Non-Engineering Elements in Factors of Safety in Soil and Foundation Engineering

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As in other fields, various elements are considered in choosing a safety factor in soils and foundation engineering. The engineering elements usually considered are the forces causing stresses and strains in materials and the resisting forces of those materials. A safety factor is chosen commensurate with the accuracy and reliability of analyzing these forces. During or following these analyses, non-engineering elements modifying this safety factor are or should be considered. These may include economic, sociological, psychological, and political elements. They may be mixed together in certain cases or clearly separate. Usually some are absent. Most cannot be quantitatively predicted. Numerous cases are described to illustrate these non-engineering elements.

•IN EARTHWORK and foundation engineering, the technical elements that enter into producing an approximate factor of safety against failure are usually recognized, although not always understood. These elements are the stresses and strains produced by the applied forces involved and the resistances of the materials to withstand them, all of which, for various reasons, may be difficult to determine accurately. Other elements should also be considered when choosing a factor of safety. These are economic, sociological, psychological, and political. It is the purpose here to discuss how these non-engineering elements should be included, when necessary, in determining the approximate final factor of safety.

In past eras it was sometimes felt, especially by laymen, that the engineer simply analyzed the engineering elements, usually by rules based chiefly on his own or others' experience, and applied a factor of safety commensurate with his confidence in his analyses. It was also felt that the construction cost should enter into his final design; that is, extravagant design or construction should be avoided. To this extent some of the economic elements were considered.

Today the picture is changing. In soils and foundations on many projects fairly reliable numerical values can be placed on stresses, resistances, and the accompanying strains, thanks chiefly to modern soil mechanics and sophisticated instruments and methods used in field and laboratory tests and observations. Recent examples are basic research on pile driving and soil-pile interaction in Michigan, Texas, and elsewhere. But the picture is also changing in other respects due to our modern complex, integrated society, the tremendous growth of knowledge and the speedy means of transportation and communication. Many fields of activity have become interwoven. The civil engineer is coordinating his work with city planners, economists, sociologists, conservationists, insurance men, and others. The soils and foundations specialist is sharing in this endeavor. His importance can be judged from the fact that "soils" or "foundations" is mentioned in one-third of the business "cards" appearing in the professional directories of civil engineering magazines. It is proper, therefore, that he

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be conscious, when choosing a factor of safety, of the economic, sociological, psychological, and political elements inherent in the situation. In the words of Cicero, "Probabilities direct the conduct of the wise man."

ECONOMIC ELEMENTS

The cost of construction for increasing or decreasing the factor of safety by varying a design can be estimated fairly easily. It is or should be common practice to estimate the additional construction cost to increase the safety factor and, conversely, the saving in cost to decrease it. "Safety and economy" are the skilled engineer's usual goal. His estimates here include not only the initial construction, but also the necessary land, the future maintenance costs, and others. But the economic cost of a failure should also be considered, even though the monetary value of this can be calculated less accurately. The cost of repairing or replacing a bridge, building, dam, or highway pavement can be estimated. To this should be added the monetary costs of injury and death to persons, damage to property, and loss of "use and occupancy", such as found in insurance policies.

The economic or cost element is often interwoven with the sociological, psychological, and political. Some cases, chiefly economic, are given here:

Case 1. A test section of a 40-ft high roadway embankment on a deep deposit of soft varved clay in a rural area was built to determine the shearing strength of the clay. Unfortunately the location was chosen at an abutment of a major bridge and the filling was stopped 2 ft short of completion for fear of a failure. As a consequence, the design was changed to provide for an additional span and wide flanking berms at an additional cost of $100,000, even though the shearing strength of the clay had not been properly determined by the field test. The motives for the changes apparently were economic (fear of large extra costs of a slide at the abutment site) and psychological (fear of being blamed).

