CHALLENGES IN THE IMPLEMENTATION OF EARTHQUAKE DISASTER REDUCTION PROGRAMS

Roberto MELI[1] And Sergio M ALCOCER[2]

SUMMARY

Results of the many efforts and programs carried out in the last decades to reduce earthquake losses are critically evaluated. Over time, earthquake damage has risen because the level of exposure, both in terms of number and value of goods and properties, has increased. It is also concluded that a significant vulnerability reduction has not yet been achieved in most countries, especially those in the developing world. The lack of a definite reduction is mainly attributed to the fact that proper knowledge and technologies have not reached those sectors involved in major parts of the construction process, namely non-specialized professionals and builders. In order to promote changes aimed at improving structure safety, the process through which construction practice evolves in these sectors should be understood. As an example, the development of "confined masonry construction" as a low-technology procedure, yet robust and redundant, directed to overcome the most critical inherent weaknesses of unreinforced masonry is described. Problems related to the implementation of earthquake-resistant reinforced concrete frame structures are examined in light of the experiences and lessons learned from recent strong earthquakes in modern cities as Mexico, Kobe and Istanbul. For non-engineered construction, solutions akin to the local practice and with a clearly understandable structural behavior and evident advantages should be promoted. For the general, typical, constructions, simplified design methods must be developed and disseminated. Additionally, simple, robust and redundant structural systems must be encouraged, such as walled structures, instead of bare moment-resistant frames. For important buildings, the participation of qualified professionals should be assured through the implementation of a registry of specialists strictly rated by peers and through peer-reviewing processes. It is for this category of structures that an advanced seismic regulation is necessary; such requirements should have the general consensus of practitioners and academics.

INTRODUCTION

The conclusion of the century and the 12th World Conference on Earthquake Engineering provide a suitable opportunity to assess the achievements and hurdles encountered in different fields of earthquake engineering. It was almost 80 years ago when the first formal effort aimed at developing an earthquake-resistant practice started; and 40 years ago, coincidentally with the 1st World Conference on Earthquake Engineering, when a vast and intense technical and scientific research activity on the subject began. Over these periods, a large wealth of knowledge and the development of seismic codes and standards are the result of the enormous investigation efforts undertaken. Since then, intense training and dissemination campaigns have been carried out altogether with national and international seismic risk reduction programs. Among them, the recently finished International Decade for Natural Disaster Reduction stands out.

Achievements can be best and most objectively evaluated through a careful look at the net reduction of earthquake damage and consequences. However, like in any assessment of this nature, great difficulties in the interpretation of available data exist. Furthermore, a systematic effort to measure the impact of seismic events is not known by the authors; some figures and lessons, however, may serve to illustrate observed trends.

---

[1] *Dir Gral, Natl Ctr for Disaster Prevention, D. Madrigal 665, Sto Domingo, Mexico DF 04360 Email: meli@cenapred.unam.mx*

[2] *Head Strl Engng & GeotechnCENAPRED, Research Professor, Institute of Engineering (UNAM), Email: alcocer@cenapred.unam.mx*

Large insurance companies have devoted considerable time and resources for determining disaster-related costs. Such efforts have been mainly geared to quantify the loss of insured goods, but also to estimate total losses as part of risk assessments. In particular, Munich Re [Münchener, 1999] yearly publishes its estimation on economic losses infringed by natural disasters. Damage evolution recorded between 1960 and 1998 for all natural phenomena is presented in Fig. 1, which shows that economic losses have increased at a rate such that, at constant value, between 1994 and 1998 they were 15 times larger than those obtained in the 1960-1964 period. A similar growth is observed in earthquake-related damages.

