A COUPLED GEOINFORMATION AND SIMULATION SYSTEM FOR LANDSLIDE EARLY WARNING SYSTEMS

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INTRODUCTION

Recurring disastrous landslides cause great damage worldwide. According to GEOTECHNOLOGIEN (2008) the losses amount up to 100 billion US-dollars per year and more than 4 million casualties have been recorded due to these hazards in the last century.

Obviously there is a strong demand for reliable warning systems to save lives and properties. Although strong efforts have been made to develop early warning systems for natural hazards like earthquakes and tsunamis, the warning and the forecasting of disastrous events, especially for landslides in soils, are particularly difficult tasks.

As a consequence to the increasing demand for warning systems, the GEOTECHNOLOGIEN-initiative has been launched by the German Ministry of Education and Research. Our research project “Development of an interconnected information and simulation system” is part of that initiative and focuses on the development of a linked GIS-FEA-module (Geographical Information System – Finite-Element-Analysis – module) for a user-friendly and assisted investigation of the behaviour of slopes due to various scenarios.

This approach enlarges existing sensor-data based warning systems, since an insight to the physical processes, which cause slope failures and may result in landslides, are provided on basis of analyses on mechanically well-founded geotechnical models (TRAUNER et al. 2008b).

The research work is carried out jointly by the Institute for Soil Mechanics and Geotechnical Engineering and the Geoinformatics Research Group at the University of the Bundeswehr Munich.

Moreover, the project is integrated in the multi-disciplinary project “Development of suitable information systems for early warning systems”, which combines approaches from the fields of geology, geotechnics and geoinformatics for the identification and investigation of landslide susceptible areas and the early warning of disastrous events. Therein, techniques like FE-Analysis (BOLEY 2007, TRAUNER et al. 2008a), statistical and linguistically analyses (GALLUS & KAZAKOS 2008, GALLUS et al. 2008) are combined with GIS (ORTLIEB et al. 2008a) and a 3D/4D geo-database for the storage and management of spatial and time-related data (BREUNIG et al. 2008).

For the detailed architecture of the joint project BREUNIG et al. (2007) refers.

COUPLED GEOINFORMATION AND SIMULATION SYSTEM

The combination of a geographical information system and a FE-Analysis-component allows for an investigation of the behaviour of slopes due to various action effects (i.e. loads, accelerations, geometrical changes, etc.) in a numerical simulation. Thereby the GIS component provides user-assistant functions for the set-up of geotechnical models and the processing as well as the assessment of computation results.

The connection between the FEA-module (simulation system) and GIS is schematically shown in Figure 1. When a geotechnical model shall be generated for a specific slope, the area of interest is selected within the GIS. The geometrical data is supplemented with information about the subsoil structure, boundary conditions and action effects.

Following the data transfer from the GIS to the FEA-module, the geotechnical model can be set up automatically to a large extent. Subsequently the simulation is executed as defined by the user in the GI system.

After the simulation the results are written to an output file and transferred back to the GIS for processing and visualization of the data in regard to the assessment of the endangering by possible slope failures. Thereby the data preparation is carried out in such a manner that the results are understandable for decision makers.

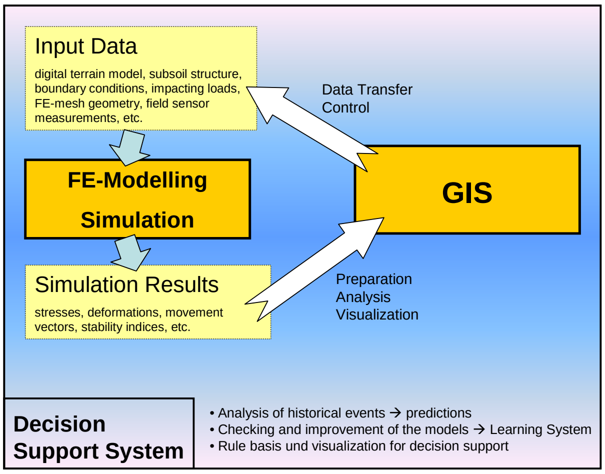

Figure 1 – Connection between FEA-module and GIS

APPLICATION MODES OF THE COUPLED SYSTEM

The coupled system of GIS and FEA is intended to be used for two different purposes (ORTLIEB et al. 2009).

