Paper No. 1256. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

AN ENGINEERING ANALYSIS OF THE CONSEQUENCES OF THE SHIKOTAN EARTHQUAKE OF OCTOBER 4(5), 1994

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ABSTRACT

On October 4, 1994, at 16:22:57 Moscow time (13:22:57 GMT) or 00:22:57 (October, 5) local time, catastrophic earthquake occurred in the south of Kuril Islands (70 km east from the Shikotan Island), M = 8.0, I = IX-X, which was accompanied by tsunami and a series of aftershocks. 27 aftershocks with magnitude M > 5.0, including two with M > 6.0, have occurred since October 4 till October 17. The earthquake had a gravest consequence on the islands of the lesser Kuril chain: Zelenyi, Anuchina, Yurii, Shikotan and in the settlements on Kunashir and Iturup Islands. There were 22400 persons in the disaster zone, 11 persons were lost, 32 persons injured with traumas of different degrees.

KEYWORDS

Earthquake; hazard; risk; consequences; magnitude; aftershock; intensity; seismicity; frequency; source.

1. BASIC SOURCE PARAMETERS

Table 1 and the map inset in Fig. 1 show the determined basic parameters of the main shock.

2. AFTERSHOCK

During the period of October 4-19,1994, a series of aftershocks was observed; the strongest occurred on October 9 and had the following basic parameters: $t_o = 07:55:39.0, \varphi = 43.97°N, \lambda = 148.22°E, H = 33\ km, M_s = 7.7$. For this earthquake, the tsunami alarm was announced, but tsunami was not observed near the margins of Russia.

Table 2 presents the list of aftershocks, and Fig. 1 shows their distribution. This figure also shows the epicenters of the two strongest earthquakes of this region, which happened in the 40 years.

During the period October 4-19, 35 aftershocks occurred including two aftershocks with magnitude $M > 7.0$, nine of them with magnitude $M > 6.0$, and others with smaller magnitudes. Perhaps, the

basic feature of this source is that within two weeks after the main shock, only two earthquakes occurred with $M > 7.0$, which is not characteristic for such catastrophes in Kuril-Kamchatka zone. However, this list does not completely reflect the development of the aftershock process. This is caused by the absence of data about aftershocks with magnitudes $M < 5.0$ in SUR (Service of Urgent Reports) and also by the fact that earthquake in the range 5.0-6.0 were represented by far not completely, especially during the first day after the main shock. All this is the consequence of deficiencies of analog recording at stations with restricted dynamic ranges (of about 40 dB), and the forced closing of five stations on Kuril Islands long before the earthquake because of insufficient funding.

3. TSUNAMI AND MACROSEISMIC PHENOMENA

Tsunami Emergency Service in Yuzhno-Sakhalinsk announced a tsunami alarm for Kuril and Southern Kuril Districts immediately after the earthquake. According to preliminary data, tsunami of heights of 2-3 m were observed in Southern Kuril District; in Shikotan Island, Malokurilsk, and Krabozavodsk its height reached 2 m and 1 m, respectively. These data were refined later: tsunami run-up heights reached 2.5 m in the Malokuril'skaya bay, more than 3 m in Yuzhno-Kurilsk bay, and 5 m on Zelenyi Island. Hawsers and port constructions in the indicated points and a number of houses in Yuzhno-Kurilsk were destroyed, ships were cast ashore, and tsunami stations were damaged.

Table 1. The main parameters of the Shikotan earthquake source determined by various seismological centers

t_o	Co-ordinates		H,	M_s	I_o,	Data
h-min-sec	φ^oN	λ^oE	km		MSK	source
13-22-51	43.5	147.5	33	7.5	9	SUR-preliminary
13-22-56.7	43.68	147.63	33	8.0	9-10	SUR-refined
13-22-57.0	43.84	147.59	33	8.0	9-10	SUR-final
13-22-59.5	44.0	147.4	33	8.2		NEIC
13-22-56.48	44.81	147.60	33	7.6		CSEM
13-22-58.6	43.66	146.78	33	7.8		SSB
13-23-00	43.4	147.6	33	7.8		RSC

First macroseismic data has arrived to SUR from the station "Severo-Kurilsk". From "Yuzhno-Sakhalinsk macroseismic data could not be transmitted in less than 1 hr because of the bad communication and power failure. The earthquake was felt in the following points: in the Shikotan Island - VI-IX, in Kurilsk - IV, in Severo-Kurilsk, in the Matua Island, and in the south of Sakhalin - II-III, in the Simushir Island - II. Surface ruptures were formed on Shikotan Island. As the result of the earthquake, substantial damages corresponding to intensity IX were recorded in Shikotan, Kunashir, and Iturup islands. Up to 80 per cent of living, public, and industrial buildings in settlements Malokurilsk, Krabozavodsk (Shikotan), Yuzhno-Kurilsk (Kunashir), and Goryachie Klyuchi (Iturup) are destroyed and damaged. The earthquake and the ensuing tsunami caused deaths and injuries.

