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MODELING AND ANALYZING EARTHQUAKE INDUCED BUILDING DAMAGES IN A GIS

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ABSTRACT

After a catastrophe like an earthquake a quick assessment of the damages has to be carried out in order to initiate repair actions. Especially building damages have to be recorded, in order to be able to give housing to the unsheltered as quickly as possible. To this end, the degree of damage of a building has to be captured, and based on these information decisions concerning the measures have to be taken (renovation, partial or total stub, etc.). Depending on the type of building, different factors influence the degree of damage and thus different actions are necessary. The damage indicators for a concrete building are for instance the number, size type and position of cracks, the position and status of damaged beams and supports, etc. A research project financed by the German Volkswagen Stiftung is dedicated to the investigation of a quick assessment and analysis of building damages. The acquisition is carried out with the help of close range photogrammetry, using digital cameras and photogrammetric analysis programs. The data is stored, managed and analyzed in a Geographic Information System (GIS). The paper concentrates on the GIS-part.

Based on international coding schemes for earthquake damage qualification and a questionnaire developed at Istanbul Technical University, a detailed data model for a GIS has been established. The model includes both spatial and thematic components; furthermore it reflects the different building types with their respective peculiarities. An important property of the system is to make use of the analysis capabilities of the GIS to automatically derive values describing the degree of damage. The system was implemented in the GIS-product ArcView 3.0a by ESRI. The automation of the analysis processes was achieved using the object-oriented programming Language Avenue.

In the paper first the detailed data model is presented. This model is then applied to several buildings of the city of Dinar (Turkey). The degree of damage of these buildings will be assessed automatically. Then the results will be compared to manually acquired results both in terms of quality and time efficiency. Furthermore, possible simplifications of the data model are discussed and their effects to the results are analyzed.

1 INTRODUCTION

The effects of disasters and earthquakes are devastating for nature and human beings. In order to be able to minimize the negative effects of such events it is important to register and document as quickly as possible the damages occurred. This damage assessment is the basis for launching appropriate remedial measures. This has to be done for every anthropogeneous infrastructure such as traffic routes and bridges but also for buildings. Quick help is necessary here in order to give shelter to the derelictsto restore the buildings or to replace them by new ones. An essential precondition for the capture of these measures is the detailed inventory of damaged objects [Grünthal 1992]. Based on this assessment, it can be clarified how strongly a building is damaged, whether it can be rebuilt or whether it must completely be torn down.

The German Volkswagen Stiftung funds this project. In a cooperation between the Photogrammetry Division of the Istanbul Technical University (ITU) and the Institute for Photogrammetry of the University of Stuttgart, methods have to be developed for the recording and in particular also to assess and speed up the analysis of the building damages. For recording digital photogrammetric methods are used, while the storage, administration and analysis of the data is done in a Geographic Information System, namely the product ArcView (version 3.0a) of ESRI company [ESRI 1996].

The data this investigation is based on was acquired by specialists of the Technical University of Istanbul in the course of an earthquake, that had happened on October 1st, 1995 close to the city Dinar, located in Southwest Anatolia [TUBITAK,1995, Barka & Eyidogan 1995].

2 SETTING UP THE DATA MODEL FOR THE BUILDING AND DAMAGE DOCUMENTATION

Setting up a data model is the first step in a GIS project in order to determine which objects are important. In this project, these are buildings, their structural parts and the damages, which can affect them [Applied Technology council 1987, Bachmann 1995]. Additional data layers are included; e.g. the geological conditions and the topographical circumstances of the investigation site, as well as additional earthquake relevant information.

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In general, after the selection of the relevant objects, the attributes, which describe the objects appropriately, have to be determined. The degree of detail depends on the scale and on the specific application. This project requires a very high resolution of information i.e. the buildings must be described very detailed. Finally, the object relations must be clarified i.e. one must determine which objects belong to each other. Thus a building has to be subdivided into its different structural parts. The structural parts in turn must are assigned the characteristic damages types they are affected by. In this way a hierarchical system of objects and object parts evolves.

