SEISMIC RISK ESTIMATION CONSIDERING THE UNCERTAINTY OF FAULT PARAMETERS FOR NEAR FIELD EARTHQUAKES

Makoto TOMATSU[1] And Shigeyuki OKADA[2]

SUMMARY

Near field earthquakes bring catastrophic disasters on large urbanized cities. Local governments must prepare the regional mitigation plans on the basis of seismic hazard and risk estimation in order to protect the building environment and the population. In case of Sapporo City, that is our research target, it is difficult to specify the source parameters of near field earthquakes affected the populated area. It is necessary to investigate the influence of indefinite parameters upon the risk assessment. In this paper, we enforce an importance of the plural estimation of seismic damages by probable earthquakes occurring near the urban area. Paying attention to the difficulties of taking measures against all of the cases on estimated damages, we give an example of the rule of making decision about the priority of mitigation plans from the point of view of earthquake engineering and political science.

INTRODUCTION

Since the 1995 Great Hanshin-Awaji Earthquake Disaster, many local governments have reviewed their regional mitigation plans. It is indispensable to prepare the plans on the basis of seismic hazard and risk estimation in order to protect the built environment and the population. Hazard and risk estimation is first requisite to designation of the seismic source parameters as magnitude, location of fault, dip angle, rupture velocity, and so on. But, specifying appropriate parameters is generally very difficult because we cannot obtain directly those parameters by means of measuring and/or survey.

It is necessary to investigate the influence of indefinite parameters upon the risk assessment. Paying attention to the difficulties of taking measures against all of the cases on estimated damages, we give an example of the rule of making decision about the priority of mitigation plans from the point of view of earthquake engineering and political science.

---

[1] *Hokkaido Prefectural Cold Region Housing and Urban Research Inst, Sapporo, Japan. E-mail tomatsu@hri.pref.hokkaido.jp*

[2] *Grad School of Engineering, Hokkaido University, Sapporo, Japan. E-mail okd@eng.hokudai.ac.jp*

2. NEAR FIELD EARTHQUAKES AFFECTED SAPPORO AREA

Our research target area is Sapporo City with a population of 1,800,000 that is the largest city in Hokkaido Island, northern Japan. Earthquakes, which bring primary damages to Sapporo City, are (1) great interplate earthquakes around Japan Sea (ex.1940 Shakotan Hanto-oki Earthquake (M7.0) and 1993 Hokkaido Nansei-oki Earthquake (M7.9)), (2) great intraplate earthquakes around Japan Sea (ex.1792 Shakotan-oki Earthquake (M6.9) and 1947 Rumoi Seiho-oki Earthquake (M7.0)), and/or (3) near field earthquakes occurred around the Ishikari plain (ex..1834 Ishikari-wan Earthquake (M6.8)). In this paper we estimate seismic damages by probable earthquakes occurring near Sapporo area.

3. SEISMIC DAMAGE ESTIMATION

3.1 The method of estimation

We use simple methods for estimating earthquake damages, because purpose of this paper is not to estimate damages accurately but to point out influence of indefinite fault parameters on the evaluation of seismic ground severity and damages. First, seismic intensity of assumed fault is evaluated on the basis of dynamic source model. Second, the number of major damages of wooden frame construction is evaluated using vulnerability function which was obtained from the relation between intensity and damage rate in recent earthquakes occurred near Hokkaido [1]. By following the above procedure we establish the limits of fault parameters and then we estimate damages in Sapporo area about many cases of seismic parameters within the limits.

3.2 Uncertainty of fault parameters

Figure 1 is epicenter distribution of felt earthquake around Sapporo City from 1900 onward [2]. According to figure 1, it is clear that seismic zone exist beneath Sapporo City. From its direction it is assumed that the strike of earthquake is the northwest-southeast direction. Kasahara(1996) suggests existence of earthquake faults that lengths is 20km, width is 10km, dislocation is 1m and M(JMA) is 6.5 on rectangular area in this figure. But Sapporo City is vastly covered with thick alluvium; it is very difficult to specify the location of fault from active fault survey. The probability that earthquakes occur around this area is equal from the present data, so it is not able to specify the source parameters. That is to say, to establish rise time, dip angle, rupture velocity, starting point of the rupture and the depth of the top of fault are very difficult, so it is necessary to investigate the influence of indefinite parameters upon the risk assessment.

