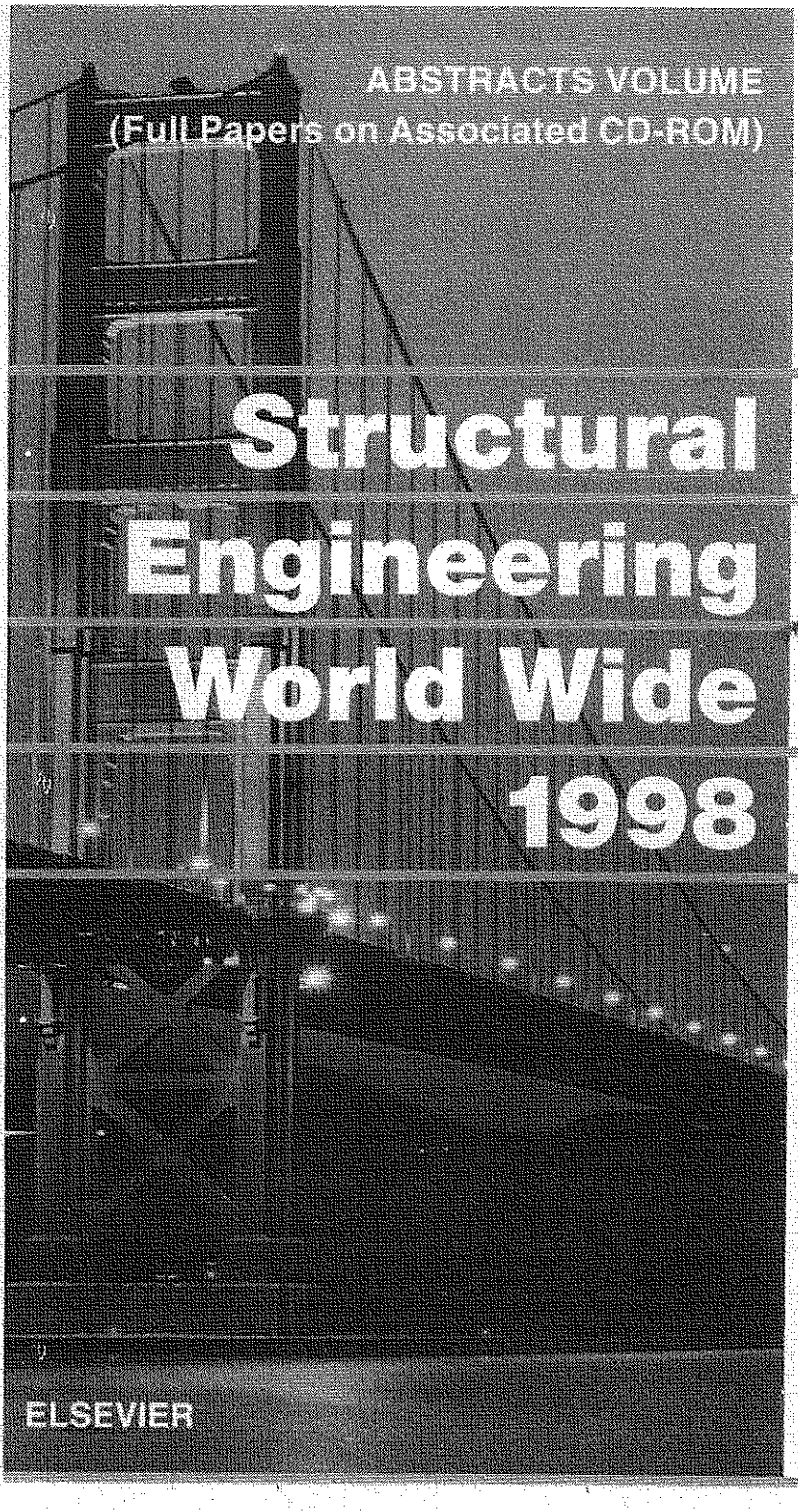

ABSTRACTS VOLUME
(Full Papers on Associated CD-ROM)

Structural Engineering World Wide 1998

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STRUCTURAL ENGINEERS WORLD CONGRESS
July 19-23, 1998,
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Editor:
N.K. Srivastava

Co-Editors:
G.L. Fenves
R.G. Domer
A.H.-S. Ang

aci international

SEI
Structural Engineering Institute
of the American Society of Civil Engineers

International association for shell and spatial structures

JSCA

SEA California

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PREFACE BY EDITOR

The theme of the Congress is "Structural Engineering World Wide", an international state-of-the-art forum from technical as well as from professional and practice point of view. The technical program was chaired by Prof. Alfredo H.S. Ang and the professional and practice issues program by Dr. Ronald Domer, an experienced practicing engineer. The two directions have been developed by two independent international control groups, each session being planned around a particular subject area then coordinated and reviewed by an expert in the area.

SEI-ASCE (Structural Engineering Institute of ASCE) has played a big part in the Technical program under the chairmanship of Professor Gregory L. Fenves. The annual Structural Conference of SEI-ASCE, it's 13th Conference on Analysis and Computation, as well as it's 2nd Concrete and Masonry Symposium have been carefully blended with other technical part of the proceedings.

