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Photogrammetry and GIS for the acquisition, documentation and analysis of earthquakes

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Keywords: Photogrammetry, GIS, Hazard Determination, Documentation

ABSTRACT: Earlier earthquakes revealed problems in the processes of documenting and analysing the building damage that occurred due to earthquake disasters which demanded much efforts in terms of time and man power. The main difficulties appeared because analogue damage assessments created a great variety of unstructured information that had to be put in a line to allow further analysis. Apart from that, documentation of damage effects was not detailed and could only be carried out on the spot of a disaster. The aim of this paper is therefore to make an improvement to this situation. It shall be reached by the combined use of a photogrammetric documentation method and a Geographic Information System (GIS). The implemented system is used in the earthquake in Dinar/Turkey in 1995. The experiences gained from this application can be used also in different natural disasters. The main part of photogrammetric data acquisition consists of a CCD-Camera (KODAK DCS200), hardware (a powerful laptop-computer) and digital photogrammetric software (PICTRAN, by Technet). The Information System Part consists of an information system software package (ARCWIEW, ARCINFO, by Esri).

1 INTRODUCTION

With each passing day, catastrophe risk for urban regions of the world is increasing. One of these catastrophes is the earthquake and recent events in Northridge and Kobe were typical examples of what can happen when a major earthquake strikes directly under a densely populated area. Megacities created by the rapid urbanisation and development in unsafe areas led to far greater losses experienced in the past. In order to reduce the property losses after an earthquake a quick repair process is a major task. This process must be based on detailed plans for rebuilding or strengthening procedures of the buildings. The aim of this paper is to present a different approach in the monitoring, documentation and analyse the damages in the buildings after an earthquake.

2 PHOTOGRAMMETRY AND GIS IN THE EARTHQUAKE RESEARCHES

Geodetic science plays an important role in the earthquake research. By means of long-term measurement, deformations caused by the breakage of the earth crust caused by the moving plates can be examined. Photogrammetry and Information System techniques are new tools in the earthquake research. Terrestrial photogrammetric methods have been used for the first time to document the damages after an earthquake in Friaul, Italy (Foramitti, 1980). A similar study to this research is the work after the Kobe earthquake (Kiremidjan and King, 1995). In this study they declare that the information system is an essential tool in the earthquake research.

They evaluate the damages of the building by using their own computer program developed in the 80's for a research project in Zagrep University (Anicic and Radic, 1990). The use of an expert system for the evaluation of earthquake damages based on expert systems using evaluation tables is

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research currently under investigation (Papnoni, Tazir and Gavarini, 1989). The research work at Karlsruhe University "Strong Earthquake", Germany, sponsored by the German Science Foundation (DFG) use data acquired at a smaller scale.

3 DATA AQUISITION BY PHOTOGRAMMETRY

Photogrammetry is an efficient tool in monitoring of spatial objects with respect to location, form and shape. Its main advantage to other measuring techniques lie in the fact that the measurement is done on the images and indirect measuring possibility opens the users of this method a wide range of application possibilities. So the recorded images contain a great extend of information so that many of the detailed acquisition of deformation can be done afterwards. To establish the deformation of a building from its complex details, three-dimensional coordinates of characteristic points related to the structure of the building must be known. In order to measure them, these points must be projected at least in two images.

With known camera calibration parameters (interior orientation parameters) the unknown 3D-object coordinates (XYZ) can be computed by measuring their image coordinates of the object (in this case of the building) points. Their values can be determined with an adjustment procedure (bundle adjustment). The faulty measurements will be eliminated by this way and a precise measuring capability can be reached. In order to relate the determined XYZ coordinates to an overall coordinate system, control points with known coordinates are used.

Today in addition to so called classical, analog ways of photogrammetric data handling, digital methods are also used. This enables an automation of data processing by means of image analysis and matching techniques. In this context 3D-object reconstruction techniques, classification or image detection and their integration into a deformation analysis procedure using information system technology can also be used.

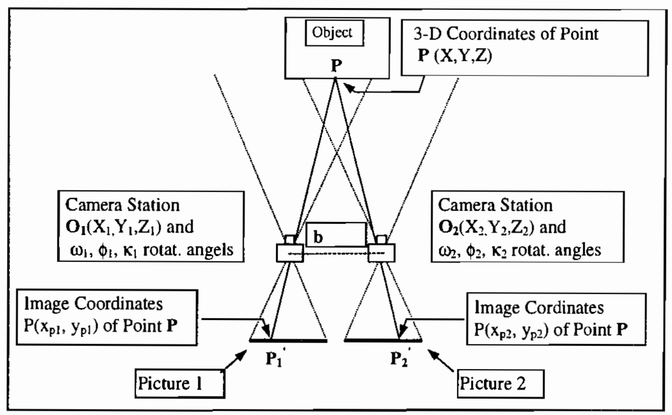


Figure 1. General case photogrammetric data acquisition.

