International Conference on Case Histories in Geotechnical Engineering
(2013) - Seventh International Conference on Case Histories in Geotechnical Engineering

01 May 2013, 2:00 pm - 4:00 pm

Role of Case Histories on Geotechnical Engineering Teaching and Practice

R. Shivashankar
National Institute of Technology Karnataka (Surathkal), India

Commemorate the Legacy of Ralph B. Peck
April 29 - May 4, 2013 CHICAGO
Seventh International Conference on Case Histories in Geotechnical Engineering
and Symposium in Honor of Clyde Baker

ROLE OF CASE HISTORIES IN GEOTECHNICAL ENGINEERING TEACHING AND PRACTICE

R. Shivashankar
National Institute of Technology Karnataka (Surathkal)
Mangalore, India 575025

ABSTRACT

Geotechnical engineering teaching can be made more interesting with the use of modern methods of teaching and learning aids, visits to construction projects, case studies etc. A faculty at an university/technical institute, who is actively involved in geotechnical designs and consultancy works, will have enough case studies, with the examples of which he, will be able to deliver his lectures more effectively and make a good impression upon the students. The universal mantra nowadays is ‘learning should be made more student centric’. At the author's institute, where a post-graduate and doctoral programme in geotechnical engineering are being successfully run for the past two decades, some of his experiences in effectively teaching geotechnical engineering subjects are being explained in the following paragraphs, with the help of a number of case histories on geopractices.

INTRODUCTION

Analyses and designs are being taught in the class rooms at both undergraduate and postgraduate levels for geotechnical engineering students. In order to make the courses more interesting to the students, use of modern methods of teaching and learning aids such as PowerPoint slides, visits to construction projects, case studies, softwares, colloquiums etc. are being tried. These methods help the students to (i) understand the complex concepts better (ii) appreciate the difficulties involved at site (iii) appreciate important projects that are successfully accomplished (iv) Analyze the causes of failures and learn important lessons from the failures i.e. the knowledge gained by analyzing the failures help us to evolve a better design methodology and increase our confidence in our designs (v) inculcate problem solving skills (vi) exercise better judgment in choosing appropriate geotechnical parameters in designs etc. The expertise and confidence in designing and teaching, comes through a lot of exposure to actual field problems. It is rightly said that "Geotechnical engineering is a science, but its practice is an art".

Generally, importance to construction aspects and case studies is lacking, and there is no subject dealing exclusively on case studies. Case histories of failures must be properly and fully analyzed. Reasons for failures, impact of failure, distress symptoms, remedial measures should all be well documented for the benefit of students and other designers. A lot of things in geotechnical engineering can be taught only at project sites outside the classrooms, even when PowerPoint slides are being used as a teaching tool. For example: many of the construction details, use of construction equipments etc. have to be seen at site for a better understanding.

GEOTECHNICAL ENGINEERING TEACHING

The ‘Chalk and Talk’ method of teaching was the most common and widely used method in most engineering institutions in India until a few years ago. It used to be more of a monologue with only the lecturer talking and trying to cover (rather uncover) the university prescribed syllabus and the students being mute and passive spectators. But of late the focus has shifted to a more learner-centric approach. With flexible syllabi, the instructor is free to a certain extent to teach the latest subjects and practices in geotechnical engineering. This will have a greater practical value when the student steps out into the professional domain after his/her graduation. Even the examination (evaluation) system, of late, has seen a revolutionary change in most of the top institutions in the country. It has moved a long way away from the old university system (of marks) which would decide the fate of a student by a single final exam at the end of the semester to a continuous evaluation system (grading system). The new system has a number of components, all through the semester, that are evaluated: such as a mid-semester exam of 1 to 1.5

hours duration (with about 20 to 25% weightage), continuous evaluation by way of quizzes, tutorials, assignments, seminars, surprise objective type tests etc. (with a weightage of about 25 to 40%) and an end semester exam of 3 to 4 hours duration (with weightage of 40 to 50%). In the new system, the end semester exam alone does not decide the grade of a student. This way the student has to be regular to his classes and actively participate in all activities in the class room to earn the maximum credits. Letter grades (on a scale of 10 at N.I. T. K.) are assigned to every student in each subject depending on his or her performance in the subject, based on relative grading. The overall performance of a student will be indicated by two indices namely SGPA which is Semester Grade Point Average at the end of each semester and CGPA which is Cumulative Grade Point Average, indicative of the performance of the student for all the previous semesters, including the latest one.

Case study approach to engineering education provides a greater understanding of the multifaceted nature of civil engineering (Akili, 2007). The role of the teacher/instructor is becoming more of a facilitator for the learning process of the students. It infuses in a student the urge to learn more and helps him to identify areas of his interest, and sparks the self-learning feature in him. That way, whatever he learns will be sort of permanently etched in his mind and helps him to become a better geotechnical engineer in his future professional career.

