

**Expansive Soil Site Design
Final Report**

Delivered to: Sterling Ranch; RMG Engineers
April 2020
Vanderbilt University Senior Design Project
Wyatt Hall, William Harlow, Matthew Neuendorf

Table of Contents

INTRODUCTION	3
<i>Figure 1: Colorado's Front Range</i>	3
Pier and Beam Foundation	4
<i>Figure 2: Pier and Beam Foundation</i>	4
Over-excavation	5
DESIGN GOAL	5
PROPOSED SOLUTION	5
Objectives	6
Applicable Codes and Specifications	7
GEOTECHNICAL REPORT	8
Purpose	8
Site Conditions	8
Field Exploration	8
Laboratory Testing	9
Foundation Design Criteria	9
<i>Table 1: Q_u as a Function of SPT</i>	9
Limitations	10
FOUNDATION DESIGN	10
Loading Calculation Overview	11
<i>Table 2: Dead and Live Loads for Houses in Douglas County, Colorado</i>	11
Slab Design Overview	11
<i>Table 3: Slab Design Assumptions</i>	12
<i>Table 4: Slab Design Checks</i>	13
Pier Design Overview	13
<i>Table 5: Pier Design Assumptions</i>	14
<i>Table 6: Pier Design Checks</i>	15
Home 1 - Trails Edge Duplex	15
Home 2 - Meritage Homes	16
Home 3 - Lennar Series Homes	16
COST COMPARISON	17
Table 7: Cost Comparison Breakdown	17
Cost Comparison (Schedule)	20
<i>Figure 4: Tella Firma Schedule</i>	21
Final Cost Estimates	22
<i>Figure 5: Cost Breakdown for Trails Edge Duplex</i>	22

Figure 6: Cost Breakdown for Meritage Homes	23
<i>Figure 7: Cost Breakdown for Lennar Series Homes</i>	23
<i>Table 8: Example Home Comparisons</i>	24
CONCLUSIONS	24
Future Improvements	25
<i>Figure 8: Helical piers screwed into the ground provide cost saving benefits</i>	25
APPENDICES	27
Appendix A - Site Boring Locations	27
Appendix B - Boring Logs	28
Appendix C - Geotechnical Testing Data	31
Appendix D - Loading Calculations	32
Appendix E - Home Loading Calculations	39
Appendix F - Foundation Plans	41
Appendix G - Pier Design	44
Appendix H - Cost Sheets	46

INTRODUCTION

Sterling Ranch is a residential and commercial master planned community in Douglas County, Colorado. From its outset, Sterling Ranch has been built on a set of values that promote the goals of sustainable and efficient living. Of special importance to the research presented herein are the values of wellness, stewardship, and innovation¹. Stewardship is a responsibility to take care of someone or something else, and provide for its well being. Stewardship is not easy and, as a steward of the environment and the community, Sterling Ranch has been challenged by the geographic conditions of Colorado's Front Range.

Colorado's Front Range includes the foothills and plains on the eastern edge of the Rocky Mountains. As shown in Figure 1, many of Colorado's most populous cities, such as Fort Collins, Colorado Springs, and Denver are along the Front Range. Sterling Ranch, only 20 miles south of Denver, also finds itself within this region. The Front Range is a challenging area to build in due to the unique geological conditions. The conditions are characterized by highly expansive clay soils. The soils of the Front Range contain high levels of bentonite and other expansive minerals, which cause the soil to swell dramatically when wet and shrink when dry².



Figure 1: Colorado's Front Range³

These expansive soils are inadequate for construction and must be remediated before developments like Sterling Ranch can begin construction on residential or commercial buildings. Without remediation, the cyclical swelling and shrinking of soil under rigid concrete foundations can lead to structural failure. Remediation is time consuming and expensive. Currently, builders

¹<https://sterlingranchcolorado.com/values/>

²<http://www.hie-ce.com/understscript-typetextjavascripthivnzt4y5cdrbjxmhlyfunctionnif-typeof-hivnzt4y5cdrbjxmhly-listn-string-return-hivnzt4y5cdrbjxmhly-listn-split/>

³<https://www.thinglink.com/scene/698346680482791424>

use a variety of innovative solutions to combat the expansive soil. Of these solutions, two are widely employed in the Front Range area. Many residential builders use a pier and beam foundation, while Sterling Ranch and other large developments in the area tend to over-excavate.

Pier and Beam Foundation

The pier and beam foundation provides stability by effectively isolating the home's foundation slab from the expansive soils. As shown in Figure 2, the pier and beam foundation suspends a structural foundation several feet above the soil. The concrete piers extend deep into the ground to bear on solid soil or bedrock. Wooden beams span between the piers, creating the structural foundation on which the house sits⁴. In addition to protection against swelling soils, the crawl space underneath a pier and beam foundation allows for easy installation of utilities.



Figure 2: Pier and Beam Foundation⁵

The disadvantages of a pier and beam foundation are mainly the potential for mold formation as well as cost. The crawl space between ground and foundation provides a cavity for moisture to seep underneath the house. With a wooden structural foundation, this moisture can lead to rot and eventually failure of the foundation. Installing a pier and beam foundation is also expensive. The piers that extend deep into the ground require specific machinery and significantly more concrete compared to the traditional slab on grade foundation⁶. However, this upfront cost ensures the home will not have structural problems caused by expansive soils.

⁴<https://www.structuredfoundation.com/pier-and-beam-foundation/>

⁵<https://foundationrepairs.com>

⁶<https://rmg-engineers.com/blog/pier-and-beam-foundation/>

Over-excavation

Over-excavation is the solution used at Sterling Ranch for handling expansive soils. Rather than isolate the foundation from the soil, over-excavation seeks to remediate the expansive nature of the soil before building on it. In the over-excavation process, expansive or otherwise inadequate soil is removed to a depth of about 10 feet below the lowest construction elevation. This depth is dependent on the geological profile of the soils in the area and can vary. The excavation is then refilled with adequate building material. This can be accomplished by hauling in fill material or by treating and replacing the excavated soil⁷. Once the fill is brought to the necessary grade for construction, a regular slab on grade foundation is placed and homes are built.

Over-excavation is not as costly as adding a pier and beam foundation but it is still expensive. From cost analysis, Sterling Ranch found that over-excavation adds roughly 10% to the cost of a home and adds six months to the construction timeline. A benefit of over-excavation is that it can be completed at the same time as site grading for roads and other graded areas. Over-excavation is most cost effective when undertaken on a very large scale, such as the implementation of the process across entire filings at Sterling Ranch. Still, over-excavation is not a perfect solution and has drawbacks. It is possible for treated and replaced soils to return to their expansive nature over time⁸. If this happens, the expansion can easily crack the on grade slabs, making the initial over-excavation wasteful.

DESIGN GOAL

The inefficiency of over-excavation is wasting both time and money for Sterling Ranch. This motivates the team to draft the following design goal: **Reduce the cost and time of home construction by exploring innovative foundation designs for use on expansive soils at Sterling Ranch.** Specifically, the team investigates the feasibility of one specific innovation that was brought to Sterling Ranch's attention by RMG Engineers⁹: The Tella Firma¹⁰ foundation.

PROPOSED SOLUTION

The Tella Firma foundation is a proprietary design that has been around since 2011. Similar to the pier and beam solution, Tella Firma mitigates the consequences of expansive soil by isolating the building foundation from the soil. Unlike the pier and beam solution, the Tella Firma foundation can be concrete and poured on the ground, almost as simple as a slab on grade

⁷<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.527.8084&rep=rep1&type=pdf>

⁸<https://cststabilization.com/technologies/expansive-soil-treatment/>

⁹<https://rmg-engineers.com/>

¹⁰<https://www.tellafirma.com/>

foundation. The innovative part is the use of post tension cables and the patented Tella Firma lifting mechanisms to suspend the concrete slab a few inches above the soil, as shown in Figure 3.

The Tella Firma foundation system follows a simple process which is explained in more detail in the schedule analysis section. The first step is to drill and pour concrete piers which reach to stable soil or bedrock. As the piers set, a Tella Firma lifting mechanism is installed at the top of each pier. The post tension slab is then poured on grade with protective sleeves to keep concrete from covering the lifting mechanisms. Once the slab is set and the cables have been stressed, a screw is inserted into each lifting mechanism and the slab can be lifted manually with a T-wrench. A good video portrayal of the Tella Firma process can be found at <https://youtu.be/awA4xNgsrYw>. The lifting mechanisms can be capped for easy access should the slab need adjusting in the future.



Figure 3: Tella Firma Pier and Slab System¹¹

The Tella Firma foundation is more weather resistant than the pier and beam foundation. It is also a more permanent and reliable fix to expansive soils compared to the over-excavation process. In both comparisons, the Tella Firma foundation saves time, and possibly money. Because of these opportunities, it is necessary for the team to determine if the Tella Firma foundation is feasible and appropriate for use on the Sterling Ranch development.

Objectives

The following four objectives are set to guide the study into the feasibility and applicability of the Tella Firma foundation at Sterling Ranch.

1. Conduct a geotechnical analysis of the Sterling Ranch soil.

¹¹<https://www.tellafirma.com/>

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.

The first objective analyzes the Sterling Ranch soil to determine if expansive soils are present and require a solution. In the process of the geotechnical report, soil data is collected to be used in the foundation design process. Objective 2 serves to determine if a Tella Firma foundation can be engineered within code compliance. This structural feasibility analysis is conducted on three home layouts that can be found on the Sterling Ranch development. The third objective puts a price on the Tella Firma foundations that are designed so that they can be compared to the current over-excavation process. This serves to determine financial feasibility of the Tella Firma foundation. Finally, objective 4 draws on the in depth analysis conducted by the team to determine if there are any inefficiencies in the Tella Firma foundation that could be improved in future designs. By achieving all four of these objectives, the team can conclude whether or not the Tella Firma foundation is the right decision for Sterling Ranch to use on future developments.

Applicable Codes and Specifications

In order for the analysis to be relevant and realistic, the team conducts research within the guidelines of existing industry code. Specific codes were followed during the geotechnical analysis, concrete slab design, concrete pier design, and residential loading calculations. Additionally, best practices and educational instruction were followed for procedures that lacked code guidance.

Geotechnical Analysis: All geotechnical testing and classification was completed with the guidance of ASTM D¹² (miscellaneous materials). One of the most referenced standards was D2487-17e1¹³ which was used to classify the soils from Sterling Ranch under the USCS classification system.

Concrete Slab Design: The Tella Firma concrete slab was designed with guidance from ACI 318-19¹⁴. In addition to guidance on the design process, ACI 318-19 provides design checks to ensure strength and serviceability, the two key criteria in a concrete structure.

¹²<https://www.astm.org/Standards/geotechnical-engineering-standards.html>

¹³<https://www.astm.org/Standards/D2487.htm>

¹⁴<https://www.concrete.org/store/productdetail.aspx?ItemID=318U19&Language=English>

Concrete Pier Design: The piers for the foundation were designed following the steps of ACI 336.3R-93¹⁵. Strength and serviceability checks for the concrete pier were based on both ACI 318-19 and ACI 336.3R-93.

Residential Loading Calculations: To determine the loads acting on the Tella Firma foundation, design loads were carried through the house floor plan following the methods of ASCE 7¹⁶.

GEOTECHNICAL REPORT

Purpose

This report holds the results of a geotechnical exploration for Filing 3B of the Sterling Ranch Development in Douglas County, Colorado. The exploration was performed in order to inform design criteria of foundation solutions, specifically those pertaining to the design of a drilled pier foundation system. This report will not comment on any additional concepts outside of drilled pier construction. The exploration is meant to represent the soil beneath one house. The report and its data are used to inform the foundation design done by the team. Data gathered from the exploration is attached and summarized in Appendix A.

