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Urban earthquake evacuation risk evaluation: An example

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ABSTRACT: A potential of seismic disasters in an urban area should be evaluated by either physical risks, e.g. collapse of building, fire, malfunction of roads or injured and loss of human lives. This paper proposes an evaluation method of evacuation risks of inhabitants in urban areas during earthquakes and shows a numerical example in Shanghai in China.

1 INTRODUCTION

There are multi-phases of characteristics in seismic disaster risks. 1)Temporal change of the phase, 2) Spatial change, 3) Many disasters are complicatedly interacted each others. A potential of seismic disasters in an urban area should be evaluated by either physical risks, e.g. collapse of building, fire, malfunction of roads or injured and loss of human lives. This paper proposes an evaluation method of evacuation risks of inhabitants in urban areas during earthquakes and shows a numerical example in Shanghai city.

Characteristics of Shanghai are in the following, [1][2][3]

(1) Shanghai is mostly covered with alluvial strata.

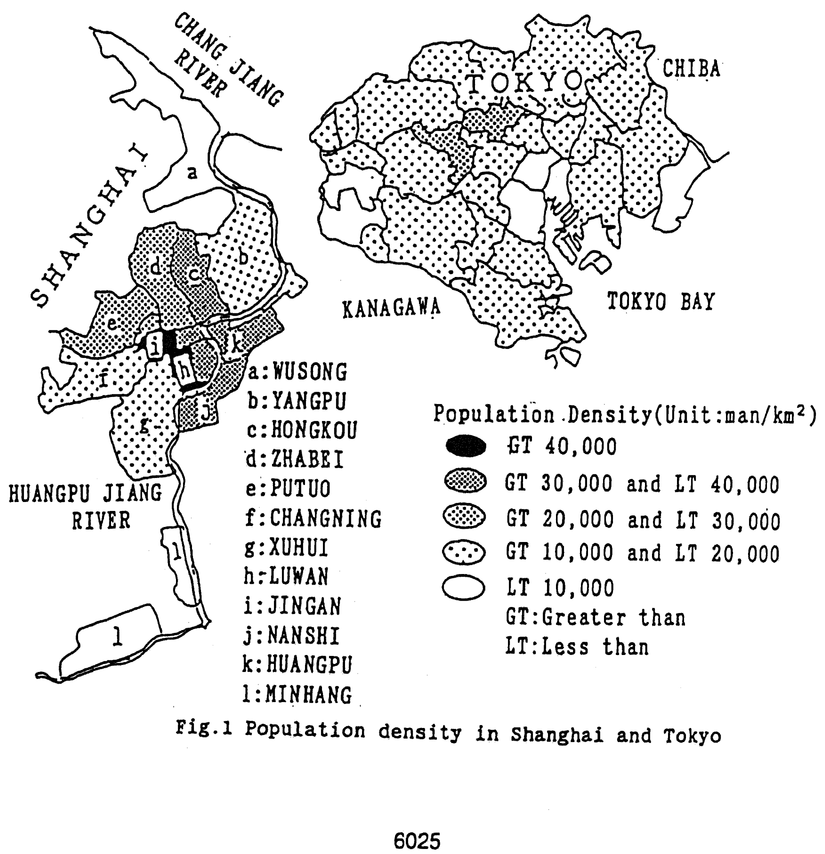

Fig.1 Population density in Shanghai and Tokyo

(2) Average density of population is about 20,000 inhabitants in one square kilometer as of 1986.

(3) Popular houses of Shanghai is two story tenement house which have high risk of fire-break-out. Fig.1 shows population density in Shanghai and Tokyo and Table 1 shows land use of Shanghai as of 1986.

(4) 67 earthquakes were recorded in the period from 419 to 1984, including once with magnitude of five on Richer scale and five times with magnitude between four and five.

Table 1. Land use of Shanghai, 1986

WARD	RESIDENTIAL AREA	VACANT SPACE	WOODEN COVERAGE
	(km^2)	(km^2)	(%)
HUNAGPU-A	4.84	0.52	0.252
HUANGPU-B	6.68	6.70	0.252
NANSHI-A	8.30	0.38	0.286
NANSHI-B	5.03	8.87	0.286
LUWAN	7.20	0.31	0.250
XUHUI	22.84	20.73	0.1631
CHANGNING	14.86	13.67	0.147
JINGAN	7.34	0.23	0.248
PUTUO	17.20	12.15	0.164
ZHABEI	13.85	13.90	0.215
HONGKOU	16.79	6.02	0.201
YANGPU	35.94	17.09	0.163
WUSONG	29.46	29.46	0.152
MINHANG	1.75	2.12	0.018

2 PROBABILITY OF BREAK-OUT-FIRE

After an earthquake occurred, fire breaks out due to collapse of fire equipment, fall and collision of combustible materials.

