Apr 13th - Apr 17th

Eleven Case Studies of Failures in Geotechnical Engineering, Engineering Geology, and Geophysics: How They Could Have Been Avoided

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ELEVEN CASE STUDIES OF FAILURES IN GEOTECHNICAL ENGINEERING, ENGINEERING GEOLOGY, AND GEOPHYSICS: HOW THEY COULD HAVE BEEN AVOIDED.

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ABSTRACT

When a failure occurs, geotechnical engineers, engineering geologists, and geophysicists assign its cause to an event that immediately precedes the failure, such as an earthquake, heavy rainfall, flood, or other natural event. Assigning the failure to the immediate event is misplaced; the metastasis occurred because marginally stable conditions were allowed to exist through substandard investigations by the technical personnel, improper design, and inadequate review by the permitting agency.

The fundamental cause of the failure is human error and is manifested in one or more of six categories. (1) Before the investigation, during discussions with the client. (2) During the investigation, by collecting inadequate, incomplete, or incorrect data; altering the field or test data to make them more favorable. (3) After the investigation, when the inadequate data and invalid conclusions are incorporated in the final report. (4) During the review process, when the reviewers accept the substandard report. (5) After the agency approves the substandard report. (6) After the agency grants the permit that allows construction to begin and after the work begins.

Eleven case studies of failures are described including landslides, dam failures, floods, and ground subsidence. Each case study identifies (1) the immediate event, (2) the fundamental cause, (3) how the inadequacies and deficiencies in one or more of the six categories contributed to the failure, and (4) how the failure could have been prevented.

Each of these failures resulted in civil or criminal court action. Depending on the facts in each case, penalties were imposed on the engineer, geologist, or geophysicist.

1.0. INTRODUCTION

This paper describes a wide range of failures in which the owner/developer (client), technical consultants, reviewing and permitting agencies, and/or politicians worked in concert to allow the conditions that led to the failure. It is important to recognize that almost all completed projects do not fail. The most egregious failures get public attention.

Failures occur because human errors allow marginally stable or unstable conditions to exist through: (a) inadequate or improper technical investigations, (b) inadequate technical review by the permitting agency, (c) interference by the owner/developer (client), and/or (d) political interference to have the project approved even though the facts indicate the report is substandard and/or the site is unsuitable. Technical professionals and permitting agencies blame the failure on an immediately preceding, natural event such as an earthquake, large amount of rainfall, landslide, or flood. **Such blame is misplaced; it is an attempt to shift the blame to a non-human event.**

The fundamental (real) cause of failures is human failure. In a proper investigation, naturally occurring events are known to exist, are anticipated, and are properly incorporated in the design. Potential consequences of these events are mitigated and the failure does not occur.

In the case studies described, we do not want to embarrass the technical consultants, the owner or developer, or the reviewing or permitting agency. Therefore, the case studies do not identify the specific location or any of the participants. The case studies are located in Iran, Italy, Pakistan, Turkey, and United States and are documented in public records of the court proceedings, permitting agencies, and Licensing Boards.

The authors of this paper have provided expert witness testimony in court in the United States and in other countries. One of us (DC) provided testimony as a "Friend of the Court" in twelve cases, including four of those described in this paper.

Floods, earthquakes, and landslides occur naturally and when facilities or people are not affected, the public has little concern. But, when they cause failures to buildings, etc., the public is concerned. All of the failures to structures described in this paper could have been prevented through proper field investigation, design, and construction. These three elements, had they been conducted and implemented honestly, would have anticipated and accommodated potential damage to the facilities from the natural events. When such failures occur, litigation follows. Engineers and geologists commonly use "standard of practice" or "standard of care" as a defense. Section 1.1 includes comments on standards of practice or care and are based on our experiences as expert witnesses and "Friend of the Court".

1.1. The Concept of Standard of Practice or Care

When failures occur, many engineers and geologists who worked on the projects claim they applied the standard of practice or standard of care to the project and argue that they should not be blamed for the failure because they applied these "standards". Although the phrases "standard of practice" and "standard of care" may seem impressive, they are meaningless for several reasons.

These "standards" are qualitative statements and are not sets of uniform criteria practiced uniformly everywhere; they differ from one jurisdiction to another. Applying these "standards" are neither synonymous with nor a substitute for applying the highest quality of professional investigation. The "standards" also should not be interpreted to be or confused with jurisdictional building codes. Building codes are more formal documents that provide, for example, design criteria for high-rise buildings, dams, and other critical structures. As such, the codes are legal documents whereas the "standards" are not. Except for the Uniform Building Code (in the U.S.), local building codes differ between different jurisdictions and these local codes are not "standard".

In effect, the codes are minimum requirements and, in reality, only provide a framework for a design criterion. For example, in aseismic design, the codes do not consider different damping that different structure may have. The decision for assigning the appropriate level of damping is left to the judgment of the engineer. The engineer or geologist who applies these minimum code requirements to every site, regardless of the adverse conditions that exist, is acting irresponsibly. How many geologic and geotechnical failures have occurred after the site or facility "was built to code"? Importantly, nothing in the codes prevents the professional from applying a more rigorous or conservative investigation or design whenever the field conditions warrant.

In the past, an engineer or geologist in a court case used the defense that he applied the "standard of practice", "standard of care", or that he "met the code" at the time the project was completed. For at least 40 years, judges and juries have not accepted this argument as a valid defense. (Judges try cases with respect to the "standard" or "code" that existed at the time to defendant investigated the site or designed the facility). In several cases, the presiding judges admonished the engineer, geologist, and the defense attorney for using the specious defense of shifting the blame for the failures from the professional by implying that the "standards" and "codes" are the reason for the failures. The judges clearly stated that the "standards" and "codes" are minimum guidelines at best, are inadequate to protect the public, and that engineers and geologists have a professional responsibility to protect the public. One judge stated that those engineers and geologists who abdicate this responsibility are fundamentally dishonest. One judge asked an engineer, if the standards and codes that existed are so good and are definitive, why are they constantly being changed and made more rigorous? The engineer had no answer.

Judges, juries, and the public expect professionals to conduct their investigations thoroughly, competently, and proficiently. They expect the work to be done correctly and the recommendations are sufficiently conservative to prevent failures. The primary responsibility of the engineers and geologists is protection of the public, regardless of other interests that may be promoted. Some engineers and geologists have not acted in this way. In Section 3.0, a case study is presented in which "other interests" were promoted to the detriment of protecting the public.

