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« Towards "Early Warning Systems": material collected from earthquakes"

Discussion document for the meeting
of the Working Group

EARLY WARNING SYSTEMS

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I. Introduction

A/ The "early warning" concept

Whatever the timescale imposed by the nature of the disaster, an early warning system[1] may be split into several parts. The number of phases to be incorporated is, of course, a matter for debate but it is suggested, in the first instance, that there be three:

i) forecasting, or detection if forecasting is not feasible;
ii) compiling the basic data that characterise the source of the disaster and processing the information gathered in general;
iii) disseminating the information compiled to the various user categories and the target populations.

While this division is applicable *mutatis mutandis* to all disasters, we will consider only cases in which it is not feasible to make forecasts at present (the possibility of progress with forecasting is not ruled out: improvements may be made at any time).

B/ The seismic risk as a reference

Typically, earthquakes are not foreseeable at present, ie it is not possible, given the current state of knowledge, to predict the time and place at which they will occur precisely enough to make such predictions useful and commensurable with the contingencies of human activities (at most, given the present state of knowledge, one might expect to have vague notions of a significant increase in the probability an earthquake occurring within a few months/years and a few hundred kilometres). Earthquakes are, moreover, phenomena of very short duration, the direct effects of which are virtually instantaneous on the human timescale.

Other natural phenomena that may lead to disasters have features that are comparable (but not always identical) to those of earthquakes, examples being:

- snow avalanches,
- massive cliff (or glacier) collapses,
- certain rapid landslides (especially under the sea),
- tsunamis (which are the consequence of other catastrophic phenomena),
- massive volcano eruptions,
- falls of huge meteorites (which have taken place and will certainly continue to take place but have rarely been properly observed),
- torrential floods in certain basins.

Disasters for which human beings are responsible (dam breaches, accidental chemical explosions, perhaps electricity supply failures) may display similar features.

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[1] For a brief historical background to the concept of an early warning system, see the relevant appendix.

II. Detection and databases

The detection of an earthquake is obviously a question of first-hand experience for anyone located in the area where its effects reach a certain level. Within and beyond that area, earthquakes are detected by instruments (seismographs, which enable the local effects of the earthquake to be quantified, or seismoscopes, which permit qualitative rather than quantitative detection).

A/ The intensity concept

It should be noted that in the former case observations are made by human beings and relate to the effects felt by them or damage done to artefacts[2]. Typically, it is observed that a certain percentage of the population of a given place has felt tremors or that 55% of brick buildings dating from the second half of the 20th century are cracked, or else that 10% of 30-to-50-year-old reinforced concrete buildings present serious abnormalities. Observatins of this type are known as “macroseismic data”. These indicate the “intensity of an earthquake” at a given place. However, it would no doubt be more correct to speak of the “intensity of the effects of an earthquake” on a given sample of artefacts. At any rate, it should be borne in mind that it is impossible to specify the intensity of the effects of an earthquake without taking account of the objects exposed to them. In particular, this intensity cannot be specified where there are no human-made objects.

For the sake of convenience and in order to compare the effects of earthquakes, possible macroseismic observations have been grouped together in categories that describe increasing effects on human artefacts. These categories do not overlap (ie, they are “disjointed”) and constitute a proper scale. Very often, the categories are designated by Roman numerals: part of the territory affected by an earthquake and containing human-made objects accordingly sustains a certain intensity, for example V, which is determined by the macroseismic observation statistics for that territory. A fractional intensity makes no sense, so that it is at most possible to hesitate over how to interpret the macroseismic observation statistics in a given area – it might accordingly be said that the earthquake had a intensity of V-VI in that area.

