First European Conference on Earthquake Engineering and Seismology
(a joint event of the 13th ECEE & 30th General Assembly of the ESC)
Geneva, Switzerland, 3-8 September 2006
Paper Number: 1133

A FIRST LOOK AT THE JUNE, 2000, M6.5 EARTHQUAKES IN ICELAND IN TERMS OF THE SPECIFIC BARRIER MODEL

Benedikt HALLDORSSON, Simon OLAFSSON, and Ragnar SIGBJORNSSON[1]

SUMMARY

The two M6.5 earthquakes that occurred in the populated South Iceland Seismic Zone (SISZ) on June 17 and 21, 2000, respectively, are the largest earthquakes to take place in Iceland since 1912 and for which high-quality strong motion data exists. The earthquakes thus provide a unique opportunity to revise earthquake modeling, ground motion attenuation, and seismic hazard estimates in the area. We investigate the applicability of the recently calibrated Specific Barrier Model to predict the ground motions of the June 2000 earthquakes. We find that the local stress drop of the earthquakes is similar to that of other interplate earthquakes. However, the attenuation of seismic waves in the region is significantly greater than that in other interplate regions. By inverting for a new attenuation function from the data, we have established a stochastic model with the Specific Barrier Model at its centre, directly applicable to high-frequency strong motion modeling for earthquakes in the region. At low frequencies, the recordings at sites in close proximity to the sources exhibited strong near-fault velocity pulses. The characteristics of the recorded near-fault pulses have been identified in terms of a simple mathematical model of near-fault pulses and compared to the worldwide database of such records. The relationship of this mathematical model to the specific barrier model makes their joint application an ideal tool for the fast and efficient broad-band simulation of strong ground motions for future events in the region.

1. INTRODUCTION

The two M6.5 earthquakes that occurred in the populated South Iceland Seismic Zone (SISZ) on June 17 and 21, 2000, respectively, are the largest earthquakes to take place in Iceland since 1912. They now provide an opportunity for researchers to improve seismic hazard estimates for the area through the improved understanding of earthquakes in the zone by using realistic models of the earthquake source and the corresponding synthesis of strong ground motions. In previous developments in that regard [e.g., Ólafsson et al., 1998, 2001] in the context of the stochastic modeling approach [Boore, 2003] the earthquake source model applied had been the well know ω-square model with Brune's scaling. The limitations of this model are well documented [Papageorgiou, 2003, and references therein) but do not apply to the specific barrier model (SBM) which was proposed and developed for the quantitative description of heterogeneous rupture and is fully consistent with the salient features of more complex theoretical models of rupture and observed source spectra [Papageorgiou, 2003; Halldorsson, 2004; Halldorsson and Papageorgiou, 2005, and references therein]. The SBM is particularly simple in application due to the few parameters needed and because their scaling with magnitude has been established for earthquakes of different tectonic regions [Halldorsson and Papageorgiou, 2005]. In this paper we investigate the applicability of the recently calibrated specific barrier model to the incoherent (i.e., high-frequency, greater than ~0.5-1.0 Hz) data of the two June, 2000, earthquakes in South Iceland. This comparison is the first step in the planned integration of the model in consistent earthquake source and ground motion modeling for Icelandic seismological and earthquake engineering applications over a wide frequency range in the context of the kinematic and stochastic modeling approaches, respectively. The kinematic approach is especially well suited to the synthesis of the coherent (low-frequency) earthquake ground motions, but it requires s considerable number of input

[1] Earthquake Engineering Research Centre, University of Iceland, Austurvegur 2A, IS-800 Selfoss, Iceland. Emails: Benedikt.Halldorsson@gmail.com (B.H.), simon@afl.hi.is (S.O.), Ragnar.Sigbjornsson@hi.is (R.S.).

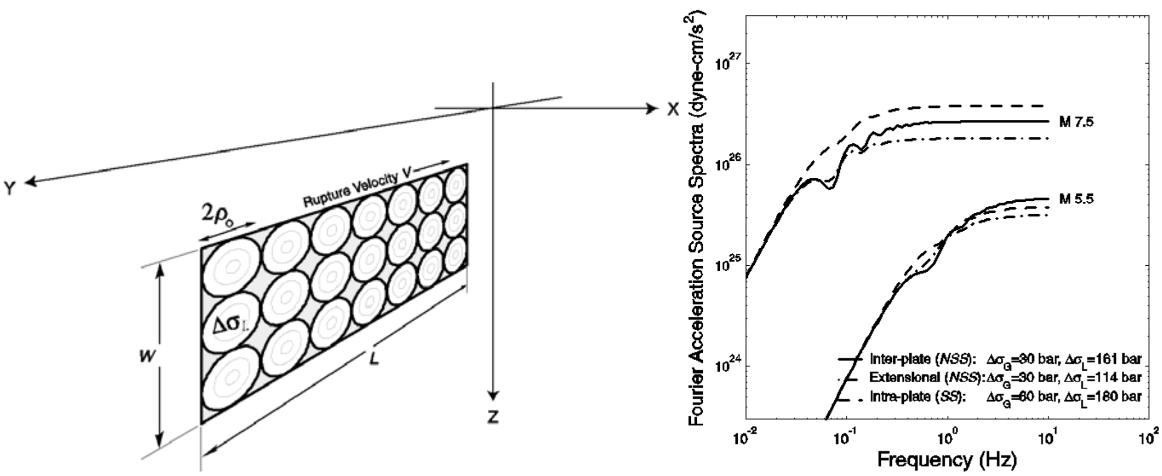

Figure 1. Left: A schematic view of the specific barrier model of Papageorgiou and Aki [1983a,b]. Right: The non-self-similar far-field S wave spectra of the specific barrier model for the inter-plate (solid), extensional (dot-dashed) and intra-plate (dashed) regime earthquakes, respectively.

