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ASSESSING SEISMIC RISK OF ULAAN BAATAR BY AEROSPACE METHODS

Enkhjargal Dalaibaatar
Faculty of Earth Science
National University of Mongolia
P. O. Box 482/46A
ULAAN BAATAR
Tel.: 976-11-310399
Fax: 976-11-320159
E-mail: enkhee_jal@yahoo.com
MONGOLIA

Paul Hofstee
ITC
P. O. Box 6
7500 AA Enschede
Tel.: 31-53-4874237
Fax: 31-53-4874400
E-mail: hofstee@itc.nl
THE NETHERLANDS

John L. van Genderen
ITC
P. O. Box 6
7500 AA Enschede
Tel.: 31-53-4874254
Fax: 31-53-4874466
E-mail: genderen@itc.nl
THE NETHERLANDS

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ABSTRACT

This paper describes the remote sensing methodology being developed for the operational assessment of the seismic risk in the capital city of Mongolia: Ulaan Baatar. The first step was to acquire the relevant satellite and airborne remote sensing data. There are three aspects to this project, namely, the geological, geomorphological and urban issues. This paper deals mainly with the urban aspects. For an area of two hundred kilometres around Ulaan Baatar, Landsat TM data was acquired to study the active faults around the city and the geomorphologists use it to study the vertical displacements. Also, complete ERS radar data of the project area was acquired. For the urban area, a ten-metre resolution SPOT Panchromatic image was obtained, as well as complete air photo coverage of the city. Using this data, coupled with ancillary data sets such as large scale topographic maps, field work, interviewing, etc. an up-to-date urban land use map of the entire city area was produced. This detailed land use map derived from the remote sensing data, included categories of buildings relating to their height, age, structure, usage, etc. By combining this with a Digital Elevation Model, the high risk areas on steep slopes could be determined.

Much of the effort in disaster management is on the policy and social side. However, decision makers must be supplied with up to date, reliable and interpreted information on the nature and geographical distribution of hazard and risk and the possible earthquake risk scenarios.

Remote sensing is ideally suited to make a rapid inventory of such elements at risks in urban areas. By using the combined information of hazard and vulnerability, one can arrive at the quantitative earthquake risk analysis of Ulaan Baatar.

INTRODUCTION:

Mongolia often experiences earthquakes as a result of the collision of the Indian-Australian plate with the Eurasian plate, as well as because of the extension of the tectonic structure associated with the Baykal rift system (Woldai and Bayasgalan, 1998; Bayasgalan, 1999). As a result, numerous faults have developed, and several new ones are emerging near the city of Ulaan Baatar, causing a serious threat to its development. Due to its site conditions, and being the political economic and population center of the country, the city is exposed to a high earthquake risk.

The project "Estimating the impact of seismic damage to Ulaan Baatar City by Aerospace Methods" is being carried out be ITC of the Netherlands, together with various partners in Mongolia such as the Faculty of Earth Science, National University of Mongolia, Department of Geology of the Technical University of Mongolia, and the Earthquake Engineering Department of the Agency for Construction, Urban Development and Public Services, the coordinating Mongolian Agency for earthquake disaster reduction activities (Dalaibaatar et al., 2001). Over the past 100 years, Mongolia has experienced four major earthquakes of a magnitude above 8 on the Richter Scale, as well as numerous moderate earthquakes. Although Ulaan Baatar is considered to be located in a seismically stable area, several lineaments have been recognized by high resolution satellite images within 200 km of the city. From 1:32.000 aerial photographs, several active and possibly active faults were identified and confirmed in the field.

Ulaan Baatar is not only the capital of the country that houses the central government agencies and the Parliament but also the economic heart of the nation as far as its non-firm economy is concerned. While 20% of the population is nomadic, the city of Ulaan Baatar contains more than a quarter of the national population of 2.4 million and generates close to 60% of the gross national products. The city is also built on the fluvial sediments of

Tuula River due to which ground motions could be amplified in the event of an earthquake. Hence, it would be prudent to assess the earthquake vulnerability of the city and take preventive and mitigation measures in time (Davidson, 1997; RADIUS, 2000).
Figure 1 shows the location of the project area.