Each of these chairs are co-editors of these proceedings and will give an overview of their portion of the proceedings in the following pages. The proceedings begin with the keynote papers to be delivered by four eminent engineers. There are nearly 90 professional and practice issues papers and 580 technical papers in the proceedings bringing a total of over 674 papers involving approximately 1400 authors around the world.

Committee members and several other individuals have voluntarily helped to develop the full proceedings of this world congress on CD ROM and a hardcopy abstract volume. The organizers greatly appreciate their efforts.

My special thanks are due to Prof. Gregory L. Fenves of the University of California at Berkeley for being a solid anchor of help; to Marc LeBlanc of the Université de Moncton, Canada for all his valuable help including creating and maintaining the database; to Dr. James Milne of Elsevier (UK) for his guidance in the layout of the CD ROM; and to Richard Higgins of Stanford, California and Betty Marton of EERC, Richmond, California, as well as to the Earthquake Engineering Research Center of the University of California and the Université de Moncton in Canada for providing their facilities to work.

We hope that the entire program will serve to advance the world wide state-of-the-art structural engineering and its profession, specially in these days of rapid globalization.

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Proceedings Editor
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Moncton, N.B. Canada

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15. RELIABILITY/PERFORMANCE

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EXPERIENCE TEACHING CIVIL ENGINEERING FAILURES: 1973 - 1997

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ABSTRACT

Experience teaching civil engineering (CE) failures via the inclusion of failure information in contemporary courses is described. The writer explains how his teaching of construction failure in CE courses evolved from the evaluation of a magazine or newspaper article in 1973 at the State University of New York at Buffalo (SUNYAB) to the development of a stand-alone course on forensic engineering at Mississippi State University (MSU) in 1994. From 1973 to the present, that development includes evaluation of an article, evaluation of a journal paper, field investigation of failure, and a stand-alone course in forensic engineering.

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Experience teaching civil engineering (CE) failures via the inclusion of failure information in contemporary courses is described. The writer explains how his teaching of construction failure in CE courses evolved from the evaluation of a magazine or newspaper article in 1973 at the State University of New York at Buffalo (SUNYAB) to the development of a stand-alone course on forensic engineering at Mississippi State University (MSU) in 1994. From 1973 to the present, that development includes evaluation of an article, evaluation of a journal paper, field investigation of failure, and a stand-alone course in forensic engineering.

INTRODUCTION

The planned inclusion of information on the failure of constructed facilities in current CE courses in the U.S., is relatively uncommon and in the embryonic stage of implementation (Bosela 1993; Rendon-Herrero 1993a, 1993b; Shepherd and Frost 1995; and Baer 1996). Inclusion of failure information in CE courses has been deemed necessary as a result of relatively recent catastrophic failures in the U.S. (e.g., L'Ambiance Plaza and Kansas City Hyatt Regency Hotel). Such failures have heralded major efforts to prevent similar tragic events from recurring. One inclusion effort is spearheaded by the Committee on Education of the Technical Council on Forensic Engineering (TCFE), American Society of Civil Engineers (ASCE). The Committee is charged with developing and promoting ways to make CE students aware of the occurrence and likelihood of building and CE systems failures. As a CE instructor and member of the TCFE Committee on Education, the writer has participated in efforts to develop methods to accomplish that end.

In 1973 the writer taught a course entitled Construction Systems at SUNYAB that included a component on failure of constructed facilities. Since 1976 at MSU, the writer has regularly included in his courses term projects that gradually evolved from the analysis of published failure case histories to the actual field investigation of constructed facilities that either had performed poorly or had failed. These developments culminated in the establishment of a stand-alone course in forensic engineering. (See Table 1 in Appendix.)

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EVOLUTION OF THE TEACHING OF CE FAILURES AT MSU

Lectures and Article Reviews

In 1973 at SUNYAB, the writer taught a course in CE entitled Construction Systems, which included a series of lectures on failure of constructed facilities. As the term project in that course, students were asked to find and review newspaper and magazine articles having to do with CE failures.

Later at MSU beginning in 1976, the same assignment was included in required courses in Soil Mechanics and in Construction Materials (formerly called Highway Materials); the assignment, however, was modified to include the review of case studies from refereed engineering journals (Rendon-Herrero 1993b).

Addition of Failure Assessment Laboratories

In 1992 in a course on Foundation Engineering (added to the CE program at MSU in 1981), the writer decided to add a hands-on laboratory component to the assignment on failure. At the beginning of the semester, teams of students in that course were asked to look for cracks and other structural defects at existing constructed facilities on the campus of MSU. In addition, during the remainder of the semester, they were to investigate and report on the likely cause of the defects. The Foundation Engineering course is a CE technical elective for which Soil Mechanics is a pre-requisite. This particular assignment is fully described in a paper by the writer (Rendon-Herrero 1994).

In the spring semester of 1995, the requirement for the evaluation of a journal case study on failure in the Construction Materials course was discontinued and replaced by the requirement that the students perform a field investigation of existing roadway pavement defects on the MSU campus. (Soil Mechanics is also a prerequisite for Construction Materials at MSU). For this particular assignment, teams consisting of 2 to 3 students were asked to locate and investigate roadway pavement defects on the MSU campus (e.g., potholes, alligator cracking, pumping failure, and rutting). In the spring semester of 1996, the assignment was modified to include off-campus roadway pavement sites.

