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MAN-MADE SEISMICITY AS ENVIRONMENTAL RESPONSE TO SPECIAL ANTHROPOGENIC ACTIVITIES

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ABSTRACT

The analysis of data given in the quoted sources reveals that the man - made shocks follow special anthropogenic activities. They are connected with the mass transfer, the changes of the water regime, the long-term vibroseismic action on the upper parts of the Earth`s crust (e.g. transport, seismic noise generators and bomb-shelling during the wars) and with rapid redistribution of the natural stress fields caused by artificial explosions. They threaten the human health and environment. To protect human population and environment the special safety provisions in conctructions and technologies must be taken into account in dependence on concrete local conditions.

KEYWORDS

Man-made seismicity.

Reservoir-Induced Seismicity

The first known example was connected with Lake Mead created by the Hoover Dam on the Colorado River in 1930`. According to R. D. Adams (in Gupta, 1992) the topic of reservoir-induced seismicity have been one of the success stories of the last two decades in seismology. He documented this assertion by :

- the results of Greek seismologists that claimed in conference in New Zealand in 1966 that damaging earthquake in the region of Lake Kremasta had been provoked by the filling of a water reservoir,
- the data concerning the Koyna earthquake in India in 1967.

The induced earthquakes of this type were recorded in Egypt, India, Japan, Greece, Africa, Italy, USA, USSR, etc. (Gupta, 1992, Plotnikova et al., 1992, Roeloffs, 1992, Talwani et al., 1992, Rajendran et al., 1992). There are now over 70 known cases of shocks of this type. It is true, however, that not with all large dams did induced earthquakes occur. The state-of -art in this domain is such that we have not yet answered to the question "When do dams make the groud shake?" that is of paramount interest to us. According to results summarized in paper (Procházková, 1988) the causes of reservoir-induced shocks are connected with the stresses provoked by the load of the dam reservoir and with effects of the hydrostatic pressure of underground water that is influenced by the water penetration of the reservoir into the rock massif.

Ohtake (1986) proposes a model of reservoir-induced seismicity, where the composive effect of loading and permeation of water causes a variety of seismicity patterns. According to the model, increase or decrease in earthquake occurrences are atributed in the tectonic stress field and the geological conditions in the vicinity of a reservoir.

According to Talwani et al. (1992) the reservoir-induced seismicity is controlled by the ambient stress field (magnitude, compresional or extensional), geologic (lithological contacts, etc.), hydrogeologic properties (fracture porosity, etc.) of the region, together with the hydraulic and spatial characteristics of the reservoir (its dimension, filling history). Reservoir affects the strength of the surrounding rocks by three ways :

- by their elastic response to reservoir load,
- by rapid increase in pore pressure in response to the load (undrained response),
- by delayed increase in pore pressure due to diffusion (drained response).

Seismic response of a reservoir consists in two temporal patterns:

- in first, the seismic activity associated with initial impoundment, is widely observed. It is characterized by one or more large earthquakes that follow filling, general stabilization and lack of seismicity beneath the middle of a reservoir and widespread seismicity on the periphery. With time, there is a decrease in both the number and magnitude of earthquakes, with the ambient seismicity returning to pre-impoundment levels,
- after several years, when "steady state" conditions have been achieved, some reservoirs continue to be active; whereas there is no seismicity at others. In this scenario in the steady-state phase, earthquakes occur at reservoir with large and / or rapid lake-level fluctuations. Seismicity is observed both beneath the deepest part of the reservoir and in the surrounding areas.

Rockbursts

According to the Cook (1976) four kinds of rock failures can be determined in mines; rockfalls (loosened rock falls mainly under its own weight), rockbursts (they are violent failures and may cause damage to the excavations), bumps (they do not cause damage to the excavations) and outbursts (the rapid release of gas caused rock to be injected into the excavations). The most horrible rock failure are rockbursts. They are experienced in underground mining at various localities in the world, causing death and injury to underground miners and damage to mine structure. They are manifestations of a very rapid episodic release of strain energy that has accumulated in the Earth`s crust like natural earthquake (Fairhurst, 1990).

The rockbursts only occur in some mine workings. We cannot answer the question "When do mines make the rockburst?". The reason for this fact are the properties of the particular geological basement and method of extraction (Båth, 1979, Šimáně, 1975, Roček et al., 1975, Drzezla and Garus, 1987, Trávníček et al., 1987, Holub and Slavík, 1987, Brož and Roček, 1979). The occurrence of rockbursts depends on dynamic loading of the mine (Tannant, 1992). But we cannot reply the question "When do technogenic interventions produce triggered earthquake?". The study of the focal processes of weak seismic events in and close to mines (Knoll et al., 1984) revealed the differences between the focal parameters of various mining districts; they are connected with the geological, geometrical and mining conditions. According to Swanson (1992) the style of deformation induced by mining is affected by geologic structure. The influence of the excavation geometry and method of excavation studied and confirmed also Urbancic et al. (1992) in Strathcona and Creighton mines. Rockbursts were also observed in the process of the tunnels creation (Ze-Bin, 1992, Brummer, 1990) and the disposal of nuclear fuel waste creation (Feignier et al., 1992).

