1247

RECORDINGS AND APPLICATIONS OF THE ICELANDIC STRONG MOTION NETWORK

Ódinn THÓRARINSSON[1], Gunnar I. BALDVINSSON[2], Símon ÓLAFSSON[3] And Ragnar SIGBJÖRNSSON[4]

SUMMARY

This paper describes current activities in the field of strong motion research in Iceland. The geophysical background is explained and discussed, and current earthquake monitoring in Iceland is summarised. Special emphasis is put on the strong motion network run by the Engineering Research Institute of the University of Iceland. The objective of the network is stated and the selection of locations explained. The network comprises ground response stations as well as structural response systems in engineered structures. Recordings made by this network are summarised, and the processing procedure for the obtained recordings is described and their derivatives outlined. Applications of the recorded data in hazard and risk studies as well as loss estimations are briefly mentioned. Finally, a description of an automatic data recovery and a near real-time monitoring system which is in the developmental stage, are outlined.

INTRODUCTION

Iceland is an earthquake country with a history of destructive earthquakes ruining dwellings, inducing casualties and taking lives. During this century, devastating earthquakes have damaged settlements both in the coastal areas of North Iceland and in the farmlands on the South Iceland Lowland. In 1912, a magnitude 7 earthquake caused excessive damage in South Iceland. Houses on nine farms collapsed into ruins and one child died. In 1934, an earthquake hit a fishing village in North Iceland and the surrounding countryside. A majority of the houses were damaged so severely that they were evacuated, and the people had to live in tents or some primitive shelters. In 1976, another damaging earthquake struck near a fishing village on the north coast. The earthquake caused significant ground deformation and settlement. A small lake near the village dried up. A majority of the buildings suffered some structural damage, the most severe being in the area of active faults. There was extensive damage to building contents and inventory, outages of electricity and interruption of the water supply to the village. A concrete quay in the harbour cracked and settled. There was general panic, and women and children were evacuated from the village.

Based on written documentation, covering roughly the last 1000 years, it can be deduced that a damaging earthquake strikes roughly twice every century on average. In fact, an examination of historic evidence shows that the South Iceland Lowland is the most active seismic area in Northwestern Europe. Furthermore, it can also be concluded that the next earthquake in the South Iceland Seismic Zone is due, at least within the framework of the theory of probability and statistics.

The earthquake hazard in Iceland has created the need for better understanding of seismic phenomena and earthquake impacts on buildings and infrastructures of modern society. This has led to increased research activities in geophysics, engineering seismology, earthquake engineering and earthquake monitoring. In the following sections, the main emphasis is put on strong motion monitoring and recording and their engineering applications.

[1] *Engineering Research Institute, University of Iceland, e-mail odinn@afl.hi.is*
[2] *Engineering Research Institute, Univercity of Iceland, e-mail gunnib@afl.hi.is*
[3] *Engineering Research Institute, Univercity of Iceland, e-mail simon@afl.hi.is*
[4] *Engineering Research Institute, Univercity of Iceland, e-mail ragnarz@afl.hi.is*

GEOPHYSICAL BACKGROUND

Iceland is recognised as a land of natural hazards. It straddles the Mid-Atlantic ridge, the borderline between the Eurasian Plate and the North American Plate. Crossing the island, the ridge runs eastward through two major fracture zones, one in the South, the South Iceland Seismic Zone (SISZ), and another in the North, the so-called Tjörnes Fracture Zone (TFZ), which extends far offshore. Earthquakes in Iceland may be divided into three main categories, reflecting the main sources of triggering. These are geothermal earthquakes, volcanic earthquakes and tectonic earthquakes.

Geothermal earthquakes, usually not exceeding magnitude three, are small tremors occurring quite frequently in high-temperature geothermal areas. They do not have any significant effect on engineered structures, but can be annoying and disturbing to exposed people.

Volcanic earthquakes are attributable to volcanic activities as the main source of triggering. These earthquakes are generally located in the vicinity of well-known volcanoes, and their magnitude will rarely exceed six. This type of quake does not normally have any significant effect on structures.

