Geosynthetics in irrigation canals in swelling soils of Gujarat, India: A case study

Vivek P. Kapadia
Water Resources Department, Government of Gujarat, India

ABSTRACT: Because of several projects implemented in recent years as developmental activities, soil of good quality has been consumed on large scale. Irrigation canals need selective soils which are not available at present in many areas. If such soils are transported form long distance, the project becomes economically unviable. In such a situation, the soil of whatever type is available has to be used with due knowledge of issues related with and the solution as well. When heavy clay is the only option to be used for construction of irrigation canal, it swells or expands while in contact of water and shrinks while it dries. In such cases, as lining in the canal can not be impervious, the soil behind it is subjected to cyclical swelling and shrinkage. The result is failure of lining, pipings in the embankment, heavy leakages and even some time undulations in bottom such that the water can not flow at all. The paper discusses the issues of canals constructed with heavy soils, detailed diagnosis of the problems and specific solutions worked out using geosyntheics by referencing a few canals specifically. It is also shown that role of geosynthetics is not limited to be a membrane between water and soil, but it can also behave as a structural element in some situation. The objective is to underline the importance of geosynthetics in a time when selective types of soils are unavailable and yet the projects can not be delayed.

Keywords: clay, geosynthetics, irrigation canal, leakage, membrane, swelling, shrinkage, structural element

1 FORMATION AND BEHAVIOUR OF EXPANSIVE SOILS

Expansive soil which is mostly clay is one type of fine-grained soil formed from expansive minerals. In general, expansive minerals are formed from montmorillonite, illite, kaolinite, halloysite, chlorite, vermiculite, and attapulgite. Expansive clays have a high ion exchange capacity resulting in high swelling and shrinkage potential development if there is a change of water content. On increasing the water content, expansive soil will swell accompanied by an increase in pore water pressure. When the water content is reduced, shrinkage will occur. A sample of pure montmorillonite may swell up to 15 times its original volume. However, most natural soils contain considerably less than 100 percent montmorillonite, and few swell to more than 1 ½ times their original volume (a 50 percent volume increase) (Jones, D.E. & Holtz 1973). A small load may decrease the actual swell to less than 1.25 times the original volume (a 25 percent volume increase). However, as 25 percent increase can be extremely destructive because volume increases of 3 percent or more are generally considered by engineers to be potentially damaging and require specially designed foundations. Expansive soils are found world over and engineers do take care of the same while implementing the projects. However, sometime if ignored, expansive soils create many problems and several damages occur to the civil engineering projects which provide a treasure of knowledge about important aspects related to expansive soils.

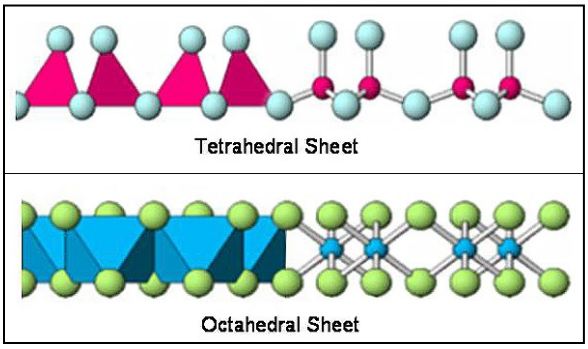


Figure 1. Silicon Tetrahedron sheets and Aluminum Octahedral sheets

As Igneous rock (primarily volcanic ash) breaks down through chemical weathering, it creates the clays.

- Weathering breaks the parent rock apart and allows the atoms to recrystalize. These form Silicon Tetrahedron sheets and Aluminum Octahedral sheets as shown in Figure 1.
- Kaolinites are formed in well drained soils, with an abundance of Oxygen, Silicon and Aluminum. Since the constituents are "pure", these form very regular shapes which bind together in regular structures. These are held together in large stacks by strong Hydrogen Bonds.
- Montmorillonites are formed in poorly draining soils so that a wide variety of atomic species are available for recrystalization. When the aluminum octahedtrals are trying to form, sometimes "isomorphic substitution" occurs in which a magnesium atom substitutes for an aluminum atom. This creates irregular shapes and unbalanced charges with weak "van der Waals" forces between them.

