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STATE-OF-THE-ART IN SPATIAL INFORMATION FOR DISASTER MANAGEMENT

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** Prepared by Mr. John C. Trinder, First Vice President of the ISPRS and Mr. Orhan Altan, Secretary General of the ISPRS.

STATE-OF-THE-ART IN SPATIAL INFORMATION FOR DISASTER MANAGEMENT

John Trinder
First Vice President ISPRS
School of Surveying and SIS
University of NSW
UNSW Sydney 2052 NSW
Australia
j.trinder@unsw.edu.au

and

Orhan ALTAN
Secretary General ISPRS
Istanbul Technical University
Division of Photogrammetry
34469 Ayazaga-Istanbul/Turkey
oaltan@itu.edu.tr

ABSTRACT

With the passing of each day, catastrophe risk for urban regions of the world, particular earthquakes, is increasing. Recent events in Northridge USA (1994), Kobe Japan (1995) Marmara Sea Turkey (1999) and more recently in Sumatra (2004) and Yogyakarta, Indonesia in 2006 are typical examples of what can happen when a major earthquake strikes directly under a densely populated area. Massive human casualties and loss of resources have occurred as a result of the tsunami in South-East Asia. Mega cities created by the rapid urbanization and development in unsafe areas have led to far greater losses than have been experienced in the past. Rapid response in gaining reliable and quick data in these cases is most important for aid management. Following an earthquake the repair of destroyed buildings is a major task. The main difficulties in providing the essential data in the past was caused by the great variety of unstructured information that had to be presented for further analysis. As well, documentation of damage was not detailed and could only be carried out at the site of a disaster. This paper aims to demonstrate the role photogrammetry, remote sensing and spatial information sciences in disaster management, and to underline the role of international collaboration in this task.

INTRODUCTION

Each year disasters, such as storms, floods, volcanoes, and earthquakes, cause thousands of deaths and tremendous damage to property around the world, displacing tens of thousands of people from their homes and destroying their livelihood. Many of these deaths and losses could be prevented with better information on the onset and consequences of such disasters. Examples of these catastrophes are earthquakes, and recent events in Northridge USA (1994), Kobe Japan (1995) Marmara Sea Turkey (1999) and more recently in Sumatra (2004) and Yogyakarta Indonesia in 2006 are typical examples of what can happen when a major earthquake strikes directly under a densely populated area. One of the aims of this paper is to present a different approach in the monitoring, documentation and analyzing the damage to buildings after an earthquake. As well, there are international efforts to combine and integrate all available data obtained during and after disasters. International cooperation has led to the newly established entity called as DMISCO (Disaster Management International Space Coordination), which will be explained in this paper.

SPATIAL DATA FOR THE EARTHQUAKE MONITORING AND ASSESSMENT

Earthquake prediction by existing ground based facilities are unreliable and the recent earthquakes in recent years (Iran, Morocco, Turkey) point to the need for scientific progress in solving this problem and in employing additional evidence for earthquake prediction. Geodetic science plays an important role in the earthquake research (Aksoy 1995). By means of long-term measurements, deformations caused by deformations in the Earth's crust caused by the movement of tectonic plates can be examined. One of the goals of geodetic measurements is for early warning of earthquakes due to crustal deformation. In recent years the use of GPS measurements gives a better possibility for detecting these movements. In a recent study, Murai at al (2005) used data from GPS stations from IGS home page to study the daily change ratio and sudden changes of signs over triangular networks. They found that the likelihood of the big Sumatra earthquake could have been detected and predicted from this data. The evidence of the likelihood of the earthquake was found in the daily change ratio of the triangular area (Singapore-Lhasa–Kunming) in the YZ plane on the 18th of December, 8 days before the earthquake and on the (Indonesia- Singapore-Lhasa) in XZ plane on the 21st and 23rd of December, 2 and 5 days respectively before the earthquake. This investigation seems to show some promise for earthquake prediction.

