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Prevention of Explosions and Fires caused by Earthquakes

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Abstract

Seismic warning and prediction systems based on precursor data packets were analysed aiming to develop a system to prevent explosions and fires caused by uncontrolled gas leaks following the deterioration of gas networks produced as a result of major seismic movements. At the current stage of knowledge, the accurate prediction in time and intensity of earthquakes is not possible. The simple information about a major earthquake, it is not a sufficient argument for shutting down gases over a large area. Closure of gases in buildings should only be done in the case of some tectonic movements that, on a local level (in that locality) exceed a certain pre-imposed threshold (considered dangerous). In this context, it is considered that an adequate seismic protection system for gas networks in a given locality must ensure: measuring /validating the intensity of local tectonic movements — preferably in 3D; generating a control signal for the closure of gases at the connections of buildings connected to the system — only if the intensity of seismic movements in the locality exceeds an imposed level (considered dangerous); secure digital communication with autonomous UPS power supply between the place of measurement /evaluation of the intensity of local seismic movements and the execution aquatics (electrovalves mounted before the gas regulation /measurement block of the protected buildings).

Keywords: earthquake, precursors, radon, gas networks, fire, explosions, protections

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1. Introduction

Predicting natural disasters such as earthquakes, in the perspective of sustainable development, is a theoretically complex issue with major material and social implications [1].

In the case of major earthquakes, the gas networks are damaged — both polymeric [2], [3] and metal [2], [4] pipelines, especially those affected by various forms of corrosion [5]-[7].

Uncontrolled gases leaks occur as a result of following damage to the pipes followed by devastating explosions and fires, leading to amplification of material damage and human casualties caused by earthquakes (representative image in Figure 1).

Figure 1. Extinguishing the fire caused (Bucharest)

Figure 1 shows the image of the fire extinguishing caused by the gas leaks following the earthquake of March 5, 1977. In this context, the prediction of earthquakes in order to limit material damage and human casualties is of great importance.

The manifestation of earthquakes and the propagation of seismic waves in the territory are phenomena difficult to predict with precision in time and amplitude.

Numerous studies highlight the fact that earthquakes are preceded by anomalies in the evolution of precursor parameters [8] such as radon emanations [9]-[12], variations in groundwater level [13], soil temperature [14]-[16], anomalies in the propagation of radio waves [17]-[19], etc.

However, the prediction of the occurrence and amplitude of earthquakes based on these data presents a high degree of uncertainty [20]-[22].

In 1977, the earthquake of magnitude 7.2 on the Richter scale, produced at a depth of 110 km in Dept. of Vrancea, destroyed 35,000 homes. There were 1,600 deaths, most in Bucharest and 11,000 people were buried under the rubble (Figure 2 a), b), c)).

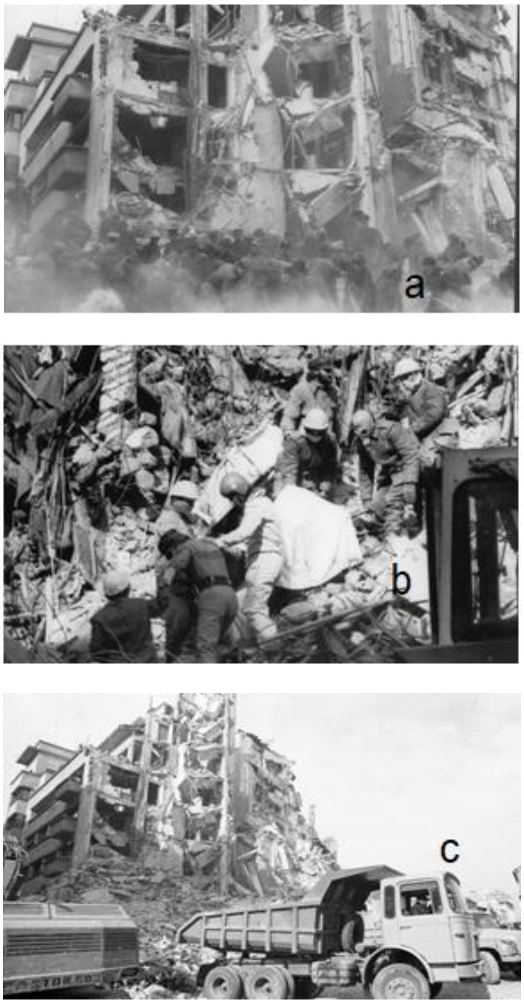

Figure 2 a), b), c). Demolished buildings in Bucharest

Figure 2a shows an image of the buildings disaffected and charged atmosphere (cloud of dust) after the earthquake of 5 March 1977, Bucharest.

