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Benefits of Case Based Instruction in Undergraduate Geotechnical Education

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BENEFITS OF CASE BASED INSTRUCTION IN UNDERGRADUATE GEOTECHNICAL EDUCATION

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ABSTRACT

The staged incorporation of appropriate case histories is one of the tools utilised at the University of Limerick to educate construction management & engineering students. This paper presents the author's experience of introducing case histories in the first year of the four-year Bachelors Degree programme and the subsequent adoption of a case-based instruction approach on an introductory module in geology and soil mechanics. A post-module student survey indicates increased enthusiasm for the subject matter and a clear understanding of how key geotechnical concepts such as compaction theory and bearing capacity influence construction projects. This is a valuable module outcome for second year students about to embark on an eight month period of mentored work experience.

INTRODUCTION

In 2005 the University of Limerick introduced a new programme from the built environment; an honours degree in construction management & engineering (CM&E). The writing of new modules for this programme provided an opportunity for a blended approach to teaching; techniques such as problem based learning, technology enhanced learning, fieldwork, class debates, technical presentations and case-based instruction are employed on the programme. In this paper, the experience of teaching through case histories is described. The author was prompted to use this approach after reading Kaminetzky's Design and Construction Failures (Kaminetzky, 1991); the concise reporting of construction failures and the sage advice offered at the end of each case history was appealing. Moreover, the format of the material presented allows it to be covered in a fifty-minute lecture. The vast and varied array of cases provides the inexperienced undergraduate with an insight into the many pitfalls that exist in the construction industry.

The writer believes that case based instruction is particularly helpful in unifying theory and practice in an applied discipline like geotechnical engineering. In addition to drawing from his experience, the writer draws from a database of literature available on the World Wide Web (www) and published texts such as Levy & Salvadori (1992), Shepherd & Frost (1995), Ross (1984), Wearne (1999) and Feld & Carper (1997) while Day (1998) and Fleming (2000) provide an excellent source of geotechnical case histories. In particular, the writings of Peck (1962a, 1962b) and Burland (1989) have been particularly inspirational, the philosophy permeating these seminal papers form an integral part in the design of new modules in the area of geotechnical engineering.

In this paper the writer describes how a case based approach is introduced in the first year of the CM&E programme and how it is extended into subsequent years through modules in geotechnics. In addition to cultivating an ethos of 'engineering curiosity,' the approach also fosters improved communication ability by developing the student's written and verbal skills through project work and formal class debates. Abridged versions of two case histories from the writer's experience are presented as examples of how case based instruction can be delivered to students of the built environment.

THE INTRODUCTION OF CASE HISTORIES

In first year, CM&E students take a Problem Based Learning (PBL) module known as Design Studio (Phillips, 2007). The module is 100% continually assessed, 85% of which is divided between two team-based assignments, the remaining 15% is for a peer assessed report and presentation on a famous engineer, structure or engineering failure. This exercise is the students' first introduction to case histories.

At the outset, the type and form that the presentation should take is outlined. A sample case history drawn from well-documented geotechnical failures from personal or secondary sources is then presented. The case is presented using Burland's Soil Mechanics Triangle (Fig. 1) as the reference framework for the geotechnical design process and for demonstrating the interplay that exists between the core areas of the discipline. It also provides an opportunity to introduce the significant role played by empiricism and experience in the practice of geotechnical engineering.

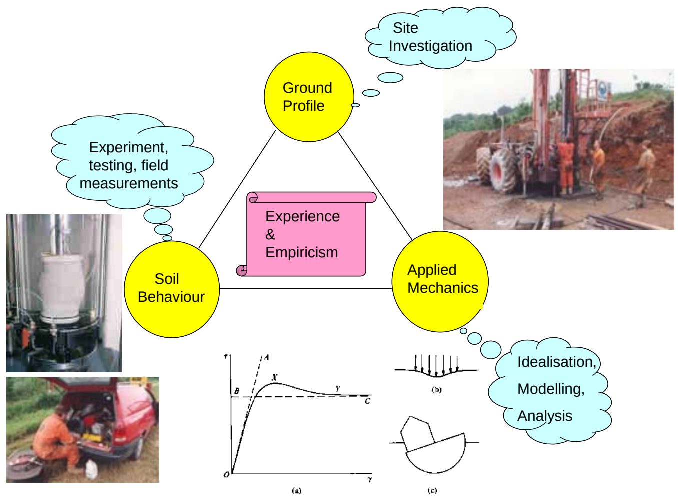

Fig. 1. Modified from Burland's soil mechanics triangle (Burland, 1989)

Guidance on communication skills is also provided and students are referred to reference material on preparing technical presentations; the guides published by Goodlad (1996) and the Institution of Engineers of Ireland (1994) are particularly useful.

