Final Report

Retaining Wall Redesign

Grand Canyon K-12 School
Grand Canyon Village, AZ

CENE 486
Due: 12/12/18

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NPS = Naional Park Service
SHPO = State Historic Preservation Office

BGS = Below Ground Surface

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Acknowledgements

This project would not be possible without the Northern Arizona University Department of Civil and Environmental Engineering. This includes the Capstone professors Mark Lamer, Dianne McDonnell, Bridget Bero, and Bill Mancini, as well as the many other professors teaching classes necessary to understand the engineering design process and content. Another acknowledgement we would like to make is to our project technical advisor Chun-Hsing Ho. He has provided much needed guidance with regards to retaining wall structural and geotechnical analysis.

1.0 Introduction

1.1 General Project Information

The capstone project focuses on redesigning a failing retaining wall, currently made with railroad ties, at the Grand Canyon School District located in Grand Canyon village. The wall currently runs along a historic trail and also has a playground on the top. The scope of services to be provided for this project is to redesign the wall by surveying the wall and the surrounding area, perform geotechnical analysis, perform structural analysis, and to determine a solution for draining or diverting water away from the wall. By performing the necessary analysis on the current conditions, a new design will be implemented following engineering standards and those of the National Park Service (NPS) and the State Historic Preservation Office (SHPO).

1.2 Project Location and Current Condition Information

1.2.1 Location Information

This project is located in the town of Grand Canyon Village, Arizona. It is within the limits of Grand Canyon National Park, approximately 1.5 to 2 hours North West of Flagstaff. The wall is located in Grand Canyon K-12 School, a school serving about 300 students in Grand Canyon Village and the surrounding area [1]. Figure 1 below shows the town of Grand Canyon Village in relation to Flagstaff, and figure 2 shows the outline of the retaining wall within the school. The red arrows in Figure 2 point at the wall location.

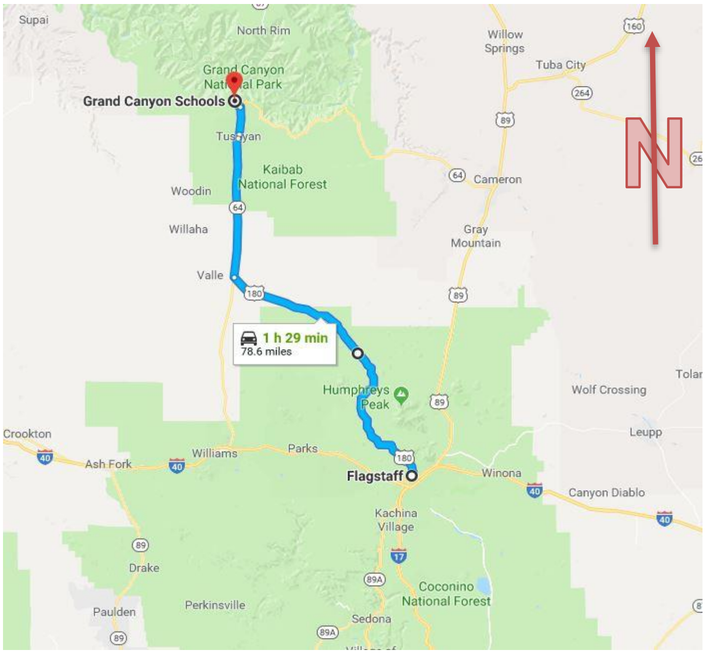

Figure 1: Location of Site Relevant to Flagstaff [2]

Figure 2: Location of Retaining Wall at GCHS

1.2.2 Description of Current Conditions

The retaining wall is currently made of railroad ties. The wall is approximately 220 feet long and ranges in height from 2 to 7 feet. There is a playground located directly above the wall which requires the wall to have a railing along it to ensure the safety of children present above the wall. The historical trail that runs adjacent to the wall is made of a thin slab of asphalt and is only inches away from the base of the wall. A drain, located at the eastern end of the wall, runs from the top to the bottom and goes directly underneath the wall. The wall is in a state of failure, tilting over an estimated 20 degrees after an initial site visit. Figure 3 below shows part of the wall in the failure condition.

Figure 3: Current Retaining Wall at GCHS

1.3 Constraints and Limitations

The codes and standards for the new retaining wall design will be followed under the National Park Service (NPS) and State Historic Preservation Office (SHPO). One of the constraints is that the retaining wall is located in the national park, which makes it difficult to realign the wall since the removal of any tree is not permitted without the NPS consent. This would make it difficult to cut back into the wall as well as there are a few trees that sit directly on top of the wall. Also, redesigning the topography of the site to divert water would be limited as the moving of dirt may be limited by the location of some trees. Another constraint is the historical trail that runs adjacent to the wall. With the historical trail running along the wall, aesthetic standards must be met by the SHPO. This limitation can provide challenges in determining the type of material used as well as the type of wall in the final design. The playground on top of the wall also brings in the issue of safety for children in which a railing will have to be designed for the top of the wall as well following regulations for playgrounds.

1.4 Objectives and Deliverables

For the completion of this analysis and design there are many aspects that need to be taken into consideration. The project can be broken up into five different parts; field work, lab work, retaining wall analysis, construction plans and a final design. The following sections discuss the detail needed for each part with any sub-sections that are deemed necessary to the completion of the design.

As discussed in previous sections there are some unique criteria that is specific to the redesign of the retaining wall in question. Any design needs to take into consideration the codes and standards that the NPS and SHPO outline. Within these deliverables it needs to be clearly identified what the organizations require and any solution given.

2.0 Field Work

2.1 Surveying

The survey work completed was done in collaboration with the Grand Canyon High School Drainage team. They established control points that were used in this survey. The team set up a robotic total station on these control points to survey the entire existing retaining wall at the toe, as well as important geographical features around it. One team member was operating the prism and data collector while another teammate was assisting with field measurements and the total station. Once all points at the toe of the wall were collected the total station was set up behind the wall to obtain all points and significant geographical features. Survey points were also collected to show paths of travel for water in the drainage analysis. Once this was complete, all points were loaded into AutoCAD Civil 3D where a site/topographic map was created of the wall and surrounding area. The map created by the drainage team was utilized, and the point collected for the survey of the wall were input into this map. The site map showing the existing retaining wall location in the school, and a map showing the existing wall and surroundings can be found in Appendix A.

2.2 Soil Sample Collecting

Six different locations surrounding the wall on the lower and upper side were picked for the collection of soil samples. Three samples were gathered on the lower side of the retaining wall and three samples on the upper side of the wall using a hand auger. Sampling procedures were completed using ASTM D1452 standards [2]. The three samples retrieved on the lower elevation side were sampled in locations where there were no obstructions and easy access. The upper elevation samples were retrieved in problem areas, locations where the wall was in the highest degree of failure.

Sample depths ranged from 1 ft. below ground surface (bgs) to 4 ft bgs. Material encountered, based upon observed assumptions, generally was a sandy clay with gravel. It was noted that samples were observed to be moist for the first 4 inches of penetration and then proceeded to change to drier material as depth increases. All samples were collected in a 5 gallon bucket and transported to the soils lab. Lab tests will identify the characteristics of the soils in each location sampled and allow for a comprehensive soils report.

See Appendix A for soil sample locations in relation to the existing retaining wall.

See Appendix B through G for notes and comments made in the field from soil sampling.

3.0 Lab Work

3.1 Moisture Content

Three tests for each of the six soils samples were completed using ASTM D2216 [2]. Three tests were completed for each sample to gather an average of the test for more accurate results. Samples of roughly 10 grams were used for the test and began with gathering the weight of the wet soil. The samples were then dried to determine the weight of the water in the soil.

The moisture content allows for the use of the soil in future construction of the retaining wall. The native soil is going to need to be re-compacted at optimal moisture, and the current moisture content will allow for the soils tester to identify if the soil needs to be scarified for less moisture content or have water added.

See Appendix H for calculations of moisture content results.

3.2 Sieve Analysis

For the dry sieve analysis, the standards under ASTM 6913-04 were followed [4]. A portion of each sample, weighing no less than 500 grams, was taken and placed in a dish. The dish was then placed into an oven where each sample was able to dry. The dry samples were then taken out and weighed again to get the dry weight of the soil. The samples were then placed into a set of sieves, that were each weighed individually, that consisted of 1", ¾", ½", and ⅜" set sieves with a pan to catch all that passed the ⅜". This was done to remove any gravel from the sample. The sieve was placed into the shaker where the shaker ran for 5 minutes, knocking the material loose so that the finer material can reach the pan. Once the material was done in the shaker, each sieve was weighed with the material that was retained. After weighing the sieve and material, the sample in the pan was then put into the another set of sieves, weighed beforehand, that consisted of a #4, #10, #20 , #40, #60, #100, #140, and a #200 with a pan at the bottom to catch the fines. Again the sieves were placed into a mechanical shaker where the material was knocked loose. After being used in the mechanical shaker, the sieves with the material retained on them were measured. Once all the material and sieves were weighed out, the amount of sand, gravel and fines could be determined for each soil sample.

See Appendix I for calculations of sieve analysis as well as results.

3.3 Atterberg Limits

The Atterberg Limits were done to find the liquid limit, the plastic limit, and the plasticity index of the soil. This test was done using the methods outlined in ASTM D4318 [2]. For the plastic limit, a sample of soil passing through the #40 sieve was wetted until a plastic-like consistency was met. The soil was then rolled by hand until a string of soil most nearly ⅛" in diameter was obtained without any cracks [2]. The moisture content of this portion was then taken, which is the plastic limit of the soil. For the liquid limit, a Casagrande Liquid Limit Device was utilized [2]. Soil was wetted until a putty-like consistency was met. The bowl of the liquid limit device was then filled, and a liquid limit tool was used to slice the soil in the bowl in half, with the two halves not touching. Once this was done, a series of blows were applied until the two halves of the soil touched together. If the number of blows making the two sides touch was between 25 and 35 blows, this was considered be the liquid limit, and the moisture content was taken [2]. This was done three times per sample for each of the six samples. With the plastic limit and liquid limit found, the plasticity index could be calculated using *Equation 1* below.

Equation 1: Plasticity Index

$$PI = LL - PL$$

Where:

PI = Plasticity Index
LL = Liquid Limit
PL = Plastic Limit

See Appendix J for the Atterberg Limits data and results.

3.4 Conclusions

Using all the soils tests completed the soils classifications of each sample was done. Using ASTM standards D2487 and D2488 [2], the sieve analysis and Atterberg limits results were used to follow the flow chart for the classification of the soils. As identified in the *Soils Testing Summary Table* as seen in Appendix L, all samples were a sand of some sort. SW represents well-graded sands, SW-SC represents well-graded sands with clay, and SC represents a clayey sand.

With the classifications of each soil sample it allows for the identification of whether the use of native soil or imported engineered soil is going to be used when backfilling the wall during construction. Since the soil identified behind the wall is a sand and not a clay, the use of the native soil will be used for backfill. This is because if the soil was clay then it would increase the bearing capacity behind the wall, since the soil is a sand then enough moisture will be able to pass through the material and out the weep holes of the redesigned retaining wall.

4.0 Retaining Wall Design

4.1 Geotechnical Analysis

After obtaining the results from the soils analysis it was determined the soil behind the wall consisted mainly of sand. Because it is mainly sand, the soil is adequate for use behind the new wall and will not require an engineered fill. The type of analysis performed on the retaining wall will be failure checks for sliding, overturning about the toe, and the bearing capacity of the retaining wall on the soil. For checking the factor of safety for overturning about the toe of the retaining wall, the sum of moments must be taken for the forces resisting overturning about the toe and the force of the soil causing overturning about the toe. In order for the retaining wall to not fail from overturning the sum of resisting moments must be greater than the overturning moment by a factor of 2.0 [3]. The next failure check for the retaining wall will be sliding failure. In order for the wall to not fail from sliding, the sum of resisting forces must be greater than the driving force of the soil behind the retaining wall by a factor 1.5 [3]. The third and final retaining wall failure check that will be accounted for is the bearing capacity of the soil underneath the footing of the retaining wall. For the wall to not fail from a bearing capacity failure the soil pressure must be greater than the maximum pressure of the retaining wall by a factor of 3.0 [3].

The soil type used for the design of the retaining wall will be well graded sand since it is the most predominant soil type on the project. With well graded sand used for analysis the soil properties can be determined for analysis. The unit weight of the soil is 115 pcf, a cohesion of 0 psf, and a friction angle of 25 degrees. Also considered in the analysis of the retaining wall is a surcharge on top of the wall of 80 psf which takes into consideration of a service vehicle. The wall is constructed out of masonry block and a concrete footing. With these materials a unit weight for both of them can be determined which would be 125 pcf for the masonry block and 150 pcf for the concrete. In order for the retaining wall to pass the failures mentioned previously while taking into consideration the soil properties and load factors, the dimensions of the wall had to be altered. Dimensions of the wall that passed the failure checks as well as the soil properties can be found in Appendix L. The minimum factor of safeties required to pass come from the International Building Code and from *The Principles of Foundation Engineering* [3]. These factors were designed for the highest point of our wall. The wall was also designed for a section that is half the size of the highest point of the retaining wall. The total results for the factors of safety for both walls can be found in Appendix L. The table showing the final results for each factor of safety for the three failures can be found below.

Type of Failure:	Minimum F.S.	Calculated F.S.
Overturning	2	3.03
Sliding	1.5	1.53
Bearing Capacity	3	3.4

Table 1: Results from soil checks

4.2 Drainage Design

The drainage for the retaining wall followed typical retaining wall designs from ADOT as well as followed considerations from the International Building Code [3] [4]. The final design for the retaining wall drainage will be weep holes. The weep holes will be placed on the bottom of the wall and will be constructed out of 3 inch diameter PVC pipe. The backside of the retaining wall will be covered with a geocomposite drain. The geocomposite drain will act as a barrier to capture any water that is behind the wall and will take the water down to the bottom towards the weep holes where the water will then be discharged.

4.3 Wall Material/Structural Design

The structural design of the wall included determining the amount of steel reinforcement necessary for the footing of the retaining wall and in the wall itself. For the material of the wall, 12” by 16” concrete masonry units (CMU) were chosen for the wall as they meet the SHPO standards. The wall footing is cast in place concrete. Finding the amount of steel needed was done using the methods and standards outlined in the ACI 318-14 reinforced concrete code. In general, the wall was divided into two sections (wall and footing) each treated as cantilever beams. Each section was analyzed for maximum bending moments due to the applied soil loads determined from the geotechnical analysis. Steel was designed based off these moment values for both of the sections. The results showed to have #5 bars in every cell of the CMU blocks, a #6 bar spaced at 12” on center for the bottom of the footing, #5 bars spaced at 12” on center at the top of the footing, and #5 bars spaced at 18” on center for the temperature and shrinkage steel. The steel reinforcement calculations can be found in Appendix M.

5.0 Construction Document

The construction documents were created to convey the final design of our retaining wall. AutoCAD and Civil 3D were the programs used for design. The cover page of the drawings indicate what the drawings are intended to be used for as well as design considerations and requirements. There is also an existing site plan shown to visualize where the project is located as well as what the existing retaining wall uses. The rest of the construction documents show the details of the final design of the wall. The topographic map previously mentioned is also included in these documents to show the existing wall and existing ground features around it. A profile view and proposed plan view of the new wall are shown on the following page to convey the new alignment and elevation of the wall. Finally, all details and section views of the designed wall are shown for construction purposes of the final proposed design. See Appendix N for construction documents.

