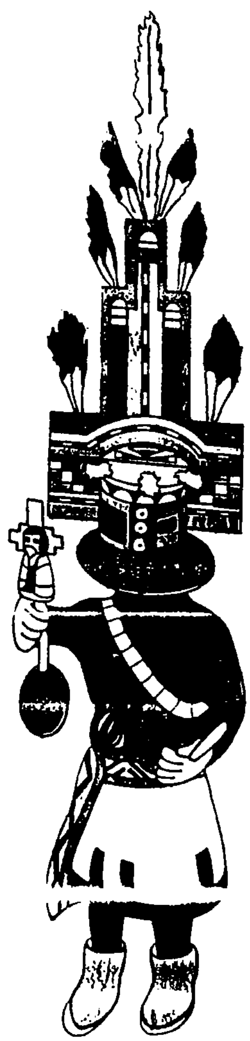
PROCEEDINGS OF THE

13th Annual HIGHWAY GEOLOGY SYMPOSIUM



MARCH 16, 1962

PHOENIX, ARIZONA

SPONSORS

ARIZONA HIGHWAY DEPARTMENT

ARIZONA STATE UNIVERSITY

CALIFORNIA ASSOCIATION OF ENGINEERING GEOLOGISTS

OPENING ADDRESS

Honorable Paul E. Fannin

Governor of Arizona

On behalf of the people of Arizona, it gives me extreme pleasure to welcome you to our State for the 13th Annual Highway Geology Symposium.

Some of you have read recently of a slight difference of opinion between Arizona and the State of California concerning the Colorado River. That is why the sponsorship of this Symposium is of special interest. It is sponsored by the Arizona Highway Department, Arizona State University ... and ... the California Association of Engineering Geologists!

To the representatives from California we say, "Gentlemen, we are happy to have you with us, and, while you are here, you are welcome to all the water you can drink, bathe in, or carry home ... in your pockets!"

You know, there is a saying about Arizona that goes something like this, "All Arizona needs is more water and a better class of people". We've never figured out if this is complimentary or not, because, after all, that's all hell needs too.

In some respects, your meeting here today could be classed as something in the nature of a homecoming. It could be said that engineers and geologists were practicing in Arizona long before Columbus discovered America. This is evident in the extensive early-Indian irrigation systems, cliff dwellings and any other works, still enduring to this day.

Our State has been termed a "geologists paradise". Arizona has been richly endowed by the Creator with nearly every type of climatic zone, and mineral and earth formation. It is indeed fitting that our State motto is "Ditat Deus"... "God Enriches".

You have our sincere thanks for holding your annual Symposium in Arizona this year. 1962 is a very significant year for us, it is our 50th anniversary as a state, and we are observing our Semi-Centennial.

In going over the history of your organization, I noted that your first meeting was held in Virginia. Your subsequent meetings were held in West Virginia, Ohio, Maryland, North Carolina, Pennsylvania, Georgia, Florida and Tennessee.

In fact, this is the first Annual Symposium you have held west of the Mississippi River, and we are indeed honored.

I note too, that the majority of your meetings have been held in Southern states. The Southerners in attendance should feel right at home here. As a matter of history, during the War Between the States, the Territory of Arizona was carried in the Confederate column, and it may come as a surprise to some of you to know that one battle of the war was fought on Arizona soil, at Picacho Peak, near Tucson.

Your organization is to be congratulated on its westward and national expansion. Additional congratulations are in order for your international expansion. I note also, that one of your delegates, and a speaker on this afternoons program, is representing our great and good neighbor to the south, the Republic of Mexico. I refer, of course, to Engineer JUAN B. PUIG, of the Mexican Ministry of Public Works.

We Arizonans enjoy an excellent relationship with our friends across the border. We constantly exchange information, ideas and trade, all in a apirit of cooperation and mutual understanding.

Last year I attended a conference at Quertearo, Mexico, just northwest of Mexico City. The subject of prime importance was the Mexico-Canada Inter-American Routes. This route extends from the far northland in Canada, through the western United States, including Arizona, enters Mexico at Nogales, and continues south through Mexico City to Acapulco. Eventually it will join the Pan-American Highway, entending through every Central and South American country.

Surely, this is additional proof, to all concerned, that an "Iron Curtain" or "Wall of Fear", does not and will not exist in the free countries on this side of the world.

To Arizona, this route has other significance. It enters our State near Monument Valley and the famed Four Corners area on the Navajo Reservation. An alternate route enters Arizona just west of Shiprock and Gallup, New Mexico.

These fine, paved routes penetrate the vast, spectacular, but hitherto almost inaccessible territory of the Navajo and Hopi Reservations. These excellent highways are enabling our Indian citizens to develop the tremendous potential of their natural resources, and they are doing an outstanding job of developing those resources. For many reason, we are very proud of this new portion of our highway system.

In fact, we Arizonans are proud of our entire Highway Department. The teamwork and know-how of our engineers, geologists and other personnel has produced an enviable record of achievement.

Many of you have come a long distance to attend this Symposium. We hope that you will extend your stay, and visit some of the numerous attractions in our state. Here in Phoenix, our famous World's Championship Rodeo is underway, and is well worth attending. Also, we are just a short distance from the border, and a visit to Mexico is one you will long remember. A tourist card or visa is not required to visit Nogales.

If my talk has seemed lengthy, please forgive me. You see, yesterday I rode in the rodeo parade, and to tell the truth, I'll welcome any excuse to stand up for the next few days. This is one of those times when the "seat of government" can be painful.

Again, a very sincere Welcome, enjoy yourselves, and ... as we say in the Southwest ... "Nuestra Casa Es Su Casa" ... "Our House Is Your House".

Presented At The 13th Annual Symposium
On Highway Geology, 16 March 1962, in Phoenix, Arizona

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STATUS OF GEOLOGIC REGISTRATION

Synopsis

This paper opens with a discussion of the pros and cons of registration in the geologic field. Examples are used to illustrate the arguments.

Part two deals with the results of a nationwide questionnaire concerning the general professional "climate" on the subject of geologic registration. The questionnaire was directed to State Geologists who, of the total, returned a 79% complete answer.

Part three covers the current activity (1962) of the California Association of Engineering Geologists in their preparation of a bill for registration of Engineering Geologists.

STATUS OF GEOLOGIC REGISTRATION

Registration together with its semisynonymous term, licensing, is generally accepted to be an expression of public control in a particular profession or craft. A review of the chronologic development of public regulation in professional fields indicates that such regulation exists when, and only when, public need could be proven to a legislative body. As an example, in colonial Virginia the medical profession consisted of physicians of two educational backgrounds. These were the colonial and European educated. Physicians having the European background felt that their medical training was the more thorough and offered the prospective patient better medical care; thus a higher degree of public welfare. For this reason a bill was passed by the Virginia legislature licensing physicians on this divided basis. However, the essential difference as prescribed was based on a divided system of fees, favoring those physicians of foreign education. Thus secondarily is illustrated one of the most controversial factors in the concept of registration. This is that registration normally incorporates a benefit to the regulated field as well as to the public it professes to serve.

The geologic field is currently in the throes of an oft repeated professional question: "Are we needful of and/or ready for regulation?" Basically, the question arises from two factors which have developed concurrently. The first is that the geologic field has, mainly in this century, diversified from the purely academic into several subdivisions showing practical application. These include petroleum and engineering geology as well as others which have evolved into sciences which, while using geology as a base, do not recognize it as the full parent. The second factor is that these new fields overlap other technical disciplines which demand recognition of their separate characters and are often already regulated through registration. The presence of these two factors forces an immediate decision on the geologic profession as a whole. Essentially this decision is whether to apply regulation, internally or legally engendered, to the technical field. This question can be resolved through exploratory discussion of the fact of geologic diversification and that of technical infringement. In view of the writer's engineering geology background, this is most easily illustrated in this field. Here engineering geology overlaps with the civil engineering subfields of soils mechanics and structural engineering. Both profess technical knowledge of surface and subsurface construction requirements. Ignorance of geologic factors involved in design and construction is not always a deterent factor to the resolution of geologic problems without recourse to geologic opinion. Additionally, even where geology is correctly understood and correctly applied, confirming geologic advice as to the correctness of techniques and implied engineering requirements often are bypassed as unnecessary. Engineering geology, then, is gradually being usurped. The reverse tendency is not true. The engineering fields involved are well organized. They recognize their prerogatives and are militant in their protection. Expansion under the magic umbrella of the term "professional engineer" is a constant theme and regulation through registration is a very strong arm in this accomplishment. To what body may the engineering geologist turn in seeking redress to a technical infraction in his professional field? There are none. His opposite number, the soils engineer, can and does refer "unethical procedures" to his local State registration board. This body can and does apply strong pressure through technical and political means. Such action is assumed valid based on statewide control vested in legislative action on regulation of that technical field. In California for instance, civil engineering regulations allow full control over design and construction in all fields where "natural phenomena" are involved. For one, engineering geology needs legislative recognition and organization or time may eliminate the field per se.

In the practical application of fields of technical knowledge, regulation through registration is an effective acknowledgement of public recognition. Registration has come to be that which the bachelor of science degree was to the academic. Without such a formal acknowledgement of the status and importance of a technical field, an unregulated discipline will remain an undergraduate in the hard world of practicality.

NATIONAL SURVEY

In assessing the status of geologic registration, one simple answer would be to list those states already offering registration to the geologist. Of the nine states so classified, only one, Arizona, registers geologists as such. Oregon registers the applicant as an engineering geologist but only after he has taken two consecutive full-day examinations. The first, sadly enough, is the engineer-in-training examination. The second is in his chosen field of engineering geology. The other seven states offer certification as geological engineers. These are Nevada, Utah, Idaho, New Mexico, Oklahoma, Texas, and Kansas. Thus eight of the nine recognize geology only as it is applied to the field of engineering.

In gathering information from the remaining states, those offering no registration to the geologist in any category, a questionnaire was submitted to the respective state geologists. Questions were asked which were organized to cover the fields of personal opinion, of existing opinion in the local technical organizations and in the legislative field. Of 39 states contacted, 31 answers (79%) were received.

<u>Question 1</u>: "Do you favor professional registration of geologists as a necessity or a desirability?" Pro - 17, Con - 9, Neutral or Mixed - 5.

<u>Comment</u>: An overwhelming majority of those answering favored registration outright. If those of mixed opinion and those not answering were to express themselves pro or con, and the average maintained, it would seem that a majority of our most prominent professional geologists favor legal registration.

<u>Question 2</u>: "What do you believe is the general attitude of the geologists within your area concerning registration?" Pro - 11, Con - 5, Mixed - 7, No statement - 8.

<u>Comment</u>: In general, no attempt is being made to accurately evaluate the opinion on registration of the mass of geologists. The "burning question" has not reached that level of investigation. Active consideration still remains local and individual.

<u>Question 3</u>: "What is the attitude, real or presumed, of those professions already registered toward registration of geologists?" Pro - 5, Con - 2, Mixed - 2, Neutral - 2, No statement - 20.

<u>Comment</u>: As in the prior inquiry, the mass question has not been asked. Before the technical professions already registered will respond to the status of the geological profession, we will have to carry the initiative to them. Individual areas have responded, both favorably and unfavorably, but the real proof is lacking.

Question 4: "Is there any active consideration being given in your state toward registration?" Yes -.8, No - 16, No statement - 7.

Comment: In view of the answers to questions 2 and 3, the positive answer is surprising. Those states with organizations actively pursuing geologic registration are California, Florida, Alabama, Idaho, Illinois, Washington, Georgia, and New Jersey.

Question 5: "Is there an organization of geologists in your state having membership requirements sufficiently stringent to be comparable to requirements for possible registration?--i.e., is there any attempt toward self-regulation of the profession in your state?" Yes - 6, No - 17, Mixed - 1, No statement - 11.

Comment: Though in the minority, a surprisingly large group (6 states) have geological organizations which have taken a strong stand in the field of self-regulation. Even more significant, such action has taken place in those areas where a relatively large population of practicing geologists exist. It would seem that where geologic practice is relatively heavy, geologists feel the need for technical regulation.

Question 6: "Is there any preference to registration by subdivisions of the practicing science?--i.e., engineering geologists, petroleum geologists, etc.?" Yes - 3, No - 16, No statement - 12.

Comment: While a small group have progressed to the point they feel strong, separate identity within their disciplines, the majority either do not favor the idea or have not considered it. This could be considered either as a mass opinion or a lack of opportunity of expression.

Question 7: "What do you believe is the attitude of your state government toward registration in general?" Pro - 8, Con - 4, Mixed - 1, Neutral - 1, No statement - 17.

Comment: This question is a trifle underhanded. Who can judge the legislative (political) mind! In view of this, it is surprising that even eight areas judge their political climate as favorable.

In many cases, those state geologists answering the questionnaire took time to present their views in more than simple answers to the questions posed. Several of these observations are so well conceived as to suggest their inclusion here.

Observation No. 1: "Engineers are primarily creators of things and services useful to man.

"Scientists are primarily discoverers and interpreters of information about nature. (From NSPE)

"Now, if scientists, or if you wish, geologists, are going to play the engineer's game, perhaps they should become registered. On the other hand, if the engineers are going to play the scientist's or geologist's game, perhaps they should be required to pass some scientific professional examination."

Observation No. 2: "My personal opinion is that we should start with a voluntary roster which would include only the names of qualified geologists, and from this work into state registration by law rather than going directly into state registration by law before the majority of practicing geologists are educated to the idea. However, if geologists are to maintain their status along with engineers, it appears that some basis for designating qualified geologists is going to be necessary. This is being brought about by the fact that too many people who are not technically trained geologists are posing as geologists and thus hurting the profession."

Observation No. 3: "I believe it is a sad commentary on a profession that more and more professional engineers, architects, and planners are moving into the fringe areas of geology and claiming that because of registration they have superior knowledge. This is particularly true in the area of ground water investigations and surveys of foundation conditions (called variously soils mechanics, soils engineering, and just plain engineering)."

Observation No. 4: "After talking with the few geologists who do the majority of the practical work in the state, I can say that they favor registration. Although I have not consulted the majority of the academic personnel, I feel fairly sure they would oppose organization.

"The practical geologist favors registration as it would place him in the group with other registered professionals with whom he is associated much of the time. This would also give him a higher standing in the eyes of the layman."

Observation No. 5: "As long as geologists cannot get together on things as the GSA or AGI, and as long as the average thinks that all geologists are those working for oil companies or the Federal Survey, I do not feel that we should be professionally registered. Rather we should educate all geologists that they are geologists first, and engineering geologists, petroleum geologists, mining geologists, paleontology geologists, or what have you, second. After all, the American Chemical Society has its strength in that its members are chemists first and specialists in the field of chemistry second."

LOCAL ACTION

I think it is clear to all that geologic regulation or regulation of geologists by geologists is a question of controversial opinion. "Burning" opinion is an apt description for many. It is not by any means a simple yes or no. The only simple element present is that there exists a problem and its character is, "do we need regulation and, if so, how do we accomplish such to our benefit?" A majority would favor effective self-regulation. Also, however, a majority opinion exists which states that this cannot of itself accomplish the task. Does the answer lie, then, in the alternate of legal regulation by the individual State, or a combination of both?

In California, after three years of intensive study, the California Association of Engineering Geologists decided that a middle course exists which combines the benefits of both. We all know, and can point to examples, that neither self-regulation nor legal registration solves the problem of public and private control in our technology. The Association has evolved the answer, not new, that the most effective control of the problem can be accomplished through a strong but private organization operating in conjunction with legal recognition through state registration. CAEG has been an effective organization since its inception in 1957. Ethical and organizational problems have been met and solved by action of standing committees formed for the purpose. In 1960 a majority of the membership voted to further the action of its registration-study committee through seeking registration for engineering geologists. A concurrent proposal to investigate registration for all geologists of whatever subdiscipline was defeated. Now, one and a half years later, a proposed registration bill has been prepared. It has been reproduced in quantity and disseminated to the full membership. It is planned that each local section will devote a full meeting to discussion of the draft bill such that the majority opinion may be expressed in the final presentation. Finally, at the time of the annual meeting in October, a significant portion of the business session will be devoted to discussion of the bill and airing of the more controversial provisions. It is clear that when this bill is presented to the California legislature in January of 1963, it will represent the majority opinion of the CAEG. The legislative fate of the bill is the next and equally difficult task awaiting the organization. This, as the Navy puts it, will be an "all hands evolution." It will require active, partisan participation on the part of all able and willing to do so.

In formulation of the CAEG bill, certain features stood out as being the more critical or controversial. These are:

a. Grandfathering. As in all such professional registration bills, this is included as a legal requirement with all the elements of abuse against the very standards the Association is attempting to create. However, in this bill control of the problem is attempted through vesting powers of application approval in the proposed State Board of Registration for Engineering Geologists. The applicant must apply within one year of the effective date of the law. He need not take the written examination but he must meet the approval of the Board as to his education, training and experience. It is hoped that the more notorious evasions of such registration laws will be thusly controlled. It should be remembered that the Association, whose membership requirements are equally high with the proposed law, will be arrayed in defense of the law and its Board.

b. The Board of Registration. This body can be a separate board or a separate committee within an existing board. Political flexibility here will enhance possibilities of legislative passage. Of five members appointed by the Governor, four will be engineering geologists and one will be either a public member or a registered civil engineer.

c. Definition of Engineering Geology. Here lies a small but critical article. It had to be carefully worded. Political and professional elements in direct opposition or even those undecided will be jealously scrutinizing this, our concept, with a view to the possibility of someone else usurping their own vested interests.

d. Reciprocity. The board is authorized to issue a certificate of registration to "any person holding a certificate of registration issued to him by any state or country when the applicant's qualifications meet the requirements of this chapter and rules established by the board."

e. Temporary Authorization to Practice. Such temporary authorization would be issued to legally qualified engineering geologists who have no place of business in California. The out-of-state geologist must appear before the board to satisfy that body as to the adequacy of his knowledge in that phase of engineering geology for which the applicant proposes to practice under the temporary authorization. The successful applicant may be issued authorization ranging from 60 to 120 consecutive days on payment of a prescribed fee.

f. Scope of Regulation. This article can be condensed as follows: Any person practices engineering geology when he professes to be an engineering geologist or is in responsible charge of engineering geology work. The registered engineering geologist may prepare and stamp or seal plans, specifications, reports, etc., dealing with engineering geology, thus establishing his responsibility. Employees of the United States are exempt from this act.

g. <u>Offenses Against the Chapter</u>. The law provides for disciplinary action against those practicing in the field but outside the provisions of this Chapter. The Board is empowered to deal with these infractions and is required to so act.

h. <u>Education, Training and Experience Requirements</u>. For the Engineering Geologist Status, the following is excerpted:

"An applicant for registration as an engineering geologist shall have all the following qualifications:

a. Be of good moral character.

b. Meet <u>one</u> of the following educational requirements fulfilled at a school or university whose geological curricula have been approved by the board:

(1) Graduation with a major in geology.

or, (2) Completion of sufficient courses in the geological sciences to qualify for a geology major in that school or university.

or, (3) Completion of 30 semester units in geological science courses leading to a major in geology, of which at least 24 units are in the third or fourth year, or graduate courses.

c. At least four years of professional geological work are required under the supervision of a qualified geologist. A qualified geologist is one who has had a minimum of five years' experience in responsible charge of geological studies.

d. Also required are at least three full years of professional work in the field of Engineering Geology under supervision of a registered Engineering Geologist or a registered Civil Engineer.

The ability of the applicant shall have been demonstrated by his having performed the work in a responsible position.

e. And, lastly, successfully pass an examination."

In closing, it is the hope of the California Association of Engineering Geologists that their bill as prepared and legislated will function as a model bill for others. Further, the CAEG realizes that their path of action is not a cure-all for problems affecting the engineering geology field. But, this is firmly believed---that if their efforts are successfully concluded, the engineering geologists of California will have taken firm action toward alleviating many unethical practices now common and will have strongly enhanced their stand with closely allied technical fields.

DESERT MATERIALS--TYPES AND USES

By

B. J. Gallaher
Materials Engineer
City of Phoenix

Desert materials sources in the State of Arizona are probably similar in some aspects to materials situations in more humid climates. One of the problems, which I should imagine we have in common, is that as far as construction aggregate deposits are concerned, it always seems to be a situation of "feast or famine." However, and I could be prejudiced, I feel that in some areas of Arizona the famine bit has been carried a little too far. But, due to necessity and demand, roads have been and will continue to be built in these areas utilizing the materials at hand in a way to achieve the desired end--a roadway which serves the purpose for which it was designed within the allowable economic limits.

The State of Arizona is composed primarily of two structural provinces. These are: the Colorado Plateau in the north and northeast portion, and the Basin and Range province in the south and west portion. In general, the construction materials found and utilized within the state vary to a certain degree with the province in which they are located. Therefore, I shall discuss these provinces separately.

COLORADO PLATEAU

This province, in general, consists of gently dipping sedimentary formations, with folds being the more prominent structural phenomena. Some of the folds are very picturesque monoclines and upwarps. Extensive volcanic activity in the Flagstaff and White River areas have produced the highest elevations in the state, with some of the peaks exceeding 12,000 feet.

The rocks in this province range in age from Pre-Cambrian to Tertiary. However, most of the rocks older than Permian are exposed only in the Grand Canyon or along the Mogollon Rim. Also, there are some small exposures of older quartzites and granites in the Defiance Uplift. Thus, most of the surface rocks are Permian or younger--unfortunate from a materials standpoint, because predominently these formations consist of sandstones, siltstones, shales, and mud stones with isolated Tertiary volcanics. Needless to say, these types of rocks are not conducive to the formation of good gravels. The sandstones do, however, serve as the source for some materials. The materials are in the form of blowsand deposits. These deposits are in good supply on the Navajo Reservation where there seems to be enough wind for their deposition. Blowsands in this area have been used for everything, from borrow to mineral aggregate, for many miles of roads.

The usual specifications set for blowsand base construction are that the material be non-plastic and the maximum amount of material passing the #200 sieve be no more than from 10 to 15 per cent. The amount of minus #200 material may be increased if frost is not a problem. While no other grading requirements are specified, the amount of material passing the #40 sieve usually runs from 90 to 100 per cent. As can be readily seen, working with material such as this, there would be difficulty in getting the material to set up. This problem is further complicated by the fact that in many places where blowsand has to be used, there is also a shortage of water. The method usually used to overcome this lack of water is bituminous stabilization. Where water is available, soil cement has been utilized for stabilization. These stabilization methods are also required in order to have a firm base for paving operations. Where it is necessary to use this sand for aggregate base, it is also usually necessary to use it for mineral aggregate. In regard to using blowsand in asphaltic concrete mixes, I would like to quote from a paper presented by Mr. C. H. McDonald, Area Engineer-at-Large, for the Bureau of Public Roads.

> "As you are undoubtedly aware, stability tests on dune sand mixes almost always indicate that the mixture would fail under traffic. The fact that it does not, when properly constructed, can probably be attributed to the resistance to displacement of very thin films of high viscosity binder to impact loading. They will displace under static loading, particularly when new, but gain resistance to that with time. The mix must be kept lean, so as to achieve thin, and therefore strong, films of asphalt on the aggregate particle. The color should be brown, and not black, in appearance. The asphaltic residue in the mix, after curing, must have a high viscosity."

The extensive volcanic activity in the vicinity of the towns of Flagstaff and Springerville have produced another interesting source of material, in the form of cinder cones. I'm quite sure that if you drove to Phoenix from the east, you made use of some cinder roads. They can usually be noted by their red color, although some are black. The cinder cones in Arizona range in age from late Tertiary to recent. In fact, some eruptions have been dated by tree rings of beams from Indian dwellings which were covered around 1000 A.D. Since cinders seem to weather to a highly plastic clay, the more recent cones are better producers of aggregate as to quality and economics of production. In situ, due to the method in which they were formed, cinders are more or less of one size. A typical grading might be as follows:

SIEVE SIZE	PERCENT PASSING
3"	100
1-1/2	96
1	82
3/8	49
1/4	40
No. 4	33
10	23
40	13
200	3

This type of grading creates a problem in that crushing, unless excessive to the point which is not economically feasible, does not produce the fines needed for a well graded material, Crushing to 3/4 inch maximum size would produce a grading as follows:

SIEVE SIZE	PERCENT PASSING
1	100
3/4	98
3/8	69
1/4	52
No. 4	39
10	32
40	16
200	4

Due to this open grading and the harshness of cinders, they are very difficult to compact during construction. However, under roadway traffic they tend to settle. This settlement has been attributed to the breakdown of the harsh particles and edges due to the dynamic loading. Because of this fact, roads constructed of cinders are usually built in stages. The roadway prism is constructed up through the base coarse, of which the top two inches is stabilized with asphalt. A surface seal coat is then applied, and the roadway is open to traffic. The asphaltic concrete pavement will not be built until a lapse of from three to five years to allow for settlement.

The use of volcanic cinders for asphaltic concrete also poses a problem, due to their porosity and open grading. The amount of asphalt normally used is from 12 to 16 per cent by weight. The amount of asphalt used is generally arrived at empirically, as the high porosity of the aggregate makes it very difficult to arrive at a usable specific gravity, and hence a usable per cent voids filled figure. The usual compacted weight of cinders is from 100 to 110 pounds per cubic foot. To illustrate the absorptive texture of cinders, on one particular sample the following results were obtained. The per cent voids filled were computed to be 70 per cent at 70 degrees F. However, when the specimen was heated to 140 degrees F. it was a very prolific producer of asphaltic cement. This pehnomena of cinder aggregate is a definite source of trouble. In cool weather the mix has stability, but lacks cohesion, which would cause cracking of the pavement if any excessive deflections occurred. In hot weather the mix has cohesion, but lacks stability, which could cause rutting. The method used to prevent excessive absorption of asphaltic cement is to keep the mix temperature as low as possible.

The areas in which cinders are used usually contain heavy clays in the subgrade, and these tend to pump up into the porous cinder base coarse. In order to alleviate this problem, the State Highway Department uses what they term subgrade seal. The type of material which makes good subgrade seal is material with enough fines and P.I. to set up very tightly much as material which would be desirable as a natural surfacing. The material usually used in this area is produced by crushing a limey sandstone facies of the Kaibab formation of Permian age. While subgrade seal is used primarily in conjunction with cinders, it is also used in other areas where highly plastic materials are encountered.

BASIN AND RANGE PROVINCE

This area constitutes the desert as most people think of it. While this province is topographically lower than the Colorado Plateau, it is structurally higher, causing older, more crystalline rocks to be exposed. The land, in general, is characterized by over a hundred individual mountain ranges alternating with broad plains, valleys, or basins. While the mountains might vary from simple to complex in their internal structure, a general cross-section would tend to be typical of a basin and range structure. The margins of these mountains are usually composed of a rock or gravel pediment which merges into an alluvial valley floor. Commonly, the rock pediment drops off abruptly into a deep valley trough which probably formed by folding or faulting. Many of the mountains are eroded, to the extent that they are virtually buried in their own debris.

cause of these numerous mountain ranges, it is within this province that st of the good gravel deposits of Arizona are found. There are many older avel pediments and terraces in and around these mountains. These, however, are ually coated and/or cemented with caliche or clay. Naturally these qualities ke the aggregate undesirable for most construction projects. Fortunately, ese terraces and pediments are presently being eroded due to climatic changes r rejuvination of another sort. Therefore, these deposits furnish good sources r the present day streams and washes. The fact that our rains usually occur the form of sudden, intense thunder storms is of great benefit also. Washes ay be running full one day, transporting a great deal of gravel, and be dry the ext, with the gravel having been deposited at certain locations. Where these ashes move across the more or less flat basins of valleys, they are constantly eworking the gravels and fanning them out. This is due to the washes continually aving their courses changes by the deposition from previous flash floods. While he washes may continue to emerge from the same point in the higher elevations, they igrate from side to side as they progress onto the flats. This procedure causes ravels to be deposited very shallowly over a large area. As one materials prosector put it, "They are like Powder River, four miles wide, a quarter-inch deep, nd go from here to yonder." These conditions are the reason for setting up the ajority of the pits in the present day wash channels and their overflow areas, s they are currently being built up and contain workable gravel deposits of from three to eight feet in thickness. As you can see, these thicknesses call for pits which cover large areas, especially for the Interstate Highways. With the present day boom in Arizona land speculation, these large areas are hard to come by and this poses a major materials problem in this province.