Once a roadway pavement defect was located at the beginning of the semester, the students were asked to submit a form on which they indicated the location of the selected defect, description of the type of pavement (i.e., flexible or rigid), and type of pavement defect. On the form, the students also were to describe the defect in as much detail as was feasible. The form was returned to the writer for approval of the selected defects and locations. The students were then directed to conduct a thorough investigation of the defects. This consisted of a reconstruction of the pavement cross-section. The cross-section shows the thickness and description of the surface course and base course(s), and the subgrade. For cases such as potholes in flexible pavements, it was feasible to dig a hole through the pavement and take samples and measure the thickness of the various pavement layers and treated subgrade soil. In other cases, where it was not feasible to dig a hole, large surface cracks or large pavement joints allowed the students to drill a small diameter hole and obtain sample cuttings with a hand auger.

Pavement and subgrade samples were taken to the Construction Materials laboratory at MSU for testing (e.g., visual identification of materials, grain-size analysis, moisture content determination, liquid and plastic limit tests, and, in some cases, Proctor compaction tests). The soil materials were also classified according to the AASHTO Soil Classification System. The results of the tests were then compared to tabulated physical index and chemical properties of the soil as shown in a USDA Soil Survey Report for Oktibbeha County, Mississippi. The students also took photographs of the defect, from close-up and at varying distances.

The field and laboratory investigations were on-going throughout the semester on the students' time. The students were, however, given a schedule for completing the various tasks assigned to them. In the second third of the semester, the writer scheduled individual meetings with the student teams at the various pavement defect location sites. At that point in the semester, they were asked to bring all of the information that they had compiled for the investigation. The meetings were scheduled in the afternoon for the students' convenience. At the defect location, the students disclosed their findings as asked, by describing the defect in detail, the composition of the pavement cross-section, and the cause of the pavement failure.

Discussions at the site were very informal and the objective was to try to reach a consensus about the causes of the creation of the particular defect. Once a consensus was reached, the students were given the go-ahead to prepare a group report. Besides the general discussion, the report was to include figures, diagrams, and tables from the soil survey report; a pavement cross-section; location map; laboratory test results; and photographs with pertinent captions. The students were asked to support their findings and conclusions by referencing their compiled data, figures, photographs, etc.

In the spring of 1996, students in Foundation Engineering were asked to investigate performance deficiencies of off-campus residential structures in Starkville, Mississippi. Starkville has a school-year population of about 36,000 people and is located right next to the MSU campus. The writer arranged for a newspaper article to be written describing the Foundation Engineering course and the special assignment to investigate off-campus houses (Starkville Daily News 1995). In the article, local homeowners with houses having structural defects were asked to volunteer their homes for the one-semester study. Thirty (30) homeowners responded to the newspaper article request for volunteers and were sent a questionnaire to obtain information about their house and property. That information was then used by the writer and the students in the course to rank the houses according to the severity of damage, whether or not construction drawings and specifications were available, etc.

The homeowners were then interviewed by the students via telephone, and permission was requested for a preliminary visit to the various residences to examine the reported defects and to inspect the house and property. This preliminary visit was performed by the students in teams of 2 to 3 individuals, and each team had 2 houses. After the preliminary visits, the students were able to "fine-tune" the rankings on the basis of the questionnaire and their observations. Ten (10) houses having the highest ranking (i.e., the worst condition) were finally selected for the study.

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By the time the houses were selected during the early part of the semester, some degree of "bonding" among the team members had developed. The writer, therefore, decided to keep the original teams together and assign them the houses they had previously examined during their preliminary visits. All of the 30 homeowners who volunteered their houses for the study were notified by mail of the outcome of the selection process. Owners of the houses selected for the study were then telephoned by the students, and a mutually agreed-to schedule was set up to conduct a comprehensive investigation of defects and their causes during the remainder of the semester.

The investigation included initial and exit interviews with the homeowners, a comprehensive visual inspection of the house and property, photographs of defects and other important structural features, collection and evaluation of existing information (e.g., construction drawings and specifications), and drilling of two hand-auger borings usually located at the opposite corners of the house. In some cases, one of the auger borings was located adjacent to a major wall or slab crack. Auger cuttings of the subsurface soil were logged according to depth and a phreatic surface and strata changes noted where pertinent. Most borings were discontinued at a depth below which it was not feasible to auger by hand. Various soil tests were performed at the soil mechanics laboratory at MSU for classification purposes and for estimation of certain physical properties of the soil. All of the field and laboratory work was done outside of the scheduled class period.

When construction drawings were not available and/or when the homeowner did not know what the foundation consisted of, the students dug an examination pit outside at a spot along the perimeter of the house to obtain the necessary information about the foundation configuration; where this was deemed necessary, the pit was dug at the location of a major defect or crack. The students also consulted the USDA Soil Survey Report for Oktibbeha County, Mississippi. This soil survey report contains useful subsurface information about the selected house sites; however, it is limited to data about the soil to a depth of about 1.83 meters (6 feet).