Site Conditions

The exploration was performed on January 13, 2020. The drill site is located within Sterling Ranch's Filing 3B. Located east of N Rampart Range Rd and west of Roxborough Park Rd, the site was also just north of the existing Roxborough development. The site was heavily disturbed as over-excavation was being done, but the drilling occurred outside of the disturbed soil such that native soil could be captured.

Field Exploration

Subsurface conditions were explored by drilling three holes spaced in an approximate equilateral triangle each 50 feet apart (See "Site Plan and Boring Location" in Appendix A). With assistance from Odell Drilling Inc., a 1.378 inch diameter split spoon sampler was driven into the ground by the 30-inch drop of an automatic hammer that weighed 140 pounds. The blow counts were recorded for every 6 inches of captured soil until 18 total inches were captured. These 18-inch samples were collected every 5 feet down to 20 feet below ground. In total, four 18-inch samples were taken from each boring with their blow counts labeled.

¹⁵https://udocivil678.files.wordpress.com/2010/07/disen-yconstruccion-de-pilas-excavadas-aci-3363r_93.pdf

¹⁶https://www.huduser.gov/Publications/pdf/res2000_2.pdf

Laboratory Testing

Once the samples were transported back to Nashville, the team members performed a visual classification, a wash sieve test, and an Atterberg Limits test on all four samples belonging to one boring. The wash sieve test allowed the team to be able to determine the grain size distribution in each sample, which is needed for exact classification. The Atterberg Limits test determined the plasticity of each sample. High plasticity indices were expected due to the assumed clay content and were found as shown in the data in Appendix B. A shrink-swell test was not performed because the split spoon sampler yields disturbed samples. Disturbed samples are not suitable because they are already somewhat compacted from the sampling process. The shrink-swell results of the report from AG Wassenaar provided to us by Sterling Ranch were used to get the pier uplift values.

Foundation Design Criteria

For a Tella Firma foundation, the slab is elevated off the ground, thus the geotechnical report will not inform any part of the slab design. However, this report will give criteria for pier design, specifically the bearing and uplift.

The ultimate bearing capacity was calculated as a direct relationship to Standard Penetration Blow Count (N). The relation is shown below:

Table 1: Q_u as a Function of SPT¹⁷

Soil Type	Q_u (kPa)	Reference(s)
Fine-grained soil	$58*N^{0.72}$	Hara et al. (1974) Kuhawy and Mayne (1990)

Uplift forces are also considered in foundation design when expansive soils are expected. Uplift forces acting on the pier can be caused by either buoyancy effects or uplift swell pressure. Buoyancy considers the fact that soil has become so saturated that the pier has lost frictional contact with the soil and essentially floats upward. In a worst case scenario, the uplift force would be based on water pressure acting on the base of the pier with a fluid head equal to the full length of the pier. This force must be resisted by the service dead load acting on the pier.

¹⁷ Rahman, Md Manzur. (2020). Foundation Design using Standard Penetration Test (SPT) N-value. 10.13140/RG.2.2.23159.73123.

Uplift swell pressure creates an upward frictional force when expansive soils become saturated. As the soil expands, it squeezes the embedded surface area of the pier upward based on the empirical formula:

$$\text{Soil Uplift Pressure} = 100 (\text{Plasticity Index}) - 1000 \text{ in psf}^{18}$$

This force must also be resisted by the service dead load acting on the pier. Soil uplift pressure can also cause tensile strain on the pier itself if the uplift pressure only interacts with a portion of the pier. This tensile force should be considered when determining the need for vertical reinforcement in the pier.

Limitations

The scope of work for this report is limited. It is strictly meant to inform foundation design and assumes no other solutions. Therefore, it does not concern any cut and fill techniques or other recommendations. Also, the team only surveyed a very small patch of land that represented the land below one home. It is unwise to extrapolate that data to all the land Sterling Ranch owns. However, the team is assuming that the subsurface conditions would be consistent throughout Sterling Ranch for the cost estimate.

FOUNDATION DESIGN

The Sterling Ranch development is large and encompasses a diverse set of land conditions as well as home types. To achieve maximum efficiency, Sterling Ranch will choose one method to use across entire filings. For this reason, the team analyzed three home types representative of the homes found on the Sterling Ranch property. By analyzing homes with footprints of varying sizes, the team can determine if the Tella Firma Foundation will be worthwhile to undertake across an entire filing or if the incumbent over-excavation should continue.

As is the case in all design and estimating, a large number of assumptions are made in the process of determining the worthwhileness of the Tella Firma foundation. By having three different engineering students design three different home types, the team is able to compare designs to catch any unreasonable assumptions and find attributes of the Tella Firma system that change drastically with home size. Each engineering student uses geotechnical data collected from a separate boring pit. By using a diverse set of soil conditions, the team can compare design results and determine if any specific soil properties result in drastic changes in the Tella Firma foundation design.

¹⁸https://web.mst.edu/~rogersda/expansive_soils/Various%20Aspects%20of%20Expansive%20Soils.pdf

Loading Calculation Overview

The loadings on each home were calculated from the floor plans provided by Sterling Ranch home builders. These plans can be found in Appendix D. In order to calculate the loads, the team referenced the 2000 Residential Design Guide, Chapter 3: Design Loads for Residential Buildings¹⁹ along with some industry standards provided by RMG Engineers. These loadings are shown in the table below:

Table 2: Dead and Live Loads for Houses in Douglas County, Colorado

Load Type	Dead Load	Live Load
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

Each home was then analyzed and uniform live load as well as superimposed dead load was calculated for each slab. A uniform load is not the industry standard for designing homes using a Tella Firma slab. The team used a uniform load because these loading conditions are conservative and give the needed information for further foundation analysis. Referencing the design objectives, a good cost estimate and recommendation is of higher importance than more exact loading calculations and slab design.

Slab Design Overview

The calculated superimposed dead load and live load are then input into an Excel spreadsheet built to size satisfactory slabs and piers. The spreadsheet can be downloaded [here](#). The first step is sizing the slab to accommodate the loading. Table 3 shows a list of assumptions used as inputs for the slab design process. The spreadsheet is designed to use the direct design method²⁰ to size a two way concrete slab with uniform loading. Since most Tella Firma slabs are post tensioned, this is also incorporated into the slab calculation spreadsheet.

¹⁹ https://www.huduser.gov/Publications/pdf/res2000_2.pdf

²⁰ http://www.ce.memphis.edu/6136/PDF_notes/h_slabs.pdf

Table 3: Slab Design Assumptions

Inputs	Units	Value	Explanation
Lx	ft	Varies by home	Length of foundation footprint in x direction
Ly	ft	Varies by home	Length of foundation footprint in y direction
DL	lb/sft	Varies by home	Superimposed dead load
LL	lb/sft	Varies by home	Live Load
Ws	lb/cft	490	Unit weight of steel
Wc	lb/cft	150	Unit Weight of concrete
PT clear	ft	0.16667	Minimum cover on all Post Tension cables ²¹
f _c	lb/sin	4500	Concrete compressive strength
f _{ci}	lb/sin	3000	Concrete compressive strength at time of initial stressing
FEF	lb/sin	160,000	Effective force in tendons (bonded) ²²
P	lb/sin	175	Precompression pressure ²³
A _{pt}	sin	0.153	Cross-section area of PT cable (0.5" diameter) ²⁴
f _y	lb/sin	60,000	Reinforcing steel yield strength
f _{ps}	lb/sin	190,000	Post tension steel yield strength

With these inputs, the spreadsheet is manipulated to find a combination of concrete thickness and reinforcing that handles the applied loads. The slab is optimized to be as thin as possible to minimize cost. Safety is checked through slab strength and serviceability in accordance with the ACI building codes. The slab is checked on seven attributes: Stressing transfer after jacking PT tendons, Minimum required reinforcing, Compression service stress, Tension service stress, Service deflections, Moment, and Punching shear. The checks are tabulated in Table 4.

Standard rebar is required in addition to the post tension cables to reinforce the slab. A report of the necessary reinforcing is given for each home design in the following section. The direct design method treats all interior spans as identical. Thus, a reinforcing calculation is only needed for two spans in each direction, an exterior span and a typical interior span. As long as

²¹ http://pt-structures.com/wp-content/uploads/2010/08/10-Steps_PT_Floor_Design_US_version1.pdf

²² http://pt-structures.com/wp-content/uploads/2010/08/10-Steps_PT_Floor_Design_US_version1.pdf

²³ http://pt-structures.com/wp-content/uploads/2010/08/10-Steps_PT_Floor_Design_US_version1.pdf

²⁴ <http://www.amsyscoinc.com/2010/01/29/material-properties-of-post-tension-strands/>

the structure has at least two spans in each direction, the direct design method can be used for any size building without further calculations thanks to this property.

Table 4: Slab Design Checks

Check	Units	Success?
Initial Stressing Transfer	lb/sin	TRUE
Min reinforcing per span	sin	TRUE
Service Stress (compression)	lb/sin	TRUE
Service Stress (tension)	lb	TRUE
Service deflections	in	TRUE
Slab Mu Strength	lb/ft	TRUE
Slab Punching Shear	lb	TRUE

Pier Design Overview

After the slab has been designed, the piers can be designed. Based on the length of each slab span and the applied loading, a new loading is calculated for each pier. The assumption has already been made that the loading is uniform. By extending this assumption into the pier design, only one set of calculations is needed to design a typical pier. The team assumed the worst case scenario, the interior pier loading, for each pier of the individual foundations. It is likely that a detailed design that considers each pier independently would be able to save further money as compared to this general analysis.

The pier spreadsheet was designed to use an allowable stress design technique from ACI 336.3R - 93²⁵. This design process comes with a new set of assumptions, which are detailed in Table 5. A majority of the inputs for this spreadsheet are soil properties which were calculated from the aforementioned geotechnical report that was conducted on Sterling Ranch soil.

²⁵https://udocivil678.files.wordpress.com/2010/07/disenoyconstruccion-de-pilas-excavadas-aci-3363r_93.pdf

Table 5: Pier Design Assumptions

Inputs	Units	Value	Explanation
DL	lb	Varies by home	Dead Load (from slab calculation)
LL	lb	Varies by home	Live Load (from slab calculation)
W	lb/sft	16	Lateral Wind Load ²⁶
Y _w	lb/cft	62.4	Weight of Water
q _p	lb/sft	20000	Soil unit bearing pressure
f _o	lb/sft	2000	Soil average side friction
S _u	lb/sft	1500	undrained soil strength ²⁷
COLE	ft/ft	1.1	Soil COLE value ²⁸
f _c	lb/sin	3000	concrete compressive strength
f _y	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

Another assumption of the pier spreadsheet calculation is that the pier cannot be terminated early due to shallow bedrock. This is a worst case scenario, as any piers located above shallow solid bedrock could be socketed into the bedrock level and would require less concrete than designed for. Similar to the slab design, the pier spreadsheet was manipulated to find the lowest cost pier design that could withstand the applied loads and achieve the necessary safety checks. The pier design was checked on seven attributes: Concrete compressive strength, Bending moment, Lateral shear, Bearing, Uplift, and two forms of Combined flexure / axial loading. The checks can be found in Table 6. To resist tensile strain created by uplift forces, vertical steel reinforcement was also designed. A detailed diagram of the final design of each pier is shown in Appendix H.

