Interim Field Guide for Construction and Testing of Concrete Shear Wall with Added FRP Layer

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Abstract

In Los Angeles, many of the hospitals are no longer up to code as they were built in the 1970's. The shear walls that the hospitals were constructed on stand to experience major failures in the event of a seismic event and this is the issue that this student research team was assigned with. This project was to design, procure, and construct all necessary constraints to be able to test a wall that is fundamentally similar to that of the sheer walls in these hospitals. Once this was complete the goal was to test two walls with an added FRP wrap and see if this provided an adequate solution to bring the walls up to code in a cost and time effective way. This paper details the steps, construction and procurement wise, so that another research team may take this project to the next level. The extent this paper reaches is that of the wall concrete pour in which a form blowout was experienced that left the team with a wall but no longer the means or funds to do anymore work.

Key Words

Concrete, Shear, Wall, Fiber, Reinforced, Polymer, Construction, Field, Guide

Introduction

In Los Angeles, many of the hospitals that were constructed during the 1970's are no longer up to code and stand to experience major damage in the aftermath of another large seismic event. As a result of this knowledge, the city is in the process of trying to identify viable solutions for this issue rather than just tearing down section by section and reconstructing it. One option that was explored was the addition of an FRP (Fiber Reinforced Polymer) layer added to the concrete shear walls to further increase their seismic resistance and therefore bring them up to code at a much more affordable price. The purpose of this project was to help identify whether adding FRP to the concrete sheer walls is a viable solution that the city of Los Angeles could use.

The scope of this project came to be that the research team was asked to design all the necessary systems for a foundation and a wall that would test to the same standards as the walls that currently exist in these hospitals. Once this was achieved, the first wall was to be constructed and then tested until failure to receive a baseline standard. After this, the wall was to be repaired (similar to retrofit that would be needed of existing damaged walls) and then the FRP layer was to be added and tested again to determine how the seismic strength was increased. Once this was complete the first wall was to be demo'd and a second wall built that would be tested with the FRP from the start instead of making it fail first as to determine the effects it would have on a standard non-damaged wall.

This project had several key phases: design, procurement, and construction. The team tasked with this project included two Graduate Architectural Engineering students, one Senior Construction Management/Architectural Engineering student, one Senior Construction Management student and two helpers for the construction: One second year Mechanical Engineering student and one third year Construction Management student. The Architectural Engineering students were tasked with the design and construction aspects of the project: identifying what forces we need to apply to the wall and designing programs to predict results and identify what one should expect from the wall. The Construction Management students were tasked with the procurement, logistics, and construction of the wall. The Construction Management students came on at different times with the first graduating in Fall of 2018. He focused on setting up the procurement for this job by establishing connections and, as an Architectural Engineering

double major, he also helped with the design aspects. The author is the other Construction Management student started with this project in Winter of 2019 and was tasked with maintaining the relationships established, procuring materials on time, ensuring the feasibility of our plans, and the construction of the wall and a foundation for it.

Deliverables

For the purpose of this paper, the project is broken up into the two main focuses, the foundation and the wall, and then further divided this into smaller components: installation of formwork, installation of the rebar cage, and the concrete pours.

Foundation

Formwork- See Appendix A for formwork plan for foundation and Appendix B for material takeoffs of lumber
Design: The foundation was to be a 7'x4' and 15" thick concrete slab at 3000 psi.
Procurement: For the procurement of materials for this project, it was necessary to take off the lumber quantities and obtain the lumber from Home Depot. Eight-foot lengths of 2x4 were selected for the foundation formwork as this made the most sense with the dimensions provided for the foundation.
Construction: The construction of the foundation was placed in Cal Poly San Luis Obispo's high bay lab so the forms were built in place. The process for this was straight forward as the open space was available and all quantities and design aspects were easily read and identifiable. There were two pieces of 4' horizontal bracing were not accounted for but it was an easy fix and not a big issue. The formwork was constructed fairly quickly and without a snag.
Lessons Learned: There was a tight budget for this project so the team tried to ensure as little waste as possible by picking and choosing what materials best fit the needs of the project while not exceeding the budget. This at a later point would prove to be costly, but for the foundation it resulted in a shortfall of only one 2x4 because of the extra structural aspect added.