Experience has shown that unless boundaries are rigidly set for the report element of the exercise, submissions generally lack clarity, become voluminous and tend to be an amalgam of information gathered from various web sites. To guard against this 'cut and paste' approach, the report is limited to a one-page submission, thereby encouraging the students to concisely summarise the salient points and lessons learned - this restriction often causes anguish amongst students as they struggle to reduce so much information into one short page.

As the students are encountering independent research for the first time they are given a detailed brief, part of which is reproduced in Fig. 2. It presents the learning objectives of the exercise and measurable learning outcomes to be accomplished at the end of the exercise.

For many, it is also the first time they have had to stand up and make a presentation in public so, to ease the stress associated with this task; a relaxed and non-threatening studio environment is promoted during the initial week of the module. Rapport within the group is developed by undertaking fun group activities such as a 'race' to build a model bridges from the K'NEX Structures series.

In the subsequent weeks, the students are encouraged to make entertaining and engaging presentations designed to inspire their colleagues about their chosen subject. Their peers, using the scoring sheet shown in Fig.3 assess the presentation under the headings provided.

UNIVERSITY of LIMERICK
OLLSCOIL LUIMNIGH

WT4202: Design Studio

ASSIGNMENT No. 1: Great Engineering Structures & Some Less Fortunate!

PURPOSE
To provide an opportunity to learn about great engineering structures and how, sometimes, things go wrong!

LEARNING OBJECTIVES

- To introduce the student to the research tools available for undertaking projects and work assignments e.g. library books, magazines, journals, video/cd, Internet, databases etc.
- To develop the skill of reading sources of reference and concisely summarising research findings
- To develop professional reporting skills including report format and referencing material.
- To encourage the development of good presentation skills

LEARNING OUTCOMES
At the end of this assignment you should be able to:

1. Undertake a desk based research exercise using the resources available at the University
2. Document a selected engineering topic in a concise professional report
3. Present the findings of your research to a peer group
4. Reference your research sources using the Harvard method

BRIEF
You are required to research an engineering topic of your choice and hence prepare a **ONE PAGE** summary of your findings **plus** a page of photographs, sketches or diagrams as necessary (i.e. report to be a maximum of two pages). Suggested topics of research include fascinating structures or engineers of our time, catastrophic building failures or any topic of general interest to the construction industry.

The report should include a brief introduction to the topic, the research methodology employed, main findings and the lessons learned. All reference sources e.g. books; Internet sites, journal articles etc. must be referenced at the end of the report. It is…………….

Fig. 2. Part Project Brief

Presenter	Imparts knowledge (Ex. 25)	Engaging Presentation (Ex 25)	Visual Aids (Ex 25)	Communication Skill (Ex 25)

Fig. 3. Peer scoring sheet for presentation

Despite the nervousness at the outset, post-module feedback indicates an overwhelming endorsement of the exercise and a sense of accomplishment having participated in delivering a presentation to their peers. An incidental benefit of attending and participating in colleagues' presentations is that each class member is exposed to 20+ cases ranging from catastrophic building collapses to the elegant and inspiring designs of engineer and architect Santiago Calatrava.

With the seeds of case based research planted, the students have taken the first steps in 'learning to learn.' The necessity of fostering such 'future proofing' skills in engineers is echoed in ASCE's vision for the civil engineer in 2025 (ASCE, 2007).

In the second year of the programme the case based approach extends to a module on geology and soil mechanics. By way of example, two case histories are presented to illustrate how such studies are integrated into the module lectures. The cases also demonstrate the value they add to the educational experience by outlining the decision-making process in engineering practice. Both cases illustrate the necessity for good communication skills and highlight important ethical issues for a career in professional practice. In regard to the former, countless building failures can be linked to poor communications, evidence of such occurrences can be traced to biblical times and the story of the Tower of Babel whose demise is directly attributed to a lack of communication skills (coupled with arrogance!). The question of ethics has always been an issue and is even more prevalent today given the propensity for ever shorter construction schedules and the associated temptation to take risks in order to honour schedule milestones.