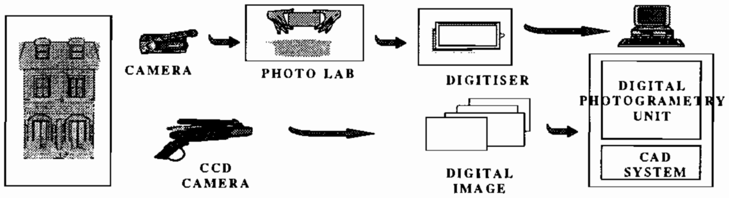


Figure 2. Data flow in photogrammetric evaluation process.

In order to determine the deformation of a building as a whole system, the 3D-shape of building must be reconstructed. This reconstruction procedure must be based on the determined coordinate of the building characteristic points. As the damaged buildings after an earthquake is a potential danger for the investigators and also passengers the first determination must be based on the points on the facade of the building.

Secondly no prior measurements of these buildings are available in order to relate the deformed values to. In this investigation the following way was chosen. At least two plumb lines hanging down on the facade of the building define a vertical plane. Based on the assumptions that the lowest points of the building can be considered stable, and the facade is build, as in most cases, vertically, all deviations can be related to this vertical plane and to the coordinate system, which can be defined for the specific case (see Külür, 1998).

This approach allows a quick documentation. Using the digital technology, the photographic processing has disappeared and on line registration can be used. In the research work a digital

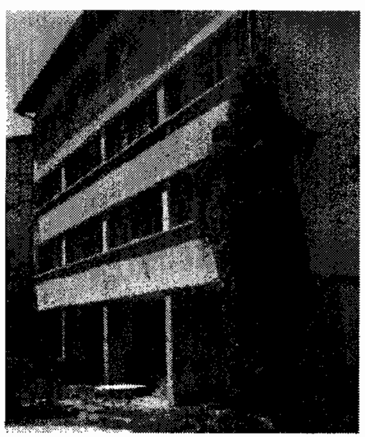


Figure 3. Digital photo of the damaged schoolhouse obtained by KODAK DCS 200 and plumb lines used as scale information.

camera by KODAK (DCS 200) has been used. This allows to load the pictures directly to the laptop computer at site and to begin immediately with the processing of the gained data. The damaged high school building in DINAR was photographed with this camera. The processing and evaluation of the images was done with a photogrammetric software package PICTRAN (Schewe, 1995). The result is the coordinates of the characteristic points defining the movement of the building. These characteristic points are on the 11 different axes of the high-school building. They are also chosen on the heights of the stories of the building (in this case 4). So by means of axes and stories as quasi-heights, a systematic grid is placed on the facade of the building.

From these coordinates displacement values are calculated according to the following formulas;

Relative Height Differences: $H_r(i) = Z(i) - Z(i-1)$
Absolute Depth Differences: $D_a(i) = Y(i) - Y(1)$
Relative Depth Differences: $D_r(i) = Y(i) - Y(i-1)$

Similarly absolute height difference or unknown values can be calculated in two other directions. Displacement values of the damaged points can be seen in Table1. These values were calculated in each of the three coordinate directions. In order to give a better possibility for interpretation of these results, these values are transferred to a CAD program. A CAD-plot of the deviation from the vertical plane in the direction parallel to the building facade (X and Y-direction) can be seen in the Figure 4. These kinds of graphical displays, the values of relative displacement of stories and the inclinations of the columns to the below one give valuable information about the buildings movement during the earthquake. These values can be compered with maximum values given in the codes of the country.

Table 1: Displacement values of the deformed points in the three coordinate directions.

DISPLACEMENTS (mm) IN Z-DIRECTION OF THE FRONT FACADE

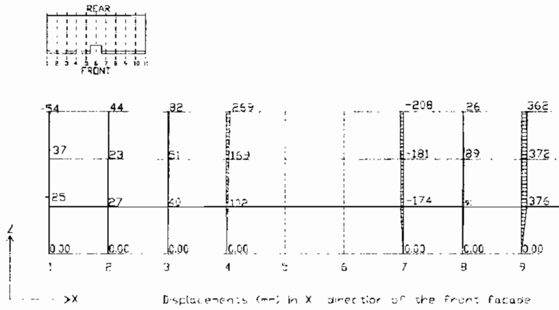
Story \ Axes	1	2	3	4	5	6	7	8	9	10
3	744	241	-380	-605	-105	105	500	61	-152	-410
2	515	203	-237	-480	-133	133	347	23	-96	-273
1	217	130	-93	-254	-56	56	198	-17	-27	-155
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISPLACEMENTS (mm) IN Y-DIRECTION OF THE FRONT FACADE

