Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

## 2-2-4

# SEISMIC MICROZONATION AS APPLIED TO RISK-EXPOSURE PLANS (PER) IN FRANCE

Pierre-Yves BARD[1], Jean-Pierre MENEROUD[1],
Jean-Louis DURVILLE[1], Pierre MOUROUX[2]

[1] Laboratoire Central des Ponts-et-Chaussées,
Paris, Grenoble, Nice, France
[2] Bureau de Recherches Géologiques et Minières
Marseille, France

## SUMMARY

The first attempts at defining the technical studies for drawing up seismic risk-exposure plans were carried out in southeast France, in view of its moderate seismic history. This work led to proposals for study methods based on seismic microzonation, whose main steps are: identification of areas where vibration is amplified, because of local geological or geomorphological conditions; estimation of the sensivity to liquefaction; analysis of slope stability under seismic action, by applying a simplified pseudo-static calculation to a classical hazard zonation. The cartographic synthesis is accompanied by proposals defining preventive measures to be taken by builders and developers.

## INTRODUCTION

The law on the indemnification of victims of natural catastrophes, dated 13 july 1982, obliges the French state to draw up risk-exposure plans (PER), in particular related to earthquake risks (seismic PER).

Even though the methodology of seismic PER's is not yet entirely defined in its details, the authors consider that seismic microzonation should form an essential step of a PER, at least in its technical-design phase. In fact, the seismic action, as it results from an inventory of seismic sources and an estimate of their activity is, in France, defined according to a national zonation that was recently revised (Ref. 1). Seismic action is modulated by local conditions, such as modification of the seismic signal and the effects caused by vibration upon soils. These phenomena are presented in a synthetic manner in the seismic microzonation, whose scale and content therefore answer the main concerns of a PER.

A seismic microzonation methodology as adapted to a PER is presented hereafter. It is already used by 38 communes in two departments of southeast France, covering an area of about 800 km2, in the preparation of individual risk-exposure plans. The proposed microzonation is drawn up at 1:5,000 or 1:10,000 scale and is based on the analysis of two types of phenomena: modification of the vibratory signal by surface layers and the topography; the effects on soils, such as liquefaction of saturated sand and induced landslides and rockfalls. For this reason, earthquake and terrain movements are treated simultaneously in the PERs. The risk of tectonic rupture, caused by appearance of earthquake-induced faults at the surface, will not be discussed here.

## MODIFICATION OF THE SIGNAL

Seismic waves can be modified in many ways at the earth's surface. Not only is this surface formed of varied and mechanically contrasting materials but the geometry of such materials can also be quite complex, because of topographic relief or folding of the rocks. Seismic waves can thus lead to highly variable surface-movement phenomena, depending on the location.

Typical configurations - Macroseismic observations, experimental studies and theoretical models identify several typical configurations, where, almost systematically, adverse local effects occur (Fig. 1).

*Weak formations overlying a rigid substratum* - This very common configuration, which is found as sedimentary basins, alluvial valleys, weathering layers, etc., forms a "trap" for seismic waves. When such weak formations are sub-horizontal and of great extension, the spectral and temporal modifications are relatively simple and easy to calculate, with a one-dimensional model. When, however, the subterranean geometry is tortured (variable soil, thicknesses, deeply-incised alluvial valleys, etc.), the modifications to the signal will be much more complex with, in general, greater amplification than in the first case, the appearance of highly-localized surface waves, and the generation of major differential movements.

*Marked lateral discontinuities and contact zones* - Numerous macroseismic observations (Irpinia, 1980; Liège, 1983) have revealed a significant increase in damages in the immediate surroundings of contact zones between highly-contrasting formations. The typical case of such a contact is a vertical or steeply-dipping fault. The most plausible explanation, independent of all movement along the fault plane itself, is the generation of very localized surface waves that propagate mostly through the weak formation.

*Topographical relief* - Even though theoretical calculations and experimental observations are not always coherent in a quantitative sense, they do agree on the fact that tops of isolated buttes (three-dimensional) or elongated crests (two-dimensional), edges of plateaus and cliffs are commonly the locus of major amplification of seismic waves, caused by diffraction and focusing phenomena (Ref. 2).

Study methods-From the foregoing it should be clear that the study of signal modification consists, first of all, of a geological and geomorphological analysis of the area. This analysis pinpoints the most unfavourable sectors and lead to a qualitative estimate of the physical nature of the phenomena. To go one step further, to quantitative or semi-quantative results as is required by a risk exposure plan, one can use simplified methods or methods for determining the transfer functions of the site.