When properly employed, the intensity is a simple and convenient parameter. Anyone can make their own macroseismic observations, and a statement of the intensity observed in a given place provides direct information about the magnitude of the damage sustained (at least for people with the relevant experience). The situation is somewhat complicated by the fact that several macroseismic scales (= scales of intensity) that differ from one another, albeit often very little, have been devised. Very simply put, the two most commonly used scales of intensity are currently the “Mercalli modified intensity scale” (MMI), which is mainly used by the American schools, and the “European scale”, which was devised quite recently in Europe.

B/ Instrumental observations of seismic activity

While the quantification of the effects of earthquakes on human beings and their artefacts is important because it reminds one that the main objective is to protect populations and property rather than develop a scientific knowledge of earthquakes (it also enables the concept

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[2] Taken to mean “works produced by human hand or by industry”, which presupposes active human involvement.

of intensity to be introduced [see above]), the fact remains that the detection of these events is mainly based on instruments. Although this is not the place to discuss the rather complex details of the construction of seismographs, some facts are worth mentioning.

a) Tools

Seismometers (= the sensors of seismographs) are usually sensitive to the speed at which the ground on which the instruments are placed shifts (for specific applications, they may be placed on parts of a supporting structure) in a given direction (they are often arrayed in groups of three and deployed at right angles in three directions for each structure – “3C seismographs”). They may be sensitive to the actual shifting of the ground or to ground acceleration (= accelerometers).

Not all seismometers respond in the same way to a movement with various frequencies. Seismographs employed to monitor local seismic activity are mainly sensitive to “high frequencies” (above 1 to 10Hz, for example) and are of the so-called “short-period” type. As high-frequency waves die off less rapidly than low-frequency waves, “long-period” seismometers are used to register the low-frequency waves generated by relatively high-energy earthquakes, which spread more easily over a long distance. There is a full range of intermediate devices. Indeed, electronic signal-processing techniques have for some decades now made it possible to build “broad-band” seismographs that combine the capacities of short- and long-period seismographs.

b) Sensibility of measurements

Seismometers are instruments that are often extremely sensitive. They register ground movements that are much weaker than those that can be detected by human beings. They even detect “seismic noise”, which is the permanent movement of the ground, which human beings obviously do not feel. Seismometers are combined with very precise clocks (nowadays, the same clock serves many seismographic stations equipped with “GPS receivers”: the clock is a global positioning system [GPS] device) that make it possible to date packets of vibratory energy emitted by seismic sources that spread through the earth in all directions and reach the seismographs. If the velocity of the seismic waves at any point of the earth is known, and assuming that the earthquake has a single source (in space and time – it is essential to make this assumption), it is sufficient, in an ideal situation, to know the times of arrival of a type of wave at four seismic stations in order to calculate the time at which the earthquake originated and the position of its focus (ie, the point to which the source is reduced).

Since there are a number of uncertainties surrounding the data used, as with any measurement, and models of the earth are not perfect, there is generally no solution to this set of four equations with four unknowns. This means it is necessary to use much more complex techniques, introduce many more observation data and resort to methods of optimising the differences between observations (measured arrival times of energy packets at the seismographic stations) and the calculated arrival times at the same stations for a given focus. An attempt is made, as it were, to determine the focus of the earthquake (in time and space) as accurately as possible by means of successive approximations, on the basis of accepted methods. One will never know definitely to what extent one is mistaken since the assumption that there is a single focus is only a crude approximation of the physical phenomena that generate the earthquake and the model for seismic velocity dispersion within the earth is only a mediocre approximation of the actual situation. In particular, the earth is assumed to be spherical (which it is not entirely) with the velocity of seismic wave propagation dependent on the radius alone (in other words, we are assuming a spherical earth with radial velocity dispersion), without lateral variations, which is obviously not the case (for example, we find in the vicinity of the earth's outer surface either oceans or continents, or transitions from one to the other).