Rebar Cage – See Appendix C for takeoff of Rebar Cage
Design: The rebar cage was to consists of Grade 40 #3 rebar
Procurement: For this project it was necessary to take off off the rebar and to send the rebar quantities to a local rebar supplier. The rebar cage was supposed to be sent preassembled but when it arrived the team only received the loose rebar. This proved to be an inconvenience but only a minor one as the cage was relatively simple and simply required man hours for us to assemble it.
Construction: The plans for the rebar were drawn up by our Architectural Engineering team and this proved to be very helpful as some aspects the author was not able to see clearly but from working alongside the team who designed it the task was made simpler as they could easily showcase what was supposed to be done. Due to this, the construction process of the cage was fairly simple and straight forward and the most difficult part was just putting in the man hours for tying all the rebar.
Lessons Learned: There were some key miscommunications as the team thought they were receiving a fully constructed cage and also being that they requested Grade 40 #3 rebar, which in present time is an outdated strength of rebar and most of the time when you request Grade 40 you are receiving something much closer to Grade 60, which was their case. This did not affect the foundation but for the wall it was an issue.

Concrete Pour – See Appendix D for mix design of concrete
Design – The slab was to be a 7'x4' and 15" thick concrete slab at 3000 PSI consisting of 3/8" angular aggregate and a 6" slump
Procurement – For the procurement of this it was necessary to takeoff the concrete quantity (1.5 CY) and coordinate a pour date between local concrete suppliers and local pump companies. The concrete mix was provided to the team by the local concrete supplier in coordination with the specifications that were necessary to conform to the standards that were set in place.
Construction: Thanks to having a concrete pump company help the team, the process was made much easier and the most difficult part about it was the mess it made. It took roughly 45 minutes to pour the foundation and experienced minimal leakage thanks to the application of silicone to all cracks and gaps in the foundation pre-pour.
Lessons Learned: 1.5 CY of concrete was requested to be delivered and this is a very minimal amount for a concrete truck to deliver. Once the concrete at 28 days was tested it was discovered that the concrete was not reaching the 3000 PSI standard and was actually hitting much lower, around 2000-2500 PSI. All sampling was performed to

ASTM standards and after talks with local suppliers and professors, it was determined that most likely the issue was that the batch was too small and in the mixing process in the truck it wasn't able to provide adequate conditions for the concrete to maintain its specifications. This helped on the next pour.

Wall

Formwork – See Appendix E for formwork plan for wall and Appendix B material takeoffs for lumber. See Appendix F for pictures of work area and work itself
Design: The wall formwork was to be 5'x5" and stand 12' tall with vertical and horizontal bracing members and some diagonals connected to anchor points.
Procurement: For the procurement of materials for this project, it was necessary to take off the lumber quantities and to obtain the lumber from Home Depot. A mix of 8', 12', and 16' lengths of 2x4 for the wall formwork due to wide variety of lengths and sections need. It was also decided to stick with the typical 4'x8' sections of plywood.
Construction: Due to the construction of this project being in a lab that had become highly congested, (*See Appendix F),* the team was forced to take more difficult approaches in the construction of the wall formwork. Add to it, the fact that the formwork also had to be preserved to ensure it could be stripped and reused for the 2nd wall that was to be constructed (Due to financial and time restrictions) and this task became exponentially more difficult than anticipated. Ultimately, the formwork was built standing up on top of the foundation and in two sections, one being a U-like section and the other being a straight section that could easily be pulled apart with the removal of screws between the two members. Doing it like this, made it so the team was required to build scaffolding that would allow them to reach the higher portions of the wall and while it was very helpful, it was very difficult to move and after having to do that four times, everyone grew weary of it. The formwork took longer than anticipated due to these and other unpredicted hiccups, but was able to be constructed with a few adaptions in time for it to be poured when required.
Lessons Learned: The formwork should have been constructed before the Simpson Strong Tie was set in place as this proved to be a major hindering factor in the constructability of the forms. Furthermore, rental of another nail gun as this was very helpful tool that the lab unfortunately only had one of. Past this, the construction of the wall forms went as well as it could have.