Geotechnical engineering is the branch of civil engineering that deals with soil, rock and underground water, and their relation to the design, construction and operation of engineering projects (Coduto, 2002). At the undergraduate level typically, only a few basic subjects of soil mechanics and foundation engineering are taught (a few core subjects) and quite a few electives are offered. More specialized geotechnical engineering subjects are taught/offered at the post-graduate level. Tables 1 and 2 shows the geotechnical engineering subjects taught at NITK at UG and PG levels. The PG programme leads to an M.Tech degree in geotechnical engineering, which is a two year course, and it is typical of most Indian universities. The first year of two semesters have course work and the second year (two semesters) is entirely for thesis work or major project work. In the summer break between the first and the second years, the PG students undergo 8 weeks of practical training/internships at a construction firm or research organization etc.. Even UG students also undergo 6 weeks of practical training or internships. Sometimes the company people, where the students go for practical training, if they feel impressed, will also offer job offers to the students on completion of their studies. This model of absorbing the internees into their company fold is gaining more acceptance than campus recruitments. Because that way the employers get to see the students for long and understand their strengths and weaknesses better. Also the students get to know well the company they intend to join, much in advance, as much as six months to one year.

Table 1. Geotechnical Engineering Subjects taught at N.I.T.K. at Under-graduate Level

I. Core Subjects taught in UG programme (B.Tech degree in Civil Engineering)
1. Engineering Geology 2. Geology lab 3. Soil Mechanics 4. Soil Mechanics Laboratory
II. Elective Subjects offered in UG programme (B.Tech degree in Civil Engineering) *Apart from a big list of Civil Engineering elective subjects, students can also choose a few subjects offered by other Departments (and PG courses) as open electives*
1. Applied Soil Engineering 2. Rock Mechanics 3. Applied Geology 4. Design of Foundations, Earth and Earth Retaining Structures 5. Ground Improvement Techniques 6. Elements of Earthquake Engineering 7. Groundwater Engineering etc.

Table 2. Geotechnical Engineering Subjects taught at N.I.T.K. at Post-graduate Level

I. Core Subjects taught in PG programme (M.Tech degree in Geotechnical Engineering)
1. Basic Geomechanics 2. Shallow Foundations 3. Geotechnical Engineering Lab I 4. Earth and Earth Retaining Structures 5. Pile Foundations 6. Ground Improvement Techniques and Soil Reinforcement (Geosynthetics Engineering) 7. Geotechnical Engineering Lab II 8. Numerical Analysis 9. Seminar 10. Practical Training/Minor Project 11. Major Project (2 semesters)
II. Elective Subjects offered in PG programme (M.Tech degree in Geotechnical Engineering) *Students can also choose a few subjects from other Departments, at PG level, as open electives*
1. Rock Mechanics 2. Soil Dynamics and Foundations 3. Advanced Engineering Geology 4. FEM for Geotechnical Engineers 5. Earth and Rockfill Dams 6. Geotechnical Instrumentation 7. Selected topics in Geotechnical Engineering 8. Environmental Geotechnology 9. Earthquake Engineering 10. Pavement Engineering 11. Marine Geotechnical Engineering

Geotechnical teaching can be made effective in following ways:

(i) Class room teaching. Although chalk and talk is the traditional and popular method still being followed in most universities, with the advent of modern teaching aids, PowerPoint presentations are also becoming popular. This way the coverage per lecture is increased and many concepts and practical examples are shown beautifully in the form of sketches /photos or videos. A teacher has to come well prepared and should be well experienced. A teacher as a consultant can take good pictures of the various sites or case studies he visits or is involved and can make an excellent PowerPoint presentation that will be very well received by the students. This way the students can see the real pictures of sites in their class rooms itself, sites that they are not able to visit or successful projects that are completed.

(ii) Practical courses: can include laboratory and field tests, use of field instrumentation, supervision of construction etc.

(iii) Field visits: Students should be taken to as many sites as possible. Taking students to sites in which there are field (geotechnical) investigations such as plate load tests, standard penetration tests (SPT) [Fig.1], plate load tests, pile load tests [Fig.2] are being conducted, the students will be able to understand the test procedures well, understand the importance of test and also appreciate the difficulties at site for a site engineer. Even visiting sites of pile installation, bored cast in place piles or driven piles will also be very useful. Lately in many big cities in India, metro constructions are going on. In these projects, there are a number of geotechnical activities, which are rare and not so common to see, such as blasting, tunneling using modern methods of tunnel boring machines, ground stabilization using rock bolting and soil nailing, dewatering, shotcreting etc. One gets to see a lot of instrumentation which will be in place to monitor the ground movements (inclinometers, settlement gauges etc.), hydraulic measurements, etc.