Case 2. A large 25 by 50-ft twin-box concrete conduit was built in a deep cut in a deposit of soft varved clay 100 ft deep. Where it crossed under a busy three-track railroad the cut was 40 ft deep. Here the factor of safety against sliding was extremely low, and before construction had progressed the cut slopes and overhead temporary railroad trestle were revised to give an adequate safety factor. The elements here were the economic cost resulting from a possible slide and the possible plunge of a train into the cut, the sociological (humanitarian), the psychological (fear of blame for a catastrophe), and perhaps the political.

Case 3. Many years ago, a major river bridge collapse occurred during construction, resulting in the death of 16 men and injury to many more (1). The girders for the first river span, where the collapse occurred, were destroyed, as well as the erection equipment. The tragedy was due to the failure of the temporary river pier made of two clusters of timber piles having timber bracing above the water only. Reconstruction some months later (2) included the use of two temporary piers, instead of one. The new piers were made of very heavy steel H-piles, pointed and reinforced at their tips and driven to refusal in bedrock with a very heavy pile hammer. A third improvement was to provide a huge steel frame, lowered to river bottom, at each temporary pier; the frames had a well for each pile through which the pile was driven and then braced soildly to the well with steel wedges. It is sad to think that any one of these three improvements would probably have averted the tragedy. The inadequate safety factor was due to skimping on the bridge erection costs. The economic cost of the failure far exceeded the anticipated savings. The sociological aspects are obvious. The psychological included an ultra-safe reconstruction to persuade construction workers that it was safe to return, and the political produced some serious undercurrents that fortunately were cleared up.

Case 4. With the use of flatter grades and wider roadways, rock cuts for highways are becoming much deeper. Consequently, the problem of rock falling onto the roadway has become more serious. The use of wide ditches at roadway grade, presplitting the rock before production blasting, steepening rock slopes to reduce bounce of falling rock, and barricades are some methods to reduce the problem. These usually increase the initial construction cost but may save much in roadway maintenance and in injury to motorists and their vehicles, in addition to removing apprehension for traveling on such roadways.

Case 5. Another situation involving the economic element is the problem of scour due to flood waters. It can cause extensive damage to highway and railroad embankments but more spectacular and usually more costly damage to bridges, buildings, and other structures. Significant research has been made on scour but choosing a factor of safety against movement or failure due to scour has uncertainties. The disastrous floods of August and October 1955 in Connecticut damaged or destroyed 300 bridges (3), washed out several miles of highways, cost over 100 lives, and destroyed $220 million worth of property. No state highway bridges, old or new, that had pile foundations or were founded at satisfactory depths were damaged by scour of the foundations. Of the bridges built without piles by the state since 1940, when soils and foundations engineering was started by the state, only one was injured by scour. This consisted of failure by scour under the west pier, which dropped 3 ft. The initial saving by avoiding piles was $11,000 at the piers and $15,000 at the abutments. The cost of reconstruction was about twice the initial saving. The expense of a temporary Bailey Bridge was considerable. Another substantial cost was to the traveling public, who were deprived of a river crossing here for a few months.

Case 6. The unusual and extremely difficult project of building a railroad embankment across the Great Salt Lake in Utah is described by Casagrande in his Terzaghi Lecture on the calculated risk (4). In this paper Casagrande illustrates his discussion by describing some unusual projects in which he was vitally involved. On the Great Salt Lake project he tells how the skill of the board of consultants and the design and railroad engineers was continuously pitted against the thick, soft, sensitive clay below the lake bottom and the project cost ceiling of $50,000,000. Because of the unusual conditions, most of the earthwork construction had to proceed on a semi-empirical basis, with strong reliance on continuous field measurements and on shear strength values derived from analyses of failure and near-failures during construction. The factors of safety during construction were close to 1.0, as the economic element was of paramount importance. The project was completed within the cost limitation and one year ahead of schedule.

SOCIOLOGICAL AND PSYCHOLOGICAL ELEMENTS

Sociology is the study of society in groups, while psychology deals with human behavior and is more associated with the individual. These elements tend to overlap and hence are discussed together.

