DRAFT

POLICY NOTE

It Is Not Too Late: Preparing for Asia's Next Big Earthquake

With emphasis on the Philippines, Indonesia and China

What East Asia and the Pacific Can Do to Prepare for the Next Big Earthquake: Developing and Implementing Regional and Countrywide Strengthening Programs for Vulnerable Structures

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Executive Summary

It is only a matter of a few years before the next major earthquake strikes East Asia and the Pacific. It is only a few decades, at most, before a major earthquake occurs near a metropolitan area. The region is generally not prepared for such an event but much can be done before a disaster strikes.

Recent earthquakes throughout the region have shown that critical public (and private) buildings and infrastructure are vulnerable to major damage and collapses. That includes both older and new structures. A clear example is the West Sumatra (near Padang), Indonesia earthquake of 2007. It had a magnitude of only 6.3 but caused 66 fatalities, 500 casualties, and severe damage or collapse of nearly 15,000 buildings. About 44,000 structures sustained damage; 60% of the buildings had medium to severe damage. As a result, over 135,000 people were displaced. About 300 school buildings collapsed and another 400 had moderate to severe damage. These are very high numbers for such a moderate earthquake in an area with a long history of much larger earthquakes.

With the exception of Japan and New Zealand, the countries of the region have initiated limited programs to strengthen and protect older, and many new buildings and infrastructure. One of the largest is the strengthening of several hundred bridges in the Philippines following the 1990 Luzon earthquake. China, following several destructive earthquakes since 1976 has strengthened to various criteria buildings with over 220 million square meters.

Other regions of the world have a similar history but have, over the years, initiated legislative actions, beyond building codes revisions, to reduce the effects of future earthquakes. In effect, they have begun to practice countrywide earthquake risk management. California serves as an example, where over the last several decades the codes have been continuously upgraded to reflect the lessons of damaging earthquakes, as have the countries of East Asia and the Pacific. However, California has also mandated and financed the strengthening of key public buildings and infrastructure and particularly hazardous private structures and is currently taking the same approach with the remaining hazardous private sector structures. Over the last several decades the risk to the public sector in the state has steadily decreased. The same can be accomplished in East Asia and the Pacific.

The key challenges in earthquake risk management and what to do about them are:

- Where and what the risks are and how strong is the shaking – update the earthquake zoning of the country,
- How to manage risk with state-of the art building codes – update the codes to the latest knowledge and include requirements for the strengthening of exiting buildings,
- How to manage risk with adequate engineering and construction practices – improve the quality of engineering and construction with proper training and licensing and tighten the inspection of construction and the construction materials,
- How to find the funds to strengthen what needs strengthening – get government or international bank financing
- How to strengthen older and more vulnerable structures that were designed to older, outdated and inadequate codes (and the lack of earthquake requirements in some earthquake regions) – start

strengthening vulnerable structures using the experience gained by other countries in reducing their risk through earthquake risk management programs like the ISMEP project in Turkey.

Both history and engineering assessments and analyses find that the following public buildings and infrastructure and their key non-structural features and equipment are highly vulnerable and could or should be addressed first:

- Schools, hospitals, and critical government buildings such as fire stations and other buildings needed for emergency response
- Public infrastructure, including key highways and bridges, airports, electric power generation and distribution systems, water and wastewater systems, and telecommunications.

Countrywide earthquake risk management programs involve risk assessments, followed by multi-phased risk reduction programs that can take from a few years to decades to complete. Such programs have been successfully carried out in several countries. The programs typically consist of three phases:

1. **Risk audit** of a specific sector, like public schools.
2. **Detailed risk assessment including cost-benefit analysis** for the particular sector.
3. **Implementation** – reducing the risk through strengthening of the structures and bracing their important equipment and other non-structural components.

Following two destructive earthquakes near Istanbul in 1999, the government of Turkey, with funding, guidance, and direct assistance from the World Bank, initiated in 2006 a major earthquake risk management program – the Istanbul Seismic Mitigation and Emergency Preparedness Program (ISMEP). ISMEP is one of several such recent projects that can serve as an example of a successful program for the management of public earthquake risk in East Asia and the Pacific. The program is multi-faceted, but its primary component is the strengthening and reconstruction of priority public buildings. The government set up a small new unit, the Istanbul Project Coordination Unit (IPCU) to manage the program, with assistance from experienced international experts. To date the project has completed the strengthening, reconstruction, and renovation, of over 620 school, hospital, and other buildings that were found be very high risks in future earthquakes. By the end of the current project in 2014 more than 1,100 such buildings will be strengthened and/or rebuilt. This affects directly the safety of over 1,200,000 students and their teachers and the lives of another 4,000,000 people – their families. The project has recently received much additional financing from several other sources for a greatly expanded scope. It is an excellent example for other countries to follow.

Based on the above history, analyses and recommendations, a recommended implementation plan for earthquake risk management, including short to long-term actions is as follows:

Short term (as soon as possible or 1 year):

1. Initiate at least one narrowly focused earthquake risk reduction program for maximum impact on potential life losses in the public sector – possibly start with schools, hospitals, and power generation and distribution systems in a major metropolitan area
2. Assess integration of earthquake risk assessments and risk reduction into infrastructure investments
3. Review and update existing building codes and their enforcement, specifically for earthquakes
4. Conduct a critical review of national earthquake risk reduction policies and laws.

Medium term (the next 5 years):

1. Complete one large but narrowly focused earthquake risk reduction program for maximum impact on life losses in the public sector as a demonstration project. The ISMEP program in Turkey is a good example.
2. Demonstrate that cost-effective strengthening options are available for vulnerable structures and gain public support – schools are easiest
3. Redefine the earthquake hazardous areas
4. Redefine tsunami hazardous areas; improve tsunami warning systems
5. Update the codes
6. Strengthen enforcement of the codes and construction quality inspection
7. Conduct training programs for structural engineers in earthquake risk analysis and risk reduction. Training programs for contractors and the trades would also be very useful.

8. Mandate professional registration for structural engineers, particularly in the earthquake areas of each country.

Long term (5 to 10 years)

1. Initiate long-term earthquake risk reduction programs to impact all key public sectors
2. Support/initiate long-term earthquake risk reduction programs for the highest risk private structures
3. Support/initiate long-term earthquake risk reduction programs for the highest risk industries and maximum financial impact
4. Pass legislation to require strengthening of private sector structures and infrastructure with or without public financing but with incentives.

Background

Strong earthquakes strike frequently countries in East Asia and the Pacific, causing building collapses and extensive damage to infrastructure and, when centered near populated areas, heavy life losses. Urban areas, with their increasing concentrations of population and infrastructure, are particularly at risk from catastrophic losses with far-reaching economic repercussions and human loss.

Although earthquakes are natural and unavoidable events, buildings and infrastructure do not need to collapse or be seriously damaged during earthquakes. The knowledge exists to lower significantly and even eliminate fatalities and to control and even minimize damage during earthquakes. The 2010 earthquakes in Central Chile (Magnitude (M) of 8.8) and the South Island of New Zealand (M 7.1) demonstrate that adequately. Both earthquakes struck near major populated areas but caused limited damage and, particularly, limited life loss when compared to other recent earthquakes such as in Haiti (2010, M 7.0) or Sichuan, China (2008, M 8.0).

The next earthquake and other large earthquakes in the East Asia region in the near future are inevitable. This paper aims at delivering the best science, risk analysis, and engineering available to help policy makers and particularly those directly responsible for mitigation, preparedness, response and recovery to anticipate and prepare for earthquakes and build safer, more resilient societies. In particular, this paper emphasizes the strengthening of existing schools, hospitals and specific infrastructure that should result in the largest possible life loss reduction and the largest possible financial loss reduction in the public sector. The paper does not address integrating, at this time, other risk mitigation technologies, such as risk transfer through insurance, primarily because (1) it concentrates on the public sector and (2) because life losses will not be generally impacted by such technologies.

The objective of this paper is to help to reduce earthquake risk through promoting safer construction, disseminating good practice for new and existing infrastructure, increasing the level of preparedness, and, particularly, promoting a decrease in existing risk and saving lives through strengthening of existing important public infrastructure.