C/ Parameters of the earthquake's source

a) Focus position

I have gone into some detail here because the fact is that the estimated focus of an earthquake will naturally depend on the values of the data used to calculate it, but also on the nature of the data available (the spatial distribution of the seismographic stations in relation to the estimated focus, for instance2.) and, to some extent, on the calculation models. In other words, the estimated focus of an earthquake may vary over time, depending on the data included in the calculation, without there necessarily being an error on the part of the operators – an estimate calculated ten minutes after the occurrence of an earthquake (when a few dozen observations are available) may be significantly modified thirty minutes later when several hundred observations can be used. It is only the nature of the situation that is responsible for this: the quality of the operations to locate the focus is not in doubt.

It is clear that this state of affairs is particularly puzzling for an uninformed user: how is it possible to reconcile (or interpret the existence of) two significantly different locations identified at an interval of thirty minutes? Why don't the seismologists make up their minds? The fact is, of course, that they can't. Particularly disturbing situations can occur, as in the case of the earthquake in Costa Rica; the epicentre[3] varied between the ocean and the continent for several hours after the event, and the consequences to be feared were clearly not the same in both cases. Only an ongoing and trusting dialogue between specialists and users can enable the confusion created by this type of situation to be overcome.

The above example showing how the location is established is a relatively simple one and there can be no question of going into greater detail here. There are, however, difficulties in interpreting other parameters that characterise an earthquake, and its depth and magnitude present specific problems.

b) Focus depth

The depth of the focus is naturally very important: for a comparable amount of energy released, the effects of an earthquake will differ on the earth's surface according to whether the focus is near the surface or deeper down, owing to the distance the seismic waves have to cover from the focus to a given point on the surface where an artefact is exposed to the earthquake's effects. The greater the distance the waves have to cover, the more they will be attenuated by the propagation medium. More important, the front of the waves radiating from a source point is spherical in a continuous homogeneous medium, and the energy of the initial impulse spreads along this spherical wave front, with its increasing radius. The energy is more concentrated at part of the spherical surface of the front of the wave if the radius is small (surface focus) than if the radius is larger (deeper focus; the phenomenon is known as "spherical expansion").

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[3] The "epicentre" of an earthquake is the point on the earth's surface (known by its latitude and longitude) vertically above the focus of the earthquake.

It is therefore crucial to know the depth of the focus, but this is very often hard to determine (explanations for this situation are beyond the scope of this working paper). In an emergency, in particular, the depth of the focus cannot in practice be determined with any acceptable precision unless data are available from a seismographic station whose distance from the epicentre is shorter than the depth to be determined. Given that it is quite unusual to have such data available in an emergency, what can be done? The answer is that there is no alternative but to carry out a probabilistic estimate of the depth – hence the need for well-developed databases (it should be noted that the determination of the epicentre and the depth of the focus are not independent of each other, which does not simplify matters).

c) Magnitude

Clearly, the quantity of energy released by an earthquake is another important parameter and creates considerable confusion. This energy is estimated by measuring the amplitude of the waves recorded by the seismographs, but not all seismometers react in the same way to the different types of seismic waves. It has therefore been necessary to establish conventions concerning the waves to be considered with a particular type of seismometer in order to ensure that measurements are comparable from one observer to another and from one seismological station to another. Many conventions of this type have been established, with the result that there are many types of magnitude.

It is not possible to go into detail here, but it is necessary to be aware that estimates of magnitude often vary considerably (a variation of one “unit of magnitude”[4] is quite common). In an emergency, there is clearly not enough time to seek a consensus. Sophisticated techniques now enable a more refined estimate to be made of the magnitude of large earthquakes. They presuppose very modern data and require quite some time to develop.

