Expedient Mitigation of Collapsible Loess in Northern Afghanistan

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ABSTRACT: *The arid climate, low water table and mountainous terrain in northern Afghanistan favor aeolian deposition of deep formations of collapsible loess with low relative density. When the loess deposits become wet, the clay cementing agents are unable to support the overburden pressure, and the soil structure collapses. Loess collapse is causing settlement basins and slope failures that damage facilities, roadways and airfields on military bases in northern Afghanistan. This paper aims to present military engineers with expedient options to identify and mitigate collapsible loess for construction in this region.*

KEYWORDS: loess, collapse, liquid limit, hydrometer, Afghanistan

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INTRODUCTION

At or near saturation, loess soils in northern Afghanistan exhibit high susceptibility for collapse, also referred to as hydroconsolidation or hydrocompaction. The loess possesses the three factors needed to produce collapse in a soil: (1) a loose, unsaturated soil structure; (2) a cementing agent, clay in this case, which stabilizes the soil in an unsaturated condition; and (3) a high enough applied or existing stress component to induce collapse (Barden et al. 1973). When loess becomes wetted so that the cementing agent is unable to support the overburden pressure, and the soil structure collapses. Collapsible soils may safely support loads considerably in excess of the existing overburden pressure, but only so long as they remain dry (Handy 1973).

Settlement basins and slope failures manifesting from loess collapse are causing structural failure to facilities, roadways and airfields on military bases in northern Afghanistan. The military bases are constructed to be expedient because operational requirements dictate temporary construction. Despite the bases' temporary function, military engineers have a responsibility to consider loess collapse in their designs and base master plans because structural failures hamper the military mission and waste resources. This paper aims to present military engineers with expedient options to identify and mitigate collapsible loess for construction in northern Afghanistan.

STATEMENT OF THE PROBLEM

The arid conditions, low water table and mountainous terrain (Hindu Kush Mountains) in northern Afghanistan favor the formation of collapsible loess problematic to military base development. Loess deposits in Balkh, Samangan, Kunduz, Baghlan, Takhar, and Badakhshan provinces in Fig. 1 were created by silt particles blown from the Karakum Desert and the alluvial plains of the Amu Darya river basin (Shroder et al. 2011). The small particles settled out of air-borne suspension, deposited slowly, forming a loose, 'card-house' or 'hay stack' soil structure cemented by clay bonds. Meier et al. (2009) present electron microscope images of undisturbed Mazar-e-Sharif loess that exhibit an open, porous structure with large voids. When dry, loess can be stable and built upon. Dry loess can even sustain nearly vertical slopes, provided it is kept unsaturated. When wetted, loess can instantaneously fail as the clay bonds dissolve or soften causing the 'card-house' matrix to collapse. Besides Afghanistan, collapsible loess has been documented in the other central Asian states, north-central China, Eastern Europe, and Russia (Handy 1973, Rogers et al. 1994).

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Figure 1. Map of Afghanistan highlighting Northern provinces Balkh, Samangan, Kunduz, Baghlan, Takhar, and Badakhshan where collapsible loess is a problem.

The U.S. military and its allies often construct bases on available land in northern Afghanistan valleys with deep loess deposits (greater than 10 m [33 ft]), land that experienced little past residential or agricultural development. The land was never inundated with water from runoff or irrigation to collapse. Construction of military facilities, often without adequate drainage, provides opportunities for spillage and ponding of large amounts of water through runoff.

The magnitude of collapse and resulting damage to infrastructure and facilities is primarily dependent on the amount of wetting. In low lying areas where water pools or flows after heavy rains, soil collapse often manifests itself in settlement basins or slope failure. Settlement basins typically occur near the perimeter of a facility beneath downspouts or on the edge of roads near drainage ditches. The facilities, in turn, experience differential settlement and structural damage, as evidenced by building settlements up to 10 cm (4 in) around Mazar-e-Sharif and Kunduz (Meier et al. 2009, SIGAR 2010). Settlement basins also cause failure to security walls (Fig. 2a-b) and damage roads (Fig. 2c). Slope failures damage the drainage system and render limited real estate unusable (Fig. 2d). Repairing damage wastes valuable resources that could be better utilized elsewhere.

