ASSESSMENT OF SEISMIC HAZARD IN THE AREA OF INTERCONNECTOR GREECE-ITALY HIGH PRESSURE BURIED GAS PIPELINE: ENVIRONMENTAL RISK ASPECTS

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Seismic hazard analysis and environmental risk evaluation have been performed for the under design route of Interconnector Greece-Italy high-pressure natural gas buried pipeline, onshore part. Seismic sources along the pipeline route were defined and its geometrical parameters, as well as seismicity rates and seismic potential ($M_{max}=6.9-7.1$) have been determined. Quantification of the ground-shaking hazard along the pipeline route have been performed in the frames of the Probabilistic Seismic Hazard Assessment using the EZ-FRISK modulus. Appraisal of ground shaking severity was performed for ground shaking levels of two design earthquakes: OBE (RT=70 years, Magnitude $M=6.0-6.3$, PGA=120-210 cm/sec$^2$) and SSE (RT=975 years, Magnitude $M=6.8-7.0$, PGA=300-450 cm/sec$^2$). High Consequence Areas, combining relatively high level of seismic hazard with specific environmental sensitivity were characterized along the pipeline route.

Introduction
Although earthquakes cannot be prevented or reliably predicted at present, there are measures, we can take to reduce their potentially destructive consequences. Since in most cases manmade environment is responsible for the casualties we suffer, the people are in turn responsible for taking preventive actions in advance. The reliable estimation of seismic hazard parameters, such as maximum expected earthquake magnitude and corresponding values of strong ground motions (acceleration, velocity and displacement), is an important issue for earthquake resistant planning and risk mitigation. Knowledge of the seismic hazard at a certain sites is essential for defining proper engineering parameters.

Natural gas pipelines are more dangerous to human life than crude oil pipelines. Buried gas pipelines subject to variety of hazards, especially to strong earthquakes, which are liable to cause large ground deformation that could damage a pipeline, resulting in a gas exposure with attendant environmental harm.

The main purpose of pipeline seismic design is the ability of buried pipeline to withstand sudden large ground movement caused by potential earthquakes and related phenomena that might be expected. A major earthquake could possibly lead to damage requiring repair but there should be no structural collapse or release of hazardous substances, and functionality of essential control, communications and emergency systems should be maintained without interruption. When strained in tension, corrosion-free steel pipe with arc-welded butt joints is very ductile and capable of mobilizing large strains, associated with significant tensile-yielding, before rupture. However, strong seismic event may damage buried pipelines in a variety of ways that include:
- Seismic wave propagation and strong ground shaking at the time of the earthquake.
- Permanent ground deformation caused by surface fault movement, seismic liquefaction and landslides.

This paper focuses on ground shaking and seismic wave propagation, which assumes that the ground does not undergo large permanent displacements.

Natural gas pipeline routing raises environmental risk concerns. More serious are the public safety concerns; especially where the pipeline traverses areas with dense infrastructure and population, and the risk from a discharge related to gas pipeline or compressor stations damage could be very high. Some related risk categories are:
- Explosion at a natural gas pipeline, gas terminal or compressor facilities,
- Pollution incident leading to persistent and/or extensive effect on air quality, major damage to ecosystems and serious impact to human health.
The main purpose of this paper is to define the seismic hazards associated with the Greek part of the proposed onshore Greece-Italy high-pressure natural gas pipeline, and to consider some associated environmental impacts.

The main goals of the present paper are to delineate regions of high seismicity surrounding the designate gas pipeline, to assess the wave propagation characteristics and to make the preliminary estimates of the expected strong ground motion for Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE). In a Probabilistic Seismic Hazard Analysis, the SSE is defined as an event with a small probability of exceedance during the life of the structure (e.g. an event with recurrence interval 975 year and probability of exceedance 3-5%). The OBE is an earthquake event that can be reasonably expected to occur at least once during the design life of the structure (e.g. an event with recurrence interval of 70 year and probability of exceedance between 40 and 50%).