Tectonic earthquakes are due to relative movements of the North American and Eurasian Plates. They are of two types, i.e., intraplate earthquakes originating inside the plates, and interplate earthquakes, related directly to plate boundaries. Intraplate earthquakes are not very frequent and have mostly been recorded in the western part of the country. Interplate earthquakes can be divided into two groups, depending on their place of origin. Earthquakes originating in the spreading zone between the plates, i.e., on the Mid-Atlantic Ridge, have a complex mechanism and seldom exceed magnitude five. Earthquakes originating in the above-mentioned fracture zones are the biggest earthquakes in Iceland and may reach magnitude seven or more. Their source mechanism is in all cases of the strike slip type. The seismic motion projected for the SISZ on the basis of plate tectonics, which is left-lateral on the east-west striking fault, is, nevertheless, not visible on the surface as a surface fracture. On the contrary, it appears that the motion can be visualised as a series of north-south striking, right-lateral faults. This is supported by the geological evidence of fault traces on the surface as well as by the north-south, elongated shape of the mapped destruction zones of large, historical earthquakes, [Björnsson and Einarsson, 1980; Einarsson, 1991], see Figure 1. In the northern seismic area, this is not as obvious since the epicentral areas are mostly beyond the coast. However, it is anticipated that the earthquakes in the TFZ can be modelled by a quite similar "book-shelf" mechanism.

EARTHQUAKE MONITORING

Earthquakes have been recorded in Iceland from the beginning of this century. From 1909 to 1927, there are sporadic recordings, but since 1927, the seismological observations are almost continuous. Strong motion recordings have now been carried out for just over 20 years. Currently, three earthquake-monitoring systems are permanently installed and operated in Iceland. They are as follows:

The seismological network of the Science Institute of the University of Iceland consists of 29 seismometers, distributed throughout the country [Einarsson and Björnsson, 1987]. The objective of this network is defined as scientific, primarily to facilitate tectonic and seismological research in Iceland.

The SIL-system (South Iceland Lowland system), operated by the Icelandic Meteorological Office, consists of 32 stations, each equipped with a short-period seismometer, connected to a central computer in Reykjavik. Despite the name, some of the stations are also located within the northern seismic zone [Stefánsson, 1996]. The main purpose of the SIL-system is defined in terms of earthquake prediction research.

The strong motion network of the Engineering Research Institute of the University of Iceland consists of 160 channels, including both ground response channels and structural response channels (see the following section). The objective of this network is primarily earthquake engineering research, emphasising the dynamic behaviour of structural systems.

STRONG MOTION NETWORK

Early in the 1980s, the National Power Company of Iceland consulted the Engineering Research Institute (ERI) of the University of Iceland for co-operation in operating and managing a strong motion system, which had been installed in some of their structures. Their intention was to investigate the dynamic behaviour of dams and hydro power plants during large earthquakes. At that time, the ERI had initiated a small-scale network, aiming at establishing data required for rational structural design, risk management and other earthquake engineering endeavours. These two networks where combined and in co-operation with the Public Road Administration and the City Engineer in Reykjavik, contracts were made concerning the operation and maintenance of a large-scale earthquake monitoring network. Installation of this network started in 1984. Initially, it consisted of 12 triaxial stations. These were mostly ground response stations but also structural response stations in dams. Since then, the system has been gradually extended and updated every year. The locations of the stations were selected on the basis of the geophysical information outlined in the preceding section, the geographic distribution of the population and location of industrial and power plants as well as the main live-line systems. The locations of the ground response stations and the monitoring systems in structures are shown in Figure 1, using appropriate signatures to indicate the type of station. Further details of the network are given in Table 1. In most cases the ground response stations are located in small structures, such as farm houses or public buildings, but others are a part of installations in structural networks**.** The network runs with a high degree of automation, using digital instruments, with the exception of four analogue instruments that record on film. The standalone instruments are of the following types: Kinemetrics SMA-1, Teledyne Geotech A-700, Terra DCA-333, Kinemetrics SSA-1, Kinemetrics K2 and Kinemetrics Etna. The instrumentation systems arrays in structures are composed of force balance accelerometers from Kinemetrics, which are connected to data acquisition equipment from Hewlett Packard (HP) and Kinemetrics (KMI).