Beyond the financial and manpower expense, collapsible soils can impact the military mission by causing failure to critical military infrastructure. Military airfield pavements have a low tolerance for settlement. For concrete parking aprons and runways, settlement at a joint or crack greater than 25 mm (1 in) is classified as a high severity pavement distress (Departments of the Army and the Air Force 1989). Because of a loess collapse, a concrete parking apron at a military airfield in Northern Afghanistan experienced settlements greater than 50 mm (2 in), forcing military engineers to close the apron.



Figure 2. a. Damaged guardhouse and security wall in Kunduz, b. security wall damaged in Kunduz, c. settlement basin through a road in Kunduz, d. slope failure next to earthen drainage ditch in Mazar-e-Sharif as evidenced by coned off area.

IDENTIFICATION OF COLLAPSIBLE LOESS

Of the methods to identify collapsible soil, two of the most common are the dry density and liquid limit graph (Gibbs and Bara 1962) and the one-dimensional compression test using an oedometer (Lutenegger and Saber 1988). By studying alluvial fan deposits in California with low dry density, Gibbs and Bara (1962) showed that when the saturated moisture content exceeds the liquid limit, the soil will likely collapse. Using this relationship, they developed the dry density versus liquid limit criteria in Fig. 3. The Gibbs and Bara approach is most applicable to clayey sands and sandy clays (NAVFAC 1986), but in the absence of a collapse test, it is a reasonable preliminary assessment for loess soils. Lutenegger and Saber (1988) introduced a collapse test that applies a vertical stress to a laterally confined, undisturbed sample of loess at its natural water content, and then introducing water to the specimen. A decrease in volume at a constant vertical stress is an indication of the collapse potential of the soil.

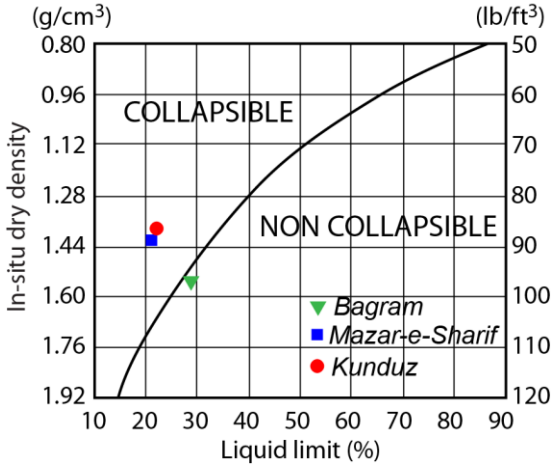


Figure 3. Gibbs and Bara (1962) criteria for determining collapsibility.

When density and liquid limit data are not available, an estimate of loess collapsibility may be made on the basis of clay content. Handy (1973) proposed loess collapse probabilities with the following clay contents: < 20% = high probability of collapse; 20 to 30% = probably collapse; 30 to 40% = less than 50% probability; and > 40% = usually safe from collapse.

Soils from Afghanistan military bases in Kunduz, Mazar-e-Sharif and Bagram were evaluated for collapse using Gibbs and Bara's criteria and Handy's criteria. Sand cone tests were conducted and disturbed soil samples were collected at a depth of 0.5 m (20 in). Three sand cone tests and three samples were obtained from Kunduz and two sand cone tests and two samples each were obtained from Mazar-e-Sharif and Bagram. An average of the soil properties are given in Table 1 and an average of the particle size distributions in Fig. 4, where fine content less than 0.075 mm was determined using a hydrometer apparatus (ASTM 2007). The Kunduz and Mazar-e-Sharif soil exhibit a uniform distribution with particles concentrated in the range 0.01 to 0.06 mm, indicating the soils are loessial and will not compact well. On the contrary, the Bagram soil exhibits a more well-graded distribution, indicating the soil is not loessial and has higher potential for compaction. According to Gibbs and Bara's criteria, the Kunduz and Mazar-e-Sharif soil is collapsible, while the Bagram soil would fall just inside the non-collapsible region (see Fig. 3). According to Handy's criteria, the Kunduz soil has high probability of collapse, the Mazar-e-Sharif soil will probably collapse, and the Bagram soil has less than 50% probability. These results match what military forces have observed. As many as 48 sites in and around the Kunduz Airfield show signs of collapsed soil (SIGAR 2010) and an earthen drainage ditch near the Mazar-e-Shariff Airfield experienced slope failure from collapsible soil. No evidence of collapse has been observed at Bagram. Lutenegger and Saber's collapse test or other collapse tests were not used in this study because the equipment to obtain undisturbed samples and equipment to conduct necessary laboratory tests are not available in Afghanistan.