parameters and computational power. The simulation of the coherent component earthquake ground motions emitted from the SBM are of particular interest since many recordings of the June 2000 earthquakes exhibit prominent coherent near-fault pulses, characterized by their large amplitude and long-period. Such phenomena are of great practical significance because nonlinear structural response studies have shown that they are the most damaging feature of near-fault strong ground motions [Stewart et al., 2002]. We identify the recorded near-fault velocity pulses and quantify their characteristics in terms of the mathematical model of Mavroeidis and Papageorgiou [2003]. In contrast to the kinematic approach, their model is particularly easy in application and captures well the characteristics of near-fault pulses. We note that the mathematical near-fault model and the SBM combine naturally in a physically consistent way which makes their joint application ideal for the synthesis of broad-band, near-source strong ground motions [Mavroeidis et al., 2004; Halldorsson and Papageorgiou, 2006].

2. THE SPECIFIC BARRIER MODEL

The Specific Barrier Model was introduced and developed by Papageorgiou and Aki [1983a,b] for the quantitative description of heterogeneous rupture [see also Papageorgiou, 1988; Aki and Papageorgiou, 1988]. According to the SBM the seismic fault may be visualized as an aggregate of circular subevents of equal diameter, 2ρ (the "barrier interval") filling up a rectangular fault of length *L* and width *W*, as shown schematically in Fig. 1. As the rupture front sweeps the fault plane with "sweeping velocity", *V*, a stress drop, $\Delta\sigma_L$, (referred to as the "local stress drop") takes place in each subevent starting from its center and spreading radially with constant "spreading velocity", v. The systematic dependence of the main parameters of the SBM, the local stress drop, and the barrier interval inferred in the original studies by Aki and Papageorgiou has been confirmed by Halldorsson and Papageorgiou [2005] for interplate earthquakes, and extended for earthquakes in intraplate regions and regions of active tectonic extension. The main parameters of the SBM were found to vary systematically with magnitude: The local stress drop is a relatively stable parameter over a wide magnitude range: ~161 bar, ~114 bar, and ~180 bar for interplate, extensional, and intraplate earthquakes, respectively, and the barrier interval increases with magnitude in a self-similar fashion [Halldorsson and Papageorgiou, 2005]. Papageorgiou [1988] presented an expression for the far-field source spectrum of the SBM, and Halldorsson and Papageorgiou [2005] modified it slightly by introducing a high-frequency source complexity factor, ζ, into the expression

$$S(M_o, f, \zeta) = \sqrt{N\zeta + N(N-\zeta)\left(\frac{\sin(\pi f T_s)}{\pi f T_s}\right)^2} (2\pi f)^2 \tilde{M}_{oi}(f) \tag{1}$$

where N is the number of subevents, Ts is the source duration, and $M_{oi}(f)$ is the source displacement spectrum of a single subevent. The factor ζ accounts for the observed deviation from self-similar scaling of the high-frequency source spectral levels of earthquakes in interplate and extensional tectonic regimes (see Fig. 1). Halldorsson and Papageorgiou [2005] identified the factor to vary with moment magnitude as follows

$$\log \zeta = 2s_m\left(M_w - M_c\right), \tag{2}$$

where s_m=-0.12 and M_c=6.35, and discussed various possible physical causes for its existence. Equation (1) facilitates greatly the simulation and prediction of far-field strong ground motions from the model. The SBM assumes identical subevents that distribute the seismic moment in a deterministic manner over the fault plane. That has to be the natural first assumption for "blind" strong motion modeling from a complex earthquake source model where the slip pattern on the fault, by necessity, must be hypothesized. It is also a prerequisite for simulating realistic near-fault motions, in which case the individual subevent time histories are synthesized for each station, and then summed up in the time domain appropriately lagged in time.

The stochastic approach is based on the assumption that the high-frequency earthquake radiation sums up incoherently at the site and strictly speaking, is not valid below 0.5-1.0 Hz where earthquake waves add more coherently. A prominent feature of coherent ground motions often observed from moderate and large earthquake are the so-called near-fault velocity pulses, characterized by their large amplitude and period [Mavroeidis and Papageorgiou, 2003, and references therein]. Mavroeidis and Papageorgiou [2003] presented a mathematical expression for near-fault velocity ground velocities (their Eq. 3)

$$v(t) = A\frac{1}{2}\left[1+\cos\left(\frac{2\pi f_P}{\gamma}(t-t_0)\right)\right]\cos[2\pi f_P(t-t_0)+\nu] \quad \text{for} \quad t_0 - \frac{\gamma}{2f_P} \le t \le t_0 + \frac{\gamma}{2f_P}, \tag{3}$$

