THEME 2

Hazard mapping in risk evaluation for engineering structures

Cartographie des risques en vue de l'appréciation des hazards potentiels pour des constructions

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A GENERAL PROCEDURE FOR REGIONAL SEISMOTECTONIC MAPPING FOR ENGINEERING PURPOSES

UNE PROCEDURE GENERALE POUR LA CARTOGRAPHIE REGIONALE SISMOTECTONIQUE EN VUE DE SON UTILISATION EN GENIE CIVIL

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Summary

So that the advances in earth sciences, particularly in tectonics and seismology, can be translated into terms helpful to planners having to cope with earthquake risk a generalised procedure for regional seismotectonic mapping for engineering purposes is developed. The procedure is particularised to a set of tasks, which can be undertaken with our current "state of the art" as the framework, while recognising the need to initiate spectral studies and use new techniques aimed at better defining the geological and tectonic controls on current seismicity.

Résumé

Etant donné les progrès dans le domaine des "sciences de la terre", plus concrètement dans la tectonique et la séismologie qu'on peut utiliser aussi très efficacement pour les planifications qui doivent tenir compte du risque de tremblements de terre, on présente dans ce travail une méthode de cartographie régionale sismotectonique, en vue de son application générale en génie civil.

Elle envisage une série d'étapes de travail, limitées par le degré de connaissance relatif à chaque instant, tout en considérant la nécessité de mettre en œuvre des études de plus grande ampleur et l'utilisation des techniques nouvelles pour une meilleure définition des contrôles géologiques et techniques de la sismicité.

Introduction

It has long been recognised that the seismicity of a region is in some way related to the tectonic processes currently in operation: Identification of seismogenetic faults has played an important part in the qualification of seismic hazard. With the general acceptance, at least in broad outline of the ideas of plate tectonics, it has become possible to formulate credible general models to describe earthquake generation at mid-ocean ridges, subduction zones, and plate collisions. Less understood are the intraplate earthquakes.

While there have been great advances at the research level, it has been difficult to define the set of tasks which can translate these fundamental advances into an improved basis for planning and engineering. For such broad planning and engineering decision some kind of hazard map is called for.

The generalised procedure for estimating seismic ground motions and the uncertainty in physical parameters that affect ground motions has been described elsewhere (Hays 1978). However this paper is intended to be a contribution towards a methodology which would be directed towards seismotectonic problems, including the characterisation of source parameters, particularly those related with seismotectonic maps for earthquake risk analysis and evaluation. It therefore seems appropriate to review briefly some examples of seismotectonic mapping carried out in the world.

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Seismotectonic mapping

Maps showing major tectonic units and features have been developed for Europe and various countries. They may contain additional information on earthquake epicentres but are not strictly "seismotectonic" maps. Maps so designated have been published which are really tectonic maps with an overprint of epicentres and additional information on magnitudes and focal depths and even focal mechanism (Beloussov et al. 1968; Berberian 1976). Others identify and classify seismogenetic features or relate tectonic style to regional stability as in China (Liu 1978). Such maps are in the main assemblages of basic data. Another category of maps contain more interpretative elements often of a predictive nature. In this category we place earthquake hazard maps with some zoning of a seismic intensity with probability (U.S.A.), Mexico and South America, (Esteva 1970; Lomnitz 1974; Donovan et al. 1976; Radbruch-Hall 1978). Then there are the seismotectonic maps which precede an earthquake hazard study for a particular site. These contain basic fault data, together with an interpretation of "seismotectonic" provinces. The interpretative element is also high in the class of maps designated "Expected Earthquake Origin Zones", which are developed from seismotectonic data (Shebalin 1974).

The necessary basic data for inclusion in a seismotectonic map are not generally agreed and it may be difficult to distinguish between "fact" and "interpretation". We suggest however that a "seismotectonic" map should embody the following features:

Basic data to be shown on maps

- Major faults with significant crustal penetration – (+ 10 km) and

  Identification of

  a) Epoch of fault formation
  b) Epoch of last movement
  c) Sense and cumulative magnitude of movement.
- Major folds and flexures, epoch of formation, orogenetic association.
- Regional stress fields operative during formation of the "basement" grain.
- Current regional stress fields deduced from neotectonic and current earthquake mechanism.

  Epicentres with coding for focal depth, magnitude.

Interpretative / predictive elements to be shown

- "Line" and "point" sources
- Seismic provinces
- Spatial and temporal gaps in "active" systems
- Potential sites of recurrent major events (see first item) with indication of "maximum potential"
- Hazard in terms of return period for a significant magnitude event or an effective peak acceleration or velocity at an appropriate probability level and confidence interval.

It is recognised that the "interpretative" element is not strictly confined to the second section but the aim should be to show sufficient basic data as background to both the epicentres and the "hazard" contouring so as to highlight the match and mismatch between tectonic data and seismicity inferences.

The following sections are devoted to the methodology and input required to develop such ideal seismotectonic maps.

