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ENGINEERING GEOLOGY OF THE SOCORRO AREA, NEW MEXICO

GARY D. JOHNPEER
New Mexico Bureau of Mines and Mineral Resources
Socorro, New Mexico 87801

and

BRENTON M. HAMIL
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801

INTRODUCTION

The area considered in this report generally coincides with the non-mountainous lands in and around Socorro (fig. 1). While the pertinent engineering-geology conditions described below are most specific to Socorro, they apply in a more general manner to the great expanse of land both north and south of Socorro. Most data presented were originally elements of reports made for other purposes. Assembled, they document the current conditions of engineering geology in Socorro and provide insight into future conditions.

The City of Socorro is in central Socorro County just west of the Rio Grande. Access is via 1-25 which runs north-south, and U.S. 60 which runs east-west from Socorro into Arizona. The city is served by bus, air charter, and rail service.

Throughout the history of Socorro, engineering-geology problems have persisted. These range from obtaining suitable material for adobe brick to flooding and strong seismic shaking. The townspeople dealt with these problems largely on a priority basis using practical remedial measures. Little is known about the testing or planning which dictated the final design and location of structures. What is known is that many have withstood the most important test of all—the test of time.

Three physiographic/geologic features dominate the present-day landscape: the north-trending Rio Grande, surficial units flanking the river, and rock units. These three interrelated features affect the local climate and geology, and profoundly influence the foundation conditions of much of central New Mexico.

The piedmont topography west of the Rio Grande is gently rolling and dominated by partly dissected alluvial fans composed mainly of volcanic materials. Elevations generally range from 1400 to 1720 m. East of the Rio Grande the area also has gently rolling topography and is dominated by alluvial fans and dissected ancient valley fill deposited in part by the ancestral Rio Grande. A primary difference, however, is that the ancient valley fill and alluvium are largely derived from sedimentary rock source areas. Elevations range between 1400 and 1520 m.

The materials of consequence to engineering geology have similar modes of origin on both sides of the Rio Grande. The clay- to boulder-size materials comprising the surficial sediments were deposited by local drainage systems emptying into broad intermontane basins. Surficial sediments are of primary concern in foundation design, construction material resources, and geologic hazard considerations.

FOUNDATION CONDITIONS

The upper Cenozoic deposits are Santa Fe Group basin fill and post–Santa Fe valley fill. The great variability of lithology and grain size within the Santa Fe Group poses severe problems in attempts to define mappable subunits having similar engineering parameters. Many engineering characteristics of mappable units within the Santa Fe Group are the same, or nearly the same, as the characteristics of post–Santa Fe valley fill. From an engineering-geology standpoint, a more fundamental distinction between these deposits would recognize this overlap. It would be based on engineering similarities of rocks or sediments within the construction zone, including such factors as grain-size distribution, slope, degree of saturation, and shear strength. It would rely less on age and geologic modes of occurrence. Little has been done in the Socorro area on delineation of such categories.

The categories suggested in this report exhibit significantly different engineering properties. The differences are largely attributable to fundamental differences in composition, grain-size distribution, and depth to water.

Of these categories, the Rio Grande floodplain has undergone the most development (fig. 1). This category is younger than the recognized Santa Fe Group lithologies. The second category is the coarser-grained alluvial-fan unit. The alluvial fans exhibit a wide range in grain size and are poorly suited for agricultural development. They have recently been the focus of increased nonagricultural development. The third category is rock. From the standpoint of engineering geology, rock lithology is less important than rock quality. Exceptions are silicic igneous rock and cherty sedimentary rock which may be alkali reactive, causing cement mixtures to expand, crack, and weaken. Primary factors which affect rock quality are weathering, fracturing, and jointing.

Floodplain

The floodplain has as much as two meters of clay- to silty clay-size material (CH-CL) overlying a much thicker unit of saturated silty sand and well-sorted sand (SM-SP). Near San Acacia, 25 km north, the composite thickness of the upper Quaternary fill (floodplain) of the inner valley ranges from about 20 to 35 m (Clark and Summers, 1971). Throughout much of the floodplain area, groundwater levels are within three meters of the surface (fig. 1). As a consequence, the relatively loose and noncohesive saturated sand compacts differentially, causing structural cracking. In northwest Socorro, several newer buildings have numerous cracks and foundation distortion indicative of differential settling. These features are also found in buildings constructed in other floodplain areas of the city.

