EPSRC Review of UK Academic Research in Ground and Structural Engineering

Review panel

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Summary

In 2009, an expert panel[1] of academics and industrialists was convened by the Engineering and Physical Sciences Research Council (EPSRC) to review UK academic research in ground and structural engineering. This is a report of their findings and recommendations.

The main recommendations of this report are:

R1 EPSRC should continue to support ground and structural engineering research in the areas where the UK has established international leadership.
R2 EPSRC, the academic community and other stakeholders should look to identify and invest in the key research challenges in ground and structural engineering, formulate a shared vision for these challenges, and communicate this vision strongly.

Other recommendations are:

R3 The UK academic community should explore opportunities to disseminate to and collaborate with researchers overseas, particularly in the US.
R4 The academic community and EPSRC should look to identify the potential research areas in which the UK can establish future international leadership.
R5 The academic community should look at the balance of the number of RAs, with respect to numbers of academic staff and PhD students, in terms of the future health of ground and structural engineering research in UK academia.
R6 EPSRC should look to promote a stronger fellowship culture among the UK ground and structural engineering community.
R7 EPSRC should look at the process of how research feeds into the production of design guidance and standards, and look at ways in which this can be facilitated.
R8 EPSRC should encourage industry to strengthen its involvement with academic research beyond a culture based on letters of support and attendance at steering group meetings.

[1] See “Review panel”

R9 EPSRC and the academic community should seek to encourage greater involvement of contractors in ground and structural engineering research.
R10 EPSRC should explore other potential knowledge exchange models (for example, industrial fellowships which include 50% time spent in academia and 50% in industry).
R11 EPSRC should look at new peer review mechanisms to support and encourage multi-disciplinary working.
R12 EPSRC should look at funding mechanisms to encourage international collaboration.
R13 EPSRC and the academic community should identify and seek to address the barriers to career progression for interdisciplinary experts in ground and structural engineering.
R14 EPSRC should look to encourage greater creativity and ambition in ground and structural engineering research.
R15 The academic community and its representative organisations should better articulate and communicate a shared vision for future research in ground and structural engineering.
R16 The academic community should continue to undertake, and EPSRC should continue to support, research to support the innovative part of the construction industry.
R17 Clients should take a greater role in helping to set the research agenda in ground and structural engineering.

1. Introduction

This review was prompted by comments by the former EPSRC Engineering Strategic Advisory Team (SAT) in 2008 that research in civil engineering in the UK was often incremental, relatively short term in vision, predominantly industry led and with little interaction with other disciplines. The SAT felt there is scope for more ambitious, longer term, transformative[2] research in civil engineering, addressing current and future challenges to the UK.

As research in other aspects of civil engineering such as design of the built environment and transportation has been reviewed elsewhere[3], this review focuses on the area of geotechnical and structural engineering, as defined in the EPSRC Landscape review (appendix I), rather than the broader area of civil engineering. This includes research in: construction materials (including steel, reinforced concrete and masonry); structural engineering (including load and impact assessments; structural dynamics; structural health monitoring, and fire engineering); geotechnical engineering (including soil and rock mechanics, ground reinforcements, tunnelling, and slopes and embankments); and pavement engineering (design of materials and methods for the construction, operation and maintenance of roads and highways).

2. Methodology

The review panel initially met in July 2009. At that time, the panel agreed upon the data and information that would be assembled and presented back to the panel at a subsequent meeting, facilitated by EPSRC, in November 2009. This report represents the conclusions drawn by the panel at the November meeting. The data and information provided to the panel by EPSRC is included in the appendices to this document.

To structure the review, the panel were asked to frame their discussions around the seven "success features" of the 2006 EPSRC Strategic Plan[4], the key features identified by EPSRC of a healthy UK science and engineering base. The report is structured around these success features, with two related success features combined. They are:

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[2] "Research that has the capability to: revolutionise existing fields, create new subfields, cause paradigm shifts, support discovery, and lead to radically new technologies…", National Science Foundation: "2020 Vision"

[3] See for example: http://www.epsrc.ac.uk/ResearchFunding/Programmes/ICT/RC/pinsreport.htm

[4] i. Stimulating creativity and adventure in research and research processes; ii. Attracting, nurturing and supporting the most talented people at every stage of their career for the benefit of the UK; iii. Building collaborations that achieve a two-way flow of knowledge between the research base and industry; iv. Encouraging and supporting research that crosses the borders between disciplines, research councils and universities; v. Developing a shared vision of tomorrow's major challenges and opportunities with stakeholders: society, industry, universities and other partners; vi. Building a better understanding of where we should focus our effort to benefit both UK society and the UK economy and increase its global competitiveness; vii. Creating and sustaining research scientists and engineers in the UK so that they are recognised worldwide as leaders in their field.

