H&RA Lacinia project – a multidisciplinary case study in the Crotone offshore (Calabria, Southern Italy) to develop good practices for studying triggerable seismicity and tsunamis

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Introduction. The Directorate General for Infrastructure and Security of the Italian Ministry of Environment and Energy Security (MASE) promoted H&RA Lacinia project (Hazard and Risk Assessment - Lacinia) as part of the research agreements for offshore safety program.
Aim of the project was to produce good practices for the study of seismicity and tsunamis potentially triggered by oil&gas production through the analysis of Crotone offshore case study (South Italy – Ionian Sea). After the 2012 Emilia earthquake, the ICHESE Commission (2014), stated that: "*Triggered and induced seismicity is a rapidly developing area of study but the present state of knowledge, and in particular a lack of experience in Italy, does not currently allow the identification of protocols of actions which can be immediately used for practical purposes for seismic risk management. The first need is the development of know-how through acquisition of detailed data, some of which must be provided by operators, and research which can improve the knowledge of the relationships between technological operations and triggered seismicity.*
The seismicity and operational parameters should be closely inspected, and it is essential to have more than one case in order to be able to derive useful tools such as a traffic-light system.
New hydrocarbon/geothermal exploration activities must be preceded by preliminary desk study and field-based screening evaluation based on an extensive and detailed 3-D geophysical and geological study, allowing the determination of the main fault systems which can be suspected to be active and their seismogenic characteristics (fault length, occurrence rate, etc.)".

The Commissione Grandi Rischi also recommended exploring these topics. Therefore, thanks to "Clypea - Innovation Network for Future Energy", the Ministry, with the national Civil Protection Department as technical advisor, started an in-depth review at national level of some possible natural sources of hazardous events (e.g., seismogenic faults and submarine landslides) that could be potentially triggerable by oil&gas activity in the framework of the project "Potentially triggerable Seismicity Offshore and Tsunami – SPOT".

Fig. 1 - Study areas of the SPOT project.

SPOT analysis, carried out by CNR-ISMAR, INGV, EUCENTRE and ReLUIS, highlighted the presence/absence offshore (Fig. 1) of seismogenic faults and submarine landslides potentially able to generate earthquakes and tsunamis that could cause damage and losses onshore (Di Bucci et al. 2017; Antoncecchi et al., 2020). Starting from the SPOT results, the Ministry, supported by the Civil Protection Department, decided to promote the development of this analysis, following a local scale approach, with the H&RA Lacinia project, which focuses on the Ionian offshore of Calabria close to gas field "Luna", in front of the Crotonese territory (Fig. 2).
H&RA Lacinia is jointly carried out by CNR-ISMAR, INGV, UniBO-DIFA, EUCENTRE, ReLUIS and RSE S.p.A. It is organised in 6 steps, in each of them more research institutions collaborate:

1. realization of the structural geological model and seismic shaking scenarios (leaded by INGV);
2. characterization of the seabed and submarine landslides (leaded by CNR ISMAR);
3. realization of the dynamic 3D model of the reservoir (leaded by RSE S.p.A.);
4. simulations of tsunamis generated by landslides and earthquakes (leaded by UniBO-DIFA);
5. analysis of earthquake impacts and losses (leaded by EUCENTRE);
6. analysis of tsunami fragility curves, impacts and losses (leaded by ReLUIS).

Fig. 2 - Study area of the H&RA Lacinia project.

To investigate the methodologies and define a workflow for risk analysis and modelling, the study benefited of production and geologic data made available by the operator of Luna field (ENI S.p.A.).

Methodology. An analysis of geological structures in the study area was conducted, aimed at better characterizing the potential seismogenic faults, and of an important submarine sedimentary body potentially unstable from a gravitational point of view, and therefore susceptible to activation or reactivation following earthquakes generated by the aforementioned faults.
This analysis was followed by an assessment of the potential impact and consequent losses caused by earthquakes and tsunamis potentially generated by the recognized structures, both faults and landslides.
With regard to earthquakes, different impact and loss scenarios have been developed, starting with damage to residential buildings and major infrastructures due to the potential activation of seismogenic faults.
With regard to tsunamis, the characterization of the vulnerability of residential buildings and of the main infrastructures present in the study area (hospitals, buildings for industries, etc.), including civil networks (bridges, viaducts, primary infrastructures of the electricity system, etc.) was deepened. The presence of potentially vulnerable cultural heritage was also considered. On this basis, tsunami impact and loss scenarios were developed.
Finally, variations in the stress values induced by the exploitation activities were investigated through the creation of a dynamic model, analysing whether the stress propagates in the studied crustal volume (and with what intensity) and if a potential interaction with the identified faults can be envisaged.

Results
All research activities ended in October 2022 achieving the following results:

- Calculation of georeferred seismic shaking scenarios potentially determined by some faults present in the area using (i) classical methods, such as shake maps also with finite faults, and (ii) numerical hybrid broadband methods for shaking simulations in three-dimensional crust models and with finite fault models, obtaining the entire time series of shaking in a wide frequency spectrum (broadband).
- Analysis, definition and mapping of some landslides along the coastline in the area of interest – AOI (Fig. 2), defining for each of them geometry, evolution and interested volume, along with some key parameters as: detachment zone and its dimensions, distance from the coast, distance from the main faults identified in the AOI, rheology and kinematics.
- 3D geological static model, dynamic simulation of the gas production, stress fields analysis.
- Numerical modelling of the coastal slopes and generation, propagation, flooding on the coast of tsunamis generated by some of the offshore landslides and faults recognised in the AOI.
- Characterization of the tsunami vulnerability of structures and infrastructures, and tsunami impact scenarios at local scale in the AOI.
- Seismic impact scenarios for residential buildings, schools, hospitals, various infrastructures and ports.

Main outcome
The primary outcome of this research is the definition of a workflow aimed at identifying the most relevant good practices for addressing the study of potentially triggerable seismicity and tsunamis in proximity of offshore hydrocarbon production activities. This outcome represents a general guideline, but it needs of course to be adapted case-by-case to be applied to individual production fields.

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