Recently (AB269, 2002) The State of California enacted a law that states, in part, "…Protection of the public shall be the highest priority…Whenever the protection of the public is inconsistent with other interests sought to be promoted, the protection of the public is paramount."

2.0. FUNDAMENTAL VERSUS IMMEDIATE CAUSES OF FAILURES

2.1. Before the Investigation

Discussions begin between the client (owner/developer) and the technical consultants. The consultant reviews existing data and reports related to the site and from nearby areas. A site-specific work plan is prepared. At this stage, potential geotechnical, geologic, and/or geophysical hazards are identified (e.g., earthquakes, floods, landslides, active faults). Staff is allocated, an estimate of time and cost is made, and the proposal submitted to the client.

2.2. During the Investigation

This category is where the most serious deficiencies develop. Quality assurance and quality control are rarely implemented and are not taken seriously. Commonly, low-level staff is assigned to conduct the field work and laboratory tests. These people are the least qualified, least experienced, and least knowledgeable to do the work properly. A senior staff member may check the work done by staff, but does not conduct detailed investigations for the purpose of identifying deficiencies in the work of the low-level staff. Examples of the deficiencies are presented below.

The staff geologist does not identify a thin clay layer that is a potential landslide plane, does not identify a bedding-plane fault, does not identify a fault as being active, or does not identify bedding or joint planes as potential flow paths for water.

The staff geophysicist chooses surface or borehole geophysical instruments that are not appropriate because the methods do not have sufficient resolution, depth penetration, do not measure the targeted properties. He designs improper or insufficient survey line orientations or station spacing and does not use complementary methods to reduce the ambiguity (or enhance the reliability of) the methods. Data are not reviewed in the field to identify "busts" resulting from instrumental causes or external sources (e.g., electric power lines, lightening); these errors are carried through the analyses and interpretations. Another source of error is related to the software used to collect and reduce data and to calculate the results. [One of us (DC) identified errors in two commonly used commercially available computers: one for frequency domain EM and the other for transient EM surveys. The developers denied the software contained errors; DC identified the locations of the errors in the programs, suggested corrections, and the developers made the corrections. Of interest, the developers did not notify existing users of the software that contained the errors.]

The staff engineer does not perform field tests adequately. Laboratory tests are conducted that may not be appropriate; samples may not be representative or, more importantly, may not be the rock type most likely to fail (i.e., the "weakest rock"). Anomalous test results are discarded without assessing the reason for the anomaly. (The reason for the anomaly may be unrecognized plane of weakness in the sample). The equipment may not be calibrated to standards and the test results would have a bias.

The measured values are reported as being accurate or precise, either explicitly or implicitly. Such reporting is misleading and dishonest. Unless the **true** value is known, the terms "accurate" and "precise" are meaningless; we never know the **true** value.

Field and laboratory data are assumed to be valid. Maps and cross-sections are prepared, test data are tabulated, and stability calculations are made. The information is assessed, interpreted, integrated, and conclusions are made. A report is prepared and submitted to the client.

2.3. After the Investigation

Both the client and the consultant have a vested interest in the report and the project. Generally, discussions occur between the consultant and client to review the essence of the report before it is submitted to the reviewing and permitting agency. The client "recommended" changes be made to the report in order to make the report "more favorable" to the project.

2.4. During the Review/Permitting Process

The reviewers may or may not identify deficiencies in the report (e.g., incorrect data, calculations, geophysical equipment, improper geotechnical test, incorrect interpretations). If, in the reviewer's opinion, the report is acceptable, the report will be approved and a permit granted.

If deficiencies are identified, the reviewer may ask for clarification, corrections be made, additional tests be conducted, etc. At this stage, the consultant will discuss the request with the client to decide the next step. The client may not want to spend more money and time on additional work. The client may request the consultant to "modify" the report in order for it to be approved. The consultant may or may not honor that request.

The consultant may deny that errors exist. The consultant may or may not conduct additional investigations. The consultant may rewrite the report such that the errors are minimized, made to appear insignificant, and stating they are not an obstacle to a safe product. A revised report is submitted to the agency and the agency may approve it. If the consultant cannot satisfy the requirements of the agency, the client may enlist the aid of a politician to speak to the head of the permitting agency and "request" the report be approved and the permit granted.

2.5. Acceptance of the Substandard Report

The agency's acceptance of the report allows the permit to be granted. Grading begins at the site. As soon as the consultant's substandard report is accepted, the permitting agency becomes a knowing party to the errors and becomes a complicit party.

2.5.1. The Key Role of the Permitting Agency. The reviewing agency conducts a technical review of the report to determine if it (1) identifies hazards and how they would impact the final product (homes, etc.), (2) omits known hazards, (3) contains correct and sufficient data to support the conclusions, (4) contains conclusions that describe the impact of the project on the existing geologic conditions and processes at and near the site, and (5) contains assurance that the recommendations will mitigate any adverse geologic conditions and will result in a safe product (Larson, 1992).

Completion of the proposed project results in a product that adds value for the public good and increases the tax base. Thus, there is a political and economic incentive to grant the permit. The agency that grants the permit certifies the site is safe for its proposed use. **In order to protect the public, the agency must remain honest, objective, and apolitical.** Most, if not all failures, would be avoided if the personnel in the reviewing and permitting agency retained integrity in the review process.

2.5.2. Agency Personnel. The agency uses reviewers who are employed by the agency or are contract personnel. Some agencies have employee reviewers who do not have a technical background, either through training, education, or experience. Yet, they are asked to review and comment on technical reports. These employees are civil servants and cannot be sued. Reviewers may be contract technical professionals (engineers, geologists) who insist on a hold-harmless clause in the contract that exempts them from culpability in a lawsuit. In effect, the reviewers can accept substandard reports and not be held legally responsible for a future failure. If the reviewers are honest in their review and recommend against granting a permit, they may be, and have been, overruled by the head of the agency.

The technical personnel who review the reports are familiar with the geologic and geotechnical facts at the site. Yet, they approve the false data and conclusions in the substandard reports. By approving deficient, dishonest, and/or incomplete reports, the reviewers and the agencies become a knowing and complicit party in the deception.

