

DETERMINISTIC EARTHQUAKE SCENARIOS FOR THE BASEL AREA, SWITZERLAND; 3D GROUND MOTION SIMULATION OF COMBINED SOURCE AND SITE EFFECTS



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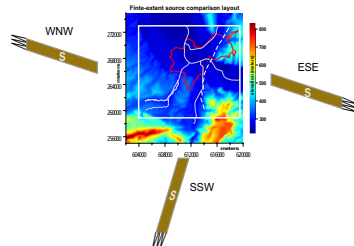
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ABSTRACT

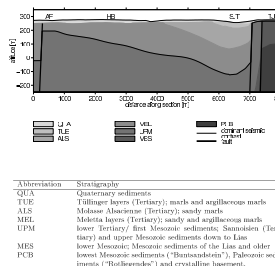
The Basel earthquake of October 18, 1356 is considered to be one of the most serious earthquakes in Europe ($M=IX$, $M=6.5-6.9$). The ground motion is modeled for the area of the city of Basel and its vicinity. The numerical modeling consists of the finite-extent source combined with the complex local structure in a two-step hybrid 3D finite-difference (FD) method. The synthetic seismograms are accurate in the frequency band 0.2-2 Hz. The 3D FD is linear explicit displacement formulation using an irregular rectangular grid including the topography. The finite-extent source is adjacent to the free surface, because the fault has been recognized through trenching on the Reinach fault. For the 1356 Basel earthquake ($M_w = 6.5$), two rupture histories are computed by a pseudo-dynamic approach. Another source is a hypothetical earthquake with the characteristics of the 1999 Athens earthquake ($M_w = 5.9$), modeled by kinematic approach. The scenario includes the sources located to the East, South and West from the city. The local structure computational model is determined from the recently established P and S-wave velocity structure of the Basel area, including the topography. The results are compared to recently established 2D simulations. The amplifications with respect to a bedrock site are given for the various earthquake scenarios. The 3D modeling gives, in some areas, reasonably different behavior from the 2D computations. The existence of the edge effect proved to be strongly dependent on the position of the source.

SETUP OF THE COMPUTATIONAL MODEL



The topography and setup of the computational model. The lines denote as follows: red - Basel-city limits, dashed white - the surface trace of the Rhine Graben master fault, grey - rivers, thick grey - the Rhine river, the white rectangle crops the area shown in later in the results. The brown patches S denote investigated positions of the finite-extent source; the coordinates are in meters (the Swiss coordinate system).

GEOLOGICAL MODEL



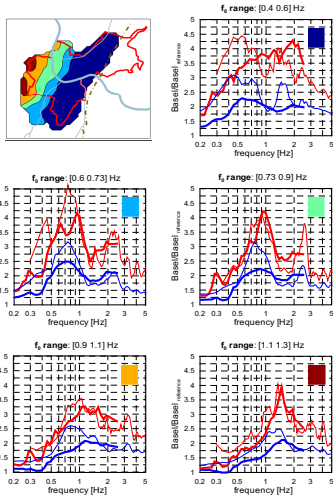
Representative cross-section of the geology in Basel. The dominant seismic S-wave velocity contrasts is indicated as a line between MEL and UPM. The table represents the stratigraphic units represented by the abbreviations (Kind, 2002).

FINITE-EXTENT SOURCE MODELS

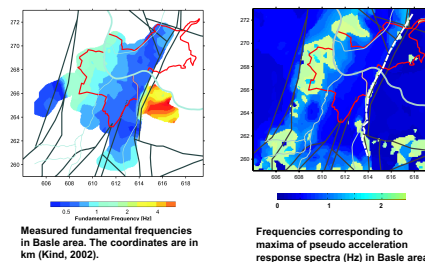
M1 slip model: $M_w=5.9$; Athens earthquake source type modeled by PEXT method (Zahradnik and Tselentis, 2002) models finite-extent source complexities by stochastic Perturbation and Extrapolation of the deterministic wavefield. The method uses complete Green's functions computed by the DWN. The model has the following parameters: length and width $L = 10$ km, $W = 8$ km, source composed of $5 \times 5 = 25$ subevents, each subevent with the slip duration ($= 1/\text{corner frequency}$) = 0.57 sec, and average slip = 0.059 m. For Figures and more details on the method and its validation see Opršal et al. (2004). The dominant frequencies of velocities were about 0.6 Hz. In this case, the acceleration spectral plateau is extrapolated up to 6 Hz from the deterministic part (2.0-2.8 Hz) by a Gaussian noise

M2, M3 slip models: $M_w=6.5$; similar to 1989 Loma Prieta source models, the rupture plane penetrating the topmost sedimentary layers (in the 1D reference model) up to the surface. The $W \times L = 12$ km $\times$ 27 km, dip angle of 75°. Pseudo-dynamic source characterization proposed by Mai et al (2001) generates a physically self-consistent rupture model; balanced fracture energy $\leftrightarrow V_r/V_s < 1$; Kostrov approximation of local slip-velocity source-time function in frequency domain. The two presented models M1 and M2 differ in the position of the hypocenters so that the prevailing rupturing is realized 'towards' and 'away from' the city of Basel.

