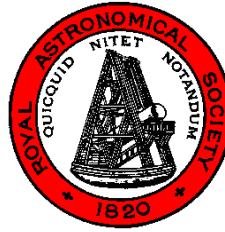


IOP Institute of Physics



British Geophysical Association



Engineering case study – Geo-engineering

Response to an Innovation, Universities, Science
and Skills Committee case study

19 September 2008

“Geo-Engineering”

Joint response to the Innovation, Universities, Science and Skills Committee’s Case Study on Geo-Engineering by:

1. the British Geophysical Association (BGA) (a joint association of the Geological Society of London (GSL) and the Royal Astronomical Society);
2. the Royal Astronomical Society (RAS);
3. the Environmental and Industrial Geophysics Group (EIGG) of the Geological Society of London;
4. the Institute of Physics (IOP).

19th September 2008

(Paragraph numbers are shown in square brackets, thus: “[1]”.)

Brief details of the respondents

[1] Geophysics is such a broad discipline, encompassing so many sciences, that UK geophysicists have not formed a single geophysical society but joined the professional society nearest to their speciality. The BGA includes geophysicists specialising in the solid Earth, geodesy and geomagnetism, who are members of the GSL and/or the RAS. It exists to promote geophysics in education, research, scholarship and practice. The RAS also represents geophysicists specialising in the physics of the upper atmosphere, Sun-Earth interactions and other planets. The BGA works closely with the EIGG, which represents applied solid-earth geophysicists working in the fields of Earth resources and civil engineering. The BGA is also working with the IOP to promote geophysics education.

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Summary

We offer a two-part response:

1. Geophysics, a predictive science from local to global level, essential for informed decisions on geo-engineering projects;
2. Education in geophysics relevant to geo-engineering.

1. Geophysics, a predictive science

- (a) Geophysics is a quantitative, predictive science essential for geo-engineering;
- (b) Without geophysics, geo-engineering projects involve unnecessary risk;
- (c) Geophysics requires long-term, global data sets, and consequently political stability.

2. Education in Geophysics

- (a) The British Geophysical Association in 2006 published a report on the state of university-level education in geophysics, after several geophysics courses closed despite high unsatisfied demand for geophysicists in the job market;
- (b) Shortages of employees with geophysical skills in the industrial and education sectors were due to profound ignorance of geophysics in schools;
- (c) Training of current and aspiring teachers in geophysical aspects of the science syllabus is essential;

- (d) Inspiring students to aim for geophysics qualifications by promoting the opportunities it brings and highlighting the need for geophysics in geo-engineering and the relevance of geo-engineering to current life and problems might help to address the shortfall.

1. Geophysics, a predictive science from local to global level, essential to informed decisions on geo-engineering projects

Main points

- (a) Geophysics is a quantitative predictive science essential to geo-engineering;
- (b) Without geophysics, geo-engineering projects involve unnecessary risk;
- (c) Geophysics requires long-term, global data sets, and consequently political stability.

What is Geophysics?

[2] Geophysics is the application of physics to the study of the Earth. It encompasses seismology, including earthquakes and “viewing” the Earth’s interior with seismic waves; magnetic fields of the Earth and the space around it; subterranean heat and volcanology; oceanography and meteorology, particularly ocean currents and ocean-earth-atmosphere energy exchange; geoelectricity; and microprocesses such as rock-fluid interaction and their effects on the macro-world in oil exploration and extraction, contaminant disposal and groundwater exploitation.

Geophysics as a Predictive Science

[3] Geophysics is used to predict the future of oil and water resources, the effects of climate change and natural disasters and the evolution of engineering sites, e.g., for waste disposal. Prediction is done by creating computer models of the physical processes involved, e.g., tsunami travel across oceans; the global atmosphere models used in climate change prediction. Geophysicists use sophisticated statistical methods to find the “best fitting” models to real data. The following are four examples of predictive geophysics.

