Deterministic approach to assess seismic hazard: contribution for an integrated assessment of risk in the alpine context.

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Abstract

An assessment of seismic hazard using a deterministic approach is presented. Two different techniques have been used. One is to use the empirical Green's functions (EGF) summation approach and the other one uses cinematic source modelling. The mean ground motion estimates (response spectra) are given by a series of calculations from sets of independent parameters. Analysis of the Sion-Sierre area (Valais, Switzerland) considering the normal faulting system of the Grimentz zone is also presented in terms of mean peak ground acceleration and design spectra.

1. Introduction

Seismic hazard assessment at small scales requires a good estimation of ground motions induced by localised or unknown faults. Statistical correlation of ground motion parameters (e.g. maximum acceleration) with the earthquake magnitude/intensity and the distance between source-and receiver, are often used. These statistical laws are often unusable for near-source modelling and strong magnitudes because of the scare set of strong ground-motion data in Europe. This has led to the development of numerical techniques for predicting ground-motion time-histories of hypothetical but realistic earthquakes. A detailed compilation of such existing methods has been carried out and two techniques have been chosen. One is to use the empirical Green's functions (EGF) summation approach and the other one uses composite source models.

The first approach utilises actual recordings of small earthquakes, typically of magnitude 2 to 3, to calculate the effect of much larger ones ranging in magnitude from 5 to 7. It uses a simple cinematic rupture model to describe the source and the EGF to constrain the propagation path and site response information [1].

The second one proposes a simple cinematic source model based on a "k^{-2}" dislocation distribution which allows the synthesis of broad-band accelerograms with a "ω^{-2}"decay [2]

These techniques have been applied in Barcelona [3] and in the region of Sion and Sierre, canton of Valais, Switzerland. Applications are illustrated with numerical results of expected magnitude 6 earthquakes at different sites and distances between source and receiver.

This information represents the basis for vulnerability estimates and seismic risk assessment and scenarios [4].

2. Analysis with the empirical Green's functions technique

This approach uses actual recordings of small earthquakes (typically magnitude 2 to 3) to calculate the effect of a much larger earthquake (magnitude 5 to 7). To understand what is happening in each part of a particular fault, its surface is divided into a grid within which are located these micro-earthquakes used as Empirical Green's Functions (EGF).

The basic idea underlying the Green's functions method takes into account the approximation that, at a particular observation point, the overall ground motion caused by a large earthquake is the sum of several moderate events. Indeed, the ground motion caused by instantaneous slip on an individual segment of a fault can be represented by this mathematical entity called a Green's function. An illustration of the approach is given in the figure 1.

Hartzell [5] first proposed the use of small recorded earthquakes as EGF to calculate a larger earthquake and later several authors have developed the technique [6, 7, 8, 9, 10, 11, 12]. Recently, this technique has been used in Europe [13, 14, 15] to evaluate seismic hazard.

The model used is based on one proposed by Hutchings [1, 9]. It uses:

- A simple cinematic rupture model to describe the source in predicting strong ground motion for the full time history.
- EGF to constrain propagation path and site response information.

It develops an exact solution to the representation relation which can be expressed as the summation of records from small earthquakes (either empirical or synthetic Green's functions) convoluted with an analytical solution for the slip function (figure 1).

