
EDIM – Earthquake Disaster Information System for the Marmara Region, Turkey

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1. Introduction

The main objectives of EDIM were to enhance the Istanbul earthquake early warning (EEW) system with a number of scientific and technological developments that – in the end – provide a tool set for EEW with wide applicability. Innovations focus on three areas. (1) Analysis and options for improvement of the current system; (2) development of a new type of self-organising sensor system and its application to early warning; (3) development of a geoinformation infrastructure and geoinformation system tuned to early warning purposes. Development in the frame of the Istanbul system, set up and operated by KOERI, allows testing our novel methods and techniques in an operational system environment and working in a partnership with a long-standing traditon of success.

EDIM is a consortium of Karlsruhe University (TH), GeoForschungsZentrum (GFZ) Potsdam, Humboldt University (HU) Berlin, lat/lon GmbH Bonn, DELPHI Informations Muster Management GmbH Potsdam, and Kandilli Observatory and Earthquake Research Institute (KOERI) of the Bogazici University in Istanbul. The work packages (WPs) are distributed among the project participants as following:

WP A: Real-time information from a regional accelerometer network (Karlsruhe University)

WP B1: The Self-Organising Seismic Early Warning Information System (GFZ Potsdam)

WP B2: Infrastructure of Self-Organising Sensor Systems (HU Berlin)

WP C1: Development of a Dynamic Geoinformation-Infrastructure (DELPHI IMM GmbH)

WP C2: EDIM Information System (lat/lon GmbH).

2. Real-time information from a regional accelerometer network

This aims on the evaluation and optimisation of the existing EEW system for Istanbul, and on establishing the best database of seismic events in the Marmara region. As already described in last year's status report [Köhler & Wenzel, 2008], a set of 280 simulated earthquake scenarios located along the segments of the Main Marmara Fault has been developed for this purpose at Karlsruhe University. Subsets of the simulated data are used by DELPHI IMM as input scenarios for estimating building damages in Istanbul. These are based on spectral displacement values calculated from spectral acceleration of the scenario earthquakes delivered by Karlsruhe University.

The spectral acceleration is calculated from the response spectra that describe the peak motion response of a single-degree of freedom elastic structure (building) towards a base acceleration (seismic ground motion). With a damping of 5 %, the spectral acceleration is calculated for pre-defined periods. A comparison of the peak ground acceleration (PGA) and spectral acceleration with standard attenuation relationships from the literature [Boore et al., 1997; Campbell & Bozorgnia, 2008; Özbey et al., 2004] showed that, for a distance range of about 10 – 100 km, our simulated ground motion is of high quality. However, the correlation with the literature values is slightly better for larger magnitudes (M ≥ 7) and hard rock sites than for soft rock sites.

Because of this year's 500th remembrance of the historic 1509 Istanbul earthquake, we decided to additionally simulate this earthquake to investigate the effects of such a major event on today's city of Istanbul.

According to Ambraseys [2001], the earthquake ruptured a 70 ± 30 km long fault segment in the Sea of Marmara. Violent and protracted ground shaking in Istanbul were caused and probably also considerable damage in its immediate vicinity. About 13,000 people were killed by the earthquake.

We simulated the event analogue to the existing synthetic data by using FINSIM, a stochastic simulation method for finite faults [Beresnev & Atkinson, 1997]. We assumed a moment magnitude of 7.3 and a rupture length of 70 km. The event is located on the central fault segment between Istanbul and the Central Basin. The fault width is set to 18.9 km, with a fault strike of 265° and a dip of 90°. The depth to the upper fault edge is set to 0.4 km. For calculating the acceleration time series, the fault is divided into 7 sub-faults in strike direction and 3 sub-faults along dipping. The slip on each sub-fault is random normally distributed and varies between 0.0 and 6.6 m. The acceleration time series are calculated for Istanbul using a dense grid with 0.005°x 0.005° grid spacing by including the according site classifications of the grid nodes. The hypocentre location is set to the middle of the fault. For comparing directivity effects, we also set the hypocentre location to both ends of the fault.

After comparing PGA and spectral acceleration with the above mentionned attenuation relationships from the literature, we set the average stress drop to 5 MPa – this led to the best correlation of ground motion with the literature values (Fig. 1).

Fig. 2 shows the simulated ground motion maps for Istanbul for the three different hypocentre locations. The PGA values range between 23.1 and 456.9 cm/s² for the hypocentre located in the middle of the fault, between 21.1 and 391.2 cm/s² for the hypocentre located at the eastern end of the fault, and between 25.3 and 445.9 cm/s² for the hypocentre located at the western end of the fault. The seismic intensity values range between 4.4 and 9.1, 4.2 and 8.6, and 4.3 and 9.0, respectively. The ground motion depends strongly

