9 米国の識者の所感

都市に起こった大震災ということで、この地震に対しては諸外国からの反響も大きい。当社ではかねてからCUREe（カリフォルニア州で地震工学の講座を有する大学の連合組織）を介して米国の著名な教授や技師と共同研究を実施中であるが、このうち主として今回の地震のために来日した方に、本報告書のために率直な感想をお寄せくださるように依頼した。以下到着順に紹介する。

9.1 スタンフォード大学　シャー教授

シャー教授は1937年インド生れ。1962年にスタンフォード大学で学位を取得後、一貫して同大学で教鞭をとり、主として地震防災の立場から多方面に活躍している。同教授は、防災技術の成果が、急速な都市化や人口集中に必ずしも適切に取り入れられて来なかったことを指摘し、米国のロマ・プリータ地震やノースリッジ地震はおろか、兵庫県南部地震さえも凌駕するような大地震がさらに発生することを想定せよと警告している。

A Clear Message

The Great Hanshin Earthquake has sent a clear message to the world. For over 20 years, emergency planners, engineers, and risk managers from all industries have been preparing themselves and their constituents for the consequences of a major urban catastrophe. Their efforts have primarily been driven by extrapolation from a historical perspective of the great earthquakes of 1906 in San Francisco, 1923 in Tokyo (Kanto), and even the 1811-1812 earthquake in the New Madrid region in the U.S. Midwest.

However, many decision-makers have discounted pessimistic projections of disaster, citing significant advances in building practices, codes and emergency preparedness. While building technology and emergency preparedness techniques have improved dramatically such advances have not kept pace with the rapid urbanization and increasing concentrations of population and infrastructure in high risk areas. As Japan has discovered, the implementation of building codes does not address the problem of an aging inventory of existing buildings that fail current design standards.

The generally manageable impacts of recent California earthquakes have fostered a passive attitude in certain circles. Many people have mistakenly treated the recent 1989 Loma Prieta and 1994 Northridge earthquakes as the ﾒBig Ones.ﾓ While these losses were significant in both economic and human terms, they pale in comparison to what has happened In Kobe. It is only a matter of time before a truly great earthquake strikes an even more vulnerable area, and when it happens, the loss and devastation will exceed that in Kobe.

The Great Hanshin Earthquake is a wake-up call for cities in regions with low-to-moderate seismic risk. Areas such as the New Madrid seismic region in the U.S. Midwest, the Seattle and Vancouver areas in the Pacific Northwest, and Salt Lake City, must take heed. While the probability of a major earthquake may be low the consequences of such an event are not. In fact, lower levels of preparedness accompanied by less stringent seismic codes and construction practices, will exacerbate the risk of disaster. The world continues to develop, urbanize, and grow increasingly interdependent, making natural catastrophe risk an ever growing threat. Risk management strategies must be developed at all levels to mitigate potential losses. For the foreseeable future, older construction,predating seismic codes, will represent a significant portion of the building inventory i even the most technologically advanced regions. Accordingly governments and property owners must take action to retrofit suspect structures, while continuing to improve both seismic codes and construction practices.

Companies must also acknowledge the disruptions catastrophes can have on their operations and develop meaningful contingency plans to minimize business interruption losses following an event. Governments witnessing the emergency response and search and rescue efforts in Kobe, must strive to develop more efficient, adaptable plans. And finally, financially, insurance and reinsurance institutions must seek to improve their management of natural hazard risk through portfolio diversification, underwriting, and loss control.

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9.2 カリフォルニア大学バークレー校（UCB） ベルテロ名誉教授

ベルテロ教授はアルゼンチンに生れ、1947年ロザリオ大学卒業後、1957年にマサチューセッツ工科大学で学位を取得。その後UCBにて教鞭をとり、現在に至る。専門は地震工学で、世銀やユネスコの顧問を務める等多方面に活躍。同教授は、阪神地域の被災状況を詳細に観察・分析した上で、日本のみならず世界各国における地震被害低減のため、都市域の土木構造物の経済的な補修・改良技術の開発と実施が急務であると提言している。