Dates for completion of each of the above tasks throughout the semester were established, and a preliminary meeting on-campus between the writer and each team to discuss the progress of the investigation and preliminary findings was scheduled. Later in the semester, the writer visited each of the selected study houses with the respective team of students. For that visit, the team was asked to bring all of the information that they had compiled about the house, point out defects and other features they had found, and provide a final explanation of what had caused the defects. As in the field investigations for the Construction Materials course, the students were asked to support their conclusions with the information they had compiled during their study. If there was a general agreement between the team and the writer about the cause of the defects, the students were then instructed to prepare a final team report. If there wasn't an agreement, then the writer suggested other things to consider that might explain what had caused the defect.

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Soils of high to very high shrink-swell potential predominate in and around Starkville, Mississippi, akin to a "jig-saw" puzzle pattern; i.e., there are areas side by side in Starkville where you do not encounter this type of soil and there are areas where you do. Soils of high shrink-swell potential will either shrink or swell excessively when subjected to a change in moisture content. Such changes in moisture content can lead to differential settlement when shrinkage occurs during extended dry periods or to differential uplift when the soil is wetted during an extended wet period. Uplift pressures can exceed 1197 kN/m2 (25,000 psf); when this potential is compared to residential foundation pressures that are on the order of 12.0 kN/m2 (250 psf), one can appreciate why these soils can be problematic. Generally, the problem is localized at a given house and can be the result of a broken or leaking sewer or potable water line, dripping garden hose spigot, or tree roots that have the GOD-given ability to find their way under the house where the water is, causing shrinkage and settlement via the removal of water from the soil. It is these types of moisture-changing situations that cause the differential movements and subsequent structural distress.

As the semester progressed, each topic in the Foundation Engineering course was supplemented with geotechnical case studies from the literature and from the writer's own experience; with specific information about what happened, how it happened, why it happened, and what could have been done to prevent it from recurring. One particular lecture was devoted to causes of performance deficiencies and failure of facilities constructed on clay soil deposits of high shrink-swell potential. The writer's personal case studies for projects in Mississippi were also presented. These particular lectures were intended for the purpose of giving the students some ideas about what they might expect to see during their investigation of the residences and what the root of the problem might be. (A similar lecture is also given in the Construction Materials course.)

Establishment of Stand-alone Course: Forensic Engineering

In the spring semester of 1994, the writer developed and offered a stand-alone course entitled Forensic Engineering. The course was divided into two parts: what forensic engineering involves and the review of forensic engineering case histories in which either litigation or an alternative means of dispute resolution was implemented. A textbook was not used; however, selected articles from magazines, books and journals were given to the students for review and discussion in class. A term paper was not assigned because most of the students enrolled in the course had had Soil Mechanics in which a term paper review of a failure case study from a journal was required.

Guest speakers included an engineer, a contractor, and an attorney who made presentations to the class on separate class meetings. The engineer and contractor talked about their experience with construction failures and claims; the attorney spoke about the legal side of engineering and construction and the law in general.

The course was again offered in the fall semester of 1997 and was modified via the addition of a textbook, Construction Failures (Feld and Carper 1997), and the addition of a Forensic Engineering laboratory. The laboratory was conducted during the last two thirds of the semester

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and involved the investigation of unique brick-veneer cracks located in the west entrance to McCain Hall, the same building in which the class met. (The cracks are reported to have begun appearing after a major renovation of McCain Hall in 1921. The cracks have continued to widen and lengthen, especially after another major renovation in 1989.)

During the second offering of Forensic Engineering, the lectures by outside speakers were more formal and were entitled "Lecture Series in Forensic Engineering" (Howard 1997; Prewitt 1997; Wardlaw 1997; and Webster 1997). This series of lectures was scheduled for presentation in the Colvard Student Union Small Auditorium at MSU. Students enrolled in the writer's Soil Mechanics course were also required to attend those lectures. (After each lecture, a luncheon was held with a pre-selected number of students from the class. This allowed the students to interact with the speaker in an informal setting.)

The 1997 lectures in the Forensic Engineering course were given by an engineer, a contractor, an attorney, and a judge during October and November, 1997. All of the speakers had had exposure to cases involving construction failures and claims. The engineer had been involved in a number of cases as an expert witness; the contractor described a number of his projects in which failures had occurred and how they were resolved; the attorney, who specializes in construction claims, spoke primarily about his experiences with expert witnesses; and the judge described the laws and rules relating to expert witnesses and his experiences with construction cases as an attorney and as a judge. The talks generated considerable discussion after the presentations.

CONCLUSION

A frequent comment from students is that the failure case studies are an eye-opener compared to material covered in some of their prior courses. They also indicate that they enjoyed the courses and benefited from the case study assignment and performance deficiency investigation of existing constructed facilities.

Although the inclusion of failure information in current courses via the review of case studies and investigation of existing constructed facilities deviates from the conventional way of teaching CE, the innovation can be adapted feasibly without excessively overburdening the instructor. Planning and monitoring the added learning activity does not require resources that do not already exist at most universities in the U. S. (e.g., library holdings of engineering journals and field sampling and testing equipment).