Very often civil engineers (geotechnical engineers) will have to work in extremely difficult and remote places, difficult to access. Figure 3 shows picture of a electrical transmission tower erected with the high tension wires deep inside a forest infested with wild animals and blood sucking leeches. The transmission towers, with four legs, very often had to be placed on benches (leveled grounds) with steep and high vertical cuts on one side of two legs, and steep hill slopes beyond the other two legs. Tower foundations, stabilization of slopes, constructing RCC retaining walls, soil nailing a good part of the hillock, diverting the flow of natural water (drainage) etc. are daunting tasks for the geotechnical engineers.

Fig.1. Geotechnical Investigation at Site

Fig.2. Field Load Testing using kentledge loading

Fig.3. Example of extremely difficult and remote places for geotechnical engineers to work. Land slide in a distant hill slope can be seen which also houses a transmission tower

(iv) Case studies. Generally there is no subject exclusively on case studies in our postgraduate programme. Every subject taught in the class room can include as many case studies as appropriate. Some case studies have had a wide publicity, globally. Some case studies are local, nevertheless help in understanding the behaviour of soil, design and construction aspects, geotechnical engineering practices etc. better. In almost all engineering colleges/technical institutions, the geotechnical engineering faculty will be involved in consultancy works. There will be many challenges at site and the geotechnical engineer will have to use all his acumen and knowledge of the subject in suggesting a practically feasible solution/s under difficult situation/s. Students can also be involved in such consultancy projects in the form of assignment problems/mini project works/field visits/practical training (internships). The teacher can also make his lecture more interesting by citing such relevant examples of case studies he has been involved in or other case studies available in literature and nowadays also available in plenty on the internet.

For example, study of sensitivity and thixotropy of marine clays in geotechnical engineering laboratories will be a very interesting topic to teach to students [Fig.4]. The students can see and appreciate why sensitive clays lose their strength on disturbance and also see for themselves the gain in their strength (unconfined compressive strengths) with time. An explanation of relevance of this behavior, in class rooms, for conducting pile load tests in sensitive clays immediately after their installation will leave a good impression with the students. There are a number of text books/reference books in geotechnical engineering, which make a good reading, in which a number of interesting case studies are discussed and geotechnical interpretations are dealt with.

A few case studies, in the authors experience, generally in the coastal Karnataka area of peninsular India, are dealt with in some detail in a latter section under title 'Discussions on geopractices and some interesting geotechnical engineering case studies'.

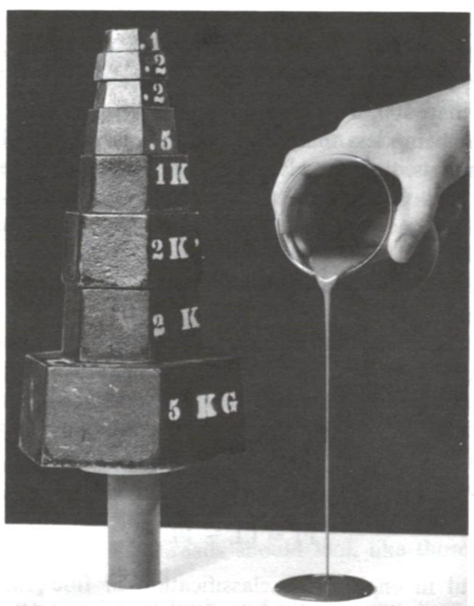

Fig. 2.9 (a) Undisturbed and (b) thoroughly remolded sample of Leda clay from Ottawa, Ontario. (Photograph courtesy of the Division of Building Research, National Research Council of Canada. Hand by D. C. MacMillan.)

Fig.4. Demonstration of sensitivity of clays (extracted from Holtz and Kovacs, 1981)

(v) Geotechnical practices being followed in the locality (local problems and practices) will also have good impact on students and will be very useful. Failures due to bad practices or poor design and construction practices will also instill good qualities in the students who are future geotechnical practicing engineers. Forensic geotechnical engineering is a very useful subject in which students show a lot of interest and it helps in developing their analytical skills.

DISCUSSIONS ON GEOPRACTICES AND SOME INTERESTING GEOTECHNICAL ENGINEERING CASE STUDIES

'Geotechnical engineering practices' refers to the application of principles of geomechanics i.e. soil mechanics and rock mechanics to practical (geotechnical) engineering problems. Geotechnical engineers are to be involved at all phases i.e. during design, during construction and also during the post-construction phases of the projects for ensuring satisfactory performance of structures. Very often the design recommendations made in analyses/designs will have to be revised later depending on the actual site conditions encountered during construction. Geotechnical engineers will also have to rely a lot on engineering judgment, which gains maturity, and becomes less subjective, with experience. However, in actual practice there are a lot of unscientific practices being followed by practicing engineers. Some such practices being followed are discussed, in the following paragraphs, through some case studies.