If a slope shall be examined for its behaviour due to various scenarios or due to events of different magnitudes (e.g. earthquakes of different intensity) the coupled system can be applied as learning system (Figure 2). That means, that no acute danger may exist, but knowledge about critical magnitudes of events and the possible consequences of these scenarios may be essential for the assessment of the susceptibility of an area to landslides and e.g. for the definition of restricted zones. In general, the mechanical characteristics of the slope under investigation can be examined to be available in future, if a concrete event has to be evaluated.

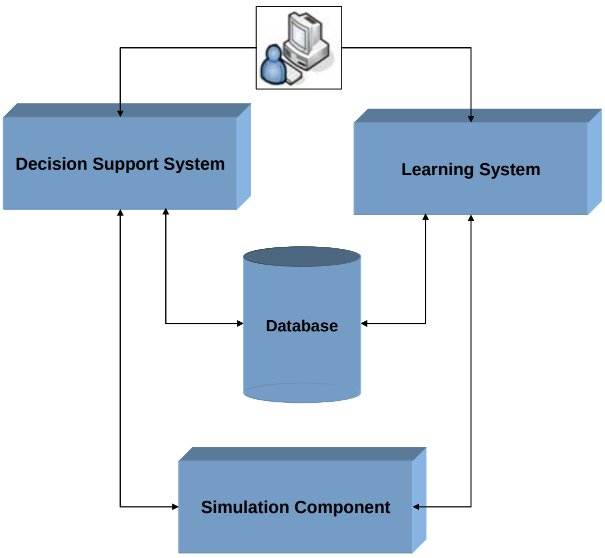

Figure 2 – Connection between FEA-module and GIS

In addition to the learning system, the coupled system can serve as a decision support system, if a specific event is awaited and has to be assessed regarding its consequences to the stability and deformation of the slope. In this mode, the focus is on a fast decision whether to issue a warning or not.

In both application modes the coupled system GIS-FEA is connected to the geo-database, where the data required for the numerical simulation is stored. Moreover outcomes of the computations are archived in the database to be available for future queries.

STUDY AREA

The illustrated concepts are implemented in a prototype to evaluate their advantages regarding the assessment of landslide susceptible slopes.

The area under investigation for the prototype is located in the Isar valley south of Munich, Germany, where the river eroded a deep valley into layers of quaternary gravels and tertiary sediments of partially high plasticity. Consequently, steep and instable slopes were formed, where landslides occurred from time to time (BAUMANN 1988).

Although the erosion of the river has been stopped for decades now, parts of the slopes are still in motion, since a state of static equilibrium has not been reached yet.

The last slope failures were observed in the early 1970s and gave reason for the installation of sensors (extensometer, inclinometer, ground water level tubes, etc.) and the start of a deformation measurement campaign for the slopes. These devices are still in the field and the measurements have been continued until this day. Thankworthy, the Bavarian Environmental Agency has made the measurement data available for use in the research project.

GEOTECHNICAL MODEL

The stability and deformation of slopes due to action effects are investigated within the simulation component by application of the Finite-Element-Method. Therefore geotechnical models, which represent the slope in a realistic manner to a large extent, have to be generated.

The area of interest, which shall be modelled, is selected within the GIS on basis of maps like topographical maps or orthophotos. In addition maps prepared by project partners can be considered, which suggest areas of increased landslide susceptibility on basis of statistical analyses (GALLUS et al. 2008, GALLUS & KAZAKOS 2008). Once the area of interest has been selected, data for the description of the geometry of the slope (topography and subsurface structure) is queried from the geo-database. In the database ground models or data obtained from site investigations (geological profiles, material properties) are stored (BREUNIG et al. 2009).