An obvious sociological aspect is the humanitarian. This includes injury and death, and also hardship or inconvenience to people from disrupting their customary living conditions. Other elements, chiefly psychological, that may be harmful often result from an unprofessional attitude by engineers or others connected with a project, careless or dishonest work on construction, division of responsibility between design and construction, fear of being blamed, and poor publicity practices.

The humanitarian is the most spectacular element and is usually well provided for. "Safety" is becoming a national watchword. Government at various levels, insurance companies, modern technology, and other forces are tending to improve the humanitarian aspects, especially in construction work. An instance at hand is the trench cave-in accident study recently begun by the Engineering Research Institute at Iowa State University (5). In a different type of problem, the design of underground reinforced concrete pipe, Spangler (6) recommends a factor of safety of 1.0 if the design is based on the 0.01-in. crack strength of the pipe. This recommendation is based partly on the assumption that "failure of this type of structure does not involve the safety of human life".

A less obvious element is connected with over-design. The owner pays for the project and there is sometimes a tendency by the designer or the contractor to build unnecessarily large, which may increase the fee or the profit. Also, over-designing is faster and saves design payroll costs. Fortunately the profession recognizes this and various methods of compensation have been devised to improve this situation. Akin to this, but more difficult to remedy, is the psychological element of careless or dishonest work in design or construction. Sometimes this may arise because of lack of coordination between the designers and the constructors, which will be discussed below.

A more excusable cause for over-design is the fear of being blamed if something should go wrong, generally during or after construction. This fear is a basic human trait. It is present in the soils and foundations engineer, the designer, the construction man, and others. The blame may be wholly, partly, or not at all justified. The penalty may vary with the project and the positions of those involved. On the other hand, in some cases this fear will spur the engineer to do a more thorough and complete job, if he has the competence.

A final component in this category is in poor publicity practices. All too often the expensive project is aggrandized in newspapers and magazines with phrases such as "the bold solution to bad foundation conditions" or "elaborate drainage system installed in bad soil", when actually a better insight into the situation or more reliance on the soils engineer's recommendations could have led to a simpler, more economical solution. Conversely, expert modern techniques in soils and foundations work, bringing large savings to the owner when compared with conventional methods, are seldom publicized. Mr. Big is more appealing to the reading public.

In his paper (4), Casagrande deals chiefly with monumental projects having risks involving engineering judgment and experience, where past knowledge and conventional methods of analysis were insufficient. These, of course, had large economic elements of risk by their very nature. His discussion of human risks also stresses the perils in the division of responsibility between designers and supervisors of construction. These can be especially serious where there is poor communication between the groups or the attitude of the construction men is one of indifference or ignorance. Casagrande also discusses the engineering and psychological difficulties arising from division of responsibilities in design. He says, "Even a brilliant man can be very sensitive when his carefully prepared design. . . is attacked by someone who on the basis of a brief review believes that he has good reasons to criticize the design." Casagrande believes the solution on large projects is to have one board of consultants appointed jointly by all parties concerned with the design.

Casagrande also points out the difficulties that may arise from failure to "follow through" in design, especially in large organizations, and to furnish adequate subsurface information to contractors. These are often due to ignoring responsibility. He also deals briefly with the purely non-engineering element of corruption, "an age-old problem".

Similarly, Terzaghi (7) discusses the difficulties and perils resulting from a rigid division of responsibilities between designers and construction forces and from a lack of communication between them. This can be serious when underground conditions are revealed or develop during construction that were not anticipated during design because of insufficient or inaccurate borings, inadequate analyses, or other reasons. If the construction forces do not have personnel competent to diagnose the changes and prescribe proper remedies and if they do not communicate with those responsible for the design, then an improper remedy will be tried. In such situations, if the soils and foundations engineering is supplied by an outside consultant, the division can be especially serious and the consultant may be made a scapegoat when trouble develops. Sometimes the contractor may be of no assistance and may even wish to compound the difficulties, as his chief incentive is to increase his profits or reduce his losses. In his conclusion, Terzaghi urges that the soil mechanics department that supervised the soils work during design should inspect subsurface conditions during construction and compare them with those assumed during design; if necessary, they should request modifications in design in accordance with the findings.