World leading researchers
For example, what is the quality of research in the UK and how does it compare internationally?

Attracting and supporting talented people
For example, what does the future look like in terms of researchers and research leaders? Is there a healthy number (and balance) of PhD students and RAs? Is there a healthy demographic balance?

Collaboration and knowledge exchange
For example, is there a healthy interaction between the research community and industry? Is research in ground and structural engineering having impact on practice?

Research across borders and disciplines
For example, to what extent does the community work across disciplines? To what extent does the community collaborate internationally?

Adventurous and creative research
For example, how adventurous, creative and transformative is research in the UK?

Research to address socio-economic challenges
For example, to what extent is the community addressing the key challenges facing industry, the UK society and the economy?

3. Explanation of the data and information supplied to the panel

The following data and information was supplied to the panel by EPSRC, and is included in the appendices to this report.

3.1 EPSRC landscape: Ground and Structural Engineering (Appendix I)

The 2009 EPSRC "landscape reviews", authored and published by EPSRC, form an overview and analysis of EPSRC's entire portfolio of grants and awards[5]. The panel were shown the landscape review for the *Ground and Structural Engineering* Sub-Programme (Appendix I), as well as the landscape reviews of the *Water and Coastal Engineering*, *Built Environment*, *Waste and Environment*, and *Transportation Engineering* Sub-Programmes.

3.2 Summaries of relevant reports and a list of related road maps (Appendices II and III)

EPSRC produced for the panel, a document containing extracts from a number of reports related to research in ground and structural engineering, including a number signposted by the working group in July 2009. They included, the 2004 EPSRC/Royal Academy of Engineering International

[5] http://www.epsrc.ac.uk/AboutEPSRC/landscapes

review of Engineering and the 2009 "National Infrastructure for the 21st Century" report by the UK Council for Science and Technology. EPSRC also compiled a list of research agenda setting documents and road maps.

3.3 Analysis of 2008 RAE Results (Appendix IV)

EPSRC compiled data from the 2008 Research Assessment Exercise (RAE) from the *Civil Engineering* Unit of Assessment (UoA). Comparison was also made to a number of other disciplines across the physical sciences and engineering. The data presented the panel is included in Appendix IV. During discussions, the panel noted that a significant number of UK civil engineering groups submitted to UoAs other than Civil Engineering (especially to *Built Environment* and *General Engineering*).

3.4 Additional EPSRC portfolio data (Appendix V)

Additional data were supplied about current EPSRC support for ground and structural engineering, with comparison to that for a number of other engineering disciplines. This included EPSRC success rates in responsive mode, a breakdown of support from responsive mode and targeted activities (calls), and a list of current grants.

3.5 Results of three online community surveys (Appendix VI)

As part of the review, three online surveys were launched aimed at, respectively, the UK academic, UK industrial and international academic ground and structural engineering communities. The surveys were live between 12 September 2009 and 31 October 2009. Links to the surveys were advertised on the EPSRC website, sent directly to industrial and international members of the EPSRC College, and sent to all Category A Civil Engineering staff who had submitted to the 2008 RAE. The surveys were also distributed in the UK and overseas via a number of organisations including the Institution of Civil Engineers, the Institution of Structural Engineers, the American Society of Civil Engineers and the Modern Built Environment KTN. In total 159 responses were received from UK academics, 67 from UK industry, and 35 from international academics. The results of these surveys are given in Appendix VI.

In their discussions, the panel noted that there had been limited response to the international survey, with most responses coming from North America. In all three surveys, the panel felt the question, asking about the characteristics they felt the UK ground and structural engineering research community should have, had been misinterpreted[6].

[6] See: Question 15, Survey to UK Academics, Appendix VI; Question 5, Survey to UK Industry, Appendix VI; and, Question 8, Survey to International Academics, Appendix VI.

