Expansive Soil Site Design

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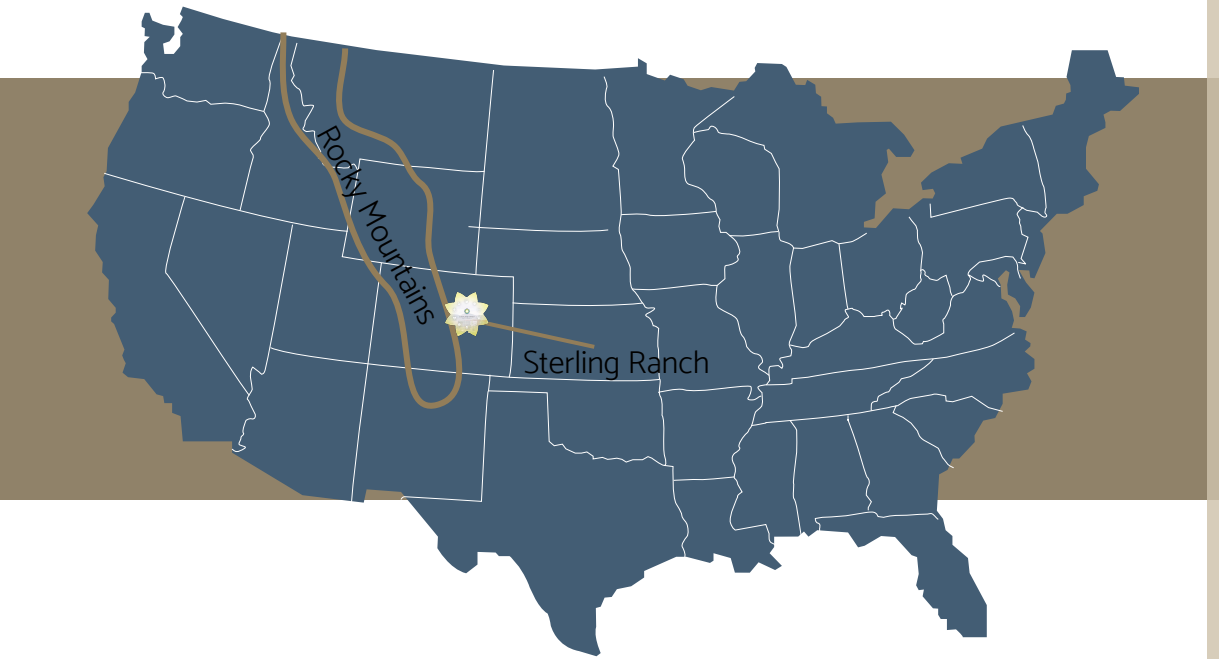


- Residential / Commercial master planned community with focus on sustainability & efficiency
- Douglas County, Colorado - just south of Denver
- Rocky Mountain foothills contain extremely expansive soils
- Rigid building foundations do not fare well when the soil expands
- Area commonly referred to as the “Front Range”

Current Solutions

Pier and Beam

Expensive and susceptible to rot

thebluebook.com

foundationrepairs.com

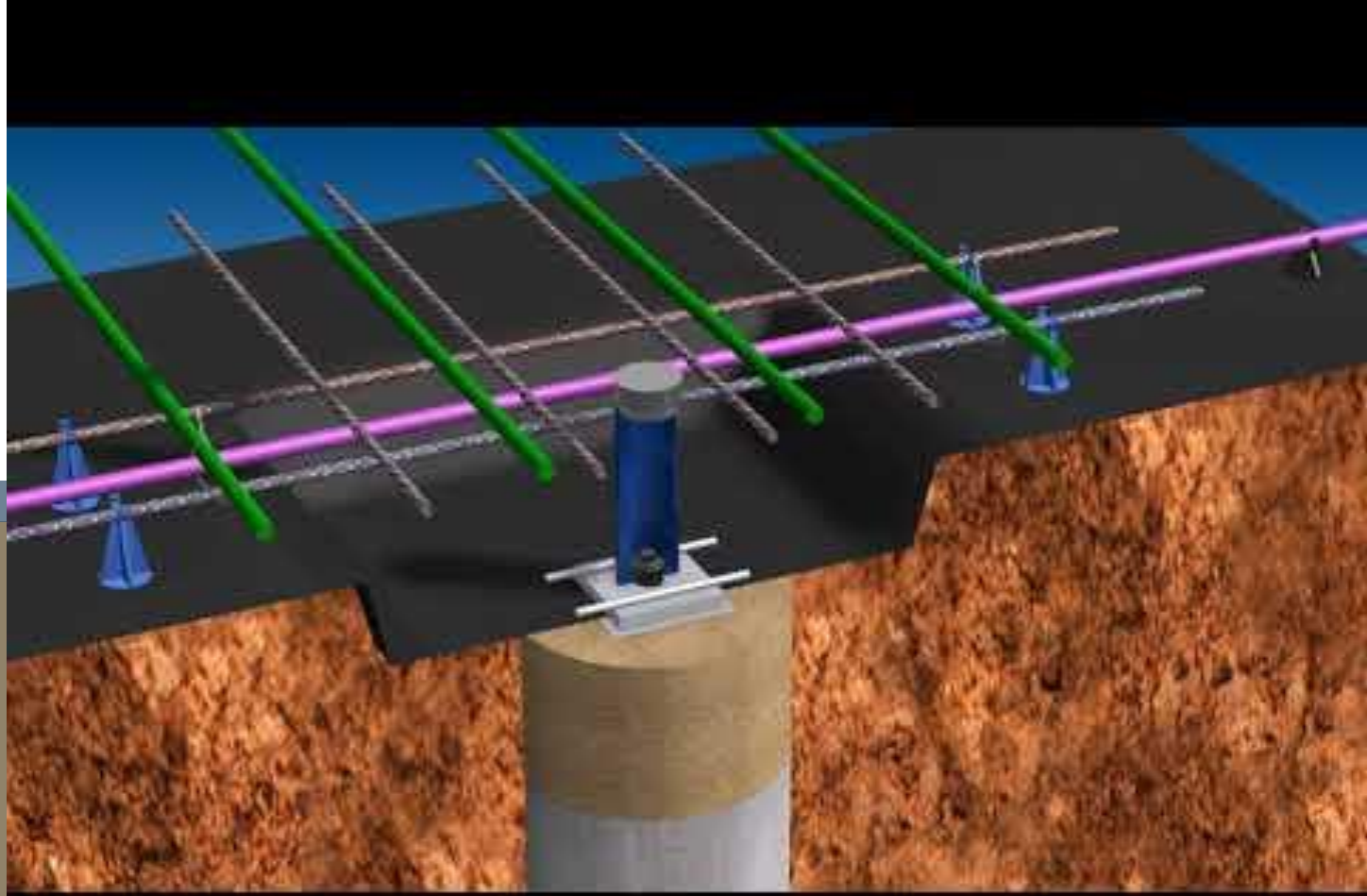
Overexcavation

Time intensive

Goal

Reduce cost and time of home construction by exploring innovative foundation designs for use on expansive soils at Sterling Ranch.