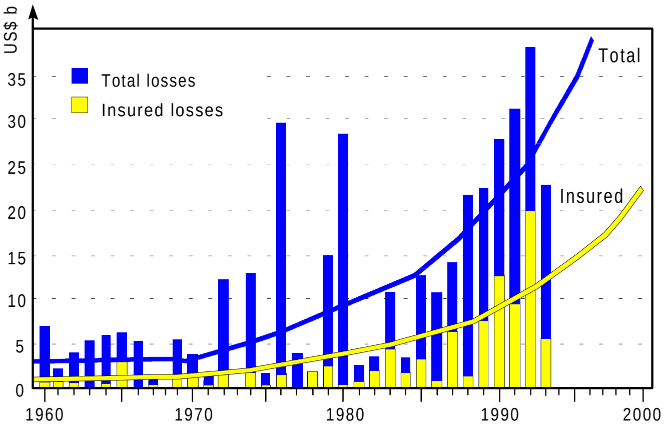

Figure 1. Losses between 1960 and 1998 for all Natural Phenomena [Münchener, 1999]

Looking at the global data and statistics, vast differences between the conditions of developed countries and those in the developing world are apparent. Statistics indicate that the loss of human lives due to natural disasters in the developing world is 20 times that in developed countries. Regarding economic losses, those expressed in absolute values are much larger in developed countries than in the developing world, but in relative terms, i.e. as a fraction of the gross domestic product, losses of developing countries are 20 times larger. These findings lead to conclude that disaster consequences are worst in developing countries, where both people safety and economic losses are severe problems, while in the developed world, economic losses and disaster consequences have peaked but the number of casualties has been reduced. Moreover, it has been observed that poverty is a determining factor of risk in developing countries; there is a clear difference in disaster effects, particularly in number of casualties and fatalities, between groups of population with distinct income levels.

Damage during severe earthquakes has been common through the years in the developing world, whereas in developed countries, a large period of time had elapsed without extreme consequences. In the absence of significant damage in developed countries it was concluded that a definite risk reduction was achieved, particularly regarding casualties, and that transfer of those successful technologies and practices used in these countries to the developing world was the one and only challenge ahead. Moreover, this idea had been assumed when IDNDR activities were proposed; however, the events occurred after 1994 have shown that such conclusion was premature. Both, Northridge and Kobe earthquakes have provided evidence of the vulnerability of regions where state-of-the-art practice and expertise were more rigorously applied. More recently, the earthquakes of Turkey, Greece and Taiwan of 1999 showed the lack of basic earthquake-resistant characteristics of buildings located in modern urban areas that may cause large numbers of casualties.

Caution should be exercised in the interpretation of data on the accelerated trends of losses due to disasters. Any argument claiming an increase in the number and intensity of seismic motions as a cause of those trends can be promptly discarded. Undoubtedly, the main cause is the considerable rise of exposed property and goods, both in terms of their quantity and value, due to growth of the population and economy in several countries and, especially, in regions exposed to high seismic hazard. Other factor that has some effect in the increased amount of losses reported is the improvement of the methodology used to assess events and losses. It is evident (Fig. 1) that technological advances worldwide have not significantly reduced global losses due to disasters and that if any, positive effects have been amply exceeded by the increase of exposure level.

The lack of satisfactory results regarding vulnerability reduction could be explained through the analysis of damage inflicted by earthquakes in different parts of the world. Some causes and explanations are only applicable to least developed regions, while others are common to all cases; therefore, they will be discussed together.

CAUSES OF SEISMIC VULNERABILITY

Similar causes of structural failures have been consistently identified by specialists in reconnaissance reports prepared to assess the effects of important events in different parts of the world. However, reports do not exhibit any clear trend on the correction of those errors and the same inadequate practices that have been repeatedly detected, explained and published through the years.

In general, the acquired knowledge on the earthquake phenomena and their effects has not yet been translated into standards and recommendations that, in turn, could be transferred to the design and construction professionals. This is a significant problem particularly in developing countries, but it is also found in some developed countries. A comprehensive, general approach is not suitable; rather, the large variety of development and organization conditions in each country ought to be considered when establishing mechanisms aimed at improving construction safety.