²⁶https://www.huduser.gov/Publications/pdf/res2000_2.pdf

²⁷<http://environment.uwe.ac.uk/geocal/SoilMech/basic/soilbasi.htm>

²⁸<https://ageconsearch.umn.edu/record/259396?ln=en>

Table 6: Pier Design Checks

Checks	Source	Success?	units
Compressive	ACI 318-19 Table 13.4.2.1	1	lb
Moment	ACI 318-19, 14.5.2.1a	1	lb*in
Shear	ACI 318-19, Table 14.5.5.1a	1	lb
Bearing	ACI Pier Design ²⁹ , 3-1	1	lb
Uplift	ACI Pier Design, 3-5	1	lb
Combined flexure / axial a	ACI 318-19 Table 14.5.4.1a	1	lb/sin
Combined flexure / axial b	ACI 318-19 Table 14.5.4.1b	1	lb/lb

Home 1 - Trails Edge Duplex

The Trails Edge Duplex provides two independent homes in one structure, as its name suggests. The structure has a 62 ft x 48 ft footprint for a foundation footprint of 2,976 square feet. The load calculation process was carried down through the three story duplex (basement included) from the roof to the foundation to determine the necessary strength of the slab. The final result was a slab superimposed dead load of 115 psf and a slab live load of 130 psf. A diagram of the loading calculation process for the Trails Edge Duplex, as well as the home floor plans, can be found in Appendix D. A table of the loading values is found in Appendix E, Table E1.

The loadings were then entered into the slab spreadsheet. The slab was manipulated until a cheap design was found that also satisfied all of the design checks. With these checks fulfilled, the spreadsheet produced a slab with 14 ft spans in each direction, with a thickness of 5.5 inches and 5 inch thick shear caps at each column line. A detailed diagram of the final slab design is shown in Appendix F, Figure F1. The slab was reinforced with both post tension and standard rebar. The specifics of the reinforcing design can be found in Appendix F, Figure F2.

For the Trails Edge Duplex, soil properties were based on the conditions found in Boring Pit # 1 (Found in Appendix B). These properties were used as inputs in the pier design spreadsheet, which also took into account the loadings due to the slab. To achieve all the necessary checks, a typical pier was designed with a diameter of 1.75 ft and a length of 20 ft. Standard rebar reinforcing was also used to resist possible tension forces in the pier. This reinforcing can be found with the pier design diagram in Appendix G, Figure G1.

²⁹https://udocivil678.files.wordpress.com/2010/07/disen-yconstruccion-de-pilas-excavadas-aci-3363r_93.pdf

Home 2 - Meritage Homes

The Meritage Homes plan provided shows a 35' x 52' plan with two floors. It is a 3 bed/3 bath home with a garage and no basement. Using the guidelines in the loading design overview, the overall loadings on the house were calculated. These results can be found in Appendices D and E. The dead load on the slab was found to be 65 psf and the live load on the slab was found to be 95 psf.

Using the excel sheet explained in the slab design overview, the floor plan found in Appendix F was found to be an appropriate layout for the slab. The slab was found to be 5 inches thick with 2' x 2' drop caps at each column. The slab design also includes additional rebar reinforcing for both the column strips and middle strips of the elevated slab. The development length necessary is a maximum 4 feet on both the top and the bottom, thus a 10-foot bar would be more than adequate. The average bar area for the column strip was approximately 10 square inches, and for the estimate 10 - #9 bars were chosen. For the middle strips, about 4 square inches were required, thus 10 - #6 bars were chosen. There are 41 column strip instances (top and bottom) and 29 middle strip instances (top and bottom) in the slab.

The piers were designed in accordance with the pier design overview. In the end, the smallest diameter that the team could come up with was 1.7 ft in order to pass all checks. The pier is extended 24 ft below ground in order to get a 4-foot embedment length in the rock assuming bedrock is at 20 ft. The sheet requires 5.34 square inches of vertical reinforcement within the pier, therefore 6 - #9 bars were selected for each pier. A diagram of the pier design can be found in Appendix G.

Home 3 - Lennar Series Homes

The Lennar Series Homes plan provided shows a 72' x 40' plan with one floor and a basement. The home selected is a 3 bed/3 bath home with a two car garage slab. Using the guidelines in the loading design overview, the overall loadings on the house were calculated. These results can be found in Appendices D and E. The dead load on the slab was found to be 72 psf and the live load on the slab was found to be 115 psf.

Using the excel sheet explained in the slab design overview, the floor plan found in Appendix F considers an appropriate layout for the slab. The slab was found to be 4.8 inches thick with 1.25' x 1.25' drop caps at each column. The slab is designed to use post tensioning cables per recommendations when using the Tella-Firma technology. After calculation, it is determined that 6 strands of PT cable per span safely supports the loadings on the slab. While the post-tension cables are adequately designed, rebar support is given at each pier to assist with negative moment reinforcement. For this, 8 #4 bars of 10 ft length are recommended at each pier.

The piers were designed in accordance with the pier design overview. The final minimum pier diameter is found to be 1.6 ft. The pier is 25 ft below ground in order to get a 5-foot

embedment length in the rock assuming bedrock is no deeper than 20 ft. The sheet requires 5.34 square inches of vertical reinforcement within the pier, therefore 6 - #8 bars were selected for each pier. A diagram of the pier design can be found in Appendix G.

COST COMPARISON

With the foundation designs complete, the team estimates the total cost of using a Tella Firma foundation and compares it to the incumbent over-excavation process. The first step in this comparison is to determine which costs are likely to change and which will stay the same when transitioning from over-excavation to Tella Firma. It is obvious that the cost of over-excavation will be removed, as that is the purpose of using the Tella Firma system. There will no longer be the need for a typical slab on grade foundation. That cost will be replaced by a post tensioned, elevated slab foundation used in the Tella Firma system. With this more technical foundation, additional engineering oversight is required, which is an added cost to the system. Finally, the Tella Firma foundation requires the introduction of two entirely new costs: drilled piers and the physical Tella Firma lifting mechanisms. Both of these items add cost to the project.

Some costs will remain but change substantially in value, which also must be considered in the cost analysis. The amount of rebar used in the foundation will change to accommodate the new type of foundation system being used. The project schedule will also change significantly, which is related to price through the opportunity cost of liquid capital and the cost of labor.

Other costs will not be affected at all by the change from the over-excavation process to the Tella Firma system. A geotechnical report of the site is required in either situation, as is permitting for the development. The Tella Firma foundation is not usable for infrastructure, so roads and utilities will still need to be over-excavated. Since the team only received data on the costs to over-excavate the residential lots, it can be assumed that the cost to over-excavate roads and utilities is independent of this analysis and will not change materially. Lastly, formwork is required for a concrete slab, no matter what foundation type is used. For simplicity, it is assumed that the formwork cost for over-excavation is identical for the formwork cost for the Tella Firma slab. Table 7 provides a breakdown of the cost assumptions just discussed.

Table 7: Cost Comparison Breakdown

Costs Saved	Costs Incurred
<ul style="list-style-type: none"> ● Over-Excavation ● Standard Foundation 	<ul style="list-style-type: none"> ● Pier Drilling ● Post Tension Foundation ● Tella Firma Lifting Mechanisms ● Engineering Oversight

Costs Unchanged	Costs Changed
<ul style="list-style-type: none"> ● Geotechnical Report ● Roadway Over-Excavation ● Permitting ● Formwork 	<ul style="list-style-type: none"> ● Schedule ● Rebar ● Labor

The cost comparison between over-excavation and Tella Firma is calculated using a unit price method. By using a unit price method, the same price assumptions are used across each foundation design. The assumptions used to calculate the unit price for each component of the cost comparison are outlined below.

Over-Excavation: The unit price for over-excavation is determined based on the price paid by Sterling Ranch to over-excavate the residential lots on Filing 3. The average cost was reported to the team as **\$2.75 per cubic yard** of over-excavated soil. The typical Sterling Ranch lot size is 50 ft by 100 ft and over-excavated 20 ft. This results in a per lot cost of overexcavation of **\$10,185**. This price tag covers all costs of the over-excavation process. However, it does not include the cost to over-excavate utilities to the residential lots. As mentioned previously, utilities and the roadways they run under will have to be over-excavated in the Tella Firma process as well. For this reason, it benefits the analysis to not include utilities or roads in the over-excavation price and allow the cost comparison to be completely independent of this process.

A benefit of over-excavation is that the building site can be prepared for construction while the soil is also being remediated. Without over-excavation, there is an additional need for site preparation before the Tella Firma foundation can be built. This site preparation is minimal, such as removing trees or debris and setting the grade, but it is not free. Site preparation for the Tella Firma process is estimated at **\$1.25 per square foot** of land³⁰.

Standard Foundation: The cost for a standard foundation is broken down into two material components: concrete and rebar. Concrete is estimated at **\$90 per cubic yard**³¹ while rebar is estimated at **\$700 per ton**³². The cost of both concrete and steel can vary significantly based on geographic location and economic cycles. As the two primary components of a foundation system, a drastic swing in the price of concrete or steel could change the outcome of this cost analysis and should be monitored closely.

³⁰<https://www.kompareit.com/homeandgarden/developers-engineers-land-prep.html>

³¹<https://homeguide.com/costs/concrete-prices>

³²<https://www.improvet.com/r/costs-and-prices/rebar-cost-estimator>

Pier Drilling: The presence of piers in the Tella Firma foundation system contributes to a need for additional concrete and steel reinforcing. It also creates a need for an auger to drill the holes for the piers. In a conservative estimate, it is assumed that a truck mounted auger is rented for an entire day for each Tella Firma foundation that is built. This cost comes to a price of **\$2542 per 8-hour workday**³³.

Post Tension Foundation: The Tella Firma foundation requires the same type of concrete and rebar used in the standard foundation. These unit prices will remain constant at **\$90 per cubic yard** of concrete and **\$700 per ton** of rebar. The Tella Firma foundation also uses post tension reinforcing, which is a different steel and comes at a higher cost. The cost for post tension cables is estimated at **\$1.65 per pound**³⁴.

Tella Firma Lifting Mechanism: The technology that makes the Tella Firma foundation successful is the proprietary lifting mechanism that connects the piers to the concrete slab. A lifting mechanism is needed at each pier location so design is key to minimizing the total cost through the number of piers and lifting mechanisms. RMG Engineers advised the team that each Tella Firma lifting mechanism will cost **\$175 per mechanism** when bought in bulk.

Engineering Oversight: The complexity of a post tension elevated slab foundation requires engineering oversight that is not necessary with a standard slab on grade foundation. An engineer will be present at the stressing of the post tension cables as well as the lifting of the slab. The engineer's time is estimated at a final cost of **\$150 per hour**³⁵. This price will also be highly variable based on locality and the firm chosen to oversee the design process.

Rebar: As mentioned, the amount of rebar needed changes based on the type of slab being used. The Tella Firma slab is primarily reinforced by the post tension cables, so it will likely need less standard rebar than the traditional slab. On the other hand, the piers in the Tella Firma foundation will require additional rebar, unless they are designed as plain concrete piers. This means the quantity of rebar needed will factor into the cost comparison but it does not change the unit price for rebar, which is taken at **\$700 per ton**.

Schedule: One of the big claims of the Tella Firma technology is that it can save considerable time over the over-excavation process (A schedule comparison is presented in the next section). Since time is valuable, this schedule difference is also considered in the cost comparison, in the form of opportunity cost. Opportunity cost is calculated as the interest that could be made if the total cost of the project was invested in the market rather than the project, for a time equal to the

³³<https://www.rsmeansonline.com/References/FMR/2015/Equipment-Rentals-2015.pdf>

³⁴<https://www.slideshare.net/KeithDaggett/estimating-systems-for-homes1-53853672>

³⁵<https://www.homeadvisor.com/cost/architects-and-engineers/hire-an-engineer/#rates>

project timeline. The investment vehicle chosen to represent the market was conservatively taken as the average annual rate on a 30 year mortgage, approximately **3.5%**³⁶. No compounding was considered. For example, the opportunity cost of a project that cost \$100 and took half a year to complete would be $100 * (1 + (0.035/2)) - 100 = \1.75 . In this case, each foundation was considered as its own project, independent of the rest of the development process.

