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Failure of Concrete Foundations On Non-Expansive Fill Over Expansive Soils

Case Study
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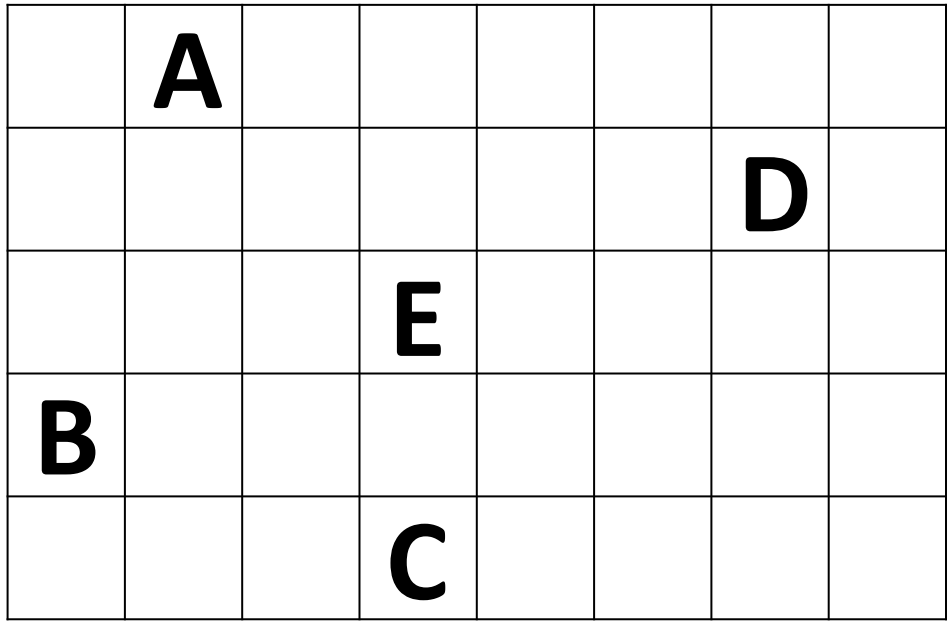
Greg Carr, PE
In collaboration with John Maier, PE

In a nutshell:
Within 90 days of completion of 20 single-story 2,000 sf homes, the foundations began to ‘fail,’ causing cracks up walls, doors that wouldn’t open, and windows that wouldn’t close

Conclusions:
Use of non-expansive fill did not stop and/or reduce underlying expansive soil uplift forces on the installed slabs