*Simplified methods* - Such methods rest on the use of a few mechanical and morphological parameters that describe the site and define the local effect in simplified fashion, such as increase of the maximum acceleration. Such methods are reliable for simple configurations, such as a large sedimentary basin that can be compared to a horizontal two-layer system. The case of the two- layer model subjected to a SH wave, for instance, is well known (Ref. 3). Approximated formulas allow to consider the case of multiple layers and lateral variations (Ref. 4).

*Methods for determining the transfer functions of the site* - Such function permits calculation of the signal modification in frequential and temporal domains. Its evaluation requires the use of relatively important means: either experimental, involving the recording of micro-seismic (background) noise, or numerical, with one or two-dimensional calculations (Fig. 2) and a linear or non-linear model.

Cartographic synthesis and application to a PER - When the modification of the seismic signal by the site conditions is large, this will lead to a change in the seismic-reference action upon constructions. For the risk-exposure plans, the adopted modus operandi consists of the following steps.

A geological map is drawn with emphasis on the lithology, at the scale of a PER. Areas are outlined that are homogeneous in a geological or geomorphological sense, on which simplified evaluations provide an amplification value and a predominant frequency of the site. Finally, these values are further defined or corrected by several two-dimensional calculations on profiles selected as a function of the site structure.

The example of the map of Menton (Fig. 3) illustrates this procedure. The proposed regulations comprise an adjustment of the foundation coefficient $\delta$ that is specific for each zone; a multiplying coefficient, limited to 1.6, is applied to $\delta$ over a period range that is centered on predominant period(s).

## LIQUEFACTION

Evaluation criteria of the liquefaction potential of a site are evaluated, based on classical susceptibility and opportunity criteria: Seed and chinese methods (Ref. 5). The mapping of liquefaction-sensitivity zonation will at least comprise the differentiation between areas that are not susceptible to liquefaction and borderline cases. This is shown on the PER map for Menton (Fig. 3).

## TERRAIN MOVEMENTS

The term "terrain movement" combines several phenomena, such as landslides in unconsolidated material, rockfalls, torrential mud or debris flows, subsidence into subterranean cavities.

In this context, only the increase of natural hazards related to landslides and rockfalls will be discussed. Such movements, which are related to the presence of slopes, can be divided into two groups:

*Instability of a general type,* for which the seismic shock plays a simple role of "trigger", analogous to the role played by heavy rain: this is the case of "purging" a rock face;

*Instability that is specific to seismic shocks,* on sites considered as stable in a static regime, even though they usually have uncommon geomorphological characteristics. This is the case of landslides caused by liquefaction of a thin soil layer (Rinihue lake in Chile, 1960), or of landslides conditioned by seismic amplification caused by a particular topographic relief.

The mechanical analysis of slope stability under seismic action, which in this case is three-dimensional vibration modified in places by local conditions, is a problem that, at present, is not yet completely solved. There are two reasons for this:

1. The numerical methods with calculation over the time span of pore-pressure evolution and deformational changes, are very cumbersome, and insufficiently calibrated by actual cases ;

2. The mapping methods with geological and morphological criteria are not yet developed in the seismic case because of lack of accumulated experience, even though these methods in the non-seismic case have reached maturity, in southeast France in particular.

Under such conditions, zonation of terrain-movement hazards, as amplified by taking seismic action into account, can only be rather crude.

Landslides in unconsolidated material - The methodology used to establish a risk-exposure plan, rests primarily on a classical mapping effort under static conditions (over 3 or 4 hazard levels, according to each case). After this, a simplified pseudo-static method is applied for determination of the hazard increase, along the following hypotheses :

1. A seismic coefficient, K, is selected, which allows the introduction of an inertial force parallel to the slope, K varying between 0.05 and 0.22 g and possibly increased by amplification due to site conditions.

2. Tentative attribution of a static safety coefficient Fs, as a function of mechanical, geometric and hydraulic parameters of the slope soils. The degree of hazard depends on the proximity of Fs to 1. For the PERs drawn up until now in areas with earthquake risk, 4 degrees of hazard were distinguished: zone 1: $1.8 < Fs$; zone 2: $1.5 < Fs < 1.8$; zone 3: $1.25 < Fs < 1.5$; zone 4: $1 < Fs < 1.25$.

3. A negligible variation of the mechanical properties ($c$, $\phi$ ) and the pore-pressure field ($u$) at failure: the liquefaction problems must be treated apart.

The method uses the slope angle as parameter and leads to a reduction of the boundary angles, which locally define the limit between hazard zones (Fig. 4). In this manner, one can determine, for each homogeneous area, an extension of the areas of elevated risk as compared with the initial, static map.

Rock slides and falls - Hazard increase due to seismic shocks is normally determined by considering the "purge" effect and lengthening of block trajectories (Friule, 1976).