(Sergey at al 2003) have recently proposed the concept of a geo-space system for prediction and monitoring earthquakes and other natural catastrophes, which is based on a system of monitoring the ionosphere and magnetosphere of the Earth and using these as indicators for short-term forecasting of earthquakes. The process involves the investigation of the interaction between ionosphere's F layer variations and different variations occurring in circum-terrestrial environment (atmosphere, ionosphere and magnetosphere) associated with seismic activity, and detected by means of ground base and satellite monitoring. It is claimed that the data leads to information on existing phenomena and the procedures offer a possibility for their practical utilization in systems for warning earthquakes.

Photogrammetry, remote sensing and spatial information system techniques are important tools for studying the impact of earthquakes. Photogrammetric data acquisition can be achieved by aerial or terrestrial means. Each method has its advantages according to the circumstances. Aerial images can provide a rapid overview of the impact of an earthquake, while terrestrial measurements can provide more detailed information of individual buildings as described later in this paper. The emergence of the new generation of digital aerial cameras with ground sampling distances as small as 5cm has led to new approaches in acquiring multiple overlapping images which lead to high accuracy and more reliable information extract with high efficiency. As well, with the acquisition of high resolution multi-spectral images from these cameras, automatic extraction of thematic information from images required for digital mapping and GIS data collection should be more easily achievable. Mobile mapping systems, based on vehicles equipped with GPS navigation and an inertial measuring unit (IMU) for real-time determination of location and attitude, multiple digital cameras and computing capability for on-board processing, may be used for rapid surveys of damaged buildings, provided the road systems are accessible. Laboratory processing of the images will enable detailed assessment of the status of buildings.

With the availability of high resolution remote sensing satellites with resolutions of 1m or better, space technologies can provide important data giving an overview of the impact of earthquake damage, especially if there is significant damage to transport facilities that limit or prohibit access to the area. In December 2004, images provided by the high resolution satellites were some of the first information available to the world of the massive damage caused by the earthquake and the subsequent tsunami in Banda Aceh, Indonesia. Noting the capabilities of space technologies for providing assistance in times of disasters, the UN Office of Outer Space Affairs included in the report of the Committee on the Peaceful Uses of Outer Space on its five-year review of the implementation of the recommendations of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), which was submitted to the General Assembly at its 59th session, the implement of an international space coordination body for disaster management (now referred to as DMISCO). At that session the General Assembly agreed:

"that a study should be conducted on the possibility of creating an international entity to provide for coordination and the means of realistically optimizing the effectiveness of space-based services for use in disaster management and that the study should be prepared by an ad hoc expert group, with experts to be provided by interested Member States and relevant international organizations."

It is expected that the resources for the core of the work for the establishment of DMISCO will be undertaken at the United Nations Vienna office (3 staff), with contributions in cash from Member States (for facilities, operational costs and staff), together with in-kind contribution (such as facilities provided by a hosting Member State) and secondments of experts. Additionally, funds will be needed to support the implementation of projects identified in conjunction with National Focal Points (NFPs) and will be defined and secured on a case-by-case basis. It is expected that DMISCO will be operational from 1st January 2007, and hopefully it contribute to considerably reducing the impacts of future disasters.

Importance of Digital Archives and Space Data

The importance of digital archives is a well know aspect of preservation of cultural heritage. The same need applies to disaster management. With the vast experience gained through operational use of space data, the concept of a space based observation and communication system for disaster management is evolving in different applications. The most important need is to assess the overall requirements of users at various levels and the delivery mechanisms that could effectively provide the services for monitoring, forecasting, warning, assessment, prediction and reduction of natural disasters. The information required by disaster managers in each of the critical phases of disaster management, which includes mitigation and preparedness, response and recovery/relief, consist of:

(i) database design
(ii) near real time monitoring/ mapping
(iii) modelling framework
(iv) networking solutions
(v) multi-agency interface.

The success of disaster management largely depends on availability, dissemination and effective use of information. The information needs to include current information on weather, infrastructure (roads, hospital, administration boundaries), demography etc. to assess the disasters. Currently such data are being generated by multiple users and stored in multiple formats and media, making it difficult to bring the data together to support disaster management activities. In addition, there is a need to assess the disaster in terms of location, extend and likely impact, so as to plan relief and recovery actions. An integrated system adequately equipped with necessary infrastructure and expertise to constantly monitor the risk profiles on all possible disasters, and maintain a national database, will become relevant. In this context, GIS technique offers a tool to analyse multiple layers.

