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Technical note

# Swell–compression characteristics of a fiber–reinforced expansive soil

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ABSTRACT

This study presents results of an experimental program with respect to fiber's capacity of mitigating the swelling behavior of an expansive soil. Two types of tape–shaped fibers, i.e. fiber A (width $f_w$ = 2.5 mm) and fiber B ($f_w$ = 7 mm), were used as the reinforcements. The fibers were included at three contents, i.e. $f_c$ = 0.5%, 1% and 1.5%, each having two lengths or aspect ratios ($f_{AR}$ = 15/2.5 and 30/2.5 for fiber A, and $f_{AR}$ = 15/7 and 30/7 for fiber B). For a given fiber type (constant $f_w$), improvement in swelling potential/pressure was observed to be a direct function of $f_c$ and $f_l$ (fiber length) or $f_{AR}$, with the former taking on a more pronounced role. In addition, for a given $f_c$ and $f_l$, the wider fiber (lower $f_{AR}$) was more efficient in restricting swelling. The compression characteristics were cross–checked with the swelling properties to arrive the optimum stabilization scenarios. For both fiber types, $f_c$ = 0.5% suggested an optimal case. However, where compressional deformations are not a primary concern, higher inclusions up to 1% could also be an acceptable choice.

## 1. Introduction

As a consequence of their inherent characteristics including low strength, high compressibility and a high potential for swelling and shrinkage, expansive soils are often characterized as unsuitable construction materials for civil engineering applications (Nalbantoglu, 2006). Therefore, such soils often require modification to satisfy design criteria prior application. Stabilization of expansive soils can be achieved through two approaches, i.e. chemical and mechanical techniques. Chemical techniques mainly involve the addition of chemical binders (e.g. cement, lime and polymers) to the soil, thereby amending the soil fabric into a coherent matrix of restricted heave and induced strength (e.g. Al-Rawas et al., 2005; Mirzababaei et al., 2009; Yazdandoust and Yasrobi, 2010; Estabragh et al., 2014; Taheri and Tatsuoka, 2015; Jha and Sivapullaiah, 2016). The mechanical approach makes use of compaction with the aid of reinforcements. Common reinforcements include fibers of synthetic (e.g. polypropylene and nylon) and natural (e.g. coir and palm) origin or other fiber–like materials such as plastic waste strips and shredded tires. As the global community is shifting towards a more sustainable mindset, alternate stabilization techniques capable of replacing or minimizing the use of traditional cementitious agents have been highly encouraged. The use of fibers may be regarded amongst the most well–received propositions in this context.

The fiber assemblage randomly distributes in the soil regime, and where optimized in dosage and geometry, amends the soil with respect to moisture insensitivity (i.e. swell–shrink related volume changes), compressibility, strength and ductility (e.g. Tang et al., 2007; Abdi et al., 2008; Al-Akhras et al., 2008; Viswanadham et al. 2009a, 2009b; Tang et al., 2010, 2012; Plé and Lê, 2012; Trouzine et al., 2012; Mirzababaei et al. 2013a, 2013b; Olgun 2013a; Estabragh et al., 2014, 2016; Phanikumar and Singla, 2016; Mirzababaei et al. 2017a, 2017b). In some cases, a combination of fibers and cementitious agents may be required to address sever expansive potential (e.g. Cai et al., 2006; Punthutaecha et al., 2006; Olgun 2013b; Ayeldeen and Kitazume, 2017; Shahbazi et al. 2017). Based on these studies, the fiber–reinforcement mechanism has been primarily reported as a function of fiber content. However, fiber geometrical properties, mainly defined in terms of aspect ratio (i.e. fiber length to the diameter/width ratio), has also been reported to portray an equally important role in yielding an effective stabilization scheme.

Some of the more recent contributions addressing the aspect ratio–dependent swelling mechanism have been summarized in Table 1. A rather common emphasis on the application of bar–shaped fibers with small diameters, yielding large aspect ratios, can be observed among the documented studies. Such materials when applied at high contents are prone to clustering, and thus would be associated with implementation difficulties under field conditions. Meanwhile, tape–-shaped fibers with large widths, resulting in relatively small aspect ratios, have been less regarded in the literature. Such materials are mainly consumed in the packaging industry and are available in abundance, posing a problem for safe disposal without degrading the environment. Therefore, its beneficial reuse as an alternative to bar–-shaped fibers could provide a more feasible and sustainable

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**Notations**

| | |
|---|---|
| $C_c$ | compression index |
| $C_{psw}$ | primary swelling rate |
| $C_{ssw}$ | secondary swelling rate |
| $e_0$ | initial void ratio |
| $f_{AR}$ | fiber aspect ratio (i.e. fiber length to width ratio) |
| $f_c$ | fiber content |
| $f_l$ | fiber length |
| $f_w$ | fiber width |
| $P_s$ | swelling pressure |
| $S_p$ | swelling potential |
| $t_{isw}$ | completion time of the initial swelling phase |
| $t_{psw}$ | completion time of the primary swelling phase |
| $t_{ssw}$ | completion time of the secondary swelling phase |
| $\varepsilon_c(\sigma')$ | compression strain with respect to effective stress $\sigma'$ |
| $\varepsilon_{isw}$ | initial swelling strain |
| $\varepsilon_{psw}$ | primary swelling strain |
| $\varepsilon_{ssw}$ | secondary swelling strain |
| $\varepsilon_{sw}(t)$ | swell strain with respect to elapsed time $t$ |
| $\sigma_y$ | yield stress |