Clay minerals are layered crystalline particles commonly occurring in the fine-grained fraction of upper floodplain soils. Two main clay types of concern in foundation analyses are expansive and non-expansive clays. Floodplain samples corresponding to the Armijo and Senelli soil series of the USDA Soil Conservation were analyzed for their clay mineralogy and grain-size distribution (fig. 1, Table 1). The primary clays of the clay-size fraction are illite, kaolinite, and chlorite. Chemically and physically, these minerals are relatively stable and non-expansive. Samples 1 and 4 contain expansive mixed-layer illite and vermiculite which can expand enough to lift building foundations when wetted. The thickness of clay at the sample localities is less than the standard footing depth generally used in Socorro. Thus, structural cracking is attributed to other causes, not excluding poor foundation design.

Other problems reported along the floodplain include poor septic tank function and difficulty of utility line excavation, both due to shallow groundwater conditions. These problems are especially prevalent in

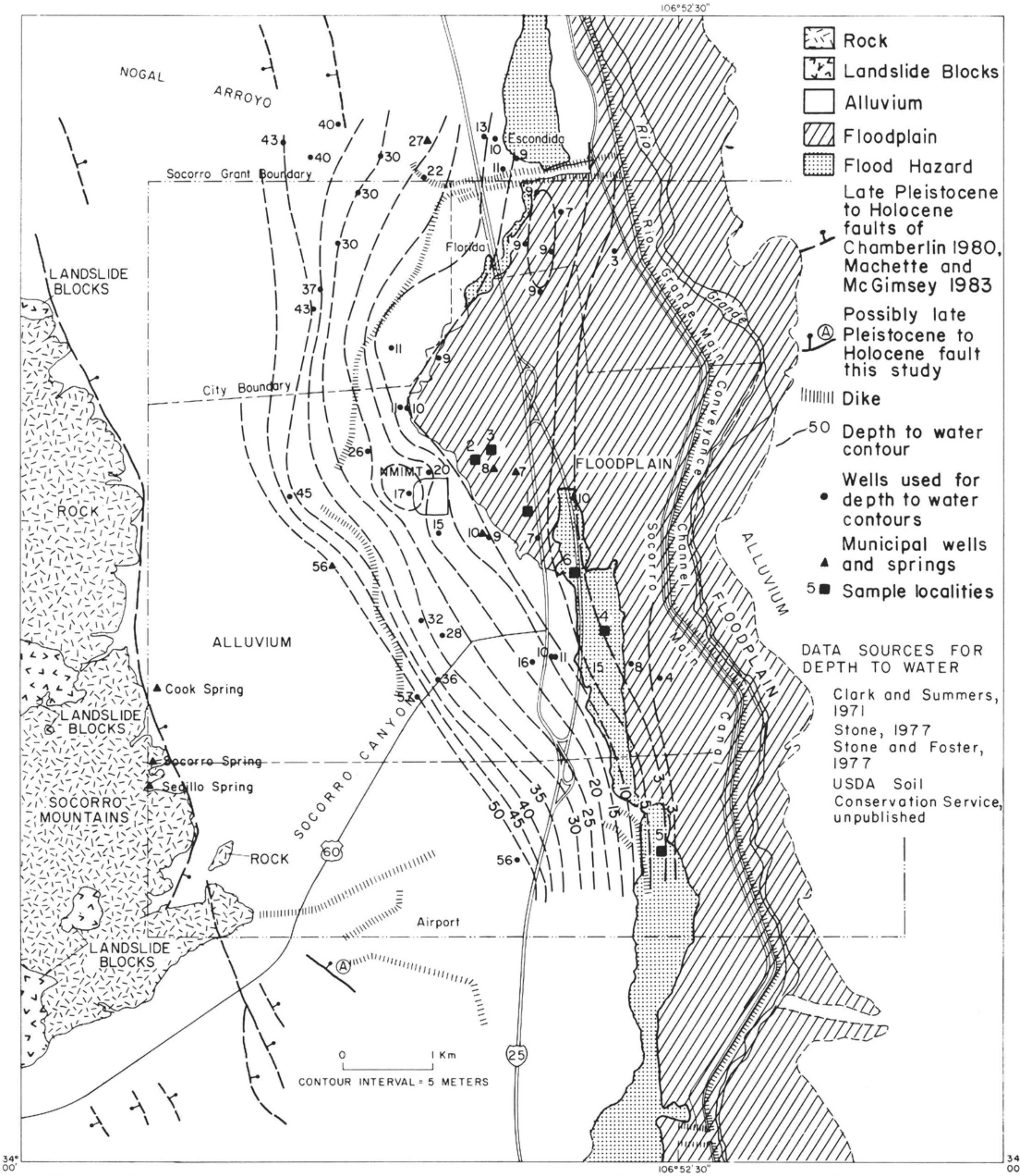

Figure 1. Map of engineering geology units, sample locations, generalized depth to water, and flood potential in the Socorro area.

Table 1. Physical properties of analyzed samples.

Sample Number	Soil Series[1]	Sample Depth (cm)	USCS[2]	Grain Size Distribution[3]			Atterberg Limits		Qualitative Clay Mineral Assemblage[4]
				Sand	Silt	Clay	LL	PL	
1	Armijo	67	CL	22	40	38	45	25	mixed layer illite, kaolinite
2	Armijo	61	CL	16	33	51	46	25	illite, kaolinite
3	Senelli	30	CH	10	27	63	62	27	illite, kaolinite
4	Senelli	43	CH-MH	6	35	59	68	33	vermiculite, kaolinite
5	Senelli	41	CH-MH	12	48	40	54	29	chlorite, kaolinite, illite
6	Armijo	38	CH-MH	29	16	55	70	34	chlorite, kaolinite, illite

1 USDA Soil Conservation Service preliminary data

2 Unified Soil Classification System designation

3 Settling technique

4 X-ray diffraction technique

housing areas on the east side of the city, where the depth to water is locally less than 1.8 meters.

Alluvial Fans

Foundation conditions within the alluvial fans are generally better than in the floodplain unit. These deposits consist primarily of sand to coarse gravel derived from flanking mountains. They exhibit a high degree of variability, may be clayey to bouldery, and are as much as several hundred meters in thickness. Locally, the alluvial fans are cemented with secondary calcium carbonate (caliche) that is in part pedogenic. Groundwater depths range from approximately 12 m to several hundred meters below the surface. Excavation difficulty and structural distress have been reported and siting of permanent structures must be carefully done.

