Preface

It is clear that the knowledge that earthquake engineers possess as well as the tools used in order to prevent earthquakes from taking place have considerably improved since the emergence of paraseismic engineering in the 1960s and 1970s. The improvements which have been made include:

– a better understanding of the causes and a better evaluation of powerful earthquakes due to the increase of recordings available of such powerful earthquakes, the increase in the number of study programs carried out on site as well as the development and advances made in digital simulation;

– a better understanding of seismic hazards for a particular site or for a particular region, i.e. the type and strength of seismic movements which are likely to occur in the future by taking into account the socio-economic importance and the life-span of existing and future buildings and constructions that may be affected by earthquakes;

– a better analysis of the behavior of structures which are subjected to strong tremors, thanks to the work carried out during post-seismic investigations, and thanks to the evolution and appearance of new trial methods (vibrating tables, reaction walls, centrifuges) as well as to the remarkable increase in computer processing capacity (particularly in the non-linear domain).

Have improvements as regards the knowledge of earthquake engineers and the improvements in study methods which are used to analyze earthquakes led to advances in relation to the prevention of earthquakes?

The answer to this question must be explained in detail because the progress that has been made and which has been mentioned above tends to highlight the complexity and variability of the different phenomena affecting earthquakes and therefore uncertainties still remain when such phenomena are used. For example, in relation to the evaluation of ground movements in a seismic risk study a lot of significant uncertainties remain in terms of the actual potential of the earthquakes (precise location of the fault, the number of faults and how active they are) as well as for the calculation of vibratory movements. If we only focus on the calculation of vibratory movements it is possible to mention the practical problems brought about by the description of the three terms (mentioned below) which are traditionally used in the field of seismology:

– source, which is characterized by magnitude and which, in reality, depends on other factors such as the type of movement of the fault, possible segmentation of the fault map into zones with different characteristics, the temporal course of the rupture outline of these zones, and the constraints associated with these ruptures. These factors can often be identified and described when there are a sufficient number of recordings available for an earthquake which has occurred in a region and in particular in a region which is well-equipped with the material which makes it possible to record the earthquakes. The factors can also be identified and described from certain hypotheses that have been made and which are deemed plausible, i.e. there is a realistic chance that a particular earthquake may occur in the future in a specific region. However, most of the recordings that are available are deliberately ignored in seismic risk analyses because these analyses, by definition, only consider earthquakes which have not yet taken place and which may occur in the future;

– propagation, which is characterized by distance (from homes, from the epicenter, from the fault), depends on the type of seismic waves (volume or area), and on the level of inelastic attenuation reached by the sound waves during their propagation as well as on the possible intervention of the effects of directivity or focalization. As is the case for the source, the influence of these factors cannot be taken into consideration in risk studies;

– site, which is characterized by the type of soil (rock, closed soil, soft soil), depends on all geotechnical parameters (thickness, inclination and the mechanical characteristics of the layers of the earth) in relation to the make-up of the soil or geological structure (more-or-less hemmed in valleys, sedimentary basins, and also synclinal and anti-clinal basins). These parameters can be evaluated and considered in simple cases of horizontal stratigraphy but cannot be used in the collection of data for risk studies or in the collection of data on a regional scale and even in the collection of data for the study of individual sites, especially when the seismic response of such sites is strongly influenced by topography (of the ground's surface or underground).

Although it would seem necessary for earthquake engineers to understand and be able to access all of the parameters in order to model and calculate virtual seismic movements in their risk analyses, the impossibility of having access to all of the parameters means that they have to use approximate formulae such as magnitude for the source, distance for propagation and type of soil for the site. This means that the standard deviation of these formulae is equivalent to the average value, i.e. in a failsafe approach which is based on the values “average plus standard-deviation”. The parameters of seismic movement (acceleration, speed, displacement) are multiplied by a factor of two in relation to their values when used in an approach which is based on average values.

This fact should never be ignored by the different people working within the field of paraseismic engineering. This fact has been confirmed and proved by all earthquakes for which it has been possible to obtain quite a large number of powerful recordings in the epicenter or in the neighboring areas of the epicenter; the large variability in the recorded movements (which not only occurs because of the site effect) must be considered as the rule of thumb rather than as an exception to the rule.

