# An Energy Sector Risk Assessment Study in Romania

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The Government of Romania has been undertaking a comprehensive hazard risk mitigation and emergency preparedness project for some years. This has included assessments, code development, training, and physical works in the mitigation of a number of natural hazards with the assistance of the World Bank. In 2010, a Beca-led team was contracted to prepare an energy sector risk assessment specifically for the seismic hazard emanating from the Vrancea Source Zone about 150 kilometres north of the capital city, Bucharest. A Romanian team of experts in each of the sectors (generation and distribution of electricity, gas and petroleum) was sourced by local engineering consultant Profesional Construct. This included staff from the Technical University of Civil Engineering Bucharest (UTCB). The Beca team also included expertise from the New Zealand Crown Research Institute GNS Science. Beca had had previous interaction with the overall project when it undertook a review of a draft building strengthening code in 2006 This paper describes the breadth of the energy sector project, and highlights the beneficial effects of international co-operation – particularly with respect to the development by the UTCB team of a new model for the seismic hazard from the very unusual source zone. It acknowledges the strong culture and history of the state design organisations responsible for much of the infrastructure.

## 1 INTRODUCTION

The Ministry of Regional Development and Housing of the Government of Romania selected Beca International Consultants Limited of New Zealand (Beca) to undertake the Preparation of an Energy Sector Risk Assessment Study. Beca chose a Romanian engineering consultant Profesional Construct SRL and a number of Romanian energy sector specialists to assist. The study was undertaken over approximately five months in the second half of 2010.

The study was to investigate the impact of the seismic hazard emanating from the Vrancea Source Zone about 150 kilometres north of the capital city, Bucharest. The likely affected area comprises more than one-third of Romania, and its approximate extent is to the South-East of a line between Craiova and Iaşi, but it stops short of the Black Sea port city of Constanţa. It includes Cernavodă where Romania's only nuclear power station is located.

The scenarios for two earthquakes emanating from the Vrancea Source Zone were investigated:

- The most probable earthquake (1000-years return period), and
- The maximum credible earthquake (Magnitude 8.1 rupturing the whole source zone).

In a first for Romania, a semi-probabilistic hazard analysis was commissioned from experts at the Technical University of Civil Engineering Bucharest (UTCB) to determine the relationship between intensity of shaking and return period across the affected area. Beca and GNS Science experts prescribed the analysis and reviewed the results for reasonableness. This analysis was, in itself, a substantial and interesting piece of work, and is being submitted to NSEE for publication in the Bulletin.

A representative selection of the most important facilities in this zone has been identified by the energy sector specialists, and site visits were undertaken to evaluate their vulnerabilities in terms of the two earthquake scenarios.

In parallel, an investigation was made of the earthquake design standards that were applied when these facilities were built or refurbished.

Representative facilities studied included hydro-power dams, thermal power stations, storage tanks, pipelines, switchyards, and control centres. For each facility studied, a set of standard assessment criteria was applied which rated it as one of four levels for each aspect so an *overall seismic risk score could be assigned*.

In our report to our client, we set out our observations, and made recommendations which included the implementation of a risk management plan, and specific detailed investigations into the seismic resilience of particular, typical facilities.

## 2 THE VRANCEA SOURCE ZONE AND AFFECTED AREA

### 2.1 Characteristics of the Vrancea Source Zone

The Vrancea earthquakes occur at an intermediate depth (i.e., focal depth 60-200 km) in the Carpathian Mountains. They are the source of the predominant seismic hazard for more than two-thirds of Romania, and also for large areas of the Republics of Moldova, Bulgaria, and Ukraine.