The process of data modeling in this investigation essentially consists in a detailed thematic data model, i.e. to establish a digital damage assessment and evaluation scheme. Furthermore, integration the building geometry as well as the geometry of the damages into the data model has to be designed. The organization of the data model represents a decisive step in this application because the quality and/or the possible use of the entire system depend on the careful conduction of this phase. If mistakes are made in this stage, inconsistencies or gaps result, as well as redundancies during data acquisition which may disturb or damage the further process of the project [Volz,1997].

2.1 Selection of the objects and of their attributes

The investigation relies on the case study "Dinar" carried out by the Istanbul Technical University (ITU). This case study was developed for manual damage evaluation and assessment. Thus in this project, the same object structure as well as the damage assessment and evaluation is applied. This allows us to use existing correct and complete example data.

Yet, the specialists of the ITU had suggested a modification in the sense of an extension of the object and damage description: some inconsistencies and errors in the current acquisition and evaluation scheme should be overcome. Also additional data sources had to be introduced in order to complement the current damage description model.

2.2 Description of the procedure applied in Dinar for the damage recording and evaluation

The procedure for the damage recording applied in Dinar is the procedure proposed by the UNIDO (United Nations Industrial Development Organization) for the Balkan area; on the other hand, it is based on Japanese standards. This concept was developed in cooperation between the departments of civil engineering of the Middle East Technical University (METU) in Ankara and the ITU. Basically, the assessment scheme consists of different parts, which are summarized, in a damage report for each individual building:

1. A total analysis of the damaged building, consisting of general information about the building, a structural description and a detailed report of the damage given by civil engineers. Furthermore a description of the quality of the built-material and the ground and finally a description of the reasons for the origin the damage
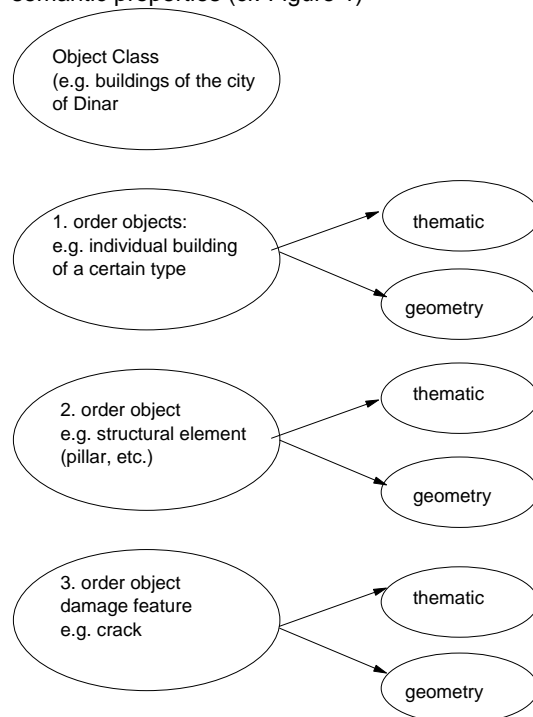
    as well as general measures for the protection and repair.
2. Plans for the building description and for the damage assessment.
3. a spreadsheet for the building description, damage recording and evaluation;
4. a report on the building material;
5. A geotechnical report.

The main point of this damage report is the 3rd mentioned item, namely the spreadsheet for the acquisition of important information, e.g. important attributes for the building description, the damage recording and damage evaluation. This sheet therefore serves as basis for the data model. The sheet is divided into five parts: The damage recording part shows that the damage evaluation for the different building types depends on the degree of damage of its structural parts. All questions of the recording form as well as the possibilities for calculation of the damage values have also to be included in the data model.

Different components sum up to the total damage calculation. In addition to the inclusion of the respective damages on the building, also conditions reflecting the general vulnerability of the building should are included (degree of dilapidation, ductility, stiffness, and resistance against lateral seismic earthquake). The key to the calculation of the so-called system damage points is based on the store of the building, which shows the strongest damage.