There are also a significant number of uncertainties in the area of seismic engineering where the progress which has been made at a theoretical and experimental level deals with simple cases (regular structures, unidirectional excitation). If for such cases the physical significance of the behavior coefficient (i.e. a coefficient greater than one which can be divided by the effort calculated on an elastic model in order to achieve realistic dimension efforts) had been better defined then the transition to more complex cases (irregular structures with a 3D response) can only be calculated with the use of a relevant coefficient coupled with the judgment of an expert who works in this field and not by a scientifically valid approach.

These difficulties in the transposition from the study of simple to more complex cases are found in both the design principles as well as in the calculation methods which are used. The “in capacity” dimension, which is a basic principle of the future European code on how to make building and civil engineering structures resistant to earthquakes (known as Eurocode 8), consists of predetermining the concentration of plasticity zones by providing these zones with the appropriate constructive measures which make it possible to control malformations by maintaining an acceptable capacity of resistance. The dimension also involves the increase in size of the other potentially critical zone in order to be sure that the plastifications only occur where we expect them to. This approach cannot be used for irregular structures which are extremely hyperstatic. In such cases the project designer is unable to control the sequence of successive plastifications that result from 3D excitation which can create unpredictable effects such as seismic movements. The “in capacity” dimension can thus become a hazard if the choice of plasticity zone does not correspond to the real outline, this dimension can often be unexpected and even completely unpredictable due to the transfer of force between the structural elements.

In relation to the calculation methods used, the pushover approach has recently been suggested (it characterizes a structure by an effort-displacement curve which is obtained through a set of non-linear static equations that represent the action of an increasing force). If the pushover approach relies more on displacement criteria (used more in seismic stress) than on criteria related to forces (used mainly in traditional construction codes and standards), then it only applies (in its current form) to structures which are quite sensitive to the 3D character of seismic movements and which are also quite sensitive to torsion efforts.

One of the most common errors made, and one in particular which is made by the decision-makers in relation to the prevention of earthquakes is the belief that the main difficulty lies in defining the actual seismic movement from which the engineer has to work (design, calculation and creation) by using well established procedures as the earthquake “is only a question of force amongst other things” and earthquake recognition is a “simple software problem”. It is surprising that such a simplistic speech, which stems from a misunderstanding of the complexity of the phenomenon of earthquakes and of an over appreciation of state of the art technology in relation to the non-linear calculations under 3D dynamic excitation still holds value in certain instances. Will we see the effects of relying only on the capability of computers coupled with a lack of understanding of earthquakes particularly in countries which experience weak or moderate earthquakes, and in which regions will these effects have to be taken into account?

The current limits in our ability to analyze non-linear behavior under seismic stress have clearly had repercussions on the reliability of our appreciation of safety margins brought about by dimensioning, regardless of the strategy that has been adopted (acceptance or refusal of material behavior laws in relation to the field of plasticity). For special risk structures, according to the terminology that is used in France, these are structures that pose significant risks to entire towns or even to a region in terms of the damage that they can cause (nuclear power stations, certain chemical factories, large dams, etc.). Research with a high degree of security up until now has led to the creation of dimensions which are primarily based on elastic calculations and on the criteria of static equilibrium between forces. It is the caution taken in this approach (linked to the conservatism of the static character of the criteria used for dynamic charge) along with a stacking up of coefficients in an approach that is carried out in several phases which forms part of the main causes of the obtained level of security and not, as is often thought, the choices made for the calculations of seismic movements.

