Evaluation, Design and Mitigation of Project Sites in Collapsible Soil Areas in Western Colorado

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Collapsible Soil Properties

Collapsible soils occur as naturally relatively dry alluvial fans, colluvium and wind-blown deposits. These soils are typically silt and sand size with a small amount of clay. Debris fan deposits usually contain from small to large amounts of gravel to boulder size rock fragments that are suspended in the finer-grained collapsible matrix. Collapsible soils show relatively high apparent strength (cohesion) in their dry state, but have a low density, porous structure and are susceptible to large settlements upon wetting. The severity of the collapse depends on the extent of wetting, depth of the deposit and loading from the overburden weight and structure. The wetting sources typically consist of landscape irrigation, poor surface drainage resulting in ponding, utility line leakage, and intentional ponding such as detention basins and water features.

Evaluation of Collapse Potential

The potential for collapsible soils at a specific project site is initially evaluated based on the geologic and environmental setting, and our experience in the area. This includes topographic and geologic maps that identify surficial deposits, their relative age, and potential geologic constraints. The subsurface conditions are then evaluated by exploration such as with power auger borings, backhoe pits and open excavations. Borings are usually preferred because they can extend to depths sufficient to define the depth of the collapsible soil deposits and they are less disruptive than backhoe pits.

Soil sampling typically consists of driving a "thick walled" sampler such as the 1 3/8 inch I.D. Split Spoon Sampler (ASTM Method D-1586) or the 2 inch I.D. California Sampler into the natural subsoils. The California Sampler contains 4 inch long liners which accept the soil "core" as it is driven into the subsoils. This is typically referred to as a relatively undisturbed sample. The liner sample is then sealed for later classification and laboratory testing. In backhoe pits and open excavations, the 2 inch diameter liners themselves are typically hand-driven into the exposed soils. This is similar to a "thin walled" sampler and can result in less disruption of the soil compared to the thick walled sampler.

Laboratory testing is performed on the samples to evaluate their compression potential and other physical properties. The compression test consists of extruding the liner sample into the apparatus confining ring, loading it to 1,000 psf, flooding the sample and additional loading. An example of a typical stress-strain curve obtained by the test is shown on Fig. 1. The collapse potential is defined as the change in sample height (h) upon wetting compared to the original sample height (Ho). The magnitude of collapse potential is usually rated as low, moderate or high. Other physical properties testing typically consists of natural moisture content and density, gradation, and liquid and plastic (Atterberg) limits. It has been demonstrated that the collapse potential of the soil depends on the composition, gradation, the initial water content and density, and the loading at the time of wetting. A relationship of density, percent finer than the No. 200 sieve (silt and clay content) and collapse potential is shown on Fig. 2.

The severity of settlement and impact to structures which can result from collapse of the subsoils depends on several conditions. These include:

- Collapse potential of the subsoils
- Depth of the collapsible soils
- Foundation loading, configuration and depth
- Sensitivity of structure to differential settlement
- Site grading and drainage

The collapse potential and depth of the problem soil are physical constraints for a given site. The foundation conditions, structure stiffness and other site improvements are design development considerations and are more controllable.

Predicting settlements due to collapsible soils is difficult due to several factors including sample disturbance problems, variability of the subsoils, extent of wetting and variable loading conditions. Settlement estimates are generally made by taking the collapse potential over the potential depth of wetting. This typically includes loading from the structure and from overburden weight. Settlements due to structure loading generally govern, since wetting usually occurs at shallow depth where the foundation loading stresses are the highest. The settlements typically occur along the perimeter of the structure and are differential. Relatively severe settlements and building distress have been experienced where the collapsible soil depth is greater than about 20 feet. Settlements up to about one foot and severe structural distress have been documented. In shallower collapsible soil areas, settlements typically do not exceed a few inches.

Design and Mitigation

The identification of the soil collapse and severity of settlement potential is the initial information needed for the mitigation design. The feasibility of possible mitigation methods at a given project site depend on the structure conditions and the level of risk that the project owner is willing to accept. More options will generally be available to new construction compared to existing structures where there are constraints to mitigation options. Some settlement and building distress is usually acceptable to owners of lightly loaded structures such as residences, especially when the risks are known to be common to the area. Less risk is usually acceptable where there are heavily loaded or settlement-sensitive structures where the consequences of distress warrant more effective mitigation measures. Mitigation methods can be divided into the following groups:

- Structure considerations
- Site features
- Collapsible soil avoidance
- Ground modification

Structure Considerations: Lightly loaded structures such as residences are usually supported on shallow spread footings. The footings should be lightly loaded with a bearing pressure of 1,000 psf or less. The building loads should be carried mainly by heavily reinforced foundation walls in a "box-like" configuration. The foundation design should limit excess surcharge loading from deep backfills placed against foundation walls. Stiffened slabs or mat foundations could be used to further reduce differential settlement potential.