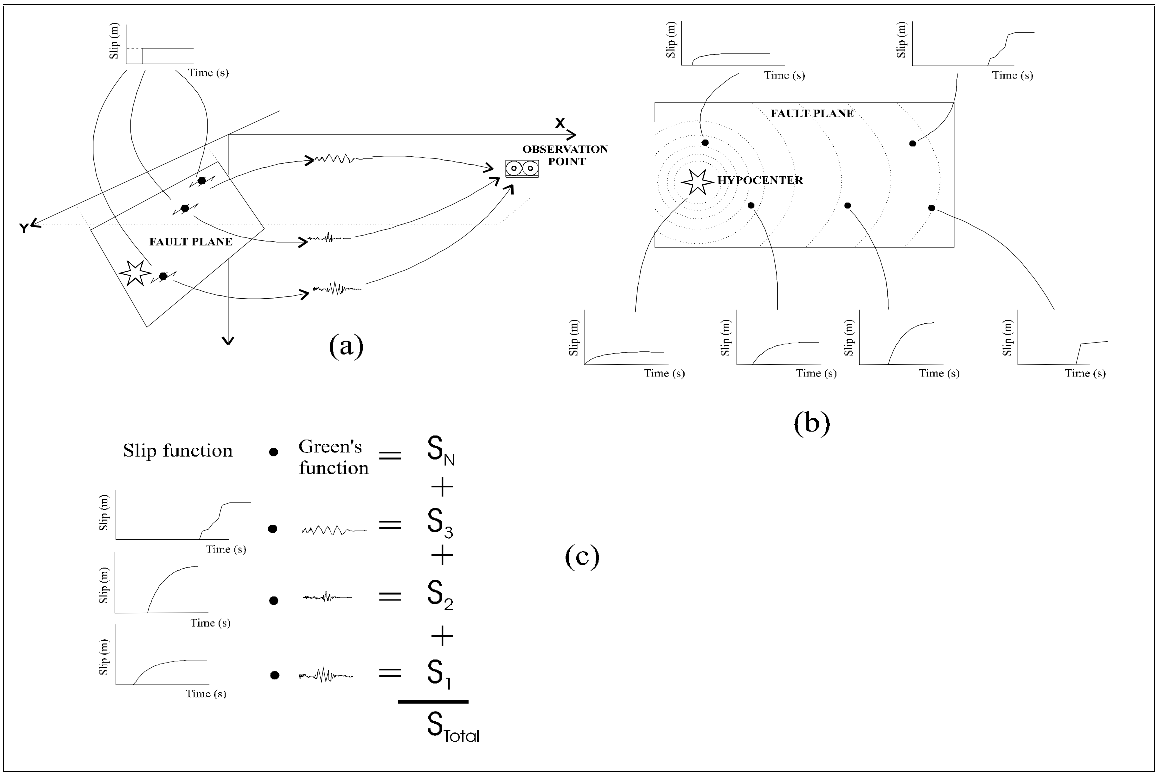

Figure 1. Schemes of the EGF approach (modified from Spudish et al. [16])
(a) Description of the Green's functions on a fault surface. Each source point is caused by instantaneous unit slip and produces its own ground motion or Green's functions.
(b) Slip functions at various points on the fault surface. The time delay and the amplitude of the slip are dependent on the location relative to the hypocenter.
(c) The convolution of the Green's function with the slip function in each fault segment corresponds to a signal (SN) which is a part of the total ground motion.

3. Analysis with a cinematic source modelling technique

The model proposed by Berge et al. [2] is a cinematic one, which implies that only the effect of slip and its propagation velocity on the rupture area are considered. The originality of this model is the dislocation distribution on the fault plane, which depends on the radial wave number k in k^{-2} ("k-square"). Based on the well-known idea of the self-similarity, the model considers numerous physical characteristics of the source, such as seismic moment, stress drop and fault size. The figure 2 illustrates the procedure for calculating strong ground motion.

The S-wave radiation is considered and the fault plane has a rectangular dimension (with the length L two-time the width W) divided up into source elements. The rupture front is assumed to propagate on the fault plane with constant velocity.