The situation

Five neighborhoods in close proximity were all built on expansive soils



- Similar expansive soil conditions
- Same void-space product used on all

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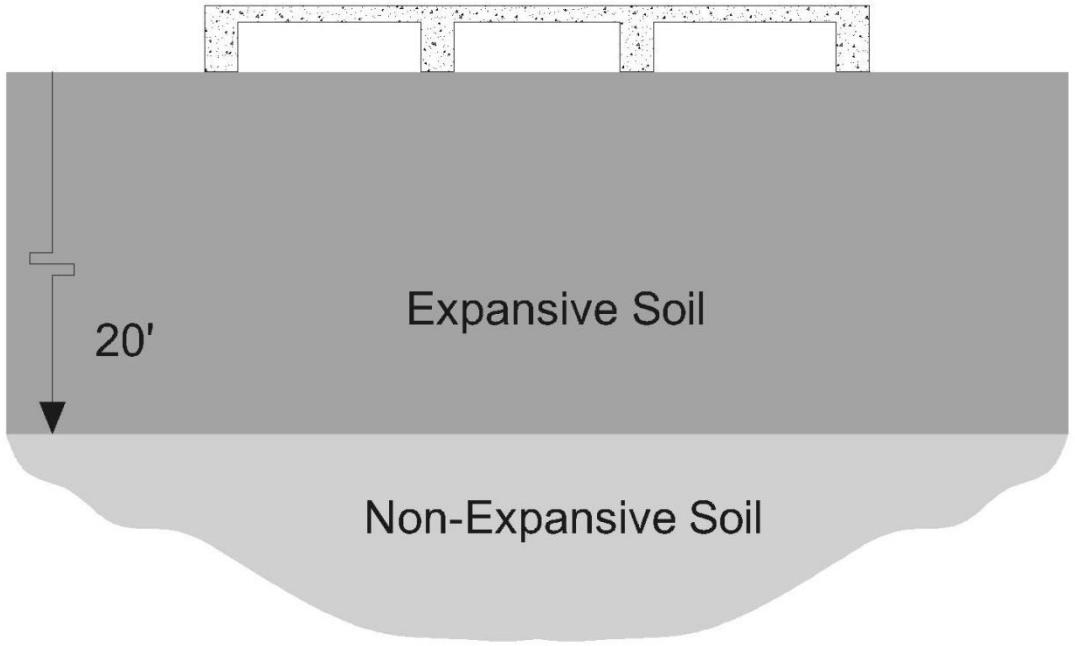
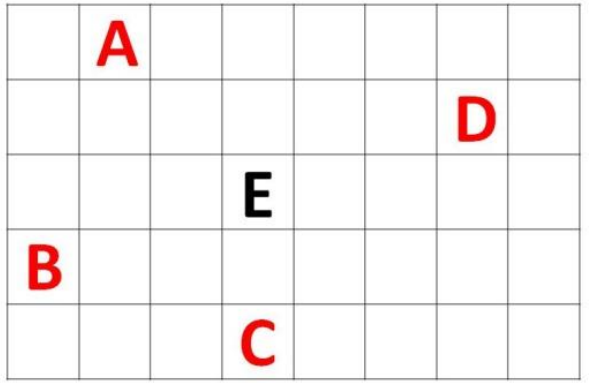
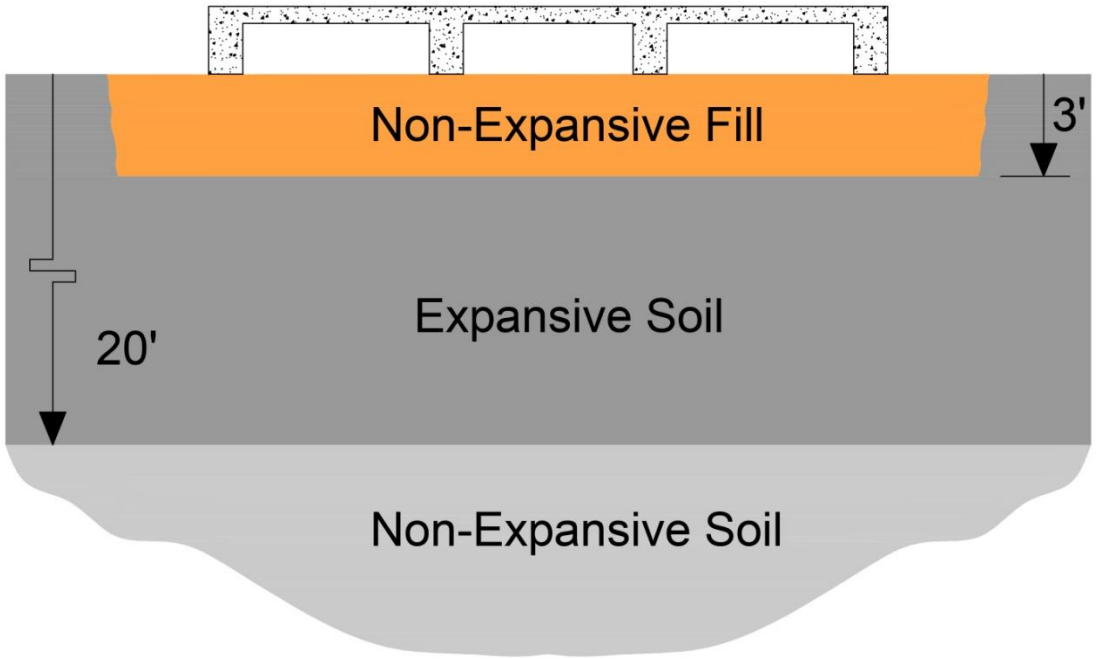
Building sites A, B, C, D