Cartographic synthesis - Such a synthesis commences with the results obtained in static conditions. After this, under dynamic conditions, certain sub-zones increase by one hazard degree (Fig. 5).

## CONCLUSION

Independently of administrative, legal and political problems, posed by the application of a seismic risk-exposure plan (PER), the technical work carried out on 38 PERs in southeast France has led to an experimental methodology. This first attempt, based on seismic microzonation techniques and operationnal, will no doubt be further refined, better to answer the strict requirements posed by a PER. Detailed geological knowledge of the site, based on mapping at scale 1:5,000 forms the basis of all attempts at synthesis in the form of microzonation.

## REFERENCES

1. Despeyroux J., Godefroy P. Nouveau zonage de la France en vue de l'application des règles parasismiques de construction et de la mise en oeuvre des PER, Délégation aux Risques majeurs. La Documentation française, Paris, 1986.
2. Bard P.Y., Méneroud J.P. Modification du signal sismique par la topographie : cas de la vallée de la Roya (Alpes-Maritimes, France). Bulletin liaison Labo. Ponts et Chaussées, 150/151, pp. 140-151, 1987.
3. Bard P.Y., Méneroud J.P., Durville J.L., Mouroux P. Microzonage sismique - application aux plans d'exposition aux risques (PER). Bulletin liaison Labo. Ponts et Chaussées, 151/151, pp 130-139, 1987.

4. Bard P.Y. La réponse sismique des dépôts sédimentaires bidimensionnels : synthèse de résultats numériques, 1er colloque national de génie parasismique, Saint Rémy-de-Chevreuse, France, vol. I, pp 2/11-2/20, 1986.
5. Seed H.B., Idriss J.M., Arango I. Evaluation of liquefaction potential using field performance data, ASCE, Jal of geotechnical eng., vol. 109, n°3, 1983.

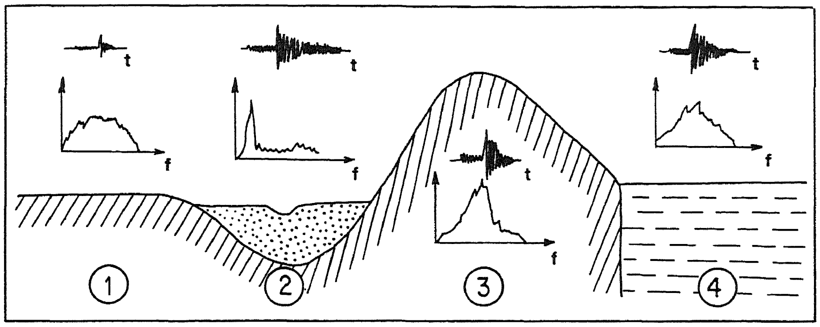

FIG. 1 _ THREE TYPICAL CONFIGURATIONS ②,③,④ THAT PROVOKE A CHANGE IN VIBRATON SIGNAL, COMPARED WITH HORIZONTAL SUBSTRATUM ①

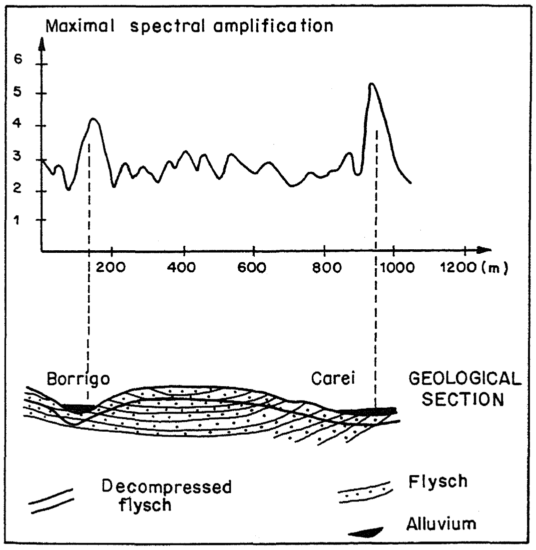

FIG. 2 _ BIDIMENSIONAL CROSS-SECTION FOR THE TOWN OF MENTON SPECTRAL AMPLIFICATION

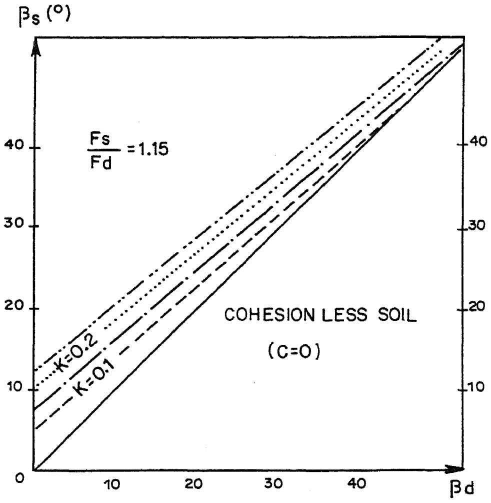

FIG. 4 _ NOMOGRAM SHOWING FOR COHESION LESS SOILS THE SLOPE βd BASED ON AN INITIAL SLOPE βs FOR DIFFERENT VALUES OF THE SEISMIC COEFFICIENT K