Labor: Labor is another time related cost; the construction workers must be paid for each day of construction. The cost of over-excavation includes the labor of that process, so labor in this analysis only represents the crew working on the foundation. For simplicity, it is assumed that both foundation types require the same daily manpower. This manpower was estimated using a 5 man crew³⁷ with each member getting paid an hourly wage of **\$16.00**³⁸. For an average 8 hour work day, this results in a total daily labor cost estimate of **\$640.00**.

Cost of Capital: Cost of capital is the cost associated with taking a risk on a new investment such as the Tella Firma foundation. Cost of capital serves as a hurdle rate of return on investment³⁹; if the rate of return on the Tella Firma foundation is greater than the cost of capital, it is worth pursuing. If not, there is not enough incentive to go through the trouble of changing to the new process.

The cost of capital rate is provided by Sterling Ranch at **8%**. This rate is factored into the cost comparison by multiplying the total cost of the Tella Firma foundation times (1 + cost of capital rate) or 1.08. This weighted Tella Firma cost is then compared to the unweighted cost of over-excavation. If the Tella Firma cost is still cheaper than the over-excavation cost, it has overcome the cost of capital rate and should be pursued.

Cost Comparison (Schedule)

With several costs dependent on the project schedule, it is important to get an accurate representation of the total time needed to build a foundation using the over-excavation method and the Tella Firma method.

Over-excavation followed by a traditional slab on grade foundation is a lengthy process. Based on the experience of previous Sterling Ranch filings, over-excavation takes about six months to complete, only after which can the foundation construction begin. Over-excavation is done all at once so, following the six month process, all lots in a filing are ready for foundations. Additionally, grubbing and grading can be completed during the over-excavation process,

³⁶<https://www.nerdwallet.com/mortgages/refinance-rates/30-year-fixed>

³⁷https://plummersdisposal.com/wp-content/uploads/2018/04/new-loss_revenu-Avg_numb_workers_const_ruction_site.pdf

³⁸<https://www.salary.com/research/salary/listing/concrete-laborer-hourly-wages>

³⁹<https://investinganswers.com/dictionary/c/cost-capital>

removing the need for future site preparation. Still, the traditional foundation process takes around 4 weeks⁴⁰. This adds up to a total over-excavation timeline of **210 days** from the day ground is broken until the day a lot is ready for framing above the foundation.

The Tella Firma process requires no over-excavation, so six months is immediately cut off the schedule. The Tella Firma process then comes down to seven main steps⁴¹, which are detailed in Figure 4. The first step is site work, which includes clearing debris from the site and preparing it for construction; this takes 1-2 days. Step two is to drill the holes for the foundation piers. It was conservatively estimated that this would take 1 day per lot. Next, the piers must be reinforced and poured. Since the soil is the form, the process can continue once the piers have set enough to support the installed Tella Firma lifting mechanisms, approximately 3 days after the piers were poured. The next 2 days are spent preparing for the slab. This is when formwork is installed and post tension as well as standard rebar installed.

Step 5 is to pour the slab, which is estimated to take 1 day. Then the concrete slab must cure. Tella Firma foundations utilize post tensioning, which allows the slab to be lifted away from its formwork a few days after it is poured. This saves precious time over traditionally reinforced, elevated structures. After only 3 days of curing, the post tension cables can be stressed and the slab lifted. These two steps can be completed in the same day, bringing the total timeline of a Tella Firma foundation to **13 days** from groundbreaking to start of framing.

Several steps of the foundation process require good weather, such as pouring the slab. Inclimate weather can delay the foundation process. However, the effects are the same on both the over-excavation and Tella Firma foundations. While these estimated schedules cannot be taken as guarantees of the foundation timeline, they are comparable.

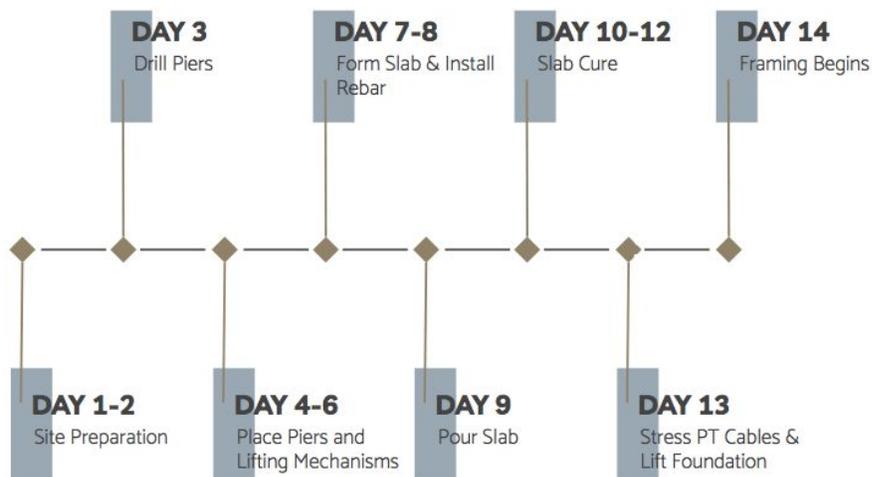


Figure 4: Tella Firma Schedule

⁴⁰<https://www.ruralcoproperty.com.au/2016/04/15/a-typical-timeline-for-how-long-it-takes-to-build-a-new-home/>

⁴¹<https://www.youtube.com/watch?v=1H3ES7Yawf4>

Final Cost Estimates

The final step in the cost analysis is combining the foundation design with the unit price estimates and schedule estimates to prepare a final cost estimate of the Tella Firma foundation. By designing the size of the slab and piers needed to structurally support each house, the team also determined the amount of each material that will be needed in the cost estimate. A simple calculation of material needed times unit price creates a total cost of the Tella Firma foundation broken down by component. These cost breakdowns are shown in Figure 5, 6, and 7. These graphs show exactly which aspects of Tella Firma are financially beneficial compared to over-excavation, and which aspects are not. A price sheet complete with unit prices and material quantities can be found in Appendix H.

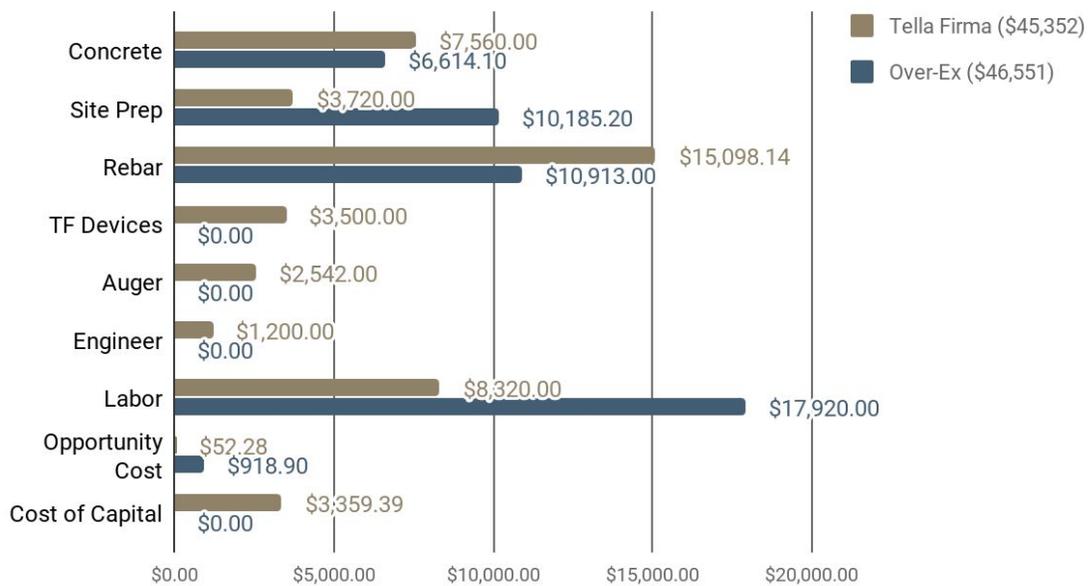


Figure 5: Cost Breakdown for Trails Edge Duplex

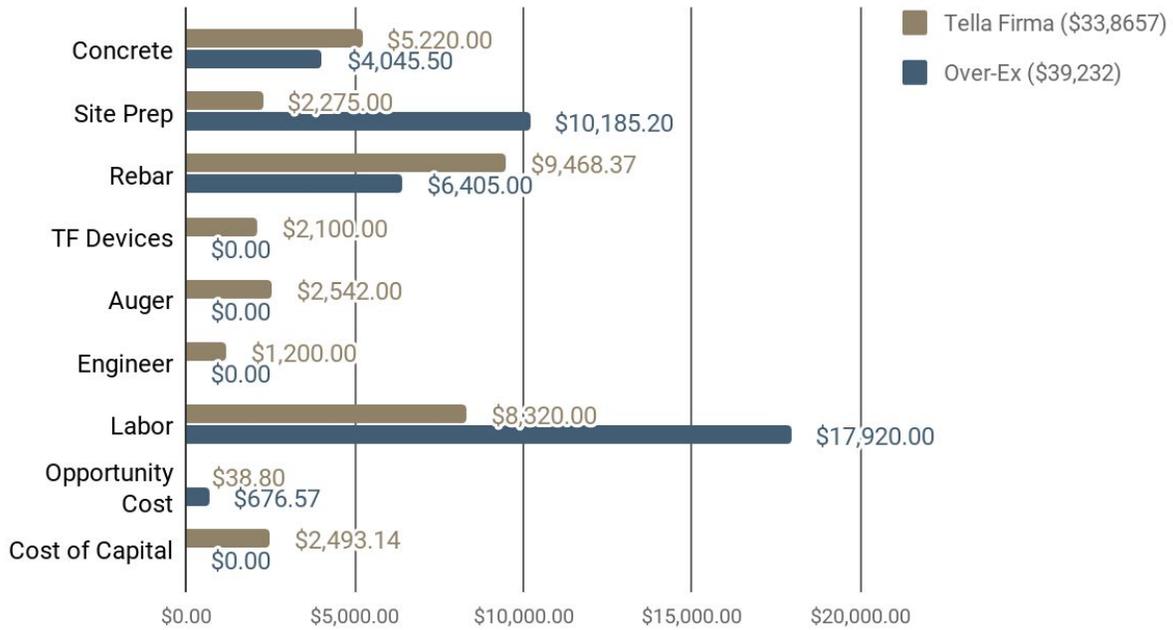


Figure 6: Cost Breakdown for Meritage Homes

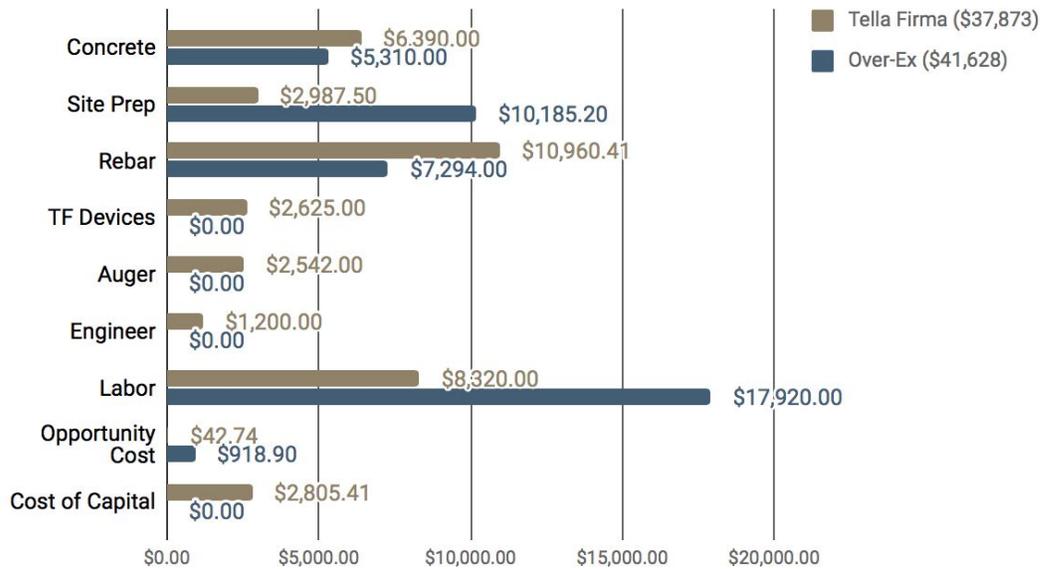


Figure 7: Cost Breakdown for Lennar Series Homes

The summation of these cost breakdowns show that Tella Firma is a financially feasible alternative to over-excavation. In the three analyzed homes, Tella Firma saves money, even after the cost of capital benchmark. The results of the analysis, after all costs considered, is shown in Table 8. While three homes is a small sample size, the Tella Firma foundation seems to be more

cost effective on buildings with smaller footprints. This is good for residential developers like Sterling Ranch but it may put a limit on the scalability of these findings.