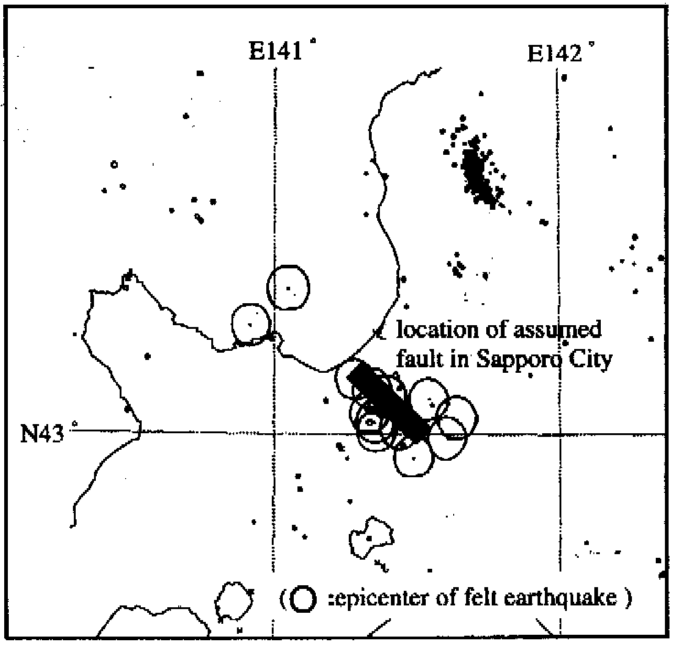


Figure 1: Epicenter of felt earthquake around Sapporo City (1900 – 1996)

3.3 Prediction of seismic intensity in local area

In case of near field earthquake, it is inappropriate to assume point source because of directivity, therefore seismic ground severity are evaluated as line source or area source. There is Kobayashi and Midorikawa (1982) method [3] of evaluation seismic ground severity considering directivity in the field of earthquake engineering. In this paper we adopt this method for the evaluation of seismic ground severity because source parameters can be established optionally in this method.

We try to estimate the seismic intensity at each 500m mesh. Now i is a mesh number. Kobayashi and Midorikawa method is to evaluate seismic bedrock acceleration and/or velocity and V_i^B is seismic bedrock velocity at division i on this method. In order to add the surface geological condition to the seismic motion on the bedrock, the following empirical equation for estimating seismic intensity at any point in Sapporo City is adopted [Okada et al. (1985)] [4].

$$I_i = I_i^S + \begin{pmatrix} 0.756 & \text{silt} \\ 0.682 & \text{peat} \\ 0.550 & \text{volcanic ash} \\ 0.540 & \text{sandy silt} \\ 0.449 & \text{sandy and clayey silt} \\ 0.344 & \text{river deposit} \\ 0.226 & \text{gravel} \\ 0.104 & \text{andesite} \\ 0.050 & \text{sand and gravel} \\ 0.004 & \text{talus} \end{pmatrix} \tag{1}$$

Where, I_i is seismic ground intensity at division i and I_i^S is standard ground intensity removed ground effect. I_i^S is derived from Muramatsu (1966) velocity – intensity equation as shown (2) [5].

$$I_i^S = 2 \times \left(\log\left(\alpha \times V_i^B\right) + 1.4\right) - 0.5 \tag{2}$$

α is the ground amplification of velocity and is derived from detailed seismic intensity in Sapporo City for 1993 Hokkaido Nansei-oki earthquake. That is to say, seismic intensity by questionnaire survey at division i for this earthquake is I_i and Eq.1, item2 is $\delta_{i,j}$. They are translated into V_i^S by Muramatsu velocity – intensity equation as shown (3).

$$\log V_i^S = \frac{I_i - \delta_{i,j} + 0.5}{2} - 1.4 \tag{3}$$

Where, V_i^S is maximum velocity of the standard ground. Adopting fault parameters of 1993 Hokkaido Nansei-oki earthquake from Abe et al (1994). and Architectural Institute of Japan(1995), V_i^S is derived from Kobayashi and Midorikawa method. V_i^S and V_i^B are derived each division and α is derived as shown (4).