Rockbursts occur not only in the deep mines but also in opencast mines (Miller and Osterwald, 1980, Herštus, 1983, Drozd and Rybář, 1983, Gibowicz et al., 1982, Hurník, 1982, Skipp and Ambraseys, 1985). In these cases major danger is connected with the stability of slopes (Herštus, 1983) and possible upsetting of the equilibrium in the Earth`s crust due to the displacement of tremendous masses with local loading in dumps and unloading in deep pits (Hurník, 1982).

To protect the human lives and the environment the projects involving government agencies, universities and different institutions are organized (e.g. Plouffe et. al., 1992).

To mitigate the risk associated with longwall mining the delineation of high stress zones prior to failure is necessary. For this purpose integrated seismic and electromagnetic methods can be used. The tests at the Coal Mine in Bruceton (Pennsylvania) and at the Foidel Creek Mine in Oak Springs (Colorado) demostrate that the relevant results can be obtained only if the full waveform is used for investigation (Williams, 1992).

Since rockbursts are responsible for great destruction of mine workings, the guide preventive measures (Mendecki, 1992) and various technological measures are taken to prevent dangerous accumulation of deformation energy in the vicinity of the mine working being driven (Roček et al., 1975, Stranz and Krawiec, 1975).

Seismicity Triggered by Injection of Fluids into Rocks

There were also found the seismic events having a connection with the injection of fluids into rocks (Batini et al., 1985, Phillips et al., 1992). In fact, many seismic events of magnitude comprised between 3 and 4 were reported in the vicinity of fields stimulated by fluid injection in regions previously considered as poorly seismically active. They occur e.g. in Denver, Ranely (Colorado), South - Central Arkansas, S Nebraska, W Texas, W Alberta, SW Ontario, Ohio, El Dorado Dale (New York). The shock sequences create often clusters (Cornet et al., 1992, Phillips et. al., 1992). Grasso (1992) gives the following mechanisms of these shocks :

> Fluid injection >>>>>> pore pressure increase >>>>>> the effective normal stress on the fault plane to be reduced >>>>>> the motion under the action of the unchanged shear stress (constant tectonic stress).

Nicholson (1992) also studied circumstances connected with fluid injection that can trigger earthquakes. According to him the mechanism of these shocks consists in the reduction in frictional strength along pre-existing, nearby faults caused by the increased formation pressure. He shows that the actual triggering process may be a very complex combination of effects, particularly if both fluid extraction and injection have taken place locally (triggered events can occur up to several years after well activities have begun or even several years after all well activities have stopped). The technique of fluid injection also influences the occurrence of the stimulated shocks (Board et al., 1992); in the region of Buffels fontain the microearhquake activity is initiated when fluid pressures is greater than 10 MPa.

Seismicity Triggered by Withdrawn of Fluids from Surface Formations

The shocks connected with withdrawn of fluids from the rock are observed in geothermal areas and in regions impacted by the oil and gas production (Kerimov et al., 1993, Baker et al., 1992). The detailed study of this problem gives Grasso (1992). According to him the understanding of how much instabilities leading to shocks develop and how they are triggered, is necessary for economical purposes (well damage), environmental concerns (often chemical facilities are located close to the hydrocarbon fields), and understanding fault mechanics. For all mechanisms the size of the events are bounded by pre-existing faults and initial tectonic deviatoric stresses. Grasso (1992) gives the following mechanisms of shocks in regions characterized by the oil production :

Fluid extraction >>>>> pore pressure reduce >>>>>
effective normal stress in the reservoir increase
>>>>> recurrent faulting inhibited.

Earthquakes induced by fluid extraction with magnitude ranging from 3 to 7 in historically aseismic areas demonstrate that a decrease in pore pressure and the transfer of mass trigger seismic instabilities of the upper crust. The estimate of the change in driving stress, few bars reagardless of the tectonic setting, implies that the continental crust must be nearly everywhere at a state of stress near failure. This suggests that the region of possible induced seismic hazard is much larger than the area where natural earthquakes are common and it testifies that fluid movement and pore pressure changes play an important role in the mechanics of earthquakes and the triggering of natural earthquakes well away from plate boundaries.

The analysis of data of Lacq field in SW France, Texas, Uzbekistan, Azerbaijan and Canada (Grasso, 1992) shows that the earthquake foci are connected with pre-existing discontinuities in the regions, that also determine the size of stimulated events. The oil / gas transport are sometimes aseismic (e.g. Groninguen in Netherlands and Buena Vista in California) and sometimes seismic (e.g. Coalinga in Californa, Uzbekistan (e.g. Gazli region), Ecuador); major events the magnitude of which reaches over 6 are related to upper crustal hydromechanical disturbances. By recording micro - seismicity we have actually monitoring changes in stress and pore pressure as a function of space and time.