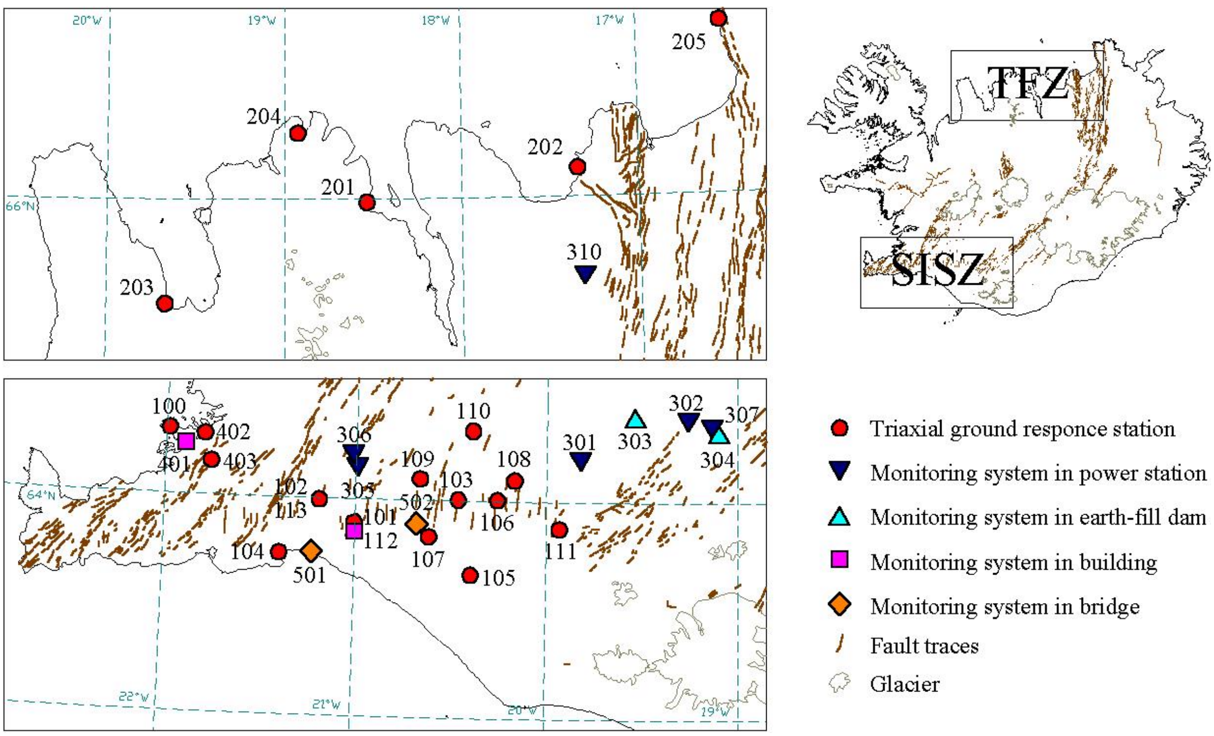

Figure 1: The Icelandic Strong Motion Network, operated by the Engineering Research Institute of the University of Iceland.

At present, the network consists of 160 channels, which can be divided as follows: (a) 39 triaxial ground response stations (including ground channels of structural systems); (b) 3 monitoring systems in earth-fill dams (30 channels); (c) 4 monitoring systems in hydro-power stations (33 channels); (d) 2 monitoring systems in office buildings (14 channels); (e) 2 monitoring systems in seismically isolated bridges (17 channels).

Table 1: An overview of the Icelandic Strong Motion Network. Listed are ground response stations and structural response networks in buildings and structures, labelled "system" in the table. Each ground response station contains one triaxial sensor. The sensors are located in buildings or structures on firm ground. Sensors from Kinemetrics are applied in structural response networks ("ch." denotes channel). The trigger thresholds are in the range 0.002 to 0.009 g, but are in most cases around 0.004 g.