Objectives

The maximal objective of a seismotectonic study is to establish the current stress field and monitor its development in such a way that it would be possible to predict, in a deterministic way, the occurrence of earthquakes in space and time within a usefully narrow window. However, the "state of the art" does not yet provide us with a definitive model which assures the achievement of that maximal objective. Therefore, a procedure is proposed which, although it does not achieve the maximal objective, will get closer to it.

Because the application of these kinds of studies is needed mostly for engineering and planning purposes, it is desirable that the results be applicable and they should improve the present models. Furthermore, they should be available in a reasonably short period of time.

It is considered advantageous to split a seismotectonic study for large regional mapping into two major levels with specific objectives at both levels. Both levels should conclude with results immediately applicable to seismotectonic and risk regionalisation in order to assist planners and authorities for coding, licensing and regional planning.

The first level deals with information which, in the main is currently available, if in diverse places, and embodies collation and interpretation of those data within the framework set by current "state of the art" procedures. The second level could require the mounting of additional studies and techniques which have not as yet been undertaken as part of a regional seismotectonic appraisal.

Methodology

We consider the methodology under three main headings; namely the principal questions (problematics) of seismotectonics, seismics and seismic risk, the contributory studies which would be directed towards the principal questions and the concrete techniques available to pursue these studies.

Principal questions

Seismotectonics

- Identification of geological regions which are seismically active.
- Tectonic features within those regions which are now active.

  Stress field analysis and tectonic models for those features.
- Determination of the maximum earthquake that could be generated on these features.
- Identification of the site on these structures where the larger earthquake is likely to occur.

  Characterisation of seismogenetic features.
- Identification of seismotectonic provinces.

Seismic

- Evaluation of the seismic parameters.
- Determination of the attenuation laws.
- Criteria for data extrapolation from other regions.
- Contribution of seismic sources located in the neighbourhood.
- Definition of mathematical models of seismicity for each seismic source and region.
- Characterisation of seismotectonic features for accelerogram matching.

Seismic risk

Estimation of probabilities for intensities in each region and features.

- Establishment of areas of minimum risk.
- Establishment of areas of maximum risk and features of maximum quantity of risk.

Contributory studies

The kind of studies to be developed will include the following specific questions:

Characteristics of the seismic sources and parameters

- Epicentral and focal co-ordinates.
- Epicentral intensity.
- Magnitude.
- Moment.
- Stress drop and average stress.
- Rupture velocity.
- Source motion.

Tectonic characteristics and pathway features

- Regional tectonic framework.
- Possible crustal models from gravimetric and seismic geophysical data.
- Mega-structures and tectonic trends of the basement.
- Subduction, rifting and spreading zones.
- Intra-plate structures.
- Types of faults and their dimensions.
- Identification of palaeo-stress fields.
- Residual stressing.
- Isostatic recovery.
- Gravity tectonics.
- Tectonic models for inter-plate regions.
- Tectonic models for intra-plate regions.
- Crustal velocity structure.
- Discontinuities.

Seismicity and seismic risk characteristics

- Mathematical models of seismicity.
- Uncertainty of the application of statistics.
- Uncertainty of the proposed seismotectonic models.
- Relations between magnitude / intensity / distance.
- Relations between intensity / magnitude / acceleration / return periods.
- Influence of the local conditions on ground motion.
- Influence of the design intensities and the structural response.

Techniques available

The most common techniques carried out to investigate the previous questions could include some of the following:

- Geological mapping and geological modelling and structural analysis.
- Remote sensing and photointerpretation with computer enhancement.
- Geomorphological and Quaternary geological techniques aimed at establishing fault history.
- Geochronometry, radiometric dating.
- Geodetics; land based nets; strain monitoring; laser ranging with satellites.
- Development of patterns of fault displacement.
- Gravimetrics and deep refraction and reflexion seismic geophysics.
- Deconvolution of seismological data to establish source functions.
- Dispersion of seismological waves to deduce crustal structure.
- Monitoring of fault deformation by acoustic emission.
- Close spaced seismograph nets.
- In situ stress from wave propagation.
- In situ stress measurement by hydrofracturing (to 5 km?).
- Numerical source modelling.
- Fracture numerical models.

Procedure for seismotectonic mapping

In Fig. 1 a flow chart is presented for a possible programme of works. This programme should be applied at both levels. However, the first level would be based mainly on the critical review of the available data. Seismotectonic models should be proposed based on seismic and tectonic models. The uncertainty of each physical model could be checked by probabilities with respect to an ideal deterministic model. Therefore those tectonic and seismic features will be established which should constitute such a deterministic model. By incorporating new data in the second level, the seismotectonic model could be improved.

In the proposed procedure the following sub-stages should be included:

Stages of geological investigations

- Definition of the target areas.
- Evaluation of the available geological data.
- Evaluation of the available geophysical data.
- Investigation of tectonic structures:

  Synthesis of mapping data
  Remote sensing and photointerpretation
  Geomorphological tectonic control
  Field visits to check desk study data
  Structural survey
  Gravimetric survey
  Seismic (refraction and reflection) survey
  Fault deformation and stress measurements
  Geochronometry.

