CHARACTERISTICS OF NETWORK RELIABILITY OF VARIOUS

TYPES OF LIFE-LINE SYSTEMS

by

Motohiko Hakuno*

SUMMARY

Study of the past damage to functions of lifeline due
to earthquakes in Japan, indicates that the disorder of
functions of lifeline happened more easily in a wider area
than the damaged area of buildings.   The author made seismic
reliability analysis about simple models of several lifeline
such as electric power, water, telephone, and railway by means
of Monte Carlo simulation and variated stochastic values of
system components, for example, maximum value, average value of
P_i, etc., and obtained the correlation between the reliability
of the system and the above stochastic parameters of components.

INTRODUCTION

It is well known that the function of Electricity, Water,
Gas supply systems was stopped by San Fernando Earthquake of
1971.   In Japan we suffered almost same functional disorder
on Electricity, Gas, Transportation by Miyagiken Oki Earth-
quake 1978 as in San Fernando, USA.   Functional disorder of
lifeline utilities did not draw so much interest of earthquake
engineer before San Fernando Earthquake.   The out of order on
lifeline occurred frequently in past earthquakes, however,
in case of severe earthquakes, many buildings were destroyed
and many lives of citizens were lost, and people did not pay
so much attention to lifeline.   Furthermore, in olden times,
people does not enjoy so convenient life as the present one
in a large city, and they did not have water supply system,
telephone, gas distribution systems to individual home, various
types of electric and electronic equipments in each house,
therefore, stoppage of lifeline function can not have a fatal
effect on citizens.   At present, wells changed to water trans-
mission system, firewood changed to gas for fuel, and fire
fighting with various machines in stead of firemen, therefore,
stoppage of lifeline due to earthquakes causes to be vital for
lives of citizens.   The author describes in the following
chapters the outlines of functional damage to lifeline in

* Professor, Earthquake Research Institute, University of
          Tokyo, Japan

Miyagiken-Oki earthquake which is one of the typical damage occurred to lifelines recently in Japan, and weakness of functions agaist earthquake and its assumed causes, and seismic reliability analysis on lifeline network models variating stochastic parameters such as maximum value of probability of failure P_i of network component, average value of P_i ,etc..

DAMAGE ON LIFELINES IN MIYAGIKEN-OKI EARTHQUAKE OF 1978

In Miyagiken-Oki earthquake of 1978 in Japan, disorder of lifeline utilities occurred easily and extensively in a wider area than a region which buildings were damaged.   In this earthquake, the maximum acceleration on the ground surface of Sendai city which is located in the center of damaged area approximately 100 km west from the epicenter, was 250-300 gals, and houses less than 1 percent were severely damaged.   Therefore, it can be said, the earthquake was not so intense, however, the function of lifeline was as follows.

i) Electricity
   Electricity supply was stopped about one day due to damages to facilities indicated in Table.1.   Electricity can not be continued to supply owing to the fear of danger to citizens such as electric shock, and fire, after cut of wire.   This causes frequent stoppage of electricity supply during earthquakes.

ii) Water supply
   Water supply was partly impossible for several days due to leakage of water caused from damage to underground pipes which were frequently seen in the border between soft and hard ground.

iii) Railway Trafic
   Railway was forced to stop for maximum three weeks in some region.   The damage of several structures occured in local region such as horizontal cut of bridge piers and slight settlement of embankment, caused stoppage of railway traffic in a wide area for a long time.   The difference between the facts that trains can not go even on the slightly deformed rail and cars can go on a little damaged pavement, produced the difference of their responses to Miyagiken-Oki earthquake.

iv) Road Traffic
   Road traffic was thrown into confusion after the earthquake due to disorder of traffic signals (74% of total) caused from electricity stoppage, damage of bridges, settlement of road embankments, water flood on the road from leakage of underground water transmission pipe.   Traffic confusion was escalated by concentration to road traffic of train commuters.

v) Gas
   Many damages occurred to joint parts of small transmission underground pipes and caused leakage of gas, however, main steel pipes in large diameter were subjected almost no damage. One gas holder suffered collapse and got fire.   Gas factory with good automation could not produce gas due to stoppage of electricity.   Gas supply must be stopped in case of leakage, therefore,it took approximately one month to serve to users again.