In an interesting and informative book on foundation failures (8) illustrated by approximately 100 cases, Széchy points out that in many of these much of the trouble was due to the construction personnel failing to carry out the plans and specifications or to consult the designers when subsurface conditions differed from the expected. This was especially true in handling of groundwater problems. Similarly, Spangler (6) cites the case of a large city's engineering department using a high factor of safety in sewer design because the construction department often made changes during installation that might influence strength of the pipeline.

As noted in the descriptions of the six cases given earlier, nearly all contained sociological or psychological elements or both. Other examples are given below:

Case 7. A reputable consulting engineering firm strongly desired to use piles under three pairs of highway bridges it was designing. The bridges were to serve as grade separation structures; all were located over some 50 ft of soft varved clay. The state vetoed the use of piles and requested the firm to provide a modest embankment overload and waiting period at each bridge. This procedure caused most of the settlements to occur before building the bridges. The end results were structure settlements of less than 1 in. and a net saving of $250,000. The consulting firm's over-caution was psychological: it had been unfairly caught in a "squeeze" on two widely different projects, one involving an incinerator that allegedly caused air pollution (later proved false) and the other a low-cost housing project where faulty work brought trouble.

Case 8. The factor of safety, so-called, is sometimes used in connection with permissible strains, rather than stresses. These strains are vertical or horizontal movements, or both, and are usually concerned with bridges, buildings, and other structures that may be sensitive to movements. Total movements and differential movements between adjacent elements of the structure are estimated by the soils and foundations engineer to the best of his ability. He then gives these estimates to the structural engineer who decides whether they are tolerable for his structure. At this stage of the proceedings, the structural engineer may become over-cautious for various reasons, such as lack of confidence in the soils and foundations predictions, lack of confidence in his knowledge of how the structure will behave with the predicted movements, or an indifferent attitude toward structural analysis of such problems. Sometimes a designer seems alarmed when told his bridge will settle 1 in., but when settlement readings taken during and after construction show settlements of more than this, with no apparent damage, he then exhibits only passing interest.

POLITICAL ELEMENTS

A final type of non-engineering element to be discussed is the political. It is confined to projects in which government is involved in all or part of the cost and the responsibility. It is more prevalent in the smaller types of government—state, county, and municipal. It exists from the fear that persons or members of an opposition political party—the "outs"—might try to discredit the administration by pointing the finger of blame on an alleged wrongdoing on a government project. This would then involve the engineers connected with the project. Consequently they may choose to raise their factors of safety when they anticipate a restless political scene.

Some examples serve to illustrate the occasional effect of this element. It was mentioned in Cases 3 and 7 above. Several other examples come to mind:

Case 9. Some 33 years ago, a parkway in a metropolitan area was closed at a conspicuous spot only a few days after it had been opened to traffic with the usual ribbon-cutting ceremony. The closing was due to a failure of the soft mud foundation under the embankment. This was later investigated by Taylor and reported in his paper (9). Unfortunately the mishap occurred only a few weeks before election day and the "out" political party took great pains to try to discredit the administration.

Case 10. The failure of a dike and boulevard (10) was used in a political action that attempted unsuccessfully to unseat a high state official. The failure, which was predicted by the only soils engineers connected with the project, occurred partly because of division of responsibility between four government organizations and partly because soils engineering was not regarded then as highly as it is today.

Case 11. A miscalculation in the design of a bulkhead was the cause of a small political stir many years ago. The 600-ft bulkhead retains a fill of sand in a harbor having a thick deposit of marine mud. Although the error was rectified, without damage but with some expense, and the installation completed, members of the "out" party attempted to discredit the administration.