7.0 Summary of Engineering Work

7.1 Schedule

Presented below in Table 1 is the proposed schedule generated in CENE 476 and the final schedule a generated in CENE 486C. There is a difference with the proposed and final schedule due to a few reasons. Field work required us to take an extra trip up to the job site to finish the surveying. Another part of the project that required more time than originally allotted is the analysis and design. Structural design required more time due to a learning curve, material need to design the wall with the correct properties were unknown to the capstone group. Once learned in class and discussed with professionals/professors the structural design was completed. This in turn pushed all dates following it back. Due to vigilant effort on the team's part the project was still completed by the final end date.

Schedule		Proposed:		Final:	
Task NO.	Task:	Start Date:	Finish Date:	Start Date:	Finish Date:
1.0	Field Work	8/31/2018	9/17/2018	8/31/2018	9/14/2018
1.1	Initial Site Visit	8/31/2018	8/31/2018	8/31/2018	8/31/2018
1.2	Surveying	9/7/2018	9/17/2018	9/7/2018	9/14/2018
1.3	Soil Sampling	9/14/2018	9/17/2018	9/7/2018	9/14/2018
2.0	Soil Testing	9/17/2018	9/28/2018	9/27/2018	9/28/2018
2.1	Moisture Content	9/17/2018	9/18/2018	9/27/2018	9/28/2018
2.2	Sieve Analysis	9/21/2018	9/21/2018	9/27/2018	9/27/2018
2.3	Liquid Limit, Plastic Limit, and Plasticity Index	9/28/2018	9/28/2018	9/28/2018	9/28/2018
3.0	Analysis / Design	9/28/2018	10/25/2018	10/16/2018	11/2/2018
3.1	Geotehcnical Analysis	9/28/2018	10/25/2018	10/16/2018	10/22/2018
3.1.1	Overturning Check	9/28/2018	10/25/2018	10/16/2018	10/22/2018
3.1.2	Sliding Check	9/28/2018	10/25/2018	10/16/2018	10/22/2018
3.1.3	Bearing Capacity Check	9/28/2018	10/25/2018	10/16/2018	10/22/2018
3.2	Structural Design	9/28/2018	10/25/2018	10/22/2018	11/2/2018
3.2.1	Wall Materials	9/28/2018	10/25/2018	10/22/2018	11/2/2018
3.3	Drainage Design	9/28/2018	10/25/2018	10/22/2018	10/22/2018
4.0	Plan Sets	10/25/2018	11/21/2018	11/2/2018	12/6/2018
4.1	Site Plan	10/25/2018	11/21/2018	11/2/2018	11/16/2018
4.2	Details	10/25/2018	11/21/2018	11/16/2018	12/6/2018
4.3	General Notes	10/25/2018	11/21/2018	11/16/2018	11/18/2018
5.0	Deliverables	10/25/2018	12/12/2018	10/25/2018	12/12/2018
5.1	30% Design Report	9/20/2018	9/20/2018	9/20/2018	9/20/2018
5.2	60% Design Report	10/25/2018	10/25/2018	10/25/2018	10/25/2018
5.3	Final Presentation	12/7/2018	12/7/2018	12/7/2018	12/7/2018
5.4	Final Report	12/12/2018	12/12/2018	12/12/2018	12/12/2018
5.5	Final Website	12/12/2018	12/12/2018	12/12/2018	12/12/2018

Table 2: Schedule for 476 and 486C

8.0 Summary of Engineering Costs

8.1 Engineering Services Costs

For the summary of engineering costs, the staffing and positions for the team members did not change and the proposed positions were still utilized throughout the project. What did change however, was the hours put into the project as the capstone team was able to cut down on time thus saving money for the client. This most likely occurred as the technical skills were gained throughout the duration of the project and by time analysis was to be performed, the team was proficient and more experienced. The tables for the proposed hours and costs and the final hours and costs can be found below in Table 3 and Table 4, respectively.

Table 3: Proposed Hours and Costs for the project

Position:	Cost ($/hr.):	Total Hours:	Cost ($):
PE	80	112	26880
EIT	65	130	12675
Drafter	65	100	9750
Intern	19	160	3648
Lab Technician	20	150	7500
Admin	25	50	3125
Meetings: 6 project meetings for $30/hr.			180
Travel Expenses: $70/hr for 6 hours total			420
Total Hours	702		
Total Cost	$64,178.00		

Table 4: Actual Hours and Costs for the project

Position:	Cost ($/hr.):	Total Hours:	Cost ($):
PE	80	90	21600
EIT	65	130	12675
Drafter	65	70	6825
Intern	19	90	2052
Lab Technician	20	50	2500
Admin	25	60	3750
Meetings: 5 project meetings for $30/hr.			150
Travel Expenses: $70/hr for 20 hours total			1400
Total Hours	490		
Total Cost	$50,952.00		

From the tables above, there is a significant amount of difference in hours put in. The Professional Engineer (PE) was in charge of complex calculations, helping employees that aren't as technically skilled, and approves on final designs. The Engineer in Training (EIT) was in charge of calculations, report typing, and organizing documents and spent the most amount of time on the project. The EIT was also in charge of fieldwork as well including collecting soil samples and surveying. The drafter was in charge of all documents for the construction plans. The intern was similar to the EIT in the sense of performing numerous calculations. The lab technician was in charge of all soil work in the lab and compiling soil reports with the intern. Administration was in charge of finalizing and writing all reports, memos, presentations, and other necessary documents. Each position played a significant role in the designing of the retaining wall and the hours as well as the costs reflect.

8.2 Materials Costs

Materials needed for the construction of the retaining wall was broken up into the following components; plain carbon steel rebar at diameters of 4/8, ⅝, and 6/8 inch, lightweight concrete at 2500 psi compressive strength, standard concrete masonry block with dimensions 8" x 12" x 16", 3 inch PVC pipe, standard school railing, and geocomposite.

Material costs were determined by determining how much of each item was needed and referencing standard pricing. Beginning with rebar, determination of wall dimensions in their respective locations allowing for lengths of rebar in linear feet to be calculated. Concrete is only used in the foundations of the retaining wall and simple calculations of the volume of footings allowed for the amount of concrete to be identified. Using the standard size of concrete masonry units given the number of total units was determined, taking into account possible errors during construction for broken units. The PVC piping needed for weep holes is shown in linear feet needed. Railing follows the total linear length of the wall as the railing shall sit upon the top of the wall for safety purposes. Geocomposite installation requires the surface area of the retaining wall that retains soil. Summary of amount needed, cost per unit and total cost of each material item can be seen in Table 5 below.

Table 5: Summary of material costs

Item:		Amount needed:	Cost ($):	Unit:	Total Cost ($):
Rebar	#4	1700 ft	5.00	20 ft	425
	#5	7400 ft	7.50	20 ft	2,775
	#6	1400 ft	11.00	20 ft	770
Concrete		82 yd^3	108.00	yd^3	8,856
CMU		1900 units	4.00	per block	7,600
PVC		20 ft	11.00	10 ft	22
Railing		200 ft	35.00	1 ft	7,000
Geocomposite		1675 ft^2	1.00	ft^2	1,675
Total Cost					$ 29,123

8.3 Total Costs

Total costs for engineering services and materials comes out to $80,075. Construction, labor, equipment and additional costs are not included in this price.

9.0 Conclusion

The objectives of this project were to design a retaining wall for the Grand Canyon K-12 School because the current wall is leaning over. To complete this it was initially proposed that the team would conduct surveying of the existing site, geotechnical testing of collected soil samples, geotechnical analysis, structural design, and drainage design. The final design of the wall also had to comply with NPS and SHPO standards. A final design of the wall was created through AutoCAD and Civil 3D that met these objectives. The wall was designed with two different heights for the varying elevations of the soil needing to be retained. All of the soils testing and structural design passed factor of safety checks and complied with current design standards. Finally, a set of construction drawings was created to convey the entirety of the final design.

This retaining wall design should be constructible and can be implemented by the client if chosen to do so. It must also be noted that there is the possibility of obtaining a more economically feasible retaining wall. This possibility stems from the soil collecting and testing of soils at a deeper depth than the ones originally obtained. It is usually recommended to gather soil samples at a depth of the retaining wall height for proper analysis. This is done through the use of drill rigs. With this proper soil data, it is most likely possible that the soil properties will be of a better condition which would allow for the dimensions of the retaining wall to be smaller and more economically feasible. The retaining wall designed by the capstone team was conservative in analysis ensuring that the retaining wall will be sufficient.

10.0 References

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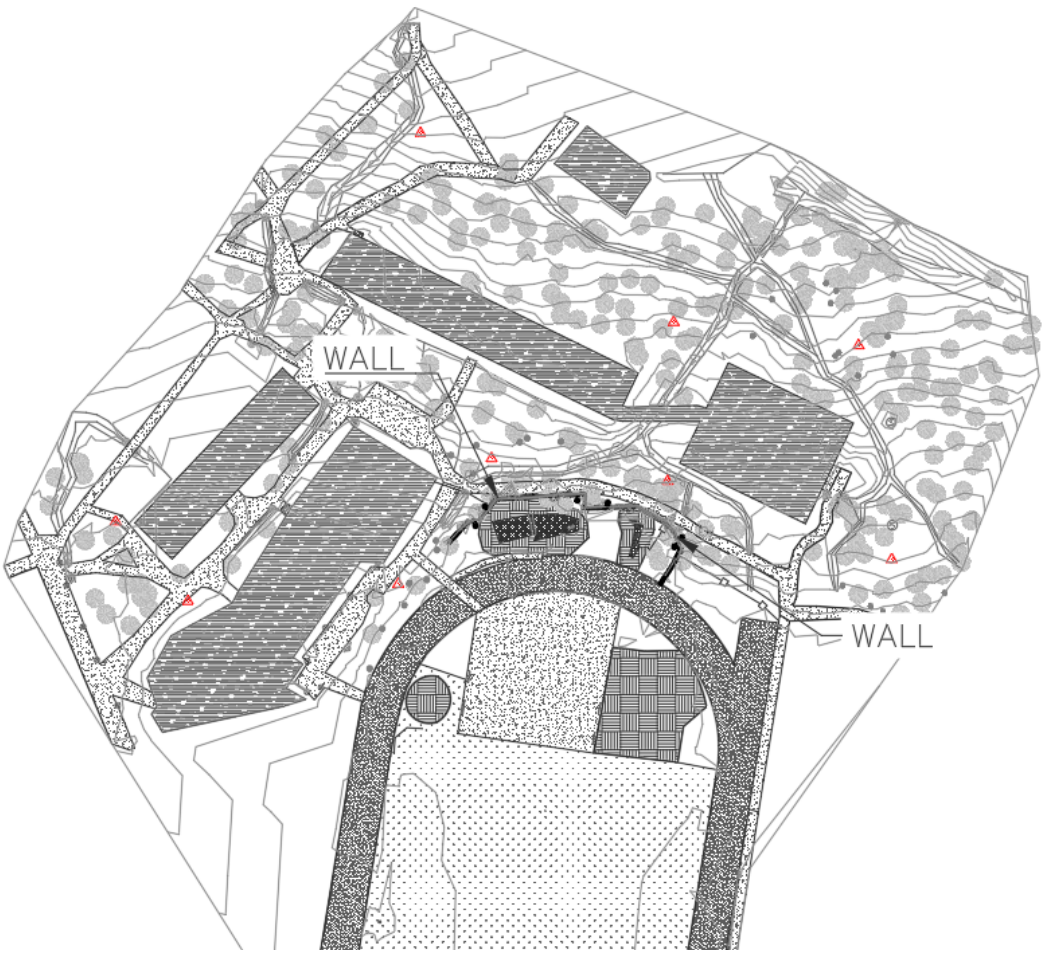
Appendices

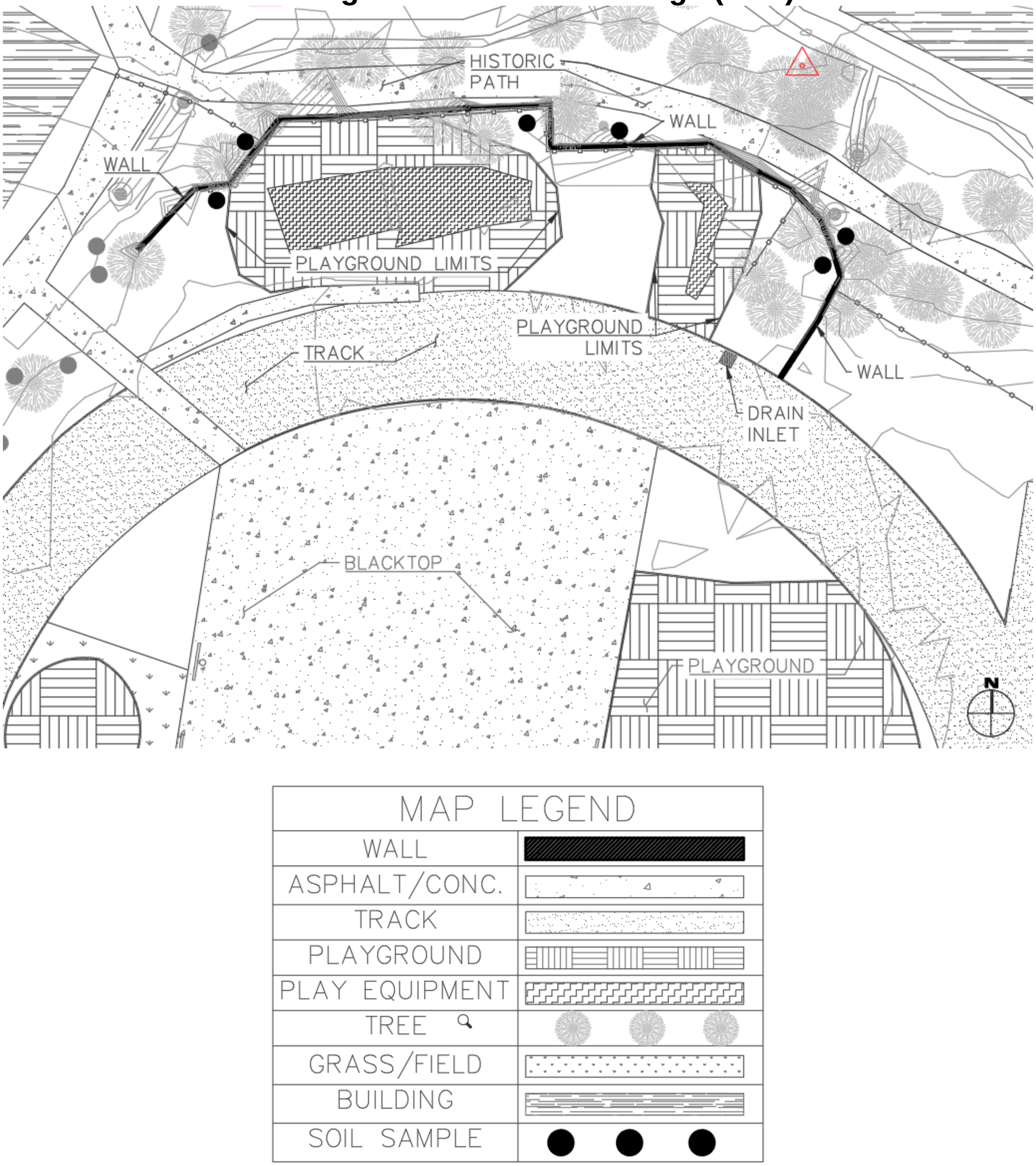
Appendix A: Existing Wall Location in the School (NTS)
Surveying Topo/Site Map



MAP LEGEND	
WALL	
ASPHALT/CONC.	
TRACK	
PLAYGROUND	
PLAY EQUIPMENT	
TREE	
GRASS/FIELD	
BUILDING	
SOIL SAMPLE	

Appendix A (Continued)

Existing Wall and Surroundings (NTS)



Appendix B: Soil Sample 1

Soil Sampling

Sample 1:) West Side of Wall (09/08)

H.O.I. = 5.2 ft.

