GLOBAL BLUEPRINTS FOR CHANGE

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The Global Blueprints for Change contain guidance for working together to improve the capability to identify indicators of physical, social, enterprise, and environmental vulnerabilities throughout the world and to select and implement realistic solutions to reduce them towards acceptable levels.

Theme A: LIVING WITH NATURAL AND TECHNOLOGICAL HAZATRDS
Topic A.7: Improving Real Time and Near Real Time Communications

"Earthquake Alarm, Rapid Response and Early Warning Systems: Low Cost Systems for Seismic Risk Reduction"

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EARTHQUAKE ALARM, RAPID RESPONSE, AND EARLY WARNING SYSTEMS: LOW COST SYSTEMS FOR SEISMIC RISK REDUCTION

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Abstract: This Blueprint for Change is written from a global perspective. The aim is to provide guidance that will assist communities throughout the world in ongoing efforts to improve their capability for adopting and using real time communicating systems for the benefit of all sectors of the community.

Introduction

Natural disasters and in particular earthquake disasters are events, which are difficult to handle. Despite the fact that the technology exists to protect the population from earthquake catastrophes, there have been great problems in drawing public attention to the ever growing seismic risk in areas of low to moderate seismicity, where destructive earthquakes are very rare.

It has been realized that alarm, rapid response and early warning systems could be very beneficial in reducing loss of lives during a natural disaster. In particular, this has been a challenging task for earthquake protection as the pre-warning times are only a few seconds. Moreover, research in earthquake prediction has shown that we are still far away from the accurate prediction of the time, location and magnitude of strong earthquakes, which would be necessary to start with a timely evacuation of the endangered area.

The need for a seismic rapid response system was already realized in ancient China, as large natural disasters were the origin of political turmoil and change. The objective of the first seismograph built in China was to find out as quickly as possible where a strong earthquake has happened in order to direct aid and to prevent erosion in the thrust of the emperor. This problem has still not been solved satisfactorily, as it took almost one day for the responsible people in Tokyo to get a reliable picture about the extent of the earthquake catastrophe in Kobe in January 1995.

However, with the earthquake rapid response system operated by the National Weather Bureau in Taiwan, it was possible to get an accurate picture about the effect of the September 21, 1999 Chi-Chi earthquake within a few minutes, which allowed the swift launching of rescue operations. The efficient emergency management of this catastrophe has certainly saved quite a number of lives and has received international attention. This system is based on several hundred seismic stations distributed over Taiwan, which are connected to a central recording station. The system can eventually be upgraded by suitable software and continuous communication with the seismic field stations to provide pre-warning for urban areas and critical facilities. However, for nuclear power plants, high speed trains, tunnels and highways, pipelines etc. dedicated systems may be more appropriate because of the lower complexity and the interface problems with the organizations, businesses and authorities, which should be integrated in such a system.

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At present, the earthquake early warning and early response system for Istanbul, Turkey, which is currently under development, may be the most advanced one for a large urban area. The early warning part of this system will first be operated on an experimental basis because experience with such sophisticated systems is still scarce.

Design Background

Even in countries where destructive earthquakes are rather frequent, most of the existing buildings have either not been designed against earthquakes or by methods which today are considered as obsolete. Therefore, the earthquake safety of these buildings is unknown and in many cases may be inadequate. A thorough seismic safety review of public buildings in Switzerland has shown that about 20% would have to be strengthened. As Switzerland is a country with low to moderate seismicity and because of the generally good quality of the constructions it may be concluded that the percentage of seismically deficient buildings – especially in the poorer countries – may be much higher than 20%. This applies in particular to the urban areas of the countries of the former Soviet Union of the Caucasus and Central Asia where specific construction methods have been used (standardised buildings made of prefabricated elements), which are located in highly seismic areas. Recent earthquakes have clearly shown systematic deficiencies in widely used building designs. Therefore, the percentage of structurally deficient buildings may easily exceed 50% in many seismic areas despite the fact that in some of these countries the earthquake regulations are very advanced as for example in Colombia. The January 1999 earthquake in Armenia, Columbia has shown that state-of-the-art building codes are no guarantee against earthquake disasters as long as these codes are not enforced. However, the main problem remains the fact that the majority of the existing buildings have not been designed against earthquakes with modern earthquake codes.