Taking into account the above aspects, a pilot study was carried out by Indian Space Research Organisation in 1998-2001, to design a prototype system that will integrate space inputs with conventional data. The study area selected was the Brahmaputra floods in Assam. The system consisted of comprehensive database design, space-based near real-time monitoring tools, modelling framework, networking and user interface. With appropriate synthesis of these core elements, flood monitoring and damage assessment was carried out. Through the use of networking, the space-based inputs were disseminated to the users. The study has led to a realistic assessment of the gaps in the current system and conceptual framework for disaster management system.

Earth observation satellites have demonstrated their utility in providing data for a wide range of applications in disaster management. Pre-disaster uses include: risk analysis and mapping; disaster warning, such as cyclone tracking, drought monitoring, the extent of damage due to volcanic eruptions, oil spills, forest fires and the spread of desertification; and disaster assessment, including flood monitoring and assessment, estimation of crop and forestry damages, and monitoring of land use/change in the aftermath of disasters. Remotely sensed data also provide a historical database from which hazard maps can be compiled, indicating which areas are potentially vulnerable. Information from satellites is often combined with other relevant data in geographic information systems (GIS) in order to carry out risk analysis and assessment. GIS can be used to model various hazard and risk scenarios for the planning the future development of an area (UN 2004) as demonstrated by the following:

- Disasters such as floods, earthquakes, forest fires, oil spills, drought and volcanic eruptions affect large parts of the globe and coordinated international efforts are required to minimize their impacts. Disaster relief requires timely and updated geo-social databases and situational analysis for the various phases of the disaster.
- Space technology such as remote sensing and meteorological satellites, as well as communications and navigation and positioning systems, can play a vital role in supporting disaster management by providing accurate and timely information and communication support.
- The utilization of space assets in support of disaster management continues to lag significantly in most parts of the globe and remain as a major challenge; however, there are several international efforts aiming to address the developmental needs and achieve effective utilization of space technology.
- A considerable gap, however, exists and is likely to remain in all areas of space technology applications for disaster management, including technical, operational, education/training, and organizational areas, unless a global, integrated, coordinated approach is taken. In virtually all countries, there is a lack of understanding of the benefits of the use of space technologies to support risk reduction and disaster management activities, especially by the disaster managers and civil protection agencies.

Earthquake Damage Assessment by Photogrammetry

The following gives an example of the application of photogrammetry for assessing damage following an earthwuake. Terrestrial photogrammetric methods were used for the first time to document the damage after an earthquake in Friaul, Italy (Foramitti 1980) and also after the Kobe earthquake (Kiremidjian 1995). The studies showed that spatial information systems are essential tools in the earthquake research. The evaluation of earthquake damage based on expert systems using evaluation tables has also been under investigation (Tazir et al 1989). Photogrammetry is an efficient tool in monitoring the location, form and shape of spatial objects. Its main advantage is that measurements are done on images indirectly, thus opening the possibility for a wide range of applications. The recorded images contain a great deal of information and hence detailed information of damage to buildings can be determined from them. To establish the deformation of a building from its complex details, three-dimensional coordinates of characteristic points on the building must be known. These points must be recorded on at least two overlapping images. With known camera calibration and position parameters (interior orientation parameters), the unknown 3D-object coordinates (XYZ) can be computed from measured the image coordinates of object points (in this case of the building), by an adjustment procedure referred to as 'bundle adjustment'. The erroneous measurements will be eliminated as part of the adjustment process and hence precise measurements of the object points will result. In order to relate the determined XYZ coordinates to an overall coordinate system, control points with known coordinates are used. With the help of imaging with modern digital cameras, automation of data processing by means of image analysis techniques are available. Therefore, techniques such as 3D-object reconstruction, semi-automatic or automatic object detection and classification, and integration of the information into deformation analysis procedures can be used.