3.6 Impact case studies from online survey (Appendix VII)

As part of the industry and UK academic surveys, respondents were asked to give examples of where research in ground and structural engineering had had a significant impact, in practice, on the UK society or economy. The responses to this question are included in Appendix VII.

3.7 Citation data for civil engineering and ground and structural engineering subset (Appendix VIII)

EPSRC compiled bibliometric data about research volume (number of publications) and research "impact" (the ratio of number of citations to the number of articles published) for the UK, over a number of years, relative to a number of international comparators. Data were produced for the wider area of civil engineering, for a subset of journals specific to ground and structural engineering, and for a smaller subset of journals within ground and structural engineering which the panel held in highest regard. The bibliometric data is included in appendix VIII.

3. 8 Research challenges identified by the survey respondents (Appendix IX)

Respondents to all three surveys were asked to give (a maximum of three) research areas or challenges they felt were currently the most important ones for ground and structural engineering researchers to be working on. The responses are listed in Appendix IX, clustered by EPSRC into a number of categories.

4. Conclusions and recommendations of the panel

The following represents the conclusions of the panel against the EPSRC success features outlined in Section 2.

4.1 World leading researchers

Overall, there is strong evidence that ground and structural engineering research in the UK is world class with 54% of respondents to the international survey saying research in the UK ranked higher than average and 26% saying it was internationally leading[7]. From among the engineering disciplines, Civil Engineering scored joint highest with Chemical Engineering in having the highest volume of 4* rated research in the 2008 RAE[8]. There is bibliometric evidence that the community is publishing in leading journals and the bibliometric impact of UK journal papers in ground and structural engineering is second only behind Germany[9], which notably has a high impact but low publication volume. Although information was not available to show this, a further measure of international esteem would be the number of ground and

[7] See Question 5, Survey to International Academics, Appendix VI
[8] See Figure 1.6, Appendix IV
[9] See Appendix VIII

structural engineering academics and researchers being attracted to the UK from overseas.

The UK research is particularly world leading in a number of niche areas, especially numerical modelling, fire engineering, vibration engineering, geotechnical engineering and earthquake engineering. This is reflected in the EPSRC grant portfolio[10].

However, although there was a limited response to the international questionnaire, there is concern about the perception that UK research is becoming less competitive on the world stage[11]. It is also worrying that a significant number of the respondents (37%) said they have a relatively low awareness of research in the UK[12]. Given that the majority of respondents were from the US, there is significant concern that a separation is occurring between the European and North American research communities.

There is also concern about the lack of academic leadership in the general area of structural engineering and design. Although there is much expertise in structural design in the UK this is predominantly based in UK design consultancies and research in structural design is not well represented in the EPSRC grant portfolio[13]. There is concern as to how this is affecting undergraduate teaching in the UK.

The panel made the following recommendations:

R3 The UK academic community should explore opportunities to disseminate to and collaborate with researchers overseas, particularly in the US.
R4 The academic community and EPSRC should look to identify and invest in the potential research areas in which the UK can establish future international leadership.

4.2 Attracting and supporting talented people

In general, the future of UK research in terms of people looks healthier than it did 5 years ago. The number of PhD students in the UK is increasing[14], with many candidates supplied by UK MSc courses and universities abroad. This is partly a reflection of the number of graduate jobs available in civil engineering. There is also evidence for a positive trend in the number of female academics in ground and structural engineering[15].

However, there is concern about the number of research assistants (RAs) relative to the number of academic staff and, potentially, with respect to the

[10] See "Current EPSRC grant portfolio in ground and structural engineering", Appendix V
[11] See Question 6, Survey to International Academics, Appendix VI: 20% of respondents said that the international standing of research in the UK was worse than it was 10 years ago and 65.7% said it was about the same.
[12] See Question 4, Survey to International Academics, Appendix IV
[13] See "Current EPSRC grant portfolio in ground and structural engineering", Appendix V
[14] See www.hesa.ac.uk
[15] See "Demographics", Appendix I

number of PhD students. For civil engineering departments in general, there is only around 1 RA for every 2 academic members of staff listed in the 2008 RAE[16]. However, there is anecdotal evidence that the balance between PhD student and RA numbers is not uniform, and partly depends on the institution. Overall, it is clear that the future generation of ground and structural engineering researchers exists, but opportunities are required to allow them to progress.

