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SEISMIC SYSTEM IDENTIFICATION OF THE VIENNA BASIN USING ARTIFICIAL MICRO EARTHQUAKES

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SUMMARY

The introduction of Eurocode 8 has brought considerable changes in the risk assessment in countries north of the Alps. In previous so called quiet zones earthquake is now the guiding design factor. For the huge stock of structures already existing the assessment of a realistic risk becomes essential and economically important.

The paper will describe the SEISMID method which stands for seismic system identification. Based on an artificial micro earthquake created by a defined falling weight, the response of the surrounding soil as well as the structures is monitored. Several sophisticated methodologies are combined in order to generate a valid risk map for the region as well as for very local circumstances. The results are microzonation for the city, which is of interest to the community, as well as detailed assessment of structures, which is of interest to the owners.

This huge initiative, started 2 years ago, produced considerable added value for the community and the population.

1. INTRODUCTION

The more precisely theoretical knowledge of dynamic soil-foundation-structure interaction (SFSI) of buildings and the increased awareness of local seismic amplification, the so called site-effect, led to an ascending request for a precise investigation of the realistically seismic vulnerability of several building constructions.

In addition it is well known that multiple large cities (Vienna, Innsbruck, Graz) in Austria are located in higher seismic vulnerable areas, in accordance with the macroseismic intensities [Grünthal, G., et al.]. Especially in the Vienna Basin, which is located predominantly on soft soil layer, waves of moderate seismic events can be major amplified. The enhancement of seismic exposure for local building structures, the so called site-effect, led to an ascending request for a precise investigation of the realistically seismic vulnerability.

One important factor that must be accounted for local hazard studies is the site response caused by the surface conditions. Earthquake damage may vary locally, being a function of the type of structures in the subsurface and/or soil mechanical ground conditions, as for example of faults and fractures, lithology or ground water table [Gupta, 2003].

Previous earthquakes have indicated that the damage and loss of life are mostly concentrated in areas underlain by deposits of soft soil. Soft soils amplify shear waves and, thus, amplify ground shaking. The fundamental phenomenon responsible for the amplification of motion over soft sediments is the trapping of seismic waves due to the impedance contrast between sediments and underlying bedrock. When the structure is horizontally layered (which will be referred to in the following as 1D structures), this trapping affects body waves, which travel up and down in the surface layers. When the structure is a 2D or 3D structure, i.e., when lateral heterogeneities are present (such as thickness variations in sediment-filled valleys), this trapping also affects the

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surface waves, which develop on these heterogeneities. The interferences between these trapped waves lead to resonance patterns, the shape and the frequency of which are related with the geometrical and mechanical characteristics of the structure [Fäh, 2000].

Permanent ground movements such as surface fault rupture, liquefaction, landslides, lateral spreading and compaction are important with regard to extended lifeline systems.

Fault segments, their bends and intersection are more apt to concentrate stress and amplify seismic shock. Intersecting fault zones could cause constructive interference of multiple reflections of seismic waves at the boundaries between fault zones and surrounding rocks**.** The highest risk must be anticipated in junctions of differently oriented ruptures, especially where one intersects the other. Compact fault zones consisting of distinct segments can be considered to be more dangerous in term of seismic risk than those, where active ruptures are scattered over a larger area. Those areas can be considered as being more exposed to earthquake shock due to amplification of guided seismic waves along crossing fault zones and to soil amplification.

2. SEISMIC SYSTEM IDENTIFICATION

Ambient vibration testing is a very attractive method for measurements in urban areas with moderate seismicity, because on the one hand the low ambient vibration amplitudes indicate better correlation with moderate seismic events and on the other hand seismic cross-hole tests are complicated in urban areas because of the disruption of building occupants and induced damages on the building structure.

However forced vibration tests with a defined falling weight have exceptional advantages concerning the parameters of the subsoil layers. To get detailed information (e.g. layer thickness, shear wave velocity or dynamic Young’s modulus) it is indispensable to have a defined input-source to get a correct interpretation of the recorded response.

2.1 Measurement Procedure

Thus both the ambient vibration method and the forced vibration technique seem to be very valuable for the SEISMID-technology.

In the following figure the forced vibration tests are described whereby the soil parameters can be determined. The refracted seismic waves are recorded by 3-dimensional geophones which are located in arrays on the subsoil surface. According to the theoretical fundamentals [Knödel, K., 2005] the distance between the geophones in the array has to be chosen in combination to the wave-numbers of the input signal..