4. AN ENGINEERING ANALYSIS OF THE CONSEQUENCES OF THE SHIKOTAN EARTHQUAKE OF OCTOBER 4(5), 1994

The Shikotan Island, which has two settlements-Malokurilsk town (3800 residents) and Krabozavodskoe village (2700 residents) - was the nearest to the epicenter among the shaked island. These settlements

most suffered from the earthquake. Both of them are situated in the northern part of the island; the distance between them is 7 km.

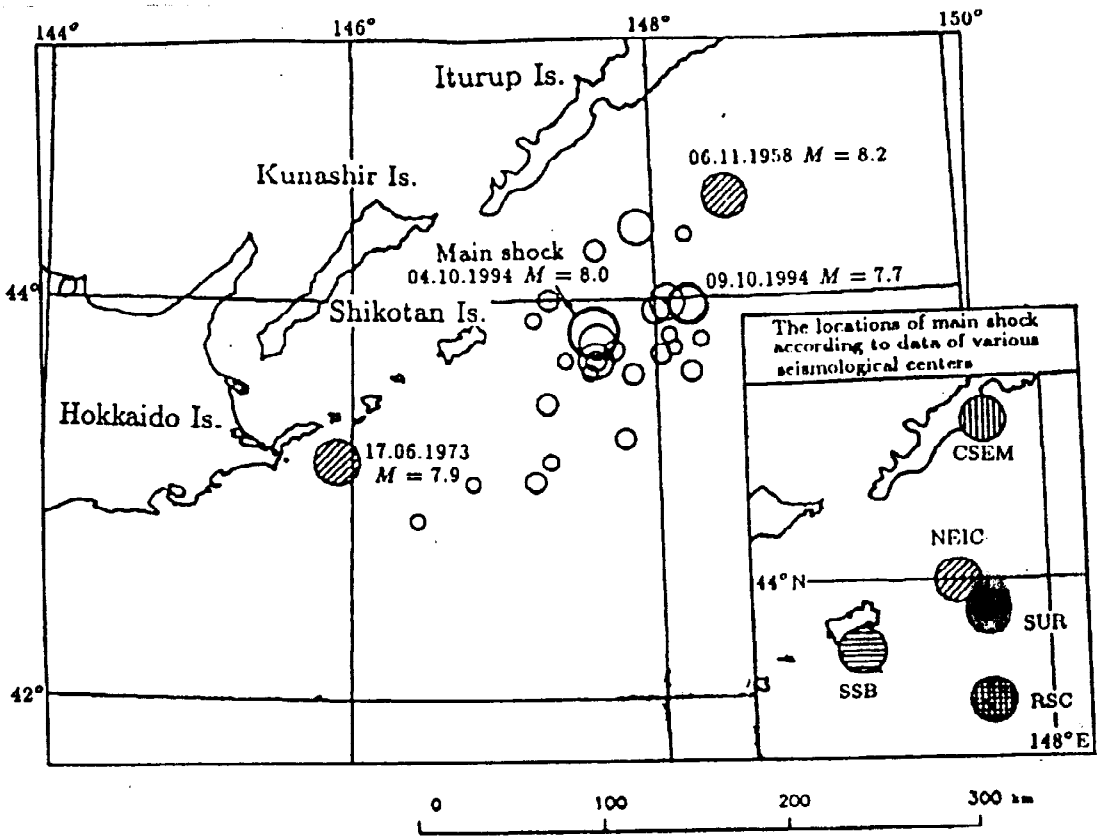

Fig. 1. The map of epicenters of the Shikotan main shock and its aftershocks (the map and the inset are given in the same scale)

4.1. Structure of Building

The town of Malokurilsk and the village of Krabozavodskoe are fairly recent settlements. Their building was started in 1960-1963. In the planning aspect, both of these settlements can be divided into two zones: the industrial zone comprising buildings and constructions of the fish-processing factory, and the residential zone comprising dwelling houses and public amenities.