In terms of research training, ground and structural engineering are unique in that there are no research jobs in industry for PhDs to go into since the industry is project rather than product driven. Therefore, there is an uncertainty in the career path (at PhD and RA level) of early career researchers in ground and structural engineering and barriers to mobility between academia and industry.

Notably, there are very few fellows in ground and structural engineering[17], related to a relatively low number of applications for fellowships in the area to EPSRC. The lack of interest in fellowships among the community is potentially a cultural issue, and should be addressed.

The development of academic researchers in ground and structural engineering in terms of additional skills and experience, for example time spent working abroad or in industry, is also important for the future health of the discipline. For example, the Engineering Doctorate scheme is an ideal mechanism for this (see Section 4.3).

The panel made the following recommendations:

R5 The academic community should look at the balance of the number of RAs, with respect to numbers of academic staff and PhD students, in terms of the future health of ground and structural engineering research in UK academia.
R6 EPSRC should look to promote a stronger fellowship culture among the UK ground and structural engineering community.

4.3 Collaboration and knowledge exchange

Compared to other discipline areas, there are strong links between the ground and structural engineering research community and industry. Professional bodies such as the Institution of Civil Engineering and the Institution of Structural Engineers, for example, play an important role in bringing industry and academia together.

The innovation chain in ground and structural engineering is distinct to other disciplines. New buildings are often unique prototypes and industry does not have the time and resource to refine the design to the extent necessary in manufacturing, or generalise individual innovations. A key role of the

[16] See Table 2, Appendix IV
[17] See “Fellowships”, Appendix I

academic researcher is therefore to fully understand the design principles involved in such prototypes, to determine whether innovations have performed as expected and their range of applicability: for example, to avoid over-engineering and minimise material usage and cost. However, there are also examples of where academia is leading practice, for example in numerical modelling. The industry is innovative, with much hidden innovation occurring on a project basis[18], but also relies on academia for advances in structural design, materials and construction methods[19].

Within ground and structural engineering, there is a clear path for knowledge transfer in terms of development of design codes and standards. Although this work is essential, it is often taken for granted. Intermediary organisations (such as CIRIA, SCI, The Concrete Centre, TRADA and BGA) play an important role in facilitating the joint development, between academia and industry, of design guidance.

There are other mechanisms for knowledge exchange between academia and industry for example Engineering Doctorates (EngDs), which are positively perceived by both industry and academia, and industrial involvement in MSc projects. However, the community would benefit from other such knowledge exchange opportunities, for example industrial fellowships which include 50% time spent in academia and 50% in industry.

More than half of EPSRC research projects involve partners from industry[20]. However, there is concern that industry involvement in EPSRC research projects can be limited to letters of support and membership of steering committees. Industry should be encouraged to strengthen its involvement with academic research beyond this and develop a stronger ethos for working with academia, as seen for example in disciplines such as aerospace engineering. Moreover, although there are numerous links between academia and industry, they are often based on personal contacts, and are usually with certain individuals within companies rather than at a higher level. Also, very little money is invested by contractors in the UK[21] (c.f. Japan for example). Finally, in the context of knowledge exchange, the construction sector is known for being regulation driven and risk conscious; as discussed in Section 4.5, this can be a barrier to innovation in the sector.

Finally, there are a number of research areas where greater industrial engagement should be particularly encouraged: for example, in construction materials, and the active monitoring of the performance of large construction projects.

The panel made the following recommendations:

[18] See “Hidden Innovation: How innovation happens in 6 ‘low innovation’ sectors”, NESTA (2007)
[19] See Question 9, Survey to UK Industry, Appendix VI
[20] See “Strengths”, Appendix I
[21] See Question 3, Survey to UK Industry, Appendix VI and “Greatest user collaboration”, Appendix I

R7 EPSRC should look at the process of how research feeds into the production of design guidance and standards, and look at ways in which this can be facilitated.
R8 EPSRC should encourage industry to strengthen its involvement with academic research beyond a culture based on letters of support and attendance at steering group meetings.
R9 EPSRC and the academic community should seek to encourage greater involvement of contractors in ground and structural engineering research.
R10 EPSRC should explore other potential knowledge exchange models (for example, industrial fellowships which include 50% time spent in academia and 50% in industry).

4.4 Research across borders and disciplines

In general, there is little evidence of collaboration between researchers in ground and structural engineering and researchers from other disciplines, apart from those within the areas of Built Environment and the Materials, Mechanical and Medical Engineering Programme[22]. Linked to the low amount of cross-discipline working, there has been little EPSRC targeted mode funding in ground and structural engineering compared to other engineering disciplines[23].