Notable foundation problems include caliche cementation and, possibly, collapsing soils. Near-surface caliche may cause excavation difficulty but areas of caliche induration can often be identified prior to excavation by conventional seismic refraction techniques. Collapsing soils within the alluvial fans have not been reported in the Socorro area, but may be the cause of observed structural cracking. Collapsing soils undergo an appreciable loss of volume upon wetting, load application, or a combination of both. The geologic condition leading to soil collapse is a young, fine-grained (CL-ML), low density mudflow that has not been wetted since deposition (Mathewson, 1981). Other geologic conditions may also be associated with soil collapse, and other sites within the state have collapsing soil (Lovelace and others, 1982). Measures to stabilize soil collapse include sub-excavation, installation of deep footings, moisture and drainage control, water-line maintenance, water flooding, deep plowing and wetting, chemical injection, vibroflotation, and dynamic compaction (Lovelace and others, 1982).

Rock

Few engineering-geology problems have been reported for the rock units west of Socorro. A minor problem affecting some utility lines is creep of ancient landslide blocks in the Socorro Mountains (fig. 1). Other problems which may be expected in the mountainous area are rock falls, topples, or slides which could be triggered by seismicity, man-made explosions, or heavy rainfall.

CONSTRUCTION MATERIALS

Adobe

Adobe brocks are among the oldest building materials used in New Mexico. The term adobe was applied originally to a clayey sun-baked brick and later to the source material constituting the brick. The most suitable source materials for adobe come from stream channels, floodplains, terraces, and alluvial fans. The majority of these deposits consist of fine-grained calcareous, clayey material.

There are no large commercial producers in the Socorro area but some individuals make and sell traditionally handcrafted adobe brick. The simple process involves mixing soil, water, and sometimes straw in a shallow mud pit using a hoe or by foot treading. The mixed material is placed into wooden forms, the top smoothed off, and the form then removed. After two to three days of drying the bricks are turned on edge and trimmed (Smith, 1982).