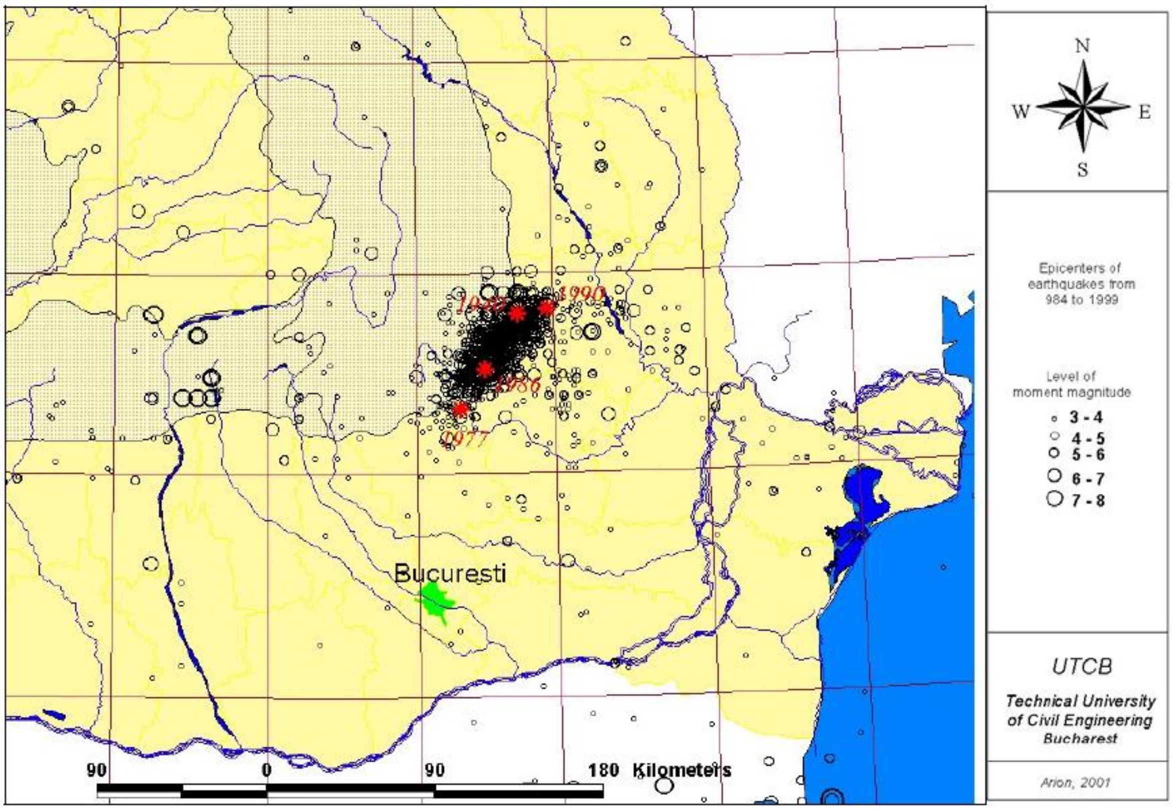


Figure 2.1 : Epicentres of earthquakes from 984 to 2000, Vrancea Earthquake Source Zone

### 2.2 Average occurrence

The catalogue of the Vrancea earthquakes indicates an average rate of one event per century that gave a maximum Intensity (MSK) of IX over the years 984-1900, and two events per century during 1901-2000. To achieve an Intensity of IX, it appears that the earthquake in the Vrancea earthquake source needs to have a minimum Magnitude (Gutenberg-Richter) of 7.2.

### 2.3 Historical earthquakes

Over the centuries, Vrancea earthquakes were felt over an area of more than 2 million square kilometres in Europe, including Austria, Ukraine, Russia, and Greece.

The most powerful Vrancea earthquake is considered to have been the 26th October 1802 event (Intensity IX-X, Magnitude 7.5-7.7). The 1977 earthquake was felt on over 1 300 000 $km^2$ and caused damage on over 80 000 $km^2$ (Ambrayses, 1977) with losses of 8 billion US$ in today's terms). In Bucharest 32 reinforced concrete tall buildings collapsed.

## 2.4 Scenario earthquakes for this study

### 2.4.1 *Maximum Credible Earthquake*

Magnitude 8.1 : The Vrancea earthquake source is renowned for its unusual characteristics. For this scenario, we needed to assess the maximum earthquake that can occur in the Vrancea subcrustal source. The hypothesis advanced by our expert seismologists was that the maximum credible earthquake is one which would rupture the entire seismic source zone. The maximum Magnitude was estimated to be M 8.1, with the relationship between return period and Magnitude asymptotic towards the M 8.1 value. A return period of 2500 years was assigned to this Maximum Credible/Considered Earthquake.