There are 327 dwelling houses in Malokurilsk and Krabozavodskoe on Shikotan, of which 209 private houses are one-storey wooden building with beam walls and wooden overlaps.

Table 3 presents the list of dwelling houses on Shikotan.

Besides dwelling houses, there are more than 50 buildings for cultural and life purposes in Malokurilsk and Krabozavodskoe (see Table 4).

Table 2. The list of aftershocks of the Shikotan earthquake according to SUR RAS data

t_o h-min-sec	Co-ordinates φ^oN	Co-ordinates λ^oE	H, km	M_s	MPV	t_o h-min-sec	Co-ordinates φ^oN	Co-ordinates λ^oE	H, km	M_s	MPV
	October, 4						October, 9				
13-42-51	55.6	147.89	33			07-55-39.0	43.97	148.22	33	7.7	
14-42-36.5	43.98	148.08	33			08-07-05.5	43.49	147.28	33	5.9	
15-24-19.7	43.79	147.61	33	7.0		08-48-49.8	43.31	147.78	33	6.0	
16-01-32.0	43.70	147.60	33		6.8	11-07-43.0	43.63	147.84	33	5.9	
16-06-26.7	43.94	148.00	33		6.4	12-24-25.0	43.70	147.40	33	5.5	
19-16-30.0	44.24	147.61	33	6.1							
20-01-05.0	43.30	147.10	33	5.5			October, 13				
						22-23-24.4	43.76	148.12	33	5.6	
	October, 5										
01-58-24.0	43.70	147.60	33	5.8			October, 16				
04-00-47.9	43.73	148.03	33	6.1		05-10-10.5	46.52	149.16	180	6.3	
07-16-04.1	43.64	148.23	33	5.9							
12-05-06.7	43.82	148.09	33	5.7			October, 17				
20-37-32.6	43.75	147.72	33	6.2		13-54-50.0	43.00	147.50	33	4.7	
20-39-50.0	44.40	147.40	33	6.2							
							October, 18				
	October, 6					10-42-47.0	43.00	147770	80	4.3	6.1
07-38-56.8	44.31	148.21	33	5.6		17-12-42.8	43.58	148.31	70	5.6	
						21-38-17.0	42.60	148.10	45	4.0	5.1
	October, 7										
02-36-04.3	43.64	147.56	33	5.0			October, 19				
07-00-48.0	43.20	147.30	33	5.6		05-21-58.0	42.40	147.30	70		5.0
15-00-15.0	43.1j	147.20	33	5.9		08-15-40.0	42.90	148.50	70		5.1
15-24-01.4	42.90	146.43	33	5.4		18-02-10.0	43.40	147.90	70		5.3
						22-28-48.0	43.90	147.70	70		5.1
	October, 8										
05-28-22.1	43.09	146.80	33	5.3							
09-54-36.7	43.77	148.16	33	5.7							

It should be noted that industrial buildings and constructions of fish-factories, as a rule, were built near port and mooring constructions in the coastal area, and dwelling houses and buildings for improvement of living conditions were built mainly on hills, i.e. on territories, characterized by steep slopes.

Table 3. The list of dwelling houses on the Shikotan Island

Type of buildings	Number of stories	Number
Wooden with beam walls	1	209
Wooden pabnelboard with claydite heating	1	47
Wooden with beam walls	1-2	30
Wooden with beam walls	2	10
Stony with cinder-block walls and prefabricated overlaps	2	25
Large-panel (at garrison)	3	6

4.2. Residual Phenomena in the Ground

Unfortunately, the microseismic zoning and hydrogeological studies were not done on the Kuril Islands.

Two large surface ruptures, strictly lined up to the epicenter, were noted on Shikotan after the earthquake of October 4(5), 1994. The depth of the ruptures reaches 10 to 15 m, their width is 3 to 20 m, and their length is up to 250 m. Numerous smaller ruptures up to 5 cm wide were also observed in the ground and concrete trails.