THE GREAT 1995 HANSHIN EARTHQUAKE: SUMMARY OF IMPRESSIONS FROM A FIELD SURVEY OF BUILDING PERFORMANCE

- This is the largest natural disaster that I have inspected.
- Most of the losses (life and property) were caused by failure of civil engineering facilities.
- The recorded EQGMs show horizontal PGA and PGV up to 0.83g and 138 cm/sec, respectively, which are significantly higher than those considered in present code regulations for earthquake-resistant design, as well as those that are being considered in the formulations of a new performance-based earthquake-resistant design Japanese building code: the PGA of the vertical component reached values up to 0.44g and in some cases they were larger than the measured horizontal PGA even up to a considerable distance from the fault rupture.
- The duration of the strong part of the EQGMs was surprisingly low for an earthquake of M = 7.2, but it contains acceleration pulses with not only high intensity but also long duration with the consequent high damage potential (high energy input).
- The orbital plots of the recorded displacement at stations near the fault show that the principal motions occurred perpendicular to the direction of the fault rupture.
- The Hanshin EQ destroyed or damaged severely a large percentage of the built infrastructure throughout the Kobe area.
- Over 107,000 buildings were rendered useless, leaving more than 310,000 people homeless.
- One third of the major hospitals were rendered inoperable.
- Many fires broke out, wiping out large densely populated areas.
- Lifelines (electricity, gas, water, telephones) were damaged over a very large area.
- Transportation systems (highways, railroad tracks) and harbor facilities suffered tremendous damage.
- It can take years to rebuild the major infrastructure of the transportation system.
- The contrast in degree of damaged buildings built on the flat soft-soil area and of those located on the harder area in the foothill slopes of the mountains is a main feature of the EQ. Several factors contributed to this contrast.
- In the flat area there are (blocks) in which the ratios of destroyed houses near the seashore reached values close to 70%, which is considerably higher than anything that has been recorded since the 1923 Kanto EQ. This high density of houses destroyed is another main feature of this EQ.

· A very distinctive pattern of failure of the housing and engineered buildings was a tendency to lateral displacement toward the mountain (i.e., toward the N). Therefore, most of the comer houses or houses facing north collapsed onto the sidewalks or even over the street. Many of those that collapsed were restrained from covering the street by trees and poles for electric wires along the edges of the sidewalks.

· The damage observed in the residential dwellings due to this Hanshin EQ points out clearly the urgent need for seismic retrofitting (upgrading) of these dwellings throughout Japan. This need is perhaps the most pressing problem that this EQ has brought before the Japanese government: research is urgently needed to find technically and economically efficient retrofitting techniques.

· This EQ confirms again that the most pressing problem for the reduction of seismic risk in urban areas, not only in Japan, but around the world, is to develop and implement in the field technically and economically efficient retrofitting techniques for the huge inventory of seismically dangerous civil engineering facilities that exist in our urban areas. This in one area in which researchers and engineers around the world can and should work together in order to mitigate the EQ hazards.

· Regarding engineered buildings, there is a striking contrast between the performance of buildings that were built after 1981 and those that were built before 1971. Most of the buildings designed and constructed after 1981 did not suffer structural damage that could be considered a threat to life safety: most of the buildings that collapsed or suffered severe damage were built before 1971.

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9.3 カリフォルニア工科大学　アイワン教授

アイワン教授は1935年カリフォルニア工科大学（CalTech）の地元パサデナの生れ。同大学で学位を取得後、現在まで30年間地震工学の幅広い分野で活躍。CUREeを提唱し初代の会長を務めている。強震観測網の整備や防災政策の確立に努めている同教授は今般の震災について、既存建物の補修の重要性、およびこれまで軽視されていた直下型地震の危険性を強調した上で、社会の耐震安全性の確保が、兵庫県南部地震とその被害が訴えるところの、難題ではあるが成功裡に解決せねばならない課題であると結論している。

OBSERVATIONS ON THE GREAT HANSHIN EARTHQUAKE

The occurrence of the Great Hanshin earthquake on the anniversary of the Northridge earthquake has given us another reminder of our awesome responsibility in mitigating the effects of earthquakes. The human suffering and economic loss associated with these events has reinforced the need for a higher level of commitment to improving the seismic safety not only of new construction but also of existing buildings and other structures.

Based on observations from the Great Hanshin and Northridge earthquakes, it is evident that significant strides have been made in the seismic design of buildings, bridges, and other structures since the late 1970's. Many of the most effective design improvements were motivated by observations from past earthquakes. No doubt, experience gained from the Great Hanshin earthquake will also lead to improvements in seismic design. However, it is unlikely that these improvements will be as revolutionary as those brought about by some previous earthquakes. In general, modern structures appear to have performed well in the Great Hanshin earthquake. The most serious problems seem to have been related to the performance of structures constructed to older seismic standards.