The magnitude provides information about the energy dissipated at the source of the earthquake in the form of seismic waves. It is a measurement of amplitude that presupposes the existence of seismographs. The parameter thus differs radically from the intensity defined above: it is based on the effects of seismic waves and does not involve the impact on artefacts. Moreover, contrary to a widely held view, there is no “magnitude scale”. This parameter may have any value, including a fractional and even a negative one (in the case of earthquakes that dissipate little energy) [this is due to the fact that its definition involves a logarithm]. Experience shows that no earthquake has been encountered with a magnitude (the type has deliberately not been specified) above 9.5 (which is perhaps the magnitude reached in the catastrophic earthquake in southern Asia on 26 December 2004). It was Charles F. Richter who introduced the concept of magnitude by studying Californian earthquakes in the mid-1930s, but the expression “open Richter scale”, which has become so common, is devoid of all meaning.

d) Mechanism at the focus

Another parameter, the mechanism at the focus of an earthquake, is very important but is rarely available in an emergency. There can be no question of going into detail here. An American seismologist, Harry F. Reid, showed in the early 20th century, after the earthquake in San Francisco (1906), that the fault rupture constituting the source of the earthquake could

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[4] This expression is very commonly used but should not be permitted. Magnitude is a dimensionless quantity and, strictly speaking, there is no such thing as a “unit of magnitude”.

be represented by a sudden shift taking place simultaneously on two perpendicular planes. This pair of planes could have any orientation in space, which they divided into four sectors in which vibratory energy radiated, but in a way that differed from one sector to another. Observation of the arrival of wave packets at seismographic stations makes it possible to deduce the orientation of the pair of planes in space and thus know whether or not the shift along the planes has a vertical component. Here, too, sophisticated techniques enable the same type of conclusions to be reached from recordings that are technically highly advanced, but these are far from being available everywhere.

The issue of the mechanism at the focus is neither anecdotal nor a matter for the fantasies of seismologists alone. An earthquake where the fault rupture affects the ocean floor is liable to set the overlying mass of water in vertical motion if the two parts separated by the rupture undergo relative motion with a significant vertical component. If this is the case, a wave is created on the surface of the mass of water and will spread out horizontally across it, generating a tsunami. If, on the other hand, the relative motion of the two parts of the ocean floor has only a horizontal component, a tsunami will not be generated. This explains the importance of the mechanism at the focus in terms of the potential consequences of an earthquake.

In short

The first component of a warning system presupposes the effective and intelligent detection of the physical cause of a potential disaster and mastery of the basic parameters reviewed above in what is no doubt a somewhat long and technical explanation. However, it is obvious that this mastery will never be absolute, that there are many problems that will have to be subjected to further study, that some of these problems are directly caused by a manifestly insufficient knowledge of the basic phenomena and that, as a result, compromises will have to be found between needs and the information available (perhaps by carrying out limited, targeted research). All this is conceivable only if there is prior, but also ongoing, dialogue, between the data providers (scientists/engineers in charge of observation systems) and those who use the information. The users of the information compiled are naturally a diverse group, and their needs will likewise vary, so it will be necessary to draw up a detailed, if not exhaustive, list.

III. Extraction and diffusion of pertinent information

Once the source parameters (or the data that, by convention, serve as source parameters in the light of the above) have been obtained, they have to be processed so that the information necessary for the various user categories can be extracted. The latter will have to be clearly defined, as will the type of information that each category wants.

A/ A difficult dialogue

There have been many attempts to do this but very few have yielded meaningful results. The problem here is the difficulty of dialogue between the people likely to hold information (to simplify matters, let us say the scientists/engineers) and those who will need it some day to take decisions in an emergency. The issue is primarily to find, in information terms, a common denominator for these two groups, but the former rarely stray from their jargon and semantic precautions, which the latter do not – or do not attempt to – understand. The latter demand information with a precision and speed that the former cannot possibly achieve, and there is not much chance of a spontaneous reconciliation. So what can be done in this situation?

An attempt could perhaps be made to initiate a dialogue with a very small number of well-intentioned people resolved to make progress at all costs. Another avenue of approach is doubtless more promising but requires a great deal of effort and patience: the introduction of vocational training to arouse the interest of as many people as possible. At any rate, it is necessary consciously to adopt a long-term view, both because training processes are inherently long and because staff change more quickly, especially at the top of the hierarchy, than the time available to train the people concerned, so the process is potentially endless.