Environment existing around the pipeline route

Physical-geographical characteristics. The IGI Project is located in areas of relatively rich and diverse environmental and social characteristics that require specific attention and could be significantly and negatively impacted if the project is not properly developed. The area’s physical geography consists of mountains, forests, pasturelands and lands under cultivation (Figure 1).

Along the pipeline route the sparse population is concentrated in 3 main urban centers with a population of more than 50,000 inhabitants and in 22 villages within 1km from the pipeline with a population of less than 5000 inhabitants (Figure 1). The indirect area of influence affects approximately more than quarter a million people.

Figure 1. Physical-geographical environment, settlements distribution and macroseismic intensity along the IGI pipeline route.
1- Mountains, 2 – Forests, 3 – Pasturelands, 4 – Lands under cultivation, 5 – Villages in adjacent to pipeline body (inside the zone of 1 km on each side of the pipeline route), 5 – Macroseismic intensity according to Modified Mercalli Scale. Intensities were modified from Seismotectonic Map of Greece, 1989 after the Kozani, 1995 earthquake, M=6.6, I=IX.

Geotectonic characteristics. The pipeline route on the mainland is crossing successively from NE-SW the Thessaloniki basin, the Kozani and Grevena basins through Aliakmon valley, the Pindus Mountains, the narrow basin of Ioannina and the mountains of Souli, Paramythias and Parga down to its end on Ionian Sea. Geologically, this route transverse the Hellenides Mountains, the Neogene’s basin of Thessaloniki as well as the Meso-Hellenic Thrench where the molassic basins of Kozani and
Grevena are located. The Hellenides Mountains running NW-SE consist of rocks mainly formed during the Mesozoic and Cenozoic times. The series that are composing the Hellenides Mountains are grouped in geotectonic zones, this term determining the areas of similar sedimentologic and tectonic evolution (Vergely, 1984).

The pipeline route is crossing the following geotectonic zones from East to West at an angle about 90°.

Pelagonian zone. The pre-alpine basement of the Pelagonian zone consists of schists and phyllites of Upper Paleozoic (Permian). The alpine unit presents a continuous sedimentation from Lower Triassic (sandstones) to Upper Jurassic (limestones and dolomites). The alpine formations continue with transgressive carbonates of Upper Cretaceous age and they end up with Maastrichtian-Paleocene flysch.

Pindus zone. It is a zone where the pelagic sedimentation of Trias-upper Cretaceous is followed by a flysch of Maastrichtian-upper Eocene age.

Gavrovo zone. The zone is outcropping further southwards from the pipeline area since it is thrust by the formations of Pindus zone which is in a tectonic contact directly with the Ionian zone. The Gavrovo zone consists of limestones and dolomites from middle Trias to Eocene and an Oligocene - lower Miocene flysch.

Ionian zone. The series basis consists of procarinian evaporites (gypsum anhydrite and mineral salt). The evaporite thickness remains unknown; however, from oil drillings performed in various points, it results that it should exceed 3,000 m. The zone is characterized by a neritic sedimentation from upper Trias to upper Lias. Further on till upper Eocene, the sedimentation becomes pelagic with schist-chert formations (middle Jurassic), pelagic limestones with cherts (upper Jurassic - upper Cretaceous) and intercalations of breccia (upper Cretaceous - upper Eocene). The flysch deposition starts from upper Eocene and ends in lower Miocene.

The Meso-Hellenic Trench is a 40 km wide NNW-SSE trending basin in which post-Alpine sediments have been deposited unconformable over pelagonian formations since upper Eocene - Miocene. Such sediments were resulting from the weathering material of neighbouring ranges and, consequently, greatly vary the in origin (marine to fluvial) and lithology. Two distinct basins are located in the aforementioned trough, the Kozani-Servia basin to the east and the Grevena basin to the west; they consist of deposits of Plio-Pleistocene age.

