

RECYCLED PLASTIC IN CONSTRUCTION MATERIALS
Project ID: CEEEn_CPST_06

by

Team Vector
Alicia Nelson Cherrington
Jackson Calder
Ian MacGregor
Joshua Carlile
Conrad Belshe

A Capstone Project Technical Report

Submitted to

Dr. W. Spencer Guthrie
Brigham Young University

Department of Civil and Construction Engineering
Brigham Young University

April 11, 2022

Executive Summary

PROJECT TITLE: RECYCLED PLASTIC IN CONSTRUCTION
PROJECT ID: CEEEn_CPST_06
PROJECT SPONSOR: Dr. W. Spencer Guthrie
TEAM NAME: Team Vector

During our studies here at BYU we are constantly taught the phrase “Enter to learn, go forth to serve”. This motto is often taught in our weekly campus devotionals and within our major’s weekly seminars. With this idea ingrained into everything we do here, we as a team decided there must be something we can do to make an impact. One of our team members in a concrete materials class came up with the idea of using recycled plastics as a potential additive or aggregate replacement for concrete or grout. The rest of the group quickly got on board and began researching the possibilities. After much research and consulting with our faculty advisor Dr. Guthrie, we came to the conclusion that with our resources and timeline we should narrow our scope to using recycled plastic as an additive for just grout.

Referencing the procedures outlined in the American Society for Testing and Materials (ASTM) standards, we were able to create a mortar mix design for Type N and Type S mortar, using 0% (control), 5%, and 7.5% replacement of mortar sand with ground plastic. After batching our mixes, we conducted a flow test and water retention test to ensure all ASTM standards were met. The cubes were cast into square molds and left to cure for 7-day and 28-day compressive testing. The ASTM standards set a minimum strength requirement for 28-day mortar cubes. This strength requirement was met by all control (0% plastic) cubes, 5% cubes, and the Type N 7.5% plastic cubes.

In the future, we recommend conducting a burn test, air inclusion test, and freeze-thaw test to better understand the effects of plastic substitution in mortar cubes. Our findings were that plastic can be substituted for mortar sand up to 7.5% in Type N mortar and 5% in Type S mortar.

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Introduction

Engineering practice in the United States lacks a drive for sustainable solutions. Often, the environment is not a large enough priority and suffers at the expense of construction and development. Construction practices commonly used today contribute 25-40% of the world's carbon emissions according to Bold Business. Current practices also contribute to air and water pollution, material waste, the burning of fossil fuels, and high energy consumption. Needless to say, there is a great environmental need for change in construction practice.

Plastic waste is a common issue throughout the United States. Too often recycling is ignored or deemed too much of a hassle. According to the EPA, in 2017 35,370,000 tons of plastic were generated in the United States, yet only 2,960,000 tons were recycled. While that is a large number of recycled materials, that is only 8% of what is generated. That means roughly 92% of recycled materials are sent to landfills to decompose in the next 1000 years or to be burned creating air pollution. All of this material is being wasted or causing more harm to the environment instead of being repurposed for a legitimate cause.

Recycled materials in construction could be the answer to so many problems Americans face. It could help with deforestation as well as combat material shortages by providing alternative materials for construction. Plastic can be removed from water sources and the ocean to encourage environmental cleanup. Rather than leaving the plastic to waste and pollute, it could be extremely beneficial in the building of eco-friendly communities worldwide.

Our team decided to tackle this issue on a smaller scale by determining how we could recycle plastic from our community and use it in our engineering practice. Due to the generosity of local business Blender Bottle, their waste products were donated to Brigham Young University to be used as a substitution for mortar sand. Our objective was to grind up the bottles into a fine-aggregate state to include in mix designs instead of shipping them off to landfills.

Schedule

Date	Milestone
10/10/2021	Complete Primary Research
11/10/2021	Complete Plastic Grinding
11/30/2021	Begin Phase 1 Testing
1/30/2022	Begin Phase 2 Testing
2/30/2022	Begin Phase 3 Testing
3/10/2022	Begin Result Analysis
4/10/2022	Project Completion

Assumptions & Limitations

When creating the mix designs for type S and type N mortar, our team assumed that the specific gravity of the sand was 2.65. While this is a common assumption, there is a possibility that the sand we used had a different specific gravity.