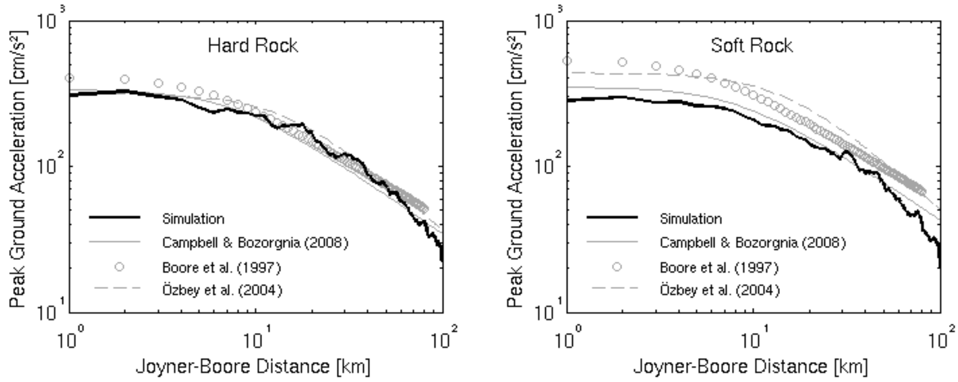

Fig. 1. Attenuation of PGA with distance from the earthquake for hard (left) and soft rock sites (right) of the 1509 scenario, with the hypocentre located in the middle of the fault. The simulation curves are smoothed over 5 km.

on the site classifications and the distance to the fault. In all three scenarios, the strongest ground motions occur on the European part of Istanbul. The fact that the nearest hypocentre position does not automatically generates the strongest ground motion is caused by directivity effects.

Another task of last year was the performance evaluation of PreSEIS, a neural network-based approach to EEW developed at Karlsruhe University [Böse et al., 2008], using real earthquake observations. The method is used as a benchmark system for performance tests of the Istanbul EEW system. However, due to the lack of real earthquake observations in the Marmara region, we tested the performance of PreSEIS using a dataset of southern California earthquakes instead. The results of this successful study have been accepted for publication by Seismological Research Letters *(Köhler, N., Cua, G., Wenzel, F, and M. Böse (2009). Rapid source parameter estimations of southern California earthquakes using PreSEIS. In press of Seismological Research Letters, DOI 10.1785/gssrl.80.5.743)*.

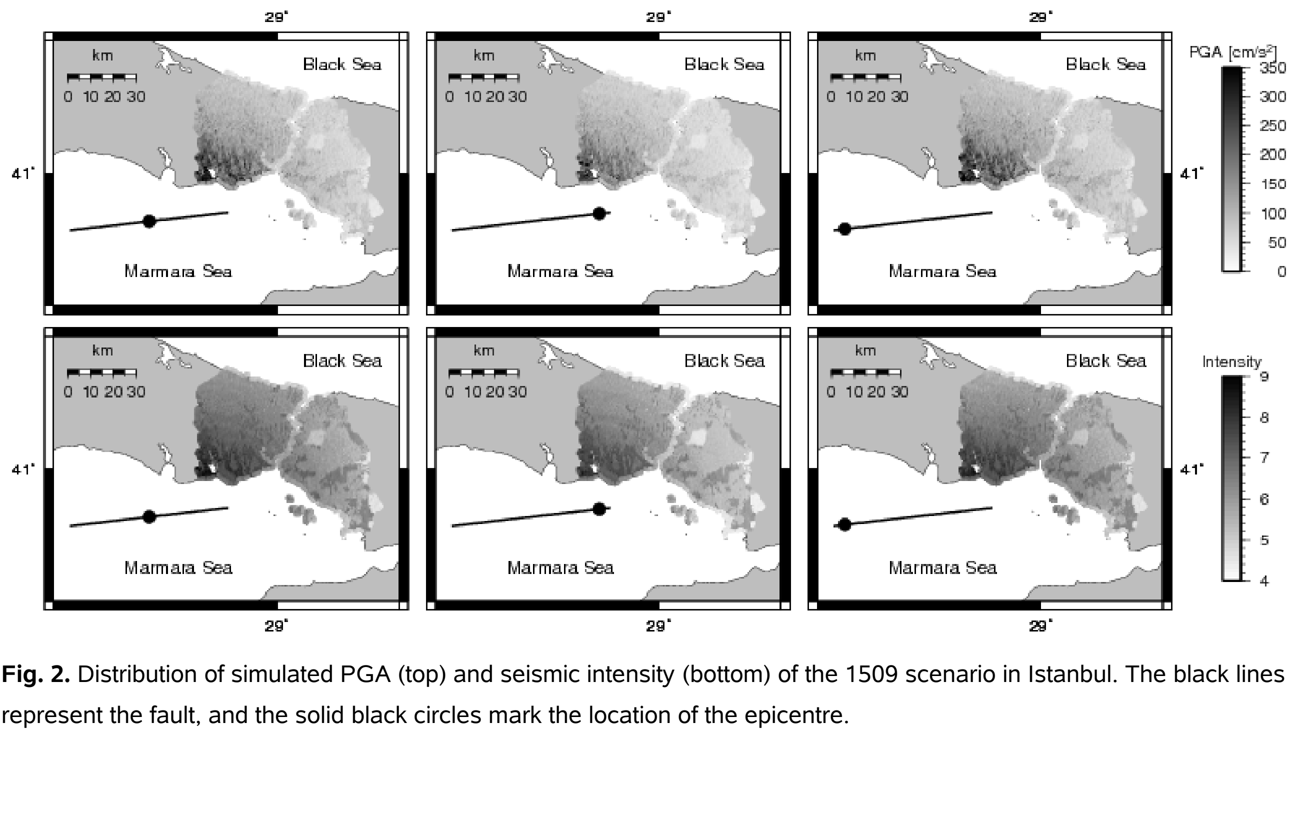

Fig. 2. Distribution of simulated PGA (top) and seismic intensity (bottom) of the 1509 scenario in Istanbul. The black lines represent the fault, and the solid black circles mark the location of the epicentre.

