4.5.7 Analysis of Geothermal Reservoir Stimulation Using Geomechanics-based Stochastic Analysis of Injection-induced Seismicity

Presentation Number: 027

Investigator: Ghassemi, Ahmad (Texas A&M University)

Objectives: To develop a model for seismicity-based reservoir characterization (SBRC) by combining rock mechanics, finite element modeling, geostatistical concepts to establish relationships between microseismicity, reservoir flow and geomechanical characteristics.
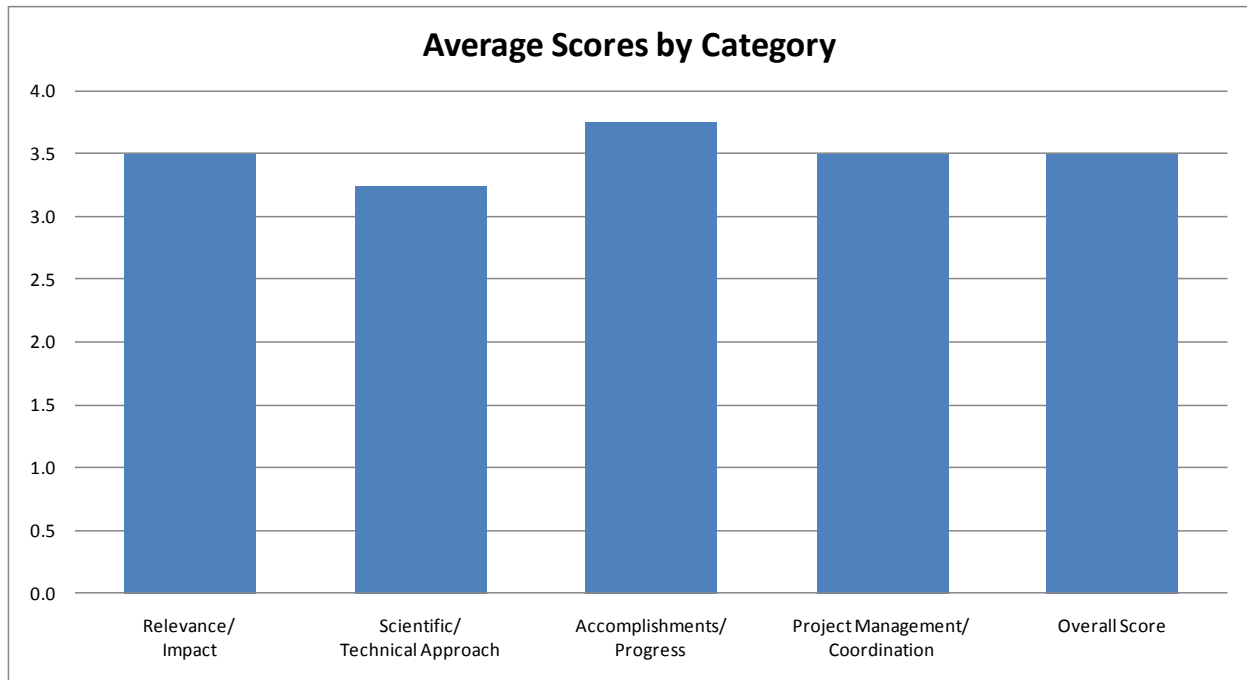
Average Overall Score: 3.5/4.0

Figure 35: Analysis of Geothermal Reservoir Stimulation Using Geomechanics-based Stochastic Analysis of Injection-induced Seismicity

4.5.7.1 Relevance/Impact of the Research

Ratings of Four-member Peer Review Panel: Good (3), Outstanding (4), Good (3), Outstanding (4)

Supporting comments:

- This project aims at developing better numerical tools for simulating induced seismicity and geothermal production in EGS. If successful, it may provide useful input into estimates of seismic hazard relationships between induced seismicity, changes in fracture density, fluid injection/withdrawal, background stress, and geothermal production. All factors are important for an efficient operation of EGS.

- Connection between FEM of reservoir properties and seismic response is critical to understanding the application of seismic techniques to exploration.

- This project intends to bring a combination of deterministic and stochastic approaches to EGS reservoir modeling, incorporating locations of MEQs and velocities in the study. This is an admirable goal, and is in line with DOE objectives. There are many ways to accomplish this, and the investigators have chosen a specific way, writing new programs from scratch, that may prove quite successful. They have made excellent progress.

- This project aims to develop a model for seismicity-based reservoir characterization by combining rock mechanics, temperature, finite element modeling (FEM), with geostatistical concepts, and if successfully completed, should make an very important contribution to the understanding of the relationships between microseismicity (MEQ), reservoir flow and geomechanical characteristic of EGSs, as well as, advance the Geothermal Program mission. The project's activities should provide a better understanding of known technical barriers, such as a more accurate prediction of the reservoir's response to stimulation. If this project is successfully completed, this reviewer is confident that the EGS program will benefit and that the results will surely add to the knowledge base.

