RESEARCH NEEDS

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INTRODUCTION

The 1984 Geogrid symposium presented the results of a major research effort aimed at developing the new concept of geogrids for use in Civil Engineering application. The initial research conducted under the auspices of the then Science Research Council (SRC) was comprehensive ranging from consideration of basic soil reinforcement mechanisms to design methods and construction technology. The research considered the use of geogrids in a number of potential applications including reinforcement of paved and unpaved roads, retaining structures and concrete reinforcement. Since 1984 the use of geogrid reinforcement has spread exponentially and now is the preferred mode of construction in many applications. Only in area of concrete has the use of geogrid reinforcement anticipated in 1984 not progressed.

Since 1984, research has been ongoing and major advances in understanding have been achieved. In particular the problem of creep which at the first Symposium was identified as being a major problem has largely been resolved. Theoretical understanding of geogrid behaviour has increased particularly in the area of soil reinforcement for walls and slopes. In a number of areas theoretical explanation of the geogrid reinforcement mechanisms and what influences behaviour is still to be achieved. This paper considers the papers presented at the Jubilee Symposium and seeks to identify those areas where research is required.

RESEARCH QUESTIONNAIRE

Prior to the Geogrid Jubilee symposium participants were asked to complete a Questionnaire concerning the state of knowledge and understanding of the how geogrids work and what influences their behaviour. The objective of the Questionnaire was to identify those areas where lack of knowledge could be addressed by future research. Sixty two participants of the Jubilee Symposium responded, the majority of the responses being from the research sector or individuals involved in design, Fig. 1. However, there were a reasonable proportion of replies from End Users and Specifiers and inspection of Fig.1 suggests that the replies can be considered to be representative of the Geosynthetics Industry and users of geogrid reinforcement.

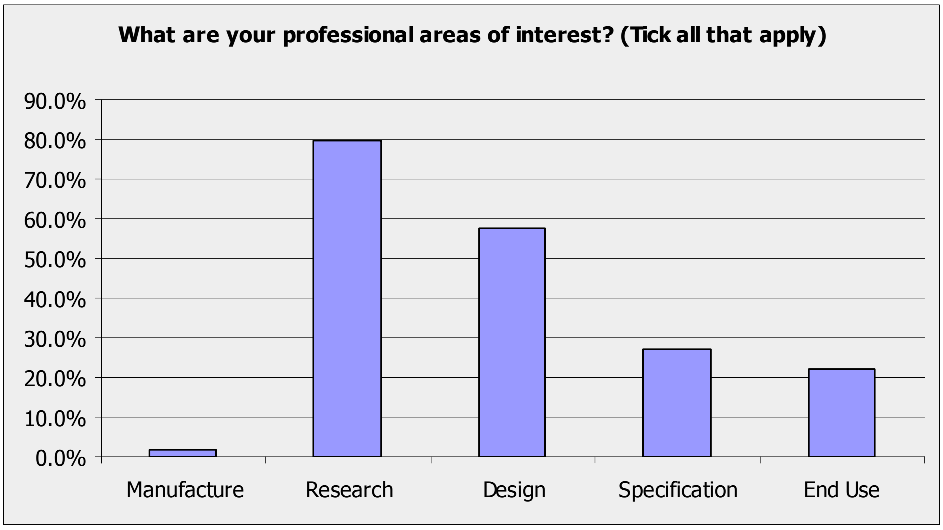

Figure 1. Areas of interest of those completing the questionnaire

The questionnaire included 26 questions. Some covered specific technical issues, others were associated with applications and the experience of the respondents. The responses provide a valuable (unique) snap-shop of the state of knowledge of geogrids, how they work and their uses. The responses clearly illustrate that there is need for focused research to resolve some clearly defined areas where knowledge is lacking. In many areas the responses suggest that knowledge is fragmented with diverse views being held. Only in a few areas is there uniformity of agreement.

The results of the pre-symposium questionnaire relating specifically to knowledge of geogrid behaviour and the factors influencing their performance are shown in Appendix A.

Six questions were particularly relevant to the mechanics and behaviour of geogrids. These and the responses are considered below.

Mechanics of geogrid interaction

Geogrids work by interacting with the soil or fill in which they are placed or embedded. Three mechanisms have been identified; surface friction, interlock and dynamic interlock, Fig. 2. Inspection of Fig. 2 shows that the mechanism of surface friction in developing geogrid interaction is well understood but that the concept of dynamic interlock is little appreciated.

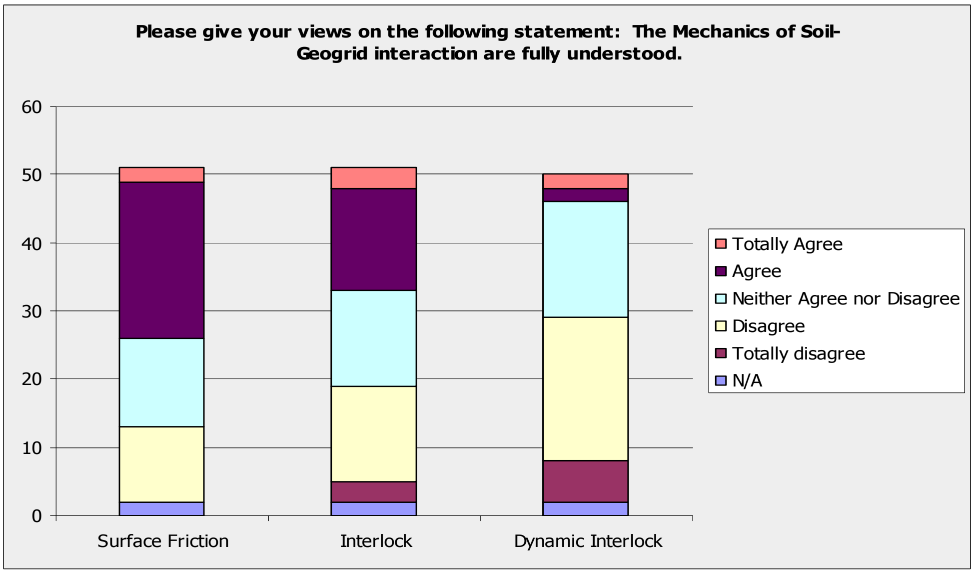

Figure 2. The mechanics of soil-geogrid interaction

Influence of compaction

Geogrid interaction is dependent on the degree of compaction of the fill or soil which has a critical influence on both surface friction and also interlock. Figure 3 indicates that few believe that the influence is fully understood.

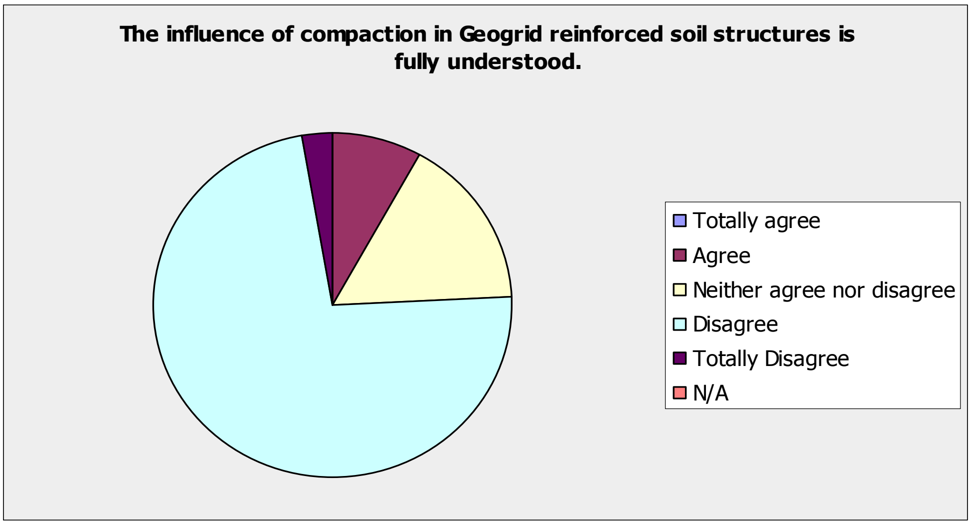

Figure 3. Influence of compaction on geogrid-reinforced soil structure

Relevance of current theories

There is strong evidence in the belief that current theories are inadequate and that new numerical methods are required to model composite material behaviour, Fig. 4.

