dr. Miyazaki research interest is



in remote sensing technologies, especially satellite remote sensing and sensor network systems. Her recent research target is the data fusion analysis using various sensor data for disaster management.

(By T. Uomoto)

ICUS Director is the first visitor at Chula Unisearch IIS Branch Office

As agreed in the Memorandum of Understanding signed between Chulalongkorn University and the Institute of Industrial Science (IIS), the University of Tokyo, on March 21, 2006, the Chula Unisearch IIS Branch Office was officially opened at the beginning of July 2006.

On August 7, 2006, Prof. Taketo Uomoto, Director of ICUS became the first visitor of this IIS Branch office. On this occasion, Prof. Uomoto discussed with Associate Professor Boonchai Stitmannaithum, Associate Dean of the School of Engineering, the possibility of collaborative research activities between ICUS and the Faculty of Engineering, Chulalongkorn University.

Located in the central Bangkok, this branch office of IIS will serve as an easy-to-access business center for IIS professors who visit Bangkok for their research activities. The communication

- Prof. Uomoto attended the 10th East Asia-Pacific Conference on Structural Engineering and Construction held in Bangkok, Thailand, during Aug. 2-8 together with Dr. Kanada. Prof. Uomoto also joined Shotcrete for Underground Support X held in Vancouver, Canada, from Sept. 11 to 17.
- Prof. Meguro attended the 1st European Conference on Earthquake Engineering and Seismology in Geneva, Switzerland from Sept. 3 to 7. Dr. Mayorca joined the same conference from Sept. 3 to 8. Prof. Meguro took part in a Center Of Excellence action study workshop carried out at Istanbul, Turkey during Sept. 10-18. Dr. Yoshimura also participated in this workshop from Sept. 9 to 20.
- Dr. Oki participated in the observation at Beijing Site in Beijing, China from Jul. 30 to Aug. 3. He joined The United Nations-Sigma Xi Scientific Expert
- Mr. Ramesh Guragain from Meguro Laboratory obtained the Furuichi Award on September 29 for his excellent Master Degree Thesis entitled "Numerical Simulation of Masonry Structures under Cyclic Loading using

ICUS Activities

- Group on Climate and Sustainable Development/World Water Week held at Washington DC, USA and Stockholm, Sweden. He attended the IPCC WGILL Meeting held at Cape Town, South Africa from Sept. 8 to 16.
- Visiting Professor Reiko Amano attended the 12th International Symposium on Aerodynamics and Ventilation Vehicle Tunnels in Portoroz, Slovenia from July 11 to13.
- Dr. Kato stayed at AIT for his research work and teaching duties at RNUS during Aug. 1-18 and Sept. 3-Oct. 5.
- Dr. Kanada attended the 6th International Symposium on Nondestructive Testing in Civil Engineering held at St. Louis, US from Aug. 13 to 20.
- Dr. Sahamitmongkol stayed at AIT for his research work and teaching duties at RNUS during July 12-Aug.16, Aug.20-Sept.14, and Sept.19-Dec.13.

Awards

- Applied Element Method."
- Dr. Kanada and Mr. Pakawat Sancharoen from Uomoto Laboratory got the Incentive Award for Excellent Paper at the 2006 Annual Meeting of the Japan Concrete Institute for their

facilities (internet and local telephone) as well as other office supplies are well prepared for the visiting IIS professors.

(By R. Sahamitmongkol)



ICUS visitors and Dr. Stitmannaithum at Chula Unisearch IIS Branch Office

- ICUS Seminar was held at Kawaguchi-ko during July 14-15.
- The RC-39 Committee met on July 25. After the meeting Prof. Ura delivered a speech on "Autonomous Underwater Robot for Observation-From Kamaishi Bay breakwater offshore to Myojin reef caldera."
- Prof. H. Wiggenhauser, Director of the Federal Institute for Materials Research and Testing, Germany, visited ICUS on July 30
- A delegation of 18 professors from the National Kaohsiung First University of Science and Technology of Taiwan led by Prof. Tai-Ping Chang, visited ICUS on Aug. 15.
- Former Visiting Prof. S. Hayashi was appointed President of the Japan Foundation for Regional Art-Activities on Sept. 1.
- ICUS Open Lecture was held on Sept. 25.

papers "Componential Analysis by Portable Fluorescence X-ray Analyzer" and "Life Cycle Repairing Cost Considering Uncertainties of Deterioration Prediction Model," respectively.

Editor's Note

The existence of the global warming problem has been confirmed by recent research results, even though some researchers still doubt about it. It is expected that natural disasters such as flood and typhoon will become more and more frequent and hazardous in the future. The reduction of CO, emission is urgent for prevention of global warming. However, it is not readily progressing. Energy and drug consumption are similar in the sense that human beings become addicted to them and cannot easily get rid of a living style based on them once they get accustom to it.

Currently, some holy human lives are taken by the struggle for energy.

The necessity of paradigm shift from a life of quantity to a life of quality has been recognized for more than 20 years. Unfortunately, this shift is not moving ahead because people do not have a concrete image of their future quality of life and thus no consensus has been reached among them. As a result, the global warming problem is not been addressed.

Incidentally, ICUS women staffs further increased with the arrival of Dr. Miyazaki. Currently six ladies belong to ICUS: one Professor, two Associate Professors, two Research Associates, and one Secretary. They are very active in their fields as evidenced in the main article of this newsletter which was written by one of them: Dr. Reiko Kuwano. Men have been the main contributors to material civilization up to the present. However, they have not paid much attention to the quality of life. I believe that women ideas and senses will be greatly useful to shift from a life of quantity to a life of quality in the future. Therefore, I am looking forward to the continuation of the active participation of ICUS women staffs.

(By R. Ooka)

If you would like to contribute an article to ICUS newsletter or have any comment or suggestion, please contact the editorial committee at icus@iis.u-tokyo.ac.jp.

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International Center for Urban Safety Engineering, ICUS Institute of Industrial Science, The University of Tokyo 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan Tel: (+81-3)5452-6472, Fax: (+81-3)5452-6476 E-mail: icus@iis.u-tokyo.ac.jp http://icus.iis.u-tokyo.ac.jp/