Sand Auger

Shovel down Auger

0-0.5' Soil CL Moist, loose

0-2'

0-1.5

Brown, Limestone frag.

Auger Refusal

Rock frag. below 6".

Blocky Texture

Trace Organics

1.5-2' Soil CL

White, Calcareous

-Brown, Dry

No-Low plasticity

Rock frag.: 2"-6"

Consistent below

Numerous rock frag.

Appendix C: Soil Sample 2

Sample 2 : North side of wall
H.O.I.: ~~6.2~~ 5.2 ft

0 - 2 in	Brown, ~~clayey~~ sandy clay, moist
2" - 20"	Brown, clay, moist, slight gravel, organics present, loose
20" - 23"	Brown, clayey, slight gravel, loose, dry silty
23"	Refusal at organic root

Shovel used for remainder of soil retrieval.
3" → 5" diameter rocks encountered.

Appendix D: Soil Sample 3

Sample 3: East End of wall HOI 6.2 5.2
0 - 1.8' Lean Clay (CL) Ref 4.4
Low plasticity firm
Roots @ 4.5" bgs
Moist to Slightly moist
Soft
Refusal @ 1.8'
Roots
Reddish brown and Brown

Appendix E: Soil Sample 4

9/14/17
Sample 4: New Top Sample
Left Top. Near playground
Offset 2" from wall

- Moist
- Fine grained sand
- Subangular - Subrounded gravel
- Organics on top, wood cloth
- rubber
- No - low plasticity

0'-1' Sample refused from rocks

Appendix F: Soil Sample 5

09/14/2018 (New Soil Samples)

Sample 5: 2' offset of wall 

Center on Top

Shoveled 8" top soil

Consists of rubber, mulch, organics

0'-10" Fine to coarsed grained sand

pea gravel (subangular)

Slightly moist

No to low plasticity

Refusal at 10") from rock

Move hole over 10"

0' [illegible] gravel (1.5") diam.

0'-1.4'

Appendix G: Soil Sample 6

SAMPLE 6 : 2.5' OFFSET FROM WALL

REMOVED 8" TOP SOIL
LOT OF MULCH ON TOP
MEDIUM PLASTICITY

8" – 4' : SOIL GOING HARD → SOFT
FINE SOIL W/ SOME COURSE
LEAN CLAY → FAT CLAY (CL → CH)
3.9' WE SEE MORE GRAVEL +
CALCERIOUS MATERIAL
END OF SAMPLE @ 4'-0"

Appendix H: Moisture Content Table

Sample	Can Weight (g)	Can + Wet Soil (g)	Can + Dry Soil (g)	Dry Soil (g)	Water Content (%)
S-1	20.69	38.85	37.08	16.39	10.80
S-2	26.05	64.72	62.24	36.19	6.85
S-3	19.8	48.49	46.38	26.58	7.94
S-4	19.15	56.23	54.66	35.51	4.42
S-5	18.73	54.87	53.84	35.11	2.93
S-6	18.29	41.46	38.95	20.66	12.15

$$\omega(\%) = 100 * (W_w - W_d)/(W_d - W_c)$$

Appendix I: Sieve Analysis Results

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: GCHS **Tested By:** S. Floyd **Date:** 9/28/2018

Location: Grand Canyon Village **Checked By:** E. Chamberlain **Date:** 9/29/2018

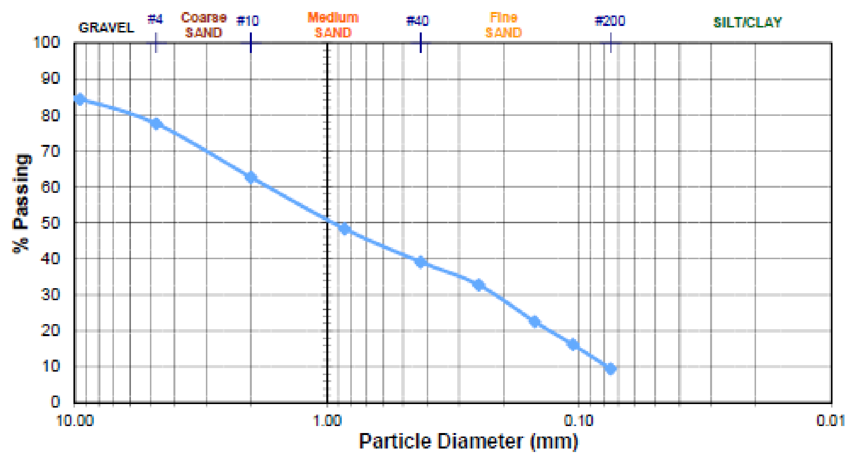
Sample No: GCHS S-1

ASTM Soil Classification: ______

Weight of Container (g): 464.8 **Weight of Container & Dry Soil (g):** 908.5

Weight of Dry Sample (g): 443.7

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1"	25.40	1361.9	1407.3	45.4	10.2	89.8
3/4"	19.00	1409.3	1409.3	0.0	0.0	89.8
1/2"	12.70	1349.2	1365.7	16.5	3.7	86.0
3/8"	9.52	1351.4	1358.9	7.5	1.7	84.4
#4	4.75	520.7	547	30.2	6.8	77.6
#10	2.00	409.2	475.3	66.1	14.9	62.7
#20	0.85	394.7	458.3	63.6	14.3	48.3
#40	0.43	385	423.9	40.8	9.2	39.1
#60	0.25	372.1	400.5	28.4	6.4	32.7
#100	0.15	351.6	378.1	45.2	10.2	22.5
#140	0.11	338.5	366.7	28.2	6.4	16.2
#200	0.075	298.4	328.4	30.0	6.8	9.4
Pan		365.4	416	50.6	11.4	0.0
			TOTAL:	383.1	86.3	



Grain Size Distribution Curve Results:

% Gravel: 22.4

% Sand: 68.1

% Fines: 9.4

14.333 Sieve Analysis Worksheet Revised 02/13 __ of __

Figure 4: Sample 1 Results

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: GCHS **Tested By:** S. Floyd **Date:** 9/28/2018

Location: Grand Canyon Village **Checked By:** E. Chamberlain **Date:** 9/29/2018

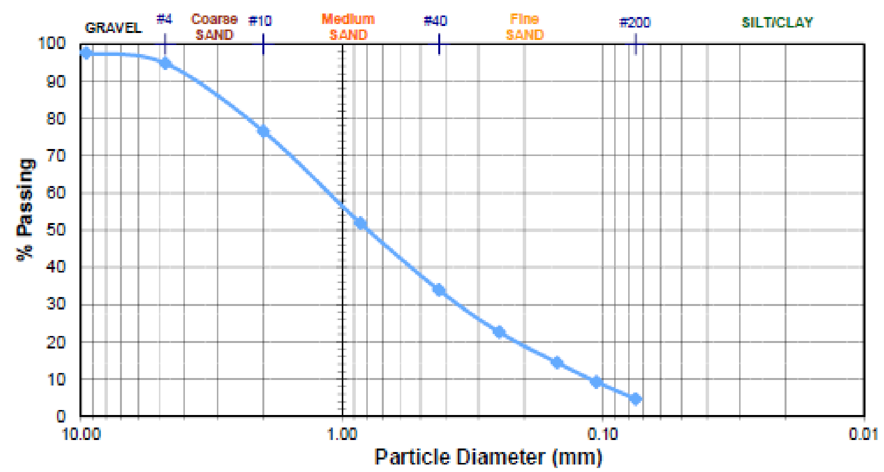
Sample No: GCHS S-2

ASTM Soil Classification: ______

Weight of Container (g): 516.4 **Weight of Container & Dry Soil (g):** 1080.4

Weight of Dry Sample (g): 564.1

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1"	25.40	1361.9	1361.9	0.0	0.0	100.0
3/4"	19.00	1409.3	1409.3	0.0	0.0	100.0
1/2"	12.70	1349.2	1354.9	5.7	1.0	99.0
3/8"	9.52	1351.4	1359.1	7.7	1.4	97.6
#4	4.75	520.7	536.4	15.7	2.8	94.8
#10	2.00	409.2	512.1	102.9	18.2	76.6
#20	0.85	394.7	534	139.3	24.7	51.9
#40	0.43	385	486.5	101.5	18.0	33.9
#60	0.25	372.1	435.8	63.7	11.3	22.6
#100	0.15	351.6	394.2	46.3	8.2	14.4
#140	0.11	338.5	366.4	29.3	5.2	9.2
#200	0.075	298.4	321.3	25.6	4.5	4.7
Pan		365.4	401.6	39.2	6.9	0.0
			TOTAL:	563.5	99.9	



Grain Size Distribution Curve Results:

% Gravel: 5.2

% Sand: 90.2

% Fines: 4.7

14.333 Sieve Analysis Worksheet Revised 02/13 __ of __

Figure 5: Sample 2 Results

Sieve Analysis Data Sheet

ASTM D422-63(2007)

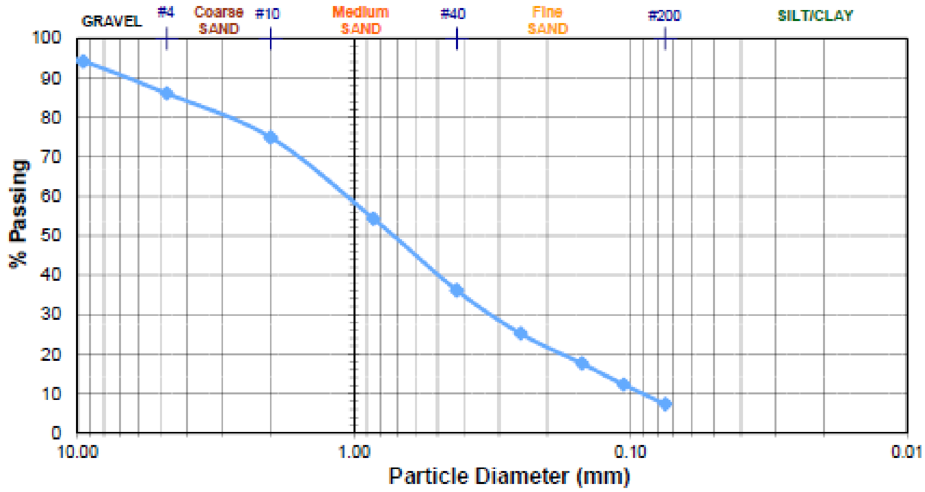
Project Name:	GCHS	**Tested By:**	S. Floyd	**Date:**	9/28/2018
Location:	Grand Canyon Village	**Checked By:**	E. Chamberlain	**Date:**	9/29/2018
Sample No:	GCHS S-3				

ASTM Soil Classification: ____________

Weight of Container (g): 471.4 **Weight of Container & Dry Soil (g):** 1022.7

Weight of Dry Sample (g): 551.3

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1"	25.40	1361.9	1361.9	0.0	0.0	100.0
3/4"	19.00	1409.3	1409.4	0.1	0.0	100.0
1/2"	12.70	1349.2	1373.2	24.0	4.4	95.6
3/8"	9.52	1351.4	1359.2	7.8	1.4	94.2
#4	4.75	520.7	565.6	44.9	8.1	86.1
#10	2.00	409.2	470.6	61.4	11.1	74.9
#20	0.85	394.7	508.4	113.7	20.6	54.3
#40	0.43	385	485.2	100.2	18.2	36.1
#60	0.25	372.1	432.5	60.4	11.0	25.2
#100	0.15	351.6	393.5	41.9	7.6	17.6
#140	0.11	338.5	368	29.5	5.4	12.2
#200	0.075	298.4	325.7	27.3	5.0	7.3
Pan		365.4	407.5	42.1	7.3	0.0
			TOTAL:	**521.4**	**94.2**	



Grain Size Distribution Curve Results:

% Gravel:	13.9
% Sand:	78.8
% Fines:	7.3

14.333 Sieve Analysis Worksheet Revised 02/13 __ of __

Figure 6: Sample 3 Results

Sieve Analysis Data Sheet

ASTM D422-63(2007)

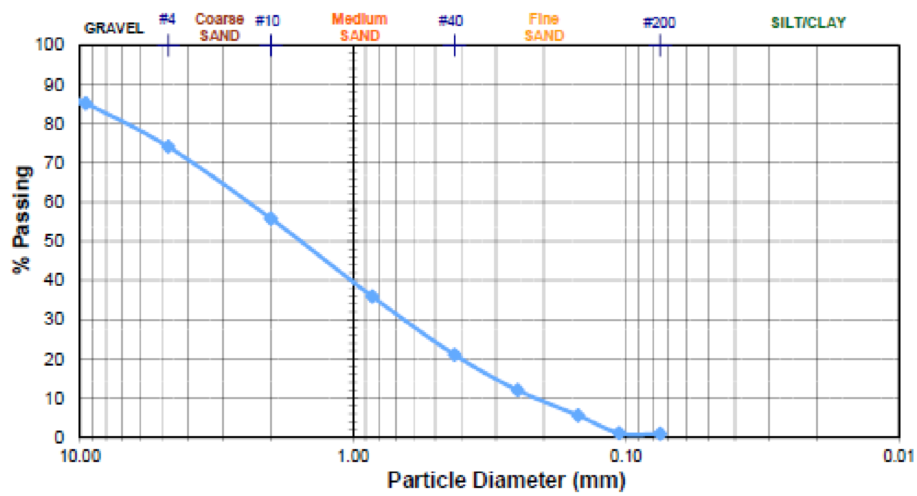
Project Name:	GCHS	**Tested By:**	K. Chivens	**Date:**	9/28/2018
Location:	Grand Canyon Village	**Checked By:**	S. Floyd	**Date:**	9/29/2018
Sample No:	GCHS S-4				

ASTM Soil Classification: ______

Weight of Container (g): 501.7 **Weight of Container & Dry Soil (g):** 1006.8

Weight of Dry Sample (g): 505.1

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1"	25.40	1361.9	1361.9	0.0	0.0	100.0
3/4"	19.00	1409.3	1422.6	13.3	2.6	97.4
1/2"	12.70	1349.2	1388.3	43.5	8.6	88.8
3/8"	9.52	1351.4	1369.5	18.1	3.6	85.2
#4	4.75	520.7	572.9	55.8	11.0	74.1
#10	2.00	409.2	496.9	92.5	18.3	55.8
#20	0.85	394.7	492.8	100.5	19.9	35.9
#40	0.43	385	453	75.0	14.8	21.1
#60	0.25	372.1	412.6	45.6	9.0	12.0
#100	0.15	351.6	381	32.6	6.5	5.6
#140	0.11	338.5	359.9	22.8	4.5	1.1
#200	0.075	298.4	314.5	18.6	3.7	0.9
Pan		365.4	389.6	26.7	5.3	0.0
			TOTAL:	470.1	93.1	



Grain Size Distribution Curve Results:

% Gravel: 25.9

% Sand: 73.2

% Fines: 0.9

14.333 Sieve Analysis Worksheet Revised 02/13 __ of __

Figure 7: Sample 4 Results

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: GCHS **Tested By:** S. Floyd **Date:** 9/28/2018

Location: Grand Canyon Village **Checked By:** E. Chamberlain **Date:** 9/29/2018

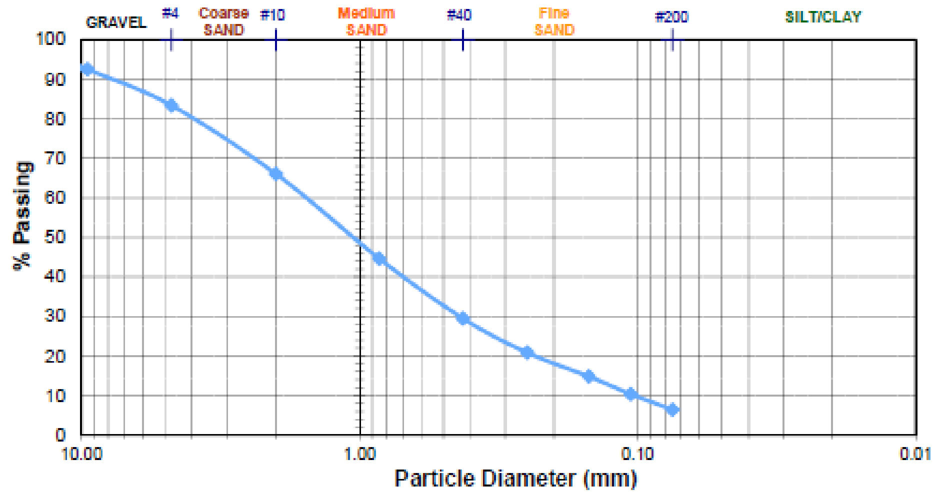
Sample No: GCHS S-5

ASTM Soil Classification: ______

Weight of Container (g): 463.0 **Weight of Container & Dry Soil (g):** 1012.2

Weight of Dry Sample (g): 549.2

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1"	25.40	1361.9	1361.9	0.0	0.0	100.0
3/4"	19.00	1409.3	1409.3	0.0	0.0	100.0
1/2"	12.70	1349.2	1367.9	18.7	3.4	96.6
3/8"	9.52	1351.4	1373.6	22.2	4.0	92.6
#4	4.75	520.7	571	50.3	9.2	83.4
#10	2.00	409.2	504.3	95.1	17.3	66.1
#20	0.85	394.7	512.4	117.7	21.4	44.6
#40	0.43	385	468.3	83.3	15.2	29.5
#60	0.25	372.1	419.5	47.4	8.6	20.8
#100	0.15	351.6	384.7	33.1	6.0	14.8
#140	0.11	338.5	363.1	24.6	4.5	10.3
#200	0.075	298.4	320	21.6	3.9	6.4
Pan		365.4	401	35.6	6.4	0.0
			TOTAL:	508.7	92.5	



Grain Size Distribution Curve Results:

% Gravel: 16.6

% Sand: 77.0

% Fines: 6.4

Figure 8: Sample 5 Results

Sieve Analysis Data Sheet

ASTM D422-63(2007)

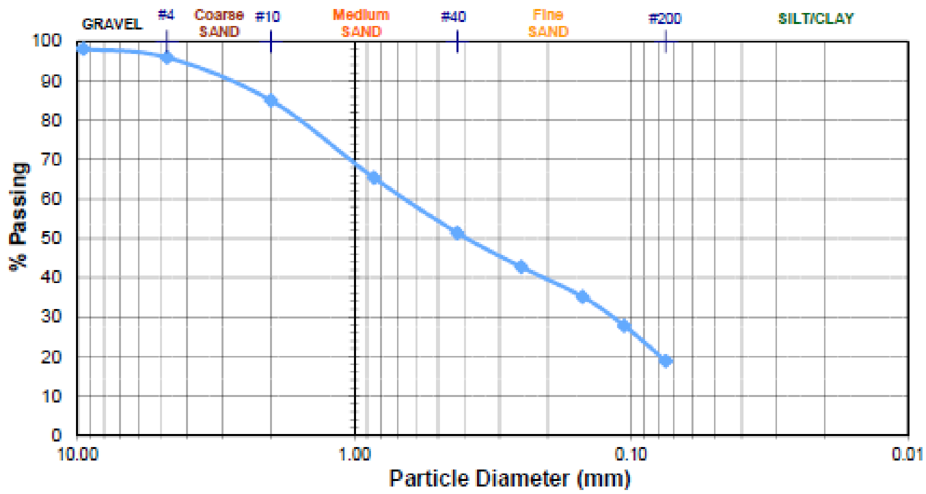
Project Name:	GCHS	**Tested By:**	J. Madrigal	**Date:**	9/28/2018
Location:	Grand Canyon Village	**Checked By:**	K. Chivens	**Date:**	9/29/2018
Sample No:	GCHS S-6				

ASTM Soil Classification: ____________

Weight of Container (g): 507.3 **Weight of Container & Dry Soil (g):** 954.8

Weight of Dry Sample (g): 447.5

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
1"	25.40	1361.9	1361.9	0.0	0.0	100.0
3/4"	19.00	1409.3	1409.3	0.0	0.0	100.0
1/2"	12.70	1349.2	1351.8	2.6	0.6	99.4
3/8"	9.52	1351.4	1357.4	6.0	1.3	98.1
#4	4.75	520.7	530.3	9.6	2.1	95.9
#10	2.00	409.2	458.2	49.0	10.9	85.0
#20	0.85	394.7	482.4	87.7	19.6	65.4
#40	0.43	385	447.6	62.6	14.0	51.4
#60	0.25	372.1	410.7	38.6	8.6	42.8
#100	0.15	351.6	385.5	33.9	7.6	35.2
#140	0.11	338.5	371.5	33.0	7.4	27.8
#200	0.075	298.4	338.5	40.1	9.0	18.9
Pan		365.4	452.5	87.1	19.5	0.0
			TOTAL:	441.6	98.7	



Grain Size Distribution Curve Results:

% Gravel:	4.1
% Sand:	77.1
% Fines:	18.9

Figure 9: Sample 6 Results

Appendix J: Atterberg Limits Results

Atterberg Limits Data Sheet
ASTM D4318-10

Project Name:	GCHS - Retaining Wall	**Tested By:**	S. Floyd	**Date:**	9/30/18
Location:	GCHS	**Checked By:**	K. Chivens	**Date:**	10/1/18
Sample No:	S - 1				

USCS Soil Classification: ______________________

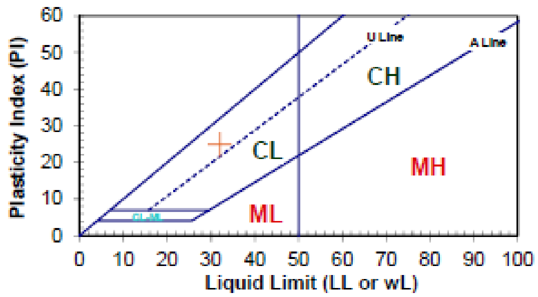
TEST			PLASTIC LIMIT				LIQUID LIMIT			
Variable	NO Var.	NO Units	1	2	3	4	1	2	3	4
Number of Blows	N	blows					26	34	29	
Can Number	---	---	S-1-1	S-1-2	S-1-3		S-1-1	S-1-2	S-1-3	
Mass of Empty Can	M_C	(g)	13.00	13.40	13.30		13.60	19.80	12.00	
Mass Can & Soil (Wet)	M_{CMS}	(g)	16.00	15.50	15.40		20.30	26.40	21.10	
Mass Can & Soil (Dry)	M_{CDS}	(g)	15.50	15.00	15.00		18.70	24.90	18.90	
Mass of Soil	M_S	(g)	2.50	1.60	1.70		5.10	5.10	6.90	
Mass of Water	M_W	(g)	0.50	0.50	0.40		1.60	1.50	2.20	
Water Content	w	(%)	20.0	31.3	23.5		31.4	29.4	31.9	

Liquid Limit (LL or w_L) (%):	32
Plastic Limit (PL or w_P) (%):	25
Plasticity Index (PI) (%):	7
USCS Classification:	CL

PI at "A" Line = 0.73(LL-20)

One Point Liquid Limit Calculation:

$LL = w_n (N/25)^{0.12}$



PROCEDURE USED

	Wet Preperation Multipoint
X	Dry Preperation Multipoint
	Procedure A Multipoint
	Procedure B One-Point

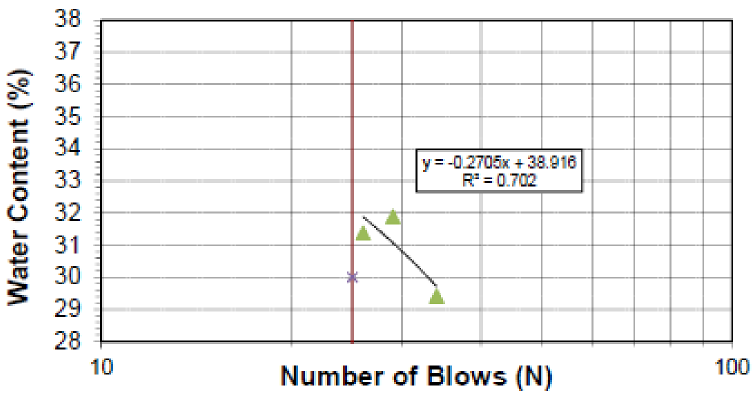


Figure 10: Sample 1 Results

Atterberg Limits Data Sheet

ASTM D4318-10

Project Name:	GCHS - Retaining Wall	Tested By:	S. Floyd	Date:	9/30/18
Location:	GCHS	Checked By:	K. Chivens	Date:	10/1/18
Sample No:	S - 2				

USCS Soil Classification: ____________

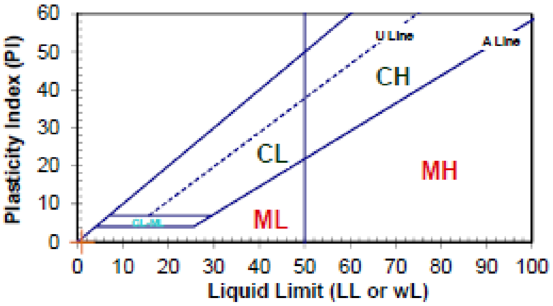
TEST			PLASTIC LIMIT				LIQUID LIMIT			
Variable	NO Var.	NO Units	1	2	3	4	1	2	3	4
Number of Blows	N	blows								
Can Number	---	---	S-2-1	S-2-2	S-2-3		NP	NP	NP	
Mass of Empty Can	M_C	(g)	13.30	13.00	13.10					
Mass Can & Soil (Wet)	M_{CMS}	(g)	15.80	14.30	14.20					
Mass Can & Soil (Dry)	M_{CDS}	(g)	15.30	13.90	14.00					
Mass of Soil	M_S	(g)	2.00	0.90	0.90		0.00	0.00	0.00	
Mass of Water	M_W	(g)	0.50	0.40	0.20		0.00	0.00	0.00	
Water Content	w	(%)	25.0	44.4	22.2		#DIV/0!	#DIV/0!	#DIV/0!	

Liquid Limit (LL or w_L) (%):	NP
Plastic Limit (PL or w_P) (%):	NP
Plasticity Index (PI) (%):	NP
USCS Classification:	

PI at "A" Line = 0.73(LL-20)

One Point Liquid Limit Calculation:

$LL = w_n (N/25)^{0.12}$



PROCEDURE USED

[ ]	Wet Preperation Multipoint
[X]	Dry Preperation Multipoint
[ ]	Procedure A Multipoint
[ ]	Procedure B One-Point

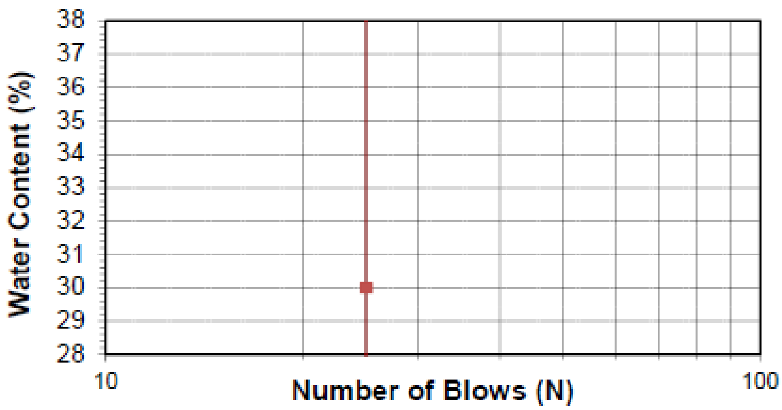


Figure 11: Sample 2 Results

Atterberg Limits Data Sheet
ASTM D4318-10

Project Name:	GCHS - Retaining Wall	**Tested By:**	S. Floyd	**Date:** 9/30/18
Location:	GCHS	**Checked By:**	K. Chivens	**Date:** 10/1/18
Sample No:	S - 3			

USCS Soil Classification: ______________________

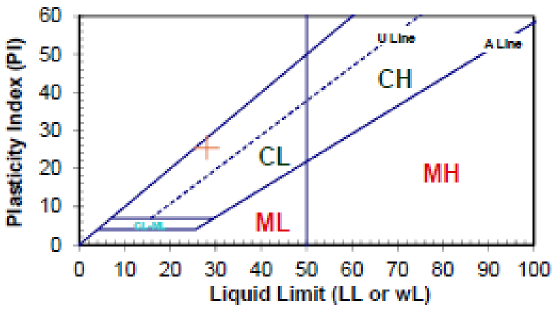
TEST			PLASTIC LIMIT				LIQUID LIMIT			
Variable	NO		1	2	3	4	1	2	3	4
	Var.	Units								
Number of Blows	N	blows					34	29	29	
Can Number	---	---	S-3-1	S-3-2	S-3-3		S-3-1	S-3-2	S-3-3	
Mass of Empty Can	M_C	(g)	13.40	13.70	13.70		13.60	13.40	13.30	
Mass Can & Soil (Wet)	M_{CMS}	(g)	16.80	15.80	16.20		25.40	24.00	21.80	
Mass Can & Soil (Dry)	M_{CDS}	(g)	16.20	15.40	15.60		23.00	21.80	20.10	
Mass of Soil	M_S	(g)	2.80	1.70	1.90		9.40	8.40	6.80	
Mass of Water	M_W	(g)	0.60	0.40	0.60		2.40	2.20	1.70	
Water Content	w	(%)	21.4	23.5	31.6		25.5	26.2	25.0	

Liquid Limit (LL or w_L) (%):	28
Plastic Limit (PL or w_P) (%):	26
Plasticity Index (PI) (%):	2
USCS Classification:	CL

PI at "A" Line = 0.73(LL-20)

One Point Liquid Limit Calculation:

$LL = w_n (N/25)^{0.12}$



PROCEDURE USED

[ ]	Wet Preperation Multipoint
[X]	Dry Preperation Multipoint
[ ]	Procedure A Multipoint
[ ]	Procedure B One-Point