and zero otherwise. In their phenomenological model the parameter A controls the amplitude of the signal (approximately constant at A = 73 cm/s at rupture distances less than 7 km), f_P is its prevailing frequency, ν is the phase of the amplitude-modulated harmonic, γ is a parameter that defines the oscillatory character (i.e., zero-crossings) of the signal, and t_0 specifies the epoch of the envelope's peak. The near-fault motions that they analyzed were characterized by fault-normal velocity pulses with a dominant pulse ($T_P = 1/f_P$) period that scales self-similarly with earthquake magnitude, as follows

$$\log T_P = -2.9 + 0.5M_w \tag{4}$$

The mean value of A is in relatively good agreement with the typical value of slip velocity, which in turn scales with the dynamic stress drop during fault rupture [Papageorgiou and Aki, 1983a]. The latter is represented by the local stress drop in the specific barrier model and has been shown to be a stable parameter for a given tectonic region [Halldorsson and Papageorgiou, 2005]. Mavroeidis et al. [2004] have shown that through the rise time τ of the specific barrier model [Aki et al., 1977; Papageorgiou and Aki, 1982], the barrier interval of the specific barrier model is proportional to the pulse period in Equation (4), according to $2\rho_0 \approx T_P$ (parameters expressed in km and s, respectively). Through this interrelation of the parameters the mathematical near-fault model complements the specific barrier model and together they serve as a fast and efficient tool for the synthesis of broad-band near-source ground motions [Halldorsson et al., 2004].

Table 1. List of SISZ events used in this study. The source information is from the Internet Site for European Strong-Motion Data (ISESD), and from Harvard CMT solutions as reported in Pedersen et al. [2003].

No.	Date	Time (UTC)	Event name	M_w	Lat. (°N)	Lon. (°E)	Dep. (km)	Style*	M_0 (dyne-cm)
1	2000/06/17	15:40	South Iceland	6.5	63.970	-20.360	6	ss	1.7E+25
2	2000/06/21	00:51	South Iceland	6.5	63.970	-20.710	5	ss	5.4E+25

* Style of faulting is denoted by "ss", indicating strike-slip

3. DATA

The events used in this study are listed in Table 1 and are the two largest events in the South Iceland Seismic Zone for which high-quality recordings are available [ISESD, Ambraseys et al., 2002; Sigbjörnsson et al., 2004]. The majority of the recording sites of the Icelandic Strong Motion Network (IceSMN) can be classified as rock or stiff soil [Thórarinsson et al., 2002]. We note that many near-fault recordings of the June 2000 earthquakes exhibit large amplitude and long-period velocity pulses. For the sake of correctly identifying the fault-normal and fault-parallel components we have reviewed, to the best of our knowledge, the recording instruments' component orientations relative to North and show in Table 2 how they relate to the component information that is provided in the ISESD datafiles (Long., Trans., Vert.). We would like to show the acceleration and velocity time traces in relation to the source-station geometry in order to facilitate the understanding of the data in terms of waveforms and how they relate to the respective sources and source-station geometries, but due to space constraints we are limited to showing the corresponding horizontal components of the velocity time traces for the June 21 earthquake in Figures 2 and 3.

Table 2. The relationship between the components as given in the ISESD datafiles (Longitudinal, Transverse and Vertical) and the actual orientation of the measured clockwise from North (N°E).

SID	Station Name	Long. (N°E)	Tran. (N°E)	Vert.
IS100	Reykjavik-University (VR-II)	90	180	up
IS101	Selfoss-Hospital	270	0	up
IS102	Hveragerdi-Church	0	90	up
IS103	Kaldarholt	90	180	up
IS104	Thorlakshofn	270	0	up
IS105	Hella	180	270	up
IS106	Flagbjarnarholt	270	180	up
IS107	Thjorsartun	180	270	up
IS108	Minni-Nupur	0	90	up
IS109	Solheimar	90	180	up
IS111	Selsund	180	270	up
IS112	Selfoss-City Hall	180	270	up
IS113	Hveragerdi-Retirement House	0	90	down
IS402	Reykjavik-Foldaskoli	90	180	up
IS403	Reykjavik-Heidmork (Jadar)	90	180	up
IS502	Thjorsarbru	90	0	up