Even in Japan, where earthquakes are rather frequent, certain types of buildings will be vulnerable to earthquakes, as was demonstrated during the 1995 Kobe earthquake. In Kobe, the average return period of destructive earthquakes is rather long as compared to e.g. Tokyo. This means, that the design acceleration in Kobe was less than in Tokyo, despite of the fact that the maximum possible earthquakes in both cities could be similar. Such a situation exists in most countries where the seismic design criteria are specified in terms of a constant return period. Usually the design earthquake is specified for a return period of 475 years, i.e. there is a 10% probability that the design earthquake motion will be exceeded within a period of 50 years. In regions of low to moderate seismicity, like central and northern Europe, the return period of a strong earthquake may be several thousand years, whereas in a region of high seismicity such as California, a very strong earthquake may occur every 100 to 200 years. If buildings in California are designed for a return period of 475 years, then they are already designed for very strong earthquakes and it is very likely that the properly designed buildings can also resist a so-called maximum credible earthquake (MCE). In low to moderate seismic areas it must be expected that an MCE with a return period of say 10’000 years will cause large-scale destruction in buildings designed for a 475 year return period. This situation can be easily understood as in a high seismic area the earthquake loads during an MCE may exceed the design loads by say 20 to 50%, whereas in low seismic areas the MCE earthquake loads may exceed the design loads by factors of 2 to 4. Therefore, we may conclude that in low to moderate seismic areas there exists a substantial seismic risk as with the present regulations based on a return period of 475 years, the buildings – this applies in particular to the brittle masonry type of buildings – are essentially under-designed. The ductility of reinforced concrete and steel buildings ensures that they will not collapse as easily as the very vulnerable masonry buildings and other structures with seismic deficiencies (soft storey, etc.).

Because of these seismic risk considerations, the new earthquake regulations in the US are now using an approach in which the seismic actions are determined based on a return period of 2500 years. The seismic actions are then multiplied by a factor of 2/3. This results in seismic design loads, which are equivalent to a return period of ca. 475 years in the high seismic areas of California (i.e. no change of the current practice) and in loads, which correspond to a return period of ca. 1250 years in the moderate seismic zones of the Middle West and the East coast of the USA.

Furthermore, based on seismic risk considerations, and besides the above problem of the return period of the design earthquake in areas of low to moderate seismicity, it is also necessary to impose higher seismic safety standards for

(i) urban and highly industrialized areas,

(ii) facilities with a high damage potential such as nuclear power plants, large dams, natural gas and oil facilities, offshore platforms, pipelines, facilities of chemical and petrochemical industry etc.,

(iii) vital facilities (lifeline systems), which must be operable during and after and earthquake,

(iv) transportation systems such as high speed trains, traffic flow on bridges and in tunnels, and

(v) expensive machines, which are vulnerable when in operation during an earthquake such as
  (a) turbo-generators, which are vulnerable to differential support movements and out-of-balance forces, and
  (b) industrial robots, which are vulnerable to ground shaking when in operation with their arms extended, etc.

In general, it is possible to apply higher seismic safety standards to new buildings and installations. However, this does not cover the existing buildings and installations and there are also seismic design limitations with respect to (ii), (iv) and (v). In those cases, the optimum earthquake safety can be achieved by a combination of seismic design and early warning.

In the case of early warning, one has to be aware that due to the high speed of the damaging shear waves of about 3.5 kilometres per second, the maximum pre-warning times in areas with well-defined fault zones can be as high as 60 to 80 seconds (Mexico City). In other areas, where the active faults are not known, such as in areas of low to moderate seismicity, the warning time may be less than 5 seconds. There may also be events with almost zero warning times, depending on the seismic network used for the early warning system. As damaging earthquakes have durations of several seconds, a zero warning time can still be very beneficial, as a system can be put into a safe state before most of the damaging seismic waves have arrived at the site.

As far as earthquake protection is concerned, the objectives of modern earthquake-resistant building codes are:

(i) To protect human lives and to prevent injuries;

(ii) To minimize economic losses (structural and non-structural damage in buildings, damage of infrastructure, etc.);

(iii) To maintain vital services and to minimize operation/production interruptions;

(iv) To protect the environment and cultural heritage.