An action plan for earthquake risk management in the public sector is presented with specific strategies and initiatives. The plan is based on best practices from around the world (and in many of which the author has participated) and gives specific disaster risk management suggestions for key sectors. A major, on-going earthquake risk mitigation program by the Governments of Turkey and Istanbul will serve as the example and focus.

The effects of recent earthquakes in the Philippines, Indonesia and China and their characteristics

All recent earthquakes in East Asia that struck populated areas have demonstrated that older and many new buildings and structures are vulnerable to major damage and collapse and have caused many casualties. Four recent, large and somber reminders are:

a. Luzon, Philippines earthquake of 1990 (M 7.8)
b. West Sumatra, Indonesia earthquake of 2007 (M6.3)
c. Wenchuan, Sichuan Province, China earthquake of 2008 (M7.9)
d. Yushu, Qinhai & Sichuan Provinces, China earthquake of 2010 (M7.1).

The Philippines earthquake of 1990 caused extensive damage to infrastructure in Northern and Central Luzon, including bridges, roads, ports and industry. It collapsed many relatively new commercial buildings, particularly multistory hotels in the resort City of Baguio, and caused 1,700 fatalities. The earthquake epicenter occurred along the 1400 km long Philippine Fault, one of the most well-known and destructive faults in the world and in a country with advanced building codes.

FIGURE 1. One of several collapsed hotels and other modern buildings in the City of Baguio, Philippines; 1990 M7.7 earthquake.

FIGURE 2. Damage to unprotected equipment and non-structural items in a clean room of an electronic components assembly plant, Baguio, Philippines, 1990 M7.7 earthquake. The building itself was not damaged significantly. The equipment damage caused a 3-month long business interruption and a major financial loss.

The West Sumatra (near Padang), Indonesia earthquake of 2007 had a magnitude of only 6.3. It caused 66 fatalities, 500 casualties, and severe damage or collapse of nearly 15,000 buildings. About 44,000 structures sustained damage; 60% of the buildings had medium to severe damage. As a result, over 135,000 people were displaced. About 300 school buildings collapsed and another 400 had moderate to severe damage. These are very high numbers for such a moderate earthquake in an area with a long history of much larger earthquakes.

FIGURE 3. A collapsed school near the Sumatra Fault which cased the 2007 M6.3 West Sumatra earthquake. 700 school buildings were damaged in this moderate earthquake, 300 of which collapsed.

The large, M 8.0 Wenchuan, Sichuan Province earthquake of 2008 struck at 2:28 p.m. local time a mountainous but populated rural region of. The earthquake occurred in the vicinity of numerous past large earthquakes of the 19th and 20th centuries with magnitudes of 7 to 8 and near or on two of China's well-known earthquake faults. This was the worst earthquake in China since the 1976 Great Tangshan earthquake (East of Beijing) killed 242,000. There were 87,264 casualties, including 69,225 deaths and 17,939 missing. Millions were injured or left homeless. About 15 million housing units collapsed. Direct losses to buildings and infrastructure are about US$122 billion (which is about 3% of China's 2008 GDP). Business interruption and other losses would increase this number substantially. Schools and hospitals were especially hit hard; many collapsed while they were fully occupied. Many of the severely damaged and collapsed buildings were relatively new. The infrastructure of the affected region, much of it new, suffered severe to extreme damage, especially critical facilities such as power transmission facilities and bridges.

The M 7.1Yushu earthquake of April 14, 2010 struck a town with population of 10,000 and the surrounding rural area in Qinhai and Sichuan provinces. About 2,700 people died and thousands were injured. 80% of earthen and brick masonry buildings collapsed or were damaged.

FIGURE 4. Near total destruction of the 220 kV Ertaishan Substation, Yingxhou in the 2009 M7.9 Sichuan, China earthquake.

FIGURE 5. Partial view of the interior of three vertically stacked school rooms in a collapsed middle school in Dujiangyan; 2009 M7.9 Sichuan, China earthquake.

FIGURE 6. Collapsed ground floor of a hospital building in Mianzhu, 2009 M7.9 Sichuan, China earthquake.

These four recent earthquakes (and most others in East Asia and the Pacific) occurred in regions with well-documented long histories of destructive earthquakes. All demonstrated that, among public buildings, schools and hospital buildings in East Asia and the Pacific are especially vulnerable given their lack of adequate (if any) seismic design and/or construction. Much of the critical infrastructure of the affected regions was also damaged severely and extensively.

All of this occurred in countries with well-developed capabilities to assess and reduce existing risk and to design and construct earthquake resistant buildings of the highest quality.

Turkey is another country that is subject to frequent and destructive earthquakes. The 7.4 1999 Marmara earthquake near Istanbul and Izmit, and the nearby1999 Duzce (M7.2) earthquake are just two of the more recent destructive earthquakes to strike the country. The fatalities and casualties from both events exceeded 18,000 and 50,000, respectively. Both caused extensive damage in a country with advanced earthquake engineering capabilities, codes and practices. The newest structures in the affected region had some of the most extensive damage, including many collapses of modern multi-story buildings. The response of the Turkish government to the twin disasters of 1999 will serve as a model in this paper for recommended future actions by the governments of countries in East Asia and the Pacific.

Earthquakes in the East Asia and the Pacific region also have dramatic impacts on the private sector, and particularly on residential structures, especially larger apartment buildings and informal settlements, and on industry and the resulting business interruptions. Landslides, soil liquefaction and other ground failures have caused extensive damage and life losses in large earthquakes in the region. Tsunamis are also destructive, particularly in Indonesia and along the shores of the Indian Ocean and sections of the Philippines. These risks are not addressed specifically in this paper. However, the conclusions and recommendations in the paper can be easily extended to cover these and other risks that will continue to cause heavy life and financial losses in the region unless they too are addressed and managed more effectively.

CASE STUDY

The history of earthquake engineering and earthquake risk reduction in California (It takes time to learn what to do and then to do it. This is what East Asian and Pacific countries generally need to do, but in a shorter time frame and more efficiently.)

China, Indonesia and the Philippines all have advanced building codes for earthquakes, at different stages of development and enforcement. All three have advanced, state-of-the-art earthquake engineering, professional and academic practices. All have benefited from the experience of many other countries that also have strong earthquakes, and are active participants in the worldwide earthquake engineering and science professional community. China has taken a very active role in the past decade; other countries in the region need to take more active roles, particularly outside academia.

Earthquake science, and particularly earthquake engineering are relatively new professions. Their two main catalysts were the devastating and large 1906 San Francisco, California and 1923 Tokyo, Japan earthquakes. As the primary author of this paper is from San Francisco, California, the history of California will be used to illustrate the development of earthquake risk reduction in one of the countries that lead the field. Other countries that could serve as good examples are Chile, New Zealand and Japan.

The 1906 San Francisco earthquake stimulated the development of seismology (the science of earthquakes), earthquake related geology and earth sciences, and the application of earthquake design to structural engineering through research and testing and the development of earthquake regulations within the California Building Code. Then, in 1933 the moderate M 6.4 Long Beach (near Los Angeles) earthquake destroyed most of the schools in the City of Long Beach. These were mostly new buildings, designed to the then current earthquake standards. Fortunately, that earthquake occurred when schools were not in session, and there were no student casualties. The State of California legislature quickly passed new legislation requiring special earthquake designs for schools that for many years would exceed significantly the requirements for all other types of buildings. Ever since 1933, California schools have performed much better than any other types of buildings in the state in strong earthquakes. No school building has collapsed in an earthquake in California since then. Over the years, the Legislature also established a special state bureau to control the design and construction of all school buildings throughout the state. The office, or bureau, which is not large, is responsible to assure that the school buildings are designed properly, that the intent of the code is met, and that the buildings are constructed as designed and approved. That is done through a simple system of engineering design and third-party independent engineering review and construction supervision by both state and private-industry engineers. Private licensed and pre-qualified engineers do most of the plan checking and review for the state (or local) agency. The cost to the state is borne by construction permit fees that are charged to the owner. The system has proven to be effective with minimal corruption.