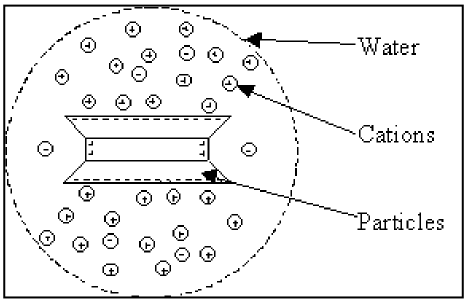


Figure 2. Montmorillonite micelles with water and cations

- To be electrically balanced, montmorillonites develop micelles with water and cations as shown in Figure 2.
- Depending on the environment in which the clays form, they may be dispersed or flocculated as shown in Figure 3. (Wyoming Multi-Hazard Mitigation Plan - Draft 2011)

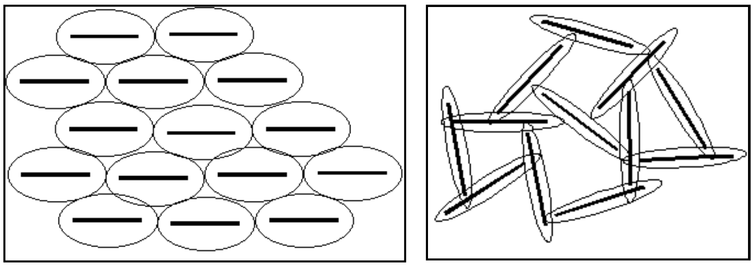


Figure 3. Dispersed and flocculated Structures

Over geologic time, these may be compressed and form clay to claystone to shale to schist. Hence, the mineral has the potential, the environment has the cause.

Clay minerals are generally flat, nearly two-dimensional plates. The clay minerals in rocks and soils are responsible for their expansion or swell. This swelling is caused by the chemical attraction of water to certain clay minerals. Layers of water molecules can be incorporated between the flat, submicroscopic clay plates. As more water is made available to the clay, more layers of the water are added between the plates, and adjacent clay plates are pushed farther apart. This pushing apart, or swelling, occurs throughout the mass of soil that is being wetted, and causes increased volume and high swell pressures within the mass. Cation hydration can expand clay mineral silicates when the soils are wet. When water bonds to the cation in the clay layer, the cation becomes hydrated. The newly hydrated cation has a larger ionic radius and the clay layers expand to accommodate the larger size (Krenz, J, Lee, B. and Owens P. 2006).

Soil shrinkage is generally confined to the upper portions of a soil. As moisture content decreases, capillary stress in the void spaces increases due to the increased surface tension. This increased surface tension tends to pull adjacent soil particles closer together resulting in an overall soil volume decrease. As moisture content continues to decrease, capillary stress continues to increase, which continues to reduce overall volume. These processes of swelling and shrinkage may occur any number of times for a single soil mass.

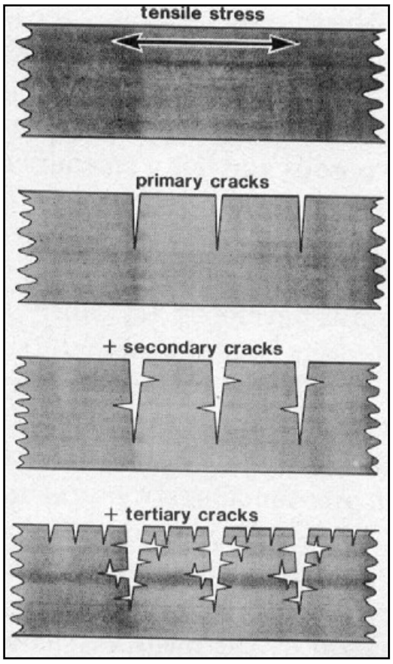


Figure 4. Formation of cracks due to shrinkage preceded by swelling (Dexter 1988)

2 SWLLING SOILS – PROS AND CONS

Soil volumetric changes may cause both unfavorable and favorable effects on human activities. Unfavorable effects are the destruction of buildings, roads and pipelines in uncropped soils, and the leaching of fertilizers and chemicals below the root zone through desiccation cracks (by pass flow). In these soils horizontal cracks break capillary flux of water. On the other hand, swelling clays can be used to seal landfills storing hazardous wastes. This sealing avoids the downward migration of contaminants to groundwater. Bentonite is used for grouting in earthen embankments of dams. In cropped soils, the development of a dense pattern of cracks on drying improves water drainage and soil aeration, and decreases surface runoff in sloped areas. Soil cracking is closely related to the recovery of porosity damages by compaction.