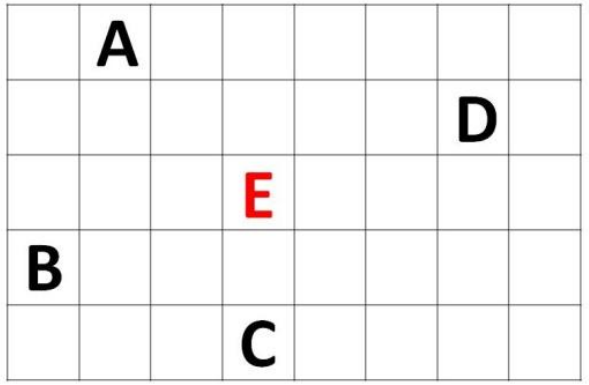




- Foundations built on expansive soil
- No non-expansive fill
- No reported foundation ‘failures’

Building site E





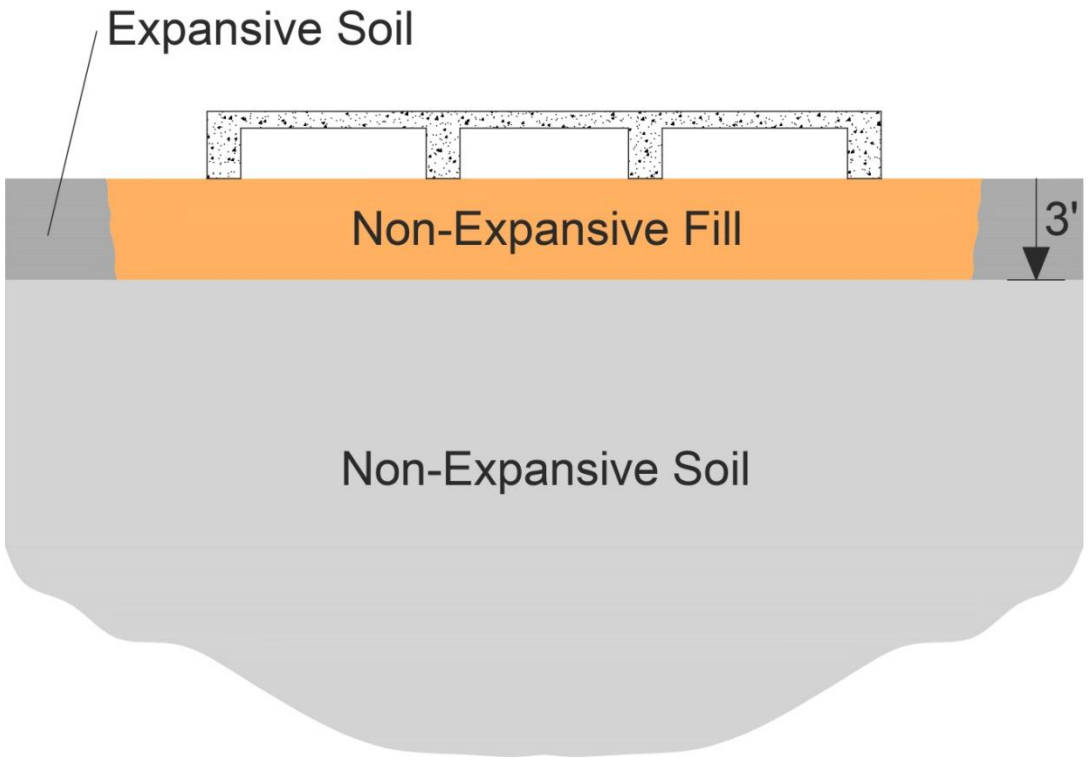
- 3’ of expansive soil was removed and replaced with non-expansive fill that was compacted to minimum 90+%
- 20 of these foundations ‘failed’

Why?

Purpose of using non-expansive fill layer

- Reduce vertical rise of underlying soils
- Reduce amount of materials used in foundation (concrete, rebar, PT cables)
- Reduce building cycletime vs. alternative slabs

Where replacement of expansive soil with non-expansive fill <u>can</u> work



- Removal of the 3’ deep layer of expansive soils completely eliminates expansive soil problems