$$\alpha = \frac{\sum_{i=1}^{n} \left(V_i^S / V_i^B\right)}{n} \tag{4}$$

Where, n is the total number of division in Sapporo City. Derived α is 2.8

3.4 Effect of indefinite fault parameters on the evaluation of seismic intensity

In this paragraph we estimate the effects of indefinite fault parameters by comparing far field earthquake and near field earthquake. Fault parameters as static parameters in Eq.4 are the location of fault, the depth of the top of fault, fault length, fault width and dip angle and as dynamic parameters are rise time, starting point of the rupture and rupture velocity. In this paper we estimate the depth of the top of fault, starting point of the rupture, rise time and rupture velocity which cannot be determined in case of near field earthquake around Sapporo City. Far field earthquake compared with near field earthquake is equivalent to the 1993 Hokkaido Nansei-oki

Table 1:Fault parameters list for the purpose of estimating seismic intensity.

Parameter	Unit	Uncertainly	Near field earthquake	Far field earthquake
Fault Length	Km	definite	20	120
Fault Width	Km	definite	10	25
Dislocation	M	definite	1	4
Starting point of the rupture		uncertain	Dividing fault plane into 12 lots	dividing fault plane into 12 lots
Rise Time	Second	uncertain	1.1±75%	4.5±75%
Dip Angle	Degree	uncertain	45,90,135	55
Depth of the top of Fault	Km	uncertain	1-26	1-26
Rupture Velocity	Km/sec	uncertain	2.3±30%	2.9
S-wave Velocity	Km/sec	definite	3.5	3.4

earthquake and the range of fault parameters is equivalent to near field earthquake one. Fault parameters are shown in Table 1.

(1) Effect of the depth of the top of fault

Far field earthquake and near field earthquake are assumed to occur in shallow. Because the average depth of seismic bedrock is 1km, the depth of the top of fault is changed from 1km to 26km each 5km and we investigate a change of maximum intensity in Sapporo City. Figure 1 shows an effect of the depth of the top of fault upon seismic intensity. In case of far field earthquake an effect of the depth of the top of fault upon seismic intensity is about 0.1, while in case of near field earthquake it is 1.4. In case of near field earthquake it becomes clear not to be able to ignore an effect of the depth of the top of fault.

(2) Effect of starting point of the rupture

Dividing fault plane into 12 lots from a southern lot to a northern lot, we estimate seismic intensity shifting starting point of the rupture from southern lot. It was assumed that fault ruptured at the same time in the width direction. Figure 3 shows isoseismal map of Sapporo City in each cases of rupture starting from southern lot, northern lot and central lot. The left side is near field earthquake (a black line shows location of fault top) and the other side is far field earthquake. In case of near field earthquake high intensity areas appear along the direction of rupture progress, while in case of far field earthquake high intensity areas always appear in the northeast of Sapporo that are covered with peat.

(3) Effect of rise time

Errors of rise time set up less than 75%. In case of near field earthquake an effect of raise time upon seismic intensity is about 0.2, while in case of far field earthquake it is no change. Rise time have little effect on seismic intensity.

(4) Effect of rupture velocity

Errors of rise time set up less than 30% and we compare seismic intensity in Sapporo City. Figure 4 shows an effect of rupture velocity. In case of far field earthquake an effect of rupture velocity upon seismic intensity is about 0.2, while in case of near field earthquake it is about 0.6. In case of near field earthquake it becomes clear not to be able to ignore an effect of rupture velocity.