Story \ Axes	1	2	3	4	5	6	7	8	9	10
3	-205	-453	174	55	478	689	900	351	57	-16
2	-134	-392	183	58	389	555	720	222	22	-48
1	118	-386	257	72	258	351	443	127	09	-13
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISPLACEMENTS (mm) IN X-DIRECTION OF THE FRONT FACADE

Story \ Axes	1	2	3	4	5	6	7	8	9	10
3	-54	44	82	269	61	-135	-208	26	362	101
2	-37	23	51	169	-12	-103	-181	89	372	128
1	-25	27	40	102	-72	-123	-174	91	376	-30
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



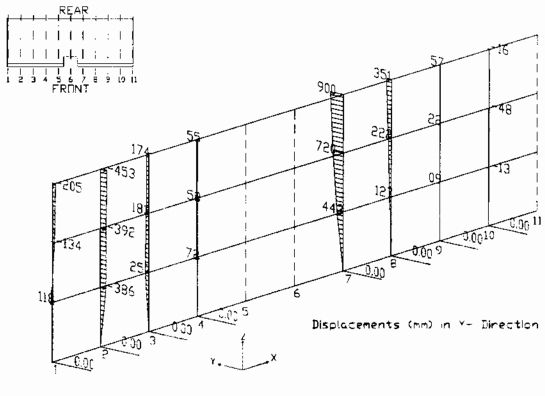


Figure 4. Deviations from the vertical plane.

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

$$\Delta_i = d_i - d_{i-1}$$

where d_i and d_{i-1} are the displacements of a column in i. and i-1. story. If we denote with h_i the height of these two adjacent stories, then the relative displacements of the point in question must be compared with two maximum values calculated as;

$$(\Delta_i)_{max} / h_i \leq 0.0035$$

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

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.

4 INFORMATION SYSTEMS AND QUERY (ANALYSIS)

Geographic Information Systems (GIS) consist of computer hardware, software and geographic data. They are designed to efficiently capture, store, update, manipulate and display all forms of geographically referenced information (Bill and Fritsch, 1991). Spatial data is obtained in digital form, rearranged, analysed according to several querying parameters and later presented in the form of either alphanumeric or graphical displays. Information systems can compile a great number of descriptive and geometric data, which is stored in a database.

The units in the geographic information systems are objects, which can be described by quantitative and qualitative components. Here the mentioned object should be regarded as a unit that exists in nature and that can be categorised geographically, physically and descriptively. Location and shapes of three-dimensional objects are defined as units with single meaning determined by point coordinates.

As mentioned above, a geographic information system differs from CAD or AM/AF systems in the joint management and administration of its geometric and thematic data. These thematic data are called as attributes. Objects are grouped according to their common characteristics or attributes. The data can be acquired by any kind of measurement technique, eg. geodetic and photogrammetric measurement techniques, digitiser, scanner, CCD-cameras and satellite images.

4.1 *Linking photogrammetry and information systems*

The main goal of the research project is the combination of the two methods described in the foregoing paragraphs. After the acquisition of the geometric deformations with photogrammetric methods, this information has to be analysed. Based on this analysis different conclusions can be drawn, eg. Evaluations concerning the stability of the building, decisions, whether it can be rebuilt or sold are torn down. Such decisions depend on many factors. An information system can provide an easy access to the stored data. In order to store the data efficiently and allow the access to it, a data model has to be established. To this end, the damage assessment sheets of the ITU, as well as international coding schemes have been analysed. Based on this study, a detailed data model has been put up, including the structural and damage related aspects of several building types (Volz, 1998). This model has been implemented in the GIS-product ArcView. Using the programming language Avenue, some of the analysis procedures could be automated; eg. the determination of damage degrees. These functions help to accelerate the analysis considerably.

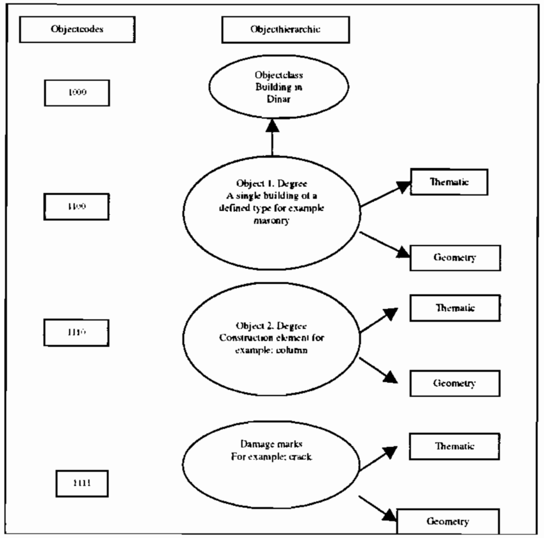

Figure 5. The object levels of data model according to the object class principle.