These objectives can be satisfied if all structures can withstand strong earthquakes. However, due to financial reasons, it will be rather difficult to make all existing structures earthquake proof, as this may simply be too expensive, especially for the poorer countries. As discussed earlier, buildings are designed for earthquakes with a return period of 475 years, i.e. they can still be severely damaged or destroyed by a stronger earthquake. As a rule of thumb, about 4 to 6 million USD would have to be invested in a developed country like Switzerland for seismic strengthening of buildings in order to save one life during an earthquake. Therefore, alternative solutions for the protection of lives with a better cost-benefit ratio as structural strengthening have to be investigated.

The first priority in earthquake protection is to save lives. For life saving the following phases of an earthquake event can be distinguished:

(i) **Several years before an earthquake**: Measures: seismic design and strengthening of buildings and installations; preparation of emergency plans, to conduct programs for earthquake preparedness of population, installation of earthquake early warning, seismic alarm and earthquake rapid response systems. Note: practically all people and buildings or facilities can be covered.

(ii) **A few seconds before an earthquake**: Safety system: ***earthquake early warning systems***; warning provided by earthquake early warning system with pre-warning times of zero to maximum 90 seconds: evacuation of buildings; shut-down of critical systems (nuclear and chemical reactors); stop high-speed trains. Note: very few people can be evacuated for pre-warning times of less than 30 seconds, however, critical facilities can be put into a safer position.

(iii) **During an earthquake**: Safety system: ***seismic alarm systems***; alarm released by a seismic alarm (or early warning) system will provide signal for shut-down of critical systems (nuclear and chemical reactors); alarm signals can be used to initiate emergency stop of high-speed trains and vulnerable machines and industrial robots. Note: critical facilities can be put into a safer position.

(iv) **Immediately after an earthquake**: Safety system: ***earthquake rapid response systems***; information provided by an earthquake rapid response system: within seconds after an earthquake damage maps based on the spectrum intensity can be made available, which show the damaged areas and form the basis for efficient rescue operations. Note: injured people trapped in damaged buildings may be rescued in time.

This qualitative analysis shows, that earthquake early warning, seismic alarm and earthquake rapid response systems can be very beneficial. Moreover, these systems are inexpensive as discussed below.

What are the differences between an early warning, an alarm and a rapid response system?

(i) **Early warning system**: An earthquake early warning system is the most sophisticated system of the above three systems and requires seismic stations (strong motion instruments, which can provide real-time spectrum intensities and peak ground accelerations) close to the source of earthquakes and continuous communication between the seismic stations and a central processing station. The early warning system can also be used as alarm and rapid response system if there are seismic stations located in critical buildings and distributed uniformly in an

urban area. Typically such a system would consist of a number of seismic stations close to a potential source zone. But for vulnerable facilities with a large damage potential such as nuclear power plants where seismic source zones are not known accurately a seismic fence or array of instruments may be placed around a nuclear power plant within a radius of say 30 to 60 km in order to achieve a reasonable pre-warning time (Wieland et al., 2000).
Main applications: urban areas; high speed trains; highways; gas distribution systems; nuclear power plants; offshore platforms and facilities of petrochemical industry; pipelines; industrial facilities (robots); commando centres, radio stations and rescue units; telecommunication centres; power generation facilities, etc.

(ii) **Alarm system**: In the case of a seismic alarm system the seismic stations (strong motion instruments) are located in the buildings or facilities, where the alarm signal is needed, e.g. in a nuclear power station. Continuous communication between the seismic station and the alarm station is also needed for a seismic alarm system.
Main application: urban areas; high speed trains; highways; gas distribution systems; nuclear power plants; offshore platforms and facilities of petrochemical industry; pipelines; industrial facilities (robots, chip factories); commando centres, radio stations and rescue units; telecommunication centres; power generation facilities, etc.

(iii) **Rapid response system**: For an earthquake rapid response system a large number of seismic stations (strong motion instruments) is needed, which are distributed uniformly over an urban area. The stations do not need a continuous communication with a central station. The stations may be equipped with mobile phones, which will send SMS messages to the central station a few seconds after the end of an earthquake. The messages sent may contain information about the peak ground acceleration and the spectrum intensity, which will be the basis for the automatic preparation of damage maps.
Main application: urban areas; commando centres, radio stations and rescue units; telecommunication centres; power generation facilities, etc.