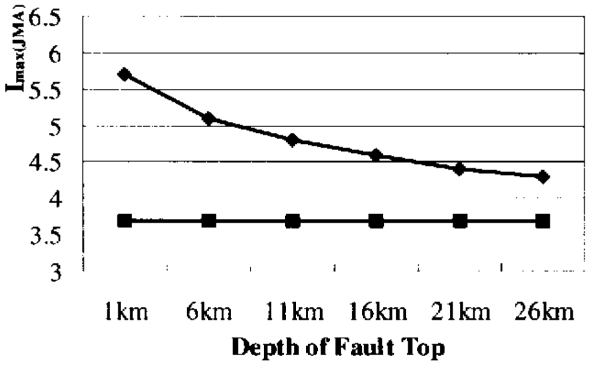


Figure 2: Effect of indefinite the depth of the top of fault

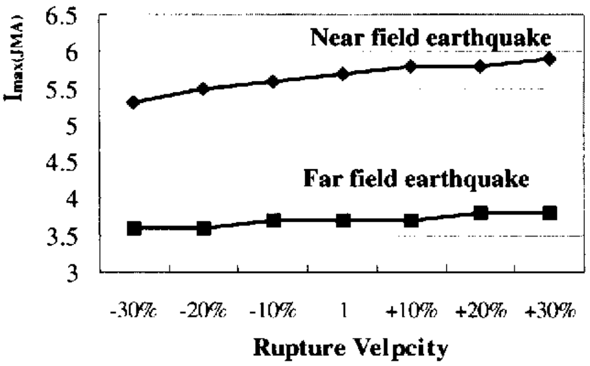


Figure 4: Effect of indefinite rupture velocity on the evaluation of seismic intensity

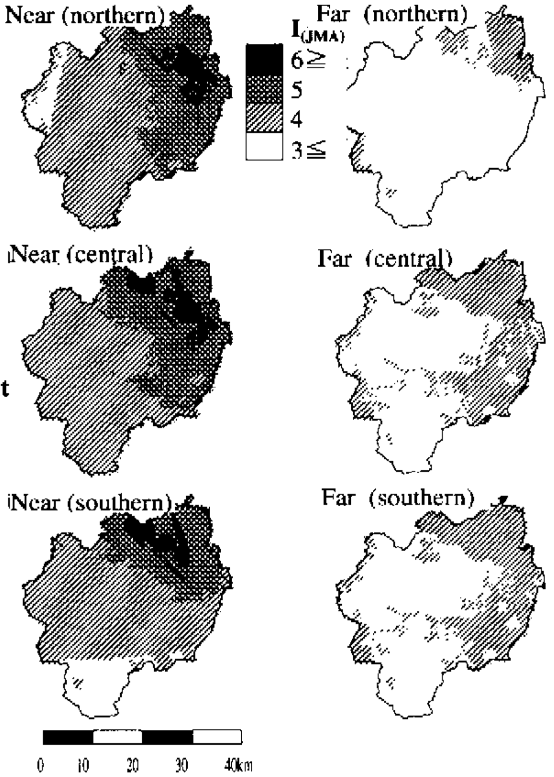


Figure 3: Effect of indefinite starting point of the rupture on the evaluation of seismic intensity

3.4 Effect on the evaluation of damages

(1) The source parameters that are paid attention on the regional mitigation plans

According to previous chapter, it is cleared that indefinite parameter effect on seismic intensity in case of near field earthquake. It is desirable that depth of fault set up shallower and rupture velocity set up faster, because seismic intensity becomes the largest. But the difference of starting point of the rupture changes seismic intensity, therefore setting up easily staring point of the rupture makes mistakes on regional disaster prevention planning. As the above-mentioned items, we consider effects of location and starting point of the rupture on the evaluation of damages.

(2) Result of seismic risk estimation

The top of fault is located on 6 places as shown in figure 5, dip angle is 45, 90, 135 degree and the staring point of rupture is a southern and northern lot of fault. We estimated damages in Sapporo area about above 36 patterns. Results are put out by zone unit, which is bounded by the main streets. Figure 6 shows zone units and city wards.

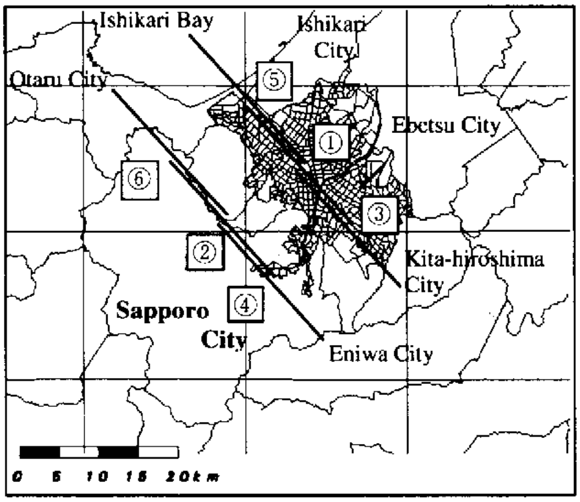


Figure 5: Location of assumed fault in Sapporo City (The numbers show location of the top of fault)