The first case is introduced when discussing soil compaction and raises ethical issues of competence and integrity.

CASE 1: BOGUS COMPACTION RESULTS RETURN TO HAUNT CLIENT

Compaction of soils is ubiquitous in the construction industry, projects of all magnitude; from the subbase beneath a house slab to the construction of a massive earth structure like the Aswan dam, has effectively ensured its place on every introductory module in soil mechanics.

This case describes the construction of a large industrial warehouse. The single storey steel framed structure is used to store household electrical products using a narrow-aisled arrangement of tall storage racks. The warehouse floor has a 150mm concrete slab-on-grade comprising some 18,581m^2 (200,000 square feet) designed to accommodate 7m high storage racks. Materials stored on the racks are accessed by computer-controlled forklifts. An electronic guidance wire, embedded near the surface of the slab and along the centre of the aisles, directs the forklifts to the correct location to retrieve the goods for shipping. Because of the storage rack heights and the narrow aisle widths, the slab was specified as a superflat floor with flatness (F_f) and levelness (F_l) values of 50.

The slab was constructed in strip pours with alternate strips skipped and filled in once the adjacent strips had hardened. During construction, the design-build (DB) contractor had to raise the level of the site to satisfy the floor levels specified by their design engineer. The site levels were raised using a combination of on site soils and material obtained from a nearby borrow pit. The proposed fill materials were submitted for laboratory testing and approval for use. The soils were classified and moisture-density relationships were established for controlling the earthworks operation on site. To monitor and test the fill during placement the contractor also retained the same testing agency that performed the laboratory testing.

Within two years of completion the slab-on-grade exhibited a number of defects; these included, pop-outs, transverse cracking, extensive surface crazing and tilting in a number of slab bays. The owner complained about excessive wear in the forklift wheels and feared that the deep transverse cracking was getting progressively worse and would eventually lead to fracturing of the guidance wires, an untenable situation in a warehouse operating by computer controlled equipment.

The owner sought recourse from the DB contractor by engaging in legally binding arbitration. Over the course of a year, several consulting engineers investigated the conditions at the warehouse. They issued reports on their observations and test results obtained from concrete cores and 'undisturbed' soil samples retrieved from beneath the slab using Shelby tubes. The writer's company was engaged to monitor the floor slab and offer expert opinion to the owner during the arbitration process.

Like most construction failures a myriad of factors were responsible for the rapid deterioration of the concrete slab, these included; poor finishing practices, presence of unsound aggregates, foreign matter in the concrete mix, absence of a subbase beneath the slab[1], improper placement of reinforcing steel, late cutting of control joints and poor compaction of the subsoils (Fig. 4). While each of these is an interesting study in itself, the case history presented to the students is limited to the investigation and analysis of the poor compaction of the engineered fill and secondly, the implications of these results on the slab's performance.

[1] It is acknowledged that the use of a subbase is not an essential requirement beneath a slab-on-grade but is considered good practice to incorporate the additional layer to regulate the surface, act as a capillary break between the slab and the subgrade and protect the subgrade from excessive stress.

Fig. 4. Warehouse slab exhibiting transverse cracking and popouts (painted orange for identification purposes).

Once the scene has been set, the students are briefed on the fundamentals of compaction theory and the associated laboratory and field control tests normally specified on such projects. The importance of incorporating the zero air voids (zav) line on the moisture-density relationship is also discussed, as are the different forms of compaction specification and field control methods. The sequence followed by the DB contractor from sourcing the borrow material, submitting the soil to the laboratory for approval and the tests performed as part of the approval process are also highlighted.

In the analysis of the case history, the students are given a set of field compaction results recorded during construction by the site technician. The corresponding moisture-density relationship and classification results are also provided. The students, working in teams of three, are required to analyse the data provided and form opinions on the role of the subsoil in the deterioration of the floor.