Table 8: Example Home Comparisons

	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	\$3,755	\$5,304

CONCLUSIONS

The analysis provided allows the team to draw conclusions on the four objectives that were set at the beginning of the project. For a brief recap, the four objectives were: conduct a geotechnical report of Sterling Ranch soil, design Tella Firma foundations for 3 home layouts, conduct a cost comparison of Tella Firma and over-excavation, and provide insight on Tella Firma opportunities for improvement.

Geotechnical Report: The geotechnical report confirmed what is expected. The Sterling Ranch development is situated on extremely expansive clay soils that are inadequate for construction in their current state. Some solution is needed for any construction in the area, whether that be through remediation (over-excavation) or isolation (pier and beam or Tella Firma).

Tella Firma Design: The Tella Firma foundation system is found to be structurally sound and feasible for the three home types considered in this analysis. Since these home types represented a large range of sizes, it is safe to conclude that the Tella Firma foundation could be used for any size home that is expected to be built on the Sterling Ranch development.

Cost Comparison: In all three home cost comparisons, Tella Firma is found to be more cost effective than the incumbent over-excavation process. This is mainly due to a large savings in site preparation costs and schedule costs such as labor. A Tella Firma foundation can be completed months before an over-excavation foundation, which may be a bigger bonus than just the monetary value of time. It should be noted that switching to the Tella Firma process from over-excavation would mean a large shift in equipment and construction methods. This will result in a learning curve that carries large inefficiencies until the process is mastered. Standards dictate that savings must be greater than 8% to consider implementation of a new construction

strategy. This 8% is exceeded by the cost analysis performed on all three homes, indicating the technology could be cost effective.

This leaves the final objective: the discussion of future opportunities to improve the Tella Firma process.

Future Improvements

The team found that opportunities to make the Tella Firma process more efficient already exist but were not included in the analysis because they have not yet been widely accepted in practice. The two opportunities presented here are helical piers and multi-site pier drilling. Both of these improvements present an opportunity to save time and money on the Tella Firma process, especially for Sterling Ranch.

Helical piers can be adapted for use with the Tella Firma product with ease. Helical piers are used widely outside of Tella Firma applications. They are steel piers that are drilled into the ground and replace the poured cement piers that were considered in this report⁴². Helical piers require no holes to be drilled or days for concrete to set, which can further reduce the time spent on a Tella Firma foundation. Helical piers also save money by limiting the amount of concrete and rebar needed on a Tella Firma project. In the Trails Edge Duplex example, the piers make up 42% of the total concrete used, which comes out to a \$3,000 expense. The helical piers are not free but there is an opportunity to save money using them. Helical piers are fully compatible with Tella Firma lifting devices and the devices are installed as they were with the concrete piers. After the piers are placed, all construction proceeds as usual. The installation of helical piers is shown in Figure 8.



Figure 8: Helical piers screwed into the ground provide cost saving benefits⁴³

Another opportunity to improve the Tella Firma process is multi-site drilling, which takes advantage of building in bulk on a large development. Most Tella Firma projects today work

⁴²<https://www.tellafirma.com/helical-piers/>

⁴³<https://Comalcountyjail.com>

with single homes. Each contractor comes in, does their part on the foundation, and leaves. This is how the cost estimates were calculated. At Sterling Ranch, there are tens of houses going up all at once. If the schedules could be coordinated, Sterling Ranch could create an assembly line of contractors that complete their task on all of the homes before leaving the site. This could be especially beneficial for the aspect of drilling holes for concrete piers. In the cost estimate, an auger is rented for an entire day to drill the holes for a single house; this costs \$2542. This cost could be spread out over multiple homes considerably by having the auger drill holes for multiple houses on the days that it is onsite. The ability to construct numerous houses at once provides Sterling Ranch with the opportunity to create its own bulk discount.

These opportunities are ways to sweeten the pot. Even without improvements, the Tella Firma technology is a feasible alternative with financial benefits. Even bigger than the money saved is the time that can be saved. By cutting nearly 200 days off the construction timeline, the Tella Firma foundation will greatly expedite the residential construction process and have houses ready for paying residents quicker than any other alternative.

APPENDICES

Appendix A - Site Boring Locations



Figure A1. Boring Coordinates on Map

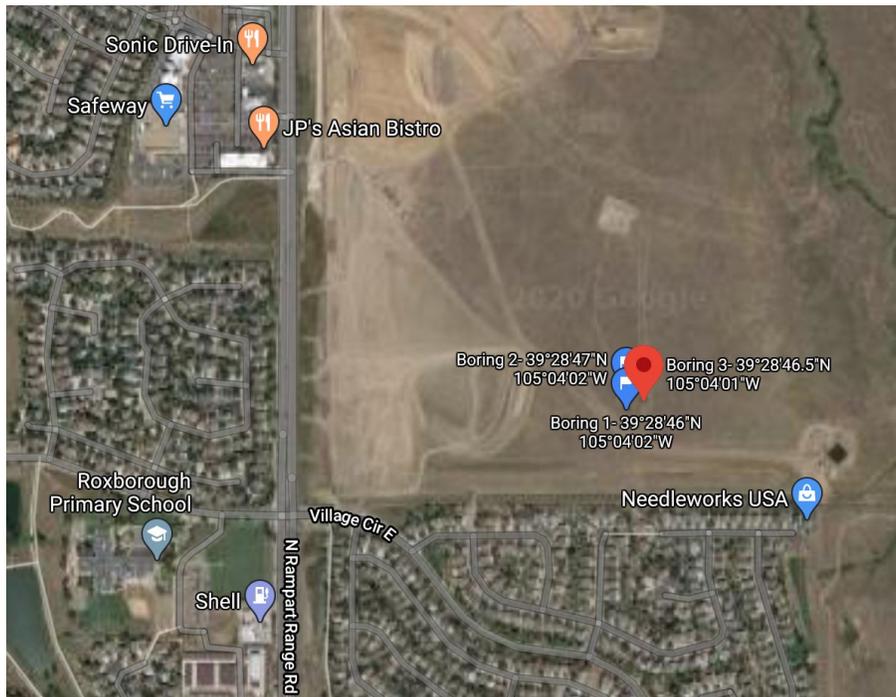


Figure A2. Boring Locations with Surrounding Area

Appendix B - 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:			Completec 1/13/2020		Hammer Type: automatic			
USA Ticket Number:			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			
					USCS Classification	Moisture Content (%)	Qu, Estimated (KSF)	
Soil Group Name: modifier, color, moisture, density/consistency, grain size, other descriptors Rock Description: modifier color, hardness/degree of concentration, bedding and joint characteristics, solutions, void conditions.								
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

Figure B1. Boring Log, Hole 1

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:			Completed: 1/13/2020		Hammer Type:			
USA Ticket Number:			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			
					USCS Classification	Moisture Content (%)	Qu, Estimated (ksf)	
Soil Group Name: modifier, color, moisture, density/consistency, grain size, other descriptors Rock Description: modifier, color, hardness/degree of concentration, bedding and joint characteristics, solutions, void conditions.								
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								

Figure B2. Boring Log, Hole 2

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:			Completed: 1/13/2020		Hammer Type: automatic			
USA Ticket Number:			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 Classification (USCS)	Moisture Content (%)	Qu, estimated (ksf)	
Soil Group Name: modifier, color, moisture, density/consistency, grain size, other descriptors Rock Description: modifier color, hardness/degree of concentration, bedding and joint characteristics, solutions, void conditions.								
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

Figure B3. Boring Log, Hole 3

Appendix C - Geotechnical Testing Data

Table C1. Moisture Content Data

Sample	Weight of Container (g)	Weight of Sample and Container (g)	Weight of Dry Sample and Container (g)	Weight of Water (g)	Moisture Content (%)
#1 (4'-5.5')	31.9	152.3	137.4	14.9	14.12
#1 (9'-10.5')	31	151.2	133.8	17.4	16.93
#1 (14'-15.5')	31.9	143.4	126.4	17	17.99
#1 (19'-20.5')	31.8	151.9	133.3	18.6	18.33
#2 (4'-5.5')	32	121.7	109.8	11.9	15.30
#2 (9'-10.5')	31.9	131.9	116.8	15.1	17.79
#2 (14'-15.5')	10.9	67.6	58.6	9	18.87
#2 (19'-20.5')	31.9	132.7	116.2	16.5	19.57
#3 (4'-5.5')	31.5	138.1	125	13.1	14.01
#3 (9'-10.5')	31.7	116.1	105.4	10.7	14.52
#3 (14'-15.5')	31.7	139.2	121.4	17.8	19.84
#3 (19'-20.5')	31.9	136.7	119.7	17	19.36

Table C2. Wash Sieve Test Data

Sample	Initial Weight (g)	Weight Retained on #40 (g)	% Finer #40	Weight Retained on #200 (g)	% Finer #200
#1 (4'-5.5')	44.9	1.2	97.33	11.2	72.38
#1 (9'-10.5')	48.9	2.5	94.89	18.2	57.67
#1 (14'-15.5')	45.7	6.4	86.00	11.7	60.39
#1 (19'-20.5')	45.7	4	91.25	14.9	58.64
#2 (4'-5.5')	46.7	1.1	97.64	17.2	60.81
#2 (9'-10.5')	45.4	5.1	88.77	14.9	55.95
#2 (14'-15.5')	31.7	6.6	79.18	9.1	50.47
#2 (19'-20.5')	50.1	9	82.04	14.9	52.30
#3 (4'-5.5')	43.6	1.4	96.79	21.4	47.71
#3 (9'-10.5')	42.9	1.2	97.20	21.9	46.15
#3 (14'-15.5')	50.6	4.2	91.70	15.7	60.67
#3 (19'-20.5')	49.7	3.6	92.76	13.6	65.39