Early warning and alarm systems are mainly used to shut down or to initiate the shut down of vulnerable systems and dangerous processes and their scope is roughly the same. Rapid response systems are mainly applicable to larger urban or industrial areas, where catastrophe management is an important public task.

Concept of seismic early warning, alarm and rapid response systems

Present technology in seismic instrumentation and telecommunications permits the implementation of a system for earthquake early warning. Such a system is capable of providing from a few seconds to a few tens of seconds of warning before the arrival of strong ground shaking caused by a large earthquake.

An earthquake early warning and rapid response system can provide the critical information needed

(i) to minimize loss of lives and property, and

(ii) to direct rescue operations.

The basic features of a seismic alarm system are shown in Fig. 1 (Heaton, 1985). Ground motions recorded by an array of seismograph stations and/or locally processed real-time data (spectrum intensity, response spectra, Fourier spectra etc.) are telemetered to a central processing site. The main parameters of an earthquake, i.e. the location, time of origin, magnitude, focal mechanism, amplitude of ground shaking and reliability estimates are computed. That may take about one minute from the time an earthquake has been detected. Although, the knowledge of the seismic parameters is desirable it is not essential for early warning or for issuing an alarm in critical facilities. The earthquake parameters are needed for rapid response systems but only if the affected urban area is not equipped with a dense array of seismic stations.

If the site is far from the source zone, which is monitored by seismic stations, then tens of seconds may be available before shaking begins. This time may be used to receive further information about the size of the earthquake. In this way, users at large epicentral distances take action only for the large earthquakes that present a real hazard. However, in practice it is more appropriate to take immediate action if an alarm is issued, i.e. if the trigger level for the acceleration is exceeded in several redundant stations and/or the spectrum intensity exceeds a predefined value. For earthquake early warning and alarm systems there is usually insufficient time to compute the hypocenter, focal parameters and the magnitude of an earthquake, as this time is needed for the more complex alarm decision making process. The benefits of an early warning system increase with increasing pre-warning time. The same applies to a seismic alarm, which must be issued at the very beginning of an earthquake. An alarm may also be worthless for critical facilities that could be damaged by ground shaking, if it is released after an earthquake. However, for secondary earthquake effects such as landslides, release of hazardous materials, flood waves due to a dam break, fires etc., which may develop shortly after an earthquake, a delayed alarm is still very beneficial.

Immediately after the occurrence of an earthquake, the seismic stations provide information regarding the strength of shaking in different locations. This information can be used to estimate areas of substantial damage, so that emergency services can be allocated promptly and properly. Because the strong motion instruments in the array would have a large dynamic range, the seismic network may routinely record ground motions from numerous small earthquakes and teleseismic events. The routine use of a seismic network for studies of small events would help to ensure that the system operates properly when relatively rare large events occur.

For an earthquake early warning system the seismic stations should be located close to the source zones where damaging earthquakes may occur. This is the case for the early warning system for Mexico City, early warning systems in Japan and Taiwan. In all three cases the potential source zones are located offshore.

In the case where the source zones are not well defined such as in most parts of Europe, an array of evenly distributed seismic stations may be needed. For that purpose the existing networks of the national earthquake services may be upgraded to provide real-time information about earthquake ground motions. For privately owned critical facilities, however, dedicated early warning and alarm systems are needed. For example, a seismic network surrounding the Ignalina nuclear power plant in Lithuania at a distance of 30 km will result in a warning time of about 8 seconds for earthquakes occurring at distances exceeding 30 km. An extension of the warning times for large earthquakes far away from the seismic fence can be achieved if the magnitude and location of the earthquake can be determined based on the P-wave rather than the S-wave. For earthquakes occurring within a 30 km radius, the alarm may be triggered by seismic station, which is located directly at the site of the power plant.

General benefits of earthquake early warning, alarm and rapid response systems

These systems are very effective when large numbers of people may be lost in a single incident, i.e. collapse of a stadium during a performance, failure of a high-rise building with high occupancy, derailment of a train, dam failure with downstream flooding or a nuclear reactor accident with uncontrolled release of radioactive substances.