2.3 The structuring of the data model in a GIS and the recording of semantic information

In order to be able to transfer the data model correctly into the GIS the actual description of building structure was modeled according to the object class principle [Bill & Fritsch 1994]. The objects are represented in different hierarchical levels and described by geometrical and semantic properties (cf. Figure 1)

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Figure 1 Object levels of the data model according to the object class principle

The highest object level represents the individual building object, which consists of the objects of the 2nd hierarchy level, the structural parts. Damage features (e.g. cracks) affect these structural parts. In case of the cracks they were assigned to another level. Structuring the thematic data within the GIS-Product ArcView is done in the form of tables, organized in the relational database dBase. The following tables are generated:

- Two tables to the general building description (owner, building use, postal address, etc.).
- A table to the description of the general structural elements of the building (type of building, foundation, ceiling, roof system, ground plan, etc.).
- Different tables for the general damage recording and to the building type specific object and damage (e.g. shifts between the stores, damages to structural parts, etc.).
- A table for the final damage evaluation.

Figure 2 shows the general scheme of the object and damage description.
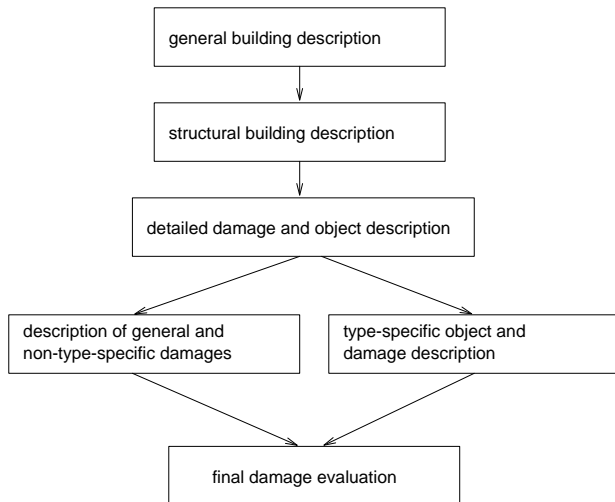
Figure 2 General scheme of the object and damage description

Data input was realized via forms in MS Access. Selection menus and default values can very much facilitate it. Figure 3 shows a form for thematic data acquisition. The transfer of the semantic information to the GIS is to be realized via the SQL-Connect-Function of ArcView.

Figure 3 Form of a data record in MS Access

3   THE PHOTOGRAMMETRIC RECORDING OF OBJECT GEOMETRY AND ITS TRANSFER TO ARCVIEW

3.1   Acquisition and evaluation of the images

The images of the damaged buildings are taken from different sites around the building, so that a complete acquisition of the entire building facade was gained. Characteristic damages are registered even in more detail. The images were then transferred and processed in the photogrammetric analysis program PICTRAN (Technet,1995).

First of all, the exterior orientation is determined via a bundle block adjustment. After that the relevant object points can be measured in 3D. In this way, all visible building and damage structures can be obtained. Furthermore, parameters of the structural elements can be determined, e.g. length, width, height, inclination and shift direction (compared to a reference plane), inclination- and tilt angles etc., as well as deformation curves of the building elements. The duration for measurement of one building is about one hour. However, this figure depends of course on the degree of the damage of building elements and on the number and the size of the registered structures.

3.2   The transfer of the geometric information to ArcView

In order to analyze the building damages automatically, the information acquired in the photogrammetric measurement system has to be transferred to the GIS and linked with the thematic data. There is no direct interface between the photogrammetric program PICTRAN and the GIS-Software ArcView. This interface is currently under development within the framework of a master's thesis. The link between the geometric objects and the thematic data is established via unique object identifiers.

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4   DATA ANALYSIS AND DEVELOPMENT OF PROJECT-SPECIFIC APPLICATIONS IN ARCVIEW

The analysis functionality of ArcView represents an important prerequisite for the evaluation of the building damages. The basic methods of analysis support e.g. the selection of objects according to given thematic or spatial criteria (cf. Figure 4).
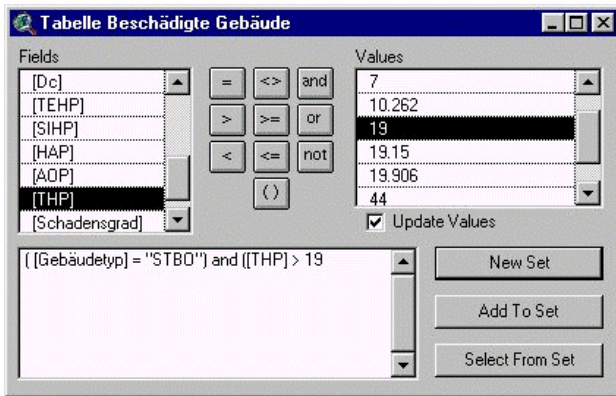

Figure 4 the "Query builder" in ArcView. It supports to easily create queries: here, the selection of buildings of type "reinforced concrete frame of concrete"(STBO), whose damage dot number (THP) is larger than 19.