Rebar Cage – See Appendix C for takeoff of Rebar Cage
Design: The rebar cage was to consist of Grade 40 #3 rebar that was to be epoxied into the foundation.
Procurement: For this project it was necessary to take off the rebar and to send the rebar quantities to the local rebar supplier. It became necessary to order rebar from a new supplier that could ensure that the rebar received would truly be Grade 40, this added on some unforeseen costs but the suppliers were very helpful and able to deliver the new rebar in a very timely matter. All the bars received were loose but this was not an issue.
Construction: As per the foundation, the wall rebar was designed and drawn up by our Architectural Engineering team which helped the process along. The rebar itself was fairly easy to put in as it was simply 8 pieces of longitudinal bar with horizontal bars and hoops placed periodically going up. The only part of this process that provided some true difficulty was the placing of the sensors on the rebar and this was because these areas had been grinded down to allow the sensors to be placed and then a layer of melted rubber placed over to provide protection and a securement. It was a rather tedious and time consuming activity but the process as a whole went smoothly and in the time frame predicted.
Lessons Learned: As for the construction of the rebar cage itself, there wasn't too many lessons to be learned as it was a pretty straight forward process but two that did come up were to always wear gloves as it was very easy to cut oneself and to put a frame on top to keep the rebar straight and in place as the long pieces were easy to get out of place the higher up they went.

Concrete Pour – See Appendix G for mix design of concrete
Design: The mix was to be 3500 PSI consisting of 3/8" angular aggregate and a 6" slump poured at a rate of 4' per hour.
Procurement - For the procurement of this, it was necessary to take off the concrete quantity (2.5 CY) and coordinate a pour date between the local concrete suppliers and the local pump company. The concrete mix was provided by the local concrete supplier in coordination with the specifications needed to conform to the standards set in place.
Construction: Unfortunately, this is the sequence in which the team experienced the most detrimental occurrences.

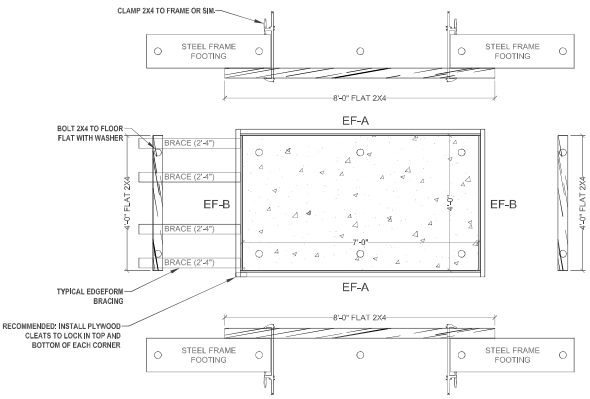
Due to the time and labor being donated to by these companies, the process was rushed and did not allow for the appropriate pour rate and ended up pouring the entirety of the wall in a little over an hour when it should have taken three. This coupled with much of the horizontal framing from snap ties being excluded and replaced by differing horizontal members that the team felt were adequate, the formwork failed and created a bulge in the center of a few inches. The wall was still able to be poured fully and be a functioning wall but with a blemish and error that ruined the formwork and created an unsightly appearance. When stripping it, it was necessary for safety reasons to tie off the wall to anchor points to ensure that the forms could be removed safely.
Lessons Learned: Before this project, the author had little to no experience with the use of snap ties and did not understand how they played into the system. Due to this, he overlooked them and in conversations with mentors helping, did not foresee that they would play a big enough part to be needed when added alongside other bracing methods. The author also did not know the difference in strength you get with how you place a piece of 2x4 bracing or the difference in using plywood and OSB board as forms. If this project were to be done again, the author would employ the help of someone who could help install and understand the use of snap ties and switch the positioning of bracing while also adding more. In the end, a wall was presented that was still able to be tested even though it was blemished but with forms that were completely ruined, putting a stop to the project due to lack of funding and time.

Conclusion

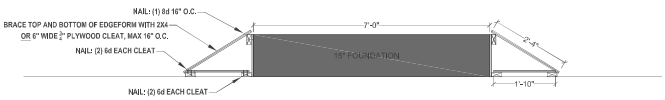
After working through this project, this project is a recommendable option for another student or research team to take on. If the issues faced were to be mitigated this project would be a viable and useful one that would function to serve a lot of good. The process it took to be able to construct, finance, and schedule this project was very educational and would aid anyone who wishes to further their construction experience. It would also be suggested that any contractor looking for solutions to this issue try out this method as all results expected to find indicated that this would be an option that would meet all necessary standards and provide a much quicker turn around for it.