### 2.4.2 *Most Probable Earthquake*

We took guidance from the Eurocode 8 normal-importance requirements (probability of being exceeded of 10 % in 50 years) rather than from the Romanian seismic code P100 (2006) which sets a much lower level of shaking (average return period of 100 years).

The Romanian code requires the earthquake design loads for energy-sector facilities to be 1.4 times those for ordinary-importance facilities/buildings.

We therefore defined the Most Probable Earthquake firstly in terms of the appropriate return period for energy sector facilities from an international perspective, and we then saw what factor can be determined from the unusually limiting characteristics of the Vrancea earthquake source zone. We recommended a return period of 1000 years (i.e., 5 % probability of exceedance in 50 years) for the majority of the facilities, and we calculated the corresponding factor between PGA for return periods of 100 years and 1000 years to be around 1.8.

## 2.5 Site-specific hazard analysis

In order to determine the characteristics of these two earthquakes, a comprehensive study was commissioned from experts at the Universitatea Tehnica de Constructii Bucuresti (UTCB).

The probabilistic hazard analysis documented the ratios of PGA corresponding to various average return periods (500, 1000, and 2500 years) to the PGA in the P100/1-2006 code, corresponding to a return period (maximum recurrence interval) of 100 years. See Figure 2.2.

The 100-year return period mapped iso-lines and their PGA values according to the P100/1-2006 Code (Figure 2.3) were accepted as reference iso-lines for mapping and adjusting the PGA values for other than 100-year recurrence intervals (500 years, 1000 years, and 2500 years) - see Table 2.1.

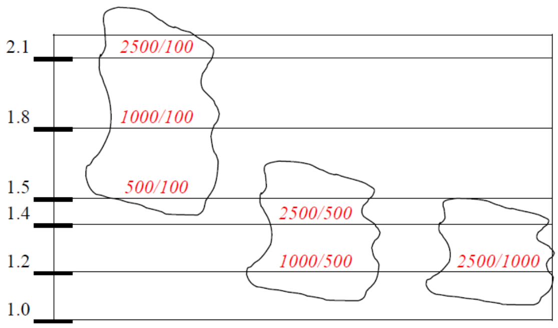


Figure 2.2 : PGA ratios for a range of Vrancea earthquake scenarios based on probabilistic analysis

Table 2.1 - PGA (g) for a range of return periods using ratios from above
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| 100 years | 500 years | 1000 years | 2500 years |
|---|---|---|---|
| 0.12 | 0.18 | 0.22 | 0.27 |
| 0.16 | 0.24 | 0.29 | 0.35 |
| 0.20 | 0.30 | 0.36 | 0.43 |
| 0.24 | 0.36 | 0.43 | 0.52 |
| 0.28 | 0.42 | 0.50 | 0.60 |

Using the P100/1-2006 contours of the PGA iso-lines and the data from Figure 2.2 and Table 2.1, the set of predictive PGA for Vrancea scenario earthquakes was derived for the mean recurrence intervals (return periods) of:

- 500 years (i.e., approx. 10 % probability of exceedance in 50 years)
- 1000 years (i.e., approx. 5 % probability of exceedance in 50 years)
- 2500 years (i.e., approx. 2 % probability of exceedance in 50 years)

Those for 1000 and 2500 years are shown in Figures 2.3 and 2.4. As explained above, the positions of the contours have been deliberately kept the same as those in P100-2006.