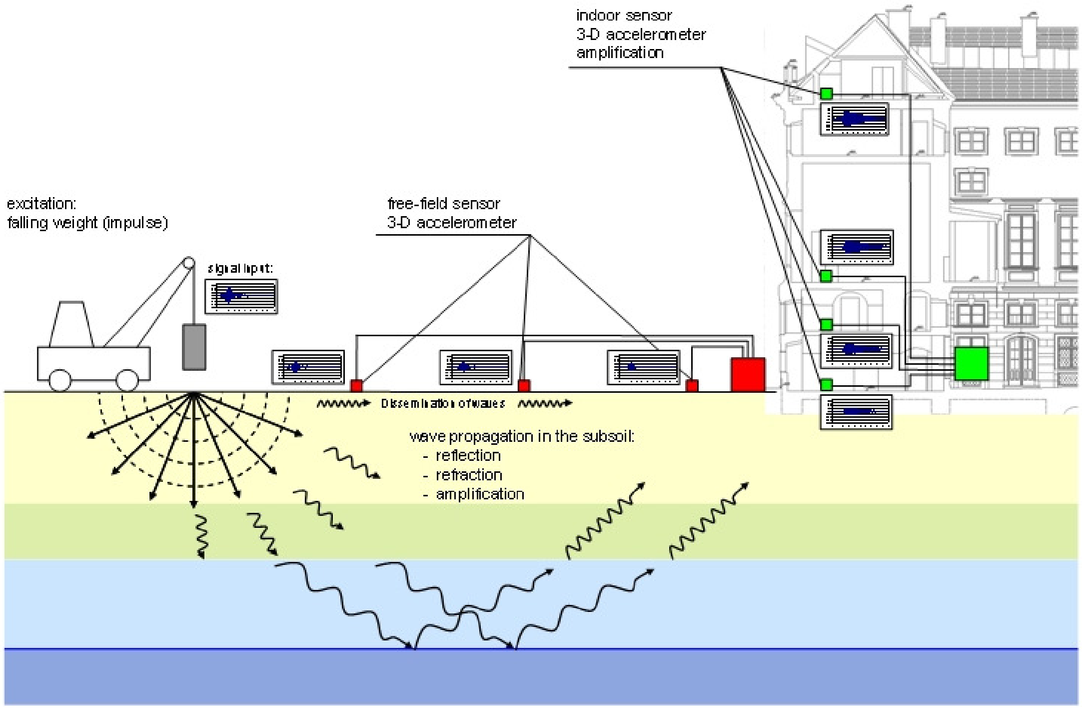

Figure 1: Experimental setup for impulsive excitation

2.2 Vulnerability of Structures

One of the most important steps in an integrated seismic hazard analysis and microzonation is the seismic vulnerability of existing building structures. The evaluation of existing buildings should be as detailed as necessary and as precise and elementary as possible. A general concept of the method based on nonlinear static procedures to develop a vulnerability analysis and calculate the capacity and seismic demand of the building structures had been done for Basel [Lang. K., 2002].

This methodology can almost completely be adapted for residential buildings of the microzonation study in Vienna, because of the similar topology of building structures. A more precisely vulnerability analysis for other types of structures (bridges, infrastructure facilities or high rise buildings) is required.

3. REMOTE SENSING AND GIS (GEOGRAPHIC INFORMATION SYSTEMS)

Numerous studies have demonstrated the value and the use of GIS integrated data sets as satellite radar data (ERS, SRTM and LANDSAT TM-data), geomorphologic and geologic field data and seismotectonic data from different earthquake prone areas [Cornet et al. 1997, Ponte, 1995, Theilen-Willige, 1999] for seismic microzonation research.

GIS techniques are used for regional analysis and prediction. Digital data sets include an inventory of seismic records; geological mapping; extensive geotechnical data on rock properties; high-resolution digital elevation data, and suitable high-resolution remote sensing data. Both space-and airborne remote sensing systems now have resolutions that permit detailed geomorphologic and geologic mapping to be conducted. This mapping procedure is used to produce hazard risk maps as base for urban development planning in Austria, especially for the area of Vienna (Figure 2).