3. The Self-Organising Seismic Early Warning Information System

The Self-Organising Seismic Early Warning Information Network (SOSEWIN) is technically a decentralised, wireless mesh sensor network, made up of low-cost components, with a special seismological application that supports EEW and rapid response tasks. The development of SOSEWIN focuses on two points. The first is the design of the low-cost nodes themselves, while the second is its self-organising, decentralised character. The low cost nodes consist of an embedded computer equipped with 2 WLAN Mini-PCI cards, a compact flash card as data storage and a digitizer board with MEMS accelerometers and a GPS unit which delivers the seismic data. The basic system software running on a node consists of OpenWRT (Linux), OLSR as a self-organising mesh network routing protocol, a Seedlink server, and further self-written components to retrieve, store and process the acceleration data measured by the SOSEWIN nodes. The system is developed by GFZ Potsdam and HU Berlin.

GFZ activities focused on testing the SOSEWIN system and the identification of operational problems: Significant progress has been made during the last year with regard to utilizing the system for seismic early warning and for civil infrastructure monitoring.
Since July 2008, a first test-bed deployment of the SOSEWIN EEW system is operative in the Ataköy district of Istanbul. The network of 20 stations provides a continuous streaming of data that a Seiscomp Server at GFZ collects in real time, and distributes them to third parties (e.g. KOERI, HU Berlin, and lat/lon).
In cooperation with the colleagues of HU Berlin, the performance of the network is continuously monitored. Nonetheless, since during this period of time no relevant seismicity has been observed close to Istanbul, the preliminary tests about the test-bed network performance focused on the various aspects of communication.
The main positive results are

- the performance and the long-term stability of the sensor nodes as strong motion sensors, which have proven to be running stable for several months;
- the performance of the installed network and its self-organisation capability.

During this period, also several problems were faced and solved: Problems with the WLAN drivers were observed and the rate of transmission of the accelerometric data had to be throttled to 1MBit/s. However, despite the low rate of transmission, there is still enough bandwidth for streaming all data out of the network with SeedLink. Modifications of the SOSEWIN's software by HU Berlin allows to increase the data rate from 1 MBIT to a higher value. In the long period we observed problems with the performance of standard, commercial CompactFlash (CF) cards (which act as the hard-disk of the SOSEWIN stations). In order to solve these problems, we tested a new industrial grade CF cards. These new hardware components showed a higher level of reliability. SOSEWIN's software was optimised for the new CF cards by HU Berlin.
A manuscript dealing with the description of the SOSEWIN philosophy, hardware, and software, as well as an overview of the communication performance for the first test-bed SOSEWIN deployed in Istanbul has been accepted for publication by Seismological Research Letters *(Fleming, K., Picozzi, M., Milkereit, C., Kuehnlenz, F., Lichtblau, B., Fischer, J., Zulfikar, C., Ozel, O., and the SAFER and EDIM working groups. The Self-Organising Seismic Early Warning Information Network (SOSEWIN), accepted to be published by Seismological Research Letters)*.

During summer 2008, the suitability of the SOSEWIN system for monitoring the vibration characteristics and

dynamic properties of strategic civil infrastructures has been tested. In particular, an ambient vibration recording field test on the Fatih Sultan Mehmet Bridge in Istanbul has been performed. The bridge is also equipped by a traditional vibration monitoring system encompassing 5 Guralp Systems CMG-5TD instruments. These instruments are located inside at the edges of the deck and provide continuous data by transmission to KOERI. One of the main goals of the experiment was to compare the signals recorded by the SOSEWIN and Guralp sensors.
Fig. 3 shows the corresponding Power Spectrum Density (PSD) functions computed for the vertical components of motion at the sensors located approximately in the middle and one-third of the bridge's deck. Despite the WSUs lying over the bridge's deck while the Guralp sensors are installed inside the deck, the agreement between their PSDs is still strong.