Proposed Solution: Tella Firma



tellafirma.com/how-it-works

Objectives

1. Conduct a geotechnical analysis of the Sterling Ranch soil.
2. Design a Tella Firma Foundation for 3 different home layouts (Large, Average, and Small).
3. Conduct a cost analysis of the Tella Firma Foundation as compared to the incumbent technology.
4. Provide recommendations to improve the Tella Firma Technology.

Applicable Codes

ASTM D	Geotechnical Testing Methods
ACI 318-19	Concrete Slab Design
ACI 336.3R	Concrete Pier Design
ASCE 7	Residential Design Loading

Geotechnical Report

Purpose and Limitations

Purpose:

- To inform pier design criteria and get an understanding of the soil in the area.
- Three borings will represent the land underneath a single household

Limitations:

- Only a small area was considered and sub-strata may vary across Sterling Ranch
- Did not pursue or consider other solutions
- Sampling method limited soil lab tests performed

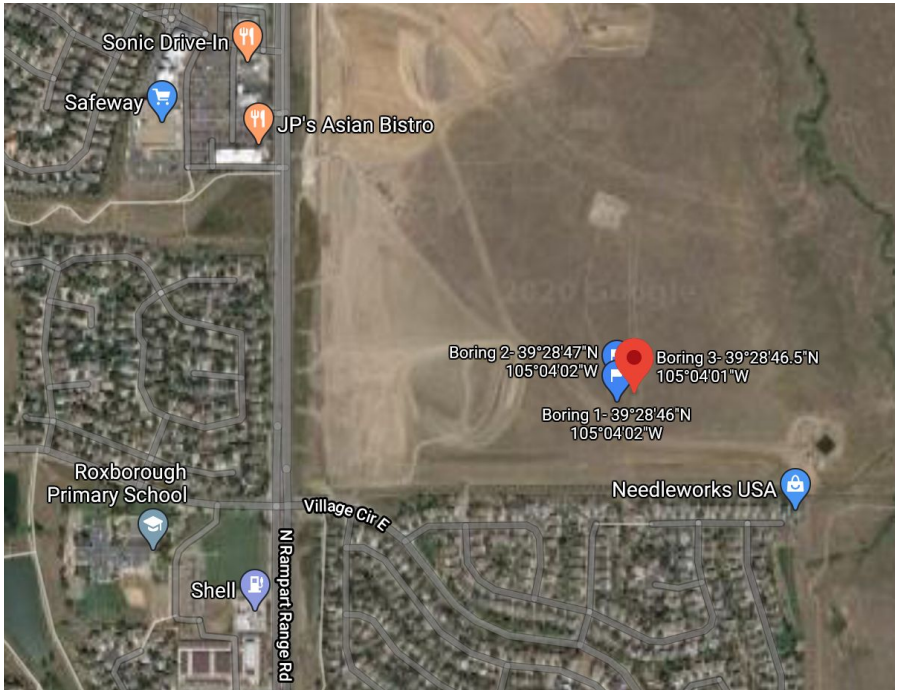
Site Conditions and Exploration

Site Conditions:

- January 13, 2020
- Sterling Ranch Filing 3B

Exploration:

- 3 separate borings
- Solid Stem Auger with Split Spoon Sampling
- 18 inches of soil captured every 5 feet to 20.5 feet
- Blow counts and location data recorded



Geotechnical Testing

Geotechnical Tests Performed:

- Sieve Testing
- Moisture Content
- Atterberg Limits
- Soil Classification (USCS)

*These tests were performed at Vanderbilt's Civil Engineering lab using ASTM standards

Design Criteria

Bearing Capacity:

- Direct correlation to SPT blow count (N)
- 20 ksf for design

Uplift:

- Direct correlation with plasticity index (PI)
- 3 ksf for design

Formula: Q_u (kPa) = $58*N^{0.72}$

Ex: $Q_u = 58*(52^{0.72})/47.88 =$ 21.4 ksf

Source(s): Hara et al. (1974), Kuhawy and Mayne (1990)

Formula: Uplift (psf) = 100 * PI - 1000

Ex: Uplift = [100*40 - 1000] / 1000 = 3.0 ksf

Source: https://web.mst.edu/~rogersda/expansive_soils/Various%20Aspects%20of%20Expansive%20Soils.pdf

Boring Logs

Project: Sterling Ranch Site Design	Project Number:	Client: Sterling Ranch	Boring No. 1
Address, City, State		Drilling Contractor: Odell Drilling, Inc.	Drill Rig Type:
Logged By: MLN	Date Started: 1/13/2020	Bit Type: solid stem auger	Diameter: 1.378 inch I.D.
Drill Crew:	Date Completec 1/13/2020	Hammer Type: automatic	
USA Ticket Number:	Date Backfilled: n/a	Hammer Weight: 140 lb	Hammer Drop: 30 inch
	Groundwater Depth: n/a	Elevation:	Total Depth of Boring: 20 feet

Depth (feet)	Sample Type	Sample Number	Blow Counts (blows/foot)	Graphic Log	Lithology (Soil Group Name: modifier, color, moisture, density/consistency, grain size, other descriptors; Rock Description: modifierm color, hardness/degree of concentration, bedding and joint characteristics, solutions, void conditions.)	USCS Classification	Moisture Content (%)	Qu, Estimated (KSF)
5		1a	11-10-8 N = 18		Strong brown elastic silt with sand, moist, very stiff	MH	14.2	9.71
10		1b	10-12-13 N = 25		Brown to dark brown sandy fat clay, moist, very stiff	CH	16.9	12.3
15		1c	14-28-32 N = 60		Brown to dark brown sandy elastic silt, moist, hard	MH	18.0	23.1
20		1d	18-31-50 N = 81		Dark brown sandy elastic silt, moist, hard	MH	18.3	28.7