Aggregate

High quality aggregate is plentiful in the Socorro area. The majority comes from numerous pits in alluvial fans and terraces along major highway routes (New Mexico State Highway Department, 1964). Suitable aggregate can also be obtained from mill tailings and many of the larger arroyos. Most is utilized for highway construction and some is used for housing construction. Little aggregate has been utilized in cement mixtures. West of the Rio Grande, the coarse-grained alluvium consists primarily of igenous material derived from the Socorro Mountains. These silica-rich materials are excellent sources of aggregate for highway construction but they may be alkali reactive in cement mixtures. Alkali reactive components may require special low-alkali cements or pozzolan additives. East of the Rio Grande, most of the fine-grained, pinkish-red sand is derived from the sandstone of the Abo Formation. The coarse-grained limestone clasts are primarily angular fragments derived from the San Andres Formation. Use of these materials is limited by prohibitive transport distances in comparison to abundant aggregate sources on the west side of the river.

Perlite

Perlite is mined in the Socorro area from the southeastern flank of the Socorro Mountains, 5 km southwest of town. Most perlite is used as aggregate in plaster, but some is also utilized in lightweight concrete. It has a variety of other uses also, including loose-fill insulation, filtration, soil conditioner, paint filler, oil-well drilling muds, and inert packing material (Bates, 1969). As summarized by Weber and Austin (1982), the occurrence has the form and structure of a volcanic dome consisting mostly of gray- to yellowish-gray perlite with concentric flow banding. The body is a late element in a series of domes of the Socorro Mountains emplaced approximately 7.4 m.y. ago (Chamberlin, 1980)

GROUND WATER RESOURCES

Ground water in the Socorro area is contained within two principal aquifers. These are the floodplain aquifers which flank the Rio Grande and the Sierra Ladrones Formation (upper Santa Fe Group) which underlies alluvial fans on both sides of the Rio Grande. The ground water within these aquifers, with the addition of water from three thermal springs, furnishes an adequate supply for the Socorro municipal water system (fig. 1).

NATURAL HAZARDS POTENTIAL

Natural hazards in the Socorro area include recent occurrences of flooding and seismicity, as well as historic and prehistoric earth fissuring, volcanism, and landsliding. A discussion of liquifaction is also given because of favorable local geologic conditions.

Seismicity

Seismicity in New Mexico is generally concentrated along the Rio Grande rift (Sanford, 1963; Northrop, 1976). The Socorro area has experienced significant seismicity, especially in the early part of this

Figure 2. Damage to the old Socorro Courthouse and the Masonic Hall caused by the November 15, 1906 earthquake. Joseph E. Smith photo, November 1906, New Mexico Bureau of Mines and Mineral Resources collection. Courtesy of Edward Smith.

century (Sanford and others, 1982). The estimated Richter magnitude 6.0 shock of July 16, 1906, and others on July 12 and November 15, 1906 (fig. 2), were the strongest seismic events to occur in New Mexico during the past 100 years (Sanford and others, 1972). With the majority of New Mexico's population now centered along the Rio Grande rift, seismicity poses a distinct threat to developed areas.

The seismicity pattern since 1960 appears to differ considerably from that of the previous years (Sanford and others, 1972). Most of the earthquakes during this period originated in the northeast quadrant of the state, implying this region also has a seismic risk. The very short historic seismicity record in New Mexico should be used with caution in estimating future seismicity. The late Quaternary history is a far more valuable tool in estimating seismicity of any region and the abundance of late Quaternary to early Holocene fault scarps (Machette, 1978; Machette and McGimsey, 1983) is perhaps the best indicator of seismic hazard.

Volcanism

In general, volcanic hazards are divisible into proximal and distal sources. Both may produce lava, hot avalanches, mudflows, floods, volcanic ash, and gases, although the main hazard posed by distal volcanism is influx of volcanic ash.

Several small intrusive magma bodies recently identified by Sanford (this guidebook; *in* Chapin and others, 1978) imply a potential for proximal volcanism. Five shallow, dike-like magma bodies distributed along a NE-trending shear zone exist at a depth of five to 18 km and overlie a deeper sill-like body. Past magmatism may have been influenced by the shear zone because numerous vents and cauldrons are clustered along it. The age of the volcanic rocks along this zone ranges from four to 33 m.y.