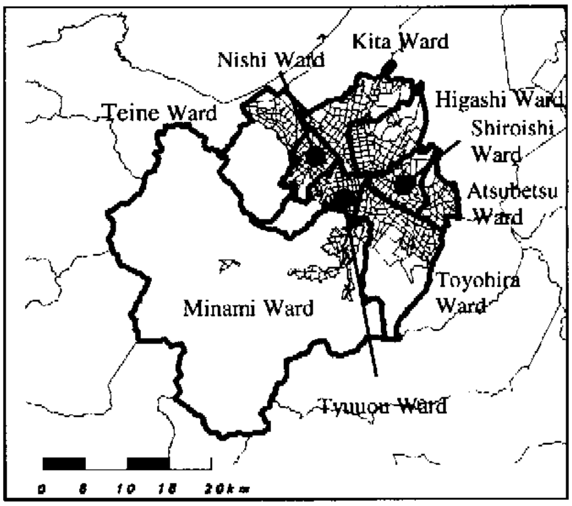
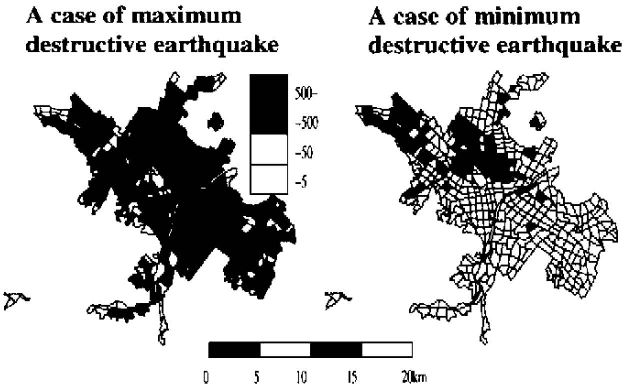


Figure 6: Estimate zone and administrative district of Sapporo City

Table 2 is a list of fault parameters and a number of major damages of wooden frame construction. Figure 7 is damage distribution of the most pessimistic case and the most optimistic case. The most pessimistic case (EQ13) brings 8.2 times as many damaged dwellings as the most optimistic case (EQ33) does. Damage distribution also has the great difference between two. The most pessimistic case damages whole city areas and the annihilated zone that the number of major damaged dwellings amounted to 500 in is over 50, while the most optimistic case has no major damaged dwellings. Heavy and moderate damaged dwellings exist on the northwest of the city in this case. Sapporo City is divided into 9 ward and figure 8 shows a number of major damages of wooden frame construction in each ward by assumed earthquake. It is cleared that damage distribution is different from each earthquake as shown figure 8.


A case of maximum destructive earthquake

A case of minimum destructive earthquake

Figure 7: Damage distribution of maximum destructive earthquake and minimum destructive earthquake

(3) The point at issue on regional disaster prevention planning

Past destructive earthquakes occurred near Sapporo City are no more than 1952 Tokati-Oki earthquake, 1968 Tokati-Oki earthquake and 1982 Urakawa-Oki earthquake. Seismic intensity in Sapporo City for these recent earthquakes is always high in the northeast area (that is covered with soft ground) and the southeast area (that is covered with non-condensed volcanic ash) and damages by above earthquakes centered on these areas. But in case of near field earthquake, it is likely that seismic intensity in the firm ground area is higher than that in soft ground area. It is likely that characteristics of source have a great effect on seismic intensity than that of ground.

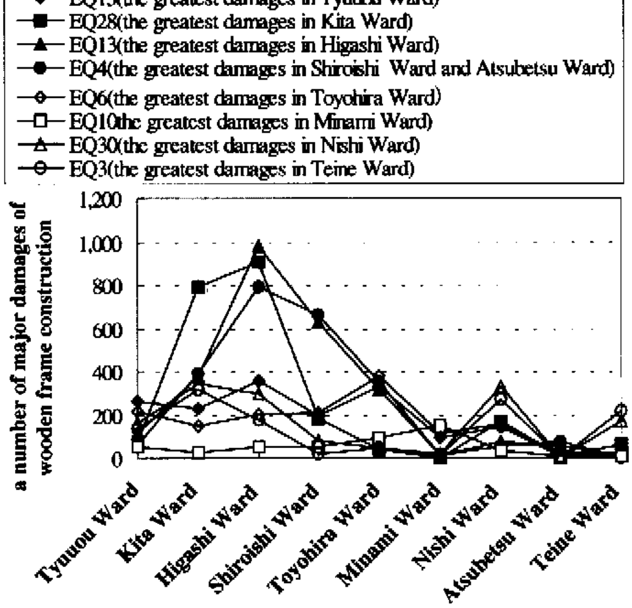


Figure 8:A number of major damages of wooden frame construction in each ward by assumed earthquake

