INSIDE: Investigating the impact of geothermal exploitation in the Munich area

The induced seismicity perspective

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Scientific research is carried out in the framework of the INSIDE project (supported by the German Federal Ministry for Economic Affairs and Energy, BMWi) to assess the impact of deep geothermal exploitation on induced seismicity in the Munich area (Germany, Molasse Basin). The project involves the research institute Karlsruhe Institute of Technology as well as two geothermal operators, Stadtwerke München (SWM) and Innovative Energie für Pullach (IEP). The research work focuses on three aspects: the monitoring, the modelling and the integration with operations.

With respect to the monitoring, the deployment of a measurement network going beyond the standard for seismological and geodetic observations is considered. Therefore, an extensive and plural monitoring network was designed to monitor high (seismicity) and low (subsidence, uplift) frequency deformation processes of the subsurface. Several types of technologies as well as several types of deployment configurations are involved. Their relative performances are intended to be compared in order to contribute to the development of suitable strategies for deformation monitoring and their data processing.

After presenting the aim and purpose of the project, we concentrate on the status of the seismic measurement network being implemented around the three geothermal sites of Baierbrunn, Pullach and Schäftlarnstrasse. In addition to “standard” monitoring stations installed in the area, we report on the deployment of various innovative technical solutions, among which a seismic mini-array and a monitoring borehole dedicated to Distributed Acoustic Sensing (DAS). We show how these stations complement the existing network in Munich and present their main characteristics, in particular the associated noise measurements. We additionally discuss the data-management system being developed to handle all these new data.

I. Project presentation
   >> General aspects
   >> WP1: Data recording

II. The seismic measurement network
   >> Deployment of the seismic network
   >> Different ways of acquisition

III. Performances assessment
   >> Guidelines for geothermal monitoring
   >> Assessment of detection / location capabilities
### Project ID

<table>
<thead>
<tr>
<th>Project duration</th>
<th>2019-09-01 – 2023-08-31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partners</td>
<td>- Karlsruher Institut für Technologie</td>
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<tr>
<td></td>
<td>- Stadwerke München (SWM)</td>
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<td>- Innovative Energie Pullach (IEP)</td>
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<tr>
<td>Funding authority</td>
<td>Bundesministerium für Wirtschaft und Energie (BMWi.IIC6)</td>
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<td>Study area</td>
<td>Greater Munich area</td>
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<tr>
<td>Granted amount</td>
<td>4.7M €</td>
</tr>
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</table>

**Who, Where, When?**

[Map showing Munich area with regions Schäftlarnstrasse, Pullach, and Baierbrunn]
WHAT WE STRIVE FOR?

Background of the project: Seismicity can be induced also in deep hydrothermal systems

<table>
<thead>
<tr>
<th>Site</th>
<th>First detection</th>
<th>Strongest event / Event number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unterhaching (UH)</td>
<td>10.02.2008</td>
<td>ML 2.4 / 657</td>
<td>27 events ML ≥ 1.0, six events ML ≥ 2.0, near inj. well, decreasing magnitude</td>
</tr>
<tr>
<td>Taukirchen (TK)</td>
<td>19.07.2012</td>
<td>ML 0.3 / 11</td>
<td>During circulation test at inj. well</td>
</tr>
<tr>
<td>Kirchstockach (KS)</td>
<td>23.08.2012</td>
<td>ML 0.8 / 33</td>
<td>30 microseismic events ML ≤ 0.8 near inj. well</td>
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<tr>
<td>Sauerlach (S)</td>
<td>19.06.2014</td>
<td>ML 1.2 / 2</td>
<td>ML 0.7 and ML 1.2, big location error</td>
</tr>
<tr>
<td>Pullach (Pu)</td>
<td>21.02.2015</td>
<td>ML -0.4 / 1</td>
<td>Near inj. well</td>
</tr>
<tr>
<td>Oberhaching (OH)</td>
<td>01.02.2016</td>
<td>ML 0.5 / 3</td>
<td>Near inj. well</td>
</tr>
<tr>
<td>Duerrnhaar (DH)</td>
<td>31.07.2016</td>
<td>ML 1.3 / 10</td>
<td>Big location error</td>
</tr>
<tr>
<td>Poing (PO)</td>
<td>19.11.2016</td>
<td>ML 2.1 / 21</td>
<td>18 microseismic events, two events ML ~ 2.1, near inj. well</td>
</tr>
</tbody>
</table>

Our motivations: Minimize risks associated with seismicity / deformation, strive for the development of a “Reservoir Management System”
I. PROJECT PRESENTATION  ||  II. PRESENTATION OF THE SEISMIC MEASUREMENT NETWORK  ||  III. PERFORMANCE ASSESSMENT

WHAT WE DO?