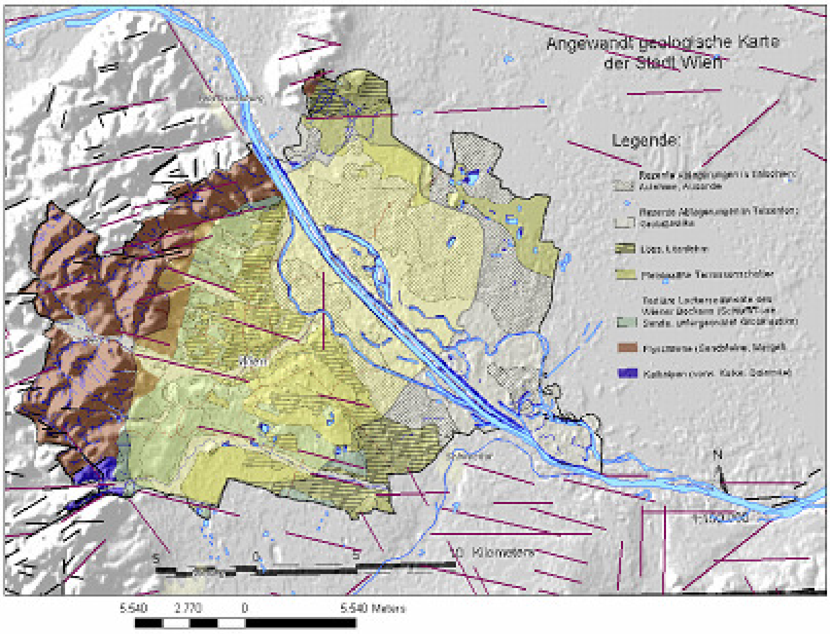

Figure 2: Investigation area Vienna

Remote sensing data can be used to map factors that are related to the occurrence of higher earthquake shock and / or earthquake induced secondary effects: factors such as lithology (loose sedimentary covers), faults, steep slopes, vegetation and land use. Special attention is focussed on precise mapping of traces of faults on satellite imageries, predominantly on areas with distinct expressed lineaments, as well as on areas with intersecting / overlapping lineaments and on areas with unconsolidated sedimentary covers. The lineament analysis based on satellite imageries can help to delineate local fracture systems and faults that might influence seismic wave propagation and influence the intensity of seismic shock. Merging for example lineament maps with isoseismal maps contributes to a better knowledge of subsurface structural influence on seismic shock intensity and about potentially earthquake induced secondary effects as for example landslides or soil liquefaction.

4. OBJECTIVES AND APPROACH

One objective is the development of standardised and common operational Information System focussed on the monitoring of infrastructure integrating different remote sensing data, geophysical and geotechnical data in order to support national and local authorities in Austria.

The aim of this study is to investigate the potential of remote sensing and GIS techniques to improve the understanding of the subsurface conditions influencing damage intensity in the Vienna area. The study is an attempt to integrate various data sets (as LANDSAT ETM data and satellite radar data SRTM), aerial photographs, and seismotectonic data from Austria to obtain a general better understanding of processes influencing the damage intensity of stronger earthquakes, including primary and secondary effects as ground motion, liquefaction potential and landslide susceptibility, and to improve hazard maps. One focus of this research is to investigate the use of satellite imageries for the detection of the tectonic pattern and of earthquake induced faults and fracture patterns at the earth's surface (Figure 3).

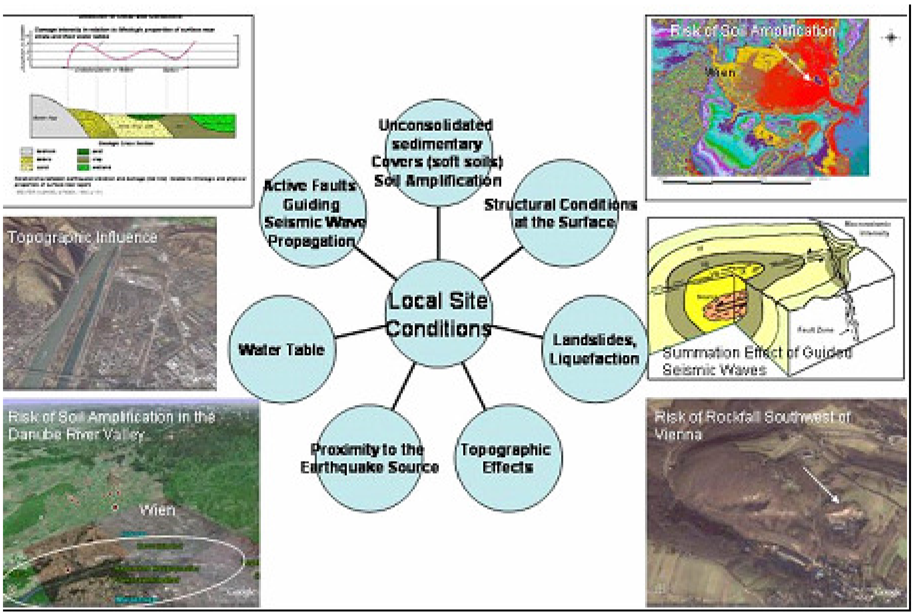

Figure 3: Visualization of earthquake damage influencing factors

4.1 Evaluation of Maps and Other Data

Results of evaluations of remote sensing image data had been compared and combined with available topographic, geological and geophysical data, especially with the maps of known faults and fracture zones. Digital Terrain Models (DTM) were used to investigate the influence of morphology on macroseismic intensity. Hillshade and slope gradient maps derived by DEM data provide a data base for hazard mapping.

The LANDSAT ETM satellite data were merged with Digital Terrain data. Compared with two-dimensional images like the available satellite pictures, digital elevation models have the advantage of representing the vertical extension of the earth's surface by giving height values for every pixel. With digital image processing techniques, customized perspective views can be generated to meet specific requirements considering risk mapping. An exaggeration of the topography often is necessary to distinguish fault segmentation associated with slip deficits and low relief. Fault segment boundaries may be identified.

Digital elevation data were available at different resolution and quality: GTOPO30- data (1 km ground resolution) provided by US Geological Survey, SRTM data provided by the Shuttle Radar Topography Mission (90 m resolution). Available geological and geotechnical data will be collected, interpreted and mapped. It is examined to what extent by overlays and linkages of the data among themselves additional information can be won and relationships can be represented more descriptive.