Since this province is a structural high, most of the present mountains are the remnants or cores of pre-existing mountains. Due to this, a lot of the exposed rocks are metamorphosed to some degree, thereby containing a large amount of schist. Concluded that schist, as a rule, is not a good source for the production of construction aggregate, this is not necessarily the case here. The reason for this is due to the constant reworking of the materials in the washes. The softer material is broken down and flushed out, leaving the more durable particles in the form of lag gravels. The problem here is in finding that choice location where the above process has been carried out to the extent that a desirable gravel deposit is the resultant. As these gravels are derived from rocks which have been subjected to intense deformation, they tend to be platy in texture. This platyness persists through crushing operations. The results of this are that a rock particle may pass the 3/4-inch sieve, but be two inches in length. This tendency of the particles causes them to orient themselves into a position, in base or pavement materials, where their long axis is parallel with the road bed. Rolling operations tend to help these particles achieve this orientation. This parallelism causes a loss of stability due to the lack of interlocking particles, while, on the other hand, it tends to increase the cohesive strength. This platyness is not always present to the extent that it is detrimental, due either to the degree of schistosity of the parent rock or an admixture of gravel from other sources.

Another problem is created because most of the thicker and more widespread volcanic flows in the desert are felsitic. This causes the aggregate found in the areas where these flows exist to be hydrophilic, or absorptive, or sometimes both.

I have probably indicated in this paper that there is nothing but problems associated with materials in Arizona. If so, it is with the thought that if there were no problems there would be no achievements.

GROUND WATER PROBLEMS IN THE LOWER GILA RIVER DESERT AREA

by

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ABSTRACT

The lower Gila River desert area lies to the west of the confluence of the Salt and Gila Rivers and stretches to the Colorado River. The area is largely covered with alluvial fill; the river tying together the separate basins.

Water problems are three-fold: too much water in times of flood; too little water with normal flow, and too saline water when pumped from the underground.

The lower Gila River area may be considered as all and in the flood plain of the river lying to the west of the juncture of the Gila and Salt Rivers. While the river itself trends westwards, it crosses a series of northwest-southeast trending mountains. These mountains are largely thrust blocks that have divided the area into a series of basins. In several localities old lake sediments indicate that these basins were cut off from each other and that the ancestral Gila River captured them one by one. At times, these intermittent lakes, were formed by lava flows which cut across the old channel and allowed sediments to build up until the lake flowed over the crest and again began cutting down in its new channel. From the Colorado River junction back towards the east, there is some evidence of estuarine deposits during the Pleistocene. Since none of the areas, where the river crosses the mountain trends, shows especially narrow or deep cuts, it is assumed that the river was established during a period of gentle down-warping along its axis.

The valley fill is composed of alluvial material at two different ages. In the flood plain, the surface deposits are usually less than 100 feet in thickness and are largely sand or sandy loams with stringers of finer-textured material and lenses of gravel at the greater depths. The older sediments tend to finer-grained, of lacustrine or estuarine origin. Where the river has cut, there are backfilled channels up to 50 feet in depth. Most of the soils were deposited after the Gila River entrenchment.

The water problems at the area are almost self-evident. First, the problem of getting any water, both for farming and for domestic uses. In former days, there was surface water available but it was necessarily in the river channel. Today, underground water, from wells is available. If one located near the channel, there is a second problem, that of floods; as recently as 1941, water flowed down much of the river and flooded farm lands. If one uses pumped water, the problem becomes one of salinity.

The underground water at the area is recharged by several methods;

(1) Surface flow in the Gila River and its tributaries, including washes.

(2) Direct precipitation, from 4" to 6" per year.

(3) Underflow of the Gila River.

(4) Irrigation waters applied directly to the land.

Because of the arid nature of the region, any surface waters have a tendency to become more and more saline the further it travels down the valley. In years past, the summer flows from the Salt River were especially high in salinity and the lake deposits had a strong tendency to concentrate salt deposits. The result is that most underground waters now have a high salinity and that, as this water is used on the surface, alkali tends to concentrate in the surface soils.

The Wellton-Mohawk area, which starts twenty miles upstream from the mouth of the Gila River and extends sixty miles upstream, illustrates many of the ground water problems of the entire area.

The original settlers in the area obtained water by making small dams (headings) in the Gila River and diverting the water onto their lands. During wet years they were flooded out and during dry years the heat killed their crops. After the dams on the Salt River stopped the low summer flows that were formerly expected, the farmers turned to another, more certain method of getting water; this time by pumping from the underground. Originally the water was quite good and the crops did well. However, as pumping increased, the water table dropped and the water became more and more saline. Eventually, most of the wells were shut down.

The Congress of the United States authorized the Gila Project in 1946 and the Wellton-Mohawk project was constructed; in 1952, the first water from the Colorado River was delivered to the land and much of the alkine land was reclaimed by leaching. However, with adequate surface water, the ground water began being recharged and eventually rose to the surface and inundated some farm lands. This "new" underground water was quite salty and apparently had mixed quite thoroughly with the saline water that underlay it. It is my personal belief that the original pumping had been from "sweet" water on top of this saline layer and that over pumping had broken the salt-membrane between them; as yet this membrane has not been re-established. In many places, where the soil was finer grained, the salts subbed up to the surface even though the water was more than six feet below the surface.

To take care of this new groundwater problem caused by irrigation, the Wellton-Mohawk District has installed a lined Drainage Canal 60 miles in length with 65 pumps dumping into it. At the present time, approximately 300 sec. ft. are being discharged through this canal.

While this has been successful in lowering the general level of the ground water localized problems remain. In several places there are layers of caliche or adobe, underneath silty soils, that cause "perched" water tables. There are also several underground rock barriers that diagonally cross the river bed underneath the surface alluvium and leave underground lakes. In these areas there seems to be a tendency for the salts to rise and create an alkaline salt flat. While the problem of flooding is not completely solved, the building of Painted Rock Dam upstream eliminated the probability of a large flood sweeping out the area.

As may be seen from the Wellton-Mohawk area, the ground water problems of the lower Gila River desert area are three-fold: not enough water, salty water, and too much water. It is to be hoped that this last problem will continue to be our major one.

APPLICATION OF SOIL MECHANICS THEORY TO FOUNDATION INVESTIGATIONS IN THE ARID SOUTHWEST

by

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INTRODUCTION

Due to the Geological and Climatic conditions that have existed in the southwest United States, one finds many of the soil types, mixtures, and conditions known to exist throughout other sections of the world.

The materials have originated from nearly every sedimentary, igneous and metamorphic condition imaginable, and are found in countless phases of degradation and forms of deposition. Volcanic activity, crest movement, great accumulation and erosion activity, presence of various minerals, and climatic conditions are among the many contributing factors that nature has provided to form the various combinations and complexity of materials found.

Modification that has occurred in materials adjusting to their environment is also accountable for many variations. Materials that may be classified identically by commonly accepted systems are found in countless conditions depending upon deposition, degree of consolidation, moisture content, mineral content, porosity, density, amount of desiccation, and so on.

Great valley fill and alluvial and flash flood deposition, combined with various stages of erosion and consequent sediments have aided in providing interesting problems to the soils engineer. As one might expect, the materials found within these deposits can be so erratic in type, and deposition, that borings less than ten feet apart may be entirely dissimilar. Although this condition is somewhat extreme, it commonly exists without surface indication. In addition, variations in the in situ moisture content are commonly found to be highly erratic.

For obvious reasons, the major portion of building construction is carried out in the valleys and lowland areas. Therefore, it follows that the soil mechanics work for foundation purposes are concentrated in these areas. From the foregoing, it can be noted that no single method of conducting field explorations, laboratory test, or engineering analyses can be satisfactorily employed. This paper is concerned with relating many of the problems that face the soils engineer with his application of soil mechanics theories to foundation investigations in the southwest, and to acquaint others with some of the methods with which these problems are being approached.

SOIL MATERIALS

Soil materials constitute that portion of the earth's crust which cannot be classified as rock. The materials are described as a natural aggregate of mineral grains that can be separated by such gentle mechanical means as agitation in water (1).

Cohesionless Soils:

Cohesionless soils are described (2) as those which have no shear resistance inherent in the materials themselves. These materials include clean sands, gravels, non-plastic silts and volcanic cinders and are found in many states of deposition throughout the southwest.

These deposits may be found in very loose states which undergo considerable compression when superimposed with a load of any consequence or decrease in volume when subjected to the slightest vibration. On the other hand, one may find these deposits highly densified in their natural state, which approach 100% of relative density. Moreover, these materials can be found with field moisture contents ranging from submergence to nearly bone-dry.

The dry materials are often found to have an apparent cohesion due to contact moisture between individual particles. The attraction thus constituted is usually relieved immediately upon the introduction of moisture, and often results in a decrease in volume. Conversely, with the addition of moisture, a bulking, and hence and increase in volume may develop.

These materials are found to vary considerably in texture and type and each must be independently considered. Cinders, for instance, may be relatively soft and flexible, or hard and brittle. Sand and gravel particles may be round or angular, transitory or durable, and so on.

Blow sands, dune sands, and the finer wind blown and sediment sands are usually well rounded marble-like grains whose stability is always questionable when unconfined or loose. However, these materials can be reworked into a dense and suitable bearing material under optimum conditions. Through various methods of stabilization, for instance, many miles of highway pavement sections have been constructed in the southwest, and are performing satisfactorily. Another example of satisfactory performance is the use for bearing material as found in the construction of shallow fills under light weight structures where conventional foundations and slab-on-ground floors are employed. The foundations may be or may not be placed within the fill itself, depending upon existing conditions.

Many of the silt-sand mixtures, particularly in the more recent deposits, are found to be exceptionally loose and highly compressible. In many cases, porosity and permeability are such that surface water may readily saturate the soil to considerable depth and hence render the materials even more unstable.

There is little difficulty experienced in deposits where coarse gravels in great quantities are prevalent, or in well graded sands where the water table has descended to considerable depth. These materials are usually very dense and experience little or no compression with extremely high allowable bearing values.

Cohesive Soils:

Cohesive soils include clays and plastic silts and are described as materials possessing shear strength as an inherent property (3).

These soils are found throughout the southwest in various degrees of consolidation, density, moisture content, mineral properties, grain size and shape, and so on. Prevalent soils include recent alluvium and sediments which are totally saturated and normally loaded, as well as deposits that are highly desiccated and precompressed.

Certainly all of these cohesive soils will exhibit changes in physical properties and structural ability when the moisture content is altered. However, some of the soils will have an almost complete change in qualitative aspects. Swelling, compression, or consolidation may result depending upon the conditions of moisture alteration and the materials in question. Some cohesive soils will indicate a high degree of swelling upon introduction of moisture when unconfined but will otherwise possess a relatively low swelling pressure. On the other hand, swelling pressures as high as 14 tons per square foot have been recorded.

Many materials will exhibit certain degrees of consolidation and compression when loaded as in a consolidation test at the in situ moisture content, but will demonstrate entirely different qualities with only a slight increase in moisture content.

In conducting consolidation tests under submerged conditions, compression is often accompanied by swelling under the lighter loads. On the other hand, complete failure of the soil structure may be incurred, indicating a high degree of settlement under increased moisture conditions.

Occasionally, a cohesive soil is encountered that outwardly possesses the qualities of a cohesionless material until wetted and manipulated. This is found in dry, fine grained mixtures where the clay particles have become bonded to silt and fine sand particles to form larger composite grains. The clay particles are often bentonitic which renders the composite material highly cohesive under the altered conditions.

Montmorillonite clays, including some of the purest deposits of bentonite found, contribute to the cohesive properties of materials found in the southwest. Clays with 100% passing the No. 200 sieve and a plasticity index as high as 212% have been recorded. Composite materials of silts and clays are deposited in great quantities and are often found to possess the undersirable properties of each material.

Other intermediate materials such as loess and modified loess are normally cohesive enough to treat as a clay and are usually investigated accordingly.

Desiccated Soils:

Desiccated soils are materials that have been exposed to the air and llowed to dry. In the arid southwest, this condition is general and extends o great depths below the surface. In valley fill materials, for instance, he moisture content of each strata of soil transported may have been allowed o stabilize with the atmosphere prior to being covered with additional aterial. Lowering of the ground water table has also aided in the drying of ubsoils far below the depths of most foundation investigations.

Upon drying, the tension that has developed in the remaining moisture contact moisture) within the various soils, developes an apparent cohesion hich usually disappears when immersed. This phenomena is prevalent in sands s well as clays and is dependent upon several conditions including grain size, degree of desiccation, mineral content, and porosity.

Apparent cohesion is found to be quite high in some materials and is readily relieved under immersed conditions. Other materials approach the consistency of hardpan, caliche or shale and possess extremely high shearing resistence in their in situ condition. A prolonged period of immersion (perhaps months) are sometimes required for some of these materials to become completely saturated so that all apparent cohesion may be eliminated.

Many of the dried clays posses extremely high unconfined compression but will immediately slake and reduce itself to a plastic, and ultimately, a liquid state with the addition of moisture. Shales that shrink and slough when exposed to the atmosphere are notable as well as siltstones and mudstones that are readily affected with the slightest change in moisture content. Many of these materials are extremely firm in situ, but are highly friable and are readily fractured upon the least disturbance upon removal from their in situ confinement.

It is not uncommon for the inexperienced to classify some of these materials as rock, as often the in situ physical characteristics greatly resemble that of rock. On the other hand, some of these materials have become solidified to the extent that little or no deterioration is experienced when exposed to moisture or the atmosphere. In this case, the accompanying hardness factor often relates the true nature of the material in question. Therefore, a relatively close examination for correct determination is often necessary.

The major soil mechanics work for foundation investigations today is being performed in the desiccated, composite soils within the sediments of large valley fills. The soils are primarily mixtures of sands, silts, and clays, composited in various percentages with no overall predominant features. Some of these soils are dangerous foundation materials in that they are sometimes hard and appear firm and non-plastic in the in situ condition. Further, they are found to be quite un-uniform in density and porosity as well as texture over relatively small areas. In view of the surface uniformity or apparent firmness of subsoils, uninformed engineers and architects will often declare that a foundation investigation, under these conditions, is an unnecessary expense to the client. We are all aware of some of the results that transpire from this attitude.

EFFECT OF MOISTURE ON SOILS

As noted previously, many of the disiccated materials have the outward appearance of being firm and highly cohesive in the in situ condition. This apparent cohesion is often eliminated immediately upon immersion, leaving little cohesive properties.

When broken up or augered, many of these materials appear to be on-plastic until wetted and checked for plasticity which may run from a ow P.I. to 50 or 60 percent or even higher.

Many soils are very similar in classification but the in situ condition is such that completely opposite effects are experienced when moisture is introduced under relatively light surcharge loading. Residences, for instance, employing continuous wall footings and slab-on-ground floor construction (independent of footings) are commonly subjected to this phenomena. Houses are frequently constructed on dry soils without satisfactory consideration of the soil conditions. Yards are consequently irrigated by flooding, or the gardener may concentrate watering in areas adjacent to portions of the structure, which in turn causes the soil to misbehave. In other cases, differences in loading conditions, among other factors, will allow the soil to react differently. Compression may occur under the foundation loads while swelling occurs under the lighter floor loads. Needless to say, this results in quite a maintenance problem.

There are many cases of differential soil movement due to changes in moisture condition (other than that occurring through consolidation) that can be pointed to. There are many instances where proper consideration of the swelling properties of clays was not given, which resulted in considerable additional expense in repairs and maintenance. Concrete walks and floor slabs have raised to the extent that normal sized doors have been cut several inches to facilitate utilization, three story (flat slab) structures have had their roofs lifted by virtue of the first floor slabs raising and exerting an upward pressure on interior non-bearing partitions. Lighter structures have been twisted almost beyond repair in less than one year after construction.

Changes in volume due to loading may be calculated and compensated for by conventional methods, but the changes in volume that may be expected to occur due to an increase in moisture content are not so easily calculated. Economic measures for ultimate and complete compensation are often not within means, and a compromise is necessarily made.

Soils with more than 60% passing the No. 200 sieve and a plasticity index over 15% are considered to require a certain amount of attention in relation to possible volume changes. Soils with a plasticity index in excess of 25% will invariably require special attention to prevent excessive volume changes from becoming a problem.

Due to the fact that moisture has such an adverse effect on many of the sothwestern soils, surface as well as ground water conditions are important factors to be considered. Special attention to the effect of watering planting areas adjacent to structures is necessary and drainage characteristics of the surface to ward off precipitation is important.

The thought of saturating a soil prior to construction, and maintaining uniform moisture content under structures, in most of the arid southwest is not valid in that the low relative humidity and high temperatures would prevent establishment of an economic procedure. Furthermore, with the variation in materials, a method of control that may satisfy one material will not necessarily satisfy another material found a few hundred feet away. Therefore, each soil encountered is analyzed and treated individually to satisfy existing conditions.

FIELD EXPLORATION AND SAMPLING PROCEDURES

Certainly from the foregoing information, it can be appreciated that ;isfactory subsoil investigations for foundation purposes are not obtain- .e by any one single method of exploration. With the various materials and ; countless conditions in which they are found, it is necessary to employ ny methods of field exploration and sampling procedures within economical ason to obtain the necessary results.

Equipment Used:

The most widely used drilling apparatus is the auger boring type. iis type of drilling is commonly performed without the introduction of water id auger boring is simple and inexpensive in the finer grained materials. ome 300 feet of bore holes drilled in a single day by this method is not ncommon. Although the most common auger used is the continuous flight auger hich drills 4 to 6-inch diameter holes, bucket type augers are used that will rill holes up to 48 inches or more in diameter. The latter method will allow he soils engineer to enter the hole for close examination and to carve sample 'rom the side of the hole if desired. However, in some materials, satisfactory ampling may be accomplished by lowering special sampling tools to the desired lepth as the hole is advanced.

Use of augers can lead to erroneous results if not accompanied by suitable undisturbed sampling techniques as the drilled soils become intermixed to the extent that proper identification is not always accomplished. Of course, this same problem exists regardless of the type of boring procedures used except where continuous coring is maintained. Needless to say, continuous coring is relatively expensive and cannot be justified on most foundation investigations.

In Materials that will not permit economical or satisfactory advancement of borings using augers, other methods are used depending upon the nature of materials and the sampling desired. For instance, in a dense deposit of sand and gravel accompanied with considerable amounts of cobbles or boulders, the only economical approach is with a churn drill or cable tool type rig normally used for water well drilling purposes. This rig employs a chopping bit aided by heavy weight on a free fall mechanism for advancement. Casing or driller's mud is usually used to maintain an open hole. Wash samples are continuously available and in situ samples may be obtained in the softer strata by bailing out the drilled hole and advancing the sampler ahead of the drilled hole.

Rotary drilling equipment is used in materials that are texturally non-homogeneous or in deposits that contain a limited amount of coarse gravel, stones, or boulders. Advancement of boring with the rotary drilling method is also found to be more practical in materials where rock such as shale, sandstone or mudstone may be intercalated or present in any quantity with other materials.

Advantages of rotary drilling include the fact that the various bits available provide advancement of boring into many different materials and into many of the materials that do not lend themselves favorably to auger boring. Upon using tools to bore holes with a suitable diameter (usually 6-inch) one may often advance a sampler ahead of the hole for test samples and observation of the in situ soil. The rigs are usually equipped so that driving of samplers and casing, hydraulic pressing of samplers, continuous flight auger drilling, core drilling and wash boring can be accomplished as well as rotary drilling. This flexibility is highly important to the soils ngineer in the southwest, and aside from flight auger drilling, is the ıost popular drilling apparatus used in foundation investigations.

Resistance to penetration by dynamic methods is widely used. The ıumber of blows required to drive samplers is used as supplemental inforıation as is the "Bull Nose" continuous penetration apparatus. The latter is relatively crude in that it is merely a hardened steel driving head that fits directly on the end of "A" rod. A 2-inch O.D. washer is placed on a seat on the drive face of the penetrometer which provides a 2-inch diameter driving surface. After the apparatus is driven to the desired depth, the "A" rod and penetration apparatus is lifted and the washer is left at the bottom of the hole. Thus removal of the apparatus and "A" rod is readily accomplished in most soils due to the slight difference in the outside diameters of the penetrometer and washer. This method provides continuous information on penetration resistance throughout the depth investigated rather effectively and economically.

In situ sampling equipment normally used includes the standard 2-inch split tube apparatus, 3.5-inch O.D. sampling apparatus with ring liners, thin walled or shelby tube samplers, and piston type samplers.

AX and NX coring is used for sampling purposes in hard soils and rock with the NX size being preferred.

Other types and sizes of samplers are rarely used and will not be discussed.

The samplers employing the ring liners consist of a rather thick outer liner with a thin brass liner, a sampler head, drive shoe and accessories similar to the Moran and Proctor sampler (4). The major differences in the two samplers is that the brass liner is made up of 1-inch wide rings to facilitate laboratory testing and alleviate sample disturbance in trimming. Effective length of sampling is reduced so that disturbance due to the dynamic means with which the sampler is advanced is minimized. For this same reason, a 340-pound drive hammer is preferred in lieu of the more standard 140-pound hammer. In many of the soils, it is found that less disturbance is actually experienced with samples of this nature than those that are trimmed from a greater size or diameter.

Sampling Procedures.

Piston samplers with stationary pistons and thin walled tubing are used in the soft and cohesive soils that lend themselves to this type of sampling. Some of the silts and loose sands are best sampled with the piston type sampler and open drive samplers made of thin walled shelby tubing is used in many of the more cohesive soils.

Block sampling is accomplished in lieu of the above methods whenever practical. Experience with many of our materials has shown that samples thus obtained and carefully trimmed are superior to those obtained by the methods mentioned above. Many of the harder, drier, and more highly cemented materials, however, do not lend themselves favorably to any of these methods of sampling and are sampled in still another manner. Relatively thick walled samplers employing brass liner rings as mentioned previously, are used in sampling these materials. The sampler is driven only 10 - 12 inches at a time to minimize disturbance due to the dynamic loading. Although the disturbance factor is greater with this sampler than it may be for many others, disturbance due to trimming is minimized and removal of material from the liner to the testing machine is not necessary for many of the laboratory tests.

Trimming of highly desiccated and friable soils always imposes a problem and usually renders the sample highly undesirable if not unusable. Trimming is therefore minimized to the greatest possible extent by the more practical sampling technique and results in obtaining much more satisfactory tests.

Sampling of materials from cuttings of rotary and churn drill rigs is accomplished in the usual wash sampling manner and the samples obtained are used for identification purposes only. However, as mentioned previously, strata may lay within the deposits where rotary and churn drilling is required which may lend itself to normal undisturbed sampling procedures.

For logging and sampling relatively shallow depths (to 12 or 14 feet) a back hoe is often used to open an excavation which enables one to enter and cut block samples from the sides. This method is widely used for highway and airfield investigation purposes and in development of areas for borrow materials.

Correlative Data Obtained:

Continuous penetration resistance information is used extensively in conjunction with the information compiled with continuous flight auger borings. Changes in soil strata are more accurately detected and relative density information is continuously obtained. Many of the smaller structures simply do not warrant an investigation consisting of undisturbed sampling and laboratory testing of undisturbed samples. Also, soils of suitable bearing capacity for these lightly loaded structures are often found at shallow depths. Therefore, with some practical knowledge of the materials, and upon exercising some judgement with the final analyses, laboratory testing is minimized with the use of penetration resistance data.

The information compiled with the continuous penetration resistance procedure is quick to indicate the materials whose in situ condition is the more questionable, and results in the more critical zones or strata being accurately located and sampled. Correlative data with laboratory test results and "Bull Nose" continuous penetration resistance values are being compiled and studied at this time.

Information obtained by geophysical methods, depending on the materials and conditions involved, is being used to a considerable extent. These methods include magnetometer, gravity meter, seismograph and electrical (resistivity) surveys. Information thus obtained is used in conjunction with test borings and supplements the subsurface exploration program by "filling in" information between borings. Information developed in this manner will often reduce the number of borings necessary in a large subsoil investigation, but caution must be exercised in this respect. Tendency to reduce the number of borings to the extent that adequate control is not developed, or to the extent that borings are eliminated altogether (where sampling is not required) is a common error found among the uninitiated.

LABORATORY TESTING PROCEDURES

Testing procedures followed in the laboratory depend upon the materials in question and the anticipated conditions under which the materials are to be subjected.

Sample Preparation:

Preparing undisturbed samples including selection, trimming and positioning for laboratory tests, is accomplished best in the cohesive soils that are in a semi-plastic or plastic state. These materials are usually subjected to the least disturbance and yield the most satisfactory and conclusive results. The samples are usually obtained in these materials with thin walled samplers with an inside diameter slightly larger than the shear and consolidation testing rings. Each sample is extracted and trimmed by the advance method into the testing ring with little disturbance.

However, sample preparation of many of the relatively stiff and partially cemented soils including clayey silts, loess, and other relatively homogenous fine grained soils is often best accomplished by trimming from block cut samples. This method is used as a matter of practice in these materials where block sampling proves to be practical. Depth below ground surface, accessibility, and moisture conditions are among the factors that impose upon the practicability of block sampling.

The cutting of test samples from block samples is performed by advance trimming into a ring or cylinder of constant cross section and known volume. The specimen may be left within the ring or cylinder, or consequently removed depending upon the test being conducted.

The more stiff and moderately cemented soils, excluding soils containing any appreciable amount of gravel or stones, are sampled with the relatively thick walled sampler employing inner liner rings. This method is employed quite extensively in that the majority of the soils sampled and tested in recent years fall into this category. The materials almost invariably contain nodules of caliche, lime or clay cemented lumps, coarse sand, or fine gravel particles that render hand trimming quite difficult. Secondary structure consisting of hair cracks, joints, and slickensides, contribute to the complexity of trimming samples. Slickensides are not too common in the materials considered in this category, but do exist however.

Materials containing an appreciable amount of slickensides are often firm enough to facilitate sampling by core boring. However, sampling by block cutting, or other methods previously described, are occasionally practical.

The thick walled sampler with inner liners yield test samples where no trimming or manipulation in the laboratory is necessary except to "slice" or separate the rings and square the surfaces. Many of the laboratory tests are conducted with the samples remaining within the rings with which they were sampled. It is true that these materials are greatly disturbed during sampling, but it is minor compaired to the disturbance inflected during the trimming procedure. In some cases, the samples cannot be trimmed at all without complete disintegration.

This latter discussion concerning sample preparation of the more highly desiccated materials is probably the only major variation from normal practices of laboratories in other areas.

Shear Testing:

Although ring shear tests, unconfined compression tests, and triaxial shear tests are extensively used, the box type direct shear test is the most popular for undisturbed samples in foundation studies in the southwest. Most of the materials lend themselves to the box type apparatus favorably where there are often limitations involved with the other methods mentioned. However, the various tests are used compatible with the soils and conditions prevailing.

Undisturbed samples subjected to the box type direct shear test are often rather highly desiccated and possess considerable apparent cohesion in the in situ moisture condition. The soils are usually mixtures, and as

THE GEOLOGIST AND THE ENGINEER

In order for geology to be more widely accepted, some understanding of the philosophy of the engineer and of the geologist should be considered. The engineer is interested primarily in fact, not theory. He wants specific data to plug into formulas. He is not interested in the why, where or age of geologic formations. He wants to know what they will do when subjected to certain loadings. He is interested in the engineering qualities, not the detailed description of formation and soils. For these reasons, a geologist must understand what the engineer wants and not fill his reports with unnecessary knowledge.