The regional disaster prevention planning must be made based upon this fact. There are several ways to utilize seismic risk estimation for disaster countermeasures. For example preparations plan of disaster prevention resources are representative beforehand countermeasures against the occurrence of the earthquake. An amount of estimated damages gives a basis for an amount of stock and distribution of damages give best arrangement. In case of far field earthquake occurred interplate, indefinite fault parameters do not have much effect on the evaluation of seismic ground siverity and damages, and seismic ground severity is stable, that is to say, epicentral distance and the ground condition characterize distribution of them. Fixed scenario is adequate for disaster measures against these earthquakes. While in case of near field earthquake indefinite fault parameters have much effect on the evaluation of seismic ground severity and damages, that is to say, it is necessary to prepare disaster prevention scenarios for each earthquake.

3.5 Seismic risk estimation with considering uncertainly of fault parameters for near field earthquakes

In case of near field earthquake it becomes clear that characteristics of source have a great effect on seismic intensity than that of ground, so we must pay attention to indefinite fault parameters as above chapter. But though it is likely that seismic intensity and damage distribution cannot to be estimated simply, disaster countermeasures are planned according to only estimation.

We estimated damages in Sapporo area about many cases of seismic parameters. As a result of 36 patterns of estimation, it was shown that the most pessimistic case brings 9 times as many damaged dwellings as the most optimistic case does. We selected the following conditions of earthquakes as the most affected impact to an urban area and as a crucial earthquake for risk assessment as shown table 3: Earthquake (1) giving the greatest primary damages, (2) causing the greatest secondary damages as human casualty, (3) bringing about major damages distributed equally in the whole area, and/or (4) bringing about major damages localized in the center of the area, non-accessible area where it is difficult to receive a mutual support, high population density area, high disabled rate area, or rapid developing area.

4. CONCLUSIONS

Near field earthquake damages are strikingly changeable by fault parameters. Estimating damages for the variety of probable fault parameters and considering damage patterns affecting seriously the target area are important to make an optimum mitigation plan.

Table 2:List of fault parameters and a number of major damages of wooden frame construction.