Superstructures are those part of structures seen above the ground, that are beautiful to see and are greatly admired by everyone. There are several wonderful, marvelous and magnificent structures built all over the world that are considered as civil engineering wonders. Substructures are buried in ground and not seen above the ground. They are often not given same importance as the superstructures. But the substructures are also equally important because they provide the vital support and stability to superstructures. Substructures deal with soils/rocks in direct contact. Behaviour of soils is dictated by the presence or absence of water and most importantly by the drainage conditions prevailing at site. Soil is considered to be a micromeretic fluid. All soils are good in dry condition. Excess water is undesirable from foundation/civil engineering point of view. Soils generally become problematic only when they come in contact with water. Dense sands, loose sands, soft clays, expansive clays, stiff clays, dispersive soils, sensitive and thixotropic soils etc. are all problematic in one situation or other. During earthquakes, the main problems are that of the tremors and soil liquefaction. Therefore understanding thoroughly the behavior of soils is very important to design safe and satisfactorily performing structures. This aspect has to be made very clear to the students.

Importance of Geotechnical Investigations

Very often builders/developers tend to ignore or skip any geotechnical investigations, let alone conduct detailed investigations, before construction of any major projects. From point of view of geotechnical engineers, to advance their knowledge and design skills, it would be desirable/recommendable to provide suitable instrumentation too, for monitoring the post-construction behaviour of structures. Both these are generally considered as unnecessary expenditures on the budget of the project, and left out as cost cutting measures. Instrumentation is never thought of at all, although some projects do undertake limited geotechnical investigations nowadays. In general, the construction practices, let alone geotechnical engineering practices, in this area are very poor. New building regulations have been brought out by the local district administration, making geotechnical investigations mandatory. Therefore, only of late, in the last 5 years or so, that a few builders get SPT done at a site [Fig.1] at a few locations to get an idea of the soil strata at site (and estimation of bearing capacity and settlements), position of groundwater table and depth of bed rock. In a few cases, rarely, plate load tests and pile load tests [Fig.2] are also conducted. Piling is the last option and rightly so. In most cases, the consultancies we get are post-mortem type, after failure or collapse. These too are got done not to analyze the causes of failure, but with a request to suggest suitable remedial measure, that too cheapest and quickest.

Case Study of Failure of Pile Foundation

Another interesting case study of failure of foundation, that I use in my lectures, is a failure of pile foundation. The failure could be said due to improper/bad geotechnical engineering practices. The piled foundation was supporting a multistoried

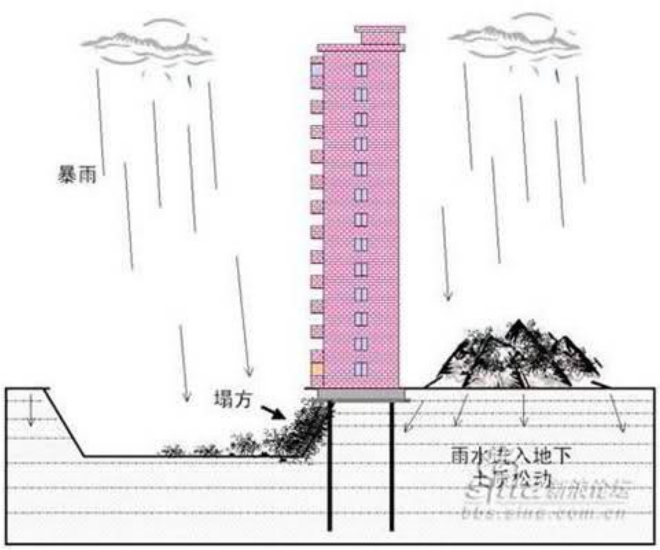

Fig. 5. Schematic representation of failure of building in Shanghai in China (Subramanian, 2009)

Fig.6. View of building after failure (Subramanian, 2009)

building in Shanghai in China. The failure occurred due to excavated soft clayey soil on one side being piled up on the other side of the building (Figs. 5 and 6). Details of this case study are available in a number of references on the internet/google search (for ex. Subramanian, 2009).

Case Study of tilt of a Hospital Building on Raft Foundation

This classic example of a medical college/hospital building construction that took place about 15 years ago, on a somewhat elevated ground (mound). It is a classic case study of geotechnical engineering. It consisted of two blocks, each of 6 floors. Block 1 construction was taken to begin with, and a few years later construction of Block 2 was done. A few boreholes were done as part of (limited) geotechnical investigation for the first block and the building was built successfully supported on raft foundation with no problems whatsoever. However, a few years later when it was decided to take up the construction of Block 2, it was decided to use the same soil investigation report of Block 1 which was just about 30 m away. It so happened that when only the skeleton of the Block 2 building was being done (i.e. just columns, beams and floor/roof slabs were in place supported on raft foundation), the building started signs to tilt slightly. All concerned raised alarm, construction was halted to stop further tilting, and detailed investigation of subsoil was ordered very close to this Block 2 building. On detailed investigation (and from enquiries with elderly locals), it was found that although Block 2 was very close to block 1, Block 2 was resting on loose filled up ground (1 to 4 m thick) while the subsoil beneath Block 1 was hard natural (lateritic) soil on mound, with hard rock at shallow depth of about 4 m below the ground level at site. It was suggested to install micro piles of 150 mm diameter by punching through the raft slab. The piles were jacked through the raft slab, bearing on the hard rock. It was not possible to drive the micropiles due to low head room conditions. Thereafter there was no tilting.