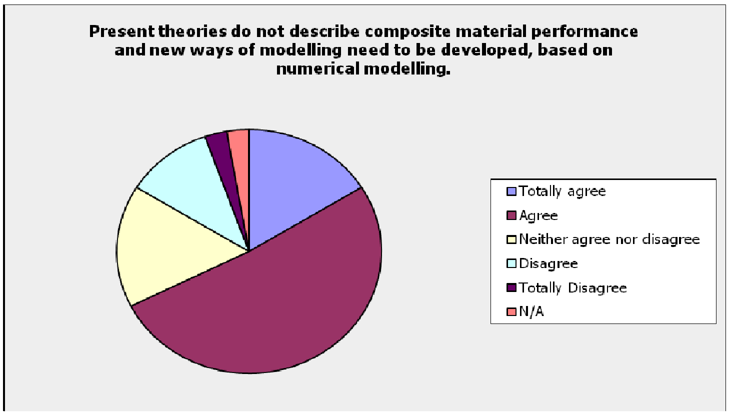

Figure 4. Relevance of current theories used to describe composite material performance

Influence of construction methods on geogrid performance

Inspection of Fig. 5 suggests that construction methods and construction technology play an important influence on the performance of geogrid reinforced structures.

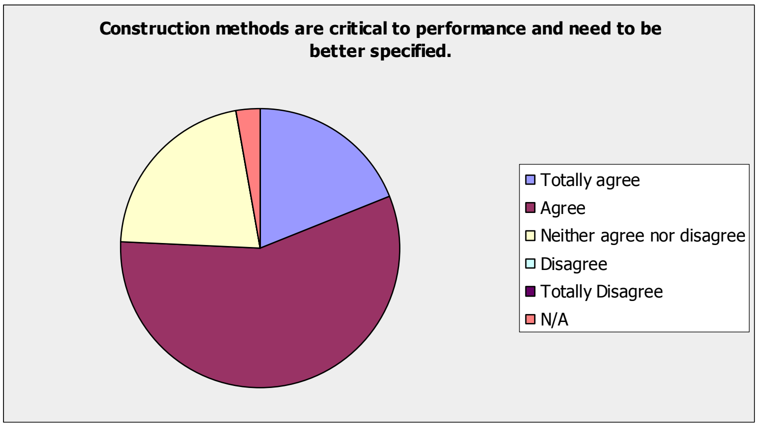

Figure 5. Relevance of construction methods

Role of drainage in reinforced soil structures

The greatest agreement from the questionnaire related to the importance of drainage in reinforced soil structures, although there were some who totally disagreed that drainage was important, Fig.6.

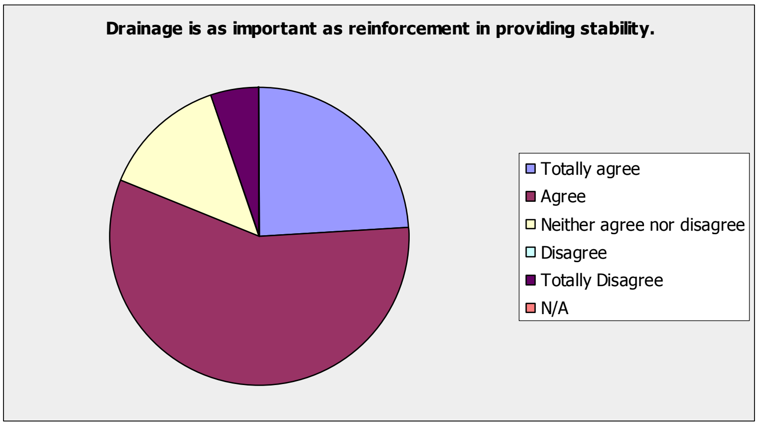

Figure 6. Importance of drainage in reinforced soil structures

Nature and quality of fill

Although the first use of geogrids reported at the 1984 Symposium was with poor quality waste fill, a significant number of researchers and practitioners currently believe that good quality fill is required when using geogrid reinforcement, Fig.7.

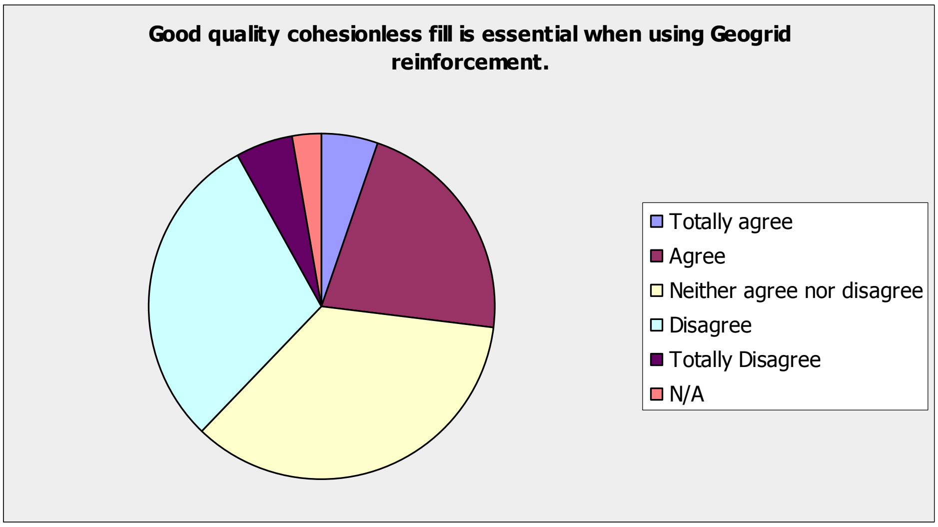

Figure 7. Importance of the quality of fill in reinforced structures

RESEARCH PAPERS

A main part of the symposium was devoted to identifying and discussing research needs. Ten eminent researchers were asked to identify what they considered to be primary research requirements covering; unpaved roads, paved roads/highways, railways, walls and slopes. Consideration of their papers show that the identified research to be heavily influenced by the assumed state of understanding (empirical and theoretical) in the different application areas which has been developed over the last 25 years since the initial geogrid symposium in 1984.

In the case of unpaved and paved roads it is apparent that current understanding and design is still largely empirical in nature. Recent advances in knowledge associated with the use of geogrids in improving the performance of railway ballast suggests that theoretical understanding has caught up with empirical knowledge. Only in the case of reinforced soil is theoretical understanding in advance of empirical knowledge, the cross over occurring at the time of IS Kyushu Reinforced Soil Conference (Japan) in 1996 and the publication of BS 8006 in 1995, Fig. 8.

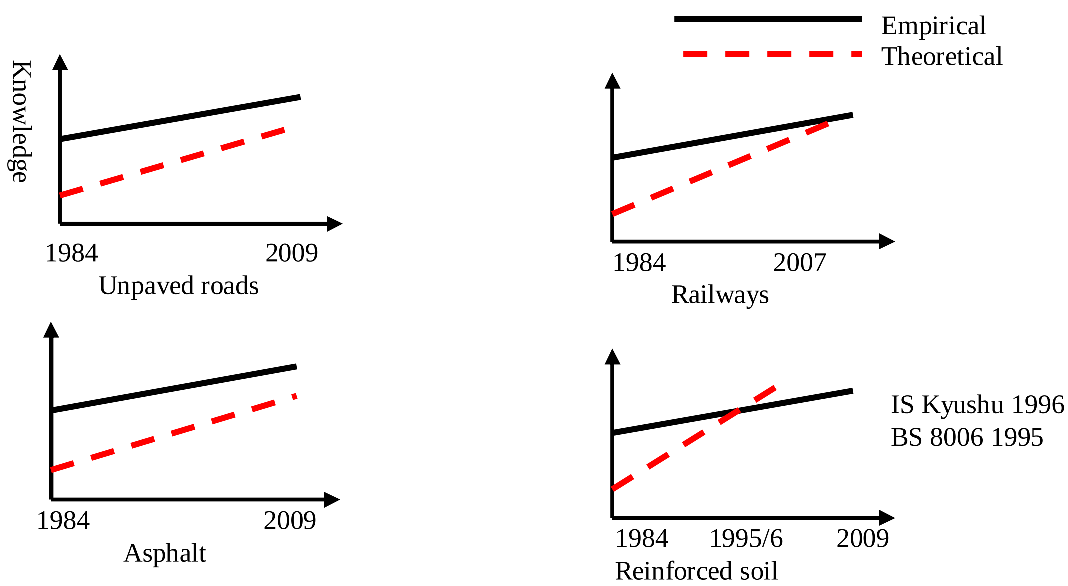

Figure 8. Empirical and theoretical knowledge associated with geogrid applications

Unpaved roads

Three papers to the symposium considered the research needs associated with unpaved roads. These were presented by Giroud, Watts and Tutumluer *et al.*

Giroud identified four areas for future research which he classified as “subtle mechanisms”:

- Geogrid-aggregate interaction
- Parameters influencing performance
- Influence of fine particles
- Composite material

Watts restricted his research needs to those arising from accelerated pavement testing. Although a number of advanced pavement testing facilities have become available there are as yet no mathematical models available which can predict the performance of geogrid reinforced pavements. To overcome this deficiency he suggested the development of mechanistic/empirical models. He also advocates the collection of much more real life data to support the calibration of any new models.

Tulumluer *et al* described the development and advances in discrete element modelling (DEM) and in a number of ways anticipate the requirement identified by Watts for predictive methods. A major advantage of the DEM method is to provide the ability to explore “what if” scenarios.

Railways and paved roads

Four papers at the Symposium considered paved roads or railways.

