Engineering Geologic Practices On The Western Slope

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Introduction

Engineering geology is the application of geologic data, techniques and principles to the design, construction, operation and maintenance of engineered works so that geologic factors are recognized and considered. Because of the mountainous terrain and complex geology in western Colorado, engineering geology has an important role in most engineering projects. The engineering geologist works closely with civil /geotechnical engineers, but also provides geologic information and recommendations to land use planners, environmental specialists, architects, public policy makers, and property owners. In western Colorado engineering geologic studies are usually conducted in conjunction with geotechnical engineering evaluations of most major facilities which include:

- Commercial, Residential, and Recreational Developments
- Highway and Transportation Facilities
- Pipelines and Power Transmission Lines
- Dams and Reservoirs
- Waste Disposal Facilities
- Mines and Mine Reclamations Projects

It is the responsibility of the engineering geologist to identify and evaluate geologic factors important to engineering analysis and design. Geologic factors which are commonly of concern in the western Colorado are:

- Landslides
- Debris Flows
- Rock Fall
- Snow Avalanche
- Collapsing Soils
- The Eagle Valley Evaporite
- Earthquakes

Landslides

Landslides are a major component of mass wasting of the continents. In terms of geologic time, landslides tend to produce a stable landscape, but in the short term landslides can be a significant concern to engineered works. Much of western Colorado is classified as having a moderate to high potential for landsliding and numerous landslide deposits are present (Wiggins and Others, 1978). The landslides vary from less than one acre to several square miles in extent and include a variety of types. The smaller landslides are predominantly rotational slumps. The larger landslides are usually earthflows and dip-slope complexes.

The identification of landslides should be part of engineering geologic studies in most areas on the western slope. Landslides can be identified by their geologic settings and topographic features based on field observations, aerial photograph interpretations and topographic map interpretations. Features indicative of landslides are arch-shaped escarpments, ground cracks, ground hummocks, hillside benches, hillside ponds and disrupted drainages. Some western slope landslides have had large displacements in historic time and are still near a critical stability state. Others appear to have been dormant for a long time and may no longer be near a critical stability state. Landslide features are well defined on recently active landslides, but with time they become subdued because of surface weathering and erosion on long dormant landslides. A method for estimating how long a landslide has been dormant based on surface features has been proposed by McCalpin (1984) for landslide inventory mapping. It is advisable that apparent age of landslide dormancy not be solely relied on when assessing the current stability state of a landslide. For many landslides, this judgement should also include subsurface exploration, slope movement and ground water monitoring and stability modeling.

Precipitation and associated ground water changes can have an important influence on landslide stability in western Colorado. Landslide activity in the area is reported to have increased during the period 1983-1987 as a result of higher than normal annual precipitation (Jochim and Others, 1988). Cyclic precipitation change has apparently occurred in this area during the past 500 years. Tree ring studies in the upper Colorado River drainage basin show that since the early 1500's wet cycles with an average duration of 10 years have occurred about every 22 years (Brubaker and Cook, 1983). Long-term monitoring of a steep, colluvial slope in western Colorado shows a correlation between winter precipitation (November through May) and annual slope creep. Most of the creep occurs during the spring snowpack melt.

Debris Flows

A debris flow is a moving, fluid mass of rock, soil, and debris. Debris flows are an active geologic process on the western slope and historic debris flows have affected several communities. Towns which have experienced historic debris flows include Aspen, Beaver Creek, Chalk Creek, Glenwood Springs, Ouray, Marble, Redstone, Red Cliff, and Vail. In western Colorado debris flows usually start as shallow landslides on colluvial slopes which are steeper than about 50% as a result of intense thunderstorm precipitation or rapid infiltration of snowpack melt. The flows thin and spread laterally on the alluvial fans where the hillside channels join the main valley. The flows have the capacity of transporting very large boulders. When confined in steep, hillside channels flow depth can reach 20 feet or more. Flow depths on the fans are typically in the range of 2 to 15 feet with the greater depths near the fan heads. Flow velocities can vary widely depending on flow depth, gradient and water to solids ratios.

Velocities in the range of 1 to 30 mph are typical of debris flows (Campbell, 1975). Flow velocity estimates for the July 27, 1977 Glenwood Springs debris flows were between 5 and 17 mph (Mears, 1977).

Engineering geologic studies in western Colorado should consider the debris flow potential on geologically young alluvial fans with steep drainage basins or on young alluvial fans where there is evidence of recent debris flow deposits. Geologically young fans are usually characterized by shallow, poorly defined channel systems. Old alluvial fans, which are no longer the sites of debris flow deposition, typically have a single, well defined channel for the entire fan length. When assessing debris flow hazards on apparently old fans, the likelihood of deposition and channel overflow should be considered, if the drainage basin is large. In addition to debris flows on alluvial fans, debris flows should also be considered on colluvial apron directly below small, first-order drainages on steep hillsides.