3 OVERVIEW OF PROBLEMATIC AREA AND ITS CANALS

In Gujarat state of India, there are vast areas that have soil quality, which is not suitable for construction of canals. Bharuch district is one such example located in central part of the state. There is no availability of good quality soil in near vicinity. The soil here is predominantly of the type “Clay of high plasticity (CH)”. It has a very high swelling pressure varying between 0.80 Kg/ cm^2 to 2.5 Kg/ cm^2. In order to avoid transportation of other types of soil and to avoid cost unviability, almost all the canals of the Sardar Sarovar Project were constructed of the locally available soil. Sardar sarovar Project is a very large one with 1.8 million hectare as the culturable command area and hence is so widespread that the canals pass through many different types of soils and topographies. It is obvious that during water flow through a canal, the water ingresses through the lining into the embankment and leads to swelling of the soil. During the subsequent dry period, when canal water flow activity is not present, the soil shrinks. These repeated cycles of swelling and shrinkage, which are differential, cause severe water piping through the canals into the neighboring terrain. This process may eventually lead to catastrophic bank failure. In several cases, heavy piping from the embankment leads to inundation of the surrounding areas and therefore leads to curtailing of cultivation activities. A few canals are referenced here as examples.

During January 2010, a medium sized canal - “Tanchha Distributary” passing from Amod Taluka was found leaking very heavily and the agricultural fields in the surrounding areas were found to be inundated with water. Average perimeter of the canal section was 5.7 meters (m); bottom width was 1.1 m; inner slope of the canal was 1.5:1; outer slope was 2:1; full supply depth of the canal was 1 m; and the bed gradient was 1 in 6000 as per original design. The designed discharge, in the middle of the length of the canal was 1.51 m^3/sec and was 0.76 m^3/sec at the tail. The total command area of the distributary was a huge 2384 hectare. The said canal was constructed some 10 years back but unfortunately every season it was tried to be operated, it used to give more and more troubles in the form of various kinds of failures.

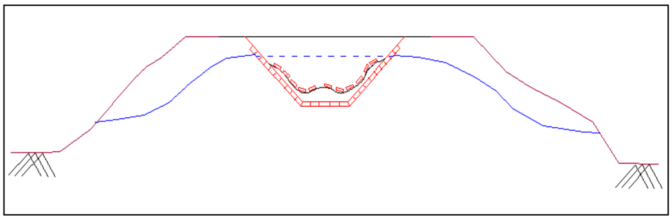


Figure 5. Disturbed Profile of Canal Due to Swelling of Embankment Soil

The overall condition of the canal was very bad; the bed of the canal was highly uneven; the brick lining was significantly disturbed. This is schematically shown in Figure 5. The deteriorated condition of the canal was visible. The bed of the canal was also unusually swollen as shown in Photograph 1.

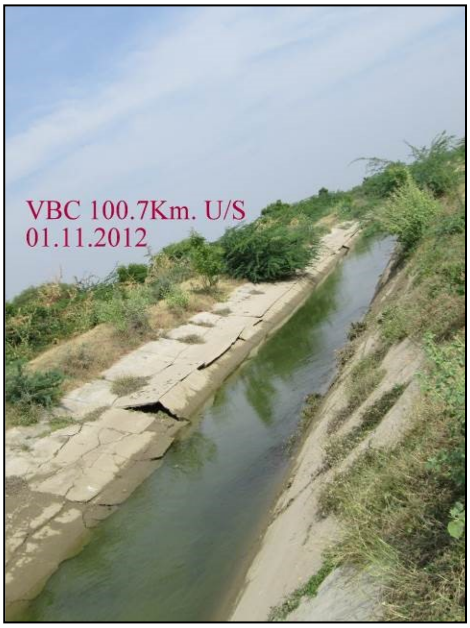
Photographs 1 and 2. Swelling of bed and sides and pipings from sides of Canal

There were several other issues. The banks were disbursed. Canal section at one location was found to be much wider in comparison to what it was originally. The embankments had also been dislocated. At several locations, cracks and breaches were patched up by cement mortar or through plastering to restrict water seepage. The local farmers were forced to construct bunds on either sides of the canal to patch up the failure of the embankment. However, the canal embankment broke repeatedly and suddenly. Piping from canal banks i.e. sides of the canal as shown in Phtograph 2 and leakage from canal siphons, both, contributed to the seepage. These occurrences used to result in water inundation of the surrounding areas.

