PLANT CARE

With risk limitation an overriding concern, integrated site characterisation investigations are coming to the fore in the evaluation of new nuclear plant sites. **Jeffrey L Bachhuber** and **Dr Rod Eddies** report.

A renaissance in nuclear power development continues throughout the globe in spite of concerns following the damage to the Daichi Fukushima plant in Japan from the Tohoku earthquake and tsunami in March this year.

However, ongoing projects are incorporating lessons learned from the Fukushima disaster. Inevitably, there is increased focus on seismic risk and increased conservatism in establishing the design bases for external events.

New nuclear plant licensing projects have created a demand for high quality, integrated site characterisation investigations to support safety analyses and site approval. These investigations are optimally performed using best available technology and techniques to provide confident evaluation of possible geologic/seismic hazards. They are then used to develop high resolution site geotechnical models to evaluate foundation conditions and construction issues.

Main considerations during regulatory review of new plant license submissions typically include:

- fault identification and assessment (ground deformation hazard and earthquake source potential);
- site dynamic properties and seismic ground motion design;
- tsunami exposure and risk;
- ground/foundation instability (eg liquefaction, soft compressible soil, karst/dissolution);
- groundwater conditions and flow regime (radiological release modeling);
- slope stability;
- man-induced hazards (eg mining or groundwater withdrawal subsidence, induced seismicity);
- existing subsurface utilities;
- existing radiological hazards (new builds are frequently located proximal to existing nuclear plant;
- archaeological features.

Significant advances have been made in exploration techniques together with site geologic model integration using geographical information system (GIS) databases. These are enabling a level of characterisation and risk assessment that was not available for nuclear plant licensing investigations in the 1970s and 80s.

Some of the advances that have been applied to current projects are:

- High resolution surface geophysical surveys that incorporate sensitive receiver arrays, adjustable and powerful source generators, and sophisticated software modeling tools to provide rapid and comprehensive 3D subsurface images of soil and rock layering, structure and physical and/or chemical properties;
- Bundled borehole geophysical tools and survey configurations that provide high-quality imaging to maximise data obtained from each borehole and develop discrete insitu measurements of the properties of specific soil and rock strata;
- Readily available and cost-effective, quantitative remote imagery (eg LiDAR, InSAR) to provide detailed topographic and land survey data for geological and geomorphic mapping and identification of possible global geologic hazards.

Regulatory guidance for developing a suitable scope of site investigative work for nuclear plant siting and licensing investigations is provided by various international and national agencies. These include broadly-applied regulatory guides issued by the International Atomic Energy Agency (IAEA) and United States Nuclear Regulatory Commission (USNRC). Industry guidance offers a useful framework for defining general requirements and scoping, but detailed investigation programs still need to be developed on a site-by-site basis.

For example, with minimal prior site information, the siting of deep exploratory boreholes can involve significant risk. Ideally, a borehole programme will comprise an optimal number of boreholes distributed in location and depth, effectively sampling the subsurface. Geophysics provides a means to minimise borehole siting risks by providing a reconnaissance overview of subsurface characteristics. Not only this, it can also extract maximum value out of each borehole by yielding geological, geotechnical and hydrogeological data to integrate and reconcile with other site data.

Site specific investigation programmes need to focus on the geological setting and potential hazards, as well as on the performance and data requirements for the planned nuclear plant design/technology.

Take, for instance, a new build plant founded within rock in a region with suspected faults and tectonic features. This will require a programme integrating deeply-penetrating geophysical surveys (eg 2D and 3D seismic reflection and refraction, microgravity) to image or detect structures deep in the rock mass which can then be traced upward into the weathered zone or superficial soils for targeted exploratory boreholes and trenches.