For determining probability of break-out-fire, assumptions are made as follows,

(1) The time of earthquake occurrence is six p.m. in winter, wind direction is north, and wind velocity is 12m/s.

(2) The fire-break-out is only due to collapse of tenement houses.

(3) A potential burnt area(called "block" below) is enclosed by isolated zones with separation width of 20 meters or more e.g. roads, streets, railways, rivers, farm lands, park and other vacant spaces.

Probability of break-out-fire is given by Eq.1.[4]

$$Pf = (6.05*10^{-3}*\delta + 8.31*10^{-5}*\exp(7.5*\delta))\ \alpha\ \beta \quad \cdots\cdots\cdots (1)$$

where, Pf is probability of break out fire, percentage of using fire in residential houses and buildings, α =2.5(at 6:00p.m.), parameter of season, β = 2.65(in winter), δ is probability of collapse houses and buildings.

Probability of houses and building collapse is obtained by the method as follows,[3]

1) The ground conditions of Shanghai is classified into five types by the era of sedimentation.

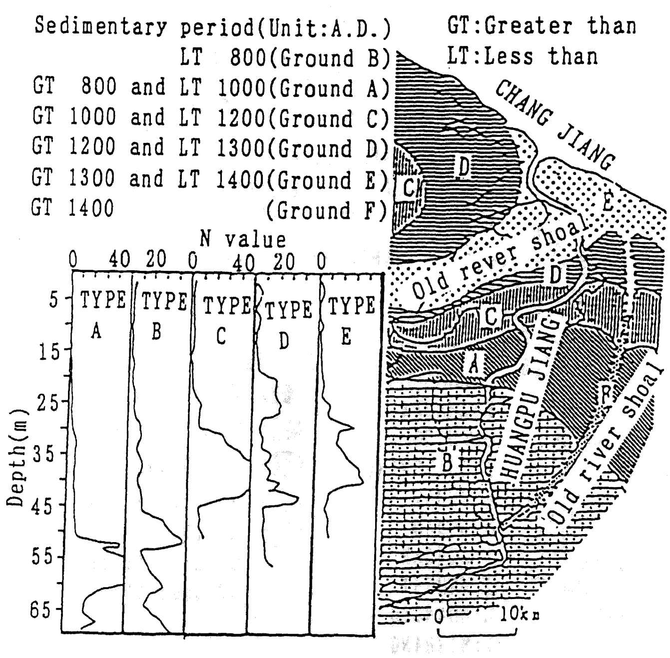

Fig.2 Soil profile in Shanghai

2) Acceleration response spectra of five kinds of grounds is estimated.

3) Probability of collapse is obtained by modal analysis.

Fig. 2 shows the soil profile in Shanghai and Table 2 shows the probability of collapse and break-out-fire.

Table. 2 Probability of collapse and break-out-fire

GROUND	PROBABILITY OF COLLAPSE	PROBABILITY OF BREAK-OUT-FIRE
	(%)	(%)
A	1.24	0.1972
B	1.40	0.2034
C	0.506	0.1689
D	5.32	0.3546
E	3.68	0.3685

3 ESTIMATION OF CUT OFF THE ROAD FOR EVACUATION

3.1 Determination of fire spread

Determination whether fire spread or not is considered from the limit distance of the spread fire recommended by Hamada S., et al [5][6] and pitch of buildings in residential areas. When the former is bigger than the later, fire spread is assumed.

$$da = 5 + 0.25 \cdot V \quad \text{------------------------} \quad (2)$$

where, da is limit distance of fire spread
V is the velocity of the wind.

$$dp = a(1/\sqrt{m} - 1) \quad \text{----------------------} \quad (3)$$

where dp is average pitch of building,
$a = \sqrt{A \cdot m / Nw}$
$m = \delta[(2-n)+(n-1)(1+0.46(1\sqrt{\delta}-1)^2)]$
A, m, δ, Nw, a are area of a district, correction average of building coverage of wooden construction, average of building coverage of wooden construction, number of wooden structures and fire protection structures, depth of houses respectively.