With these documented shallow magma bodies in a structural setting associated with loci of past volcanism, the likelihood of renewed volcanism warrants some consideration. Unfortunately, techniques presently available do not give adequate knowledge of fundamental factors such as magma composition, volume, or pressure and temperature conditions.

The potential for renewed volcanism in the Socorro area is appreciable, but relatively unknown in a quantitative sense. Volcanism has not occurred in New Mexico during historic time. A recent U.S. Geological Survey report (Bailey and others, 1983) identifies Socorro as an area of concern relative to potential volcanic eruptions. Renewed proximal volcanism could range from quiet eruptions of basalt to very explosive eruptions, such as those that produced the welded tuffs in the area. Holocene basalt flows, approximately 1200 years old near Carrizozo, New Mexico, may have disrupted Indian dwellings, not only by lava, but also from ash and gas contamination of the air. Similar eruptions west of Socorro could have the same effect on the present-day inhabitants.

Bailey and others (1983), list Socorro in a group of volcanic sites that last erupted more than 10,000 yrs ago but are known to overlie large magma chambers (see Sanford, this guidebook). This group also includes Yellowstone caldera (Wyoming), Long Valley caldera (California), Clear Lake volcanoes (California), Coso volcanoes (California), and the San Francisco Peaks (Arizona). Three sites in this group—Yellowstone, Long Valley, and Socorro—have well-documented seismic activity (Sanford and others, this guidebook), high heat flow, and modern uplift (Larsen and Reilinger, this guidebook).

Explosive volcanism from distal sources would produce ash which could be carried into the area by winds. Several well-known ash beds originating in this manner occur in central New Mexico. Ash from 6,600-year-old eruptions of Mt. Mazama (Crater Lake, Oregon) is widely distributed over western North America and ash from the 1.58- to 1.23-m.y.-old Cerro Toledo eruptions in the Jemez Mountains area of New Mexico occurs at two localities near Socorro (Izett and others, 1981). Other ash layers also occur nearby. Renewed volcanism from potentially explosive sources, such as Yellowstone, Long Valley or the San Francisco Peaks, could cover parts of New Mexico with several centimeters of ash.

Flooding

The potential for flooding exists mainly along major arroyos, the upstream sides of levees, roads, and railroad embankments (fig. 1). The city is protected on the west by an 8-km-long earthfill dike. Other dikes divert water away from Socorro Municipal Airport and Socorro Canyon (fig. 1). Prior to their construction, water would periodically flow down major arroyos through town, causing considerable damage (Socorro Chieftain, 1897). A diversion dam at San Acacia directs water to the Socorro main and conveyance canals, helping to reduce the flooding of low-lying areas of Socorro. These hydraulic works of the U.S. Bureau of Reclamation and the Middle Rio Grande Conservancy District allow only the peak flows through the main river channel. Prior to the formation of the conservancy district, irrigated valley lands were becoming increasingly waterlogged, and spring runoffs presented an annual threat (Nanninga, 1982). Individual communities had their own acequias for irrigation, but few had a measurable degree of flood control other than shored levees or drains to prevent waterlogging.

The Conservancy District was formed in 1925 to address the dual problem of flooding and waterlogging of lands along the Rio Grande. The District constructed the principal system of levees, drains, and irrigation ditches between 1930 and 1935. The U.S. Bureau of Reclamation later rehabilitated, expanded, and improved the system to the point where waterlogging has been eliminated, and irrigation and farming have become widespread (Kelley, 1982). The measures needed to control the Rio Grande were not possible to implement totally and in 1941, major flooding broke levees in numerous places causing widespread inuandation of lands in the Socorro area (fig. 3). Since then, attempts to improve the levees and maintain a clear channel have reduced the danger of flooding upstream in the Albuquerque area (Kelley, 1982). However, the system has not recently been fully tested and low-lying areas of downstream cities, such as Socorro, remain threatened by destructive Rio Grande floods.

Earth Fissures

Because groundwater pumping takes place in the area, potential for ground subsidence exists. Elsewhere in the southwest, groundwater pumping has led to significant ground subsidence and earth fissuring. These problems are prevalent in central Arizona and have recently been reported in Deming, New Mexico (J. Hawley, 1983, oral commun.).