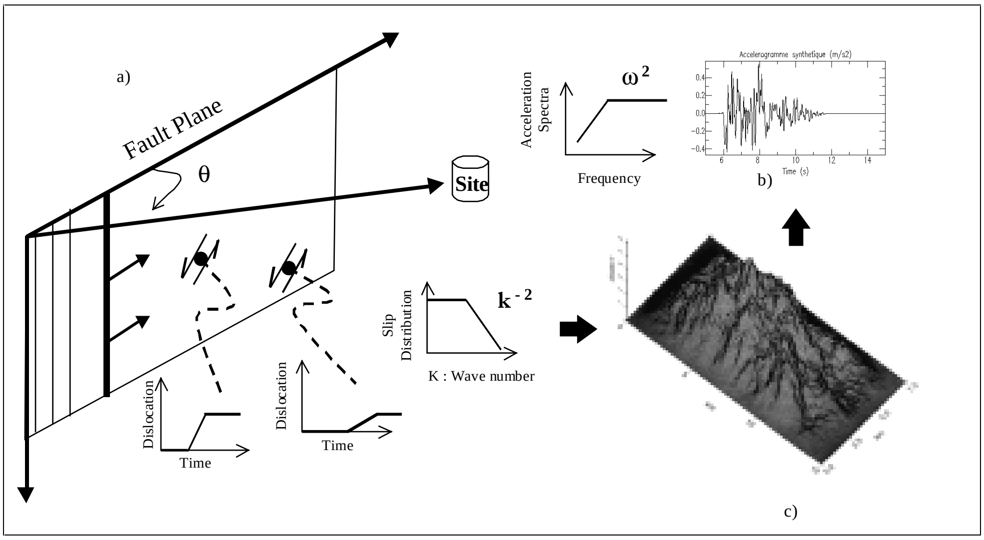

Figure 2. Schematic representations of the cinematic source modelling
(a) Description of the fault surface and the associated slip dislocation in relation with the rupture front. The time delay and the amplitude of the slip is dependent on the location relative to the hypocenter
(b) Synthesised accelerogram for a magnitude 6 earthquake following the "k square" relation.
(c) Slip distribution the fault plane for a magnitude 6.5 earthquake and a stress drop of 4 MPa. This distribution follows a "k square" relation.

4. The earthquake prone area of Valais, Switzerland

Results presented come from computation on seismogenic faults in the Sion area (SW of Switzerland). This region is one of the most active in the country along with those of Basel (northern part) and Grisons (NE part). The figure 3 shows the recent and historical seismic activity, the tectonic context and the studied faults of the area. Scenarios have been realised considering different seismogenic areas of the region.

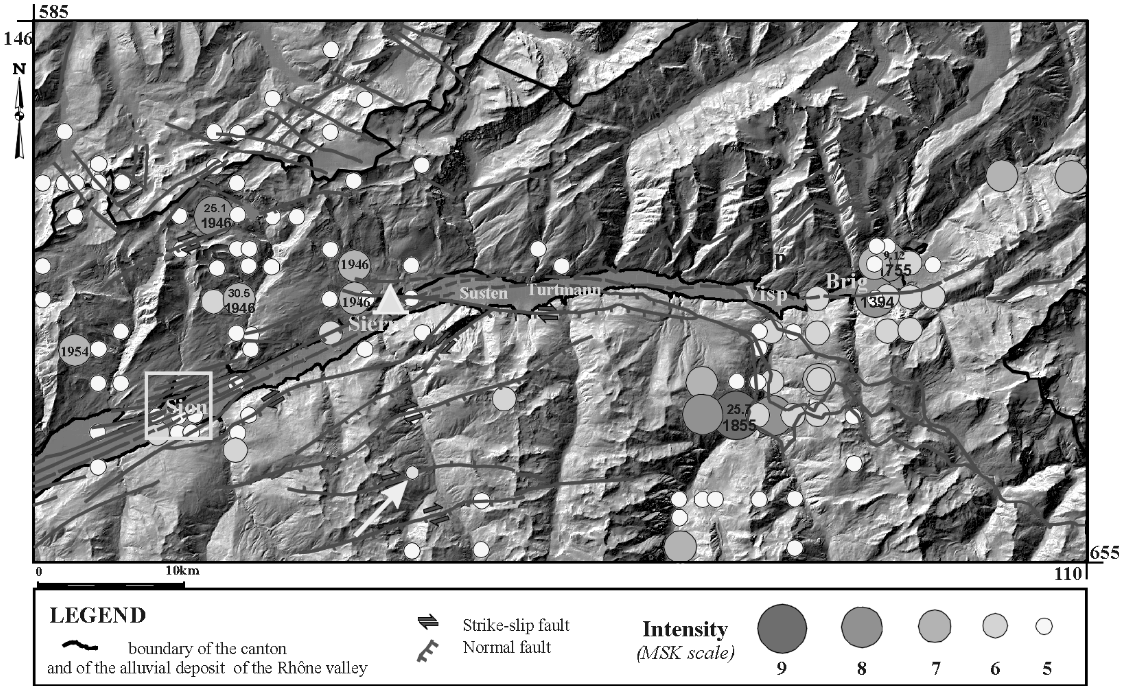

Figure 3: Seismo-tectonic context of the Sion area. The results presented consider the Sion area (unfilled square) and the Sierre area (filled triangle) in the case of the seismic activity of the fault zone of Grimentz (southern part of the map). The epicentre of the swarm of earthquakes which occurred in December 1998 is pointed with arrow (adapted from Wagner et al. [17]).