WEAKNESS OF FUNCTION OF LIFELINE UTILITIES AGAINST EARTHQUAKES

According to survey of damages to structures and lifeline utilities in Miyagiken-Oki earthquake of 1978, although the intensity of the earthquake was not so severe and gave only slight damage to ordinary buildings, disorder of function of lifeline occurred easily in a wider area than the damaged area of buildings. This characteristics on function of lifeline utility is not limited to only Miyagiken-Oki Earthquake. Table-2 indicates whether out of order of lifeline utilities occurred or not among earthquakes in Japan which did not give severe damage to buildings.

Function of lifeline utilities is recognized to be much weaker than strength of houses against earthquakes from the table. In order to make functional weakness of lifeline clear, the author selected only earthquakes which did not give heavy damage to houses for this table. Further, the autor prepares Fig.1 to bring weakness of lifeline to earthquake into relief. Fig.1 indicates the blocked part of railroad service, area of electric power failure, and damage area of houses. It is seen that the area of functional disorder of electric power and railway is much wider than the area of houses damage, therefore, even people who lives in the region where suffered no damage with houses, could not get on the train and had no electric power.

PROBABILITY OF FUNCTIONAL DISORDER OF LIFELINE SYSTEMS

Weakness of function of lifeline utilities during earthquakes shown previously is considered to be caused from system characteristics of "Series". For example, the author made a model for railroad as shown in Fig.2, and we can recognize a railroad without branch lines is a "Series" structure. In this case, probability of failure of total system increase exponentially according to increase of number of structural parts. For example, assume equal probability of failure of each parts p to be 0.01, and number of connected part $n=100$, then, probability of functional disorder of railroad P_f is given as belows,

$$P_f = 1 - (1-p)^n = np - \frac{1}{2}n(n-1)p^2 + - - -$$

$$= 1 - (1-0.01)^{100} = 0.634$$

The value of p of 1 percent for each structural part is not so large for during earthquakes, however, the estimated results tell that railroad traffic will probably stop. And assumed number 100 is not so large. In the city of TOKYO, averaged length of a piece of underground water transmission pipe is 4m, therefore, total length of 100 pieces of water pipe is only 400m, and is not considered to have another loop line within such a short distance, so the system is of complete series.

The author considers the previously mentioned properties "Series" are why the function of lifeline was so weak in past earthquakes. Reliability characteristics variate corresponding to types of systems such as electric power, water, railroad traffic, etc.. In order to improve reliability of existing networks, it is necessary to know which is the most efficient parts to improve the total systems. For example, in the pure series structure as shown in Fig. 3 (a), reliability R of total system to vary P_2 is shown in Fig. 4 (a). These figures tell us that in series network, to improve the weakest component is the most efficient and in parallel network, improvement of network components is not efficent, but to make another parallel component is an efficient way.

However, since the existing utility systems are not so simple as the above cases, the author made simple networks corresponding to each utility as shown in Fig.s 5-7 and estimated reliability of function of each total system by means of Monte Carlo simulation and Matrix method from the assumed probability of failure (P_i) of the components.

After making one thousand trials of the simulation, probability of failure of the total system was obtained. And the author variated stochastic values of the system components, for example, maximum value of P_i, average value of P_i, etc., and obtained the following correlation coefficients with reliability R of total system;

   $\bar{R}$: Average value of seismic reliability R of total system,
   ZA: Correlation coefficients of R and average of probability
       of failure of network components P_i,
   ZM: Correlation coefficients of R and maximum of P_i,
   ZOI: Correlation coefficients of R and average of P_i
       which is larger than 0.1.
   ZN: Correlation coefficients of R and number of network
       components P_i of which are larger than 0.1.
   MCC: Multiple correlation coefficients of R and above
       metioned various values such as averaged P_i, maximum
       of P_i, averaged $P_i > 0.1$.

The obtained results are shown in Tabie.3. In the table, Electric power (+ parallel) indicates the case which have a detour route between substations in the network model of Electric power in Fig.5. From the results in Table.2, it is seen that network with many parallel routes are more reliable against earthquakes thanwith a few parallel routes, and the probability of failure of the weakest structure of the network has most infiuence on reliability of the total system in the network with few parallel routes. Therefore, the value of ZM in Table.3 could be an index indicating the characterist⁷⁷s of "Series" of a network system.