Brown and Thom point out that, to date, asphalt (paved roads) research has been essentially experimental. Research that is now required includes:

- Improved modelling of basic mechanisms
- Understanding the zone of influence of reinforcement
- Development of a new design philosophy (based on the concept of a composite material?)
- Development of field installation techniques
- Laboratory methods to determine the properties of different materials
- Can the recent advance in the optimization of railway ballast reinforcement be applied to roads?
- Couple field results with theoretical studies using DEM.

Reck argues that geogrid performance in both flexible and rigid pavement structures can only be described by the use of either shift factors or complicated numerical analysis. Based on these two extremes he advocates the following research needs:

- Develop subgrade transfer functions for each geogrid family with the aid of accelerated testing methods
- Develop an empirical model to account for the retained stiffness benefit on surrounding materials for each geogrid family
- Develop current field testing equipment to enable the benefit of geogrid reinforcement families to be captured
- Develop an accelerated testing programme to compare geogrid families from which transfer functions can be developed
- Develop a long term pavement performance testing protocol to permit the performance of different geogrid families to be validated and the calibration of transfer functions
- Develop a test method that can be used to compare geogrids within a family (but not between families)

Reck considers that accelerated full scale testing should be used as the sole means of comparison between different geogrid families.

deBondt points out that the research effort required to make meaningful advances in understanding geogrid reinforcement in pavements is such that this can only realistically be achieved by a consortium representing Universities, Government Agencies and Industry.

Walls and slopes

The nature of the research needs for walls and slopes largely reflect the fact that the theoretical understanding of the mechanism of reinforced soil is well established. Some theoretical work is required and **Bussert** identifies three areas of study:

- Design methods to consider the concept of reinforced geogrid structures being a composite material
- Test methods to determine composite properties
- Stress flow in the reinforced stabilized system.

McGown suggests one theoretical area of research covering the application of the concept of strain energy to the interpretation of geogrid behaviour. However, he argues that the main focus for future research should be of a more practical/professional nature and should be devoted to:

- Quantification of partial factors used in design
- Use of natural soils and waste as fill (innovative soil improvement/dewatering required)
- Numerical modelling for performance assessment
- Influence of construction techniques on performance
- Concentrate on the environmental benefits of reinforced soil.

Corbet supports McGown in concentrating on practical issues, he advocates research covering:

- Full integration of reinforced soil design methods with EN 1997-1
- Use of displacement or finite element methods as routine design tools
- Prediction of reinforcement stresses resulting from the construction process.

POST SYMPOSIUM QUESTIONNAIRE

In order to close the loop on research needs, it was decided to repeat the questionnaire after the Jubilee symposium to see if the symposium had changed or modified opinions regarding the state of knowledge and research needs. The response to the post symposium questionnaire was modest and thus cannot be considered truly representative but nevertheless is interesting. In some areas there is a clear change in the responses, mostly recording a hardening of opinion and polarization of apparent understanding.

Mechanics of geogrid interaction

The responses to the post Jubilee questionnaire showed that there had been a major change in opinion regarding the level of understanding of soil-geogrid interaction, Figure 9. Comparison of Figures 2 and 9 suggests that soil-geogrid interaction is an area where research is clearly required. The concept of dynamic interlock is clearly not understood and significant study of geogrid interaction is still required.

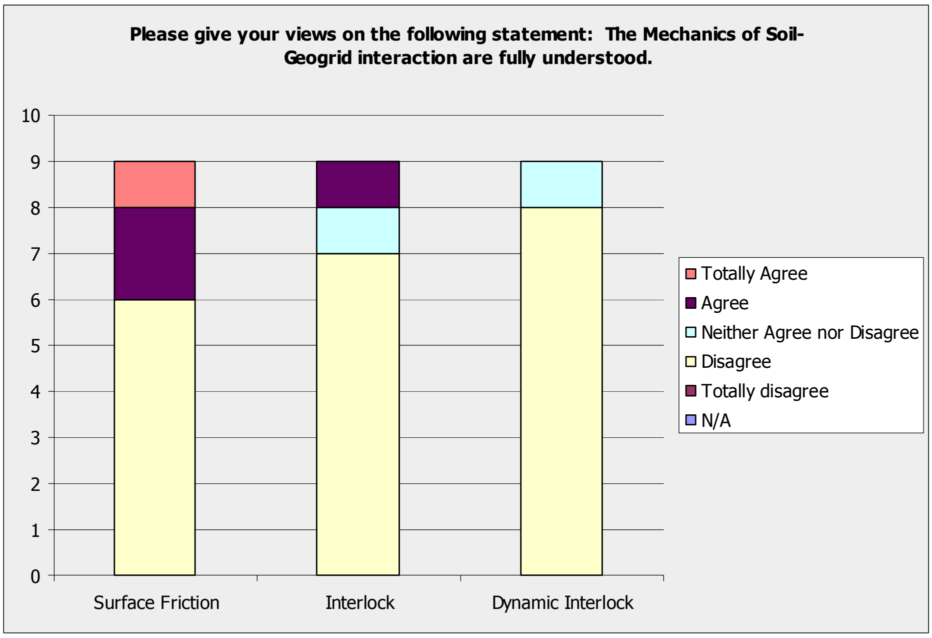

Figure 9. The mechanics of soil-geogrid interaction (post Symposium)

Influence of compaction

Comparison of Figure 3 and 10 indicates that the Jubilee symposium had little influence on opinion concerning the relevance of compaction on the performance of geogrid structures.

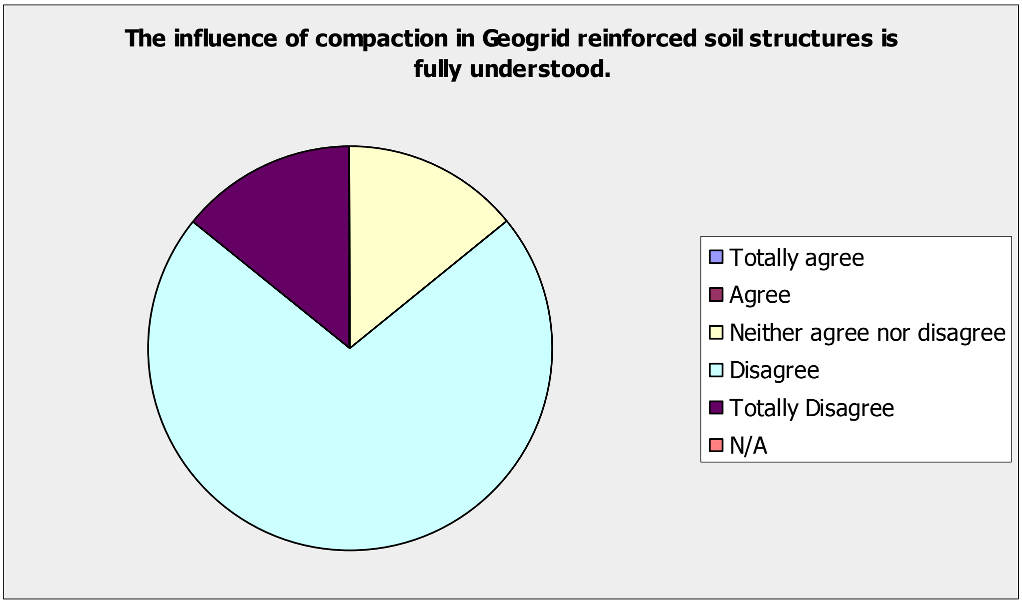

Figure 10. Influence of compaction on geogrid-reinforced soil structures (post Symposium)

Relevance of current theories

The Jubilee symposium resulted in a clear hardening of opinion that present theories do not describe composite material performance and that new ways of modelling need to be developed.

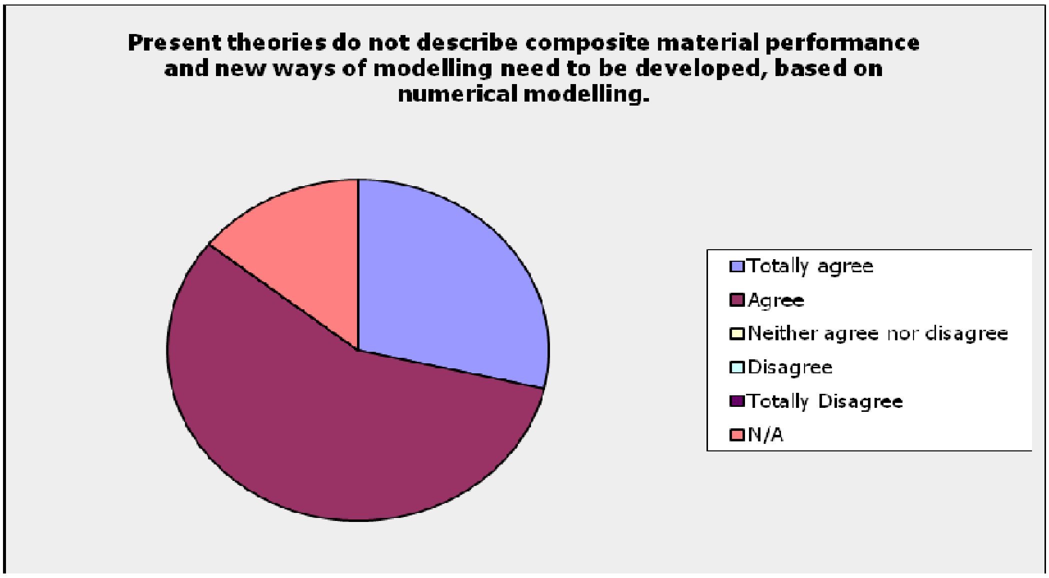

Figure 11. Relevance of current theories used to describe composite material performance (post symposium)

Influence of construction methods on geogrid performance

A marked change of opinion was recorded relating to construction methods and their role in geogrid reinforcement performance. The post Jubilee symposium responses were 100% in agreement that improved specifications are required.