Both the Great Hanshin and Northridge earthquakes have made it clear that one of the most pressing problems faced by owners, engineers, and public officials is what to do about existing potentially hazardous structures. Many older structures in our communities are hazardous due to either inadequate design or poor quality of construction. These high risk structures need to be identified and economical measures need to be found to reduce the risk to an acceptable level. These are not easy problems to solve.

Certain classes of structures are known to be potentially hazardous. However, the degree of risk associated with a particular structure can vary greatly depending on many factors. It is not a simple matter to quantify the seismic risk of a given structure. We need to develop improved techniques to make such risk assessments.

Once the risk of an existing structure has been assessed, it is often a more difficult challenge to develop a strategy to reduce this risk to an acceptable level. There are serious issues of public policy which need to be resolved as well as the technical engineering issues. Public policy issues include the designation of publicly acceptable levels of risk, and the establishment of responsibilities of owners, engineers, and public officials in achieving these levels of risk. Then, there are the equally difficult issues of devising economic retrofit techniques which will meet the target levels of risk, Much research remains to be done to resolve this important set of issues.

Another important issue that has arisen from the Great Hanshin and Northridge earthquakes is the nature of near-field ground motions and their effects on structures. In the past, seismic designs have been largely based on far-field measurements of earthquake ground motions. In the Landers earthquake and again in the Northridge earthquake, we observed a different type of ground motion within the near-field (or near-source) region. In this region, the ground motion was characterized by high peak ground velocities and a pulse-like wave form. This type of ground motion can have serious effects on certain types of structures. These effects have been mostly ignored in the past.

It is suspected, although not yet confirmed by measured data, that near-field type ground motions may have been present in the Great Hanshin earthquake within approximately 5 km of the surface projection of the fault rupture plane. These motions may have contributed to the observed patterns of damage. This is an important area of research which needs to be vigorously pursued.

In conclusion, the Great Hanshin Earthquake is a dramatic call for us to increase our efforts to reduce the earthquake threat to society to an acceptable level. The task before us is not an easy one, but the need is great. We must succeed.

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9.4 カリフォルニア工科大学　ベック助教授

ベック助教授はニュージーランドに生れ、1979年に同大学で学位を取得。1981年から同大学にて教鞭をとり、現在に至る。最適設計、地震応答のシステム同定、確率論の応用から制震に至るまで、地震工学および構造力学の分野で活躍。同助教授は今般の地震とノースリッジ地震の共通点として、直下型地震故の高い地表速度の破壊ポテンシャルに着目している。また、日本の鋼構造は接合部設計の優秀さ故良い挙動を示した事実を指摘しつつ、無補強の住宅の脆弱さが多数の人命の損失の一因であるとしている。

COMMENTS ON THE GREAT HANSHIN EARTHQUAKE

The Great Hanshin earthquake was not an unusually large earthquake for Japan, but it was a severe disaster because, for the first time in many decades, a major earthquake produced fault rupture directly below a heavily urbanized area of Japan. Earthquake engineers and researchers can draw solace, however, from the evidence that modern buildings performed well, showing that their efforts in improving the earthquake-resistant design of structures prevented an even greater calamity.

It was a remarkable coincidence that the most disastrous earthquake to hit Japan for many decades occurred on the first anniversary of the Northridge earthquake, the most disastrous to hit the USA for many decades. It is natural to draw comparisons between these two severe events.

First, strong motion records from both earthquakes demonstrate that exceedingly strong ground motion velocities can occur in the near-field region of a major earthquake in the direction of the fault rupture. One instrument in Kobe went off-scale at 100 cm/sec, while in the Northridge earthquake, several accelerographs produced ground velocities exceeding this level, with the largest peak of 180 cm/sec occurring at the Rinaldi station. These large velocity pulses, which were anticipated earlier by seismologists on the basis of new source mechanism models and directivity effects, present a major challenge to earthquake engineers. The damaging potential of these near-field pulses was recently demonstrated for tall steel buildings and base-isolated buildings, in a joint study by Caltech earthquake engineers and seismologists [1].