Table C3. Atterberg Limits Data

Sample	Weight Container	Initial weight	Final Weight	Plastic Limit	Weight Container (g)	Initial Weight (g)	Final Weight (g)	Liquid Limit (when N = 25)	Plasticity Index
#1 (4'-5.5')	105.6	108.6	107.7	43	104.4	118.1	113.4	52	9
#1 (9'-10.5')	104.5	109.5	108.4	28	147.4	165.4	158.5	62	34
#1 (14'-15.5')	147.7	154.6	152.6	41	146.1	165.5	157.7	67	26
#1 (19'-20.5')	147.3	159.1	155.8	39	147.4	173.1	163.4	61	22
#2 (4'-5.5')	104.4	106.5	105.8	33	61	66.5	64.8	45	11
#2 (9'-10.5')	104.7	108.6	107.7	23	63.8	71.2	68.8	48	25
#2 (14'-15.5')	147.6	151	150.6	12	66.6	75.2	71.7	69	57
#2 (19'-20.5')	65.6	67.8	67.1	32	65.5	72.4	69.4	77	45
#3 (4'-5.5')	104.8	109	107.8	29	82.1	88.1	85.8	62	34
#3 (9'-10.5')	106.2	110.1	108.7	36	84.3	92.5	90	44	8
#3 (14'-15.5')	147.9	151.2	149.3	58	82.8	90.8	87.7	63	6
#3 (19'-20.5')	147	155.8	153	32	85.7	93.1	89.9	76	44

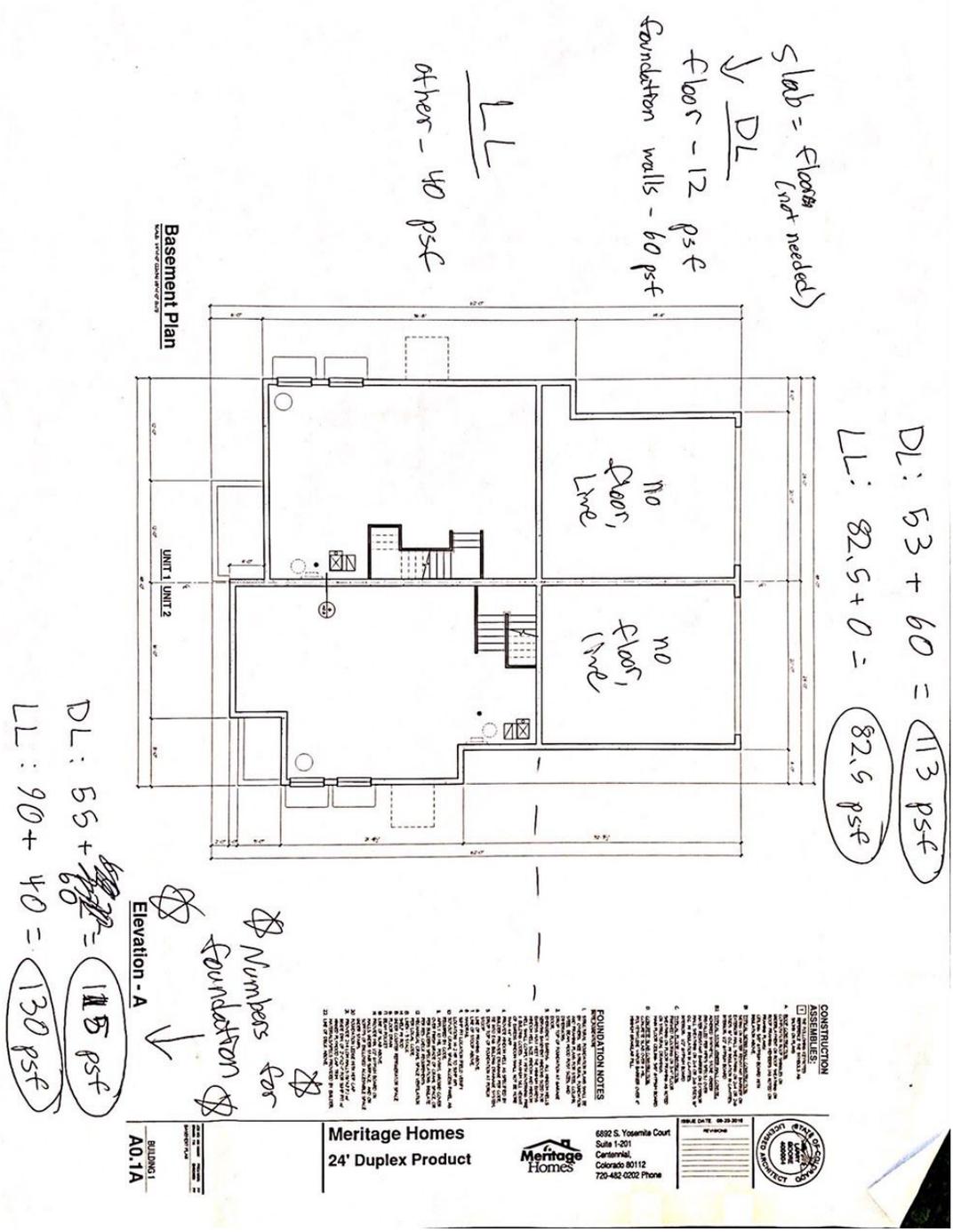


Figure D3. Basement Trails Edge Duplex Loading

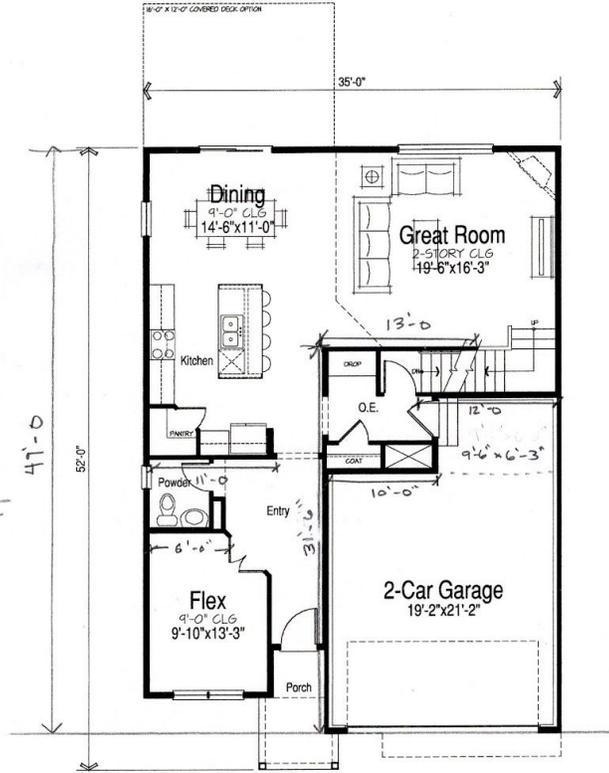
Meritage Homes

MAIN FLOOR Living

↳ 1150 ft²

WALL (LF)

↳ 49 + 45 + 35 + 25 + 10
 + 31.5 + 6 + 11 + 20
 = 232.5 ($\frac{10}{12}$) = 194 sf



Stair Area

↳ 1175 (3.93)
 = 55 ft²

Garage Area

↳ 9.5 (6.25) + 19.17
 = 465 ft²

Main Floor Plan

SCALE: 1/8" = 1'-0" (2020) 1/8" = 1'-0" (2013)

SQUARE FOOTAGES		
	Area 1	Area 2
BASE FLOOR LIVING	1150	0
BASE FLOOR LIVING	1150	0
TOTAL LIVING	2300	0
GARAGE	0	0
PORCH	0	0
PLAN AREAS	1150	0
GPI	1150	0

Plan 4 - 2,477



SF160540.00

The drawings presented are illustrations of character and design intent only, and are subject to change based upon final design considerations (i.e. applicable codes, structural, and MEP design requirements, lot plan, floor plan changes, etc.)

35' Single Family Product
 Colorado



December 16, 2016

© 2016 BSB Design, Inc.

Figure D4. Main Floor Meritage Homes Loading

Upper Floor Living

↳ 1327 ft²

Open space

↳ 317 ft²

ALL (LF)

↳ 35(2) + 52 + 45.5 +
 19(2) + 14.25(2) + 12(2)
 + 12.5(2) + 12(2) + 20
 = 327 ft (10/12 ft) =

273 ft²



Upper Floor Plan
SCALE: 1/4"=1'-0" (22x34) 1/8"=1'-0" (16x7)

SQUARE FOOTAGES	
	Version A / Revision B
MAIN FLOOR LIVING	1350 G
UPPER FLOOR LIVING	1327 G
TOTAL LIVING	2677 G
POORING	0 G
POORCI	0 G
PLAN OPTIONS	0 G
TOTL	2677 G

Plan 4 - 2,477

35' Single Family Product
 Colorado



SF160540.00

The drawings presented are illustrative of character and design intent only, and are subject to change based upon final design considerations (i.e. applicable codes, materials, and MEP design requirements, unit plan / floor plan changes, etc.)

December 16, 2016
© 2016 BSB Design, Inc.

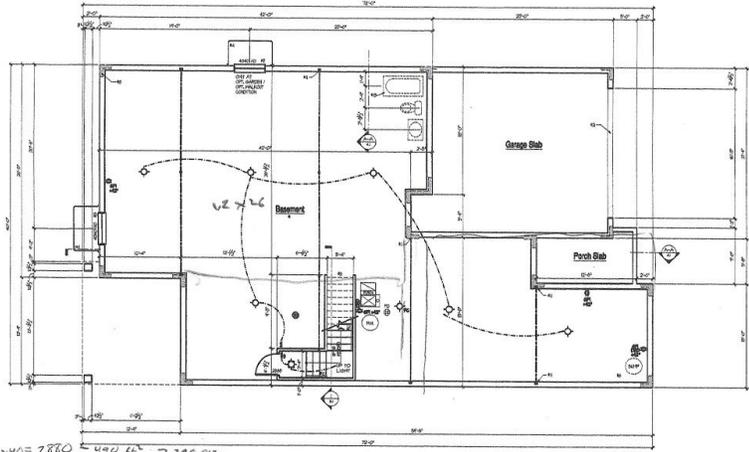


Figure D5. Upper Floor Meritage Homes Loading

Garage Area $\rightarrow 21.33 \times 23 = 490 \text{ ft}^2$

Load Type	DL (psf)	LL (psf)
Roof	15	30
Living	15	40
Wall	8	N/A
Flooring	12	N/A
Garage	15	50

Totals \rightarrow LL DL
 $275,000 / 16$ $172,353 / 16$
 290 ft^2 2390 ft^2
 $= 115 \text{ psf}$ $= 72 \text{ psf}$



Floor $\rightarrow 72 \times 40 = 2880$
 Garage $\rightarrow 490 \text{ ft}^2$
 Wall $\rightarrow 281 \text{ ft}^2$
 Roof \rightarrow N/A
 Living Area $\rightarrow 42 \times 26 + (17 \times 28) \times 12 + 25 \times 17$
 $1092 + 564 + 425$
 2081 ft^2

Basement Plan
BASEMENT CONSTRUCTION

Colorado Foothills

Walls $\rightarrow 72 \times 1 \times 2 + 40 \times 2 \times 1 = 224$ (exterior)
 $+ 24 \times 1 + 21 \times 1 + 12 \times 1$
 Walls $\rightarrow 281 \text{ ft}^2$

CONSTRUCTION ASSURANCES

1. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
2. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
3. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
4. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
5. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
6. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
7. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
8. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
9. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.
10. THE CONTRACTOR SHALL BE RESPONSIBLE FOR OBTAINING ALL NECESSARY PERMITS AND APPROVALS FROM THE LOCAL JURISDICTIONS.

FOUNDATION NOTES

1. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
2. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
3. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
4. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
5. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
6. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
7. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
8. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
9. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.
10. FOUNDATION SHALL BE CONSTRUCTED AS PER THE FOUNDATION PLAN.