The San Marcial Crack is an earth fissure approximately one kilo-

Figure 3. Oblique aerial view looking southwest toward the Socorro and Chupadera Mountains showing the Rio Grande flood of May 26, 1941. The Rio Grande main conveyance channel just south of San Acacia is in the left foreground. Photo courtesy of Stafford C. Happ, U.S. Department of Agriculture, Soil Conservation Service.

meter long trending NW-SE in Quaternary-Tertiary alluvium about 40 km south of Socorro. It has prompted the New Mexico State Highway Department to reinforce a section of 1-25 where it crosses the fissure (W. Bennett, 1983, oral commun.). The cause of this fissure in an area of no significant groundwater pumping is not known, but it is being studied at New Mexico Institute of Mining and Technology. Because of its unknown origin, it is not possible to determine if similar fissuring may occur in the Socorro area.

Liquifaction

Earthquake-induced liquifaction has caused major damage to buildings, earth embankments, and retaining structures in the western United States, Japan, and Alaska. The phenomenon of liquifaction has not been reported in the Socorro area, but local geologic conditions favor its occurrence. Loose, saturated, medium- to fine-grained sand tends to compact and decrease in volume when subjected to ground-shaking. If drainage cannot occur, the pore-water pressure increases. As ground-shaking continues, pore pressure increases until it exceeds overburden pressure and the effective stress decreases to zero. At this point, the soil no longer has any shear strength and enters a liquified state. The floodplain sediments in the Socorro area are particularly susceptible to liquifaction because of their well-sorted nature, lack of cohesion, the shallow water table, and the local seismic risk.

EARTHQUAKE ENGINEERING CONSIDERATIONS

The level of seismic risk and associated ground-shaking characteristics are extremely difficult to quantify. Most detailed studies of risk have been conducted in areas to be developed for dams, nuclear power plants, and nuclear-waste repositories. For these relatively few localities, the potential for earthquake occurrence and the associated ground-shaking characteristics are reasonably well known. Using techniques developed for critical-facility siting, historic seismicity, and local and regional geologic relationships, the following discussion considers expected ground-shaking characteristics that would be encountered during an earthquake of Richter magnitude 6.0.

It is convenient to study the acceleration of the ground, expressed in terms of the acceleration of gravity at the earth's surface (g), which can be measured directly from accelerograph records. The peak acceleration is widely used to specify the ground motion a structure should be able to withstand. The acceleration decreases with the distance from the fault, both because the seismic waves spread out as they propagate from the source and because the energy is attenuated by the inelasticity of the materials through which they propagate. Measured acceleration and horizontal-velocity data were statistically compiled for the area by Algermissen and others (1982).

Using very conservative Socorro-area values of 0.05 g as the probable horizontal acceleration (Algermissen and others, 1982), and magnitude 6.0 as the maximum probable earthquake in a 100-year period (Sanford and others, 1972), the length of surface rupture that can be expected in the Socorro area is about 6.5 km (Haley and Hunt, 1974). Nearby, late Pleistocene to Holocene faults with surface ruptures of 10 km or more indicate this estimate is conservative (Machette and McGimsey, 1983; P. Kuzushko, 1983, unpub.). Seed and lndress (1969) relate the distance from causative faults to predominant periods of shaking, indicating a shaking period of 0.25 to 0.30 seconds for faults within 40 km. Similarly, for estimates of the duration of strong motion for a magnitude 6.0 earthquake, Lee and Chan (1973) report 15 seconds. Useful earthquake probability estimates over a given time period can be made by assuming a Poisson distribution of seismicity where events occur randomly in space and time. A Poisson distribution is commonly assumed in earthquake and volcanic probability assessments (Haley and Hunt, 1974; Johnpeer and others, 1981) and is deemed applicable to the Socorro area, even though seismicity may not be totally random. The Poisson probability (P) that at least one event (magnitude 6.0) will occur in a period of time (t) is given by the equation $P = 1 - \exp(-Xt)$ where X is the average annual rate of earthquakes of magnitude 6.0. Note that the reciprocal of X is the average return period; in this case one magnitude 6.0 earthquake per 100 years. Solving this equation for P, using a value of 0.01 as X, gives the following probabilities of a magnitude 6.0 earthquake in the Socorro area:

Time Interval (years)	Calculated Probability (percent)
10	9
25	22
50	39
75	53
100	63

It is instructive to note that probability of a magnitude 6.0 earthquake during the approximate life expectancy of a typical structure is not negligible.