	Dip Angle	Starting point of the rupture	Location	Tyuuou Ward	Kita Ward	Higashi Ward	Shiroishi Ward	Toyohira Ward	Minami Ward	Nisi Ward	Atsubetsu Ward	Teine Ward	Whole City
EQ1	45	south	①	30	703	727	189	26	0	113	1	91	1,882
EQ2	90	south	①	43	388	293	47	19	0	140	0	120	1,050
EQ3	135	south	①	134	317	174	20	48	11	272	0	219	1,195
EQ4	45	north	①	64	393	792	662	356	17	56	75	2	2,419
EQ5	90	north	①	92	201	333	315	316	34	67	30	4	1,393
EQ6	135	north	①	214	152	203	209	379	117	156	18	17	1,456
EQ7	45	south	②	16	64	38	4	7	7	88	0	99	316
EQ8	90	south	②	0	2	0	0	0	1	5	0	32	40
EQ9	135	south	②	0	0	0	0	0	5	0	0	15	20
EQ10	45	north	②	53	26	54	55	97	147	36	5	7	479
EQ11	90	north	②	0	0	4	3	15	78	0	0	0	100
EQ12	135	north	②	0	0	0	0	2	80	0	0	0	82
EQ13	45	south	③	113	377	981	628	319	12	73	54	12	2,569
EQ14	90	south	③	143	264	502	293	263	25	89	14	15	1,610
EQ15	135	south	③	266	230	357	195	334	96	142	5	21	1,646
EQ16	45	north	③	1	0	87	278	204	4	0	58	0	632
EQ17	90	north	③	0	0	16	87	151	9	0	17	0	279
EQ18	135	north	③	9	0	4	38	202	48	0	6	0	308
EQ19	45	south	④	91	103	132	44	63	122	84	0	18	656
EQ20	90	south	④	3	17	25	5	3	56	12	0	6	126
EQ21	135	south	④	1	1	2	0	0	62	2	0	1	69
EQ22	45	north	④	0	0	0	1	32	63	0	0	0	96
EQ23	90	north	④	0	0	0	0	1	25	0	0	0	26
EQ24	135	north	④	0	0	0	0	0	32	0	0	0	32
EQ25	45	south	⑤	1	195	65	0	0	0	13	0	52	326
EQ26	90	south	⑤	0	58	6	0	0	0	12	0	75	151
EQ27	135	south	⑤	1	26	0	0	0	0	40	0	159	227
EQ28	45	north	⑤	71	793	909	183	44	3	167	8	59	2,236
EQ29	90	north	⑤	92	443	454	112	40	7	199	3	82	1,431
EQ30	135	north	⑤	166	348	301	81	48	18	331	0	167	1,461
EQ31	45	south	⑥	0	3	0	0	0	0	2	0	56	61
EQ32	90	south	⑥	0	0	0	0	0	0	0	0	9	9
EQ33	135	south	⑥	0	0	0	0	0	0	0	0	1	1
EQ34	45	north	⑥	73	108	137	44	24	18	132	0	70	604
EQ35	90	north	⑥	3	13	30	7	2	7	18	0	15	95
EQ36	135	north	⑥	1	0	4	1	0	9	4	0	2	21

Table 3:Earthquake patterns for planning disaster countermeasures

Types of maximum damages
◇Earthquake giving the greatest primary damages (EQ13)
◇Earthquake causing the greatest secondary damages as human casualty (EQ28)
◇Earthquake bringing about major damages in developing area
·Population increasing area (EQ3,EQ30)
·City planning emphasis area (EQ4)
Types of disaster countermeasures
◇Earthquake differing in disaster countermeasures
·Earthquake bringing about major damages distributed equally in the whole area (EQ15)
·Earthquake bringing about major damages localized area (EQ4,EQ13,EQ28)
◇Earthquake where it is difficult for administration to correspond
·Earthquake bringing about major damages localized in the center of the area (EQ15)
·Earthquake bringing about major damages localized in non-accessible area where it is difficult to receive a mutual support (EQ10)
·Earthquake bringing about major damages localized in high population density area (EQ4)
·Earthquake bringing about major damages localized in high advanced age density area (EQ3,EQ6)
◇Earthquake where scenarios are necessary for each ward
·Earthquake bringing about major damages in Tyuuou Ward (EQ15)
·in Kita Ward (EQ28), ·in Higashi Ward (EQ13), ·in Shiroishi Ward (EQ4), ·in Toyohira Ward (EQ6),
·in Minami Ward (EQ10), ·in Nishi Ward (EQ30), ·in Atsubetsu Ward (EQ5), ·in Teine Ward (EQ3)

6. REFERENCES

1. Tomatsu, M., Okada, S. (1997), "Seismic risk estimation for earthquake occurring near urban districts - A case study for the city of Sapporo, Japan -", *Papers of the annual conference of the Architectural Institute of Japan Hokkaido Branch*, 70, pp221-224.
2. Kasahara, M. (1996), "Earthquake occurred near Sapporo City", topography and geology, *Sapporo library (Hokkaido Shinbun Press), vol.77*, pp253-266.
3. Kobayashi, M., Midorikawa, S. (1982), "A semi-empirical method for estimating response spectra of near-field ground motions with regard to fault rupture", *Proc. of the Seventh European Conference on Earthquake Engineering*, 2, pp161-168.
4. Okada, S., Miyakawa, T., Ohta, Y. (1985), "Questionnaire survey for describing microzoning characteristics in terms of seismic intensity – A case study in Sapporo, Japan -, *Journal of Structural and Construction Engineering (Transactions AIJ)*, the Architectural Institute of Japan, No.348, pp11-18.
5. Muramatu, I.(1966), "Expectation of maximum of earthquake motion within 50 years throughout Japan", *Sci. Rep. Gifu Univ.*, 3,pp470-481.