The Thessaloniki Basin. Unconformable sediments cover this neotectonic basin. The sediments of middle-upper Eocene and Oligocene constitute a sedimentation cycle with alternating marine and lacustrine phases of thickness more than 3000m.

**Earthquake potential**

Based on Maximum Intensities Map (Figure 1) there are fore areas with different earthquake potential along the pipeline route. From NE to SW, from 350km of pipeline route length, 23% belong to the territory where the earthquake intensity is rated to VII on the MMS (Modified Mercalli Scale); 17% is rated to VIII-IX on MMS, 14% is rated to VI-VII MMS, and 46% is rated to VII-VIII MMS. So approximately 86% of the 350-kilometer pipeline lies within the territory where the earthquake potential is rated at VII or higher on the MMS, i.e. at very strong to severe perceived ground shaking. At some places on the pipeline route is determined that relatively short segments of the pipeline route have a earthquake potential (seismic hazard) rating one increment higher than the general area. The corresponding Peak Ground Acceleration (PGA) values are approximately of 18% g to 124% g depending on ground conditions at the particular site. Figure 2 displays the epicentre distribution of historical and instrumental recorded strong and felt earthquakes as well as structural and geodynamic background of seismicity.

**Anisotropy in wave propagation in the area of the pipeline route.**

A pipeline buried in soil that is subject to the passage of seismic waves (compression, shear and surface waves) will incur longitudinal and bending strains as it conforms to the associated ground strains. As the seismic waves travel from the epicentral region, the ground motions at any two points
along the propagation path of the waves are out of phase. Such an out-of-phase motion will induce strain and curvature in the pipeline and can cause the damage of the pipeline (Tan and Ueng, 2004). Deformations in buried pipeline are generated by the components of seismic waves that produce motion parallel to the axis of the pipeline and cause alternating compression and tension. Bending deformations are caused by the components of seismic waves producing particle motions perpendicular to the longitudinal axis. Bending in a buried pipeline is induced by the ground curvative resulting from the wave propagation, but the resulting pipe strains are generally small compared to the direct axial strain effect.

According to the simplified analysis procedure proposed by Newmark (1968), the maximum normal or axial strain in the soil, $\varepsilon$, is

$$\varepsilon = \frac{V_{\text{max}}}{C_p}$$  \hspace{1cm} (1)

where $V_{\text{max}}$ is the maximum horizontal ground velocity in the radial direction and $C_p$ is the compressive wave propagation velocity. In addition, the maximum ground curvature, $k$, due to the seismic shaking can be expressed as

$$k = \frac{A_{\text{max}}}{C_s^2}$$  \hspace{1cm} (2)

in which $A_{\text{max}}$ is the maximum ground acceleration during a seismic event at the site and $C_s$ is the propagation speed of shear wave. For the pipe with small sizes, the structural response induced by ground curvature is negligible. Therefore, under the assumption that there is no slippage between the pipe and the soil, equation (1) provides an upper bound for the structural strain in the pipe. This implies that a larger ground velocity may cause a higher degree of damage. Therefore, the PGA values, derived from SHA are used to estimate the curvature of a buried pipeline due to wave propagation, and the PGV values may be used to obtain preliminary estimates of the axial strains in the buried pipe by earthquake wave propagation.

As the ground failure that results in large permanent deformation do not concern of this paper, the focus shifts to the transient ground deformation induced by seismic wave passage. The deformation can be quite complex due to the interaction of seismic waves with surficial soft deposits and the generation of surface waves (Hashash et al., 2001).

Consequently, in any particular case, the seismic wave direction and the ratio of waves attenuation in their propagation depending on media characteristics (path effect), play a big role in strain accommodation and amplification.