Moreover, this is not a one-way process: while it is more or less pointless to try to make scientists/engineers understand the various aspects of the day-to-day activities of the users of information, it is very important to urge them to find a (no doubt incomplete and probably temporary) basis for solutions to the unresolved issues. The example of the depth of the focus is instructive in this regard. Given that it is clear that this issue cannot be ideally resolved in the present situation (short of covering seismically active areas with seismographs every five kilometres, which is definitely not feasible with current technology, being far too expensive), shortcuts must be sought – what is the most likely depth of the focus today, given the depths observed in the region in the past?

B/ **A priori** *impact forecasts*

Apart from information on an earthquake that has just taken place, which is obviously essential, many users will want details of its likely consequences. Several countries are equipped to answer this question at national level. The response here requires a detailed knowledge of the national territory and of the distribution of the population, amenities, the property at risk in general, and so forth. This knowledge represents a massive amount of data, which governments are reluctant to make public (even assuming this is actually feasible). Moreover, it is virtually impossible to obtain an idea of the efficiency of these national systems, which are usually a jealously guarded secret.

Another aspect needs to be taken into account: a major earthquake is often of such a magnitude that individual countries, regardless of which ones, find it difficult to deal with it with their own resources alone, especially in the first few hours, and mutual aid is a virtual necessity. Many countries are ready to help another if a disaster occurs and must form a picture of the needs created and, accordingly, the magnitude of the disaster, in order to prepare for action, but they do not seek very precise information. In addition, the country affected may have access to an outside reference point as a means of checking its own estimates, so that a response must be provided as quickly as possible after the event has been detected.

a) Some existing models

Some attempts have been made in various parts of the world to estimate the potential damage. Some are not, strictly speaking, attempts at producing a damage scenario but, rather, intelligent “notebooks” in which the observations made on the ground are recorded and organised. The Chinese were interested in very big earthquakes and tried to estimate the impact on the country’s overall economy. The two most elaborate attempts have been conducted in Russia and, more recently, the United States.

The latter, carried out by the US Geological Survey, was organised around the construction of “shake maps”: there are so many data available in California that, on the basis of the parameters at the source of the earthquake, it is possible to obtain a picture of what the ground acceleration is likely to be at any point. The same Californian data are used for other regions, apparently with some success. Today, the model has not yet been developed further to establish how much damage would be caused by the probable acceleration field.

The model built in Russia is significantly different. It was initially designed as a national system ten or so years ago under the name of “Extremum” and has apparently been successfully applied in that country, especially for earthquakes in the Kamchatka peninsula. Since then, many versions have been developed, improved and applied to numerous earthquakes outside Russia.

b) Calculation principles

As might be expected, many different ingredients are necessary for codes of the “Extremum” type to function. A first set of data is made up of the parameters describing the source: the epicentre, the depth of the focus, the energy dissipated by the source and the mechanism at the source (all these parameters have been discussed above). Each of these quantities is associated with uncertainty, whether it be due to the calculations carried out or “epistemic” (ie, associated with the very fact of describing physical phenomena with an arbitrary set of parameters), or indeed due to the fact that the parameter values simply cannot be estimated (the depth of the focus when the observation conditions are poor).

The codes calculate the acceleration field created by a simple source model to which the parameter values available, or arbitrary values when there is no alternative, are assigned. This field obviously depends on the propagation of the seismic waves through the medium. It is thus necessary to know the laws of wave attenuation in the region where the earthquake takes place. The attenuation depends on the geological nature of the region and, accordingly, more often than not on the direction of the wave propagation from the source. Most of the time, not much is known about this attenuation function (for want of reliable data), so one is reduced to imposing an attenuation law which is all the more arbitrary the less is known about the geological structure. It is common to use an attenuation function that is quite well known for a given region (such as California) and apply it to less well documented regions (this is done in particular in the case of the US Geological Survey’s “shake map” approach).