It has been found that lack of compliance with construction codes mainly occurs when imposed requirements are largely apart from the actual construction process and are solely understood and correctly applied by few designers and contractors. Besides, it should be acknowledged that the set of rules and requirements of today’s standards is more the result of an informal trial and error process and progressive adjustments after collecting evidence of inadequate performance than the logical and explicit consequence of principles, verified theoretical models and robust research results. The outcome of this process is that construction safety is not necessarily adequate.

The most striking evidence of this process is found when the origin and evolution of code-specified seismic actions are analyzed. The base shear coefficient (BSC, defined as the ratio of the ground story shear and the total building weight) is a fundamental design parameter that could be used to compare distinct methods with different levels of refinement. Since the inception of seismic design in the 1920’s, this coefficient was established at around 0.10. BSC´s for typical buildings have fluctuated around this value, despite the much larger ground accelerations recorded during intense earthquakes. Inelastic design spectra of some modern codes are compared with elastic response spectra obtained from actual records in Fig 2. Assumptions on inelastic behavior and over-strength do not suffice to explain the large differences in spectral ordinates. It is inferred that there is not a clear connection between design actions and recorded ground motions during intense shaking, nor a rational explanation of design values. To cope with this shortcoming, seismic design procedures aimed at defining more rationally the design actions and the acceptable performance of the structure are currently under development. However, status of these procedures indicates that its practical application in the design of typical buildings is still distant

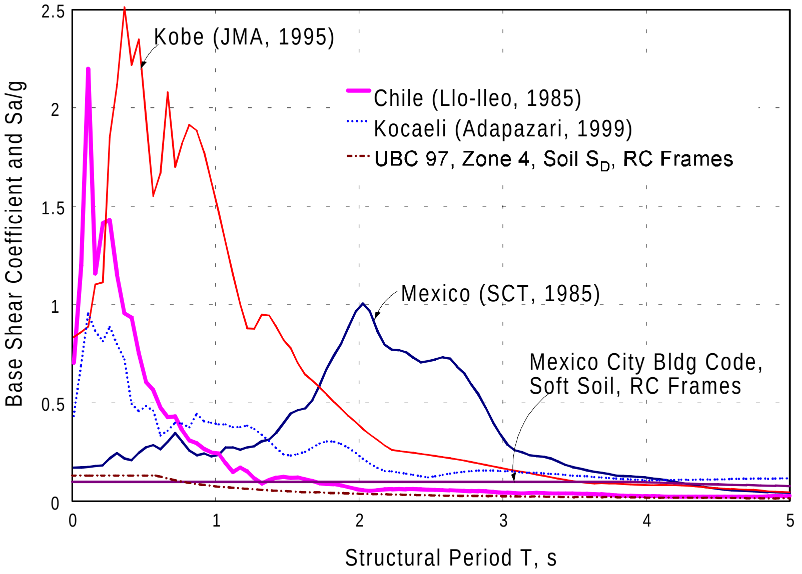

Figure 2. Comparison of Some Design Spectra and Response Spectra for 5% Damping

Damage to non-structural elements, installations and contents is responsible for the vast majority of economic losses reported in developed countries. However, its reduction is another aspect where actual seismic design criteria are inadequate. Rational methods to define limits on lateral displacements/velocities/accelerations of buildings and preventive measures to protect contents and non-structural elements are still pending of development and consensus.

Additionally, the seismic performance exhibited by some construction systems has consistently been either superior or inferior to that explicitly or implicitly assumed in the design criteria and procedures, thus forcing the requirements and standards to be continuously adjusted. Reinforced concrete (RC) frame construction is one example that deserves special attention. This case will be studied ahead in more detail.