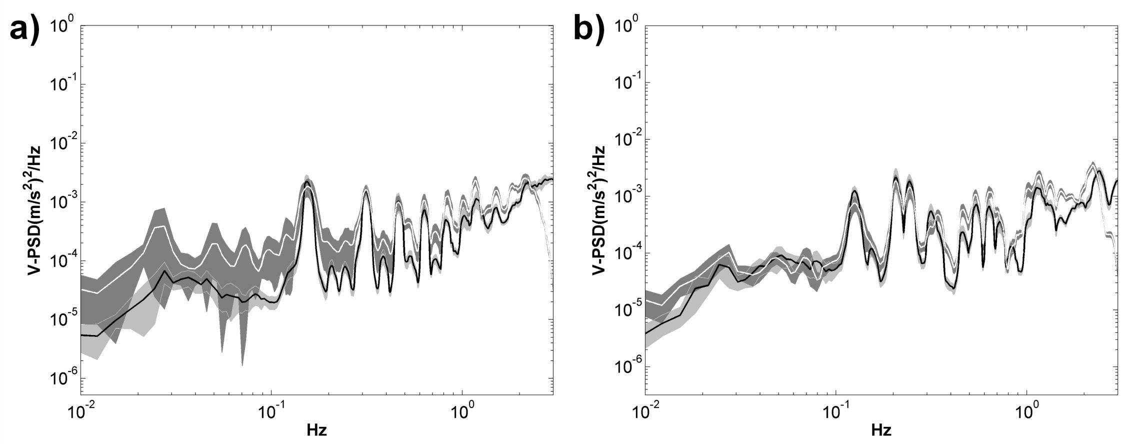

Fig. 3. PSD functions for the vertical components of motion. Average PSD plus +/-95% confidence interval for SOSEWIN (*white and dark grey, respectively*) and Guralp (*black and light grey, respectively*). (*a*) Sensors located on the middle of the bridge's deck (i.e. WSUs over the deck, and Guralp within the deck). (b) Similar to (a), but with nodes located at about 1/3 of the way along the bridge's deck.

Fig. 4 provides an overview of the ambient vibration analysis results for a pair of SOSEWIN stations installed at characteristic locations on the bridge (i.e. the deck, and the towers, respectively). When comparing the average spectral ratio (SR) curves (Figs. 4c and d) for pairs of sensors installed at different points, it is clear that SOSEWIN stations provide consistent and robust results, with a clear image of how the diverse parts of the bridge react differently to the ambient vibrations. Moreover, SR spectrograms (Figs. 4e and f) show that ambient vibrations have a stationary character, and indicate that the SOSEWIN stations provide stable estimates.

Comparisons with standard instrumentation and results obtained in terms of modal properties of the bridge indicate an excellent performance of the low-cost WSU. The results were found to be consistent with those from the studies of Brownjohn et al. [1992], Apaydin [2002], and Stengel [2009].
A manuscript dealing with the testing of SOSEWIN for the monitoring of the Fatih Sultan Mehmet Suspension Bridge has been accepted for publication by Bulletin of Earthquake Engineering (*Picozzi, M., Milkereit, C., Zulfikar, C., Fleming, K., Ditommaso, R., Erdik, M., Zschau, J., Fischer, J., Safak, E., Özel, O., and Apaydin N., (2009). Wireless technologies for the monitoring of strategic civil infrastructures: an ambient vibration test on the Fatih Sultan Mehmet Suspension Bridge in Istanbul, Turkey. In press on Bulletin of Earthquake Engineering, DOI 10.1007/s10518-009-9132-7*).

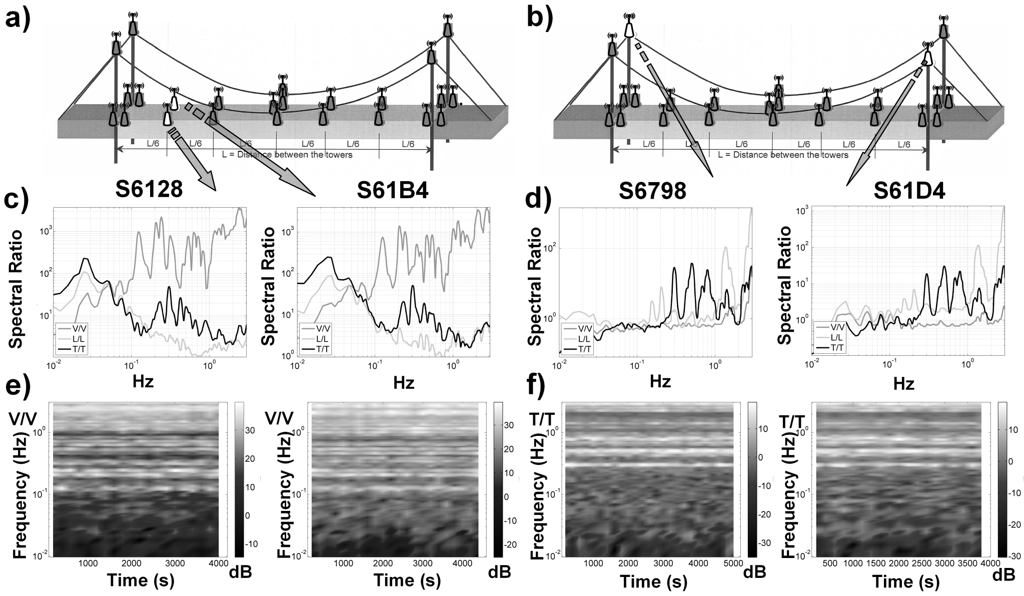

Fig. 4. Results for pairs of WSUs. *(a)* Selected sensors (*white symbols*) placed at the bridge's deck. *(b) is* similar to *(a)*, but of sensors placed on top of the bridge's towers. *(c)* and *(d):* Spectral Ratio (SR) functions for the vertical (*dark gray*), longitudinal (*light gray*), and transversal (*black*) components of motion. (*e)* and (*f*