In most cases, litigation is the last recourse for those damaged after other attempts have been exhausted to resolve the damage caused by the failure. Among the defendants is the governmental reviewing agency.

2.6. After the Work Begins at the Site

Geotechnical or geologic conditions may be identified that were not expected or may be different than those described in the report. These conditions may be adverse to the project and (1) may be allowed to remain because the cost to repair the condition would be too high or (2) the adverse condition is opined to not pose a hazard to the safety of the project. The project is allowed to continue as planned. In addition, adverse conditions may not be identified. If they are not identified, they cannot be corrected.

3.0. A CASE STUDY THAT CONTAINS ALL SIX CATEGORIES

This case study describes the events that led to several homes having been destroyed in the immediate vicinity of an active fault (Halper, 2002). The current geotechnical consultant blames the homeowners for the distress to the homes by over-watering their lawns. The key participants in this study include the original owner/developer, subsequent developers, original geotechnical/geologic consultants, subsequent consultants, local permitting agency, local politicians, and attorneys.

3.1. General Conditions at the Site

Topography at the 3,300-acre site in Southern California consists of hilly terrain with jagged ridges and steep slopes; geology consists of folded and faulted sedimentary rocks. One of the faults shows evidence of recent fault displacement. Earthquakes have been instrumentally located along the fault, the two most recent were a M_L=2.4 and 4.6 occurred on September 3, 2002. Because of the recency of displacement and the presence of earthquakes along the fault, geologists classified it as being “active”. The fault was designated by the State to be in the Alquist-Priolo Special Studies Zone Act, before the initial site-specific investigations were made.

3.2. Alquist-Priolo Special Studies Zone Act

In the 1970’s, a M_L=6.4 earthquake occurred in Southern California; 65 people died and $500,000,000 in damage occurred. As a result, the State Legislature passed the Alquist-Priolo Special Studies Zone Act. Its purpose was to protect the public by requiring detailed geologic studies be conducted at sites within an active fault zone and to prohibit construction of homes, schools, hospitals, office buildings, etc. over an active fault and within the fault zone. It required a set-back of 15 meters (m) on either side of an active fault or any of its branches. The locations of the faults are published by the State (Alquist-Priolo Special Studies Zone Maps); these maps are periodically up-dated.

The first draft of the law included provisions for strict guidelines for investigations in areas of active faults and strict guidelines for assessing the safety of the site and facilities placed on the site. The real estate interests objected to those strict guidelines; some geologists and engineers objected on the grounds that the law would expose them to lawsuits. As a result, the strict provisions were removed. The effect of removing the provisions allowed unsafe conditions to exist or not be reported.

3.3. Geologic Investigations at the Subject Site

The consultant hired by the original owner/developer identified the active fault and four active fault branches at the site and homes were built outside the 30-m set-back zone. The property was not completely developed and the vacant property was sold to another developer who hired a different consultant who also identified the active fault. The developer removed that consultant and hired a geotechnical engineer who concluded that additional homes could safely be built; geologists advised against the construction and additional homes were built. These home are now experiencing structural distress. This developer sold the undeveloped property to a third developer.

3.4. City Personnel and the Reviewing/Permitting Agency

The homeowners became upset. They accused the city government of allowing the construction to proceed regardless of the geologic hazard. They claimed a former Assistant City Manager was hired by the developer after leaving his City position and argued that such action is a violation of State lobbying laws. In effect, the former employee acted as a representative for the developer. In addition, the City Attorney who reviewed the approval process worked for the developer at a different real estate company. Although the City Attorney informed the manager of his connection to the developer, the City Manager ruled that the City Attorney need not recuse himself. Members of the City Council and the former mayor were not aware of this apparent conflict of interest and the City Attorney did not recuse himself.

A critical element in protecting a potential home buyer is to give the buyer a document that factually discloses existing geologic hazards at or to the property. During the original construction, the former Assistant City Manager asked the Planning Commission if the term "active earthquake zone" could be deleted from the disclosure documents that would be given to prospective home buyers. His reason was that such a disclosure might frighten prospective buyers. The Commission agreed to modify the "active earthquake zone" language and indicated that prospective home buyers could be told that they were moving into a "potentially active earthquake zone". [Author's note: A significant technical difference exists between "active earthquake zone" and a "potentially active earthquake zone".] The City Council approved the construction in the active earthquake zone and inserted the "potentially active" language in the disclosure documents.

Litigation by homeowners was begun related to the distressed homes.

3.5. Lessons Learned

All six categories are present in this case study. Category 1 exists because subsequent developers and their consultants attempted to circumvent the law. Categories 2, 3 and 4 exist because the subsequent consultants claimed they did not see the active fault and related branches -- even though they existed, were identified by the original consultant, were shown on the State map, site maps, and described in reports. The different opinions are not a matter of geologic interpretation! The subsequent consultants allowed homes to be built within the restricted set-back zones because the consultants chose not to recognize the active faults -- if an active fault does not exist, there is no set-back zone. Category 5 exists because the permit process failed as a result of inadequate review of the reports, probable conflict of interest, deception by not disclosing material facts (not properly identifying the first geologic report and not properly defining the significance of the Alquist-Priolo Special Studies Zone Act to prospective home buyers). Category 6 exists because the construction was allowed to proceed within the active fault zones. Homes are currently being destroyed. The only recourse for the homeowners is litigation.

Unfortunately, it is not uncommon for unscrupulous developers to hire consultants who will provide a report that is favorable, regardless of facts of existing hazards. It is even more unfortunate that consultants would provide such a report.

4.0. TEN CASE STUDIES OF FAILURES

The case studies described below are in the public record. They are separated into Geotechnical Engineering, Engineering Geology, and Geophysics based on the predominant discipline. We will not identify the consultants because we do not want to further embarrass them. For the same reason, we do not precisely locate the site of the investigation. Quotation marks are direct quotations from reports, court proceedings, or Licensing Boards.

