Proposal of Regional Safety Factors for Balance in Risk- Response Ability of Local Voluntary Disaster Prevention Organizations and Their Application to Sendai City, Japan

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ABSTRACT

This paper proposes an evaluation method of Regional Safety Factors (*RSF*) for local voluntary organizations to support their planning and measures for earthquake disaster prevention/mitigation. The *RSF* is defined as the ratio of the Emergency Response Potential Ability (*ERA*) to Earthquake Disaster Risk (*EDR*) of each organization. Against the expected Off Miyagi Earthquake with M_j=7.9, which is one scale larger than the usual assumption model with M_j=7.5, the proposed method is applied to all of the 1,391 organizations in Sendai City. First, based on the evaluated results, variance of earthquake disaster risk over the city-region is clarified. Second, despite higher risks being expected in some organizations, most of their preparedness levels for emergency response were uniformly low. Therefore, a strategy for disaster prevention promotion should be developed considering the spatial risk differences. When a voluntary organization creates a community action plan and/or a local government decides on a performance-based regional planning for earthquake disaster prevention, this proposed method can be expected with long-range monitoring and re-assessments depending on the occurrence interval of the target earthquake scenario.

Keyword: Earthquake preparedness, Emergency response potential ability, Earthquake disaster risk, Vulnerability, Regional safety factors, Local voluntary disaster prevention organizations

1. INTRODUCTION

Miyagi Prefecture is one of the most earthquake-prone regions in Japan. The Earthquake Research Committee under the Japanese government evaluated the occurrence probability of earthquakes on major active faults and subduction-zones in Japan. The Off Miyagi Earthquake with a magnitude of M_j=7.5±0.1 (JMA scale) is one of the major earthquake scenarios for Miyagi Prefecture whose occurrence probability within 10 years is around 70% based on the estimation on January 1st, 2009. M_j=7.5 events have occurred periodically at an average occurrence interval of about 37 years. The most recent event with M_j=7.4 occurred on June 12th, 1978.

For all seats of the prefectural governments in Japan, The Earthquake Research Committee (2005) expressed and compared the influences of different types of expected earthquakes with tremors equal to or larger than a JMA seismic intensity of Lower 6 in the next 30 years. These results are calculated by the 'occurrence probability of an earthquake within a fixed period' multiplied by the 'probability that tremors caused by the earthquake exceed a certain intensity'. Then a summation is conducted over all earthquakes. The result was published as the probabilistic seismic hazard maps by the committee. Sendai City is the largest city in Miyagi Prefecture as the prefectural capital with a population of one million. Sendai City has several earthquake scenarios. The major earthquake scenarios are based on the Off Miyagi Earthquake, the inland earthquake along the Nagamachi-Rifu fault zone, earthquakes along unspecified active onshore faults and others. Among these earthquakes, the Off Miyagi Earthquake is the most influential and has a probability of 79%. The inland earthquake along the Nagamachi-Rifu fault zone has the secondary influence at 17%. The influence of the remaining earthquake consists of only 4%. Sendai City is highly influenced by the nearby seismic source region of the Off Miyagi Earthquake, which has an occurrence probability of higher than 99% in the next 30 years. Against these backgrounds, the Off Miyagi Earthquake is the most important target scenario for Miyagi Prefecture and Sendai City.

We conducted a questionnaire survey to grasp the earthquake preparedness of residents in Miyagi Prefecture focusing on the spatial difference of the earthquake disaster risk (Sato et al., 2005). As described later in Section 2, the low interest and poor preparedness among the residents are clarified in spite of the high probability of the target earthquake occurrence. In addition, the actual situation is such that the preparedness is not related to the difference of the earthquake disaster risk. The disaster prevention administrator takes the conventional approach, which is usually based on the risk message or the persuasive one-way communication. But Kohiyama et al. (2004) suggest a limitation in the effect of the approach. A new approach of interactive risk communication has appeared recently. Masaki et al. (2005) and Matsuda et al. (2006) applied the risk communication based on community diagnosis in Japan. However, the setting of the evaluation indexes, scale of target areas and technical terminology vary according to the situation and disaster type. In any case, the incentive information should be utilized effectively to improve the vulnerability to earthquakes. In Japan, the percentage of neighborhood associations that have founded voluntary disaster prevention organizations is rapidly increasing so that a simple and user-oriented method and tools for the risk communication should be developed. The organizations are formed voluntarily based on a sense of solidarity by a shared territorial bond. The organizing ratio, which is the ratio of the number of households included in the organization to all households, is 69.9% in Japan (2008). The number for Miyagi Prefecture is 83.5%.

In this paper, the definition and an evaluation method for the regional safety factors (*RSF*) of local voluntary disaster prevention organizations are proposed to support their planning and measures for earthquake disaster prevention/mitigation. As a concluding remark, strategic perspectives are expected to improve the vulnerability for local voluntary disaster prevention organizations under time and budget constraints to prepare for the next earthquake occurrence.

2. QUESTIONNAIRE SURVEY ON EARTHQUAKE PREPAREDNESS OF RESIDENTS IN MIYAGI PREFECTURE

2.1 Outline of survey

A questionnaire survey was performed from March to June 2005 to clarify the present condition of earthquake preparedness of residents in Miyagi Prefecture. This work was supported by a Grant-in Aid for projects that spread research regarding disaster prevention founded by the Japanese Ministry of Education, Science, Sports and Culture. Twelve neighborhood associations in Miyagi Prefecture were selected as investigational targets by considering the number of households and the different seismic risks based on Miyagi Prefecture's estimation of forecast earthquake damages (2004). Three neighborhood associations were selected from each of the four major cities in Miyagi Prefecture: Ishinomaki, Ohsaki, Shiroishi and Sendai (**Fig. 1**). Upon the selection of three neighborhood associations, the relative difference of the seismic risk was considered in each city. **Table 1** shows a summary of the questionnaire survey of each neighborhood association and the physiographic province as a determinant factor for seismic tremors. The questionnaire sheets were distributed to all of the member households of twelve neighborhood associations. Each respondent sent completed sheets by direct mail to the author except the members of *KM* Neighborhood Association in Ishinomaki. The total average of the response ratio was 37.1%. The number of responses from *KM* was especially high at 72.9%, because the leaders of the association collected the completed sheets by hand voluntarily.