By using Eq. 2 and 3, the occurrence of fire spread on Huangpu, Nanshi, Luwan, Jingan, Hongkou, Zhabei wards can be found. Hence, fire spread on others wards are not considered in this study.

3.2 Assumptions

The assumptions are made as follows. [4]

1) The block is distracted by fire when there are one or more fire-break-out points.

2) Fire fighting activity and flying fire balls are not considered.

3) Fire is not spread against windward and wind-side of the block.

3.3 Probability of fire-break-out

Probability of occurrence of fire-break-out points is given by Eq. 4. [7]

$$P(K) = \frac{N!}{K! \cdot (J-K)!} i^{K} \cdot (1-i)^{J-K} \quad \text{------} \quad (4)$$

where k is number of fire-break-out point
J is total number of fire break out points in the ward, i is ratio of fire-break-out = block area/ward area.

By using Eq. 4, probability of occurrence of fire break out points is given by Eq. 5.

$$A = 1 - P(K=0) \quad \text{------------------------} \quad (5)$$

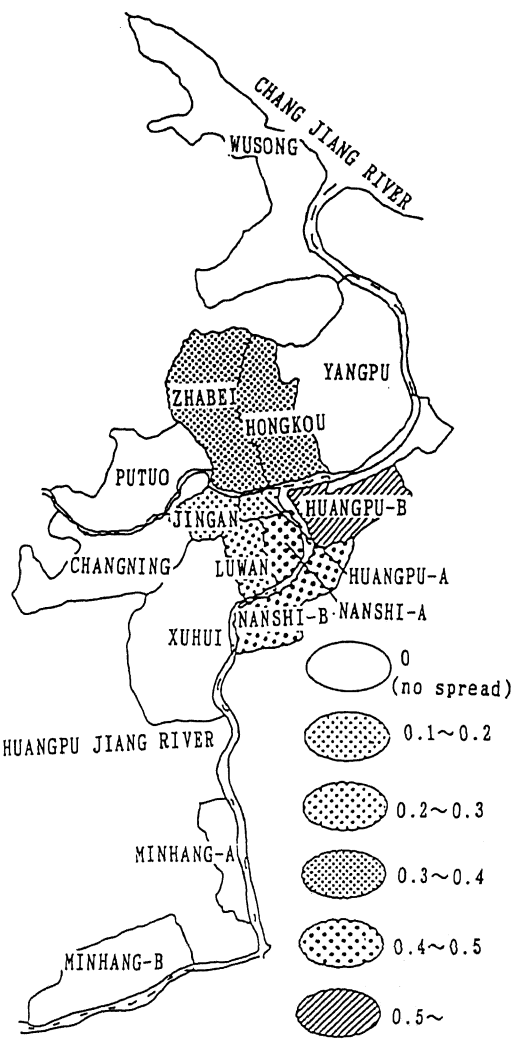

Fig. 3 Probability of destruction by fire

3.4 Fire arrival time [8]

Evacuation roads are cut off when fire arrives. Shape of spreading fire is assumed as an ellipse shown in Eq.6.

$$\left.\begin{aligned}\frac{(X-XJ)^2}{S_{1,t}} + \frac{m(Y-YJ)^2}{S_{2,t}} &= 1 \\ \frac{(X-XJ)^2}{S_{2,t}} + \frac{m(Y-YJ)^2}{S_{3,t}} &= 1\end{aligned}\right\} \quad (6)$$

where $S_{1,t}$, $S_{2,t}$, $S_{3,t}$ are leeward spreading fire distance after an instance of t minutes, windward spreading fire distance after the instance, wind-side spreading fire distance after the instance, respectively. XJ, YJ are co-ordinates of geographical gravity center, X, Y are co-ordinates of spreading fire after the instance.

3.5 Probability of cut off the evacuation road and ratio of burnt area

Determination whether fire spread or not is given by Itoigawa.E, et al.[9] In their study, more than 20m wide roads functions as a cut off spread fire belt. Evacuation road is cut off according to probability of both sides block's fire break out. Ratio of burnt areas at the city are obtained by Eq.7.

$$M = \frac{\Sigma (D * B)}{C} \quad (7)$$

where M is ratio of burnt area at a ward,
B is area of block, C is area of ward
D is ratio of burnt area at a block

Fig.3 shows the probability of destruction by fire.