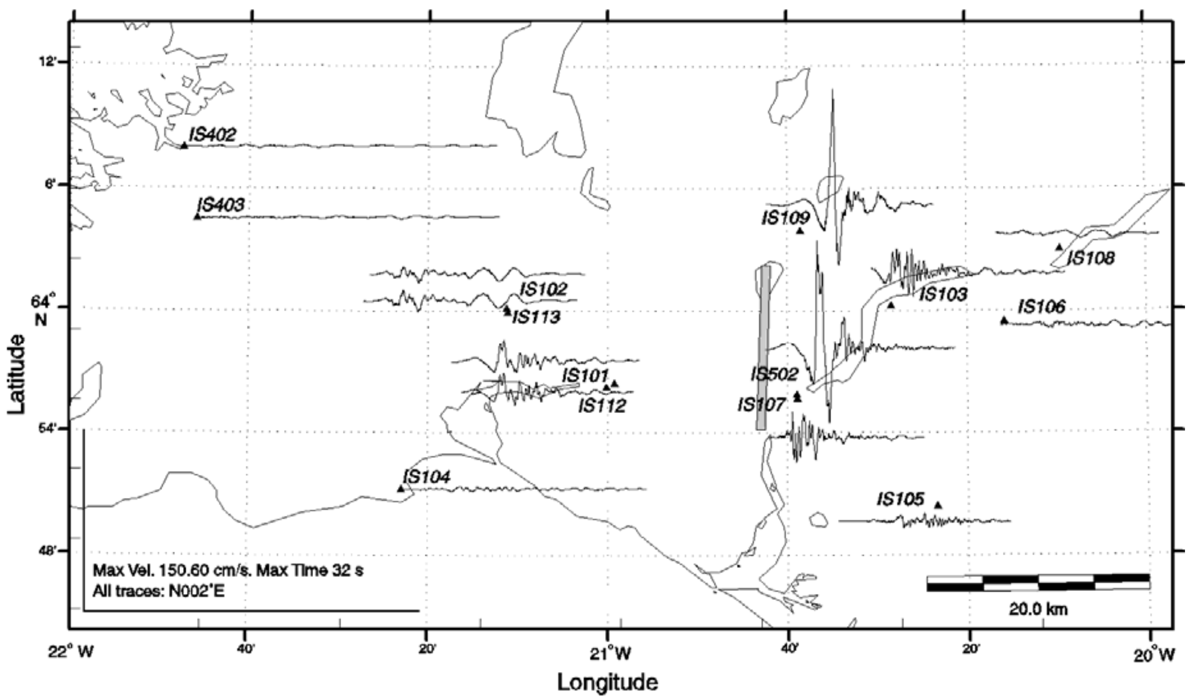

Figure 2. Map of the IceSMN stations that recorded the June 17 and 21, 2000, earthquakes in the South Iceland Seismic Zone, along with the recorded fault-parallel velocity time histories during the June 21 earthquake. The vertical surface projection of the fault plane is denoted by the gray rectangle. Note especially the strong and clear velocity pulses at the near-fault stations.

4. PRELIMINARY ANALYSIS OF THE RECORDED STRONG GROUND MOTIONS

The earthquakes in the SISZ are shallow crustal earthquakes and the tectonic environment of the region is interplate, as the SISZ is a transform zone between adjacent spreading centers of the Mid-Atlantic Ridge which separates the North American plate and the Eurasian plates. As such, we apply the interplate specific barrier model in the following analysis of the high-frequency ground motions, which is carried out in the context of the stochastic method [e.g., Boore, 2003]. We note that the applicability of self-similar source scaling is out of the scope of this paper as the two earthquakes in June, 2000, are almost of the same magnitude as the transition magnitude, M_c, that appears in Equation (2) of the non-self-similar interplate specific barrier model. Additionally, previous studies on Icelandic strong motions [e.g., Ólafsson, 1999; Ólafsson and Sigbjörnsson, 1995, 1999; Ólafsson et al., 2001; Sigbjörnsson and Ólafsson, 2004] had noted through comparison with common empirical attenuation relationships for shallow crustal earthquakes that Icelandic data exhibit greater attenuation.

In the context of the stochastic modeling approach and random vibration theory, we have compared the attenuation with distance of the high-frequency part of the ground motions by predicting pseudo-spectral acceleration (PSA) at a few discrete oscillator periods *T*, as well as peak ground acceleration (PGA) for the magnitudes of the events considered, with the corresponding recorded data in the SISZ and is shown in Figure 4a. The agreement between the near-fault data and predictions is reasonably good in both cases, indicating that the interplate earthquake source strength is appropriate for earthquakes in the SISZ. At far-field distances however discrepancies are observed for the June 17 and 21 earthquake comparisons, respectively. While the June 17 measures agree well with the attenuation of the interplate SBM model, the attenuation of the June 21 ground motion measures indicates that the attenuation in the SISZ is indeed higher (smaller Q) than compared to other interplate tectonic regions. Furthermore, researchers have identified that the June 17 earthquake signal is contaminated by a few other earthquakes, possibly through dynamic triggering, in the SISZ and the adjacent western volcanic zone [Clifton et al., 2003; Pagli et al., 2003; also O. Thorarinsson, personal communication]. We therefore suspect that, in agreement with the previous studies above, that the ground motions of the June 21st event are more representative of the attenuation in the region. For that reason we have inverted for a new attenuation function for the interplate SBM, resulting in r_x = 35 km, $Q(f) = 47f^{0.91}$. Comparing the PSA and PGA now shows a better agreement of high-frequency stochastic predictions to the data, as shown in Figure 4b. We note that this agrees also better with the attenuation of the data of the third largest earthquake in the SISZ, the Mw5.8 Vatnafjoll earthquake of May 28, 1987 (results not shown here).