Table 1. Summary of questionnaire survey of residents

City	Ishinomaki			Ohsaki			Sendai			Shiroishi			Ave.
Neighborhood association	KM	TD	IZ	NK	NS	TK	NG	OK	KS	MN	MD	FK	
(a) Number of households	630	299	266	450	304	327	750	450	420	320	276	300	399
(b) Number of answers	459	86	107	143	99	84	243	141	170	164	84	80	155
Response Ratio (b/a %)	72.9	28.8	40.2	31.8	32.6	25.7	32.4	31.3	40.5	51.3	30.4	26.7	37.1
Physiographic province	A, C	C	F	B	C	B	C	C	E	B	D	E	

Notes: Mark of the physiographic province

A: Beach ridge, B: Natural levee, C: Backswamp, D: Mountainous district department land developed for housing, E: Terrace surface, F: Mountainous district

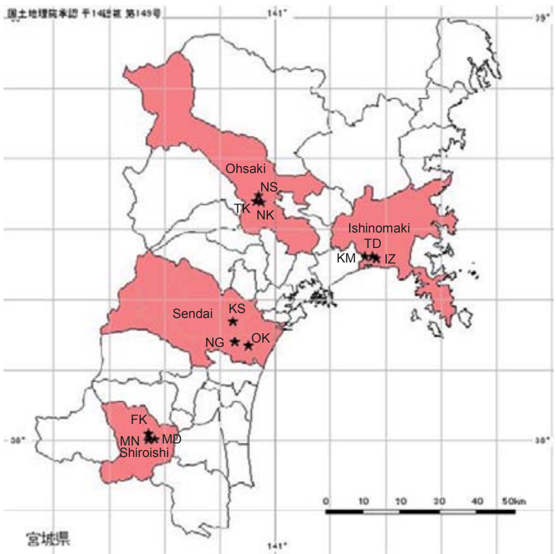


Fig.1 Location map of four major cities in Miyagi Prefecture

(★ : location of twelve neighborhood associations)

2.2 Results of survey

Table 2 shows the implementation ratio of three important countermeasures to reduce earthquake disaster risk: 1) seismic diagnosis of wooden houses; 2) removal or reinforcement of block walls; and 3) prevention of furniture overturning. It was confirmed that there were no major differences of preparedness for a major earthquake among the cities except for a few specific neighborhood associations.

The Japanese Seismic Design Code for Housing was revised in 1981. Thus houses predating 1981 have become the targets of seismic diagnosis and retrofit. Although respondents who live in the houses constructed after 1981 are included in the denominator, the consulting ratio of easy diagnosis at 6.0% is extremely low. In actual fact, the grant-in-aid for seismic diagnosis of wooden houses is only covers several hundred cases per year in Sendai City government. In addition, the target houses occupy 50% of all building structures and amount to approximately 150,000 in Sendai. There remain many problematical wooden houses in urban society and the pace of improvement is slow because such measures as retrofit or rebuilding are costly.

The situation of concrete block walls is also problematic. Sendai City government investigated the safety level of stone and concrete block walls from 1997 to 2000. The walls that needed to be repaired and reinforced amounted to 42% of the investigated 22,851 locations (Sendai City, 2002). Although respondents who have safety walls are included in the denominator, the ratio of taking countermeasures (removal or reinforcement of the walls) is only 7.0%. Although fragile block walls were the most serious factors causing human damage in the Off Miyagi Earthquake in 1978, the stock of weak walls remains problematic.

The implementation ratio for preventing furniture overturning is 36.7% on average. This level is equal to or slightly higher than the results in the capital region and Tokai region, which are expected to be exposed to serious seismic hazards in Japan (Asahi Inquiry and Research, 2005). The situation in Miyagi Prefecture is not unique in Japan.

The willingness to cooperate in eight types of emergency response immediately after an earthquake disaster by residents in neighborhood associations is shown in **Table 3**. These operations may contribute to the mitigation of secondary or extended damage. For example, the ratio of the residents who cooperate in the first aid treatment or rescue operation is approximately 15% on average. But the residents with a cooperative mindset do not necessarily have the skill and knowledge to be able to get things done. Every row in the table shows that the present situation of earthquake preparedness regarding emergency response is insufficient in Miyagi Prefecture. The cooperator ratio on supporting foreigners, row F, is the lowest at 1.5% on average. It was clarified that the results were almost the same regarding major earthquake preparedness in Miyagi Prefecture.

Table 2. Earthquake preparedness: countermeasures to reduce earthquake disaster risk

City	Ishinomaki			Ohsaki			Sendai			Shiroishi			Ave.	SD
Neighbor-hood association	KM	TD	IZ	NK	NS	TK	NG	OK	KS	MN	MD	FK		
A (%)	3.5	3.5	4.7	4.9	7.1	9.5	7.8	4.3	10.0	7.3	3.6	6.3	6.0	2.3
B (%)	6.1	7.0	6.5	4.9	9.1	10.7	11.9	7.8	4.7	5.5	4.8	5.0	7.0	2.4
C (%)	36.6	39.5	35.5	37.8	38.4	29.8	45.7	46.8	45.3	32.3	35.7	17.5	36.7	8.0

Note: Implementation ratio of the following measures to the total household in each neighborhood association
A: Seismic diagnosis of wooden houses, B: Removal or reinforcement of block walls, C: Preparedness of furniture overturning

Table 3. Earthquake preparedness: Willingness to cooperate in an emergency response

City	Ishinomaki			Ohsaki			Sendai			Shiroishi			Ave.	SD
Neighbor-hood association	KM	TD	IZ	NK	NS	TK	NG	OK	KS	MN	MD	FK		
A (%)	10.7	14.0	21.5	12.6	18.2	21.4	13.2	15.6	11.2	16.5	14.3	16.3	14.1	3.6
B (%)	12.0	18.6	18.7	23.1	16.2	23.8	16.0	22.0	14.1	22.0	16.7	26.3	17.5	4.3
C (%)	10.2	18.6	16.8	18.2	19.2	19.0	14.4	23.4	10.0	20.1	11.9	25.0	15.6	4.8
D (%)	10.2	17.4	29.0	22.4	19.2	23.8	17.3	16.3	15.9	22.6	16.7	30.0	17.8	5.7
E (%)	6.5	12.8	20.6	17.5	17.2	14.3	10.7	8.5	10.0	12.8	14.3	15.0	11.7	4.0
F (%)	0.9	0.0	0.9	2.1	1.0	1.2	1.6	0.0	5.3	0.6	2.4	1.3	1.5	1.4
G (%)	20.9	30.2	37.4	32.9	33.3	36.9	24.3	27.0	24.1	31.7	29.8	43.8	28.1	6.5
H (%)	13.3	16.3	29.0	18.9	22.2	23.8	18.9	15.6	17.6	26.8	25.0	26.3	19.3	5.1

Note: Cooperator ratio of the following operations to the total residents in each neighborhood association
A: First aid treatment, B: Early fire fighting, C: Rescue operation, D: Instruction to refuge location, E: Collection of damage information, F: Support for foreigners, G: Transportation of supplies, H: Administration of refuge location

2.3 Relationship between risk and preparedness for earthquake disaster

For the purpose of discussing the relationship between earthquake risk and preparedness, three predicted damage ratios at the location of the associations are listed in **Table 4** as the earthquake disaster risk being faced by each of the twelve neighborhood associations, based on the estimation of damages for the Off Miyagi Earthquake scenario with M_j=7.9 conducted by Miyagi Prefecture government in 2004. The difference of the risk in location ranges from 0% to 30% in the case of the wooden house damage ratio.