Second, both earthquakes reinforce the lesson that has emerged time after time, that non-ductile structures, even those of high strength, pose a threat to society in seismically active areas. Although commendable efforts have been made by the City of Los Angeles to establish policies which ensure that pre-code unreinforced masonry buildings are seismically upgraded or replaced, much less has been done to tackle the problem of the numerous nonductile reinforced concrete buildings designed under earlier seismic codes. Many buildings, and some bridges, of this type suffered structural damage, and even collapse, in the Northridge and Hanshin earthquakes. The issue of how to promote seismic upgrading of nonductile structures merits serious attention in both the USA and Japan.

Third, both earthquakes demonstrated the vulnerability of even modern highway bridges to damage at their expansion joints when subject to severe ground shaking. Further research, and perhaps new approaches, are needed to eliminate this weakness.

Finally, the evidence we have seen so far suggests that the different practice in Japan compared with the USA in the design of steel connections produced better behavior of steel-frame buildings in the Hanshin earthquake than during the Northridge earthquake. On the other hand, non-engineered residential buildings in Kobe proved to be more vulnerable than typical residential buildings in California, which is a major factor accounting for the greater loss of life in the Hanshin earthquake.

The generosity of our Japanese colleagues in the construction companies and the universities in providing valuable data and in assisting our field investigation team in the Hanshin area is gratefully acknowledged. The rapid appearance of detailed engineering reports on the Great Hanshin earthquake [2], supplemented by English versions [3], and the early release of strong-motion records [4], are particularly appreciated by researchers in the USA.

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9.5 スタンフォード大学　キレミジアン教授

キレミジアン教授はコロンビア大学卒業後、スタンフォード大学で学位を取得。その後同大学で教鞭を執り、現在はJohn A. Blume地震工学研究所の所長。同教授の担当分野は地震工学、構造解析、確率論的方法、および構造信頼性。ASCEやEERIを初めとする多くの団体に関与し幅広く活躍している。

IMPLICATIONS OF THE GREAT HANSHIN EARTHQUAKE OF JANUARY 17, 1995

As the dust slowly settles from the January 17, 1995 earthquake that devastated the city of Kobe, and the effort to return to normalcy begin, it is time to reflect on the earthquake, its characteristics and the lessons learned from the disaster. While earthquakes occur on annual basis with at least one great ($M \geq 8.0$) event somewhere in the world, it has been primarily in the past several years that significant earthquakes ($Mo \geq 6.5$) have occurred in the vicinity or right in the heart of major metropolitan areas providing valuable information. This article examines some of the characteristics of the event and its aftermath and offers some thoughts on approaches for solutions to the problems revealed by the earthquake.

The Hyogo-Ken Nanbu earthquake of January 17, 1995 (origin time 05:46:53.9, JST) has been located by the Japan Meteorological Agency at 34.60° N AND 136.00° E at a depth of 22 km and with a MJA magnitude of $M_J = 7.2$ (Kanamori, 1995). The mechanism of the earthquake is found to be almost a pure strike-slip with several estimates of seismic moments ranging from 1.8 to 3.1×10^{26} dyne-cm resulting in a moment magnitude of $M_W = 6.9$. The earthquake occurred on a known Quarterly fault. Two other earthquakes are known to have occurred in the vicinity of Kobe ($M>7.0$ in 868, and $M - 6.0$ in 1916) (Kanamori, 1995).

Several organizations recorded the strong ground shaking that resulted from the earthquake (e.g., Japan Rail, Osaka Gas, JMA, Japan Highways, Building Research Institute and the Committee on Earthquake Observation and Research (Professor M. Sugito, personal communications)). The highest accelerations were recorded at Fukiai reaching 818 gals in the horizontal direction and durations were as long as 100 seconds at some soft soil sites. In general, the ground shaking can be considered to be comparable to recordings in California and perhaps somewhat smaller. Liquefaction, lateral spreading and settlement was widely observed throughout the affected area which had serious implications for the performance of lifelines and harbor facilities.