The students draw from the information delivered in the lectures and uses these data to develop a ‘feel’ for the conditions prevailing at the warehouse site. Information such as the maximum dry density and optimum moisture content are obtained in addition to the working range of moisture within which the specified degree of relative compaction can be obtained (Fig. 5.)

The influence of compaction energy is summarised in Fig. 6. The sensitivity of the moisture-density curve to changes in moisture content and the issue of overcompaction are also considered as part of the student’s investigative brief.

Once the data provided is analysed and the results plotted on the moisture-density relationship (Fig. 7), the students observe that the field dry densities reported by the technician all have moisture contents greater than the optimum moisture content and plot above the zav line (Fig. 7). Only two conclusions can be drawn from this result:

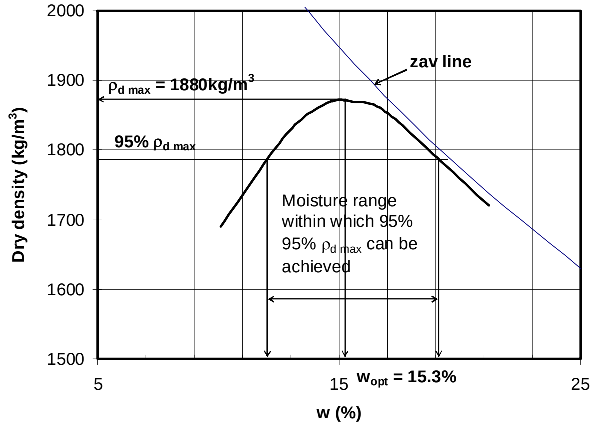

Fig. 5. Identification of critical information from the Proctor curve

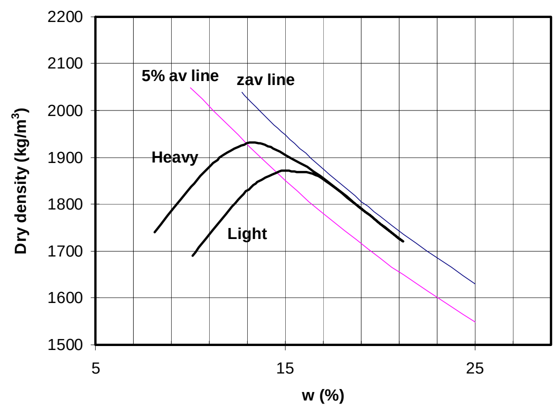

Fig. 6. Effect of compaction energy on moisture-density relationship

1. The material represented by the moisture–dry density relationship used to assess the field compaction has changed and the material being compacted needs to be submitted to the laboratory for testing, or the more sinister option

2. The technician was falsifying the results!

There can be little argument that poorly controlled fill contributed to the tilting of slabs observed in some bays of the defective floor. The student’s are left to ponder on these outcomes in advance of a lively class debate on the subject of ethics.

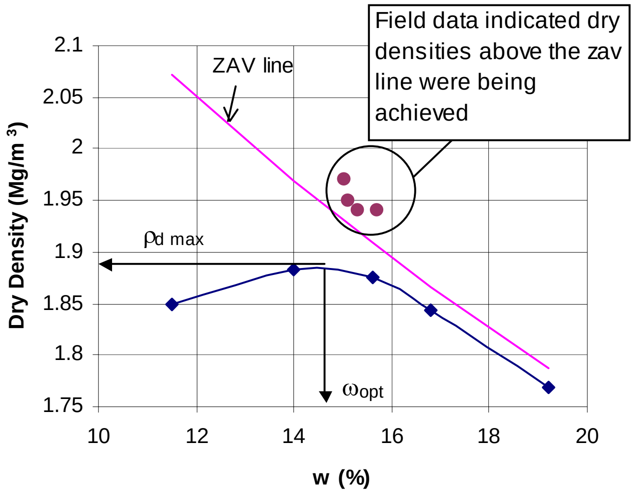

Fig. 7. Reported field densities plotted on moisture-dry density graph.