No.	*Site name*	*Long.*	*Lat.*	*Instrument type*	*Structures*
100	Reykjavík	21.96	64.14	Kinemetrics SMA-1	University building, 3 story
101	Selfoss	21.00	63.94	Terra DCA-333	Hospital, 3 story
102	Hveragerdi	21.19	64.00	Geotech A-700	Church
103	Kaldárholt [1)]	20.47	64.00	Terra DCA-333	Farm house, 2 story
104	Thorlákshöfn	21.38	63.85	Kinemetrics SMA-1	School building, 1 story
105	Hella [1)]	20.39	63.84	Kinemetrics ETNA	School building, 2 story
106	Flagbjarnarholt	20.26	63.99	Kinemetrics SSA-1	Farm house, 2 story
107	Thjórsártún	20.65	63.93	Geotech A-700	Farm house, 2 story
108	Minni-Núpur	20.16	64.05	Kinemetrics ETNA	Farm house, 2 story
109	Sólheimar [1)]	20.64	64.07	Kinemetrics ETNA	School building, 2 story
110	Hvítárbakki	20.39	64.16	Kinemetrics SMA-1	Farm house, 1 story
111	Selsund [1)]	19.95	63.94	Kinemetrics SMA-1	Farm house, 1 story
112	Selfoss, Rádhús	21.00	63.94	KMI K2 (6 ch. system) [4)]	Office building, 3 story
113	Hveragerdi, Grund	21.19	64.00	Kinemetrics K2	Retirement home, 2 story
201	Dalvík	18.53	65.97	Kinemetrics SSA-1	Office building, 3 story
202	Húsavík	17.36	66.05	Kinemetrics K2	Fire Station, 3 story
203	Saudárkrókur	19.64	65.74	Kinemetrics SSA-1	School building, 2 story
204	Siglufjörður	18.91	66.16	Kinemetrics SSA-1	Retirement home, 3 story
205	Kópasker	16.44	66.30	Kinemetrics SSA-1	House, 1 story
301	Búrfellsvirkjun	19.84	64.10	HP/KMI (16 ch. system) [6)]	Hydroelectric power station
302	Hrauneyjarfoss	19.24	64.20	KMI K2 (4 ch. system) [4)]	Hydroelectric power station
303	Sultartangastífla	19.57	64.19	HP/KMI (18 ch. system) [6)]	Earth-fill dam
304	Sigöldustífla	19.10	64.16	HP/KMI (6 ch. system) [4)]	Earth-fill dam
305	Írafossvirkjun	21.01	64.09	KMI SSA-1 (4 ch. system) [4)]	Hydroelectric power station
306	Ljósafossvirkjun	21.01	64.10	KMI K2 (9 ch. system) [5)]	Hydroelectric power station
307	Sigölduvirkjun	19.13	64.17	Kinemetrics K2	Hydroelectric power station
310	Laxárvirkjun	17.31	65.82	Kinemetrics SSA-1	Hydroelectric power station
311	Blöndustífla	19.67	65.23	KMI SSA-1 (6 ch. system) [4)]	Earth-fill dam
401	Reykjavík, Hús Versl	21.90	64.14	KMI SSA-1 (8 ch. system) [4)]	Office building, 14 story [2)]
402	Reykjavík, Foldaskóli	21.79	64.13	Kinemetrics SSA-1	School building, 2 story
403	Reykjavík, Heidmörk	21.76	64.08	Kinemetrics SSA-1	Well-house/pump station
501	Óseyrarbrú	21.21	63.88	KMI SSA-1 (8 ch. system) [4)]	Concrete bridge 3)
502	Thjórsárbrú	20.65	63.93	KMI K2 (9 ch. system) [5)]	Steel arch bridge 3)

1) Site-dependent magnification observed
2) Concrete shear walls
3) Bridge with seismic base isolation
4) Including one ground response station
5) Including two ground response stations
6) Including three ground response stations

RECORDINGS

The strong motion network has currently been activated in 180 earthquakes, in which peak acceleration exceeded 0.4% g. In these earthquakes over 1000 time series have been recorded, including recordings from both ground and structural response channels. In addition to these series, recordings of more than four hundred time series have been made as a result of acceleration triggered by structural response. At present, the database contains well over 1400 time series recorded in earthquakes with magnitudes in the range of 2 to 6 and source distances ranging from close to zero up to roughly 80 km. This is indicated in Figure 2. Table 2 shows parameters for earthquakes, of magnitude greater than 4.0, recorded after triggering ground response channels.