The relationship between potential manpower supply (human preparedness to cooperate) and demands for emergency response (damage ratios) are shown in **Fig.2**. **Figure 2 (a)** indicates the relationship between the cooperator ratio for rescue operation and the estimated damage ratio for wooden houses; **2 (b)** the cooperator ratio for first aid treatment and the estimated human damage ratio. Both of the cooperator ratios are around 15% independent of the earthquake disaster risk.

The relationship between physical preparedness to reduce the earthquake risk and damage ratio (level of risk) is shown in **Fig.3**. **Figure 3 (a)** indicates the relationship between the implementation ratio of countermeasures for furniture overturning and the estimated overturning ratio. The ratio of furniture overturning in every neighborhood association was evaluated using the fragility function proposed by Okada and Kagami (1991). **Figure 3 (b)** shows the relationship between the diagnosis ratio and the estimated damage ratio of wooden houses. Even if a neighborhood association is exposed to higher risk, the level of the earthquake preparedness trying to reduce the earthquake risk itself does not increase and remains uniformly lower.

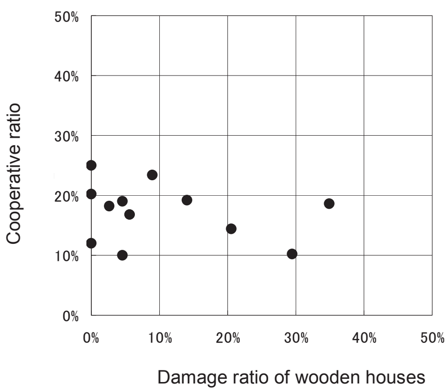
The present situation concerning major earthquake preparedness is not balanced with the disaster risk estimated in the case of the Off Miyagi Earthquake scenario. The strategic reduction measures of disaster risk should be conducted in a cost- and time-effectively to prepare for the next event occurrence.

Table 4. Major estimated damages as earthquake disaster risk

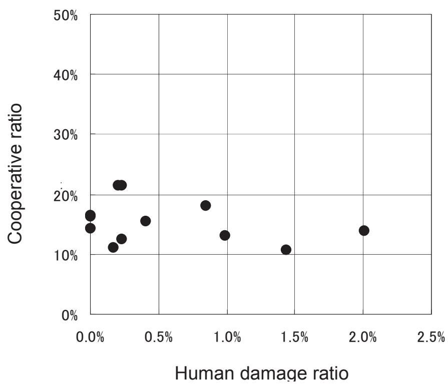
City	Ishinomaki			Ohsaki			Sendai			Shiroishi			Ave.	SD
Neighbor-hood association	KM	TD	IZ	NK	NS	TK	NG	OK	KS	MN	MD	FK		
A (%)	29.5	35.0	5.5	2.7	14.1	4.6	20.5	8.9	4.6	0.0	0.0	0.0	10.5	11.9
B (%)	77.1	77.5	32.7	34.6	62.7	49.6	61.1	53.9	33.0	0.3	0.3	1.1	40.3	28.3
C (%)	1.4	2.0	0.2	0.2	0.8	0.2	1.0	0.4	0.2	0.0	0.0	0.0	0.5	0.6

Note: Damage ratio of the following items research on estimating earthquake forecasted damage for the Off Miyagi Earthquake scenario by Miyagi Prefecture in 2004

A: Wooden houses including collapse, heavily and moderate, B: Furniture overturning, C: Dead and injured

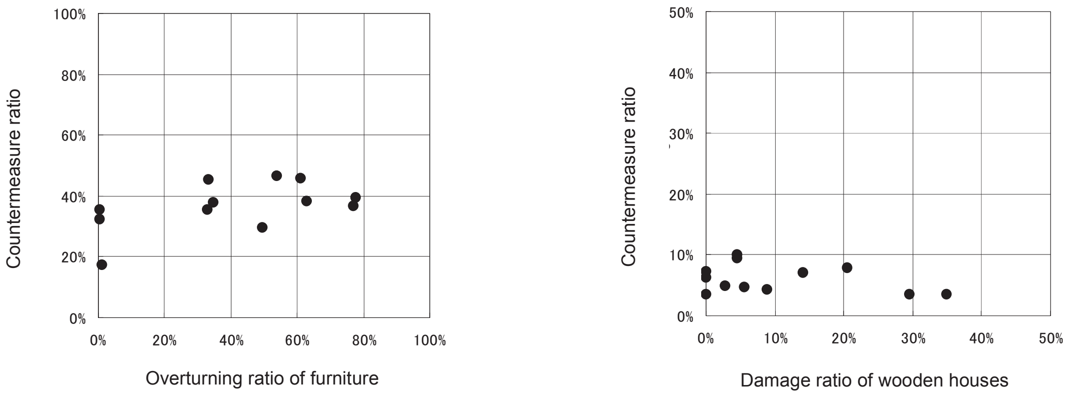


(a) Rescue operation



(b) First aid treatment

Fig.2 Relationship between emergency response demand and human preparedness



(a) Furniture overturning (b) Seismic diagnosis

Fig.3 Relationship between risk and physical preparedness

2.4 Distance decay effect on real lessons from disaster

Two good opportunities to start taking measures for preventing furniture overturning in Miyagi Prefecture were presented recently. **Table 5** shows the influences of the events. One is the information disclosure of the occurrence probability of the Off Miyagi Earthquake scenario by the Earthquake Research Committee (2005). Even though most of the residents had known the information as one of the risk messages, only 30% of them were sufficiently influenced to implement the countermeasures by the information.

The other is a real disaster lesson of the July 26th 2003, Northern Miyagi Earthquake with M_j=6.4. The earthquake was a medium-sized, in-land type so the damage did not extend to the entire area of Miyagi Prefecture. The distance from the hypocenter to each location of the associations is included in **Table 5**. The distance decay on real disaster lessons is shown in **Fig.4**. While the information of the occurrence probability of the Off Miyagi Earthquake had a uniform influence for Miyagi Prefecture residents, the influence of the real disaster lesson diminishes similar to an exponential function in terms of distance from the focal point. This suggests that the utilization of lessons of real damage is not easy in a remote area, where the amplitude of earthquake ground motion diminishes.