The general public perception is that foundation cost should be about 10-15% of the overall project cost, for general construction of residential buildings/residential apartment buildings. But sometimes, due to poor soil conditions at site or due to complex superstructures, it would be required to adopt deep foundations (pile foundations) even for small buildings (2-3 storied buildings) and adopt other drainage control measures, in which case the cost of foundation increases enormously. Even some sort of ground improvement technique adopted at site to marginally increase the bearing capacities for shallow foundations will also incur quite some foundation cost (cost of substructure). It is seen in many extreme cases, the cost of foundation (substructure) will be as much as the cost of the superstructure or even more, and the geotechnical engineer could be branded as inefficient.

Slopes and Excavations

In many constructions/projects, slopes are generally not engineered or designed for safe slope angles. Most often these slopes are one single slope of great heights, steep, with no intermediate berms. Backfill soils in highway embankments are just dumped and not properly compacted. Even if they are compacted, the density and moisture content are not monitored. Luckily nowadays, major projects insist on use of only vibratory rollers for compaction and these rollers can easily attain over 100% of Proctor density (standard/modified). Drainage, such as providing side drains on top, chute drains on slopes and bench drains on berms, which is the most important factor in design of slopes and construction is generally given the least importance.

Most sites adjacent to highways are sloping. Builders/developers usually excavate their sites to be in level with the adjacent highway leaving vertical cuts of large heights in dispersive shedi soil in the rear and on the sides. These cuts are also sometimes made so close to existing adjacent buildings at top. Nowadays with availability of advanced mechanized excavation and earth moving equipments, excavations are done very fast and large areas are excavated inordinately with steep and high slopes overnight. Excavations generally tend to change the existing drainage pattern and the seepage forces that result from these changed

Fig.7. Excavation changing drainage pattern and endangering stability of excavated slope

Fig.8. Adjacent structures endangered due to excavation

drainage patterns are main causes for failure of many excavated slopes and land slides (Fig.7). Slopes are cut steep and high without any intermediate berms and suitable drains. There is no concern for safety of neighbouring structures. The adjacent structures are many times deprived of their rightful ground support. Foundations are left to hang in air (Fig.8). Sheet piling or soil nailing are not at all the norm. Slopes adjacent to highway and railway lines are not engineered and sights of slope failures and formation of caves are very common. Dispersive soils, like shedi soil (the locally available soil, which is a lithomargic clay, a product of laterization) have a high erosion potential and this nature of soil in slope actually hastens the slope failures. Soil nailing are being adopted in some places, but their effectiveness is questionable. They are not constructed using the proper driving/installing equipments and one cannot be sure if these reinforcements (soil nails) are properly embedded in the passive zone (behind the failure surface). In many places, face of excavated slopes with nails, the surface has caved indicating that these nails were merely in the active zone.

Case Study of a Land Slide due to changed Drainage Pattern due to Human Activities

Mangalore and surrounding places are generally on a sloping terrain. The large number of geotechnical failures that one observes in this area are slope failures. First of this kind are failure of natural slopes like land slides or land slips etc. due to changed drainage patterns because of numerous human activities in the name of development. Secondly, other manmade slope failures are more common too. These are due to steep slopes or vertical cuts or near vertical cuts excavated. A classic example of land slip due to changed drainage pattern, in this area, is the Kethikal slope failure, reported in detail in Setty et al. (1999) and Bhat et al. (2008).

Slope Protection Measures

After experiencing difficulties and problems with failed slopes, in some places, authorities in charge are becoming more aware of slope (in)stability problems. Slopes angles are being designed based on properties of soil in slope, berms are being provided appropriately and proper drainage facilities are being provided. Appropriate slope protection measures are being practiced or being tried out such as stone pitching, turfing (especially with vetiver grass) and gabion walls where possible and necessary.

Fig. 9. A full grown vetiver root (www.vetiver.org)

Vetiver, is a very fast growing grass and until very recently a relatively unknown plant. It possesses some unique features of both grasses and trees by having profusely grown, deep penetrating root system (Fig.9). The roots of vetiver grass can offer both erosion prevention and control of shallow movement of surficial earth mass. Parameters obtained from recent research reveal that vetiver grass roots are very strong with an average tensile strength of 75 Mpa or about one-sixth of ultimate strength of mild steel. The massive root system also increases the shear strength of soil, thereby enhancing slope stability appreciably. In addition to its unique morphological characteristics, vetiver is also highly tolerant to adverse growing conditions such as extreme soil pH, temperatures and heavy metal toxicities. Figure 10 shows a slope protected with vetiver grass on the Konkan railway stretch.