A paraseismic experiment which was carried out more than 25 years ago has enabled me to address different aspects (methods of calculation, paraseismic devices, regulations, post-seismic work) for the different types of structures (nuclear power stations, dams, bridges, tunnels) and has also given me the opportunity to work with specialists from several disciplines (geologists, seismologists, soil engineers, as well as civil and mechanical engineers). This work convinced me that it was necessary to make those people involved in the creation of earthquake-resistant designs and structures aware of the factors that they sometimes did not pay enough attention to, or which were deliberately ignored by these very same people. The majority of these factors will probably contradict a more triumphalist view of paraseismic engineering. These factors include:

– the recent and incomplete character of the information available on powerful seismic movements and their effects on certain types of constructions. It occurs quite often that a new earthquake which has been recorded and studied, in relation to its consequences, highlights certain things which up until now have been under-estimated or completely ignored in terms of both the movement of the ground (such as the killer pulse which is a strong oscillation at low frequency and which is felt at neighboring faults) as well as the behavior and reaction of the structures (for example the reaction of buildings with welded metal frames during the earthquakes at Northridge in 1994 and Kōbe in 1995);

– the importance of experience when analyzing the calculations. There is a tendency to forget that the basis of the paraseismic codes which are applied to everyday constructions are applied for a purely practical reason, and in particular in relation to constructive precautionary methods. The preeminence of feedback must be ensured especially at a time when common sense and critical thinking are being replaced by the use of computers and calculations;

– the fundamental role of the detailed design of the different methods used for effectively preventing earthquakes from causing too much damage. Media coverage tends to show the damage caused by an earthquake and prefers to highlight the faults or the refusal to apply preventative regulations which certainly play a part in but which are not the main causes of earthquake disasters. The main causes of these disasters generally come from the fact that the paraseismic codes and standards do not apply to new constructions and only affect a small number of buildings in a town if we take into consideration the recent date for when it became compulsory to apply these standards in the majority of countries worldwide, as well as the vulnerability of the constructions built before this date. The paraseismic codes and standards which have been introduced do not make it possible to pass value judgments on the design of buildings which means that two structures that meet the standard requirements can possess very different safety levels in the sense that one of them can resist powerful earthquakes (which are more powerful than predicted in the codes) without collapsing, whereas the other one which does not have any reserves will collapse;

– the current development of the majority of paraseismic codes which on one hand is characterized by increasing complexity. It can be questioned if this increasing complexity is justified because of the current knowledge available in relation to the creation of earthquake-resistant designs and structures, and if it will pose or is already posing practical problems in terms of the classification and the correct use of the codes. On the other hand this increasing complexity is characterized by a somewhat dogmatic and illusionary presentation; this type of presentation and the fact that these codes are standardized (which reduces explanations on the required measurements to a minimum) tends to obscure the fundamental importance of the detailed design of the methods used for effectively preventing earthquakes from causing too much damage;

– the risks of confusion, in the field of creating earthquake-resistant designs and structures just as in other areas, between research and practical engineering; the unquestionable progress which has been made by researchers in the seismology of strong earthquakes as well as in the analysis of structures are often difficult to echo in operational procedures. These difficulties focus primarily on the availability of necessary data for the implementation of more elaborate procedures, as mentioned earlier for the calculation of earthquakes in a risk study; by way of a comparison the research work carried out in paraseismic engineering is similar to the research work undertaken by a medical examiner which rests on the dissection of the body to be studied (recordings and post-seismic observations, models subjected to trials, results from paraseismic studies on digital models). This essential work does not necessarily have any immediate positive consequences on preventive medicine ("constructive hygiene", i.e. design) or the vaccination policy (the contents of paraseismic codes and their imposition by statutory means).

It is the factors that have been described above coupled with the lack of understanding of such factors by some of the people working in the creation of earthquake-resistant designs and structures and in the minds of the majority of decision-makers which have been my motivation behind the writing of this book whose first edition (in French) was published in 2003. The aim of this book is not to explain what paraseismic engineering is or to explain some of the aspects which form part of this topic (such as the seismology of strong earthquakes, the dynamic calculation of structures or the principles of paraseismic design) for which excellent texts are currently available, but to give a personal point of view on the following three subjects:

– the analysis of the current knowledge that earthquake engineers possess. This analysis was created in 2000 and aims at distinguishing between what information is available (in the long term) through results from research, from information which can now be used under certain conditions instead of in the current methods of paraseismic engineering;