The most likely ground acceleration in the light of all the accumulated hypotheses at any point in a region potentially affected by an earthquake is thus obtained. (An initially puzzling paradox should be noted: while it has been stressed above that the “intensity” of an earthquake at a given point can be established only in the presence of artefacts exposed to its effects, the estimated probable ground acceleration is often given in terms of “intensity”, while the model has up to now not made any reference to any exposed artefact. This paradox is only an apparent one since many macroseismic observations in the strict sense of the term have been compared with (unfortunately much less numerous) acceleration measurements carried out in the field. There is accordingly an empirical relationship between the two parameters that links the two quantities (macroseismic observations on the one hand and acceleration measurements on the other) but does not claim to reflect a physical link between the cause (acceleration imposed by the ground) and the effects on artefacts.

c) Model limitations

* Site effects

In any case, there are many other limitations to this approach – the laws of attenuation are in fact approximate rules that ignore many details (the effects of which are sometimes well known). To mention just a few effects: the detailed geometry of the geological structure may cause the seismic waves to converge/diverge locally, thus modifying the local vibration energy (there are methods of calculating these effects, at least for low-frequency signals, and these methods could perhaps be adapted to higher-frequency waves that produce seismic effects and, in particular, to the conditions in which calculations are carried out in an emergency); the effects of topography, especially slopes; and effects due to the soil and its ability to propagate/attenuate shear waves.

All these effects can be subsumed under the general heading of "site effects", well-known to engineers/seismologists. Taking them into account presupposes complicated (indeed, very complicated) calculations, which are not necessarily compatible with emergency situations. It would also be worthwhile checking whether there is any point in including them in the calculations carried out in an emergency – do the cumulative approximations not make them futile?

* Artefacts' response

When the ground acceleration caused by the effects of the seismic source is known, interest turns to the artefacts resting on the ground and questions arise as to the transfer of energy between the ground and the artefacts, ie the ground/structure linkage via the artefact's foundations. These are difficult questions. An even more difficult aspect is knowing how the artefact will respond to the pull exerted by the foundations. While the (incidentally, very detailed) algorithms needed to calculate the response of certain very specific (mainly metal or reinforced concrete) structures are available, a great deal of progress remains to be made (for example, on the role of the filling material located between the structural elements and on the relationship between the vertical elements [pillars] and horizontal elements [beams].

In addition, damage to structural elements can be estimated as long as it remains relatively minor, but it will – for obvious reasons – be difficult to carry out a large number of experiments concerning serious damage that might result in the collapse of the structure. In fact, one is limited to a few controlled experiments on a number of elements and/or on scale models and to field observations after a serious earthquake. In other words, not much is known about the fragility/vulnerability of such structures in relation to the stress exerted on them. Furthermore, these ideal structures account for only a small minority of the total number of artefacts exposed to the effects of earthquakes.

Most types of construction are beyond the scope of the calculation methods currently available. Moreover, they are extremely diverse in that the parameters that would make it possible to describe their behaviour in the event of seismic stress depend very largely on the initial quality of their construction and the conditions in which they have aged (in particular, the history of their maintenance). In an emergency, there can be no question of taking account (to what little extent this is possible) of the characteristics of each artefact, and a statistical approach is called for. A statistical knowledge of artefacts exposed to the effects of an earthquake must accordingly relate not only to their number and geographical distribution but also to some of their physical characteristics.

* Contrasting use of artefacts by populations.

In addition, not all structures are used for the same purpose. Some serve to house the population, while others are used for industrial purposes; some may accommodate the public at certain times of day (public services, schools, etc) or certain times of the year (tourist amenities, for instance), while others may have very specific functions (hospitals, health services in general, centres where administrative/political decisions are taken, emergency services, police stations, prisons, etc).