However, in ground and structural engineering, the necessity to work with researchers from other disciplines is not as large as in other disciplines (such as transport and water engineering). Interdisciplinary working is context specific. There is also anecdotal evidence that ground and structural engineering researchers are undertaking cross-disciplinary work in areas outside of ground and structural engineering (for example, in the EPSRC Sustainable Urban Environment Programme, and waste and brown field engineering). There are some notable examples of multidisciplinary working, from the EPSRC portfolio and beyond: for example, research in radioactive waste disposal and human-structure interactions.

There are research areas which would clearly benefit from interdisciplinary working in future, for example issues around the public perception of structures, and novel structures and materials (for example, inspired by nature).

However, it is a concern that all of the potential barriers to multidisciplinary working listed in the survey were seen as either minor or major barriers by the majority of respondents[24]. The academics surveyed felt that the biggest barrier to multidisciplinary working was the peer review process, both of grant proposals and journal articles[25]. Although there are mechanistic and structural barriers to cross-disciplinary working, the survey suggests there are also cultural barriers to such activity.

[22] See Question 4, Survey to UK Academics, Appendix VI
[23] See "Balance of support: Responsive Mode vs. Targeted Mode", Appendix V
[24] See Question 5, Survey to UK Academics, Appendix VI
[25] See Question 6, Survey to UK Academics, Appendix VI

The majority (81%) of UK academics surveyed had undertaken collaborative research with researchers overseas within the last 10 years[26]. However, the respondents also indicated that they felt there are a number of barriers to international collaboration, particularly in terms of external support and funding mechanisms. From the 2008 RAE, although there was less international and EU funding in Civil Engineering than other engineering disciplines in real terms, the amount of international funding was similar as a proportion.

An area ripe for international collaboration was in the effect of climate change, where foreign expertise of climates elsewhere, relevant to the future climate of the UK, could be brought in.

The panel made the following recommendations:

R11 EPSRC should look at new peer review mechanisms to support and encourage multi-disciplinary working.
R12 EPSRC should look at funding mechanisms to encourage international collaboration.
R13 EPSRC and the academic community should identify and seek to address the barriers to career progression for interdisciplinary experts in ground and structural engineering.

4.5 Adventurous and creative research

Although "creative" is an appropriate feature of successful ground and structural engineering research, "adventurous" is not. In ground and structural engineering, safety is of paramount importance and concern is for robustness, reliability, insureability, resilience, and compliance with regulations. This results, necessarily, in a conservative, risk-conscious culture. In this context, "adventure" is inappropriate.

However, there is scope for greater creativity in ground and structural engineering research, although there is evidence of creativity in a number of the case studies supplied by respondents to the survey (see Case Studies[27]).

Transformative research is also important but, notably, transformations can take many years and can involve multiple actors. Incremental research is also required.

What is most needed is a longer term vision and ambition for research in ground and structural engineering in the UK. There are opportunities for ground and structural engineering researchers to get involved in the important challenges now being faced by the UK and worldwide. These challenges are beginning to be signposted, for example, by the Institution of Civil Engineers[28], as well as others.

[26] See Question 7, Survey to UK Academics, Appendix VI
[27] See Appendix VII
[28] For example, the Institution's strategic knowledge themes are Resilient Infrastructure, Education of Civil Engineers, and Carbon Economy and Technology (www.ice.org.uk).

As a community, civil engineers are not good at communicating their ambition and vision. The academic community should look to address this.

The panel made the following recommendations:

R14 EPSRC should look to encourage greater creativity and ambition in ground and structural engineering research.
R15 The academic community and its representative organisations should better articulate and communicate a shared vision for future research in ground and structural engineering.

4.6 Research to address socio-economic challenges

The academic community is undertaking research to support the innovative part of the construction industry in a number of ways (see Section 4.3). This should continue. However, as well as the construction industry, clients (especially government as the largest UK procurer) should have a greater role in helping to set the research agenda.

The community is also addressing a number of important research challenges which are important to the UK economy and society. However, there are new challenges on the horizon, which the community is only beginning to think about. For example, the UK historically has few environmental threats, but this is now changing. Maintenance of ageing infrastructure is becoming ever more important. A number of other key research challenges in ground and structural engineering are identified in Section 6.