One of the limitations that our team faced was performing a water retention test. Since our lab did not have a water retention test, we had to build one using the materials available. We used a plastic funnel and modified the vacuum in the laboratory so that we could run the test as closely as possible to the procedure listed in ASTM C 1506. The dimensions of the water retention testing apparatus is outlined in ASTM C 1506, and the test was physically built to match them. Figure 3.1 shows the water retention test that our team built. While it is as close to the specifications as possible, it is not an official test, and there is a potential for error in our water retention results.

Another limitation that our team faced was a limited amount of time. In the time allotted for this project, we were only able to perform compressive strength tests on the finished cubes. If given a longer time to research, we would have liked to perform a tensile strength, freeze-thaw and burn depth tests to see how these properties were affected by plastic waste replacement.

Figure 3.1: Water retention test created by the team



Design, Analysis & Results

In order to test the viability of incorporating fine plastic aggregate mortar we had to create a mortar mix design that met the ASTM mortar mixing parameters. The four standard ingredients we used in our mortar design were water, portland cement, lime, and sand. The sand is the fine aggregate of the mix. The plastic that we incorporated into this project replaced a percentage of the volume of the fine aggregate. Below is figure 4.1 which was the table used in our mix design.

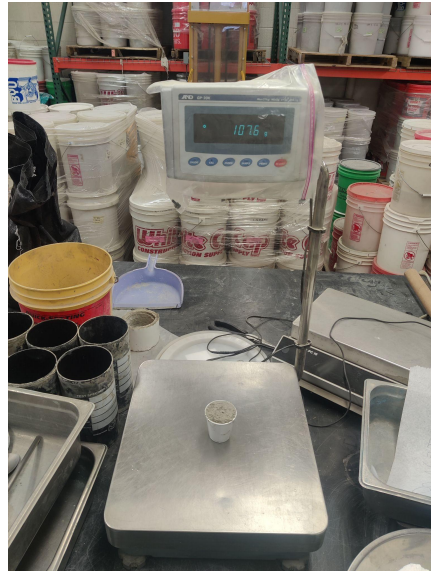
Figure 4.1: Table used for our mix design (ASTM C 270 Table 1)

TABLE 1—ASTM C 270 Proportion Specification Requirements (ref. 4)										
Proportions by volume (cementitious materials)										
Mortar	Type	Portland cement or blended cement	Mortar Cement			Masonry cement			Hydrated lime or lime putty	Aggregate ratio (measured in damp, loose condition)
			M	S	N	M	S	N		
Cement-lime	M	1	1/4	Not less than 2 1/4 and not more than 3 times the sum of the separate volumes of cementitious materials.
	S	1	...	...	...	...	...	over 1/4 to 1/2	
	N	1	...	...	...	...	...	over 1/2 to 1 1/4	
	O	1	...	...	...	...	...	over 1 1/4 to 2 1/2	
Mortar Cement	M	1	...	...	1	...	...	...	...
	M	...	1	...	...	...	...	...	...
	S	1/2	...	...	1	...	...	...	...
	S	...	...	1	...	...	...	...	...
	N	...	...	...	1	...	...	...	...
Masonry Cement	O	...	...	...	1	...	...	...	...
	M	1	...	...	...	...	1	...	...
	M	...	...	...	...	1	...	...	...
	S	1/2	...	...	...	...	1	...	...
	S	...	...	...	...	1	...	...	...
	N	...	...	...	...	...	1	...	...
O	...	...	...	...	...	1	...	...

Note—Two air-entraining materials should not be contained in mortar.

The table uses the proposition of volume to specify the mix design’s dry ingredients. This is so that mortar can be mixed by a trade worker on-site only using a simple measuring cup. This practical approach works great in the field, however, it presented us with a difficult task for our lab testing. Our lab mechanism for measuring the ingredients out was using a scale that measured in grams. Due to the different densities of each material we had to find some way to convert the volume measurement to weight in order to stay within the ASTM mixing parameters. This was done by measuring the weight of each material in the same size cup as seen in figure 4.2 below. This was then used as a key to convert the volume ratios to weight ratios for our mix design.

Figure 4.2: weight of portland cement in one 3.3g cup



The amount of water inclusion for the mortar was determined from the previous testing. The ratio of water to cementitious material (portland cement plus lime) ranged from around 1 to 1.5 based on the percentage of plastic that was used in the batch. We found that the higher the plastic content the greater amount of water was needed in the batch. We suspect that this is because the molecular structure of the plastic particles is rougher than the normal sand aggregate. The greater gap void area in the plastic causes a space where more water can fill.