On the other hand, the geologist is reluctant to give specific engineering facts regarding formation or soils for several reasons. One reason is that very few geologists have had an opportunity to learn what the engineering facts are regarding formation and soils. Another reason is that the geologist is fully aware of the extreme variables which occur in the formations — both vertically and laterally, and he knows that no single figure will give the absolute bearing value of the formations. This is where the trained engineering geologist can act as a liaison between the engineer and the geologist. The engineering geologist has been trained in engineering subjects or has worked with engineers for a considerable period to understand the problems facing the engineer. He knows the importance of determining some value or figure which the engineer can use to solve his problem. He knows it is impossible to give an absolute correct figure because of the variable nature of the material. However, he has devised some methods of investigation and testing not familiar to the average geologist. These techniques, together with his understanding of the geologic formation, enable him to arrive at an average figure which can be plugged into a formula or used as a basis for design.

would be such that practically all multi-story structures would be placed on raft foundations. Therefore, two or more consoldiation tests on the same material are often conducted simultaneously under various moisture conditions, including the in situ condition, so that more conclusive and practical information is developed.

It is recognized that the settlements computed in desiccated materials at the in situ moisture content are greatly due to compression and plastic deformation in lieu of actual consolidation.

The degree of compressibility may or may not be proportional to the void ratio among other aspects depending somewhat upon the degree of cementation. Thru introduction of moisture by absorption, for instance, the structure of a highly cemented soil would be relieved, and the amount of compression increased 2 or 4 fold over that experienced at the in situ condition. Yet material with a higher void ratio and less cementation may exhibit considerably less increase in compressibility and less total compression under the same conditions.

Volume Change Characteristics:

Tests conducted to include these characteristics include swell tests, volumetric change tests based on the field moisture equivalent, and consolidation tests previously discussed.

Swell tests are conducted to determine percentage of swell, swelling pressure, and potential vertical rise under estimated surcharge loads. The tests may be conducted on undisturbed samples, remolded samples, or both depending upon the ultimate use of the soil in question.

The volumetric change test has been intensively used to aid in establishing moisture characteristics but is becoming less popular.

Procedures for these tests are more or less standard, and sample preparation has been outlined. Test results are straight forward and require a minimum of interpretation.

Identification:

Tests not previously mentioned that are commonly conducted for identification purposes include mechanical analysis and plasticity index. These tests will aid in placing the materials in a particular classification and often offer some explanation as to the behavior of the soils observed during shear or consolidation testing, for instance. Other tests often conducted to aid in identifying soils and determining physical characteristics include the shrinkage limit, shrinkage ratio, specific gravity, permeability, and capillarity.

Mechanical identification tests as well as the field and visual identification procedures are used to minimize the duplication of the more elaborate and expensive tests necessary to satisfy an investigation. Although, some duplication of tests are necessary, particularly in the larger scaled investigations, undue costs are checked with confidence in this manner.

ANALYSIS AND APPLICATION

The particular analysis and application of data compiled in an investigation naturally varies considerably with the conditions that will prevail, or are likely to prevail, during and after construction. These factors are taken into consideration.

Bearing Capacity:

Bearing capacity is estimated through the use of conventional formulae based on cohesion and angle of internal friction of the materials in question. As mentioned earlier, there is often considerable difference between the shear strength obtained under saturated conditions and that obtained under existing in situ moisture conditions. This is particularly true of highly desiccated soils. The problem is, therefore, to determine which condition should be used and the safety factors to be applied to the values calculated for these conditions. The solution to this problem will vary with site conditions such as drainage, intended use, paving, planting, proximity of ground water and so on.

When site conditions are such that probability of saturation occurring is very low, safety factors against shear failures based upon saturated conditions are reduced. Saturated shear strength should always be considered in the calculations, thus representing the poorest conditions for which a safety factor comparable with the probability of saturation occurring can be maintained. Commonly, a safety factor of 2.0 for the maximum probable loading and 1.5 for the maximum total loading, is applied to the ultimate values calculated for saturated conditions.

Concurrently, however, it is considered necessary to maintain accepted values against shear failure at the in situ moisture content. Safety factors of 3.0 for the maximum probable loading, and 2.0 for the maximum total loading, are usually maintained for values calculated under these conditions.

Settlement Analyses:

Estimating probable settlements of structures founded on desiccated soils is difficult and must be approached from a practical standpoint.

A similar problem to that outlined in the discussion on bearing capacity exists where in settlements calculated for the saturated condition may be 2 or 4 times as great as settlements calculated for the in situ moisture condition. There is, however, a major difference in that quite often "excessive" settlement will cause only repairable damage to a structure, whereas shear failure could be catastrophic. Again, the influencing factors must be carefully studied, and the settlement analysis conducted in accordance with good judgement.

Commonly, where the probability of saturation is low, the settlement analysis is based upon the consolidation test data obtained for in situ moisture conditions. However, probable settlement data based upon saturated conditions is usually compiled concurrently. It is always possible that saturation could occur under portions of the foundations (i.e., under a single footing) resulting in extreme differential settlement. If possible differential movement of this order could cause structural failure or damage beyond feasible repair, then an adjustment or redesign of the foundations is necessary to include an adequate margin of safety.

Swelling:

Soils that are found to possess unfavorable swelling characteristics react in several different ways. There are the soils that exhibit a high degree of swelling ability but are readily retained even with a very light surcharge. There are the soils that exhibit only a limited degree of swelling ability, but will exhibit considerable swelling pressure. Then, there are the soils that will exhibit both, a high percentage of swell, and a highswelling pressure.

The problems are considered separately in each investigation and are studied concurrently where settlement is being analyzed. Obviously, the heavier structures are not as subceptible to damage by swelling soils as are the lighter structures, and consequently these soils have become more of a problem to small structures, such as houses.

Depending upon the situation, several methods are being used to meet this particular unstable soil condition. Introduction of voids under the foundations and floor slabs on ground using coarse rock or some other method, floating and semi-floating slabs, slab on pier, or grade beam and pier construction are methods used to prevent damage caused by swelling soils.

Often the weight of base course and concrete slab for slab on ground floor construction is ample surcharge to counteract the uplift tendencies. Occasionally, recompaction of the soil in question can reduce the swelling characteristics. However, the opposite affect is often achieved and therefore the merit of recompaction must be considered.

SUMMARY AND CONCLUSIONS

Although highly desiccated and calcic soils are not peculiar to the arid southwest, these soils do constitute a major portion of our foundation materials. Sampling techniques and testing methods are continuously being upgraded to provide more satisfactory and realistic information. A failure to recognize the true ability of these soils can lead to gross over designing or under designing, depending upon the prevailing conditions.

While the above mentioned soils are prevalent, many other soils and conditions are found to exist. For this reason, various methods and techniques must be employed in obtaining the desired information. A wide variety of soils are found. Highly expansive clays, highly compressible silts, and loose sands are on hand to inject their particular problems. Many soils are hard and appear extremely firm in situ, but one must consider the consequence when the soil is allowed to become moist or saturated. For this reason, it is common to conduct duplicate tests in the laboratory to study the soils under these conditions. Keeping in mind that the end result must be workable for design criteria, one must exercise his objective views and decide the validity of data on which to base his assumptions and the emphasis to be placed upon final recommendations.

A practical approach is necessary to ascertain feasible designs in the majority of investigations. It often becomes a necessity to assume a calculated risk against the soil ever becoming saturated and result in placing the foundation at sufficient depth to be protected against normal surface waters and smaller floods. This approach is made where ground water is not likely to become a problem. In most areas, the ground water level is at considerable depth.

The continuous probe or penetration apparatus is used extensively with the usual 6-inch bore holes to aid in establishing changes in strata, moisture, density, and firmness. It is an inexpensive method of "feeling out" strata of particular interest. Information is being compiled in an effort to establish a correlation of this apparatus with in situ shear strengths of the more common fine grained soils and conditions found in the valley deposits.

Settlement more often controls the design of foundations in the valley fill deposits. The probable settlement is usually estimated on the basis of consolidation tests. These tests are usually more accurately referred to as "laterally confined compression tests" as actual consolidation does not exist to any great degree. Most of the settelment is attributed to compression, plastic deformation, and realignment of the soil particles under load. The false structure prevalent in many of the soils provided by mineral contact is relieved when moistened and will quickly compress under load as the larger air voids are replaced by smaller voids filled with water. This action greatly increases the settlement one may expect within these soils. As mentioned previously, the increase may be 2 to 4 times as great. It is therefore a matter of judgement to determine whether the founding material will be subjected to an appreciable rise in moisture content or not. Depth of footing again plays an important roll in guarding against surface waters - providing, of course, that ground water is not a matter of concern.

Perhaps the problems encountered with soils found in the southwest are not as numerous, nor as plentiful, as encountered in other sections of the country, but there are problems and there is a wide variety of problems for consideration. Each investigation is a separate investigation in that the materials and their uniformity is highly unpredictable.

THE CURVES SHOWN BELOW ARE TYPICAL OF MANY DESSICATED SOILS OF THE SOUTHWEST. AFTER THE TEST PERFORMED AT THE IN SITU MOISTURE CONTENT WAS COMPLETE UNDER A PRESSURE OF 8.26 TONS PER SQUARE FOOT, THE SAMPLE WAS SUBMERGED AND THE TEST CONTINUED FOR AN ADDITIONAL LOAD INCREMENT. A DUPLICATE TEST WAS PERFORMED UNDER SATURATED CONDITIONS.

PRESSURE vs. VOID RATIO

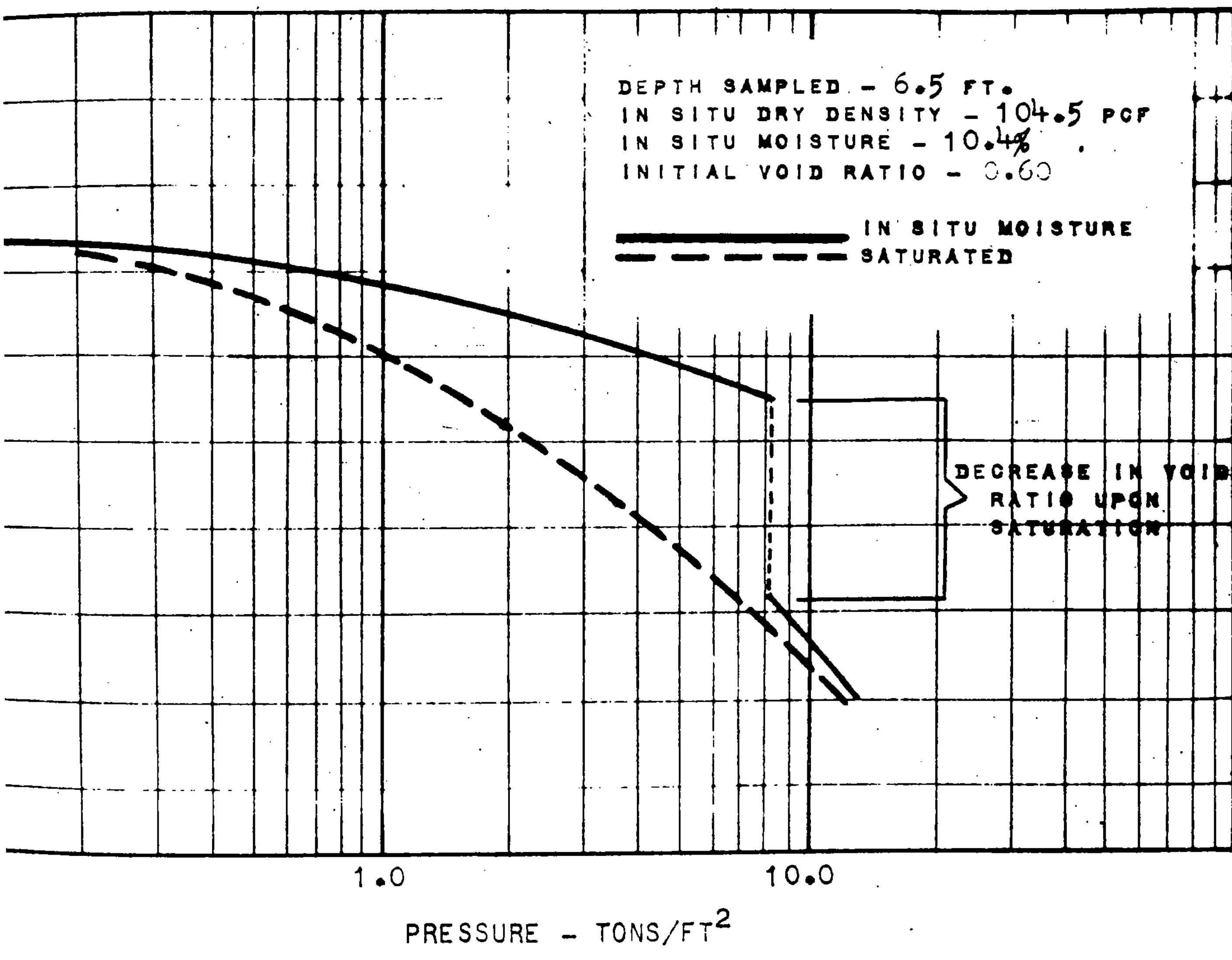

FIGURE I

THE CURVES SHOWN BELOW ARE TYPICAL OF MANY DESSICATED SOILS OF THE SOUTHWEST. DUPLICATE TESTS WERE PERFORMED WITH SAMPLES AT THE IN SITU MOISTURE CONTENT AND UNDER SUBMERGED CONDITIONS.

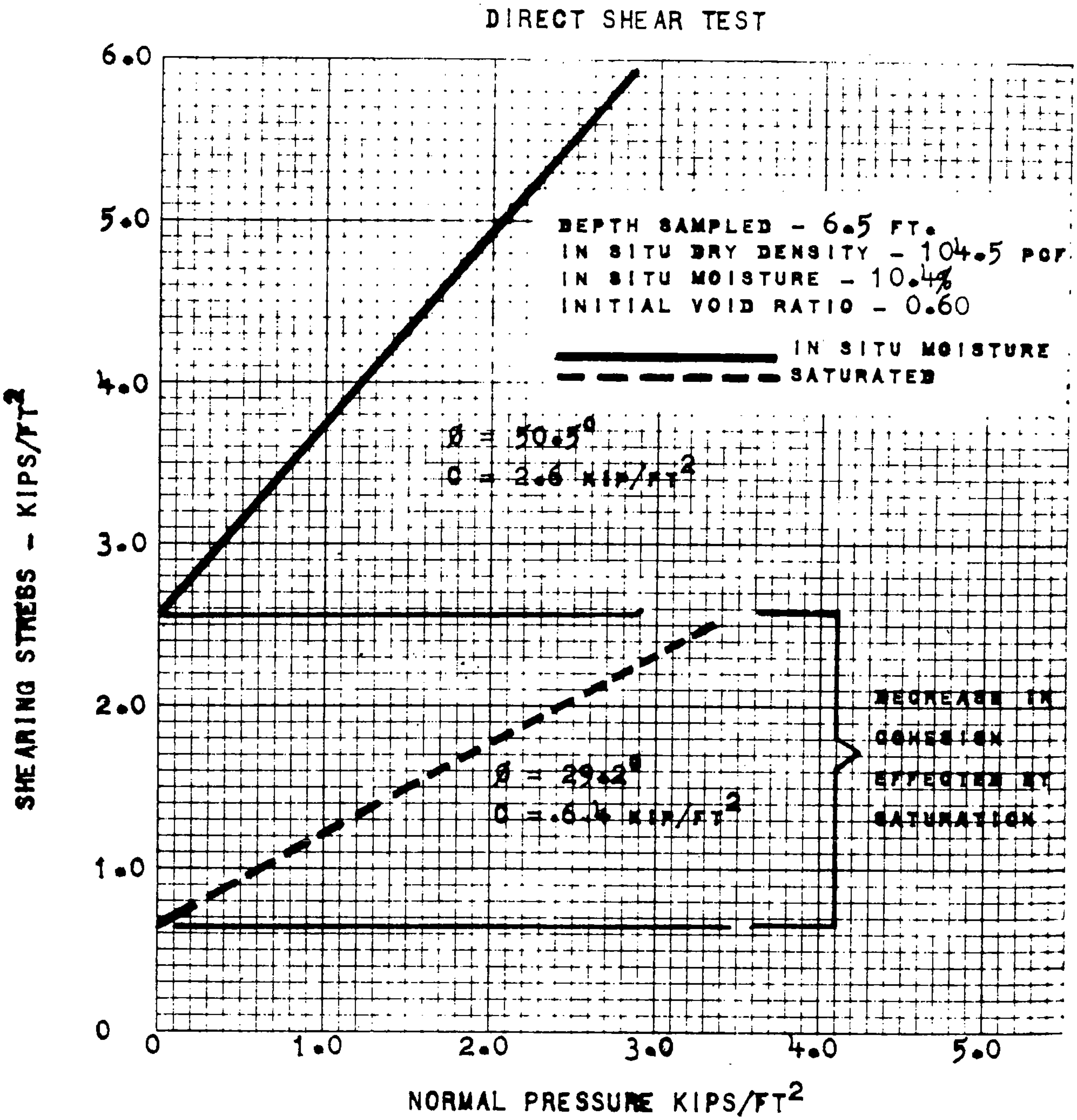

FIGURE 2

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PHOTOGEOLOGY APPLIED TO PROJECTS OF LAND COMMUNICATION

Ing. Juan B. Puig de la Parra

SYNOPSIS

One of the most important problems for the majority of countries is the construction of lines of communication. It is necessary to know the geological conditions for the region over which a highway will be built if satisfactory results are to be obtained from the design, construction, and maintenance since ignorance of these conditions can cause costly problems and may endanger human lives.

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The principal uses of aerial photographs by means of photogeology and photogrammetry have been to further the studies of pure geology applied to exploration for oil, mineral exploration, preliminary studies of water sheds for dams, river control, water supply for cities, and studies of soil erosion. On the other hand, geology applied to engineering is applied to highways, railroads, dams, airports, river and sea ports, flood control, drainage projects, pipe lines, telephone networks, etc., and in a general way can aid in city planning, geographic maps, evaluation of forests, agriculture and grazing lands, colonization of new areas, and military objectives.

The cost of making aerial photographs is justified by their value to any one of the objectives mentioned before. They may also be used subsequently in the exploration to obtain control and exploit almost all the natural resources that man needs for his development.

SECTION I

OBJECTIVES OF PHOTOGEOLOGICAL PROCEDURES

A detailed photogeological study of the area in which a land communication project is to be built can give information of great interest not only from the standpoint of engineering but from the standpoint of geology. For example:-

Engineering

a) Geographic Maps
b) Layout of the General Route
c) Secondary Roads
d) Bridge Locations
e) Preliminary Studies for Tunnels
f) Scheduling of Construction
g) Photogrammetry
h) Boundaries of Area Affected

Geology

a) Regional Geology
b) Lithology
c) Stratigraphy
d) Tectonics
e) Geomorphology
f) Water Supply
g) Location of Construction Materials
h) Special Problems

ENGINEERING ASPECTS

a) Geographic Maps: To construct any engineering project it is indispensable to have a topographic map at a scale which is adequate to the objective which is in mind. From a photographic mosaic and with the help of contact prints a very detailed map of the area is obtained where cities, towns, farms, and isolated houses are shown. It also shows the roads and trails which exist, as well as other human works such as dams, bridges, canals, etc. The knowledge of the distribution of these cultural elements is basic in planning the route that the highway or railroad which is to be constructed will take. The photogrammetric map is also very useful when other studies of this particular area must be made--for geological studies, engineering works, geography, agriculture, grazing, etc.

b) Layout of the General Route: Aside from the terminal points which are required for a road, the general route is located by considering the morphological characteristics or the topographic expression from which the location of the preliminary route can be determined. These morphological characteristics may be recognized with sufficient precision upon studying the terrain by means of stereoscopic photography. By employing this method in selecting the location of the route it is possible to eliminate dead end canyons, swamps, or zones of high relief where construction would be costly. Aside from the purpose for which this line of communication has been planned, one must consider all the points which are to be found within an area close to the straight line that connects the two ends and whose economic importance may require a detour from the principal route or, simply, the construction of a service road if the economic study so dictates. Those locations of commercial importance may be small towns, agricultural zones, forests, mines, oil camps, recreation parks, tourist attractions, etc.

c) Secondary Roads: The location of connections to the principal roadway from other important places or from towns through which it passes within the region covered by aerial photographs, where no great amount of precision is required, may be decided directly from study of sterioscopic photographs keeping in mind the relief characteristics, hydography, and general geology. The secondary roads make up the true communication in a region since a road, a highway, or a railroad, important as they may be, cannot by themselves benefit the zones which are situated a certain distance from the main line. It is, therefore, necessary to pay attention to these secondary roads when one constructs a communication line of the first order since without them about fifty per cent of its utility would be lost.

d) Bridge Locations: In the selection of the location for the construction of a bridge, the engineer has little choice since the location is determined by the route within narrow limits. Under this limitation the engineer selects the crossing which requires the construction of the shortest structure and where the morphological characteristics of the valley or the river which must be crossed are the most favorable. This selection is facilitated if aerial photographs of the area are studied. The use of the photogeological map is a great advantage in this case since it is possible to discuss the merits of constructing a larger structure and reducing the distance, or vice versa, or possibly constructing two small bridges instead of one large one and, in general, any problem of an economic type which may be presented by this concept and whose solution by means of common topographic survey procedures would require too much time and perhaps cost considerably more. To protect the bridges from lateral erosion of the rivers, alluvial deposits, and floods during maximum rainfall, a study by means of photogeological reconnaissance may be made whose results are of great importance for the project.

e) Preliminary Studies for Tunnels: From the aerial photographical reconnaissance it is possible to determine the location of the preliminary route. One may consider the convenience of constructing a tunnel through a mountain. The topographic maps which are necessary to design it are not obtained by aerial photographs directly, nevertheless, a general estimate of the length and the thickness of the roof may be made. This is very useful in discussing the economy of the project. Keeping in mind the engineering deductions which must be considered in conjunction with the geological deductions, it may be possible to prove the feasibility or to show the tunnel is unsafe or not economic.

f) Scheduling of Construction: When one proceeds to make a photogeological study of the area where the road will be constructed it is important not to neglect the method of scheduling the construction of the road or the railroad.

It is decisive to consider the total economy of the operation. The topographical, geological, and social characteristics which determine the route the line should follow must be considered in conjunction with the different procedures or scheduling of construction since the appropriate application of this technique may make the construction of a secondary line which on first glance may seem unacceptable, geologically or topographically feasible. The geological engineer who specializes in the study of interpreting aerial photography for communication lines must have the basic knowledge of the technique of construction and must be familiar with the terminology used by the civil engineers so that his information will be understood clearly by them. The unfavorable conditions which are present in locating the general route are not unsurmountable since they may be modified until they disappear completely by means of proper construction techniques. When there are two or more possibilities the photogeologist can generally choose the most convenient route, and in case of doubt, my present the problem clearly giving all the data that is obtainable so that the problem can be resolved when studied in the field. In all cases, economy is the decisive factor. In most cases where the construction of the roadway requires the use of special construction procedures, due to geological or topographical conditions, the geological engineer has the knowledge to recommend a variation or innovation to the general technique. In so doing the cost will be reduced by providing better service, or providing a better job, or a lower maintenance cost.

g) Photogrammetry: A very important advantage that is obtained from aerial photographs is that they may be utilized before rectification in photogrammetry. Photogrammetry is a technique to obtain topographic maps from these photographs and is as useful as any other method may be made in the laboratory. For projects such as highways, railroads, city planning, development of ports, studies for the industrial localization, etc., when a project for one of these construction works requires that the preliminary study be conducted in the shortest time the aerial photographs provide the most rapid and economic means. It is worthwhile to note that the cost of the photogrammetric map very rarely exceeds that of construction from data obtained in the field; it is also more complete. It must also be kept in mind that the total cost of the original photographs that were used in this photogeological study must be subtracted from the total cost of the project.

h) Boundaries of Area Affected: When the line of land communication is constructed, this frequently crosses areas of culture and other private lands whose owners must be paid according to the damage which it sustains. In order to estimate the area affected by the roadway and the right of way the aerial photographs are very useful since one can scale the area which will be necessary for the roadway directly from the photographs and, in some cases, the type of land which will be affected. Through supplementary investigation of the land it is often possible to eliminate or change some feature of construction so as to reduce the area affected. In some cases, these photographs may be employed as legal documents since they are a real copy of the land.

GEOLOGICAL ASPECTS

To determine the location of the preliminary route aside from the morphological characteristics one must keep in mind the geological condition of the terrain and the source of supply of materials necessary for the construction of the highway. The interpretation that is made from aerial photographs from the geological standpoint is governed by the information which is required to establish the preliminary line which is most economical, not only from the purely geological aspect but from the application of the theoretical understanding of the solution of practical problems such as the distribution of construction materials, the location of springs and water supply, and other geological conditions which may present problems.

a) Regional Geology:. From the photogeological study of an area it is possible to study the regional geology gaining a general idea of the physiographic, lithological, stratiographical, and structural characteristics which are predominant in the region. Taking advantage of this information a photogeologist may foresee the problems which can arise during construction. These problems stem from the different factors which influence a condition that will be actually encountered on the project. The most important is the climate which affects, directly or indirectly, since it governs in large part the ecology of the region and the different conditions of wathering of the outcrops of rock. The morphology, characteristics of the relief which predominates in the area, is at the same time related to the climate, to the type of rocks, and to the orogenic forces to which the region has been submitted. All of these are decisive factors in the selection of the location of the communication route. The superficial aspect of hydrology is studied, noting the distribution of bodies of water and the drainage systems. Also of importance is lithology, from whose study one can see the possibility of obtaining the best rock as construction material and whose characteristics affect the stability of slopes and the general characteristics of the various superficial formations. Stratigraphy is valuable to help foresee the action of the rock masses with relation to slides and falls. Tectonic features indicate the structural situation of the region with respect to intrusions, folding, and faulting, and other geological conditions which may be seen from its study.

All aforementioned geological divisions that have been discussed are from the regional standpoint, which is the one that is obtained from the general photogeological study. Subsequently, over the area covered by the section of road, a local and detailed geological study may be of interest due to unique conditions which may endanger construction or because of outcropping of rock can be identified as being suitable as source of material.

b) Lithology: Due to the lithological characteristics and to weathering, there exist in nature different conditions which affect principally that superficial portion of the upper layer of the earth. The engineering pertaining to roadways is concerned particularly with the superficial rock. It is indispensable in studying its composition and origin to make plans for construction projects with the most proper procedures in each case and to foresee and prevent the conditions which may endanger the construction due to the nature of the affected formation. Generally, it is possible to infer photogeologically the lithology of the rocks that are outcropping having as a base the criteria for the interpretation and identification such as density or tones of the photographs, texture, geomorphology, and landscape. In many cases it is necessary to know the detailed lithological characteristics of these varied formations. To obtain this, it is indispensable to make tests with samplers, since the information that can be obtained from the aerial photograph in this case is insufficient. The contact between formation can be clearly defined in the majority of cases making it possible to limit the area covered by fill materials and those occupied by firm rock. The contact between different types of deposits in lacustrine zones is of great importance since these deposits indicate within certain approximation the areas which will be flooded during heavy rains.

c) Stratigraphy: Stratigraphic relations of locally distinct formations that are present in the area show up well on aerial photographs. Generally, one cannot deduce the order of deposition from the photographs but, nevertheless, the surface strata show a certain amplitude of horizontal outcropping. It is not possible to see them in elevation but it is easy to determine from the photographs the locations which are appropriate to conduct these investigations marking them on the photogeologic map with the intent to make a study rapidly and accurately. The Highway Engineer is principally interested in the condition of the rocks which are outcropping and he is also interested, in many cases, to know the properties of the underlying rock. For this it is necessary to explore with soundings. They may be open holes or by drilling. This type of study has come to be complemented with geophysical methods combined with drilling, which make explorations much more economical. This type of study is conducted in well defined locations when it is necessary to make special tests for a tunnel, a bridge, a large cut, or along the line when the original ground is in such condition that it cannot resist the overburden or weight of the embankment. In making these special studies the photogeological map is very useful not only for the location of the site where they will be performed but for the geological information that is provided after the type of rock can be determined that will be encountered and springs to supply water for drilling are found. The locations of the drill holes needed can be plotted directly on the photographs.

d) Tectonics: The geological structure such as folds, faults, intrusions, etc., has decisive influence over the mechanical properties of the rock masses. Generally, the presence of unusual structural conditions may be taken as a factor to reduce the resistance capacity of the rock since the fracturing, folding, and the general deformation tend to weaken them. In some other cases such things as intrusions, fractures sealed with silica, and others, the affect from tectonic movements combined with other agents which act at the same time or later tend to improve the strength of the formations. The structural conditions are, in many cases, the ones which determine the stability of the cut slope. They also define the location where a tunnel is to be constructed and the procedure of construction which must be adopted. They may also require modifications to be made in a section where, in order to avoid fracture or contact zones which may endanger the construction, one must do what is practical and not what is easier. The structural characteristics in a region in the majority of cases may be determined by means of the photogeological study with speed and accuracy since it is easy to determine the position of the strata, the existance of faults, the presence of igneous flows, or the presence of intrusions which are reflected at the surface. It is for these reasons that the photogeologic study of the structural geology of the region must be taken into account when it is necessary to locate and construct the route of land communication.

e) Geomorphology: The description of the superficial or the surface land forms must be made in a systematic and precise manner, being convenient to divide it into 1) orography and 2) hydrography.