The lack of compliance with design codes shall not be understood as a mere illegal situation that must be solved only through enforcement actions. The vast distance between the level of knowledge and quality of practice of a relatively small group of well-informed specialists and of most professionals and non-professionals is apparent, especially in developing countries. Moreover, construction standards and codes are typically developed by this group of specialists who often neglect the actual construction practice of the region or country. In some instances, code regulations are neither understood nor adequately applied by a large sector of construction professionals. Additionally, in less developed countries, the phenomenon of informal construction (i.e. non-engineered construction) is common. In this process, a large percentage of the building stock (in some cases more than 50 percent of the total) is carried out without construction permits, without complying with the codes and without the participation of qualified professionals, as it is done in the formal construction process. Although this phenomenon is prevalent in rural zones, it is also characteristic of large urban areas in developing countries. Based on the above, the most effective disaster mitigation programs in these countries will be those aimed at improving the practice in the non-engineered construction sector, which is, also, the most difficult to impact by common technology transfer mechanisms. The problem of attaining proper seismic safety in non-engineered buildings becomes more complicated since construction practice evolves with little, if any, influence of specialists. In this evolution, cultural and economic aspects, as well as improvement of living conditions, are commonly more important to users than the concern in improvement of structural safety.

SEISMIC VULNERABILITY OF HOUSING IN DEVELOPING COUNTRIES

Unreinforced masonry made of stones, adobe or hand-made clay bricks, is the type of housing construction system that has exhibited the largest damage. Since early studies were conducted, the inherent weaknesses of this system under earthquake attack and the necessary modifications to improve its performance were identified. Countless manuals, leaflets and booklets have been developed through national and international organizations with the aim of disseminating those improved practices. Among them, those produced by the International Association for Earthquake Engineering [1986], German Society of Earthquake Engineering [1991] and Coburn *et al.* [1995] have been distributed worldwide. An assortment of solutions proposed to increase seismic safety is available; while some solutions are directed to new construction, others are for strengthening existing buildings. One example of a strengthening scheme suggested is shown in Fig. 3. It can be stated that the impact of these publications has been very limited, particularly because the target population was never reached or because information arrived untimely.

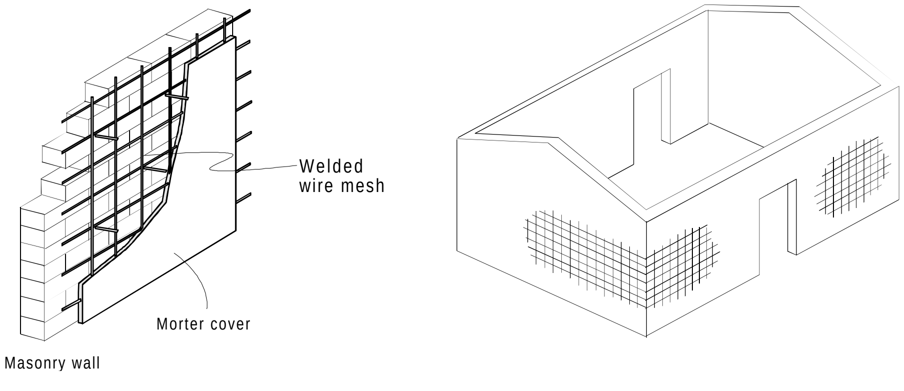

Figure 3. Rehabilitation Technique Suggested for Existing Dwellings

However, in order to identify the factors that contributed to the success and to apply them in new mitigation programs, it is convenient to carefully study those cases where significant improvements of seismic safety have been attained.

The use some type of reinforcement is probably responsible for the single most effective change in reducing earthquake damage of masonry constructions made with distinctly different materials. Confined masonry is a prime example of this situation. Since the beginning of this century, walls reinforced with vertical and horizontal RC elements (around the perimeter) were included in the reconstruction of some cities practically destroyed by earthquakes, such as in Messina after 1908. The objectives of the confining RC elements were to tie together the walls, floors and roofs, as well as to provide some out-of-plane flexural strength. As a result, confined masonry was developed, and slowly used, supported on evidence of adequate performance under successive moderate and intense shaking; it was not an outcome of an organized and systematic effort. Since then, confined masonry has been adopted in several countries, especially in the south of Europe and in Latin America. It is interesting to mention that this system was embraced in Mexico City in the 1940's to control the wall cracking exhibited due to large differential settlements recorded in the soft soil. It was several years later that, after examining its excellent seismic performance that this system became popular, even outside the soft soil area of the city.

