CS 4 - 1 〔Ⅰ〕

NEURAL NETWORKS FOR ESTIMATION OF EARTHQUAKE DAMAGE SEVERITY

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SUMMARY: During a strong motion earthquake, the range of structural damage is quite wide. Earthquake strong motion records must be reconcilable with observed damage. For past 70 significant ground motions, the effect of different earthquake severity indices on the structural damage was analysed using neural networks. As already pointed out in the literature, peak ground acceleration (PGA) does not correlate well with the structural damage. The network identifies peak ground displacement (PGD) as the most influential index. Also, the peak ground velocity (PGV) and spectral intensity (SI) values are strongly correlated with the damage. In case of a strong earthquake, the decision to maintain or to shut off a facility is a sensitive issue. For each ground motion index, an operational threshold value is estimated with more than 90% precision.

NETWORK MODEL: In this study, back-propagation network with the supervised learning scheme is considered. A net input value is calculated by summing the weighted input values. This becomes the input to the transfer function, which specifies the output of the particular Processing Element [1]. During the learning phase, several ground motion indices were assigned as the inputs and the structural damage as the desired output (Figure 1). SI value, PGA, PGV, PGD and JMA Intensity scale were selected as reference ground motion indices. JMA Intensity is a function of the predominant period and PGA. The type of structure varies from one place to another. Damage depends upon the surrounding structures. It is difficult to correlate the damage of two places on the same scale. Therefore, three discrete damage categories are used; namely, negligible, moderate and severe. Structural damage includes damage either to buildings or to civil engineering structures or both. The damages in 70 locations resulting from 11 earthquakes were used in the analysis. These were classified according to damage severity and shown in Table 1. Different damage categories in terms of SI and PGA values are shown in Figure 2. It is clear that damage severity can be better defined in terms of SI value. During the learning phase, the data set was presented 50,000 times to the network.

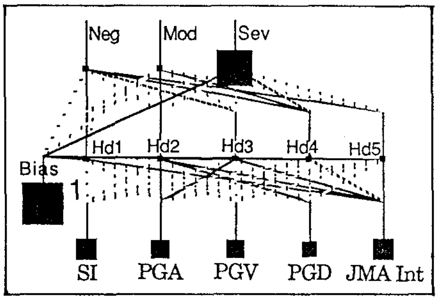

Figure 1 Network Model

Table 1 List of earthquakes with damage classification [2]

	Negligible	Moderate	Severe
Niigata (1964)	0	0	1
Matsushiro (1965)	20	2	1
Off-Tokachi (1968)	0	0	3
Off-Miyagi (1978)	2	0	2
Nihonkai-Chubu (1983)	0	0	2
Chibaken-Toho-Oki (1987)	6	2	0
Izu Peninsula eastern offshore (1989)	2	2	0
Imperial Valley (1940)	0	0	1
San Fernando (1971)	0	2	2
Mexico (1985)	0	0	2
Loma Prieta (1989)	3	2	13
Total	33	10	27

RESULT INTERPRETATION: Three outputs were considered to describe the discrete damage categories. The output corresponding to the specified category is activated (1) and the rest are inhibited (0); thus representing the presence or absence of the feature. The output "negligible" is expressed by (1,0,0) while "moderate" and "severe" by (0,1,0) and (0,0,1), respectively. However, this ideal condition is not observed and the network suggests values from its own evaluation. If the maximum of the three outputs is greater than 0.5, then it is accepted as an activated damage category. For example, for network's estimation (0.624, 0.201, 0.007), the corresponding damage category was considered as "negligible" damage. With this criterion, the network correctly estimated 64 events out of 70. The actual network's estimation corresponding to each damage category is shown in Figure 3. For moderate damage, the network shows poor adaptation. It may be due to less representation of moderate damage in the learning set.

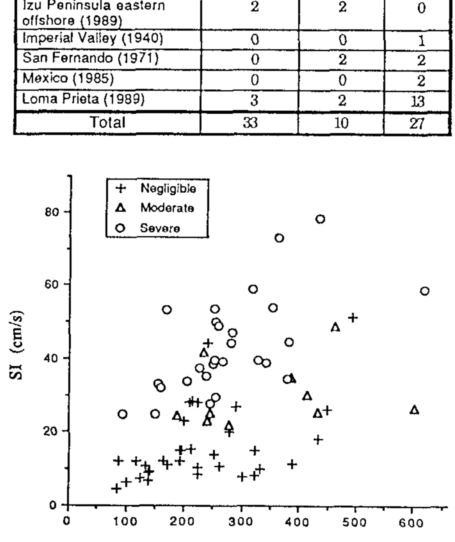

Figure 2 Distribution of SI and PGA for different damage categories

CORRELATION BETWEEN DAMAGE AND GROUND MOTION INDICES: During a strong ground motion, the decision to maintain or to shut off a facility depends on the expected damage. For gas networks, in