Photograph 3. Very high swelling and severe damage in Keshlu minor

Soon then in 2010 was found many such failures of many minor canals in the same district. One such minor was "Keshlu minor" meant to supply water to a village name by Keshlu of the same district. The damage in minors was found to be widespread and more severe as compared to bigger canals. As shown in Photograph 3, Keshlu minor was so badly distressed that the brick lining was completely disintegrated and the canal profile was badly disturbed and hence the canal had become defunct. This is an example to give an idea as to how severe was the distress but many such canals were found. All the minors were 4 to 6 Kilometer long with designed discharge of 0.1 to 0.3 m^3/ sec.

A very big canal – Vadodara Branch Canal of the Sardar Sarovar Project was found to be very severely damaged due to swelling. It was 100 Kilometer long a canal with designed discharge of 76 m^3/ sec. In the initial reach, the canal passes through intermediate clay (CI) type of soil and the embankments were also made up of the same soil and hence was no problem. But in the tail reach i.e. Chainage 105 Kilometer onward it was heavy clay and hence the swelling was very high. Concrete lining of 7.5 cm thickness was upheaved and broken in to pieces for a long stretch as shown in Photograph 4. Seepage through embankment was also very high and the canal was not flowing with full capacity. There were huge pipings behind the lining as shown in Photograph 5.



Photographs 4 and 5. Severe damage and pipings in the tail reach of Vadodara Branch Canal

4 DIAGNOSTIC ANALYSIS

How canal embankments in swelling soil fail is interesting to understand. Soil of canal embankments made up of swelling soils tends to swell when comes in to contact of water. Because concrete or brick lining becomes saturated or some fine cracks give way to water, soil of embankment can not remain dry for a long time after commissioning of the canal. When the soil comes in contact of water, it swells. During the initial stage of swelling, hogging tendency in lining dominates and concrete or brick lining undergoes cracks as it has only little flexural and shear strength and then more water seeps through and further wetting the soil of embankment takes place. Then swelling aggravates gradually. It causes further upheaval of lining.

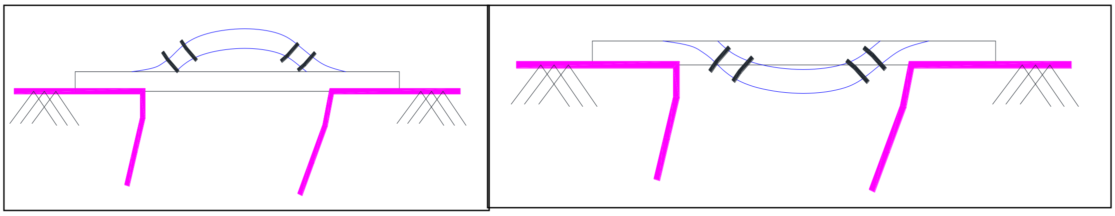


Figure 6. Hogging and sagging of lining due to cyclical swelling and shrinkage

When the canal is closed as per schedule, drying of the soil of the embankment results in to shrinking which causes wide cracks and gaps in the embankment. This causes sagging in the lining. Hogging and sagging due to cyclical swelling and shrinkage is shown in Figure 6. Subsequent operational phase of the canal, along with aggravating the swelling phenomenon, obviously signals piping as the passage to water through cracked lining and gaps in the embankment as well, is unobstructed and many such paths are created after some time in the embankment which not only saturate the embankment very soon but also raise the position of the phreatic line. Brick lining is more vulnerable than concrete lining due to poor bending strength. This phenomenon finally forms a continuous pipe like mechanism within the embankment.

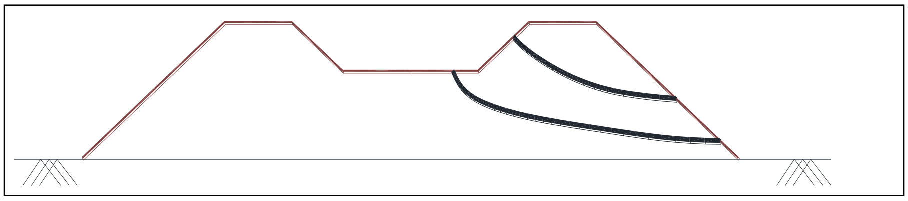


Figure 7. Pipings Through Embankment

If the embankment does not have any internal drainage arrangement, raised phreatic line becomes a major reason for embankment failure. Heavy pore pressure in addition to several pipings make the embankment unstable and it becomes difficult to judge as to whether disintegration or dispersion of embankment under pore pressure first takes place or soil erosion through piping followed by crumble or subsidence happens prior to that or both the kinds of failures are mixed.