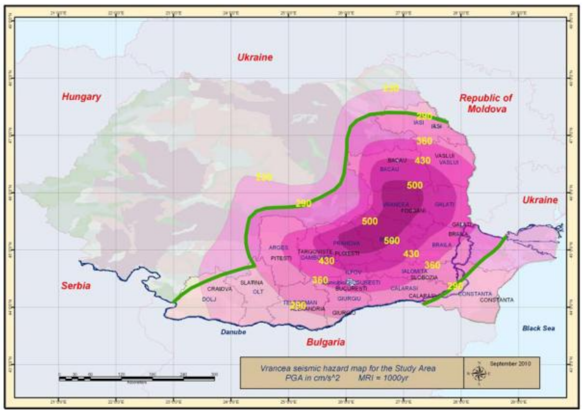


Figure 2.3 : Peak Ground Accelerations (cm/s$^2$) for 1000-year return period

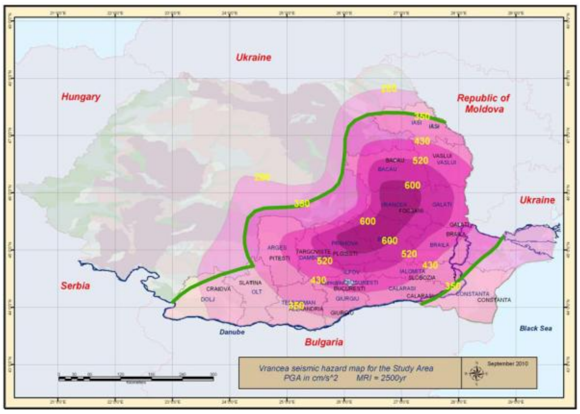


Figure 2.4 : Peak Ground Accelerations (cm/s$^2$) for 2500-year return period

The Romanian P100/1-2006 code shows normalized elastic acceleration response spectra for the three site conditions characterised by the control/corner periods, $T_c$, of 0.7, 1.0,:and 1.6 seconds. It also has a map defining zones for each corner period. The zones envelop the maximum recorded $T_c$ based on the set of available ground motion records from the 1977, 1986 and 1990 Vrancea earthquakes.

# 3 SEISMIC DESIGN STANDARDS IN ROMANIA

## 3.1 Seismic Zoning

Before 1940, there were no requirements for earthquake shaking to be considered in the design of Romanian buildings. Following the 10 November 1940 earthquake, provisional guidelines early 1942. Later, a four-zone design shaking intensity map (STAS 293-52) was promulgated. In 1963, the map was revised and design intensities were raised is some areas, but reduced in Bucharest. After the 1977 earthquake, immediate changes were made to the 1963 zoning map by extending the intensity Level VII zone to the south-west of the country. In 1991 and 1993, Bucharest and Iaşi were included in the Level VIII intensity zone, and Dobrogea and south-east Transylvania were assigned Level VII.

### 3.1.1 *Determination of seismic coefficients*

A summary of the changes to the seismic design loadings for a particular location are presented below in the form of response spectra for each of the Romanian Standards from 1963 to 1992.

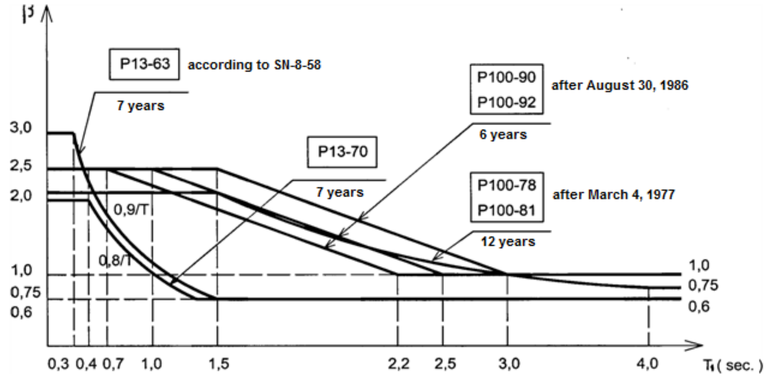


Figure 3.1 : Seismic design loadings for a particular location from 1963 to 1992

### 3.1.2 *Concerns*

Our study documented concerns in the Romanian earthquake engineering community about the legacy of inconsistencies in past codes. These included:

- The 1970 spectrum reduced the spectral ordinates of the 1963 prescription for rigid structures (in the period domain under 0.4 s) because of economic constraints at the time.
- The 1978 and 1981 spectra characteristics were only valid for some local conditions specific to the East of Bucharest. The dynamic amplification in the P100-78 and P100-81 Standards was underestimated. The maximum dynamic amplification of those codes was fixed at 2, while the maximum dynamic amplification due to the north-south component of INCERC's earthquake recording of March 4, 1977 in Bucharest was 3.2.
- The minimum value of acceleration in the normalised elastic response spectra for the 1990 and 1992 Standards was fixed at 1.0, which contradicts the laws of structural dynamics.
- It has been suggested that the corner-period zoning on Romanian territory, indicated in the 1990 and 1992 Standard should be modified because it is not consistent with the analysis of data obtained in 1986 and 1990.

## 3.2 **Conclusions relevant to our study**

Energy sector assets designed or constructed before 1970 are likely to be significantly under-designed with respect to the current seismic design norms – particularly if they are flexible structures.

There are significant concerns among leading professional engineers in Romania about the validity of the response spectra currently being used for seismic design in Romania.

# 4 DESCRIPTION OF THE ENERGY SECTOR

## 4.1 **Sectors Assessed**

The main focus of our risk assessment of each energy field is shown below:

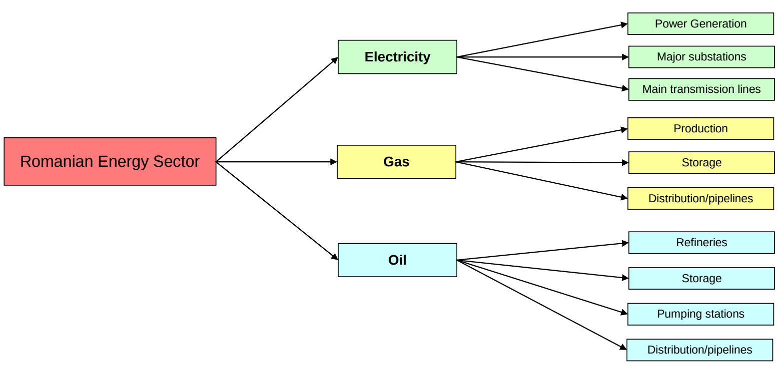

Figure 4.1 : Romanian Energy Sector Items at Risk

In 2009, the European Network of Transmission System Operators for Electricity took over all operational tasks of the six existing transmission system operators associations in Europe, including the Romanian one. This is very relevant as it allows Romania to provide and receive assistance to/from the interconnection partners if in-country generation capacity is temporarily lost in a severe earthquake. It also underlines the importance of the seismic resilience of the Romanian grid and associated distribution switchyards and control centres to maintaining power to consumers after a major earthquake.

## 4.2 **Thermal Power Plants**

There are three generations of thermal power plants in Romania. They can be characterised as pre-1968, 1968-1975, and post-1975. The post-1975 period has been the most prolific one for new construction. A number of the plants from the 1950s have now been demolished. Some sites have multiple units of different ages, and some units have been refurbished. Some units are part of industrial complexes such as refineries, and only a proportion of the steam is used for producing electricity for the national grid. Fuels include coal, natural gas and oil. In 1949, the National Institute for the Design of Power Plants (ISPE) was founded in Romania. This had the effect of introducing conformity to the design of the units.

No damage was reported in power plants in the 1977 earthquake. Although two years prior to this earthquake the government was trying to decrease design standards in order to create more economical structures, after the earthquake designers often added more strength than was required by the Code of the time.

In all, 27 thermal power plants have been considered in this study.

### 4.2.1 *Oil*

Romania produces more oil in the Vrancea Source Zone than elsewhere – the rest of the production fields are giving more gas than oil. Oil production in the region is declining steadily, although there is a thriving refinery industry. The refineries are linked by pipelines to Bucharest, Constanţa, and the Danube river port of Giurgiu. Many of the processing facilities are in Ploieşti, about 70 km north of Bucharest, and close to the Vrancea Source Zone. Imported crude is shipped to the Constanţa Oil Terminal, and transported by pipeline to the Ploieşti refineries.