Finally, the geometrical description is supplemented by boundary conditions, action effects and other details and a geotechnical model of the slope is compiled. A simple three-dimensional model for a segment of the slopes in the Isar valley with its FE-mesh is shown in Figure 3.

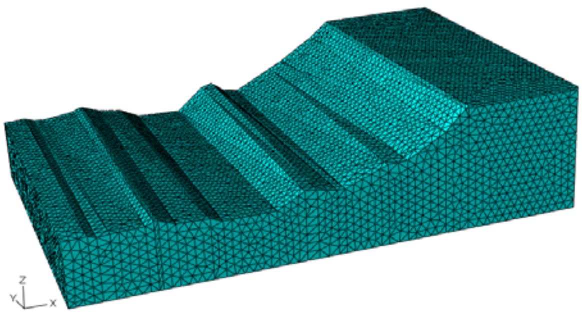

Figure 3 – FE-model for a segment of the slopes in the Isar valley

To represent the slope's behaviour in large parts almost realistically, the applicable description of the material's characteristics is essential. Thus, appropriate constitutive equations with corresponding material parameters have to be applied and reasonable values for the parameters defined.

The calibration of the model is done on events observed in the past. Recorded slope deformations by sensors are compared with computation results in the GIS environment and the model adjusted (e.g. variation of material parameters, change of constitutive equations or geometry of the model) to bring the simulation in line with the slopes' real behaviour.

Once the geotechnical model has been calibrated successfully and shows similar behaviour compared to the real slope, it can be applied for prognosis purposes. The consequences (deformations, change in material strength utilization, etc.) of different scenarios for the slope under investigation and adjacent areas can be determined.

Subsequently to the simulations, relevant computation results are compiled in an output file and transferred to the linked GIS for further processing and visualization of the data.

DATA PREPARATION FOR DECISION SUPPORT

The outputs of the simulation are several parameters (e.g. stresses, strains or deformations, degree of material utilization). In Figure 4 the deformation vectors of a 3D simulation are shown.

Figure 4 – Visualized 3D simulation results

To identify the important parameters, namely the deformation direction and deformation length of the deformation vectors, the depiction has to be strongly enlarged. But therewith the overview of the whole slope will get lost. That means, the simulation results are too complex and too extensive to be presented like that for decision support. Therefore they have to be linked with decision rules to allow for a user-friendly preparation with appropriate methodologies.

In a first step the deformation vectors can be divided according to their length and their deformation direction into classes. Afterwards clusters can be detected, which include deformation vectors, which belong to the same deformation class, to the same direction class and are spatially adjacent. After the aggregation of the deformation vectors in the clusters the area of validity is determined. The result of this method can be visualised and presented the responsible decision-maker for decision support (ORTLIEB et al. 2009).

Moreover, the prepared computation results can be enriched by additional data from any other resources in the GI system (e.g. land development plans, infrastructure facilities plans or susceptibility maps obtained by statistical or linguistic analyses) to support the decision-making process.

CONCLUSIONS

With the focus on innovative methodical investigations and the implementation of new easy-to-use information technologies into the operational workflow of hazard management, the research project contributes to the reduction of threats posed by landslides.

The generation of geotechnical models in a coupled GIS-FEA-module allows for the improvement of early warning systems, since calibrated models can be applied to determine critical values of action effects (thresholds) that may trigger landslides, on a physical basis.

The conception of the module with its possibility for connection to other modules based on different approaches (statistics, analytical computation methods, etc.) via GIS and the integrated assistance functions in the module for decision-makers, provide a user-friendly and reliable medium for warning purposes.

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REFERENCES

BAUMANN, H. J. 1988. Bruchvorgänge in Folge der Isareintiefung südlich Münchens und die kritischen Höhen der Talhänge, Schriftenreihe des Lehrstuhls und Prüfamt für Grundbau, Bodenmechanik und Felsmechanik der Technischen Universität München, Vol. 12, 287 p.