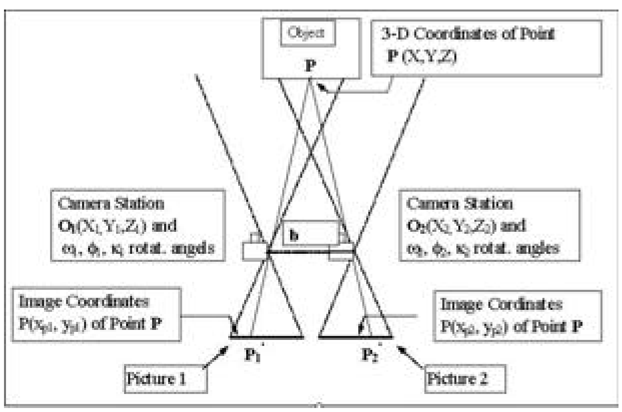

Figure 1. General case photogrammetric data acquisition

Determining Damage to Buildings

For the 3D shape of buildings to be reconstructed, it is necessary to determine the deformation of a building as a whole, based on determined coordinates of characteristic points of the building. As the damaged buildings are a potential danger for the investigators and other persons in the region, the first determination must be based on the points on the facade of the building.

Since no prior measurements of damaged buildings are usually available to relate the deformed values to, the following method can be used. At least two plumb lines hanging on the facade of the building define a vertical plane. Based on the assumptions that the lowest points of the building are stable, and the facade is built vertically in most cases, all deviations from the vertical plane can be related to a coordinate system defined for the specific case (Külür 1998).

The approach provides for quick documentation. Research using a KODAK (DCS 200) digital camera allowed the images of the high school building shown in Figure 2, to be loaded directly onto the laptop computer on site and immediately processing them in near real-time. Processing and evaluation of the images was done with a photogrammetric software package PICTRAN (Schewe 1995). The results were a grid of coordinates based on the characteristic points defining the movement of the building. These characteristic points were on the 11 different axes of the building, which include points on the top storey (4 points in this case).

Figure 2. Digital photo in Dinar, Turkey, of the damaged schoolhouse and plumb lines used as scale information

From these coordinates displacement values between corresponding points, numbered i and i-1, were calculated according to the following formulas:

$$\text{Relative Height Differences: } H_i(i) = Z(i) - Z(i-1)$$
$$\text{Absolute Depth Differences: } D_a(i) = Y(i) - Y(1)$$
$$\text{Relative Depth Differences: } D_r(i) = Y(i) - Y(i-1) \qquad (1)$$

The relative displacement in one direction of two overlaying storeys is calculated from their displacement values as;

$$\Delta_i = d_i - d_{i-1} \qquad (2)$$

where d_i and d_{i-1} are the displacements of a column in i^{th} and $i\text{-}1^{th}$. storeys.

If we denote the height of these two adjacent storeys as h_i, then the relative displacements of the point in question must be compared with two maximum values calculated as;

$$(\Delta_i)_{max} / h_i \leq 0.0035$$
$$(\Delta_i)_{max} / h_i \leq 0.02 / R \qquad (3)$$

Here the coefficient R is the load reduction factor of the building with respect to the structural system and natural response coefficient of the building.