Spatial distribution of the PGV and PGA-values, recorded by the network of strong ground motion stations during the Kozani-Grevena main shock, which occurred at 13.05.1995 with $M=6.6$, is shown on the Figure 3. It is worth to noting, that the distribution of the maximum PVA and PGA-values, in the case of the Kozani-Grevena main shock, follows the SW-NA direction exactly along the pipeline route in accordance with the seismogenic fault direction. Moreover, as could be concluded analyzing the Figure 3, the attenuation of ground motion along the pipeline route is more expressed than across one. It testifies the anisotropy in seismic wave propagation along, and across the pipeline route, which is attributed to evidence, that the pipeline route crosses the main geotectonic zones of the area at an angle up to $80^\circ - 90^\circ$.

Seismic Hazard Assessment

Seismic Hazard Assessment methodology The methodology used for the probabilistic seismic hazard assessment is well established in the literature (Cornell, 1968, Cornell & Vanmarke, 1969, Cornell & Merz, 1975; McGuire, 1976, McGuire, 1995 et al.). In current study, the EZ-FRISK program was used for calculations of seismic hazard (Risk Engineering, 2005). Calculation of hazard requires specification of three inputs: a) Source geometry, which is the geographic description of the seismic sources in the region around the site. A seismic source is the portion of the earth crust associated with a tectonic fault or (if individual faults cannot be identified) with an area of homogeneous seismicity; b) Seismicity, which is the rate of earthquakes occurrence and c); Attenuation Equations, which are the relationships that allow the estimation of ground motion parameters at the site as a function of earthquake magnitude, source- to-site distance and soil conditions at the site.
If a peak ground acceleration is chosen as scalar parameter, the calculations for different values of threshold level allows the construction of the seismic hazard curve for the site, that is a plot of annual frequency of exceedance, or return period, versus the parameter level. If the parameter of the ground motion is expressed in terms of spectral acceleration, $S_a(f, \xi)$, a family of seismic hazard curves for the site can be evaluated for different values of $f$ and $\xi$, where $f$ is the frequency (or return period) and $\xi$ is the percentage of the critical damping.

**Inputs to Seismic Hazard Analysis.** As with any quantitative analysis, the inputs to a seismic hazard analysis are critical. It is the case for all inputs to the seismic hazard analysis that alternative interpretations must be made where significant uncertainty exist.

**Earthquake Catalogues.** Analysis performed in the current study is based on the following recent catalogues: Papazachos et al., 2000 & Papazachos et al., 2009 (completeness 1981-2009 $M \geq 4.0$); Papanastasiou et al., 2001 (completeness $\geq 4.5$ for the period 1950-2000); the current catalogue of IG-NOA for the period 1964-2009 available on the site [www.gein.noa.gr](http://www.gein.noa.gr). The completeness of this last catalogue is characterized as $M \geq 3.5$. Joint catalog was constructed for the under study area 39.95N-40.95N/20.40E-22.00E; all the magnitudes in this catalogue were set equivalent to moment magnitude $M_W$, in the magnitude range $4.0 \geq M \leq 8.0$ according to (Papazachos et al., 1997).

**Seismic Sources Definition.** For seismicity analysis the borders of the region under study have been set approximately 50 km away from the pipeline along both sides of the pipeline route. According to strong motion data, observed in the Greek area (Theodoulidis et al., 2003), the current seismic activity outside of this region cannot produce on the pipeline route ground acceleration exceeding 100cm/cek$^2$ because of the seismic waves attenuation.

An area Seismic Source is characterized by a polygon in the horizontal plane with fixed depth h. Earthquake locations assumed to be uniformly distributed in space inside the polygon. Figure 4 shows the epicentre distribution of instrumental recorded earthquakes with magnitude equal and greater than 5.0 and location of area seismic sources delineated on the basis of earthquake epicentres and foci distribution, as well as mechanisms of earthquake and type of faulting.