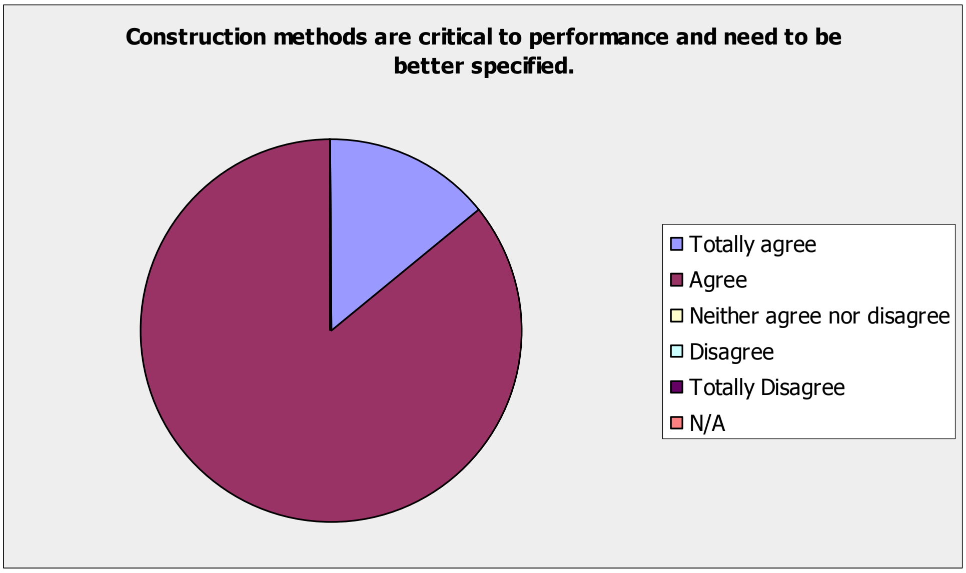

Figure 12. Relevance of construction methods (post Symposium)

Role of drainage in reinforced soil structures

As with the responses to the question on construction methods, opinion regarding the role and importance of drainage in reinforced soil showed a significant shift in opinion with 100% agreeing that drainage was critical.

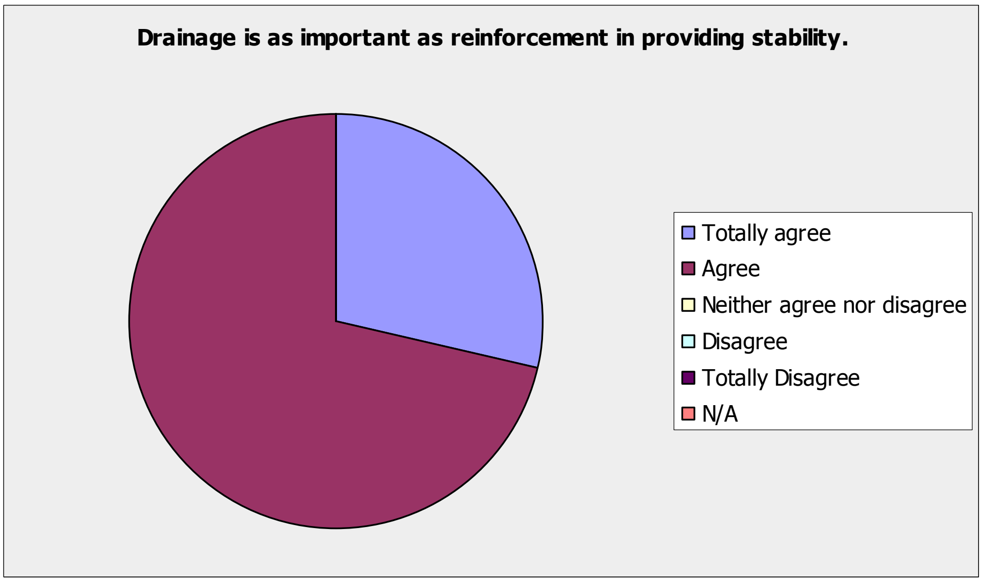

Figure 13. Importance of drainage in reinforced soil structures (post Symposium)

Nature and quality of fill

Interestingly the number agreeing that good quality fill is a requirement for geogrid reinforced structures did not change. However those implying that poor quality fill could be used increased.

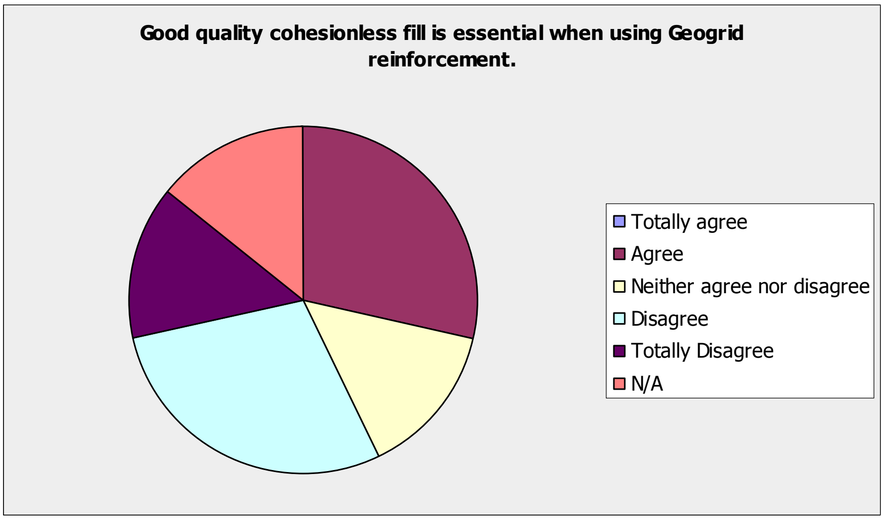

Figure 14. Importance of the quality of fill in reinforced structures (post Symposium)

Creep

The most dramatic change in opinion pre and post Symposium related to creep. Pre the Jubilee Symposium, the majority did not believed geogrid creep to be a major problem. Post the Symposium the majority considered that creep induces continuing deformations in geogrid reinforced structures and is a major problem in practice. (This is a surprising result and may be the result of a small sample).

DISCUSSION

The research papers presented at the Jubilee symposium identify areas of future research which are seen to be largely in agreement with the implied research needs from the questionnaire. One glaring difference is that, with the exception of McGown, no mention was made by any of the experts of the role/importance of drainage on the performance of geogrid reinforcement in any application. This is in direct disagreement with the replies to the Questionnaires, Figures 6 and 13.

As comprehensive theoretical understanding of the mechanism of geogrid reinforcement in unpaved and paved roads (and to an extent in railways) is still required the future research effort in these areas is still likely to be associated with fundamental systems. This is not so with walls and slopes where essentially new areas of research are possible. In particular the benefits to be obtained by the use of waste materials or poor quality fill has the potential of offering significant economic benefit. It is interesting to note that the fills used in the first geogrid reinforced soil structures reported in the initial 1984 geogrid symposium was industrial waste in the form of mine stone and pulverized fuel ash. The latter was used on Dewsbury Bypass and was the first use of geogrid reinforcement in permanent highway structures producing a saving on the overall cost of the whole scheme of 46 per cent. The ability of geogrids to be used with waste materials appears to have been forgotten by many researchers and practitioners. The introduction of electrokinetic geosynthetics (EKG) has demonstrated that it is possible to use ultra poor (liquid) fill in the construction of vertical reinforced soil structures, Hamir *et al* (2001), Jones and Pugh, (2001), Glendinning *et al* (2005). It is not widely appreciated that the first practical form of EKG was an electrically conductive geogrid.

The technical benefits of geogrid reinforcement have been demonstrated in numerous applications across the world. The economic benefit from the use of geogrid reinforcement is also well established, but little consideration is given to the environmental benefits which these materials offer. The environmental benefit of using reinforced soil rather than conventional reinforced concrete in the construction of retaining structures has been illustrated in Jones (1996) and Hong Kong Geoguide 6 (2002). The Hong Kong case compared the embodied energy (EE) of the construction materials used were embodied energy is defined as “the energy used to extract and transport raw materials, refine and manufacture them, package, deliver and install them on site”.