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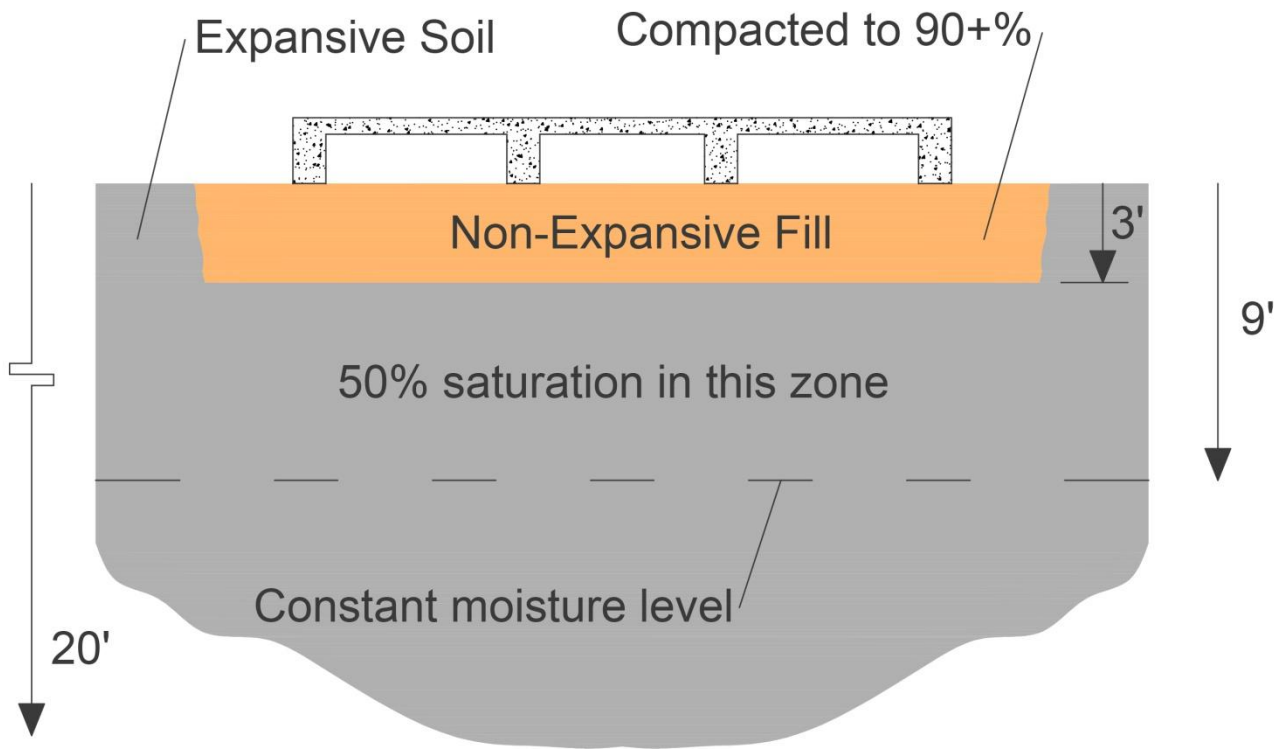
Where replacement of expansive soil with non-expansive fill <u>does not</u> work



- Removing 3' of expansive soil does not significantly reduce the potential expansion of the deep underlying soil

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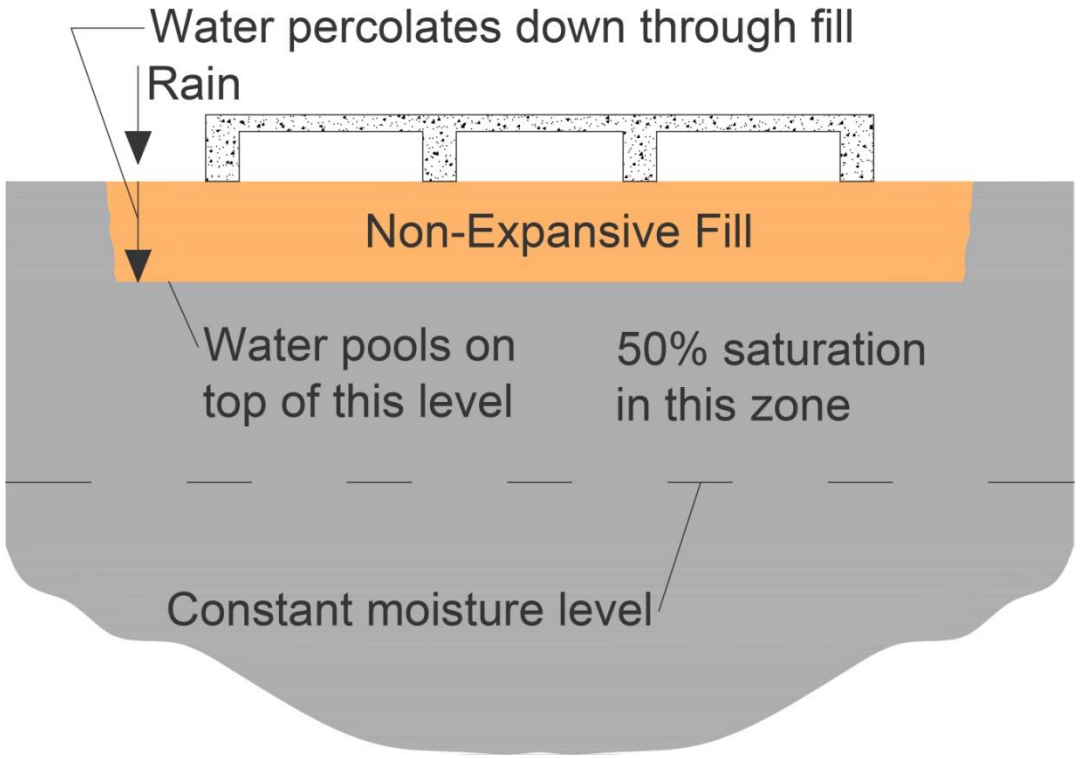
What happens when it rains?