Table 2: Earthquakes of magnitude greater than 4.0 recorded by the Icelandic Strong Motion Network.

Date	*Origin time GMT*	*Magnitude* [1)]				*Epicentre*		*Number* [1)] *of stations*	*Shortest epic. dist.* **[km]**	*PGA* [1)] **[g]**
		M_T	m_b	M_s	M_w	*Lat.*	*Long.*			
26.08.1986	04:00:00	4.0			4.6	63.96	20.32	2	14	0.07
25.05.1987	11:31:54	5.8	5.8	5.9	5.9	63.91	19.78	7	24	0.06
09.09.1988	14:40:41	4.4	4.4	4.2	4.6	66.66	17.91	1	82	0.01
19.03.1990	10:46:31	4.7	4.8		4.7	63.95	21.93	3	16	0.03
30.01.1991	07:43:44		5.1		4.7	64.38	20.75	3	35	0.01
23.04.1991	10:26:48				4.8	64.00	20.40	3	4	0.12
27.12.1992	12:23:22		4.3		4.6	64.02	21.18	9	2	0.11
28.08.1993	19:59:08		4.2		5.3	65.97	17.94	3	27	0.04
08.02.1994	03:27:52		5.5		4.0	66.45	19.25	4	36	0.02
19.08.1994	19:18:41				3.5	64.03	21.25	3	4	0.05
20.08.1994	16:40:25		4.3		4.4	64.03	21.24	3	4	0.05
17.01.1996	18:02:03				4.3	66.01	18.13	2	11	0.02
14.10.1996	20:59:57		4.3		5.0	64.05	21.05	3	5	0.10
22.07.1997	16:21:40		4.1		4.9	66.29	18.40	2	27	0.03
24.08.1997	03:04:22		4.8		4.6	64.05	21.25	4	6	0.17
20.09.1997	15:38:18		4.5		4.8	66.22	18.34	4	27	0.05
20.09.1997	15:51:49		4.6			66.24	18.33	6	28	0.06
03.06.1998	06:47:42		4.2			64.06	21.26	2	7	0.01
04.06.1998	19:04:45		4.4			64.09	21.27	6	11	0.04
04.06.1998	21:36:54		5.1		5.5	64.05	21.26	12	6	0.18
04.06.1998	22:59:57		4.4			63.99	21.30	8	6	0.06
13.11.1998	10:38:34		4.9			63.95	21.34	11	10	0.13
14.11.1998	14:24:07		4.7			63.96	21.24	9	5	0.24
25.05.1999	13:19:39		4.1			64.06	21.15	8	7	0.07

[1)] M_T - magnitude based on duration of the seismic signal on local seismograms (Division of Geophysics, Science Institute, University of Iceland); m_b - body wave magnitude (obtained from United States Geological Survey); M_s - surface-wave magnitude; M_w - moment magnitude calculated according to the Hanks-Kanamori relation; number of stations refers to the number of stations recording the event after ground response channel triggering; PGA - Peak Ground Acceleration.

The amount of earthquake data has grown fast during the last three years. This is mostly due to increased seismic activity in the western part of South Iceland, where several earthquake swarms have passed over. In one of these swarms, in November 1998, the highest ground channel acceleration so far was recorded. This was recorded in a small village called Hveragerdi, Station No. 102, with an epicentral distance of less than 5½ km. The maximum peak acceleration was 24% g and the duration approximately 6 seconds. The most significant event so far is, however, the so–called Vatnafjöll earthquake, which occurred on May 25th 1987. Seven stations recorded this earthquake with epicentral distances ranging from 20 to 80 km. The highest ground channel acceleration recorded in this earthquake was 6% g at a station with a roughly 30 km epicentral distance.