This project served to provide a very valuable life experience which closely related to what one would be doing in a future career in Project Management. Working alongside subcontractors, tracking and procuring materials, managing and constructing an actual project, and dealing with and learning from failure. There are always things to be learned from in life and this wall has taught many valuable lessons that the author will use to his advantage for the remainder of his life. At this point, this interim field guide is to help anyone who would wish to continue this project in being able to efficiently and correctly recreate this project and take it to the next step of testing the wall and adding the FRP layer to it.

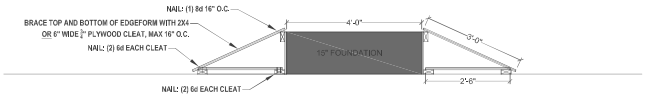
Appendix A



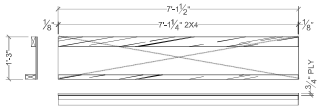
1 FOUNDATION PLAN VIEW



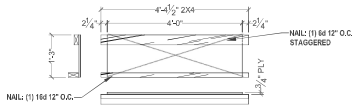
2 FOUNDATION EDGE-FORM



3 FOUNDATION EDGE-FORM



NAME: EF-A
QUANTITY: 2



NAME: EF-B
QUANTITY: 2

4 EDGE-FORM FABRICATION

GENERAL NOTES:

1. FORMS ARE **NOT** DESIGNED FOR FULL LIQUID HEAD. LIMIT CONCRETE POUR RATE TO 4 VERTICAL FEET PER HOUR.
2. ALL LUMBER STUDS IN PANELS ARE DESIGNED AS 2X4 DF #2 OR BETTER
3. ALL PLYWOOD IS ¾" MDO PLYFORM OR SIM.

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FOUNDATION FORMWORK FABRICATION AND LAYOUT
CAL POLY SLO
SAN LUIS OBISPO, CA 93407