Table 1. Soil properties of Kunduz, Mazar-e-Sharif and Bagram soil.

Parameter	Kunduz	Mazar-e-Sharif	Bagram
Specific gravity	2.66	2.69	2.70
Liquid limit	22	21	29
Plastic limit	19	15	19
Plasticity index	3	6	10
Void ratio	0.91	0.89	0.74
In-situ dry density [g/cm^3 (lb/ft^3)]	1.39 (86.8)	1.42 (88.6)	1.55 (96.8)
Moisture content	7	6	9
% passing 0.075 mm sieve (No. 200)	94	89	73
Clay content, < 0.005 mm	13	24	31

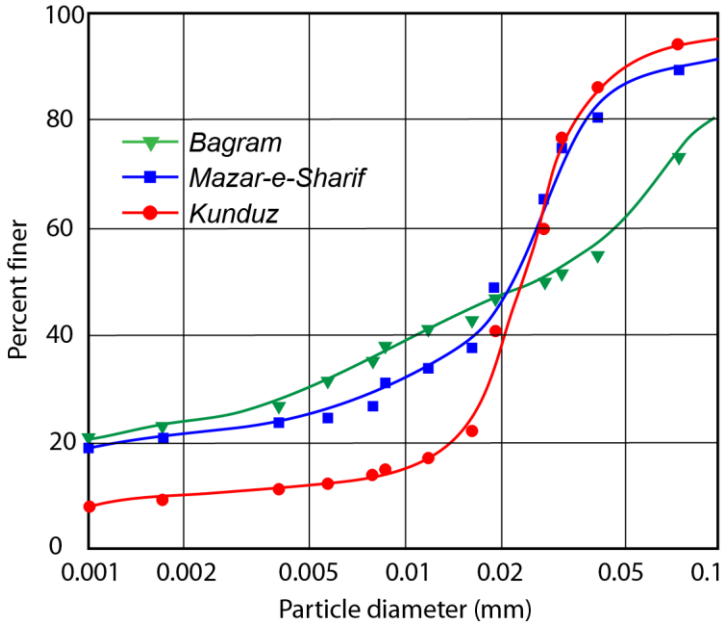


Figure 4. Particle size distributions of Kunduz, Mazar-e-Sharif and Bagram soil.

MITIGATION

Because of the high to moderate probability of loess collapse in Kunduz and Mazar-e-Sharif, as well as other areas of northern Afghanistan, military engineers must mitigate collapsible soils in drainage and foundation design. The most cost effective mitigation strategy is drainage. Designs for new military bases in northern Afghanistan must begin with a well-conceived drainage plan. Northern Afghanistan is ringed by 5,000 m (16,400 ft) high mountains that experience a rainy season in the winter and significant snowmelt in the spring. Coupled with a lack of vegetation, excess water can flow quickly over the ground as surface runoff.

A suitable drainage design at expedient military bases is open channel drains and a gravel cover over the ground surface. Cast in place concrete trench drains (as shown in Fig. 5a) should be trapezoidal or rectangular with depths generally ranging from 0.15-1.0 m (0.5-3.3 ft), depending on local hydrological conditions. The drain bottom and side walls must be reinforced to withstand earth pressure and anticipated loads. Grouted stone channels (see Fig. 5b) are also acceptable. Such channels are common in Afghanistan given the abundance of naturally occurring cobble stone deposits in river beds. Downspouts from buildings should feed into the drains. Ungrouted riprap-lined channels or earthen drainage ditches (see Fig. 2d) are not recommended because water infiltration may cause collapse and/or slope failure.