Table 5. Effect of risk message and real disaster lesson

City	Ishinomaki			Ohsaki			Sendai			Shiroishi		
Neighborhood association	KM	TD	IZ	NK	NS	TK	NG	OK	KS	MN	MD	FK
Distance (km)*1	7.4	9.1	9.7	27.6	29.2	28.8	33.6	31.3	31.9	67.3	67.3	66.9
Ratio A (%)*2	62.5	73.5	60.5	42.6	55.3	52.0	20.7	22.7	29.9	24.5	16.7	21.4
Average (%)	65.5			50.0			24.4			20.9		
Ratio B (%)*3	22.6	26.5	31.6	35.2	21.1	20.0	40.5	34.8	32.5	24.5	36.7	14.3
Average (%)	26.9			25.4			35.9			25.2		

Note:
*1 Distance from hypocenter of the 2003 Northern Miyagi Earthquake with M_j=6.4
*2 Influence ratio of the countermeasure implementation by disaster lessons
*3 Influence ratio of the countermeasure implementation by risk message as earthquake occurrence probability

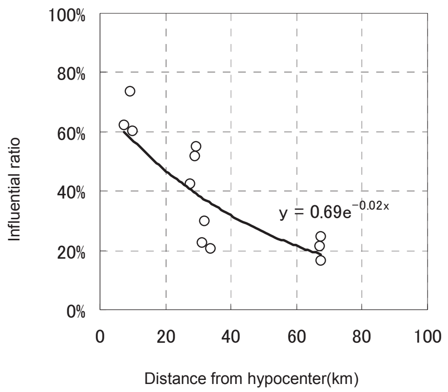


Fig.4 Distance decay on real disaster lesson

3. ESTIMATION OF REGIONAL SAFETY FACTORS FOR NEIGHBORHOOD ASSOCIATIONS

3.1 Fundamental concept of proposed method

The results of the previous chapter show low interest and preparedness of the residents in spite of the high probability of an expected earthquake occurrence. The limit in the effect of a mere risk message such as earthquake occurrence probability is suggested. Strategies for disaster prevention promotion should especially consider the spatial differences of risk. If an effective disaster prevention strategy based on the risk recognition is progressed, improvement of the vulnerability and the preparedness will be requested in the region where the earthquake risk is higher under budget and time constraints. Risk communication is expected to be the most effective method of improving the situation. In Japan where local voluntary disaster prevention organizations are widely established, an improvement method based on a community action plan for earthquake disaster prevention/mitigation can be adopted. An evaluation method for regional safety factors (*RSF*) of the organizations to support them in creating a plan and taking measures for earthquake disaster prevention is proposed. The *RSF* is defined quantitatively in detail later as the ratio of the emergency response potential ability (*ERA*) to the earthquake disaster risk (*EDR*) of each organization. If this proposed method with long-range monitoring depending on the occurrence interval of the target earthquake scenario is utilized as incentive information to improve the vulnerability for the community, we can expect a correction of the imbalance between the disaster risk and emergency response ability.

3.2 Definition and evaluation of RSF

(1) Regional safety factor: RSF

RSF for an arbitrary voluntary disaster prevention organization in neighborhood *i* on an arbitrary point in time *k* is defined by the following equation.

$$RSF(i,k)=\frac{ERA(i,k)}{EDR(i,k)} \tag{1}$$

Where *EDR* (*i*,*k*) means earthquake disaster risk in the following **Eq. (2),** which is defined by the relative value normalized by the maximum value considering the location where each organization is located. *ERA* (*i*,*k*) of each organization means the emergency response potential ability in the following **Eq. (3)**, which is defined as the earthquake preparedness level normalized by full score using the check sheet in the APPENDIX.

Equation (1) is interpreted as follows. Earthquake disaster risk can be approximated by a product of the earthquake hazard and the vulnerability of society to earthquake disaster. Vulnerability is evaluated as the reciprocal of the disaster resistance ability. Therefore, *RSF* is replaced as the earthquake preparedness level as a product of the disaster resistant ability and the emergency response potential ability of the organization

(2) Earthquake disaster risk: EDR

EDR is defined as the following equation.

$$EDR(i,k)=\sum_{m=1}^{M}\left[\left\{\frac{r(i,k,m)}{r(m)_{\max}}\right\}^{p}\cdot w(m)\right]\times 100 \tag{2}$$

Where *i*: the number of voluntary disaster prevention organizations in neighborhood, *k*: the number of evaluation points in time, *m*: the number of a certain earthquake disaster risk factor, *M*: the maximum number of *m*, *r* (*i*,*k*,*m*): the forecast damage ratio regarding *i*, *k* and *m*, $r(m)_{\max}$: the maximum value of *r* (*i*,*m*) in the target region on each *m* at k_1 as the first step of *k*, *p*: the strategy coefficient of *EDR*, *w* (*m*): the weight coefficient of *m*. The summation of *w* (*m*) is equal to 1.

The results of the estimated damage investigation for a major scenario earthquake by local government can be used as the risk information of **Eq. (2)**. As a result of the improvement of social vulnerability to earthquake disaster, even if strong tremors struck the organization, *EDR* could be lower.

(3) Emergency response potential ability: ERA

ERA is defined by the following equation.

$$ERA(i,k) = \sum_{n=1}^{N}\left[\left\{\frac{a(i,k,n)}{a(n)_{\max}}\right\}^{q} \cdot w(n)\right]\times 100 \qquad (3)$$

Where *i*: the number of voluntary disaster prevention organizations in the neighborhood, *k*: the number of evaluation points in time, *n*: the number of a certain emergency response factor, *N*: the maximum number of *n*, $a(i,k,n)$: the preparedness score regarding *i*, *k* and *n*, $a(n)_{\max}$: the full score of $a(n)$ by the check sheet in each *n*, *q*: the strategy coefficient of *ERA*, $w(n)$: the weight coefficient of *n*, with the summation of $w(n)$ of 1.

The domains of the check sheet are classified into four groups: *knowledge*, *skill*, *resource* and *management*. The original categories were proposed by Takanashi (2000) as four factors to demonstrate emergency response potential ability by local voluntary disaster prevention organizations. The expansion of damage and the occurrence of secondary damage are reduced by attaining a higher level of *ERA*. A reasonable preparedness in building/developing the ability of emergency response for the relief demand in higher risk areas is required. In addition to the progress of the emergency response potential ability, the reduction of the earthquake disaster risk itself by improving the vulnerability of society to earthquake disaster is more important.

(4) Ranking of regional safety factors

The ranking of *RSF* as shown in **Table 6** is established to recognize the position of the organizations and monitor the changing of the condition. An example of *RSF* evaluation is shown in **Fig.5**. When a voluntary organization creates a community action plan and/or a local government decides on performance-based regional planning for earthquake disaster prevention, this proposed method with long-range monitoring depending on the occurrence interval of the target earthquake scenario can be utilized. The rules and condition of ranking were originally designed by the authors, while referring to the ranking method of the Building Environmental Efficiency (*BEE*) in the Comprehensive Assessment System for Building Environmental Efficiency (*CASBEE*).