The very strong M 6.5 San Fernando earthquake struck the heart of the Los Angeles Metropolitan area in 1971. No public schools were destroyed, or even severely damaged, but the 3-month old, state-of-the-art 6-story reinforced concrete Olive View Hospital collapsed partially and was a total loss. The nearby, old, brick San Fernando Veterans Hospital collapsed completely, causing most of the deaths from the earthquake. Immediately following that, California's legislature passed new, much stricter requirements for the earthquake design of hospitals and organized another bureau within the state government to regulate the earthquake design and construction of hospitals. The bureau is similar to that for schools. The stronger M 6.7 1994 Northridge earthquake, in the same part of Los Angeles, caused no structural damage to the replacement Olive View Hospital, but damaged some of its critical building-service and medical equipment. After that, special new regulations were adopted in California for the protection of important equipment within hospitals so that they would remain functional after future strong earthquakes. All of these regulations for schools and hospitals are in a constant state of improvement, as engineers learn new applicable lessons from earthquakes around the world, including, for example, the recent M8.8 2010 Chile earthquake where many schools and hospitals, designed and built to criteria that are similar to and often exceed those in California, were affected.

FIGURE 7. The collapsed three month old main building of the Olive View Hospital, San Fernando (Los Angeles, California) M6.7 earthquake of 1971.

Advances in reducing the earthquake risk to infrastructure in the state followed a similar pattern. The M 7.7 Kern County earthquake of 1952 in south-central California caused extensive damage to power facilities. Some of the state's power companies, most of which were and are private, adopted the first simple requirements for earthquake protection of power plants and other facilities that went beyond the requirements of the Building Code for conventional buildings. Then, the 1971 San Fernando earthquake destroyed some of Los Angeles' new power transmission facilities (the Sylmar Converter Station) and new freeway bridges (overpasses) along California's most important road – Interstate 5. That prompted major changes in the earthquake design of both power transmission facilities and highway structures. And, following the massive damage to highway and other older bridges and viaducts in the M 6.9 1989 San Francisco (Loma Prieta) and M 6.7 1994 Northridge (Los Angeles) earthquakes, the State Legislature mandated the review and strengthening, as necessary, of all highway and other bridges in the State of California. Many billions of dollars have been spent over the last 20+ years to strengthen California's infrastructure to acceptable levels. Many thousands of bridges have been strengthened; some were simply replaced based on cost-benefit analyses. A prominent example of that is the eastern half of the famous San Francisco-Oakland Bay Bridge, whose partial strengthening and partial replacement is on going. The strengthening of the Golden Gate Bridge is also near completion, some 21 years after it was affected by the 1989 earthquake and more than 35 years after it was found to be dangerously inadequate in a large nearby earthquake. Massive programs for the reduction of earthquake risk takes many years, much patience, and some good luck to be successfully completed.

The 1971 earthquake also collapsed a moderately large dam structure, the Lower Van Norman Dam. Fortunately, the failed hydraulically filled 1915 structure did not collapse completely and release water. Over 80 thousand people had to be evacuated. Other dams had collapsed before in earthquakes, but none in the middle of a metropolitan area. The State of California organized another bureau and mandated the review and strengthening of all significant dams. Over the last 39 years most dams have been strengthened. Many were replaced completely.

Starting in the early 1970s, California also required the review and, when necessary, strengthening of existing school, hospital, and other important state buildings, including emergency facilities, police and fire stations. Codes had changed and improved and the older buildings needed to be updated, as necessary, to reduce the risk to levels compatible with new construction. Over the years, tens of thousands of structures have been strengthened to standards similar to, but not necessarily the same, as those for new buildings. The standards for strengthening are not the same as they account for the potentially higher costs of providing additional earthquake strength to old buildings when compared to the ease with which new buildings can be made stronger. The programs are still on going and will continue for several more decades until all vulnerable structures (and their key equipment and other non-structural features) are strengthened or replaced. New lessons will also be learned in future earthquakes and engineers expect that additional future strengthening work will be necessary.

Private industry, the State of California and the Federal Government, including the military, have also undertaken many programs to assess the existing risk to specific sectors of the economy and to reduce that risk through earthquake strengthening programs. Starting in the early 1980s, many companies in California, led by some in San Francisco's Bay Area and Silicon Valley, started to evaluate the risks to their buildings (including building contents, building service equipment, production equipment, inventory, etc.) and to reduce the risks though strengthening programs of existing vulnerable buildings and their contents. A major driver for spending valuable funds on strengthening older buildings and equipment was the realization that massive business interruptions could be reduced or eliminated and future production losses would be dramatically reduced and sometimes eliminated. The state, with support from the Federal Government, has carried out extensive earthquake risk reduction programs at California's universities, for example. Several campuses, each of which is in effect a fully functional and sophisticated city of 30,000 to 50,000 people, have been strengthened. The Berkeley campus is discussed in some detail elsewhere in this paper.

Other countries, notably New Zealand and Japan have embarked over the last 30 years on similarly ambitious earthquake risk reduction programs, particularly in the public sector. Fundamentally, these are earthquake loss-control programs. These programs were successfully tested in earthquakes in both countries – in the 2007 M6.7 Niigata, Japan earthquake and the 2010 M 7.1 Christchurch area, South Island earthquake in New Zealand. In the Niigata earthquake, undamaged and recently strengthened older public schools in the Town of Kashiwazaki were standing near collapsed older (and not strengthened) private buildings.

4. Key lessons and challenges for countrywide earthquake risk management

The key challenges in earthquake risk management and what to do about them are:

- Where and what the risks are and how strong is the shaking – update the earthquake hazard zoning of the country,
- How to manage risk with state-of the art building codes – update the codes to the latest knowledge and include requirements for the strengthening of exiting buildings,
- How to manage risk with adequate engineering and construction practices – improve the quality of engineering with proper training and licensing and tighten the inspection of construction and the construction materials,
- How to strengthen older and more vulnerable structures that were designed to older, outdated and inadequate codes (and the lack of earthquake requirements in some earthquake regions) – start strengthening vulnerable structures using the experience gained by other countries in reducing their risk through earthquake risk management programs like the ISMEP project in Turkey.

Governments in the region must take active roles in this process, and particularly in the understanding (studying and quantifying) and the reduction (management) of existing earthquake risk. That role is vital for reducing as quickly as possible and as much as possible major life and economic losses. Governments can start first with the public sector and most likely with public schools.

4.1. Earthquake hazardous areas and strength of shaking

Most, if not all, recent destructive earthquakes in East Asia and the Pacific have occurred in known earthquakes areas. That means one, more, or all of the following:

- The seismology and geology of the region were not understood adequately,
- The codes did not reflect the existing knowledge in seismology, geology, and geotechnical engineering (and structural engineering)
- The region did not adequately apply the requirements of the national codes to the local situation.

The earthquake hazard, especially the strength of the shaking, in most countries is underestimated. China is a clear example. Of the 14 strongest earthquakes that occurred in China between 1949 and 2009, 11 occurred in regions where the hazard and the strength of shaking were previously underestimated. For example, the buildings in Beichuan in the 2008 earthquake were designed by code for intensity (strength of shaking) of VII, but during the earthquake, the intensity reached XI. That is at least three times stronger shaking and that is why so many buildings collapsed.

All countries in East Asia and the Pacific need to reevaluate the adequacy of the mapping of earthquake hazard (strength of shaking) in the codes. Well-known earthquake areas, based on historical data, are not adequately covered by the earthquake requirements concerning strength of shaking in most countries. This is critical if the most hazardous areas are to be addressed first. Historically, the most hazardous areas are areas with long earthquake history that continue to be zoned incorrectly within the codes. That was, for example, the case with the moderate but destructive M6.3 L'Aquila, Italy earthquake of 2009.