4.1. Geotechnical Case Studies

4.1.1. A geotechnical engineer investigated a site for a housing tract that contained a known active fault. Earth materials consisted of 3 m of alluvium overlying bedrock. The fault was shown on published maps, described in the open literature, and in reports of adjacent sites. The engineer's final report submitted to the permitting agency stated that "The fault was not exposed at ground surface and, therefore, did not exist at the site." He did not conduct trench studies. The reviewing agency's reply was that available information indicated the fault existed at the site and provided the consultant with published maps, reports of adjacent sites, and references to the consultant. The agency recommended a trench be placed across the strike of the fault. The engineer refused, stating that his investigation was conclusive. The agency persisted and the engineer agreed **only** because the agency stated it would not approve the report without documentation that the fault either did or did not exist at the site.

A 4-m deep trench was dug. The trench walls were not supported with shoring. The consultant's staff engineer entered the trench, identified the fault in bedrock, and traced it through overlying alluvium to ground surface. He began to photograph and map the fault when the trench collapsed and killed him. Work stopped; the engineer did not complete the project.

The initial investigation did not identify the fault because it was "not obvious at ground surface", being covered by grass and bushes. The engineer's decision to not conduct subsurface investigations was not consistent with the standards of practice for active fault investigations. The active fault was an existing adverse condition and posed a hazard. The agency correctly requested additional work be done and refused to grant a permit based on the information contained in the initial report.

The death resulted in criminal action against the engineer. At trial, the engineer blamed the collapse of the trench on "Evaporation of soil moisture; the surface tension of the pore water was reduced and no longer held the grains together." That argument was dismissed by the court as being not relevant; the trench collapsed because it did not have shoring. In addition, the engineer violated Federal and State laws by not shoring the trench. The court remanded the engineer's technical report to the Licensing Board. The Board's action has not been made public.

The permitting agency acted properly. The engineer did not follow standard practice for (a) not investigating subsurface conditions of a known active fault and (b) not shoring the trench. His argument that evaporation of soil moisture caused the trench to collapse was specious. Had he followed Federal and State laws to shore the trench, the death would have been avoided.

4.1.2. A landslide occurred under a housing tract after several days of heavy rain. The geotechnical report prepared for the developer and submitted to the permitting agency stated that the slope was stable and the site did not contain potential slide planes. A building permit was granted based on the information in the report. Following the landslide, a lawsuit was filed by the homeowners; both the engineer and permitting agency were named as defendants.

A geotechnical engineer hired as an expert witness by the attorney representing the homeowners drilled several holes through the landslide, identified the basal slide plane and several overlying slide planes, all of bentonite. All bentonite layers had adverse orientations and would daylight in the proposed cut slopes.

During the trial, the engineer who worked for the developer blamed the failure on the rain, the related rise in ground water, and the increase in pore-water pressure. Discovery for the trial identified boring logs from the investigation for development. The logs revealed the presence of the same bentonite layers identified by the (plaintiff's) attorney's engineer. Handwritten notes on the logs included the comment "These bentonite layers are not potential slide planes. No need to test these materials." and was followed by the initials of the developer's engineer. The values used in the stability calculations were those of a tested sandstone, with much higher values of cohesion and shear strength than those of bentonite. Calculations were not made where the cut slopes excavated earth materials in the toe area of potential landslides.

During the trial, the permitting agency claimed it never saw the logs or the handwritten notes; it granted the permit based on the data submitted. However, the agency acknowledged it knew that bentonite layers were present in the area from its review of reports of adjacent sites. For unknown reasons, the agency did not request the logs of the subject site. In court, the developer's engineer stated that bentonite layers were not potential slide planes. The court's appointed independent expert stated that the developer's engineer's statement was not consistent with the geologic conditions at the site and with the proposed construction of the cut slopes. The court found that the instructions of the developer's engineer's to not test the materials was not consistent with standard professional practice.

The court also found that the agency accepted a substandard report and should not have granted a permit. It stated the agency should have requested the boring logs, given the fact that it had reports in its files and knowledge of surrounding sites. The agency should have requested calculations be made for those areas where the toe area of potential landslides were excavated.

The engineer for the homeowners conducted tests on the bentonite and made stability calculations. The calculations showed marginally stable conditions without water overlying the slide plane (FS=1.0) and unstable for 0.5 m of water above the slide plane (FS=0.95).

The court found that the failure resulted because an unstable condition was allowed to exist because of inadequate site studies, inadequate testing, the engineer's incorrect conclusion that bentonite was of no consequence to stability, absence of stability calculations for the areas where the toe of potential landslides, and others.

The court found that the engineer's decision not to test the bentonite was troubling. The engineer knew of their adverse orientations based on the design and locations of the proposed cut slopes. In court, the engineer was asked why he did not conduct stability calculations in the area of the cut slopes and in the toe of areas of potential landslides that would result in a withdrawal of lateral support. His reply was that "The land was stable and there was no need to make those calculations."

The site was unstable before the rains and construction aggravated the condition. The engineer's actions were deemed by the court to be substandard. He was ordered by the court to pay damages to the homeowners. The engineer's work was not sent to the State's Licensing Board.

4.1.3. A landslide occurred under a housing tract after a M_L=6.7 earthquake occurred and destroyed homes. The geotechnical engineer who developed the site stated the slippage was "caused by the ground shaking and that the site did not contain slide planes."

Discovery during litigation revealed several potential slide planes with adverse orientations. The report for development of the site that was submitted to the permitting agency contained stability calculations **only** for the static case. The agency did not request calculations for the dynamic case. Discovery during trial revealed that calculations for the dynamic case **were made** by the engineer. Handwritten notes by the engineer, containing his initials, had the words "Destroy these notes!" The calculations showed that for the dynamic case was, FS=0.90, well below the value acceptable to the permitting agency. The agency granted the permit without having those calculations on the relative stability of the site subjected to earthquake shaking.

The court concluded that the agency should not have granted the permit; granting a permit without calculations for the dynamic case was against the agency's written policy. The engineer knew of the adverse conditions and made no attempt to mitigate them. With respect to the stability calculations for the dynamic condition, he provided instructions to "Destroy these notes!". The court found that the engineer's instructions to "Destroy these notes!" was an attempt to deceive. In effect, he submitted a report that was not factual and was professionally dishonest. The court concluded that the engineer "…purposely and willfully acted to deceive…in order to have the site appear stable."

The court submitted the engineer's report to the Licensing Board. The Board's conclusions were that the engineer "Purposely withheld information not favorable to the client, attempted to destroy evidence, and was negligent in conducting his professional activities." A monetary fine was imposed.