Table 1 shows the (EE) associated with the construction materials of reinforced soil and reinforced concrete structures. Figure 10 shows the difference in Embodied Energy between reinforced soil (RS) and reinforced concrete (RC) for a range of wall heights. Similar comparisons can be made regarding the carbon footprint in terms of embodied tCO_2 per tonne of material of the two types of structure. This could be a valid area of future research as reduction in carbon footprint in the construction sector is a major environmental priority.

Table 1. Embodied energy of construction materials (After Geoguide 6 2002)

Reinforced soil wall		Reinforced concrete wall	
Concrete (ready mix)	= 1.3 GJ/ton	Concrete (precast)	= 2.0 GJ/ton
Steel	= 32.0 GJ/ton	Steel (galvanized)	= 35.0 GJ/ton
Fill	Nil	Fill	= 0.2 GJ/ton
Formwork	= 19.0 GJ/ton		

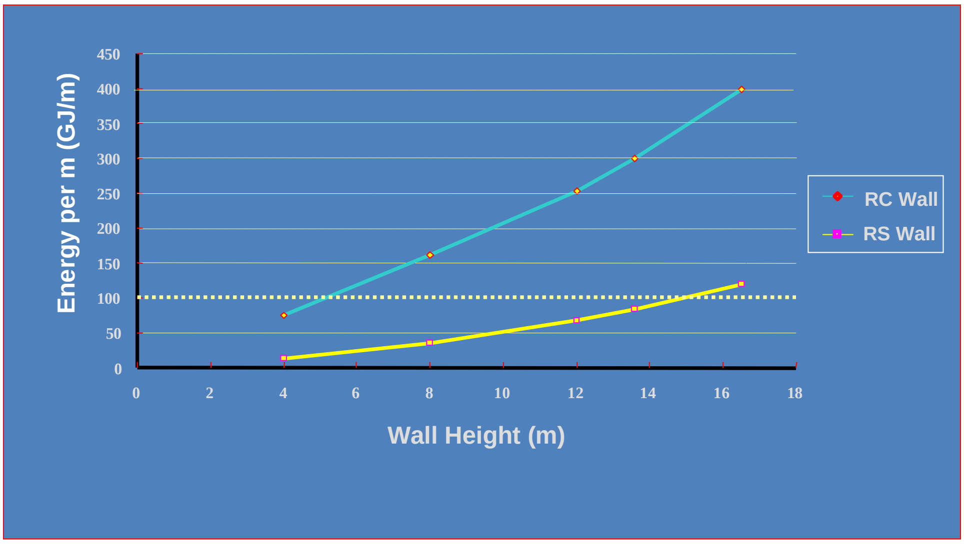

Figure 10. Comparison of the embodied energy of reinforced soil v reinforced concrete walls (After Geoguide 6, 2002)

RESEARCH STRUCTURES

When undertaking new research it is important to consider the structure and form of the research team. Some subjects are suitable for consideration/research undertaken by a single Agency or University. An example of this could be the development of design models for specific applications.
Some areas of research can only be undertaken with the close involvement of an end user, essentially a user champion. Research of this nature usually requires access to full scale highway or rail structures.
There are some research areas which can only be undertaken by a research consortium representing all parties having a vested interest. This was the format of the research team which led to the introduction of geogrid reinforcement announced at the initial Geogrid symposium in 1984. In 1984 the research team consisted of an international consortium made up of; manufacture/universities/government agency/consultants/end user. When considering the current research requirements it appears that a consortium approach would be needed to progress development in the use of geogrids in paved and unpaved roads to the logical conclusion.

CONCLUSIONS

The development of geogrid reinforcement has been a spectacular success resulting in major economic and technical benefits in the construction industry. However, the full potential of geogrid applications has not yet been realized and additional research to widen the applications and usage of geogrids is required. Some of this research needs the approach of the original EPSRC (SRC) consortium.

A number of common themes for future research can be identified, these are:

- Understanding geogrid-aggregate interaction
- The concept of geogrid reinforced soil being a composite material
- The development of numerical models
- The need for real life data from geogrid applications
- The development and understanding of the influence of construction technology
- The development of new testing methods

To these it is possible to add:

- Environmental benefit of geogrid usage
- Use of natural soil and waste materials as fill
- Development of new innovative geogrids

In addition, there are major possibilities for beneficial application of geogrid technology in areas other than the construction industry including:

- Waste treatment and minimization (Mining and Water engineering)
- Composting (Water engineering)
- Horticulture (Agricultural engineering)

Development of geogrid technology in these application areas will require a complete range of research studies.

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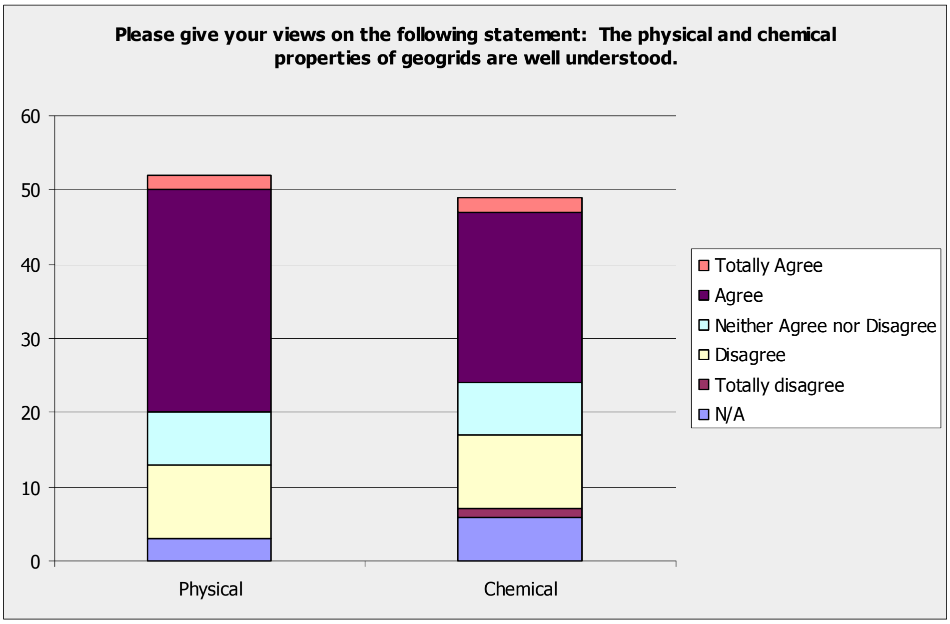
In Landmarks in Earth Reinforcement, Eds. Ochiai *et al*, 1, 219-223, Swets & Zeittinger

APPENDIX A

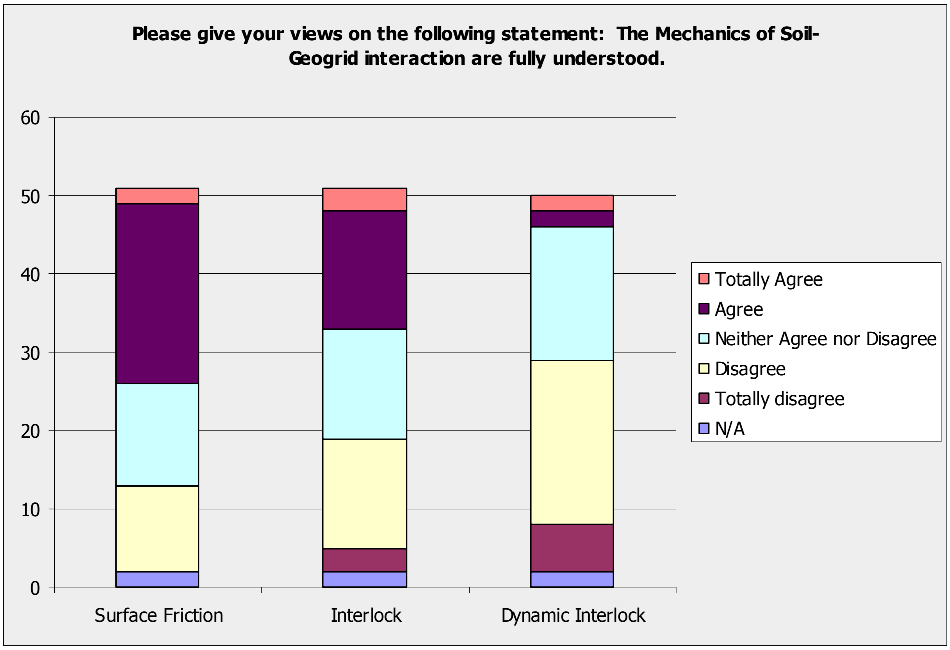
RESPONSES TO THE PRE JUBILEE SYMPOSIUM RESEARCH QUESTIONNAIRE

Those questions relating to the understanding of geogrid reinforcement behaviour are provided below.