- Non-expansive fill is porous
- It does not prevent water from quickly reaching the underlying expansive soil with 50% saturation

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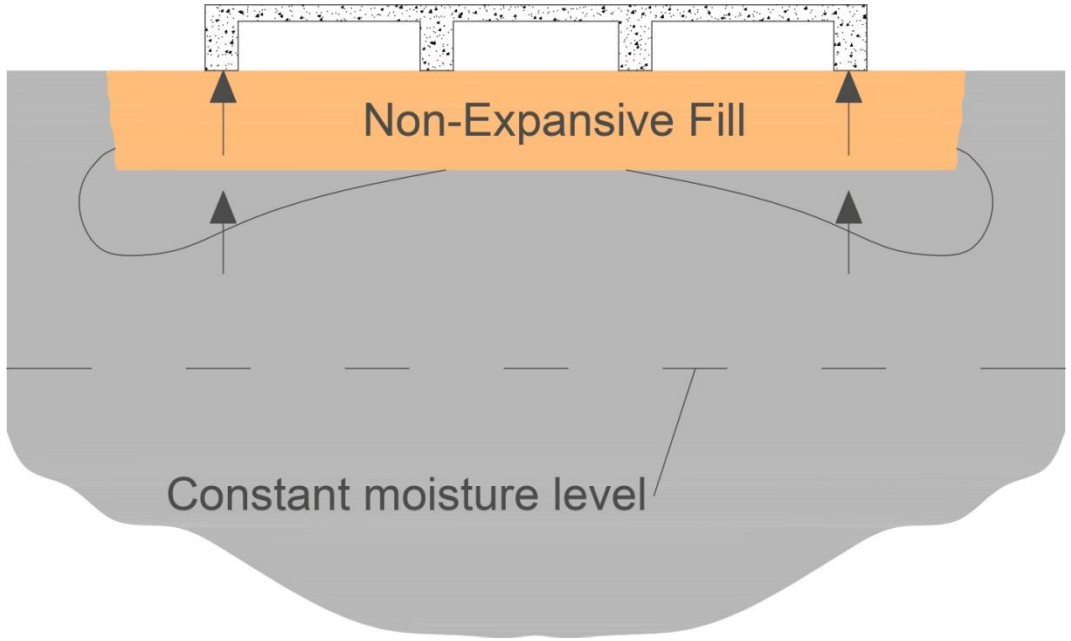
Expansive soil with 50% saturation absorbs water & expands



- Non-expansive fill has a high friction angle
- When compacted, it transmits the uplift force from the underlying expansive soil to the foundation