Reports on total damaged and collapsed buildings vary from 84,988 (Kobori, 1995) to 98,960 (1995). These represent a very significant number, approximately 17 to 20% of the total building stock of Kobe. Furthermore, 30% of the housing stock was destroyed either by collapse or by the ensuing fires that followed the earthquake. Among the buildings damaged or collapsed were a considerable number of important structures such as hospitals, fire stations, schools, and religious buildings. Structures of all materials were affected with some failure modes never observed with previous earthquakes. Failure of masonry and nonductile reinforced concrete structures were not a surprise, nor would one consider the failure of single family wood frame dwellings without shear walls and heavy clay tile roofs unexpected. However, the failure of intermediate stories in mid to high rise structures is somewhat surprising and still to be fully explained. Damage to steel structures first drew the attention of structural engineers following the Northridge, California earthquake. However, the type of damage to steel observed in the Hyogo-Ken Nanbu earthquake surpasses that of Northridge. While majority, if not all of the damage to steel structures in the Northridge earthquake was confined to welded joints, brace buckling and base plate failures, there were material failures to key structural components such as first floor columns never observed in steel structures prior to the Kobe earthquake. Furthermore, there were considerable number of steel structures that failed. In only one previous earthquake, the Michoacan earthquake of 1985 which affected the steel frames at the Pino Suares complex in Mexico City, have steel structures collapsed. In that respect, the Northridge can be said to have sounded a bell of warning while Kobe should be sounding a major alarm among structural engineering professionals.

Similar to the 1989 Loma Prieta and 1994 Northridge, California earthquakes, significant number of bridges, overpasses and sections of elevated highways either collapsed or were severely damaged resulting in closures of important highways. The complex railway system in the region was also affected extensively with lines severed due to collapses on almost all the railway systems. Damage to the underground rapid transit facility is of particular importance because it is the "first instance of severe earthquake damage to a modern tunnel for reasons other than fault displacement" (O'Rourke, 1995). Ports and harbors were damaged due to extensive liquefaction at these facilities. Airports appeared to have been spared.

All lifelines suffered damage with water and gas not fully restored for more than two months following earthquake. Power and communications services, however, were restored within a short period following the event. Loss of water contributed to the spread of fires and the overall losses.

Collapses in houses and highway structures and the fires caused 5,420 deaths, more than 27,000 injuries and approximately 300,000 lost their homes.

The full extent of the economic losses from the earthquake will not be known for some time. What is certain is that they are of catastrophic proportions. In addition to the direct damage the long term economic losses will be staggering.

What can be done to prevent such a catastrophe is the question that has been raised by all professionals, politicians, decision makers and the public at large. The following list is an attempt to provide a series of recommendation of possible tasks to be undertaken. It is limited in its scope and many of the recommendations probably are well under way of being addressed. However, they attempt to view the problem from an infrastructure system point of view in the hope that some new views are offered.

· As a first step in minimizing the threat of earthquakes, it is important to identify the potential for seismic activity in a region. Even though such information may be obvious to the scientific community, it needs to be communicated equally to professionals, government officials and the public at large. More reliable models for estimating the potential earthquake hazard in an area need to be developed and most importantly when the hazards are found to be high a proper mechanism needs to be developed to communicate these findings to the proper authorities and to the public at large in a timely manner. In the case of Kobe, the hazards were recognized but actions were not in time to prevent the disaster.

· Structural collapses are the primary causes of deaths and injuries. Given the large number of collapsed and damaged structures the number of casualties in Kobe could have been larger, had the earthquake occurred during regular business hours. This earthquake has shown that no location and no metropolitan region is devoid of hazardous structures. As our knowledge of the behavior of structures and structural systems improves our seismic codes improve. New codes, however, apply to new designs with older structures still posing a threat to society. Thus, all seismic regions need to recognize that the stock of all buildings that do not meet current design criteria is probably larger than the number of buildings designed according to more modern seismic codes. This is true for all regions in the world. Thus, a systematic retrofit program needs to be in place with reasonable and economically feasible approach for implementation. While not all old buildings are hazardous, a reevaluation of many is probably warranted.

· It should be recognized that implementation of any retrofit program is a long and extremely expensive process. A program that enables owners of all economic levels to address the issues needs to be developed. Special financial aid packages may need to put in place in order to insure their implementation. Still, this process can be achieved over a time period that can easily stretch over a decade as is the case in California.

· Critical structural and lifeline systems need to be evaluated independently first and as part of the overall infrastructure of a region. The dependence of various lifelines on each other is one of the critical issues that still remain to be investigated.

· Emergency response and disaster management can greatly be improved with the implementation of modern technological tools. Information retrieval and communication of information have been considerably facilitated with the advent of modern database management systems and geographic information systems. The implementation of such systems by emergency response agencies can prove to be a tremendous tool in the development of emergency response plans for monitoring and management of catastrophes. For example, if building, transportation and other lifeline systems information is stored prior to any event in such systems, real time damage assessment can provide information on the level and extent of damage. Decisions on emergency response can be made in a timely fashion and as more specific information on damage becomes available, relocation of homeless, allocation of resources, etc. can be effectively made.