The obvious objection would be the added time required to plan and manage the activity. The results, however, will prove to be very beneficial to the student in the long run. The awareness that this activity may impart to the student, that some constructed facilities do indieed fail during or after construction, may mean the difference between success and catastrophe of a future project.

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APPENDIX

TABLE 1
EVOLUTION OF WRITER'S INCLUSION OF FAILURE INFORMATION IN CE COURSES AT SUNYAB (1973-1976) AND MSU (1976-PRESENT)

University	Dates	Course	Inclusion of Failure Information
SUNYAB	1973	Construction Systems	Evaluate a failure case study from a newspaper or magazine article
MSU	1976 - present	Soil Mechanics *Highway Materials	Evaluate a failure case study from a refereed engineering journal
	**1984	Foundation Engineering	Evaluate a failure case study from a refereed engineering journal
	1992 - present	***Foundation Engineering	Find, investigate, and report on a constructed facility on the MSU campus which exhibits performance deficiencies/failure
	1995 - present	***Construction Materials	Find, investigate, and report on roadway pavement (rigid or flexible) on the MSU campus which exhibits performance deficiencies/failure. (In the spring 1996, off-campus pavements were investigated.)
	1994	Forensic Engineering	Stand-alone course (with handouts) including guest lecture series
	1996	Foundation Engineering	Find, investigate, and report on single-family residences in Starkville, Mississippi, which exhibit performance deficiencies/failure (Starkville is located next to MSU)
	1997	****Forensic Engineering	Stand-alone course (with class textbook) including guest lecture series. Laboratory: Investigate and report on unusual brick veneer cracks located at the west entrance to McCain Hall Engineering Building, MSU Campus

* Changed to Construction Materials in 1989.

** Foundation Engineering added to the curriculum in 1984.

*** Requirement to evaluate a case study was dropped and replaced by hands-on field investigation of performance deficiencies/failures of constructed facility. For Foundation Engineering, this occurred in the spring 1992; for Construction Materials, in the spring 1995.

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Forensic Geotechnical Engineering Case Studies

by Oswald Rendon-Herrero, Ph.D., P.E. (076A)

INTRODUCTION

When foundations and earth structures fail, it is usually the result of excessive settlement and/or shear failure of the soil which bears them. The cause may sometimes be readily discernible or obvious; however, like the foundation itself, the answer is often deeply buried and can be discerned only by examining the technical data and project documents. A comprehensive geoforensic engineering investigation can usually determine the cause and the party responsible for the failure. This generally entails a thorough examination of many forms of documents and information, visits to the site, sampling and testing of soils, interviews with pertinent individuals, and meetings with the client and their attorneys. In some situations, however, success in determining the cause in an efficient and timely fashion is highly dependent on the geoforensic engineer's education, experience, judgment, thoroughness, and Sherlock-Holmes-like ability to identify the weak link in the problem. The geoforensic engineer, in addition to being an adept investigator and analyst, must also have an encyclopedic knowledge of soil mechanics and foundation engineering if he is to be able to scan the myriad bits of information and data and focus on what may often seem an insignificant or trivial clue.

The following five cases illustrate this point; the first three cases involved legal disputes that ended up in court; the last two are examples of geotechnical engineering troubleshooting.

Case I: Collapsible Soil (Loess), Vicksburg, Mississippi.

Developers purchased a relatively large tract of land along a major highway in Vicksburg, Mississippi. Vicksburg is located on the east bank of the Mississippi River and is well known for its wind-deposited loessial hills. The developers' land and surrounding properties are shown schematically in Figure 1a.

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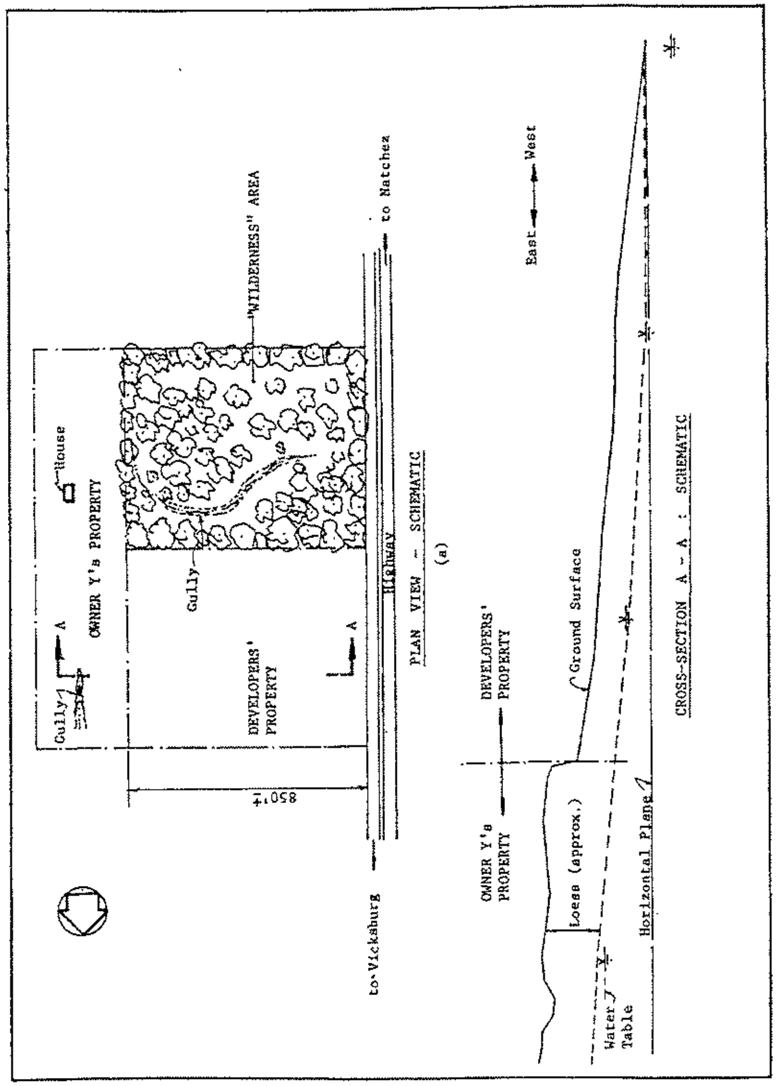

