GEOMETRY BASED ESTIMATION OF TRAPPED VICTIMS AFTER EARTHQUAKES

Christine Schweier

ABSTRACT

For the large majority of earthquakes, especially for those in urban areas, casualties are primarily caused by building collapse. An early and reliable estimation of the victims trapped in the collapsed buildings would help those responsible to respond in an optimised way to earthquake disasters. In the framework of the Collaborative Research Centre (CRC) 461 “Strong Earthquakes: A Challenge for Geosciences and Civil Engineering” at the University Karlsruhe a casualty estimation method was developed, which uses as input the fast determination of collapsed buildings in large urban areas based on laserscanning data and offers thus the possibility to fulfil this task.

By using airborne laser scanning measurements the location of collapsed buildings and the dimension and characteristic of their damage can be determined by a damage analysis. To interpret the found damage, the knowledge about typical damage types of collapsed buildings is necessary. Existing building damage classifications didn’t meet the requirements of this novel technique. For this reason, observations and reports of building collapses were analysed leading to a new classification of collapsed buildings and the definition of the so-called damage catalogue. This provided the basis for the development of a novel casualty estimation method, which allows to assess the trapped victims for each individual collapsed building of a stricken area and to support in this way the work of the emergency operation centres after earthquakes.

In this paper, first the above described reconnaissance technique will be briefly delineated. Then the conception and the implementation of the damage catalogue and its role for this reconnaissance technique as well as its use for the casualty estimation will be discussed. Subsequently, the developed casualty estimation method and its application possibilities will be presented in detail.

INTRODUCTION

The main cause of death and injury in urban areas in most large earthquake disasters is the collapse of buildings (Coburn and Spence, 2002). The losses in life could often be reduced by fast and efficient search and rescue (SAR) measures. But in the aftermath of earthquakes, especially in urban areas, the prevailing situation in the stricken area is often insufficiently known and the SAR resources are scarce. For this reason the early and reliable determination of the collapsed buildings and the estimation of the number of trapped victims in these buildings could help to optimally allocate the limited SAR resources and improve in this way the disaster response.

In the framework of the Collaborative Research Centre (CRC) 461 “Strong Earthquakes: A Challenge for Geosciences and Civil Engineering” at Karlsruhe University a casualty estimation method was developed, which uses as input the fast determination of collapsed

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buildings in large urban areas based on laserscanning data. In this paper first the concept of the rapid damage detection based on the airborne laserscanning technology will be briefly described. For the interpretation of the data collected by this surveying technology the knowledge about the structure of collapsed buildings is necessary. Since existing classifications didn’t meet the requirements of this new technique, a so-called “damage catalogue” was developed. The conception and implementation of this catalogue and its use for the above mentioned reconnaissance technique will be presented in the second chapter. Based on this classification of collapsed buildings a novel casualty estimation method to assess especially the trapped victims in each collapsed building of the stricken area was developed, that will be presented and discussed in the last part of the paper.

CONCEPT OF RAPID DAMAGE DETECTION

One of the important requirements for successful disaster response activities in urban areas after strong earthquakes is the fast retrieval of reliable information about the location, the extent and the characteristics of totally or partially collapsed buildings. To rapidly obtain information about the damage situation of buildings in affected areas, a method based on airborne laser scanning is being researched within the CRC by our colleagues from subproject C5.

The airborne laser scanning technology allows producing height data sets, e.g. digital surface models (DSM), for large areas without the necessity of entering these areas. The damage analysis is carried out by comparing planar surfaces extracted from post-earthquake laser scanning data with pre-event building models composed of planar surfaces and stored as reference models for the endangered area in a database. Differences found by comparing the planar pre- and post-earthquake surfaces of affected buildings are quantified in terms of change measurements like volume differences, inclination change, height reduction, or size alteration.

After the extraction of parameters indicating changes in the geometry of single buildings, a fuzzy logic classification concerning damage types can follow. This is a comparison of extracted parameters against those stored in the damage catalogue (see following chapter). That damage type with the highest degree of match is assigned to the building, but the likelihood for this classification result is given in addition. For more details see the paper of Rehor & Bähr, 2007 in these proceedings or Rehor, 2007.