It is thus necessary to work out a kind of exposure index for the populations concerned in order to assess potential physical damage (with varying degrees of severity as far as the consequences are concerned – death, serious injuries, minor injuries, etc). It is obviously not a question of seeking to establish a detailed link between injuries sustained and the extent of the damage to buildings, although this damage is the direct cause of those injuries (with the exception of some well-known effects of an earthquake, such as heart attacks, which do not call the architecture into question). Accordingly, expressing the effects of an earthquake on the building stock in terms of probable victims (in various categories) can be envisaged only on the basis of statistics that are themselves based on properly recorded observations.

* Secondary effects

In the context of estimating probable damage, account should be taken of the “secondary effects” of earthquakes, which may prove very dangerous. Among them, it is necessary to distinguish between “natural” secondary effects and those of human origin. In the first category, tsunamis are definitely the most formidable. They are due to a sudden vertical movement of the ocean floor (caused, for example, by an earthquake), which affects the overlying column of water, causing sudden distortion of the free surface of the water. The surface distortion spreads horizontally at a speed that depends on the depth of the water. When this depth diminishes (when the water approaches the coast) the phenomenon takes the form of very long breaking waves, which can be enormous, dissipate a large amount of energy and cause considerable damage. Other secondary effects less dangerous than tsunamis sometimes have tragic consequences: rock falls/cliff collapses and landslides, which can be enormous in the earthquake zone (mountainous areas with unstable rock bases, and submarine slope areas, which may, incidentally, trigger local tsunamis).

An earthquake can damage all kinds of man-made installations. There is the well known case of the fires which, in 1923, destroyed a major part of the town of Tokyo which was built essentially from highly inflammable materials. There are numerous, even more recent examples, i.e. Northridge, CA. Many industrial installations are also likely to multiply by a high factor the number of direct earthquake victims. Everybody remembers the nuclear factories. However it should be noted that they very frequently benefited from the building of over-proportioned security structures. In 1988 during the Spitak earthquake in Armenia (Soviet at the time), the Leninakan nuclear plant narrowly escaped a disaster. It hardly bears thinking about what the consequences of an important earthquake could be on certain chemical plants which treat highly aggressive products.

Other more apparently safe installations are nevertheless very exposed to earthquakes : high hydraulic dams are obviously built in favorable locations, namely in narrow valleys often associated with faulted zones which could imply the breaking of the dam and its possible consequences on downstream locations are unfortunately well-known. These very same installations are also at risk due to other reasons : the waters retained upstream from the dam are often situated in very hilly areas, which are likely to be subject to massive landslides suddenly generated by an earthquake; the sudden arrival of land masses in retained waters can generate a wave, which itself can submerge the dam or even lead to it breaking.

In short

It is clear from the foregoing analysis that, unless one is considering a limited territory whose characteristics are known in great detail (which presupposes very large and constantly updated databases, which may contain “sensitive” information), the entire process of estimating the probable consequences of an earthquake can only produce results of a rough order of magnitude, even when the time needed to produce “scenarios” is available. This applies all the more when an assessment has to be made in an emergency. In the latter case, it is possible to employ only very simplified assessment models, very straightforward fragility/vulnerability functions and highly averaged population distributions (depending on the time). It will be necessary to make do with estimates like “less than a hundred dead”, “between a thousand and five thousand victims” or “more than thirty thousand dead”. Any attempt to achieve precision will be pointless.

Even if very rough, there are *a priori* estimations containing very interesting information~~s~~ for some users : for example, should one or two (or more) cargo planes with material and emergency intervention staff be prepared ? Then there is the difficult question of sorting relevant information, of dispatching it to the interested users, in a way in which it may be accurately interpreted and understood. A steady dialogue between the different actors and information providers is obviously a necessary basis; idem for the further training of the staff concerned at all levels.

