Document 525
PRE-IMPLEMENTATION REPORT

CHAPTER: Ohio University
COUNTRY: USA
COMMUNITY: Maase-Offinso
PROJECT: Solar Water Pumping System
TRAVEL DATES: July 1, 2010–July 22, 2010

PREPARED BY
Nick Stormer, Jeff Antill, Brent Willey
Kegan Kavander, Adam Hensel
Special thanks to Eric Gilliland

3-14-2010

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Document 525 - Pre-Implementation Report
EWB Ohio
Maase-Offinso, Ghana
Solar Water Pumping System

Pre-Implementation Report Part 1 – Administrative Information

1.0 Contact Information

	Name	Email	Phone	Chapter
Project Leads	Nick Stormer	ns287405@ohio.edu	(330) 631-7861	EWB-Ohio
President	Sonja Abbey	sa110305@ohio.edu	(740) 359-7675	EWB-Ohio
Mentor #1	Greg Kremer	kremer@ohio.edu	(740)593-1561	EWB-Ohio
Mentor #2	Jeff Giesey	giesey@ohio.edu	(740) 593-1573	EWB-Ohio
Faculty Advisor (if applicable)	Jeff Giesey	giesey@ohio.edu	(740) 593-1573	EWB-Ohio
Health and Safety Officer	Greg Kremer	kremer@ohio.edu	(740)593-1561	EWB-Ohio
Assistant Health and Safety Officer	Nick Stormer	ns287405@ohio.edu	(330) 631-7861	EWB-Ohio
NGO/Community Contact	Nana K. Owusu-Kwarteng	kokwarten2003@yahoo.com	(011-233) 246-606261	
Education Lead				

2.0 Travel History

Dates of Travel	Assessment or Implementation	Description of Trip
12/14/05-12/22/05	Assessment	Teacher Accommodations
06/27/06-07/19/06	Implementation	Teacher Accommodations
12/02/07-12/09/07	Assessment	Teacher Accommodations
December 2009	Assessment	Power Quality

3.0 Travel Team

Name	E-mail	Phone	Chapter	Student or Professional
Greg Kremer	kremer@ohio.edu	(740)593-1561	EWB-Ohio	Professional
Nick Stormer	ns287405@ohio.edu	(330) 631-7861	EWB-Ohio	Student
Jeff Antill	ja159107@ohio.edu	(740) 739-3526	EWB-Ohio	Student
Brent Wiley	bw299105@ohio.edu	(843)421-2277	EWB-Ohio	Student
Kegan Kavander	kk158005@ohio.edu	(740) 503-1029	EWB-Ohio	Student
Adam Hensel	ah927205@ohio.edu	(614) 578-1693	EWB-Ohio	Student

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4.0 Safety

4.1 Travel Safety

4.1.1 Department of State Travel Warning/Alert and International SOS Travel Risk Ratings

There are currently no State Department travel warnings for Ghana, however there is currently a moderate travel risk according to International SOS global security information

4.1.2 Point to point travel detail

The team will arrive in Kotoka International Airport in Accra, Ghana and meet with a representative of the village of Maase-Offinso. We will then travel to the village by way of roads until we reach the city of Kumasi where we will pick up the project materials that we have ordered (i.e. solar panels, mounting materials, piping, etc.). From there we will travel to the village. The team is using American Field Services for assistance in travel and cultural assistance. We are hiring a driver through AFS to transport the team.

4.1.3 On-the-ground phone number and email for travel team

We will be renting cellular phones for the time we are in-country and will contact the faculty advisor with the phone numbers upon acquisition. Email will not be available in the village.