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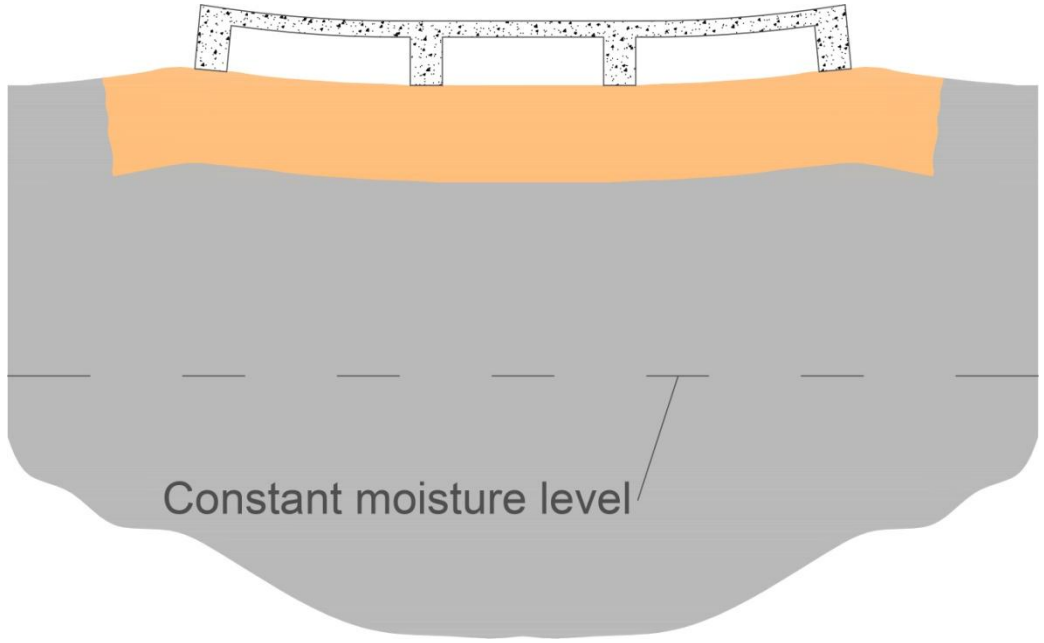
Exaggerated deformation of foundation and soil uplift



- Foundation perimeter pushed up first
- Water migrates toward the center of foundation

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How is use of non-expansive fill supposed to reduce expansive soil effects?

PTI Manuals:

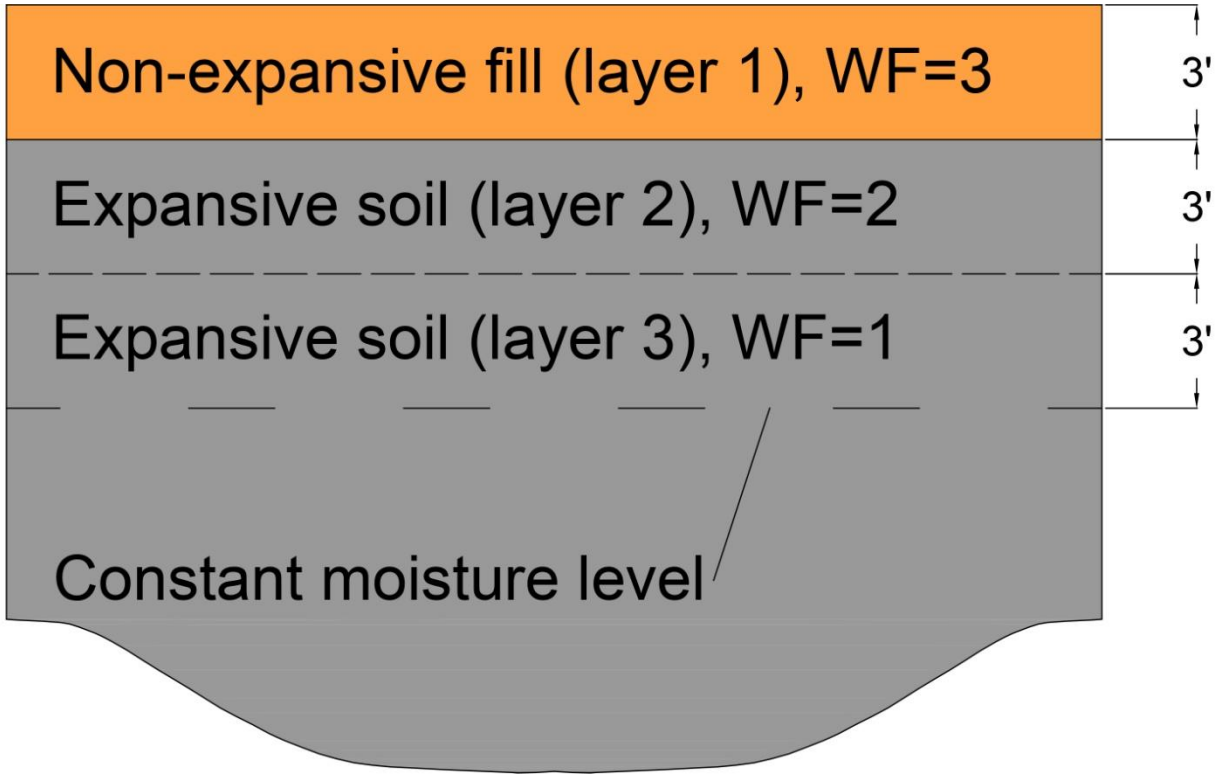
- Design of Post-Tensioned Slabs-on-Ground
- "*Standard Requirements for Design and Analysis of Shallow Post-Tensioned Concrete Foundations on Expansive Soils*" allow determination of Em & Ym to be made using non-expansive fill layers