Comparison of averaged (red) / enveloped (blue) amplifications 2D computation - thin lines; 3D computation - thick lines

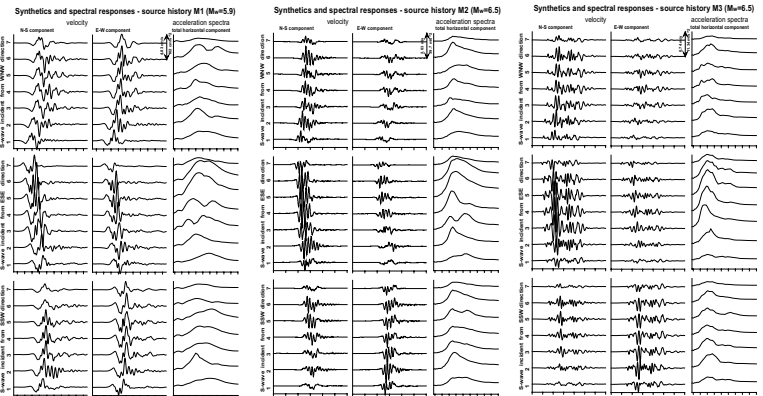
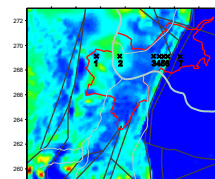


Comparison of measured fundamental frequencies and computed frequencies corresponding to the maxima of pseudo-acceleration response spectra



Comparison of the amplification zonations for particular zones covering the City of Basel. The spatial extent of five (fundamental-) frequency zones (Kind 2002) with the frequency increasing from the south east to the north west are indicated by colors. The thick lines correspond to the overall averaged data from 3D modeling. The thin lines are data obtained from 2D modeling by Kind, 2002. For each frequency/spatial zone the red (light) lines show the maximum amplification from all points inside the spatial/frequency range. By analogy, the blue (dark) lines denote the average amplification over all corresponding range points.

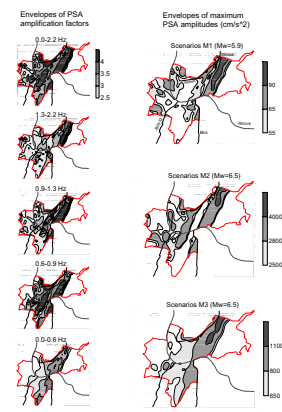
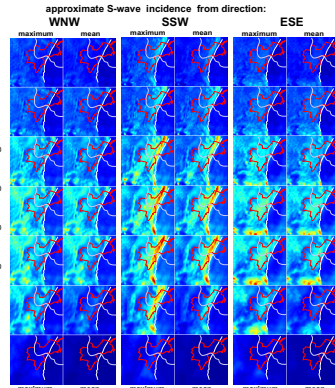
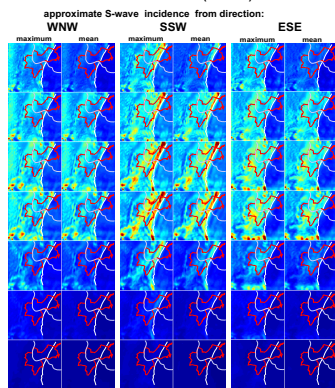
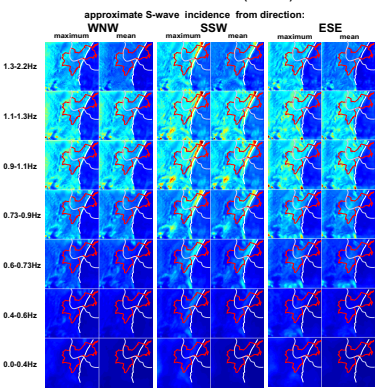
Synthetic seismograms and their corresponding PSA for receivers R1-R7 (Figure below). All computed for source models M1, M2, M3 and three positions of the source plane. The panels show horizontal components of velocity (left panels), the PSA is computed for total horizontal component (right panel). The arrows show the amplitudes corresponding to their denoted values.



Source model M1 ($M_w=5.9$)

Source model M2 ($M_w=6.5$)

Source model M3 ($M_w=6.5$)



Pseudo acceleration response (damping 5%) for M1, M2, and M3 finite-extent source models and three source-positions. WNW, SSW and ESE. The results are shown for a set of frequency bands corresponding to each of the rows. The left and right sides of each panel correspond to the maximum and mean amplitudes in the frequency band. The red line denotes Basel city limits; dashed white line the surface trace of the Rhine Graben master fault; grey lines are rivers, thick grey line is the Rhine River.

CONCLUSIONS

- The earthquake scenario modeling for the city of Basel showed that the S-wave incidence from SSW direction show generally stronger amplification right to the west from (and along) the master fault. This is caused by combination of the edge effects and waves guided by the lower-Tertiary sediments west and demands a potential damage zone. The ESE and WNW incidences feature fringes at higher frequencies instead of the single amplification belt strip from the master fault.
- Models with WNW incidence show smaller amplitudes in the eastern part of the city than corresponding models with ESE incidence. A verification of the accuracy of the digital geological model is indicated by a very good fit of the measured fundamental frequencies. The frequency-zoning, shows that the 2D behavior for the assigned frequency zones of the city is generally not substantially different from the 3D behavior; however, the site does not feature long-period oscillations typical for closed sedimentary basins.
- The high spectral-response amplitudes along the master fault is caused by a combination of the edge effect and guided-wave phenomenon. Balance between these two is driven by the direction of the incident S-wavefield.

ACKNOWLEDGEMENTS:

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Potential strong-motion areas of the city of Basel. Shown is spectral amplification depending on investigated frequency band or specific scenario.