The Seismic Source N1 is located in the SW part of the pipeline route and coincides with geodynamic zone A (Fig.2) which is characterized by prevailing ENE-WSW compressional quaternary active stress. High level of seismicity, insofar as historical and instrumental (period 1964-2008) events, is characteristic for the seismic source. 1657 events with $M_W > 2.5$ were recorded from this source for the instrumental observation period 1964-2008. 38 of them are of magnitude range 5.0 $\geq M \leq 6.1$. Five earthquakes with magnitude 5.4 $\geq M < 6.0$ are located in close (up to 30km) vicinity to the pipeline. 23 historical earthquakes with magnitude ranging between 6.0 and 6.5 for the time period 1651 – 1895 were recognized in this area (Papazachos & Papazachou, 2003), four of them in close vicinity to the pipeline route (1732, $M=6.5$; 1740, $M=6.2$; 1867, $M=6.2$ and 1898, $M=6.3$). The foci of instrumental earthquakes in this zone are distributed up to 70 km depth, most of them located at a depth interval 0-15km. The felt (I$\geq$VI Modified Mercally Scale, MMS) earthquakes of instrumental period with magnitude $M=5.4-6.1$ fall in shallow depth intervals 1-5km and 15-27km.

The Seismic Source 2 is of the moderate to low seismicity level area, which is located in the central to SW part of the pipeline route. The seismic source corresponds with geodynamic zone with prevailing E-W extensional quaternary active stress. 259 events with $M_W > 2.5$ were recorded by this zone for the period 1964-2008. 8 of them are of a magnitude range of 5.0 $\geq M < 6.0$. As for the magnitudes $M=6.0$, only one historical event with magnitude $M=6.0$ (19 June 1787, I=VII MMS) and one instrumental event with magnitude $M=6.4$ (01.05.1967, I=IX MMS) were recognized in this area at a distance up to 50km to the SE from the pipeline route. The foci of instrumental earthquakes in this zone are distributed mostly up to 40 km depth, most of them located at the depth interval 0-15km. The foci of the earthquakes of instrumental period with magnitude $M=5.0-6.0$ are located in shallow depth interval 1-11km.
Figure 2: Seismotectonic environment in the IGI pipeline route area

The Seismic Source N3 is located in central to NE part of the pipeline route and is characterized by moderate to high level of seismicity. The source belongs to geodynamic zone with prevailing N-S extension (Fig. 2). This source includes the mesoseismal zone of Kozani-Grevena (1995, M=6.6) earthquake and before 1995 was characterized as relatively low seismicity region: no strong earthquake, except the M=6.6, has occurred in this area in the 20 century. 1349 earthquakes with M_{W} > 2.5 were recorded from this source during the instrumental observation period 1964-2008, 18 of them are of magnitude range 5.0 ≥ M ≤ 6.6. From instrumental earthquakes only the Kozani-Grevena main event with magnitude M=6.6 and 9 of its aftershocks with magnitudes 5.0 ≥ M ≤ 5.6 are located very close (up to 15km) to the pipeline (Figure 2). Six historical earthquakes with magnitude ranging between 6.0 and 6.7 for time period 896 – 1759 were recognized in this area (Papazachos & Papazachou, 2003), four of them in close vicinity (up to 20km) to the pipeline route: 896, M=6.0; 1211, M=6.4; 1695, M=6.5 (in the area of Kozani-Grevena, 1995 earthquake) and 1759, M=6.5. The foci of instrumental earthquakes in this zone are distributed at up to 60 km depth. Most of the foci are
located at the depth interval 0-15km. The foci of the earthquakes of instrumental period with magnitude M=5.0-6.6 fall in shallow depth intervals 1-7km and 13-18km.

The characteristics of defined area sources used in SHA calculations are displayed in the Table 1. The earthquake occurrence model (parameters of seismic sources activity - b-value and activity rates) was specified using the above-mentioned catalogues for each of the delineated area seismic sources.

