URBAN SEISMIC DAMAGE
-Osaka Case Study-

C. SCAWTHORN*
H. IEMURA**
Y. YAMADA***

Introduction In the urban seismic environment, one of the greatest sources of damage is building damage. While studies of individual damaged buildings abound, studies of building-class damage and damage models are very scarce. This paper summarizes such damage models for two classes of buildings, low and mid-rise buildings, which encompass almost all urban buildings. These two seismic damage models are useful in estimating damage distributions for various potential earthquakes, and have been used to estimate annual expected seismic damage, which is a much better parameter for seismic design level optimization than individual postulated earthquakes. In these studies, probabilistic response spectra[1] for three soil classes (soft, intermediate and hard) are used as the measure of the seismic hazard.

Low-rise damage estimators and seismic damage model, based largely on data from the June 12, 1978 Miyagiken-oki earthquake, have been previously published[2,3]. The therein Damage Cost Factor (DCF) has been revised to give more accurate results in the expected acceleration range, and is:

$$DCF = 0.0019\Delta^{1.2257} \qquad (1)$$

(eg, for a 2 story building, $\Delta=(24.02-.83Br)Sa_{.75}^{1.37}$, Br=no. of bracing-equivalents in excess of present code required stiffness, $Sa_{.75}$=response spectral acceleration at 0.75sec), where Δ is the story deflection of the first story. For low-rise wooden buildings such as are common in Japan, earthquake-caused fires are a great danger. Using results of Mizuno[4] re post-earthquake fire outbreak, and Hamada[5] re fire spreading, a fire spreading model has been developed, which considers wind velocity probability density, post-earthquake fire-fighting response and effectiveness. In Osaka, for example, this resulted in (where $P[FTL|Sa_{.75}]$ is the probability of total loss due to fire given the $Sa_{.75}$):

$$P[FTL|Sa_{.75}] = \exp[-e^{-2.256(Sa_{.75}-0.86)}] \qquad (2)$$

Another danger to buildings in earthquakes is liquefaction, such as occurred in 1964 in Niigata. Iwasaki's[6] simiplified method, using as the only random variable probability of maximum ground acceleration , was employed, together with, based on investigations of Niigata data, a probability of total loss given liquefaction of 0.23 for wood buildings and 0.115 for steel and concrete buildings up to 4 stories, in order to estimate damage due to liquefaction.

Mid-rise building damage estimators, based on Miyagiken-oki data collected by Abe et al[7], have also been reported[8]. Basically, if damage is characterized by a damage state, DMG (0=no damage, 4=total damage), then:

$$DMG = 1.95[Dr-.14]^{.4} \quad , \qquad Dr = 1.33\, N^{-.5} Sd \qquad (3)$$

where Dr=maximum interstory displacement (cm), N=no. of stories and Sd=response spectral displacement at period of the building, $\overline{T}_1$, which can be estimated by:

$$\overline{T}_1 = 0.096N^{.65} \qquad (4)$$

$\overline{T}_1$ is the estimated period of RC and SRC buildings designed according to present practice. Thus, the above relationships permit damage estimation under alternative design levels, by calculating the natural period corresponding to the alternative designs and using this rather than relation (4) in the damage estimation algorithm (3). For example, for a nine-story building subjected to response spectral accelerations in the 0.4 to 0.5 sec range of, say, 0.5g, the expected damage is reduced by 40% if the stiffness is increased by 56%. Liquefaction, except as noted above, and fire were not considered for mid-rise buildings.

Discussion and Conclusions The above outlined seismic damage model permits simulation of potential earthquakes in an urban region, such as Osaka, Fig 1, (see references 1 and 9 for soil classifications, response spectra etc. used for Osaka.). In this figure, which presents mean damage estimates for a medium size earthquake fairly close, substantial damage is concentrated in the central business district (CBD), while an approximately equal amount of damage is more evenly distributed across the city, reflecting the concentration of building capital in the CBD and the much more dispersed

*Monbusho Scholar, **Assoc. Prof., ***Prof., Dept. Civil Engg., Kyoto Univ., Kyoto 606

low-rise building inventory. The relatively light damage south of Tennoji is due to a combination of lesser building density and the firm soil of the Uehonmachi plateau and its southward extension. Comparable damage estimates for other earthquakes are:

Magnitude 5.5 at 20 km. ¥ 828 $\times 10^8$
" 8.0 at 160 km. ¥ 81 $\times 10^8$

with significantly different ratios of low-, mid-rise shaking, fire and liquefaction damages, indicating the changing shape of response spectra as a function of magnitude and distance. However, of more value than individual earthquake estimates, is the annual estimated seismic damage, since this combines the damage effects of all possible earthquakes, according to their probability. Fig. 2 shows the per annum expected damage for low-rise buildings due to shaking only, totaling ¥ 159 $\times 10^8$. Other expected damage p.a. (not shown) is:

Mid-rise buildings (shaking only)	¥ 175 $\times 10^8$
Liquefaction	¥ 39 $\times 10^8$
Fire (wood buildings only)	¥ 40 $\times 10^8$

(all ¥ are 1978 Yen). All of the above estimates are for structural damage only, neglecting damage to contents as well as human casualties. Preliminary calculations show that, using monetary approximations for human casualties equivalent to airplane accident insurance awards in Japan, casualties would be equivalent to about 30% of structural damage. The model also permits structural optimization studies to be conducted, which, using realistic construction cost functions, indicate potential savings of 2% of total cost for low-rise buildings (seismic damage reduced by 60%) and 3.2% of total cost for mid-rise buildings (damage reducted by 45%), where total cost is construction cost plus expected seismic damage. It is interesting to note that if it were possible to build all of Osaka on hard soil, comparable savings could be realized, indicating that a mix of microzoning and strengthening is the best approach to the seismic damage minimization problem.

References 1. C. Scawthorn, H. Iemura, Y. Yamada, Seismic Risk Analysis of Urbar [illegible]gions, 5th Japan Earthquake Engg. Symp. (JEES), Tokyo, 1978,
2. C. Scawthorn, H. Iemura, Y. Yamada, Statistical Studies of Low-Rise Japanese Building Damage, 2nd U.S. Nat'l Conf. Earthquake Engg., Stanford, 1979,
3. C. Scawthorn, et al Studies Earthquake Damage..., 7th World Conf. Earthquake Engg., Istanbul, 1980
4. H. Mizuno, Jishiji Shuka ni kan suru kisoteki kenkyu, Kyoto U., Kyoto, 1978
5. M. Hamada, Kasai no Enshou sokudo ni tsuite, Kasai no kenkyu, Sagami shobo, 1951
6. T. Iwasaki, Sashitsu jiban no jishinji ryudoka no kani hanteiho to tekiyorei, 5JEES, Tokyo,
7. Y. Abe, et al, Change of Natural Periods..., Tr. AIJ, Tohoku Branch, No.33, 1979
8. C. Scawthorn et al, Seismic Damage Estimation for Low and Mid-rise Buildings in Japan, submitted to Earthquake Engg. and Structural Dynamics.
9. C. Scawthorn et al, Osaka niokeru..., Kansai Branch, JSCE, Kyoto, 1980

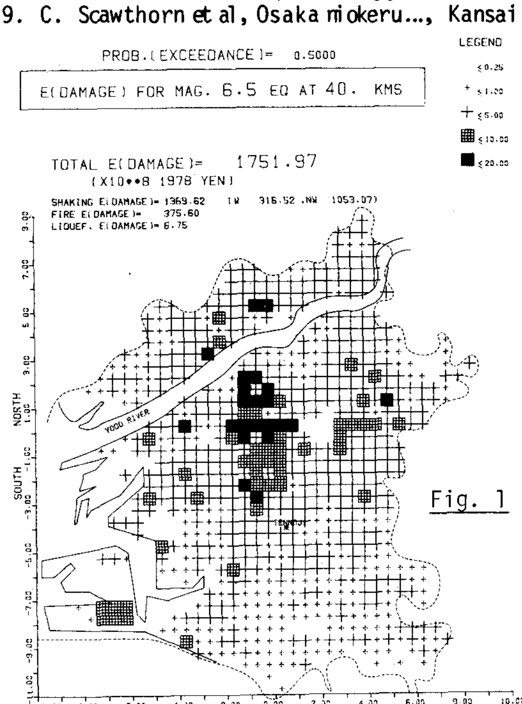

Fig. 1

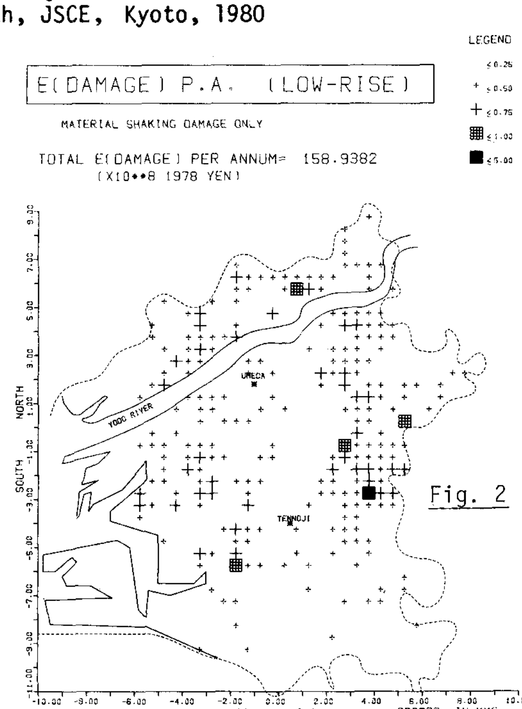

Fig. 2