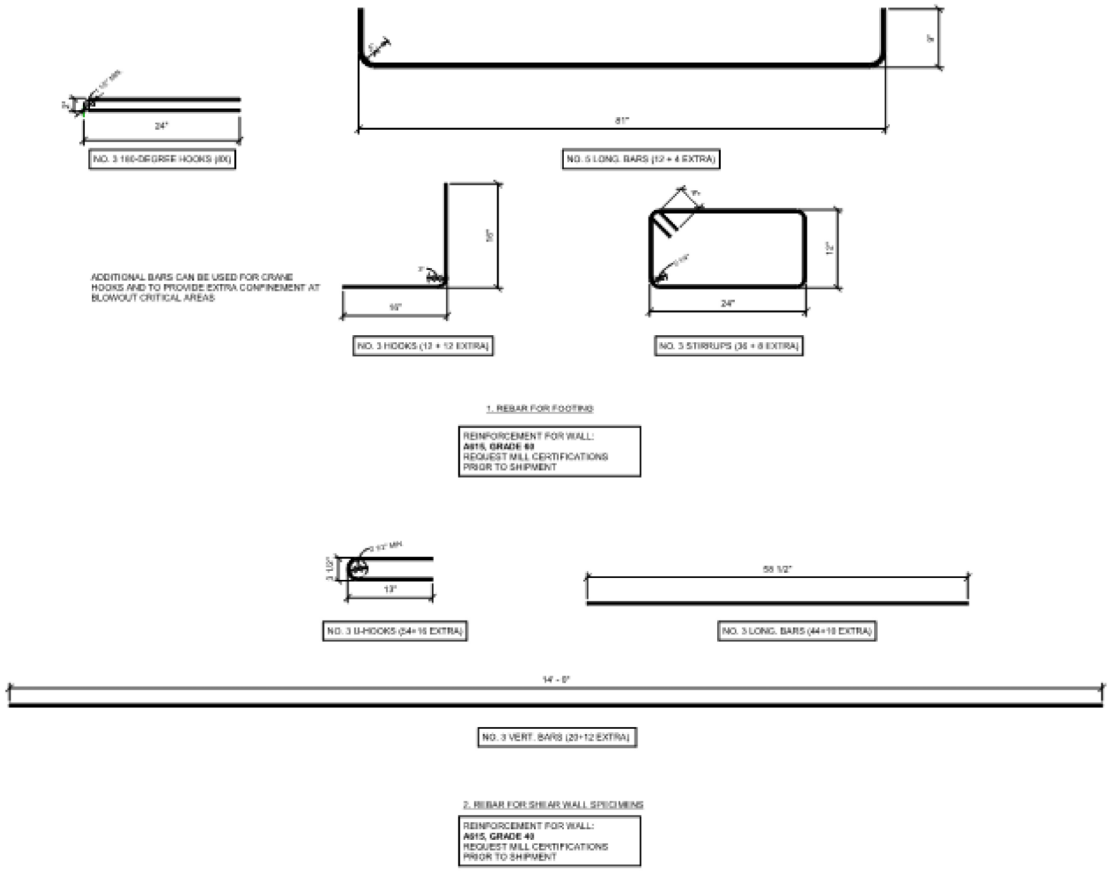
FOR CONSTRUCTION

W-1

Appendix B – Takeoff for Lumber in Foundation and Wall Formwork

Materials for formwork				
Foundation -				
Plywood 3/4"	24	Ft	15" Height	1 4'x8' Sheath
2x4	24	Ft	2 12' long pieces for 2 8' long and 2 4' long sections	
Edgeform Bracing 16" O.C.	50	Ft	5 12' long pieces for 3 8' long and 2 4' long for diagonal sections	
			Same for horizontal sections	
Wall - 5"x60"				
WP-B				
2x4			4 14' Long Sections for vertical bracing	
Plywood			2 4'x8' Sheath	
WP-A				
Plywood			6 4'x8' Sheath	
2x4			6 14' Long sections for vertical bracing	Horizontal Bracing 6' Length x 2 top and bottom x 6 instances x 2 sides
				12 12' long for horizontal bracing
4x6			1 4x6 Block	
Extra Sticks			2 12' Long 2x4 for Walers 1 12' Long 2x4 for plates	
			10' Long Brace to ground @ 3 spots, 3 12' 2x4	
Total				
Plywood			9 4'x8' Sheaths	
2x4				
12'			31 12' Long, 35 to be safe?	
14'			10 14' Long, 12 to be safe?	
4x6			1 4x6 Block	

Appendix C - Takeoff of Rebar Cage



CONCRETE MIXTURE DESIGN NUMBER: 611GM3090

May 29, 2019

Appendix D - Mix Design of 1st Pour

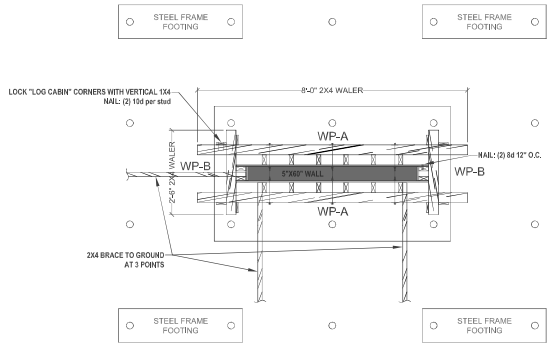
USE:

DESCRIPTION: 6.5 sks/yd^3 Total Cementitious; 3/8" Maximum Aggregate Size; 6.5" ± 1" Slump; 3000 psi @ 28 days; W/CM = 0.48; gal/sack = 5.39