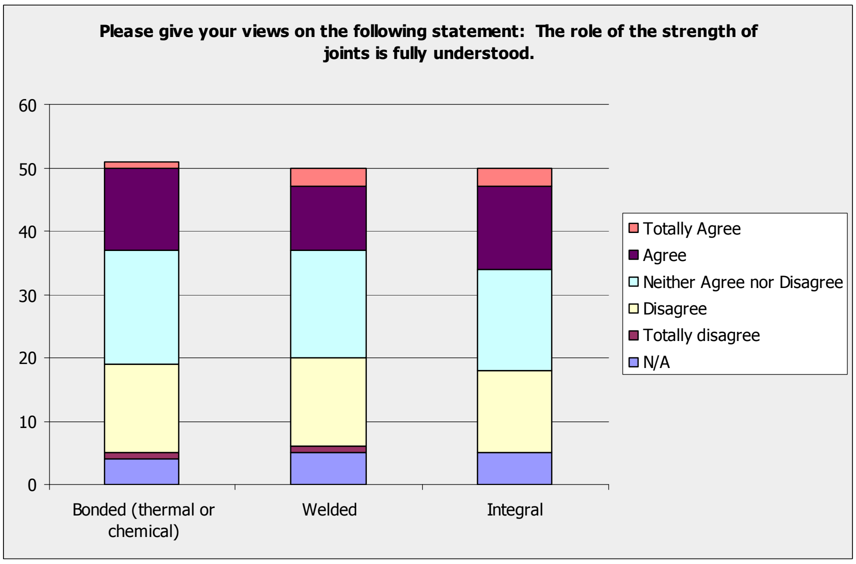
Q1. Chemical and Physical properties



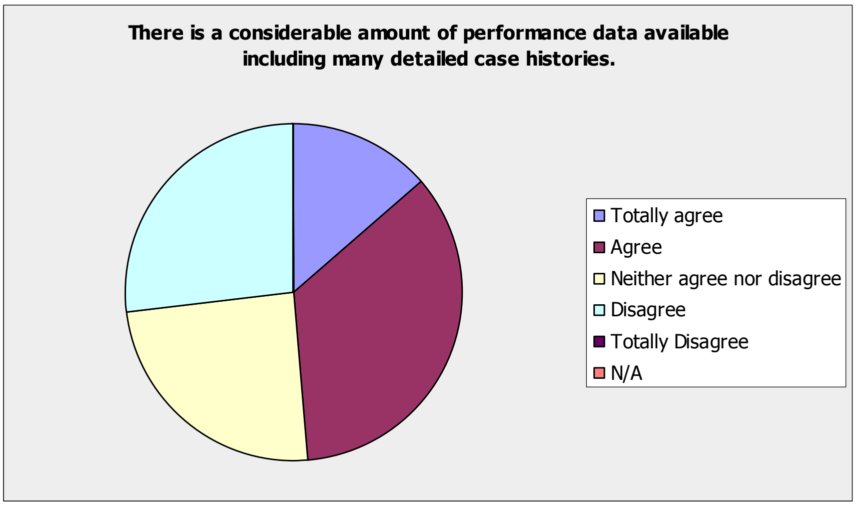
Q2. Mechanics of soil-geogrid interaction



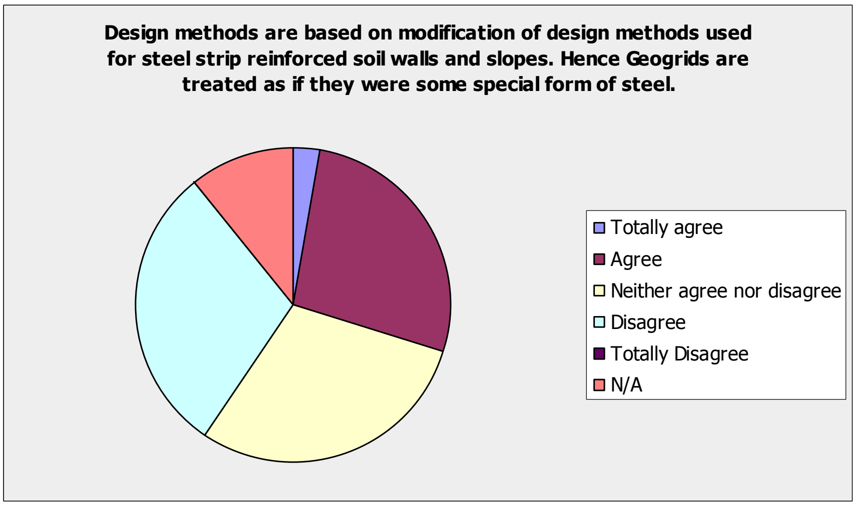
Q3. Role of junction strength



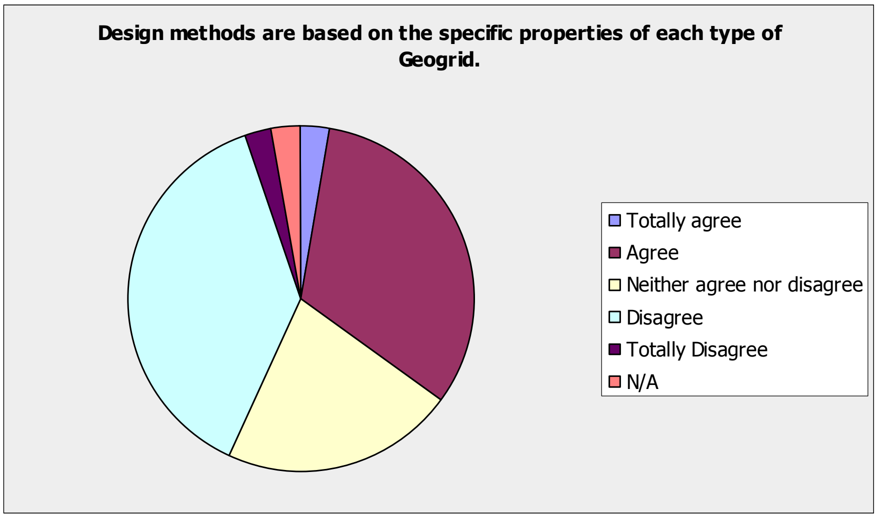
Q4. Availability of Case History data



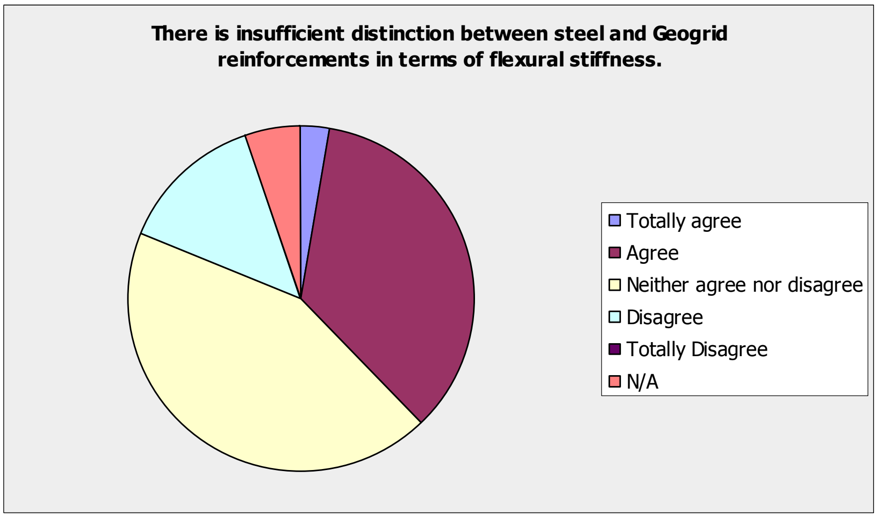
Q5. Design methods (geogrids considered as a form of steel reinforcement)



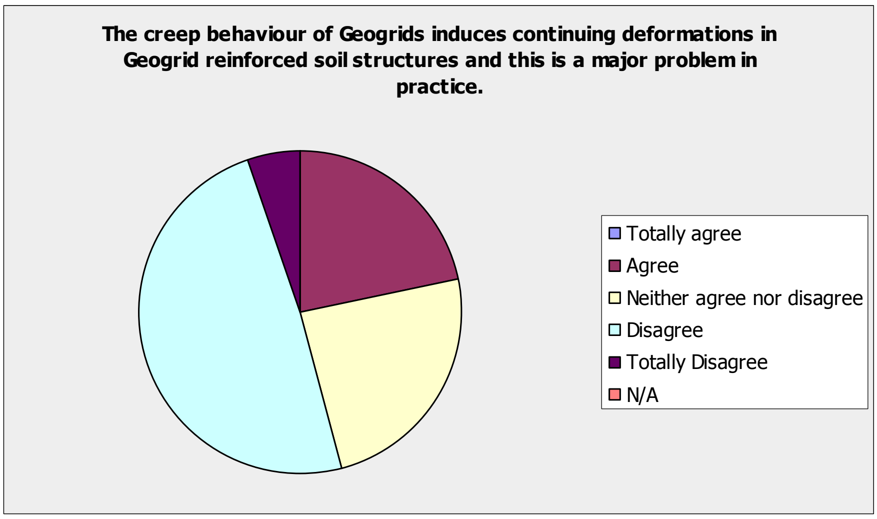
Q6. Design methods and geogrid properties



