Paper No. 1847. (quote when citing this article)
11 WCEE
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

THE EARTHQUAKES OF NORTHRIDGE 1994 AND KOBE 1995 - LESSONS FOR RISK ASSESSMENT AND LOSS PREVENTION WITH SPECIAL REFERENCE TO EARTHQUAKE INSURANCE

A. SMOLKA and E. RAUCH

Geoscience Research Group, Munich Reinsurance Company, D-80791 Munich, Germany

ABSTRACT

The earthquakes of Northridge/California 1994 and Kobe/Japan highlighted the vulnerability of modern cities to the effects of natural hazards. Both events have brought new, and sometimes surprising, findings, which can be summarized as follows:

. When determining risk factors for all parts of the world, greater importance must be given in future to the possibility of major conurbations being hit by earthquakes on unknown or seldom active fault lines in their immediate vicinity.

. Compared to previous assumptions, stronger ground motion, sometimes in the form of pulse-like motions, has to be expected in the near field. Accordingly, higher losses must also be expected, since current building codes make no allowance for such effects.

. The role of subsoil as a contributory factor for losses must be seen in a different light in future. Other loss factors can have an equally strong influence, at least in the near field. High losses can occur even with average subsoil conditions in the epicentral zones. The loss potential from liquefaction must always be assessed in conjunction with the countermeasures taken.

. Contrary to the belief up to now, steel frame constructions without diagonal bracing can no longer be regarded as especially earthquake-resistant. Base isolated buildings affected performed satisfactorily, but structures of this kind have yet to face a true test of strong shaking.

. Closer attention to damage to nonstructural elements and contents offers considerable potential for loss reduction which may has been underrated up to now.

. Indirect losses following earthquakes represent a high loss potential. Quantitative assessments are feasible, as a study on the Northridge quake has shown. A similar study on Kobe would be of invaluable worth for improving assessments of the very serious follow-on effects after earthquakes and other natural disasters.

Taking action against the trend to increased earthquake losses which has been so conspicuously demonstrated by the Kobe and Northridge earthquakes requires the cooperation of all affected parties in science, industry, non-governmental organizations and public authorities.

KEYWORDS

Kobe earthquake; Northridge earthquake; Earthquake losses; Risk assessment; Earthquake Insurance; Loss mitigation; Interdisciplinary cooperation

INTRODUCTION

Within the space of exactly one year, the Northridge and Kobe earthquakes hit two large cities in the world's two most important industrialized countries. These are the two most serious earthquakes in the industrialized world for many decades. They can be classed alongside the major urban earthquake catastrophes of this century, which include San Francisco in 1906, Tokyo in 1923 and Tangshan in 1976. The economic losses they caused have set new records and have given an idea of the loss potential that can be expected from earthquakes in the future in major cities like Tokyo, Osaka, San Francisco or Los Angeles.

Both events have brought new, and sometimes surprising, findings. These relate to seismological, geotechnical and engineering aspects, and to general economic loss effects. The intention of the present paper is not to give a detailed description of the two quakes, but to make a comparative assessment of the two events, to summarize the results and look at the implications for the assessment of the earthquake risk, particularly for large conurbations.

KOBE AND NORTHRIDGE - GENERAL DATA

Table 1 compares the key seismological data and loss data for the two earthquakes. The reason for the much higher loss in Kobe lies in the combination of seismological and inveentory-related loss factors. The sum of purely seismological factors is roughly equivalent. The magnitude of the Kobe quake was 0.2 points higher, with an energy release about twice as great, while Northridge probably had a more destructive focal mechanism (thrust fault). The principal reason for the difference in impact lies more in the inventory-related risk factors than in the hazard-related features of each event. The Northridge quake affected a well-spread suburban district, with a mixture of residential and commercial districts, but had no industrial plants of any great size. In Kobe, on the other hand, the entire urban area was hit, with a high concentration of population and buildings in the city centre, major industrial plants and a large port area. The following sections will categorize and examine various aspects of the two quakes.