4.2 GIS Based Evaluation of Remote Sensing-Data and Image Enhancement

Innovations in GIS technology are increasingly accepted tools for the presentation of earthquake hazard vulnerabilities and risks. Over the past few decades, earth observation technology has proved to be an increasingly powerful tool to monitor and assess the Earth's surface on a regular basis. Earth observation satellites as NOAA, LANDSAT, SPOT, ERS, or ENVISAT with increasing capabilities in terms of spatial, temporal and spectral resolution allow a more efficient, reliable and affordable monitoring of the environment over time. Thus, remote sensing technology has become a fundamental input for Geoinformation Systems (GIS).

Remote sensing data, in particular aerial photographs have become a standard tool aiding the study of earthquake damage inventory. The application of stereoscopic imagery, satellite imagery and RADAR imagery has not yet become common. Hence there is a huge potential for forecasting purpose in this area. Image data, either remotely sensed or from terrestrial systems are innovative tools in this area.

Exchange of information and communication practices play key roles in the realization of effective disaster risk reduction activities. Integrating new developments in information management with established and more traditional methods can help create a better understanding about hazards and risks. Effective information management and communication are also instrumental for early warning systems and effective mitigation efforts. It will help to enhance Austria's security, which is in itself a precondition of numerous community policies (transport, energy, telecommunication, etc.). It would foster cross-border cooperation.

The primary objective of the research is the development of standardised and common operational Information System focussed on the monitoring of infrastructure integrating different remote sensing data in order to support national and local authorities as shown schematically in Figure 4. Reaching the objective of the request considering the improvement of security measurements requires the development of reliable and cost effective information systems being able to provide national and local authorities with accurate, timely and continuous information about the status of the infrastructure and processes influencing their safety. Special interest must focus on areas of risk where urgent measurements are required to be implemented.

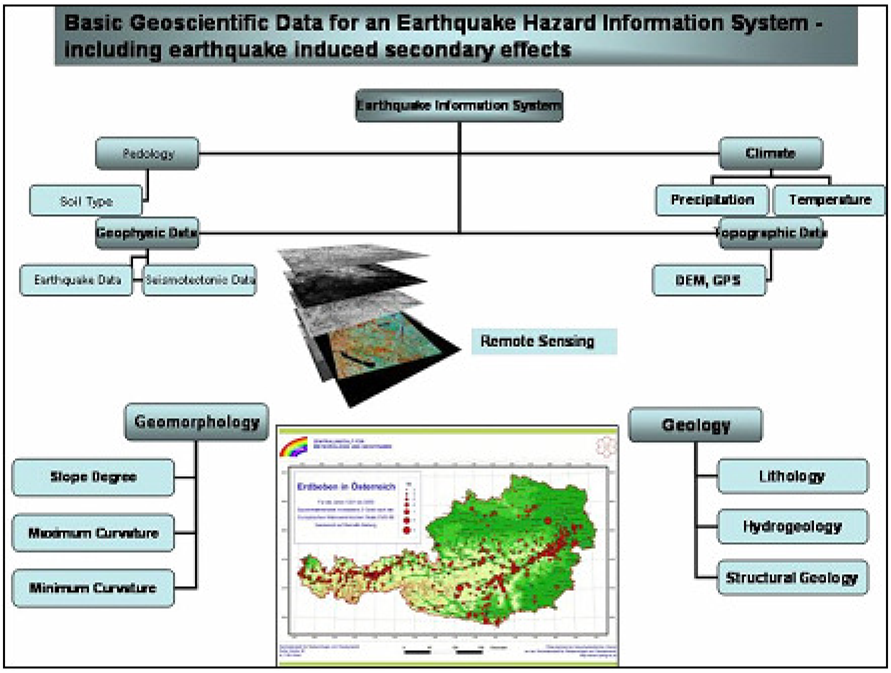

Figure 4: Remote Sensing and GIS Contribution to a GIS Database

The remote sensing data will be used for generating an image based GIS, see Figure 5. The various data sets as LANDSAT TM and satellite radar (SRTM) data, topographic, geological and geophysical data from the investigation area are integrated as layers into GIS using the software ArcView GIS 3.3 with the extensions Spatial Analyst und 3D-Analyst and ArcGIS 9.0 of ESRI. The Hydro-tools of ArcView are used as well.

4.3 Digital Image Processing and Evaluation

The technology of actual earthquake prediction, to enable sounding of warning alarms beforehand to save people and resources is still in infancy. However, seismic risk analysis can be carried out for designing structures as bridges, buildings, etc. Local site conditions influencing damage intensity can be mapped. Remote sensing and GIS can provide valuable inputs to this aspect, for example for active fault mapping.

For enhancing the satellite data of the test sites digital image processing will be carried out. Various image enhancement tools delivered by ENVI Software/ CREASO was tested, for example for finding the best suited RGB combinations or contrast stretching parameters for geologic-tectonic evaluation purposes. Image classification and colour coding variations of the different remote sensing data will be tested in order to enhance the detectability of geologic structures as fault zones in the subsurface that might influence the security of infrastructural facilities for example during earthquakes or landslides.