<u>4.1.4.</u> An earth dam was built in a canyon to prevent floodwater from entering a community downstream. Five years later, the dam failed after a series of heavy rains. Water accumulated behind the dam, flowed over the dam, eroded a "V-slot" in the dam that widened and deepened through erosion, and the dam broke. Flood waters flowed into the community downstream, killed 3 people and 500 livestock, resulted in $25,000,000 in damages to commercial and residential buildings, a school, a firehouse, a police station, utilities, roads, and railroad tracks. Commerce was disrupted for four weeks. The engineer blamed the failure on the rains.

The community was flooded several times previously; a decision was made to build a dam. The contract between the engineer and the City Council was to design a dam and included the instruction that the dam was "…to prevent the community from future floods and crippling economic losses." The engineer used the "design storm" to determine the height of the dam, and referenced the book "Hydrology for Engineers" (Linsley, Kohler, and Paulhaus, 1975, McGraw Hill, 2nd ed.). Litigation followed the disaster.

Discovery during the trial indicated the proposal and contract were not subject to competitive bids, but was sole source to the engineer. During the trial, it was revealed that the engineer was chosen because he was a relative of a member of the City Council. The report, calculations, and recommendations were accepted by the City Council without independent technical review.

The court found that the engineer did not have the knowledge, experience, or technical qualifications to design dams or flood control structures, either by education or experience, and that the decision to choose the engineer by nepotism was inappropriate. The court found that the engineer's design criterion was not appropriate. The same reference used by the engineer cautioned against the general acceptance of the "design storm" as the only criterion for design of the dam: "The design storm, even if the frequency is known accurately, is inadequate for economic analysis which should be made for flood mitigation…" (p. 360). During the trial, the engineer stated he used this design "Because it was described in standard text and I relied on that reference."

The court appointed expert stated that a professional review of the proposed design prior to construction would have identified the deficiency. A different design would have been proposed, one that would have been appropriate for the purpose of the dam and the failure would have been avoided. She stated "The dam was located in a canyon with steep walls and the engineer's design height of the dam was too low. My calculations for design would have resulted in a dam that was 75 m higher, and the walls of the canyon above (her design) height would still be another 150 m."

The engineer was instructed by the court to pay for damages. His work was submitted to the State Licensing Board and his license revoked. A separate criminal trial followed because of the death of three people.

4.2. <u>Engineering Geologic Case Studies</u>

<u>4.2.1.</u> A geologist conducted hydrologic tests at a site to assess its suitability as an underground liquid toxic waste disposal system. Investigations indicated that the rocks contained three sets of fractures. One prominent set, with open fractures (≤ 0.5 cm), was orientated such that fluids would flow downgradient, toward a livestock ranch. Based on percolation tests and analyses of transmissivity, the contaminants would be expected to reach the ranch about two years after injection. The geologist concluded the site was <u>**not suitable**</u> for the disposal system and recommended that the site not be used.

About a year later, the geologist was asked by the same client to conduct additional percolation tests and analyses at the same site. The results of these studies were different than those of the previous study. He concluded that the site <u>**is suitable**</u>. Based on his report, a permit was granted to proceed with the design and construction of the disposal plant and system. Two years after the toxic liquid waste was injected, toxic materials were identified in water wells at the ranch. Litigation followed.

The plant operator and the geologist were named in the suit. In court, the geologist stated that his second set of tests and analyses were correct and blamed the operator of the plant because he "…used too much pressure in injecting the toxic liquid waste." The operator denied that allegation.

The court appointed expert stated that "Both sets of tests were conducted in the same area. The first set of tests and analyses were more rigorous and were conducted using appropriate methods and analyses. The later tests and the analyses were substandard because they did not comply with standard practice and with local ordinances." The values of transmissivity used in the later study included values of hydraulic properties different than those in the earlier study; the previous values were based on laboratory tests whereas the later values were not.

The court appointed expert conducted field tests and analyses that confirmed the results of the earlier study. He testified the argument used by the geologist that "…the operator used too much pressure in injecting the liquid waste…" was not correct and that "…the liquid was put underground by pouring it into the casing installed in the disposal wells, allowing the liquid to fall by gravity and flow out through perforations in the casing."

During discovery, minutes of a meeting between the geologist and the operator indicated the operator told the geologist "…to determine that the site could be used for liquid waste disposal." After that meeting, the second set of tests and analyses were conducted.

The court determined "…that a collusive act occurred and an attempt was made to deceive the permitting agency." The court dismissed the geologist's argument of excess pumping pressure and admonished him of trying to shift the entire blame to the operator of the plant." The court instructed the geologist and plant operator "…to pay for all damages incurred to the ranch and to extract the toxic liquid from the groundwater." The court ordered the Licensing Board to revoke the license of the geologist.

The toxic waste contamination would have been avoided if the geologist had been honest, relied on his original tests, and not engaged in collusion to deceive. The permitting agency accepted the conclusions of the report, but did not question its validity by conducting a more rigorous technical review.

4.2.2. A geologist was hired to determine the cause of extensive fracturing in soil, in walls and foundations of homes, and in other hardscape at a housing tract. The geologist was the same one who conducted the geologic investigation for development of the tract.

He conducted a two-year field geologic program. He mapped the area every month during the spring, summer, and fall; field work was not done during the winter because snow covered the ground. His detailed studies included: mapping the areal distribution of fractures; mapping zones of fractures and individual fractures within each zone; defining orientation, width, concentration, and spacing between individual fractures and the fracture zones. He prepared topographic maps (C.I.=0.3 m) each month, updated the fracture and topographic maps every month, and compared the updated data and maps with previous sets. The homeowners received semi-annual reports. The final report stated that "The fractures in the soil were related to expansion and contraction of expansive soil. Distress to the foundations and walls of the homes were in response to the expansive soil. There was no cause for alarm." He concluded "…the fractures in the soil were natural and not the cause of distress to the homes, either directly or indirectly."

A year later, the homeowners complained that the cracks were getting larger, the ground was sinking, and 3 houses were tilting. The geologist restated his earlier conclusion. Six months later and during a period of two hours, the 3 houses tilted further and dropped into a linear depression, 100 m x 1000 m in area and 4 m deep. The geologist, in a report to the homeowners, stated that the "…depression was a result of excess watering of the lawns by the homeowners and that the excess water resulted in underground piping of the soils." Litigation followed.