4.2 Site Safety – Health and Safety Plan

We plan to follow the recommendations in EWB document 602 – Travel Tips Presentation. These include:

- Always stay in pairs
- Keep a limited amount of money on person.
- Be/stay in the accommodations before/during dark unless accompanied.
- Do not eat food that is not cooked or in a peel
- Drink only bottled water
- We will have access to a local hospital in case of emergency
- Any medications and pre-existing conditions of team members will be addressed before the trip

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Document 525 - Pre-Implementation Report
EWB Ohio
Maase-Offinso, Ghana
Solar Water Pumping System

5.0 Budget

5.1 Cost

Expense	Total Cost
Airfare	$13,200
On Ground	$9,150
Materials	$25,950
Other	$1,700
Total	$50,020

5.2 Hours

Names	# of Weeks	Hours/Week	Trip Hours	Total Hours
Project Lead Nick Stormer	30	6	168	348
Mentor Greg Kremer	30	1	168	198
Other Team Members Jeff Antill Brent Wiley Kegan Kavander Adam Hensel	30 30 30 30	6 6 6 6	168 168 168 168	348 348 348 348

5.3 Donors and Funding

Donor Name	Type (company, foundation, private, in-kind)	Account Kept at EWB-USA?	Amount
Ohio University Student Activities	Company	No	$2,000
Department of ME 'pledge'	Company	No	$5,000
Total Amount Raised:			$7,000

6.0 Project Location

Longitude: 1°30'00 W
Latitude: 6°45'00 N

7.0 Project Impact

Number of persons directly affected: 5000 (approximate village population)

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Number of persons indirectly affected: 7500 (village population plus surrounding inhabitants

8.0 Mentor Resume

Dr. Greg Kremer has been a professor of Mechanical Engineering since 1998, and chair of the Mechanical Engineering Department at Ohio university since 2006. He also has five years of experience working on turbomachinery as a Mechanical Design Engineer in the large engine compressor section for General Electric Aircraft Engines. Over the past decade he has been a mentor and advisor for numerous student groups including an Electric Bobcat racing team, a student chapter of the Society of Automotive Engineers, and since 2004 he has been a co-advisor of the Engineers Without Borders Ohio group. He has also been an instructor and mentor for the Mechanical Engineering Senior Capstone Design Projects since 2000. In that capacity, Dr. Kremer mentors 8-10 teams per year as they form relationships with a customer in need, then design, build, test, and provide technical support for products that are intended to 'Make a Difference' in the customer's life.

Dr. Kremer is also an Associate Director and conducts research in a division of the Institute for Sustainable Energy and the Environment, and has a solar and wind energy system that provides all of the electrical energy used at his home. He has helped develop and implement the safety plan for the research institute, including standard operating procedures, hazard identification algorithms, and Failure Modes and Effects Analysis based Safety Evaluation Reports. He is also active in the Scholarship of Teaching and Learning, and in educational assessment

Dr. Kremer has been a part of all of the EWB-Ohio activities, including being the technical and project planning leader for the teacher accommodations implementation trip in the village of Maase-Offinso in the summer of 2006. During that visit Dr. Kremer established strong relationships with the chief of the village as well as the village elders and others throughout the village.

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Pre-Implementation Report Part 2 – Technical Information

1.0 INTRODUCTION

This document provides the pre-implementation information concerning the Water Pumping System Implementation project proposed by the Ohio University chapter of Engineers Without Borders. The trip will take the team to the village of Maase-Offinso located in the Ashanti Region of central Ghana. By request from the village, the team was asked to focus its efforts on redesigning the village's water supply system due to the inefficiencies and overall unreliability of the current pumping system.

2.0 PROGRAM BACKGROUND

Previous projects undertaken in Maase-Offinso by the Ohio University chapter have included assessment and implementation of the construction of teacher accommodations, the assessment of power quality and reliability in the village specifically for the water pump, and the assessment of water quality and effects of erosion surrounding the pump house and spring box. These trips have concluded that there has been a gradual decline in pump efficiency due to an unreliable power supply, possible damage to the spring box, and/or leaks in the pipelines. Water quality assessment has determined that total coliform and fecal coliform tests were positive for water sampled from the spring box and from the water pump.

The current proposed trip is an extension of the work being done on the water pump and the spring box due to the urgent need for a reliable water source in the village. With the system currently nonfunctional the residents of Maase-Offinso have been forced to use streams and privately owned wells in the area to gather water.