The '“*early warning system*” concept must not be considered in a too restrictive meaning : if it is obvious that information transfer mechanisms progressively lose their emergency nature as time passes after a major event, it is still the case that during a time lapse arbitrarily fixed at twelve or twenty-four hours after the event, the “normal” channels for information communication are not restored, or if they are, they are completely saturated. However, during this period some information keeps its emergency nature and must be treated in practically the same way as the very first initial information.

ANNEX 1

The concept of 'early warning systems'

(First draft)

Jean Bonnin
23 May 2005

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Historically, the concept of 'early warning system' derives from a specific prevention concern: taking in consideration that prediction of earthquake occurrence is out of reach presently, how to protect the populated zones in California against the effects of the shaking of certain objects at risk. A typical example is the dense gas-pipe web, largely developed because gas is the main source of energy used in urban areas for heating : if shaken to a certain degree, pipes can break and fires result (like in Northridge); hence, shutting down valves on gas-mains before the shaking damage them is likely to limit the danger of big gas-fires in the cities just after an earthquake. It obviously requires that a procedure be established which includes several steps : detection of the occurrence of an earthquake; evaluation of its parameters and its capability to generate certain types of progressive seismic waves (declaration of the alert); transmission of the alert to the control room(s) of the objects at risk, within a time delay shorter than the seismic wave propagation time between where the wave front was at the time of detection and the location of the objects at risk; shutting down of the gas-valves. Assuming an average wave propagation velocity of 8 km/sec (depends on the type of waves considered) gives a delay of about 30 sec maximum if to shut down gas-valves in Los Angeles upon detection (right at its source) of an earthquake occurred in the Parkfield region (a well renown seismogenic zone in California). It is clear that the whole procedure must be automated (and/or very efficiently supervised by well-trained persons on 24 hrs duty) to be effective; in particular, the detection of the earthquake and evaluation of its parameters must be entirely automated : this has been possible roughly in the 80ies when very dense seismographic networks have been operated in California, and the corresponding data management software developed. At the same time, the whole procedure must have been carefully designed and tested, owing to the potential economic impact of shutting down gas delivery.

The concept of 'early warning system', as defined above, is also applied to the control of the potential effects of earthquake shaking on hazardous industrial plants; the goal being to mitigate the consequences of failure of industrial systems triggered by the shaking; examples are many and very diverse : one of the most well-known case (because very much frightening) is the falling down of control-bars in the heart of an atomic reactor in an attempt at avoiding over-heating which could lead to destruction/explosion. Of course, many other industrial facilities would require similar protection (like the oil refineries) and very few are properly equipped; most often, systems are designed to trigger if integrity of the plant is affected in some of its parts, not as a prevention measure.

In a few cases, regions have been instrumented in order to protect populations and goods against the effects of earthquakes (Japan, Taiwan, Istanbul [Turkey more recently); systems require highly-automated functioning mode and extreme rapidity; there exist systems in which data transmission is based on cell-phone technology : it is assumed that data be transmitted to the processing centre(s) within the few seconds preceding the likely failure (through over-saturation, for example) of transmission facility. Fastness and robustness of the systems are obviously essential, and the above-concept of 'early warning system', *mutatis mutandis*, does apply. In other cases, the words have been kept, but the concept has been largely expanded. Applied to tsunami in the Pacific Ocean, it is valid and close to its initial meaning in the case of local tsunami affecting the costs of Japan with a triggering earthquake source 'nearby', so to speak; it is valid as well concerning a tsunami which has travelled the whole Pacific Ocean from offshore Chile to Japan where it arrives many hours later. The concept has been also commonly extended to part of the response phase to a just occurred disaster; in the case of an earthquake disaster, the causative event cannot be predicted within our present knowledge; 'early warning systems' include collecting information on the occurred event (earthquake source parameters), on the possible consequences in terms of modeled extent of damage and loss; eventually on the first clues of the field truth; all that encompasses several hours after the event's occurrence itself.

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