5. Earthquake scenarios on Sion-Sierre area considering the normal faulting system of the Grimentz zone

The Grimentz zone is composed of a large network of normal faults dipping to the North and orientated WSW-ENE. Vertical slip surfaces have been observed in the field with hectometre displacement. During December 1998 (7^{th} to 22^{nd}), a swarm of earthquakes (with a maximum magnitude of 3.4) has affected this area and four of them have been recorded at the seismic station SIES [18].
The P-wave velocity model used for the computation is given by Vp=0.0175z+5.6 [19] and validated down to a depth z of 40 km. The rupture velocity is considered to be constant from 75 to 90 % of the S-wave velocity. Seismic moment are given following the Hanks and Kanamori [20] law considering the M_L magnitude close to M_w around 6.
Statistical approach of the numerical calculations has been used in order to deal with hazardous parameters such as rupture velocity, fault mechanism and location of nucleation point. Results are proposed considering a range of Fourier or response spectra and their associated accelerograms.
A general normal fault rupture with strike-slip movement has been chosen [21]. After calibration with observed small earthquakes, the rupture has been modelled for magnitude 6 earthquake scenarios on Sion and Sierre. For EGF technique, four aftershocks are used (table 1).

Fault Parameters	Date	UTC Time	Lat. (°N)	Lon. (°E)	Depth (km)	(M_L)	M_0 (Dyn.cm)	Az. (°)	Dip (°)	Slip (°)
Modelled event			40.943	1.566	4	6.0	$0.13*10^{26}$	260	70	110
EGF Event	07.12.98	13:46	46.189	7.556	4	3.3	$1.11*10^{21}$	260	70	110
-	08.12.98	21:17	46.189	7.561	5	2.4	$0.50*10^{20}$	260	70	110
-	09.12.98	13:49	46.187	7.559	5	2.5	$0.70*10^{20}$	260	70	110
-	09.12.98	22:08	46.191	7.552	3	3.4	$1.58*10^{21}$	260	70	110

Table 1. Physical parameters of the computed synthetic time histories and aftershocks used as EGF at the SIES station. Focal mechanisms are given following the convention of Aki and Richards [22].

Figures 4 and 5 show the results of analysis done with the cinematic source model and EGF model respectively. Rupture velocity varies from 2.4 to 2.9 km/s (75 to 90% of the S-wave velocity). Resulting slip velocity is constrained around 2 to 8 m/s. Variability of the used parameters is considered with a set of calculation and the mean ground motion (and its design spectra) is given as reference.

6. Discussions

Deterministic techniques are efficient tools to assess seismic hazard. They can provide quantitative and qualitative estimates of a range of ground motion hazard, but these numerical calculations are based on hypotheses on the physical characteristics of earthquakes. In order to estimate variability of calculation, suites of time histories are generated from sets of independent parameters. Moment and fault geometry (extent of rupture and its orientation) are kept fixed. When records of small earthquakes with well-known source parameters are available, EGF's technique should be preferred because it provides realistic earthquake taking into account site effects. As far as possible, both techniques necessitate to be calibrate using observed seismic events.
In the Sion-Sierre area, magnitude 6 scenarios on the fault zones of Grimentz (hypocentral distance around 12-17 km) have been performed. Both techniques presented provide acceleration time histories with PGA around 0.2g and their corresponding design spectra. In coupling these results with methods for estimation of site effects and vulnerability, one are able to perform seismic risk analysis.

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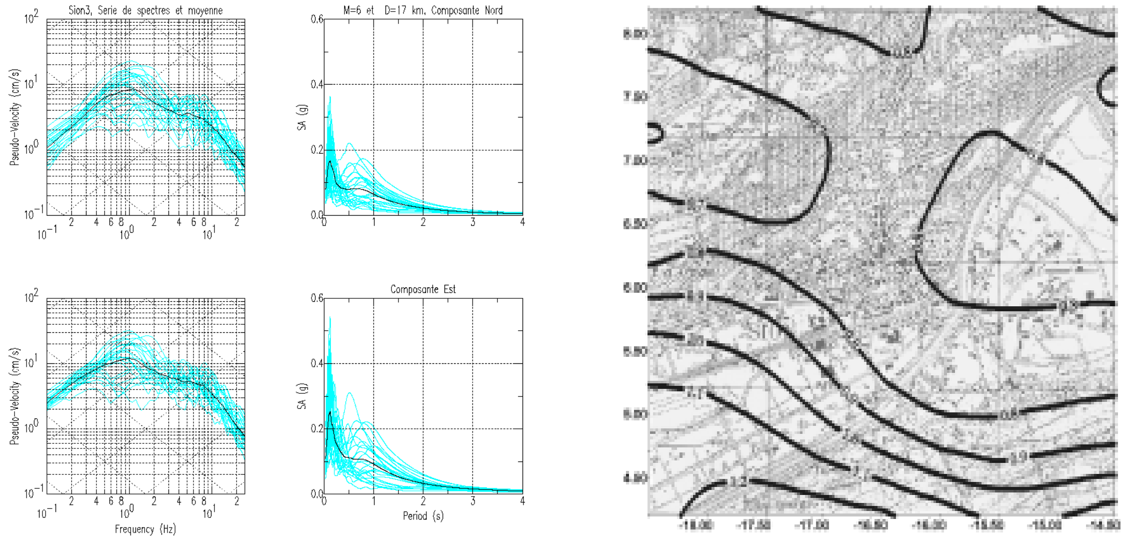