HU Berlin focused on further development of the system architecture and software improvements: Fig. 5 shows an overview of the current SOSEWIN layer architecture with several services. The core functionality of SOSEWIN is the EEW and therefore it provides a hierarchical alarming system, defined by the alarming protocol. Following a model-based development approach, the alarming protocol is based on common structure and behavioural models. The alarming protocol was defined informal and based on this, a formal description language (SDL in addition with ASN.1/UML/C++) was used to build up a formal model of its functionality. Using such a formal model, code for the target hardware platform (sensor nodes) and for different kinds of simulators supporting different experiment scenarios (including the system and its environment) in preparation for the implementation is generated. A further speciality of our approach is the integration of the model-driven tool chain into a spatial-time-based Experiment Management System (EMS) in connection with a Geographic Information System (GIS). This allows us to describe the WSN topology and the distribution or movement of the physical phenomena in a geographic map. All tool components are integrated by our GIS-based Development and Administration Framework for Wireless Sensor Networks (GAF4WSN). With this infrastructure large networks with thousands of nodes can be simulated in their behaviour and evaluated. It allows also administrating the prototype SOSEWIN installed in Ataköy, Istanbul.

The functionality of the alarming protocol depends on several parameters with certain value ranges (e.g. earthquake event parameter, group topology). All the combinations of the parameter values are setting up a huge parameter space which has to be taken into account in the test and the evaluation of the alarming protocol. Experiments covering (interesting parts of) this parameter space have to be done within different execution environments (different simulators and real-world prototype), where each has different limitations, feasibility and significance. The aim is to observe the complex dynamic reaction of the system using different input configurations according to the identified experiment sets in different execution environments, answering particular questions about the system's behaviour.

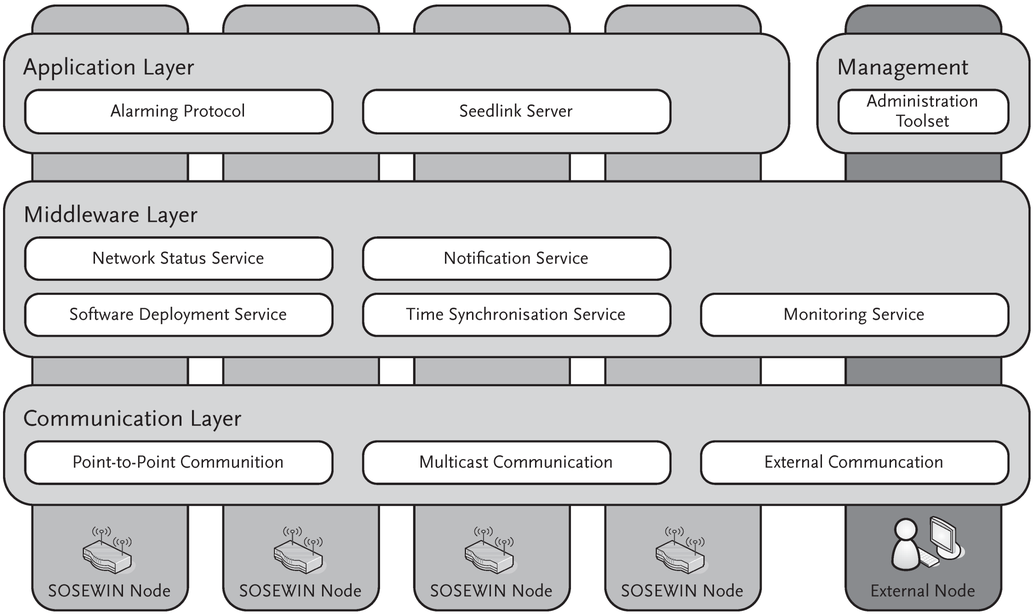

Fig. 5. SOSEWIN layer architecture.

For example, Fig. 6 shows the results of a simulation experiment set of 20 experiments whereas the distance between the epicentre and the first station of the network varied from 2 to 40 km in a step width of 2 km. All other parameters (e.g. wave travel speed, rupture characteristics, network topology, P-wave detection parameters) are constant. As expected, there is a linear correlation between the distance and the time when the early warning message leaves the network: increasing distances result in later detections due to the longer way the seismic waves are travelling.

In the future work we will continue experimentation (e.g. with larger SOSEWIN topologies) and connect the SOSEWIN prototype installation in Ataköy with the visualising infrastructure developed by our project partners lat/lon and DELPHI IMM.