Table 1. Basic data for the Northridge and Kobe earthquakes

	Northridge	Kobe
Seismological data:		
magnitude M_w	6.7	6.9
duration (in s)	ca. 15	ca.15
Maximum intensity MMI	IX	X
peak acceleration	0.93g[1)]	.83g[2)]
Loss data:		
death	61	6055
injured	10,500	27,000
homeless	25,000	310,000
heavily damaged buildings	15,000	210,000
total loss (US$)	>30 bn	> 100 bn
insured loss (US$)	12.5 bn	3 bn

1) without Tarzana record
2) largest unclipped record

SEISMOLOGICAL ASPECTS

Unknown or Seldom Active Faults

The Northridge quake occurred on a blind thrust, which had remained undetected until then. The location of the focus came as a complete surprise to seismologists, even though the region is one with high earthquake activity. The opposite was true for the type of quake, occurring as it did on a thrust fault. In the last few years, several hidden fault zones of this kind have been identified (Dolan et al., 1995), which have drastically altered the picture of the earthquake risk for the greater Los Angeles area. On the practical side, the quake has dramatically impressed the validity of this picture in the minds of public and private decision-makers, who may have tended to see it as a rather theoretical scenario.

Unlike Northridge, Kobe was an example of a quake on a known fault line, but one which was seldom active. To this extent, it cannot be classed as an unexpected event. In fact, the relevant section of the Rokko fault had already been classified as a higher risk zone by Matsuda (1981), but nevertheless the actual efforts in earthquake prediction research in Japan had been focussed on other areas.

The message from both events is simple: the expression "worst case" is no theoretical abstraction, but something which can become a reality at any time and anywhere in the world. Since its foundation, more than 1,000 years ago, Kobe had never been hit by such a devastating earthquake as that of 17th January 1995. And if there are unknown faults in such an intensively studied area as Los Angeles, then it is certain that there are many further unidentified faults in other regions of the world which are not so well observed. The possibility of earthquakes on unknown or seldom active faults must therefore be taken as a basic risk assessment factor when making planning decisions.

Stress Drop

The greater the stress drop in an earthquake, the greater the ground motion should be. The high stress drop in the case of the Northridge quake (100 - 200 bar), in conjunction with the thrust fault mechanism of the earthquake source, is widely seen as the reason for the unusually high ground accelerations, which were well above average for Californian earthquakes (Celebi, 1995). On the other hand, first evaluations of the Kobe records show a similarly high stress drop, despite its horizontal source mechanism. For risk analysis purposes, the stress drop is currently difficult to estimate in advance for particular events (also in defining earthquake scenarios), although regional differences have been described (e.g. Atkinson and Hanks, 1995). A systematic study of the relationship between stress drop and source mechanism on the one hand and between stress drop and ground motion (and eventually damage) on the other hand would be an interesting undertaking in this context.

Near Field Effects

This section addresses two phenomena: Firstly, what is termed "fault fling", which refers to one or several velocity pulses which can occur in the immediate epicentral area perpendicular to the propagation direction of the earthquake rupture. This effect is produced by the interaction between the rupture front and the propagating shock waves (Naeim, 1995). The accompanying energy pulse is particularly damaging for higher structures. This feature, together with structural deficiencies, has been seen as the reason for the unexpectedly high level of damage to steel-frame constructions in Northridge (see below). There are also ground motion records for Kobe which indicate that "fault fling" may have played a role there too. Current regulations for earthquake-resistant building make no allowance for this phenomenon, despite the fact that it has been known since the San Fernando earthquake in 1971. In consequence, introducing a "near field factor" into the building regulations is now being seriously considered in the USA. Secondly, there is the strength of vertical acceleration. An analysis of the records for Northridge and Kobe reveals that vertical ground acceleration in close proximity to the focus tended to achieve similar or even higher values than horizontal acceleration (Toki, 1995, and EQE & OES, 1995). For an earthquake with predominantly horizontal displacement as observed in Kobe, this may seem surprising. In this case once again, current building regulations make no allowance for the possibility of such high vertical acceleration occurring. However, before regulations are amended in the light of this observation, it must first be determined whether the high accelerations which were observed in the near field are caused by special circumstances or, in fact, typical. Furthermore, and even more improtant, it must be established to what extent structures are sensitive to vertical accelerations at all, which is a contentious issue.