The main benefits of an earthquake early warning and rapid response system are as follows:

- Earthquake early warning systems help to reduce the loss of lives but they do not help to reduce economical losses due to damage to buildings and infrastructure.
- They are efficient tools in urban areas where a significant portion of the buildings and infrastructure are deficient seismically.
- In cases where the seismic source zone is clearly known and sufficiently far away (Mexico City), large segments of the population can be warned by radio, television, etc. In Mexico City, public schools and government agencies are directly connected with the alarm system. Operation of critical facilities and processes can be stopped.
- When sufficient warning time is available, critical facilities and systems can be put into safe position and fast hazardous processes can be stopped in time.
- In the case of very short pre-warning times of a few seconds, it is still possible to slow down trains, to switch traffic lights to red, to close valves in gas and oil pipelines, to release a SCRAM in nuclear power plants, etc.
- Early warning systems also form part of alarm systems and can be used to alarm the population where rapid response is needed. A typical example would be to issue the so-called water alarm, i.e. alarming the population living in the downstream region of a large dam.
- Early warning systems are useful for facilities and processes where rapid response can contribute to the reduction of the seismic risk. These are nuclear power plants, high speed trains, gas mains, highways etc.

A modern earthquake early warning system for an urban region shall include

(i) monitoring of the seismic activity in the potential seismic source zones, and

(ii) monitoring of the ground motion within the urban area.

The signals obtained from (i) are used for early warning of the population and to shut down critical facilities and processes, and those of (ii) are basically used to determine the areas with major damage, and to initiate rapid response measures.

The seismic stations can send their signals through radio, the mobile phone network or the internet. However, this may cause unnecessary delays. It has to be studied on a case by case basis if inexpensive public telecommunications systems can be used or if rather expensive dedicated lines have to be used for selected stations.

Reliable hardware for earthquake early warning systems is available. Solutions for telecommunications and data transfer also exist. However, the main problems are

(i) to distinguish a strong earthquake from other signals, in order to avoid false alarms as all alarms have to be automated due to time constraints,

(ii) to determine to which agencies and facilities the alarm shall be forwarded, and

(iii) to determine how the alarm shall be implemented in critical facilities.

Implementation aspects of early warning and rapid response systems

A seismic early warning system has excellent prospects where the seismic source zones are far away from urban centres. Unfortunately this is the exception. Many cities are already located within a seismic source zone. In this case, the benefits of an earthquake early warning system are not that obvious and public acceptance may me limited. Moreover, early warning systems require more advanced technology than rapid response systems. Time plays a lesser role in rapid response systems than in early warning systems. Hence, it is possible to use inexpensive mobile phones for data transfer in rapid response systems, whereas continuous data transfer via radio is needed in early warning systems.

The same type of seismic sensors can be used for early warning and rapid response systems, if they are located in an urban area.

As earthquake early warning systems are still under development, it is recommended to install first a rapid response system and to expand that eventually to include the features of an early warning system (continuous communication, dedicated software).

Special Applications

1.Tsunamis early warning system

Tsunamis early warning systems have been around in Japan, Hawaii and along the Pacific Coast of North and South America for quite some time. Because of the large distances and the wave propagation velocity of tsunamis of less than 0.3 km/s, it may take hours before a tsunami hits the shore. Accordingly, there is often ample time to evacuate the people. Tsunamis warning systems have been very successful. Because of the relatively comfortable warning times and the known stretches of the coast, which can be endangered by a tsunami, the technological challenge of these systems is much smaller than that of earthquake warning systems for urban and industrialized areas.

2. Earthquake early warning system for high speed rail systems

In the following part, the scenario of an accident of a high speed train due to earthquake-induced track damage and vibrations is analysed. A train travelling at ca. 350 km/h needs over a minute to come to a standstill. During that time, it will travel at least two to three kilometres. Without any warning, a train would continue travelling at high speed and, eventually, it may hit a damaged section of the track and derail. With a timely warning, the train would slow down and the chances of hitting a damaged section of the track would be greatly reduced because of the low speed. In addition, the severity of an accident would also be reduced substantially. The obvious benefits of an earthquake early warning system have been recognized for the bullet train system in Japan. The earthquake early warning and damage assessment system called UrEDAS has been in operation for several years and useful experience has been collected.

The main benefits are as follows:

- Severity and probability of accident during and after a strong earthquake can be greatly reduced.
- Number of casualties can be reduced substantially.
- The cost of an earthquake early warning system is low compared to other measures (improvements of rolling stock, rail/track system, embankments, tunnels, bridges etc.).