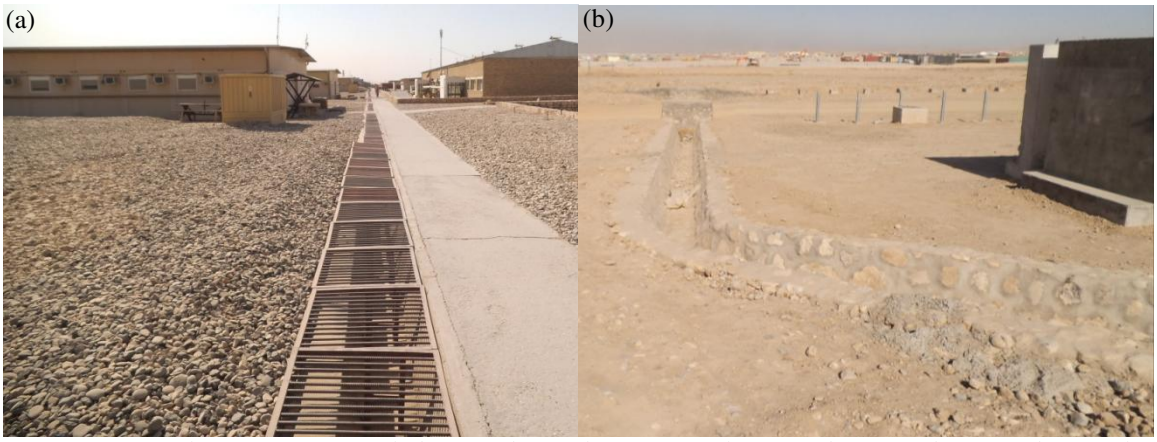


Figure 5.a. Cast in place concrete trench drain and gravel cover over the ground surface, b. grouted stone channel constructed with locally available cobble stones.

To aid in surface drainage and prevent soil disturbance, a 100 to 200 mm (4 to 8 in) layer of compacted crushed gravel should be placed on the ground surface where military personnel operate on a base camp. Geofabric should always be placed between the soil and gravel. The aeolian loess in northern Afghanistan is protected from water infiltration in nature by a weathering layer of semi-impermeable clay formed from the breakdown of minerals in the loess. This is why, even in climates of medium rainfall, loess deposits are naturally either unmodified or only partially modified (Clemence and Finbarr 1981). The gravel will protect the weathering layer from being excessively disturbed by traffic or other work that can crush the loess, making it more susceptible to penetration by water.

Road and foundation design in collapsible soils, even for lightly loaded structures, is challenging because settlement is unpredictable and often uneven. Given the limited construction capabilities in Afghanistan, two recommended mitigation methods for lightly loaded structures on collapsible loess are partial excavation and replacement with compacted granular fill, and pre-wetting with water. These methods can be used in road design and in spread and continuous footing designs.

Rollins and Rogers (1994) evaluated treatment methods for collapsible soils using 85 kPa (1775 lb/ft^2) load tests on 1.5 m (4.9 ft) square footings. To assess excavation and replacement, they removed a 0.75 m (2.5 ft) layer of collapsible soil in a test cell and replaced with a well-graded, sandy gravel compacted to 95% of modified proctor. Under load, the test cell was inundated with 9,000 L (2379 gal) of water. The footings settled less than 25 mm (1.0 in). By comparison, the application of 9,000 L resulted in 240 mm (9.4 in) of settlement in the no-treatment case and 100 mm (3.9 in) of settlement in the pre-wetting with water case. Pre-wetting does not result in a substantial decrease in void ratio near the surface since the overburden pressure is very low at shallow depths. In addition to reducing total settlement, the removal and replacement with compacted fill caused the footing to settle very uniformly in comparison with footings in the other treatment methods that underwent large differential settlement. The Rollins and Rogers (1994) study suggests that removal and replacement with compacted fill is a more effective approach than pre-wetting to mitigate foundation settlement. However, pre-wetting

may be more practical for expedient construction because of cost savings. Due to a lack of time and resources, replacement with compacted fill and pre-wetting were not tested for this paper.

Heavily loaded or settlement-sensitive structures may require more robust mitigation measures such as dynamic compaction or cement stabilization. Piles are not recommended in northern Afghanistan because of the large depth of the loess deposits. Dynamic compaction involves dropping a 5-30 ton tamper weight from a height of 15-30 m (49-98 ft) on the soil surface. Cement stabilization involves excavation of 1.5-10 m (5-33 ft) of material, stabilization with 3-12% cement, replacement, and re-compaction. These methods have been successful in the U.S. and Europe, but require complex equipment and experienced workers not readily available in Afghanistan.