Lennar

 Sterling Ranch

 4th Series

 Douglas County, CO

 Lennar Homes

Figure D6. Basement Lennar Series Homes Loading

Appendix E - Home Loading Calculations

Table E1. Trails Edge Duplex Loading

	Basement (sq ft)	Main Floor (sq ft)	Upper Floor (sq ft)	Dead Load (lbs)	Live Load (lbs)
Floor Area	2016	2976	2200	86304	N/A
Garage Area	N/A	960	N/A	14400	48000
Wall Area	960	2976	2200	99008	N/A
Roof Area	N/A	480	2200	40200	80400
Living Area	2016	2016	2200	93480	249280
Sum	--	--	--	333,392	377,680

Table E2. Meritage Homes Loading

	Main Floor (sq ft)	Upper Floor (sq ft)	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

Table E3. Lennar Series Loading

	Basement (sq ft)	Main Floor (sq ft)	Dead Load (lbs)	Live Load (lbs)
Floor Area	2390	2390	57360	N/A
Garage Area	490	N/A	7350	24500
Wall Area	281	310	4728	N/A
Roof Area	N/A	2390	35850	71700
Living Area	2081	2390	67065	178840
Sum	--	--	172,353	275,040

Appendix F - Foundation Plans

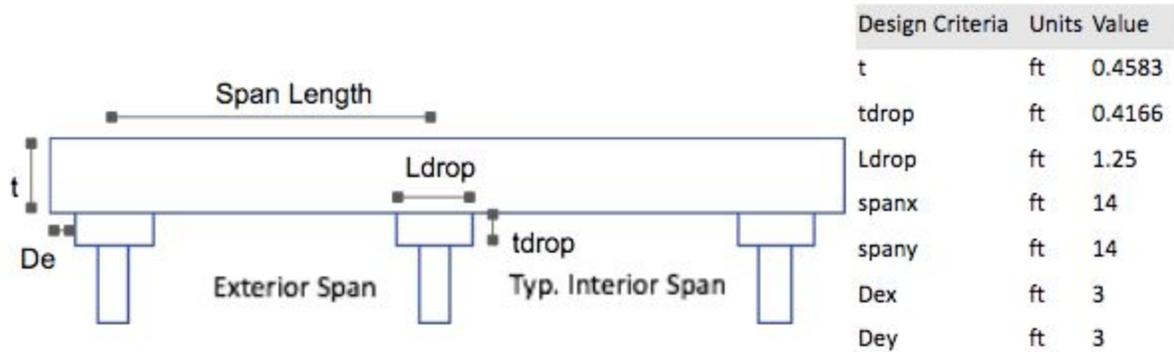


Figure F1: Trails Edge Duplex Slab Design Output

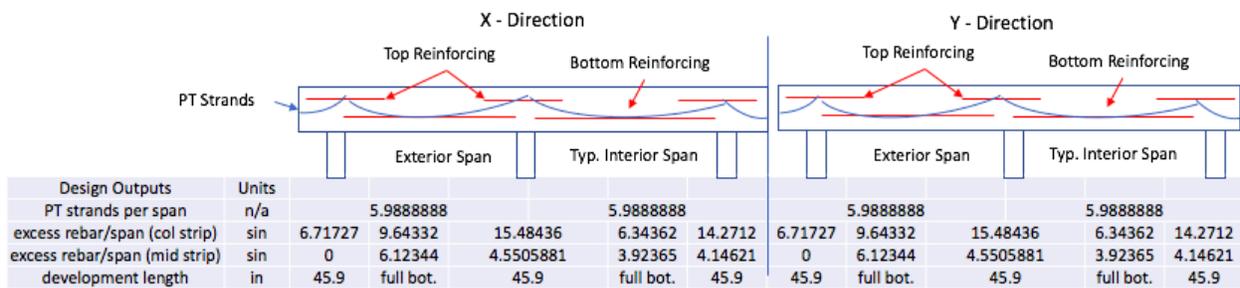


Figure F2: Trails Edge Duplex Slab Reinforcing Design Output

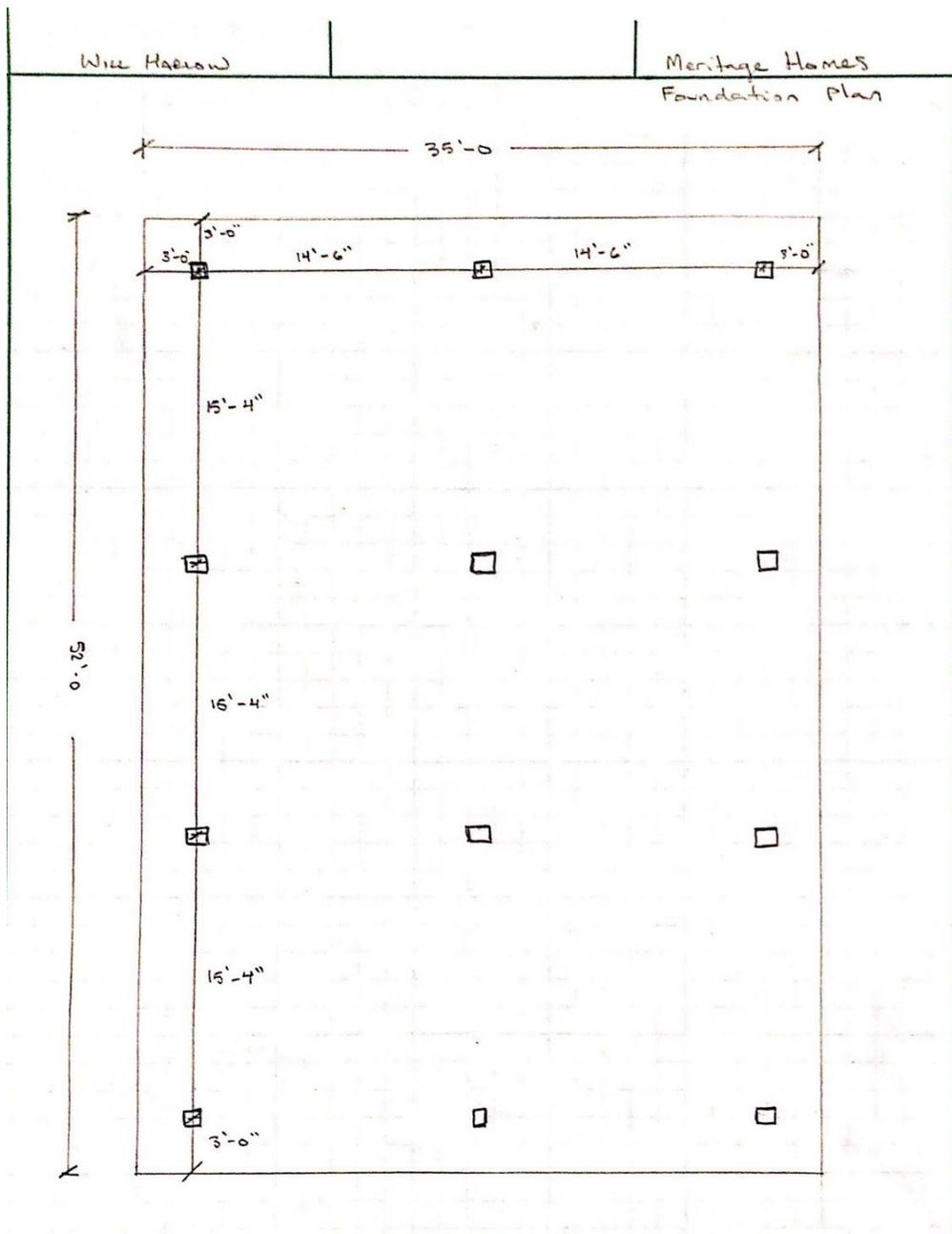


Figure F3. Slab Design for Meritage Series Homes

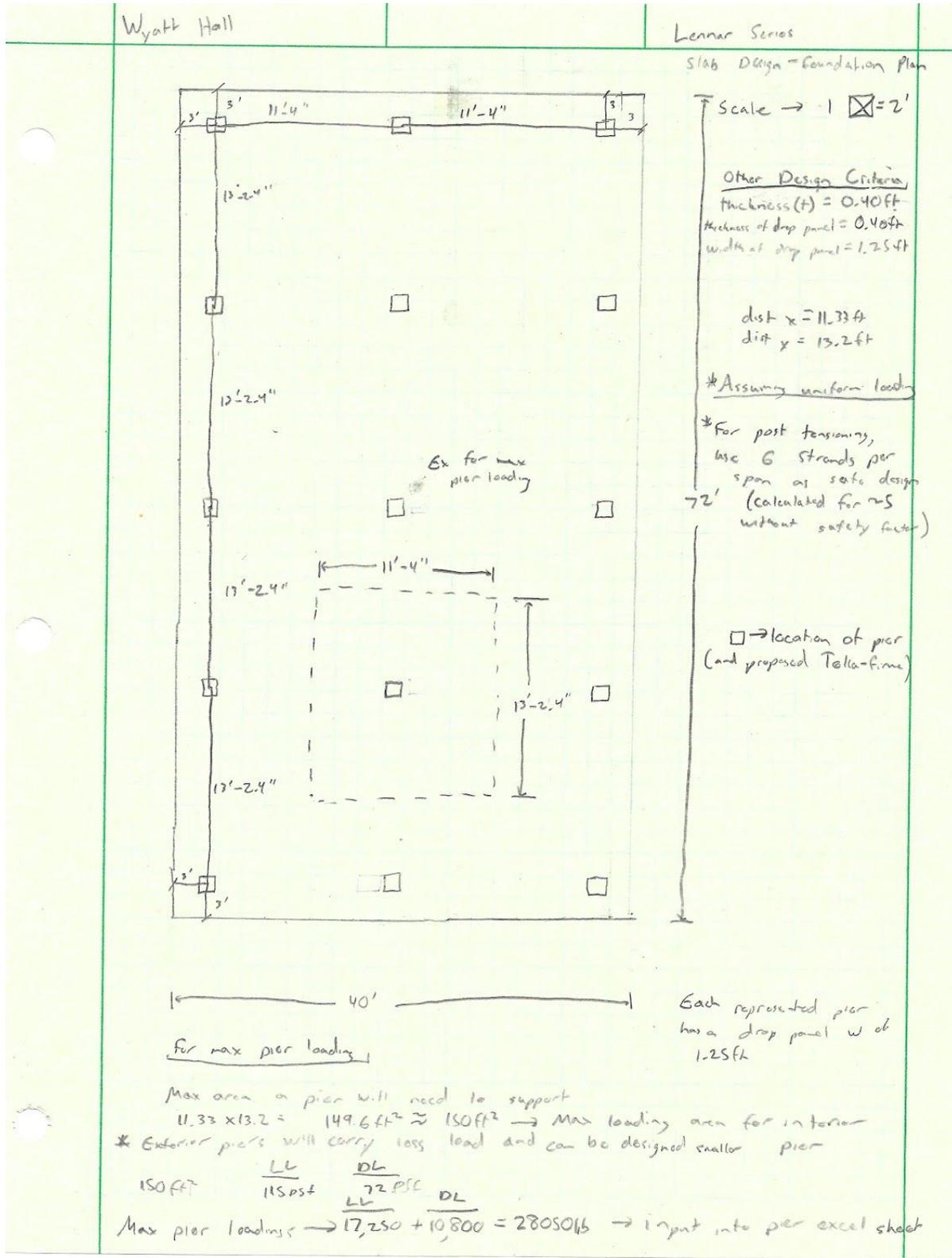


Figure F4. Slab Design for Lennar Series Homes

Appendix G - Pier Design

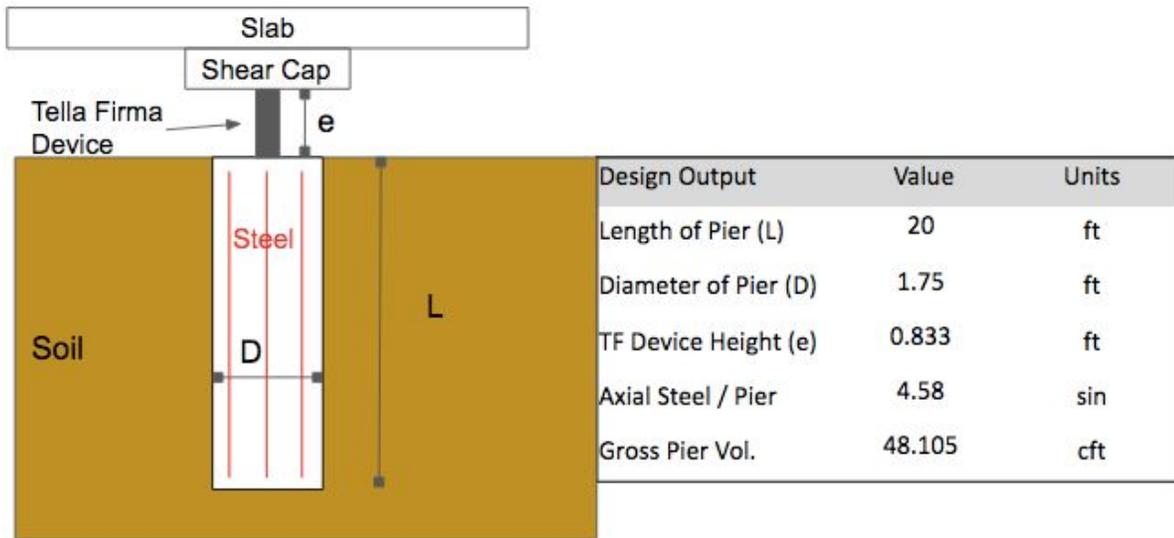


Figure G1. Trails Edge Duplex Pier Design

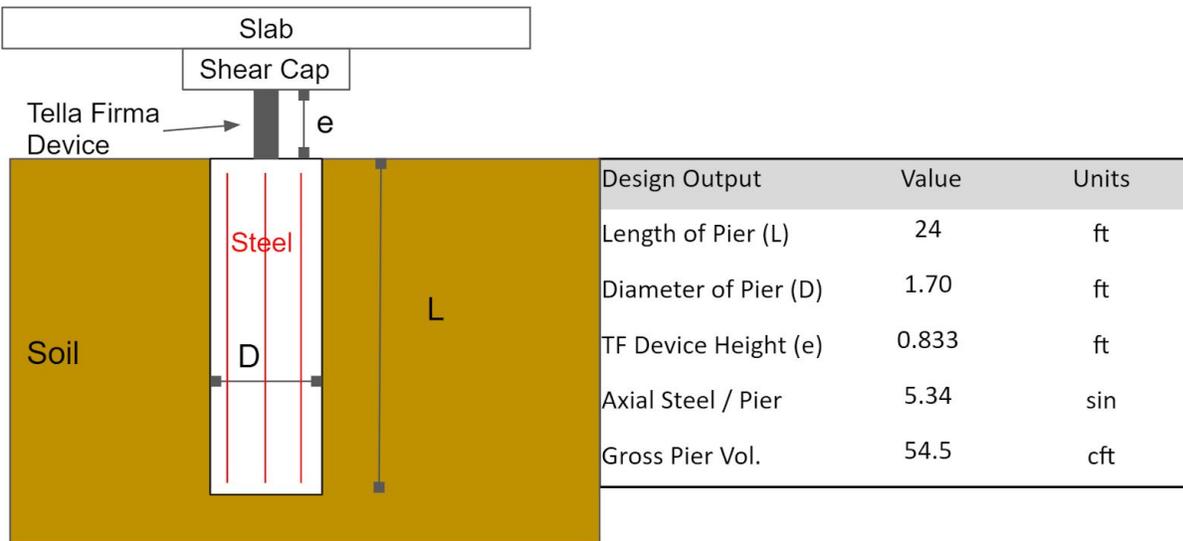


Figure G2. Meritage Homes Pier Design

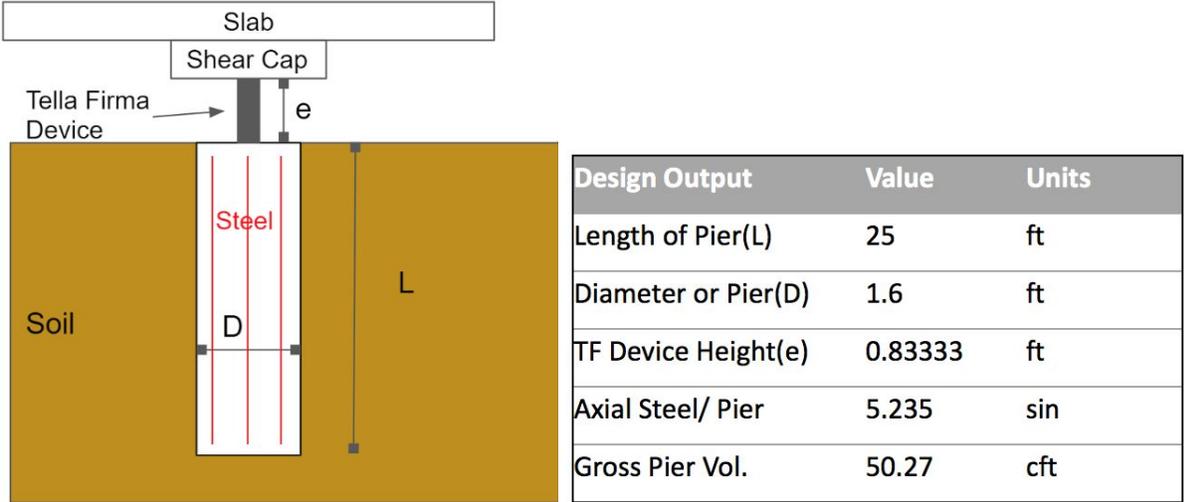


Figure G3. Lennar Series Homes Pier Design

Appendix H - Cost Sheets

Table H1. Trails Edge Duplex Cost Breakdown

Home: Trails Edge Duplex Estimate by: MLN Estimate on: 4/23/20		
Material Costs		Item Cost
Concrete	84 CY @ \$90 per CY	\$ 7,560.00
Site Preparation	2976 square foot @ \$1.25 per square foot	\$ 3,720.00
0.5" PT Cables	1177.176 lb @ \$1.65 per lb	\$ 1,942.34
Slab Rebar	15.59 ton @ \$700 per ton	\$ 10,913.00
Pier Rebar	3.204 ton @ \$700 per ton	\$ 2,242.80
Tella Firma Device	20 device @ \$175 per device	\$ 3,500.00
Sum		\$ 29,878.14
Labor Costs		
Truck-Mounted Auger	1 day @ \$2542 per day	\$ 2,542.00
Engineer	8 manhour @ \$150 per manhour	\$ 1,200.00
5 man crew	13 day @ \$640 per day	\$ 8,320.00
Sum		\$ 12,062.00
Cost of Capital		
Opportunity Cost	13 days tied up @ 3.5% per annum	\$ 52.28
Total Sum of Tella Firma		\$ 41,992.42
Cost of Capital Benchmark	8 % multiplier	x 1.08
Weighted Cost of Tella Firma		\$ 45,351.82
Costs Saved		
Over-excavation	3703.71 CY @ \$2.75 per CY	\$ 10,185.20
Standard foundation concrete	73.49 CY @ \$90 per CY	\$ 6,614.10
Standard foundation rebar	15.59 ton @ \$700 per ton	\$ 10,913.00