Table 4. The list of buildings for cultural and life purposes on the Shikotan Island

Constructive design	Number of stories	Number
Wooden with beam walls, plastered inside, foundations are wooden and columnar brick filling (club, post-telegraph-telephone exchange, drug store, hospitals, dispensarty, library, kindergartens, and stores)	1	22
Stony with cinder-block (40x20x20 cm) walls and with bearing walls as well as overlaps fabricated from precast hollow-core or ribbed slabs (schools, boiler-houses, store-houses)	1-2	8
Buildiings with uncomplete reinforced-concrete framework and silica-brick walls (administrative buildings, bath and laindary center, store-houses)	1-2-3	7
Reinforced-concrete framework with brick filling (gymnasiums, club, schools)	1	4
Buildings with cinder-block walls, with monolithioc reinforced-concrete overlap (restaurant, bakery, storage facilities, club)	1-3	5
Wooden with beam walls, with lower reinforced-concrete framework and cinder-block's barrier (fire outposts, administrative buildings)	2	6
Monolithic (boiler-houses)	1	3

Such residual displacements give grounds to believe that the intensity of the earthquake reached IX and more on Shikotan.

4.3. Character and Degree of Damages to Building on Shikotan Island

Weakenning of the constructions caused by the materials aging (wooden structures), and low construction quality - influenced the character and degree of the damages to the buildings damages.

Wooden panelboard dwelling houses, heated by claydite, have been built in early 60s as a temporary residence of workers of the fish production. No antiseismic measures were taken. The foundations are strip, concrete, or concreted wooden stands. The degree of damage to these buildings is 3 to 4.

The typical damage of panelboard houses is the following:
- through vertical and tilted cracks in the foundation up to 1 cm wide;
- a break-off of the longitudinal walls from the cross ones;

- a fall-through of thr floor of the ground floor because of the foundations displacement, damages of furnaces, and collapse of the chimneys;
- mass collapse of plaster of walls and ceilings.

Wooden beam one- and two-storey houses, built in 60s to 70s, have a 2 to 3 degree of damage. These damages were mainly in the foundations: through cracks in the tape foundations and considerable displacements in columnar wooden foundations up to 5-7 cm. In the overlying structures, there is a mass collapse of plaster from the walls and the ceiling, sagging of the floor, cracks between longitudinal and cross walls, damage of furnaces, and collapse of chimneys.

It should be noted that the main cause of damages in these structures is the exchaustion of the bearing strength due to material againg, because rotten lower wall rows and foundation stands were observed in many houses. In the stony buildings of Shikotan Island 400x200x200 mm cinder blocks are used in the enclosing structures of walls.

Part of the two-storey dwelling houses with cinder-block walls of the new construction of the 80s have monolithic tape foundations, prefabricated overlaps, and seismic belts. The walls are plastered inside over lath. The degree of damage to such houses is 2 to 3.

Basically, the foundations were damaged (vertical and tilted cracks), the joints between longitudinal and cross walls opened up. Destruction of the exterior corners was observed in several houses. Part of such houses was built in the 70s, no antiseismic measures were taken. The degree of damage is 3 to 4.

Diagonal cracks in the piers of longitudinal self-supporting walls, as well as horizontal cracks at the level of the window stills and lintels, are typical damages to these buildings. As a rule, through diagonal cracks were observed in cross bearing walls; partitions were greatly damaged. First stories were damaged much more than the ground ones.

Opening of the horizontal and vertical connecting joints of panels, as well as the collapse of the entrance canopies in some houses, were the most typical damages to large-panel houses. Their degree of damage is 1 to 2.

The character and degree of damages in wooden buildings for social life purposes with beam walls are the same as in dwelling houses of such type.

The strong damages were caused to the story buildings with cinder-block or brick walls and incomplete reinforced concrete framework (school, restaurant, bakery, fire outposts, bath and laundry center, and storehouses of the fish-processing factory). The degree of damage in such buildings is 3 to 4. Considerable damage to the foundations, diagonal cracks in the piers of longitudinal bearing walls, diagonal cracks in cross self-supporting walls and partitions as well as partial collapse of the partitions, floor slabs and end walls, were typical.

Framework buildings with brick or cinder-block filling were damaged most heavily. Almost all of them had a 4 to 5 degree of damage.

The two-storey school in Malokurilsk is built in a monolithic reinforced-concrete framework with brick filling. The school had two cross-perpendicular sections: the class-rooms and gymnasium. Damages the brickwork of the filling by through diagonal cracks and a partial collapse of partitions were observed in the educational section. The framework of the ground-floor had tilted cracks up to 0.5 mm connection

of the columns with the cross-bars. The gymnasium's self-supporting end walls were damaged and partially collapsed.