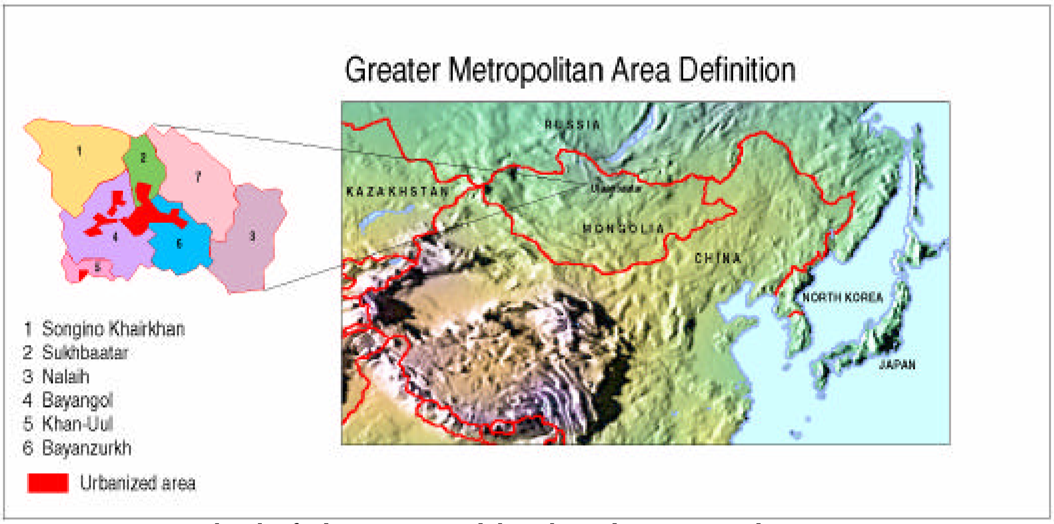

Figure 1: Location sketch of Ulaan Baatar and the urban administrative districts.

BACKGROUND

The government has taken a number of measurements towards making Ulaan Baatar a safer place to live. The establishment of the Department of Earthquake (DOE) in the Architectural and Construction Agency of the Ministry of Infrastructure Development (MOI) has been a noteworthy addition to the array of specialized technical institutions already on seismic hazard for Ulaan Baatar under the aegis of the Research Centre of Astrophysics and Geophysics (RCAG, Mongolian Academy of Science) in collaboration with the Laboratoire de Dètection et de Gèophysique (LDG) of France, should be able to provide valuable information for developing engineering code of practice. In addition, the Information Centre of Mongolian Academy of Science has a Geo-informatics Division that has been doing research in fault behaviors and the identification of new faults using remote sensing airborne and satellite imageries.
Based on the above background the priority needs of the country in earthquake disaster preparedness, particularly in Ulaan Baatar, fall under the following four broad areas:

1. Developing an earthquake disaster preparedness strategy not only in terms of final outputs (safe buildings, rescue and relief organizations, etc.) but also identifying critical steps required and the institutions involved in implementing it (Armillas, 1989).
2. Enhancing co-ordination among various agencies and private sector in identifying and prioritizing needs and promoting sharing of knowledge.
3. Assisting DOE to play its critical role in influencing a safer development of Ulaan Baatar by being an effective provider of information and guidelines that meet the current needs of public agencies as well as private builders, and a proactive player in undertaking risk assessments.
4. Raising public support to earthquake disaster preparedness by providing reliable information on the likelihood of the impact and the response strategy, and calling for support in the implementation of the strategy through citizen groups performing as watch dogs and awareness builders. The U. N. Habitat office has recently carried out a desk study to evaluate Ulaan Baatar's seismic disaster preparedness (Anon., 2000).

OBJECTIVES

The specific research objectives can be grouped into three sections:

1. **Geological:** Here the first objective is to systematically map all active faults in a radius of 200 kilometres around the city of Ulaan Baatar using Landsat TM data (4 images). The older (and therefore much cheaper) TM images can be used for this purpose. Secondly, a database (GIS of all such active faults and related

geological and seismic data) will be established, to provide a significant input for making seismic hazards assessments. joint field research will be carried out to verify the remote sensing results.

2. **Geomorphological:** Geomorphological field work will measure the scarps, zones of fresh outcrops in bedrock eroded terraces, etc. to determine amplitude of the vertical displacements along the lineaments and faults measured and mapped by the geological researchers. Many of the faults result in clear geomorphological evidence of Late Quaternary and possible Holocene faulting. The geomorphology researchers will prepare the seismic hazard maps of the area. These will form an input for the assessment of the potential damage to urban buildings in the city, and to other infrastructure (roads, bridges, blocked rivers, etc.).
3. **Urban research:** The first objective will be to make an up to date and detailed land use map of Ulaan Baatar. This will in first instance be done using the most recent stereo airphotos of the city. Subsequently it is planned to update this using stereo IKONOS high resolution satellite data. On the basis of this detailed urban land use map, the hazard factor for each of the building types will be calculated.

The overall objectives of the project are:

1. Undertaking an earthquake risk assessment of Ulaan Baatar (which includes earthquake hazard assessment, assessment of the vulnerability of the city and the impact in the event of a probable earthquake). The assessment is being carried out using Landsat TM, ERS 1/2 SAR Data, SPOT imagery aerial photographs and fieldwork.
2. Reviewing the draft seismic code to make it more user friendly and of immediate use either by introducing guidelines for non-engineered build or by adapting codes from other cities in similar situation and development level.
3. Making a detailed urban land use map from the remote sensing data in order to identify critical structures and lifelines that need be protected in the event of an earthquake, as a way of sensitising respective owners of such facilities towards taking preventive measures.