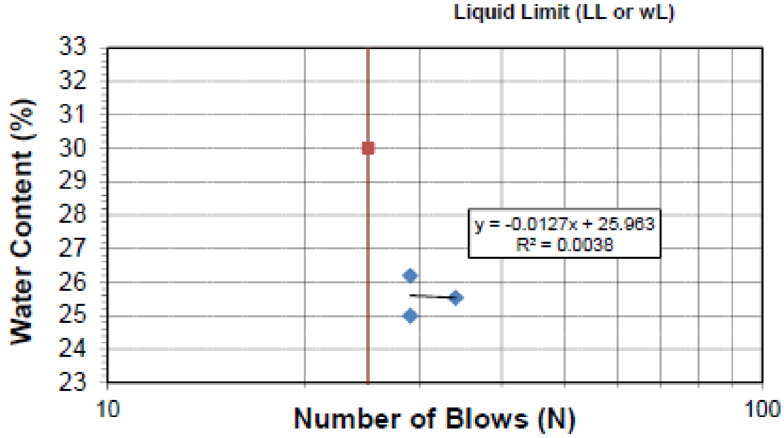


Figure 12: Sample 3 Results

Atterberg Limits Data Sheet

ASTM D4318-10

Project Name:	GCHS - Retaining Wall	**Tested By:**	S. Floyd	**Date:** 9/30/18
Location:	GCHS	**Checked By:**	K. Chivens	**Date:** 10/1/18
Sample No:	S - 4			

USCS Soil Classification: ______________________

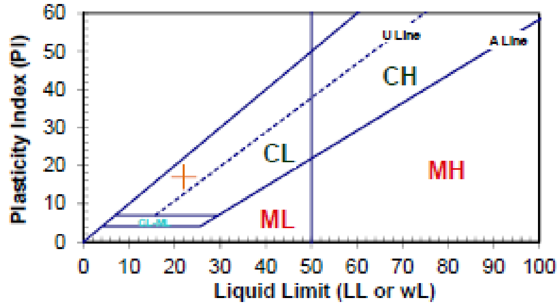
TEST			PLASTIC LIMIT				LIQUID LIMIT			
Variable	NO Var.	NO Units	1	2	3	4	1	2	3	4
Number of Blows	N	blows					35	29	25	
Can Number	---	---	S-4-1	S-4-2	S-4-3		S-4-1	S-4-2	S-4-3	
Mass of Empty Can	M_C	(g)	13.30	13.50	13.10		13.30	13.50	13.40	
Mass Can & Soil (Wet)	M_{CMS}	(g)	15.10	15.10	15.20		31.30	31.90	29.80	
Mass Can & Soil (Dry)	M_{CDS}	(g)	14.80	14.90	14.90		28.10	28.80	26.70	
Mass of Soil	M_S	(g)	1.50	1.40	1.80		14.80	15.30	13.30	
Mass of Water	M_W	(g)	0.30	0.20	0.30		3.20	3.10	3.10	
Water Content	w	(%)	20.0	14.3	16.7		21.6	20.3	23.3	

Liquid Limit (LL or w_L) (%):	22
Plastic Limit (PL or w_P) (%):	17
Plasticity Index (PI) (%):	5
USCS Classification:	CL

PI at "A" Line = 0.73(LL-20)

One Point Liquid Limit Calculation:

LL = w_n(N/25)$^{0.12}$



PROCEDURE USED

- [ ] Wet Preperation Multipoint
- [X] Dry Preperation Multipoint
- [ ] Procedure A Multipoint
- [ ] Procedure B One-Point

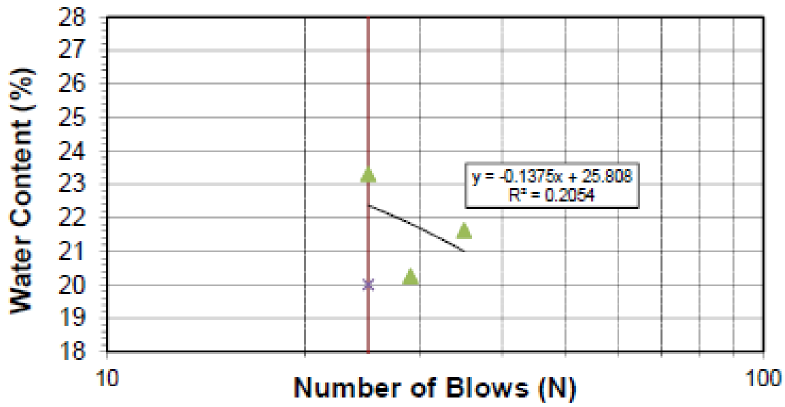


Figure 13: Sample 4 Results

Atterberg Limits Data Sheet
ASTM D4318-10

Project Name:	GCHS - Retaining Wall	Tested By:	S. Floyd	Date: 9/30/18
Location:	GCHS	Checked By:	K. Chivens	Date: 10/1/18
Sample No:	S - 5			

USCS Soil Classification: ____________

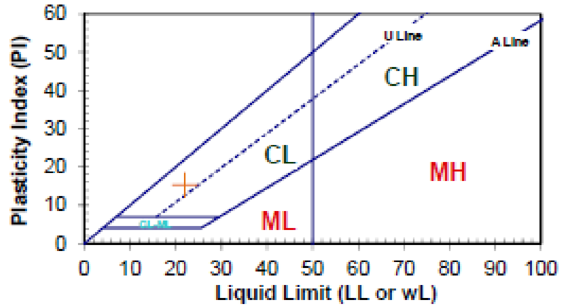
TEST			PLASTIC LIMIT				LIQUID LIMIT			
Variable	NO Var.	Units	1	2	3	4	1	2	3	4
Number of Blows	N	blows					27	27	29	
Can Number	---	---	S-5-1	S-5-2	S-5-3		S-5-1	S-5-2	S-5-3	
Mass of Empty Can	M_C	(g)	13.50	11.40	13.10		13.40	13.30	13.20	
Mass Can & Soil (Wet)	M_{CMS}	(g)	15.70	13.10	15.20		27.30	26.90	29.70	
Mass Can & Soil (Dry)	M_{CDS}	(g)	15.30	12.90	15.00		25.00	24.60	26.70	
Mass of Soil	M_S	(g)	1.80	1.50	1.90		11.60	11.30	13.50	
Mass of Water	M_W	(g)	0.40	0.20	0.20		2.30	2.30	3.00	
Water Content	w	(%)	22.2	13.3	10.5		19.8	20.4	22.2	

Liquid Limit (LL or w_L) (%):	22
Plastic Limit (PL or w_P) (%):	15
Plasticity Index (PI) (%):	7
USCS Classification:	CL

PI at "A" Line = 0.73(LL-20)

One Point Liquid Limit Calculation:

$LL = w_n (N/25)^{0.12}$



PROCEDURE USED

	Wet Preperation Multipoint
X	Dry Preperation Multipoint
	Procedure A Multipoint
	Procedure B One-Point

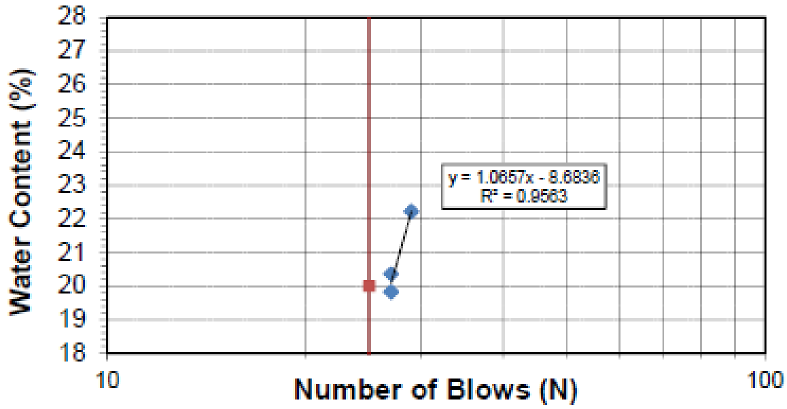


Figure 14: Sample 5 Results

Atterberg Limits Data Sheet

ASTM D4318-10

Project Name:	GCHS - Retaining Wall	**Tested By:**	S. Floyd	**Date:**	9/30/18
Location:	GCHS	**Checked By:**	K. Chivens	**Date:**	10/1/18
Sample No:	S - 6				

USCS Soil Classification: ______

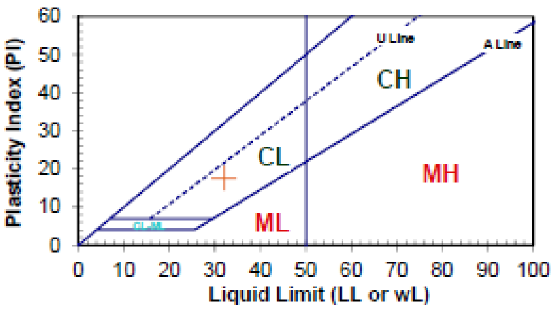
TEST			PLASTIC LIMIT				LIQUID LIMIT			
Variable	NO Var.	NO Units	1	2	3	4	1	2	3	4
Number of Blows	N	blows					31	30	27	
Can Number	---	---	S-6-1	S-6-2	S-6-3		S-6-1	S-6-2	S-6-3	
Mass of Empty Can	M_C	(g)	13.50	13.60	13.70		13.50	13.50	13.30	
Mass Can & Soil (Wet)	M_{CMS}	(g)	15.60	16.90	16.30		29.40	21.90	22.00	
Mass Can & Soil (Dry)	M_{CDS}	(g)	15.30	16.40	15.90		25.90	19.80	20.00	
Mass of Soil	M_S	(g)	1.80	2.80	2.20		12.40	6.30	6.70	
Mass of Water	M_W	(g)	0.30	0.50	0.40		3.50	2.10	2.00	
Water Content	w	(%)	16.7	17.9	18.2		28.2	33.3	29.9	

Liquid Limit (LL or w_L) (%):	32
Plastic Limit (PL or w_P) (%):	18
Plasticity Index (PI) (%):	14
USCS Classification:	CL

PI at "A" Line = 0.73(LL-20)

One Point Liquid Limit Calculation:

$LL = w_n (N/25)^{0.12}$



PROCEDURE USED

☐	Wet Preperation Multipoint
X	Dry Preperation Multipoint
☐	Procedure A Multipoint
☐	Procedure B One-Point

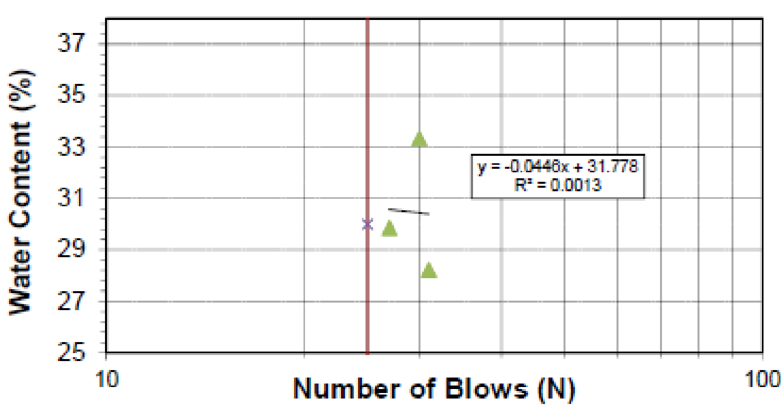


Figure 15: Sample 6 Results

Appendix K: Soils Testing Summary Table

Sample No.	Moisture Content (%)	Particle Distribution			Plastic Limit	Liquid Limit	Plasticity Index	Soil Classification
		% Gravel	% Sand	% Fines				
1	10.8	22.4	68.2	9.4	7	32	25	SW-SC
2	6.9	5.2	90.1	4.7	NP	NP	NP	SW
3	7.9	13.9	78.8	7.3	2	28	26	SW-SC
4	4.4	25.9	73.2	0.9	5	22	17	SW
5	2.9	16.6	77.0	6.4	7	22	15	SW
6	12.1	4.1	77.0	18.9	14	32	18	SC

Appendix L: Geotech Calculation Details

Table 6: Soil Properties

Soil Properties:		
Soil Type:	SW	
Unit Weight:	115	pcf
Cohesion:	0	psf
Friction Angle:	25	degrees
Surcharge:	80	psf

Table 7: Final Tall Wall Dimensions and Properties

Wall Properties		
Height of Wall:	10	feet
Wall Thickness:	12	inches
Depth (D):	4.5	feet
Total Height:	11	feet
Footing Length:	8	feet
Footing Thickness:	1	feet
Footing Toe:	3.5	feet
Footing Heel:	3.5	feet
Unit Weight of CMU:	125	pcf
Unit Weight of Concrete:	150	pcf

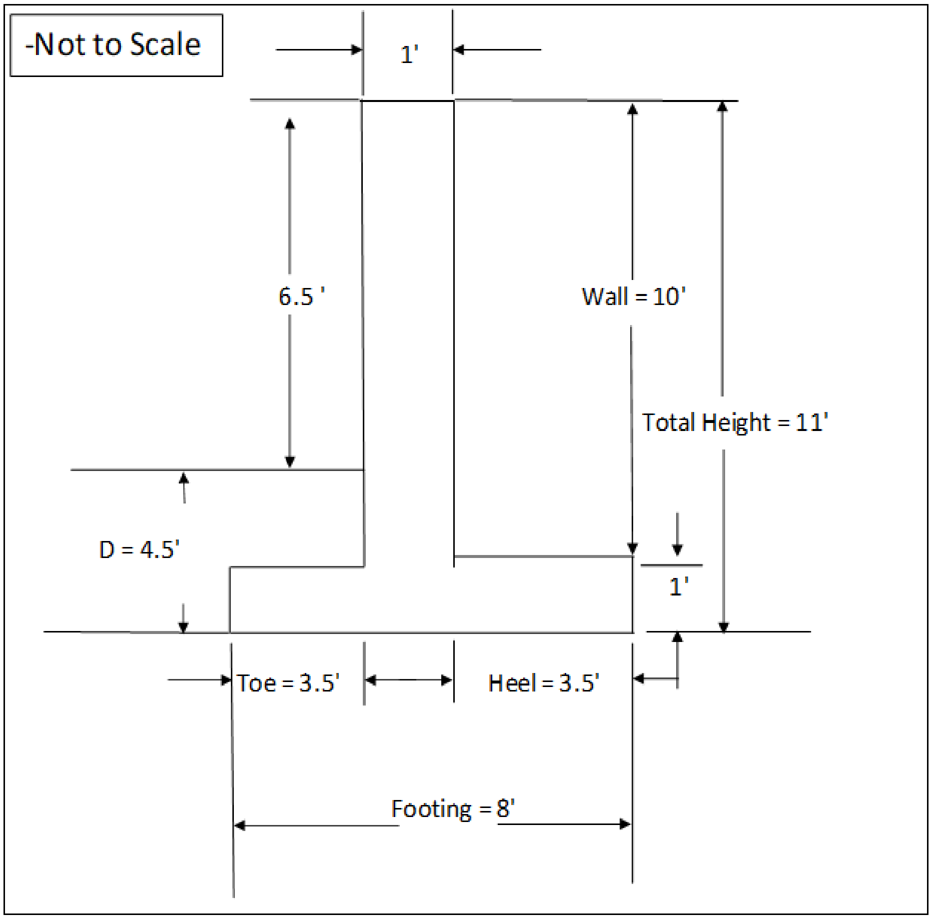


Figure 16: Visual Representation of Wall Dimensions

		Overturning and Sliding Calculations:				
	Ka:	0.4059		z:		
	Kp:	2.4639				
	σa':	513.4110243	lb/ft^2			
Soil:	P1:	2823.760633	lb/ft	2823.760633		
Surcharge:	Pq:	324.6868138	lb/ft			
Total:	Pa:	3148.447447	lb/ft			
	σ':	1150	lb/ft^2			
	Section No.:	Area (ft^2):	Weight (lb/ft.):	Moment Arm (ft):	Moment (lb*ft./ft.):	
	1	10.00	1250.00	4.00	5000.00	
	3	8	1200	4	4800	
	4	35.00	4025	6.25	25156.25	
KeyWay:	6	0	0	6.5	0	
		ΣV:	6475.00	ΣMr:	34956.25	
	Mo:	11544.30731	lb*ft./ft.			
	F.S.:	3.028	>	2		Overturning
	k1=k2:	0.67				
	Pp:	2868.918479	lb/ft			
	δ':	16.66666667				
	tan(δ'):	0.299380347				
	F.S.:	1.527	>	1.5		Sliding
	qu:	3547.577686	lb/ft^2			
	F.S.:	3.403	>	3		Bearing Capacity

Figure 17: Excel Sheets for Calculating Failure Checks (10-foot) 1/2

Bearing Capacity Calculations:							
Mn:	23411.94	lb*ft	β:	0.411	Cosa:		1
e:	0.384256	ft.	β:	23.56211	Pa*Cosa:		2823.760633
I:	42.66667	ft.^4			Pa*Cosa/ΣV:		0.436102028
M:	2488.057	lb*ft			PI()/180:		0.017453293
My/I:	233.2554	lb/ft^2					
qmax:	1042.63	lb/ft^2					
qmin:	576.12	lb/ft^2					
Nc:	20.72	20.72					
Nq:	10.66						
Nγ:	10.88						
B':	7.23	ft.					
L:	1E+99	ft.					