Fig. 10. A slope protected with vetiver grass on the Konkan railway stretch.

Fig. 11. A gabion toe retaining wall on the Konkan railway stretch using hexagonal wire meshes

Gabions are rectangular baskets fabricated from a hexagonal mesh of heavily galvanized steel wire or they can also be fabricated from polymeric geogrids. Even sand bags qualify as a type of gabions, especially used for river protection works. The wire or grid baskets are filled with rock and stacked atop one another to form a gravity type wall. Gabion walls are also designed similar to gravity walls. Gabions depend mainly on the interlocking of the individual stones and rocks within the wire mesh for internal stability, and their mass or weight to resist hydraulic and earth forces. Gabions are a porous type of structure that can sometimes be vegetated. Gabions are considered to be a “hard” structural solution that has minimal habitat and aesthetic value. Figure 11 shows a gabion toe retaining wall on the Konkan railway stretch.

Retaining Structures

Perhaps retaining structures or retaining walls are the most abused of all geo-structures from the point of view of design and construction (Shivashankar and Nayak, 2005). Many times these structures built are not designed (engineered) at all. No checks are made for sliding failure, overturning failure and checked for the base pressures. Very high vertical cuts (up to 8-10m high) are made and a cosmetic masonry wall is built, less than 1m thickness at base. No proper drainage and no weep holes are provided. Person standing in front of the wall will see a stone facing and feels a false sense of security. Such walls fail within 2-3 monsoon seasons and reveal their true nature. Figure 12 shows one such failed masonry retaining wall. Figure 13 shows another failed retaining wall, of great height, and no ability to resist the lateral driving forces. The most important thing to impress upon students is that for a proper design, the designer has to correctly identify all the driving forces and all the resisting forces and calculate the F.S.

Fig.12. A failed masonry retaining wall (cosmetic wall) due to under-design

Fig.13. Another failed (so-called) masonry retaining wall

Highways and Airport Runway Pavements

Drainage, which is the most important factor in highways and airfield pavements design and construction, is given the least importance. Many times due to restricted right of way, no side drains are provided. Even when provided, their gradients are not properly adopted in site. We see many times that the highways are becoming drains for surface water from surrounding high areas. All the drains are clogged due to poor maintenance. Highways are thus becoming low-ways. We see damage of the highway pavements and pot holes mainly due to such bad practices, use of poor quality of construction materials, poor drainage and poor maintenance of highways.

Highways are built on soft clay subgrades by directly placing the sub-base materials on the soft subgrade. Either the aggregates just go into the weak subgrade or the clay gets into the voids of the aggregates, destroying the friction between the aggregates and defeating the very purpose for which the aggregates are provided. Now-a-days with the advent of geosynthetics, it would be proper to provide a geotextile separator between the soft clay subgrades and the flexible pavement layers placed above it. The geotextile separator will allow only water to migrate and improves the performance of the pavement. Our engineers are very slow to adopt newer technologies such as applications of geosynthetics in civil engineering practice. Figure 14 shows the use of geotextile separator in a pavement construction.

Compaction

For geotechnical engineers, soil compaction [Figs. 15 and 16] is one of the most important activity of earthwork construction (Coduto, 1999), apart from controlling water at site by providing proper and suitable drainage. Compaction improves the engineering properties of the fill in many ways. It increases the shear strength of soil, improves bearing capacity at site, reduces possibility of slope failures, drastically reduces settlements, drastically reduces hydraulic conductivity, increases erosion resistance – both internal erosion and surface erosion. About a decade back it was being said that achieving laboratory density values in the field is very difficult. The argument was that in laboratory only a small amount of soil is handled, while in field several million cubic metres of soil are to be handled. Nowadays with the advent of advanced compaction equipments, it is the other way around and there is a revolutionary improvement in quality of compaction that can be achieved. Field compaction equipments, especially vibratory rollers, with their enormous input energy (compactive effort), it is possible to achieve better compaction at site than that is achieved in laboratory. Probably compaction monitoring at site need not be given so much importance at site with these modern compaction equipments.

Fig. 14. Use of geotextile separator in a pavement construction (Mcgown, 2002)

Fig.15. Compaction for an approach embankment to a flyover

Fig.16. Proper compaction at site is very important for highway and airport runway pavements