**Table 1**
A summary of some of the more recent contributions addressing the aspect ratio–dependent swelling mechanism.

| Reference | Fiber shape | $f_c$ (%) | $f_l$ (mm) | $f_d$ or $f_w$ (mm) | $f_{AR}$ | Highlights |
|---|---|---|---|---|---|---|
| Abdi et al. (2008) | Bar [1] | 1<br>2<br>4<br>8 | 5<br>10<br>15 | N/A | N/A | - The swelling potential was dependent on $f_c$ and $f_l$, with the former taking on a more pronounced role. The greater the fiber content the lower the swelling potential.<br>- At any given $f_c$, the lower $f_l$ resulted in lower swelling behavior.<br>- $f_c$ = 8% corresponding to $f_l$ = 5 mm promoted the lowest swelling potential, and thus could be considered as the optimum choice for counteracting the heave. |
| Al-Akhras et al. (2008) | Bar [2] | 1<br>2<br>3<br>4<br>5 | 5<br>10<br>15<br>20 | 0.2 | 25<br>50<br>75<br>100 | - The swelling potential/pressure followed a monotonic decreasing trend with increase in $f_c$.<br>- At any given $f_c$, increase in $f_{AR}$ adversely affected the swelling potential/pressure, while still maintaining a major advantage over the unreinforced sample.<br>- For similar $f_c$ and $f_{AR}$ conditions, increase in fiber diameter (i.e. from $f_d$ = 0.2 mm–0.4 mm) resulted in lower swelling behavior. |
| | Bar [3] | 1<br>2<br>3<br>4<br>5 | 10<br>20<br>30<br>40 | 0.4 | 25<br>50<br>75<br>100 | - For both fiber types, $f_c$ = 5% corresponding to $f_{AR}$ = 25 was suggested as the optimum solution to achieve maximum reduction in swelling potential/pressure. |
| Viswanadham et al. (2009a, 2009b) | Tape [1] | 0.25<br>0.50 | 30<br>60<br>90 | 2 | 15<br>30<br>45 | - The swelling potential/pressure was dependent on $f_c$ and $f_{AR}$, unanimously decreasing up to $f_{AR}$ = 30 then rising at $f_{AR}$ = 45. At any given $f_{AR}$, the higher $f_c$ resulted in lower swelling behavior.<br>- At higher lengths, i.e. $f_l$ = 90 mm, the fiber is subjected to bending and folding, which reduces the contact area between soil and fiber, leading to lesser resistance to swelling. |
| Estabragh et al. (2014) | Bar [4] | 0.5<br>1.0<br>1.5 | 10<br>20<br>30 | 0.3 | ≈33<br>≈67<br>100 | - The swelling potential/pressure was dependent on $f_c$ and $f_l$, with the former taking on a more pronounced role. At any given $f_c$, the higher $f_l$ resulted in lower swelling behavior.<br>- Tape–shaped fibers consistently outperformed bar–shaped fibers. At any given $f_c$ and $f_l$, the wider fiber was more efficient in reducing the effect of swelling.<br>- In terms of swell improvement, the performance of 1.5% fiber with $f_w$ = 5 mm and $f_l$ = 30 mm was similar to that of 8% lime or 5% cement at immediate curing conditions. |
| | Tape [1] | 0.5<br>1.0<br>1.5 | 10<br>20<br>30 | 3.0 | ≈3<br>≈7<br>10 | |
| | Tape [1] | 0.5<br>1.0<br>1.5 | 10<br>20<br>30 | 5.0 | 2<br>4<br>6 | |
| Phanikumar and Singla (2016) | Bar [2] | 0.05<br>0.10<br>0.15<br>0.20<br>0.25<br>0.30 | 15<br>20 | 1 | 15<br>20 | - The swelling potential/pressure was dependent on $f_c$ and $f_{AR}$, unanimously decreasing up to $f_c$ = 0.25% then rising at $f_c$ = 0.30%. At any given $f_c$, the higher $f_{AR}$ resulted in lower swelling behavior.<br>- The secondary consolidation rate was aspect ratio–dependent and decreased with increase in $f_{AR}$.<br>- $f_c$ = 0.25%, preferably with the higher aspect ratio of $f_{AR}$ = 20, was suggested as the optimum stabilization scheme. |
| Shahbazi et al. (2017) | Bar [5] | 0.2<br>0.9<br>1.6<br>2.3<br>3.0 | N/A | N/A | 5<br>15<br>25<br>35<br>45 | - The response surface methodology (RSM) technique was adopted to optimize slag–fiber additive ratios.<br>- $f_c$ = 0.8% corresponding to $f_{AR}$ = 45 (along with 14% slag) was suggested as the optimum solution to ensure maximum strength improvement while minimizing the swelling potential/pressure. |

Notes: [1] polypropylene; [2] nylon; [3] Palmyra fiber; [4] polyethylene; [5] polyacrylonitrile; $f_c$ = fiber content; $f_l$ = fiber length; $f_d$ = fiber diameter; $f_w$ = fiber width; and $f_{AR}$ = fiber aspect ratio (=$f_l/f_d$ or $f_l/f_w$).

stabilization scheme. To address any remaining uncertainties associated with selecting appropriate fiber contents and/or aspect ratios, this study intends to evaluate the effect of other less adopted fiber types on the swell–compressibility characteristics of a highly expansive soil through a series of oedometer swell–compression tests.

## 2. Materials and methods

### 2.1. Soil

The soil used in this study was clay of high plasticity (i.e. CH). X–ray diffraction (XRD) analysis identified the minerals of quartz, calcite, Na/Ca–feldspar, K–feldspar, and clay minerals group consisting of illite and montmorillonite. Other soil properties included a pH of 8.3, electrical conductivity (EC) of 10.25 dS/m and cation exchange capacity (CEC) of 17.95 meq/100gr. Mechanical properties of the soil, determined as per