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9.6 カリフォルニア大学バークレー校　メーイン教授

メーイン教授は1946年カリフォルニアに生まれ、1975年にUCBにて学位を取得。現在はCUREeの会長のほかノースリッジ地震による鉄骨造の被害調査の委員長。専門は鉄骨造、RC造、および木構造の耐震設計・解析。これまで20以上の地震の震害調査を行っている。

Reflections on the Great Hanshin - Awaji Earthquake

The Great Hanshin - Awaji earthquake is a compelling reminder of the destructive potential of earthquakes and of the importance of the efforts undertaken by engineers, architects, contractors, public officials and others to reduce seismic hazards. The tremendous damage and injury caused by this earthquake give us pause to reflect on how far earthquake engineering has come and on what still needs to be done. This is especially appropriate as this earthquake occurred exactly one year after another urban earthquake in Northridge, California. While the consequences of the Northridge earthquake were far less severe, due in part to the lower population density and congestion in the heavily shaken area of the San Fernando valley, the similarities and dissimilarities of these urban earthquakes and their effects provide significant insight into directions for future action.

Both earthquakes clearly demonstrate that we have made great progress during the past two to three decades in our ability to design and construct seismically safe structures. Damage due to the Great Hanshin-Awaji and Northridge earthquakes, especially life threatening catastrophic failures, occurred primarily in structures designed prior to or during the early stages of our understanding of seismic resistant design.

None the less, our knowledge and skill are still imperfect. Certain forms of construction did not perform as well as expected. For example, in the case of the Northridge earthquake, engineered steel buildings were found to suffer brittle failures in their welded connections. While steel building construction in Japan differs in its detailing from that used in the U.S., welding problems were apparently associated with severe damage and collapse of many modern, low rise steel structures in Kobe. Both earthquakes also suggest that we need to improve our understanding of the seismic behavior of long, elevated highway viaducts, ductile detailing of large diameter bridge piers, and the effect of bearings and displacement restrainers on earthquake performance of bridges.

The Northridge and Great Hanshin-Awaji earthquakes had great consequences in part because they both occurred within the confines of major metropolitan areas that have undergone significant development during the past half century. This subjected many engineered structures to intense ground motions, even though both earthquakes were relatively moderate in magnitude. However, there is increasing evidence that special characteristics of ground motions in the vicinity (within 5 km) of a fault rupture may have particularly severe consequences for certain types of buildings. Our understanding of these near-fault characteristics and of their implications for structural performance may have as profound an effect on engineering practice as did earlier observations regarding the deleterious consequences of siting tall buildings on soft soil sites.

Similarly, recent moderately-sized earthquakes, centered under urban areas in California, such as the 1994 Northridge, 1987 Whittier Narrows and 1971 San Fernando Valley earthquakes, and to a lesser extent the 1989 Loma Prieta earthquake, have had a profound effect on how engineers, government officials and the public in the U.S. view earthquakes and acceptable earthquake risk. Attention has begun to quickly turn from life safety as the primary design criteria to a situation where issues such as the cost and time required for repair or the need for continued operation following an earthquake are being considered. The tremendous impact of structural damage on the social and economic well being of a city, state or nation need to be considered, as well as the financial or institutional well being of the owner. Similarly, the dependency of a urban area on its infrastructure of highways, utilities, harbor facilities, and so on, increases our awareness that such structures must be given special attention in seismic-resistant design. Damage to underground utilities, such as water and gas, caused major difficulties during both earthquakes in extinguishing fires, as well as hampering longer-term recovery efforts.

Major efforts began in California as a result of the Loma Prieta earthquake to determine means of assessing the seismic vulnerability of existing bridge structures and to develop effective and economical means of upgrading their seismic integrity. These efforts have extended nationwide following the Northridge earthquake. Improved design procedures are also being developed in California for new bridges to account for their importance as "life lines."

The Great Hanshin-Awaji and Northridge earthquakes have also renewed concern for the safety and post-earthquake functionality of several important forms of public buildings. These include hospitals, schools and government offices. These forms of construction suffered damages in these earthquakes, and the closure of a hospital or government office building have obvious implications immediately following an earthquake as well as in the longer term. Even though schools did not generally suffer severe structural damage in the Northridge earthquake, damage to nonstructural elements and contents caused many schools to close temporarily. Because schools form the focal point for many neighborhoods, as well as for relief efforts, these closures and the assignment of students to other schools had a significant social impact.