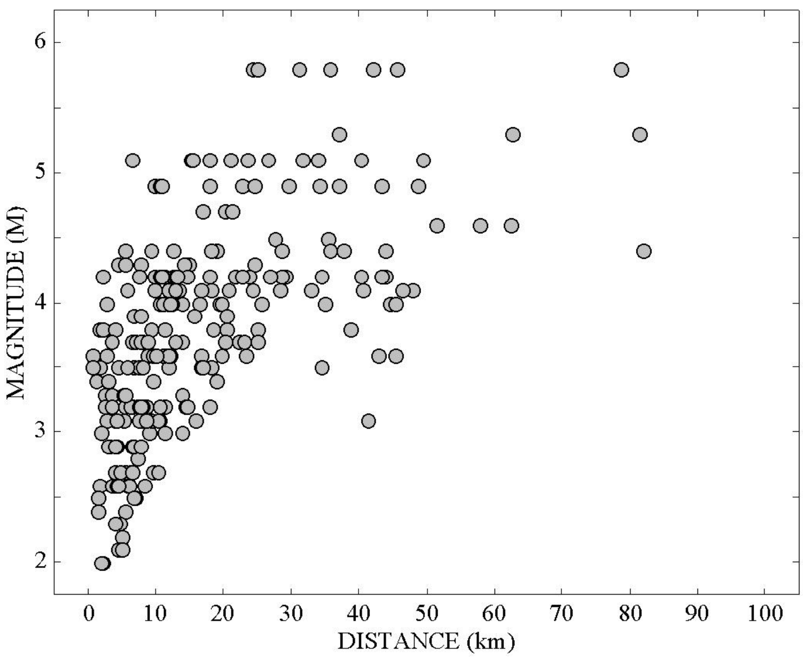

Figure 2: Magnitude and epicentral distance of earthquakes recorded by the Icelandic Strong Motion Network in the period 1986 to 1999. Only earthquakes triggering ground response stations are included.

BASIC DATA PROCESSING AND ROUTINE OPERATION

The recorded data are normally run through a basic data processing procedure to evaluate the quality of the data and to perform necessary corrections. The main steps in this procedure are the following: visual inspection and selection of records as well as selection of time intervals for processing; digitisation of analogue recordings; correction of time series for sensor characteristics, baseline errors and trends, as well as band-pass filtering for spikes and low-frequency noise signals; calculation of velocities and displacements; calculation of Fourier acceleration spectra and linear earthquake response spectra for pre-selected natural periods and critical damping ratios; storage of all data and obtained information in a database.

The sampling rate of the digital recordings is from 100 Hz to 250 Hz, while the sampling rate of the digitised, analogue recordings is 200 Hz. The digitisation is carried out along the lines described in [Trifunac and Lee, 1973]. Most of the application software for data analysis has been written at the Engineering Research Institute. Maintenance and rewriting of this software is more or less a continuous task because of the updating of hardware and basic software. Furthermore, the rewriting aims at more efficient routines and greater automation. Currently the improved storage of both the raw data and their derivatives is given high priority. The ground response data obtained have been included in the Strong Motion Databank at the Imperial College of Science, Technology and Medicine.

APPLICATION OF THE DATA

The recorded data have been analysed and studied emphasising attenuation of ground motion and structural response, duration of shaking, spectral structure of ground motion, spatial coherence of ground acceleration and structural behaviour under earthquake excitation. Some highlights of the studies and on-going projects will be mentioned in what follows.

Based on Icelandic data, engineering models for earthquake motion have been put forward. These include regression models for attenuation of peak ground acceleration and earthquake response spectra [Sigbjörnsson and Baldvinsson, 1992], parametric models of the ARMA type [Ólafsson et al., 1995 and 1996] and source models and Green's function approaches [Halldórsson, 1999]. Furthermore, applying these models, probabilistic response spectra have been derived, for both linear and non-linear behaviour.