Figure 2b shows the intervention of teams to save possible human lives caught during the collapse of some buildings.

Figure 2c shows some equipment used for removing debris created during seismic movements.

In view of these considerations, in the perspective of developing a system to prevent explosions and fires caused by uncontrolled gas leaks due to damage to gas networks produced as a result of major seismic movements, the aim of the paper is to define the characteristics and performance of a seismic protection system of the gas networks.

2. Gas networks

In order to optimize the pipe diameters depending on the flow rates transited for gas networks, in principle, four pressure levels are practiced, respectively high pressure (HP, usually 10-80 bar), medium pressure (MP, usually 2-6 bar), low pressure (LP, usually 2-0.05 bar) and extra low pressure (ELP, usually 0.05 bar).

The HP pipelines are the ones on the mains highways of transport among the washing and treatment stations from the extraction areas towards the urban centres with the domestic consumers and the big industrial consumers. Due to their specificity, the HP pipes present a high risk in operation and are strictly used outside the localities. Manoeuvres (closing /opening flow regulation) on these pipes are performed with caution, only by strict procedures to avoid damage by hammer effect.

The MP pipes are used among the regulation and teaching /measurement stations at the edge of the localities and the regulation stations for the neighbourhoods.

The LP pipes are usually used on distribution networks, respectively among the neighbourhood regulation stations and the pressure regulators for to the gas subscribers' connections.

The ELP pipelines are specific to natural gas use installations, respectively those through which gas consuming equipment is connected to the regulation and measurement block related to the gas connection (connected to the LP distribution network).

Preventive closure of gases installations following the finding of anomalies in the evolution of precursor parameters or small amplitude seismic movements (not dangerous for gas networks) is not appropriate because it can cause disturbances /serious incidents in the supplying of gas for the population.

In the event of a major earthquake, the pressure adjustment and measurement block of gas connections (usually mounted at the property boundary of gas subscribers) and ELP pipes (usually mounted on the walls of buildings) are the most vulnerable (Figure 3).

Figure 3. Gas network - pressure adjustment and measurement block

Figure 3 shows a system for connecting to the gas distribution network (pipelines and connection) that provides controlled supply of natural gases for some buildings in a neighbourhood. In this context, it is found that in order to prevent uncontrolled gases leaks through the cracks produced at these elements, it is necessary to close the gases through a valve (properly designed and operated in real time for caused events of major local seismic movements) mounted on the LP pipe connection (before the adjustment and measuring block).

It should be noted that closing the gas from the regulation /measurement stations on the HP, MP and LP pipelines related to the gas networks cannot ensure the fire protection of the buildings because the volume of gas remaining in the distribution pipes is sufficient to cause explosions and fires. These accidents can occur as a result of gas leaks due to damage to the ELP pipes.

3. Precursor parameters evolution: Seismic warning systems

3.1. Seismic warning systems

The issue of real-time warning of administrations of infrastructure elements vulnerable in case of earthquake (railways, subway, nuclear power plants, gas networks, energetic plants, etc.) is of particular importance.

Globally, there are sustained concerns for the development and improvement of seismic warning systems [23-32].

Seismic warning systems consist in the transmission of information/warning signal generated by a national /territorial dispatcher following the processing of precursor data and/or the recording of tectonic movements in the territory.

The probabilistic seismic hazard estimation (which considers the recurrence of events) is important for developing viable insurance policies and for increasing level the readiness for earthquakes, by planning appropriate actions to reduce their effects. Following a strong earthquake, which represents a major risk for the natural and anthropogenic environment, the deterministic approach becomes relevant based on the maximum expected seismic input.

So, a recursive analysis, in which interpretations of stored data are initiated by probabilistic results, can lead to the most realistic assessments, and to the best-informed decisions. The level of seismic hazard is determined by the presence of several seismogenic areas with destructive potential.

The most important, both in terms of seismic energy released and the area of damage caused, is the source of major earthquakes of intermediate depth (60-200 km), located at the bend of the Eastern Carpathians in Vrancea region. Some studies performed by probabilistic approaches, their analysis being based on methodologies that include complex local input data for seismic zoning as well as parameters for describing ground motion (macro-seismic intensity, maximum acceleration) so that the results of the analysis are consistent notable concordance.