GEOTECHNICAL ASPECTS

Subsoil Conditions

One of the chief lessons learnt from the Northridge earthquake is that very high losses can occur in the epicentral area, even if the subsoil conditions as indicated by surface geology are not specially poor. This does not dispute the negative effects of poor subsoil conditions, which have been amply documented by other earthquakes. Regional loss concentrations, such as in Sherman Oaks or Santa Monica, however, suggest that factors other than subsoil conditions were to blame for the high level of losses in particular areas. Loster & Smolka (1995) indicate that such factors would include, for example, surface topography (focusing of the shock waves at the crests of hills), basement topography (basin edge effect, caused by constructive interference between direct and reflected shock waves) and construction related features (topography changes in hillside construction).

The loss pattern in Kobe also deviates from the classic picture of the influence of subsoil conditions. A particularly noticeable feature in Kobe was the narrow band of major losses along the central axis of the city (Kameda, 1995). From prior experience, it might have been assumed that earthquake losses on the man-made islands and in other landfill areas close to the shore would be more severe than in the areas of natural sediment on which most of the city is built. However, while it is certainly true that liquefaction occurred over wide areas of man-made land the extent of losses was limited by the use of deep-pile foundations, see below. Construction features were probably a decisive factor in producing the "loss band" along the city centre. Most of the weaker structures were located in this zone. It may therefore be argued that construction-related factors outweighed the influence of the subsoil in this case.

To sum up, it can be said that the influence of subsoil conditions, which has been such a major factor in past earthquake disasters, played a somewhat ambiguous role in the two most outstanding earthquakes in recent decades. Instead, however, the importance of other loss factors was more clearly underlined, factors which, up to now, have not been paid the attention they perhaps deserve. The specific role of each of these factors has still to be analysed, but their relevance for loss estimates for future earthquake catastrophes should not be underestimated.

Liquefaction

The Northridge and Kobe earthquakes have each provided rather different insights into this phenomenon, whose loss potential was first illustrated in spectacular fashion by the Niigata quake in Japan in 1964. In Northridge, the degree of liquefaction which occurred was much less than exposure maps for the area would have led one to expect. Since, from a seismological point of view, the conditions for liquefaction had been met, this means that current geotechnical parameters for assessing the liquefaction risk are in need of improvement . A comprehensive evaluation of the various options has been given by Glaser & Chung, 1995. In Kobe, on the other hand, the pattern was as expected: there was widespread liquefaction within the large area of artificial landfills. What was interesting in this regard, however, was that the loss extent of the structures affected was less than expected. Thanks to the use of pile foundations for the buildings, which had been driven to a stable subsoil depth of more than 20 metres, losses were well contained. This represents an impressive success for engineering prevention measures. Taken as a whole, observations from the two earthquakes suggest that both the liquefaction hazard itself, and the resulting loss risk may need to be revised in many regions.

ENGINEERING ASPECTS

Building Regulations and Earthquake Losses

In Kobe, there was a much closer relationship between the loss pattern and the age of the structures involved than in almost any previous earthquake. Two key dates in this regard for Japan are the years 1971 and 1981. In the latter year, the principle of ductility was introduced in the Japanese earthquake code. Many of the older buildings of medium height in the business centre of Kobe reacted with brittle fractures, resulting in sections or sometimes entire floors of the buildings collapsing. Older buildings in the Kansai district were designed, on average, to withstand 20% of the gravitational acceleration. The values measured in Kobe exceeded the original design values by up to 400%. The geographical distribution of losses indicates that, in line with the situation described above, in places (such as Osaka) where the design values were not, or only marginally, exceeded, even older structures performed satisfactorily. The divergence between the behaviour of old and more modern structures was only noticeable in cases where the design specifications had been exceeded by a clear margin.