SUMMARY

In an increasingly complex and populous world, the engineer is becoming more involved with the non-engineering aspects of our society. The soils and foundations engineer, having attained a position of importance in civil engineering, should consider the non-engineering elements that enter into his work. These elements are economic, sociological, psychological, and political; their importance varies with different projects. The seasoned and conscientious soils and foundations engineer is aware of these elements and modifies his factors of safety upward or downward according to their importance. He agrees with the poet Gibson, who says through the lips of a North Sea fisherman's wife, ". . . and life itself's a chancy thing".

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Discussion

LYLE K. MOULTON and JAMES H. SCHAUB, Respectively, Assistant Professor of Civil Engineering and Associate Dean, College of Engineering, West Virginia University—Mr. Keene is to be congratulated for his fine paper dealing with the consideration of economic, sociological, psychological, and political elements in establishing factors of safety in soils and foundation engineering. He summarized the situation rather succinctly when he stated: "The seasoned and conscientious soils and foundations engineer is aware of these elements and modifies his factors of safety upward or downward according to their importance." Unfortunately, the seasoning of a soils and foundations engineer is not like the seasoning of lumber, and it often involves more than simple aging in an appropriate environment. Many soils and foundations engineers obtain their seasoning the hard way, through many years of enlightening and, sometimes, sad experience. While it is often said that there is no substitute for experience, papers such as Mr. Keene's can provide the younger and less experienced engineer with a measure of vicarious experience that can help to accelerate the seasoning process.

There are several situations involving one or more of the non-engineering elements presented by the author that, in the opinion of the writers, deserve special recognition and emphasis. These include the case of the soils and foundations engineer being called upon to solve a problem after failure has taken place; the lack of proper supervision during construction; the need for unusually rapid analysis and design brought about by an accelerated building program; and the sometimes tenuous relationship that may exist between factor of safety and economy.

Often, when the soils and foundations engineer is engaged after a failure has occurred, he finds that it is necessary to employ different soil parameters and a different factor of safety than he would normally use. Both the owner and the engineer may be sensitive to the economic impact of a second failure. The engineer may not wish to put his reputation in jeopardy and, because of the peculiar material and psychological conditions that often exist following a failure, may be tempted to adopt an unusually high factor of safety. On the other hand, there is the tendency on the part of some owners to want to cut corners in order to keep the unanticipated additional costs resulting from the failure as low as possible. If the engineer honestly attempts to satisfy the owner by holding down the cost of corrective measures while maintaining an adequate factor of safety, he often has to depend on good construction practices and a well-controlled sequence of operations to do so. Under these circumstances, the lack of proper supervision of construction can lead to very undesirable results.