Moreover, research in ground and structural engineering is mostly reactive in its response to key challenges. The new set of challenges presents an opportunity for the research community to become more proactive. The community is now at the “tipping point” of beginning to address these challenges.

The panel made the following recommendations:

R16 The academic community should continue to undertake, and EPSRC should continue to support, research to support the innovative part of the construction industry.
R17 Clients should take a greater role in helping to set the research agenda in ground and structural engineering.
(See also **R2**)

4.7 Overall

The panel scored UK research in ground and structural engineering, using a five point scale from 1 to 5 where 1 is poor, to describe the extent to which it was meeting the six individual success features listed in Section 2. The results[29] are shown in figure 1. Although these give a static picture, there is a positive trend in a number of areas, particularly in "Research to address socio-economic challenges" and "Research across borders: between disciplines".

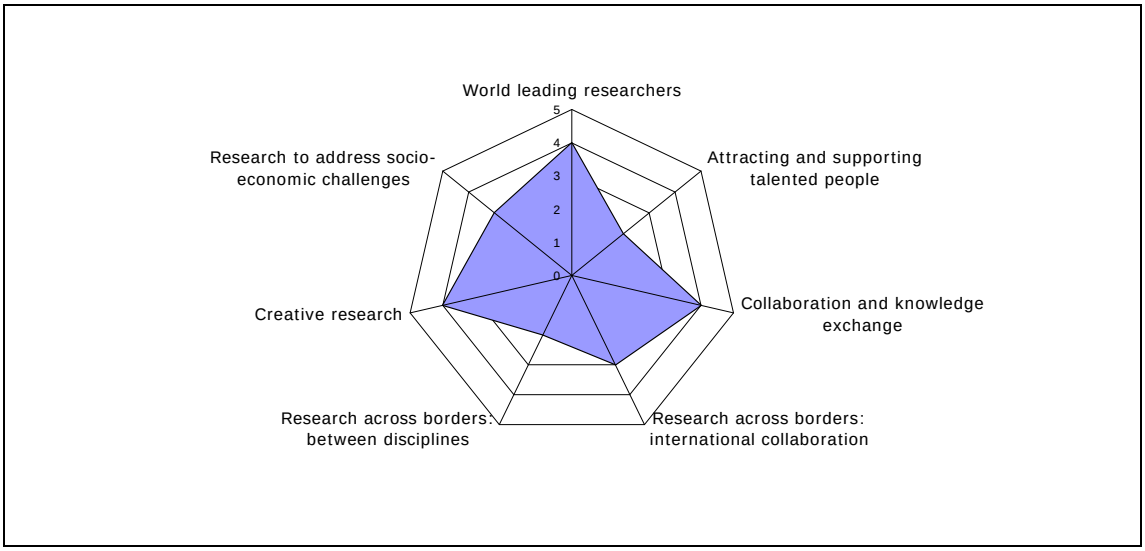

Figure 1: Scores awarded by the panel against the EPSRC "success features" for ground and structural engineering research in the UK

5. Impact case studies

An impressive number and range of case studies, of where research in the UK had had a significant impact in practice, were highlighted in the surveys of UK academia and UK industry[30]. In particular there were a number of examples of research in field monitoring, novel materials (for example composites), the use of ICT for monitoring information flow, improvement of construction processes, use of construction waste, and in fire engineering. There were also examples of testing (for example, the Cardington fire tests) where the data collected had had a transformative effect on practice. Other highlights included work on ground movements for tunnelling of the Jubilee line, and work over the last decade on crowd induced vibrations which will have a profound effect, through state-of-the-art design guidance, on the stadiums that will be built for the London 2012 Olympics.

[29] The panel chose to give different scores to international collaboration and working with other disciplines.
[30] See Appendix VII

6. Future research challenges in ground and structural engineering

A large number of research challenges were identified by respondents to the three online surveys. These ranged from specific and focused challenges such as "large scale hybrid testing of structures under combinations of extreme loads" to more general challenges such as "climate change" and "earthquake engineering". The diverse challenges were clustered by EPSRC into 24 categories ranging from "Adaptation to Climate Change" to "Waste and Recycling" and are included in the Appendices to this report[31].

Although these categories provide a useful way of presenting the survey results, they inter-relate and overlap in a number of ways. Further work is required to develop these categories, and the individual research challenges beneath them, into a future vision for UK research in ground and structural engineering (see recommendation R2).