– the role of the generalist which, in my opinion, is vital. The gaps in our knowledge and the extent of the uncertainties that exist in assessing the level of safety to be researched, depending on the type of structure and on the definition of the methods used in order to reach the required level of safety should not result from a series of decisions which are taken only by specialists working in different fields. When paraseismic engineering was as its founding stage, at a time when there were not a lot of recordings of strong earthquakes (and at a time when not a lot of seismologists were interested in this branch of seismology), generalists were recruited alongside the engineers who wrote and edited the codes. Current developments, which are geared towards an ever-increasing specialization of the different people working in this field, make it increasingly difficult for the engineers to improve their career prospects when it comes to working in this job as a multidisciplinary vocation. Career development is just as important nowadays as it was in the past, especially for the co-ordination of studies and for controlling the coherence of the different choices which contribute to the best protection possible against earthquakes;

– the importance of being able to remember the size and scale of earthquakes (or to be able to find them through reasoning or simple formulae) which not everyone can remember because earthquakes do not occur that often in our lifetime and when they do they only last for a short period of time. The fact that the majority of people working in paraseismic prevention, at least in countries with moderate seismic activity, have practically no personal experience of earthquakes exposes them to imagine what powerful earthquakes might be like or to make errors when estimating the scale of earthquakes. An understanding of the size and scale of earthquakes is therefore much more essential in paraseismic engineering than in other engineering domains and can be acquired by understanding earthquakes and by comparing some of the earthquake models which have been created in order to simulate earthquake processes.

The nature of these three subjects and the limits of my knowledge mean that the text which I have written is subjective and will certainly contain certain caps, questionable judgments or even errors. The approach that I used was to review the different aspects of paraseismic engineering in a logical order (i.e. the phenomena associated with paraseismic engineering, the quantification of their appearance, the description of their effects, the principles and methods used in the prevention of risks). Each aspect has been commented upon in relation to the knowledge that the earthquake engineers have on that specific aspect as well as on determining the orders of magnitude. I have tried to state hypotheses and their limits in terms of their validity as well as stating the pros and cons linked to feedback.

Certain parts of this book are rather descriptive and serve as a history to the evolution and development of ideas which in my opinion is very important for the training of generalists. The evaluation of the orders of magnitude relies on analytical calculations on simple models by following a traditional approach which may seem outdated in this era of computing and modern technology, but which forms the basis of the engineer's job, as long as the engineer does not solely rely on the use of computer software. As far as the calculations are concerned I have done my best to only use basic mathematical methods which normally form part of the basics that is taught to engineers. I have also done my best to distinguish between what comes from deductive reasoning taken from hypotheses and the results that come from feedback.

The outline that has been adopted and the content of the different chapters have been chosen so that the text can be read by someone who has no previous knowledge of paraseismic engineering on the condition that the reader is prepared to make a certain effort in terms of assimilation. Certain formulae are given without the explanation of their calculations. Some parts of the text include relatively specialized developments which have occurred within the field of paraseismic engineering and which can be omitted by people who are reading the book with the sole aim of having an overall view of paraseismic engineering. The book is divided into seven parts.

Part 1 introduces the seismic phenomenon from the point of view of its causes and what the phenomenon appears like on the surface of the Earth. The presentation of this part (for which I was largely inspired by the layout of a large number of popularized books) aims at covering all of the important aspects which should be taken into consideration in relation to paraseismic prevention (and in particular the following resulting phenomena: soil liquefaction, landslides and tsunamis), yet the first part remains essentially qualitative and not too detailed, except where faults and the significance of the magnitude are concerned. As far as these last two subjects are concerned I believe that the majority of engineers have insufficient knowledge regarding them both, which in turn does not enable them to have a clear perception of the ideas of focal depth, distance from the source and the extension of the fault map. A simple mechanical model, based on the theory of elastic rebound by H.F. Reid, and the examination of a certain number of well documented cases of faults have led to the definition of the moment magnitude and to its interpretation in terms of energy, the extension of the fault map and the range of potential damage that earthquakes can cause. Precise indications are also given on seismic waves and their propagation without which it would not be possible to understand both the softening mechanisms of movements and the causes of site effects.