WP1
Survey and Data recording

WP2
Data management

WP3
Monitoring and Data processing

WP4
Reservoir Modelisation

WP5
Communication

WP5
Data Integration
Expansion of a measurement network going beyond the standard

WP1: Survey and Data recording
WP2: Data management
WP3: Monitoring and Data processing
WP4: Reservoir Modelisation
WP5: Communication
WP5: Data Integration
➢ Expansion of a measurement network going beyond the standard
➢ … and related data management

**I. PROJECT PRESENTATION** || **II. PRESENTATION OF THE SEISMIC MEASUREMENT NETWORK** || **III. PERFORMANCE ASSESSMENT**

**WHAT WE DO?**

- WP1: Survey and Data recording
- WP2: Data management
- WP3: Monitoring and Data processing
- WP4: Reservoir Modelisation
- WP5: Communication
- WP5: Data Integration

Other

KIT

Azure

SWM

IEP
WHAT WE DO?

- Expansion of a measurement network going beyond the standard
- … and related data management
- **Self-performance comparison** of measurement instrumentations and configurations

WP1 Survey and Data recording

WP2 Data management

WP3 Monitoring and Data processing

WP4 Reservoir Modelisation

WP5 Communication

WP5 Data Integration
WHAT WE DO?

- Expansion of a measurement network going beyond the standard
- … and related data management
- Self-performance comparison of measurement instrumentations and configurations
- Integration of results in *dvlp. of innovative modelling approaches*
- Towards a “Reservoir Management System”

WP1 Survey and Data recording

WP2 Data management

WP3 Monitoring and Data processing

WP4 Reservoir Modelisation

WP5 Data Integration

Slip-tendency modelling
Schäftlarnstrasse geothermal field
Expansion of a measurement network going beyond the standard
INSIDE

I. Project Presentation

II. Presentation of the Seismic Measurement Network

III. Performance Assessment

Surface station 3C-seismometer TC-120s

Well trajectories

- INSIDE seismic stations
- Seismic stations of «Operator Network» (LMU)
I. PROJECT PRESENTATION || II. PRESENTATION OF THE SEISMIC MEASUREMENT NETWORK || III. PERFORMANCE ASSESSMENT

Downhole station
3C-seismometer
TC-Posthole 20s

Well trajectories
- INSIDE seismic stations
- Seismic stations of « Operator Network » (LMU)
I. PROJECT PRESENTATION

II. PRESENTATION OF THE SEISMIC MEASUREMENT NETWORK

III. PERFORMANCE ASSESSMENT

Mini-array:
- 9 x 3-components seismometers
- Possibility to compare the results of various recording configurations at this location
- Not yet installed

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Well trajectories
- INSIDE seismic stations
- Seismic stations of « Operator Network » (LMU)
Distributed Fiber-Optic Sensing (DFOTS) measuring station for:

- DAS
- DTSS

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I. Project Presentation || II. Presentation of the Seismic Measurement Network || III. Performance Assessment

Distributed Fiber-Optic Sensing (DFOTS) measuring station for:
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Well trajectories
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Distributed Fiber-Optic Sensing (DFOTS) measuring station for:
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Well trajectories
- INSIDE seismic stations
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DAS / DTSS interrogators
I. PROJECT PRESENTATION

II. PRESENTATION OF THE SEISMIC MEASUREMENT NETWORK

III. PERFORMANCE ASSESSMENT

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Well trajectories

- INSIDE seismic stations
- Seismic stations of « Operator Network » (LMU)
Evaluating the performance of the surface stations

Working Group "Induced Seismicity" Forschungskollegium Physik des Erdkörpers e. V. (FKPE e. V.), et al., 2012; Groos and Ritter, 2009
I. PROJECT PRESENTATION

II. PRESENTATION OF THE SEISMIC MEASUREMENT NETWORK

III. PERFORMANCE ASSESSMENT

EVALUATING THE PERFORMANCE OF THE SURFACE STATIONS

Working Group "Induced Seismicity" Forschungskollegium Physik des Erdkörpers e. V. (FKPE e. V.), et al., 2012; Groos and Ritter, 2009

I95 values = a measure of soil turbulence

Source: BVG Guideline 1101.

Statistical distribution of I95 values estimated for the Z comp.
PPSD on vertical component for each station

5-40Hz

NHNM

NLNM

(Peterson, 1993)
Surface area where the detection capability has been assessed
In depth, targets the reservoir at a depth of 2250 (below MSL)
For 1 position, comparison between the theoretical spectrum for different Mw + cut-off spectrum from msts of station “FRIE”

Source signal is theoretically evaluated (Boatwright et al., 1980)

Threshold signal from noise measurements at a given site
Map at a depth of 2250 m – spatial evolution of the minimum event energy that can be detected with three stations.
From the noise msts. and source spectra, corresponding signal-to-noise ratio, converted in picking error dT.
Take home messages

Several acquisition techniques are implemented in the INSIDE network, their suitability for monitoring seismicity will be compared.

INSIDE surface and borehole stations meet the FKPE recommendations.

- **1.3 →** minimum event energy that can be detected by three stations in the network.

- **10 ms to 20 ms →** error in picking the P-wave arrivals for an event of magnitude MW = -1.

**Outlook:** how are these results comparable with real data, and what are the performances of the other implemented acquisition methodologies?

... more info on inside-geothermie.de