When it came to batching our mortar, we followed the procedure listed in ASTM C 1437. We mixed plastic in with the sand. Figures 4.3 through 4.5 show our performance of several steps of the process.

Figure 4.3: Plastic waste mixed in with the sand



Figure 4.4: Measuring mortar workability according to ASTM C 1437



Figure 4.5: Mortar that passed the water retention test put into the molds according to ASTM C 1437



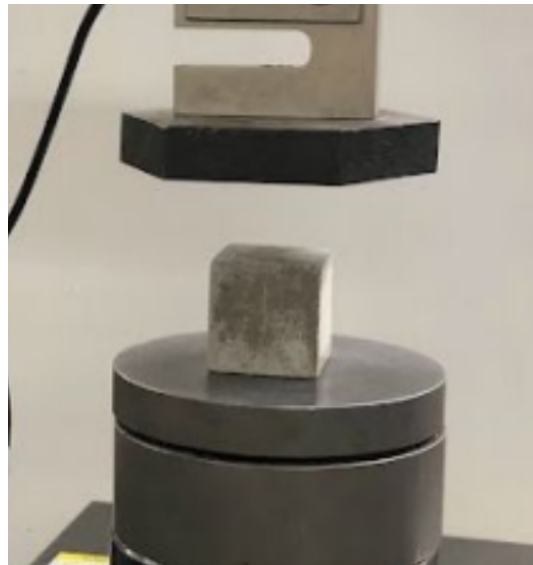
The plastic we substituted into the mortar replaced the percentage of the volume of the sand, not the entire volume of mortar mix. This was calculated by using the specific gravity values of 1.18 for the plastic and 2.65 for the sand.

The compression test was performed according to the standards established by ASTM C 109. Figure 4.6 shows a team member measuring out the area of the cube, and figure 4.7 shows the cube in the testing machine.

Figure 4.6: Team member measuring the area of the cube face.



Figure 4.7: Cube with plastic waste inclusion undergoing the compressive strength test



Once the maximum load was measured, the compressive strength was determined by dividing the load by the area of the face that was bearing the load. Figure 4.8 and 4.9 shows the results of the 28-day compression test for all type N and type S mortar samples. For figure 4.8 the values in green mean that the sample met the ASTM’s minimum compression value for that type of mortar as shown in figure 4.10. The red values did not meet the minimum compressive value. Figure 4.9’s bar graph shows the amount that the compressive was over or under for each sample average. As you can see, when plastic was included with the mix type N mortar met the minimum compression values where type s only passed for the 5% plastic conclusion.

Figure 4.8: Type N and S Compression Test Results

28-Day Compressive Strength (psi)				
Type	Type N		Type S	
Cube	Strength	Pass	Strength	Pass
0%	1236	Yes	1933	Yes
0%	1315	Yes	2072	Yes
5%	909	Yes	1956	Yes
5%	869	Yes	2147	Yes
7.50%	872	Yes	1529	No
7.50%	874	Yes	1458	No

Figure 4.9: Ave Compressive Strength for each Plastic Supplement.