A very important quality of ArcView is the possibility to classify each attribute according to its values into classes and create new object levels. This allows for a generation of new views of the data depending on the specific application. This information can later e.g. be used for the introduction of suitable redevelopment measures or for the identification of potentially endangered regions. In addition to purely attribute-related queries, also neighborhood queries can be carried out.

In the center of the investigation is the detailed evaluation of the damage information of an individual building. In order to accelerate the evaluation process, an automation of the necessary analysis, evaluation and calculation procedures had to be developed. This corresponds to a project-specific application, which is achieved using the ArcView programming language "Avenue".

4.1   The concept of the damage analysis

Starting with an example data set which describes a building of the model "reinforced concrete frame"; first a concept was set up for the automated damage analysis and damage evaluation. This was worked out for the structural part model "reinforced concrete pillar" due to its importance for the damage recording and the damage rating of buildings. Furthermore, all necessary investigations within the framework of the project may be carried out with this type. It is generally necessary for the damage analysis to start on the lowest object level, since the degree of damage of the upper levels is determined from the sum of its partial damages. Accordingly, the cracks must be examined first. An individual crack can for example be described by different parameters like length, width, position, etc. Depending on those values the crack influences the damage degree of an affected structural part. Further damage indicators have to be added up to yield the total evaluation. In the case of the pillar, in

addition to the investigation of the crack structures, also for example whether the pillar was crushed or how strongly it is bent, whether its steel-bar reinforcement is visible or deformed, whether concrete cover declined, and so forth have to be considered. Only if all factors are considered, the correct damage value of an individual pillar can be calculated. Based on this, all structural building elements have to be assigned to damage categories ("without damages", "light damages", "mean damages" and "heavy damages"). All those values then add up to the total damage of a building.

4.2   The automation of the damage analysis

In order to be able to determine the effect of a crack on the damage of a supporting element, indices were introduced. They assess the degree of the damage relevant type of a crack via the evaluation of its parameters (width, length, situation etc.). As soon as an indicator achieves a certain numeric threshold and/or exceeds it or is described via a specific text, it is assigned a corresponding quality factor. If e.g. the value of the width of a crack is larger than 1,5 mm, this corresponds to weighting '3' in the table field 'Width_Index'. If the orientation of a crack is characterized as 'vertical', the 'Orientation_Index' receives value '2' and so forth. Based on the individual indices finally a preliminary crack-index can be determined, which indicates the effect of the crack on a specific element.

The information of the location of the crack within a structural part is also of greatest importance. It is very decisive, whether it is located in a certain distance to a frame knot (that is a crossover of girders and pillars in a reinforced concrete frame building). A pure consideration of its attributes can not reveal this importance, thus for this purpose; a spatial analysis is necessary. If a crack is within the specified distance of a frame knot, another value is added to the preliminary crack index. The determination of the total crack index is possible only now. After all crack indices were computed; these can be assigned to the structural part they belong to. After the sum of the crack indices of every reinforced concrete pillar was determined, the total damage degree of a pillar can be calculated. This presumes that also the other damage indicators of the pillars (e.g. the tilt) have been assigned corresponding indices (e.g. Tilt_Index). All the indices were summed up using specific weights to indicate importance of the factors. As a result, the total damage sum results for an individual structural part and therefore a damage rating like "heavy", "mean", etc.. Based on the damage values of the respective structural parts of a specific building type finally the calculation of the total damage value of an individual building and with that the assignment to a damage category is possible. This damage evaluation then in turn represents the basis for the elaboration of redevelopment concepts.