METHODOLOGY

After acquiring the necessary satellite imagery, as well as all related existing, urban, geological, seismic and other published reports/data on the area, the geological researchers from both sides will research into the tectonic setting of the area. Together with the geomorphologists, they will make the seismic hazard assessment (SHA). In the meantime, the urban specialists will make the detailed, up-to-date urban land use map of the city. The following section explains the rationale of this methodology:

The assessment of seismic hazard depends upon our understanding of how earthquakes are generated and distributed and how they recur in space and time. Three approaches are commonly used in probabilistic seismic hazard assessment (SHA) at regional scale. The *historical* method attempts to reproduce the patterns of historical seismicity (location in space and time, frequency-size distribution) by a statistical model of the seismogenic sources. For a country like Mongolia with a lack of historical records on large earthquakes this method is not much use. The seismotectonic approach incorporates geological and geophysical evidence to supplement the historical record of seismicity. The fundamental level uses comparable tectonics activity over which all available information can be averaged. More advanced approaches incorporate fault locations and rates, by gauging crustal deformation through geomorphology and space geodesy, and average recurrence intervals by analyzing records of individual paleoearthquakes. The time-dependent approach utilizes non-poissonian statistics to incorporate the memory of past events in the probabilistic scheme, so that fault zones that ruptured in recent large earthquakes become less hazardous than others that did not rupture in recent history.

During the past few years, the availability of records of individual paleoearthquakes and reliable indicators of the long-term activity of large active faults has provided key input to extend the historical record to cover recurrence times of 100 to 100000 years. These accomplishments (made possible by the results of new disciplines such as paleoseismology, geomorphology, geochronology, remote sensing and space geodesy) resulted in substantial improvements in the identification of seismic source regions adopted in traditional seismotectonic SHA.

An active fault of interest for SHA is a structure that has an established record of activity in late Pleistocene (i. e. in the past 125 ka) and a demonstrable or inferable capability of generating major earthquakes.

From the length and amplitude of displacements the size of possible events which could produced ruptures can be infered. The most commonly used parameter in estimating maximum earthquake magnitude is defined by the relationship:

M_o=ìAD, where M_o is the earthquake moment, ì is the shear modulues (~$3\text{x}10^{10}$N m²). A is the rupture area, and D is the average slip. Since ì is usually treated as a constant, and the average slip, D, is limited to values of few metres, the rupture area, A, is the dominant variable in influencing M_o. Furthermore, since fault depth is constrained by the thickness of the seismogenic crust and is not grossly different from one region to another, the area of rupture is primarily a function of *length* of rupture.

Thus, for example the Deren fault, close to Ulaan Baatar, with an average displacement of 2m, length of 40 km and seismogenic thickness of 20 km the earthquake moment can be calculated:

$M_o=3x10^{10}\ x\ 40km\ x\ 20km\ x\ 2m=48x10^{18}\ N\ m$. Thus a moment magnitude, which is $M_w=2/3log_{10}M_o\ -6.0$, can be calculated as 7.1 on the Richter Scale.

Similarly, moment magnitudes for all faults around Ulaan Baatar city will be derived and then used for the urban damage assessment, also using differential InSAR techniques from the ERS 1/2 SAR data (Genderen et al., 2000).

The new tools of paleoseismology and concepts of fault in active fault studies are especially important in assessing seismic hazard. Paleoseismology is a study of the age, frequency, and size of prehistoric earthquakes. It provides a means to expand the limited view of earthquakes offered by the historical and instrumental record and helps us understand the long-term behavior of seismogenic faults, to identify variations in the spatial and temporal distribution of earthquakes, and to detect patterns of long-term and regional seismicity. When combined with the interpretation of satellite imagery in terms of geomorphology, it can be very useful for estimating urban damage for earthquakes at various intensities. Such a quantitative methodology as proposed, is crucial for the totally unprepared city of Ulaan Baatar.

DISCUSSION

Contributing most to Ulaan Baatar's seismic hazard factor is its collateral hazard potential. This is mainly due to the high percentage of wooden buildings in the city, which form major fire hazard after an earthquake.

Also of considerable importance is the city's ground shaking potential, with a relatively large percentage of urbanized area with soft soil. The city is built on the fluvial sediments of the Tuula River, due to which ground motions would be amplified in the event of an earthquake.

Figure 2 is a Landsat TM image of part of the city of Ulaan Baatar (Landsat TM Bands 4,5,2, acquired 10 Septmeber 1990, 131(027). This shows the city along the Tuula River, and the urban expansion taking place up ever increasing slopes on the north side of the river.

The population of Ulaan Baatar will grow more rapidly then before as the economy is monetised and the service sector takes hold of the economy.

The cost of living in general and the price of housing in particular have been rising because of the removal of various public subsidies, among other things. This trend coupled with the time required to adjust to a dynamic market process will have the effect of forcing sizeable population to live in either dilapidated houses or "squat" in areas of the city that are vulnerable to the effects of the natural disasters like earthquake.

Using remote sensing data, a seismic risk assessment of the city is being prepared, to assist the State Civil Defense Committee in preparing their earthquake disaster preparedness plan for the city.

The oral presentation will include examples of the various satellite and airborne remote sensing data used, results of the land use classification, due to the limitation of six pages for the proceedings.

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Figure 2: Landsat TM sub-image of part of Ulaan Baatar (Bands 4,5,2)