For such a system, seismic sensors would be needed approximately every two kilometres along the track. The sensors should be located at some distance away from the track, in order to minimize traffic-induced vibrations at the sensor stations. Transmission of the alarm signals could be via UHF/VHF radio or via dedicated cellular phones with direct connection to the control centre using the telecommunications system for the trains or a commercial system.

It must also be kept in mind that it is not possible to prevent all possible earthquake-induced track damage by seismic design and strengthening, as fault movements may occur at unknown faults during a strong earthquake, and in mountainous regions, mass movements and rockfalls cannot be controlled completely. Similarly, it will also not be possible to eliminate all train accidents by an earthquake early warning system. An earthquake early warning system shall be used to reduce the seismic risk for the high speed rail project. It shall not be used as a tool to reduce the seismic safety standards of the tunnels, embankments, bridges, etc.

3. Pipeline earthquake early warning system

A large oil pipeline may transport 5'000 tons of oil per hour. Expressed in energy figures this corresponds to roughly 50'000 MW or the equivalent of 50 large nuclear power plants. With gas pipelines, the corresponding figures are somewhat lower but still very important.

Considering the huge economic assets of pipelines there are two main requirements concerning the behaviour of pipelines in case of an earthquake:

- The integrity of the pipeline is to be maintained also at strong earthquakes because a pipeline rupture would result in the unavailability of the pipeline for an extended period of time and may cause loss of lives and huge environmental damage.
- The oil flow shall not be interrupted. If at an earthquake it appears too risky to continue normal operation, it is preferred to maintain at least a reduced flow.

Considering the huge number of oil and gas pipelines in the world, the number of accidents with environmental damage is surprisingly low. However, this depends strongly on the local conditions and in areas of high seismicity the earthquake risk might be the most important aspect
Generally, the following aspects should be taken into consideration for pipelines:

- Seismicity of the region and potentially active faults crossed by pipelines;
- Landslide and rockfall hazard, and differental soil movements;
- Subsea earthquakes, tsunamis and subsea landslides may jeopardize offshore pipelines; and
- Flooding due to dam failure near pipelines.

4. Earthquake early warning system for nuclear power plants

The advantages and benefits of an earthquake early warning system for a nuclear power plant are as follows:

- It reduces the risk of release of radioactive material during a strong earthquake.
- It reduces the consequential damage in heavy equipment (steam turbine generator, large circulation pumps, depressurization system of reactor pressure vessel, steam generator, etc.).
- It reduces the seismic risk and thus the amount of insurance coverage.
- The cost of an earthquake early warning system is low compared to other safety improving systems.
- It is recommended in cases where the seismic safety design criteria for an existing nuclear facility have been made stricter.
- An early warning system can be installed without interfering with power production
- It is a short-term solution for reducing the seismic risk; in the long-term, improvements of the critical components have to be implemented.
- Shutting the nuclear reaction or releasing control rods in various types of nuclear reactors requires only about three seconds of pre-warning time.
- Similar system has been installed at the 2x1500 MW Ignalina Nuclear Power Plant in Lithuania.

It is obvious that low-cost seismic early warning and alarm systems can contribute significantly to the reduction of the seismic risk in nuclear power plants. This is particularly true for areas of high seismicity. An early warning system shall not serve as an alternative to structural upgrading but as a complementary safety device.

It must also be pointed out that the details of an automatic SCRAM would require further in-depth studies.

The cost of a seismic alarm system for a nuclear power plant would be of the order of 2 million USD and the annual operation and maintenance costs would be about 10 to 20% of the initial investment costs.

Experience with earthquake early warning systems

At the moment there are several early warning systems in operation for civilian purposes, i.e.

1. Urgent earthquake detection and alarm systems (UrEDAS) in Japan

This real-time earthquake disaster prevention system is used for railways. The special feature is the rapid alarm using information from P-wave data. Systems for different railways have been in operation since 1983 (Nakamura, 1996). UrEDAS detects initial P-wave motions, estimates epicenter azimuth and magnitude, calculates epicentral distance and local depth within about 3 seconds. This system is not only useful for railways but also for nuclear power plants, etc.

2. Seismic alert system (SAS) for Mexico City; Mexico

Most of the large earthquakes, which are likely to cause damage in Mexico City have their source in the subduction zone of the Pacific coast at a distance of about 320 km. The warning time varies between 58 to 74 seconds.