The individual parts of the program were integrated into a menu interface and can be activated from there. The user is guided during the carrying out of the processes via dialog boxes in order to minimize the sources of errors using the individual programs [Volz 1997]. In total about 60 individual programs were written, which allow the calculation of the total damage sum for all building models in accordance with the damage calculation methodology applied in Dinar. Considerable timesaving can be

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achieved by the automation of the calculation processes. Whereas for analogue calculation 5 min per building are necessary, the automatic system produces the solution within seconds.

5   EXAMPLES

As explained in the previous paragraph, using Avenue, which is the macro programming language of ArcView, several menus were established. The aim of the programming with ArcView was to automate the damage analysis of a building located in an earthquake area. For this purpose, several steps were executed. To test the properties of ArcView example data were created. In the damage calculation process all features that have an effect on the damage evaluation of a building have to be considered. Figure 5 shows the automatic selection of the crack structures in the given example data.

Figure 5 Automatic selection of the crack structures using example data and the results for the indexes.

The first step is the evaluation of a single construction element. In order to do that, all the damage indicators of special construction elements have to be examined. We give an example for the reinforced concrete column. Indicators for the damage of a reinforced concrete column are: its inclination, its movement, cracks that occur on it, etc. The cracks are more important because of all damage indicators they have the strongest effect on the damage of a construction element. These effects can be described in terms of damage indicators. For each crack all features that characterize this crack, such as its length, its width, its area, its position etc. have to be determined. However, the indicators of a crack are not all of the same importance, so the importance of special indicators has to be provided, e.g. the width of a crack is of higher importance than its length. This is done by indexes. Adding all damage indicators of a crack results in a "preliminary crack index".

A total crack index is written to a table, where also all the other indicators of a construction element have to be described. All indicators of a construction element are added up to yield a result, the so-called Element Damage Point (EHP) for the columns, beams etc. This process is repeated for all the construction elements of a special type. In order to get reliable, i.e. worst case values, the damage assessment is calculated for the most damaged floor, which usually is the first floor. The final result is the so-called Total Damage Point (THP) value for the building. This final value is used to determine the total damage degree of the building.

Figure 6 visualizes the result of the photogrammetric measurement of the cracks in the image using the facilities of ArcView. This image of a slightly damaged building has been taken using the Kodak DC200 Digital Camera. The crack measurement was performed with the digital photogrammetric software PICTRAN. The damage indicators of the cracks (e.g. the length and the widths of the cracks) are stored in the related attribute tables. Future work will focus on the automatic calculation of these values directly from the measured data.

Figure 6 Overlay of the CAD file of the cracks obtained by means of digital photogrammetric software and image of the building.

Both damages of the on the first floor obtained by photogrammetric evaluation and image of the same floor can be seen on the Figure 7. A part of a map of Dinar is also added to this figure to show the location of the damaged building in the city.

Figure 7 Result of photogrammetric measurement of the damages of the first floor of the building and related image (left); part of the City of Dinar with location of damaged building (right).

6   CONCLUSION AND OUTLOOK ON FURTHER WORK

Building type specific modeling of structure and damages led to a highly non-redundant data structure. As a result, a fast access to the data is guaranteed. On the other hand, the data acquisition based on this data model is afflicted with some problems. The main source of the problems is the acquisition of the geometry of all registered structures

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(that is from the building facade down to the individual crack). In order to speed up this data acquisition, there are several possibilities. On the one hand building templates can be given; thus only the individual damages have to be measures. On the other hand, automation in digital image processing can lead to an automatic recognition and measurement of damages In addition, it is subject to further investigations to clarify whether the high degree of detail of the building model is and where higher aggregates of information is sufficient.

With regard to the query, analysis and presentation of the project data, there are no restrictions. ArcView is a slim GIS-product; nevertheless the query and analysis possibilities are very suitable for this project, just because of their simple handling. Furthermore, the presentation of results in the form of maps and charts is appealing. Moreover, correlation of different attributes can be illustrated easily in diagrams.

The automation of the process of damage analysis and evaluation can easily be achieved with ArcView. It is of special importance, that also spatial analysis operations can be included into the automatic damage assessment, and that the valuation codes can be chosen individually. Thus the use of a GIS leads to a considerable timesaving.

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