It is a scenario typical of UK sites where there is often a need to identify and evaluate faults and shear zones within bedrock that

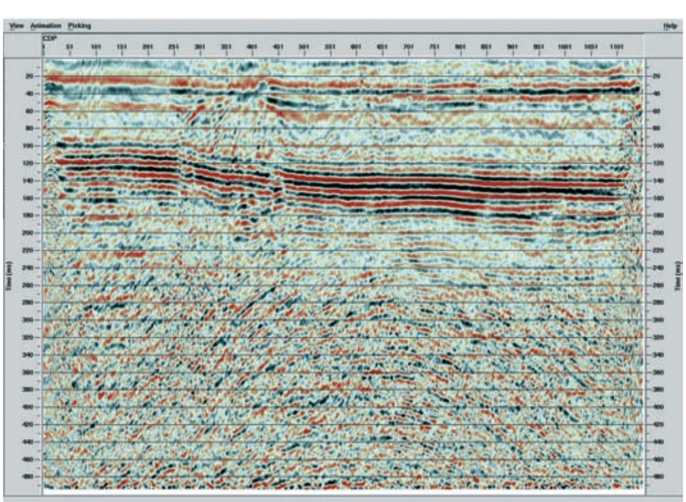

Figure 1: Seismic reflection image revealing faulted Permian strata at about 150m below surface, where no expression of faults had been detected in the near surface.

Figure 2: Comparing results from a borehole P-S suspension survey log against the corresponding recovered core as part of multiple borehole testing methods to define critical parameters.

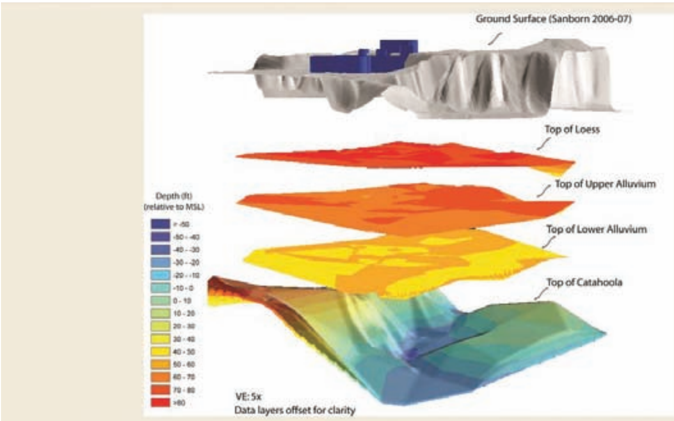

Figure 3: Composite 3D geologic model, developed on a GIS platform, identifying and correlating subsurface stratigraphy under a proposed nuclear site.

are difficult to identify in the upper weathered zone.

Figure 1 shows a high-resolution reflection seismic image of faults in Permian bedrock at a UK site that do not have a geophysical expression and remain undetectable in the overlying weathered mantle and soils.

In such applications, surface geophysical surveys can form part of an initial phase of "site screening" in conjunction with interpretation of remote imagery (LiDAR, InSAR) and reconnaissance geologic/geomorphic mapping to provide initial rapid assessment of the site. The results from the initial screening allow effective planning of follow-on phases involving exploratory boreholes and other intrusive subsurface explorations.

For instance, initial geophysical surveys allow optimal siting of targeted angle boreholes inclined to intercept bedrock structures of importance. Such features can then be "chased" up through soil layers by a combination of linear arrays of cone penetrometer soundings, and shallow trenches.

Exploratory boreholes are relatively expensive, time-consuming and disruptive. It is therefore advantageous to extract as much information as possible from each borehole by performing a full suite of tests and geophysical borehole logging surveys.

Geophysical borehole logging methods commonly considered for nuclear projects include seismic logging; density, porosity, resistivity and natural gamma measurements; pressuremeter, televiewer, and water pressure packer testing.

More recently, new advances in flowmeter logging now allow the measurement of vertical and horizontal hydraulic flow. Certain conditions or potential hazards, such as karst/limestone dissolution, can also be much better identified and characterised using multiple borehole tools (especially borehole televiewer surveys).

The improving availability, economics and application of modern borehole methods is making it increasingly viable to commission a full suite of such tests across significant numbers of boreholes for nuclear site investigations.

In Figure 2, the results from a borehole P-S suspension survey log are being compared against the respective recovered core to correlate discrete and anomalous slower and higher velocity responses to specific geological layers and features.

These types of in-field comparisons are extremely valuable in developing a comprehensive understanding of the interactions between geological materials and measured properties. They also assist the field program by deriving information from initial boreholes and surveys to help modify and optimise subsequent boreholes and borehole testing.