1) Orography: The relief of a region is defined by mountains and valleys whose description from the morphological, genetic, and lithological view is of great use when the construction of a line of land communication is being projected. The morphological importance is evident since the location is governed principally by the topographical expression of the land. The relief characteristics are clearly recognized in the aerial photograph by means of sterioscopic vision. From their origin mountains have been classified as folded mountains, fault blocks, intrusion, complex mountains, and volcanoes. Each orogenic unit requires special studies that

determine each individual problem of that unit and its variation. In the majority of cases it is possibly to classify these units by means of photogeological studies. The lithological characteristics which are intimately in relation with the morphology and the origin of the mountain may also be determined in a general way by means of photogeology. To know the lithology of the rocks which comprise the unit it is necessary to formulate an idea of its mechanical properties and its reaction to weathering and, also, to investigate the possibilities which may be advantageous to the work. It must not be overlooked that after the photogeological study it is necessary to conduct direct exploration.

2) Hydrography: Each stream to be crossed by the proposed route must be known and as much detail as possible in relation to its hydraulic properties must be obtained by study of the aerial photographs. The limits of the water sheds can be clearly defined and the characteristics of the channel determined. With this data and that related to the climate it can be determined whether to construct a bridge or culvert and what means are necessary to protect it. In the lacustrine regions photological methods make it possible to identify the bodies of water and the areas which may be flooded during heavy rains, which permits the section of road to be carried to a higher location. In these regions the rivers generally flood, which is dangerous to the construction, but this danger may be avoided if the stream is studied in detail by means of sterioscopic photographs since the abandoned meanders and canals which were formed within the channel proper can

clearly be seen. For irrigation study or to foresee possible floods photogeology is a procedure which cannot be improved upon. It is always useful to have an idea of the general morphology of the area which can be clearly known by means of photogeology.

f) Water Supply: The water problem in some regions is very difficult to resolve since the lack of water may increase considerably the construction cost of a section of highway. Water can always be obtained by means of drilling wells, but the depth at which it may be found is not always economical. An additional service which is very useful and can be provided by photogeological study is the location of the water supply, which is indispensable not only for the compaction of the subgrade but for the machinery and the human element. Water may be taken from a lake or spring by means of water trucks, but this must be as close as possible. These features are easily identified on the aerial photograph. In some cases it is not possible to count on surface water being at a reasonable distance, making it necessary for contractors to look for it in the ground. The more appropriate location of wells which need to be drilled should be given by a geologist, who will find photogeology very helpful, too.

g) Location of Construction Materials: In addition to the information which has been obtained from a lithological study it is possible to locate rock strata suitable as construction material. The lithological classification that can be made on the rock from aerial photographs is notprecise in the majority of cases, nevertheless, it is almost always possible to recognize the principal divisions of igneous or sedimentary rock, but it is more difficult if the rock is metamorphic. In general, within the sedimentary group the harder rocks such as limestone, sandstone, or conglamorate can be identified. Softer rocks such as shale can also be identified. Each rock outcrop is marked on the photogeological map, thereby making it easier to study it directly in the field and, in addition, shows the access roads which exist or which will be necessary to construct for its exploitation. The distribution of the supply of materials is a decisive and important factor in selecting the location of a ground communication route, this being completely determined by means of photogeology.

h) Special Problems: The geological phenomena which presents the most common problems, not only in the construction of land communication systems but in other engineering works of importance, are the large rock slides and faults. In the preliminary geological study that is made when highway or railroad is to be constructed it is important to consider in great detail the danger which may be present during the construction of the project. This is preferred to the intervention of the phenomena noted previously. Slides are usually produced in materials which are generally not coherent and composed of finer particles. They may also be present in any type of rock under special conditions. They occur from different causes, the most common being the variation of subsurface water in the zone adjacent to the slope. When the geological reconnaissance is made by means of aerial photographs it is possible, in many cases, to foresee these failures since they clearly show the area of infiltration and the general type of formations in which they occur. During the photogeological study sometimes one can discover evidence of a fracture zone which generally precedes slides. Upon observing conditions which favor slides direct field study should be made and, combining the deductions obtained through both methods, procedures should be started to correct such conditions or to alter the location of the route. In both cases, photogeology is a helpful tool.

The existance of faults and other fractures which are geological accidents introduce problems, in many cases of very great importance due to the alterations which are produced in the masses of rock that are encountered. The influence exerted by these faults in movement and displacement of rocks may be great in magnitude. Many faults can be discovered by means of photogeology that are not visible on the ground, which is an advantage of this technique. The areas which have been affected by a system of fractures can be defined by means of a geological study of the aerial photographs and the location of a communication route over these zones can be avoided. In general, it is not possible to determine photogeologically if a fault is active or not, but this problem can be resolved upon direct investigation of all the faults discovered with this procedure.

SECTION II

STEPS TO LOCATE A ROAD USING AERIAL PHOTOGRAPHY

a) Determination of the Geographic Points Which are to be Connected

b) Obtaining Aerial Photographs

c) Photogeological Study

d) Locating a General Route

e) Establishment of Ground Control

f) Development of Photogrammetric Control

g) Preliminary Line

h) Direct Geological Study

i) Staking the Line in the Field

a) Determination of the Geographic Points Which are to be Connected: The first aspect which must be kept in mind in developing a project for a communicational line is to determine on the map the geographic locations of the points which are to be connected. These points, generally, are cities of some importance which provide a volume of traffic and justifies the investment. In other cases it may join productive zones such as agricultural or natural resources with cities or seaports, which justify economically the construction of the project. It is necessary to consider the distance which is to be covered and thetype of construction which will be employed. It is also of interest to know the climatic conditions of the areas that will be traversed by the road, which are obtained from the different meteorological stations which are encountered in the area where the road will be located.

b) Obtaining Aerial Photographs: The designation of the section of ground which is to be photographed is made by marking its limits by means of features visible from the altitude of the airplane. These features should preferably be natural points. The boundaries are set by an engineer, requiring one or more flights parallel to the line identifying points on maps or by means of a sketch which shows the more notable morphological elements which serve as reference. The taking of aerial photographs must be carried out in the most convenient season since in some places the clouds, snow, or foliage may obscure the ground.

In case aerial photographs exist of the zone on which the road is to be located the problem is simplified, it being necessary only to ask the aerial photographic company for the use of said photographs, mosaics, and contact prints which cover the ground in question. In this case, the cost of the photographs is less than the previous method.

c) Photogeological Study: The application of the photogeology to the roadway project is practically unknown by the majority of the technicians who are dedicated to this type of construction in Mexico. The photogeological study provides ample information not only pertaining to geology but to topography and the culture which is of great importance for the design and construction of the project. The quality and quantity of information which may be obtained from the interpretation of the contact prints depends on the clarity of the copies, the morphological and ecological characteristics of the region, and the understanding, experience and aptitudes of the photogeologist. The principal advantage presented by photogeology is economy. This procedure reduces the time required for surface reconnaissance from three to nine times compared to that required for surface geology. Also, from the larger perspective which it presents, it is possible to observe features and elements of importance which could not have been seen with direct methods exclusively even though the reconnaissance on the ground is indispensable to define certain local geological factors which could not have been identified in the aerial photographs. It is necessary that the photogeologist be the one to carry out the direct surface study since he is more familiar with the area and knows the problems which may present themselves and the locations where they may be encountered. Thus, then, photogeology combined with surface geology allows the geological study to be made in much less time, be technically more complete, and be made at a lower cost than if field geology alone were used.

d) Locating a General Route: It is probably in this phase of the project that the advantages of this procedure will be of the greatest value since the location of the general route can be more easily and quickly made. The various possibilities from the construction and conservation standpoints can be studied as several possible locations can be drawn on the photographs at the same time. This feature of being able to study two or more locations at no additional expense makes possible the best solution, as time and cost do not make the first one the necessary choice. The morphological and geological characteristics of the zone may be seen with sufficient precision over the general route by means of the sterioscopic observation of the aerial photographs from which the more appropriate line may be drawn on the photogeological map. Other important factors which influence the location of the general route are the distribution of material locations and the towns which may be located close to the line. These factors also may be determined, in general, by means of the photogeological study.

e) Establishment of Ground Control: When the general route is chosen the ground control points are selected and marked on the photographs in such a manner that it will be easily identifiable on the ground and, if possible, readily accessible. These points which can be seen on the contact prints may be corners of houses, road intersections, division of land under cultivation, the intersection of streams with trails, unusual alignment of river, noticeable trees, and other objects which can be found in any particular region. On the photographic mosaics, and in the appropriate plans, the points which were chosen as reference for establishing ground control are marked clearly. With this information, a topographical crew is sent out to connect these points with triangulation network which is later drawn on transparant paper at the same scale as the photographs. This triangulation will serve to orient the photographs or to correct the distortions produced by differences in ground levels affecting points which are located far from the center of the photographs and, also, those distortions due to tilting of the airplane in flight.

f) Development of Photogrammetric Control: The photographs which cover the terrain where the general route is located and on which the control points are joined typographically are enlarged and corrected before proceeding with the photogrammetric development. For this type of studies the scales of 1:1000 to 1:5000 are common with contour intervals from 50 cm. to 2 meters. The more advanced photogrammetric procedures make it possible to combine the contouring with electronic computations to directly obtain data for construction. Considering that the maps may be as useful, one as well as the other, the photogrammetric map can be made more rapidly and has less possibility of error over the contour map obtained from ground survey. On the photogrammetric map the general route obtained from the photogeological map is drawn, modifying it according to the contour. The line obtained may be considered as preliminary, keeping in mind that upon locating it on the ground it may be necessary to make certain local alterations due to the presence of geological or topographical features which could not be foreseen from the photogeological and photogeogrammetric studies. On the topographic plans obtained from the photographs the mileage, movement of material, construction of bridges, etc., may be determined even though the precise calculations which are required for the construction in detail may not be obtained.

g) Preliminary Line: On the photogrammetric map the preliminary line is drawn following approximately the alignment of the general route which was located on the photogeological map after adjusting it to the topographical configuration. The object in first locating the general route by means of direct sterioscopic vision and finally drawing it on the contour map developed through photogrammetry is to eliminate the development of photogrammetry of the total area, as described above. The work involved in ground control and the copying of the aerial photographs by means of costly equipment would greatly increase the cost for preliminary study. The preliminary line obtained by this method will be the more accurate since its location was determined taking into consideration all the factors which intervene in the construction and maintenance of the project, as well as the social benefits which affect the region.

h) Direct Geological Study: The photogeological procedure is limited by some unavoidable obstacles even with all the advancements to date, limitations such as not being able to determine with certainty the lithology and the properties of the exposed formation; not being able, in general, to develop a statographical column for the area studied; not being able to define the depth of the resistant layer; and others of lesser importance which make it indispensable to make a reconnaissance on the ground to obtain all the information that is required. Once the preliminary line is drawn on the photogeological map and photogeometric plans, one proceeds to carry out a geological reconnaissance on the ground, in fact, it is unanimously accepted by civil engineers that the success of any engineering project depends principally on how well the structure is adapted to the geological features on which it is built. The application of geology to the solution of practical engineering projects belongs to geological engineering. The study on the ground consists of two principal phases, 1) the surface reconnaissance and 2) the study of the subgrade in the locations which may require this in accordance with the results found from surface reconnaissance. With the direct geological study doubts may be removed pertaining to the existing geological conditions, principally proposed bridge sites, or where there will be large cuts or fills. The location of construction materials which were photogeologically located and which are proposed as source of material for the project will be studied in detail. From this data the geologist can also recommend changing the location of the road where ground conditions will not guaranty its safety.

i) Staking the Line in the Field: The line that was developed on the photogrammetric map is located on the ground having as reference the triangulation points which serve as control of the photographs or other points which may be easily identifiable, not only on the map but on the ground. The photogrammetric study does not exclude the topographical development of the line and its cross sections since the precise calculation for movement of material, excavation, etc. requires a greater degree of accuracy than that which is provided by photogrammetry.

In regions which present conditions particularly difficult for the construction of a highway such as deserts, steep slopes, swamps, forests, etc., the usefulness of photogeology is invaluable in making a more adequate location since in all cases these features can be weighed and the best route selected. Photogeology does not exclude work in the field, in any case, but this does make it more effective and incomparably more rapid. Photogeology is a procedure of great usefulness in any kind of geological reconnaissance and its application to highway engineering has a brilliant future. From the great perspective which it provides it permits detailed study of the zone which gives a clear appreciation of the cultural and natural elements encountered. At the same time, as was mentioned before, photogeology provides a very detailed plan of the region which will serve for any other geological and engineering project. Aside from the convenience of using photogeology, from a technical point of view, its usefulness in the application is accentuated to the point of being indispensable when conducting surface reconnaissance in a limited amount of time. It is important to keep in mind that photogeology is not panacea which will solve all the problems and to know what can be obtained from this procedure without expecting more than what it can possibly provide.

Even though, technically, photogeology offers advantages of unquestionable value from the reduction of time and work, which results in greater efficiency, its application develops greater importance from the economy which is provided for the study of lines of ground communication. From the previous discussion, it is to be expected that this procedure will enter a period of greater importance within this application since its understanding is extended with use and its application made broader and more complete in large parts of the world.

FILL SLIDE ON THE TOLUCA-IXTAPAN DE LA SAL ROAD

by

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and Alfonso Rico

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ABSTRACT

This paper describes a fill slide in plastic material caused by water seeping down-slope on the top of the fractured and partially altered basalt bedrock. The overlying clay surface mantle (fill foundation) was softened and caused the slide. The residual clay layer (plastic layer) is, in part, a product of decomposition of said basalt. It also presents the solution to the problem, which consists of a rock embankment and drainage which has functioned satisfactorily in the two years since this construction.

Introduction

This paper describes a fill slide occurring in the clay layer which cover a formation of fractured rock which is partially altered, at Kilometer 108+372 on the Toluca-Ixtapan de la Sal Road in the Republic of Mexico.

The area in question is situated in the western mountainous part of the central plateau in the valley of Mexico approximately 50 Kilometers west of Mexico City. The predominant formations of this area are basaltic, more or less altered. The climate is cold-temperate. The region is heavily forested and the rainfall is of medium intensity (close to 1,000 mm yearly), most of it occurring in the rainy season.

The section of the road where the slide occurred is in a cut where the left (outside) shoulder extends almost to the line of the natural slope. It was precisely on this slope where the slide occurred.

The slide occurred in January 1959, some three months after the last rain, and causing a movement of some 20,000 cubic meters of superficial clay, a product of decomposition of the fragmented basaltic bedrock. The ravine towards which the slide moved has a depth of some 50 meters and a small stream runs in its base. Topographic maps of the slide zone (plan and profile) are presented in figures 1 and 2. The slide extended back to the guard rail line on the left shoulder of the existing road. It threatened to progress farther due to the high slope at the head of the slide.

It is worth while to note that at least two previous slides have occurred at the same location, which had made it necessary to change the location of the road by eliminating the original fill section and moving into the hillside by enlarging the cut. It is also of interest to note that in these two cases the adopted solutions were based solely on the principle of reducing the slope angle in the mass of material which has moved without taking into consideration the drainage conditions prevalent in the location.

Field Study

Geological study of the location indicated that the clay layer that caused the slide was probably a thin layer lying above the rock formation that outcrops in some places in the cut and extends toward the slope of the ravine. To define or determine the thicknesses of the clay, borings with a split tube sampler were taken at the road level and in the slide zone. These borings were augmented by the excavation of nine test holes from which undisturbed samples were taken. The borings confirmed the geological conclusions and made it possible to accurately plot the clay thickness and the profile of the altered rock. In figures 1 and 2 these data are shown. It was also observed that various seeps or springs were present in the cut slope and at other places on the hillside.

Laboratory Studies

Laboratory study classified the samples of the residual clay which covers the altered basalt. These clay samples belong to the CH group of the Unified System of Classification of Soils, because of their predominently silty character. Also, in some places the clay is mixed with sand in variable proportions. The moisture content of the clay was in the order of 50 per cent, somewhat less than its liquid limit. The shear resistance of the undisturbed material taken from the test holes gave a value of 7 tons/m2 in unconfined compression tests.

Cause of the Slide

The cause of the slide, which is representative of others which have occurred in similar situations on other roads of the Republic of Mexico, is fundamentally the decrease in shear resistance of the residual clay due to the water seeping along the rock surface. This movement of water is evident in the springs which were mentioned previously. Water is also probably carried in the fractures of the upper part of the bedrock.

Adopted Solution

After excavating the slide area and uncovering the underlying rock, a blanket or transitional layer of sandy gravel was placed as a drain. This formed the base for the rock embankment which replaced the clay fill and restored the width of the roadway (figures 1 and 3 and photograph number 1).

The slope of this rock embankment is 1.1:1 which permitted the minimum use of rock material. At the base of the rock fill a cut-off trench consisting of a concrete lined ditch was constructed for the collection and diversion of the subsurface water. Also, in the lower portion of the rock fill horizontal drainage pipes were carried through the embankment to the gravel layer to facilitate the removal of subsurface water (photograph number 2).

It was originally intended to remove all the clay layer from beneath the roadway as well as the slide area (figure 3), however, considering the good condition of this material it was decided to leave it in place. This made it unnecessary to replace the pavement in the affected zone and the work was able to proceed without interrupting the flow of traffic on the roadway. The stability of the rock fill, considering the hydrostatic force of the clay, was calculated using the method of G. Gilboy, used in the design of earth filled dams, taking into account the probable force due to the partial saturation of the clay.

This work, constructed two years ago, has proved very satisfactory.

Resume and Conclusions

The slide that was described is typical to what could happen to slopes in plastic soils whose resistance may decrease from increasing the water content by the flow of water in the underlying soil. In this case, the underlying soil was formed from partially altered fractured basaltic rock. The solution, which has proved satisfactory, consisted of constructing a rock fill to replace the plastic material, which was removed, and taking necessary steps to guaranty good drainage of the affected zone.

Fig. 1. Retaining wall constructed in the slide area at Km. 108+372 on the Toluca-Ixtapan de la Sal highway.

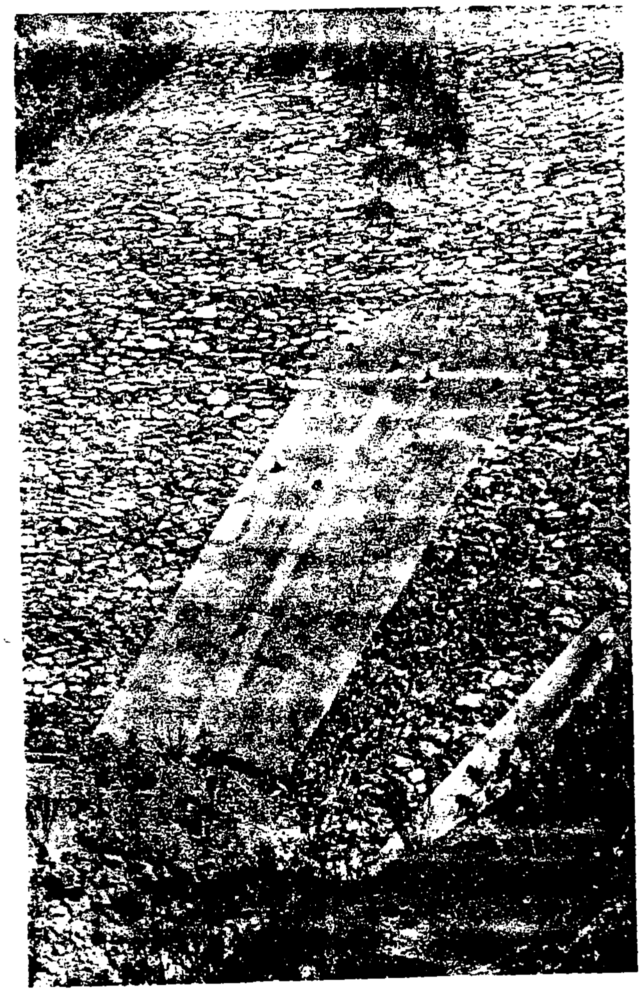
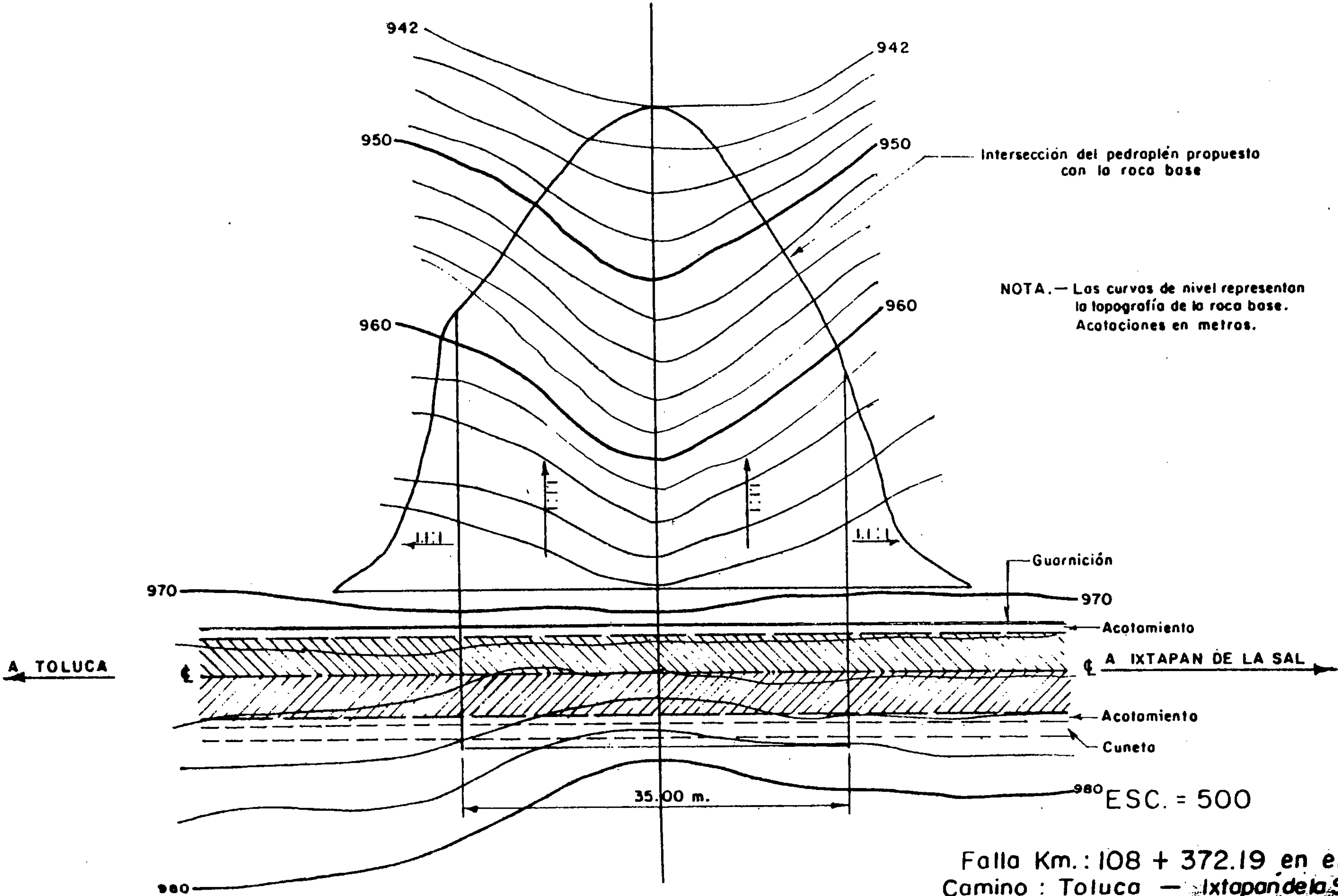


Fig. 2. Horizontal pipes installed to aid drainage of the slide area at Km. 108+372 on the Toluca-Ixtapan de la Sal highway.