Various types of ground failure cause much of the damage in earthquakes. For example, much of the damage in the 1990 Philippine earthquake was due to foundation failures due to liquefaction – a type of ground failure in water saturated sandy soil. That affected buildings, roads and bridges, ports, etc. Landslides caused substantial damage and life loss in the 2008 Wenchuan, China earthquake. Much of the damage in large Indonesian earthquakes is caused by tsunamis. All of these hazards need to be understood and mapped and are part of any comprehensive risk analysis.

4.2. Adequacy of the building codes and their enforcement

Building codes are based on our knowledge of seismicity, geology, geotechnical and structural engineering. Every strong earthquake teaches us new lessons – where earthquake occur, which type of structural designs and which details are inadequate, what innovations in engineering and construction are not covered adequately by the existing codes, what non-structural details and equipment are not adequately covered by the codes, etc.

In the Philippines, for example, the structural code revision of 1992 introduced significant provisions to anticipate soil liquefaction potential. Meanwhile, structural detailing for ductility was emphasized, especially for reinforced-concrete structures. In the subsequent code revision in 2001, earthquake fault maps were introduced, together with provisions for near-field earthquake effects. The latter revision, it may viewed in retrospect, was hastened by a major government fault-mapping project, substantially updated by the year 2000, as well as the 1995 Kobe, Japan earthquake that provided another grim reminder of the hazards of faults that cross highly urbanized areas (such as Manila).

Building codes, by their nature are evolutionary and need to be updated constantly. All countries, worldwide, have to keep up with this evolution, which is often based on lessons in distant, but also earthquake-prone, countries. All governments in East Asia and the Pacific can and should improve the earthquake requirements of their codes and need to do a much better job of updating them when it comes to earthquakes. China, Indonesia and the Philippines, for example, are building very tall buildings in earthquake areas, yet their codes were not specifically written for such buildings. The codes do not account, for example, that some of these buildings have thousands of occupants, yet they are designed for earthquakes to the same standards as low-rise small buildings, except perhaps for a stricter requirement for design review for complex high-rises according to some codes, such as the Philippine code. It is arguable, however, how much or how well this is implemented. California also shares the same problem. The codes were never designed specifically for high-rises. That needs to change.

Many of the existing older buildings in the region were not designed with any earthquake provisions. For example, China's first required earthquake regulations were not officially issued until 1974. That code was quickly revised following the 1976 Tangshan earthquake and some long-term strengthening programs were initiated. The code was revised again in 1978, 1989, and following the 2008 Wenchuan earthquake, in 2010. Besides, the actual implementation in construction may be in question for many or most mid-size structures.

To start with, the codes in all countries are intended to protect human life, even in the largest earthquakes. They are not designed to protect against financial losses or to provide functional buildings in very large earthquakes. That is why, for example, schools and hospitals in California, are designed to higher standards than other buildings. All countries in East Asia and the Pacific need to reevaluate their codes to ensure that they provide additional life-safety and investment protection, as needed, for critical buildings, systems, and infrastructure. This is particularly important in the fast-growing economies of the region.

Providing a high level of earthquake design is not as expensive as most people and organizations think. Most of the cost of earthquake design is in making the structural frame more robust. The structural frame itself is a small portion of the overall cost of a completed building – usually it is between 10% and 20% of the total cost for more complex and larger buildings. Most of the cost in a building is in its architectural features and finishes, furnishings, and equipment systems. The added cost for earthquake design of the frame may be 20% of the cost of the frame. Most of that cost in East Asia and the Pacific would be for additional materials such as extra reinforcing steel and concrete. Thus, the earthquake protection in the building may cost between 2% and 4% of the total cost of the building. Adding additional strength to a building, as in the case of schools, would increase the cost proportionally even less. The cost of protecting most of the architectural features and the equipment is trivial when compared to the cost of the entire building, particularly in countries with lower labor costs.

Some of the codes in the region include requirements for the strengthening of existing buildings for earthquakes. Typically, the codes do not have such requirements, particularly if they are enforced at the local level. All countries in the region should have such requirements. They can be developed in two different ways: (1) as part of the building codes themselves, or (2) as separate guidelines that are required to be used for the strengthening of existing buildings.

Successful earthquake risk management is not possible without good enforcement of the requirements of the building codes. That includes engineering design and construction. Better enforcement of the building codes in earthquake prone areas is required across the entire region of East Asia and the Pacific. Much, if not most of the recent damage and life loss in newer structures in the region from earthquakes happened because of the inadequacy of government enforcement of code requirements at the local, regional, and countrywide levels. Successful performance in earthquakes requires good engineering design and good quality of construction and the construction materials. The only way that can be achieved is through government enforcement. Different countries around the world have used somewhat different systems for that control, but the most successful applications include (1) the training and licensing of professional engineers and (2) the tight control of the quality of engineering and construction. That is especially necessary in the public sector and can be accomplished over a reasonably short time frame.

4.3. Earthquake risk to (1) buildings and their contents and (2) critical infrastructure and its equipment in East Asia and the Pacific

All recent and large earthquakes in East Asia have demonstrated that much of the building stock and the critical infrastructure of the region are highly susceptible to earthquake damage. That is the case with recent earthquakes in the Philippines, Indonesia and China, and it is the case with both older and many new structures. Non-structural items and equipment have proven to be even more vulnerable as most of the building codes still do not include requirements for their protection. It is estimated that as much as half of the direct damage and business interruptions in the 2010 M8.8 Chile earthquake was caused by damage to inadequately braced non-structural features and equipment.

As discussed briefly above, old and recent experience with strong earthquakes throughout the world indicates that much of the public infrastructure is vulnerable. The following have proven to be some of the most vulnerable classes of buildings and infrastructure. Based on experience, these are the classes of existing and vulnerable buildings and other structures that should be strengthened first in the public sector in East Asia and the Pacific. Similar work has already been completed in several countries.

4.3.1. Buildings and their contents

Schools tend to be some of the most vulnerable buildings, if not the most vulnerable, in strong earthquakes. From an architectural and an engineering perspective, the main reason is that school buildings tend to have large rooms and many large windows. They have many fewer interior walls than apartment buildings, for example, that have small rooms encircled by many more walls. For that reason, schools in the 2008 Sichuan, China earthquake, collapsed whereas adjacent apartment buildings stood up. Both were designed and built to similar standards. Because of their architectural and structural simplicity, school buildings are also relatively easy to strengthen. They are probably the most cost effective buildings to strengthen.

Hospitals and other medical buildings and their equipment have proven to be some of the most damageable public and private buildings. Like schools, they tend to have larger rooms and fewer walls, but they also have more complex architectural geometries and tend to be larger and taller than schools. Further, hospitals contain much medical and other equipment that needs to be protected so that the hospitals remain functional after a destructive earthquake, when they are needed most. These are the most needed public buildings in the aftermaths of strong earthquakes.

Critical government buildings, such as Emergency Response Centers, police stations, and fire stations must remain functional after strong earthquakes. In East Asia, as in much of the rest of the world, these facilities were and are usually designed to the same earthquake standards as conventional buildings. Fire stations, in particular, have proven to be highly susceptible to earthquake damage because they often house the fire engines and thus require very large openings in the walls to accommodate the parking of the engines. Further, the codes do not have adequate (or any) requirements for the protection of the critical equipment (electrical, mechanical, electronic, communication, etc.) that is housed in such structures and needs to remain functional. City Halls (and similar government buildings) are another class of structures that are usually needed after destructive earthquakes and most countries with advanced earthquake risk reduction programs, as discussed above, have strengthened such structures. These tend to be more expensive to strengthen, as they are typically one- of-a-kind, are larger and are often historic buildings.

4.3.2. Critical public utility infrastructure and equipment

Countywide, and most citywide earthquake risk reduction programs include the assessment and strengthening of much of the public utilities infrastructure. Functional infrastructure is necessary for recovery after a major disaster. Interruptions of services as well as the direct damage to infrastructure typically contributes on the order of 50% of the overall financial losses from a major earthquake in an urban area. For those reasons, the strengthening of infrastructure, as needed, is expected to be a key component of any public earthquake risk management programs.

