

Model behaviour

[Key Facts]

- The MEM technique gives engineers a clearer picture of the subsurface formation and the stresses and loads that may change as a well is drilled.
- Chevron has many MEM projects running around the world and is using integrated field management teams to deploy the technology.

Improvements in the geological and geophysical modelling techniques used in exploration have given engineers a much clearer picture of the subsurface picture, enabling greater flexibility in well design. World Expro talks to **Harvey Goodman**, a research consultant at **Chevron Energy Technology Company**, to find out how the technology behind the Mechanical Earth Model is pushing this capability further than ever, particularly for deepwater exploration.

As the search for energy resources goes deeper under the sea and into ever more challenging environments, exploration and production companies face greater uncertainties about subsurface structures and their behaviour. The lack of a clear picture of the subsurface presents a high risk of well failure.

Modelling the subsurface more accurately has been a challenge but novel approaches combining imaging data with numerical models have shown great promise. Among them is the Mechanical Earth Model (MEM) used by Chevron.

By combining seismic imaging data with sophisticated geomechanical models, MEM is leading to greater flexibility in well design, improved drilling efficiency and a lower risk of well failure. The MEM technique gives engineers a clearer picture of the subsurface formation and the stresses and loads that may change as a well is drilled.

'We perceived a gap between the geology and geophysical community and the engineers who are responsible for optimal well design,' says Harvey Goodman, a research consultant at Chevron Energy Technology Company's drilling and completion department. 'It is our strategy to bridge that gap with geomechanics. We can take acoustic-dominated maps and turn them into reliable geological properties.'

Geomechanics, the study of rock deformation and failure, is the key ingredient. 'In the exploration phase you get more information, so you have a much clearer idea of the subsurface structure. We need the flexibility to account for the remaining uncertainty and get the best design for our asset,' says Goodman.

The mechanics of the model

Chevron is not alone in pursuing the development of models for dynamically mapping stresses and structures of subsea fields.

'Some, including ourselves and Schlumberger, call it the Mechanical Earth Model, others call it a Geomechanical Model or just the Earth Model. Either way, awareness of it is growing in the

industry. Our goal is to build our models faster and to learn more about how quickly stresses change,' says Goodman.

Formation strength and in-situ stress are the key components of the MEM technique that are critical to well engineering design. Rock stress and strength values are calibrated to formation properties and are mapped against offset well performance. Formation layer rock physics or elastic moduli values must be in agreement with the lithology types coming from the geological model and the impact on formation strength and stress character reconciled.

Goodman says: 'MEM has been made possible by advances in seismic imaging and a growing awareness of the potential role of geomechanics, which acts as a Rosetta stone for translating geophysical data from the drill well and seismic information. We can then know how hard or soft the subsurface structure is and how the stresses and hardness will change. That can have an impact on drilling, such as determining where to put the casings.'

Drilling performance for offset wells, such as rate of penetration (ROP) modelling, is used to constrain the formation strength estimate. Production history – a general term that includes hydraulic fracture and sand production performance in the reservoir – is among the core data used to constrain the static elastic moduli values estimated from acoustic data sources.

Different stresses can be dialled into the model, which can be calibrated using measurements taken early in the drilling process. The MEM accounts for different rock stresses from the start, which helps improve stability and well positioning. Companies have their own proprietary models for well failure, but the MEM gives a common reference point against which these models can be evaluated.

'We take 3D seismic imagery based on acoustic data and turn it into a rock module defining hardness, stiffness and other parameters. Then we create a mesh and apply numerical methodologies to get a more accurate guess of an individual well and how it reacts with other wells,' says Goodman. 'Models can forecast things like the consequences of subsidence, so we know what will happen as we produce, given that the stresses and loads change as the well is depleted.'

MEM in action

Chevron says its first numerical model was put to work in a pilot programme in Papua New Guinea, following which the team moved to a new subsalt development in the Gulf of Mexico. Goodman believes, however, that the most complex mix of lithologies currently exploited by Chevron is probably in the Cretaceous Pinda formation, off Angola. There, reservoir sands are very clean, fine to medium-grained friable sandstones, while bounding bed lithology is dominated by a varying mix of dolostone, limestone and shale.

The environments in which the company operates are certainly among the most challenging, particularly where drilling crews must work through salt layers, such as in the Gulf of Mexico.