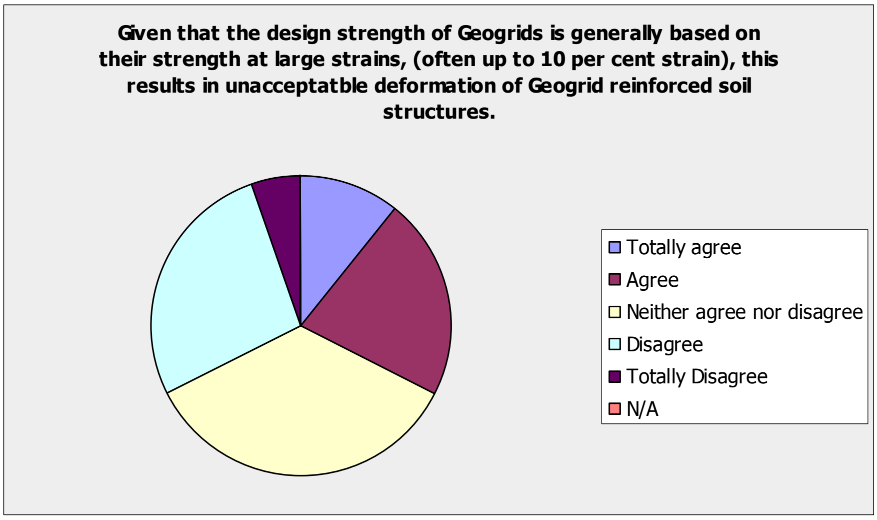
Q7. Relevance of flexural stiffness



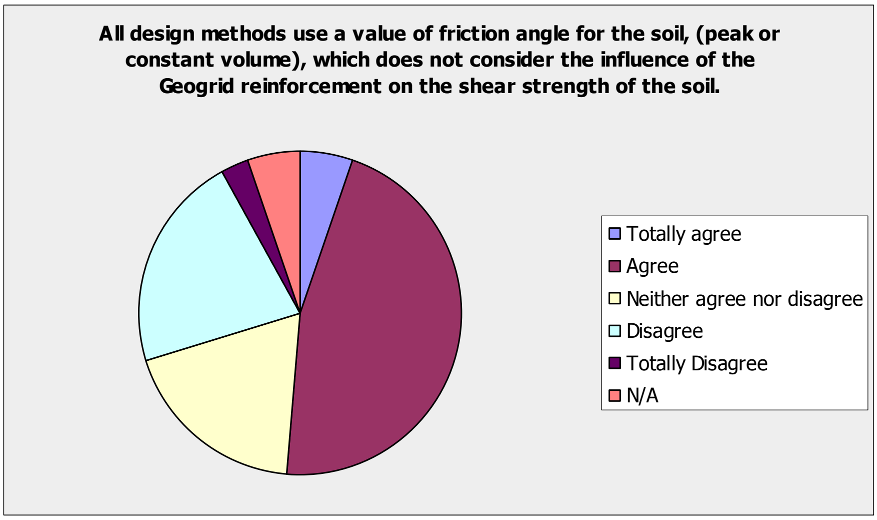
Q8. Influence of creep on performance



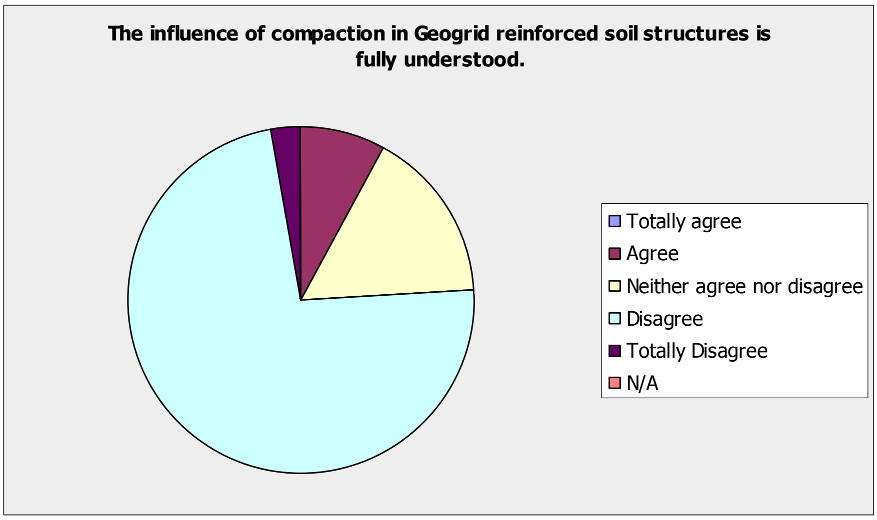
Q9. Deformation of geogrid reinforced structures



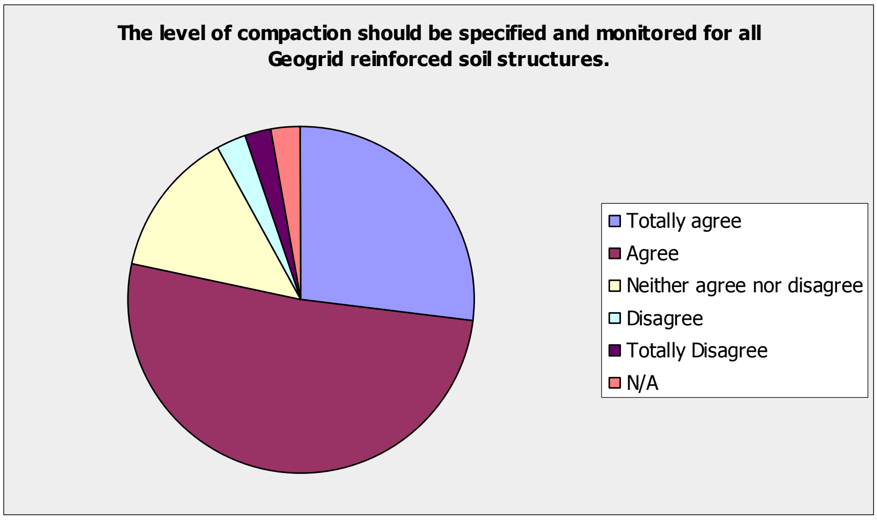
Q10. Design methods – influence of geogrid reinforcement on shear strength