The relatively minor damage suffered by modern structures which were erected after the revised building code was introduced in 1981 has demonstrated that it is possible to design earthquake-resistant buildings after all, despite the many adverse accompanying factors described above. Needless to say, a precondition for this is that the regulations are adhered to in practice. This can vary from one country to another and is the main reason why, in previous earthquakes, the relation between the age of the structures and losses has not been as noticeable. However, it is worth stating in this context that modern structures still represent a high risk of monetary loss as long as safety of collapse is the only design criterion, i.e. no loss control features are considered in the code.

On the other hand, the earthquakes in Kobe and Northridge have once again demonstrated, this time very forcibly, that a major problem lies in the behaviour of older structures which no longer conform to revised building codes. This factor is of crucial importance in precisely those countries with advanced seismology and technology. In such countries, the main goal of earthquake-resistant construction - to safeguard human lives - has to a large extent already been achieved, see above. The continuing high death risk and the enormous financial losses resulting from the destruction of older buildings make it imperative that increased efforts are made to protect such structures from the effects of earthquakes (and other natural hazards). In this context, projects such as that in Los Angeles, with the aim of identifying URM (unreinforced masonry) structures and ,then, rehabilitating or replacing them, have set a good example and, in the Northridge example, indeed, have already paid dividends.

Nonstructural Damage

The Northridge quake also focused attention on a further important source of financial losses, namely losses to building contents or to nonstructural building components. The latter include components which form parts of a building, or completely detached side structures such as free-standing garages, swimming pools, driveways, and walls around a property. A remarkable feature in this context was damage by sprinkler systems which ranged from the destruction of suspended ceilings, to water damage after the system was accidentally activated by the earthquake motion. Damage to the appurtenant structures mentioned above contributed 20-25% of the total residential insured losses. In addition to this, there were the nonstructural components in the buildings themselves. A rough estimate shows that in the worst affected area, for every building with structural damage, there were at least twelve, and in some areas as many as 40 examples of nonstructural damage (EERI, ed. 1995). In more distant areas, the proportion shifts even more to nonstructural damage. It can, therefore, be assumed that structural losses, which building codes are primarily designed to prevent, contributed no more than 10-15% of the total building losses in the Northridge quake. In Kobe, the percentage would probably have been higher because of the higher percentage of older buildings. Nevertheless, there is no doubt that addressing the nonstructural issue represents a very cost-effective measure to prevent or reduce earthquake losses.

Moment-resisting Steel Frames

Northridge, however, also shed new light on structural losses. Long-tail losses are generally more familiar in the field of environmental risks, but Northridge produced a further variation, albeit with not quite such a long tail: the discovery, weeks to months after the earthquake, of structural damage to moment-resisting steel frame structures. The problem which emerged in Northridge - damage close to weld joints in the connections between horizontal and vertical supports, and even total shearing of vertical columns - does not affect every steel frame structure, but only moment-resisting steel frames which have no diagonal braces. There was extensive damage to steel frame structures in Kobe too, though the loss pattern is more variable on account of the wider range of steel frame structures affected.

The damage observed with steel constructions is a worldwide problem, rather than a specifically American or Japanese one. Regional differences in welding technology may be a factor in the case of losses to steel frame structures. For the present, however, it appears inadvisable to class steel frame structures as less susceptible to earthquake damage than reinforced concrete ones.

Base Isolated Buildings

The example of one building, situated 30 km from the epicentre of the Northridge quake, shows that the intended result - to reduce ground motion by means of damping elements before they begin to affect the building - was achieved. However, no conclusions can be drawn from this on how such buildings would behave closer to the epicentre of a stronger earthquake. Computer models show that in such cases there is a danger of the building crashing against the foundation walls, resulting in serious damage (Heaton et al., 1995). Kobe provided no examples of base isolated buildings. The extremely high accelerations there would certainly have served as a conclusive test for the behaviour of such structures.

INFRASTRUCTURE AND INDIRECT LOSSES

The Northridge quake already provided ample evidence of how susceptible the infrastructure of large modern cities can be. In this case, the breakdown of the road transport system led to serious disruption lasting up to several months for commuter and goods transport. A study carried out by the University of Southern California estimates the figure for losses resulting from damage to other infrastructure systems (power, gas and water supply), and from direct damage to production centres, as being in the region of US $ 6 billion (Gordon & Richardson, 1995). This is the equivalent of about 20% of the actual property losses.