Shape Factors:	
Fcs:	1
Fqs:	1
Fγs:	1

Depth Factors:		Df/B:	0.5625
Fcd:	1.193		
Fqd:	1.175		
Fγd:	1		

Incline Factors:	
Fci=Fqi:	0.54
Fγi:	0.00

Figure 18: Excel Sheets for Calculating Failure Checks (10-foot) 2/2

Table 8: Final Small Wall Dimensions / Properties

Wall Properties		
Height of Wall:	5	feet
Wall Thickness:	12	inches
Depth (D):	2.5	feet
Total Height:	6	feet
Footing Length:	5	feet
Footing Thickness:	1	feet
Footing Toe:	2	feet
Footing Heel:	2	feet
Unit Weight of CMU:	125	lb/ft^3
Unit Weight of Concrete:	150	lb/ft^3

			Calculations			
	Ka:		0.4059		z:	
	Kp:		2.4639			
	σa':		280.0423769	lb/ft^2		
Soil:	P1:		840.1271306	lb/ft	840.1271306	
Surcharge:	Pq:		162.3434069	lb/ft		
Total:	Pa:		1002.470537	lb/ft		
	σ':		575	lb/ft^2		
	Section No.:		Area (ft^2):	Weight (lb/ft.):	Moment Arm (ft):	Moment (lb*ft./ft.):
		1	5.00	625.00	2.50	1562.50
		3	5	750	2.5	1875
		4	10.00	1150	4.00	4600.00
KeyWay:		6	0	0	5	0
			ΣV:	2525.00	ΣMr:	8037.50
	Mo:		2004.941075	lb*ft./ft.		
	F.S.:		4.008845996	>	2	Overturning
	k1=k2:		0.67			
	Pp:		885.4686665	lb/ft		
	δ':		16.66666667			
	tan(δ'):		0.299380347			
	F.S.:		1.637358886	>	1.5	Sliding
	qu:		2449.51985	lb/ft^2		
	F.S.:		4.280986354	>	3	Bearing Capacity

Figure 19: Excel Sheets for Calculating Failure Checks (5-foot) 1/2

Bearing Capacity						
Mn:	6032.559	lb*ft	β:	0.321	Cosα	1
e:	0.110868	ft.	β:	18.4035	Pa*Cosα	840.1271306
I:	10.41667	ft.^4			Pa*Cosα/ΣV:	0.332723616
M:	279.9411	lb*ft			PI()/180:	0.017453293
My/I:	67.18586	lb/ft^2				
qmax:	572.19	lb/ft^2				
qmin:	437.81	lb/ft^2				
Nc:	20.72	20.72				
Nq:	10.66					
Nγ:	10.88					
B':	4.78	ft.				
L:	1E+99	ft.				

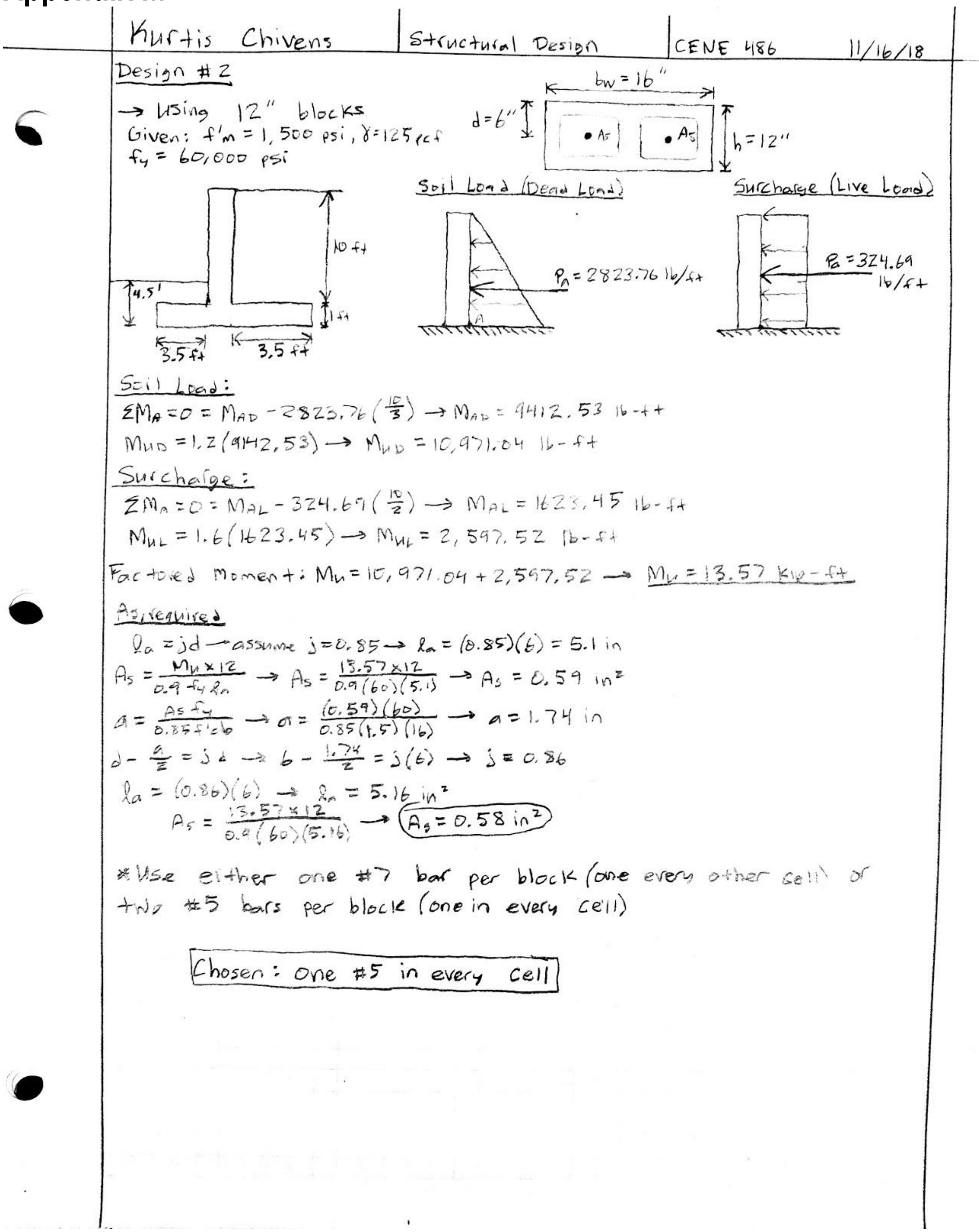
Shape Factors:	
Fcs:	1
Fqs:	1
Fγs:	1

Depth Factors:		Df/B:	0.5
Fcd:	1.172		
Fqd:	1.155		
Fγd:	1		

Incline Factors:	
Fci=Fqi:	0.63
Fγi:	0.07

Figure 20: Excel Sheets for Calculating Failure Checks (5-foot) 2/2

Appendix M



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Design #2

→ Using 12" blocks

Given: $f'_m = 1,500$ psi, $\gamma = 125$ pcf

$f_y = 60,000$ psi

Soil Load:

$\Sigma M_A = 0 = M_{AD} - 2823.76\left(\frac{10}{3}\right) \rightarrow M_{AD} = 9412.53$ lb-ft

$M_{uD} = 1.2(9142.53) \rightarrow M_{uD} = 10,971.04$ lb-ft

Surcharge:

$\Sigma M_A = 0 = M_{AL} - 324.69\left(\frac{10}{2}\right) \rightarrow M_{AL} = 1623.45$ lb-ft

$M_{uL} = 1.6(1623.45) \rightarrow M_{uL} = 2,597.52$ lb-ft

Factored Moment: $M_u = 10,971.04 + 2,597.52 \rightarrow M_u = 13.57$ kip-ft

As, required

$l_a = jd$ → assume $j = 0.85 \rightarrow l_a = (0.85)(6) = 5.1$ in

$A_s = \frac{M_u \times 12}{0.9 f_y l_a} \rightarrow A_s = \frac{13.57 \times 12}{0.9(60)(5.1)} \rightarrow A_s = 0.59\ in^2$

$a = \frac{A_s f_y}{0.85 f'_c b} \rightarrow a = \frac{(0.59)(60)}{0.85(1.5)(16)} \rightarrow a = 1.74$ in

$d - \frac{a}{2} = jd \rightarrow 6 - \frac{1.74}{2} = j(6) \rightarrow j = 0.86$

$l_a = (0.86)(6) \rightarrow l_a = 5.16\ in^2$

$A_s = \frac{13.57 \times 12}{0.9(60)(5.16)} \rightarrow A_s = 0.58\ in^2$

*Use either one #7 bar per block (one every other cell) or two #5 bars per block (one in every cell)

Chosen: one #5 in every cell

Figure 21: Wall Calculation Details (1/4)

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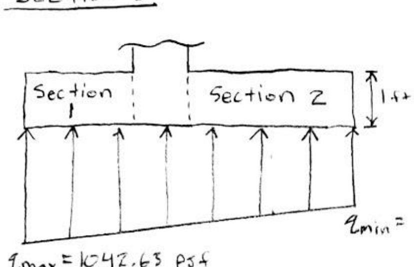
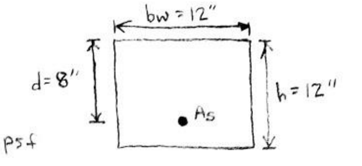
Section 2



Assumptions:
$f'_c = 2500$ psi 4" of Cover
$f_y = 60{,}000$ psi

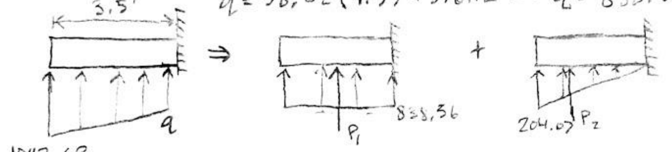


$y = mx + b$, $m = \frac{y - y_1}{x - x_1} \rightarrow m = \frac{1042.63 - 576.12}{8 - 0} \rightarrow m = 58.32$

$y = 58.32x + 576.12$

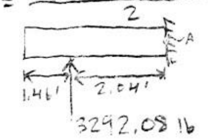
Section 1

$q = 58.32(4.5) + 576.12 \rightarrow q = 838.56$ psf



$P_1 = 2934.96$ lb, $P_2 = 357.12$ lb $\rightarrow$ $P = 3292.08$ lb

$\bar{x} = \frac{\frac{1}{2}(3.5) + \frac{1}{3}(3.5)}{2} \rightarrow \bar{x} = 1.46$ ft



$+\circlearrowleft \Sigma M_A = 0 = M_A - 3292.08(2.04) \rightarrow M_A = 6715.84$ lb-ft

$M_u = 1.6(6715.84) = 10745.55$ lb-ft

$M_u = 10.75$ kip-ft

As, required:

$l_a = jd \rightarrow$ assume $j = 0.85 \rightarrow l_a = 0.85(8) \rightarrow l_a = 6.8$ in

$A_s = \frac{M_u \times 12}{0.9 f_y l_a} \rightarrow A_s = \frac{10.75 \times 12}{0.9(60)(6.8)} \rightarrow A_s = 0.35$ in^2

$a = \frac{A_s f_y}{0.85 f'_c b} \rightarrow a = \frac{(0.35)(60)}{0.85(2.5)(12)} \rightarrow a = 0.82$ in

$d - \frac{a}{2} = jd \rightarrow 8 - \frac{0.82}{2} = j(8) \rightarrow j = 0.95$ in

$l_a = (0.95)(8) = 7.6$ in $\rightarrow A_s = \frac{10.57 \times 12}{0.9(60)(7.6)} \rightarrow A_s = 0.31$ in^2

* Use one #6 bar per every foot of wall

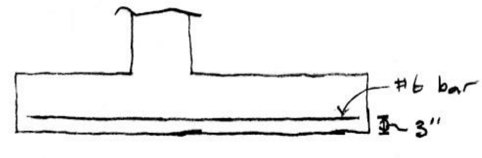
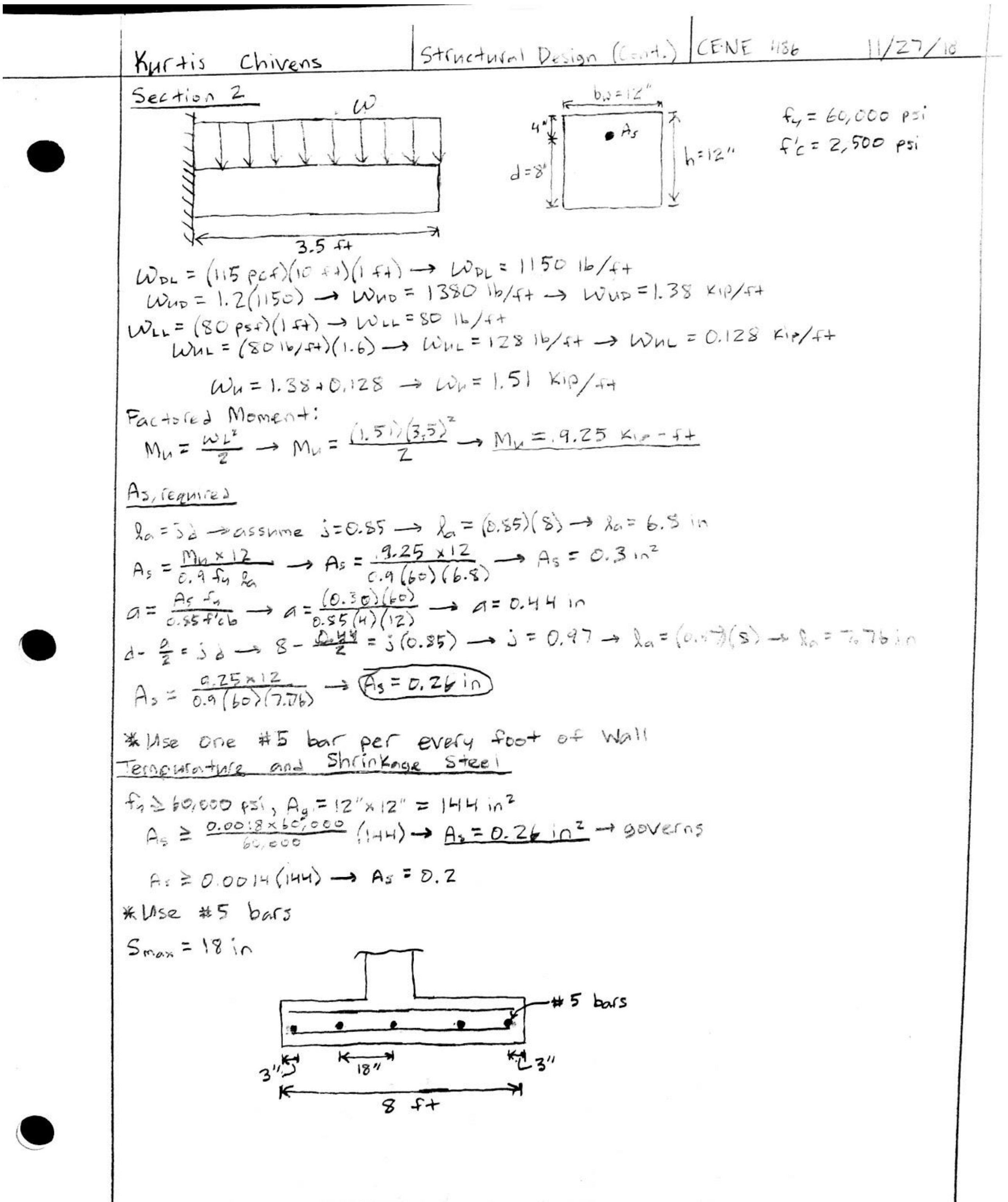