The decisions have as informational support the integration of data on magnitudes and distances for each seismogenic source, in order to obtain the probabilistic hazard values, in the form of a cumulative distribution for the parameters of the ground movement.

The integration curves performed, as a result of the effects of seismogenic zonal earthquakes, of different sizes, produced from different locations and with different probabilities of occurrence, expresses the probability of exceeding in a specified period of time (usually one year), respectively, the return period-of certain values of the parameters of the seismic movement in the site.

In this context, a national network for monitoring precursor parameters and seismic events was developed (Figure 4)

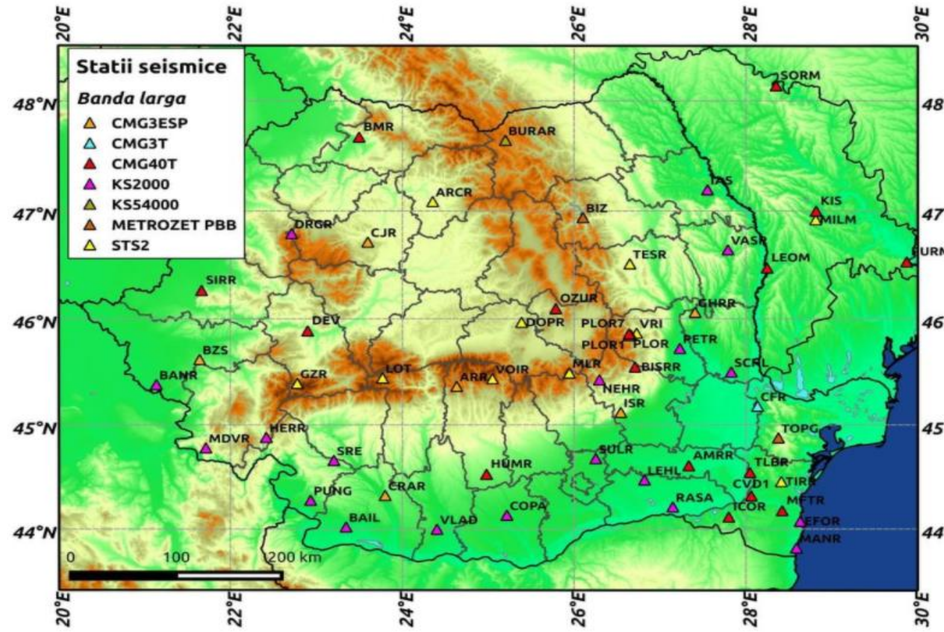

Figure 4. National network for monitoring precursor parameters and seismic events

Figure 4 shows the real-time broadband network at national level.

The national network has a monitoring system, developed in cooperation with JICA (Japan International Agency Cooperation), which includes 62 seismic stations equipped with the following types of broadband speed sensors: CMG40T (24), KS2000 (18), STS2 (11), CMG3ESP (5), Metrozet PBB (2), CMG3T (1) and KS54000 (1), and it is intended to monitor small and moderate local earthquakes, as well as regional and remote events (teleseism). The data transmission to the national seismic dispatcher is done in real time, thanks to STS (Special Telecommunications Service), GPRS modems, Radiocom and several local providers.

The recordings of high frequency movements, about 20 Hz, of the earthquakes that can occur in the Vrancea area represent important data in the investigation of the co-seismic contributions at frequencies higher than 1 Hz with the help of GPS technology. For this reason and for the realization of a complex research, 11 of the permanent GPS stations are provided with accelerometers.

Usually, the data purchased from the territory are:

- the evolution of precursor data such as: radon concentration in groundwater and/or in soil level, in groundwater, ionization level of the atmosphere, anomalies in the propagation of radio waves, the evolution of the electrical conductivity from the lithosphere layers, etc. It is noted that the anomalies in the level of atmosphere ionization and those in the propagation of radio waves are direct consequences of radon emissions from the lithosphere. On the other hand, the electrical conductivity evolution is in directly connection with the mechanical stress evolution (of the mechanical stress) in the lithosphere. Following the processing of these data, predictions regarding the imminence of an earthquake are possible. It should be noted that at the current stage of knowledge, the manifestation of the occurrence of the event and the magnitude of the imminent earthquake are not possible.
- *seismic events produced and its characteristics* (epicenter, depth, intensity, etc.). Based on these data and information on the physical and mechanical characteristics of the layers from lithosphere, it can be estimated with relatively good accuracy the speed of propagation and intensity of tectonic movements which will to occur in various localities located at various distances from the epicenter [34]. Because the speed of propagation of seismic waves through the lithosphere is relatively high, the remaining time available to take preventive measures in various localities is short (of the order of tens of seconds — depending on the distance to the epicentre).