Fig. I

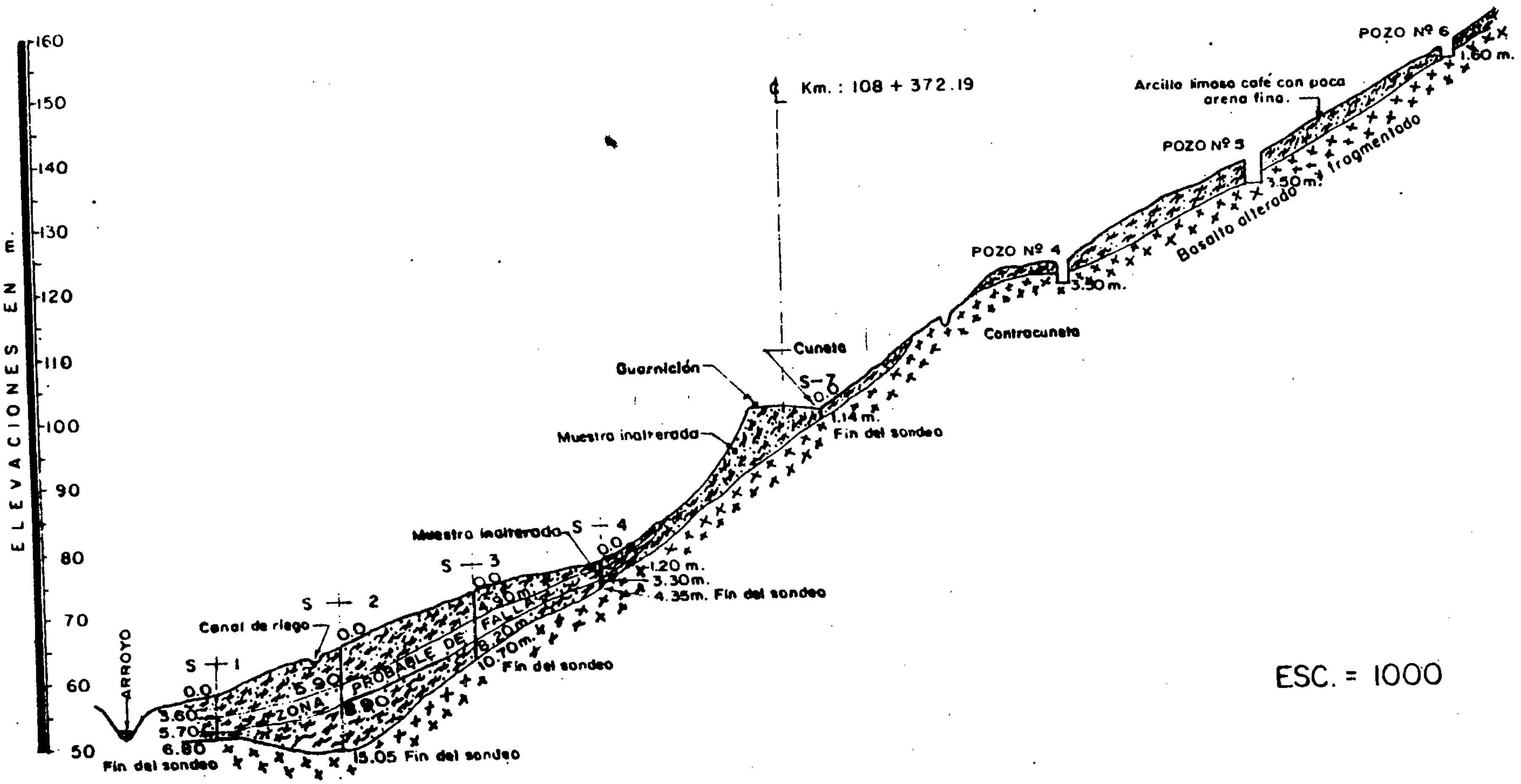


ESC. = 500

Falla Km.: 108 + 372.19 en el Camino : Toluca — Ixtapan de la Sal

PLANTA

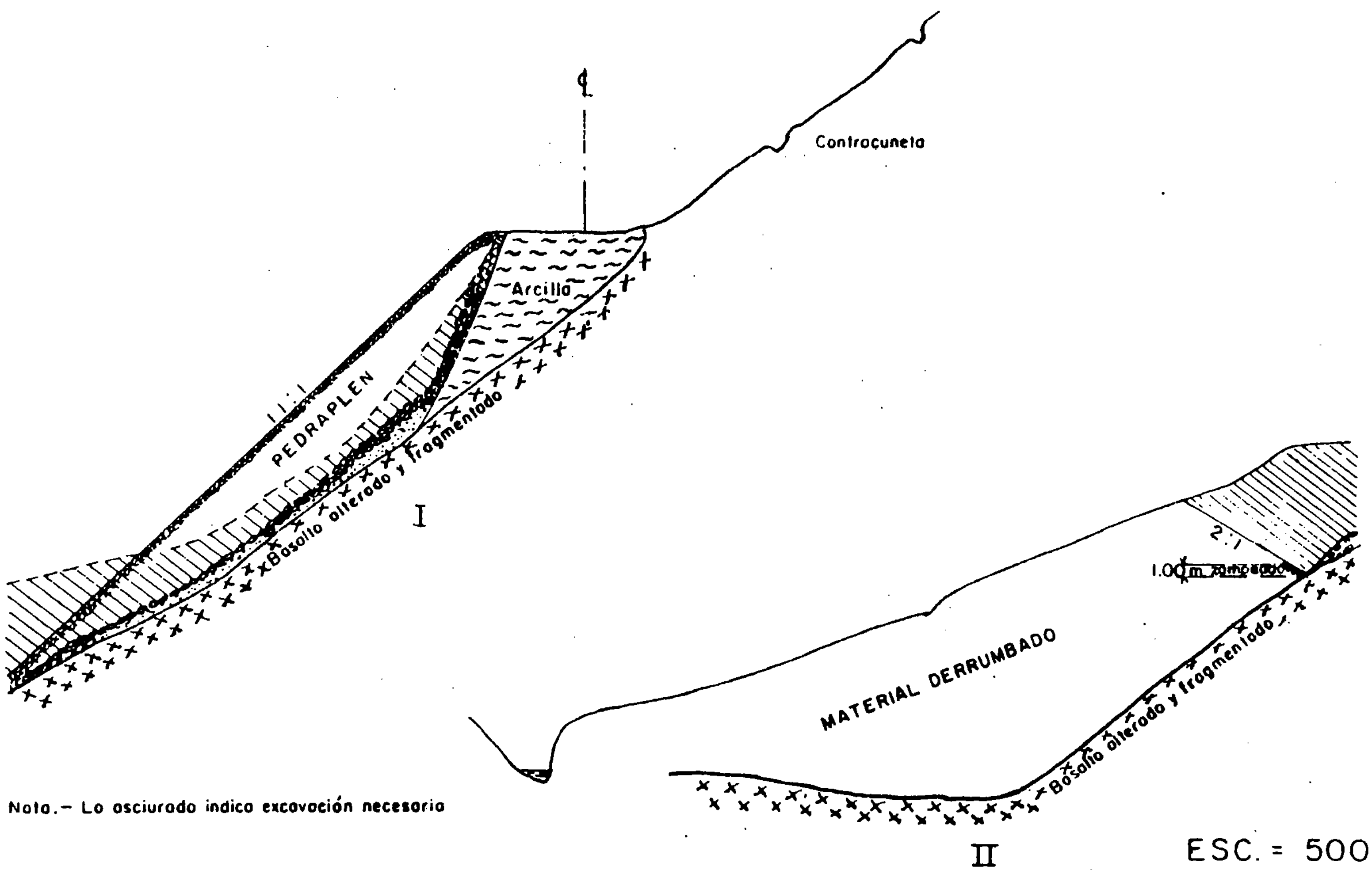
Fig. 2



ESC. = 1000

Falla Km. : 108 + 372.19 en el Camino : Toluca — Ixtapan de la Sal
PERFIL DE SUELOS

Fig. 3



Nota.- Lo asciurado indica excavación necesaria

ESC. = 500

Falla Km. : 108 + 372.19 en el
Camino : Toluca — Ixtapan de la Sal
SOLUCION CONSTRUIDA

GEOLOGICAL NOTES PERTAINING TO THE MEXICO-PUEBLA HIGHWAY

by

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The direct road from Mexico to Puebla, or Mexico-Puebla Highway, connects the capital of the Republic with the capital of the State of Puebla. It has an approximate length of 125 kilometers, beginning with an elevation of 2,235 meters above sea level (Mexico City), crosses a mountainous barrier at an elevation of 3,196 meters (Puerto del Aire), and ends at an elevation of 2,162 meters (City of Puebla).

The present alignment of this route is a result of a study of various proposed alignments, each with advantages and disadvantages—economy being the decisive factor. All routes were seriously affected by the behavior of the subgrade over the terrain occupied up to recent times by Chalco Lake.

The first part of the road is located on recent lake bed sediments of Lake Texcoco, which extend in a southeast direction against the slopes of the Santa Catarina peak, which lies in a northeast-southwest direction. The line passes between Caldera peak and Santa Catarina peak, two volcanoes located at the northeast end of a small chain of basaltic volcanoes. This same chain forms part of the barrier that separates the basins of Texcoco and Chalco lakes.

After crossing the pass the highway enters the area occupied by Chalco Lake, between Kilometer 22 and 32, approximately. At Kilometer 28, this route touches the southern slope of the andesitic mountain of Tlapacoya. This rock has been used to construct the base for the first 10 kilometers of the highway. The difficulties presented by the subgrade of this terrain, due to the presence of compressible layers of peat, will be discussed later. These difficulties were experienced with the stability of the embankments, the foundations for the various grade separations, for the railroad crossing, and the access lane embankments for the highway to Cuautla.

The actual ascent of the mountain begins approximately at the Town of San Marcos, Kilometer 33. "Tepetate" is first encountered in a cut at Kilometer 47. This is a local term that refers to a finely granular material, more or less cemented, formed from a heterogeneous mixture of sand, silt, and clay, sometimes with fragments of pumice, and occasionally impregnated with caliche. Laboratory analyses determine which of those materials is predominant to indicate the appropriate use of tepetate in the roadway. It is used principally in the construction of the embankments but can be used as subbase or select material. The origin of this rock is varied, but in the majority of cases it comes from altered volcanic cinders, principally basaltic, and can be formed from severely altered rock, either basalt or andesite, or, can come from mixed products of eolian origin. As an example, a badly altered rock has formed part of the original surface of the land and has been covered by cinders, which in turn were altered, and now when the cut is made the contact between these two materials is apparent because of a difference in colors. Since the lower rock contact has more or less the rounded shape of a mature, old topography, the cut gives a false impression of an anticline. The "tepetate" has in some places a thickness of more than 50 meters, as can be observed at Kilometer 38+500 and Kilometer 64, the first in the slope of a ravine and the second at a place called Selva Obscura.

Upon leaving Kilometer 47, dense basaltic rocks begin to appear, not as flows but in blocks which are large, isolated, and surrounded by "tepetate". There are blocks of large dimensions, which can reach a thickness of 20 meters. The thicker exposures are always fractured and they occur two or three times in a length of 15 kilometers.

The basalt has a fundamentally dark appearance, almost black; is of uneven texture with abundant large, white crystals of plagioclase; and, also, contains large crystals, not olivine, of a dark green color.

Some contacts appear between the basalt and the underlying andesite. At Kilometer 52+400 there appears a gray to pink rock of a type intermediate between andesite and basalt, similar to that which appears in the Cantil de Topilejo on the highway to Cuernavaca, and which represents a contact between andesite and basalt. At Kilometer 54 appears an outcrop of glassy andesite which extends some 100 meters along the roadway. This outcrop is one kilometer from the highest point of the road, called Puerto del Aire, at an elevation above sea level of 3,196 meters. This rock is very fragile and is composed of white crystals of feldspar in a matrix of black glass. It weathers easily. Between Kilometer 54 and Kilometer 57 there are several outcroppings of this rock. At Kilometer 57 there is a platy andesite, giving the appearance of a dike, compressed between two masses of basalt. Andesite of any type is not encountered throughout the rest of the route until we reach the Ciudad de Puebla. With the exception of those small areas occupied by andesitic rock, the whole route through the mountain is entirely in basaltic rock.

These volcanic rocks that have been mentioned have required considerable excavation. However, they have provided construction materials which required little haul.

Other construction materials obtained in economic haul distances are basaltic sand, taken from the southern slope of the Caldera peak, at Kilometer 21, and besalt from the slope of Cerro del Pino at the turnoff to Cuautla of the old roadway and at 3 kilometers to the north of the new one. This formation is called the Santa Barbara although it actually is located in the area of the Hacienda de Acozac formation; other rock used was a basalt from the cerro de Cocotitlan, in the proximity of Chalco and at 9 kilometers to the south of the highway; and the Solution formation that is formed from a great mass of disintegrating andesite, found between the old highway and the new one, at a distance of one kilometer from Kilometer 38 of the new roadway. On the other side of the mountain or on the side of the valley of Puebla, the following volcanic rock deposits are found: basalt from the San Lucas formation to the north and close to the Town of the same name, at a distance of 5 kilometers at Kilometer 86 of the highway; basalt from the Santa Justina formation, 11 kilometers from the highway on the road from San Martin Texmelucan to the mountain of Tlaxcala; basalt from the San Rafael formation at Kilometer 102 of the highway, at a distance of 3 kilometers to the north.

The basalt is used for asphalt aggregate, the weathered pyroclastics are used as ditch lining, and the finer materials are used for embankments which are not required to carry much weight over compressible soils.

As a final consideration of the route through the mountains, it is necessary to point out three flat places like meadows, located from Kilometer 53 to Kilometer 60, at approximately 3,000 meters above sea level, and which are: Llano Grande, El Ameyal, and Rio Frio. They are all covered by recent sediments (organic soil), but it is almost certain that at a shallow depth rock would be encountered.

It has been pointed out that the rock ends at approximately Kilometer 68 along the route of the new highway, although, at Kilometer 64 there is a cut made in "tepetate", of a thickness of 50 meters. Between the mentioned kilometers there are sporadic outcroppings of basalt where as the old roadway, which runs very close to the new one, cuts through large exposures of basalt.

The cuts through the mountain have confirmed the surface geological observations of the age of the rock and their tectonic relations. In some places there has been discovered the old andesitic profile which was in a state of very advanced erosion before it was covered by basaltic flows, already described in description of the "tepetate" cut.

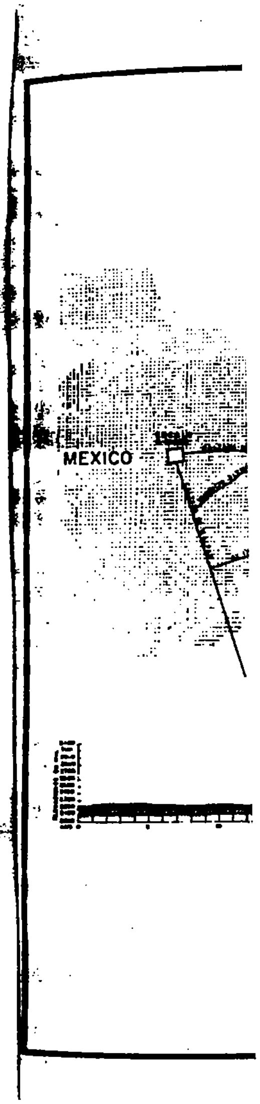
From Kilometer 68, to a little beyond the bridge of the Emperor, "tepetate" appears. At a detour located between the Town of Tlahuapan and the Bridge of the Emperor, the cut encounters a thickness of 15 meters of "tepetate". Between the two bridges of the Emperor (the one of the old roadway and the other on the new) "tepetate" appears covering lacustrine sediments, and at the bottom of the ravine crossed by these two bridges, some 200 meters upstream from the new bridge, altered andesite appears. At the contact of the andesite with the "tepetate" there is a small spring.

At Kilometer 80, the "tepetate" is succeeded by alluvial material from the slopes of Iztaccihuatl and farther on from the slopes of Popocatepetl. These materials are andesitic and consist of gravel, sand, and silt.

The level stretch between San Martin Texmelucan, Kilometer 92+140, and Atoyac, Kilometer 120+630, is covered by these alluvial deposits which have been classified in part since the sands are abundant. In the final part, close to the River Atoyac, these alluvial deposits are also andesitic, which come from the slopes of la Malinche. It is probable that this alluvium lies above lacustric sediments, since it shows at various places of the periphery indicating the existance of a large continental lake that once covered the region now occupied by the States of Puebla and Tlaxcala. The embankments of the roadway in this location have suffered settlement no greater than 0.50 meter.

Past the Atoyac River, Kilometer 122+124, the alluvial deposits are mixed with some caliche. It is probable that the presence of this caliche may have some relations with the great mass or thickness of this material, over which a large part of the City of Puebla has been built.

In the City of Puebla there are two outcrops of basalt—one in the hill of San Juan, and the other in the area of los Fuertes; the latter may have some relation to the new roadway, since there is now a project to construct a connection for the entrance and exit to the city that may use this rock.


MEXICO

HIGHWAY MATERIALS INVENTORY

by

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Astronomical quantities of aggregates are being consumed in construction of our highways. The Bureau of Public Roads recently estimated that 72,000 tons of aggregates were used per million dollars contract construction cost for the Interestate highway system in 1958-60 (1) 1/. At this rate, approximately 3 billion tons of sand, gravel and crushed stone will be used in the base and subbase courses, bituminous surfaces, concrete pavements, and other concrete structures in the 41,000-mile Interstate system. Double that quantity will probably be used in construction of the other highway systems during the same period.

When the highway materials engineer considers that other construction industries also need great quantities of the same kinds of aggregates, he wonders whether you geologists can evoke some vast cataclysmal event that will produce the materials needed in highway construction. Another possibility would be that the nuclear physicist and engineer combine their efforts and use nuclear energy to economically produce suitable artificial aggregates. Since neither of these possibilities seems to be imminent, many State highway departments are making highway materials inventories.

1/ Number in parentheses indicates reference at end of paper.

Conservation and Economic Utilization of Aggregates

The known supply of naturally occurring, high-quality aggregates that are suitable for use in structural concrete, concrete pavements, bituminous surfaces and base courses is very limited in many areas of the United States. High-quality aggregates are frequently shipped 50 miles or more for road construction. Consequently, in such areas optimum use should be made of lower quality aggregates in subbases, shoulders and backfill.

Some States have no immediate concern regarding the supply of high-quality aggregates. However, in these States, the design of each construction project is based on economy, and the use of lower quality aggregates in some construction items may be technically and economically feasible.

In areas where high-quality aggregates are scarce, medium-quality aggregates may be improved satisfactorily for use in some construction items. Blending of aggregates from two sources, crushing the over-size particles and recombining with the acceptable fraction, heavy-media separation, and various stabilization methods have been used. Small percentages of portland cement have been used extensively to upgrade base course materials having excessive plasticity. Bituminous materials have been used to stabilize clean sands and other aggregate mixtures in base courses.

Research regarding the physical and chemical nature of some sand-gravel and quarry materials may be needed to determine the reason for their poor performance in highways, and to determine means of reducing or eliminating the characteristic causing the poor performance. For example, basalts are being examined in Idaho, soft limestones in Kansas, sandstones in West Virginia, and cherts in New York. This type of research can be included in the State's highway planning program, using 1½-percent HPS funds.

Conservation of aggregates may be effected by stabilization of moderately plastic soil materials. Portland cement-soil and lime-soil mixtures are used extensively in subbase and base courses in many States. Other chemicals, such as phosphoric acid, are being used to improve the bearing capacity and waterproofing characteristics, and reduce the volume change of plastic subgrade soils. Some of these newer products are being evaluated in experimental projects.

Aggregate conservation and economy may also be effected by "selective earthwork," or conserving the better materials encountered in excavation and using them in topping the fills. Borrow or "topping" material may be obtained from outside the right-of-way and used in the highway subgrade to provide higher bearing capacity and reduce the required thickness of pavement.

Far-sighted planning officials have recognized that some types of land use prevent development of aggregate sources. Consequently, zoning restrictions have been adopted to conserve aggregates in some metropolitan areas.

Need for Inventory

Replies to a questionnaire by the Highway Research Board to the State highway departments in 1948 showed that 34 States thought there was a need for an inventory of aggregate sources (2).

Economic usage and conservation of aggregates depend on the development of adequate information regarding materials sources and presentation of the information in a manner that it can be readily used by the highway engineer. The aggregate inventory provides a record of known sources of materials and indicates potential sources that may be used in the production of materials for specific construction items. Further field sampling and laboratory testing of materials from potential sources must be made at the time of the project design to determine whether the natural material is suitable for the specific construction item, or whether mechanical alteration or stabilization is necessary to make the material suitable for use.

The highway department needs a permanent record of materials searches to prevent duplication of work. An area may be resurveyed for materials sources because the prospector did not know an earlier survey had been made. The record should also give information regarding sources that were found unsuitable for a specific purpose; the material may be suitable for a later construction use. Transfer or retirement of materials engineers has caused some States to recognize the need for an adequate materials inventory.

Many State highway departments depend on commercial suppliers for high-quality aggregates, hence have given primary concern only to development of information regarding local sources of low- or medium-quality aggregates for subbases, shoulders and similar construction items that do not require high-quality aggregates. This is particularly true in metropolitan areas, where a high percentage of the aggregate production is used for building construction and other municipal construction. Consequently, some States have only recently become interested in making aggregate inventories because the expanded highway program has created a need for a greater volume of all types of aggregates.

Inventory Progress

Two of the earliest States to make comprehensive aggregate inventories were Michigan and Maine. Starting in 1930, the Michigan State Highway Department has published a gravel pit inventory every few years, which includes information regarding some quarry and mine waste materials. One volume of the Michigan publication gives test data and ownership information available in the Testing and Research Division. A second volume contains county road maps and shows the location of gravel pits. The publications are of value to contractors and commercial aggregate producers, as well as State and county highway personnel.

The initial Maine publications in 1934 were primarily concerned with sand and gravel deposits, but gave data on a few quarries (3). Supplementary inventories of limited areas were made in 1948-52 by the Maine State Highway Commission, in cooperation with the Bureau of Public Roads, and the work is currently being extended to other portions of the State (4).

The Bureau of Public Roads determined in 1957 that 26 States had made or were making some sort of aggregate inventory, and that 18 States were interested in making a comprehensive survey of known and potential aggregate sources.

Some States have been reluctant to make a comprehensive materials survey in areas where there is no immediate need for the aggregates, because they fear commercial interests will purchase the property and the materials will not be available to the highway department when needed, or will be available at an exorbitant cost. Some States take options on the important potential sources; others refuse to release the inventory information to any except highway personnel.

Many of the State highway departments have included comprehensive materials inventories in their Highway Planning work programs, using "1½-percent" funds. Engineering soil surveys, which include source information and test data on sand and gravel deposits, were completed in New Jersey in

1955 (5) and Rhode Island in 1957 (6). A materials survey for the Interstate system was completed in North Dakota in 1959 (7). Other cooperative materials inventories are under way in Arizona, Colorado, Connecticut, Maine, Massachusetts, New Mexico, New York, Oklahoma, Oregon, South Dakota, Vermont, Washington, West Virginia, Wyoming and Puerto Rico. These inventories (1) summarize the information available in the materials laboratory regarding natural materials sources that have been utilized in project construction or maintenance, and (2) most of them develop generalized information regarding potential materials sources of materials for long-range construction planning. Two examples will be described.

Arizona Materials Inventory

The inventory of aggregate materials in Arizona was started in 1958. Inventory folios have been completed for Maricopa, Gila and Santa Cruz Counties, and considerable work has been done in other counties. The folios have three principal parts: (1) pit and quarry map, (2) geologic information, including a photogeologic map and description of the geologic formations, and (3) test data. Appropriate ground and aerial photographs illustrate the various geologic units.

Figure 1 shows a small portion of one of the 11 sheets of the "Pit and Quarry" map of Maricopa County (8). Symbols are used to show the highway use made of material from the pit or quarry. In figure 1, a large black dot indicates a source of mineral aggregate or aggregate base material, a circle with half of it solid black indicates select material, and a circle with inserted numeral indicates borrow and the grade of borrow (1 through 7). The serial number adjacent to a circle or dot corresponds to a pit or quarry number given in the table of test data, and also is the file number for further information on the source. Appropriate symbols are used in other areas to indicate: (1) a source belonging to a public agency other than the Arizona Highway Department, (2) a commercial source, and (3) a source that has been abandoned for a specific highway use.

The photogeologic map (figure 1) shows the location of the pits and quarries, as well as the areal distribution of geologic formations and deposits. Except for some of the younger alluvial deposits, the geologic formation are indicated by various color patterns; consequently, the differentiation of geologic units on the map is not as striking in the black-and-white reproduction in figure 1 as in the original map. The photogeologic map is based on existing geologic reports and maps, agricultural soil surveys, interpretation of aerial photographs, and field work. The geologic formation are described in the text of the folio, and some geologic sections are presented. The map is useful in prospecting for new sources of aggregates.

The test data sheet for each pit-and-quarry and geologic map sheet gives information on pit or quarry location (including reference to highway routes), estimated quantity, general description of material (sand, gravel, rock, etc.), laboratory test data, proposed or known use of the material, and a quality rating (excellent, good or fair) for the specific use. More detailed information on a specific pit or quarry is available in the Materials Laboratory, through reference to the serial number. This type of summary data sheet is similar to those in materials inventories of other States.

The completed folios, as well as unpublished inventory information, has proved useful to field personnel in selecting sources of material for specific construction projects. Personnel in the Materials Laboratory have been benefited by having a more readily available source of information for discussions with materials, location, design, and construction personnel.

New Mexico Aggregate Resources and Soils

The New Mexico aggregate inventory was started in 1959. The work includes a survey of soils, geology and construction materials. The initial work has been confined to strips containing the Interstate highway routes, but will be extended to primary and secondary highways of the State.

The "Soils and Geology" maps (figure 2) for the Interstate system are for strips extending 3 to 4 miles each side of the proposed route (9). Geologic information on maps and in the text is based on other geologic maps and reports, interpretation of aerial photographs, and field reconnaissance. Significant structural geologic features and physical characteristics of the geologic formations are described. Geologic cross-sections are given on the map sheets. Geologic formations older than Quaternary (Q) are differentiated by use of various green patterns, giving greater contrasts than shown in the black-and-white reproduction in figure 2.

The "Soils and Geology" maps also show the AASHO soil classification (number after the geologic symbol) of the Quaternary (Q) deposits and the residual soils developed on the older geologic formations. A summary table of boring logs and classification of soil-sample materials obtained at various depths accompanies the map.

The New Mexico folio also includes "Construction Materials Inventory" maps, some of which are for wider strips than the "Soils and Geology" maps. The maps show (1) pits or quarries from which materials have been tested for use in construction projects and (2) prospective locations of pits or quarries, from which only a few samples have been obtained and tested but a detailed source investigation has not been made. A summary table for each map sheet gives the following information for each pit or quarry: geologic age and type of formation, thickness of the usable portion of the formation or deposit, depth of overburden, estimated quantity available, haul distance, test data, and highway use for which the material is recommended.

The completed maps have proved useful in the search for aggregates for use in highway projects. Prospective sources indicated on the constructive materials inventory maps have proved to have materials of proper quality and be more economical on specific construction projects than the previously known sources.

Inventory Aids

The above description of the work in Arizona and New Mexico gives a general idea of the sources of information for materials inventories. Published and unpublished geologic and agricultural-soil maps and reports have great value in reconnaissance for potential sources of aggregates, and in the preparation of materials maps. Accuracy of the information in the reference maps and reports, particularly of the older ones, must be determined before reliance is placed on them. Where geologic mapping in a State has been done by two or more agencies, correlation of formations throughout the State may require considerable preliminary study.

The rapid expansion in the use of aerial photographs in materials surveys is of interest. The 1948 Highway Research Board questionnaire revealed that "only two States have experience in airphoto methods" (10). Currently, most of the 16 States that have either completed cooperative materials inventories or have them in progress in their Highway Planning programs have used aerial photographs extensively in the work. Many other States are using aerial photographs in searches for construction materials in inventories or on a project-to-project basis. An important contribution of the Bureau of Public Roads in the cooperative materials inventories has been the instruction of highway personnel regarding aerial photographic interpretation techniques.

Preliminary study by the Bureau of Public Roads in materials surveys in Yellowstone National Park and other Rocky Mountain areas indicates that color aerial photographs may be a useful supplement to black-and-white photographs in the location of prospective sources of aggregates (11).

Water resources or ground water reports and maps are useful. Well logs have been of considerable value in the search for sand and gravel deposits in some regions, particularly when an overburden of several feet of finer grained soil makes detection of the coarse-grained material difficult or impossible by means of aerial photographic interpretation.

Geophysical apparatus, particularly electrical resistivity, has proved to be of great value in identification of materials and in outlining the vertical and lateral extent of deposits or strata in the reconnaissance stage of materials surveys. In 1948, only 4 States had used geophysical methods in materials surveys. Most of the States currently making inventories of potential sources of aggregates are using geophysical apparatus. The Bureau of Public Roads, by giving demonstrations and training personnel in use of equipment and making interpetations, has been very influential in this expanded use of geophysical apparatus.

Appropriate mechanical equipment must be used in prospecting for new sources of materials, to determine the extent of the deposit and obtain samples, even though it is planned that only generalized information regarding materials at specific sites will be obtained in the aggregate inventory.

The State highway department's files regarding materials site investigations, including test data, are a major source of information in the materials inventory. However, many States have learned that an improved filing system is needed to make the office information more readily available. Card indexing and machine methods of recording and sorting data have been of considerable help in making the initial materials inventory, and keeping it up-to-date, as well as being useful to the personnel engaged in project design, construction and maintenance.

Programming and Personnel

Compilation of a comprehensive inventory of aggregates for a State usually requires several years. Consequently, most of the States that have included the inventory in their Highway Planning programs have established priorities for mapping. Since 1956, the initial work in many of the States has been to inventory materials for the Interstate routes. However, Oklahoma spent considerable effort initially to rate the State highway system with respect to aggregate needs for construction and maintenance before setting up priority areas for inventory work. A few States have started the inventory in areas where the known aggregate sources were scarcest.

A major factor involved in programming the materials inventory is the availability of trained personnel. Most of the State highway departments making the inventories have decided that assignment of personnel full-time to the inventory project for a period of a few years is more efficient than to have various persons (perhaps with no special training) for short periods of time when not needed on routine highway projects. The project should have one or more geologists who have had experience in making materials surveys and are trained in aerial photographic interpretation. Materials engineers assigned to the project also should have a knowledge of geology and aerial photographic interpretation. States that plan to expend a considerable portion of the inventory effort in locating potential aggregate sources, and developing generalized information regarding such sources, should have at least one field crew with mechanical augers and drills, and sampling equipment, assigned to the project.

The programed cost of Statewide materials inventories has ranged from about $1.50 to $5.00 per square mile for the various States that have included the work in Highway Planning programs. The average cost per square mile is somewhat greater when only strip mapping is planned, because greater emphasis is placed on selection of potential aggregate sources within a reasonable haul distance from highway routes planned for construction, reconstruction or maintenance; also, more detailed site investigations, sampling and testing are done near the proposed routes than in other areas. The unit cost may vary considerable for various parts of a State because of different geologic formations or deposits, terrain, and available supplementary information, as well as the specific need for inventory information — for example, more time and money may be expended in exploring for potential sources for an Interstate highway location than in an area where aggregates are needed only for secondary or local roads. No State has reported the actual cost per square mile for an aggregate inventory.