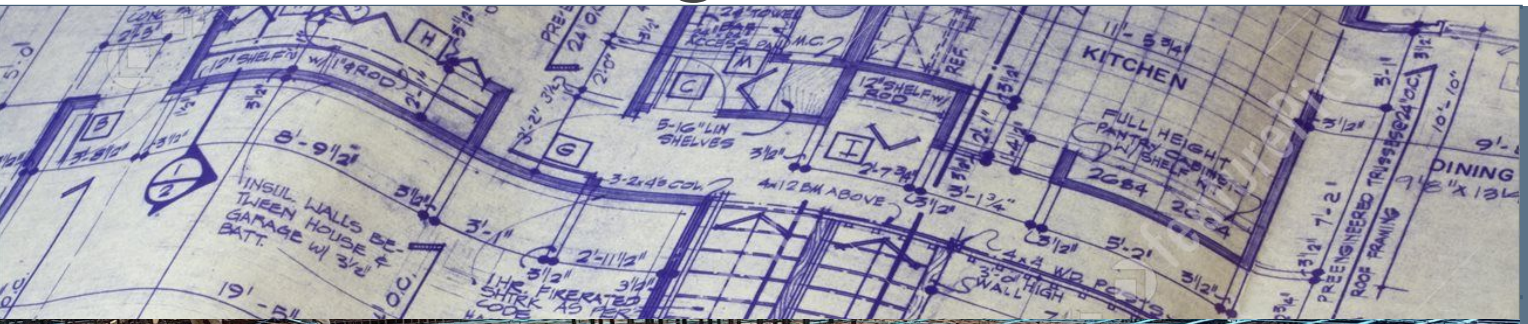
Project: Sterling Ranch Site Design	Project Number: 1	Client: MW2 Inc.	Boring No. 2
Address, City, State		Drilling Contractor: Odell Drilling, Inc.	Drill Rig Type:
Logged By: WJH	Date Started: 1/13/2020	Bit Type: Solid Stem Auger	Diameter: 1.378 in (Inner Dia)
Drill Crew:	Date Completed: 1/13/2020	Hammer Type:	
USA Ticket Number:	Date Backfilled: 1/13/2020	Hammer Weight: 140 lb	Hammer Drop: 30 in
	Groundwater Depth:	Elevation:	Total Depth of Boring: 20.5 ft

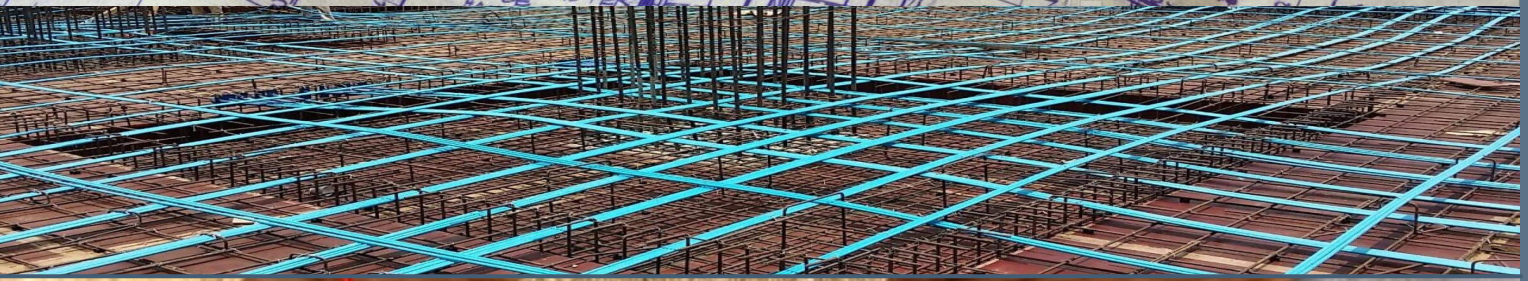
Depth (feet)	Sample Type	Blow Counts (blows/foot)	SPT N Value	Graphic Log	Lithology (Soil Group Name: modifier, color, moisture, density/consistency, grain size, other descriptors; Rock Description: modifierm color, hardness/degree of concentration, bedding and joint characteristics, solutions, void conditions.)	USCS Classification	Moisture Content (%)	Qu, Estimated (ksf)
5		11, 12, 18	30		Brown, moist, Silty Sand, very stiff	ML	15	14.0
10		8, 10, 11	21		Brown, moist, Sandy Lean Clay, very stiff	CL	18	10.8
15		13, 18, 24	42		Olive brown, moist, Sandy Fat Clay, hard	CH	19	17.9
20		15, 21, 33	54		Olive brown, moist, Sandy Fat Clay, hard	CH	20	21.4
					End of Boring: 20.5 ft			

Project: Sterling Ranch Site Design	Project Number: 1	Client: Sterling Ranch	Boring No. 3
Address, City, State		Drilling Contractor: Odell Drilling, Inc.	Drill Rig Type:
Logged By: WJH	Date Started: 1/13/2020	Bit Type: solid stem auger	Diameter: 1.378 in (inner dia)
Drill Crew:	Date Completed: 1/13/2020	Hammer Type: automatic	
USA Ticket Number:	Date Backfilled: N/A	Hammer Weight: 140lb	Hammer Drop: 30 in
	Groundwater Depth: N/A	Elevation:	Total Depth of Boring: 20.5 ft

Depth (feet)	Sample Type	Sample Number	Blow Counts (blows/foot)	Graphic Log	Lithology (Soil Group Name: modifier, color, moisture, density/consistency, grain size, other descriptors; Rock Description: modifierm color, hardness/degree of concentration, bedding and joint characteristics, solutions, void conditions.)	USCS Classification	Moisture Content (%)	Qu, estimated (ksf)
5		3a	11-12-14 N=24		light brown-red sandy silt, moist, very stiff	SC	14.01	11.3
10		3b	9-11-12 N=23		brown, moist, sandy clay, very stiff	SC	14.52	12.1
15		3c	13-20-28 N=48		dark brown, sandy clay, moist, elastic, soft	ML	19.84	19.8
20		3d	19-28-37 N=55		dark brown, moist, sandy, hard, claystone	CH	19.36	21.2

Foundation Design





Loadings

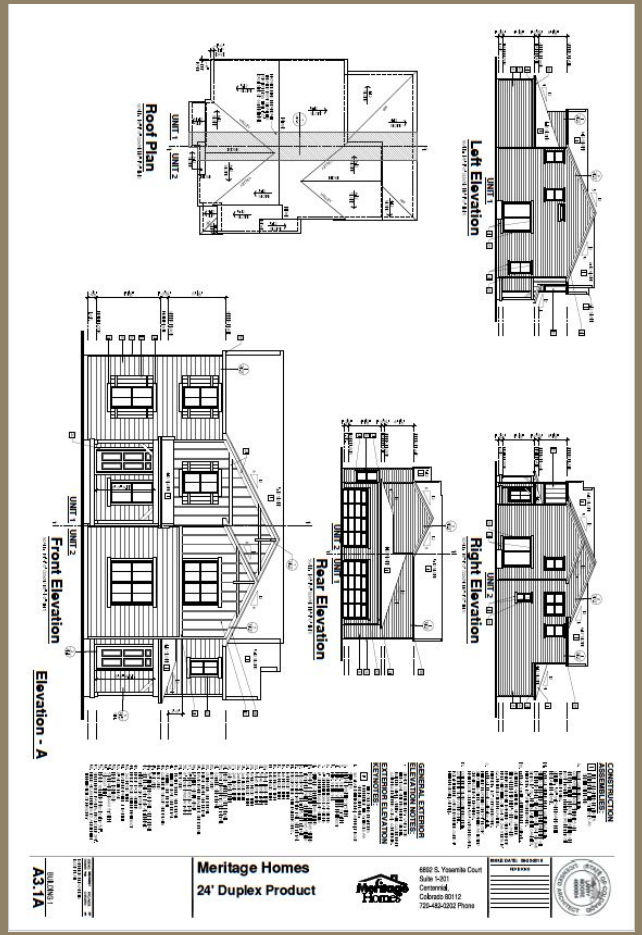
Slab

Pier

Loadings

Key Assumptions:

- A single uniform load
- Only five sources of load:
  - Roof
  - Living
  - Garage
  - Flooring
  - Walls
- LRFD Load Combos built into design spreadsheet

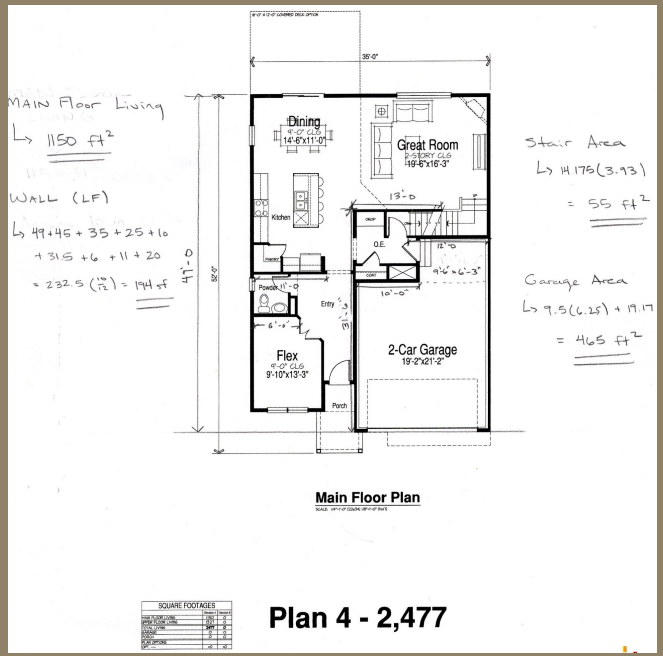


Loadings

Dead and Live Loads as per 2000 Residential Design Guide, Chapter 3: Design Loads for Residential Buildings

	Dead	Live
Roof	15 psf	30 psf
Living	15 psf	40 psf
Wall	8 psf	N/A
Flooring	12 psf	N/A
Garage	15 psf	50 psf

https://www.huduser.gov/Publications/pdf/res2000_2.pdf



Loadings

Example: Home: Meritage Homes

	Main Floor	Upper Floor	Dead Load (lbs)	Live Load (lbs)
Floor Area	1820	1820	43680	N/A
Garage Area	465	N/A	6975	18600
Wall Area	194	273	3736	N/A
Roof Area	N/A	1820	27300	54600
Living Area	1150	1327	37155	99080
Sum	--	--	118,846	172,280

Load to Slab Design:

Input Dead Load (Service):

- **118,846 lbs/ 1820 sf = 65.3 psf**

Input Live Load (Service):

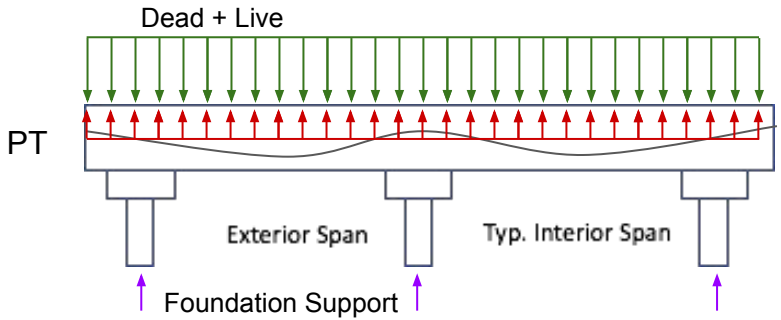
- **172,280 lbs/ 1820 sf = 94.7 psf**

Slab

Design slab and reinforcement to understand feasibility, process, and cost

Designed using Direct Design Method

- Calculate load on each span
- Distribute load to areas of importance



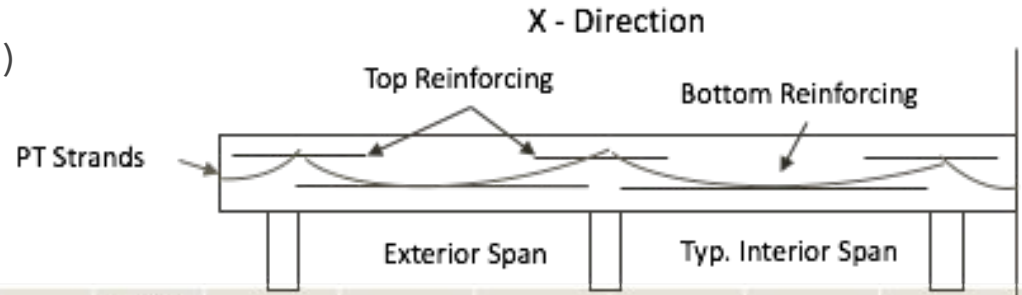
Assumptions

Inputs	Units	Value	Explanation
Ws	lb/cft	490	Unit weight of steel
Wc	lb/cft	150	Unit Weight of concrete
PTcl	ft	0.16667	Minimum cover on PT cables
f'c	lb/sin	4500	Concrete compressive strength
f'ci	lb/sin	3000	F'c at time of initial stressing
FEF	lb/sin	160,000	Effective force in tendons
P	lb/sin	175	Precompression pressure
Apt	sin	0.153	Cross-section area of PT cable
fy	lb/sin	60,000	Reinforcing steel yield strength
fps	lb/sin	190,000	Post tension steel yield strength

Slab

Design Checks:

- Initial stressing transfer
- service stress (tension + compression)
- Minimum reinforcement
- Service deflections
- Slab punching shear
- Slab moment



Design Outputs	Units					
PT strands per span	n/a		5.9888888		5.9888888	
excess rebar/span (col strip)	sin	6.71727	9.64332	15.48436	6.34362	14.2712
excess rebar/span (mid strip)	sin	0	6.12344	4.5505881	3.92365	4.14621
development length	in	45.9	full bot.	45.9	full bot.	45.9