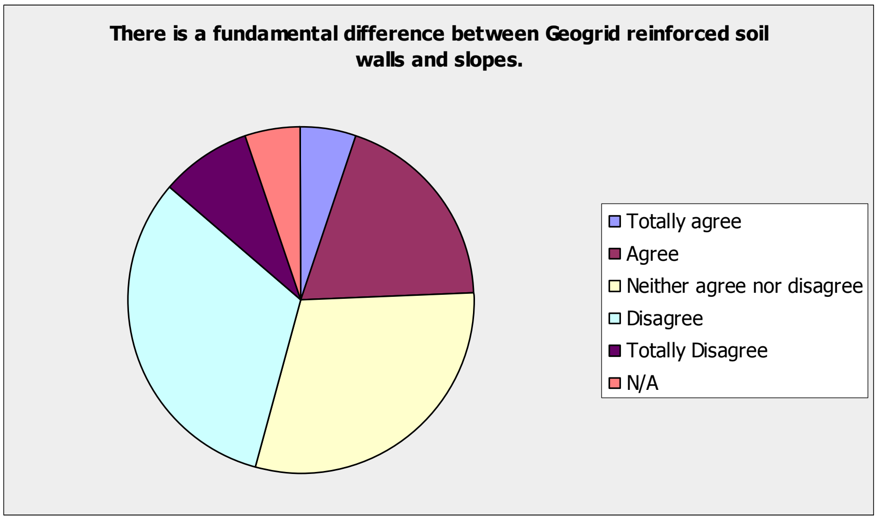
Q11. Importance/influence of compaction



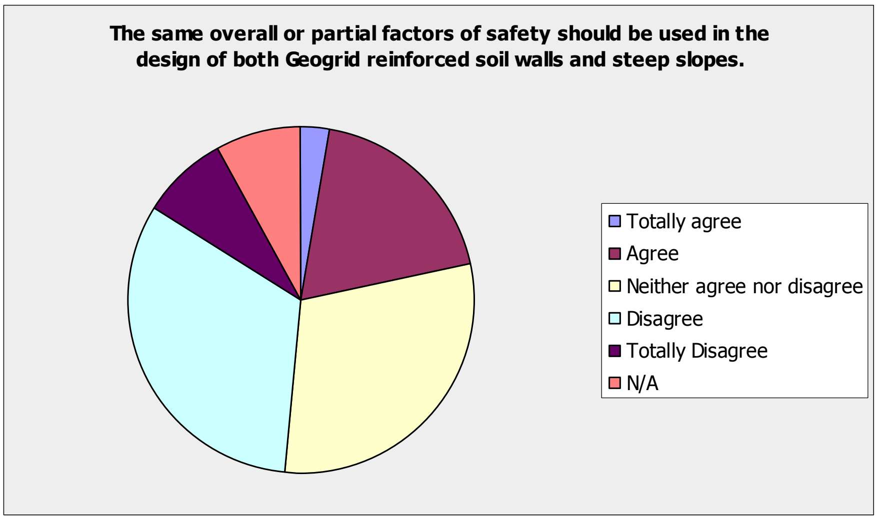
Q12. Specification of compactions



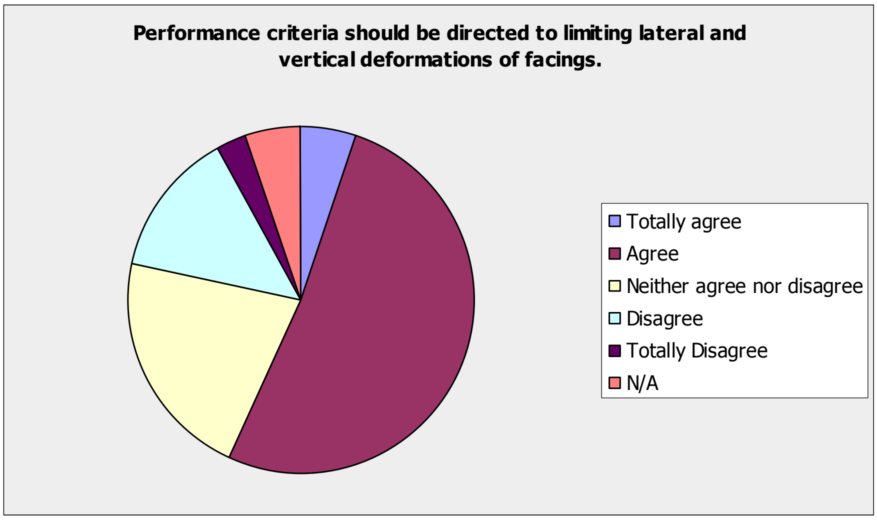
Q13. Difference between geogrid slopes and walls



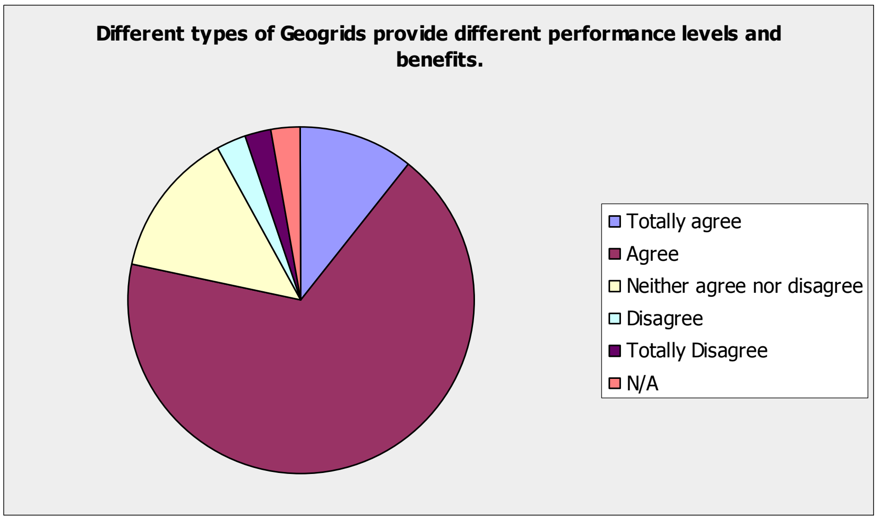
Q14. Partial factors for geogrid reinforced slopes and walls



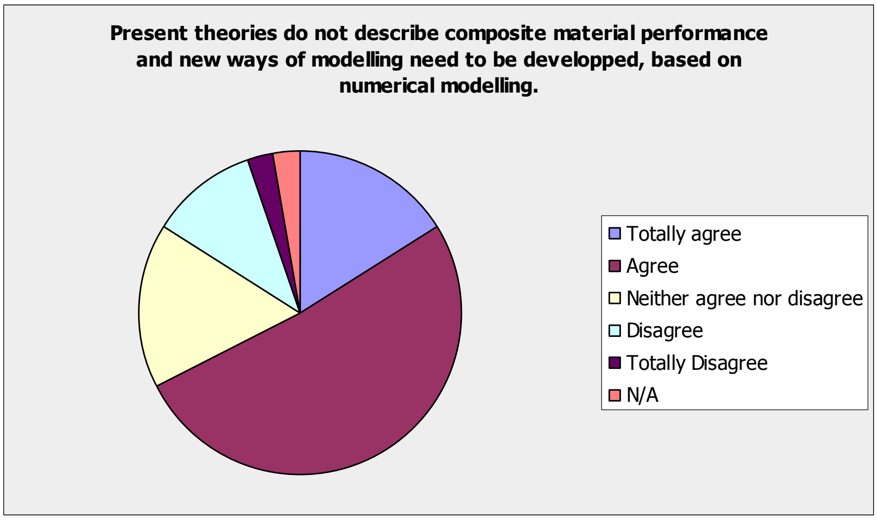
Q15. Limiting performance criteria for geogrid reinforced walls



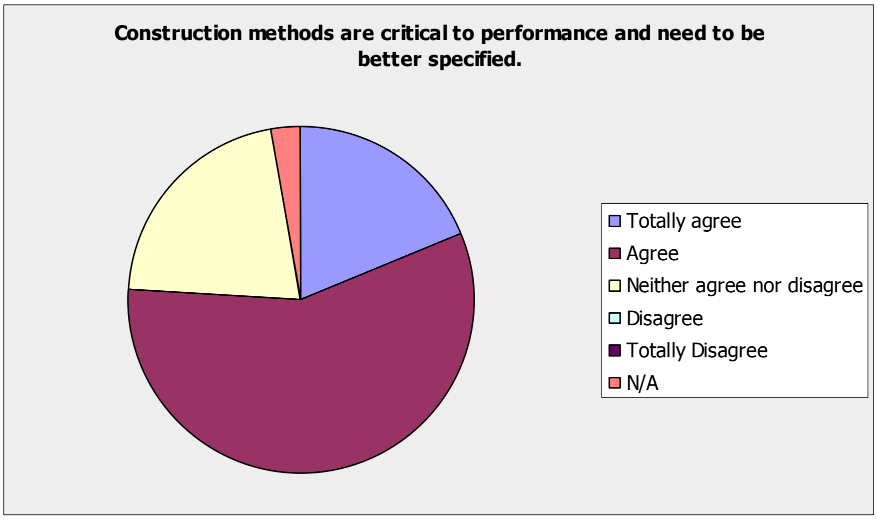
Q16. Different types of geogrids and performance



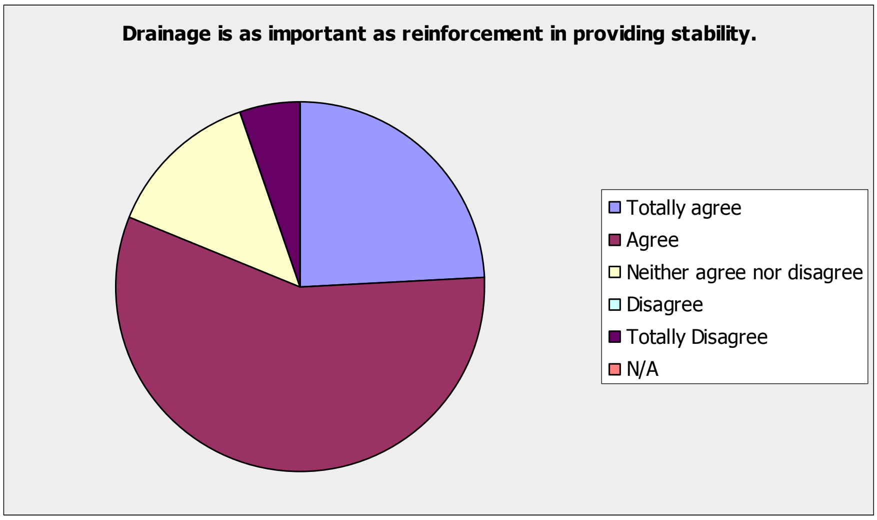
Q17. Design theories and composite material behaviour



Q18. Specification of construction materials



Q19. Importance of drainage in providing stability



Q20. Importance of fill quality