Both earthquakes resulted in widespread damages to residential construction, leading to numerous homeless families and a tremendous stress on the financial resources of individuals, insurance companies and national emergency relief funds. While residential construction in the U,S. has been viewed as being able to protect life safety, the collapses of several wood homes and numerous apartment buildings, and the tremendous economic and social consequences of structural damages, has led many in California to consider the need to enhance the design of residential construction to minimize damage, and find better methods to fund (insure) the repair of damage to residential construction.

Economic and social costs of these and other recent earthquakes has in the U.S. turned attention towards the need for a more performance-based design approach. Current U.S. codes are indirect in their approach. Structures are designed for forces that do not correspond to those anticipated in actual earthquake, and evaluated and detailed using response parameters not related to realistic estimates of actual inelastic seismic demands. This results in a wide variation in the performance of structures during earthquakes. Efforts have begun to develop a framework for a consistent performance-based design and analysis methodology that can be used to design structures capable of performing in conformance with stated criteria. There is an increased interest in assessing seismic performance in a more quantitative manner in order to aid in the establishment of insurance rates, issuance of mortgages, and development of public policies regarding seismic risk management.

The Northridge and Great Hanshin-Awaji earthquakes also emphasize the need to improve our ability to evaluate reliably the seismic vulnerability of existing buildings and infrastructure elements and systems. Even if we can quickly remove the hazard posed by all forms of new construction, the overall seismic hazard will not reduce significantly due to the large inventory of existing structures. Reliable means for assessing hazards are needed to make individual decisions, as well as to set priorities for retrofit/replacement of public facilities and to establish public policy.

Procedures to upgrade the seismic resistance of existing buildings need to be improved, and engineers need to be educated on the special problems and techniques that are involved. While considerable research has been conducted in the U.S, and Japan on methods to retrofit existing buildings, evidence in the U.S, suggests that much more needs to be done and uniform standards need to be established.

The profound economic and engineering consequences of structural damage suggest that repair procedures and their economic implications should be explicitly considered in the original design of a structure. In experimental research aimed at understanding the behavior of mew structural elements and systems, it may be desirable to consider repair and retesting of test specimens to assess their likely performance in a subsequent earthquake. Thus, rather than testing all specimens to failure, it may be appropriate to stop some at a level corresponding to the design earthquake, and then repairing and retesting them. Little data is available on the performance of re paired structures. Research is needed on various methods that can be used for repair.

In both Great Hanshin-Awaji and Northridge earthquakes, the public was dismayed by the performance of the built environment. In many cases they expect engineered structures to sustain the earthquake effects with little serious damage. The difference of this view from that of the engineering community that often designs for life safety, and of owners who are often unwilling to pay for increased seismic performance, needs to be discussed openly and thoroughly. Greater exchange of information with the public by the engineering community on the risks associated with earthquakes and the likely damages that may occur are needed.

While the damage resulting from these earthquakes was severe, it was not the worst imaginable. Both the Northridge and Hanshin-Awaji earthquakes occurred early in the morning. Neither was the largest that could have occurred in the affected areas. Had the earthquakes been larger, or had they occurred later in the day when citizens were utilizing highways (or other means of transportation) or in their offices, factories or schools, injuries and damage could have been far greater in both cases. In particular, one is struck by the role of luck in determining the severity of casualties. For instance, Loma Prieta earthquake occurred at a time when many people would have been on highways that collapsed but traffic was unusually light because of the beginning of the World Series between the two local baseball teams. The San Fernando earthquake occurred early in the morning before many of the buildings that collapsed were fully occupied. The Great Alaskan earthquake occurred on a holiday so that heavily damaged structures schools and store buildings were vacant. While luck can sometimes be good, it sometimes can be bad.

The tremendous gains in earthquake engineering over the past three decades has been accompanied and accelerated by sharing of information and cooperative efforts between the various nations affected by earthquakes. Notable among these efforts have been the U.S. - Japan Cooperative Earthquake Research programs. The recent events in Japan, the U.S., Mexico, Armenia, and elsewhere suggest that we still have much to do. The damage due to earthquakes in urban areas indicates the importance of sounding engineering and construction practices. It indicates also that greater interchange is needed between engineers, those working in the earth sciences to characterize the risk and characteristics of earthquakes, and those in the social and economic sciences who are concerned with economics and public policy. This effort can be aided by the continued efforts of researchers, engineers, contractors and others from around the world.

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