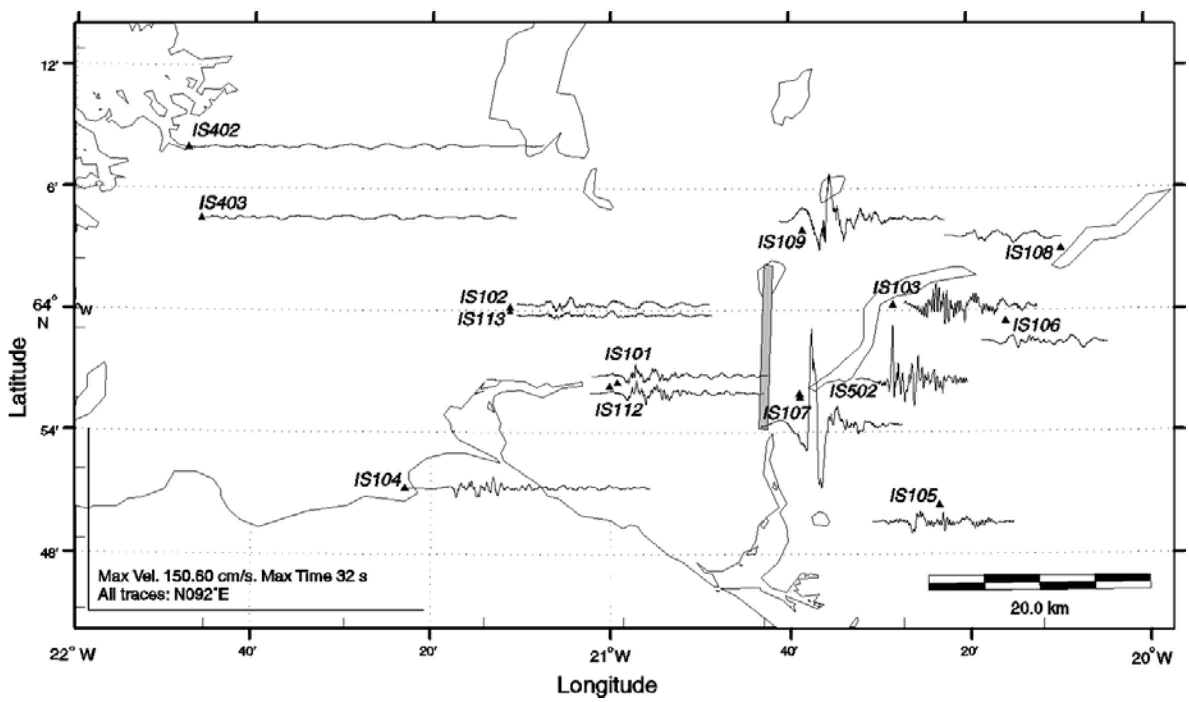

Figure 3. Same as in Figure 2 except for the fault-normal component.

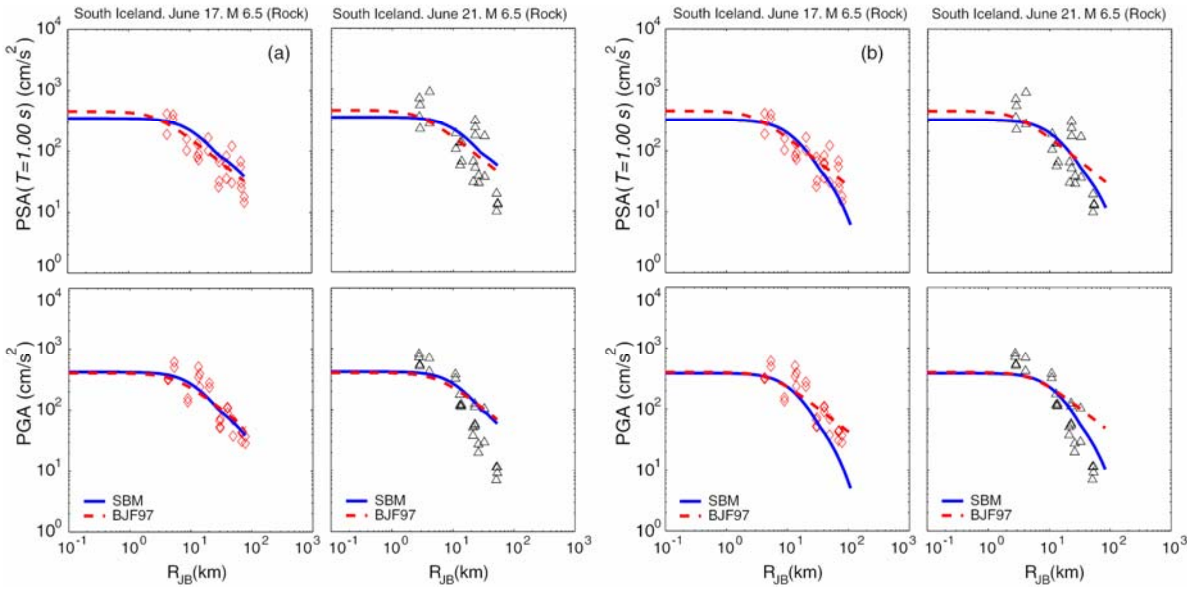

Figure 4. The attenuation of 1.0 s PSA (top) and PGA (bottom) data with distance for the events considered in this study, compared with (a) the RVT predictions of the interplate SBM [Halldorsson and Papageorgiou, 2005] and the empirical relationship of Boore et al. [1997] for shallow interplate earthquakes. (b) Same comparison except now the interplate SBM uses a different attenuation function. In each case, the June 17 data is on the left, and June 21 data on the right.