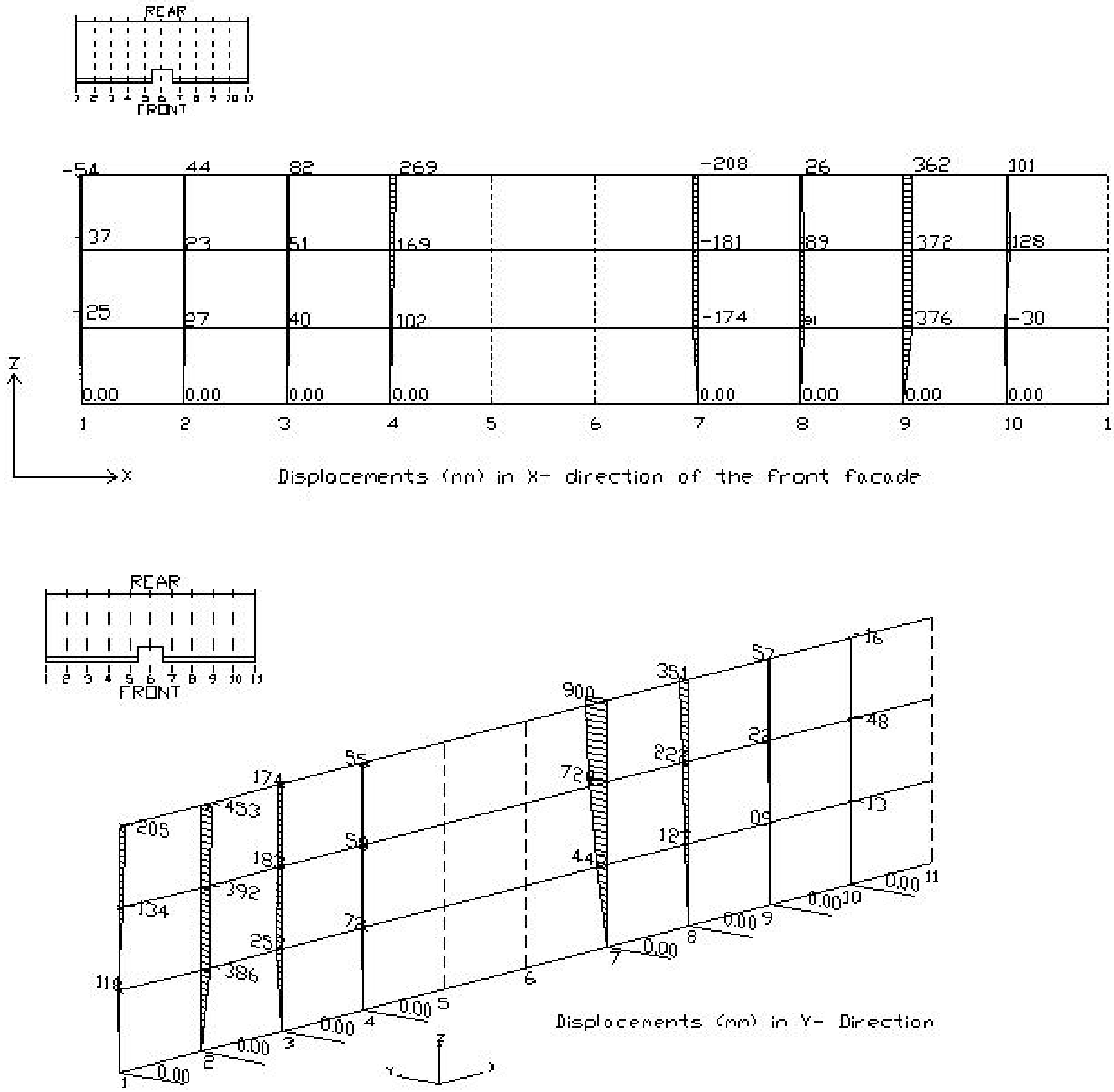

Figure 3. Deviations from the vertical plane

Linking Photogrammetry and Spatial Information Systems

The information acquired on the geometric deformations from the photogrammetric measurements must be analysed, leading to appropriate conclusions, eg. evaluation of the stability of the building, or decisions as to whether it can be rebuilt or demolished. Such decisions depend on many factors. A detailed data model has been established, including the structural and damage related aspects of several building types (Volz 1998), and implemented in the GIS software ArcView. Using the programming language Avenue, some of the analysis procedures could be automated, e.g. the determination of damage degrees, to accelerate the analysis considerably.

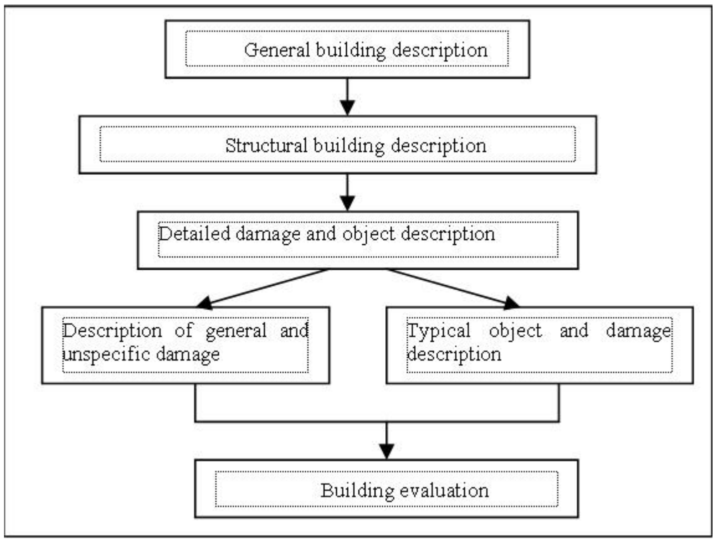

Figure 4. The object levels of data model according to the object class principle