4.5.7.2 Scientific/Technical Approach

Ratings of Four-member Peer Review Panel: Good (3), Good (3), Good (3), Outstanding (4)

Supporting comments:

- The PI and his team developed a new Finite Element (FE) code to calculate stresses and deformation due to fluid injection into a borehole. The code makes use of the damage mechanics formulation to relate computed strains to potential seismic activity, via a stochastic model. This approach is one of many possible implementations of the damage mechanics formulations and needs to be carefully benchmarked and validated before it can be used for routine interpretations of data from geothermal production sites. In particular, it is unclear if damage simulated via reductions in the effective elastic constants of rocks is a good proxy for the likelihood of earthquake occurrence. Alternative approaches (described in literature in recent years) include, for example, bulk yielding based on the rate-and-state of friction formulation.

- Needs larger three-dimensional models to be of use in real applications. Parallel computational grids should be employed.

- There are so many different aspects of reservoir modeling that are themselves multi-faceted. The investigators have chosen a specific approach that is focused, and is going to produce good results.

- The overall technical approach looks outstanding. A verified 3-D poro-thermoelastic FEM with damage mechanics and stress dependent permeability coupled with a geostatistical description of rock permeability and criticality, a stochastic description of rock mass stress and strength to predict MEQs is very innovative and valuable. Adequate resources are evident (graduate

students), and there is sufficient rigor to the work elements, procedures and methods to achieve the project objectives. The design of the project is straightforward and deemed reasonable and the technical approach is adequately described and clear tasks descriptions are provided. What are not evident are a project timeline and a delineation of tasks and subtasks. The overall quality of the research team, equipment and facilities looks good given the PI's experience and publication history. However, the credentials of the graduate students were not presented and cannot be evaluated. As long as the professor is involved with the details of the project this will be high-quality R&D. Relevant experience and the balance of appropriate skills of the research team cannot be assessed. This reviewer does not know the PI but was impressed by the quality and clarity of his presentation.

4.5.7.3 Accomplishments, Expected Outcomes and Progress
Ratings of Four-member Peer Review Panel: Good (3), Outstanding (4), Outstanding (4), Outstanding (4)

Supporting comments:

- The PI and his team have written and benchmarked a new FE code tailored to simulate injection-induced damage and seismicity. The code appears to be working as expected. Future plans include conducting laboratory experiments on rock fracture at high pressures and temperatures. Results from these experiments will be used to further test the code predictive capabilities.

- Looks like significant progress has been made by students in the modeling.

- The results to date are phenomenal.

- There are several significant accomplishments to date and results look very promising. The PI estimates project completion between 25 to 30%. According to calendar the project should be 32% completed so my guess is that the project is on schedule and there is no schedule variance. This reviewer was not able to ascertain the accomplishments as compared to costs to date (Cost of Work Performed) since current costing was not given.

4.5.7.4 Project Management/Coordination
Ratings of Four-member Peer Review Panel: Good (3), Outstanding (4), Outstanding (4), Good (3)

Supporting comments:

- The PI has reached the stated milestones and the software development and testing appear to be on track.

- Project is progressing at a good pace and I expect important results will be applicable very soon.

- The project seems to be very well-managed. It is being run as a typical university project, dependent on students and their Ph.D. goals. The PI seems to be able to corral these energies nicely, and direct the students very well.

- The technical, policy, business, and spend plans for the project are not presented simply or clearly in one place. The individual tasks make sense and are on-track but project decision points were not mentioned. The business plan predominates and the technical, policy, and spend plans are not clearly described. It is recommended that an integrated project plan with timeline should be developed that includes all of the requisite plans described and appropriate decision points put in place.

4.5.7.5 Overall

Ratings of Four-member Peer Review Panel: Good (3), Outstanding (4), Good (3), Outstanding (4)

Supporting comments:

- While there exist a number of numerical codes (both commercial and academic) capable of performing similar tasks, this project is worthwhile as it focuses on specific aspects of modeling of geothermal reservoirs. Also, it provides training for students and early-career scientists. The PI may want to look at the existing literature on high-temperature rock fracture experiments.

- Overall I would say this project is excellent. I await the results from the modeling and connection to real world data.

- The project is a good one, and is accomplishing its goals, even if some of the effort being put out is directed toward giving students experience at things that could have been done more efficiently different ways. It will be good to have the first fully-coupled P-T reservoir model explored, and this will lead to competing models, and that is good for the industry as a whole.

- Overall, this reviewer enthusiastically recommends that the project proceed. In the reviewer's opinion, this project is an outstanding contribution to the overall EGS portfolio and should be funded. If it can be verified, a 3-D poro-thermoelastic FEM with damage mechanics and stress dependent permeability coupled with a geostatistical description of rock permeability and criticality, a stochastic description of rock mass stress and strength to predict MEQs is very innovative and valuable asset to the EGS program.

4.5.7.6 PI Response

I thank the reviewers for their comments and suggestions. They will help us in improving our approach where necessary to achieve the project objectives.