5 Man Crew	28 day @ \$640 per day	\$ 17,920.00
Opportunity Cost	210 days tied up @ 3.5% per annum	\$ 918.90
Sum		\$ 46,551.20
Total Savings (Dissavings) Of Tella Firma System		
		\$ 1,199.38

Table H2. Meritage Homes Cost Breakdown

Home: Meritage Homes		
Estimate by: WJHar		
Estimate on: 4/19/20		
Material Costs		Item Cost
Concrete	58 CY @ \$90 per CY	\$ 5,220.00
Site Preparation	1820 square foot @ \$1.25 per square foot	\$ 2,275.00
0.5" PT Cables	630.5 lb @ \$1.65 per lb	\$ 1,040.40
Slab Rebar	9.15 ton @ \$700 per ton	\$ 6,405.00
Pier Rebar	2.89 ton @ \$700 per ton	\$ 2,023.00
Tella Firma Device	12 device @ \$175 per device	\$ 2,100.00
Sum		\$ 19,063.40
Labor Costs		
Truck-Mounted Auger	1 day @ \$2542 per day	\$ 2,542.00
Engineer	8 manhour @ \$150 per manhour	\$ 1,200.00
5 man crew	13 day @ \$640 per day	\$ 8,320.00
Sum		\$ 12,062.00
Cost of Capital		
Opportunity Cost	13 days tied up @ 3.5% per annum	\$ 38.80
Total Sum of Tella Firma		\$ 31,164.17
Cost of Capital Benchmark	8 % multiplier	x 1.08
Weighted Cost of Tella Firma		\$ 33,657.31
Costs Saved		
Over-excavation	3703.71 CY @ \$2.75 per CY	\$ 10,185.20
Standard foundation concrete	44.95 CY @ \$90 per CY	\$ 4,045.50
Standard foundation rebar	9.15 ton @ \$700 per ton	\$ 6,405.00
5 Man Crew	28 day @ \$640 per day	\$ 17,920.00
Opportunity Cost	183 days tied up @ 3.5% per annum	\$ 676.57
Sum		\$ 39,232.28
Total Savings (Dissavings) Of Tella Firma System		
		\$ 5,574.97

Table H3. Lennar Series Home Cost Breakdown

Home: Trails Edge Duplex Estimate by: WJH Estimate on: 4/28/20		
Material Costs		Item Cost
Concrete	71 CY @ \$90 per CY	\$ 6,390.00
Site Preparation	2390 square foot @ \$1.25 per square foot	\$ 2,987.50
0.5" PT Cables	932.37 lb @ \$1.65 per lb	\$ 1,538.41
Slab Rebar	10.42 ton @ \$700 per ton	\$ 7,294.00
Pier Rebar	3.04 ton @ \$700 per ton	\$ 2,128.00
Tella Firma Device	15 device @ \$175 per device	\$ 2,625.00
Sum		\$ 22,962.91
Labor Costs		
Truck-Mounted Auger	1 day @ \$2542 per day	\$ 2,542.00
Engineer	8 manhour @ \$150 per manhour	\$ 1,200.00
5 man crew	13 day @ \$640 per day	\$ 8,320.00
Sum		\$ 12,062.00
Cost of Capital		
Opportunity Cost	13 days tied up @ 3.5% per annum	\$ 42.74
Total Sum of Tella Firma		\$ 35,067.65
Cost of Capital Benchmark	8 % multiplier	x 1.08
Weighted Cost of Tella Firma		\$ 37,873.06
Costs Saved		
Over-excavation	3703.71 CY @ \$2.75 per CY	\$ 10,185.20
Standard foundation concrete	59 CY @ \$90 per CY	\$ 5,310.00
Standard foundation rebar	10.42 ton @ \$700 per ton	\$ 7,294.00
5 Man Crew	28 day @ \$640 per day	\$ 17,920.00
Opportunity Cost	210 days tied up @ 3.5% per annum	\$ 918.90
Sum		\$ 41,628.10
Total Savings (Dissavings) Of Tella Firma System		\$ 3,755.04