Highways and bridges (and other related structures) always suffer major damage because some are always located in the most affected areas of an earthquake. Bridges, in particular, are more vulnerable and tend to suffer disproportionate part of the overall damage. They are typically located in areas with poorer soils, such as rivers, which tend to amplify the ground motion. Bridge design has been greatly influenced by the damage observed after earthquakes and has changed dramatically over the last three decades. Much of that knowledge is not yet commonly applied in East Asia. Several countries, like California, have already strengthened most of their bridges. The Philippines, for example, has implemented, in the aftermath of the 1990 Luzon Earthquake, a foreign-loan assisted earthquake retrofit program of hundreds of bridges. Arguably, this effort has covered only a small fraction of all infrastructures. The technology can be easily replicated elsewhere.

Airports, and especially major airports, tend to be vulnerable because of their architecture, size, and dependence on equipment to remain functional or to be brought back into service quickly. Some of the most modern airports in the world have suffered disproportionate amounts of damage in recent earthquakes. Santiago, Chile, International Airport, a brand new and modern airport, was shut down for an extensive period of time because of massive non-structural and equipment damage in the 2010 earthquake. The structures themselves were not damaged significantly.

Electric Power Systems are critical for the return to normalcy in urban areas after strong earthquakes. Typically, the structures of power facilities such as generating stations, because of the nature of their designs, tend to be relatively earthquake resistant. However, most of the equipment needed to run the electric system is not protected in East Asian countries. That was demonstrated in all of the earthquakes discussed in this paper. The most vulnerable components of the system are the substations and their ceramic components. The most vulnerable components of generating stations tend to be the ones that are easiest to strengthen but are usually unprotected – the emergency power generating systems and electrical equipment that is not properly braced. Bracing this equipment is probably the most cost effective strengthening possible anywhere for all types of infrastructure.

Water and Wastewater Systems, like power systems, are needed to return a stricken area quickly back to functionality. The plants themselves tend to be more robust than most public infrastructure. However much of the equipment is inadequately protected. It can be braced at a very moderate cost. Underground piping tends to suffer disproportionate damage in urban areas with softer soils (as is the case with most urban areas in East Asia) and is difficult and more expensive to strengthen.

Telecommunication Systems have undergone major changes over the last three decades. From an earthquake engineering perspective, the overall risk situation has improved because new equipment is much smaller and lighter and new buildings are smaller and therefore easier to strengthen if the codes under which they were built are inadequate. The systems require much more protection; the codes do not often have any specific requirements for the protection of equipment in earthquakes. Much of that protection is easy to install and is very cost effective. Telecoms are both private and public systems; they both need to be upgraded for earthquakes.

4.4. Earthquake scenarios and prioritization

Many organizations in the public and private sectors around the world have found it useful to develop scenarios of what would be expected to happen in strong earthquakes in a given area. A multi-year study that ended in 2004 has simulated in detail a M7.2 earthquake scenario in Metropolitan Manila. As yet, however, major structural strengthening programs have not been triggered by that study.

Engineers and scientists conduct these studies in order to estimate the expected effects of major earthquakes, typically in metropolitan regions. Organizations, such as an electric power utility, conduct the study to understand what can happen specifically to their system. Many earthquake risk reduction programs have started after earthquake scenario studies indicated that major losses are expected unless strengthening programs are initiated. For example, the University of California conducted such a study for the Berkeley Campus. Buildings were rated in order of overall risk, based on criteria involving level of risk to the building, number of occupants (in a 24-hour period), function of the building, financial impact from the loss of the building, etc., before any strengthening programs were initiated. The results of the studies also tend to be helpful in gathering public and political support for risk management. Such studies can be done at a very moderate cost in a short time frame. The initial studies can be simple scenarios; later and more advanced scenarios can be probabilistic

5. Principles of earthquake risk management – developing regional and countrywide earthquake risk assessment and risk reduction programs

Earthquake risk assessment and risk reduction programs typically are structured as multi-phased, long-term programs. In California, for example, both the public sector and the private sector have typically initiated programs consisting of three phases. The programs can be citywide or statewide and administered by local or state government organizations. The typical three phases are:

1. Risk audit of a specific sector, like public schools or bridges.
2. Detailed risk assessment including cost-benefit analysis for the particular sector and prioritization of the assets to strengthen.
3. Implementation – reducing the risk through strengthening of the prioritized buildings and non-structural features and equipment systems. This is mostly construction and is usually about 90% of the total cost.

In addition to the three phases above, countries that are just starting earthquake risk reduction programs in the public sector typically also have to initiate programs, at the government level, to address the various factors that have led, over time, to worsening of the earthquake risk in their country. In Turkey, for example, many if not all of the newer buildings that collapsed in the 1999 earthquakes simply did not meet the requirements of the building codes. The problem was caused by lack of enforcement of the code – both the engineering designs and the construction were inadequate since no one seemed to be checking anything in much of the affected area, including whether the engineering designs met the code requirements for earthquake resistance or the construction was of adequate quality. A further serious problem in the case of Turkey is that there is no professional registration for structural engineers. That is a country-specific issue. Anyone that graduates with a degree in Civil Engineering from the country's universities can immediately sign design drawings. In California, for example, graduate engineers are required to obtain licenses, which involve testing on the subject of earthquake resistant design, before they can sign structural drawings. Young engineers typically practice design under the direction of licensed and experienced engineers for several years before they take their professional examination. The licensing process is supported by the profession and is enforced by the State of California. Detailed courses are offered to accelerate the learning process. Such courses can easily be set up through either professional societies or universities in all East Asia and Pacific countries, as was recently done in Turkey. In the Philippines, a specialty association of civil-structural engineers has existed since 1961 and has been assisting the national government in updating the structural code. Its association of civil engineers has also, more recently, been certifying specialist structural engineers. Both associations have been proposing to the government and the private sectors to require specialist structural engineers in the design and construction of large or complex structures. Other, similar issues must be addressed in different countries in East Asia and the Pacific to resolve the long-term issue of increasing earthquake risk because of increasing population and inadequate new designs.

Phase 1 - the **Risk Audit** is a risk analysis, or more simply, a risk assessment to determine the severity of the problem – for example, how much damage would occur to schools in a given city in a strong earthquake whose size and strength of shaking is based on a realistic assessment of the local seismicity and geology? Which schools, specifically, would be damaged and what will be the extent of the damage? In many cases this would be a relatively simple and inexpensive analysis as in many cases in East Asia, none of the schools would have significant seismic design and would be expected to suffer extensive damage. The risk audit then must estimate the extent of the potential damage and rate the schools so that the most vulnerable and damage prone (dangerous) buildings will be strengthened first, or possibly rebuilt entirely. This audit can be conducted in a matter of a few weeks to months at a relatively low cost.

The risks are identified using state-of-the-art screening methods, risk assessment and analysis technology, and engineering experience. The screening and analyses are also based on Earthquake Experience Data collected worldwide from recent earthquakes on the types of structures of interest. The structures are then rated in order of priority for strengthening. It is absolutely necessary to involve the owners of the buildings (e.g. a Ministry of Education) as they know best their assets and the various impediments that would have to be overcome to arrive at a politically acceptable and a cost effective solution in a reasonable amount of time.

In **Phase 2**, the **Detailed Risk Assessment and Cost-Benefit Analysis**, preliminary recommendations for strengthening important buildings and key equipment are developed. An engineering and business analysis will be performed to evaluate the costs and economic benefits associated with such upgrades and the resulting decrease in risk. In the case of schools, for example, this would simply determine the criteria to what levels of earthquake resistance the existing schools would be strengthened. Should the schools be strengthened so that they will experience absolutely no damage? That would be a very expensive proposition. Should they be strengthened to allow non-injury threatening damage, such as cracks in walls and damage to finishes of non-structural items (tiled walls in bathrooms) that can be fixed in a few days? That would be a much more cost effective solution and would allow the strengthening of more schools under the given program budget. It is also usually more cost effective to strengthen existing school buildings than to entirely rebuild them. Generally, experience shows that 5 to 7 schools can be strengthened for the cost of a new building. The intent of this phase is to optimize the number of strengthened structures under the expected budgets while meeting the selected criteria for the performance (extent of damage and business/mission interruptions) of the buildings.