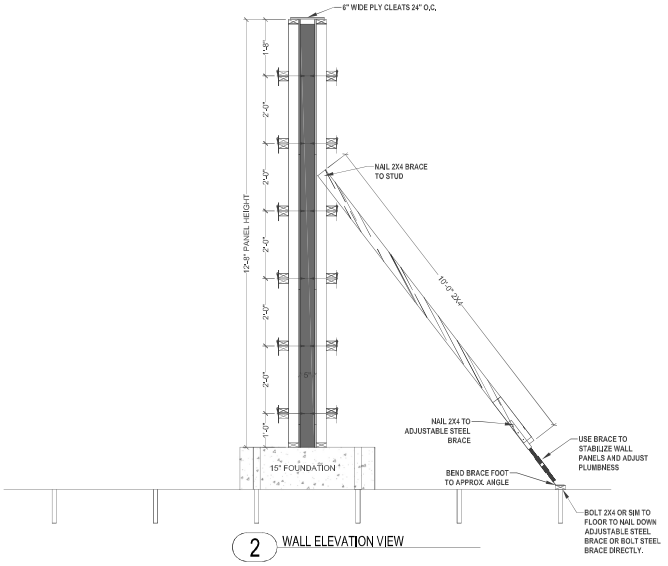
MATERIALS		PERCENT USED	SPECIFIC GRAVITY	ABSOLUTE VOLUME, ft^3	SSD WTS. lbs/yd^3
CEMENT - TYPE I/II/V LOW ALKALI		85%	3.15	2.640	519
POZZOLAN - CLASS F: REPLACEMENT FOR CEMENT @		15%	2.20	0.670	92
WATER	35.1 gal.	--	1.00	4.679	292
AIR	ENTRAPPED	2.0%	--	0.540	--
GAREY HMS GRAVEL	3/8" x #8	55.0%	2.62	10.092	1650
GAREY	C 33 SAND	45.0%	2.58	8.377	1349
			TOTALS	27.000	3902

MIRA 62 @ 10 oz/cwt **61 oz/cy**

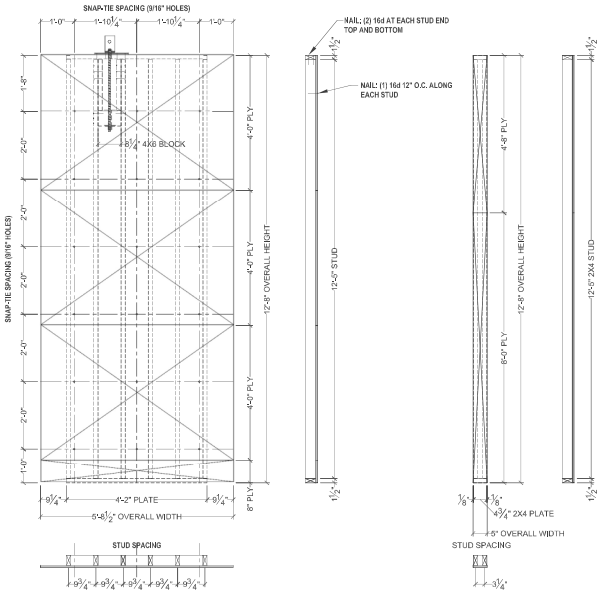
Appendix E - Formwork Plans for Wall



1 WALL PLAN VIEW



2 WALL ELEVATION VIEW



NAME: WP-A
QUANTITY: 2
WEIGHT: ~250 LBS

NAME: WP-B
QUANTITY: 2
WEIGHT: ~50 LBS

3 WALL PANEL FABRICATION

GENERAL NOTES:

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3. ALL PLYWOOD IS ¾" MDO PLYFORM OR SIM.

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WALL FORMWORK FABRICATION AND LAYOUT

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W-2

Appendix F - Pictures of Work Area





Appendix G - Mix design of 2nd Pour

USE:

DESCRIPTION: 6.00 sks/yd^3 Total Cementitious 3/8" Maximum Aggregate Size
6" ± 1" Slump 3500 PSI @ 28 days
W/CM = 0.53
gal/sack = 6.00

MATERIALS		PERCENT USED	SPECIFIC GRAVITY	ABSOLUTE VOLUME, ft^3	SSD WTS. lbs/yd^3
CEMENT - TYPE I/II/V LOW ALKALI		82%	3.15	2.350	462
POZZOLAN - CLASS F: REPLACEMENT FOR CEMENT @		18%	2.20	0.743	102
WATER	36.0 gal.	--	1.00	4.808	300
AIR	ENTRAPPED	1.5%	--	0.405	--
GAREY HMS GRAVEL	3/8" x #8	52.7%	2.62	9.787	1600
GAREY	C 33 SAND	47.3%	2.58	8.907	1434
			TOTALS	27.000	3898

MIRA 62 @ 8.0 oz/cwt **45.1 oz/cy**