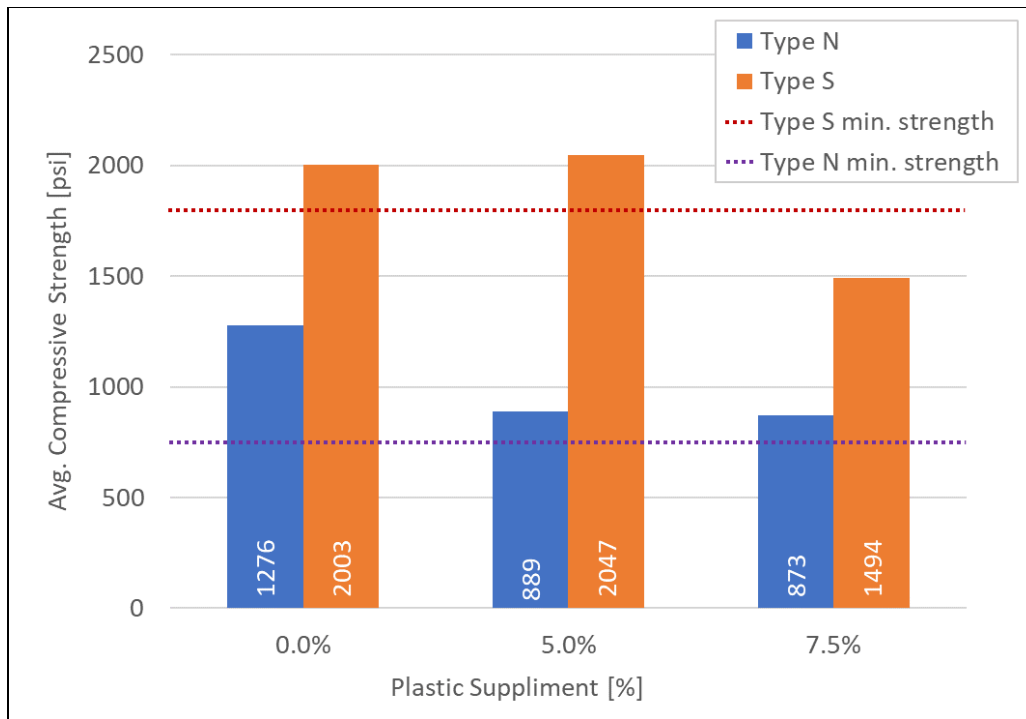


Figure 4.10: Min. 28-Day Compressive Strength Values (ASTM C 270 Table 2)

Mortar	Type	Average compressive strength at 28 days min. psi (MPa)	Water retention, min. %	Air content max. %	Aggregate ratio (measured in damp, loose conditions)
Cement-Lime	M	2500 (17.2)	75	12	Not less than 2 ¹ / ₄ and not more than 3 ¹ / ₂ times the sum of the separate volumes of cementitious materials.
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14 ^b	
	O	350 (2.4)	75	14 ^b	
Mortar Cement	M	2500 (17.2)	75	12	
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14 ^b	
	O	350 (2.4)	75	14 ^b	
Masonry Cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20 ^c	
	O	350 (2.4)	75	20 ^c	

^A Laboratory prepared mortar only
^B When structural reinforcement is incorporated in cement-lime mortar, the maximum air content shall be 12%.
^C When structural reinforcement is incorporated in masonry cement mortar, the maximum air content shall be 18%.

Related Issues

Our project has a potential impact on the environment and the economy. Using plastic waste in design can reduce the amount of plastic in landfills and the amount of pollution in the environment. Additionally, sand for construction can be expensive to transport. The shortage of construction sand in the world further demonstrates the costs associated with obtaining and using sand. If some of the sand can be replaced with plastic waste, the mortar will be less expensive. Mortar made with plastic waste has the potential to not only reduce pollution but to be economically viable. This reduction in plastic waste can also increase public health. With less waste in the environment, people have the potential to live healthier lives.

In regards to safety, the results of our research demonstrate that type N mortar passes ASTM standards up to 7.5% replacement, while type S can safely pass up to 5% replacement. This mortar is safe enough to use in practice when regarding compressive strength. It is apparent from our research that plastic inclusion does not make mortar safer, but it is still safe enough. This research demonstrates that mortar could be used in lower risk structures and still meet the design requirements. However, further research should be done regarding freeze-thaw testing and burn depth testing to see if mortar with plastic waste is safe enough according to those standards.

Socially, this project can gain a lot of momentum as companies with lots of plastic waste such as Blender Bottle can find a more effective way to dispose of their plastic waste. There is potential for companies to receive an incentive such as tax breaks if they grind their plastic waste themselves before sending it to an aggregate yard. As more companies grind their plastic for use in mortar mix, then less of it will go into landfills. On a global scale, while plastic is one of the most common elements in waste, there are many other waste products such as glass. Additional research could be done investigating the impact of compressive strength with glass waste replacement. Countries that may have difficulty turning plastic into aggregate could use different types of waste. The more that any type of waste is used in mortar mix can lead to a reduction in pollution worldwide.

Another factor that needs to be considered is practicality. Most aggregate yards have piles of sand out in the open. This is so loaders can take from the piles directly and load the trucks so that the sand can be taken to be mixed. When it comes to fine plastic aggregate, it may need to be stored differently. Since plastic waste is so light, it can blow away easily, and has potential to cause even more pollution to the environment. Therefore, in order to use plastic waste in plastic, additional measures must be taken when storing it before mixing.