Example 1 – Antarctic ice sheet prognosis and global sea level rise

[4] The flow of “ice streams” off the ice caps of Antarctica and Greenland makes a large contribution to the removal of ice to the sea. Geophysical techniques, including ground-penetrating radar and shallow seismic commonly used in ground engineering investigations, are combined with geodetic surveys to monitor the flow rate and investigate the wetness of the glacier bed (Murray 2008). A wet bed is more slippery, so increased flow of meltwater into the bed of the glacier might lead to collapse and hence global sea level rise. Ice sheet collapse does not cause a uniform rise in sea level, because the unburdened land also rises, and ocean currents, modified by the influx of fresh water, in turn cause different amounts of thermal expansion of the water in different places (Milne 2007). Predicting the exact rise at a given place, e.g. the Thames Barrier, requires geophysical knowledge about all these sources.

Example 2 – Underground methane hydrate

[5] Although carbon dioxide (CO₂) is accepted by most scientists to be the main cause of the modern increase in greenhouse effect, methane might be more crucial. It is a greenhouse gas ten times more potent than CO₂, so much smaller quantities can seriously impact global temperature. Most of the Earth’s available methane is now held in the form of “methane hydrate” in sub-seafloor sediments and permafrost (USGS 1992). The methane gas molecules are each held in a fragile “ice cage”, which is stable over only a narrow range of temperatures and pressures. A modest warming disrupts the cages, releasing methane, from which a runaway effect might occur as the additional greenhouse warming caused by the methane releases more methane. This effect may have contributed to an episode 55 million years ago (the “Palaeocene-Eocene thermal maximum”) (Maclennan and Jones 2006) in which global temperature rose by 6°C. The amount of methane available now in hydrate is thought to be twice the carbon equivalent of the Earth’s fossil fuel reserves, and its confining, capture or even use as fuel would be massive geo-engineering projects. Research is ongoing on how vulnerable this methane hydrate is to the present rise in

global temperature. Geophysical surveys detect the hydrate, determine what proportion of the sediment it fills, and reveal its past release (which in itself was catastrophic: e.g. the Storegga underwater landslide offshore Norway has been blamed on hydrate, Bugge *et al.* 1988, and may have caused a tsunami round northern Scotland, Smith *et al.* 2004).

Example 3 – Massive hydrofracturing to release stress before earthquakes

[6] The stress in the Earth's crust that is eventually relieved by an earthquake affects a volume of rock many times larger than the eventual rupture zone. Cracks of all sizes between microns and tens of metres respond to this stress and can be monitored via their scattering of waves passing through them from any seismic disturbance. It has been suggested that if some of the stress could be relieved, then the eventual earthquake would be smaller, and that pumping high-pressure water into the ground in many places to widen the cracks and encourage small slippage on many small faults would achieve this. This would be a geo-engineering project dependent on geophysics: for the hypothesis, the historical seismicity record, prediction of the effect of hydrofracture based on geophysical measurements of rock properties in the lab and *in situ*, choice of sites and drilling techniques, and quantifying the amount of stress reduction from the effect of crack modifications on seismic waves (Crampin *et al.* 2008).

Example 4 – Effects of Geo-Engineering on Existing and Proposed Facilities

[7] The effects of geo-engineering on existing and proposed infrastructure and culture must be predicted and monitored, and possibly prevented or mitigated. This includes everything from our archaeological heritage to waste disposal facilities. Past global changes are recognised through their effects on archaeological and prehistoric remains; locating and investigating these remains is partly a geophysical task, as shown by the "Time Team" TV programmes, for which electrical and ground-probing radar were used. Geophysical monitoring with permanently installed instruments can detect pollutant leakage from landfill waste sites (White and Barker 1997). For nuclear waste sites, geophysical projects are needed (CoRWM 2006, recommendation 4) to determine site suitability (e.g., Holmes 1997, Norton *et al.* 1997, Haszeldine and Smythe 1996). The Yucca Mountain site in the USA (US DoE 2002a) is in an area of recent tectonic activity close to lavas erupted only 75,000 years ago (Detournay *et al.* 2003). The water table is now at least 160 m below the proposed repository, but might rise in the future (US DoE 2002b). Geophysics, including measuring permeability and heat flow, dating the lavas, and modelling, is being used to predict risks to the site during 10,000 years after it is sealed (OCRWM 2003). Crucial groundwater resources worldwide are sensitive to environmental change. Geophysical techniques monitor level and salinity, and model the effect of (geo-engineered or other) change on water supplies.