Rockfall

Rockfall is the precipitous movement of newly detached rock blocks from a cliff or other very steep slope. In western Colorado rockfall is common on many highway cuts in jointed rock. Rockfall also occurs along cliffs which border many of the mountain valleys. In a few areas rockfall blocks have reached down slope developments and transportation corridors. Notable areas of historic rockfall are the Booth Creek area in east Vail and along Interstate Highway 70 in Glenwood Canyon. Rockfall can occur any time of the year, but it is most frequent in the spring when there is a repeated freezing and thawing of water in the rock joints. After dislodging from the outcrop, the rockfall blocks travel rapidly down slope generally in a relatively straight line by a series of leaps and bounces. Individual rockfall blocks can vary from less than one foot to ten's of feet in size depending on the joint spacing at the outcrop. Bounce heights and velocities are relatively high in the upper and middle part of the rockfall path. Velocities and bounce heights only substantially decrease near the end of the runout. Rockfall simulation modeling for rockfall mitigation in Glenwood Canyon indicated that a one ton rock block is expected to have maximum velocities between 30 and 50 mph and maximum bounce heights between 1 and 14 feet in the upper part of the rockfall path (Pfeiffer and Bowen, 1989). Bounce heights were less than 1 foot in the lower part of the path and velocities decreased to about 20 mph.

Engineering geology studies in western Colorado should consider the rockfall potential at all sites where jointed rock cliffs are located above the site. If rockfall has been frequent there should be several rocks block at the ground surface on the lower hillside down slope of the cliff. Cliff outcrops should be observed to determine if there are potentially unstable rock blocks even if there are no rockfall blocks below the cliff. Estimates of future rockfall block size can be based on the size of past rockfall and joint spacing at the outcrop. It is important to estimate the runout of past rockfall for use in calibrating the rockfall simulation models for site specific conditions.

Snow Avalanche

Numerous snow avalanches occur each season in the high mountains of western Colorado, but most are located in remote mountain areas and only present a threat to backcountry travelers. Some are located along transportation corridors where controlled, artificial avalanche release is feasible. Of engineering concern is where occupied facilities are planned or exist in potential avalanche paths. The Colorado Geological Survey has published avalanche hazard zone maps for some, but not all, avalanche areas in western Colorado (Mears, 1979).

The identification of potential snow avalanche paths should be part of engineering geologic studies in western Colorado with steep mountain slopes above an elevation of about 8,000 feet. The identification of avalanche paths usually includes topographic map analysis, aerial photograph interpretation, field observation and, if available, review of written histories, newspapers and museum records (Mears, 1992). The avalanche path consists of a start zone with an average slope of 60% to 120%, a track where slopes are usually between 30% and 60% and a runout zone where slopes are less than 30%. For many large Colorado avalanche paths the start zone is typically above timberline, the track in timber, and the runout may be below timber in grass and brush. In these cases a well-defined swath is usually present in the timber. Vegetation in forested avalanche tracks can be used as an avalanche-frequency indicator (Mears, 1992). In non-forested areas avalanche tracks are difficult to identify.

Collapsing Soils

Much of the colluvium, loess, and alluvial fans along the Colorado, Eagle, and Roaring Fork River Valleys below an elevation of about 8,000 feet can have a collapse potential. The collapse susceptible soil has a low field moisture content and a low plasticity index. The plasticity index average about 6%. At the low field moisture content the soil experiences little settlement under the light foundation loads typical of residential and small commercial buildings. If soil moisture content increases substantially after construction, the soils can collapse resulting in relatively large differential foundation settlement and structural damage. Increases in soil moisture causing soil collapse in western Colorado have been related to landscape irrigation, poor surface drainage, and leakage from ponds, water lines and sewer lines.

The collapse potential severity for soils in western Colorado is usually evaluated by the one-dimensional consolidation test (Mock and Pawlak, 1983). If the test shows a collapse of less than 1% under a load of 1,000 psf after wetting the soil is considered non-collapsible. The collapse potential is considered low for 1% to 3% collapse, moderate for 3% to 5% collapse, and high for greater than 5% collapse. In site evaluations, other factors besides the collapse potential severity should be considered. Foundation settlements also depend on the thickness of the collapsible soils and the extent of wetting. In the Glenwood Springs area, problems at most sites have been minor where consolidation tests indicate a low collapse potential. Foundation movement, when it has occurred, has not required extensive repairs and the problems are generally tolerated by most home owners without repairs. Locally, relatively large settlements have occurred. The most severe collapse and structural distress has been in areas where the soil is greater than 20 feet deep and has a moderate to high collapse potential. In these areas, differential foundation settlements in the range of 9 to 12 inches has occurred when water line breaks resulted in deep wetting. In areas where the soil is less than 10 feet deep and has a moderate to high collapse potential foundation settlements have generally not exceeded 4 inches.