The Seismic Alert System for Mexico City consists of four parts: the Seismic Detection System, a Dual Telecommunications System, a Central Control System and a Radio Warning System for users. The seismic detector system consists of 12 digital strong motion field stations located along a 300 km stretch of the Guerrero coast, arranged 25 kilometers apart. Each field station includes a microcomputer that continually processes local seismic activity which occurs within a 100 km radial coverage area around each station.

The Dual Telecommunications System consists of a VHF central radio relay station, located near Acapulco, and three UHF radio relay stations located between the Guerrero coast and Mexico City. Two seconds are required for information sent by one of the field stations on the Guerrero coast to reach Mexico City, this data is sent digitally coded.

The Central Control System continually receives information on the operational status of the field stations and communication relay stations, as well as the actual detection of an earthquake in progress. Information received from the stations is processed automatically to determine magnitude and is used in the decision to issue a public alert.

The Radio Warning System for users disseminates the seismic early audio warnings via commercial radio stations and audio alerting mechanisms to residents of Mexico City, public schools, government agencies with emergency response functions, key utilities, public transit agencies and some industries. Public and private entities are equipped with specially designed radio receivers to obtain the SAS alert. In each place there is a person in charge of the SAS receivers. His duties are to check the status of the receiver and coordinate all the activities of a disaster prevention as exercises and drills of evacuation. There exist 98 radio receivers, 28 of them are installed in public schools. During rush hours approximately 4.4 million people are covered by the system. The system has been operating since 1991. The system had a cost of $ 1.2 million for development and installation and $ 0.2 million per year for operation and maintenance (Espinosa-Aranda et al., 1996).

3. Seismic alarm system for the Ignalina nuclear power plant in Lithuania

The system consists of a Seismic Alarm System (SAS) and a Seismic Monitoring System (SMS). The SAS is designed to detect potentially damaging earthquakes and to provide an alarm before the arrival of the shear waves at the reactor. Six SAS stations are installed at a distance of 30 km from the power plant forming an array, which is referred to as seismic "fence". An earthquake having an epicenter outside of the fence is detected about 4 seconds before it is "felt" by the reactor. The required time to insert the control rods is 2 seconds. Potentially, the reactor could be shut down before the earthquake arrives. At present, the SAS will initiate an alarm signal only. Later on, it is foreseen to produce a control rod insertion command signal by the SAS. The sensor switches of the SAS are factory preset to an acceleration value of 0.025 g, which is adjustable by a software command. This setting will determine the number of false alarms and the number of earthquakes not detected by the system. Before the SAS can be used to initiate a control rod insertion command, the value of 0.025 g will have to be reinvestigated. Aspects to be considered in that respect will be the experience acquired with the SAS and operational aspects of the power plant, while maintaining the high reliability of the SAS to detect earthquakes, which could affect the power plant (Wieland et al. 1998 and 2000).

Conclusions

Earthquake early warning and alarm systems are low-cost solutions for the reduction of the seismic risk of important facilities such as high speed trains, nuclear power plants, pipelines etc. They are also feasible for large cities, which are exposed to earthquakes occurring at known faults. For all urban and highly industrialized areas earthquake rapid response systems are recommended, which can be upgraded into early warning and alarm systems. The technology for such systems is available.

Earthquake early warning, alarm and rapid response systems are the most economical solutions for the reduction of the seismic risk as their cost is only a fraction of those required for structural upgrading of existing structures in urban areas.

Early warning systems help to reduce the loss of lives but they do not help to reduce economical losses due to damage in buildings and infrastructure.

As with the current seismic codes used in most parts of the world, the seismic risk in urban areas of low to moderate seismicity is still very high, earthquake early warning, alarm and rapid response systems are recommended worldwide.

A state-of-the-art alarm and rapid response system for an urban area may cost about USD 5 millions.

The benefits of earthquake early warning, alarm and rapid response systems do not increase significantly if the investment costs are increased beyond a certain level.

The installation of an earthquake early warning, alarm and rapid response system shall not be a substitute for the seismic strengthening of critical facilities such as seismically under-designed nuclear power plants.

Decision makers have recognized the great advantages of earthquake early warning systems. Several systems have already been installed during the last couple of years. Most of them are in Japan. Many more systems are under discussion or in the planning phase.

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