Two cases on the use of reinforcement in masonry houses that gave rise to distinct conditions are described herein. In the south of Chile, after repeated events that had destroyed adobe houses mainly in rural villages, adobe was forbidden as a construction material. In lieu of adobe, reinforced masonry was promoted. The new construction practice was rapidly disseminated and applied at large; a noticeable damage reduction inflicted by subsequent earthquakes could be easily observed. Monge (1969) reports conclusive damage statistics on the usefulness of reinforcing schemes. In this example, specialists and government authorities implemented a useful construction practice through an organized effort. It is convenient to underline that in most cases of destruction of unreinforced masonry houses in rural areas, the original construction process and even the same materials are used for re-building the dwellings, but without any modification to increase their safety.

The second case is that of Huajuapan de Leon, a village located in central Mexico that suffered extensive destruction during a local earthquake in 1980. The adobe houses destroyed in large numbers were mainly replaced by dwellings made of confined masonry, apparently as a result of a quite spontaneous process based on the practice observed in larger cities. Recently, in June 1999, an earthquake of equal magnitude occurred in the same region and caused severe damage to houses in several villages. However, damage recorded in Huajuapan was substantially smaller than that observed in neighboring towns, where traditional unreinforced masonry is used. Efforts should be carried out to use this experience to promote similar changes when damaged or destroyed houses are rehabilitated or rebuilt.

Several characteristics of the above mentioned case study on confined masonry should be emphasized and taken into account for the development and implementation of disaster reduction programs. The dissemination of this structural system was based on a clear evidence of its superior performance under severe earthquakes. It was easily accepted because previous construction practices were not significantly modified and because its execution was relatively simple. The advantages of the system were rapidly understood by users, without resorting to arguments only clear for specialists.

Although confined masonry appeared as an informal modification of small dwellings, it has been adopted as an engineered construction in several countries. Moreover, extensive analytical and experimental research programs have been carried out and its design and construction have been codified. In some developing countries, small dwellings and single-family houses are mainly built of confined masonry; however, multi-family buildings, up to six stories high, are also constructed with this system. The focus of confined masonry codes has been on standardization of the design and construction practices that have led to adequate performance. As a result, design methods are quite simplified and emphasize geometric requirements, mainly related to minimum wall densities, distribution and characteristics of confining elements, as well as symmetry and regularity (Fig. 4). All these simple, yet conservative, requirements have produced structures with uniform characteristics and quality, which have exhibited very satisfactory seismic performance.

In this regard, it is useful to compare the effectiveness of confined masonry construction and of internally reinforced masonry in the developing world. Differently from confined masonry, the latter has been developed on an engineering basis, where quantitative design procedures (consistent with structural mechanics), as well as efficient and almost industrialized construction processes are followed. Analogously to confined masonry construction, masonry intrinsic weaknesses are coped with both vertical and horizontal internal reinforcement that additionally increase the in-plane wall shear capacity (in terms of strength and deformation). Although reinforced masonry is quite popular in some developed countries, little information and dissemination have been carried out in developing countries, where some major failures have been documented. The substandard performance observed in developing countries should not be attributed to any shortcoming of the system itself, but rather to gross construction errors, commonly characterized by neglecting some reinforcing bars and more often, by incomplete placement of grout in hollow blocks. Reinforced masonry is not a construction system amply suitable for inspection, since deficiencies can not be easily detected and isolated. It seems that inadequate construction by common masons has more to do with the lack of understanding or conviction of the positive role of reinforcement in wall behavior. This fact clearly indicates that the effectiveness of a construction system does not solely depend on its technical merits, but also on other cultural or practical factors.