Discovery during trial showed that the houses were built over an abandoned, near-surface coal mine. Maps on file with the State Mining Commission showed the locations of the rooms, pillars, their lengths and widths, and the thickness of overlying rocks to ground surface. Direct correlations existed: (1) the 3 homes that collapsed were located over one of the mine's rooms, (2) the locations and orientations of the ground cracks were over and parallel to the length of the rooms, (3) the topographic depressions mapped at ground surface were located over the rooms, (4) the areas of maximum depression shown on the geologist's topographic maps were located over the center of rooms, and (5) the areas at ground surface over the pillars had the fewest fractures.

The court found that "The distress to the homes was directly related to subsidence of the ground over the abandoned mine." The court rebuked the geologist "…for not disclosing the fact that he worked at that mine as chief geologist, that he knew the maps of the mine existed at the State Mining Commission, and failed to reveal their existence." The court found that he "…probably recognized the correlation between the fracture pattern at ground surface and the locations and orientation of the mined rooms, and that he purposely provided a misleading interpretation of the cause of the fractures." The judge ordered the geologist "…to pay for all damages incurred by the homeowners related to the subsidence." and "…to reimburse any homeowner for future structural damages that may result during the next 10 years related to subsidence." The court ordered the geologist to reimburse all homeowners for loss of property value.

The court found that the geologist was negligent and acted fraudulently in not informing the developer of the existence of the abandoned mine under the property and the related potential for subsidence when he (the geologist) conducted the initial study for the housing tract. The geologist was also aware of subsidence over the mine in areas elsewhere. The court referred the matter to the State Licensing Board, and recommended that "…the geologist's license be revoked." The Board acted to revoke the license.

The damage to the homes could have been avoided by preventing development at the site.

4.2.3. A geologist investigated a site at the base of a hill to assess the site's suitability for several school buildings. The investigation included surface geologic mapping, and subsurface investigations (borings, trenches).

The site was located on an alluvial plain with a gentle slope. Near-surface materials under the site were composed of alluvial cobbles, pebbles, sand, silt, and clay. One edge of the site was at the base of a hill. Rocks in the hill consisted of interbedded sandstone, siltstone, and shale. A river was located at the edge of the alluvial plain, 2 kilometers (km) from the site.

Borings in the alluvium indicated its thickness was 1 m at the base of the hill and increased to 30 m at the edge of the site, a horizontal distance of 1.0 km. Groundwater was not present in the alluvium under the site. Trench investigations indicated a thin soil cover of weathered alluvial materials over lenses of alluvium. Liquefaction potential was considered highly unlikely, based on the level of expected seismic shaking at the site. One trench crossed the boundary between the alluvium and the rocks of the hill. Orientations of the bedding planes in the rocks were into the hill. Drilling on the hill was not done.

A report was submitted to the permitting agency, a permit was granted and the school was built. The engineer for the school district located one of the school buildings a few meters from the base of the hill. The base of the hill was not excavated; its original slope was maintained. On the hill and behind the building, fences were placed at different elevations to prevent rocks from rolling down and damaging he building. Diversion channels were built to divert surface water runoff and debris flows away from the building. A retaining wall (3.0 m high) was placed at the base of the hill and behind the building as added protection.

Eight years after the building was completed, a series of heavy rains occurred. The school site was not flooded from overflow of the river's banks. Rocks dislodged along the hillslope were caught by the fences and the 3 m wall. Debris flows and surface water runoff were diverted away from the building.

Two months later, cracks appeared in the retaining wall behind the building; rocks and debris that accumulated behind the wall were removed. Several weeks later, the retaining wall bowed away from the hillside and toward the building. During the next several weeks, the distress to the wall increased and the bend in the wall became more pronounced. The accumulated debris behind the wall was removed. The geologist was called to the site. He examined the wall and interpreted the distress to be a result of "…a combination of the weakening of the wall's footing by the rain water and to settlement of the alluvium under the footing."

A week later, the lower part of the hill moved against the school building, breaking its outer wall in several places. A landslide occurred. At the first indication of distress to the building, everyone was evacuated. Signs were posted to prohibit occupancy. Within a week, movement of the hillside destroyed the building.

Subsequent investigation of the landslide indicated that the current movement was a reactivation of an ancient landslide. Site studies included borings on the hill; the slide mass moved on a soft shale layer. The dips of the rocks were oriented toward the face of the slope (adverse), not into the hill as observed in the trench at the base of the hill. The dip into the hill at the slope's base was interpreted as the change in dip of the rocks at the toe of the ancient landslide. Litigation followed.

In court, the geologist blamed the landslide on the water seeping into the hill from the heavy rains.

The court found and all parties agreed that "…the design of the fences, diversion channels, and retaining wall functioned properly." The court found that the initial investigations were substandard and should have included borings higher on the hill; the ancient landslide probably would have been identified.

The court appointed expert (geologist) stated that "Given the site's geology, reactivation of the ancient landslide probably would have occurred anyway. Construction at the school site did not contribute to the failure because there was no disturbance of the slope that would have lowered the factor of safety. "To have constructed a buttress at the base of the hill would not have been effective in preventing the landslide from being reactivated; the landslide was too large. Had the landslide been identified during the initial study, the building would have been located farther from the base of the hill. Construction of an engineered buttress or other structure would not have been effective in preventing the landslide from being reactivated; the landslide was too massive."

The geologist was ordered to pay damages. The State did not have a Licensing Board.

4.3. Geophysical Case Studies

4.3.1. Up-Hole Shear Wave Survey to Determine Characteristic Site Period. A 10-story building was proposed to house a medical facility. The proposed foundation was to be a reinforced concrete slab, resting on compacted alluvial materials. Geologic conditions under the building site included 10 m of alluvium (interbedded gravel, sand, silt, and clay) overlying bedrock (sandstone).

The geotechnical engineer decided that geologic investigations were not required. Because the region experienced large magnitude earthquakes and the building should be constructed to withstand strong ground motion, the engineer decided to conduct an up-hole shear wave investigation and calculate the Characteristic Site Period. A 17 m boring encountered alluvium (15 m), bedrock (sandstone, 2 m), and 2 m of water in the alluvium above the alluvium/bedrock contact. The engineer conducted one up-hole shear wave survey; measurements were made at ½-m intervals. Measurements were made in 2 m of bedrock and only in 1 m of the overlying saturated alluvium. The Characteristic Site Period was calculated using these data. A report was submitted to the reviewing agency. The report did not include a ground response spectra for the site.