CONCLUSION

This paper presented evidence of collapsible loess in northern Afghanistan and offered advice to military engineers for expedient identification and mitigation. The dry density and liquid limit graph (Gibbs and Bara 1962) and clay content criteria (Handy 1972) are recommended as quick identification methods for collapsible loess. The optimal recommendation to mitigate collapsible soil is to improve drainage with open channels and gravel surfacing. Foundation design recommendations include removal and replacement with compacted fill, and pre-wetting with water. Future research should consider laboratory testing of undisturbed samples and in-situ full scale load tests. Future research should also examine why some large structures in northern Afghanistan cities experience differential settlement and others do not.

DISCLAIMER

The views expressed in this paper are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. government.

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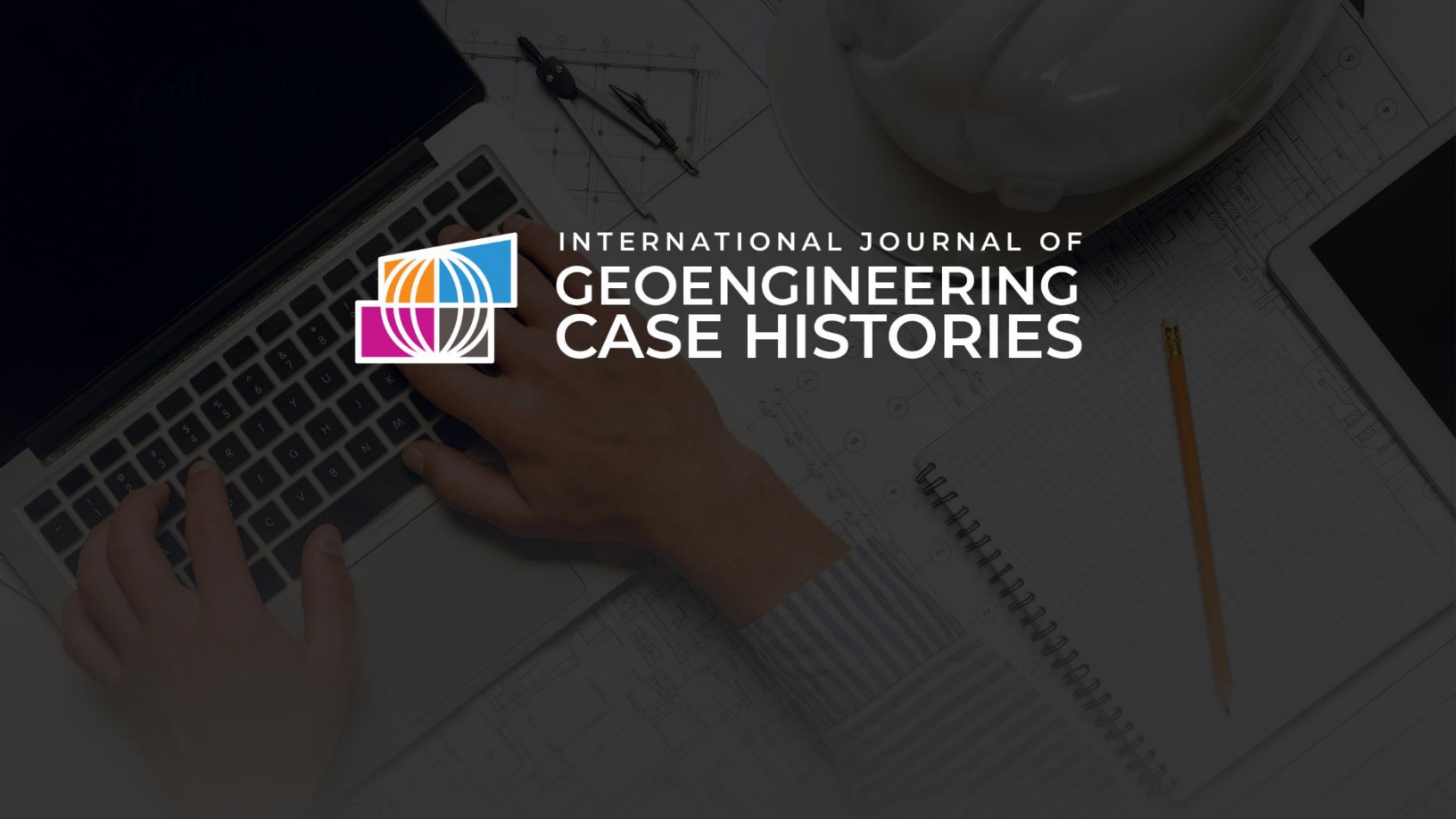
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