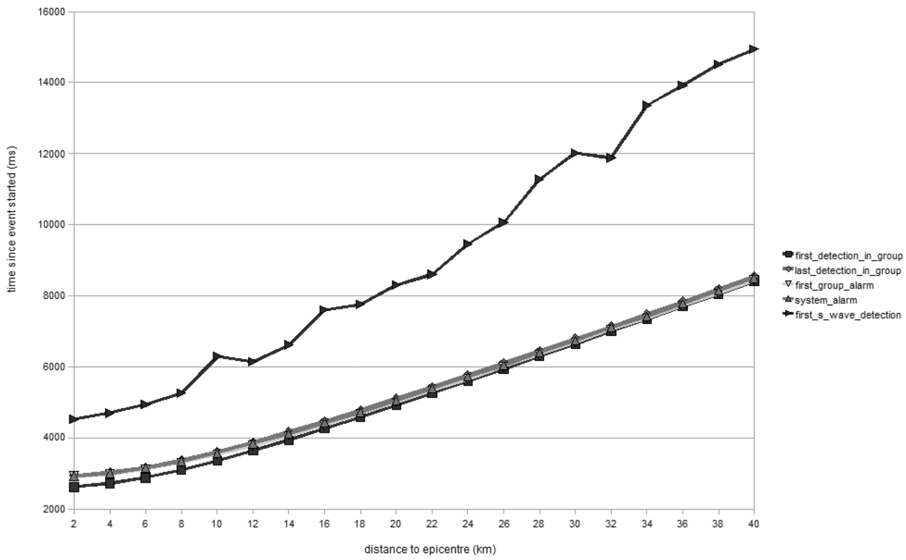

Fig. 6. Results of simulation experiment.

4. Geoinformation Infrastructure and geoinformation systems

EEW and rapid response are – to a large extent – based on information provided in a geospatial context and to a specific, generally restricted, set of users. In this frame information services such as rapid damage estimates and a mediation system are needed (Work Package C1 of DELPHI IMM GmbH) and the organisation of access to information and real-time sensor data must be assured (Work Package C2 of lat/lon GmbH).

Damage calculation due to earthquakes is fundamental in regions at high risk of earthquake and with dense population. Both conditions apply particular to the Megacity Istanbul, which is less than 10 km away from the Main Marmara Fault with a rapidly growing population (see Fig. 7). The dynamic geoinformation infrastructure consisting of a damage estimation service for buildings and a mediation system for flexible visualising earthquake information responds to these current requirements in the field of disaster management. Here we also integrate achievements of the other work packages dealing with ground motion prediction and information and sensor networks. Results of work package C1 were presented and discussed in May 2009 at a meeting in Istanbul with members of AKOM (Afet Koordinasyon Merkezi) and KOERI. User requirements are already considered in our geoinformation infrastructure.

Rapid assessment of building damage after an event (rapid response) is important information for operating a disaster task force, getting a quick damage overview or doing cost estimations. Damage estimation service (DES) is implemented in JAVA as a web service as it aims at quick calculation, at being available for many users and especially at being integrated in a spatial data infrastructure. DES procedure is based on the FEMA356 coefficient method, modified by KOERI. This performance-based method assesses the damage probability with respect to vulnerability of buildings due to building structures. A main item of this method is the building inventory of Istanbul, classified with respect to building type (e.g. RC frame building, masonry building or pre-fabricated building), building height and construction date. Construction date is an important factor to classify the design level for buildings because it gives some hints about the applied seismic code. Probability values of each damage class and building class for every grid cell is an intermediate result of this six-stepped processing. Finally, the number of affected buildings will be calculated. The expertise of KOERI was thankfully used for validation.
The use of DES for planning (long before an earthquake) or scientific scenario analysis is as import as the use in the event of damage. The above described simulated scenarios of the historic 1509 Istanbul earthquake from Karlsruhe University were used as input for damage calculation to show the impact on the current building inventory.

Fig. 7 shows the results of the three scenarios differing in the position of the hypocentre. With the help of DES, the different impact on buildings caused by shifting the hypocentres can be shown. As for the distribution of ground motion, not the nearest hypocentre location affects the most damage on buildings. For scenario 1 and 3, almost the same number of buildings is affected (about 30 %). The distribution of damage classes is almost identical, as well. The area of extensive destroyed buildings stays the same for all three scenarios.