Taking into account these considerations, it is found that the accuracy of seismic event predictions and the efficiency of warning systems can be improved by:

- increasing the monitoring points of the precursor parameters and the continuous, real-time transmission of the acquired data toward the national/territorial dispatcher [8];
- development and implementation of software (specialized) to ensure both the processing of purchased data and the generation [8] of a warning signal in case of imminent earthquake;
- ensuring secure and fast communication lines (independent of GSM networks - which are overcrowded in the event of an earthquake — and/or other networks powered by the electricity network — which often becomes malfunctioning in the event of an earthquake) between given points of purchase data and the respective national /territorial dispatcher between the national /territorial dispatcher and the notified administrations (subscribers to the system services) [38].

3.2. Radon a precursor of earthquakes

Following the detailed specialized analysis of the great earthquake of 1966 that practically completely destroyed the city of Tashkent, for the first time Ulomov and Mavashev (1967) reported as precursors of earthquakes the rapid variations of radon concentrations at the ground surface [22].

Subsequently, based on the findings and conclusions of [22], numerous studies have been conducted related on the radon emissions in the air and groundwater or from the soil surface as a precursor to earthquakes — more representative studies being [9]-[12], [15], [16], [21], [35], [36].

These studies show local monitoring of radon concentrations, recordings (anomalies) of positive (increase in concentration) or negative (decrease in concentration) [35]. As a precursor to earthquakes, important is the gradient, the variation / evolution over time and not its meaning (sign). Recently — in 2015 — Chelnokov & al. states that "radon is considered to be one of the few potential earthquake precursors" [15].

In [16], it is stated that:

> Radon concentration in ground water increased for several months before the 1995 southern Hyogo Prefecture (Kobe) earthquake on 17 January 1995. From late October 1994, the beginning of the observation, by the end of December 1994, radon concentration increased about fourfold. On 8 January, 9 days before the earthquake, the radon concentration reached a peak of more than 10 times that at the beginning of the observation, before starting to decrease. These radon changes are likely to be precursory phenomena of the disastrous earthquake.

*Radon (*Rn-222) is a radioactive gas that is continuously formed in the Earth's crust by the disintegration of its direct precursor — the radius Ra-226, which is formed by the decay of uranium and thorium.

Uranium — 3-5 grams /ton in the earth's crust (lithosphere) — in soil 0.7-11 ppm — but can reach 15ppm in soils intensively treated with phosphate chemical fertilizers (phosphate rocks used as fertilizer contain between 8 ppm and 400 ppm uranium). In general, Ra-226 the direct precursor of Rn-222 is in radioactive equilibrium with U-238.

Thorium — is 3-5 times more abundant in the soil than uranium. The most widespread is Th 232 with a half-life of 14.1 billion years. The other isotopes of thorium present in their own series or in the uranium and actin series are found only in very small quantities.

Both uranium and thorium are elements strongly dispersed in the lithosphere, they are practically found everywhere in a concentration of at least approx. 1ppm (1 gram /ton).

The level of radon and CO_2 emissions from the subsoil toward the atmosphere is determined by several factors directly related to the morpho-structural and compositional characteristics of the geological layers in the lithosphere.

Both radon and CO_2 have a much higher density than air (about 8 and about 1.5 times, respectively) — which makes their penetration from deep geological layers into the atmosphere to be done through complex transport phenomena. These phenomena can be convection through porous layers, diffusion due to differences in concentration or transport by expansion due to differences in pressure, etc.

On the other hand, both radium (the main precursor of radon in the soil) and CO_2 are relatively soluble in water, so both radon and CO_2 can reach the surface through groundwater.

It is also noted that the solubility of radium compounds in geological layers is higher in acidic waters, so for those with higher CO_2 content.

In this context it is observed that the evolutions in time of the content in radium, radon and CO_2 of the groundwater's (of the springs of carbonated mineral waters) are direct consequences of the pressure ratios generated by the tectonic displacements from the perimeter of the respective springs.

Of course, radon and CO_2 are independent and/or associated compounds that can reach the surface and directly in the gas phase, a typical example being mofettas.

The variations in time of the quantities of emitted gases (of the flows) are determined by the changes of the pressure and porosity ratios in the geological layers.

The evolutions /variations over time of radon and CO_2 emissions from the soil of a given (specific) geographical area are determined by *the evolutions of mechanical stresses due to tectonic activity* in those areas.