We have inverted for the parameters of the mathematical model in Equation (3) from the near-fault data recorded during the June 17 and 21, 2000, earthquakes. Figure 5 shows the five clearest recorded pulses (as solid lines), along with the fitted synthetic velocity traces (as dashed lines). Mavroeidis and Papageorgiou [2003] used ~40 near-fault records in their worldwide database of such motions and the Icelandic data thus constitute a significant addition. For that reason we show in Figure 6 the quantitative comparison of the near-fault pulse characteristics for the five clearest, large amplitude pulses during the June 2000 earthquakes with those of the worldwide database. When the peak ground velocity (PGV) is plotted against either rupture distance or magnitude in Figure 6, the Icelandic data do not appear to fall outside the general range of the PGV estimates of the worldwide dataset. When the pulse period T_P is plotted vs. magnitude in Figure 5, the Icelandic estimates fall below the general trend of the regression line, a deviation which would be more noticeable if it were not for a few other estimates at around the same magnitude that fall above the line. A more detailed source modeling along with investigation of possible site effects [e.g., Bessason and Kaynia, 2002] on the near-fault motions is required to resolve if the pulse-period estimates are indeed representative of the worldwide dataset, or if a different scaling applies to the earthquakes in Iceland. At this time however, the estimates are not significantly different from the estimates in the worldwide dataset.

5. CONCLUSION

The June 17 and 21, 2000, earthquakes were the largest events to occur in Iceland since 1912 and are of fundamental importance for the revised, and more reliable, estimates of seismic hazard from future earthquakes in the South Iceland Seismic Zone. The recordings by the Icelandic Strong Motion Network run by the Earthquake Engineering Research Institute of the University of Iceland have significant implications for future strong motion research in Iceland, as well as worldwide because they provided numerous clear samples of near-fault velocity pulses which are the most damaging feature of near-fault motions. Furthermore, the recordings constitute a significant addition to the worldwide database of near-fault records. Using a mathematical near-fault ground motion model the parameters of the near-fault pulses have been inferred and their main characteristics compared to those of the worldwide dataset of Mavroeidis and Papageorgiou [2003]. The comparison indicates that the Icelandic near-fault pulses are not significantly different, although we allow for the possibility of a more thorough analysis revealing if that is indeed the case. The mathematical model complements the specific barrier model and the analysis of the high-frequency motions further indicate that earthquake sources in the SISZ scale

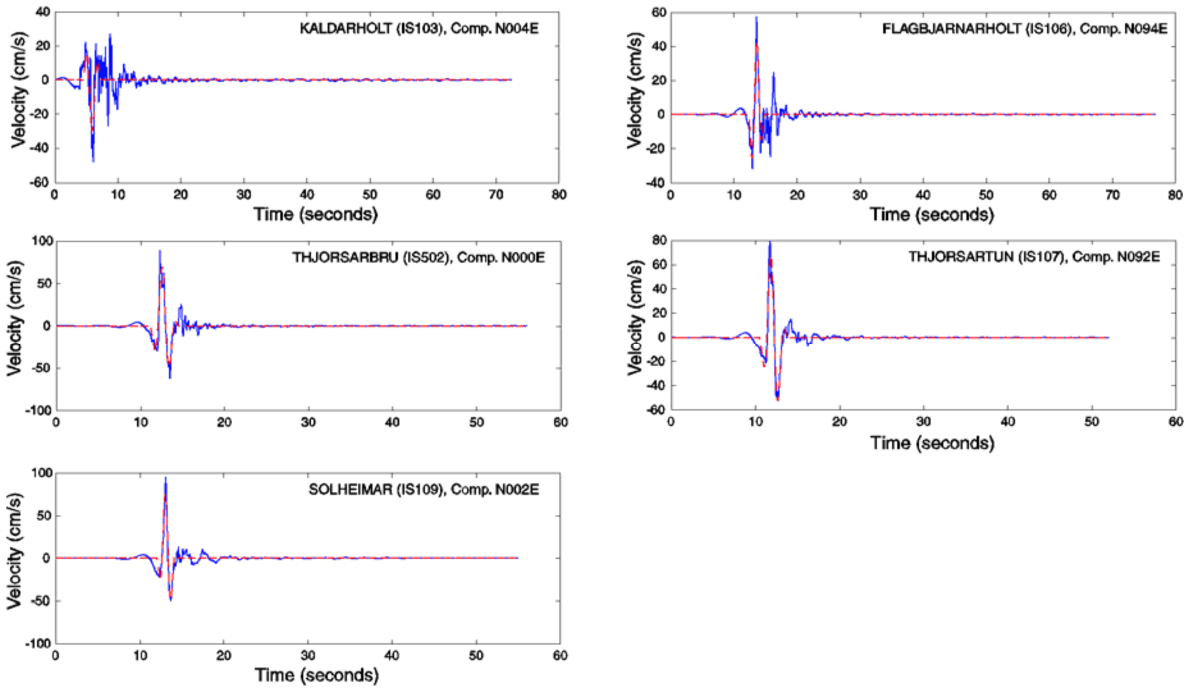

Figure 5. The five near-fault velocity recordings (solid lines) that exhibit the largest (and clearest) pulses. The fitted velocity traces of the mathematical model are shown as dashed lines. The left and right plots show the fault parallel and fault-normal recordings, respectively, while the top row corresponds to the June 17 event, and the second and third rows to the June 21 event.

self-similarly but are of comparable source strength as the interplate earthquakes studied by Halldorsson and Papageorgiou [2005].