The reviewing agency questioned the absence of a ground response spectra, validity of up-hole survey, and the calculated Site Period. It requested additional shear-wave data be collected throughout the thickness of the alluvial section and the Site Period be recalculated, as well as a ground response spectra.

In his response, the engineer stated that additional up-hole surveys in the alluvium were not necessary because (1) the Characteristic Site Period refers **only** to bedrock, citing one of his previous reports as a definitive reference, (2) alluvium **dampens** seismic waves as they pass through it, and (3) alluvium provides a better foundation than rocks. He refused to prepare a ground response spectra because "The area had not experienced a major earthquake in the last 20 years and there was not need for a spectra." The agency denied approval and denied the permit.

The engineer discussed the denial of both the report and the permit with the client. The client enlisted the Mayor of the City to have the report approved. The mayor discussed the report with the agency's chief. Three days later, the permit was granted. The architect questioned the validity of the Characteristic Site Period and the absence of a ground response spectra; he refused to design the building using the information provided. The owner hired a different architect who accepted the report and prepared a design.

The hospital was built. Eight years later, an earthquake (M_L=6.8) occurred. The ground shaking at the site caused extensive damage. The top 4 stories collapsed and two outside walls fell away from the frame, resulting in 22 deaths and 117 injuries. A lawsuit followed.

The court found that the agency was in error by approving the consultant's substandard report, granting the permit, and accepting the architect's design of the building. The court found that the engineer erred in his up-hole shear wave survey and calculations; that the engineer did not understand how seismic waves are transmitted from the bedrock through alluvium, that alluvium does not dampen the seismic waves, and the absence of a ground response spectra. The court submitted both the engineer's report and the architect's design to the respective Boards. Both Boards revoked the respective licenses.

Because deaths occurred, criminal action was taken against the engineer, the architect, and the owner. All were found guilty of having contributed to the deaths. The laws of the country provided that the guilty be imprisoned.

The failure could have been prevented if a geophysicist conducted several proper up-hole shear wave surveys across the site, including several under the proposed location for the building. Calculations of the Characteristic Site Period would be done for all survey locations. Preparation of a ground response spectra would have aided aseismic design. The court also stated that a conservative aseismic design for the building certainly would have been appropriate, especially because it is a hospital.

4.3.2. Gravimetric Survey to Locate Cavities in Limestone. A housing tract was proposed at a 2 km x 2 km area of known karst topography. The owner wanted to locate the homes in areas that would not be subject to distress caused by subsidence or collapse into solution cavities. The engineer's design criterion was to avoid cavities (1) with areal extent of 50 m x 50 m and located within 50 m of ground surface. The engineer knew that his previous work at and near the site identified sinkholes in the general area and cavities under the site; the cavities had diameters as large as 200 m x 300 m in area and at depths of 25 m. Initially, a drilling program was proposed to locate the cavities but it was discounted because of the cost and the high probability that cavities would not be intersected.

The engineer conducted a risk analysis and concluded that any cavities under the site would not pose a hazard within the life expectancy of the homes. The engineer recommended a geophysical survey be conducted to provide data of sufficient detail to meet the engineer's design criterion. The survey lines were to be oriented north-south and spaced 50 m apart, station spacing along the lines were to be 50 m apart.

Eight proposals were submitted from geophysicists. Each proposed a single method: either electrical resistivity, seismic refraction, gravimetric, frequency domain electromagnetic, or transient electromagnetic.

The engineer chose the gravimetric method. To keep costs low, the engineer decided that he would conduct the survey and he changed the original proposed survey grid to survey lines separated by 400 m with station spacing at 75 m.

A map was prepared of the completed survey; it showed several geophysical anomalies, interpreted as cavities. Cross-sections were prepared that showed the shape and depths of the cavities. Two cavities of the specified size were within the 50 m depth criterion. The engineer allowed a surface set-back of 75 m x 75 m over the geophysical anomalies. The tract was built based only on the results of the geophysical survey.

Twelve years after the homes were built, the area experienced 2 years of unusually heavy rains. About a year later, 28 homes experienced distress and 11 homes collapsed into sinkholes. The collapsed and distressed homes were aligned along 3 separate trends, each oriented N30E. Litigation followed.

In court, the engineer argued that the collapse and distress were the result of the recent rains. The court found that the engineer relied on his geophysical survey to locate the cavities. Based on expert testimony from several renowned geophysicists, the changes made by the engineer to the initial survey design could not have provided sufficient resolution to identify (1) individual cavities with diameters of 50 m x 50 m, (2) depth of the cavities, (3) areal shape of the cavities, and (4) their areal extent under the tract.

The court found that the potential for collapse existed prior to the rains because the cavities existed under the homes prior to the rains. Similar heavy rains and the rise in groundwater occurred twice during the 12 years since the homes were built and failures did not occur. Importantly, the survey design would not have been able to distinguish a small anomaly caused by a small cavity under the survey station or a large cavity that existed outside the survey station but part of the cavity extended under the station. The court found that prudent engineering practice would include drilling at least one hole, at least 50 m deep, at each home site. Drilling was not done anywhere at the site.

The court found for the plaintiffs and awarded monetary damages. The court recommended that the Engineer's Licensing Board review the engineer's past practice. The Board found that its files contained several previous complaints against the engineer related to different projects. It also found that the engineer had, in his files, maps and reports that indicated solution cavities occurred along a joint set oriented N30E. The Board used two geophysicists to review the geophysical surveys and both agreed, independently, that the geophysical survey conducted by the engineer was substandard. They stated that the survey lines should have been oriented perpendicular to the N30E trend, spaced 25 m apart with station spacing 25 m apart along each line. They both agreed that a gravimetric survey probably would not be the best method to use for the purpose of the survey. The Board levied a fine against the engineer and stipulated that he cease conducting geophysical surveys.

Although the subsidence probably could not have been prevented, the homes need not have been damaged. They would not have been located over the cavities. A drilling program of several borings, each 75 m deep, under each home site would have minimized the probability of placing a home over a cavity.