CLASSIFICATION OF THE COLLAPSED BUILDINGS

To be able to use the data collected by the reconnaissance technique described above for the estimation of the trapped victims a novel classification system of collapsed buildings was necessary. Therefore a so-called ‘damage catalogue’ was developed. The damage catalogue is a compilation of different damage types of entire buildings typically occurring after earthquakes and their characterisation by geometrical features like volume reduction or inclination change. The damage catalogue was set up using various after-action and damage reports as well as photographs of damaged buildings, which were collected and analysed for this purpose.

Damage Types

In this approach damage types describe the damage situation of entire buildings. The classification suggested by Okada & Takai (2000) provided the base for the definition of the damage types. But their classification system was developed for a fast survey of damage by observers walking within the affected areas and it only covers a part of the possible damage structures after earthquakes. For the present task, to make the laser scanning data usable for the casualty estimation, their damage type list had to be adapted and enhanced.
Important criteria at the compilation of possible collapse forms were to cover all typically occurring damage types at earthquakes and to differentiate the damage types that cause different casualty numbers or have different SAR rescue requirements. In addition importance was attached to the fact that the peculiarities of the damage types are detectable in airborne lasercanning data.

The resulting damage catalogue contains 10 different damage types and numerous subtypes that can be summarized in five groups (cf. also Table 1):

- Inclined layers
- Pancake collapse
- Debris heaps
- Overturn collapse
- Overhanging elements

The group of the ‘inclined layers’ consists of the three damage types ‘inclined plane’, ‘multi layer collapse’ and ‘outspread multi layer collapse’. The damage type ‘inclined plane’ describes the inclination of the highest level of the building. The difference in height can be maximum the height of one storey. At a ‘multi layer collapse’ several upper floors are affected and the floor slabs form stacked layers to one side of the building. The difference in height is several floors. In both cases the lower storeys are no or not much damaged and the extent of the damage can concern the whole footprint or just a part of it. At an ‘outspread multi layer collapse’ the whole building is affected. The structural components of the building fall to one side or a corner and the expansion of the damaged structure goes beyond the borders of the initial footprint area. The floor slabs are mostly well preserved whereas the supporting structure of the involved floors is destroyed (cf. photo in Table 1).

Pancake collapses are characterised by the failure of particular floors, which collapse almost uniformly. To a large extent the building is preserved in its form and structure but has been reduced in height. Seven types of pancake collapses are distinguished, depending on the part of the building that is damaged and if one or more storeys are affected. Seen from above the most characteristic attribute is the nearly uniform height lowering over the entire footprint area.

Debris heaps result from the failure of all structural elements. Four forms of debris heaps are differentiated. The damage type ‘heap of debris on uncollapsed storeys’ describes the case that the upper floors collapsed and the top surface of the building is formed by a completely non-uniform structure of small debris parts whereas the lower floors of the building are not destroyed. For the damage type ‘heap of debris’ many or all floors are collapsed in a disordered way. No larger parts of the building are preserved. The surface is irregular and consists of small debris. For the damage type ‘heap of debris with plates’ all or almost all floors are concerned, too. Within the heap of debris larger plates can be identified, which withstood the collapse in one piece (cf. photo in Table 1). At the damage type ‘heap of debris with vertical elements’ not destroyed vertical elements, e.g. walls can be found in the heap of debris.
Table 1. Damage types

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<tr>
<th>INCLINED LAYERS</th>
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<tr>
<td>1) Inclined plane</td>
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<td>2) Multi layer collapse</td>
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<td>3) Outspread multi layer collapse</td>
<td>Example for an outspread multi layer collapse, Boumerdes/Algeria, 2003. Photo: M. Markus</td>
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<tr>
<th>PANCAKE COLLAPSE</th>
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<td>4a) Pancake collapse – ground floor</td>
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<td>4b) Pancake collapse – one intermediate storey</td>
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<tr>
<td>4c) Pancake collapse – top storey</td>
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<tr>
<td>5) Pancake collapse – all storeys</td>
<td>5a) Pancake collapse – several lower storeys</td>
</tr>
<tr>
<td>5b) Pancake collapse – several intermediate storeys</td>
<td>5c) Pancake collapse – several upper storeys</td>
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<th>DEBRIS HEAPS</th>
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<td>6) Heap of debris on uncollapsed storeys</td>
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<td>7a) Heap of debris</td>
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<td>7b) Heap of debris with plates</td>
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<tr>
<td>7c) Heap of debris with vertical elements</td>
<td>Example for a heap of debris with plates, Boumerdes/Algeria, 2003. Photo: M. Markus</td>
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<th>OVERTURN COLLAPSE</th>
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<td>8) Overturn collapse – separated</td>
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<tr>
<td>9a) Inclination</td>
<td>9b) Overturn collapse</td>
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<td>Example for an inclined building, Boumerdes/Algeria, 2003. Photo: M. Markus</td>
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<th>OVERHANGING ELEMENTS</th>
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<td>10) Overhanging elements</td>
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The group ‘overturn collapse’ consists of the damage types ‘separated overturn collapse’, ‘inclination’ and ‘overturn collapse’. For a ‘separated overturn collapse’ the lower part of the building is still at its original position, whereas the upper part lies separately next to it. At the damage type ‘inclination’ the building is inclined to a side or a corner (cf. photo in Table 1). For a complete ‘overturn collapse’ the building still forms only one corpus but it lies outside of the footprint area on one of the sides or corners.

