Mitigation strategies of expansive soils for low-cost housing projects in the Philippines

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ABSTRACT

The continuous growth of the construction industry due to many building projects in the Philippines cultivated the consciousness of many geotechnical challenges. One of these challenges is the existence of expansive soils around the country due to its geological properties. Expansive or swelling soils, mostly identified as clay, is not uncommon due to volcanic deposits. However, knowledge on the properties of the said soil type is still very limited compared to other Asian countries. Expansive soils can cause damages such as heaving, cracking and breakup of foundations to the structures due to swelling; which in turn, along with shrinking, is caused by varying amounts of moisture content. The identification of these type of soils based on available geotechnical investigation data for a specific site is a very important step to give a more convenient, effective and economical mitigation strategy. Numerous strategies can be applied on expansive soils, however, many of the said strategies are not practical and economical especially for low-cost housing projects. Low-cost housing projects in the Philippines have a price ceiling in order for it to be saleable to a specific income class hence, more stable but more expensive foundation interventions are not economically feasible. This paper aims to create a guide of handling expansive soils by collating available and applicable mitigation strategies for low-cost housing projects in the Philippines. Low-cost housing projects all over the Philippines were chosen as specific sites for this study. This paper covers the identification and mitigation of expansive soils. The mitigation strategies proposed mainly covers the geotechnical solutions and some structural responses.

Keywords: expansive soils, ground improvement, mitigation, low-cost housing, soil swelling

1 INTRODUCTION

The housing backlog in the Philippines is estimated to be 3.9 million according to the Department of Trade and Industry and Board of Investments. One of the major problems that low-cost housing projects encounter are expansive soils since most of these houses are designed as bungalows or single detached units which are considerably light. Foundations constructed on such clays are subject to large uplifting forces caused by the swelling. These forces induce heaving, cracking, and the breakup of both building foundations and slab-on-grade members (Das, 2007). Expansive soils are clays that tend to swell and shrink due to factors such as its density, amount and type of clay material, changes in water content and surcharge pressure.

The climate plays a huge role with regards to the water content of soils. According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the climate of the Philippines is tropical and maritime. It is characterized by relatively high temperature, high humidity and abundant rainfall. Two major seasons are experienced by the country are the rainy season (June to November) and the dry season (December to May). Expansive clays exposed on both seasons will surely swell and shrink.

The objective of this paper is to identify the swelling potential of soils and offer prevention and mitigation strategies convenient for low-cost housing projects.

2 NATURE AND IDENTIFACATION OF EXPANSIVE SOILS

Clays are composed of very small, plate-shaped particles. Gravels, sands and silts on the other hand, are relatively inert bulky particles. The engineering properties of the former is influenced by the very small particle size and large surface area with inherent electrical charges. While the latter depend primarily on size, shape and texture of the particles.

The structural configuration and chemical makeup differ clay minerals from each other. Three of the most common clay minerals are kaolinite, illite and montmorillionite. Based from field observations, the greatest problems occur in soils with a high montmorillionite content; it has two (2) types, namely: calcium montmorillionite and sodium montmorillionite (bentonite). The latter is much more expansive, but less common (Coduto, 2016).

Qualitative evaluation uses information from field data and laboratory tests. Identification of expansive soils using the *National Structural Code of the Philippines (NSCP 2015)* has its first three (3) out of four (4) steps that are qualitative. *Expansive Soil Classification System* by O'Niell and Poormoayed and Correlations of *Swelling Potential from Common Soil Tests* by Chen can also be used for the identification of expansive soils.

2.1 The National Structural Code of the Philippines (NSCP 2015)

NSCP (2015) discusses expansive soils on section 303.5 wherein consideration of expansive soils is under the following provisions:

3.1.1 Plasticity index (PI) of 15 or greater, determined in accordance with ASTM D 4318.

3.1.2 More than 10 percent of the soil particles pass a No. 200 sieve (75 mm), determined in accordance with ASTMD-422.

3.1.3 More than 10 percent of the soil particles are less than 5 micrometers in size, determined in accordance with ASTM D-422.

3.1.4 Expansion index greater than 20, determined in accordance with ASTM D-4829.

Readily available data were used to determine if the soil is expansive based on the criteria by NSCP. Since items 3 and 4 are usually not conducted for low cost housing projects, only items 1 and 2 were considered.

2.2 O'Niell and Poormoayed

Table 1 shows an expansive soil classification system summarized by O'Neill and Poormoayed (1980) from the U.S. Army Waterways Experiment Station. Potential swell is the vertical swell under a pressure equal to overburden pressure.