Strong vibratory movements, which are the basic elements for the definition of seismic action, are the subject of the second part of this book. In this part there is an introduction to strong-motion recordings (without addressing the issues linked to the instruments used and the processing of the signals). In Part 2 there is also a presentation of the softening laws that are applicable to earthquakes which have been derived from theoretical models, as well as simple diagrams which are used in order to explain site effects and directivity effects and which are also used to estimate the dominant frequency of accelerograms (in terms of displacement, speed and acceleration). The current state-of-the-art digital simulation material used for seismic movements is briefly mentioned both for rupture models on the fault map and for the sites' response in the linear and non-linear domain.

Part 3 deals with the seismic risk in relation to the data that characterizes the spatial and temporal distribution of seismicity and its evaluation methods (both determinalistic and probabilistic). Indications on risk studies are given for studies carried out in entire countries (zoning of the paraseismic codes), towns or small local villages (micro-zoning), or on individual industrial structures (especially in the case of nuclear structures). Orders of magnitude are supplied for hazards which occur due to the faults (surface ruptures and vibratory movements) and which occur because of a non-localized seismic zone, so that the influence of certain parameters (e.g. the envisaged maximum magnitude, the depth of homes and residences, and the dimensions of extended sites such as large tunnels and large towns and cities) can be evaluated. Long-term and short-term seismic forecasting is also mentioned.

Seismic action, i.e. the characterization of seismic phenomena relating to the calculation of their effects is presented in different forms in Part 4 (seismic coefficients, response spectra, accelerograms and random processes). This subject is undoubtedly one of those subjects that is misunderstood the most, even by some specialists who work in this field and which may be due to the fact that the study of seismic actions is the interface between two different disciplines (seismology and engineering). Seismic action is, on one hand, linked to safety objectives regarding the creation of buildings and structures that are resistant to earthquakes, and on the other hand linked to the calculation methods and verification criteria that are used. Characterizing the seismic phenomena through the use of a response spectrum, which is the most commonly used approach, is linked to the use of linear models for carrying out calculations. Such calculations can be questioned in the case of paraseismic codes that are applied to everyday buildings that are subject to a high level of plastic damage, i.e. due to the non-linear behavior.

In the case of using non-linear models, reference to the spectrum is not very appropriate for the choice of entry accelerograms of these models whenever the plastic damage mechanism is cumulative and therefore depends on the duration of excitation (which is poorly represented by the response spectrum). Assessment and evaluation elements are provided and they explain the limits of the use of the spectra and on the selection of accelerograms for both linear and non-linear calculations.

Part 4 also introduces the coefficient (known as behavior) which is used in the majority of recent paraseismic codes in the only case where the coefficient can be precisely defined, i.e. when used in regular structures which can be represented by an electro-plastic oscillator (a model with one degree of freedom). This introduction makes it possible to highlight the predominance (for security assessment) of the criteria of displacement on the criteria of equilibrium that exist between forces and that are generally used in codes nowadays. Resorting to random and unpredictable processes in order to characterize seismic action is explained in a simple fashion by only referring to the case of pure white or filtered noise in such a way that in Part 6 quadratic combination rules can be justified and the methods of stochastic linearization can be presented.

Part 5 describes the effects of earthquakes on buildings and constructions; these effects also form the databases from where the paraseismic codes for the different materials that are commonly used in construction work are taken (i.e. concrete, steel, brickwork and wood). All possible variants of the seismic phenomenon are dealt with; surface ruptures, reversible and irreversible deformations of the ground, vibrating movements which shake buildings or which make them collide with one another, and resulting phenomena (such as liquefaction, effects on traffic, effects on the environment and fires). These descriptions are supplemented by comments on the influence of the overall design and detail of the causes of the damage that is observed as well as on the practical problems which the interpretations of post-seismic observations can pose.

The use of the effects of earthquakes in order to characterize their level (i.e. the concept of macroseismic intensity) is also presented in Part 5. A short introduction is given to the scales of intensity of the earthquakes, to the abbreviated description of some of the scales and there is also a discussion on the values and limits of this motion of intensity. The digital correlations of intensity along with the parameters of movement (acceleration, speed) and the magnitude of the earthquakes are then studied as well as the softening laws in relation to distance.