Study of Wilmington oil - field near Los Angeles (California) carried out by Nicholson (1992) reveals that the oil output in years 1928 - 1970 resulted in the rapid subsidence of the city Long Beach and in damaging earthquakes that occurred in 1947, 1949, 1951, 1954, 1955, 1961, 1983, 1985 and 1987 years, i.e. the damaging shocks also occurred several years after the oil output stopping.

Earthquakes Stimulated by Vibroseismic Signals

There were found shocks the connection of which with the production of the vibroseismic signals is very probable (Kissin, 1993). Nikolaev and Beresnev (1993) studied the vibroseismic influence and noise signals evolution in detail and they revealed the non - linear properties of the medium. E.g. in the consequence of periodic seismic signals produced by seismic vibrators the increase of seismic noise in the broader region (as far as at distances first tenths of km) in the whole range of frequencies were observed. The nonlinearity of the geological media is a major property resulting from the intricate rheological state of rock (Beresnev and Nikolaev, 1988).

Long term investigation of the vibroseismic influence on oil and gas deposits and oil output in the Krasnodar region revealed connection between vibrations and the oil output of oil wells. The idea about the possible changes of the oil output of oil wells in destructed oil deposits in Kuwait, which has lead to the increased oil stream was propossed (Kissin, 1993).

Man - Made Shocks Stimulated by Artificial Explosions

The shocks following the nuclear explosions were described by a lot of scientists, e.g. Barosh (1993), Kisslinger (1976), Nikolaev and Vereschchagina (1991). The study of seismic regime of regions in which nuclear underground explosions are affected (Nevada, Semipalatinsk) in the period 1982 - 87 revealed that nuclear underground explosions caused change of seismic regime of focal regions in a broader surroundings of test sites; within 1 x 1 degree areas in the first ten days after nuclear underground explosion the increase of the number of the middle shocks ($M \geq 4.5$) is observed and in the following time interval the decrease of this number is observed; the increase and the decrease of the number of shocks is judged with regard to the background determined as a mean value for the time interval 30 - 60 days after the nuclear explosion. In the space distribution of the epicenters the mosaic-like pattern appears (Nikolaev and Vereschchagina, 1991).

The analysis of the results of monitoring seismic activity in mines showed, however, that even quarry blasts may induce weak shocks; the quarry blasts are often consituent part of the mining technology. Miller and Osterwald (1980) described aftershocks following blasts in the Powder River Basin (U.S.A., Wyoming and Montana); here the coal is extensively mined in opencast mines about 60 m in depth; weak shocks are localized by a special network of seismographic stations along the Big Horn Mts., most of them originated within 30 minutes after a blast in a broader environs of the firing point. This reality shows the redistribution of natural stresses as a result of a great amount of coal in its overburden under blast. Research of microseismicity in the hard - rock mine in the Coeur d`Alene district of Northern Idaho reveals that aftershock sequences following mining blasts contain several hundred to over a thousand events occurring in time period lasting hours or the first tens hours (Kranz et al., 1992). Near the same effects were observed in the Most area (Czech Republic) with open - pit brown coal quarries (Procházková, 1992).

Conclusion

The tectonic processes, have always been passing in the Earth, represent the major source of the stress cumulation, the consequences of which are various disastrous phenomena from time to time. Man`s interventions to the nature, particularly those connected with displacing masses on the Earth`s surface or in its close vicinity, create additional stresses. The sum of the natural tectonic forces and additional tectonic forces may trigger stronger disastrous phenomena.

Earthquakes occur in response to building up of the stress pattern imposed by tectonic activity and controlled by boundary conditions of all sorts. The arrangement in space and time of the occurrences of events is a direct reflection of the local (in space and time) properties which permit triggering when and where necessary conditions are met. A careful examination of the time / space seismicity pattern in area where stress change mechanical properties of the involved medium are constrained and known, provides unique opportunities to interpret seismic instabilities.

In most cases, the pertubation of the underground mechanical equilibrium due to industrial activities (mining, dams, geothermy, hydrocarbon reservoirs) induce deformation of involved sites. The amplitude and the rate of the deformations are key parameters for optimum economical production as for minimum environmental impact (Knoll, 1992). This paper gives the survey of main results that have been obtained in the domain under account.

The sites where man-made earthquakes occur are worlwide located in different tectonic settings. These sites share together both a large amount of major economical tools and toxic chemical facilities. Therefore, it is necessary to investigate the possible occurrence of seismic instabilities in order that to prevent potential instabilities to optimize the production parameters.

The man-made shocks threaten the human health and environment. To protect the human population and the environment the special safety provisions in conctructions and technologies must be taken into account in dependence on concrete local conditions. It means that before the constructions of structures and installations of technologies that can produce man-made shocks the special investigation of locality in this respect must be carried out. If some hazard exists the monitoring of weak seismic activity and stress in-situ must be taken into operation and the special technical means must be used to mitigate the impacts of eventual occurrence of man-made shocks.

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