The Red, Green, Blue - RGB-Principle is reviewed briefly: Three images from the different LANDSAT bands to be used as end-members in a triplet are projected, one image through one primary colour each, i.e. one image is coded in blue, the second in green and the third in red. In this way, each image is given a particular false colour [Gupta, 1991, 2003]. In principle, any image can be coded in any color.

The LANDSAT data were merged with SRTM derived maps. Compared with two-dimensional images like the available satellite pictures, digital elevation models have the advantage of representing the vertical extension of the earth's surface by giving height values for every pixel. With digital image processing techniques, for example customized perspective views can be generated to meet specific requirements considering risk mapping. For getting a geomorphologic overview SRTM data terrain parameters were extracted from a DEM as shaded relief, aspect and slope degree (magnitude of maximum gradient, steepest slope angle), minimum and maximum curvature or plan convexity maps representing surface parameters. Digital processing of elevation data may provide as well evidence for neotectonic activity. As a complementarsy tool was used Google Earth Software in order to benefit from the 3D imageries of the various investigation areas (http://earth.google.com/).

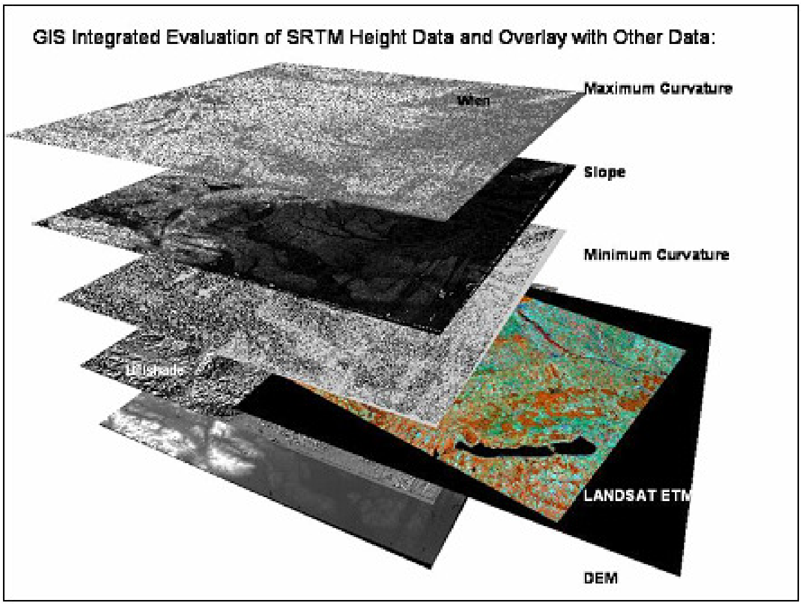

Figure 5: SRTM based Maps: Combining LANDSAT and Shuttle Radar Topography (SRTM) data in order to detect sites of higher damage risk

4.4 Lineament Analysis

Detailed lineament analysis helps to detect areas prone to slope failure. The movements of slopes are structurally controlled by surfaces of planes of weakness, such as faults, joints and bedding planes. A careful search to locate areas with close spacing of faults and joints, especially where they overlap and intersect, helps to look for evidence of possible continued movements and of potential take-off domains.

A very important component of this part of the project is the methodology of lineament analysis (mapping of linear features visible on the imageries) based on satellite imageries for providing information of the geologic structure of the subsurface. A combined evaluation of structural field data, seismotectonic data and lineament analysis based on satellite will be carried out. The following linear and curvi-linear features and risk sites will be identified and mapped in the investigation areas:

- Lineaments
- Probable fault zones
- Structural features
- Probable sites of slope failure, liquefaction, subsidence

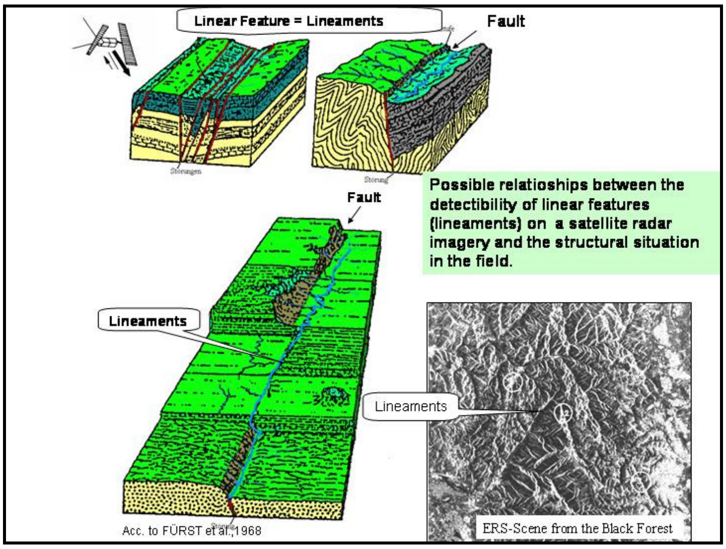

Figure 6: Lineament Mapping

As risk areas will be mapped regions with higher risk of earthquake ground shaking, of earthquake induced secondary effects such as landslides or liquefaction, or of stronger ground motion due to seismic wave amplification.