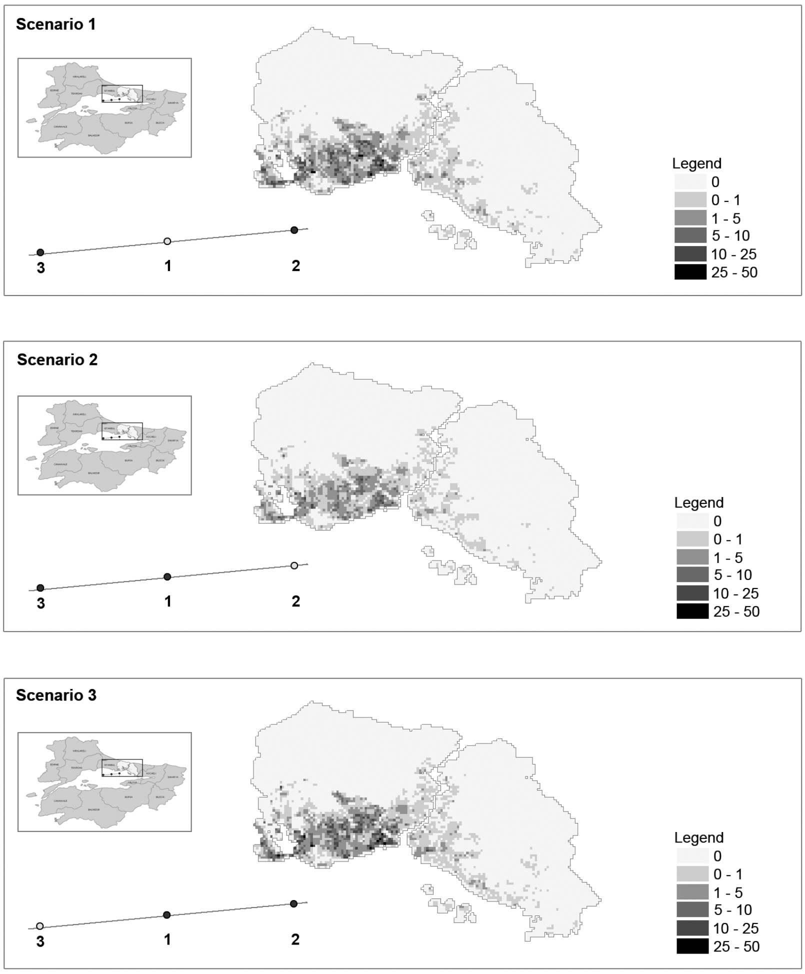

Fig. 7. Comparison of complete building damages of the three simulated scenarios for the 1509 earthquake.

The Mediation system visualises information of earthquakes, especially the results of building damage, by using user-flexible functions. It is realised as an OGC (Open Geospatial Consortium) compliant MapClient and address to further web services, for example DES. In the field of disaster management it is necessary to analyse information according to individual requirements in order to give strong statements and make the right decisions. For this purpose, a flexible filter system is available which allows the selection of any combination of building and damage classes. In addition, a statistical statement of the total number of affected building for the five damage classes (slight, moderate, extensive and complete) supports the interpretation. The simultaneous viewing of two earthquake results is a new implemented function which is very helpful for comparing scenarios in detail. The individual selected view of damage data can be OGC compliant integrated into the EDIM information system to view the information in a broader context.

Work package C2 as part of the overall goal of the EDIM project deals with providing access to data relevant for analysing earthquake related information in the Marmara region. Besides the access to data and information, an EEW and rapid response component should also be accessible to restricted user groups. As potential user groups lat/lon has identified scientists analysing historical as well as most current data sets, EEW/rapid response specialists from AKOM, and interested parties from the general public. During an on-site demonstration in Istanbul the information system (Fig. 8) and the underlying concepts have been presented to local stakeholders and the assumed set of user groups has been verified. In order to restrict access to classified data to an authorised user group, the system has been enhanced by a user-/and rights management component.

The access-restricted EDIM information system is realised as a Spatial Data Infrastructure based on the deegree framework [Fitzke et al., 2004] and is therefore implemented as a set of loosely coupled services adhering to OGC interfaces.
While the first two project years were coined by development and enhancement of the service architecture, the integration of components by project partners has been focused since 2009. This includes an integration of the EDIM DES provided by DELPHI IMM, an integration of various data sets provided by KOERI as well as a connection to the SAFER middleware for Geographical Applications [Fischer et al., 2009].

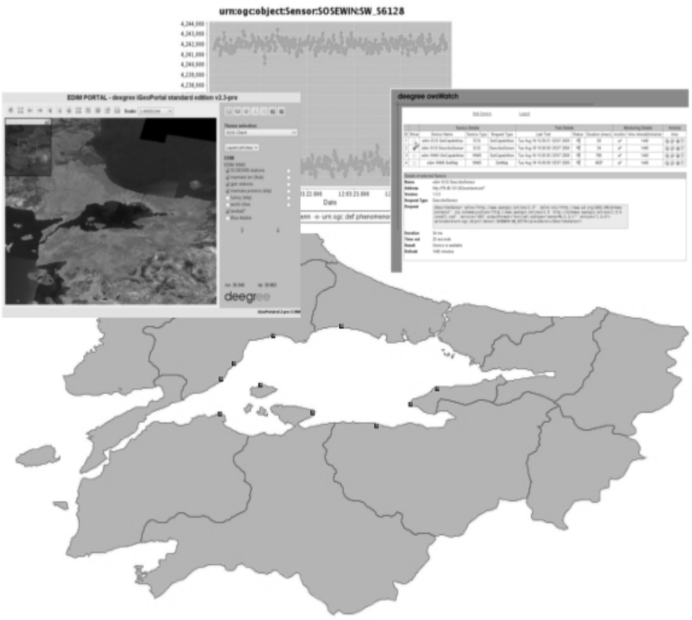

Fig. 8. Three screenshots of the EDIM Information System (backed by a vector dataset illustrating the Marmara region).

In addition to software implementation the following goals have been archived:

- Project partners as well as potential users of the information system have been informed about the current project status during a workshop in Istanbul.
- Project partners as well as potential users in Istanbul have been granted with access to the Information System in order to provide feedback on the usability and functionality of the system.
- User access to the system has been restricted. Classified data will only be visible to authorised persons. Authorisation is ensured through the deegree user rights management system.
- A concept for realising high availability of the infrastructure is under development. This concept utilises the paradigm of Grid computing [Foster & Kesselman, 1998] to archive service availability, short response times as well as advanced back-up mechanisms for data and services.
- Documentation of available components (https://wiki.deegree.org/deegreeWiki/deegree3) to ensure a sustainable availability of the developed components.