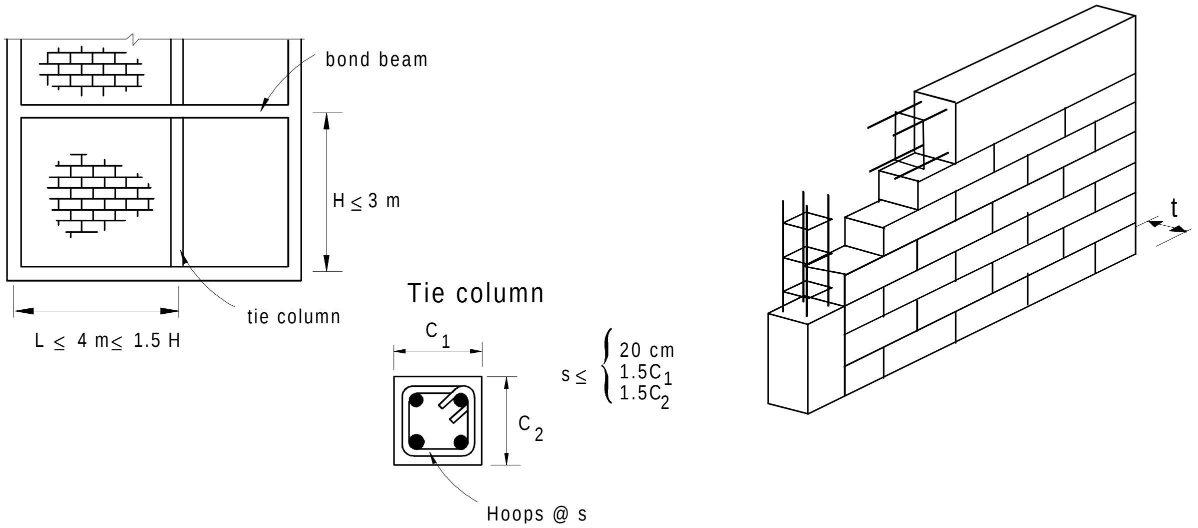

Figure 4. Main Characteristics of Confined Masonry Construction

VULNERABILITY OF MULTISTORY REINFORCED CONCRETE BUILDINGS

A high rate of failure of RC frame buildings, without walls and braces, has been consistently recorded in largely damaged urban areas. Lessons learned from such failures have motivated series of changes in their design standards. In general, design requirements have become more stringent, thus increasing the actual safety factors, as it is evident by looking at the detailing rules. The latter, in contrast, has contributed to increase the structure's cost and to negatively affect frame constructibility. It is, therefore, useful to examine whether these changes have actually reduced the frame seismic vulnerability and their damage.

One lesson learned from the Kobe earthquake (Hyogoken Nanbu earthquake of 1995) is that damage in modern frames designed in accordance with present strict requirements was less severe than that in frames built during the 1950's and 1960's, when lax design requirements and detailing were in use. In contrast, during the Mexico earthquake of 1985, this trend was not so apparent. Although Mexican construction codes had evolved through the incorporation of new information and refined design methodologies, requirements were not made significantly stricter. If so, it was observed that older buildings, constructed between 1930 and 1950, with flexible, inadequately detailed and almost unconfined RC elements, performed better than more recent construction. Such difference was attributed to the thick masonry walls used as infills and in facades that increased the structure seismic capacity. These thick masonry walls were not explicitly considered in design (Fig. 5). In contemporary buildings, the RC frame was forced to resist the earthquake-induced loads since masonry walls were substituted by lighter and weaker elements. The absence of infill walls, that unintentionally could contribute to seismic resistance, was the cause of the inferior performance exhibited by those recent RC bare frames, although they were provided with better structural characteristics than the old ones. During the recent earthquake in Turkey (Kocaeli earthquake of 1999), most severe damage was concentrated in modern buildings. In recent years, Turkey´s modernization led to a fast urban growth and a change in housing patterns; single-family or small buildings have been substituted by medium-rise structures, and in fewer cases, by high-rise constructions. Contemporary buildings are made of RC frames or flat-slab systems infilled with hollow clay blocks. Principal causes of damage were deficiencies in the structural configuration, probably due to absence of seismic design, and to non-ductile detailing of reinforcement (Fig. 6). Construction errors and low-quality materials certainly exacerbated the damage. In general, it is fair to say that design and construction practices were clearly inadequate for a zone subjected to a high seismic hazard.