Part 6 is the most developed part of the book. It is devoted to seismic calculations and is made up of three chapters:

– the first chapter (Chapter 15) deals with linear calculations in the form of spectral model analysis which is used for most linear models. Its principles and different phases (such as determining the relevant elements, frequencies or periods used in spectral model analysis, and model distortions, combinations of model responses and directions of excitation as well as the stress calculations used for dimensioning) are presented for general seismic calculations (different ground movements under the supports of structures) and in the case of larger scale movement (translation or translation with rotation) of all the supports. The emphasis is placed on the problems that can be encountered in the selection of the methods used and the use of pseudo-models as well as on certain difficulties that are linked to the application of quadratic combination rules. Attention is given to the risk of errors which is insufficiently understood by the users (especially by those who use and rely on black box software). These errors are a result of reciprocal incompatibilities between the displacement fields, the acceleration fields and the internal efforts which are determined by quadratic combinations. In this chapter I also show that the common practices used in the calculation of dimensioning efforts stemming from "maximum" acceleration (in the sense of quadratic combinations) lead to a systematic overestimation that is often moderated (by 15% to 25%) but can sometimes be moderated by more than 100% (which is absurd) for certain, sometimes quite simple structures (such as a continuous section console which is embedded in its base foundations);

– the second chapter (Chapter 16) gives an insight into the phenomena surrounding the interaction between the ground and the structures and their consideration in dimension studies. The consideration of such phenomena normally lies with the specialists who work in this discipline (a discipline that can be found at the interface between seismology and the dynamics of soils and structures). However, it seems necessary to me to provide the generalist working in this field with the necessary tools so that they can estimate the size and scale of the earthquakes with the aim of being able to appreciate the interaction phenomena, the influence of the different parameters and the difficulties that can be encountered in relation to radiation, which occurs from the waves that are emitted in the ground from the foundations of the structures;

– the third chapter (Chapter 17) introduces non-linear calculations. In this chapter some generalities on the hypothesis and the acceptability of the results can be found (which forms part of the most sensitive issue that needs to be resolved if we want non-linear calculations to become common practice in the dimensioning process). Chapter 17 also gives a brief introduction to the methods used in non-linear calculations including those methods which rely on linear techniques (stochastic in particular). Six examples of non-linearity are then described and commented upon; these examples have been chosen in order to illustrate the diversity of problems and to establish some formulae in relation to the scale and size of earthquakes and which are relative to phenomena that are widely misunderstood. Amongst these examples we can mention the non-linearities linked to the liaison with the ground (the detachment of concrete slabs, the rocking and sliding of blocks), and the plastic deformations of structures (already mentioned in Part 4 when talking about the behavior coefficient) which also gives the opportunity of introducing the pushover method and the design of shock-absorbers that are used for making bridges resistant to earthquakes (illustration of the stochastic linearization method).

By way of a conclusion the different aspects of paraseismic prevention are the subject of Part 7. In relation to the technical aspects, the information and commentaries which have been made in the preceding parts are supported and completed by a brief presentation of the experimental methods used (feedback synthesis, trials and experiments using vibrating tables, loaded oscillators, reaction walls or centrifuges, and static experiments with presses). Special paraseismic devices and the strengthening of the existing frame of buildings are also presented (these form part of the key issues in paraseismic prevention in both the short and mid-term, since the application of paraseismic codes only affects new constructions).

The principles and methods used in the application of technical texts (standards, practical guidelines, recommendations by professional associations) are also briefly presented and commented upon for both everyday constructions (affected by a normal risk of earthquakes according to the French terminology) and for everyday constructions that are affected by a special risk (once again in accordance with the French terminology which has been used and explained above). Experience has shown that there can be a significant difference between what the engineers actually do and what they think they can do when you take into consideration expressions which come from articles such as the non-collapsing objectives, intrinsic protection or the maximum earthquake.

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