5 SOLUTIONS USING GEOSYNTHETICS AND THEIR PERFORMANCE

Brick lining, on its own, allows the water to seep through because of the porous nature of bricks and the consequent soaking property of bricks. Deterioration of bricks and weakening of joineries are issues which will clearly be encountered with passage of time, if bricks are left unprotected. In such an unprotected environment, water seeps through the brick lining and comes into contact with the soil of embankment. Concrete lining gets saturated after some months but is less permeable as compared to brick lining. Since it is the inherent nature of the soil to swell, it absorbs the moisture and takes uneven shape. Because of its impermeability, a geomembrane offers many solutions to the challenge of expansive soils. Geomembrane reduce moisture change and therefore minimize volumetric changes in expansive soils. (Steinberg, Malcolm L. 1998)

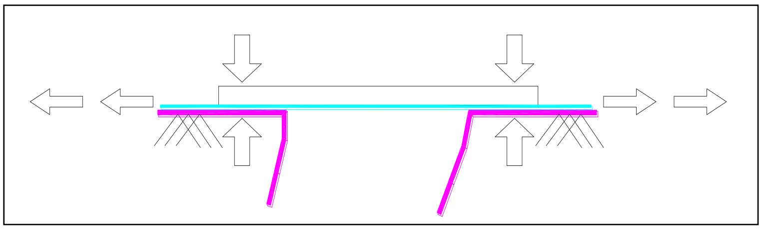


Figure 8. Bending of slab converted to tension in geomembrane

But in the existing canal in swelling soil wherein there are many piping paths in the embankment all of which are not visible during restoration, the role of geomembrane can not be limited to check the seepage. During swelling, hogging of lining takes place at the mouth of the piping and during shrinkage, sagging. The geomembrane is gripped all around the mouth of the piping under the load of the lining and water and hence the uniformly distributed load occurred by swelling or shrinkage (due to residual water content) of soil beneath is taken by it in the form of tension which relieves the slab from bending. Thus, tension mechanism replaces bending mechanism due to geomembrane as shown in Figure 8. Therefore, geomembrane should possess sufficient tensile strength. Moreover, cropping of weed from the soil would tend to puncture the geomembrane and hence it should possess sufficient puncture resistance. Therefore, right choice of geomembrane and workmanship as per site situation becomes very important.

The polyolefin designed by the Indian Institute of Technology - IITD Polyolefin was felt easy to handle - both weight-wise as well as in its ability to bend and conform to all surfaces. It was having a textured surface. In evaluating all comparable geomembranes, critical material properties were tested and studied which are given in Table 1. Ease of application is a critical parameter in geomembrane selection. From an application standpoint, aspects such as handling ease, efforts in making joinery, grip of geomembrane with soil and lining, life of the project, workability, etc. are the issues which need to be allowed serious and proper consideration because engineering aspects of such practical projects are of as much importance as of other measurable parameters.

Table 1. Comparison of various geomembranes (Testing by IIT, Delhi)

Property (Test Method)	Units	IITD Poly-olefin	HDPE	LDPE
Thickness (ASTM D5199)	mm	0.6	0.5	0.25
Weight	gm/m^2	260	470	230
Puncture Strength (ASTM D4833)	kN	0.5	0.2	0.06
UV Resistance (EN277 For 200 hours)	----	Pass	Pass	Pass
Breaking Strength (ASTM D638 Type IV)	kN/m	36	10	2
Breaking Elongation (ASTM D638 Type IV)	%	20	500	100
Tear Resistance (ASTM D5884)	kN	0.20	0.22	0.08
Water Permeability (ASTM D1499)	cm/ sec	10-6	10-6	Variable