FIG. 1. (a) Schematic plan view showing three properties in Vicksburg, Mississippi.
(b) Schematic cross-section of analyzed slope.

This tract of land slopes gently upward toward the east from the highway at an angle of about 7 degrees. Upslope from the developers' property is another relatively large tract of land belonging to owner Y, which approximately parallels the highway; this property includes a house, exterior buildings, a swimming pool, and at one time a pond, all located on a ridge on one of the highest points of the property. North and downslope of the house is a gully which is actively eroding and widening. Cracks and sinkholes are located around its perimeter. The pattern of cracks suggests that movement of the ground surface is toward the center of the gully. Downslope and directly to the west of owner Y's house is a very densely wooded tract of land extending to the highway and located south of the developers' property. Because of the wilderness-like condition of this particular property, access to it is very difficult.

To clear and level the property in preparation for eventual construction, the developers began excavating and selling the soil near the bottom of the slope next to the highway. This operation was discontinued in 1981. Some time after April 14, 1983, owner Y reported that he had deep "holes" and long relatively parallel cracks, some severely faulted, around the west and northwest sides of his house. He reasoned that the removal of soil from the developers' property had created an unstable condition allowing the ground in the upslope area to slide and crack. Thinking that his house, pool, and surrounding buildings were in imminent danger of collapse, owner Y sued the developers for damages. It is important to note that the cracks, slumps, and "sinkholes" on owner Y's property, were reported to have occurred after an abnormally intense rainfall in April 1983. (Rainfall records from the Military Park in Vicksburg indicated that an abnormally high rainfall of 5.59 inches had occurred on April 14, 1983. Total precipitation in 1983 had exceeded the record in the previous 7 years. According to Lutton, "rainfall is the most important climatic factor that affects Vicksburg loess . . . Most cases of slope failure closely followed periods of heavy rainfall . . . The relation is so conspicuous that no effort was made to document it" [4]. The adverse effects of rainfall on loess soils, however, has been documented in the literature [1, 12, 19].)

As part of his lawsuit, owner Y obtained the services of geotechnical engineers in an attempt to support his contention against the developers. A geotechnical investigation was conducted including soil sampling and testing and field monitoring of the movements of the ground surface. Owner Y's engineers concluded that the soil profile generally consisted of a loess overlying a clay of high shrink-swell potential, and that removal of the soil from the developers' property was the cause of the upslope movements and cracks. It was approximately at that time that the developers' attorney asked the writer to make an independent investigation of the movements and cracks.

After a few visits to the properties and after a review of the available case documents, the writer conducted a geotechnical investigation to assess the soil conditions and evaluate the stability of the excavated slope. The soil profile indeed consisted of loess overlying clay of high shrink-swell potential; a phreatic surface was encountered at the bottom of the loess. The stability analysis showed that the slope extending from the bottom of the developers' property, where removal of soil had occurred upslope to owner Y's property, was stable with an appreciable margin of safety. The particular cross-section of slope that was evaluated is shown on Figure 1b.

A literature review revealed that loessial soils are subject to collapse when they come in contact with water; in fact, loessial soils are also known as collapsible soils [2, 5, 13, 18]. Wu points out that "any increase in the moisture content usually weakens the cementing bonds . . . only a slight increase in moisture content may affect the strength significantly" [20]. The literature review revealed that the disturbance of a loess deposit as a result of the removal of the natural surface cover, vegetation, and trees, creates a condition whereby the "exposed" loess surface is subject to collapse as a result of the "improved" downward percolation of rainwater; thus, are formed "sinkholes", cracks, and "faulting". Leonards points out that "in the natural state the loess is protected against excessive wetting by a blanket of topsoil and vegetation. Stripping these materials leaves the porous loess vulnerable to rapid wetting by rainfall. Water from construction operations and from leaking pipes and improper site drainage are other causes of excessive wetting and loss of structure in loess" [3]. Turnbull also provides an excellent review of loessial soils and their behavior in the presence of water [1, 17, 18].