A hazard map for Iceland showing peak acceleration has been put forward [Sigbjörnsson and Baldvinsson, 1992]. This map was derived using a tentative catalogue of historic earthquakes and an attenuation model, based on the strong motion data mentioned above. A comparative study of earthquake hazard in Southwest Iceland, using various attenuation formulas, and a synthetic earthquake catalogue, derived using probabilistic models, has likewise been carried out [Bessason, 1992]. A probabilistic simulation model for the assessment of earthquake hazard has been presented in [Sigbjörnsson et al., 1995 and 1996].

The earthquake resistance of Icelandic buildings has been investigated in [Thráinsson et al., 1994], using data from two damaging earthquakes in this century, in 1934 and 1976. This includes both unreinforced and reinforced concrete buildings, wood frame buildings and some old “traditional” turf buildings.

An important on-going part of the structural response data analysis program deals with the application of system identification methods, including the use of ARMAX and related parametric models. Such methods are useful for interpretation of the data and provide an essential tool in structural modelling. The system identification and response of a 14-story office building in Reykjavik is dealt with in [Snæbjörnsson and Sigbjörnsson, 1993].

Unified probabilistic risk assessment for Iceland is a long-standing and on-going project. The analysis of earthquake damage to buildings and structures in Iceland provides an important frame of reference used in calibration of the models. Applications deal with the development of a risk management system for hydro power plants in earthquake zones [Henje et al., 1996], an on-line loss estimation system for emergency planning purposes and an expert alert system aimed primarily at problem solving in earthquake risk management.

Development and application of seismic base isolation systems have been an important project [Bessason, 1992]. These have resulted in the extensive use of seismic base isolation in Icelandic bridges [Haflidason et al., 1996]. Currently, two base isolated bridges, located in the South Iceland Seismic Zone, have been instrumented and are included in the strong motion network (see Table 1).

A seismic method utilising surface waves of the Rayleigh type, the so-called “spectral analysis of surface waves method” or SASW method, is currently being applied to assess the effect of (loose) surface layers of soil or gravel, including comparative studies using results from the “cone penetration test” [Bessason et al., 1998].

The rationalisation of methods for aseismic design of buildings and structures is a long-term project of high practical value. Traditional probabilistic earthquake response spectra are useful in static and quasi-static design of regular buildings and structures. In the case of complex structures, dynamic approaches based on earthquake scenarios have been used. These scenarios are described by appropriate source models and used for the simulation of earthquake ground motions that provide the input to structural models. These models can include any degree of complexity deemed necessary for practical purposes. Examples of recent studies dealing with geothermal power plants can be found in [Sigbjörnsson et al., 1997].

CONCLUSIONS AND FINAL REMARKS

In recent years, the strong motion network has been consistently upgraded, and increased emphasis has been put on making it more reliable and automatic. New and technically improved instruments together with a more secure and efficient communication process now allow more advanced monitoring. New instruments from the Kinemetrics Altus series have been used to replace old and obsolete instruments. In addition to remote control, the Altus K2 and ETNA are capable of alerting a central station to an event or an auto-diagnostic failure. Together with several older instruments, which are also capable of remote control, they will form a group or subsystem, which will be called automatically after an earthquake alarm. Collection of recorded data and primary signal processing by the monitoring system will be used to characterise the earthquake and provide information for on-line loss estimation in the affected area.

Finally, it should be mentioned that the earthquake-research section of the Engineering Research Institute will move to the town of Selfoss, which is situated in the middle of the SISZ. The move is scheduled for the beginning of the year 2000, and from that time, the earthquake-research section will become a part of the International Earthquake Engineering Research Centre, which will be established there.

ACKNOWLEDGEMENTS

The work presented herein was supported by a grant from the University of Iceland Research Fund. The strong motion program is supported by the National Power Company, the City Engineer of Reykjavík and the Public Road Administration. This important support is gratefully acknowledged.

REFERENCES

Bessason, B. (1992), "Assessment of earthquake loading and response of seismically isolated bridges", *Doctoral Thesis*, The University of Trondheim.

Bessason, B., Baldvinsson, G. I. and Thórarinsson, Ó. (1998), "SASW for evaluation of site-specific earthquake excitation", *Proceedings of the Eleventh European Conference on Earthquake Engineering*, Balkema, Paris.