Summary

A comprehensive materials inventory should result in conservation of high-quality aggregates and economic utilization of all available natural aggregates.

The materials inventory provides a record of location and materials-quality characteristics of known pits and quarries, and indicates the location of potential sources of materials for specific highway uses. This aids the design engineer in making preliminary cost estimates for highway projects and in designing pavements and other highway structures so as to make maximum use of local materials. It also lessens the effort required by the materials engineer to find suitable materials for specific highway uses, including maintenance.

Procedures used in other States can be adapted to a materials inventory in the specific State. Rapid reconnaissance and exploration tools, such as aerial photographs and geoplhysical apparatus, should be used to the maximum extent applicable in the materials surveys, so all aggregate sources will be identified and delineated with minimum effort and cost.

The State highway departments that have not made a materials inventory should consider whether one is needed. Updating an old inventory should also be considered. Preparation of the initial materials inventory or bringing an earlier inventory up-to-date can be included in the State's Highway Planning program using 1½-precent funds.

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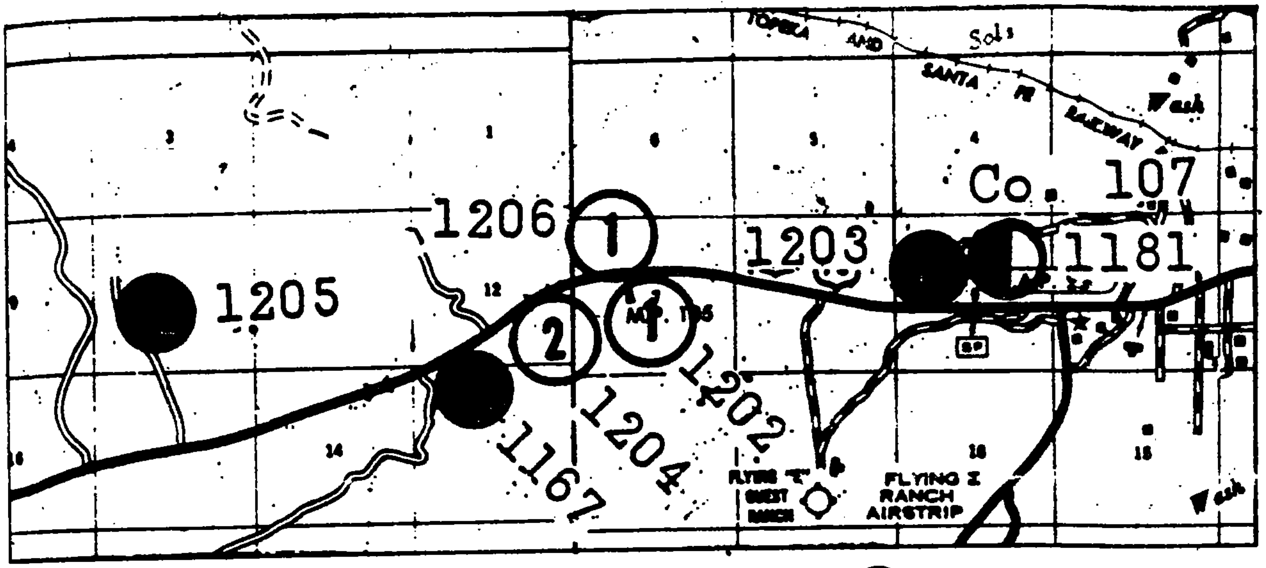
PIT AND QUARRY MAP



Mineral aggregate or aggregate base

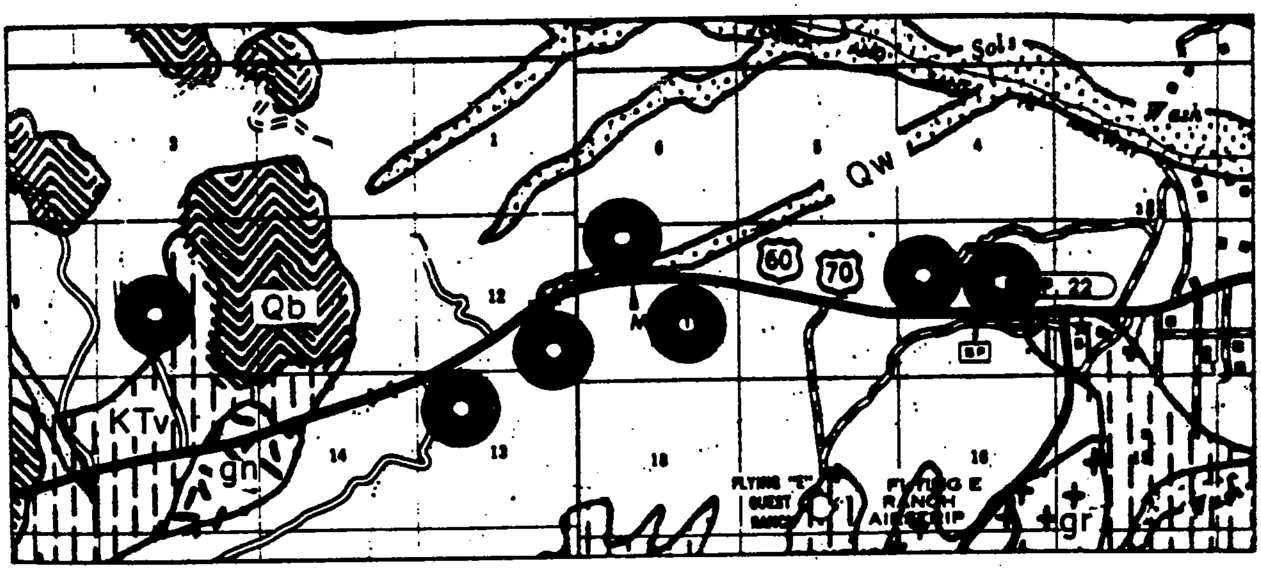
Select material

Borrow (grade I)

1205 Pit number

0 1mi

PHOTOGEOLOGIC MAP



Qb Basalt

KTv Older andesitic flows and tuffs

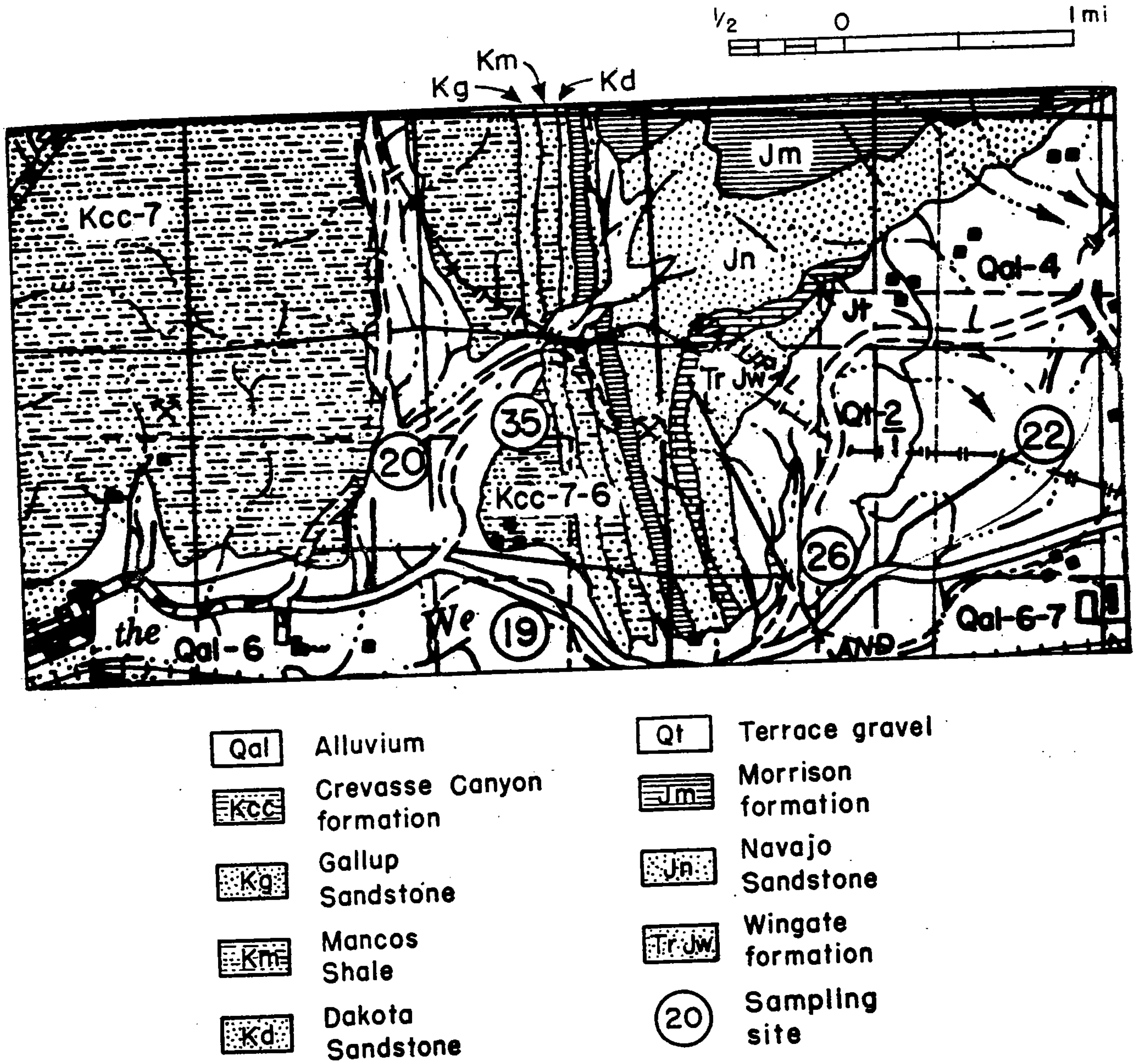
gn Granite gneiss

gr Granite

Qw Younger alluvial deposits

Materials source

FIGURE I -PORTIONS OF PIT-AND-QUARRY AND PHOTOGEOLOGIC MAPS, MARICOPA COUNTY, ARIZONA



(NUMBER FOLLOWING GEOLOGIC SYMBOL INDICATES AASHO SOIL CLASSIFICATION)

FIGURE 2 - PORTION OF SOILS AND GEOLOGY MAP 40-2, NEW MEXICO

PROBLEMS FACING AN ENGINEERING GEOLOGIST WORKING FOR A HIGHWAY DEPARTMENT

by

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ABSTRACT

The reluctance to change present procedures together with an ignorance of what can be done by angeologist, retard the establishment of engineering geology in highway departments. However, these obstacles can be overcomed when a well trained engineering geologist sells his services to a highway department and then demonstractes what can be done.

A geologist must have a good knowledge of highway engineering or considerable experience working with engineers in order to understand their problems and come up with practical solutions. He should be able to handle all phases of engineering geology as it applies to: 1. Locating granular materials; 2. Conducting soil profile investigations and making backslope recommendations; 3. Supervising bridge soundings and making recommendations for substructure design of bridges or retaining walls; 4. Tunnel investigations; 5. Ground water studies; 6. Geophysical surveys; and 7. Slide studies.

The progressive engineering geologist should be capable of conducting research studies that deal with the above phases of engineering geology and assist the soil engineer in problems dealing with expansive soils, degradation of aggregates and frost heave.

The geologist must understand the engineer's problems and assume responsibility for making specific recommendations for the solution of these problems. It is only in this way that engineering geology will be established as a recognized profession.

The foremost problem facing an engineering geologist working for a highway department is the resistance to change. Most departments are quite satisfied to leave the status quo. To get a new idea started or to change accepted procedures requires a good sales pitch, patience and perseverance. But this goes for most any profession or business.

The engineering geologist must have experience, know-how, common sense and the ability to get along with all sorts of people. His job at first is primarily one of salesmanship. He must convince others that his services can be of value and then be able to produce the goods.

Unless he should be fortunate enough to be working in a state highway department where engineering geologists are already accepted, the engineering geologist must establish his own position. In some states, the engineering geologists work with the design section; in others, they work with the materials engineers. At first, the geologist may find his activities restricted to one of the following categories: Materials location, soil profile, bridge soundings, back slopes or to special problems dealing with slides, drainage, fill settlement, reactive aggregates or petrographic analysis. Very few states use their engineering geologists for all these categories.

The field of engineering geology is relatively new to many highway engineers. Therefore, the geologist must "sell" his services to the engineer by demonstrating what he knows. He must also develop new approaches to investigating subsurface conditions. He must, in a sense, become an engineer capable of solving special problems and making definite recommendations for remedial work. He is then qualified to be called an engineering geologist. There is today a great need for trained geologists in the field of highway engineering, but this need has yet to be recognized both by the highway engineer and the geologist himself. The day will come when the engineering geologist will be used in the highway departments in the same manner as they are now used on major dam or tunnel investigations by federal agencies. Their services will become standarized procedure on most preliminary investigations.

Although the subject of this paper deals with the problems facing an engineering geologist, it also deals with their opportunities and responsibilities. New and challenging opportunities await the enterprising geologist who wishes to enter the field of highway engineering. Geologists seeking new ways to broaden their activities and who are willing to learn highway engineering first-hand may develop jobs where none exist. What does he need to know? What can he do? What is his training? These questions will be answered along with a general discussion of the application of geology to highway planning, design and construction.

WHAT DOES HE NEED TO KNOW

The well trained engineering geologist should know all phases of geology that may pertain to highway planning, investigation, design, right-of-way, construction and maintenance. This means he must have first-hand knowledge of materials used in highway construction. He must know the significant laboratory tests used in his state and be able to determine which tests to run to qualify the materials he has investigated or sampled. He must know something about highway design in hilly or mountainous terrain in order to determine the most economical, safe back slope for highway cuts — slopes that will not slump or slide, but that will not be so excessively flat that the initial cost is prohibitive. This is a field of engineering geology which needs to be utilized better by highway departments.

The geologist must: 1. Be thoroughly familiar with land forms, a keen student of geomorphology and capable of recognizing any feature which might be indicative of surface or deep seated movement that has, is or will take place. 2. He must learn something about rock mechanics in order to predict intelligently how various formation will stand when excavated for highway cuts. Here is a field of engineering geology that needs much study but could yield very practical results when intelligently applied to highway construction. 3. The geologist should become thoroughly familiar with the principles of soil mechanics as they relate to slope stability in soft formations. He should be able to work out mathematical solutions which satisfy the physical condition as he sees it and at the same time convince the engineers he knows what he is talking about. 4. The geologist contemplating work for the highway department, or those now working as engineering geologists, should observe actual construction jobs as much as possible to see how contractors are handling their excavation and to note how various geological formations stand. Much can be learned from observation and this experience helps the geologist formulate his recommendations on new jobs. This approach is a practical one and often is superior to recommendation based on theoretical analysis alone.

WHAT CAN HE DO

The services of the geologists should be used on all preliminary investigations, particularly on new alignments in the mountains. Even rolling terrain may be subject to slide conditions which the geologist would recognize. Realignment or change of grade would eliminate the slide condition in many instances. A knowledge of potential slide areas prior to final design and purchase of right-of-way could save many dollars for the highway departments.

The engineering geologist is the logical person to determine or anticipate the problems of rock excavation. One of the great hidden costs of highway construction is the lack of information regarding the depth of rippable and non-rippable materials. This is reflected in the high unit bid for highway excavation. When the cut is opened, it is often found that so-called solid rock can be ripped, and the contractor stands to get paid on the basis of solid rock. The engineering geologist is in a good position to save much of this unnecessary expense by utilizing his knowledge of geology and rock formation, thereby making much closer estimates of probable depth of rippable materials. The use of resistivity and seismic equipment can often reduce the guess work and has been used successfully in some states.

TRAINING

The engineering geologist should prepare himself for the field of civil engineering by taking as many engineering subjects he can take along with his regular geology curriculum. He should, by all means, include one or more courses in soil mechanics. Some colleges now offer courses with a degree in engineering geology. More colleges should give consideration to preparing their geologists for civil engineering work just as they do for petroleum or mining engineering. There possibly could be more opportunities today in civil engineering for properly trained geologists than there are in both petroleum and mining engineering. Geology professors should be made aware of this fact and prepare their geologists for civil engineering jobs.

An engineering geologist should prepare himself to take the Registered Engineer Exam as soon as he is eligible. With the Register Engineer's license, the geologist has the respect of other engineers, and his recommendations carry more weight.

A good place for a prospective geologist to start in the highway department is in the soils section. He should work on a field party taking soil profiles. Here is where he should be able to prove that he can assist measurably in: 1. Determining the mappable limits of soil types along the highway alignment. 2. Identifying the rock formations and pointing out their significance to highway construction. 3. Determining the rock structure and physical features as they may affect excavations or slope stability. 4. Recognizing active or potential slide areas. 5. Locating suitable aggregate sources. 6. Determining ground water conditions. Here is a relatively new field for geologists to get into and make jobs for themselves. The geologist should be willing to work from the bottom up as just outlined, and his advancements will be measured by his ability to develop the position into a recognized profession.

Once the geologist has established a position in the highway department, he should extend his activities by preparing himself to handle foundation problems as they relate to bridges and retaining walls. This is a highly specialized field of engineering geology which needs to be developed in all highway departments.

BRIDGE SOUNDINGS

An engineering geologist should be capable of supervising all bridge soundings including the drilling, sampling and testing of foundation materials. He should have a good knowledge of soil mechanics to be able to interpret the results of the drill logs and test data so as to make definite recommendations to the bridge engineer. These recommendations should include bearing value of the soils at various depths, type of piles best suited for the site and the depth and loading of individual piles. He also should establish depth to water table and possible scour depth.

Here is a phase of engineering geology which has come into its own in the past 10 years. Still, only a few state highway departments give their geologists a free hand in the matter of supervising bridge soundings in the way they should be done. Unfortunately, many state highway bridge departments still follow the old tradition of driving piles to refusal at most bridge sites. With our expanded highway program, many bridges have been built and will continue to be built, for inter-changes on dry land where stream scour will never be a problem. Often these dry land bridges can be placed on spread footings when an adequate bridge sounding has been conducted and an intelligent appraisal of the boring logs and test data made.

Some bridge engineers are unaware of the fact that they may have over-designed the substructure with a safety factor of 20 or more in one instance and have only a safety factor of less than 1/2 in another instance. Actual pile load tests made by the Engineer Corps in the Los Angeles area have reported these conditions. The more progressive foundation engineer perfers to determine pile lengths and their loading by more thorough sub-surface investigations. Here is where engineering geologists have done a very good job in those states where highway departments have turned over subsurface investigations to their geologists. These same geologists have the responsibility of recommending the type of pile best suited for the ground conditions, their loading and estimated lengths. This information is invaluable to bridge engineers and does much to keep substructure costs to a minimum.

GEOPHYSICAL SURVEYS

The engineering geologist should have a good knowledge of the use of resistivity and seismic equipment which are useful tools during preliminary investigations. They have been used in some states for locating gravel, determining depth of water table, depth of rippable material in deep cuts, and stream profiles at bridge sites. However, the use of the equipment and the interpretation of the data for both resistivity and seismic survey is a specialty which, for best results, requires a person who can devote almost his full time. There are so many variables in handling the equipment and that affect the interpretation of the data, the average engineering geologist does not have time to ferret out and solve the many problems that arise. This probably accounts for the fact that some states which have used either, or both, resistivity and seismic equipment have not had consistently good results. It is the speaker's opinion that both resistivity and seismic exploration should be utilized more than they are in highway work, but he feels that a specialist should be employed to operate and maintain the equipment and assist in the interpretation of the results.

NEW DEVELOPMENTS

An engineering geologist should be alert to new developments of highway engineering, design and investigation made both in this country and abroad. He should be well posted on available current literature pertaining to his specialty.

The engineering geologist is in a good position to supervise research programs for the soils engineer in highway departments. Usually the soils engineer is committed to supervise routine laboratory tests and pass on daily reports sent to the field engineers. As a rule, he finds little time to do research unless he is fortunate enough to have funds and personnel to conduct special studies. More and more highway engineers are recognizing the need for research, particularly as to problems dealing with expansive soils, subgrade moisture, location of suitable aggregates and the like. If the geologist is looking for ways to extend his services and usefulness to the highway department, this field of research is a fertile one for development.

Probably one of the most pressing problems facing many highway departments is the matter of sub-drainage. A statement has been made that "some states attribute as much as 90 per cent of their highway failures to poor drainage." Many highway engineers handle these problems after they arise and damage has already been done to the roadway. Relatively few engineers recognize the signs of potential subsurface drainage problems and provide adequate subsurface drains in the original design. Here again, the research approach may prove profitable to highway departments, and the engineering geologist is the logical person to conduct this work. He has learned how to identify evidences of near surface seepage or ground water table that will affect the roadway prior to construction. Plants, animals and soil types often assist in locating possible sources of near surface water. Well planned location of drill holes is needed to supplement surface evidences. A knowledge of general geology and attitude of strata or joints often give a clue as to the possibility of artesian water than might be intercepted by highway excavations.

There are many problems pressing for solution. A few of these are:

1. Expansive Soils

   A very acute problem in Colorado.

2. Potential Landslides

   Not often recognized until they do damage.

3. Surface Creep

   Often attributes to pavement failure where no other cause can be determined, especially on side hill cuts.

4. Safe, Economical Backslopes

   Often left to design engineers who may never get into the field. Often designed with no knowledge of rock type, dip of strata, adverse jointing, depth of weathering, or seepage channels. Many costly maintenance problems later arise because of faulty backslope design.

5. Bridge Foundations

   This has already been discussed in the earlier part of the paper.

6. Location of Suitable Aggregates

7. Degradation of Aggregates

8. Reactive Aggregates

9. Frost Heave

WRITING THE REPORT

Probably the most important phase of the engineering geologist's work is the report he prepares for the engineer. The field work, testing and interpretation of the data can be top rate, but if the data and conclusions are not presented to the engineer in the manner that he can fully understand, the geologist's work is of little value. His report must be clear and concise, contain definite recommendations that can be used in the design, and, where applicable, have drawings or sketches to illustrate specific points.

CONSULTANTS

Considerable engineering and geological work is done by private consultants for some state highway departments. This may be a necessity for those states which have not established an engineering geology section. It is regrettable that those states which have an engineering geology section should continue to use consultants on routine investigation.

It is the writer's (speaker's) opinion that a well-trained engineering geologist, attached to the highway department will very often do a more thorough and conscientious job than the consultants, and it will cost the highway department a lot less. The consultant is anxious to get the job done in a hurry so he can get at another job. When his work is done, he is gone from the area and seldom has to account for what is found during construction. On the other hand, the highway engineering geologist has to live with the problem through construction. Therefore, he has a greater interest in doing his preliminary investigation thoroughly. He has access to records of former highway jobs not available to the average consultant. Once an engineering geology section has been set up in a state highway department, it should follow up preliminary investigations with field inspections during construction to determine how correctly the preliminary field work and analysis checked with actual conditions. If this is consistently done by the highway engineering geologists, it will be hard for outside consultants to do better.

expected, properties of sand, silt and clay are often combined to further complicate the analyses. Depending upon the conditions under which the soil is considered to be subjected, the tests are usually conducted under various moisture and loading conditions. Popularly, a stress envelope is developed at the in situ moisture content and another envelope developed after the soil has been allowed to become fully saturated under variable normal pressures. Thus, one may determine more clearly the extent of apparent and true cohesion while differentiating these values from shearing resistance due to internal friction.

Drainage conditions, rate of loading, and other variables are also taken into consideration depending upon the applicable condition.

Quick and consolidated quick methods are used on the materials that tend to possess more of the characteristics of clay.

Whenever the material being tested permits, triaxial shear tests are conducted, thereby eliminating many of the inherent disadvantages of other shear testing methods. Unfortunately, many of the soils are so friable at the in situ moisture condition that suitable trimming or preparation for this type of testing is practically impossible.

Consolidation Testing:

Consolidation testing is accomplished in much the same manner as shear testing in that controlled drainage and moisture conditions are varied in an attempt to similate field conditions. This includes present as well as anticipated future conditions. If it were necessary to design footings on many of the soils where consolidation tests were conducted under submerged or even saturated conditions as a matter of course, estimated settlements

This phase of engineering geology is the most difficult to explain both to the engineer and to the average geologist. The engineer cannot understand how the geologist can take a series of apparently unrelated facts and come up with a logical answer or reason to explain a physical phenomenon. The average engineer is not trained to do this, and for this reason he is reluctant to accept the geologist's explanation. The geologist can come up with an engineering value to the formation of soil, knowing full well that the figure is not a valid one if applied to a specific layer or area. The figure given is based upon the sampling and testing to give the best overall average that will apply for the interval in question, a knowledge of the general geology of the area, experience with similar formations or soils in other areas, and an intuitive sense that most engineering geologists develop over a period of years.

RESPONSIBILITIES OF AN ENGINEERING GEOLOGIST

1. He must prepare himself for the great challenge.
2. He must sell his services.
3. He has to prove his worth by introducing new methods of exploration which will be reflected in savings made in design, construction and maintenance.
4. He should assume responsibility for supplying the engineer with quantitative, as well as qualitative data, which can be used as a basis for design or construction purposes.

How much responsibility a geologist should assume in making definite recommendations for engineering design is one question on which geologists themselves do not agree. Until geologists are willing to assume this responsibility, they are not engineering geologists in the strict sense of the word. There needs to be a clarification of this matter of "responsibility" by the engineering geologists actively working with engineers. It is those geologists willing to assume responsibility who will eventually establish engineering geology as a profession comparable to engineering. It it toward this end that geologists working for highway departments can do much to forward the acceptance of engineering geology as a recognized profession. It goes without saying that engineers will utilize geologists as soon as they prove themselves capable of, and willing to, assume responsibility. It has been the writer's hope and purpose in giving this talk to encourage geologists to seek opportunities in highway departments and then develop these opportunities into realities. Some of the steps in developing these opportunities have been pointed out, some of the practical problems that will need to be solved have been mentioned, together with some of the obstacles to be overcome in the matter of resistance to new ideas. The writer has tried to bring out the challenging aspect of engineering geology and hopes this will spark other geologists to take up the fight to establish engineering geology as a distinct profession.

REGIONAL – AREAL GEOLOGIC INVESTIGATIONS IN HIGHWAY GEOLOGY

by

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INTRODUCTION

Project sponsors utilizing geologists in highway engineering frequently restrict their efforts to investigations adjoining the alignment, whether for planning-design, constructions, or maintenance purposes. Commonly disregarded is the importance of regional-areal geologic investigations for assembling, evaluating, and extrapolating much of the critical data that pertains to such aspects of a project as: the route location, stream crossings and pattern of bank scour; excavation characteristics; slope and foundation stability; sources and properties of construction materials; drainage pattern; and legal claims. Because the geologic conditions along a route invariably possess local differences, forecasts rarely can conform to a type interpretation. Consequently an understanding of the controlling factors responsible and causes thereof can prove more advantageous to many engineering objectives than a detailed knowledge of the narrow route-strip.

Early use of geology in highway practice was largely confined to a study of the alignment only for design or the location of construction material sources. However, with the increased mileage, width, and load requirements placed on highways in the past decade, the value of geology in the

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planning stage has received wider acceptance. Competitive planning and economics have been largely responsible for this attitude. Today another phase, the preparation of unit-bid prices (Kiersch, 1957), is a field of growing demand for the highway geologist. Regional-areal investigations can contribute critical data needed in any of these phases, as well as during maintenance of the highway.

THE REGIONAL-AREAL ASSESSMENT

Scope and Meaning

In order to clarify the meaning of regional-areal investigations, the following summarizes the manner as used herein.

The initial consideration of any highway project would include an assessment of the regional geologic setting of the proposed alignment route. This reconnaissance evaluation involves many possible circumstances and items, a few of which are briefly described below under "Method of Approach" and "Significant Geologic Data as Provided..."