4.5 Geomorphologic Setting

Part of a GIS integrated standard investigation should be the analysis of earthquake density and distribution and the spatial relationship of areas with higher earthquake occurrence to landslide occurrence. The concentration of larger fault zones and intersecting fault and fracture zones is another important factor influencing slope instability which can be visualized as layer in a GIS.

The investigation of spatial relationships between the occurrence, distribution and intensity of landslides and the position of fault and fracture zones can be carried out in a standard manner using the geoprocessing wizard tools of GIS software.

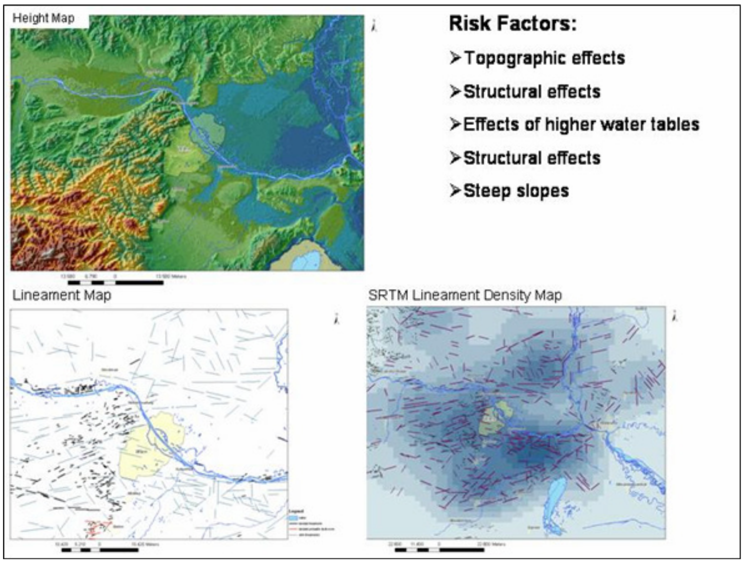

Figure 7 Risk Factors

5. CONCLUSIONS

ENVISAT and LANDSAT imageries were used to create maps within an "Earthquake Hazard Information System" as important layers in a GIS data base in order to perform user-defined computations of earthquake hazard maps as required by [Erdik & Swift-Avci (1997)]. ENVISAT ASAR are of high importance and value concerning the detection and mapping of areas prone to earthquake damage. Lineament analysis based on

ENVISAT ASAR radar-imageries can help to delineate those local fracture systems and faults that might influence seismic wave propagation and, thus, influence the intensity of seismic shock as larger outcropping faults can cause for example a reduction of seismic velocities or multiple reflections amplifying vibration intensity and duration.

A GIS based satellite image interpretation technology gives the opportunity to monitor the current condition and offers therefore reliable actual information.

On local scale a knowledge based system which uses field data, gained through permanent monitoring, and a knowledge base, extracted from human experience, know-how, but also from history data is ideally for early warning. The rules for the knowledge based system uses a factor matrix with influence factors for mass movements and take-off domains.