Ranking of five stages from S to D is proposed. While an organization located in rank D requires much effort for the improvement, an organization located in rank S is in the best condition to handle the scenario earthquake disaster. In the development of the ranking system, the condition of B of the middle rank was set at first. The *RSF* value 2.0, which is on the border of rank A and B, means that rank A cannot be realized in the case of an *EDR* value larger than 50 even if *ERA* has full scores. The improvement of the vulnerability is required by all means to advance further the rank of *RSF*. Additional conditions concerning *ERA* in rank-S and A were subjectively determined.

Table 6. Ranking of RSF

Rank	Conditions
D	$0.0 \leqq$ RSF<0.5
C	$0.5 \leqq$ RSF<1.0
B	$1.0 \leqq$ RSF<2.0 $2.0 \leqq$ RSF and $0 \leqq$ ERA<40
A	$2.0 \leqq$ RSF<5.0 and ERA $\geqq 40$ $5.0 \leqq$ RSF and $40 \leqq$ ERA<60
S	$5.0 \leqq$ RSF and $60 \leqq$ ERA

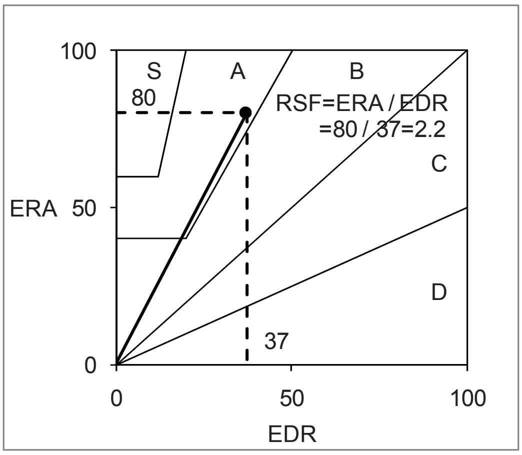


Fig.5 An example of RSF evaluation

(5) Advancement degree and monitoring of RSF

The advancement degree is defined by the following dual expression to monitor the changing of *RSF*.

$$\alpha(i,k) = \frac{RSF(i,k)}{RSF(i,k-1)}\times 100 \qquad (4)$$

$$\beta(i,k) = \frac{RSF(i,k)}{RSF(i,1)}\times 100 \qquad (5)$$

An advancement degree $\alpha(i,k)$ is defined as the ratio of the kth evaluation of *RSF* to one previous evaluation. Another advancement degree $\beta(i,k)$ is defined as the ratio of the present value of *RSF* for the initial evaluation point in time. Higher values of advancement degree mean that the *RSF* value was improved during the time to the scenario earthquake occurrence. Increase in the social vulnerability or decrease in the emergency response potential ability of an organization causes an advancement degree value of less than 100%. The importance of advancing the *RSF* value by performing periodical evaluation of *RSF* and checking the achievement degree for the community action plan by the organization is suggested.

4. APPLICATION OF RSF TO SENDAI CITY

4.1 Evaluation of EDR

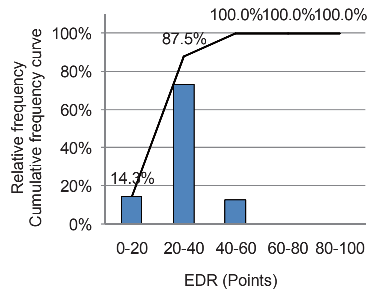
(1) Applicable condition

EDR is applied to Sendai City under the following conditions. The estimation results of earthquake damage by local government are used as the risk information. In this paper, we use the earthquake-damage data forecasted for the Off Miyagi Earthquake as the major earthquake scenario by Miyagi Prefectural government in 2004. The factors of *EDR* were selected arbitrarily. For example, damage to building structure, indoor space, outdoor space and humans can be used as the major factors of *EDR*. The ratio of the collapse of wooden houses, the overturning of furniture and the collapse of fragile stone and concrete block walls is nominated as an important damage factor in Japan. The improvable factor by the neighborhood association should be selected for earthquake disaster prevention planning voluntarily. While the human damage depends on the previous factors, the ratio of the casualties is nominated as an important factor for a neighborhood association. As the indicated number of earthquake disaster risk factors, m was assumed to be 4. The weight coefficient of m was simply set to be one quarter.

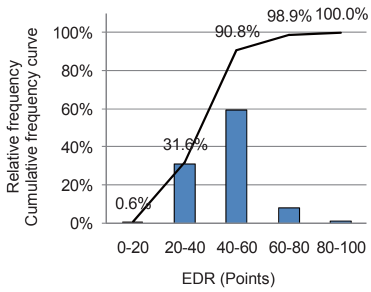
Evaluation of *EDR* changes by selecting coefficient p. In the case of $p<1.0$, the result of severe evaluation is caused. The coefficient p is freely selected depending on the strategy by local government policy for earthquake disaster prevention. The coefficient p was determined as 0.5 here from the former feasibility studies by the author.

(2) Results of evaluation

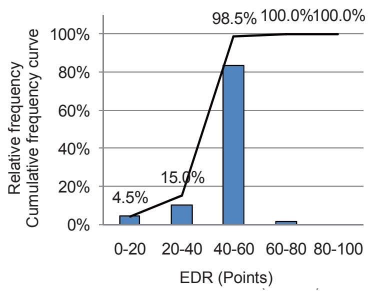
The *EDR* frequency distribution at 20 point intervals in each ward is shown in **Fig.6**. Sendai City is composed of five wards: Aoba, Miyagino, Wakabayashi, Taihaku and Izumi. Most of the area of Miyagino ward and Wakabayashi ward is occupied by swamp. For example, the accumulated frequency up to 40 points reached 85% in Izumi Ward, while it was only 15% in Wakabayashi Ward. The difference of *EDR* in Sendai City can be recognized. To correct the imbalance for earthquake disaster risk, it is suggested that a disaster prevention strategy considering the spatial difference of the risk is important under budget and time constraints. If an effective disaster prevention strategy based on the risk recognition is progressed, the improvement of the vulnerability and the preparedness will be requested in the regions where the earthquake risk is higher.