Pier - Assumptions

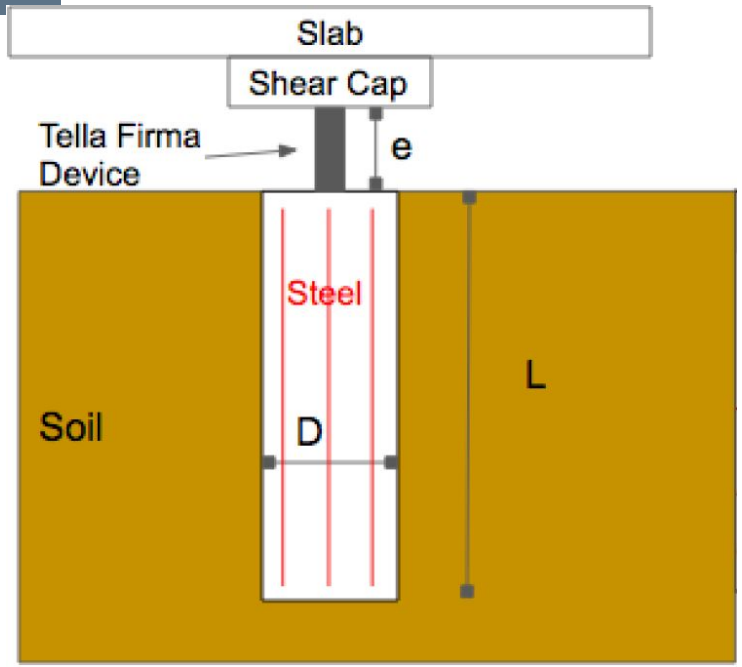
- Uniform slab loading on piers assumed
- Assumed that bedrock is not encountered in soil less deep than the designed pier length
- One set of calculations needed to design conservative foundation pier (uniform loading)
- exterior piers will likely have smaller diameter
- Many assumptions are made due to the chosen design technique (ASD) and are tabulated here

Assumptions

Inputs	Units	Value	Explanation
DL	lb	36015	Dead Load (from slab calculation)
LL	lb	25480	Live Load (from slab calculation)
W	lb/sft	16	Lateral Wind Load[8]
Yw	lb/cft	62.4	Weight of Water
qp	lb/sft	8000	Soil unit bearing pressure
fo	lb/sft	720	Soil average side friction[9]
Su	lb/sft	1500	undrained soil strength[10]
COLE	ft/ft	1.1	Soil COLE value[11]
f'c	lb/sin	3000	concrete compressive strength
fy	lb/sin	60,000	reinforcing steel yield strength
FS1	n/a	3	Soil Bearing factor of safety
FS2	n/a	3	Side Resistance factor of safety

Pier - Design

- Designed using an allowable stress technique following ACI 336.3R
- Pier design depends heavily on site soil conditions
- Design based on slab span length and applied loading
- Each home's piers were designed based on data from boring samples taken at Filing 3B
- Vertical steel reinforcement designed to resist tensile strain from uplift forces



where D=diameter of pier and L=length of pier

Pier - Design

- Pier design is not impacted by use/absence of Tella Firma
- Other pier types such as helical piers are compatible with Tella Firma and can be used where appropriate
- Design looked for exclusively the lowest cost pier that met design criteria and safety checks
- Piers are used in the Sterling Ranch area and are comparable to calculated pier parameters

Pier Design Parameters for Trail's Edge Duplex

Design Output	Value	Units
Length of Pier (L)	19.25	ft
Diameter of Pier (D)	3	ft
TF Device Height (e)	0.833	ft
Axial Steel / Pier	7.559	sin
Gross Pier Vol.	136.070	cft

Pier - Design Checks

Design Checks (7 total)

- concrete compressive strength
- Bending Moment
- Lateral Shear
- Bearing
- Uplift
- 2 combined flexure/axial loading checks

Our piers were designed conservatively with ASD design method using a high safety factor, ensuring pier stability in changing ground conditions common on the Front Range

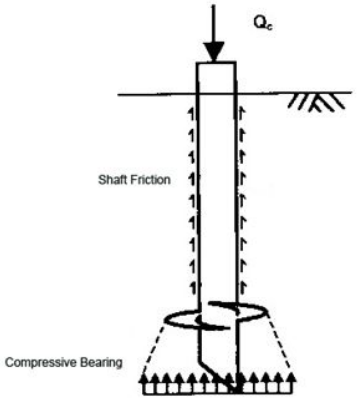


Figure 5.1 Compressive Pier Loading[1]

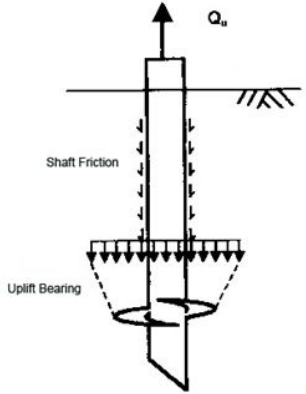
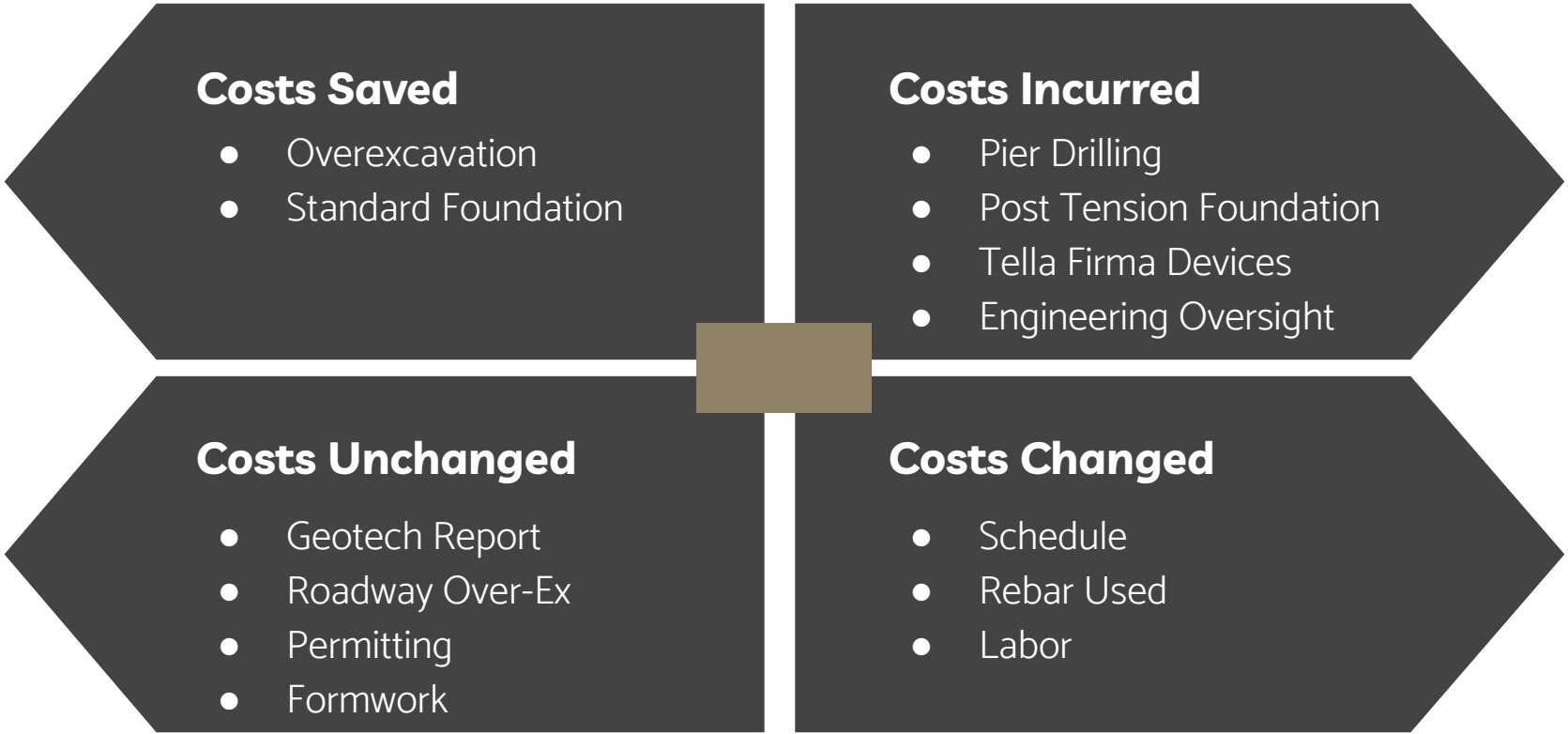