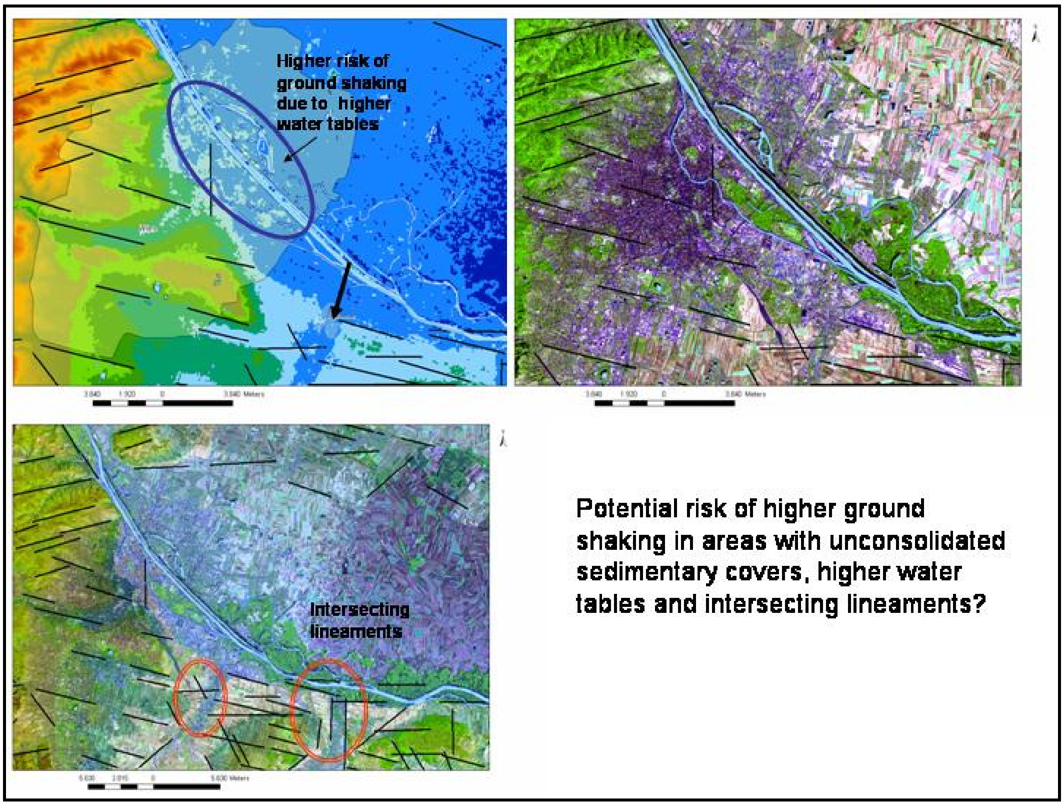

Figure 8: Potential risk of higher ground shaking for the Vienna Basin

By providing up-to-date information and integrating the results with traditional earthquake hazard assessment studies, coherent and secure information are provided. By these means the information can be used for early-warning, for decision support in disaster management.

6. REFERNCES

Conrad,O. (1998): Ableitung hydrologisch relevanter Reliefparameter aus einem Digitalen Geländemodell (am Beispiel des Einzugsgebietes Linnengrund / Kaufunger Wald).- Diplomarbeit angefertigt am Institut für Geographie der Georg-August-Universität zu Göttingen

Cornet, F.H., Helm, J., Poitrenaud, H. & Etchecopar, A., (1997). Seismic and aseismic slips induced by large scale fluid injections, Pageoph, 150, 563–583.

Crozier, M.J., "Landslides - Causes, consequences and environment", Croom Helm, London, 1986, pp 252.

Erdik, M. und J. Swift-Avci (1997): Utilizing GIS for earthquake damage scenario development. In: D. Massonet, 1997: Radar-Interferometrie zur Messung der Erdkrustendynamik, Spektrum der Wissenschaft 9/1997, Heidelberg, 56-65

Fabbri, a.G. & Chung,Ch.F. (2001): Spatial Support in Landslide Hazard Predictions Based on Map Overlays

Franzke, H.- J., Werner W. & Wetzel, H.-U.(2003): Die Anwendung von Satellitenbilddaten zur tektonischen Analyse des Schwarzwalds und des angrenzenden Oberrheingrabens.- Jh. Landesamt f. Geologie, Rohstoffe und Bergbau, Freiburg im Breisgau, Baden-Württemberg, 39, S. 25–54, 11 Abb., 30. Oktober 2003

Fäh, D., Bachmann, H. (2000): Earthquake Scenarios For Switzerland, Proceedings of the EuroConference on Global Change and Catastrophe Risk Management: Earthquake Risks in Europe IIASA, Laxenburg, Austria, 6–9 July 2000

Giardini,D.,Wiemers,S., Fäh,D. & Deichmann,N.(2004): Seismic Hazard Assessment of Switzerland,2004.- Swiss Seismological Service, ETH Zürich, Zürich,Switzerland

Geyer, O. Schober, Th. & Geyer, M.(2003): Sammlung geologischer Führer 94 – Die Hochrhein-Regionen zwischen Bodensee und Basel.- Gebr. Bornträger, Berlin –Stuttgart,526 p.

Grünthal, G.: et al.: “Abschätzung der Erdbebengefährdung für die D-A-CH-Staaten”, Bautechnik 75 (1998), Heft 10, Verlag Ernst&Sohn, Berlin.

Gupta,, R. P.(1991): Remote Sensing Geology.- Springer-Verlag, Heidelberg

Knödel, K., Krummel, H. and Lange, G. (2005); “Handbuch zur Erkundung des Untergrunds von Deponien und Altlasten – Band 3: Geophysik”; *Springer Verlag Berlin*, ISBN: 35-4059-4620.

Landesamt für Geologie, Rohstoffe und Bergbau, Baden-Württemberg (1998): Geowissenschaftliche Übersichtskarten von Baden-Württemberg, 1: 350.000, 20 landesweite Karten für Planung, Wirtschaft und Umwelt, CD

Lang, K., (2002); “Seismic vulnerability of existing buildings”. *Dissertation ETH Zürich,*No. 14446.

Lee, S., Digna G. Evangelista. Landslide Susceptibility Mapping using Probability and Statistics Models in Baguio City

Mälzer, H. et al. (1988): Höhenänderungen in der Nordschweiz und im Südschwarzwald bis zum Bodensee.- NAGRA Technischer Bericht 88-05, CH-Baden

Plate, E.J. & Merz,B.(2001): Naturkatastrophen – Ursachen - Auswirkungen – Vorsorge.- E. Schweizerbart’sche Verlagsbuchhandlung, Stuttgart

Ponte, S., Moccia, A., 1995: Validating a spaceborne SAR simulator by using SIR-C/X-SAR data. 46th International Astronautical Federation (IAF) Congress, Oslo, Norway, Oct. 2-6, 1995. Paper IAF-95-B.6.03.

Popescu, M. E.: Landslide Causal Factors and Landslide Remediatial Options.- http://www.geoengineer.org/Lanslides-Popescu.pdf

Popescu, M. (1994): A suggested method for reporting landslide causes.- Bull IAEG, No. 50, Oct. 1994, pp 71-74.