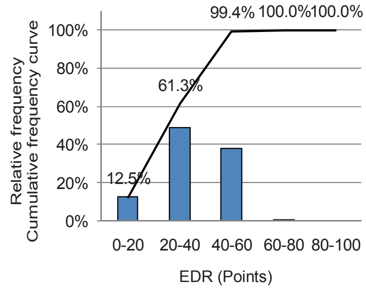
(a) Aoba Ward



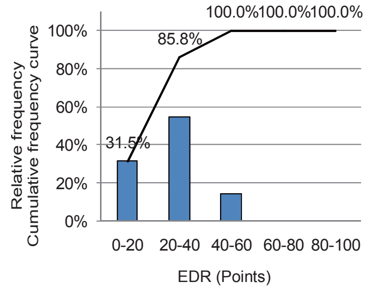
(b) Miyagino Ward



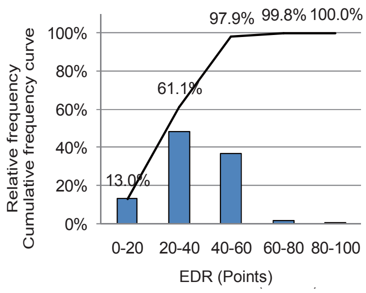
(c) Wakabayashi Ward



(d) Taihaku Ward



(e) Izumi Ward



(f) Sendai City

Fig.6 Frequency distribution of EDR

4.2 Evaluation of ERA

(1) Outline of investigation

The authors developed an original check sheet to construct the data set of $a(i,k,n)$ in **Eq.3**. The sheet is composed of 32 check items, which are shown in the APPENDIX. The cognitive level of earthquake disaster risk is judged from the *knowledge* domain. The higher score of the *skill* domain means that the organization has sufficient ability to conduct rescue operations and first aid treatment. The *resource* domain is composed of manpower supplies and useful cooperators in an organization. The organizing ability is evaluated in the *management* domain of planning and collaboration. The setting of the activity level of the organizations is summarized by a review and investigating the existing research in **Table 7**. The sheet was amended and improved by the feedback from a pre-test respondent and a user. In the early stage under consideration of the sheet, a test investigation for some organizations and an opinion exchange with disaster prevention administrators were conducted as the primary evaluation.

The sheet was distributed to every chief of an organization in Sendai City in July, 2007. An outline of the investigation is shown in **Table 8**. The distribution and collection of the sheets was adopted by direct mail between the chief of each organization and the fire defense office of Sendai City. The response ratio was 69.5%.

Table 7. Activity level for the local voluntary disaster prevention organization

Level	Concrete activity
1	The disaster prevention organization was established. The allotment of the role was decided.
2	The organization participates in the public activity for earthquake disaster prevention.
3	The organization investigates the present condition regarding local earthquake vulnerability voluntarily. Weak points and the theme of the organization were clarified.
4	The organization conducts an investigation that is more advanced and detailed than level 3. The organization has been active in earthquake disaster prevention continuously.
5	The organization creates a community plan to improve the regional earthquake vulnerability voluntarily. The organization can confirm the achievement of the plan and reconsider the plan.

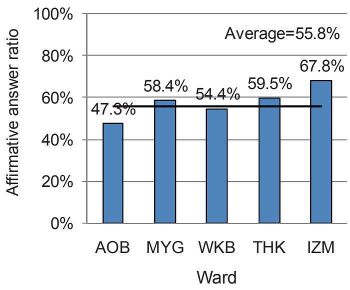
Table 8. Summary of questionnaire survey of the organization chiefs

Ward	Number of distributions A	Number of responses B	Ratio B/A (%)	Number of effective responses C	Ratio C/B (%)
Aoba	513	334	65.1	322	96.4
Miyagino	215	152	70.7	142	93.4
Wakabayashi	181	121	66.9	121	100.0
Taihaku	272	208	76.5	197	94.7
Izumi	210	152	72.4	138	90.8
Sendai	1,391	967	69.5	920	95.1

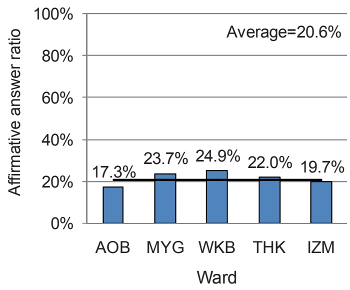
(2) Results of investigation

The highest ratio of positive responses among check items was 79.6% for “Temporary refuge subspace was prepared in a community area.” The lowest was 1.9% for “Emergency response training was performed in cooperation with medical facilities.”

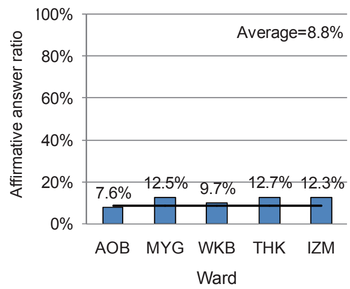
The average ratio of positive responses sorted by the level of check items on the sheet is shown in **Fig.7**. The entire average of level 1 in Sendai City was 55.8%. Because the decrease in the score is confirmed as the level progresses, the arrangement of the check items is suggested to be consistent and valid.



(a) Level-1



(b) Level-3



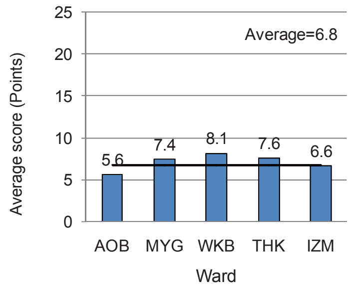
(c) Level-5

Fig.7 Average response ratio of each level of check items on the sheet

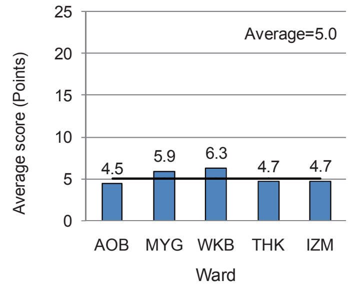
(3) Results of evaluation

The average score of each of the four domains with a maximum of 25 points is shown in **Fig.8**. The average scores are equally low around 5 points (one fifth of the maximum points).

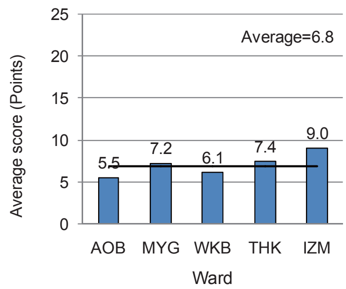
The evaluation value of *ERA* changes according to the selection of coefficient q. In the case of q which is larger than 1, a result of rather strict evaluation is obtained. The coefficient q is freely selected like *EDR* depending on the strategy by local government policy for earthquake disaster prevention. The coefficient q was decided as 1 from a feasibility study by the author. As the number of emergency response potential ability factors, n was assumed to be 4. The weight coefficient of n was set to be one quarter as well as the coefficient m.