Lessons Learned

Initially, we planned to add plastic waste into concrete and asphalt mix designs; however, there was not an efficient way to grind the amount of plastic to replace the fine aggregate we would need for concrete and asphalt. Our system of using angle grinders was a slow process and was not efficient for a large amount of plastic needed for each batch of concrete and asphalt. Therefore, we decided to pursue plastic inclusion in the mortar which required a much lower amount of fine aggregate.

As we proceeded with type N and type S mortar mix designs, we had issues with our water retention test. Several of our batches required multiple iterations due to failure in the mortar flow and water retention tests. One of the assumptions in our mix design was the water ratio, so the amount of water used was variable. While it was based on the previous testing from guidance from our faculty mentor, it sometimes made our designs too liquid and sometimes not enough. The solution required iterations of adding equal parts of lime, sand, cement, and plastic when the solution was too liquid and vice versa; however, in our later designs, we consciously underestimated the amount of water needed because adding water to the mix design was much easier and faster than adding in several other ingredients. This allowed us to pass the mortar flow test more consistently.

The water retention test had a couple of other challenges that had to be resolved. First, we constructed the apparatus on our own and made sure that it met standards; however, the construction was not perfect and based on materials we had available. The paper material that covered the bottom of the apparatus where the water seeped through became soggy and would tear easily. This made it difficult for us to transfer to the mortar flow test. Additionally, the vacuum sucked at power much larger than what was required which led to lower water retainage value and distorted our values. There was no easy solution to this problem because there were no other materials available to us to make the apparatus work better; however, with enough iterations we were able to get the designs to meet ASTM standards despite these concerns.

Conclusions

We conclude that plastic waste is a viable substitute for fine aggregate in type N and type S mortar. Type S compressive strengths show that at 5% substitution of fine aggregate with recycled plastic can still meet the 1800 psi requirement per ASTM C 270, but 7.5% replacement does not. Type N compressive strengths show that at least 7.5% of the sand can be substituted by plastic waste in this mortar mix design.

Recommendations

We would recommend that future research determine the optimum percentage of plastic inclusion that still meets the required minimum compressive strength. Additionally, we would recommend additional tests such as fire testing and freeze-thaw testing that allow for a wide range of mortar applications.

Appendix A

Ian MacGregor

(503) 784-0256 • ianmacgregor940@gmail.com • linkedin.com/in/ian-macgregor-370679185/

EDUCATION

Brigham Young University Dec 2022
Bachelor of Science/Arts: Civil and Environmental Engineering, Emphasis in Structural Analysis Provo, UT
Minor in Business
▪ GPA 3.96
▪ Scholarships received at BYU for Academics
▪ Currently enrolled in Structural Analysis

PROJECTS/RESEARCH

Earthquake Engineering Research Institute Sep 2019
Team Member Location
▪ Designed the structural framework for a 30-story building
▪ Collaborated with seven other team members as well as a small team of architects

EXPERIENCE

Vector Structural Engineering Oct 2020-Present
Project Manager Provo, UT
▪ Analyzed the structural integrity of residential structures to determine if they could support the added weight from solar panels. Most project analysis was completed in about 20 minutes
▪ Worked with 3 professional engineers when analysis was more difficult
▪ Communicated analysis results with and informed them if a retrofit was necessary and why

Brigham Young University Sep 2020-Present
Statics Teaching Assistant Location
▪ Tutored 40 students in physics and engineering concepts, helping them to become better engineers
▪ Led midterm exam reviews with 20 participants, allowing students with extra opportunities to study and perform better on their exams
▪ Coordinated with five other TAs and the professor to determine which topics needed to be emphasized to help the students have a better understanding of the material

VOLUNTEER EXPERIENCE

Church of Jesus Christ of Latter-Day Saints Aug 2016-Aug 2018
Missionary Lima, Peru
▪ Provided leadership for 14 volunteer representatives, inspiring them to obtain both personal and group goals
▪ Organized and set agendas and flight schedules for representatives moving in and out of Peru, often in groups of 25 or more
▪ Started conversations with people daily, often talking about religious beliefs and theologies

SKILLS/INTERESTS/ACHIEVEMENTS/ABILITIES

-
- Professional Working Spanish
 - Eagle Scout Award
 - Enjoy hiking as well as watching cinema

ALICIA CHERRINGTON

Civil Engineering Student

SKILLS

AutoCAD
Revit
RISA
ArcGIS Pro
Coding (Python, VBA)
Graphic Design
Time Management
Responsibility
Leadership
Hard-Working
Fast-Learning
Spanish Speaking

GOALS

Using Civil Engineering to create sustainable and affordable infrastructure for low-income communities.