The three examples discussed before (Kobe, Mexico and Turkey earthquakes) provide evidence of the fact that the advancement of knowledge and expertise are not always transferred and observed in practice and, even more, that in some instances, vulnerability is increased by altering the regional, well-established, construction trends.

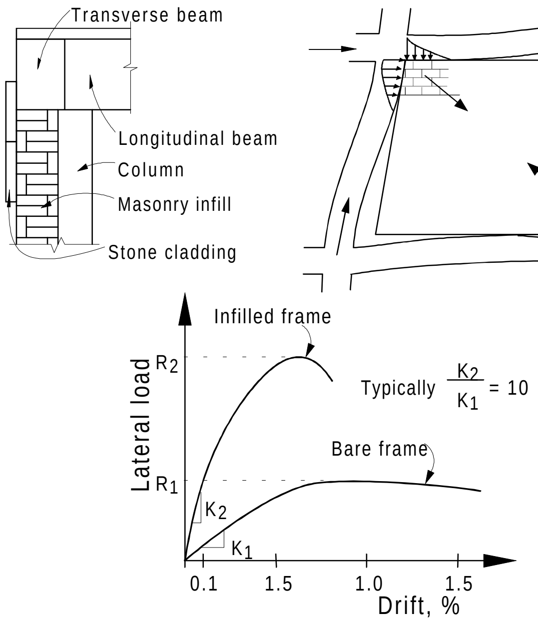

Figure 5. Reinforced Concrete Frame with Infill Walls

Figure 6. Typical Damage Observed during the 1999 Kocaeli Earthquake in Turkey

In most recent earthquakes, as it is the case of Turkey, it has been found that deficient structural configurations are commonly the prime causes of failures. Soft stories, short “captive” columns, as well as discontinuities, eccentricities and asymmetries in structural elements are the most recurrent and critical causes of distress. It can be safely stated that in all reconnaissance evaluations causes of failure described correspond to those just indicated, and that all textbooks on seismic design discuss in detail the drawbacks of ill-conceived layouts and poor detailing and, moreover, give recommendations to avoid those deficiencies. It is obvious the rather critical divorce between a group of well-prepared and specialized engineers, included academics, and a group of those professionals (and non-professionals) that are in charge of the vast majority of buildings. This, in turn, results in non-compliance with code requirements and in a generalized failure to follow what is acknowledged as “good practice”. Though the former is often intentional, in most cases it is probably due to ignorance or inadequate interpretation of design requirements. Sometimes, code interpretation is made difficult since language is not clear or is ambiguous for common practitioners. Efforts should be devoted to simplify and clarify code statements.

Research programs and, especially, failures observed during earthquakes lead to conclude that RC frames are inherently weak. Such deficiencies can only be overcome through extremely careful designs aimed at avoiding irregular structural configurations, but at the expense of achieving rather complex reinforcement details. The latter is particularly difficult and time consuming to design and construct; errors can be easily produced, giving rise to poor performance, often of catastrophic consequences and proportions. To cope with this problem, it is advisable to promote the use of other structural systems with built-in large seismic capacity that depends on general characteristics, say related to geometry rather than on refined design and detailing procedures. In this regard, RC wall buildings or braced structures are effective solutions for most common cases. RC frames with walls and braces can be readily designed following procedures that can be rather easily codified. The seismic performance of RC frame buildings with walls and braces has been remarkably better than that of bare moment-resistant frames. Chile is a convincing example of the advantages of using walls; in the 1960’s, as a consequence of the extended damage observed in bare RC frame buildings, placement of an abundant number of walls in multistory structures was encouraged, but not required by codes. An assessment of the performance during subsequent severe earthquakes clearly indicates that the adoption of this design and construction practice led to a drastic reduction of damages and of losses of human lives.