Large programs, where many similar buildings are strengthened have a big cost advantage because the project engineers, after handling a relatively small number of buildings, quickly optimize the overall program based on their newly acquired experience and the guidance of their international consultants.

The third and final Phase of the Earthquake Risk Management Program is its **Implementation**. This is the expensive phase of earthquake risk management – the final engineering design of the strengthened buildings and their contents and equipment, as appropriate, and the actual construction. Typically, the construction cost is on the order of 90% of the total cost. Engineering, administration of the program, field inspections, etc., make up the remaining 10% of the total program cost, including all three phases.

As discussed below, international strengthening programs have typically used international engineers to help direct the risk management programs, especially in the evaluation of the existing risk and the design of the retrofits. These project consultants should have extensive international experience with earthquake damage and earthquake design and should have completed numerous similar projects. The costs of such consultants are offset very quickly because their experience prevents costly mistakes and the repetition of lessons already learned the hard way. This is discussed further below. The second major reason for engaging international consultants is technology transfer. These individuals and/or companies are the best and lowest priced access to international experience and technology transfer, particularly for larger projects.

Again, larger programs have proportionally smaller costs, as discussed above. As more and more buildings are strengthened, the prices charged by the contractors (builders) tend to decrease as they also gain experience. Tight control and the size of the program resulted in very large cost savings for the "best practices" project in Turkey discussed below.

6. BEST PRACTICES

The Istanbul Seismic Mitigation and Emergency Preparedness Program (ISMEP) – an example of a successful and on-going earthquake risk management program

Following the destructive 1999 earthquakes in Turkey, the government of Turkey initiated a wide-ranging program to reconstruct the damaged area. One of the main projects was the World Bank-funded Marmara Earthquake Emergency Reconstruction Project (MEER). The government also realized that nearby Istanbul, Turkey's largest city with a population exceeding 20 million, faced the same problems as the affected area. The extent of the expected damage, however, could easily exceed the damage and casualties of the 1999 earthquakes by on order of magnitude. Other large cities in Turkey face the same risks. An example program was needed to kick start the process of reducing existing earthquake risk in Turkey.

6.1. Overview of the risk

More than 20% of Turkey's population lives in Istanbul and the city metropolitan area generates an even larger portion of Turkey's GDP. The city has grown rapidly in the years after the 1999 earthquakes. It has seismicity that is comparable to California and Japan and, as in those areas, there is a high probability of a major earthquake occurring in the next 20 to 40 years. If the city is not prepared, such an earthquake will cause high casualties and tremendous economic losses

6.2. ISMEP project scope and organization

To address the vulnerability of public buildings in Istanbul and to reduce the devastation that could occur in the next major earthquake, the Government of Turkey and the World Bank initiated the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The first engineering assessment and preparation mission for the project was conducted in October of 2002 by the author of this paper. The World Bank-financed project is implemented through the Istanbul Special Provincial Administration (ISPA). A separate government unit, the Istanbul Project Coordination Unit (IPCU), was especially established for the project under ISPA and is responsible for implementing the ISMEP. Primarily engineers and other professionals with earthquake engineering and related experience staff the unit. The ISMEP project started officially in February of 2006. It is expected to be completed by the end of 2014. The total original World Bank loan amount was about US$ 610 million. Overall funding, at the end of the project, including other sources, is expected to be much greater. The primary objective is to provide life safety performance for as many buildings as possible, using cost-effective strengthening. Other goals of the project include:

- Strengthening institutional and technical capacity of emergency management
- Increasing emergency preparedness and response awareness
- Strengthening/Reconstruction of priority public buildings
- Studying the inventory and the vulnerability of cultural and historical heritage structures and strengthening a few
- Providing support for the efficient implementation of real-estate development laws and building codes.
- Setting up training programs for structural engineers in earthquake engineering, and particularly for the strengthening of existing structures.

This paper is focused on the evaluation and strengthening of public buildings (item 3 above) under the ISMEP project.

6.3. Strengthening and Reconstruction of Public Buildings

6.3.1. Task organization:

First, the project developed (1) standards for the selection of structures to be strengthened, (2) procedures for the design and third-party review of the structural designs, (3) detailed procedures for quality assurance of design and construction quality, etc. In order to ensure successful strengthening and the use of state-of-the-art procedures from around the world, a collaborate effort between domestic (Turkish) and international engineering firms (New Zealand, USA, etc.) was established. This arrangement took advantage of the strengths of both groups. The local engineers are familiar with local design and construction practices and can readily identify vulnerable structures. The international consultants are much more experienced with strengthening of existing buildings and are better versed in the art of seismic rehabilitation and can more readily identify deficiencies in proposed retrofits, given their experience with many diverse projects elsewhere.

6.3.2. Strengthening (Rehabilitation) Guidelines

The project included the development of (1) comprehensive structural engineering strengthening guidelines and (2) guidelines for their implementation. The guidelines are based on the provisions of the Turkish code with input from ASCE 41(U.S. guidelines). While the Turkish code is written for new construction, the Guidelines are intended for strengthening work. In order to ensure the strengthening encompasses as many structure as possible, the Guidelines are less stringent than the Turkish code and a certain level of damage is deemed acceptable in the provisions.

The guidelines are written to be easy to follow and implement. The engineer for a specific building or groups of buildings is charged with condition assessment, followed by analysis and determination of deficiencies. Both conventional and state-of-the-art strengthening measures are discussed in detail. The implementation phase relies on local engineers and international experts to work together and identify suspect building inadequacies using construction documents, analysis and evaluation tools, and site visits. The key provisions of the Guidelines are:

- **Condition assessment**: Data are to be gathered in sufficient detail to identify structural and nonstructural components that are critical for optimizing earthquake resistance. As-built condition evaluation should utilize construction documents and testing among other resources.
- **Seismic deficiencies**: Common structural deficiencies, such as an irregular configuration, non-ductile reinforcement detailing, and rigid unreinforced masonry infill walls are identified.

- **Seismic hazard (strength of the earthquake shaking)**: The level of earthquake design is expressed in terms of design response spectra or suites of acceleration histories. The hazard due to earthquake shaking is defined on either a probabilistic or deterministic basis.

- **Analytical procedures**: The use of acceptable procedures, ranging from simplified static to nonlinear dynamic analyses, is allowed based on the building properties, configuration and proposed strengthening scheme.

- **Structural performance levels**: Various performance levels are defined and the level of damage for each level is described. The appropriate performance level for a given earthquake intensity is identified.

- **Strengthening**: Both conventional and innovative techniques are described and their proper use and application are elaborated.

6.4. Implementation

Throughout the project, the international consultants work closely with the local engineers. Technology transfer is and has been an important feature of this project. To ensure the strengthening is properly designed and constructed, the international consultants review both the design and the actual construction. They also often participate directly in the engineering designs. Their findings are submitted to IPCU as individual project reports. In the design phase, structural plans and calculations are reviewed to ensure that the strengthening design is effective. In the construction phase, the consultants visit the site to survey the retrofit work first hand.

In addition to the reviews at the design level, two additional design reviews are conducted. A World Bank earthquake-engineering consultant reviews the general quality and direction of the project work while an earthquake-engineering consultant to the IPCU reviews further many specific projects. The IPCU spends much of its time assuring the quality of both the designs and the construction. This redundant system for quality assurance is a primary factor in the success of this complex and large project.

It is projected that by the end of calendar year 2010, over 620 school, hospital and other buildings would have been evaluated and strengthened or reconstructed. That number will go up to about 1,100 buildings by the end of 2014. The bulk of the effort has been and will continue to be concentrated on schools and hospitals. If it is assumed that the schools have roughly 2,000 students and staff per building, that means that already the project has protected the lives of more than 1,200,000 students and their teachers. If it is assumed that each family of a student has four people, then the project has already affected directly the lives of about 5 million people in Istanbul.

FIGURE 8. Three school buildings under construction in Istanbul. All are completed today. Additional reinforced concrete walls are being added to strengthen the buildings.

