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GEOMORPHOLOGICAL CONTRIBUTIONS TO SEISMIC RISK ASSESSMENT (**)

Abstract: PANIZZA M., *Geomorphological contributions to Seismic Risk assessment.*

The author analyses the contributions provided by *Geomorphology* in studies of the assessment of *Seismic Risk*: this is defined as a function of the *seismic hazard*, of the *seismic susceptibility*, and of the *vulnerability*.

The geomorphological studies applicable to seismic risk assessment can be divided into two sectors:

a) *morpho-neotectonic* investigations conducted to identify *active tectonic structures*;

b) *geomorphological* and *morphometric analyses* aimed at identifying the particular situations that amplify or reduce *seismic susceptibility*.

The morpho-neotectonic studies lead to the identification, selection and classification of the lineaments that can be linked with active tectonic structures. The most important geomorphological factors that can condition seismic susceptibility are: slope angle, debris, morphology, degradational slopes, palaeo-landslides and underground caivities.

KEY WORDS: Geomorphology, Seismic Hazard and Risk.

Riassunto: PANIZZA M., *Contributi della Geomorfologia alla valutazione della pericolosità sismica.*

L'Autore analizza i contributi che la Geomorfologia fornisce negli studi tesi alla valutazione del *rischio sismico*, definito come funzione della pericolosità sismica, della *suscettibilità sismica* e della *vulnerabilità*. Gli studi geomorfologici applicabili alla valutazione del rischio sismico possono essere suddivisi in due categorie:

a) ricerche di *morfoneotettonica*, finalizzate all'identificazione di *strutture tettoniche attive*;

b) *analisi geomorfologiche e morfometriche*, volte all'individuazione di particolari situazioni che amplificano o riducono la *suscettibilità sismica*. Gli studi di morfoneotettonica permettono la caratterizzazione, la selezione e la classificazione dei lineamenti che possono essere connessi con strutture tettoniche attive. I principali fattori che influenzano la *suscettibilità sismica* sono l'acclività, la presenza di copertura detritica, la morfologia, i versanti in degradazione, le paleofrane e le cavità sotterranee.

TERMINI CHIAVE: Geomorfologia, Rischio e pericolosità sismici.

INTRODUCTION

Using che definitions provided in PANIZZA (1988), *seismic risk* will be defined as the probability of an earthquake occurring, of a pre-established Magnitude, within a given number or years, with specific consequences on the environment. Thus, seismic risk is specified not only by the expected seismic event itself, but rather, by the setting of this event in the geological and physical geographical conditions of the area affected, including the density of the population, the conditions of the existing buildings and construction, the type of economy, the level of preparation for and knowledge about seismic events on the part of the population, the presence of aid facilities, and the efficiency of the civil defence network (IACCARINO & *alii*, 1979). In fact, the factors converging into the definition of seismic risk may be summarised according to the outline shown in fig. 1.

A *seismic hazard* in a strict sense, connected with the earthquake and the seismotectonic characteristics in an area, is distinguished from *seismic susceptibility*, that represents a hazard induced by the physical geographical situation of the area considered. The *seismic hazard* should refer to the types, features, mechanism, and phenomena of earthquakes, that is, to the energy propagated by them, to the depth at which they occur, to their recurrence according to sequences of time that may even be relative brief, to the dimensions of the focus area, etc. As far as *seismic susceptibility* are concerned, the term refers to local geological, morphological, and hydrological factors, of both the surface and substratum, which may amplify or reduce seismic vibrations or constitute situations of precarious geomorphological equilibrium.

The *geomorphological studies* applicable to seismic risk assessment can be divided into two sectors:

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b) *geomorphological* and *morphometric analyses* aimed at identifying the particular situations that amplify or reduce *seismic susceptibility*.

These two sectors will be summarized in the following.

MORPHO-NEOTECTONICS

Morpho-neotectonic research is based on the concept that tectonic movements have brought about changes in the

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- SEISMIC RISK
  - **seismic hazard**
    - earthquake characteristics
      - *Magnitude*
      - *focus area dimensions*
      - *epicentre*
      - *etc.*
    - seismotectonic characteristics
      - *seismicity*
      - *tectonic structure*
        - *Geology*
        - *Tectonics*
  - **seismic susceptibility**
    - lithology
    - geomorphology
    - hydrogeology
    - etc.
  - **vulnerability**
    - exposure
    - economy
    - social organisation
    - programme plan

Fig. 1

Earth's surface. In general, and with the movements being of equal intensity, these changes appear more marked and evident, the more recent the movements are. The identification of such changes can therefore lead one back to the neotectonic movements at their origin and thus to an estimation of the chance of their continuance or the recurrence of others in the future. From investigations of this type and thus through the identification of active tectonic structure, geomorphology makes its contribution to the assessment of an area's seismic hazards.

Morpho-neotectonic studies are generally organized according to various phases, that lead to the classification of the lineaments according to certain categories (PANIZZA, CASTALDINI & *alii*, 1987; CASTALDINI & *alii*, 1988; PANIZZA, 1988) such as active and inactive tectonic elements, or qualified and unqualified lineaments.

Some lineaments are associated with significant rocks or forms, where the term «significant» is used for rocks and forms to indicate that their age lies within the neotectonic interval considered.

GEOMORPHOLOGY AND SEISMIC SUSCEPTIBILITY

As mentioned above, there are particular geomorphological situations that can condition the seismic susceptibility and that can offer local responses to seismic acceleration, causing mitigation or amplification of earthquake intensity. The most important geomorphological situations that can condition seismic suceptibility, are the following:

— *slope angle;*
— *debris characteristics;*
— *slope morphology;*
— *degradational slopes;*
— *existence of paleo-landslides;*
— *existence of underground cavities.*

Slope angle

It is well known that, in a static situation, other variables being equal (lithology, moisture, etc.), slope instability increases with slope angle.