The Kobe quake provided an even more graphic confirmation of the lessons of Northridge, both in terms of the effect on the city itself, and in terms of the repercussions for the surrounding economic area and the rest of the country. In contrast to Northridge, it was the centre of a major city, not a suburban area, which was hit by the quake. On top of this, the city was the site of the largest container harbour in Japan. The port of Kobe is of crucial importance for the economic life of this city of 1.5 million people, and it was hit with devastating effect by the earthquake. Full reconstruction is projected to be finished in 1997 only. Only time will tell if the port of Kobe will ever regain the position of strategic economic importance which it held in Japan and the Far East region before the earthquake. Furthermore, major transport links connecting central Japan with the west of the country were so badly damaged that their repair took several months, e.g. the Shinkansen railway line. Repairing the Hanshin expressway will even take two years. There was a complete breakdown in the local transport systems lasting several days, and work to fully reconnect the commuter train link between the heavily damaged city centre (Sannomiya) and the rest of the dense rail network went on for several weeks. Telephone connections and power supply were reestablished within a relatively short space of time (roughly 2 weeks). Area-wide reestablishment of water and gas supplies, on the other hand, took between a few weeks and several months.

The serious disruption to transport systems and infrastructure make the Kobe quake a text book example of indirect losses through loss of production and delivery problems. The "just-in-time" delivery system was affected in various industrial sectors. The impact was particularly hard in the automotive industry because of losses at two large steel producers. However, after only three weeks, the companies concerned were able to announce "business as usual". Apart from the loss suffered by one of the mentioned steel producers - the highest earthquake loss ever recorded in an industrial plant, amounting to US$ 1.3bn - the most serious loss occurred probably in a factory producing high-resolution screens for portable computers. Here, there was a break in production lasting several weeks, which in turn affected as many as five major computer manufacturers around the world. An investigation of indirect losses along the lines of the Northridge study mentioned above would be extremely valuable for refining estimates of indirect losses from earthquakes and other natural disasters worldwide.

INSURANCE ASPECTS

Northridge in particular, brought some surprising aspects to light, which refer to the insured loss potential of natural disasters and to the efficiency of measures to limit this loss potential. With US $ 12.5 bn the insured loss amount covered 30-40% of total losses and was by a factor of 6-7 higher than had been expected on the basis of estimates of loss modelling software made directly after the event.

Deductibles, coinsurance, liability limits

Self-participation of the insured party in the loss is acommon insurance instrument aimed mainly at reducing the loss in catastrophic events. There are various forms of self-participation: deductibles (flat amount or percentage of the sum insured), coinsurance (fixed percentage of the loss) and liability limits (setting a ceiling to the loss in percent of the sum insured).

In Northridge, the nominally large deductibles, usually 10% for residential buildings, turned out to be less effective than expected, mainly due to widespread underinsurance and the failure of policy conditions to adequately address the questions of rehabilitating seismically damaged buildings and upgrading them to actual code provisions. On the one hand, underinsurance reduces the real percentage value of the deductible, i.e. in relation to the full value of the object. On the other hand, it does not seem to have received very much attention in the process of claims adjustment. It is not easy to judge to what extent this observation could be transferred to other countries. The experience gained in Mexico in 1985, for instance, was different. The problem may, in fact, be only a question of quantities, with well over 300,000 (mainly housing) losses in Northridge compared with 10,000 in Mexico. This means that, as the number of claims increases, the tendency may be to adopt a more liberal approach towards settling them. For pragmatic reasons, one should be more cautious in the evaluation of the effect of deductibles in those areas where residential buildings represent a significant part of the insured values.