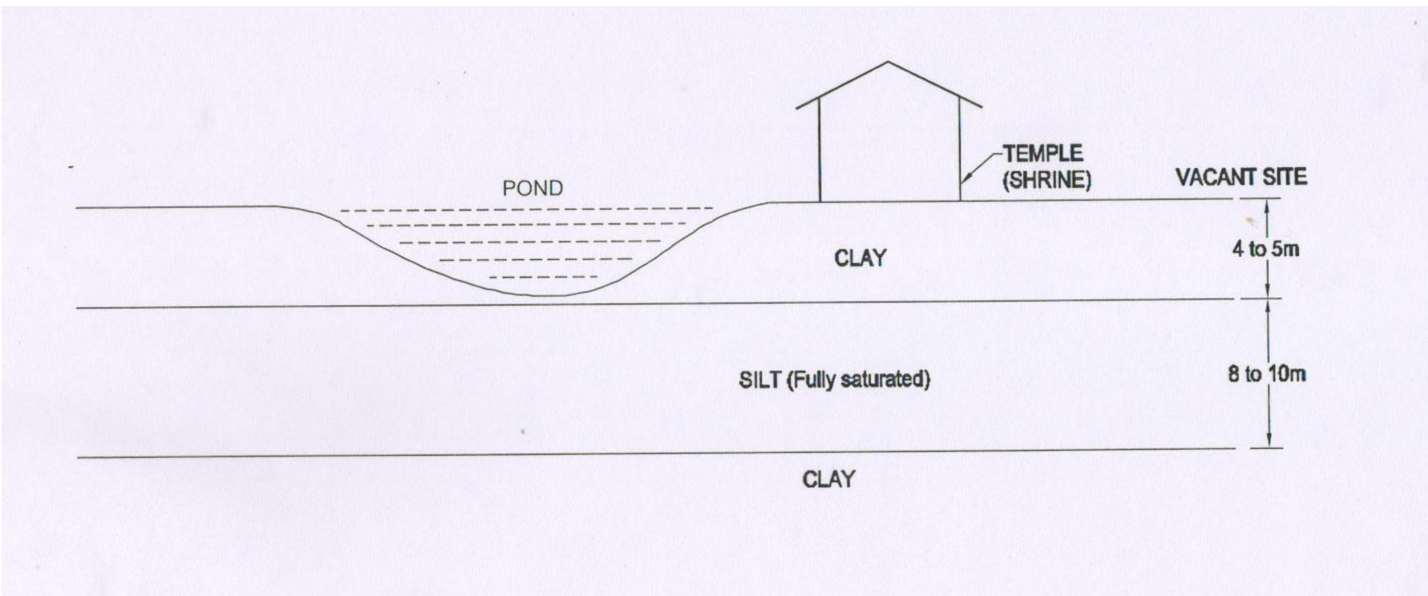

Fig.17. Condition before start of piling activities in vacant site

Case Study of distress in a Shrine Building due to Piling Activities in an adjacent site

This is a very interesting case study. There was a small building that housed a shrine that was built several years before. The shrine was supported on simple masonry strip footing. Soil stratification at site is as shown in Fig.17. There was a pond on one side of the shrine and a large vacant site on the other side. All the problems began after the owner of the neighboring vacant site decided to construct a multistoried building supported on bored cast in place replacement RC piles. After cleaning and leveling the site, hundreds of boreholes were drilled for installation of the piles, bearing on hard strata. Soon after all the boreholes were made, water began to seep out through the boreholes and with it also some fines due to erosion of silty soil underneath the top clay crust. The level of water in the pond was reported to be receding. This was followed by cracks appearing in the shrine building [Fig.18]. In order to investigate the cause of this distress in the shrine building, about 6 boreholes were drilled very close to the shrine building and it was observed there were large cavities in the silty soil zone. Large migration of fines had taken place and this must have caused settlement, rather differential settlement of the structure, showing off by way of cracks. Prior to boring the holes, the silty soil was fully saturated and water had no way to escape. It was confined. But once the boreholes were made, it gave a way out for the water to escape with great force and with it, large amounts of fines were carried out, resulting in formation of cavities underneath the shrine building. What this case study teaches is that the engineer/builder must analyze all the possible reactions to his actions, such as the boring of a large number of holes in this case. The site engineer very well knew the site conditions, but he did not perhaps anticipate such a response.