The need for long data sets

[8] Much of the prediction is based on understanding past behaviour. Weather records dating back to 1659 (Met Office website) and national tide gauge records to 1953 (Proudman Oceanographic Lab website) are part of the UK's rich legacy of geophysical observations. Globally, instrumental records of earthquakes now span over 100 years, but the return period of devastating earthquakes such as the Sumatra-Andaman (26 December 2004) one is many times that. UK seismological records spanning centuries are required for risk assessment of critical facilities such as nuclear reactors and waste disposal sites, not only from earthquakes but from decadal or longer-term trends in the weather, which can be inferred from seismic records because weather affects the "noise" measured by seismometers between earthquakes.

[9] Possible solar activity effects on climate and effects of "space weather" (rapid large fluctuations in the magnetic field surrounding the Earth, and hence arrival of high-speed particles from the Sun), on national electricity grids and satellites (Hapgood & Cargill 1999), have highlighted the need for long data sets of observations of the ionosphere and magnetosphere. Measurements of many terrestrial phenomena need to be made continuously at fixed places (Douglas 2001): breaks in continuity, by either moving the instruments or interrupting the measurements, cause long-term effects to be lost or disguised by the "jump" in values at the discontinuity.

[10] Another sort of long dataset is repeated surveys, for instance, satellite and airborne radar, geomagnetic and electromagnetic and radioactivity measurements, and so-called “4-D seismic”, repeated high-density seismic surveys over the same target. These are needed for “before” and “after” records of the effects of single events and for the recognition of gradual effects of, for instance, oil extraction, urbanisation and coastal erosion.

[11] Long-term datasets require political commitment of: funding for their continued collection and archiving, regulation to allow the measurements to continue undisturbed, and staffing by experienced professionals to ensure quality. Short-term grants and contracts, and funding fluctuations causing abrupt cuts and loss of “institutional memory”, all threaten continuity. The recent cut to STFC funding for solar-terrestrial physics is an example. It is not clear yet whether the bidding process to be introduced by NERC for science carried out by its institutes will cause disruption of long-term dataset collection, particularly in the Antarctic.

Conclusions

[12] Geo-engineering will waste resources or cause more harm than good if it is not underpinned by thorough, good-quality retrospective and predictive geophysics, which in turn depends in many cases on long and unbroken data sets of measurements of natural phenomena. The political climate encouraging the collection and maintenance of long-term datasets and the recognition of geophysics as a vital contribution to geo-engineering should be nurtured.

2. Education in Geophysics relevant to Geo-Engineering

Main points:

- (a) The British Geophysical Association in 2006 published a report on the state of university-level education in geophysics (Khan 2006), after several geophysics courses closed despite high unsatisfied demand for geophysicists in the job market;
- (b) A shortage of employees with geophysical skills in the industrial and education sectors was caused mostly by profound ignorance of geophysics at school level;
- (c) Training of current and aspiring teachers in geophysical aspects of the science syllabus is essential;
- (d) Inspiring students to aim for geophysics qualifications by promoting the opportunities it brings and highlighting the need for geophysics in geo-engineering and the relevance of geo-engineering to current life and problems might help to address the shortfall.

What is Geophysics Education?

[13] Since geophysics is the application of physics to the study of the Earth, it is a broad subject involving major sciences – physics, engineering, geology, environmental science, oceanography, meteorology, astronomy and planetary science. Aspects of most of these are taught in geophysics degree courses. Modern geology, including engineering geology, is largely based on geophysical observations, and Earth Science courses accredited by the GSL must contain elements of geophysics. The sophisticated interpretation by geophysicists of field observations frequently underpins engineers’ planning of major developments; hence civil engineering courses also contain geophysics. Archaeology degrees use geophysics, made popular by recent TV coverage. A geophysics education followed by work experience can lead to a varied career involving: deducing geological structure and physical properties beneath the surface for exploration for oil, gas, geothermal energy, water, and other raw materials; environmental monitoring; civil engineering; the disposal of CO₂ and nuclear waste; military activity; the location of archaeological remains; and forensic science including the monitoring of test-ban treaties. Geophysics as a predictive science, for instance in climate prediction as mentioned above, requires research-oriented graduates with strong mathematical and computing skills.