The last damage type ‘overhanging elements’ describes the case that supporting external walls are destroyed, but the slab or the roof above remains at its initial position. Through the missing support a cantilevering slab is formed.

Geometrical features

To determine the damage types in the course of the damage interpretation from airborne height measurements, geometrical features must be defined which are detectable when comparing the pre- and post-event data. For this reason, geometrical features were determined by means of photographs from collapsed buildings and their development for the different damage types were analysed. The selection of the geometrical features that were to be examined was made on the condition that the features are recognisable from the air, can be recorded with the used technology and show different characteristics for the different damage types. Some of the twelve determined geometrical features are listed in the following:

- Total height difference to initial height
- Volume reduction
- Recognisability of the footprint borders
- Surface structure (unchanged, erratic, with large planes)
- Inclination change with reference to the initial situation within the footprint

Each damage type is characterised by the combination of different geometrical features and by the development of the different features.

Damage Catalogue

To find the typical development of the geometrical features for each damage type, 1865 pictures of 155 different damaged buildings were analysed and stored in a database so far. The database is continuously enlarged to improve the analysis results. The damage catalogue database contains the indication of the damage type and specifications to the geometrical features for each of the 155 damaged buildings. It specifies whether the respective feature could be found at the regarded building and if so in which development. In addition, further data, like the construction type of the buildings, their social function and the initial number of floors are also stored. The data records are complemented with the photographs, which were used for the investigation of the building.

The collected data was evaluated with the help of the database to set up the damage catalogue. In the damage catalogue a compilation of typical geometrical features is provided for each damage type and if possible the typical development of the features is also quantitatively indicated. This makes it possible to infer from the found geometrical features to the existing damage type by comparing the laserscanning derived pre and post event data. Separate compilations are provided for the frequently occurring combinations of damage types since many collapsed structures can’t be characterised by just one damage type and this circumstance has relevant effects on the geometrical details that can be observed. Not only quantifiable but also soft features were regarded, since they also contribute to the determination of the damage type.
Great importance was given to find those geometrical features which distinguish one damage type from the other. For more details concerning the damage catalogue compare Schweier and Markus, 2006.

Although the fast determination of the collapsed buildings and the determination of their damage degrees and damage types are already a great help in earthquake cases, it is sensible to use this information as input for further important tasks in disaster cases such as the estimation of the casualties.

**HUMAN CASUALTY ESTIMATION**

In most earthquake disasters deaths and injury are primarily related to building damage (Coburn & Spence, 2002). To reduce losses in life caused by collapsed buildings, it is crucial to rapidly identify the collapsed buildings, to search and rescue the victims trapped in these structures and to give them adequate medical care. Time is thereby a critical factor, because the survival chances of the trapped persons decrease quickly with the time (compare e.g. Coburn & Spence, 2002 or Tiedemann, 1992).

The developed casualty estimation based on the evaluated laserscanning data offers support for these important tasks. As mentioned above, by evaluation of the laserscanning data the collapsed buildings of an urban area can be identified rapidly. To find the collapsed structures amongst the undamaged or only lightly damaged buildings is especially important, because these buildings have the largest number of trapped persons. Moreover, in collapsed buildings most of the heavily trapped victims can be found, for whose rescue professional personnel and equipment is needed and whose rescue times are expected to be very long.