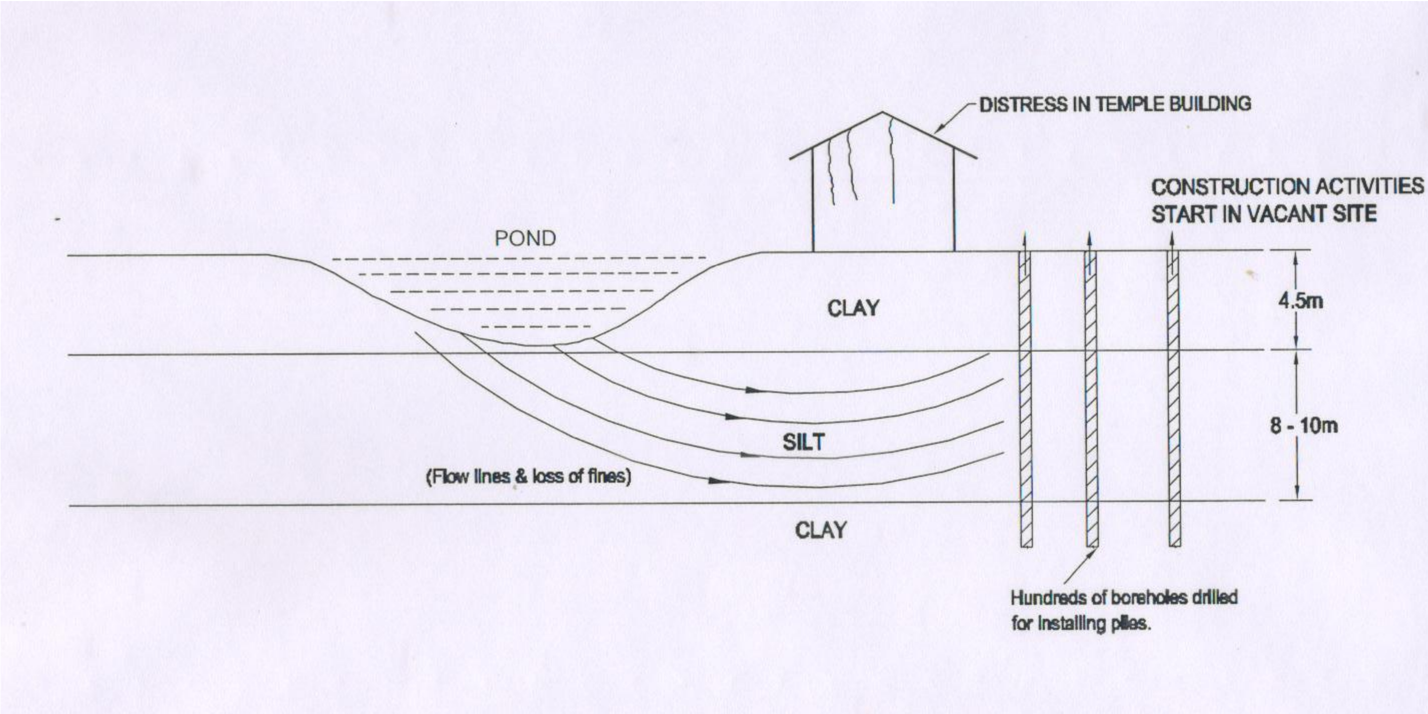

Fig.18. Condition after boreholes are drilled in adjacent vacant site (shrine building started developing cracks)

CONCLUSIONS

Even though, a teacher may be teaching the same subject for quite a few years, he is expected to improvise each year. Improvise in terms of his understanding the subject, presentation and also in evaluating the students. A teacher gets to understand better and get a clearer picture of the subject when he is preparing for his lectures, for teaching the students. In case of teaching of geotechnical engineering subjects, or in case of teaching of civil engineering subjects in general, he has ample opportunities to improvise his presentation, year after year, of his case studies which he uses as a tool to impress upon the students the various aspects of geotechnical engineering. It could be a design concept or construction related topic. Teaching is not dictating some obsolete notes or writing information on the blackboard for students to copy and memorize. No more marking it right only when the student has repeated all this faultlessly in the tests and exams. Students must be encouraged to think, question, analyze and then come to a conclusion. Case studies are a very important and a very useful tool in geotechnical engineering teaching.

REFERENCES

Akili, Waddah [2007], "Better Teaching and Learning Using Case Histories in Geotechnical Engineering", *Proc 37th ASEE/IEEE Frontiers in Education Conference*, Milwaukee, WI, pp. S2A-22 to S2A-27.

Bhat, Arun Kumar; R. Shivashankar and R. K. Yaji [2008], "Case Study of Landslide in NH13 at Kethikal near Mangalore, India", Sixth Intl. Conf. on case histories in Geotechnical Engg. Arlington, VA, USA, paper No. 2.69, 12 pages.

Coduto, Donald P. [2002], "*Geotechnical Engineering - Principles and Practices",* Prentice-Hall India, New Delhi.

Holtz, R. D. and W. D. Kovacs [1981], "*An Introduction to Geotechnical Engineering",* Prentice Hall, Upper Saddle River, NJ.

Mcgown, A. [2002], "Geosynthetics as Separators", International Geosynthetics Society Mini Lecture Series (CD distributed to IgS members)

Setty, K.R.N., R. Shivashankar and Lakshman Rao Peshwe [1999], "Kethikal Slope Failure – A Case Study", *Proc. Indian Geotechnical Conference, Calcutta.*

Shivashankar, R. and Nayak, Sitaram [2005], "Geotechnical Practices in Coastal Karnataka", *GEOPRACTICE-2005, Proc. Natl. Conf. on Case Studies in Geotechnical Engg., I.I.Sc.(Bangalore),* Interline Publishing, pp.105-110.

Subramanian, N. [2009], "Rare Foundation Failure of a Building in Shanghai, China", NBM and CW publication for construction sector in India, NBM Media, August 2009, pp.100 - 105.