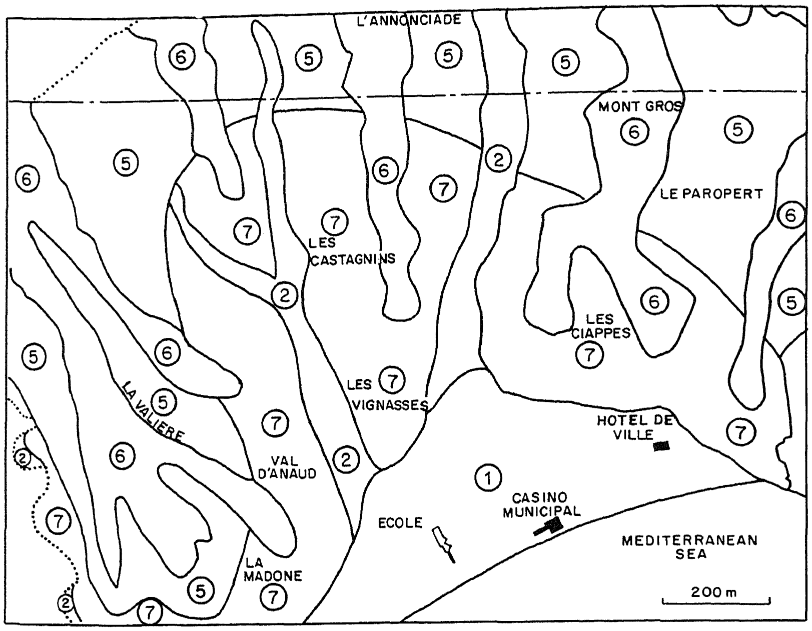

FIG. 3_EXCERPT FROM THE SITE EFFECTS MAP OF MENTON, FRANCE
A COEFFICIENT δ (FRENCH BUILDING REGULATIONS FOR SEISMIC AREAS) IS ASSIGNED TO EACH ZONE DEPENDING ALSO ON THE PERIOD OF BUILDING_
ZONE ① IS MOREOVER POTENTIALLY LIQUEFIABLE

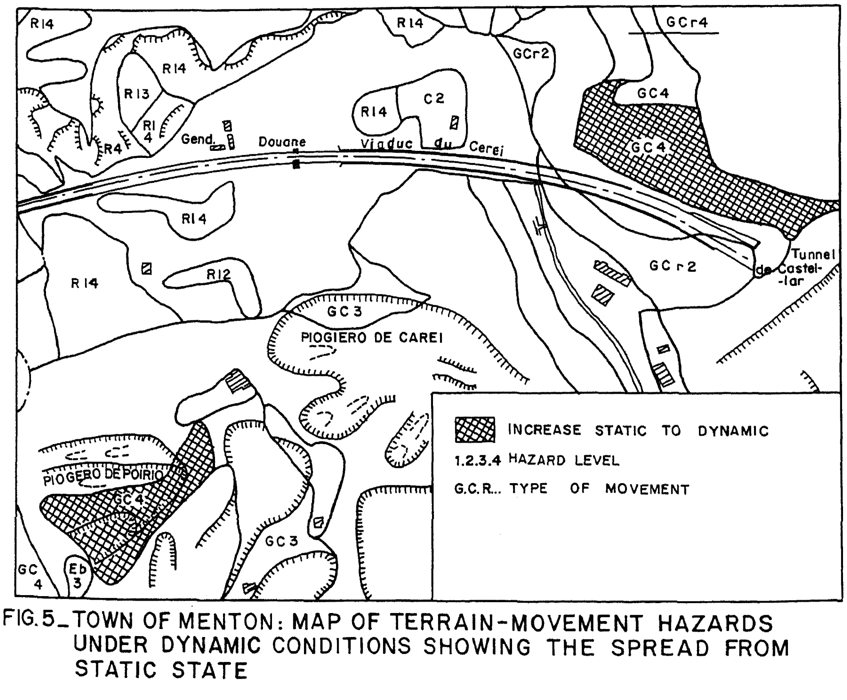

FIG. 5_TOWN OF MENTON: MAP OF TERRAIN-MOVEMENT HAZARDS UNDER DYNAMIC CONDITIONS SHOWING THE SPREAD FROM STATIC STATE