CONTACT

PHONE:
956-400-9000

WEBSITE:
<https://www.linkedin.com/in/aliciacherrington/>

EMAIL:
alicianelson23@gmail.com

ENGINEERING INTERESTS

Looking for opportunities to learn and grow in the industry.

Interest in geotechnical engineering, with seismic implications.

Interest in global outreach and research.

Willing to try new things, and work on various project types.

Open to graduate school as well as full time work beginning in May 2022.

Looking for a company that would be a good fit, has a driving mission and is looking to grow and help its employees succeed.

EDUCATION

Brigham Young University

Anticipated Graduation - April 2022

- B.S in Civil and Environmental Engineering
 - Emphasis in structures and materials science
- Lead RA studying usage of recycled plastic in construction

WORK EXPERIENCE

Vector Structural Engineering - Solar Project Manager

August 2020 – Present

- Existing home structural analysis as well as engineering design. Interacting with clients to meet their needs.
- Learning about building code and design criteria requirements.
- Shadowed projects dealing with steel framing, custom residential homes, and commercial buildings.

BYU Online – Administrative Assistant

July 2018 – August 2020

- Learned coding, graphic design, and web development.
- Supervised student employees; managed personnel info.
- Worked with instructors to ensure the production of quality content.

City of Saratoga Springs – Civil Engineering Intern

February 2019 – August 2019

- Learned about the role of government in construction.
- Participated in pre-construction meetings, city planning and site inspections.
- Learned about the roles each organization plays in construction.

PARTICIPATION AND ORGANIZATIONS

- Teaching Assistant – CE 304/306. Materials Science Courses.
- WCE (Women in Civil Engineering) Officer and Member
- SWE (Society of Women Engineers) Member
- HSPE (Hispanic Society of Professional Engineers) Member
- ASCE (American Society of Civil Engineers) Member

NOTABLE COURSES

Structural Wood Design
Foundation Engineering
Mechanics of Materials

Design of Reinforced Concrete
Structural Analysis
Statics/Dynamics

Conrad H. Belshe

197 Wymount Terrace Building 4C, Apt. #197 Provo, UT 84604
(480) 415-8145 conrad.belshe@gmail.com

Education

B.S. Civil Engineering, Brigham Young University (Provo, UT) GPA: 3.67/4.00 Sep. 2017-Present

Interests: Structural Engineering

Classes Taken: Advanced Steel Design, Wood Design, Reinforced Concrete Design, Foundation Design

Estimated Graduation: April 2022

Research Assistant- BYU (Provo, UT) September 2021-Present

- Designed braced frames for a three-story steel structure
- Analyzed braced frames for large wind loads to determine response modification factors

Work Experience

Project Manager- Vector Structural Engineering, LLC (Provo, UT) May 2018-Present

- Designed and detailed small-medium scale residential homes
- Developed spreadsheet, optimized chicago solar certification process
- Certified high priority commercial solar projects using RISA/Enercalc
- Analyzed roofs structural stability with solar installation providing solar certification letters
- Collaborated alongside certified senior engineers

Garde Manger Student Manager- Culinary Support Center, BYU (Provo, UT) Sep. 2017- Aug. 2018

- Supervised 15-20 students in coordination with supervisor
- Made, packaged, sorted sandwiches, salads, soups, and other food products

General Labor- Scott's Diversified Construction (Gilbert, AZ) June 2012- June 2015

- Executed general labor- excavating, dust control, asphalt packer, layed sewer and water pipe
- Accomplished 50 hrs/week at peak of Arizona heat during the summer
- Managed landscaping of 3 customers yards

Extracurricular/Volunteer Work

Volunteer Representative- Czech Republic, Slovakia June 2015-July 2017

- Speak, read, write in Czech fluently
- Supervised 80+ missionaries providing training seminars
- Refined processes to improve efficiency by 20%

Public Library Volunteer, Southeast Regional Library (Gilbert, AZ) Sep. 2013-May 2015

- Supervised 8-10 volunteers to manage used books in nonfiction section
- Increased sales to record levels (over \$20,000)

Relevant Skills

Bilingual (Czech)

Office Suite

RISA

CAD

Enercalc

Retain Pro 10

Jackson Calder

76 West 1200 North
Mapleton, UT 84664

(385) 221-1445

jacksoncalder@gmail.com

Experience

PROJECT MANAGER/INTERNSHIP

AUGUST 2018 – PRESENT

Vector Structural Engineering – Draper, UT

At Vector Structural Engineering I have had the privilege of working directly with senior engineers in a wide range of structural engineering disciplines including steel design, foundation design, and commercial and residential structures. I manage projects from start to finish while working with clients to ensure the use of accurate information and that projects are completed correctly and on time.