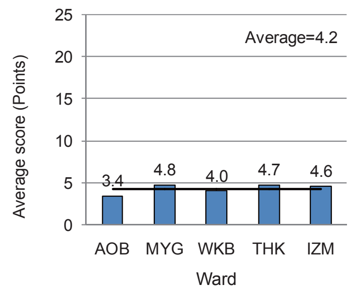
(a) Knowledge



(b) Skill



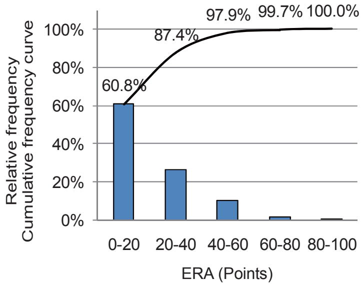
(c) Resource



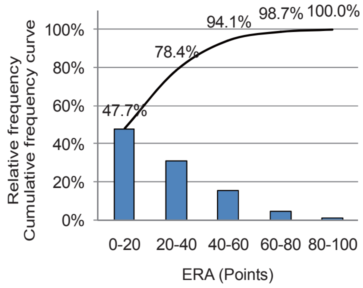
(d) Management

Fig.8 Average score of each domain of ERA

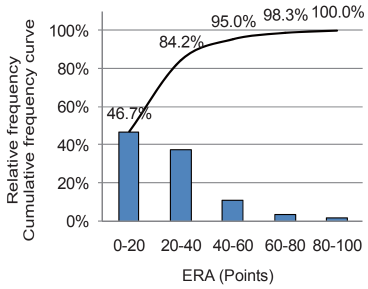
The *ERA* frequency distribution at intervals of 20 points is shown in **Fig.9**. The organization with 80 points or more accounts for only 1% (seven organizations), while the organization with less than 40 points in the *ERA* accounts for 80% of the total. The unharmonious actual situation with the difference of the *EDR* was confirmed (see **Fig.6**).



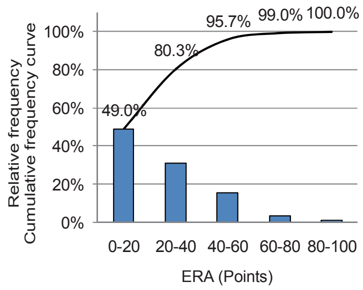
(a) Aoba Ward



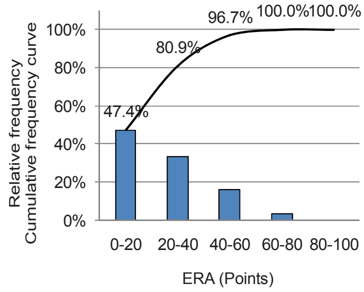
(b) Miyagino Ward



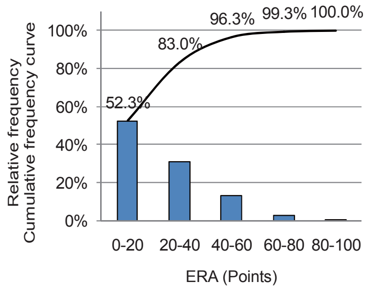
(c) Wakabayashi Ward



(d) Taihaku Ward



(e) Izumi Ward



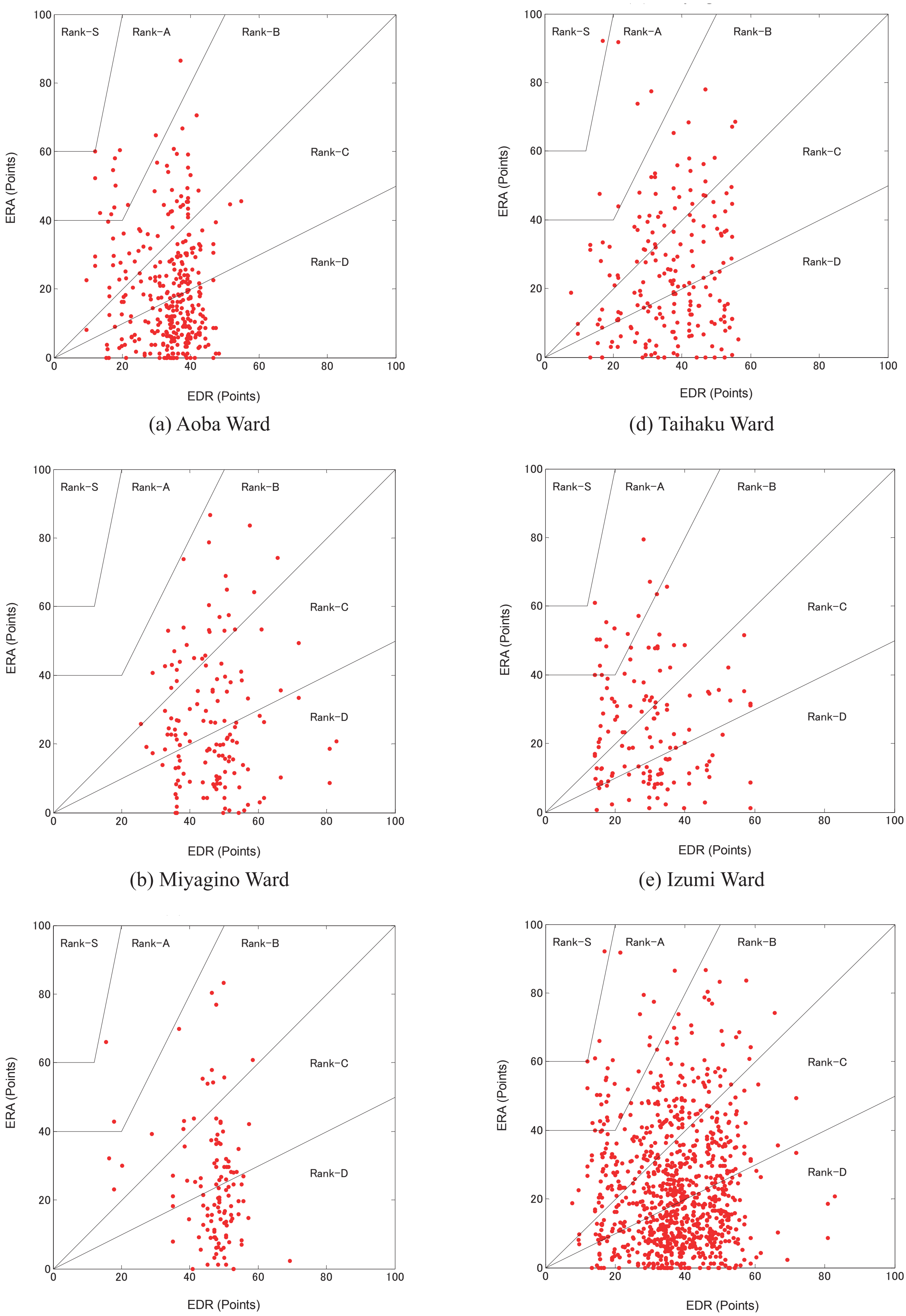
(f) Sendai City

Fig.9 Frequency distribution of ERA

4.3 Evaluation of RSF

The *RSF* can be evaluated from *EDR* and *ERA* by **Eq.1**. The results of *RSF* evaluation in each ward are shown in **Fig.10**. The correlation coefficient of *EDR* and *ERA* is extremely small because the coefficient is from -0.215 to +0.105.