65 % of all oil is distributed by pipeline (65 %), with the balance by rail.

## 4.3 **Gas**

A majority of the gas production in Romania is located outside the Vrancea Earthquake Zone. In 2009, 62.5 % of the gas extracted came from the Mureş County in Transylvannia. Romania has the third-largest natural gas reserves in the European Union. In the winter, 20-30 % of the gas demand is imported from the pipelines coming down through Ukraine to the east of the Vrancea Earthquake Zone study area.

There are many commercial gas distributors. One network has 13 110 km of pipelines with diameters between 50 and 1200 mm, with an annual transport capacity of 30 billion $m^3$. The Arad-Szeged, Giurgiu-Ruse and Nabucco pipelines are outside of the study zone, as is the Azerbaijan–Georgia–Romania Interconnector project. Romania earns around €60 million per year from transit fees from pipelines.

Romania has eight underground storage facilities with a combined capacity of 3 billion cubic metres. The largest in the Vrancea Earthquake Zone is the Bilciurești facility 40 km north of Bucharest. It has a 1.3 billion $m^3$ capacity at a depth of 2 000 m.

# 5 ASSESSMENTS OF SEISMIC RESILIENCE

## 5.1 Methodology

### 5.1.1 *Determination of Vulnerability*

Energy sector infrastructure can be vulnerable to the two earthquake scenarios in a number of ways. The equipment components themselves can be physically robust to survive the shaking unscathed, but the ability of the total system to keep operating can be compromised by the vulnerability of the:

- supporting structures
- connections with other equipment
- foundations
- protective devices/systems

Three levels of seismic performance were considered:

i) The process continues without interruption during and after the earthquake without safety being compromised.

ii) The process is interrupted and some misalignment and minor damage is acceptable, but the process can be restored within a short time.

iii) The process is damaged to a severe extent such that restoration of service takes many days or weeks.

We undertook an assessment of a selection of each of the facilities in each of the energy sectors. Scoring sheets were developed on which we documented qualitatively the types of vulnerabilities observed, and the possible mitigation measures that could be undertaken. Our Sector experts determined the criticality of vulnerable items to the operation of the energy sector by interviewing where possible.

Expert judgement was undertaken for each representative facility to assess its vulnerability. This took into account:

- The design norms in place at the time of construction
- The seismic resilience of the structural type employed
- The vulnerability of the energy process to the vulnerability of the equipment and its supports

Indicative structural response spectra for the sites of each facility were prepared for each of the two earthquake-source scenarios with reference to the results of the hazard analysis.

### 5.1.2 *Determination of Risk*

A seismic risk score was determined for each facility, for each scenario earthquake, based on the facilities assessed vulnerability (as described above) and the assessed severity of consequences of the predicted damage.

These consequences were combined into one indicative value for each facility through an assigned importance weighting.

## 5.2 Consultation

It was recognised that it would be important to speak to older members of the Romanian design institutes who controlled much of the design before 1989. Eventually, we were able to arrange to meet a number of the senior counsellors at one of these institutes - Institutului de Studii şi Proiectări Energetice (Institute of Power Studies and Design, ISPE), set up in Bucharest in 1949. The information gained in discussions with these counsellors confirmed many of the impressions that the study team had been forming up till this time.

# 6 SUMMARY

## 6.1 Re the Hazard posed by the Vrancea Earthquake Source

The two earthquake scenarios investigated give levels of ground shaking that are considerably higher than those that energy sector structures were designed for when complying with the Romanian Code P100.

The semi-probabilistic seismic hazard analysis undertaken as part of this study advances the understanding of the hazard posed by the Vrancea earthquakes on approximately one-third of Romania. This analysis gives consistent results with the peak ground acceleration contours for a 100-year return period that are specified in the current Romanian Code.

The average return period of earthquake shaking such as experienced in 1977 appears to be of the order of 100 years.

## 6.2 Re the Vulnerability of the Energy Sector

It appears that a considerable proportion of Energy Sector structures and equipment have been designed for levels of shaking considerably less than those likely to be experienced from either of the two scenario events.