The above has important practical applications because the combination of sophistication and simplicity of the SBM makes it the most viable and optimal model for a self-consistent synthesis of earthquake strong ground motions over a wide frequency range [Aki, 1992, 2000, 2003], which is especially computationally efficient in the simulation of high-frequency motions via the stochastic method. Furthermore, its interrelationship to the parameters of the near-fault model makes their joint application an ideal tool for the fast and efficient *broad-band* simulation of strong ground motions for future events (i.e., "blind" simulations) in Iceland in the far-field and the near-fault region [Halldorsson et al., 2006], with implications for earthquake engineering and seismic hazard assessment in the SISZ.

6. ACKNOWLEDGEMENTS

This work was supported by The Icelandic Research Centre (RANNIS) and the University of Iceland Research Fund.

7. REFERENCES

Aki, K. (1992). Higher-order interrelations between seismogenic structures and earthquake processes, *Tectonophysics* 211, 1.12.

Aki, K. (2000). Scale-dependence in earthquake processes and seismogenic structures, Pure Appl. *Geophys.* 157, 2249.2258.

Aki, K. (2003). A perspective on the history of strong motion seismology, *Phys. Earth. and Planet. Int.* 137, 5.11.

Aki, K., M. Bouchon, B. Chouet, and S. Das (1977). Quantitative prediction of strong motion for potential earthquake fault, *Ann. Geofis*. XXX, 341.368.

Aki, K. and A. S. Papageorgiou (1988). Separation of source and site e¤ects in acceleration power spectra of major California earthquakes, in Ninth World Conference on Earthquake Engineering, volume Vol. VIII, SB-8, Tokyo-Kyoto, Japan.

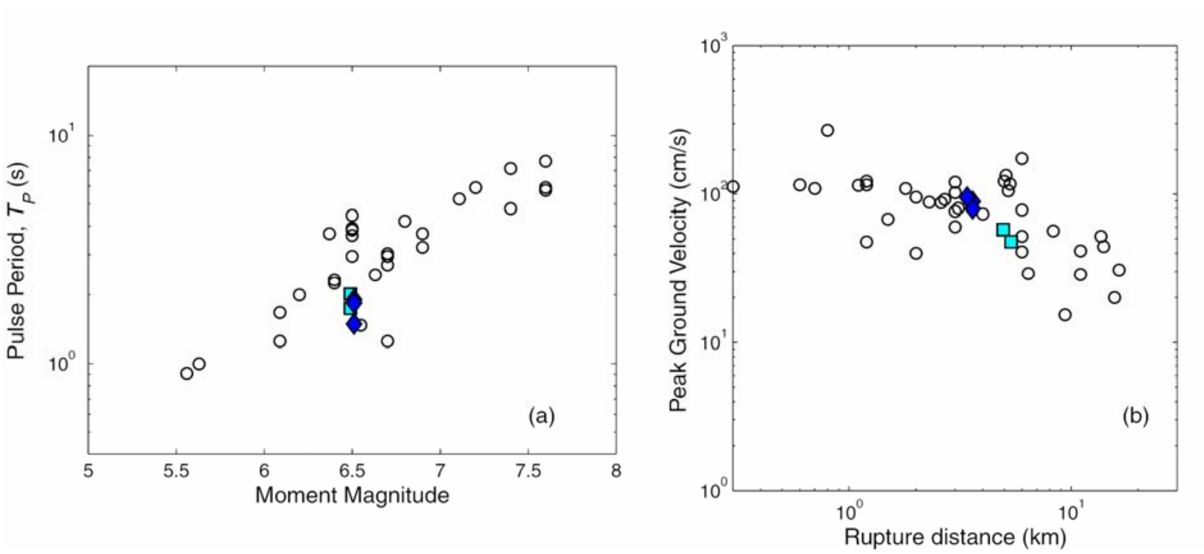

Figure 6. Comparsion of the near-fault pulse characteristics of the five clearest, large amplitude pulses during the Icelandic earthquakes with those of the worldwide dataset (circles). The Icelandic data is shown in filled square and diamond markers denoting the June 17 and 21 data, respectively. (a) The magnitude scaling of the pulse period of the mathematical near-fault model. (b) Peak ground velocity vs. rupture distance.

Ambraseys, N., P. Smit, R. Sigbjörnsson, P. Suhadolc, and B. Margaris (2002). Internet-site for European strong-motion data, in European Commission, Research-Directorate General, Environment and Climate Programme.

Bessason, B. and A. M. Kaynia (2002). Site amplification in lava rock on soft sediments, *Soil Dyn. & Eq. Eng.*, v. 22, p. 525-540.

Boore, D. M. (2003). Simulation of ground motion using the stochastic method, *Pure Appl. Geophys*. 160, 635.676.

Brune, J. N. (1970). Tectonic stress and the spectra of seismic shear waves from earthquakes, *J. Geophys. Res*. 75, 4997.5009.

Clifton, A. E., C. Pagli, J. F. Jónsdóttir, K. Eythorsdottir, and K. Vogfjörd (2003). Surface effects of triggered fault slip on Reykjanes Peninsula, SW Iceland, *Tectonophysics* 369, 145.154.

Halldorsson, B. (2004). The Specific Barrier Model: Its Calibration to Earthquakes of Different Tectonic Regions and the Synthesis of Strong Ground Motions for Earthquake Engineering Applications, Ph.D. thesis, University at Buffalo, State University of New York, Buffalo, New York.