During the construction of owner Y's house, a large area of the property was cleared of vegetation and trees, leaving large filled and unfilled tree stump holes. After the land was cleared, some landscaping was done; in some areas excavations were made including the construction of a pond south of the house. Long swales west of the house redirected and concentrated surface runoff at their effluent points. Because of all these changes on the natural soil cover, water was now able to penetrate the ground surface more efficiently and erode or collapse the loess subsoil structure [5, 15]. (Situations like this have caused vast farm areas in Nebraska to collapse as much as 7 feet in a period of 15 years [17, 19, 20].) Krynine and Judd have reported a case in which a house on loessial soil had settled and cracked overnight due to water discharge from a hose forgotten on the lawn [2].

On one visit to locate and photograph "sinkholes" shortly before the trial, the writer noticed that there was a subtle but definite drainage gully at the boundary downslope between owner Y's property and the eastern side of the "wilderness" area. Up to that time, no one had suspected that the wilderness area was in any way responsible for the ground movements. That day, the writer and one of the defense attorneys on the case decided to follow the gully into the densely wooded area. It was discovered that the further one went downslope in the direction of the highway to the west, the deeper the gully became; places were found where the gully was as much as 45 feet in depth. Flanking the bank of the gully were many large trees, which had in recent times collapsed toward and down the steep ravine. Numerous spalls and slumps of the sides of the gully were observed along its course. "Pipes" in the loess were also found in the slopes of the gully with evidence that soil had washed through and had been deposited at the exit point on the gully slope. These "pipes" are conduits that connect horizontally to sinkholes and cracks; surface runoff enters these openings upslope, eroding and carrying soil particles to the gully [1, 2, 17]. Nearer the highway, the gully widened, meandered, and gradually became shallower, disappearing where it reached the highway's drainage system.

If the wilderness gully had not been there prior to the development of the large tracts of land, what caused it to develop? Was the gradual deepening and widening of the gully west of owner Y's house the primary cause of ground movements and cracks? A comparison of old and recent Soil Conservation Service aerial photographs of the area showed that the gully was contemporary with the urbanization of the upslope area.

It is the writer's opinion that the wilderness gully developed fairly recently; this was primarily a result of the increased effects of surface runoff on a denuded slope and the construction of drainage swales which collected and directed surface runoff to concentrate its erosive power toward the wilderness area. As the gully became more incised, washing more and more soil away, the ground on its banks spalled and slumped with the soil behind it slumping and spalling upslope in a domino-like sequence, eventually generating the ground surface cracks on owner Y's property.

The writer's stability analysis had shown that the excavation that had taken place on the developers' property had not been sufficient to cause the cracks and ground surface movements that were manifested on owner Y's property. (Owner Y's house is much closer to the wilderness gully than it is to the area of excavation on the developers' property. Also the depth of excavation on the developers' property is considerably less than the depth of gullying in the wilderness area.) The available literature clearly shows what water will do to loessial soils, especially when the natural surface cover of these collapsible materials is disturbed via land clearing, excavation and/or landscaping [1, 3, 10, 16]. According to Terzaghi, loess is among the most treacherous of foundation soils [13]. The soil counterfort that was removed by the creation of the gully in the wilderness area (about 6000 cubic yards), combined with upslope surface disturbances, was the cause of the cracks and movements on owner Y's property.

Case II: Sensitive Clay Soil, Ascalmore Creek-Tippo Bayou, Mississippi

Construction of a flood diversion structure near the Mississippi River in Tippo Bayou, Mississippi, required the excavation of a 49-foot deep "bowl"-shaped depression in clay sediments known as channel filling deposits; the sediments include plastic "CH" clays of high shrink-swell potential. The 230 to 40 foot diameter excavation was carried out in two stages from elevation 140 feet (msl) at the ground surface to elevation 116 feet, and then from a bench at elevation 116 feet to elevation 91 feet at a 1:3 slope. The excavation was kept free of water with an extensive dewatering system. After the excavation had reached an elevation of 91 feet, the project engineers realized that a 50 foot wide 1:2 fill wedge was required from elevation 91 to 116 feet as the base on which a portland cement concrete monolith could be constructed. Figure 2 is a schematic plan view and cross-section of the excavation.

The contractor constructed the 1:2 fill wedge on the 1:3 cut slope from elevation 91 to elevation 116 feet without any objections from the project engineer's resident inspector. By the next morning, however, the 1:2 fill wedge had slid into the excavation. The project engineer then ordered the contractor to rebuild the 1:2 fill wedge. Again, under the watchful eye of the resident inspector, the contractor resumed construction of the 1:2 fill wedge, which also failed before it was completed. Since the contractor felt that they were prudently following the project engineer's plans and specifications, they decided to obtain legal assistance and engineering advice before proceeding with the construction of the third fill wedge. At that point, the sliding problem was delaying the contractor's schedule and increasing his project costs.