Widespread use is made in the United States of liability limits on individual risks. As might be expected in theory, Northridge showed that these limits are not capable of reducing the claims burden because the majority of individual losses are only partial losses and are generally below these limits.
One certain way of restricting the claims burden, however, is a percentage coinsurance, as the example of Kobe - albeit an extreme case with 70% coinsurance in the industrial sector - clearly demonstrates. Of all the types of self-participation mentioned above, coinsurance is obviously the most effective means of loss avoidance and loss prevention. This is because it is only when the self-participation increases proportionally to the loss incurred that the policyholder is really interested in limiting the extent of the loss. Deductibles,

which in theory are similarly effective, can all too easily be circumvented or rendered less effective by, for example, bills that are fictitious or too high, especially in major catastrophes where there is a large number of individual claims. Nevertheless, from the insurer's point of view they are without doubt a good way of eliminating minor losses.

Scope of cover

As mentioned above, 20% - 25% of residential building claims in Northridge stemmed from the cover of outside facilities not directly connected with the buildings themselves (garages, swimming pools, entrance gates, surrounding walls, driveways, etc.). Insurers were generally aware of the scope of this cover in principle, but the large loss potential it involves was not largely recognized before Northridge. Similar considerations apply to the loss potential arising from the coverages of Earthquake Sprinkler Leakage and of Additional Living Expenses (for loss of use of damaged buildings). The general, and since Northridge very clear lesson to be learnt from this is that close attention must be paid to the exact scope of cover in the processes of underwriting and accumulation assessment.

Industrial losses

A definitive assessment of the losses in this sectoris neither possible for Northridge nor for Kobe due to the unavailability of sufficiently detailed documentation. In line with what we had assumed prior to these events, the overriding impression gained so far is that industrial risks, in spite of their higher average loss, were less severely affected than residential buildings and the services sector. A few spectacular individual losses, e.g. that of a hi-fi producer in Northridge and of a large steel company in Kobe, show that the loss variance is considerable in the field of industrial risks. This must be duly taken into account when assessing PMLs for one specific plant.

Earthquake losses in other insurance lines

Non-property insurance lines and lines covering movable property account for about 7% of the overall insured loss recorded in Northridge, with Marine contributing more than 6% and Motor a further 0.65%. The corresponding figure for Kobe is 16%. In this case, the largest share stems from life insurance, but this is a particularly Japanese phenomenon, first because of the high spread of life insurance, and second because of the strict limitations to earthquake property coverage in Japan, which shift the proportion of insured values evn more to other insurance lines. Nevertheless, both events confirm a tendency for non-building related losses to gain importance with the size of a disaster as shown earlier by model calculations for California (Friedman, 1987).

CONCLUSIONS

Northridge and Kobe have shown that earthquake disasters are by no means simply a third world problem. There, the dominating factor is the high death toll. Highly developed countries have achieved a much better standard in terms of life safety, although the Kobe earthquake is a warning sign that the standard may be not as high as one may have assumed before. But here an additional and serious problem is the enormous financial loss potential from earthquakes striking conurbations such as Tokyo, Osaka or Los Angeles as directly as happened in Kobe. A recently released estimate indicates a loss potential of up to US$ 1,800 bn for a large Tokyo earthquake (RMS, 1994). Concerted efforts to avoid future losses through loss prevention and loss minimizing measures in every category are essential in order to protect such areas and their economically dependent hinterlands from serious setbacks. In order to maximize the results of such efforts, a „risk partnership“ of all affected parties in the public and private sector is called for. Some key features of this partnership and the specific role played by the insurance industry are set out below.

Taking action against the alarming trend to increased disaster losses which has been strikingly demonstrated by the Northridge and Kobe earthquakes affects all elements of the risk management process. These elements are risk identification, risk evaluation, risk control and risk financing. Beyond its obvious role in financing the risk the insurance industry can make valuable contributions in the fields of risk evaluation and risk control. In respect of risk control insurance measures can be used to motivate the policyholder in favour of loss prevention. Such measures start with the introduction of a substantial self-participation of the insured in the loss which can be partially circumvented by investing in loss mitigation, and which in addition is rewarded by an equally substantial premium rebate. In cases of extreme risk situations the complete denial of coverage can act as an effective tool to force state and local authorities to formulate and, above all, enforce land use and building regulations in such areas. Aside of their prime role in providing the legislative regulatory framework the public authorities can create their own incentives to loss mitigation. Such incentives would be tax reliefs, on an individual level in order to promote loss mitigation, and in the industry in order to facilitate the accumulation of special reserves for the compensation of future disaster losses, or direct funding of loss mitigation programmes. Finally, authorities and insurance should cooperate in educating the public to increase its risk awareness.