It is also noteworthy that roughly between five to seven school buildings can be strengthened in Istanbul for every single building that is rebuilt completely. So, strengthening has proven to be very cost effective. Also, in a typical strengthening of a school about 50% of the budget goes into the actual strengthening (structural work) and 50% is expended on reconditioning the school. Thus, at the end, the schools are effectively new buildings with new plumbing, electrical and mechanical systems, new bathrooms, mostly new architectural finishes, new exterior thermal insulation, etc. Hospitals have proven much more difficult. The buildings can be strengthened and the cost is typically a fraction of the cost for new construction for reasonably modern, reinforced concrete buildings. The real cost, however is in hospital equipment, other non-structural features and business interruptions. While a typical school can be temporarily evacuated and completed in 4 to 6 months, hospitals cannot be evacuated without major interruptions in service. This is the primary reason why ISMEP has strengthened so many school buildings as compared to hospital building. ISMEP has much valuable data on all of this, including detailed cost evaluations, cost benefit analyses, etc.

6.5 Technology transfer

The ISMEP Project has had another important success – the various international consultants engaged in the project worked with the ISMEP staff and all of its Turkish engineers and contractors and transferred much of their technology. That occurred naturally during both the design and the construction processes. Today, there are many experienced Turkish engineers and contractors who have designed and constructed successful earthquake strengthening projects to the highest international standards.

7. Other “Best Practices” Examples

Two other major and ongoing projects are summarized below. Much additional and detailed information on both can be obtained from the University of California, Berkeley and from the World Bank and the Government of Romania.

The **University of California’s Berkeley campus** is a complex, small city with a population of about 30,000 students and a large faculty, administration, and support community. The campus is on hilly terrain and contains particularly complex systems for running its varied operations. The campus actually straddles one of California’s main earthquake faults – the Hayward Fault, a branch of the larger and famous San Andreas Fault. The Berkeley Campus, which dates back to the early 1870s, thus faces one of the highest earthquake risks in the world. The fault can generate an earthquake with a magnitude in the low to mid-sevens. The probability of such an earthquake is believed to be one of the highest known through a major area – on the order of 1 to 2% per year. That probability, for example, is comparable to that for Istanbul, Turkey. The campus could be considered to be a mini-version of Manila, Philippines, which is also crossed by active faults and contains a widely varied mixture of old and new buildings. The surrounding City of Berkeley, with a population of about 110,000 has also implemented a wide-ranging earthquake risk reduction program that, in itself would be an excellent “best practices” example but will not be discussed here.

With state and federal funding, the campus has been transformed over the last 30 years. Structural strengthening of some of the oldest and most dangerous buildings (unreinforced masonry/brick) on campus began in 1978. In 1997, the University created the Seismic Action plan for Facilities Enhancement and Renewal (SAFER) as a comprehensive, long-term framework for devoting more resources to strengthening or replacing vulnerable buildings. By 2006, half of the total floor space identified in SAFER as needed retrofit was strengthened, to various standards depending on occupancy, etc. About 75% of the work will be completed by 2011. Most existing buildings have been strengthened, some at great expense because they are also historical buildings and could not be easily strengthened without affecting their historical architectural features. Many buildings built in the 1960s and 70s were also strengthened, illustrating the progress made in earthquake engineering over the last several decades. Numerous multi-story dormitory buildings were found to be very risky and were strengthened, reducing very substantially potential future life losses to students, faculty, and administrators. The retrofits include a variety of state-of-the-art techniques methodologies for providing additional protection to existing buildings of many types. The campus has become a laboratory for the implementation of the latest techniques for strengthening of buildings. The work continues and hopefully will be completed before the next major earthquake on the Hayward Fault.

The **Romania Hazard Risk Mitigation and Emergency Preparedness Project (HRMEP)** is a large project, funded jointly by the Government of Romania and the World Bank in 2003 to reduce the risk from natural hazards throughout Romania. Component B1 of the project addresses the strengthening of key buildings and infrastructure in Romania’s earthquake regions. The project is generally similar to Turkey’s ISMEP project but has a broader scope with smaller funding. To date, several dozen key buildings throughout Romania have been strengthened; several are nearing completion and the project should be completed by 2011. Several public buildings each from several Ministries of Romania, including Education, Public Health, Defense, etc., were selected for strengthening. The project aims to reduce risk while setting examples of state-of-the-art strengthening techniques of all types for different types of public buildings. This ranges from historic buildings to relatively new government buildings needed for emergency response. The inventory of strengthened buildings includes school and university buildings, hospitals and related buildings, emergency response buildings, fire, police and military buildings, city hall buildings and other important municipal buildings. An on-going sub-project is studying the risk from earthquakes to the nation’s power grid and system and major energy infrastructure components, including oil and gas.

Engineered Confined-Masonry Buildings are masonry buildings (typically un-reinforced brick) built with reinforced concrete frames that are poured in-between the bricks, thus providing interlocking and some continuity in the structures. This is by far the most inexpensive type of earthquake resistant construction that has performed well in strong earthquakes. When properly designed and built, one and two story buildings of this type performed very well in the 2010 M8.8 Chile earthquake, even in areas that experienced very strong and long shaking. This type of buildings has been popular in Chile since the late 1930s and has repeatedly performed well. It appears that confined-masonry could be a good solution for inexpensive residential and small commercial buildings in the less developed areas of East Asia and the Pacific.

8. Summary and main conclusions

It is only a matter of a few years before the next major earthquake strikes East Asia and the Pacific. It is only a few decades, at most, before a major earthquake strikes near a metropolitan area. The region is generally not prepared for such an event but much can be done before a disaster strikes.

Recent earthquakes throughout the region have shown that critical public (and private) buildings and infrastructure are vulnerable to major damage and collapses. That includes both older and new structures.

With the exception of Japan and New Zealand, the countries of the region have initiated limited programs to strengthen and protect older, and many new buildings and infrastructure. One of the largest programs is the strengthening of several hundred bridges in the Philippines following the 1990 Luzon earthquake. China, following several destructive earthquakes since 1976 has strengthened to various criteria buildings with over 220 million square meters.

Other regions of the world have a similar history but have, over the years, initiated legislative actions, beyond building codes revisions, to reduce the effects of future earthquakes. In effect, they have begun to practice countrywide earthquake risk management. California serves as an example, where over the last several decades the codes have been continuously upgraded to reflect the lessons of damaging earthquakes, as have the countries of East Asia and the Pacific. However, California has also mandated and financed the strengthening of key public buildings and infrastructure and particularly hazardous private structures and is currently taking the same approach with hazardous private sector structures. Over the last several decades the risk to the public sector in the state has steadily decreased. The same can be accomplished everywhere else, including East Asia and the Pacific.

The challenges for countrywide earthquake risk management and their solutions involve the following:

- Recognizing where the risks are – what are the areas most likely to be affected by the next potentially devastating earthquake

- Assuring that the building codes are up to date both for new construction and for existing construction that needs to be strengthened

- Assuring that (1) the practice of design engineering and (2) the construction itself meet the requirements and the intent of the codes

- Obtaining the funds to strengthen what needs strengthening

- Conducting strengthening programs, starting with simpler, focused programs concentrated in one metropolitan area.

Both history and engineering assessments and analyses find that the following public buildings and infrastructure and their key non-structural features and equipment are highly vulnerable and could or should be strengthened first:

- Schools, hospitals, and critical government buildings such as fire stations and other buildings needed for emergency response

- Public infrastructure, including key highways and bridges, airports, electric power generation and distribution systems, water and wastewater systems, and telecommunications.

Countrywide earthquake risk management programs involve risk assessments, followed by multi-phased risk reduction programs that can take from a few years to decades to complete. Such programs have been successfully carried out in several countries. The successful programs typically consist of three phases:

1. Risk audit of a specific sector, like public schools.
2. Detailed risk assessment including cost-benefit analysis for the particular sector.
1. Implementation – reducing the risk through strengthening of the structures and bracing their important equipment and other non-structural components.