- Designed and reviewed metal buildings, interior/exterior signs, foundations, and seismic anchorage.
- Created and implemented an Excel spreadsheet with VBA code expediting a previously lengthy process.
- Entrusted with team training and the mentoring of new interns.

CONCRETE FINISHER

JULY 2017 – AUGUST 2017; MAY 2018 – AUGUST 2018

Western Paving Inc. – Spanish Fork, UT

Working at Western Paving gave me the unique experience of being on the job site and seeing how engineering plans are interpreted and used in the field by the contractors and construction workers. As a concrete finisher I worked long hours overnight with city engineers and inspectors to ensure our concrete work was accurate and up to code. I also led a jack hammer crew in raising and lowering manholes and water valves for mill and paving operations.

- Worked 60+ hours a week setting concrete forms and finishing concrete for curb and gutter, handicap ramps, sidewalks, and waterways.
- Entrusted with the safe and timely arrival of construction equipment to job site.
- Acted as liaison/translator for Latino coworkers.

Education

BRIGHAM YOUNG UNIVERSITY

- Civil Engineering Major
- ASCE Student Chapter Member

RELEVANT COURSEWORK

- CE EN 321 – Structural Analysis
- CE EN 341 – Elementary Soil Mechanics
- CE EN 170 – Computational Methods

Skills

- RISA 3D: About 2 years of experience using RISA 3D for structural analysis and design.
 - Also proficient in other RISA programs such as RISA foundations, RISA Connections, and RISA Sections.
- AutoCAD: 1.5 years of experience creating and updating plans in AutoCAD.
- REVIT: Have taken 2 classes on architectural design and using REVIT.
- Microsoft Excel: Proficient in creating and using spreadsheets to expedite structural analysis and design. This includes experience using VBA coding to increase the efficiency of spreadsheets.
- Spanish Fluency: Over two years of Spanish speaking experience.

JOSHUA CARLILE

485 South State Street, Provo, Ut 84606 · (801)830-2322

Email: joshuacarlile97@gmail.com,

Linkedin: www.linkedin.com/in/joshua-carlile

EDUCATION

GRADUATION, APRIL 2024

MASTERS OF CIVIL ENGINEERING & MINOR OF CONSTRUCTION MANAGEMENT

BRIGHAM YOUNG UNIVERSITY, PROVO, UTAH

EXPERIENCE

OCTOBER 2017 – AUGUST 2019

CUSTOMER SUPPORT REP., SQUEEZE MEDIA CALL CENTER, AMERICAN FORK, UTAH

- Place up to 500 calls daily to prequalify individuals for tax debt relief
- Excellent phone edict as well as ability to personally connect with others
- Top performer on the tax team, almost always earning the bimonthly bonus

JUNE 2019 - CURENT

STRUCTURAL ENGINEER ANALYST, VECTOR STRUCTURAL ENGINEERING, DRAPER UTAH

- Analyzed hundreds of differed commercial and residential structures for solar installation
- Daily interaction with certified engineers, cad specialist and general contractors

APRIL 2020 - AUGUST 2020

GLASS INSTALLATION, DIXON GLASS AND MIRROR, SALT LAKE UTAH

- Learned process and techniques for installing variety of different glass items such as euro showers, mirrors, store front, windows, and curtain wall
- Installed over 200 units of glass on various construction sights

MAY 2021 - AUGUST 2021

FIELD ENGINEER, STOUT BUILDING CONTRACTORS, BOUNTIFUL UTAH

- Assisted in managing and building 2 tilt up concrete warehouses
- Participated in weekly meeting with the Owner, Architect, and Contractor

VOLUNTEER

JUNE 2015 - SEPTEMBER 2017

FULL TIME VOLUNTEER, THE CHURCH OF JESUS CHRIST OF LATTER-DAY SAINTS, UTICA NEW YORK

- Participated in leadership roles where I taught 10 people a week on average.
- Managed over 40 volunteers in monthly trainings conferences helping to improve the mission success rate by 100%