4 EVALUATION METHOD OF EVACUATION RISK[10][11]

4.1 Assumptions

1) Refugees can evacuate themselves.
2) All refugees have same evacuation characteristics.
3) Refugees are uniformly distributed in the block.
4) Refugees in site of roads is ignored.
5) Population of residents is only considered.
6) Walking speed is 60m/min.
7) Change of walking speed due to damage to transportation structures is not considered.

4.2 Expression of evacuation road and refugees

Evacuation road is expressed as a network consist of nodes and links. Refugees are expressed as a party of 500 people.

4.3 Orientation of evacuation

The party of refugees in the block evacuate to the nearest node from the refuge island. The party remained in the block evacuates to the other node where is not influenced by fire and the nearest to the refuge island.

4.4 Selection of evacuation routes

The party knows a geographical information well, and evacuate to the nearest refuge island by one of the shortest routes. The selection of the shortest route is done by Diacustra Method.[12]

4.5 Refuge island

Refuge island is defined as a vacant space. To determine effective refuge island area, radiant heat is considered. Occupant area of refuge island is a $1m^2$/person.[13]

4.6 Method of evaluation

Fire-break-out and cut off the evacuation routs is expressed as a probability. So, probability in evacuation is calculated by employing Monte Carlo Method every ward and block. If refugees are isolated by fire or arrived at the refuge island where exceeding its capacity, refugees can not be evacuated. The evacuation risks is evaluated by Eq.8.

$$EL = \frac{SR}{NR} \quad (8)$$

where EL is evacuation risk, SR is sum of refugees who could not be evacuate, NR is total number of refugees.

5 CONCLUSIONS

As for an evaluation of evacuation risks the following can be concluded.

1) The probability on destruction by fire will reach to 0.462, and dangerous areas are designated to Nanshi-A, Nanshi-B, Huangpu-B, in Shanghai as shown in Fig.4.
2) The probability on destruction by fire will be influenced by probability of fire break out, building coverage of wooden construction and blocking areas.
3) The evacuation risk is estimated as 0 to 0.089 and about 130 thousand people could not be evacuated in Shanghai.

4) The evacuation risk can be influenced by probability of the destruction and distribution of refuge islands.

Table.3 Evacuation risk and number of refugees who can not be evacuated.

WARD	EVACUATION RISK	NUMBER OF REFUGEES
	(%)	(PEOPLE)
NANSHI-A	0.089	37,776
NANSHI-B	0.000	0
HUANGPU-A	0.005	1,377
HUANGPU-B	0.076	28,877
LUWAN	0.024	11,530
JINGAN	0.010	4,965
HONGKOU	0.056	37,268
ZHABEI	0.011	9,008

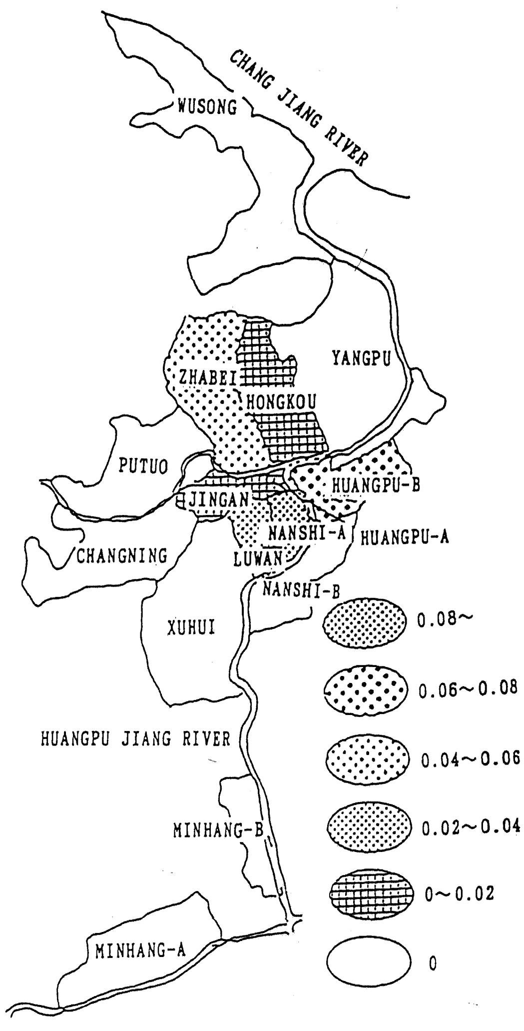

Fig 4. Evacuation risk

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