<u>Lessons Learned</u>

The following are the principal lessons learned from this case:

- A thorough understanding of compaction theory is necessary in order to assess the validity of field data. The zav line, compaction energy and its influence on the optimum moisture content are important concepts when evaluating the acceptability of engineered fill.
- Absence of appropriate checks and balances when field staff submit their reports to their superiors is evident in this case. All field reports should be reviewed and signed-off by a professional engineer.
- The importance of carefully selecting and training site staff is abundantly evident in this case. A company's ability to retain competent field staff is a mark of its commitment to ensuring the quality of construction. This can only be achieved through proper training and remuneration of staff.
- Personal and corporate integrity plays an important role in the engineer's responsibility to ensure the public's safety.

In the second case history the links between ground profile, soil behaviour and applied mechanics as presented in Fig. 1 are emphasised through a bearing capacity failure. The importance of promptly highlighting engineering concerns in writing once they emerge during construction is key learning outcome in this case.

CASE 2: FOUNDATION TO BULK STORAGE TANK FAILS DURING HYDROTESTING

The well-documented bearing capacity failures of the Transcona grain elevator (Peck and Bryant, 1953) and the grain elevator at Fargo, North Dakota (Nordlund and Deere 1970) feature in many foundation courses throughout the world. The writer outlines how he incorporates a similar case from his own experience. This case also illustrates the importance of clear communications between the engineer and the client when engineering data does not support the proposed construction.

As in the previous cases, the students are presented with a set of learning outcomes to be achieved after receiving instruction on bearing capacity theory. The lectures, based on Terzaghi's classical approach[2] clearly distinguish between drained and undrained bearing capacity and the conditions that prevail in each case.

This project involved the construction of two bulk storage tanks along the banks of the Delaware River in 1993. The two steel tanks were 14.63m (48ft) in diameter and 12.19m (40ft) high; the units were sandwiched between a row of six existing (smaller) tanks to the north and running parallel with the river. To the south, one 27.43m (90ft) diameter x 12.19m (40ft) high tank had been constructed since 1991. The row of six tanks had been constructed on a concrete raft circa 1980 and showed signs of having undergone settlement. The large tank sat on a reinforced concrete ring beam embedded in a geogrid reinforced aggregate mat. Other tanks, remote from the proposed construction, showed evidence of significant settlement but remained in service (albeit at a reduced capacity) due to careful on-going maintenance.

Prior to construction, the owner's geotechnical consultant advised against erecting the new tanks without a site investigation (SI). However, the successful completion and operation of the large tank in 1991 left the owner confident that two 'smaller' adjacent tanks could be safely supported in a similar way without the 'unwarranted' expense of a site investigation (SI). The flexibility of the tanks to accommodate a certain amount of settlement was also a factor in the owner's decision to forego the SI, and so, an instruction to prepare a foundation design based on the limited geotechnical data gathered during the 1991 construction was issued. The consultant remained concerned and wrote to the owner restating the risks of proceeding without a SI. The following extract from the letter clearly outlines the consultants concerns and urges the client to reconsider:

> *"…..on the basis of the limited geotechnical information at our disposal and the settlement damage observed in the foundations of the nearby row of tanks, we strongly recommend that a site investigation be undertaken. This will reveal the ground profile at the proposed*

[2] As modified by Skempton (1951) and Brinch-Hansen (1970)

tank locations and enable the most appropriate foundation solution to be selected."

This advice was again ignored and the tanks were constructed on reinforced aggregate mats identical to that used for the 27.43m (90ft) diameter tank.

During integrity testing of the tanks, the owner noted that one of the tanks started to visibly tilt in a northerly direction as it was filled with water. There followed a panicked call to the geotechnical consultant who advised immediate unloading of the tanks and the execution of a level survey to establish the pattern and magnitude of the ground movement around the tanks. A maximum vertical settlement of 400mm (16 inches) was recorded in a sixteen-hour period – obviously indicating a bearing capacity failure in the underlying soils. Fig. 8 shows the failure in the ground and the downward movement of the flexible connection pipe that once stood at an elevation higher than the crown of the horizontal distribution pipe.

The owner immediately agreed to a detailed SI to establish the exact cause of the failure and more importantly from his viewpoint, how to straighten the listing tanks so they could be commissioned for service. The SI and soil testing programme revealed that the tanks were constructed over a layer of miscellaneous fill on top of a deep deposit of soft alluvial silt. Significantly, the fill material varied in thickness from 1.22m (4 ft.) to the south of the tanks to 5.49m (18 ft) on the northern end (Fig. 9); trial pits revealed the fill to be a mixture of silt ash, and granular material and also contained timber railway sleepers and tyres.