The existing spring box lies in a valley on the outside of the village. The water will be pumped a distance of 1,100 ft to the existing collection site which has two 2,000 gal tanks and two more will be added. The pump must overcome 87 ft of physical head from the surface of the spring box to the bottom of the collection tanks. The tanks are eight to ten feet high, and the water level of the spring box can fluctuate between ten and fifteen feet deep. Therefore, the maximum physical head the pump must overcome is 112 feet.

When the previous system was operational the village of Maase-Offinso was a "regional watering hole" providing relatively clean water to not only the inhabitants of the village, but also people in the surrounding area. The previous system used a large electric motor powered by the electric grid; however, due to voltage fluctuations the motor was put into low voltage regime and the electrical current increased to unsafe levels, causing regular system break downs. In addition to the problems of the villagers being without water this slowly became a village economic problem because the water distribution provided the greatest source of income for the village. Due to this unreliability over the last five to ten

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years the village has gone into debt trying to purchase new pumps and water from other villages.

3.0 SYSTEM DESIGN

3.1 Description of the Proposed System

The final design concept for the water pumping system of the village was made based on expert opinion, customer needs and considerations, and a cost analysis over a twenty year period, the expected lifespan of the system.

The final primary power generation system chosen is a dual photovoltaic (PV) solar array used to power two independent submersible positive displacement pumps. The use of two separate pumps allows for a redundant system and also acts as a backup. When one pump or solar array fails the other can continue to function until the additional pump or array is fixed. Two additional 2,000 gallon plastic water storage tanks will be purchased and placed in conjunction with the current water storage tanks, effectively giving the village an 8,000 gallon storage capacity. The entire piping system will be replaced as well. Lastly, one way check valves will be placed through the piping system and flow meters will be placed at the pumping and collection sites to monitor system reliability.

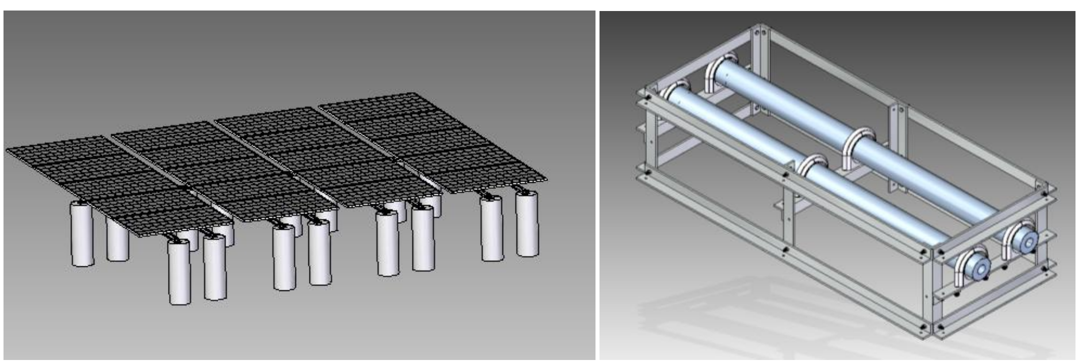

Figure 3.1: Solar panel array, left, two mounted positive displacement pumps, right

3.2 Description of Design and Design Calculations

The system pump design utilizes two helical rotor submersible pumps. After consultation with professionals from Sun Pumps Inc. and Africa Energy, we chose the Grundfos SQ Flex 11-2 pump. The data presented by Grundfos for the pump shows that under conditions of 4.0 peak solar hours, the minimum solar hours in the region per day, at 133 ft of head, a total of 4,300 gal of water can be pumped. Using two pumps will achieve the goal of 8,000 gal per day. The pumps were selected because they are very simple to maintain and are relatively as simple as the Archimedes screw. The helical rotor pump was also selected because it will pump water at varying powers, and considering the power from a solar panel fluctuates, anytime the pump receives power water will be

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displaced. This is advantageous compared to a centrifugal pump which normally requires a specific operating power to run, and would not be suitable for use with stand-alone solar panels.