Figure 22: Wall Calculation Details (2/4)



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Section 2

w

$b_w = 12''$

$4''$ A_s $h = 12''$ $d = 8''$

$f_y = 60{,}000$ psi
$f'_c = 2{,}500$ psi

3.5 ft

$w_{DL} = (115\ pcf)(10\ ft)(1\ ft) \rightarrow w_{DL} = 1150\ lb/ft$
$w_{uD} = 1.2(1150) \rightarrow w_{uD} = 1380\ lb/ft \rightarrow w_{uD} = 1.38\ kip/ft$
$w_{LL} = (80\ psf)(1\ ft) \rightarrow w_{LL} = 80\ lb/ft$
$w_{uL} = (80\ lb/ft)(1.6) \rightarrow w_{uL} = 128\ lb/ft \rightarrow w_{uL} = 0.128\ kip/ft$

$w_u = 1.38 + 0.128 \rightarrow w_u = 1.51\ kip/ft$

Factored Moment:
$M_u = \frac{wL^2}{2} \rightarrow M_u = \frac{(1.51)(3.5)^2}{2} \rightarrow M_u = 9.25\ kip\text{-}ft$

A_s, required

$l_a = jd \rightarrow$ assume $j = 0.85 \rightarrow l_a = (0.85)(8) \rightarrow l_a = 6.8$ in
$A_s = \frac{M_u \times 12}{0.9 f_y l_a} \rightarrow A_s = \frac{9.25 \times 12}{0.9(60)(6.8)} \rightarrow A_s = 0.3\ in^2$
$a = \frac{A_s f_y}{0.85 f'_c b} \rightarrow a = \frac{(0.30)(60)}{0.85(4)(12)} \rightarrow a = 0.44$ in
$d - \frac{a}{2} = jd \rightarrow 8 - \frac{0.44}{2} = j(0.85) \rightarrow j = 0.97 \rightarrow l_a = (0.97)(8) \rightarrow l_a = 7.76$ in
$A_s = \frac{9.25 \times 12}{0.9(60)(7.76)} \rightarrow A_s = 0.26$ in

* Use one #5 bar per every foot of wall

Temperature and Shrinkage Steel

$f_y \geq 60{,}000$ psi, $A_g = 12'' \times 12'' = 144\ in^2$
$A_s \geq \frac{0.0018 \times 60{,}000}{60{,}000}(144) \rightarrow A_s = 0.26\ in^2 \rightarrow$ governs

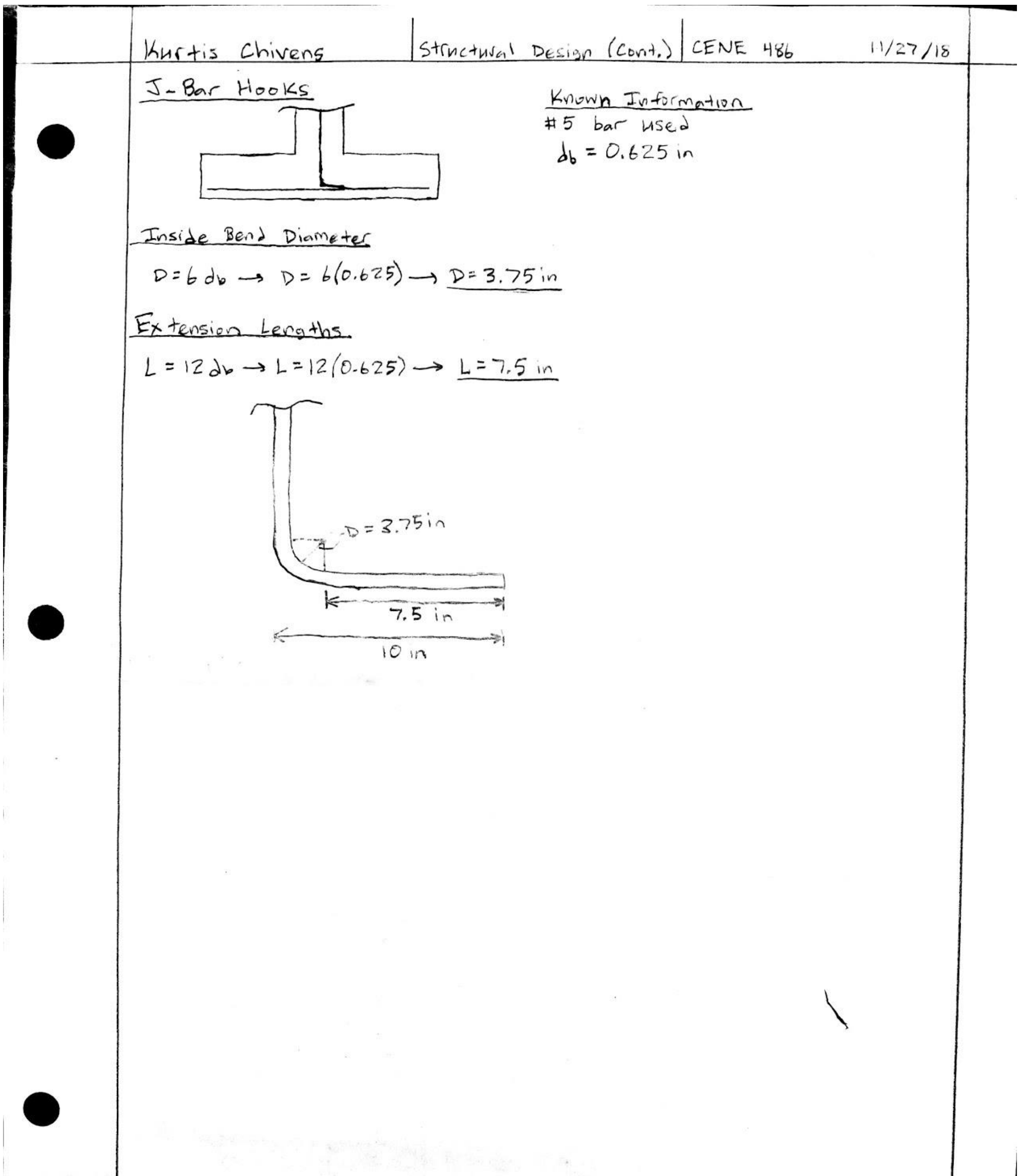
$A_s \geq 0.0014(144) \rightarrow A_s = 0.2$

* Use #5 bars

$S_{max} = 18$ in

#5 bars
3'' 18'' 3''
8 ft

Figure 23: Wall Calculation Details (3/4)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J-Bar Hooks

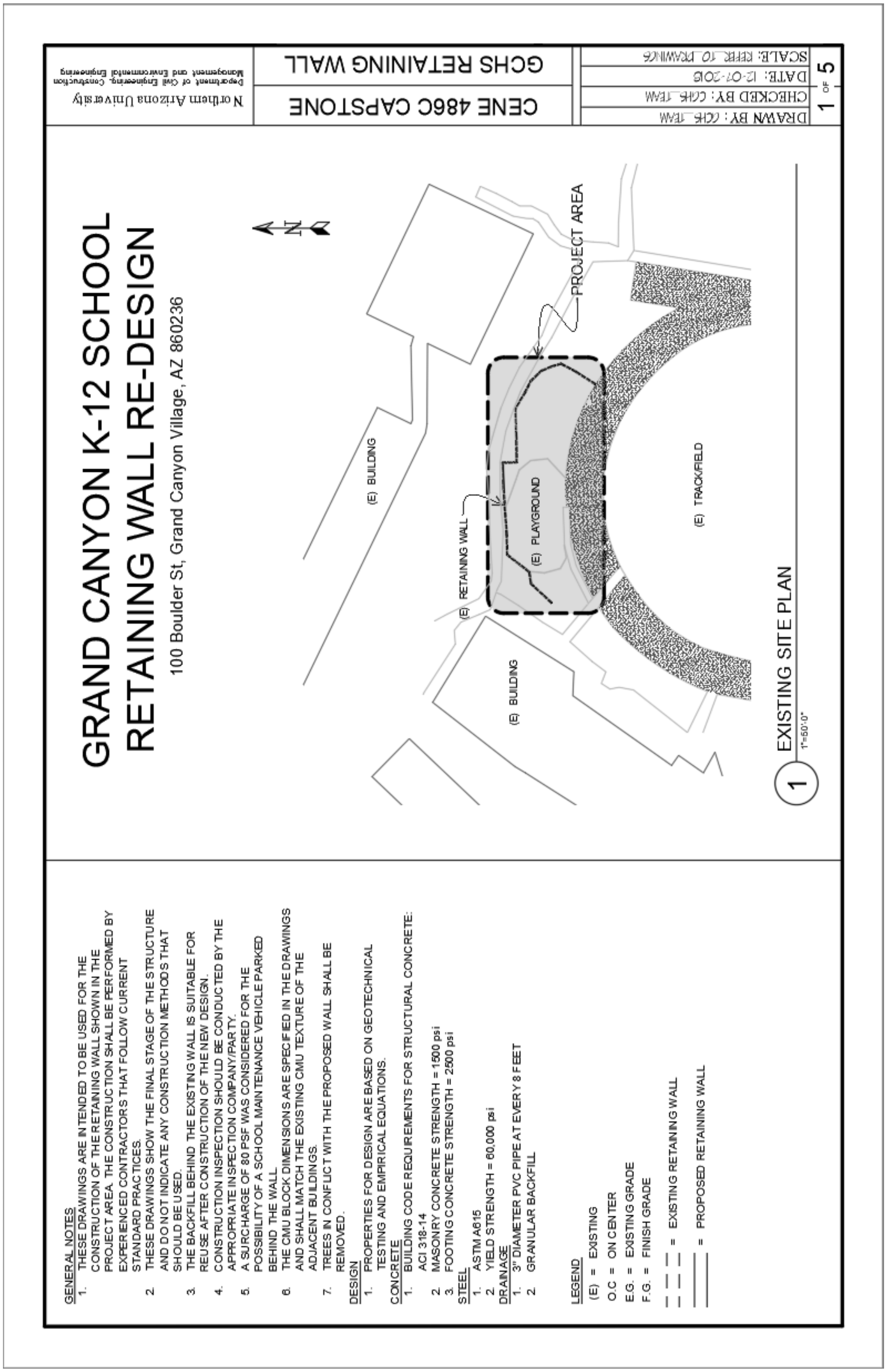
Known Information
#5 bar used
$d_b = 0.625$ in

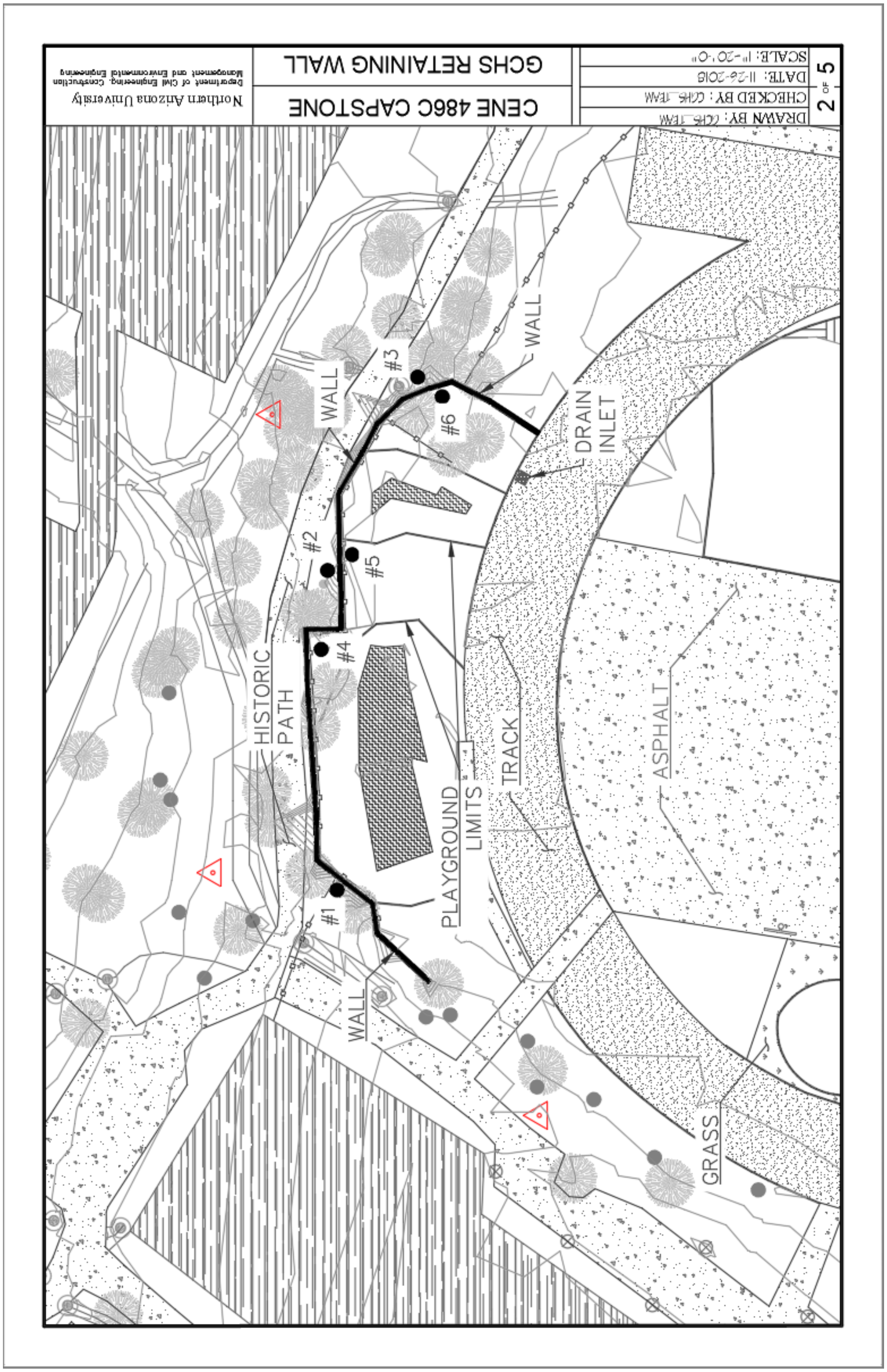
Inside Bend Diameter
$D = 6 d_b \rightarrow D = 6(0.625) \rightarrow D = 3.75$ in