Table 1. Area Seismic Sources Parameters

<table>
<thead>
<tr>
<th>Area Seismic Sources</th>
<th>Maximum magnitude M&lt;sub&gt;min&lt;/sub&gt;</th>
<th>Depth, km</th>
<th>b-value</th>
<th>Activity Rate, event/year at M&lt;sub&gt;min&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>7.1</td>
<td>5.0</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>N2</td>
<td>6.9</td>
<td>5.0</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>N3</td>
<td>7.0</td>
<td>5.0</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>

Seismic hazard assessment results.

Strong ground motion on the site of interest, which might be induced by earthquake of certain magnitude from certain distance, at certain soil conditions, is modelled by attenuation relationship and is a key element of any seismic hazard model. In the present study for Seismic Hazard Assessment, the Ambraseys et al (1996) attenuation law has been used. This attenuation law was developed for use in construction of hazard consistent design spectra in Europe and Middle East. Seismic Hazard Analysis was performed for 3 sites, located along the designated pipeline route. Seismic hazard was evaluated for rock conditions; in accordance with terms for the appropriate attenuation equation choose.

Total Hazard. Seismic Hazard Analysis (SHA) integrates the contribution of all possible earthquakes (seismic sources) and calculates the probabilities that selected ground motion parameters will be exceeded within the specified exposure time. The results of an SHA for an individual site is typically displayed as a Seismic Hazard Curve – a plot of annual probability of exceedance or return period versus a specified ground motion parameter, often peak ground acceleration (PGA).

Table 2. Magnitudes of OBE and SSE events and related Peak Ground Acceleration as a function of return period for each particular part of IGI pipeline route

<table>
<thead>
<tr>
<th>Sites</th>
<th>Return period, years (Annual frequency of exceedance)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OBE event 70 (0.002)</td>
</tr>
<tr>
<td></td>
<td>Magnitude</td>
</tr>
<tr>
<td>N1</td>
<td>6.3</td>
</tr>
<tr>
<td>N2</td>
<td>6.0</td>
</tr>
<tr>
<td>N3</td>
<td>6.2</td>
</tr>
</tbody>
</table>

The PSHA for the 3 sites along the designated pipeline rout was performed using the EZ-FRISK, version 7.01 program (Risk Engineering, 2005). The analysis was based on the input data shown and discussed above. The Total Hazard PGA values are given in Table 2 for the specified return periods for OBE and SSE events.

Summary and conclusions
Preventing pipeline failures is imperative to protecting our communities and our natural resources. Gas pipeline has to be designed with a specific focus on protecting the area’s biodiversity and ensuring respect for the indigenous communities living in the IGI surrounding areas. “Pipeline development inevitably results in economic, social and environmental change, both positive and negative. It is the responsibility of the pipeline promoters, construction contractors and government to manage such developments in a manner that ensures minimal negative impact and maximum sustainability” (Dr Janet Swan, Environment Director, RSK Pipelines International — September 2009)

Calculated seismicity rates and seismic hazard parameters values (Table 2) show that the most hazardous part of the pipeline route is related to the zone A (Figure 2) where the strongest earthquakes of the historical and instrumental periods of earthquake study were recorded and relatively high values of ground shaking parameters were calculated. Moreover, the earthquakes mechanisms in this zone are represented by mostly reverse motion, which is more dangerous, because of the stronger ground shakings on the surface creating by reverse motion in the earthquake source. Compression geodynamic stress axis in this area elongated at relatively small (less than 45°) angles to pipeline route.

In Zone C two areas of relatively high level of hazard have to be taken into account. The first one is the 1995 Kozani-Grevena (M=6.6) earthquake mesoseismal area in SW part of Zone C; the second one is the area of Veroia-Edessa-Pella strong historical and instrumental earthquakes in NE part of the Zone C. The active faulting in this area is predominantly normal and extensional geodynamic stress axis directed at angles up to 90° to the pipeline route.