Figure 5.2 Pier Loading in Tension[1]

executivepier.com

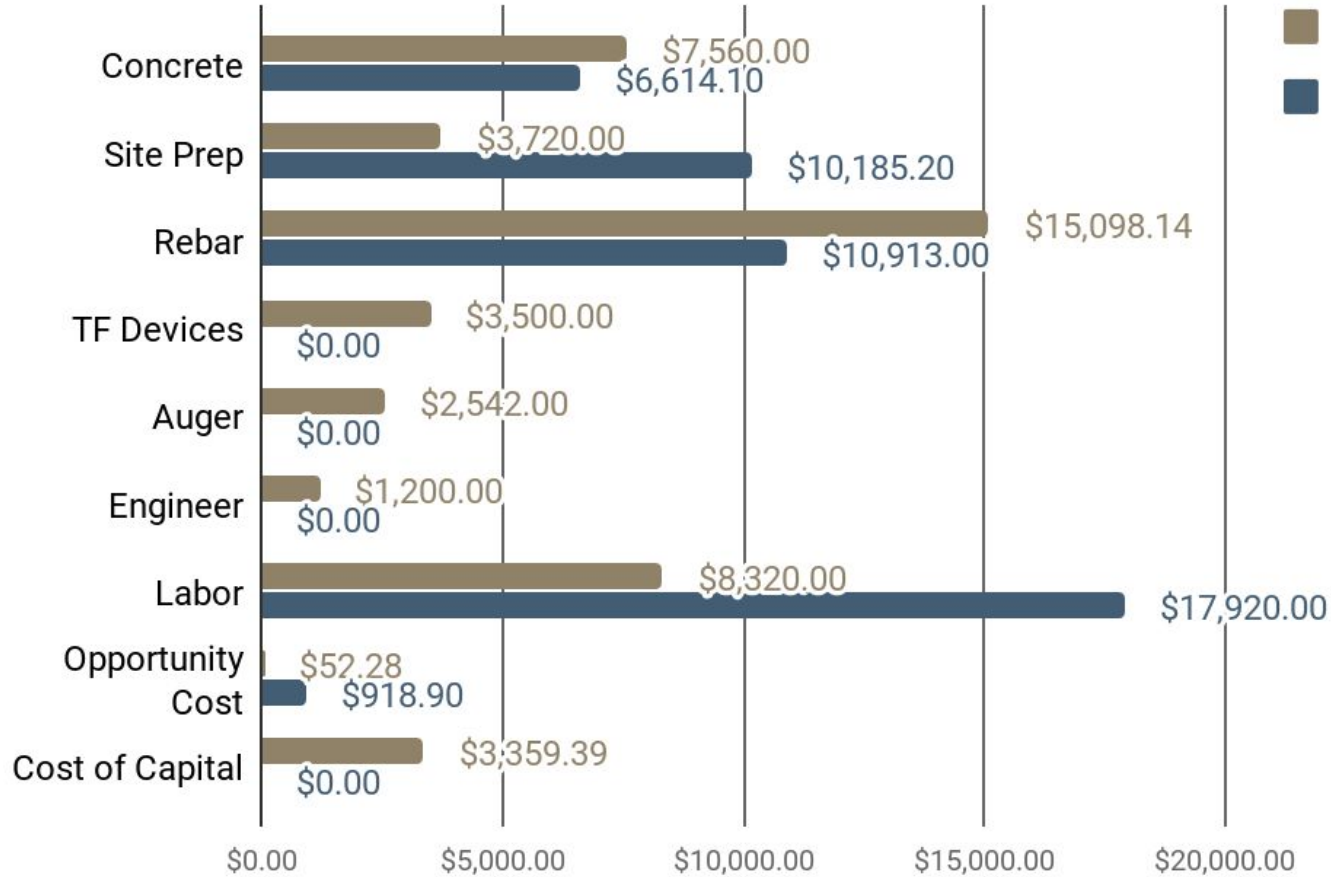
Tella Firma Cost Breakdown



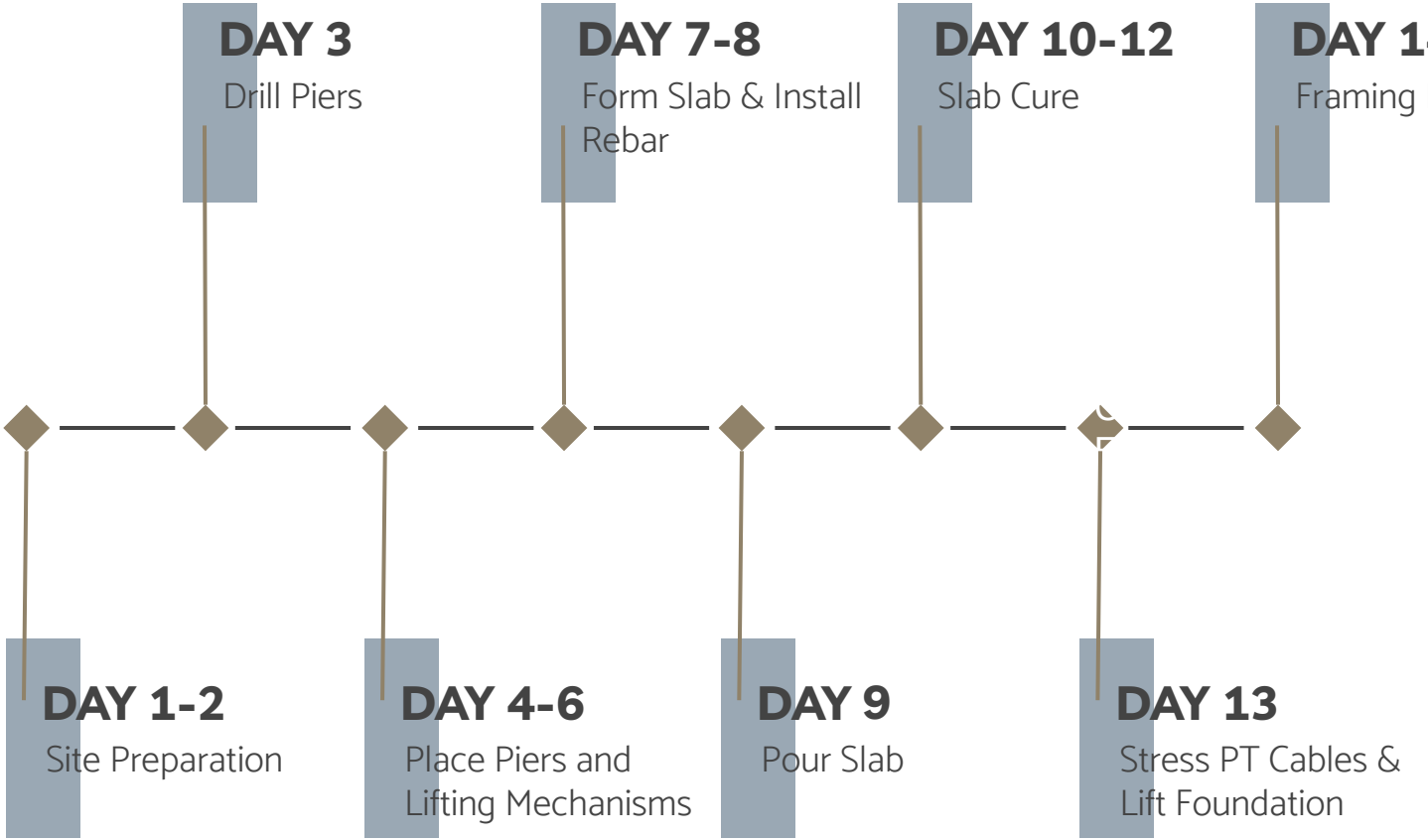
Example Homes Comparison

	Trails Edge Duplex	Lennar Series Homes	Meritage Homes
Footprint:	2,976 sq. ft	2,358 sq. ft	1,820 sq. ft
Bedrooms / Bathrooms:	6 bd. / 5 ba.	3 bd. / 3 bath	3 bd. / 3 bath
Tella Firma Savings:	$1,199	$900	$370

Trails Edge Duplex Comparative Cost Breakdown

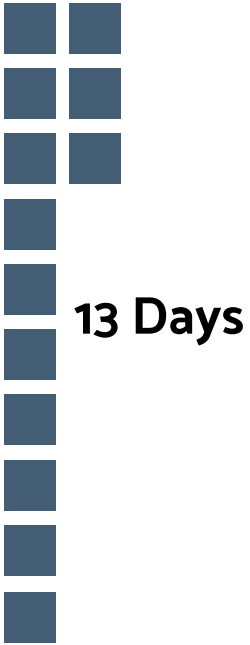