These considerations are well illustrated in a recent project that involved the design and construction of several heavy structures and conveyor systems. The site was selected by the owner and it was decided that the structures would be founded on a bench cut into an existing slope. The site work and grading were designed by the owner's engineers, none of whom was a soils and foundations engineer, without the benefit of adequate soils explorations. After the excavation was well under way, the owner engaged soils and foundations engineers to supervise the foundation exploration and the foundation design for the structures and conveyor supports. It was agreed that the soils and foundations engineers would arrange for and supervise the subsurface explorations, perform any required tests and analyses, and provide foundation recommendations. It was stipulated that this work should be started as soon as the bench excavation was complete. However, when the level of the bench excavation was approximately 5 ft above finished grade, a slide involving between 150,000 and 200,000 cubic yards took place, and the construction was halted. Since the owner, by this time, felt that he was unalterably committed to the use of the site and the proposed structure grades, the soils and foundations engineers were required to provide recommendations for stabilizing the slope. The subsurface explorations were made, necessary testing and analysis performed, and a report containing recommendations for stabilizing the slope was submitted to the owner. The soil in the slope consisted of colluvium with numerous slickensides. Recommended limits of excavation were clearly defined in the report and the necessity for strict adherence to the recommended sequence of operations was emphasized. This sequence involved the unloading of the head of the slide and installation of surface and subsurface drainage before proceeding with any further excavation at the bench level. Unfortunately, the factors involved in the mechanics of slope failures of this type were not understood by the owner's engineers or the contractor. As a result, the supervision of construction provided by the owner was, at best, haphazard. When the bench excavation was almost to planned grade, the slope failed again. Cross sections taken after the slide showed that the as-built toe of slope was located approximately 30 ft farther into the hillside than had been recommended, the recommended unloading of the head of the slide had not been completed, and neither surface nor subsurface drainage had been installed, ostensibly because of a delay in the delivery of perforated pipe. Obviously the combination of these effects had reduced the factor of safety to less than one. Corrective measures were undertaken a second time, and, at the insistence of the soils engineers, the proper supervision of construction was established and the recommended sequence of operations was followed. Although the slope stabilization was successfully completed, the cost to the owner was quite high. It is likely that many of the problems and much of the expense could have been avoided if the soils and foundations engineers had been consulted during the site planning stage, or an early assessment of the influence of the pertinent non-engineering elements on factor of safety had been obtained.

Another situation that can exert considerable influence on factor of safety is brought about by the expanded commercial and industrial building program in many areas. Often, the foundation exploration, analysis, and design are scheduled to be conducted simultaneously with the structural design. At the same time major planning decisions are being made by the owner's executive personnel. All too frequently the structural designer may be pushing the soils engineer for allowable bearing capacities or other foundation recommendations when the design loads, size of footings, and even the location of the structural units have not been finalized. The discussants have found themselves involved in several such projects. Although in each case the possible alternatives have been known, the tendency was to use a higher factor of safety than might ordinarily be used, in order to take into consideration the effects of a change in location or configuration of the structure that could involve interpolation or extrapolation of boring data and the attendant uncertainties.

Although maximum safety and economy, as noted by the author, are generally accepted as being the basis for engineering decisions during design, the soils and foundations engineer is often faced with the question of how much money to spend to achieve an adequate factor of safety. More important, however, may be the determination of just what factor of safety is adequate, especially where human life is involved. In a recent project involving the expansion of an industrial plant, a soils and foundations engineer was charged with investigating the adequacy of an existing foundation for a gantry crane column. The load on the column was to be increased as a result of the proposed construction. Subsequent investigations led the soils engineer to the conclusion that the factor of safety with respect to bearing capacity under the new load would be quite low. However, the cost of providing a new foundation for this column greatly outweighed the cost of any damage resulting from settlement or tilting of the column. Therefore, it was recommended that the column be instrumented to provide warning of impending difficulty with settlement or tilting, and the foundation was left unchanged. In this instance, the relationship between economy and safety was clear-cut, and the potential danger to human life was negligible. This relationship is not always quite so clear. In the design of dams, use is made of the statistical probability of flooding. Experience has shown how dams designed for different storn frequencies have performed. Thus, a meaningful relationship between safety and economy has been developed. No such detailed statistical data are generally available with respect to the design and performance of many soils and foundations projects. Additional research and correlation of existing data are necessary to provide adequate insight into this problem.

Finally, it is the discussants' opinion that those involved in educating soils and foundations engineers can provide a measure of "instant seasoning" by frankly relating their experiences to their students and emphasizing the important non-engineering elements that can sometimes override strict engineering considerations.

PHILIP KEENE, Closure—The discussion by Professors Moulton and Schaub adds considerably to the paper, both in their emphasis on the possible consequences of poor communication and coordination in design and construction, and in their three illustrative cases. In many papers, such as this one, actual case histories serve to illustrate the points or principles expounded in the paper, with lasting value to the readers. The student who hears of these cases in classroom lectures not only learns more engineering but also is made aware of pitfalls to be avoided in his future career.