Neuhäuser, B.(2005): GIS-Gestützte, Probabilistische Beurteilung der Gefährdung durch Massenbewegungen - Einsatz von Geoinformationssystemen (GIS) zur Multikriterien Beurteilung der Rutschanfälligkeit dargestellt am Beispiel der Schwäbischen Alb.- Master Thesis, eingereicht am Institut für Geographie und Angewandte Geoinformatik der Paris London Universität Salzburg zur Erlangung des akademischen Grades Master of Science in Geographical Information Science & Systems MSc (GIS)

Ruff, M. (2005): GIS-gestützte Risikoanalyse für Rutschungen und Felsstürze in den Ostalpen (Vorarlberg, Österreich). - 144 S. , Dissertation Fakultät Bau-, Geo- und Umweltwissenschaften, Universität Karlsruhe (TH); Karlsruhe, http://www.uvka.de/univerlag/volltexte/2005/46/

Savvaidis,P., Theilen-Willige,B. & Neuhäuser,B.(2006): LANDSLIDE ALERT SYSTEM: Guidelines for the Standardization of Landslide - GIS Layer Structure. - Integrated Optimization of Landslide Alert Systems(OASYS), EVG1-2001-00061, Final Report, VCE, Wien

Sieberg, A. & Lais, R. (1925): Das mitteleuropäische Erdbeben vom 16.11.1911, Bearbeitung der makroseismischen Beobachtungen.- Veröff. Reichsanstalt für Erdbebenforschung, 4, Jena

Schneider, G.(2004): Erdbeben – Eine Einführung für Geowissenschaftler und Bauingenieure: 246 p., Spektrum Akademischer Verlag, Elsevier, München

Teledata GeoConsult GmbH-srl, 2003: ALPSLOPE Monitoring of Unstable Slopes in the Italian Alps Based on Remote Sensing, DUP – Small Service Project, ESA//ESRIIN Contract No. 15646//01//II-LG – Executive Summary –, December 2003

Theilen-Willige,B., 1999: Erdbebengefährdung im Bodenseegebiet - Fernerkundungsmethoden bei der Erfassung von untergrundbedingten Effekten bei Erdbeben im westlichen Bodenseegebiet. – Habilitationsschrift, TU Berlin, im

Theilen-Willige, B.(1999): Erdbebengefährdung im Bodenseegebiet Abschlußbericht für das XEP-Projekt (Erstellung beispielhafter X-SAR-Produkte) des DFD/DLR, Oberpfaffenhofen, beim DLR bestellbare CD-ROM

Theilen-Willige, B.(2000): Seismic Hazard Zoning based on Evaluations of Remote Sensing Data (LANDSAT TM-/SIR-C/X-SAR-Radar) of the Lake Constance Area/ Southwest Germany in Comparison with Field

Check.- Photogrammetrie Fernerkundung Geoinformation (PFG),1,19-32, Schweizerbart'sche Verlagsbuchhandlung, Stuttgart

Theilen-Willige, B.(2002): Beitrag der Fernerkundung zur Erdbebenvorsorge - Fernerkundungsmethoden bei der Erfassung von durch Erdbeben und durch Erdbebenfolgeschäden gefährdeten Bereichen.- in: FIEDLER,F.(2002),Hrsg.): Naturkatastrophen in Mittelgebirgsregionen, Verlag für Wissenschaft und Forschung GmbH, VWF,Berlin, 245-270

Theilen-Willige, B. (2005), Remote Sensing and GIS Contribution to Seismic Microzonation Studies in NE-Austria – Vienna Area

Theilen-Willige, B.& Neuhäuser,B.(2006)Remote Sensing and GIS Contribution, GIS Integrated Geologic Evaluations of Remote Sensing - Data from the Test Sites for the Detection and Monitoring of Landslides.- Integrated Optimization of Landslide Alert Systems(OASYS), EVG1-2001-00061, Final Report, VCE, Wien

Wood, J. (2004): The Geomorphological Characterisation of Digital Elevation Models.- Thesis, http://www.soi.city.ac.uk/~jwo/phd/

Internet Data Sources:

Satellite Data:

LANDSAT ETM and SRTM data: Earth Science Data Interface (ESDI) at the Global Land Cover Facility,University of Maryland, USA: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

NASA: ftp://e0srp01u.ecs.nasa.gov/srtm/version1/Eurasia/

GTOPO30 DEM data: DataServer: Free maps and GIS data
http://www.diva-gis.org/data/DataServer.htm

Earthquake data:

http://www.lgrb.uni-freiburg.de/lgrb/Fachbereiche/erdbebendienst/erdbebenkarten
http://nhss.cr.usgs.gov/aboutUs.htm
http://www.seismologie.bgr.de/www/sdac/erdbeben/ger_jahr_list.htm
http://www.seismologie.bgr.de/www/sdac/erdbeben/catalogue_ger.htm

Interactive Maps and Shapefiles for Downloading:

http://www.ngdc.noaa.gov/maps/interactivemaps.html