'We were worried about the intrusion of the salt layer, especially as the fidelity of seismic data was not good, but we found that very smart structural geologists could compensate for that. Then we could bring in the numerical modellers, says Goodman. 'The team has a mathematician to work on numerical solutions, alongside experts in geomechanics, seismic imaging and structural geology. That team is still growing.'

This combination of expertise, encapsulated in the MEM approach, has helped Chevron succeed in harsh environments.

'We push fields farther than ever and we are going very deep. With MEM we can help manage the uncertainty as we drill and produce. We call it having a UMP – an uncertainty management plan,' says Goodman. 'In some developments with a salt/shale interface we can see the salt moving on top. The materials have different properties, and movement can rotate the principal stress fields, which causes instability. So we need to map accurately.'

“There are many stakeholders whose needs must be met, so it pays to get people talking earlier.”

Developing the MEM methodology has highlighted for Chevron the importance of bringing in the know-how of well engineers at the earliest possible phase of exploration. Already the company has noticed that this brings economic benefits to major capital projects, which is important given that a single well costs at least \$25 million.

'There are many stakeholders whose needs must be met, so it pays to get people talking earlier. For deepwater operations cost is an issue, so it pay to take your time, as you would expect the wells to last longer and be more profitable,' notes Goodman.

As well as having benefits in deepwater exploration, MEM is improving the flexibility of well design and cutting costs on land-based projects, where it can help to map the surface topography, such as canyons where stresses will change as a well is built.

This is crucial for Chevron's development of a pipeline in Angola passing under the vast Congo River Canyon, a project incorporating the world's first use of well-intersection technology on such a large scale. Chevron used the MEM as the basis for its construction of the pipeline connecting wells on either side.

In Bangladesh, too, the model has shown its worth. Previous attempts by drilling teams had failed due to the great stresses in the foothills of the Himalayas, but Chevron's team was able to use more accurate data from the MEM to successfully complete the well.

How MEM tackled salt in the Gulf of Mexico

For deepwater, subsalt operations the capital outlays can be immense. The cost of a single well rises sharply in such environments to around \$100m, so the potential return from MEM technology is also far greater.

So far, Chevron has found the model to yield significant advantages in characterising drilling risks associated with well exit points below salt, where in-situ stress perturbations can occur. These perturbations are being reliably mapped using MEM techniques, enabling Chevron to better address their impact on borehole stability.

Use of MEM technology in the Gulf of Mexico is particularly valuable. A massive salt sheet stretches from Mexico to eastern Louisiana, beneath which oil reservoirs have been found in water depths of over 6,000ft, overlain by more than 10,000ft of salt. Well costs are, therefore, high and extensive pre-drill planning is necessary so that fewer wells are drilled, though these should produce reliably for longer than average.

MEM in deepwater, subsalt environments creates a 3D, in-situ stress forecast. To achieve this the team must first:

- build an earth model geometry, utilising mapped salt and geological formation bed boundaries across the structure
- create a finite element analysis (FEA) mesh that corresponds to geological model geometry
- build a material model based on an acoustics-dominated data set that contains salt and non-salt elastic moduli (layer rheology)
- apply far field loads constrained by the geological and structural model.

Chevron's use of these techniques in the Gulf of Mexico has helped it to overcome many of the technical challenges facing its drill team.

Learning from experience

Chevron has many MEM projects running around the world and is using integrated field management teams to deploy the technology. The company is now scaling down some of the research and taking the technology to the implementation phase. The promise of the technology is great, but Goodman says further development is needed, though this is more likely to be informed by the experience of using MEM in development projects.

'As the MEM approach gains wider acceptance it will help companies align their vision of exploration and operation. We have the reservoir simulation capability now, but it needs more focus. I am wary about numerical models and I feel we need the tools to be tested. There are still a lot of questions about the tools. We are always looking for ground truth, an understanding of the constraints and limitations, but there is certainly low-hanging fruit that we can target,' he says.

'My challenge as the top dog on the technology side at Chevron is to integrate the model at operational level. It's easier to invent it than to integrate it, but we have to get out there and make it work.' ●

Harvey Goodman

Harvey Goodman is a research consultant at Chevron Energy Technology Company's drilling and completion department.

His key responsibilities include rock mechanics technology development and the application of geomechanics to well design using the common earth model approach.