Table 1. Expansive soil classification system

Liquid Limit	Plasticity Index	Potential Swell (%)	Potential Swell Classification
< 50	< 25	< 0.5	Low
50 – 60	25 – 35	0.5 – 1.5	Marginal
> 60	> 35	> 1.5	High

2.3 Chen

Correlations of swelling potential with common soil tests proposed by Chen (1988) is shown in Table 2. Percent passing on the #200 sieve and liquid limits are the test data used whereas the SPT N-Value is also utilized in the said table on determining the degree of expansiveness of the soil which includes the probable expansion, swell pressure and the swelling potential.

Table 2. Correlations of swelling potential with common soil tests

Percent Passing #200 Sieve	Liquid Limit	SPT N-Value	Swelling Potential
<30	<30	<10	Low
30-60	30-40	10-20	Medium
60-95	40-60	20-30	High
>95	>60	>30	Very High

3 MITIGATION STRATEGIES

Strategies discussed mainly focuses on preventive measures, structural modifications are also mentioned. In reality, combinations of both preventive measures on soil and structural modifications are done so that the problem on expansive soils is largely reduced or eliminated. It is expected that proper execution and monitoring are observed for each method to be effective.

3.1 Preventive Measures on Soil

3.1.1 Bypassing Expansive Clay Layers: In order to mitigate the swelling of the expansive soil, construction of the foundation below the said layer is one of the solutions. Fluctuation of the moisture content causes the heave and shrinkage of the soil near the ground surface. The layer wherein this happens is called the "active zone". Bypassing some or all of the active may be done as long as the expansive soil layer is thin and is underlain by non-expansive soil.

3.1.2 Moisture Barriers: To stabilize the moisture content of the soil under a structure, installation of impermeable moisture barriers can be effective. Horizontal barriers can be installed around the structure in the form membranes or buried under the ground surface in the form of sidewalks or paved areas. In slowing the rate of swell and uniformity of the water content distribution, vertical barriers are more effective.

3.1.3 Adequate Drainage: An adequate drainage system for surface and subsurface water can control water fluctuation which can be done by surface grading and subsurface drains. A positive slope away from the structure promotes rapid water runoff and to avoid ponding of water near the structure. Slopes should be greater than 1% and preferably 5%.

3.1.4 Remolding and Compaction: By compacting clay at its optimum moisture content, the swell potential of the soil will be reduced. That state should be maintained while erecting the structure. If the soil dries before the placement of the structure, the method will not be effective and may cause the soil to become significantly more expansive.

3.1.5 Prewetting: Saturation by soaking the soil reduces the compaction density which in turn, lessens the total swell magnitude. Moisture contents should be increased to at least 2-3% above the plastic limit. Construction of the foundation on swelled clay follows. Increasing the moisture content in the active zone takes a year or more. This method is usually followed by lime treatment at the surface for an increased soil strength, protection against evaporation and surface slaking

3.1.6 Surcharge Loading: If some deformation is acceptable and the swell potential is low, a surcharge may be effective. A soil testing program is necessary to determine the depth of the active zone and the maximum swell pressures that needs to be counter acted. When using a surcharge, drainage is an essential factor in moisture migration.

3.1.7 Soil Replacement: For relatively shallow thin layers of expansive soils, removal and replacement with non-expansive soils is one of the easiest methods to mitigate the problem. Materials that will be used to replace the soil should be non-expansive and impermeable. The depth of the active zone is the basis on determining the depth of the soil that should be replaced.

3.1.8 Fly Ash: One of the many uses of fly ash products is to control the shrink properties of expansive soils. Commonly used fly ash products are Class C and Class F. Typical stabilized soil depths are 15 to 46 centimeters (6 to 18 inches). Elapsed time measured between the fly ash first comes in contact with water and final compaction of the soil, fly ash and water mixture (delay time) is critical to the rapid nature of the tricalcium aluminate reaction that occurs when Class C fly ash is mixed with water. Typically, a one-hour compaction delay is specified for construction purposes. Maximum strength of soil-fly ash mixture generally occurs at moisture content below the optimum moisture content. Typical fly ash rates are 8-16% based on the dry weight of soil (FHWA, 2017). Soil modification and stabilization using fly ash should be referred to the local environmental requirements.

3.1.9 Sand Mixing: Mixing at least 30% of sand in expansive soils improves the maximum dry density and the California Bearing Ratio (CBR). The deformation characteristics of the expansive soil is reduced due such as the Liquid Limit and the Plasticity Index. Materials should be thoroughly mixed together and soil samples from the mixture are tested in the laboratory to confirm the change in the properties of the soil.