Radon and its isotope thoron are continuously formed and is present everywhere in the lithosphere, their concentrations at the soil surface being determined by the local concentrations of uranium and thorium in the lithosphere and their morphological structure.

It is noted that the diffusion coefficient of radon in water is 1000 times lower than in air [37], which makes the radon emanations to the surface to be more pronounced through the porous and cracked layers than through the wet layers.

Under these conditions, it is found that the local concentration of radon in air and water at the soil surface is given by two components, namely: *one of them is relatively constant over time*, given both by uranium and thorium concentrations in the lithosphere of that area and the structure /permittivity of local geological layers and weather conditions (precipitation — water slows transport by diffusion, wind — disperses radon emitted) — and *one is variable over time*, given by energy accumulations /discharges and pressure ratios (mechanical stresses) due to tectonic movements from the lithosphere — from the respective perimeter /area. In view of these considerations, it is found that the accuracy of the seismic events predictions formulated by the national /zonal seismic dispatchers is given by the volume and accuracy of the recorded complex data packets.

4. Seismic protection system of gas networks: design criteria

Undergrounds pipelines connected to gas networks are mechanically required by ground vibrations — both those caused by car and/or rail traffic [39], [40] and those induced by earthquakes [41].

In the case of major earthquakes, pipelines are often damaged /broken, especially those that connect the street network and the connections of buildings and especially those inside buildings (mounted on walls).

In order to prevent explosions and devastating fires due to pipe cracks caused by major tectonic movements, it is recommended that the gas connections of buildings, especially schools, apartment buildings, public institutions, etc. be provided with a protection system, properly designed, which ensures (in case of dangerous local tectonic movements) the real-time closure of the gases, of the regulation /measurement block through which the building is supplied with gases.

In the case of earthquakes (Figure 5), the movement of seismic waves from epicenter into the territory is random (determined by the geological structure of the lithosphere), so the simple information that a major earthquake has occurred is not a sufficient argument for gas closure over a large area.

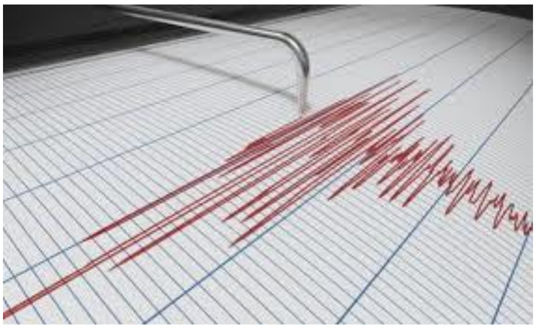

Figure 5. Seismic activity: recording with seismographs

Under these conditions, an adequate seismic protection system for gas networks in a given locality must ensure:

- measuring, evaluating /validating the intensity of local tectonic movements — preferably in 3D;
- generating the control signal for closing the gases at the connections of the buildings connected to the system — only if the intensity of the seismic

movements in the locality exceeds an imposed level (considered dangerous);
- secure digital communication — with autonomous UPS power supply — between the place of measuring /evaluating the intensity of local seismic movements and the execution aquatics (electrovalves mounted in front of the gas regulation /measurement block of the protected buildings).

On the other hand, for a better knowledge in the field of earth physics, it is particularly useful that the information on the local intensity of seismic movements as well as any precursor data acquired locally be transmitted to the national /territorial seismic dispatcher.

5. Conclusions

In the perspective of developing a system to prevent explosions and fires caused by uncontrolled gas leaks due to damage to gas networks as results of major seismic movements, seismic warning and prediction systems based on precursor data packets were analysed.

The analyses carried out showed that, at the current stage of knowledge, accurate prediction in time and intensity of earthquakes is not possible.

It also turned out that gas shut-off in buildings should only be done in the case of tectonic movements that locally exceed a certain pre-imposed threshold (considered dangerous).

Thus, an adequate seismic protection system for gas networks in a given locality must ensure:
- quantification (preferably in 3D) of the intensity of local tectonic movements;
- generation of the automatic blocking signal of the gas network connected to the system for a predetermined level of seismic intensity registered locally (considered dangerous);
- secure digital communication with autonomous UPS power supply for the gas regulation /measurement block of the protected buildings).

Information on the local intensity of seismic movements as well as complex data packets of recorded earthquakes precursor parameters must be transmitted to the national /territorial seismic dispatcher for proper assessment and validation of these events of maximum interest to the population and authorities.

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