Estimated ground-shaking characteristics such as rupture length, horizontal acceleration, predominant period of shaking, duration of strong motion, and probability provide insight into the conditions which would exist given a magnitude 6.0 earthquake in Socorro. While the techniques and procedures utilized in making these first approximations are still in infancy, they can be used with geologic and engineering judgment as tools for estimating building performance. Such estimates are useful as reference guidelines in building design.

LOCAL EXPLORATION AND TESTING METHODS

Exploration and testing methods to investigate building sites include limited surface mapping, trenching, drilling, representative sampling, and field and laboratory testing. In most cases, site-exploration programs are conducted by local geotechnical firms having familiarity with surrounding soil characteristics. For structures requiring more detailed soil testing, the exploration program is conducted wholly or in part by larger, better-equipped firms elsewhere.

Laboratory capabilities of local firms are limited to common soil-engineering tests, such as Atterberg limits, grain-size distribution, dry unit weight, moisture content, and soil classification. Selected laboratories at New Mexico Institute of Mining and Technology have testing equipment utilized for teaching and research.

The use of subsurface sampling tools is limited so most routine exploration programs are designed around the use of grab samples obtained from auger borings or backhoe trenches. Such samples are suitable only for the more common tests listed above. Split spoon samplers, Shelby tubes, and drive-cone penetrometers were utilized in the foundation exploration of some of the larger local structures.

SUMMARY

The silts, sands, and clays of the floodplain are the materials on which approximately one-half of the City of Socorro is situated. These poorly-cohesive materials, combined with shallow, fluctuating groundwater conditions, contribute to foundation instability and drainage problems and are highly susceptible to liquifaction during seismic shaking. The alluvial fans bordering the floodplain cause fewer engineering problems because of their coarse, well-graded consistency and drainage characteristics. In places, caliche development prevents water infiltration and contributes to flash-flood potential at lower elevations. Mudflow deposits may be susceptible to collapse when wetted, causing foundation instability.

Few engineering geology problems have been reported for the rock outcrops west of Socorro. Locally, landslide blocks undergo creep, causing disruption of utility lines. Potential exists for rock fall or slope failure in response to earthquakes or explosions.

Surficial deposits are utilized locally for a variety of construction purposes with many of the finer-grained, clay-rich floodplain deposits being used in adobe brick. The coarser sediments are used as aggregate in road and foundation fill. Aggregate is now obtained from alluvial deposits on the west bank of the river and perlite is mined on the southeastern flank of the Socorro Mountains.

Ground water occurs both in the floodplain units of the Rio Grande and in the Sierra Ladrones Formation. Depth to water in the floodplain is approximately 3 to 15 m and in the Sierra Ladrones Formation the depth to water ranges from 10 to more than 50 m below the surface. Socorro obtains a year-round supply of water from the constant flow of three springs issuing from bedrock at the base of the Socorro Mountains, and from five wells drilled through the alluvial-fan gravels into axial-river sands of the Sierra Ladrones Formation. Chemical analyses indicate reasonably constant, acceptable quality for these sources.

Socorro has historically experienced moderate seismicity levels with estimated Richter magnitudes as high as 6.0. Since 1906 activity has been infrequent and moderate.

The volcanic hazard for Socorro is appreciable. Several small, shallow intrusive bodies imply a potential for proximal volcanism.

Potential for flooding of areas within the city exists, mainly along major arroyos and upstream slopes of levees, roads, and railroad embankments. A diversion dam at San Acacia reduces the risk of flooding on the east side of town, but low-lying areas remain at some risk of inundation.

Subsidence and earth fissures caused by groundwater withdrawal have recently been reported near Deming, New Mexico. Groundwater pumping and the San Marcial crack (of unknown origin) indicate a potential for fissures in the Socorro area.

Most geotechnical investigations in the area consist of routine soil borings, trenching, and standard soil-engineering tests. Geotechnical investigation and appropriate foundation design can accommodate the local unstable soil conditions.

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