3.1.10 Lime Treatment: Hydrated lime improves expansive clay by increasing its shear strength and reducing its swelling potential and moisture content. Lime can be mechanically mixed with the soil at a rate of about 2 % to 8% by weight. This method is generally limited to shallow depths, about 0.30 meters (~1 foot). Another method is the “Pressure Injected Lime” (PIL) which forces lime slurry into the soil under high pressure using special equipment. This method is capable of treating soils to depths of up to about 2.5 meters (~8 feet.) The delay between the application and final mixing improves workability and compaction. Quality control is very important during pulverization, mixing and compaction.

3.2 Mitigation Actions in the Structure

A rigid foundation system can control the differential settlement of the structure and can counteract the effects of soil swelling. Tie beams connecting the isolated footings are usually done to satisfy this requirement. “Waffle” or “floating foundations” which is another type of a rigid foundation system would not be distorted in an event of a differential heave.

Flexible construction, super slabs and California slabs are other types of mitigation actions on structures built on expansive soils.

4 CASE STUDY

4.1 Initial Assessment

The potential swell of a case study area was assessed using the previously mentioned identification systems of expansive soils and readily available laboratory data such as the Atterberg limits, percent passing of #200 sieve and SPT-N values shown in Table 3. Low and high plasticity silts are considered expansive by the NSCP classification since percentage of soil particles that are less than 5 micrometers in size and the expansion index was not measured. The said values can be obtained by tests that are usually not conducted for low cost housing projects.

Table 3. Potential swell classification of the case study area using different potential swell classification systems

Borehole	Idealized Depth (m)	USCS	Potential Swell Classification		
			NSCP	O’Neill and Poormoayed	Chen
BHA	0.0 - 12.0	CH	E	H	VH
BHB	0.0 - 7.5	CH	E	H	VH
BHC	0.0 - 4.0	CH	E	H	VH
	7.5 - 9.0	ML	E	L	VH
BHD	0.0 - 1.0	ML	E	L	H
	1.0 - 2.0	MH	E	M	H
	2.0 - 4.0	CH	E	H	VH

Legend: E = Expansive, L = Low, M = Marginal, H = High, VH = Very High

The classification by Chen is more conservative than the classification system by O’Niell and Poormoayed. Note that more than one criterion was used for both classifications; percent passing #200 sieve, liquid limit and SPT N-value for the former while liquid limit and plasticity index for the latter. In some cases, there are different potential swell classification for each criterion, i.e. a clay was identified to have high potential swell for both % passing of #200 sieve and liquid limit, however it has a medium potential swell from the SPT-N value, the said soil will be considered to have a high potential swell.

Expansive soil layers of the first three boreholes are identified to have high to very high potential swells from the soil surface up to depths of 12.0m, 7.5m and 4.0m. The remaining borehole on the other hand, have a 2-meter thick clay layer with high to very high potential swell found at a depth of 2.0 meters. Bypassing, prewetting, surcharge loading, remolding, compaction and soil replacement would be very inconvenient due to the thick expansive layers. Sand mixing may be an option if the sand is readily available, however, this would create additional cost and time on the soil displacement, mixing and compaction. Fly ash and lime stabilization are the most convenient options as for the construction measures wherein the latter was highly recommended.

4.2 Post Treatment

Lime treatment was conducted on the case study area by mechanically mixing lime with the soil at a rate of 2% (by weight). Quantitative evaluation based from the Atterberg limits of the soil samples was done to determine the potential swell classification of an untreated soil sample and three (3) lime-treated soil samples shown in Table 4. Based on the table, the expansive potential of the soil was reduced.

Table 4. Potential swell classification of an untreated sample and three (3) lime-treated samples

Sample	Potential Swell Classification	
	O'Neill and Poormoayed	Chen
Untreated Soil Sample	High	Very High
Treated Soil Sample A	Low	Low
Treated Soil Sample B	Low	Low
Treated Soil Sample C	Low	Low

5 CONCLUSIONS

Expansive soil classification by quantitative evaluation is highly dependent on the results from laboratory tests conducted and the preferred classification system/s. Many mitigation strategies are available however, due to the price ceiling set for low cost housing projects, the most appropriate and convenient ones should be chosen. For areas with thick expansive soils such as the case study area presented, lime treatment is the most convenient mitigation method on site. Post-treatment checking on preventive measures should be conducted to insure the improvement of the soil. Quality control and assurance plays a huge factor both on the planning and execution of the mitigation strategies.

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