Tella Firma Schedule



Schedule Comparison

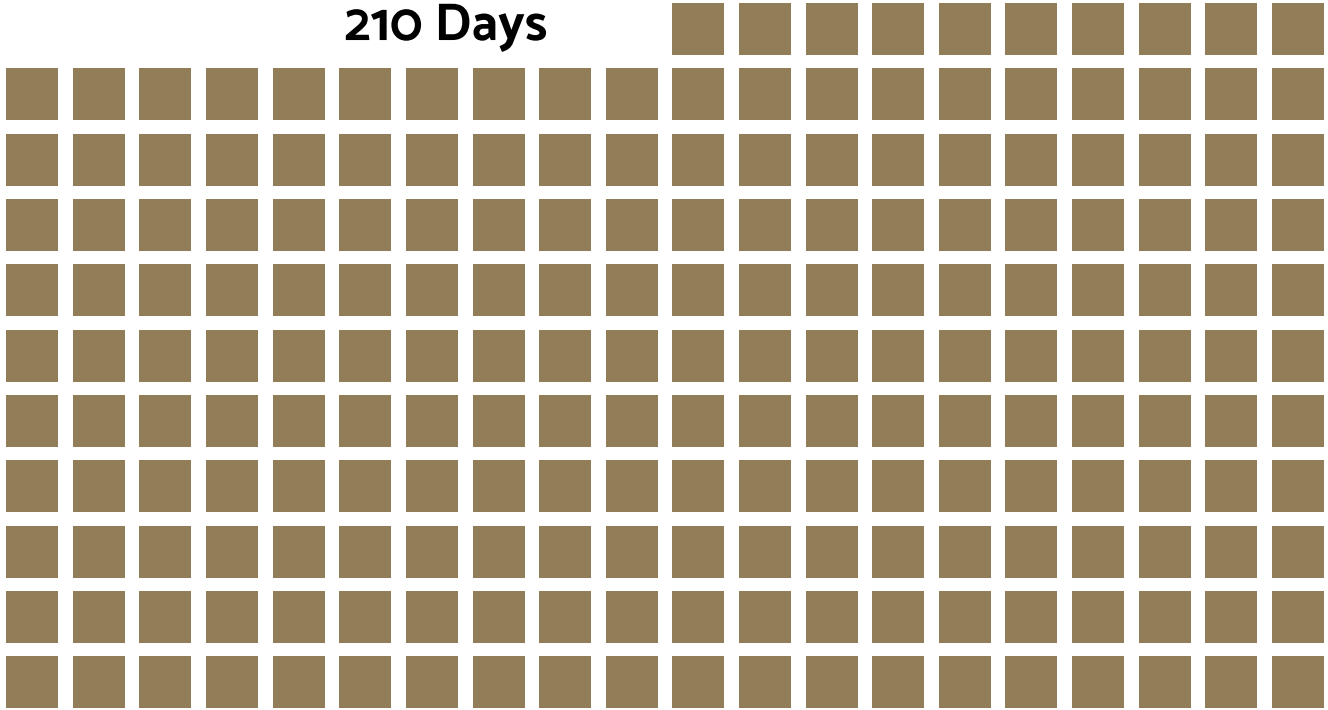
Tella Firma Foundation



13 Days

Over Excavation With Slab on Grade

210 Days



Future Improvements

comalcountyjail.com

Helical Piers

- Piers made up 42% of total concrete used ($3,000)
- Can reduce the number of days needed to place piers (need no time to cure)

deere.com

Drill Piers for Multiple Homes At Once

- Auger is large cost, even if rented for only one day ($2,500)
- Split cost among multiple homes