QUESTIONARE SURVEY ON ASEISMICITY OF COMPUTERS IN JAPAN

A computer was subjected damage by Miyagiken-Oki earthquake of 1978. At present, computers become important center in industries, and in other fields. For example, super express train in Japan runs with help of a computer, and even TV programs are being controlled by computers. Therefore, once computers shut down during earthquake, our daly life would be affected seriously. The author made a questionare survey to 1900 enterprises in Japan, concerning what kind of consideration is paid to aseismicity of computers. The questionare has ten items;
1) Adress of location in Japan,
2) purpose (Scientific Calculation, Control, Business),
3) Number of floors where the computer is installed,
4) Whether the computer is fixed to the floor or not ?
5) Whether the computer has own emergency generater of electric power or not ?

6) And equipped with own water tank for cooling the above generater ?
   etc.
   The analysed results of answers from 45% of enterprises are shown in Fig.s8-12. Computers in Japan concentrate to Tokyo, and most of them are located in the central part of the downtown the surface ground layer of which is a thick and soft alluvium deposit and considered to be bad place at the time of a future earthquake.
   It is recognized from Fig.9 that many computers are installed on the top of buildings which will shake more than on the 1st floor.
   Fig.10 shows that most of computers are not fixed to the floor and they might fall down or move.
   Most of computers do not have own generater for electric power failure during earthquake (Fig.11).

CONCLUSION

The followings are concluded from this research.
1) Function of lifeline is much weaker than strength of structures. Therefore, we have to expect stoppage of electric power, water supply, railroad traffic, etc. during severe earthquake.
2) By means of reliability analysis of networks through Monte Carlo simulation, behaviors of lifeline networks during earthquake can be estimated qualitatively.
3) A usefull information to improve reliability of existing lifeline systems was obtained, however, it costs too much to improve systems not to occur any stop in lifeline function, therefore,, at best improvement, necessary time to repair will be shortened.
·4) Questionnaire survey concerning computers which come to be more important to control lifeline systems, shows that most of computers are not installed taking account of earthquake force.

REFERENCES

(1) Panoussis, G. (1974), "Seismic Reliability of Lifeline
    Networks", Seismic Design Decision Analysis - Report
    No.15, Massachusetts Institute of Tchnology, Dept. of
    Civil Eng. Research Report R74-57.

(2) Shinozuka, M., Takada, S. and Kawakami, H., (1977),
    "Risk Analysis of Underground Lifeline Network Systems",
    US-South East Asia Symposium on Engineering for Natural
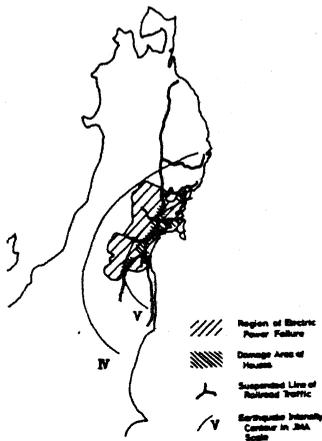   Hazards Protection, Manila, Philippines,

Fig.2 Network model for railway

Fig.1 Damaged area of lifeline
utilities in Miyagiken-Oki
earthquake 1978

(a)Series Model   (b)Parallel Model
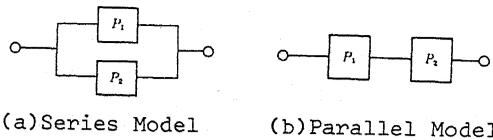
Fig.3 Simple model for series and
parallel structure

(a)Series Model   (b)Parallel Model
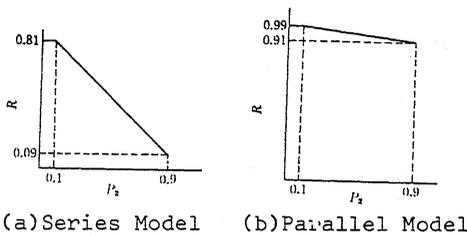
Fig.4 Relationship between R and P_2

278
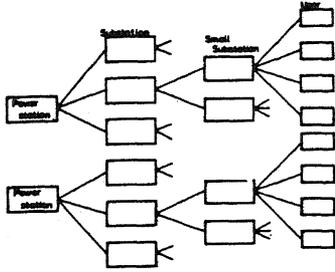
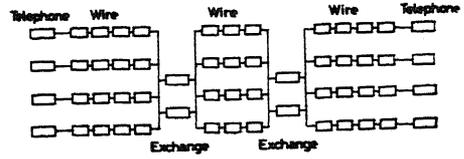Fig.5 Network model for electric power system