With the evaluated information from the laserscanning overflights it is not just possible to determine, which buildings exactly collapsed, but also which height and volume reduction they experienced and in which way they collapsed. This detailed input information allows on the one hand the determination of the victims for each concerned building and on the other hand a more exact estimation of the victim numbers than it was possible with past methods. Thereby primarily the number of the trapped persons is estimated, but in addition also an estimation of the injured and killed victims, subdivided in four injury classes, is given.

In addition to the mentioned there are further essential differences compared to existing estimation models, like for example the HAZUS method (National Institute of Building Sciences, 1999). Firstly, the casualties are estimated at the level of single buildings and not for an entire zone or region. Secondly, the estimation is carried out after the event using the real damage situation of the buildings as input. Other models estimate the casualties based on the damage degrees of the buildings calculated before the event. And finally only the casualties for collapsed buildings are estimated and not for all damaged buildings. Consequently the purpose of this estimation tool is to use the results to support those responsible during the disaster response to organise the rescue works and to optimally allocate the limited rescue resources.

The human casualty estimation model requires first input information about the damage state of the buildings. This is obtained from the evaluated data of the laserscanning overflights. For this casualty estimation is especially of interest which buildings collapsed, the damage type of the collapsed structures as well as the computed changes in the geometry caused by the impact, e.g. like height and volume reductions. The second required input information is the number of the people present in the buildings at the time of the earthquake (occupancy). This information is calculated based on data collected for each building before the event, e.g. like the social function, the total area and if known the number of the occupants. The occupancy of the buildings is determined for three scenario times; day (2:00 a.m.), night (2:00 p.m.), and commute (5:00 p.m.) time.
The time of a real earthquake is assigned to one of these scenario times and the computed occupancy for this scenario time is used to estimate the number of the victims.

The sequence of the casualty estimation for the collapsed buildings is outlined in Fig 1. Starting from the volume reduction of the building the number of the collapsed and uncollapsed storeys is determined using a specific volume reduction factor of the storeys. This factor was determined for the different damage types based on the collection of photographs in the damage catalogue. It describes the typical percental volume reduction of particular storeys for the certain damage type.

Then the occupancy of the building at the time of the earthquake is calculated as described above. If the building has different social functions, the occupancy is calculated for each part separately and then summated. Under certain circumstances - dependent of the time of the day, the social function and the footprint of the building - it is assumed that a part of the people present in the ground floor of the building could leave the building before it collapsed. This fact is considered at the calculation. The calculated occupancy for the entire building is then split up to the collapsed and uncollapsed storeys.

The persons within the two areas are then assigned separately to the four injury classes using injury rates. The number of trapped victims is calculated using the specific volume reduction factor mentioned above.

For the assessment of the trapped persons the damage type and the volume reduction of the collapsed structures are the most influencing factors. The construction type of the buildings enter just indirectly in the assessment, since the damage types of the buildings are amongst others depending on the used construction materials. The estimation model is based on the assumption that there is a strong correlation between the volume reduction of a building and the number of the persons trapped in it. In this model no prediction is given neither if the trapped people are alive nor about their health condition, because these facts depend too much from the individual case.

Besides the estimation of the trapped persons the total number of the victims for the concerned buildings, subdivided in four injury classes can be estimated with the presented estimation model. These estimations are for the individual buildings due to the used statistical methods not significant enough. But they can be entered in more general casualty estimation models in order to improve their results.
Such models are for example used to assess the impact of the earthquake on the population for certain areas (e.g. a city) before precise information from firmed sources is available.

CONCLUSIONS

This paper presents an approach to assess the casualty situation in urban areas shortly after an earthquake based on the evaluation of laserscanning data. The data collected by the airborne sensors at the overflight of a stricken area can be used to detect the collapsed buildings and to assess their damage type. To support this evaluation process, a damage catalogue including typical occurring damage types was developed. Based on the detected damage types the number of the trapped victims can be computed for each collapsed building with the presented human casualty estimation model. These estimations are especially of use in the first phase of the disaster response, at the organisation and coordination of the SAR rescue works. To further support those responsible in this field, also methods to assess the demand for SAR resources were developed (cf. Schweier and Markus, 2004).

The geometry based casualty estimation model is part of the so-called “Disaster Management Tool” (DMT). The DMT is a software system supporting decision makers, surveillance and intervention teams during disaster response. It is developed within the Collaborative Research Center 461 "Strong Earthquakes" based on the results of its engineering research projects. For more details compare Gehbauer et al. (2007).

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