As regards risk evaluation the potential contribution of the insurance industry lies in the data on previous loss experience. This data source has so far not been tapped to the extent possible by the scientific community which is partially due to simple communication problems (Loster & Smolka, 1995). The analysis of actual losses occurred, insured or not insured, is of prime importance for the efficient formulation of loss mitigation strategies. Therefore this paper concludes with an urgent plea to concentrate all efforts on securing and evaluating the extremely valuable statistical loss information produced by the two most important earthquake disasters of the last decades according to the guidelines set out in the foregoing sections.

BIBLIOGRAPHY

Atkinson,G.M. and T.C.Hanks (1995). A High-Frequency Magnitude Scale. *Bull.Seism.Soc.Am.*, **85,3**, 825-833

Celebi,M.(1995). Northridge (California) Earthquake of January 17,1995: Unique Recorded Ground and Structural Response Motions. *Workshop on Implications for the Future for the Financial and Scientific Sectors after the Northridge Earthquake, San Francisco, February 6-8,1995*

Dolan,J.F.,Sieh,K.,Rockwell,T.K.,Yeats,R.S.,Shaw,J.,Suppe,J.,Huftile,G.J. and E.M.Gath (1995). Prospects for Larger or More Frequent Earthquakes in the Los Angeles Metropolitan Region. *Science*,**267**, 199-205

Earthquake Engineering Research Institute (ed.1995). Northridge Earthquake Reconnaissance Report,vol.1. *Earthquake Spectra*, **suppl.C vol.11**

EQE International and California Office of Emergency Services (1995). *The Northridge Earthquake of January 17,1994: Report of Data Collection and Analysis*

Friedman,D.G.(1988). *Earthquake Losses Under Workers Compensation and General Liability*. AIRAC, Oak Brook.

Glaser,S.D. and R.M.Chung (1995). Estimation of Liquefaction Potential by In Situ Methods. *Earthquake Spectra*,**11,3**, 431-455

Gordon,P. and H.W.Richardson (1995). *The Business Interruption Effects of the Northridge Earthquake*. Lusk Center Research Institute, University of Southern California, Los Angeles

Heaton,T.H., Hall,J.F., Wald,D.J. and M.H.Halling (1995). Response of High-Rise and Base-Isolated Buildings to a Hypothetical M_w 7.0 Blind Thrust Earthquake. *Science*,**267**, 206-211

Kameda, H.(1995). An Overall View of the Great Hanshin Earthquake Disaster - The Hyogoken-nanbu Earthquake. *Proceedings Workshop World Seismic Safety Initiative on Catastrophic Risk Management, Singapore, May 16-18,1995*

Loster,T. and A.Smolka (1995). GIS: A Tool for Loss Estimation and Scenario Development in the Insurance Industry. *Proceedings 5th International Conference on Seismic Zonation, Nice, Oct 17-19, 1995,vol.1*,pp.290-297

Matsuda,T.(1981). Active Faults and Damaging Earthquakes in Japan - Macroseismic Zoning and Precaution Fault Zones. In: *Earthquake Prediction - An International Review. Maurice Ewing Series Nr.4*, pp.279-289. American Geophysical Union, Washington D.C..

Naeim,F.(1995). On Seismic Design Implications of the 1994 Northridge Earthquake Records. *Earthquake Spectra*,**11,1**, 91-110

Risk Management Solutions (1994). Just How Big is the Big One? Cited in: *dyp Catastrophe Reinsurance Newsletter*, **19**, 173

Toki, K.(1995): Fault Parameters and Strong Ground Motions of the Hyogoken-nanbu Earthquake. *Proceedings Workshop World Seismic Safety Initiative on Catastrophic Risk Management, Singapore, May 16-18,1995*