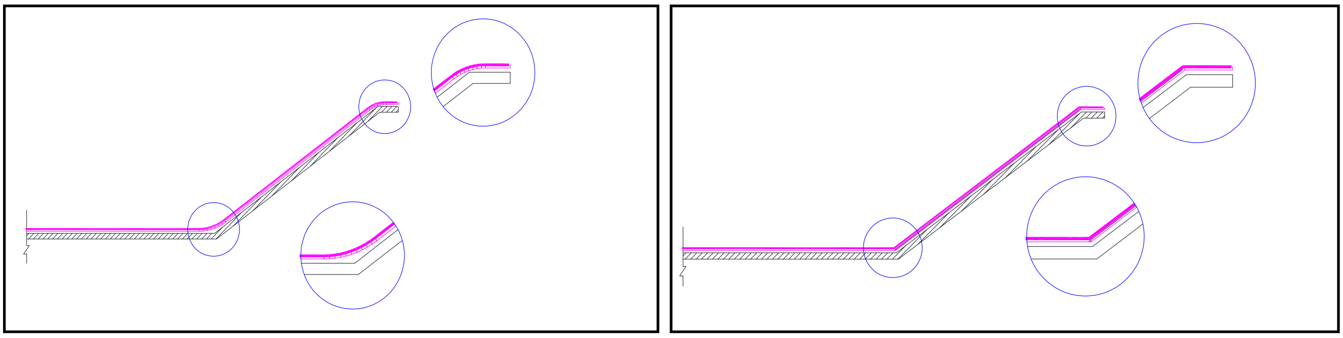


Figure 9. Bending ease – nonconformance with sub-base and conformance with sub-base

Photographs 6 and 7. Restoration of Tanchha Distributary

Conventional brick lining generally requires a 12 mm thick cement mortar layer on the earthen slopes and bed of the canal up on which the bricks are laid with frog downward and then pointing is done to fill up the joinery between adjoining bricks. But in this case, once the geomembrane was laid in the canal section, 12 mm thick cement mortar layer could not be placed up on it due to lack of bond. Therefore, bricks were placed with frog up i.e. right position; and were place closely without joints to be filled in with cement mortar as pointing. Then 18 to 20 mm thick single mala cement plaster was applied on top of the brick layer. The function of the cement plaster was to keep proper positioning of the bricks and as well as to provide a smooth surface. The inside surface of the canal was found smoother than the conventional brick lining. "Tanchha Distributary" was repaired this way as shown in Photographs 6 and 7.

Photographs 8 and 9. Restoration of Keshlu minor and Vadodara Branch Canal

In case of concrete lining, water cement ratio was decided on trial basis and the concrete was cast from bottom to top. Plasticizers were also added to the concrete to enhance workability. As in minor canals, vulnerability was greater and hence concrete lining with welded wiremesh with different diameter and spacing of steel was adopted as per requirement. Photograph 8 shows repairs of Keshlu minor. Restoration of Vadodara Branch Canal was done with plain concrete lining only as shown in Photograph 9. Its section was big and hence the vulnerability was less.

Over seven years have been spent and the performance of all the canals restored have been working well. In other districts wherever the same kind of challenges were found, similar solutions have been implemented and they have also been working well. Weed growth has also been effectively addressed as an additional advantage. The same way, issue of damage due to burrowing animals has also been controlled. Wet clay attracts them to dig in burrows but the embankments remain almost dry when geomembranes are applied.

6 CONCLUSION

Geosynthetics can provide solutions of very difficult challenges arising out of non-availability of selective natural materials. Considering all these benefits and reduced maintenance cost, the life cycle cost analysis of the canals with geomembrane would certainly become very promising as compared to the conventional technique of Cohesive Non Swelling (CNS) treatment for the canals in swelling soils. Actual requirements of different projects could be different, and, therefore, depending on the situation, an appropriate proposition for the geomembrane should be decided on. Proper understanding of all the practical aspects of the problem at hand combined with intuitive abilities, a skillful consideration of all relevant attributes and judgmental strength of the designer or the solution provider are required.

REFERENCES

Dexter, A.R. (1988), Advances in characterization of soil structure, Soil and Tillage Research, p. 199-238
Jones, D.E. & Holtz, W. J. 1973. Expansive soils: The hidden disaster, Civil Engineering, ASCE, Vol. 43, No. 8
Krenz, J, Lee, B. and Owens P. 2006. Swelling Clays and Septic Systems, Purdue University Department of Agronomy, Perdue Extension, RW-3-W, http://www.ces.purdue.edu
Steinberg, Malcolm L. 1998. Geomembraanes and the Control of Expansive Soils in Construction, Mc Graw-Hill, p. 14-15
Wyoming Multi-Hazard Mitigation Plan - Draft 2011. Chapter-7, Expansive Soil