- Compliance testing of the Sensor Observation Service with OGC in order to provide a standardised interface for sharing observations and measurements (http://www.opengeospatial.org/resource/products/details/?pid=761).

The EDIM information system is able to access static (historical) spatial data but also – and more importantly - real time data through a sensor observation service. A direct access to sensor nodes placed in-situ at the Istanbul test site has been established by HU Berlin and GFZ Potsdam. The inter-sensor communication is based on a proprietary protocol which triggers alerts containing detailed information on seismic events [Fischer et al., 2009]. To get notified about an alert (i.e. a seismic event exceeds a predefined threshold), a notification is issued by a Message Notification Broker (MNotiBroker). This webservice (based on the SOAP-protocol and described by WSDL) has to be registered (subscribe) at the Message Notification Service provided by HU Berlin. After subscribing to the MNotiBroker, any seismic event is propagated to the registered webservice.

Within EDIM, lat/lon has developed an integration layer providing a mechanism to subscribe to the seismic notification service. The notification, which is not based on standardised interfaces, is evaluated by the integration layer and propagates the relevant information to portal users. Fig. 9 illustrates the workflow between a portal user accessing iGeoPortal (lat/lon's web-based client for the EDIM information system) and the MNotiBroker. The MNotiBroker is a webservice within the SOSEWIN middleware provided by HU Berlin and located on-site. The integration layer (Fig. 9: alerting subsystem) provides the necessary functionality to subscribe to the MNotiBroker and receive alerting messages. These messages are evaluated by a message processing component (Fig. 9: MessageProcessing). The portal component (iGeoPortal) polls the necessary messages and propagates the information to the portal user.
This implementation realises the connection between the EDIM information system and the on-site sensor system and makes the required information available to the stakeholders accessing the information system.

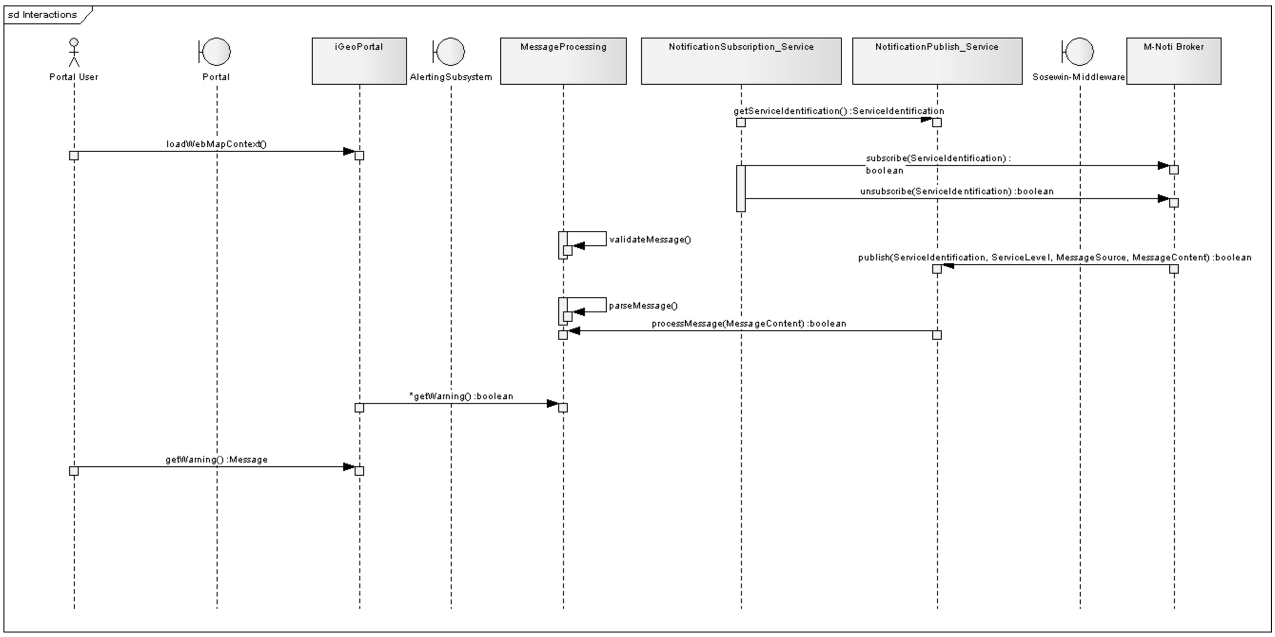

Fig. 9: UML Sequence illustrating the information flow between a portal user and an event notification from the SOSEWIN-System.

5. Summary

The integration of strong motion seismology, sensor system hard- and software development, and geoinformation real-time management tools prove a successful concept in making seismic early warning a novel technology with high potential for scientific and technological innovation, disaster mitigation, and many spin-offs for other fields. EDIM can serve as a model for further developments in the field of early warning on a global scale.

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