Employers' views of geophysics education

[14] Responses from 36 employers (25 in the oil industry) strongly emphasised the need for high quality geophysicists, and pointed out difficulties in recruiting such UK graduates. A typical geophysics-dominated degree does not lead directly to an engineering qualification, but would fit the student to the role of a geophysicist in geo-engineering, working in a team with engineers or as a consultant. It provides a rigorous training in physical science and key technical and computing skills required for research and industry, as well as teamworking, presentation and other transferable skills.

[15] To the employers responding in 2006, the "taught MSc" was the best-known and most desired qualification, and the major employers bemoaned their reduction to only one (at the University of Leeds). The more broadly based BSc is also highly favoured by some. The MSci and the MRes degrees introduced in the late 1990s were not well understood. The most desired skills were: theoretical and practical geophysics with geology and IT. Overall, there was concern about the growing shortfall in the supply of well-trained geophysicists at a time when demand is increasing. While physics or other numerate graduates can be employed in geophysical roles, their on-the-job retraining is an expensive burden to employers (G. Tuckwell, pers. comm., 2008).

Present and future employment destinations of geophysics graduates

[16] At the time of the survey (2005-6), 14% of graduates went into careers in the environment sector, 3% into mining and 43% into the oil industry. The Khan report predicted that increasingly sophisticated geophysics will be needed as resources become scarcer and targets more elusive, and that there will be a growing demand for well-educated geophysicists. Three examples related to geo-engineering are: (1) a major contractor with a CO₂-sequestration section (Gould 2008) states that hydrocarbons are becoming increasingly challenging to extract, and the shortage of engineering talent is the single largest factor stopping customers from investing more; there is an estimated \$2-3 billion cost to the oil and gas industry of the shortage of skilled employees (First Break 2008); (2) repeatedly, disasters have occurred where underground engineering decisions were insufficiently informed by geoscience, hence modern civil engineering operations require sophisticated geoscientific preliminary investigations (Turner 2008); and (3) there is an increasing need to control risk from hazards like earthquakes, volcanoes and tsunamis as population grows in regions affected by these.

[17] 40% of geophysics students in 2006 were female, which is a good proportion for a physics-based science and suggests that increasing the number of geophysics graduates might have the additional benefit of increasing the proportion of women in science.

Causes of decline of UK university-level geophysics courses

[18] During the past three decades, geophysics education in the UK has declined, with many courses started in the 1960s and 1970s being discontinued in the late 1990s. In particular, the five Research Council-funded vocational MSc courses in geophysics are now reduced to one, and in 2008 there were only seven BSc or MSci courses in geophysics and 14 others with minor geophysics content.

[19] The 2006 report found that probably the main reason was that most students entering university were ignorant of the existence of geophysics. Universities' efforts on their own to increase awareness of geophysics were limited by resources. The MSc courses used to be the safety net for those students who discovered the subject while on university first degrees in other sciences, but the numbers applying have been decreasing rapidly. This is partly due to the discontinuation of 80% of the geophysics MSc courses over the last 15 years. Other factors include: graduate debt, exacerbated by the better quality undergraduates being encouraged to complete four-year MSci programmes in their own undergraduate disciplines before or instead of an MSc; the static numbers of physics graduates; and the wide range of careers open to them in physics, finance, IT, computing, and commerce.

Recommendations of the Report

[20] The strongest recommendation of the 2006 report was that geophysics must be included in the physics A-level syllabus to add to the interest and encourage more students into physics, as well as to increase awareness of geophysics as a career. Training in geophysics for teachers is consequently needed. The employment of a dedicated geophysics promotions officer was recommended. Despite a warm reception from industry, this was stalled by simple lack of time of the volunteers on the BGA committee, most of whom were academics beset with the pressures of the 2008 Research Assessment Exercise. The greatest need now is to re-launch the initiative, finding a base for the proposed officer in an institution specialising in education promotion and above all, support for volunteers from the academic/industrial community (minimal money: the issue is penalty-free time) to form a committee to oversee the work.

Conclusion

[21] UK leadership in geo-engineering will depend on a healthy and well-supported industrial and academic geophysics community, starting at school level.

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