The principal value of a regional-areal assessment of the setting and natural conditions is to learn of the origin and important geologic events responsible for site conditions and the physical properties of the natural materials. This appraisal will invariably determine some inherent problems of a site which are fundamental to the geologic origin; primarily this information will be concerned with formational units, structural features, erosional features, and the surficial deposits.

To acquire these data, the most effective and efficient means is a general geologic history of the region or area which in essence is a sequence-of-events that has affected the site rock and features along the proposed alignment. This investigation is, of course, on a limited basis, with its duration and extent a function of the project's scope and complexity of geology.

The geologist is in a better position than anyone else to correlate interpretations of natural processes in the historic and geologic past with the relationships between such processes and land uses proposed. In doing this, he should make every effort to evaluate processes in terms of their rate or specifically, distinguish between geologic time and time in the engineering or human sense. Quantitative estimates are needed concerning features such as: natural compaction; bearing characteristics; transmissibility rate of groundwater flow; gross stability of earth materials; and the expected yearly rates and magnitudes of erosional processes and ground movements.

Paramount then, is the ability of the highway geolgoist to analyze the evidence of a problem from more than one point of view. Successful analysis depends upon a creative approach, in which frequently, the task is to see anything at all. However, fragmentary clues organized into a pattern usually have a meaning. Many geologic situations require the fragmentary evidence approach, with the remaining parts of the puzzle available only after exposure by subsurface excavation or laboratory test data (detailed exploration of Stage III).

Geology in Elements of Highway Practice

Irrespective of whether for planning-design, construction, or maintenance phases, the practice of highway geology can be conveniently classified into the following three separate categories.

EXPLORATION, includes regional-areal and detailed studies, bases on direct and indirect data from all possible sources.

INTERPRETATION-DESIGN, an assessment based on all forms of exploration data.

RESEARCH, whether required in the exploration and/or interpretation-design stages or special studies required in the maintenance phase due to circumstances previously unrecognized. Often, operation of a highway results in changes taking places that alter the properties of site materials; this may require extensive research for ultimate design of remedial treatment.

The three geologic categories are of equal importance in highway practice where engineering operations are conveniently subdivided into the following major elements.

1. Roadway, section and alignment.
2. Earthwork (embankments and their foundations, excavation materials, cut slopes).
3. Structures (bridges, retaining walls, conduits, tunnels, and others).

Method of Approach (Attack Philosophy)

Regardless of the geological category (exploration, interpretation, or research) in highway practice, the most successful method of utilising regional-areal studies is the "convergence-of-evidence" plan (Fig. 1). This approach integrates four inter-dependent stages.

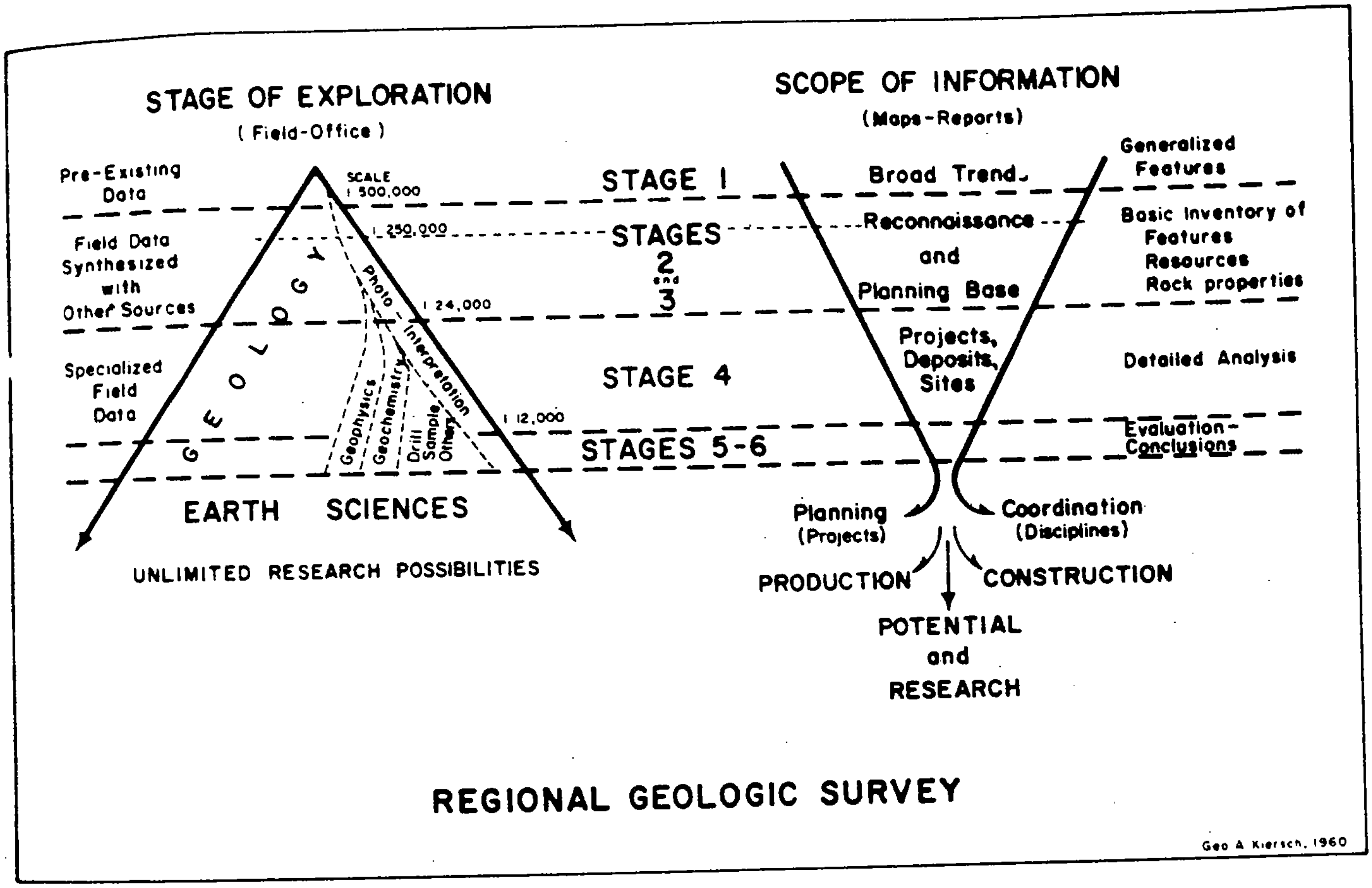


Figure 1. A diagram showing the six stages fundamental to Regional Geologic Surveys. This approach is modified in text for Highway Geology practice into four basic stages in which: STAGE II encompasses stages 2 and 3, STAGE III is stage 4, and STAGE IV encompasses stages 5 and 6. (From Kiersch, G.A., 1960, "Regional Geologic Surveys-basis for areal development of natural resources, agriculture and industry").

STAGE I - Initial[1/] Regional and areal reconnaissance incorporating direct and indirect data. Prepare appropriate map (s) and compilation (s) from such sources as: State and Federal geologic maps, bulletins, reports; State and Federal soil maps, vegetation and timber maps, hydrologic charts; and aerial mosaics and photogeology study. Data largely within categories described under heading "Significant Geologic Data Provided.."

STAGE II - Interim Summation. Interpretation of Stage I data with extrapolation along proposed routes. Forecast preliminary geologic conditions and enumerate potential problems for investigations Stage III.

STAGE III - Route Alignment or Site. Detailed on-the-ground mapping supplemented by specialized exploration and research techniques as justified. Magnitude depends on needs of project and complexity of site conditions; scale of map (s) and/or overlays determined by relative needs.

STAGE IV - Interpretation and Forecasts. Comprises a synthesis of all physical and engineering data on geologic conditions along route that includes: origin of materials; changes after deposition or emplacement and agents responsible; and the chemical-petrographic factors affecting use of the natural materials. Appropriate scale maps, overlays, and cross-sections utilized according to project needs for design and construction.

1/ Studies undertaken by many State Geological Surveys (Bureau Sources of Mines, Mineral Resources, et al.) or the U.S. Geological Survey are excellent for the STAGE I assessment.

SIGNIFICANT GEOLOGIC DATA AS PROVIDED BY REGIONAL-AREAL STUDIES

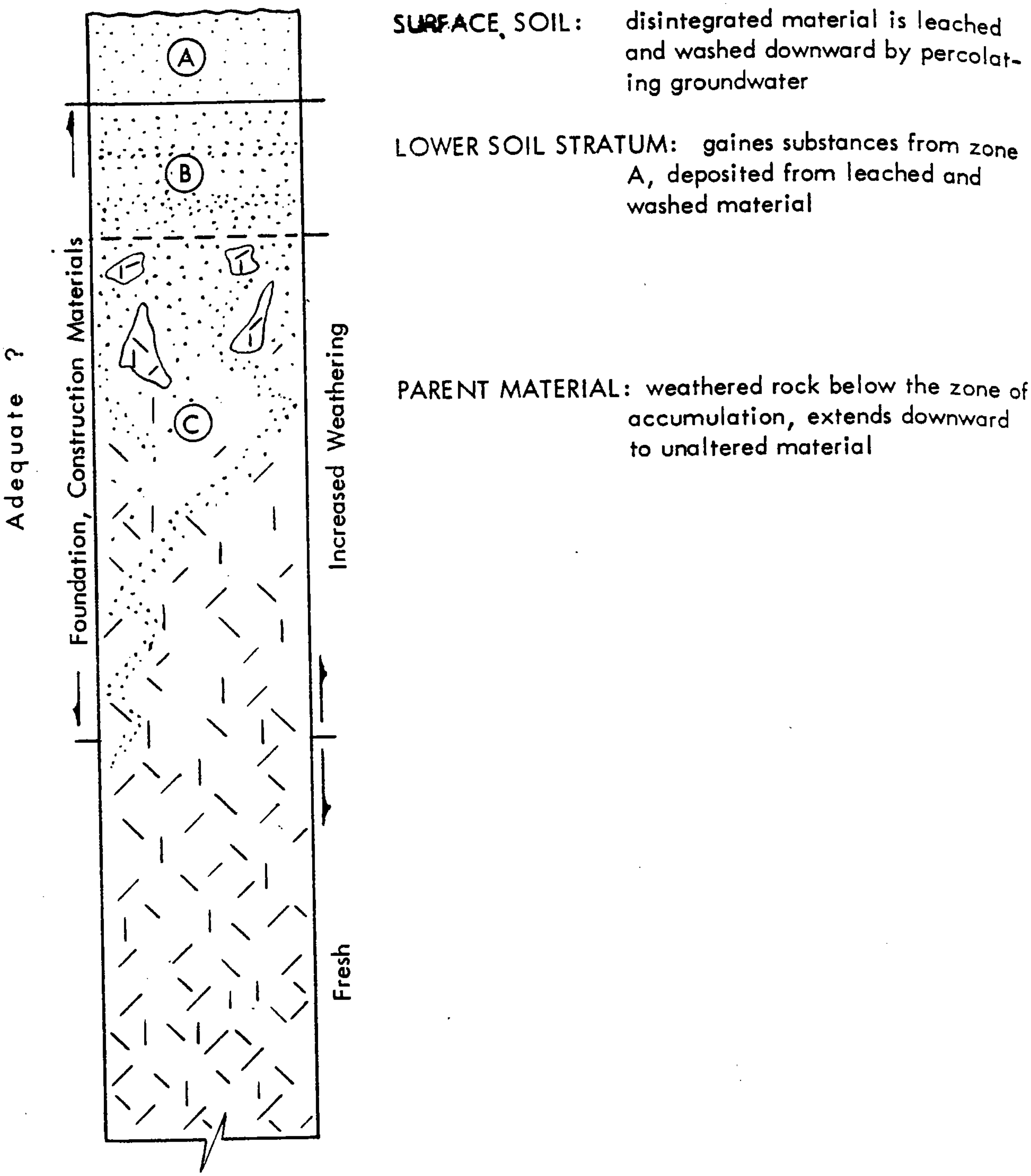
Invariable, significant data collected at a distance from the strip-route can be utilized to advantage in evaluating and interpretating conditions anticipated along the proposed alignment (Stage I and II). Frequently, the geologist is restricted to a minimum of borings and excavation cuts in the route studies (Stage III). Under such circumstances, it becomes necessary to correlate the scattered subsurface data with that extrapolated from natural exposures and areal sources (Stage 1) in order to reconstruct the geologic history, and thereby forecast the problems and conditions anticipated along the route alignment.

Relative cost evaluation has been proposed on the basis of a numerical value (relative cost factor) for such significant engineering needs as: terrain analysis, excavation characteristics, subgrade conditions, stream crossings, vegetation, and construction materials by Nicol (1959, p. 120). This systematic approach has wide application and warrants acceptance wherever possible.

Some of the significant information required in highway geology that can be collected advantageously by regional-areal investigations is tabulated as follows:

1. Rock column sequence. Subdivide the rock units on basis of their physical properties and reaction to engineering needs; extrapolate concealed rock units along route and forecast expectable site conditions and characteristics.

2. Rock properties and stability. Determine pattern and cause of, e.g., inherent structural features and deformation; rock-soil



- Schematic diagram -- Relationship of Parent Material to overlying weathered mantle and soil profiles.

(From Holdredge & Kiersch, 1953)

Figure 2. Cross-section of rock-soil weathering at depth and common engineering characteristics of rock mantle and material in depth.

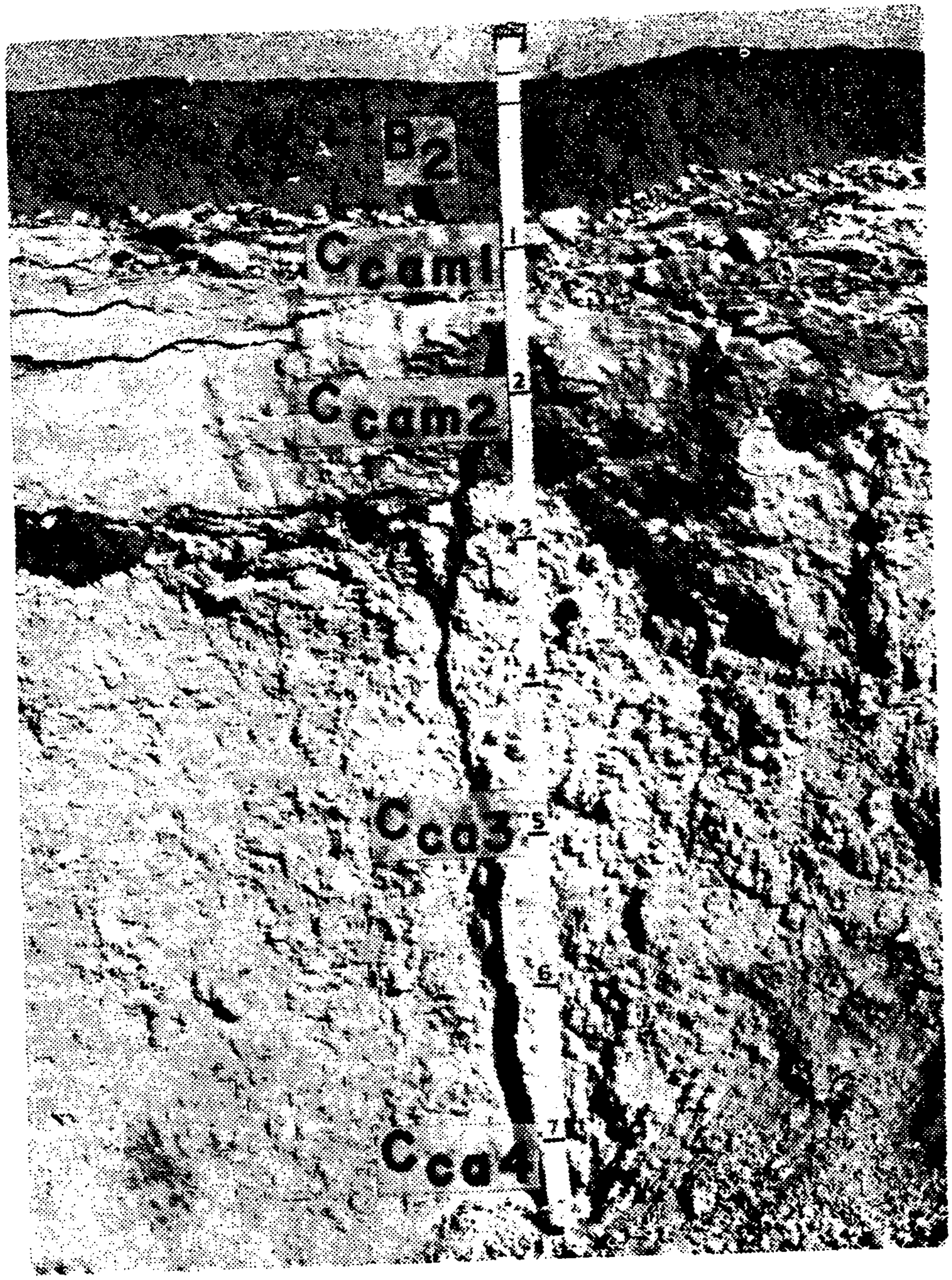


Figure 6—Soil No. 1: Very strong ca horizon. C_{cam1} horizon is very strongly and strongly indurated. Scale is in feet.

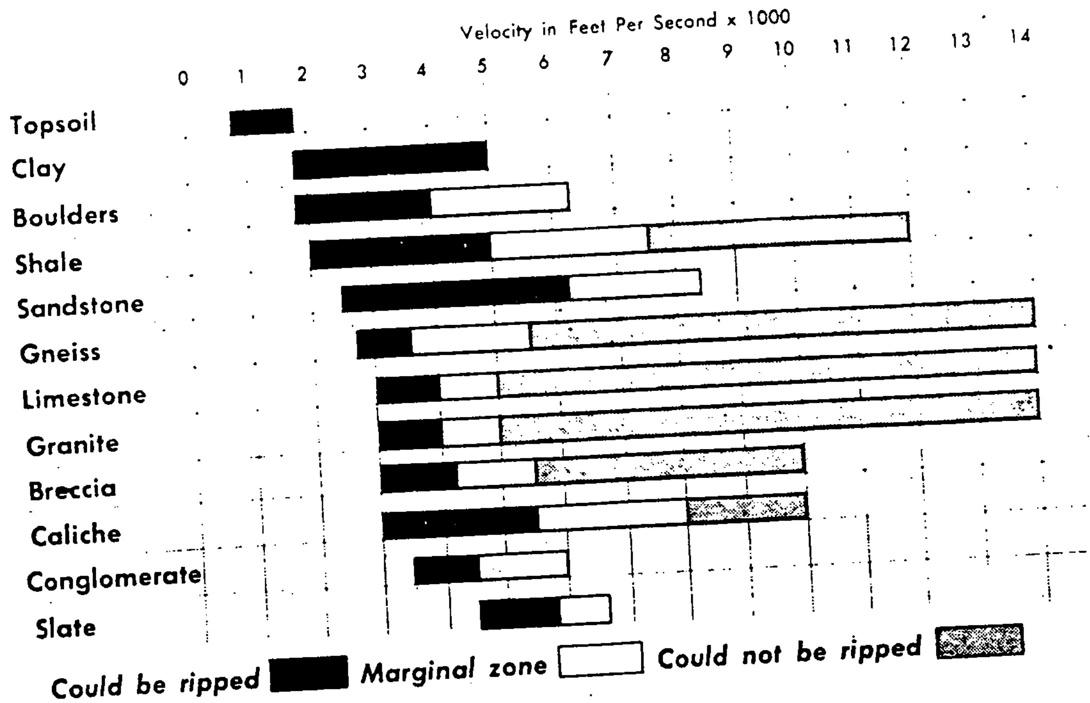
Figure 3. Caliche-Horizon in surficial deposits of arid region. Caliche subdivided into units according to properties and induration: C_{caml} is very strongly indurated; Cca4 slightly indurated. (See text). Scale in feet. (From Gile, L.H., 1961)

weathering and alteration (Fig. 2); seismicity and potential intensity (damage factor); slope stability and downslope movement; ground water occurrence and controls; susceptibility to solution action and cavitation; subsidence activity (shallow and/or deep) and extent.

3. Geomorphic history and influence on near-surface conditions. Surficial sediments, their origin, properties, and correlation with laboratory test data; extent and characteristics of e.g., caliche "beds" (Fig. 3), lateritic soils, glacial deposits, organic soils and muck, and construction material deposits.

4. Excavation characteristics. Establish classification of potential excavation materials on basis of rock-soil properties. Subdivide into either, rock, common (soil) or unclassified (combination rock and soil or unknown) utilizing fresh cuts for in-situ evaluation. Determine drilling, blasting, and fragmentation properties (includes re-interpretation and results of former excavations, construction drill holes and costs, and power consumption records).

To ascertain excavation quantities, classification and unit-bid prices, utilize data from such scattered scources as highway and railroad cuts, gullies, stream canyons and other exposures of the rock column concerned with route which demonstrates e.g., weathering at depth; primary and secondary structural features; typical surficial overburden; and any vegetation unique to certain rock units useful for delineating subsurface conditions (Kiersch, 1957).



RIPPABILITY VELOCITY CHART

Figure 4. Ripability chart, based on seismic velocities of rock-soil and the weathered mantle. Most reliable results realized when velocity data is calibrated against drill hole core and open-cut exposures of materials; groundwater conditions affect physical data. (From Caterpillar Tractor Co. chart, 1960).

The following conditions strongly influence or govern economics cuts on a unit-basis:

a. Deep cuts are less expensive than shallow ones;

b. Lava and other highly "vesicular" rocks can cost twice as much as dense rock to drill and shoot because of excessive fractures and clay seams that stick steel and the loss of explosive pressures along open fractures. For "vesicular" rocks usually advantageous to keep overburden in place until blasting completed, thereby providing a greater degree of confinement (Sidrer, 1957).

c. The seismic method is a good tool for estimating the rippability and excavation characteristic of rock-vs-soil classification. However more reliable results if data is calibrated against a known drill hole core or exposure (Fig. 4).

5. Cut-slope characteristics. Cut-slopes converge rapidly on a 1:1 or 1 1/2:1 slope with bulk of yardage within upper half of excavation. The "toughest" material to remove generally occurs along the gutter line of the roadway at toe of slope where costwise this can be as much as ten times the cost of excavating other yardage (unit basis).

a. The design of cut slopes in soft rock should parallel the natural weathered slopes, commonly on 1:1. This approximates the talus slope angle for soft rocks such as shale, sandy shale, argillaceous limestone, and friable sandstone. Where natural elements disintegrate rock to small fragments in a short time (few years) due to wetting-drying, solar insolation or freezing and thawing, a slope approximating the talus angle has proven the ideal design for minimum maintenance (P.H. Bird, 1957).

6. Backfill characteristics. Establish a shrinkage (or swell) factor for common-fill; expansion factor for rock-fill.

7. Drainage pattern-climatic effects. A critical factor in roadway maintenance, drainage pattern affects, viz:

   a. Slope erosion subsequently triggers mudflows, earthflows and slides, slumps, and gullying due to inadequate surface drainage and/or underground seepage.

   b. Rockslides and falls occur due to improper slope design as influenced by attitude of bedding, water infiltration and seepage, and inherent fracture pattern within rocks.

   c. Embankment failure or roadway settlement of fill sections where unstable foundation, either can be caused by excessive ground water infiltration.

   d. Deterioration of roadway shoulders by excessive erosion of run-off or infiltration.

   e. Pollution of streams and ponds by inflow of silt transported by run-off from soft-cut slopes or fills.

8. Erosion and scour of stream banks. Sediment load and scouring pattern are a function of steam hydraulics and properties of bank materials; control design of crossings, maintenance of channels, bridge piers, and embankments.

9. Construction materials sources. Commonly necessary to location adequate quantities of acceptable materials (discussed by P.C. Smith this symposium, paper on "Highway Materials Inventory").

10. Service record of construction materials. Rate of weathering and degradation as factor in development of plastic fines. Occurrence of deleterious minerals in source rock for aggregates.

11. Equipment Performance. Influence of geologic conditions on e.g., drilling, fragmentation, and loading of rock; stripping-loading with or without rooting-scarifying of common excavation; exploration drilling and core recovery, dozer or backhoe excavation pits and trenches; orientation of bedding and joint planes in rock affect cost of rooting, influence direction of excavation work area (Kiersch, 1955, p. 62-64).

a. Normally if a tractor and a heavy-duty rooter cannot economically scarify a rock unit, a power shovel cannot dig the same formation unless it is blasted.

b. Daylight or sidehill cuts in rock are less expensive than through-cuts because work area is confined.

c. Half of drilling time is lost in moving and changing bits.

12. Geologic factors affecting legal and contractual claims.

Contraversies frequent concerning:

a. Ground water conditions modified due to numerous possible causes such as: change natural flow from springs by lowering the water table through drainage of tunnels, deep open cuts, or diversion of surface flow; lowering water table due to changes surface or subsurface excavation; creating water-logged land by the introduction of excessive surface inflow, or restricting underground flow; diverting underground flow (piracy) at the headwaters of a stream across the natural divide into adjacent watershed by surface excavation, channeling, or tunnel construction.

b. Mineral potential of condemned land and fair-worth appraisal.

c. Quality and value of mineral claims and/or aggregate deposits.

d. Stability of slopes, and adverse effect on property near-by the right-of-way, hazards, or damage experienced.

e. Vibration damage to property during blasting for construction or excavation; and damage due to operation heavy equipment.

f. Riparian rights to land lost or gained: by sediment deposited by streams due to changes in channel; or by accretion of alluvial deposits (imperceptible changes by channel), as influenced by engineering works.

g. Riparian rights gained or lost by avulsion, a sudden change in stream channel due to engineering works.

UTILIZING REGIONAL-AREAL DATA IN HIGHWAY PRACTICE

Case Histories

Coordinated studies comprising STAGE I-IV investigations are taken for granted in highway practice, if maximum usefulness is to be obtained from a knowledge of the geologic conditions. The following brief case histories demonstrate the value and manner in which regional-areal geologic data are utilized in overall operations.

Figure 5. Panoramic view of area-looking westward across slide area and U. S. Highway 40 alignment; railroad on right edge (November 1959). Note excavation for deep French drains to Tertiary channel gravels. Lower benched slope above railroad grade shows horizontal drains and network to eliminate groundwater.

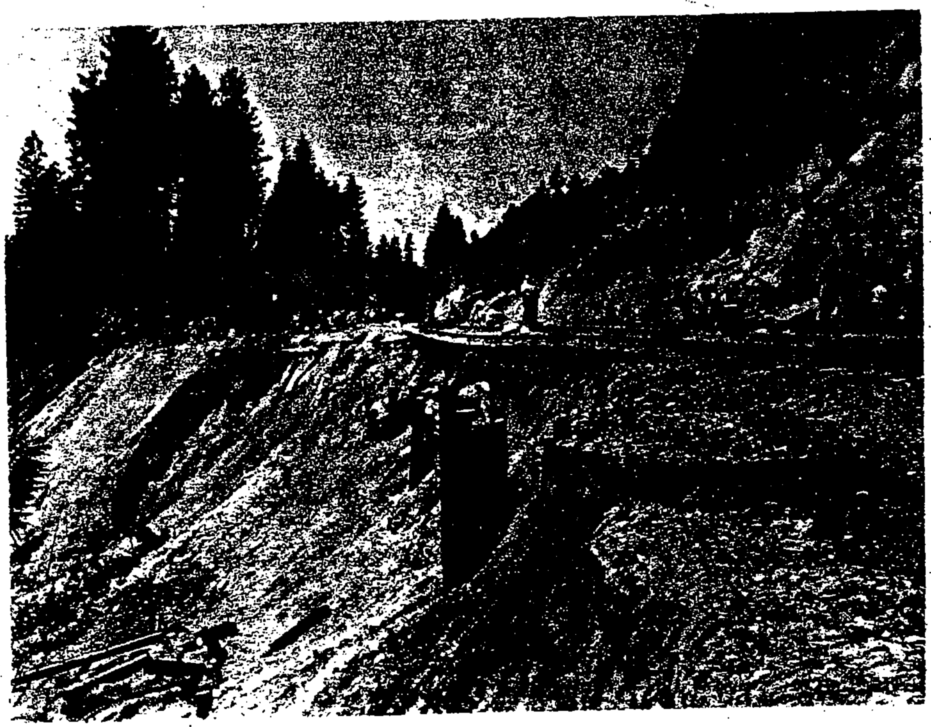


Figure 6. Initial "slide" of April 1958 which resulted in caving as shown (looking west). Note over-steep cliff of case hardened tuff on right overlain by old landslide debriss (dark soil). Piling foreground serves as marker Figures 5-7.