4.2 *Description of the methods used in earthquake damage acquisition and analysis.*

The method used in Dinar for the purpose of damage acquisition is developed by a joint research of the Department of Civil Engineering of the Middle East University in Ankara and the "TTU" working group "Earthquake Engineering". This concept is developed upon request of the Ministry of Building and Housing. Basically the acquisition consists of different parts, which was grouped later on for a building. The main part of this damage report is the "report", where all important information, attributes for building description, damage acquisition and analyse, are listed.

The total damage description is divided in different components. Besides analysing the damage for building in discussion, the building condition in a case of an earthquake is also considered. The geotechnical properties of the ground degree of the settlement of the basement are also considered. The essential description of the building is done by means of object class principle. The objects are described in different hierarchical level, by means of geometrical and semantically data see Figure 6.

The highest level of object class is the building itself, which consists of construction elements, objects of the second level. At this construction elements one can observe damage marks, eg. cracks which are the elements of a further level. The structuring of the data within the GIS-products Arc-VIEW is done in form of tables, which was constructed by means of the relational database dBase. Figure 7 shows the general layout of the object and damage description structurally.

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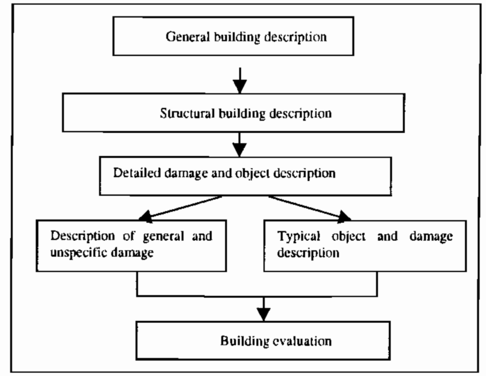

Figure 6. General layout of object and damage description

The input of data was realised by forms in MS Access. It was made easy by means of default values. Figure 8. Show such a form. There a question of buildings of the type "reinforced concrete whose damage points exceed 19 is listed.

4.3 *Analyse by means of GIS*

The essential part of a GIS is its analysing capability. The fundamental analysing methods are used in selection of objects according of typical descriptive or spatial criteria, their aggregation, etc. So one can easily define and locate all buildings with definite damage descriptions and this can be very helpful for possible repair process. See Figure 9.

Starting from the sample data, the first item was to design a concept for the automatic damage analyse and assessment. This was done for the construction element "reinforced concrete column".

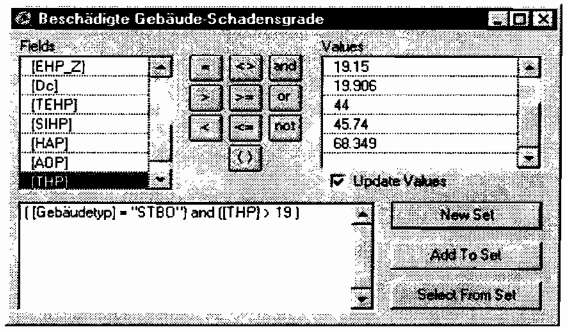

Figure 7. The "Query-Builder" in ArcVIEW.

Basically the damage analyse must start from the lowest object level, as the damage of an upper level element has to be calculated from the sum of investigated levels, at first. A single crack can be described by many parameters like, length, width, trajectory, position etc. According to these parameter values, the crack influences the damage grade of the specific element. For the total assessment of one element, other damage indicators must also be considered. In 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. After the consideration of all these parameters the damage grade of a column can be calculated. After the completion of the damage grades (eg. "Without damage", "slight damage", "middle damage" and "strong damage") for all the construction elements the total damage grade of a building can be calculated. This procedure reflects the basic idea of the damage determination used in earthquake analysis.

5 CONCLUSIONS

The documentation and analysis method explained in the above paragraphs reflect the results of a short-term study. In the preliminary evaluations so far made, the results displayed great differences from the manually obtained ones. In the current prototype, the building model is very detailed - further investigations have to focus on a thorough investigation of this data model in order to point out ways to accelerate the acquisition process. In general the use of an information system allows for the integrated documentation and analysis of earthquake damages and can be extended for a wider use as a catastrophe management system in general.

The main problem for further investigation is the acquisition of detailed object geometry by means of photogrammetric methods. In order to accelerate this procedure there exist appropriate tools. For instance the use of exemplary model in digital form for specific building types and to complete it by individual damage attributes has to be investigated. The completion of photogrammetric acquisition could lead to an automatic object extraction so that the digitisation effort can be minimised.

In this preliminary work the marking of control points on the facade as hanging plumb lines with weights was a job with some riscs. In further study these hanging down from the windows of the building should be replaced by mobile control-point systems.

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