Site Features: Subsurface wetting from shallow sources can severely impact structures founded on shallow foundations. The foundation backfill should be adequately compacted and have positive surface drainage to prevent ponding. Gutters should be provided with drain downspouts that discharge away from the building. Landscape irrigation should be restricted and, in some cases, essentially eliminated by the use of xeriscape. Basement foundation drains should be underlain with an impervious liner to prevent water seepage below the foundation. On-site detention basins or water features should be lined with an impervious membrane.

Avoid Collapsible Soils: When the collapsible soils are shallow, they can be removed for bearing on the underlying soils or replaced and compacted to re-establish design bearing levels. Piles or piers can be used to extend the bearing level to below the collapsible soils. This alternative is typically considered where the structure is relatively heavy or settlement-sensitive and the depth to adequate bearing material is economically feasible.

Ground Modification: Various ground modification methods can be used to prevent or limit collapse from occurring, or cause the collapse to occur before construction. These methods include: partial removal and replacement of the collapsible soils compacted; densification of the collapsible soil in-place, such as by compaction grouting or dynamic compaction; and pre-wetting of the collapsible soil followed by surcharge loading to cause settlement before construction.

Summary

Collapsible soil deposits are commonly found in western Colorado. These areas can be successfully developed with the identification, evaluation and appropriate mitigation designs to limit the settlement potential. The selected mitigation usually requires the involvement of the owner and their knowledge and acceptance of some risk of settlement and building distress.

References

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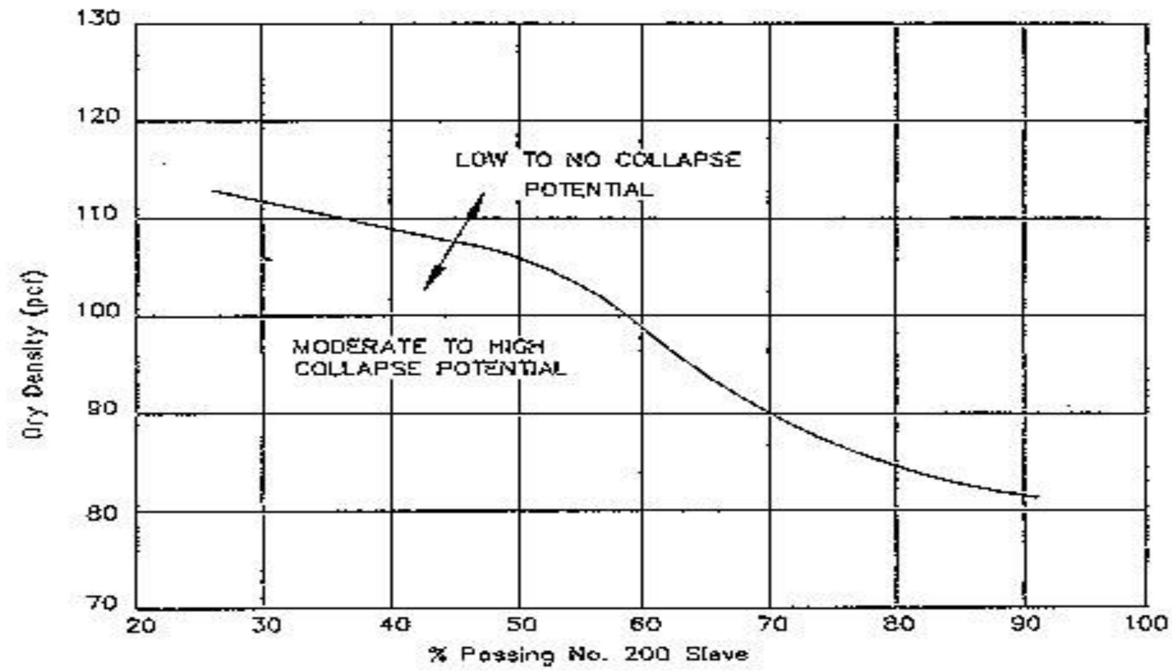

FIG. 2 — RELATIONSHIP BETWEEN DRY DENSITY, % PASSING THE NO. 200 SIEVE AND COLLAPSE POTENTIAL (Mack, R.G. and Pawlak, S.L., 1983).

TYPICAL COMPRESSION CURVE FOR COLLAPSING SOIL - FIGURE 1