In respect of the towns located in the Region of Campania and Basilicata affected by the earthquake of November 23rd, 1980, the C.N.R. Progetto Finalizzato «Geodinamica» (1983) adopted a correction coefficient for buildings and structures located in seismic areas (*Sp*), which depends on the slope angle as follows:

$$Sp = 1 + 1.5.i$$

where i is the average slope expressed as a percentage.

The *Sp* coefficient, which expresses the increase in seismic activity, is multiplied by the seismic coefficient C, which defines the force employed for the seismic testing of buildings structures ($C = 0.1$ for the earthquake regions in the 1st category; $C = 0.07$ for those in the 2nd category).

Slope angle limits for several types of terrain, according to stability during seismic shocks

	$i°$ limit
Incoherent debris (including cataclastic debris), with water-table depth > 10 m	20°
Incoherent debris (including cataclastic debris), with water-table depth < 10 m	10°
Marls and very compact clays	30°
Semi-coherent sands and clays (that may also be mylonitic), with water-table depth > 10 m	25°
Clays of compact texture, but very «tectonized» and/or fissured	10°

Fig. 2

The C.N.R. Progetto Finalizzato «Geodinamica» (1983) advises against construction under the following conditions in cases of slopes with an average gradient, *i*°, greater that the established limit. This limit depends upon the type of terrain, as shown in the fig. 2.

Debris

Slope deposits made up of incoherent material, as is the case with talus, moraine, alluvial deposits, etc., in general constitute geomorphological situations that can amplify seismic susceptibility. More specifically, increases in seismic intensity can be linked to:

a) the surface slope angle of the debris;
b) its grain-size characteristics;
c) the thickness of the deposit.

The slope angle has already been considered in the last section.

Increases in seismic intensity for some types of debris, compared to granite	
Rock type	Seismic intensity
granite	0
pebbles and gravel	1 - 1.6
sands	1.2 - 1.8
clays	1.2 - 2.1

Fig. 3

Grain-size characteristics can significantly amplify seismic intensity. They are outlined in fig. 3, adapted from Medvedev (1965) with some simplifications. Some incoherent rock types are compared with solid granite, under conditions in which there is no water infiltration. Infiltration of water can further increase the seismic intensity to reach values of 3 to 4 approximately.

The *thickness* of the deposit also plays a part in amplification of seismic intensity. In case of deposits of thicknesses greater than 5-10 m, SIRO (1985) indicates critical thicknesses on the basis of the most probable frequencies of the arriving vibrations and the average propagation velocities of the transverse waves, which determine the amplification of seismic intensity. For velocities of transverse waves from 200 to 600 m/s., the critical thicknesses are shown in the fig. 4, along with the proposed corresponding coefficients of amplification ranging from 1.5 to 2.5.

Critical thicknesses of debris compared with the velocities of transverse seismic waves, with amplification coefficients ranging from 1.5 to 2.5	
Average velocities (m/s)	Critical thicknesses (depth in m)
200	8 - 40
300	11 - 60
400	15 - 80
500	19 - 100
600	23 - 120

Fig. 4

Morphology

Amplification of seismic intensity with a resulting increase in damage to building structures, has often been observed to correspond with particular morphological situations such as crest lines, terrace borders, scarp edges, or abrupt variations in slope angle. These amplifications appear to be due to phenomena involving the concentration of seismic waves that are reflected, as a result of their different inclination angles, with respect to the vertical, corresponding with abrupt topographical changes. Studies aimed at investigating this topic further are still in progress (CASTELLANI et al., 1982) and seem to indicate amplifications as great as 3.5.

Similar amplification phenomena have been observed to correspond to buried morphological structures, such as palaeoriver beds, fossil terraces or forms of erosion masked by superficial deposits. These are also cases involving seismic wave concentration phenomena, due, however, to refraction phenomena where the angles of incidence prove to differ from the vertical.

Degradational slopes

The amount of weathering on slopes and therefore the degree and type of rock disintegration taking place, can affect seismic susceptibility. For instance, frost action exerts a slow and progressive shattering of the rocks, enlarging preexisting cracks or joints (tectonic, strata, etc.) until it produces fragments that become detached from the rock. When the force of gravity exceeds the resistance to sliding, and fall to the foot of the slope; this is often a seasonal phenomenon. In the case of seismic shock, the fragments detached are not only unbalanced debris, which would have fallen in any case owing to frost action and gravitational processes, but also includes material that is still partially attached to the rock or on slopes lower than those with detached fragments. It is as if the seismic shocks complete a sort of «cleaning operation» on the slopes, eliminating the weathered material.

Similar phenomena occur on slopes subject to other types of physical or chemical weathering.

Palaeo-landslides

Earthquakes sometimes set into motion older landslides. The towns of Calitri, Grassano, Senerchia and other localities in Irpinia affected by the earthquake of 1980, provide examples of this. The landslides occurred in mainly clayey rocks, in flysch facies, sometimes chaotically arranged or very tectonised. They affected tracts of land several kilometres long and there was nass transport involving hundreds of millions of cubic metres of material.

Underground cavities

Earthquakes in calcareous areas with underground karstification can cause the falling in or collapse of cave roofs or the removal of debris in dolines. The consequences on the surface are depressions or subsidence of the ground with the resulting danger of collapse for the building above.

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