Using PTI method, with non-expansive fill, allows a significant reduction in Em and Ym

PTI manual allows weighting factors to be used for the layers

- Allows use of multiple layers of different types of soil in determining Em and Ym
- Uses 3 layers in equal depth down to 9’ total
- Layers have weighting factors of 3, 2, and 1 from top to bottom

PTI weighting methodology



PTI calculation method for Em and Ym

- g_h = Change of soil volume for a change in suction corrected for actual % fine clay. Also referred to as Matrix Suction Compression Index (PTI definition)

- PTI states: "*If g_h varies by more than 10%, a computer modeling program is required to accurately calculate Ym. Non-expansive layers shall be modeled using g_h equal to 0.01*."

PTI calculation method for Em and Ym

- PTI Commentary states: "*This method should only be used if a typical trumpet-shaped final suction profile can be assumed, and g_h does not vary by more than 10% between layers in the soil profile. Otherwise, this method may not be accurate*."

What happened to the foundations in this case study?

Comparison of Em and Ym calculations

- With non-expansive fill

  Em = 9.0’ CL / 5.2’ EL

  Ym = -0.08” CL / 0.66” EL

  With no fill

  Em = 7.8’ CL / 4.1’ EL

  Ym = -0.19” CL / 0.96” EL

Remember:

Em = Edge Moisture Variation Distance

Ym = Maximum Unrestrained Differential Soil Movement

(These values are used to design the foundation)

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Why did foundations on non-expansive fill fail?

- Foundations in four neighborhoods without non-expansive fill did not fail. They were designed for the in-situ expansive soil with higher Em and Ym values
- Foundations in one neighborhood used non-expansive fill and 20 ‘failed.’ They were designed with lower Em and Ym values

Why did foundations on non-expansive fill fail?

- Non-expansive fill is granular with high friction angle. When compacted to 90+%, it becomes rigid
- Water quickly percolates down through non-expansive fill and pools on top of the in-situ expansive soil that has 50% saturation
- The underlying expansive soil absorbs the water, expands, and pushes up against the compacted non-expansive fill

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Why did foundations on non-expansive fill fail?

- Expansive soil has high percentage of fines and a low friction angle
- When wetted, expansive soil becomes plastic in nature and easily flows into void spaces
- The granular fill above is pushed upward, but does not easily flow into void spaces, resulting in higher transmission of uplift force

Conclusions

- When in-situ expansive soil is deep and has low saturation, don't expect reductions in Em and Ym from a non-expansive fill layer to work
- Non-expansive fill transmits uplift forces of underlying expansive soil
- Compacted non-expansive fill does not flow into void space
- Expansive soil has a low friction angle and can easily flow into void spaces when wetted, thereby reducing uplift force on the foundation

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This case study was presented for developers, engineers, and contractors by the Biax foundation-forming system, a 4th generation, on-grade, waffle slab designed and engineered specifically for expansive, compressible, or rocky soils. A Biax slab delivers superior performance and significant hard-dollar cost savings – especially when compared to in-ground ribbed and/or uniform thickness foundations.

For more information on Biax go to www.biax.com.au or call Tom Richards at 925.683.2739