The *RSF* frequency distribution at intervals of 20 points is shown in **Fig.11**. There is only one organization that achieves S-rank; on the contrary, D-rank organizations occupy half the number of the 930 organizations in Sendai City. For the advance of the *RSF*, the necessity of a disaster prevention strategy considering the spatial difference of the risk is suggested under budget and time constraints. The evaluation result of RSF with long-range monitoring and re-assessments can be used as one of the risk communication tools for local voluntary disaster prevention organizations.



(a) Aoba Ward

(d) Taihaku Ward

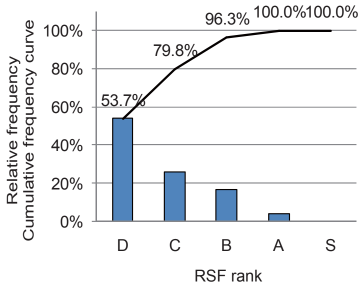
(b) Miyagino Ward

(e) Izumi Ward

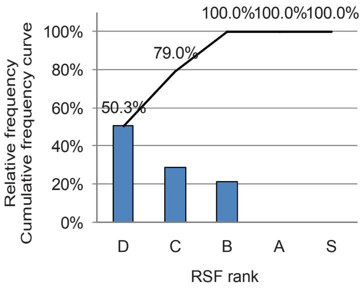
(c) Wakabayashi Ward

(f) Sendai City

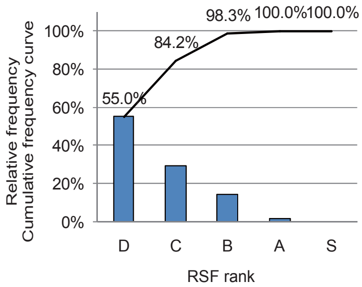
Fig.10 Evaluation results of RSF



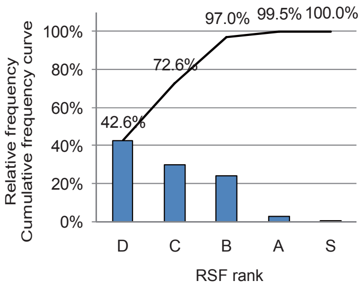
(a) Aoba Ward



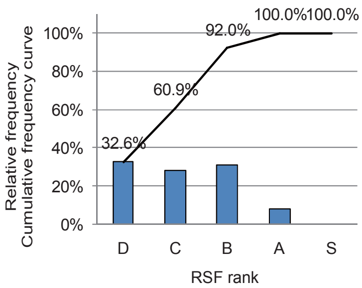
(b) Miyagino Ward



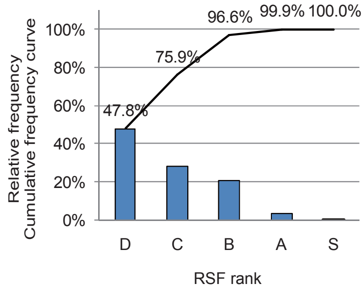
(c) Wakabayashi Ward



(d) Taihaku Ward



(e) Izumi Ward



(f) Sendai City

Fig.11 Frequency distribution of RSF

5. CONCLUSIONS

The main conclusions obtained are as follows.

(1) Consciousness and actions of the residents in Miyagi Prefecture, which will be struck by a major scenario earthquake, were clarified by a questionnaire survey. Low interest and preparedness of the residents was shown in spite of the high probability occurrence of the Off Miyagi Earthquake. In addition, as for the situation of earthquake preparedness, the difference of the risk depending on the location is not reflected. Therefore, it is necessary to develop a strategy for disaster prevention promotion considering the spatial risk differences under time and budget constraints.

(2) The influence of real disaster lessons diminishes the further the distance from the focal point. It was suggested that the utilization of real disaster lessons and the risk messages based on the scientific estimation is not quite as easy as everyone had imagined.

(3) An evaluation method for regional safety factors (*RSF*) of local voluntary disaster prevention organizations to support their planning and measures for earthquake disaster prevention/mitigation was proposed by increasing the social demand for interactive risk communication. The proposal method was applied to all of the 1,391 organizations in Sendai City.

(4) If this proposed method with long-range monitoring depending on the occurrence interval of the target earthquake scenario is utilized as incentive information to improve the vulnerability for the organizations, we hope to correct the imbalance for disaster risk.

ACKNOWLEDGMENTS

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Finally, we thank the residents of the twelve communities and the chiefs of the local voluntary disaster prevention organizations in Sendai City.

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APPENDIX: Check sheet to evaluate the emergency response potential ability for local voluntary disaster prevention organization

■**Level-1** (1 point each)

Check items	Yes	No	Domain
Local voluntary disaster prevention organization was established.			[M]
Members were decided in each specialized organization group.			[M]
Location of emergency response headquarters for the organization was decided.			[M]
Temporary refuge subspace was prepared in community area			[M]
Major routes to refuge location were decided			[M]
Usual activity as organization was performed periodically			[M]

■**Level-2** (2 points each)

Check items	Yes	No	Domain
Major members were dispatched periodically to emergency response drills by local governments			[S]
Major members were dispatched to lecture classes or seminars for disaster prevention			[K]
Major member were dispatched to first aid treatment training by the Red Cross or fire administration			[S]
Useful information for disaster prevention was supplied to households from the organization			[K]
Emergency response manual was prepared			[M]
Map for disaster prevention was drawn with hazardous information			[K]

■**Level-3** (3 points each)

Check items	Yes	No	Domain
Forecast damage level in community area was recognized based on public research on estimating earthquake damage			[K]
Map for disaster prevention was distributed to all households			[K]
Fire safety resources in community area were investigated			[R]
Water resources in community area were investigated for suspension of water supply			[R]
Emergency response training was performed without electrical supply			[S]
Dual system of night and day was prepared			[M]

■**Level-4** (4 points each)

Check items	Yes	No	Domain
List of people vulnerable to disaster was prepared in collaboration with social welfare			[M]
Rescue resources in an association were investigated			[R]
First aid treatment resources in the community area were investigated			[R]
Resources for emergency response were inspected periodically			[R]
Useful persons as emergency cooperator with experience in nursing, radio operation, and so forth were investigated			[S]
Map for disaster prevention was renewed periodically			[K]

■**Level-5** (5 points each)

Check items	Yes	No	Domain
Emergency response was conferred with medical facilities in a community area			[M]
Emergency response training was performed in cooperation with medical facilities			[S]
Information exchange was performed with other organizations			[K]
Agreement on emergency assistance was concluded with other organizations			[M]
Emergency response was conferred with corporations in a community area			[M]
Disaster prevention community plan was formed to improve fragility against earthquake disaster			[M]
Disaster prevention plan was distributed to all households			[M]
Achievement degree as contrasted with disaster prevention plan was checked periodically			[M]

Note: Four domains in the sheet:
[K]: Knowledge, [S]: Skill, [R]: Resource, [M]: Management