Conclusions

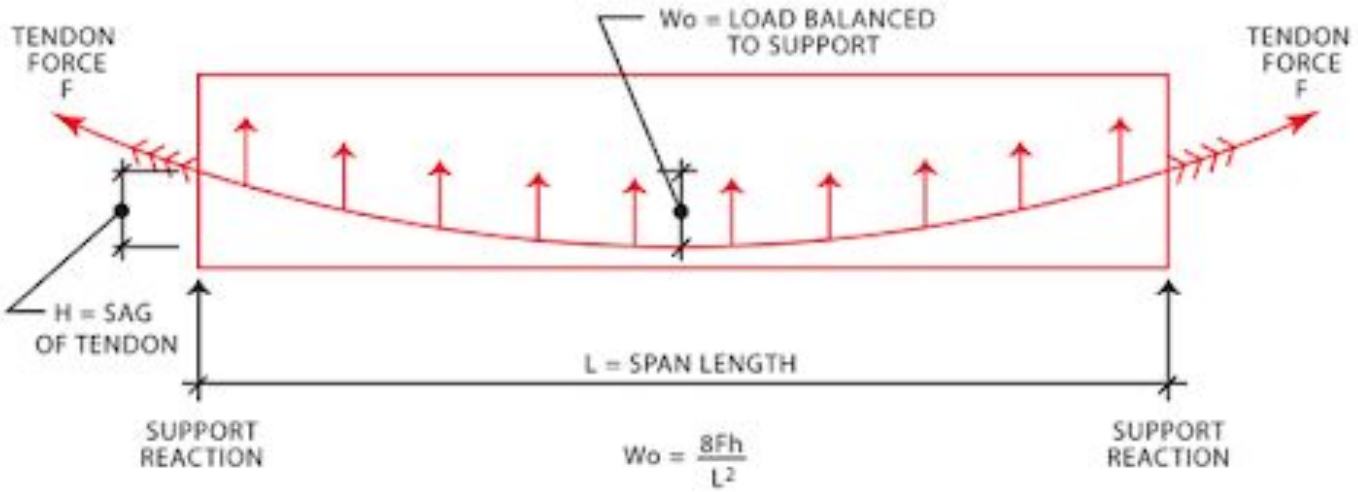
Geotechnical analysis of Sterling Ranch soil	→ Expansive soils require special consideration
Tella Firma foundation across three home sizes	→ TF is structurally feasible across expected home sizes
Tella Firma foundation cost comparison	→ After learning curve, will save money and time
Recommendations to improve TF technology	→ Improved efficiency is available in design options

Questions?

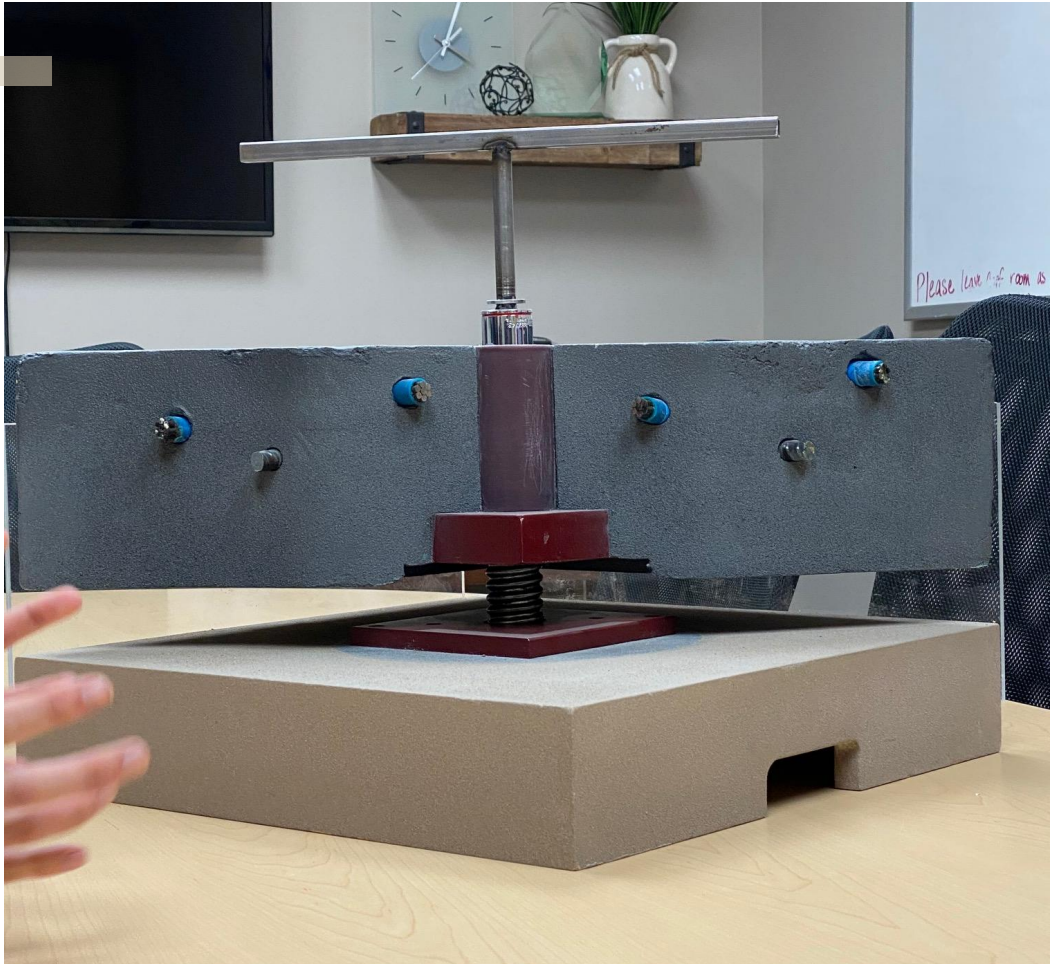
Special Thanks to:

Our Sponsor Sterling Ranch
Our Mentor RMG Engineers
Our Life Mentor Dr. Troxel
Our Lab Mentor Rich Teising

ONE WAY LOAD BALANCING



https://www.eng-tips.com/viewthread.cfm?qid=459458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"...a wise man, which built his house upon a rock."
-Jesus (Matthew 7:24)

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