Fig. 8. Flexible connection indicates movement and ground failure

Standard penetration test N values within this material varied from N = 0 (weight of hammer) to N=8. The low strength, variability in depth and miscellaneous composition of the material undoubtedly caused the failure.

A compaction-grouting programme was selected as the most feasible remedial solution (Fig. 10). The tanks were initially ballasted with 0.30m (12 inches) of water to avoid damaging the flexible base during grouting. Strategically located vertical and inclined grout holes (Fig. 11) were initially used to inject grout at low pressure beneath the tanks to lift them into the vertical position. The underlying weak soils were then strengthened using deep holes grouted under high pressure as the probe was raised to the surface. The remedial work was a success and the tanks were re-commissioned at a cost approaching $175,000. This case is further proof of the adage, you pay for a SI whether you have it or not!

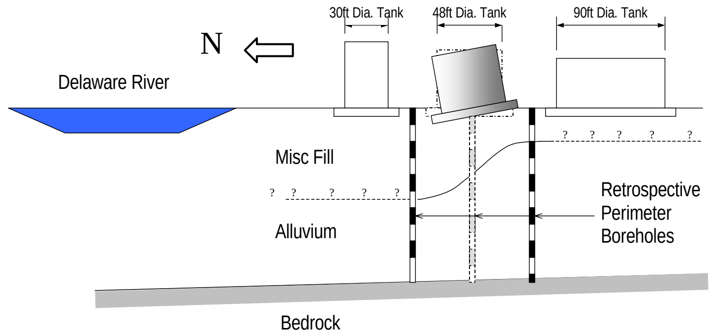

Fig. 9. Site stratigraphy revealed by the retrospective SI and its relationship to the tanks as constructed

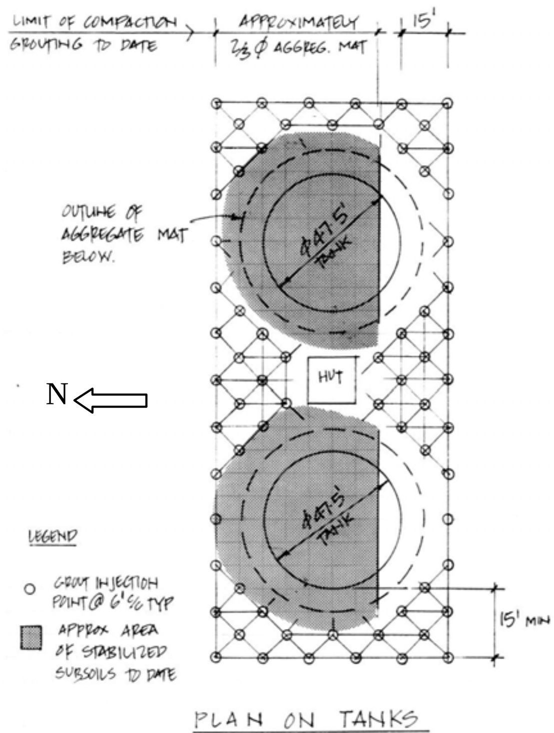

Fig. 10. Remedial Grouting Programme

Lessons Learned

The key lessons learned from this case include:

- Clients must be informed in writing of engineering concerns once they become apparent.

- Owners and design professionals must recognise that cost savings that reduce the quality of geotechnical services may purchase liabilities several orders of magnitude greater than their initial savings.

Fig. 11. Remedial grouting programme in progress

CONCLUDING COMMENTS

The paper demonstrates the benefits to be gained by introducing case based instruction in an undergraduate engineering programme. Student feedback at the end of the various modules is unanimously positive with requests that other modules adopt a similar format.

Given that there never is (and never will be!) enough time to cover the lecture material in the detail desired, the writer has found that the case based instruction provides an extra dimension to the learning experience of the student. It stimulates critical thinking and creates a maturity of approach when analysing engineering problems.

These exercises give the undergraduate an element of exposure to the real world from within the classroom. There can be little doubt that there is no substitute for site experience but the cases discussed in class help the student develop an acute awareness of the issues in geotechnical engineering prior to embarking on an eight month mentored site experience.