BOLEY, C. 2007. Caution, Landslide ahead!, Brochure: Scientific research for a safer tomorrow, University of the Bundeswehr Munich, pp. 6-7.

BREUNIG, M., REINHARDT, W., ORTLIEB, E., MÄS, S., BOLEY, C., TRAUNER, F.-X., WIESEL, J., RICHTER, D. 2007. Development of suitable information systems for early warning systems (EGIFF), Early Warning Systems in Earth Managment, Kick-Off-Meeting 10 October 2007, Technical University Karlsruhe, Geotechnologien Science Report No. 10, L. Stroink (ed.), pp. 113-123.

BREUNIG, M., BROSCHEIT, B., REINHARDT, W., ORTLIEB, E., MÄS, S., BOLEY, C., TRAUNER, F.-X., WIESEL, J., RICHTER, D., ABECKER, A., GALLUS, D., KAZAKOS, W., BARTELS, A. 2008. Towards an information system for early warning of landslides, Proceedings of the EnvironInfo 2008 – Environmental Informatics and Industrial Ecology, Lüneburg, Germany, September 10-12, pp. 476-481.

BREUNIG, M., BROSCHEIT, B., THOMSEN, A., BUTWILOWSKI, E., JAHN, M., KUPER, P. V. 2009. Towards a 3D/4D Geo-Database supporting the Analysis and Early Warning of Landslides, Proceedings of Cartography and Geoinformatics for Early Warning and Emergency Management: Towards Better Solutions, Prague, Czech Republic, January 19-22, pp. 100-110.

GALLUS, D., ABECKER, A., RICHTER, D. 2008. Classification of landslide hazard/ susceptibility in the development of early warning systems, Proceedings of the 13th International Symposium on Spatial Data Handling, Montpellier, France, June 23-25, pp. 55-75.

GALLUS, D., KAZAKOS, W. 2008. Einsatz von statistischen Methoden zur automatischen Erstellung von Gefährdungskarten in Frühwarnsystemen am Beispiel gravitativer Massenbewegungen, Proceedings of AGIT 2008, Salzburg, Austria, July 2-4, pp. 771-782.

GEOTECHNOLOGIEN 2008. Geotechnologien Forschungsschwerpunkt "Frühwarnsysteme gegen Naturgefahren", http://www.geotechnologien.de/forschung/forsch1l.html

ORTLIEB, E., MÄS, S., REINHARDT, W., TRAUNER, F.-X. 2008a. Coupling Simulations of Landslides with Geoinformation Systems for Decision Support and Early Warning, Proceedings of the 11th AGILE International Conference on Geographic Information Science, Girona, Spain, May 5-8.

ORTLIEB, E., REINHARDT, W., TRAUNER, F.-X. 2009. Development of a coupled Geoinformation and Simulation System for Early Warning Systems, Proceedings of Cartography and Geoinformatics for Early Warning and Emergency Management: Towards Better Solutions, Prague, Czech Republic, January 19-22, pp. 483-492.

TRAUNER, F.-X., MEYER, F., BOLEY, C., ORTLIEB, E. 2008a. Neue innovative Methoden zur Frühwarnung auf Basis von gekoppelten Informations- und Simulationssystemen am Beispiel gravitativer Massenbewegungen, Proceedings of 6. Kolloquium Bauen in Boden und Fels, Technische Akademie, Esslingen, Germany, January 22-23, pp. 433-439.

TRAUNER, F.-X., BOLEY, C., ORTLIEB, E. 2008b. Coupling of geotechnical models and GIS for early warning purposes exemplified on landslides. Proceedings of the International Conference and 106th annual meeting of the Deutsche Gesellschaft für Geowissenschaften and 98th annual meeting of the Geologische Vereinigung e.V. (Geo2008) – Resources and Risks in the Earth System, Aachen, Germany, September 29 - October 2, Journal: SDGG Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften, Vol. 60, p. 329.