Figure 4: Results obtained with the cinematic source model.
Reference scenarios at the centre of Sion for a magnitude 6 earthquake induced by the normal faulting zone of Grimentz. The hypocentral distance at the centre of Sion is around 17 km.
(Left) Response spectra and PSA (5% damping) for the two horizontal components. 24 calculations have been performed with a range of rupture velocities and nucleation locations on the fault surface (in grey) and the mean curve (in black) corresponding to the mean scenarios.
(Right) PGA map (in m/s^2) centred on Sion for a magnitude 6 earthquake induced by the same normal fault. Co-ordinates on X and Y axis are the distance from the hypocenter (in km).

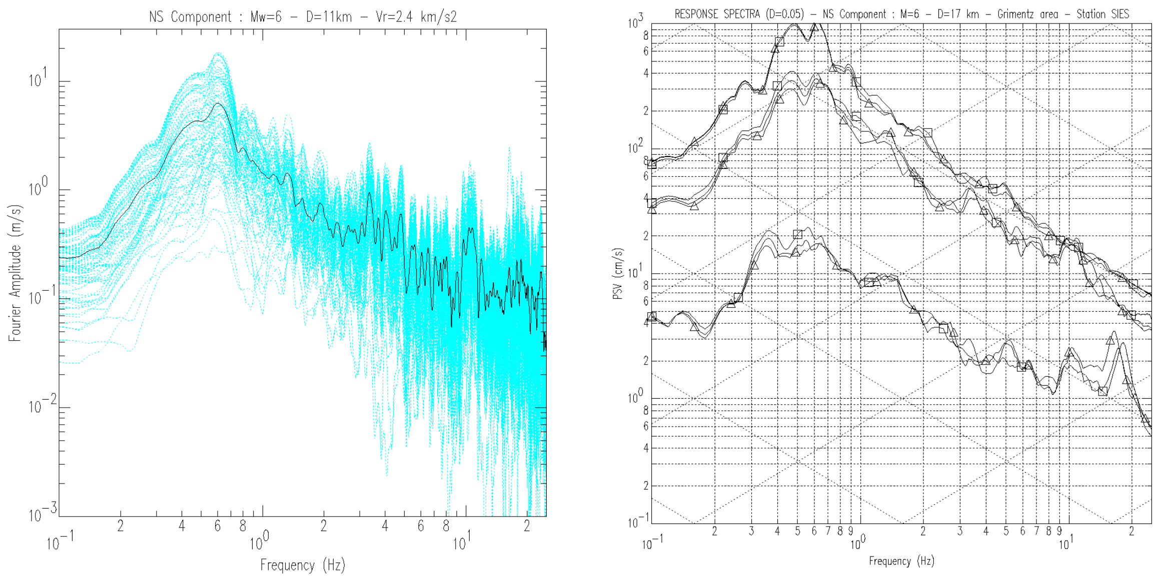

Figure 5: Results obtained with the EGF technique.
Reference scenarios on the centre of Sierre for a magnitude 6 earthquake induced by the normal faulting zone of Grimentz. The hypocentral distance to the station SIES is around 11 km.
(Left) Fourier amplitude spectra of the NS component. A series of 100 calculations have been performed with a rupture velocity Vr of 2.4 km/s. The location of the hypocenter and focal mechanism have been randomly chosen within a range of predictable values. The mean spectrum (in black) is obtained from the average of the 100 calculations (in grey).
(Right) Response spectra (damping of 5%) for the maximum, minimum and mean spectra issued of the 100 calculations. The figure shows the results for 3 values of the rupture velocity Vr, 2.4 (line with triangular symbol), 2.6 (continuous line) and 2.9 km/s (line with square symbol). It corresponds to a ratio of 75, 80 and 90 % of S-wave velocity respectively.

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