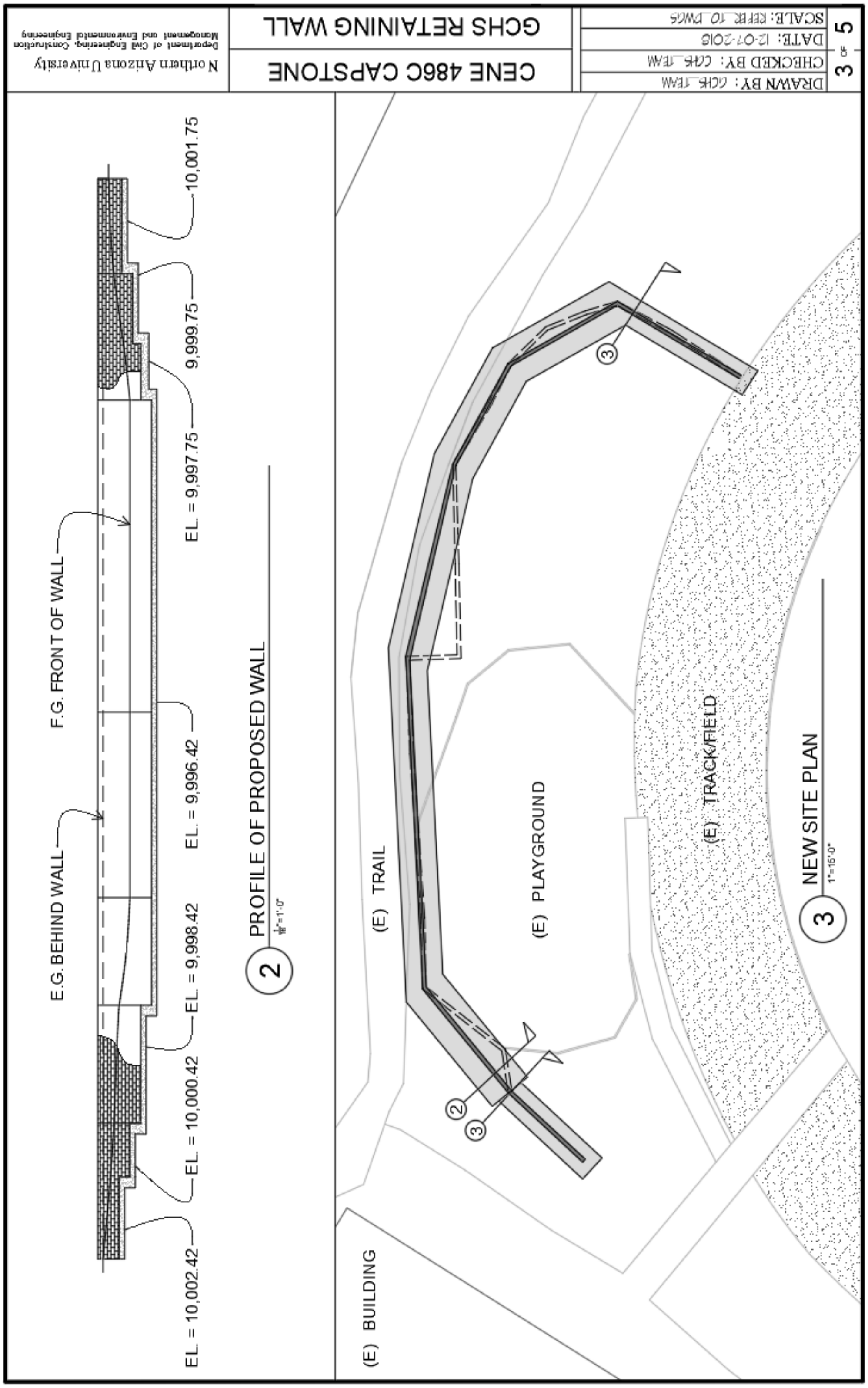
Extension Lengths
$L = 12 d_b \rightarrow L = 12(0.625) \rightarrow L = 7.5$ in

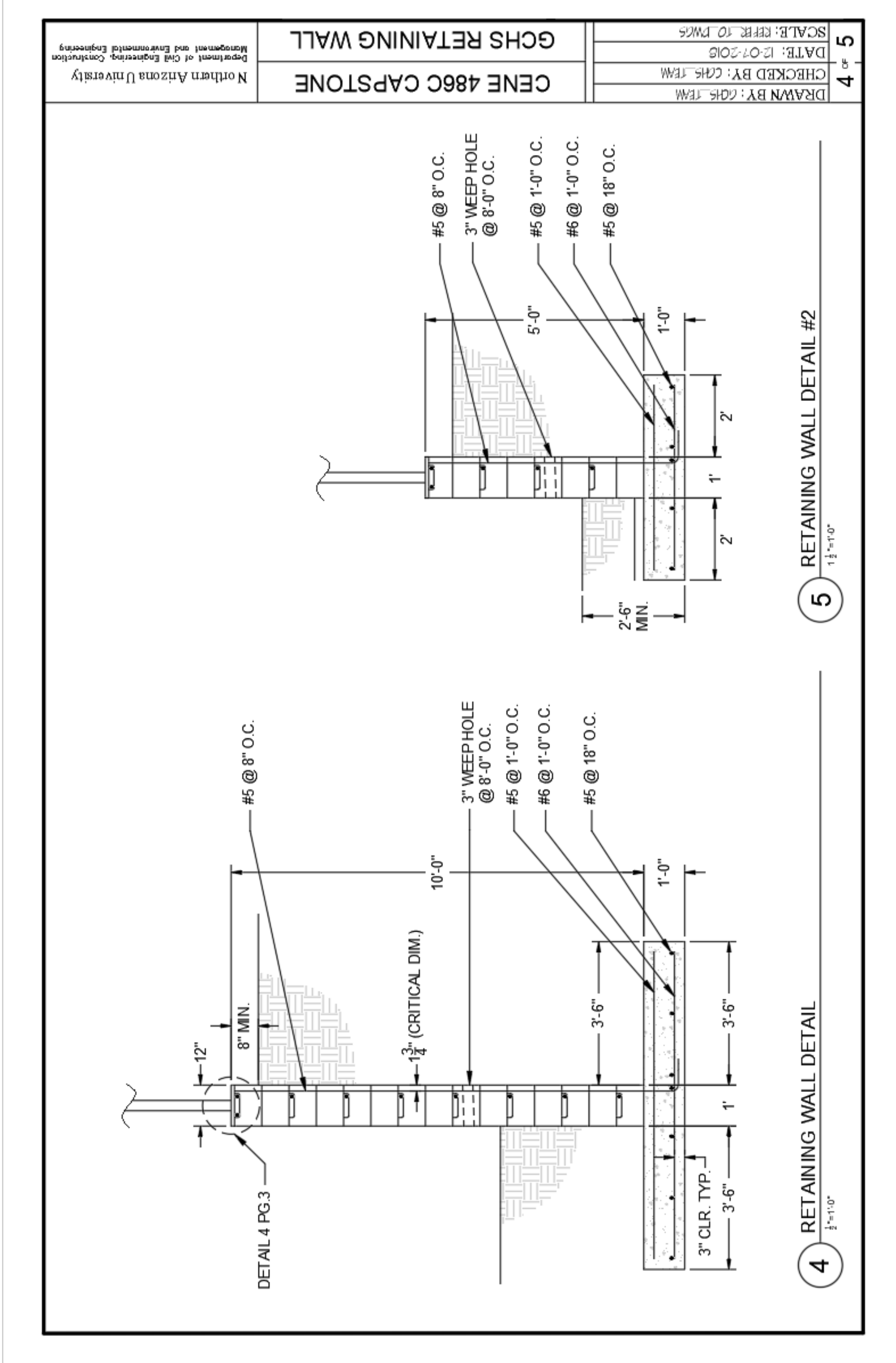
Figure 24: Wall Calculation Details (4/4)[

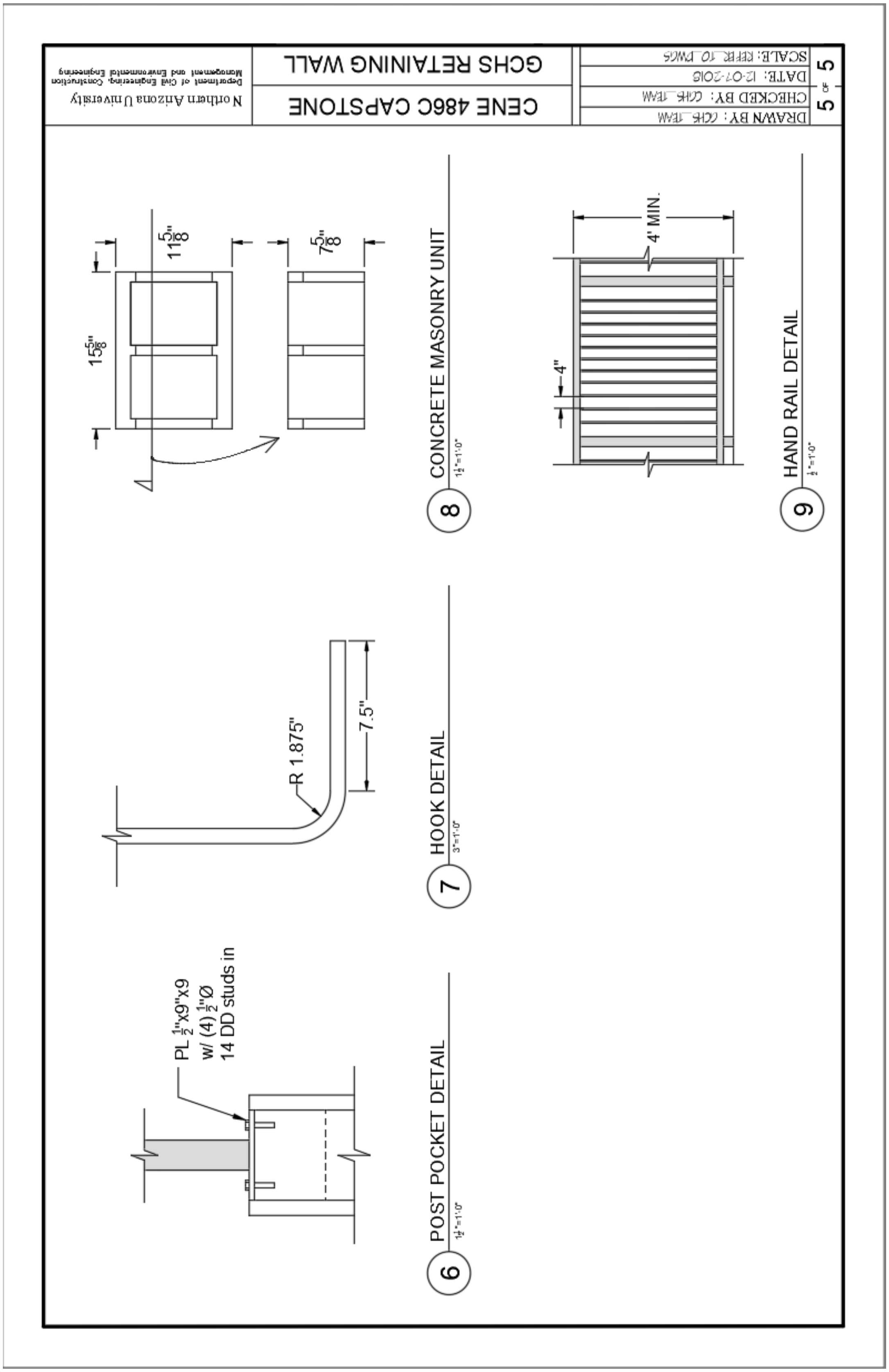
Appendix N: Construction Documents




CENE 486C CAPSTONE
GCHS RETAINING WALL
Northern Arizona University
Department of Civil Engineering, Construction Management and Environmental Engineering
DRAWN BY: GCHS TEAM
CHECKED BY: GCHS TEAM
DATE: 11-26-2018
SCALE: 1"=20'-0"
2 OF 5
WALL
#3
#6
DRAIN INLET
#2
#5
#4
HISTORIC PATH
PLAYGROUND LIMITS
TRACK
ASPHALT
#1
WALL
GRASS


CENE 486C CAPSTONE
GCHS RETAINING WALL
Northern Arizona University
Department of Civil Engineering, Construction Management and Environmental Engineering
DRAWN BY: GCHS TEAM
CHECKED BY: GCHS TEAM
DATE: 12-07-2018
SCALE: REFER TO DWGS
3 of 5
E.G. BEHIND WALL
F.G. FRONT OF WALL
EL. = 10,002.42
EL. = 10,000.42
EL. = 9,998.42
EL. = 9,996.42
EL. = 9,997.75
9,999.75
10,001.75
2 PROFILE OF PROPOSED WALL
(E) BUILDING
(E) TRAIL
(E) PLAYGROUND
(E) TRACK/FIELD
3 NEW SITE PLAN
1"=15'-0"


Northern Arizona University
Department of Civil Engineering, Construction Management and Environmental Engineering
CENE 486C CAPSTONE
GCHS RETAINING WALL
DRAWN BY: GCHS TEAM
CHECKED BY: GCHS TEAM
DATE: 12-07-2018
SCALE: REFER TO DWGS
4 OF 5
#5 @ 8" O.C.
3" WEEP HOLE @ 8'-0" O.C.
#5 @ 1'-0" O.C.
#6 @ 1'-0" O.C.
#5 @ 18" O.C.
5'-0"
1'-0"
2'
1'
2'
2'-6" MIN.
5 RETAINING WALL DETAIL #2
1 1/2"=1'-0"
DETAIL 4 PG.3
12"
8" MIN.
1 3/4" (CRITICAL DIM.)
10'-0"
3'-6"
1'
3'-6"
3" CLR. TYP.
3'-6"
4 RETAINING WALL DETAIL
1/2"=1'-0"


Northern Arizona University
Department of Civil Engineering, Construction Management and Environmental Engineering
CENE 486C CAPSTONE
GCHS RETAINING WALL
DRAWN BY: GCHS TEAM
CHECKED BY: GCHS TEAM
DATE: 12-07-2016
SCALE: REFER TO DWGS
5 OF 5
PL ½"x9"x9
w/ (4) ½"Ø
14 DD studs in
6 POST POCKET DETAIL
R 1.875"
7.5"
7 HOOK DETAIL
3"=1'-0"
15⅝"
11⅝"
7⅝"
8 CONCRETE MASONRY UNIT
4' MIN.
4"
9 HAND RAIL DETAIL