Eagle Valley Evaporite

The Eagle Valley Evaporite presents unusual engineering considerations because of the soluble and plastic evaporite in the formation. The Eagle Valley Evaporite is of limited regional extent, but is present in parts of Eagle, Garfield, Rio Blanco, Moffat, and Routt Counties. The evaporite is predominantly gypsum and anhydrite with appreciable halite and traces of potash salts (Mallory, 1971). The evaporite is interbedded with sandstone, siltstone, and carbonate rocks. Sinkholes and subsidence depressions are locally present in many areas where the Eagle Valley Evaporite is at or near the surface. In some areas along the larger river valleys regional deformation is probably an ongoing geologic process. The regional deformation is apparently related to upwelling, diapiric intrusion, and lateral evaporite flow along the larger river valleys (Mallory, 1971). In the Roaring Fork Valley south of Glenwood Springs, the regional deformation is indicated by faulted basalt flows which are about 8 and 22 million years old and by tilted and faulted Pleistocene terraces and deposits (Stover, 1986; and Kirkham and Others, 1995).

The presence of sinkholes and subsidence depressions should be identified by engineering geologic studies in areas where the Eagle Valley Evaporite is at or near the surface. Sinkholes and subsidence depressions can be identified by field observations, aerial photograph interpretations, and sometimes on topographic maps when detailed maps are available. Occasionally, shallow subsurface cavities have been encountered in borings and excavations at sites where there is no surface indication of a sinkhole. Therefore it is important that site-specific foundation studies include a detailed subsurface exploration program in areas where sinkholes may be present. The sinkholes apparently result from piping or upward caving of the overburden rock and soils into subsurface solution cavities in the Eagle Valley Evaporite. The subsidence depressions are apparently related to gradual ground subsidence by the slow solution of evaporite over a broad area in the subsurface. The sinkholes are typically circular and 10 to 50 feet in diameter with depths between 2 to 10 feet. The subsidence depressions are considerably larger and have areas which range from several acres to several hundreds of acres. Many sinkholes occur in areas which have been flood irrigated, but sinkholes are also present in non-irrigated settings.

The regional deformation along the larger river valleys is apparently occurring very slowly at a rate which is nearly the same as regional erosion rates The regional deformations do not appear to be a concern to engineered works. An exception may be where the regional deformations are localized along geologically young faults. Engineering geologic studies in areas underlain by the Eagle Valley Evaporite should identify geologically young faults and evaluate if the faults should be considered in project design.

Earthquakes

Over 200 earthquakes have been felt or instrumentally recorded in western Colorado since 1867 (Kirkham and Rogers, 1985). Most have been small and have maximum Modified Mercalli Intensities of less than V. The largest historic earthquake was probably located in the northern Front Range to the west of Fort Collins. This earthquake occurred on November 8, 1882 and produced a maximum intensity of VII. Nine other moderate size earthquakes which produced maximum intensities of VI have been located in the western part of the state. When the intensity data from all historic earthquakes in Colorado and adjacent states is combined, intensity distributions show that most of western Colorado has experienced maximum intensities of V-VI (Kirkham and Rogers, 1985). There does not appear to be a good association between the distribution of historic seismicity and geologically young faults and structures.

Earthquake related surface fault rupture has not occurred in Colorado during historic time. Well documented evidence of geologically young surface fault rupture is present along the Sangre de Cristo fault and Sawatch fault (Coleman, 1986; and McCalpin 1986). These faults are in the northern part of the Rio Grand rift which extends from New Mexico into the San Luis and upper Arkansas Valleys of Colorado. Fault displacements in this part of the rift occurred in the Holocene and late Pleistocene. Detailed fault scarp profile and trench studies suggest that magnitude M_L 7.0 to 7.3 earthquakes occur along the Sangre de Cristo fault zone every 10,000 to 40,000 years (McCalpin, 1986). Probable Quaternary faulting appears to extend north of the rift in the upper Arkansas Valley into the Blue River Valley (Kirkham and Rogers, 1981). Studies have also documented Quaternary faults in South Park (Shaffer and Willamson, 1986) and in places along the eastern side of the Front Range (Dickson and Others, 1986).

Crustal deformations of the Uncompagre uplift in western Colorado may have continued into the Pleistocene. Quaternary faults are suspected to be present along its northeast and southwest flanks (Kirkham and Rogers, 1981). The uplift is bounded on the south by the Ridgway Fault which is a Quaternary fault which has micro-seismicity (Sullivan and Others, 1980).

Geologically young faults are also present along the collapsed salt anticlines in the Paradox Valley region of southwestern Colorado (Kirkham and Rogers, 1981). Flow deformations may still be active in the region and the faults may be experiencing slow creep displacements. Similar geologically young faults are associated with the Eagle Valley Evaporite.

The historic seismic record and Quaternary geology show that moderately strong earthquake-related ground shaking should be expected in most parts of western Colorado. Modified Mercalli Intensities of V to VI are likely during the service life of most facilities, but the probability of stronger ground shaking is low except in the vicinity of the Rio Grand rift. The potential for earthquake related surface fault rupture outside of the Rio Grand rift is low. It should be appropriate to design most facilities in the region to withstand moderately strong ground shaking with little or no damage and not to collapse under stronger ground shaking. Critical facilities such as large dams may require more conservative design criteria depending on their locations.

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