Students enjoy dealing with real problems with real results and discovering that, in engineering, there is no unique solution to a problem. Moreover, the cases permit the marrying of geotechnology techniques with theoretical soil mechanics as various remedial measures are considered to address given scenarios - the importance of getting it right first time however is the overriding theme throughout the module.

The discussions on ethical issues raised in the case histories are an important element of a student's education. It creates an awareness of the need for them to be paragons of the profession and responsible citizens in a civilised society.

Finally, the role of precedents in geotechnical engineering is an important learning tool in avoiding similar failures in the future. The students are encouraged to embrace the notion of documenting and distributing case histories involving difficult ground conditions encountered on projects. Such case histories would mutually benefit both engineering and building professions; after all, none of us live long enough to make all the mistakes – so let us learn from each other!

REFERENCES

ASCE, (2007). *The Vision for Civil Engineering in 2025*, Summit on the Future of Civil Engineering – 2025, ASCE Steering Committee to Plan a Summit on the Future of the Civil Engineering Profession in 2025.

Brinch Hansen, J. (1970). *A Revised and Extended Formula for Bearing Capacity*, Danish Geotechnical Institute, Bulletin No. 28, pp. 5-11.

Burland, J. (1989). *The teaching of Soil Mechanics – A personal view*, Nash Lecture, Trinity College, Dublin. pp. 1427-1447.

Carper, K, L. (2001). *Why Buildings Fail*, Nat. Council for Arch. Registration Board, ISBN 0 941575 36 5.

Day, R. W. (1998). *Forensic Geotechnical and Foundation Enineering*, MCGraw Hill, ISBN 0070164444

Feld, J. and Carper, K. L. (1997). *Construction Failures*, 2nd Ed., Wiley, ISBN 0-0471-57477-5.

Fleming,, W.G.K. (2000). *Failures and Case Histories*, IEI Modular Course on Foundations and Earth Retaining Structures for Building and Infrastructure Projects, Module 3: Pile Foundations, Institution of Engineers of Ireland, Dublin, February 10, 2000.

Goodlad, S. (1996) *Speaking Technically*, Imperial College Press, London, ISBN1 86094 034 X.

Kaminetzky, D. (1991). *Design and Construction Failures: Lessons from Building Failures*, McGraw Hill, ISBN 0070335656.

Levy, M. and Salvadori, M. (1992). *Why Buildings Fall Down*, Norton, New York, ISBN 0 393 03356 2.

Nordlund, R. L. and Deere, D. E. (1970). *Collapse of the Fargo Grain Elevator*, J. of Soil Mechanics and Foundation Division, Proc. of ASCE, Vol. 96, SM 2, pp. 585-607.

Peck, R. B., and Bryant, F. G. (1953). *The Bearing Capacity Failure of the Transcona Grain Elevator,* Geotechnique, Vol. 3, pp. 201-208.

Peck, R. B. (1962a). *Art and Science in Subsurface Engineering*, International J. of Soil Mechanics & Foundations, Geotechnique, pp. 60-66.

Peck, R. B. (1962b). *Engineering Geology on the Job and in the classroom,* Discussion, J of Boston Soc. of Civil Engineers, V49, Pt. 1, pp. 73-78.

Phillips, D. T. (2007). *Bridge Building using Teamwork,* Int. Symposium on Engineering Education, Dublin City University, Session 3, Paper No. 1, pp. 85 – 90, ISBN 1872 327 64 8.

Ross, S. S. (1984). *Construction Disasters: Design Failures*, Causes and Prevention, McGraw-Hill, ISBN 0 07 053865 4

Shepherd, R. and Frost, J. D. (1995). *Failures in Civil Engineering: Structural, Foundation and Geoenvironmental Case Studies,* ASCE Books, ISBN 0 7844 0122 5.

Skempton, A. W. (1951). *The bearing capacity of clays*, Proceedings, Building Research Congress, ICE, London, pp.180-189.

The Institution of Engineers of Ireland, (1994). *Communication Skills for Engineers and Scientists*, 2nd Ed., IChemE, U.K., ISBN 0 85295 354 2.

Wearne, P. (1999). *Collapse – Why Buildings Fall Down*, Macmillan Publishers, London, ISBN 0 7522 1817 4.