At the few facilities visited, the major structures appeared to be seismically robust. However, there appeared to have been little consideration to allowing substantial seismic movement between interconnected structures. With respect to smaller items of equipment (and, in particular, electrical equipment), two extremes of seismic robustness were generally observed. One the one hand, items such as station batteries were robustly secured in all places they were observed – possibly because of a standard detail being used from many years ago. One the other hand, nowhere was it observed that power transformers were adequately secured against movement (and in particular, overturning) in moderate earthquakes. This is a serious omission as the vulnerability of these transformers in earthquakes is well-known internationally. Moreover, it is believed that new transformers are currently being installed in the Vrancea Earthquake Zone with no provision for such securing.

## 6.3 Re the Current Seismic Design Code

The current Romanian seismic Code is, like in many other countries, prescriptive rather than performance-based. It is clear that some respected senior professional engineers in Romania are concerned about the:

- Validity/provenance of the seismic factors used to derive seismic design loads, and
- The apparently low level of design load (in terms of probability of exceedance) with respect to international norms.

# 7 CONCLUSIONS

Across all energy sectors, there seems to be no appreciation of the potential hazard of an earthquake in the Vrancea Source Zone. Seismic design has been undertaken in accordance with the Code of the time.

There are concerns about the validity of codified Importance Factors applied to the seismic design – now that the probability of exceedance function for the Vrancea Source Zone has been estimated.

In the electricity sector, it appears that there has been a culture of not checking whether equipment sourced internationally has met the procurement specifications for seismic design. There does not appear to be a culture of a holistic overseeing of the installed equipment with respect to seismic performance. It is possible that each subsector works in a silo with respect to accommodating seismic interaction with the adjacent equipment.

The aspects of the oil sector assessed suggest that there is very little acknowledgement of the existence of the Vrancea Earthquake Zone, or of the damage experienced in historic earthquakes. There is a real willingness on the part of at least one petroleum company to be made aware of the hazard.

The gas sector appears to be the least vulnerable to a Vrancea Source earthquake. The major international pipelines are generally outside the Zone, and buried pipelines are not usually as badly affected as elevated or on-grade ones. The highest vulnerability will be around distribution centres and compressor stations.

The principal finding of this Energy Sector Risk Assessment Study was that no evidence has been seen of a co-ordinated or quantitative approach to the seismic vulnerability of the energy sector in Romania. In our discussions with designers and managers within individual sectors (electricity, oil, gas), we saw/learnt of specific mitigation efforts with respect to individual items of plant. Commonly, we were told that items comply with the seismic code/norms of the time of construction. Nowhere have we seen evidence that the energy sector knows of the seismic hazard posed by the Vrancea Earthquake Zone. Similarly, we have not been able to find any evidence of sectors understanding quantitatively the physical or consequential risk to which they are exposed.

This study has produced the first authoritative quantification of the seismic hazard in the region that can be affected by earthquakes in the Vrancea Earthquake Source Zone.

There is no doubt that those controlling the supply and distribution of energy within Romania have a great deal of knowledge on how to manipulate their networks in the event of isolated losses from whatever cause. Indeed, it is understood that there are formal and informal agreements with adjoining countries to supplement Romanian energy sources in emergency situations.

The energy sector is extremely vulnerable to widespread disruption if either of the two scenario earthquake occurs. The overwhelming reason for this vulnerability is the lack of appropriate seismic detailing of equipment restraints/holding-down.

The current seismic design standards need to be increased and made consistent performance-wise across all sectors.

A programme of strengthening needs to be undertaken across all sectors if these two scenario events are to be resisted with only minor disruption.

A Risk Management Planning process should be undertaken to produce a priority list of items/facilities requiring improvement in seismic resilience.

Cost-benefit studies should be undertaken to decide on the appropriate level of seismic resilience for existing and new facilities.

Mutual assistance arrangements with surrounding countries should be negotiated for assistance of post-earthquake restoration of services. This should be done in conjunction with a spare parts inventory and accompanying purchase policy.

### 7.1 **Acknowledgements**

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