COMPLEX DOWN-SLOP MOVEMENT, CENTRAL SIERRA NEVADAS, CALIFORNIA 2/

Introduction

The areal setting of a large-scale, complex landslide in the central Sierra Nevadas near Alta, California is shown in Figure 5. Movement resulted from the differential shear strength of "units" within a varied thickness of Tertiary sediments and tuffaceous rocks. This slide, which became active in April 1958, initially moved the tuffaceous sediments and underlying gravels in two separate but related landslide areas; one located above and the other below the railroad grade. Both Interstate Highway 40 and the double-track main line of the Southern Pacific Railroad were involved. After five months of partial remedial action the two slides threatened to join and form one large-scale, deep-seated slide involving a wide area and both transportation routes. Geological studies undertaken then in September 1958 determined the underlying causes and subsequent remedial treatment stabilized the active ground.

Geologic Setting - Above railroad grade, a thick section of alternating tuff, rhyolitic tuff, and interbedded gravel of the Mehrten formation comprises the main rock column which totals over 120 feet in height (Fig. 6). A thick surface debris of soil and recent gravels overlie the Mehrten rocks and at the site a mass of old landslide debris (movement before 1914) blanketed the main slope to near track level throughout the central part of the active slide.

Below railroad grade, the tuffaceous beds continue in depth for over 75 feet (contact concealed) and overlie Tertiary gravel deposits (part of

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2/ After investigations and private reports by author 1958-60. Thanks are due the Southern Pacific Co. for permission to describe the general features of the unstable area near Alta, California.

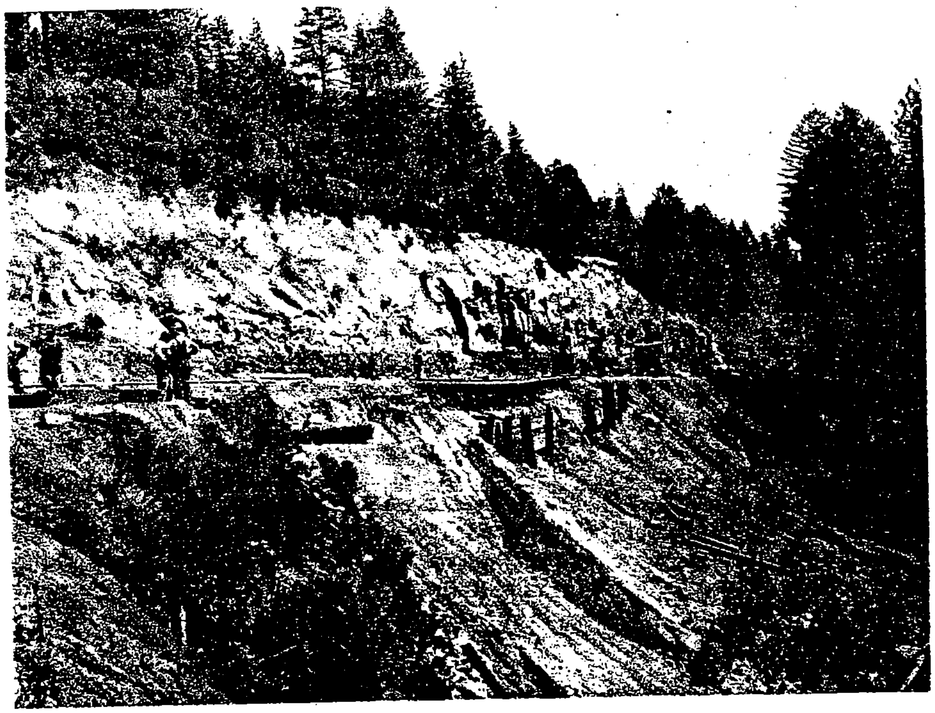

Figure 7. Initial "slide" of April 1958 (looking east). Note steep cliff of case-hardened tuff, contact between rock units just above track level. For downhill extension see Figure 6, using piling in distance for marker.

the famous gold-bearing Tertiary channels of the Sierras). Depth of the Tertiary gravels varies from 10 to over 100 feet locally. The channel gravels rest on the ancient bedrock of schist, gneiss, and intrusive rocks of the Calaveras series.

Areally the tuffaceous beds extend over a large part of the western slope of the central Sierras and dip at a low-angle westward (Fig. 5 and 7). At the site, the beds dip southwestward 1 to 3 degrees, a feature which contributed to the downslop movement that occurred.

Geologic Circumstances Relevant to Movement - The rhyolitic tuff units vary in mineral composition and degree of alteration throughout the thick section from fresh to thoroughly altered. Selected zones of the mineralogically crystal to glassy tuff have been progressively argillized to montmorillonite and illite or kaolinitic clays.

Petrographic features influencing stability of the tuff beds are: interlocking structure of grains; close packing; and cementation of particles. Petrographic conditions contributing to the instability and sliding of the tuff, altered rock, and clays are: 3/

1. The least stable clay is montmorillonite and mixtures with illite. When clay forms, eliminates irregular-shaped boundaries of glass shards and grains of the tuff and reduces interlocking. Also swelling inherent to montmorillonite reduces interlocking and shear strength.
2. The most stable clay is the kaolinitic material.
3. The most stable tuff is the unaltered rock, with secondary cementation of particles (includes case hardening as shown Fig. 7).

3/ From mineralogical analysis and letter report on representative material from slide area by W. D. Keller, December, 1958.

The areal ground water pattern is strikingly evident by its confinement to the more porous tuff beds and gravel zones; several perched water tables exist throughout site (Fig. 7). The underlying Tertiary channel gravels are water-bearing and control the static groundwater level and flow.

The extensive inflow of groundwater, enhanced by the numerous perched water zones, and a prolonged period of heavy surface water runoff at the site, resulted in the initial caving along the railroad grade in April 1958 (Fig. 6 and 7). The geologic significance of this "saturated" block of ground (and delicate stability conditions) was not investigated or recognized at that time. To "remedy" the initial caving of the railroad grade (slumping of outside bank and loss of one track) the immediate engineering activity of April-August 1958 consisted of cutting into the toe of the steep cliff face to provide additional width for the trackway. This excavation triggered a large-scale collapse of the slope debris with creep and serious movement within the Mehrten rocks above railroad grade caused by:

1. The weak, water-saturated condition of the porous tuff units overlain by a thick section of rock and soil (Fig. 7);
2. The unstable condition of the old landslide debris blanketing the original cut-slope (Fig. 6); and
3. The reduction in strength of tuffaceous beds in fresh cut slopes, sufficient to exceed the shear strength. The original, steep-cut slopes in the tuff had developed an added strength by surface case hardening, since excavated in 1916 (Fig. 7).

Concurrent with the above track movement, the slope and toe below

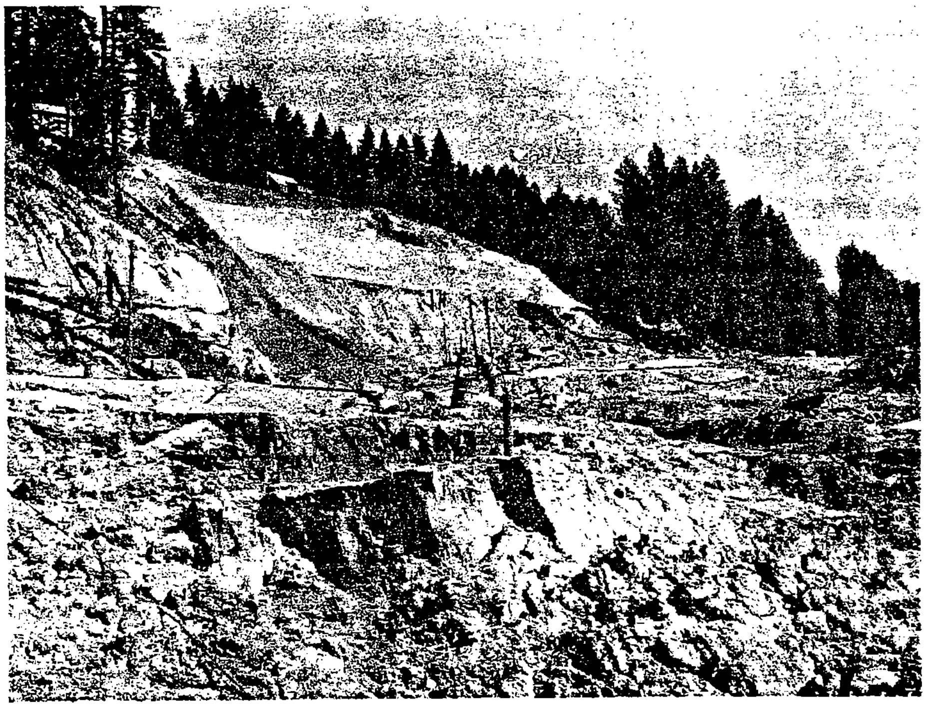

Figure 8. Looking uphill from highway alignment in October 1959 after cut above railroad grade was benched and stabilized (note piling for marker). Foreground of recent fill with tuff beds; cliff behind that have undergone extensive movement (highway alignment). Stabilization required deep French drains to underlying Tertiary channel gravels (Fig. 5). Network of drill holes and water flow testing shown.

railroad grade began to move due to: (1) the abundant infiltration of water, both underground seepage, and runoff; and (2) added weight supplied by the slump-slide material from the slope and waste rock removed from the above railroad excavation (Fig. 8). As the lower-level, slide-plane moved headward, the lower slide threatened to engulf the railroad grade. Consequently, had the lower slide plane progressed to join with the upper slide-plane above the railroad, one continuous block of moving ground would form over 225 feet in vertical section, some 600 feet wide and 700 feet long. Consequently with this threat in September 1958, and the lower or highway subgrade creeping and sliding at an ever increasing rate, a geological appraisal was undertaken.

Areal Features Important To Site And Remedial Treatment - The problems encountered at this site, illustrate the influence of several areal geologic conditions, such as:

1. The significance of the areal distribution of the tuff beds with downslope dip into the steep-cut; control on recharge of goundwater.
2. The strong influence of groundwater flow on the rock stability of a fresh cut slope and particularly the numerous perched water zones.
3. The underlying, thick Tertiary gravels and main groundwater channelway beneath the site. Being part of a major, interconnected system, these channels supplied very large quantities of underground flow and contributed to strong hydrostatic uplift pressure that enhanced sliding and creep.
4. The weathering and argillization of selected tuff "beds" within the Mehrten formation to montmorillonite, illite or kaolinitic

clays. These less-stable horizons also aided development of the numerous perched groundwater levels by acting as impervious "floors" and "caps".

5. The case-hardening effect on a cut-slope in tuff. The added strength and stability attained by a long-exposed cut in tuff (added cementation) compared to properties of a freshly cut slope is considerable.

6. Excavation of a fresh face in the soft, and weakened tuff units accelerated the goundwater flow through the porous units; this action further reduced the shear strength of the rocks (hydrostatic head increased) and contributed to movement along interbedded clay horizons.

Considering all factors, stabilization was achieved by: (1) design and excavation of flat slopes above the railroad with two wide benches; (2) an extensive horizontal drain system that tapped perched water tables throughout the cut slope in tuffaceous rocks (Fig. 5); (3) control of surface runoff with lined ditches above railroad grade; and (4) French drains beneath the highway alignment to reduce hydrostatic pressure by carrying off the underground water moving through the Tertiary channel gravels (Fig. 5). After completing this remedial treatment in 1958-59, the combination two-stage slide was stabilized. For example, wide tension cracks (to 6 inches) that developed around the crest of the slide area (top of hill) in September, 1958 were arrested and no further movement occurred.

CALICHE-HORIZONS IN SURFICIAL DEPOSITS OF ARID REGIONS

Introduction

Surficial deposits that possess prominent calcium carbonate accumulations or "beds" are major features of many soils and alluvium throughout the arid regions. Generally termed caliche, the characteristics of these "beds" directly influence the excavation classification at many sites and likewise they influence the "beds" as potential foundation material (Fig. 3).

Unfortunately the significance of the occurrence and physical properties of caliche has been commonly misunderstood, or frequently disregarded in planning, design, and/or construction of excavations and highway cuts. A long list of examples could be cited of contractors who miscalculated the excavation charateristics of surficial materials containing caliche "beds" and subsequently "lost-their-shirt".

The following summary outlines the physical characteristics of common caliche "beds" and their important properties; these can be widely applied in supplying geologic interpretation and data for highway engineering. Much of these data can be gained from a regional-areal study, when exposures or exploration are lacking along the alignment.

Properties of Caliche-Horizons - Bretz and Horberg (1949, p. 491) used the term caliche to indicate material of calcareous composition which is formed in the zone of weathering. Field investigations have shown that caliche ranges widely in carbonate content, bulk density, consistence, texture, and manner of carbonate occurrence: groundwater penetrates some "beds" easily, others not at all; some caliche is soft while other "beds" are extremely hard and indurated.

Induration - Induration of caliche is caused dominantly by cementation by calcium carbonate. Indurated "beds" maintain their coherence whether wet or dry, while the non-indurated slakes in a few seconds when

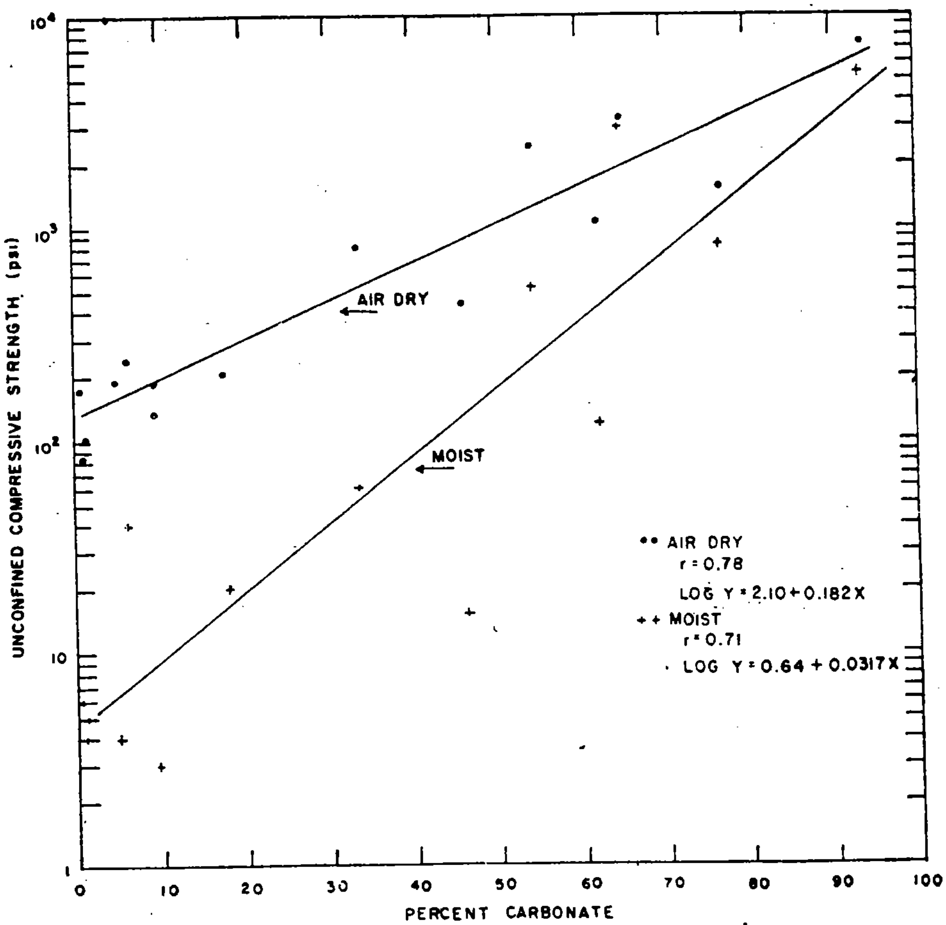

Figure 9. Relation between carbonate content and unconfined compressive strength of caliche. (From Giles, L. H., 1961).

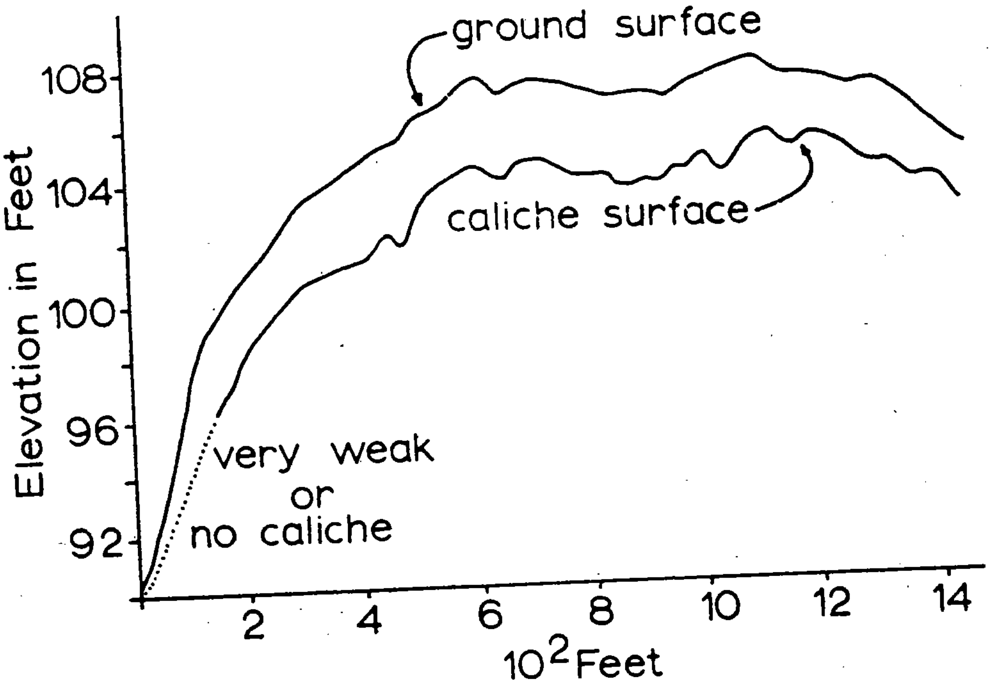

Figure 10. Cross-section of a railroad cut in arid region that demonstrates the correlation between the present ground surface and the top of caliche-horizon. (From Stuart, D.M., et al. 1961).

an air-dry portion is placed in water (Gile, 1961):

1. Very strongly indurated - Extremely hard; compressive strengths range from 3000 to 8000 psi; material requires blasting to remove, does not soften noticeably or slake after prolonged wetting.
2. Strongly indurated - Very hard; compressive strengths range from 750 to 3000 psi; material requires pickaxe to remove; some blasting.
3. Moderately indurated - Hard, compressive strengths range from 150 to 750 psi; material readily removed by pickaxe, can be broken by heavy-duty rooter, power shovel.
4. Slightly indurated - slightly hard; compressive strengths under 150 psi; material readily removed by power shovel, scarified by rooter.

As expected, compressive strengths are much higher in "beds" of high carbonate content than those low in carbonate; a correlation between carbonate content and both air-dry and moist compressive strengths is given in Figure 9.

Relevant Geologic Circumstances to Desert Sites - A close correlation exists between the top of the caliche horizon and the present ground surface as shown in Figure 10. On the ancient terrace levels above a valley floor, the same relationship exists as throughout areas of undulating topography and the stream valleys. Slight variations in correlation are apparently explained by minor differences in soil permeability. When the slope increases to between 12 and 15 percent, the caliche horizon usually disappears. This is probably due to reduced percolation and increased erosion which tend to prevent the accumulation of dissolved materials in the soil solution (Stuart, et al., 1961). As demonstrated in Figure 10, where slopes are steep there is a decrease in amount of caliche.

This relationship to topography is critical to a sound evaluation of site conditions in surficial deposits for:

1. Excavation classification, hardness and induration properties of caliche horizons;
2. Thickness and areal extent of caliche horizons;
3. Strength of caliche horizons for foundation purposes.

DEFORMED AND UNSTABLE FOUNDATIONS ROCKS IN GLACIATED TERRAIN 4/

Introduction

The unsuspected conditions of unstable, highly solutioned, deformed, areally subsided and locally collapsed beds were encountered during an excavation for building sites and prospecting for a proposed highway alignment in up-state New York. This situation emphasizes how critical factors in a site design can be influenced by, or due to, the geologic history of the area. Initially thick evaporite beds were laid down throughout the region followed by alternating sandstone, siltstone and limestone strata with frequent salt and gypsum as separate units and/or interbeds. A complex series of events changed some of these units to a very unusual mixture of unstable clay, mud, and altered rock.

Areal Site Conditions - Subsurface data revealed several varied rock lithologies at the sites. Although no complete stratigraphic sequence can be reconstructed because of the complex nature of the distorted rock exposed in open cuts and from the drill hole cores, an approximate sequence

4/ Most of data on this site is through courtesy of and after a report of 1960 by Paul H. Bird, senior engineering geologist, New York Dept. Public Works, Albany, N. Y.

of the types found can be given as follows.

	Thickness
Surficial blanket of glacial till and alluvial material: veneer over sites and ridge	3-8 ft.
"Vescular" dolomite: fine-grained solutioned, vesicular, and fractured.	
Intermixed With	to 39 ft.
Dolomitic Siltstone: resistant, very fine-grained, locally solutioned, with lower portion of a soft, friable silt.	
Clay-Shale: black, with selenite gypsum, highly deformed, strongly altered; rock gypsum solutioned out in lower part and voids filled with black, highly plastic clay	to 80 ft.
Intermixed With	
Fragmental Dolomitic Siltstone: gouge material in a silty, plastic matrix	Few ft.
Dolomitic Siltstone: very fine grained, sound foundation rock, minor fractures sealed with gypsum (selenite)	To depth
Salt Beds: solutioned with areal subsidence	At depth site below

Geologic Sequence of Events - The Camillus series of rocks, in which the proposed foundation site is located, was deposited in late Silurian time in the famous Salina Sea basin. The evaporite beds of the Series are primarily rock salt, and gypsum (originally anhydrite). South of the site, salt layers were mined by the solution process in former years. Evidence suggests that at the site proper, extensive natural solutioning removed at least 200 feet of salt; resultant subsidence deformed some site rocks. Although no conclusive surface expression of this phenomenon exists, it is strongly inferred by the surface swelling and subsidence of gypsum that has occurred in old gypsum workings nearby. Following removal of the salt, the original anhydrite absorbed water, probably from circulating ground water, and became gypsum ($CaSO_4 \cdot 2H_2O$). With the addition of this water, there was a volume increase of approximately 40 percent (above original mass of anhydrite) and this phenomenon created more disruption in the area. The volume increase and expansion was then followed by a second collapse, as the newly formed gypsum was subsequently removed by solution action. Therefore, there is evidence of at least two separate periods of collapse due to removal of soluble evaporites and one volume increase because of hydration. With the widespread solution activity, black muds accumulated as a residue; the accompanying collapse movements, accelerated by circulating ground water and/or tectonic forces, were paramount in their deformation and squeezing.

In addition to these events, continental glaciation further modified the region. The intense squeezing of the residual clays and other distortions at the site may be related in part to a glacial shove against the northwestern side of the site ridge, which is perpendicular to direction of ice movement.

Another possible contributing cause is that a portion of the gouging and fracturing of the dolomitic siltstones and other deformation is related to elastic rebound, resulting from removal of the thick continental ice sheet. Furthermore, some of the gouge and fracturing may be the result of tectonic activity, known to have cause minor thrust faulting in the immediate area.

Geologic Circumstances Relevant to Proposed Engineering Projects - The physical properties of the rocks encountered beneath the topographic ridge and proposed sites have resulted from at least five geologic events, Page 152 missing from original

Figure 11. View of quarry in rhyolitic rock. Shows such significant features as, "bedding" planes, joints, clay "seams", fault zones, oversize blocks from primary blasting due to inherent rock characteristics, and weathered condition effects some parts. (Photo by J. B. Hauskins).

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Figure 13. View of quarry face in basaltic rock mass, showing fresh rock from surface to depth, natural fractures and manner in which rock fragments when blasted in foreground. Micro-features in Figure 14. (Photo by J. B. Hauskins).

volcanic units and subsequent geologic events are largely responsible for individual conditions at any site.

Throughout the Mogollon Rim country of Arizona-New Mexico over 900 feet of volcanic flows and interbedded pyroclastics were laid down from scattered source vents during the Pliocene-Pleistocene time. Dependent upon the structural history or the petrographic characteristics of the individual flows at any site, quarry rock within a short distance may possess wholly different features, e. g., degree of weathering and/or inherent alteration; percentage of clayey rock developed and clay-filled seams; intensity and spacing of fractures and joints; moisture content and sorption; quarring and crushing characteristics; waste ratio; and durability and service potential. A majority of these characteristics and features can be largely assessed by utilizing regional-areal data which is extrapolated for appraisal of a site.

Contrasting Site Conditions - The following features and properties of two quarry-site rocks located in the same volcanic series, demonstrate the wide range of potential conditions that can occur.

Rhyolite and Rhyolite Porphyry - A group of rhyolitic flows, located near the base of the volcanic series (Fig. 11) is underlain by a section of welded tuff, easily mistaken for rhyolite but even poorer in quality for aggregate. The fine-grained rhyolites consist of thin flows, separated by "bedding" planes; gentle folding of site has superimposed an extensive fracture and fault pattern on the normal system of joints and "bedding" planes of the flows. Weathering and alteration is severe throughout, aided by the abundance of structural features; clay-seams fill all joints, faults, and fracture planes to below economic quarrying depth. Flow structure is

Figure 14. Micro-photograph of basalt, showing fine-grained to porphyritic texture. Note typical interlocking of grains with random orientation of crystals. (crossed-nicols, 40 magnification). An olivine basalt composed of 75 percent plagioclase laths, with augite and olivine; latter replaced by "iddingsite".

pronounced in the fine-grained, mosaic fabric of groundmass with phenocrysts oriented sub-parallel and fractured (Fig. 12). Quarrying and fragmentation is largely controlled by pre-existing fractures, "bedding" planes, and clay seams; an abundance of over-sized blocks and fines result. Crushing is controlled by flow structure and fractured phenocrysts; aggregate of all sizes is dominantly platy, tabular and elongated pieces. Quarrying conditions and aggregate quality are both poor.

Basalt and Basalt Porphyry - A large body of basaltic rock is located well within the volcanic series and consists of fine-grained basalt grading to porphyritic basalt on margins of site (Fig. 13). This occurrence probably represents an ancient volcanic plug or "vent" which served as the channelway for lava flows. The massive basalts are fractured by moderately-spaced, steeply dipping joints. Rock is fresh and unaltered, clay-seams are absent. Phenocrysts are unfractured and irregularly spaced throughout groundmass of interlocking, lath-like crystals (Fig. 14). Ease of quarrying and thorough fragmentation is largely governed by "homogenous" nature of rock with breakage into predominantly small pieces. Crushing of hard, tough, equigranular basaltic rock produces irregular, well-shaped pieces. Both quarrying conditions and aggregate quality are excellent.

Geologic Circumstances Relevant to Quality of Crushed Aggregate - Both the megascopic and microscopic features of each site rock influences its quality for crushed aggregate. This is critical for the rhyolitic site due to: quarry and fragmentation characteristics; crushing to platy, elongated and slabby pieces of all sizes; weathered condition and clay content that contributes to abundance of fines; high moisture content and sorption potential; difficulty in placing the crushed rock as sub-grade due to tabular shapes; and durability and poor service potential due to inherent engineering properties.

In contrast, the megascopic and microscopic features of the basaltic site rock enhanced the quarrying, crushing, and aggregate properties of the material produced.

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