After the second slide, the writer was asked to investigate the problem and determine why the 1:2 fill wedge was sliding. After a preliminary meeting with the contractor and his construction superintendent and after reviewing the available construction documents, a clue was found in the geotechnical data

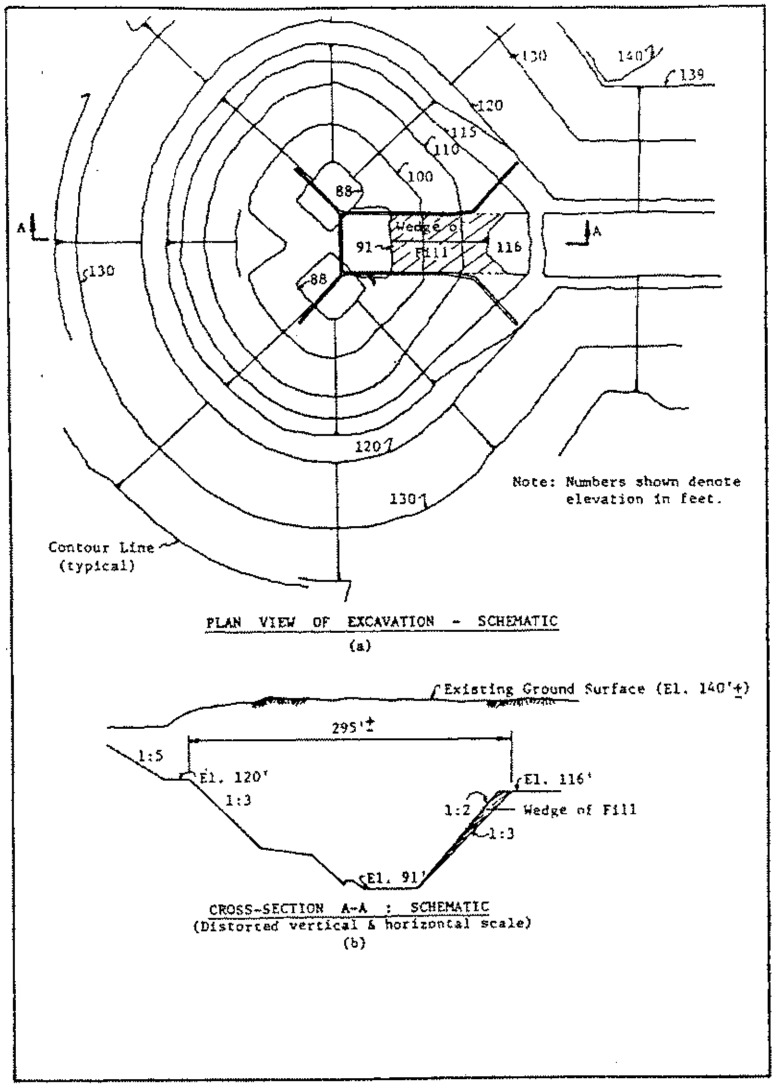

FIG. 2. (a) Schematic plan view of excavation for Control Structure, Ascalmore Creek — Tippo Bayou, Mississippi.
(b) Schematic cross-section of excavation.

that offered a reasonable explanation for the wedge failure. A consolidation curve of a specimen of soil, that was sampled from the soil zone in which the slide had occurred, exhibited a peculiar downward concave shape which led the writer to suspect that the soil on the 1:3 slope was sensitive to remolding; i.e., its shear strength would be decreased as a result of the disturbance caused by the excavation equipment and other operations. A sensitive soil is one whose shear strength after being remolded at a given moisture content is appreciably less than its original unremolded condition at the same moisture content. For example, a soil that has a moisture content of 30 percent by weight, sensitivity of 8, and a virgin compressive strength of 800 psf, will have a strength of 100 psf after it is remolded, recompacted, and tested at the same moisture content. A consolidation curve provides information as to how a soil will deform as water is squeezed out of it with time under a given pressure.

A review of the literature on sensitive soils and geotechnical data provided by the project engineer revealed that the soil was indeed very sensitive to remolding. (For a classification of soil sensitivity, see Table 1 [8].) Therefore, when the excavation was made from the ground surface down to the 1:3 soil slope, the clay was relieved of the pressure imposed by the soil overburden thus causing it to expand and lose some of its strength; however, more important was the loss of strength due to remolding by the excavation equipment itself.

The project engineers had not accounted for the high degree of sensitivity of the clay soil in their analysis; therefore, they determined that the fill wedge would be stable. When the actual sensitivity of the soil at the fill wedge-subgrade interface is accounted for, however, one finds that the wedge fails in sliding. It is very likely that the project engineers had not suspected or considered the clay to be sensitive because soils with a high shrink-swell potential generally are not known to be sensitive. There is also a prevailing view by geotechnical engineers that such materials do not exist "this far south." The present writer has described this case in detail [6].

Case III: Omission of Vapor Barrier and Tennis Court Surfacing Bubbling, Central Mississippi

Bubbles began to appear on the surfaces of tennis courts shortly after they were constructed for a major city in Mississippi. The contractor who had built the tennis courts was told to remove the bubbled elastic surfacing material and install a new one as specified in the plans and specifications. The contractor complied with the request and installed a new surfacing at his expense. The

TABLE 1. Classification of *Sensitivity Values [8]

	S_t
Insensitive	1.0
Slightly sensitive clays	1-2
Medium sensitive clays	2-4
Very sensitive clays	4-8
Slightly quick clays	8-16
Medium quick clays	16-32
Very quick clays	32-64
Extra quick clays	>64

$$^{*}\ S_t = \frac{\text{Virgin (Undisturbed) Compression Strength}}{\text{Remolded (Disturbed) Compression Strength}}$$