Björnsson, S. and Einarsson, P. (1980), "Jarðskjálftar", *Nátttúra Íslands*, AB, Reykjavík, pp. 121-155.

Einarsson, P. and Björnsson, S. (1987), "Earthquake research at the Science Institute of the University of Iceland (in Icelandic)", *Í hlutarins eðli*, Menningarsjóður, Reykjavík, pp. 251-278.

Einarsson, P. (1991), "Earthquakes and present-day tectonism in Iceland", *Tectonophysics,* 189, pp. 261-279.

Halldórsson, B. (1999), "On Modeling of Earthquake Wave Motion and its Effects on Multi-Support Pipelines", *Acta Polytechnica Scandinavica,* Civil Engineering and Building Construction (Ci 115)*,* Espoo.

Henje, J. C.-I., Einarsson, S. and Sigbjörnsson, R. (1996), "Earthquake risk management applications: A study on hydro power plants", *XXV General Assembly of the European Seismological Commission, Abstr.*, Reykjavík.

Ólafsson, S. and Sigbjörnsson, R. (1995), "Application of ARMA Models to Estimate Earthquake Ground Motion and Structural Response", *Earthquake Engineering and Structural Dynamics*, pp. 951-966.

Ólafsson, S. and Sigbjörnsson, R. (1995), "Simulating of Earthquake Ground Motion and Structural Response", *Acta Polytechnika Scandinavica,* Civil Engineering and Building Construction (Ci 102), Helsinki.

Ólafsson, S., Remseth, S. and Sigbjörnsson, R. (1996), "Simulation of probabilistic nonlinear response spectra", *Structural Dynamics,* (Editors: G.Augusti, C. Borri & P. Spinelli), Balkema, pp. 97-104.

Sigbjörnsson, R. and Baldvinsson, G. I. (1992), "Seismic hazard and recordings of strong ground motion in Iceland". *Proceedings of the 10th World Conference on Earthquake Engineering*, 1, Balkema, pp. 419-424.

Sigbjörnsson, R., Baldvinsson, G. I., Thráinsson, H., Gardarsdóttir, G. Th. and Thórarinsson, Ó. (1995), "On seismic hazard in Iceland - A stochastic simulation approach", *Proceedings of the 10th European Conference on Earthquake Engineering*, Balkema, pp. 111-116.

Sigbjörnsson, R., Baldvinsson, G. I. and Thráinsson, H. (1995), "A stochastic simulation approach for assessment of seismic hazard maps", *European Seismic Design Practice - Research & Application* (Editor: A. S. Elnashai), Balkema, pp. 541-547.

Sigbjörnsson, R., Baldvinsson, G. I. and Thráinsson, H. (1993), "The mapping of seismic hazard using stochastic simulation and geographic information systems", *Eleventh World Conference on Earthquake Engineering*, Pergamon, Paper No. 710.

Sigbjörnsson, R., Baldvinsson, G. I., Snæbjörnsson, J. Th., Bessason, B. and Einarsson, P. (1997), "Áhrif jarðskjálfta á tæknibúnað í stöðvarhúsi Kröfluvirkjunar (Earthquake induced effects on technical systems in the Krafla Geothermal Power Station)", Engineering Research Institute, University of Iceland, Report No. 97001.

Snæbjörnsson, J. Th, and Sigbjörnsson, R. (1993), "A Study of Earthquake and Wind Induced Structural Response", *Structural Dynamics* (editors T. Moan et al.), 1, Balkema, pp. 41-48.

Stefánsson, R. (ed.), (1996), "The SIL system monitoring and data evaluation procedures", Icelandic Meteorological Office, Reykjavik.

Trifunac, M. D. and Lee, V. W. (1973), "Routine computer processing of strong-motion accelerograms", *EERL 73-03*, California Institute of Technology.

Thráinsson, H. and Sigbjörnsson, R. (1994), "The attenuation of damage", *Proceedings of the Fifth US National Conference on Earthquake Engineering*, III, pp. 419-427.