<u>4.3.3. Temperature Surveys in an Earth Dam to Monitor the Flow of Water through Fractures in the Dam.</u> Visual inspection along the base of a concrete dam revealed three sets of near-vertical fractures. The three sets were approximately 7 m apart. One set contained 20 fractures, the second set contained 35 fractures, and the third set contained 60 fractures. The length of fractures ranged from 5 cm to 20 cm. Widths ranged up to 0.25 cm. Spacing between the fractures within each set ranged from 2 cm to 5 cm. Water was not observed seeping through the fractures in the dam.

A request was made for proposal to geophysically monitor the flow of water through the fractures. Responses included several methods: electrical resistivity, frequency domain electromagnetic, and temperature. The temperature survey was chosen and the geophysicist was a professor at a local university.

Data from the geophysical survey were to be used as an early warning system. If the survey indicated a pattern of increased water flow, then a decision would be made to open the gates and drain the water in a controlled manner to avoid a flood should the dam fail. Thermistors were installed. After a baseline survey, the thermistors were monitored on a weekly basis to determine if changes occurred. Each set of weekly measurements was compared to the baseline and to preceding weekly measurements.

Physical changes in the fractures were monitored on a daily basis by the operator of the dam. Individual fractures were measured. Changes were measured in length and width of individual fractures, spacing between fractures, number of fractures in each set, and whether fractures were developing elsewhere in the dam.

Weekly meetings were held; both sets of data (temperature measurements and physical observations) were compared and were discussed. After two months, the physical measurements showed that the fractures were getting noticeably longer and wider, that new fractures were developing, and that water was observed seeping through the fractures. The values of the thermal measurements remained constant—the same value as the baseline measurement.

Three months later, the 3 separate fracture sets merged to become one large set and the length of individual fractures grew to about 1 m and widths ranged to up to 1 cm. Water flowed from the cracks at a rate of 5 liters/hour. The values of the temperature remained as they were at the time of the baseline measurement.

An emergency meeting was called by the dam's operator. The minutes of the meeting indicated the geophysicist stated (1) the temperature data were more reliable than the physical (observed) measurements, (2) the data did not show temperature changes and, therefore, the dam was not leaking, (3) the source of the water coming through the dam was not coming from behind the dam (but did not offer an explanation for the source of the water), (4) that 5 liters/hour was not significant and even 1 liter/hour would not be significant, and (5) stated, emphatically, that the integrity of the dam was not being compromised by the fractures.

The operator expressed concern that the dam might fail and ordered the spillways be opened to allow the water level behind the dam to be lowered to 20% capacity. The geophysicist became upset because he was not consulted and continued to insist that the integrity of the dam was solid. He wrote a letter to the Governor of the State indicating that he was an expert in geophysics, that he was an expert in dam safety, and that the operator acted irresponsibly by lowering the water.

About a week later, an earthquake (M_L=5.6) occurred in the general area. Three months later, the dam failed and the stored water (at the level of 20% capacity) flowed downstream. Damage caused by the floodwater was minimal, restricted to minor overflow of the drainage channel. Several buildings along the banks experienced minor flooding. Litigation followed.

The court found that the operator acted properly in lowering the water in the dam; the operator's decision was based on the physical measurements. Insurance covered the claims.

In court, the geophysicist argued that a fault existed under the dam and the earthquake caused the dam to fail. Court appointed expert witnesses presented facts that (1) a fault did not exist under the dam, (2) based on inspections by dam safety experts immediately after the earthquake, the dam did not fail and retained its integrity after the earthquake, and (3) the level of earthquake ground shaking at the site would not have been sufficient to cause failure.

The court found that the geophysical method did not meet the objectives of the contract: (1) to determine changes in flow of water through the dam and (2) to act as an early warning system. During discovery, the court found that the thermistors were not sufficiently sensitive to detect changes in temperature related to flowing water. Discovery also revealed that the geophysicist knew of these deficiencies. The court also found, during examination at trial, that the geophysicist (1) did not understand the physics of temperature in a flowing liquid, (2) how the temperature would be dampened by contact with the concrete in the dam, and (3) the limitations of the method.

The university professor (geophysicist) did not have a license to practice. The only Licensing Board for the State was for Engineers; the geophysicist did not qualify as an engineer, by either education, training, or experience. The judge ruled that (1) the geophysicist was not competent to practice geophysics, (2) the geophysicist did not know of the limitations of the method and falsely represented the value of the method to the client, (3) the geophysicist's letter to the Governor was a blatant attempt to identify himself as an expert in dam safety, and (4) ordered the geophysicist never to consult. The geophysicist appealed the court's decision; the Appellate Court stayed the decision. The court ordered the geophysicist to reimburse the operator of the dam for all costs related to (1) the geophysical surveys and related reports and (2) time charged for meetings. The court ordered the geophysicist to reimburse the insurance company for its costs.

A catastrophic dam failure and flood was avoided by the action of the operator to lower the water. But for the insistence by the geophysicist that his method was working properly, the water behind the dam probably would have been lowered earlier and flooding would have been avoided.

5.0. CONCLUSIONS

Failures are not caused by natural events (earthquake, flood, landslide, and others) that immediately precede a failure. **Failures are caused by human errors that allow marginally stable or unstable conditions to exist through substandard investigations, dishonesty and deceit, approval of substandard reports by reviewing agencies, and political influence.** Litigation is the last resort of the parties who are harmed.

6.0. REFERENCES

California Assembly Bill 269, 2002. Requirements of this bill apply to architecture, professional engineers, geologists and geophysicists, contractors and other licensed professionals. This bill applies to licensing boards, commissions and bureaus.

Larson, R. A., 1992, A Philosophy of Regulatory Review., Assoc. Engin. Geology, Proc. 35th Ann. Mtg. p. 224-226.

Halper, E., 2002, Fault Lines in Law Leave Homes on Shaky Ground. p. A22-A23. Los Angeles Times, August 11, 2002.

Ten of the eleven case studies are taken from court records; all are in the public domain and available for review. Four of the court proceedings are from Iran, Italy, Pakistan, and Turkey. Six are from the United States: 2 in California; 1 in Colorado; 1 in Florida; 1 in Tennessee, and 1 in Virginia. The eleventh case study is in California and is the one described by Halper (2002), presented in Section 3.0.