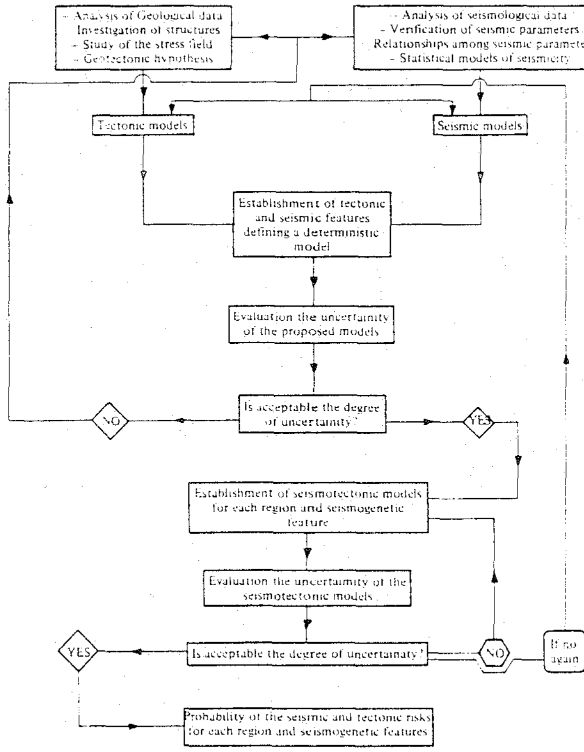

Fig. 1: Generalized procedure for seismotectonic mapping

Geotectonic investigation

- Evolution of the fracture tectonics.
- Deformation history from the Mesozoic.
- Identification of pre-Mesozoic basement features especially for intra-plate regions.
- Stress field–crustal interaction modelling.
- Geotectonic modelling.

Stages of seismological investigations

- Re-examination of historical seismicity and re-establishment of epicentres and intensities.
- Re-establishment of magnitudes of early instrumental events.
- Local station network.
- Explosion seismology to calibrate network.
- Strong motion instrumentation network.
- Microseismic instrumentation network on selected active faults.
- Assemble and review focal mechanisms.
- Relations between intensities / magnitudes / acceleration / distance.
- Mathematical modelling of seismicity.
- Application of probability theories to seismic risk evaluation.

Concluding discussion

A seismotectonic map is a continuous process carried out by a small enthusiastic and dedicated interdisciplinary group. Full understanding among geologists, seismologists and engineers is essential. The proposed methodology is task orientated and achievable for engineering objectives as distinct from the research proposals. However, it should be applied to regions with acceptable geological information. This geological information must be re-examined with emphasis on the distinction between intraplate and margin processes and deeper crustal tectonic structures. Careful re-establishment of important epicentres with deep geology and better statistical models will be linked to major tectonic structures. Because of the lack of rigorous models for intraplate events the paleotectonics of such areas along with definition of minimum risk zones and optimum size of crustal elements could be of the greatest importance.

While recognising that seismological information is our most obvious indicator of the state of stress in the crust, proper use of geological and tectonic data embodied in operational models affords a promising framework for future developments.

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ENGINEERING GEOLOGIC MAPPING AND POTENTIAL GEOLOGIC HAZARDS IN COLORADO

CARTOGRAPHIE DE GEOLOGIE DE L'INGENIEUR ET RISQUES GEOLOGIQUES AU COLORADO

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Summary

Land-use planning requires identification of areas where geologic conditions may be adverse to development and construction. In montane Colorado, where long-term experience with geologically hazardous conditions is usually not available, development accompanying increasing population necessitates engineering-geologic studies that contain predictive modelling of situations that may be encountered if geologically hazardous areas are inhabitated.

Some hazardous geologic conditions in Colorado are unstable slopes, hydrocompactive soils, surface subsidence over abandoned underground mines, and fluvial processes related to water flooding. Traditional mapping of such categories usually involves recompilation of existing geologic map data in an engineering-geology format. The resulting map presents a correlation of generalized engineering properties with map units, leaving judgments about potential hazards entirely to the map user. An alternative approach to mapping these kinds of hazard-prone areas uses map units based primarily on the nature of the potential hazards associated with them. The map and its explanation are then combined with a land-use-type / geologic-hazard-area matrix that indicates engineering problems likely to be encountered in the mapped area, shows effects of local changes in slope and mechanical properties of soils and rocks, and generally evaluates hazard severity for various land uses.

Résumé

L'aménagement du territoire exige l'identification des zones dont les conditions géologiques pourraient s'opposer au développement et à la construction. Dans les montagnes du Colorado, où l'on n'a pas une expérience à long terme sur les conditions des risques géologiques, le développement lié à un accroissement de la population nécessite des études de géologie de l'ingénieur incluant des modèles prévisionnels de situations possibles si les zones à risques sont inhabitées.

Parmi les catastrophes d'origine géologique, il y a l'instabilité des pentes, le tassement des sols, les tassements au dessus de mines abandonnées et les phénomènes fluviatiles dus aux inondations. La cartographie traditionelle de telles catégories comprend d'habitude la recompilation des données des cartes géologiques existantes sous une forme adéquate. La carte résultante présente une corrélation des propriétés géotechniques générales avec les unités cartographiées, laissant à l'utilisation

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