Analysis of Damage in a GIS

Starting with the sample data, the first issue was to design a concept for the automatic damage analysis and assessment. This was done for the construction element "reinforced concrete column". Basically the damage analysis must start from the lowest object level, as the damage of an upper level element has to be calculated from the sum of other levels, at first. A single crack can be described by many parameters, such as, length, width, trajectory, position etc. According to these parameter values, the crack influences the assessment of level of damage of the specific element. For the complete assessment of one element, other damage indicators must also be considered. In the case of a column, besides the investigation of the cracks, the deflection of the column from vertical line, the visibility of the steel reinforcement or the falling off the concrete mantle should be investigated. The level of damage of a column can be assessed after considering these parameters. Finally, after the completion of the assessment of the grades of damage of all construction elements (e.g. "Without damage", "slight damage", "middle damage" and "strong damage") the total damage grade of a building can be calculated as shown in Figure 4. This procedure reflects the basic idea of the damage determination used in earthquake analysis.

CONCLUSIONS

The paper has described the sources of spatial data that are available for monitoring and assessing the effects of earthquakes. The data ranges from physical measurements on the ground and the ionosphere and magnetosphere of the Earth as a means to attempt to predict earthquakes, to photogrammetric and satellite data available for assessing the impact and damage caused by earthquakes. The importance of the archival of sources of spatial data for is demonstrated by potential applications of such data for disaster assessment. As a result of the demonstrated capabilities of space based data for disaster monitoring and assessment, the implementation of DMISCO will provide an international coordination body for future assistance to countries affected by disasters.

The documentation and analysis method of damage assessment explained in this paper reflect preliminary evaluations of a short term study. The main problem for further investigation is the acquisition of detailed object geometry by photogrammetric methods. In order to accelerate this procedure there exist appropriate tools. The completion of photogrammetric acquisition could lead to automatic object extraction so that the digitization effort can be minimized.

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References

Aksoy A. 1995 Kurzer Überblick über die Vermessungsarbeiten in der Türkei, Neue Technologien in der Geodäsie (Altan and Lucius - Eds.), pp1-10, Istanbul.

Foramitti H. 1980 Erdbebeneinsatz der terrestischen Photogrammetrie in Friaul, ISPRS XIV Congress, Comm. V, Vol. XXIII, part B5, pp 191-299.

Kiremidjian A.S., King S. 1995. An integrated earthquake damage and loss methodology through GIS, VII. International Conference on Soil Dynamics and Earth-quake Engineering (SDEE 95), p. 664, (UB: 4B 1252), Boston.

Külür S., 1998 Kalibrierung und Genauigkeitsuntersuchung eines digitalen Bildaufnahmesystems, PFG.

Murai S., Araki H., 2005 Was Early Warning of Sumatra Earthquake Possible? Coordinates magazine, July 2005, p8-11

Schewe H., 1995, A PC-Based System for Digital Close-Range Photogrammetry, Proceedings of the First Turkish - German Joint Geodetic Days, (Eds: Altan-Gründig), Istanbul, p. 255-261.

Sergey P., Kirill B. 2003: Ionospheric Precursors of Earthquakes, Springer Verlag

Tazir T. Z. H., Gavarini C. 1989. AMEDEUS, A KBS for the Assessment of Earthquake Damaged Buildings, Report of the IABSE Colloquium on Expert Systems in Civil Engineering, pp 141-150, Bergamo.

UN Office or Outer Space Affairs, 2004, Final Report of the Action Team on Disaster Management, Document A/AC.105/C.1/L.273, 23 December 2004

Volz S., 1998 Versuch zur Optimierung der Dokumentation und Analyse von Erdbeben-schäden und Gebäuden mittels eines Geo-Informationssystems am Fallbeispiel der Stadt Dinar/Türkei, Diploma Thesis, Univ. Stuttgart.