Following two destructive earthquakes near Istanbul in 1999, the government of Turkey, with funding, guidance, and direct assistance from the World Bank, initiated in 2006 a major earthquake risk management program – the ***Istanbul Seismic Mitigation and Emergency Preparedness Program (ISMEP)***. ISMEP is one of several such recent projects that can serve as an example of a successful program for the management of public earthquake risk in East Asia and the Pacific. The program is multi-faceted, but its major component is the strengthening and reconstruction of priority public buildings. The government set up a new unit, the Istanbul Project Coordination Unit (IPCU) to manage the program, with assistance from experienced international experts. To date the project has completed the strengthening, reconstruction, and renovation, of over 620 school, hospital, and other buildings that were found be very high risks in future earthquakes. By the end of the current project in 2014 more than 1,100 such buildings will be strengthened and/or rebuilt. This affects directly the safety of over 1,200,000 students and their teachers. The project has recently received much additional financing from several other sources for a greatly expanded scope. It is an excellent example for other countries to follow.

9. Recommendations – Future Action Plan

Based on the above history, analyses and recommendations, a recommended implementation plan for earthquake risk management, including short to long-term actions is as follows:

Short term (as soon as possible or 1 year):

1. Initiate at least one narrowly focused earthquake risk reduction program for maximum impact on potential life losses in the public sector in a major metropolitan area – possibly start with schools, hospitals, and power generation and distribution systems.
2. Assess integration of earthquake risk assessments and risk reduction into infrastructure investments
3. Review and update existing building codes and their enforcement, specifically for earthquakes
4. Conduct a critical review of national earthquake risk reduction policies and laws.

Medium term (the next 5 years):

1. Complete one large but narrowly focused earthquake risk reduction program for maximum impact on life losses in the public sector as a dem-

onstration project. The ISMEP program in Turkey is a good example.

2. Demonstrate that cost-effective strengthening options are available for vulnerable structures and gain public support – schools are easiest
3. Redefine the earthquake hazardous areas
4. Redefine tsunami hazardous areas; improve tsunami warning systems
5. Update the codes
6. Strengthen enforcement of the codes and construction quality inspection
7. Conduct training programs for structural engineers in earthquake risk analysis and risk reduction. Training programs for contractors and the trades would also be very useful.
8. Mandate professional registration for structural engineers, particularly in the earthquake hazard areas of each country.

Long term (5 to 10 years)

1. Initiate long-term earthquake risk reduction programs to impact all key public sectors
2. Support/initiate long-term earthquake risk reduction programs for the highest risk private structures
3. Support/initiate long-term earthquake risk reduction programs for the highest risk industries and maximum financial impact
4. Pass legislation to require strengthening of private sector structures and infrastructure with or without public financing but with incentives.

10. References and Credits

American Society of Civil Engineers, ***ASCE 41, Seismic Retrofit of Existing Buildings***, Virginia, USA, 2006

Comerio, M., Tobriner, S., Fehrenkamp, A., *Bracing Berkeley, A Guide to Seismic Safety on the UC Berkeley Campus,* PEER 2006/01 Report, Pacific Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, USA, 2006

Earthquake Engineering Research Institute (EERI), *Summary Report on the Great Sumatra Earthquakes and Indian Ocean Tsunamis of 26 December 2004 and 28 March 2005,* EERI Report 2006-06, Oakland, CA, USA, 2006

Earthquake Engineering Research Institute (EERI), *Scenario for a Magnitude 7.0 Earthquake on the Hayward Fault,* EERI Report HF-96, Oakland, CA, USA, 1996

ELGİN, Kazım Gökhan, Director ICPU, Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, Istanbul, Turkey, Personal communications, 2010

EQE International, Inc., *The July 16, 1990 Philippines Earthquake, A Quick Look Report,* San Francisco, CA, USA, 1990

Federal Emergency management Agency, *FEMA 356: Prestandard and Commentary for Seismic Rehabilitation of Buildings,* Washington DC, USA, 2000

Global Risk Miyamoto Inc., *L'Aquila M6.3 Italy Earthquake, April 6, 2009, Earthquake Field Investigation Report,* Lafayette, CA, USA, 2009

Istanbul Project Coordination Unit (IPCU), ISMEP, ***G**uideline for Seismic Retrofit of School and Hospital Facilities in Istanbul,* Istanbul, Turkey, 2008

Kenneth, H., Elwood, J., Whittaker, A., Mosalam, K., Wallace, J., Stanton, J., *Structural Engineering Reconnaissance of the August 17, 1999 Earthquake: Kocaeli (Izmit), Turkey.* Report No. PEER 2000/09. PEER center, University of California, Berkeley, California, USA, 2000

Ministry of Public Works and Settlement, *Turkish Earthquake Code, Specifications for Structures to be Built in Earthquake Areas, and Appendix,* Ankara, Turkey, 2007

Miyamoto International Inc., *2007 West Sumatra Earthquake, Reconnaissance Report,* West Sacramento, CA, USA, 2007

Miyamoto, K., Gilani, A., and Wada, A., *Reconnaissance report of the 2008 Sichuan Earthquake, damage survey of buildings and retrofit options,* Proceedings of the 14th World conference on Earthquake Engineering, Beijing, China, 2008

National Information Service for Earthquake Engineering, The Earthquake Engineering Online Archive, PEER center, University of California, Berkeley

Pacheco, B.M., *Disaster Risk Management: Background of DMAPS for Infrastructure,* Philippine Engineering Journal, Vol. 28, No.2, 2007

Punongbayan, R.S., Rimando, R.E., Daligdig, J.A., Besana, G.M., Daag, A.S., Nakata, T., and Tsutsumi, H., *The 16 July 1990 Luzon Earthquake Ground Rupture,* Interagency Committee for Documenting and Establishing Database on the July 2990 Earthquake, Technical Monograph, Philippines, 2001

Technical Council on Lifeline Earthquake Engineering (TCLEE), *Wenchuan (Sichuan) China M 7.9 Earthquake of May 12, **2008***, Edited by J.M. Eidinger, Virginia, USA, 2008

United States Geological Survey, Circular 1193, *Implications* *for Earthquake Risk Reduction in the United States from the Kocaeli, Turkey, Earthquake of August 17, 1999,* Washington, D.C., USA, 2000

World Bank, *Marmara Earthquake Reconstruction Project,* Ankara, Turkey, 2007

Yanev, P., Miyamoto, H.K., Gilani, A., *Developing and Implementing City- and Country-Wide Earthquake Strengthening Programs for Vulnerable Structures,* Annual of the University of Architecture, Civil Engineering and Geodesy, Vol. XLIV, Sofia, Bulgaria, 2009

Yanev, P., Medina, F., and Yanev. A., *The Magnitude 8.8 Offshore Maule Region Chile Earthquake of February 27, 2010, Preliminary Summary of Damage and Engineering Recommendations,* World Bank, Washington, D.C., USA, 2010

Yanev, P. I., *Observations on Earthquake Risk and Engineering Practices in Istanbul, Turkey,* Report to the World Bank, Washington, D.C., USA, 2002

Yanev, P. I., Thompson, A.C.T., *Peace of Mind in Earthquake Country – How to Save Your Home, Business, and Life,* Chronicle Books, San Francisco, CA, USA, 2008

Ye, Yaoxian, *Sustainable Housing Reconstruction Following Wenchuan Earthquake,* Paper presented at Seminar on Integrating Disaster Risk Reduction into Disaster Recovery and Rehabilitation, September 27-29, 2010, Chengdu City, Sichuan Province, P.R. China

Ye Yaoxian, *Earthquake performance of strengthened structures,* Proceedings of USA-PRC Bilateral Workshop on earthquake Engineering, IEM, China, 1982

Ye, Yaoxian. *Seismic Strengthening of Existing Structures and Earthquake Disaster Mitigation,* Proceedings of US-PRC-JAPAN Trilateral Symposium on Engineering for Multiple Natural Hazard Mitigation, SSB, Beijing, China, 1985

Ye, Yaoxian. *Planning and Management for the Prevention and Mitigation from Earthquake Disasters in China,* International Seminar on Regional Development Planning for Disaster Prevention, Japan, 1986

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