Damages of the one-storey framework buildings of storage facilities and of the cantonment were similar. The club-house in Malokurilsk was under construction. It has an intricate configuration in plan and consists of several separate sections. The first phase of this building (gymnasium) was put in operation in 1993. Its foundations are tape, monolithic, bearing cinder-block walls, the roof was treated from reinforced-concrete slabs on the roof trusses. This roof totally collapsed after the earthquake of October 4(5), 1994. The degree of damage is 5.

The remainder of the club had partial overlaps from precast slabs and was not overlapped partially. The degree of damage to this buildings is 4. The break-off of the hinged panels from the framework and the collapse of some slabs of the overlaps were observed.

4.4. Behavior of Buildings and Constructions on Kunashir and Iturup Islands during the Shikotan Earthquake

The Kunashir Island (about 15 thousand residents) is 230 km west from the earthquake epicenter. Therefore the caused detriment was much less than on Shikotan Island. Damage was mainly caused to the buildings and constructions in Yuzhno-Kurilsk town, Otrada, Golovnino, and Dubovoe settlements. Intensity on Kunashir Island was VI to VII. The design philosophy of the dwelling houses and buildings for social and cultural purposes (schools, kindergartens, clubs, sports constructions, bath and laundry centers) is the same as on Shikotan.

Old panelboard dwelling houses with wooden stands, as well as frame and reinforced-concrete buildings for social, cultural and life purposes have a higher degree of damage. However, it should be noted that the detriment, caused by the earthquake on Kunashir is less than on Shikotan. The degree of damage is less by 1 to 2.

The earthquake intensity on Iturup was VI. Among significant damages in Kurilsk, it should be noted that chimneys were collapsed, furnaces were damaged, and power transmission lines were broken. The degree of damages in schools, kindergartens, administrative buildings, as well as in other constructions of public amenities, which are a framework with stony filling or an incomplete framework with load-bearing exterior walls (cinder blocks or bricks), is 1, i.e. cracks in joints between structures were typical damages.

The military hospital, which is an incomplete framework with exterior bearing brick walls was a load-bearing structure, collapsed in the settlement of Goryachie Klyuchi on Iturup Island, 27 km south-east from the town of Kurilsk (about 140 km north from the earthquake epicenter). The hospital was built at the river backwater and the degree and character of this collapse appear to be affected by the ground conditions.

In this settlement, more than 20 three-storey large-panel dwelling houses were built for the service personnal. The degree of their damages was 1 and is characterized by negligible cracks in the joints between panels.

CONCLUSIONS

The survey of buildings and constructions, damaged by the earthquake of October 5, 1994, on Kuril Islands, as well as the engineering examination of the obtained data, have given a considerable material

on improvement of the aseismic-building code, as well as providing seismic reliability of buildings and constructions.

The data obtained have mainly confirmed the up-to-date concepts of the seismic stability of constructions; it also exposed a number of new facts. Among the main facts and postulates, learnt after the past earthquakes, are the following:

1. The high seismic stability of large-panel buildings.

2. The rather high seismic stability of wooden buildings, well projected and constructed.

3. The low seismic stability of buildings with walls of a low quality stone- and brickwork, of combined constructions with a compounded bearing structure: partially brick walls and a partially reinforced-concrete framework (incomplete framework), and a reinforced-concrete framework with the stony filler. The situation was worsened by the fact that the buildings were built without following the projecting standards "Building in seismic zones".

4. A rather substantial effect of local ground conditions on the degree of seismic destructions. The striking example is the collapse of the hospital in Goryachie Klyuchi (Iturup), built in the backwater area, where, apparently, the intensity on the platform of shakes was IX, whereas it was VI to VII on the other platforms of Iturup, i.e. lower by 2 to 3 in comparison with the backwater area. The same picture was observed for the Petropavlovsk-Kamchatskii's earthquake on May 5, 1959, where the intensity reached IX in the vicinity of the Pogranichnaya street on the mud flooded grounds and the provinicial hospital collapsed, while the earthquake intensity did not exceed VII on the rocks in the other parts of the town.

5. The excessive collapsing in general because of the low quality of projects without regard to the requirements of the seismic standards.

It should be reffered to the relatively new facts, revealed by the buildings inspection after the Shikotan earthquake:

1. The strong damages of foundations that were not observed at all after the Spitak's earthquake and rarely observed after other earthquakes.

2. The collapse of canopies of large-panel buildings.

3. The excessive damages of the reinforced-concrete framework buildings (the combination of the framework with stony bearing elements).

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