From the research challenges identified in the survey, the panel identify a number of overarching themes. These relate to the wider challenges faced globally and in the UK of climate change, demographic growth, resource depletion and energy security, and the encompassing drive to achieve sustainability. These themes provide a starting point for the development of the key research challenges in ground and structural engineering. They are:

1. Sustainable construction and infrastructure: whole life cycle approach[32]
Achieving sustainability in construction and infrastructure requires a whole-life approach considering, in an integrated way: commissioning (including planning, design brief, and design and modelling stages); the construction process; exploitation and use; and, de-commissioning. As an example, if there is a move towards reuse, rather than recycling of materials, then this will effect both how infrastructure is both designed and built. Sustainability should also encompass all other challenges faced globally, for example climate change and increasing urbanisation.

2. Resilient infrastructure[33]
Both new and existing infrastructure need to be resilient to a number of hazards both natural (such as those from extreme weather caused by climate change and geohazards) and manmade (such as incidents of blast and fire).

[31] See Appendix IX
[32] This theme includes a number of the research challenges identified in Appendix IX, including: a. Adaptation to climate changing; c. Carbon and resource reduction; u. Urban systems and design; and, w. Waste and recycling.
[33] This theme includes a number of the research challenges identified in Appendix IX, including: d. Design against blast and impact; f. Environmental hazard engineering; g. Flood risk management; and, k. Improvement of safety.

3. Monitoring and field investigation of existing infrastructure[34]
A crucial link that is currently missing to ground and structural engineering design is the provision of long-term field data, both in use and at the end of use, to close the design cycle, such has been achieved for example in aerospace and mechanical engineering. This theme has clear links to the Sustainable Construction and Resilient Infrastructure themes. For example, if material and energy usage is to be minimised, then better data is needed about performance in practice.

4. Novel materials and novel use of materials
This is an area of clear potential for innovation in ground and structural engineering. Advanced materials are required to reduce embodied carbon and energy in use, to reduce resource consumption and waste, and for adaptability and durability.

Finally, human factors and the relationship between people and infrastructure are important elements of the challenges faced, particularly those in sustainability, resilience and monitoring; they cannot be ignored in research to address these challenges.

7. Overall conclusions and recommendations

This review has been good in the way it has engaged with the community through the online surveys. It is encouraging that broadly similar results were seen from the surveys of UK academics, the international academic community, and UK industry.

Overall, the evidence shows that there is a strong research base in the UK in ground and structural engineering, with excellent research being undertaken. The UK is particularly strong in a number of niche areas, especially numerical modelling, fire engineering, vibration engineering, geotechnical engineering and earthquake engineering.

Much research undertaken is creative and ambitious. There are many examples from the UK of progressive research having a positive effect on the built environment.

This is also an area which is well linked to industry. The construction industry is a project-based industry which works on one-off structures. It is innovative, but relies on academia for advances in structural design, materials and construction methods, and for the development of design codes and standards which underpin safety. Although collaboration with industry is largely appropriate, there is scope for more involvement, particularly from clients and contractors. Academia is also important for the training of people for industry, although the sector differs from other sectors in that there are no formal career paths for doctoral researchers in the construction industry.

[34] This theme includes a number of the research challenges identified in Appendix IX, including: h. Investigation and Sensors; and, s. Structural Health Monitoring.

This review has also addressed a number of negative perceptions of research in ground and structural engineering civil engineering, partly related to how the research community projects itself and its ambitions. These perceptions also relate to a wider public perception that civil engineering is dull and unexciting. In reality, the results of research in ground and structural engineering are often taken for granted as infrastructure is “invisible” when it works: it is often only noticed during failures. Given the importance of infrastructure to society, research in ground and structural engineering is in fact of critical importance. Such research underpins the infrastructure which in turn underpins society; when infrastructure breaks down so does society.

Most importantly, the UK is entering a new era where it will face a number of difficult challenges. The UK ground and structural engineering community will now need to take a more proactive approach to address these challenges. The research community must establish a shared vision for what research is needed now and in the future, and communicate that vision clearly. To do this, the academic community, with the support of EPSRC, will need to work outside of geographic and disciplinary silos and overcome the structural and mechanistic barriers, and perceptions of these barriers, to doing the research they feel is necessary.

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