Integration of these various surface and borehole exploratory data sets is achieved using a GIS system that provides geo-referencing of discrete exploration points and interpolation. Derivative cross-sections and 3D contour maps assist geologic interpretation and hazard evaluation utilising all acquired data. Figure 3 is a composite 3D geologic model, developed on a GIS platform, illustrating the distribution, thickness and variability of soil layers and the subsurface bedrock surface under a proposed nuclear plant footprint.

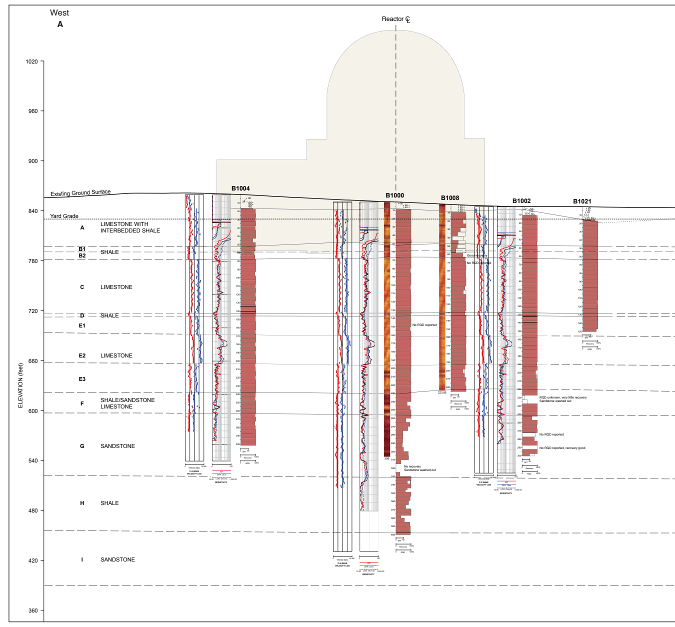

Figure 4: Integrated cross section incorporating data from multiple investigative approaches.

Integrated exploration data-sets also form the basis for developing input to safety-related calculations. These might be applied in site seismic ground motion design, or in the evaluation and confirmation of geotechnical foundation conditions.

Calculations implicated in the safety performance of nuclear plant structure receive a particularly high level of regulatory review, and benefit greatly from incorporation of multiple investigation data-sets.

Critically needed parameters include the seismic shear wave velocity profile and shear moduli/damping characteristics of soil and rock for seismic ground motion site response calculations. These are important as the ground below the site may amplify or attenuate certain seismic frequencies.

Critical parameters should be confirmed by performing at least two independent test/investigative methods.

An example approach for developing a defensible shear wave velocity profile could involve both P-S suspension logging and downhole (or crosshole tomographic) seismic logging in boreholes, coupled with surface SASW/MASW surveys.

Here, the borehole methods provide discrete and highly-detailed velocity profiles representative of the localised borehole environment. The surface methods provide velocity data between and beyond boreholes, assessment of bulk average velocity, as well as defining lateral variation. The resulting dynamic soil/rock model provides a robust 3D characterisation. It also permits evaluation of variability for defining average and bounding values for site response analyses.

Figure 4 illustrates a detailed integrated cross-section for the purpose of seismic and foundation calculation input that incorporates information from multiple investigative approaches.

Given the potential severe consequences of a nuclear incident, a high level of site characterisation is warranted and expected by regulatory agencies.

A thorough, integrated site investigation programme will facilitate agency acceptance of the initial licensing submittal, It also improves confidence in project scheduling, and will deliver overall cost savings in comparison with initial deficient characterisation that could lead to rework and multiple mobilisations as part of corrective action.

Additionally, a comprehensive study and understanding of site conditions provides greater leverage with regulators, and shows a commitment to safety and environmental protection.

Significant advances have been made in exploration techniques together with site geologic model integration using geographical information system (GIS) databases

Jeffrey L Bachhuber is senior vice president at Fugro Nuclear Services; Dr Rod Eddies is global co-ordinator at Fugro Engineering Geophysics