Concerning Zone B, it must be mentioned, that extensional geodynamic stress axis inside this zone is directed almost parallel to the pipeline route (Figure 2). Despite the fact, that the seismic hazard level in this zone is relatively low, the serious attention has to be done to this zone at the stage of the pipeline basic design, computing the response design spectra. The complicate geological and geomorphologic conditions in this part of the designated pipeline route have to be taken into account because of likely soil-topographic effects, amplifying the values of ground shaking parameters.

The design focus, besides of ground failure that results in large permanent deformation, have to be shifted also to the transient ground deformation induced by seismic wave passage. The deformation can be quite complex due to the interaction of seismic waves with surficial soft deposits and the generation of surface waves (Hashas et al., 2001). As the example of Kozani, 1995, M=6.6 earthquake shows, the attenuation of ground motion along the pipeline route is more expressed than across one, because the pipeline route crosses the main geotectonic zones of the area at an angle up to 80° - 90°. So, it can be assumed that the pipeline route will undergo mostly longitudinal bending deformation than axial compression and extension, that is one of the main types of deformation that express the response of buried pipeline to seismic motion.

Due to the already existing problems in the NW Greece regarding biodiversity loss, soil erosion, and deforestation, constructing the pipeline without any serious environmental risk assessment could lead to an even faster pace of environmental degradation.

In the under study region the High Consequence Areas, i.e. the most environmental sensitive areas to be potentially affected by strong ground shaking are the lands under cultivation with dense population (dense clusters of villages), belonging to zones A and C. The pipeline right of way (ROW) refers to a maximum area of 30 meters, but essentially has an area of direct influence defined as 1000 meters on each side of the pipeline alignment, where amount of villages falls.

The segment of the pipeline route belonging to zone B, which is characterized by relatively low seismic hazard, travels through the area of low environmental sensitivity (mountains), and the probability of significant environmental impacts is expected to be minimal. The main criticism for zone B is that the pipeline endangers rich ecosystems, as it required to clearing of large areas of forest. There were also concerned that the ROW opened for the pipeline could create wind corridors that could be catastrophic in case of fire.

The performed analysis is related to the feasibility study of IGI project. For the basic design study, in the Figure 5, the flow chart of seismic hazard assessment, displaying the required work packages proposed for on shore part of Interconnector Greece-Italy, is represented.
Figure 3. Spatial distribution of the PGV and PGA-values, recorded on the network of stations during the Kozani-Grevena main shock.

Upper left box – graphics of strong motion parameters attenuation along and across the pipeline route. 1: IGI pipeline body. 2: Location of the epicenter of Kozani-Grevena strong (1995, Mw=6.6) earthquake. 3: Geology at the basis of accelerometer: A-Limestones, B-Sands, clays, C-Alluvial materials. 4 – Contours of recorded Peak Ground Velocity (A) and Peak Ground Acceleration (B) values.

Figure 4. Location of area seismic sources involved in calculation of ground shaking parameters within the framework of Probabilistic Seismic Hazard Assessment.

1: Epicentres distribution of instrumental recorded earthquakes with magnitude equal and greater than 5.0 (A-M=5.0-5.4, B-M=5.5-5.9). 2: Area of Kozani 1995, M=6.6 strong earthquakes’ aftershock sequence. 3: Contours
of area seismic sources delineated on the basis of geological and seismological data. Sites, for which the PSHA calculations have been performed.

**Figure 5.** Flow chart of Seismic Hazard Assessment study.

To minimize the risk of accidents and environmental impacts that could rise from seismic excitation during project activities, the monitoring of surface deformation using seismological and GPS networks, as well as Differential and Permanent Scattered SAR Interferometry is proposed, as it have been proposed for gas pipeline rout in the area of the Athens in terms to be controlled happening
buckling and rupture failure in gas pipelines. In this case, managing of this situation and timely putting into operation the Emergency Situation Plans could preclude the environmental consequences.

References


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