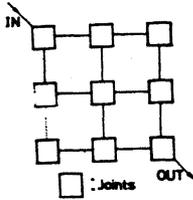Fig.6 Network model for telephone service

Fig.7 Network model for water transmission

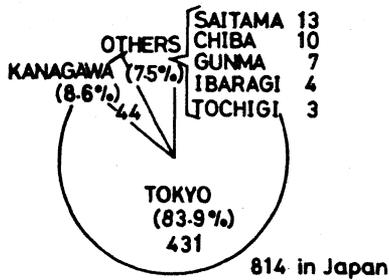Fig.8 Where are computers installed ?

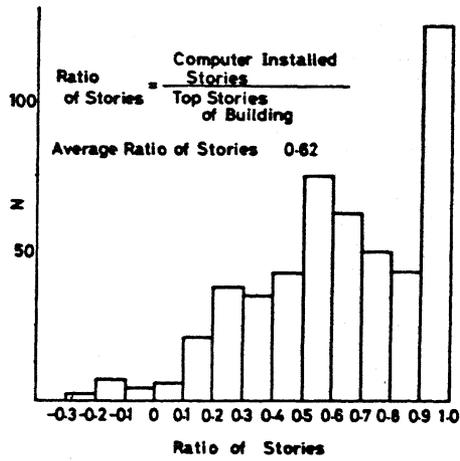Fig.9 Is the top of building the safe place for computers ?

279

No Answer
(1·4%)
7
Yes
(12·9%)
66

No
(85·7%)
439

EQUIP.
(8·0%)
41

NO EQUIP
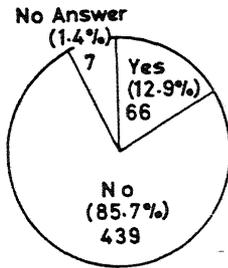(92·0%)
470

Yes
(11·7%)
60

No
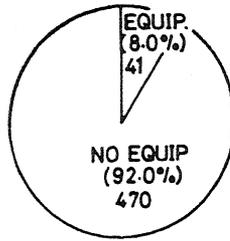(88·3%)
452

Fig.10
Are computers
fixed to floor ?

Fig.11 Do computers
have own generater
for earthquake stoppage
of electric power ?

Fig.12
Whether computers
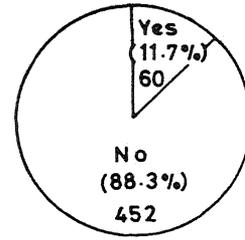have water tank for
above generater ?

Damaged Facilities and Type of Damage	Number of Damage
Thermal Power Station	3
Hydroelectric Power Station	1
Substation	17
Facilities for Power Distribution	
Fall down of pole	68
Inclination of pole	387
Disconnection of High Volt. Wire	285
Disconnection of Low Volt. Wire	350
Disconnection of Incomming Line	163
Damage to Transformer	2583

	Damage to Building	Number of Died	Road Traffic	Railroad Traffic	Electric Power	Water Supply	Gas Supply
1978 Izu Oshima Kinkai	Moderate	25	×	×	×	×	−
1978 Sitaken -Chubu	Moderate	8	×	×	×	×	−
1974 Izuhantō -Oki	Moderate	36	×	△	×	×	×
1973 Nemurohantō -Oki	Slight	8	×	×	×	×	−
1969 Gifu Chūō	Slight	1	×	×			
1961 Hyūganada	Slight		○	×		○	−
1961 Kitamino	Slight		×	×			

X :Function Stoppage . △ :Partly Stoppage
○ :No Function Damage. □ :No Facilities
Blank :Not Clear .

Table.1 Damage to equipments of
electric power system in Miyagi
earthquake of 1978

Table.2 Function disorder
of lifeline in past earthquakes
in Japan

	$\bar{R}$	MCC	ZA	ZM	ZOI	ZN
Water	0.80	0.57	−0.54	−0.36	−0.24	−0.46
Electric power	0.69	0.87	−0.87	−0.65	−0.48	−0.74
Electric power(·Parallel)	0.79	0.75	−0.73	−0.63	−0.43	−0.62
Railroad traffic	0.73	0.81	−0.81	−0.74	−0.67	−0.71

Table.3 Correlation cofficients of reliability
of total system and stochastic parameters of
system components