SOME RECOMMENDATIONS FOR VULNERABILITY REDUCTION PROGRAMS

Legal actions characterized by enforcement of strict standards, mechanisms of inspection and vigilance as well as by punishments by local authorities, are the most obvious solutions to reduce the seismic vulnerability. Though necessary, legal actions have demonstrated to be ineffective or insufficient in developing countries and also in some developed countries. Groups of engineers, in adequate numbers and expertise, dedicated to inspect and enforce the regulations for most buildings are not available to local authorities of many countries. The outcome is a generalized disobedience of codes and standards, which is intentional in only few cases, but that, in most instances, is the result of unawareness and incorrect interpretation of the regulations. Therefore, for most countries, it is deemed necessary to admit the existence of an ample sector of the profession with low levels of expertise and training and that a full, formal, implementation of quality assurance and code enforcement mechanisms is not possible.Therefore, as a starting point, the diverse levels of scholarship and expertise, as well as of interests and cultural characteristics of individuals involved in the construction process must be acknowledged when defining seismic vulnerability reduction programs. Programs should also include strategies specifically designed for each one of the main sectors in the process. In these efforts, legal actions should be complemented by a whole new series of measures on educational aspects, financial incentives and technical support.

In the developing world, programs targeted to non-engineered construction are probably those with highest benefit-to-cost return ratios. Vulnerability reduction programs in developing countries must firstly face the facts. Programs should promote solutions akin to the local practice as well as with a clearly understandable structural behavior and advantages over others. Several options are available as strategies for reduction programs. User participation should be promoted; periods of hyper-receptivity immediately following severe earthquakes should be exploited; successes attained in similar areas should be presented and pilot projects should be executed. Also, economic incentives, mostly related to the availability of materials at reduced prices, should be supplied; and vulnerability reduction measures should be coupled with other actions aimed at improving housing habitability. Safety is not a concept easily “sold” to a population with serious lacks, but it can be better “sold” if it is complemented with living improvements whose benefits can be daily enjoyed.

Redundant and robust structural solutions should be implemented for the majority of urban and rural constructions carried but by professionals who have distinctly different levels of scholarship and expertise and who also exert varied levels of quality assurance. These solutions should be inherently strong under earthquake motions and should not depend on refined and complex design and construction details. Examples of this approach are walled structures (instead of bare moment-resistant RC frames) as well as construction materials whose mechanical characteristics are less dependable on labor quality. Simultaneously, simplified design rules and procedures, easy to understand and apply for most professionals, must be implemented as an option to minimize the likelihood of errors.

Participation of highly qualified professionals in the construction process of structures of large importance should be assured. To attain this objective, development of a registry of specialists, strictly rated by their counterparts, has proved to be effective in some countries. Furthermore, the requirement of a liability statement on structural safety issued by one of these qualified specialists, who participates during the whole process (preliminary studies, design and construction) has improved building quality. Besides, peer reviewing of important projects is required in some countries. It is for this category of structures that an advanced seismic regulation is necessary; such requirements should have the general consensus of practitioners and academics.

REFERENCES

Coburn A., Hughes R., Pomonis A., and Spence R. (1995). “Technical principles of building for safety,” *Intermediate Technology Publications,* London, 74 pp.

DGEB (1991). “Aseismic constructions” (in Spanish), *German Society of Earthquake Engineering and Structural Dynamics*, Berlin.

International Association for Earthquake Engineering (1986). “Seismic guidelines for non-engineered constructions,” Revised edition of “Basic concepts for seismic codes,” Vol. I, Part 2, Tokyo, October, 171 pp.

Monge (1969). “Seismic behavior and design of small buildings in Chile,” Proceedings, *Fourth World Conference on Earthquake Engineering*, Santiago, Chile.

Münchener Rückversicherungs-Gesellschaft (1999). “Catastrophes due to natural forces,” *Topics*, Munich.