Halldorsson, B., G. Mavroeidis, F. Zhang, G. Dong, and A. S. Papageorgiou (2004). Simulation of earthquake strong ground motion using the specific barrier model, *Eos Trans. AGU 85*, fall Meet. Suppl., Abstract S13D-1098.

Halldorsson, B. and A. S. Papageorgiou (2005). Calibration of the specific barrier model to earthquakes of different tectonic regions, *Bull. Seism. Soc. Am*. 95, 1276.1300, doi: 10.1785/0120040157.

Halldorsson, B. and A. S. Papageorgiou (2006). Application of the specific barrier model to the simulation of earthquake strong ground motions, Proceedings of the 8th U.S. National Conference on Earthquake Engineering, April 18-22, 2006, San Francisco, California, USA. Paper No. 1206

Halldorsson, B., S. Olafsson, and R. Sigbjornsson (2006). A fast and efficient simulation of the far-field and near-fault earthquake ground motions associated with the June 17 and 21, 2000, earthquakes in South Iceland. *J. Earthq. Eng.* (accepted for publication).

Mavroeidis, G. P., G. Dong, and A. S. Papageorgiou (2004). Near-fault ground motions, and the response of elastic and inelastic single degree-of-freedom (SDOF) systems, *Eq. Eng. Str. Dyn*. 33, 1023.1049.

Mavroeidis, G. P. and A. S. Papageorgiou (2003). A mathematical representation of near-fault ground motions, *Bull. Seism. Soc. Am*. 93, 1099.1131.

Ólafsson, S. (1999). Estimation of Earthquake-Induced Response, Ph.D. thesis, Norwegian University of Science and Technology.

Ólafsson, S., S. Remseth, and R. Sigbjörnsson (2001). Stochastic models for simulation of strong ground motion in Iceland, *Eq. Eng. Str. Dyn*. 30, 1305.1331.

Ólafsson, S. and R. Sigbjörnsson (1995). Simulation of earthquake ground motion and structural response, Acta Polytechnica Scandinavica 102, 1.30.

Ólafsson, S. and R. Sigbjörnsson (1999). A theoretical attenuation model for earthquake-induced ground motion, *J. Eq. Eng*. 3, 287.315.

Ólafsson, S., R. Sigbjörnsson, and P. Einarsson (1998). Estimation of source parameters and Q from acceleration recorded in the Vatnafjöll earthquake in South Iceland, *Bull. Seism. Soc. Am*. 88, 556.563.

Pagli, C., R. Pedersen, F. Sigmundsson, and K. L. Feigl (2003). Triggered fault slip on June 17, 2000 on the Reykjanes Peninsula, SW-Iceland captured by radar interferometry, *Geophys. Res. Lett*. 30, doi:10.1029/2002GL015310.

Papageorgiou, A. S. (1988). On two characteristic frequencies of acceleration spectra: Patch corner frequency and f_{max}, *Bull. Seism. Soc. Am*. 78, 509.529.

Papageorgiou, A. S. (2003). The barrier model and strong ground motion, *Pure Appl. Geophys*. 160, 603.634.

Papageorgiou, A. S. and K. Aki (1982). Aspects of the mechanics of earthquake rupture related to the generation of high-frequency waves and the prediction of strong ground motion., *Soil Dyn. Eq. Eng*. 1, 67.74.

Papageorgiou, A. S. and K. Aki (1983a). A specific barrier model for the quantitative description of inhomogeneous faulting and the prediction of strong ground motion. I. Description of the model, *Bull. Seism. Soc. Am*. 73, 693.722.

Papageorgiou, A. S. and K. Aki (1983b). A specific barrier model for the quantitative description of inhomogeneous faulting and the prediction of strong ground motion. Part II. Applications of the model, *Bull. Seism. Soc. Am*. 73, 953.978.

Pedersen, R., S. Jónsson, T. Árnadóttir, F. Sigmundsson, and K. L. Feigl (2003). Fault slip distribution of two June 2000 Mw6.5 earthquakes in South Iceland estimated from joint inversion of InSAR and GPS measurements, *Earth and Planet. Sci. Lett*. 213, 487.502, doi:10.1015/S0012.821X(03)00302.9.

Sigbjörnsson, R. and S. Ólafsson (2004). On the South Iceland earthquakes in June 2000: Strong-motion effects and damage, *Bollettino di Geo.sika Teorica ed Applicata* 45, 131.152.

Sigbjörnsson, R., S. Ólafsson, and Ó. Thórarinsson (2004). Strong-motion recordings in Iceland, in Proceedings of the 13th World Conference on Earthquake Engineering, Mira, Vancouver, BC, Canada, paper No. 2370.

Stewart, J. P., Chiou, S., Bray, J. D., Graves, R. W., Somerville, P. G. and Abrahamson, N. A. (2002). Ground motion evaluation procedures for performance-based design," *Soil Dyn. Eq. Eng*. 22, 765-772.

Thórarinsson, Ó., B. Bessason, J. Snæbjörnsson, S. Ólafsson, G. I. Baldvinsson, and R. Sigbjörnsson (2002). The South Iceland earthquakes in 2000: Strong motion measurements, in Proceedings of the 12th European Conference on Earthquake Engineering, Elsevier Science Ltd.