Table 2 Optimum threshold value for ground motion indices

Severity Index	Threshold value	Actual observation			Network estimation		
		P_D	P_N	$(P_D+P_N)/2$	P_D	P_N	$(P_D+P_N)/2$
SI	29 kine	0.94	0.93	0.93	0.94	0.95	0.95
PGA	230 gal	0.68	0.76	0.72	0.71	0.72	0.71
PGV	25 kine	0.92	1.00	0.96	0.97	1.00	0.99
PGD	7 cm	0.92	0.97	0.95	1.00	0.97	0.99

particular, decision should be made quickly otherwise serious secondary disasters may follow the structural damage. On the other hand, if the supply is shut off unnecessarily, it will inconvenience the customers since recovery takes time. Therefore, the ground motion severity should be expressed in an appropriate threshold value of the ground motion index for which minimum damage is expected [3]. Consider that at a threshold value x, $P_D(x)$ is the ratio of occurance of damage for ground motions smaller than x, and $P_N(x)$ is the ratio of non-occurance of damage for ground motions larger than x. Then, the evalluation function can be considered as the weighted sum of these ratios:

$$f(x) = w_D P_D(x) + w_N P_N(x) \quad (1)$$

where w_D and w_N represent the corresponding weights. In this study both atre taken as 1. The optimum threshold value for a ground motion index is the value which maximize Eq. 1. P_D and P_N are calculated for actual damage and for the network's estimated damage for each ground motion index. Moderate damage is considered as a member of both P_D and P_N. The optimum threshold values for each ground motion index are shown in Table 2. The same values are observed for actual damage and for the network's estimated damage. As mentioned earlier, PGA does not correlate well with damage. For PGA, a figure of 0.72 (0.71 by network estimation) is obtained at the threshold value. This indicates that out of the past 10 earthquakes, the system was efficiently controlled in 7 events only. On the contrary, SI value shows a good distribution with respect to the damage; with a figure of 0.93 (0.95 by network estimation) at the threshold value. PGV and PGD also show a high value for optimum system control. However, for PGD, P_D tends to decrease for displacements greater than 8.0 cm. This behavior indicates that the evaluation of PGD from acceleration records needs more consideration. No well-defined relation can be found between JMA Intensity and damage severity. The estimation of threshold value for SI and PGA by evaluation function is shown in Figure 4.

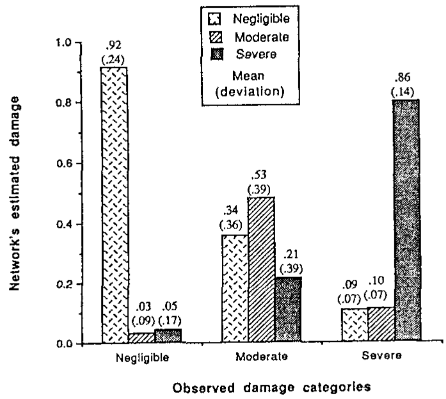

Figure 3 Network's estimated damage

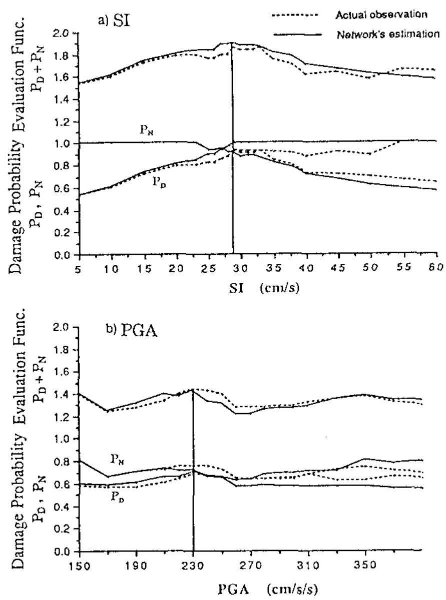

Figure 4 Estimation of optimum threshold value for SI and PGA

CONCLUDING REMARKS: Neural systems may be a very useful tool for damage estimation. Once the network is set up, damage estimation is very fast. The network efficiency can be improved by adding new data. The learning data should be representative of all expected cases otherwise network's efficiency may be affected. Considering the observed damage ratios, SI and PGV are considered to be the most appropriate indices for estimating earthquake damage severity. With either of these two, antiseismic control is expected to be carried out with more than 90% efficiency. The PGA fails to suggest an effective value for operational suspension.

REFERENCES:

[1] James A. Freeman and David A. Skapura (1991). *Neural Networks: Algorithms, Applications and Programming Techniques*. Addison-Wesley Publishing Co.

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[3] Iwata, Yamazaki, Nakane, Kodama, Tazou, Shimizu, Kataoka (1991). Demonstrative evaluation of variables indicating severity of earthquake applicable to earthquake sensor for control (in Japanese). *Proc. of 21st JSCE Earthquake Engineering Symposium.*