To achieve the required flow rate, each pump will require 1150 W of power to each pump. This will require an arrangement of seven 24V- 175 W panels in series for each totaling 1225 W and 168 V peak. Sharp NT 175 UI mono-crystalline panels were selected for the system because their efficiency is greater than poly-crystalline panels. Sharp panels were also selected because of the high quality and their availability in Ghana, supplied through Africa Energy. Ten panels were chosen for each pump to provide a safety factor of approximately 1.4 to compensate for uncertainty in the sloar peak hours and system losses.

The panels will be mounted at an angle of approximately 6 degrees fixed facing south, as suggested by Sun Pumps Inc. They are mounted on painted steel c-channel rails supported on the ends by concrete footers. Figure 3.1 presents the model of our system. This structure design was chosen to mimic other solar panel installations. The majority of large array structures support the panels in a similar manner. The footers will be aligned by bolt location and will have a tolerance of +-0.25 in in height. The system is designed to allow for slight variation in the height of the footers. See Appendix A for a description of the mounting structure, all associated parts, materials and stress calculations that verify the design.

Pump head calculations and solar system selection are presented in Appendix B. The total head calculated was 130 ft, including the physical head and head created by friction loss. The structure that the pumps will be mounted in to be placed in the spring box is presented in Appendix B, as well as all associated drawings, parts and calculations that verify the structure design.

Piping for the system was selected and sourced in Ghana from Interplast Piping and is 2.5 inch diameter HPVC plastic water pipe rated to 100 psi. The friction head loss based on this pipe size and length is approximately 13 ft, as presented in Appendix B. The village has a pre-existing spring box where the water will be collected from. There is no other clean source of water in the village.

The piping diagram for the project is included in a rough topographical map of the entire project, and is presented in Appendix C. The map includes the location of the water storage site, which is pre-existing, containing two 2,000 gal storage tanks, piping and a foundation large enough to support two additional tanks. The water collection site is also presented; again it is an existing location with existing hardware for water distribution.

A wiring diagram for the solar panels and the pumps is presented in Appendix D

See Appendix E for associated pictures of the village and locations of existing structures such as the spring box and collection site.

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See Appendix F for a complete Bill of Materials.

3.3 Drawings

For solar panel array structure and calculations see Appendix A
For pump mounding structure drawings and calculations see Appendix B
For piping diagram see Appendix C
For electrical wiring diagram see Appendix D

4.0 PROJECT OWNERSHIP

The chief og the village has been consulted throughout the project desgn and is in favor of the solar pumping system. Villagers will contribute to the construction and initial testing of the system so that they will feel a sense of ownership of the system.

When the current system was operational the village employed several of its citizens to help collect money for the water and also for maintenance of the system. This new pumping system will have the same infrastructure supporting it; in fact it is a requirement for the long-term operation of the system. It is expected therefore that the village leaders run this system as a business, collecting money for each bucket of water. Using this money the village will pay overseers that will collect the money, and maintenance personnel trained by team members to keep the system in working order. This method has been previously used by the village and found to be a reliable method.

5.0 CONSTRUCTION

5.1 Construction Plan

Note: This schedule includes built in ‘slack; to allow for unseen delays.

Day 1

- Cultural customs and language lessons in Accra

Day 2

- Travel to and meet and greet with Village
- Pick up materials
- Start site layout

Day 3

- Search for most suitable location
- Remove old piping
- Finalize site layout
- Arrange for cement, aggregate and other materials

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Day 4
- Remove old piping
- Pour concrete footers

Day 5
- Remove old piping
- Cut PV mount materials

Day 6
- Finish removal of piping

Day 7
- Assemble mounting structure
- Rest

Day 8
- Mount and connect panels and test system output
- Prep the inside of the spring box for the pump crate

Day 9
- Install junction box and controller
- Modify existing piping to fit the flex hose that runs from pump to spring box

Day 10
- Run output cable to spring box
- Build pump crate and secure pumps within crate

Day 11
- Finalize building and securing pumps within crate
- Begin installation of pump crate

Day 12
- Finish pump crate installation, finalize connections

Day 13
- Layout new piping and connections, including check valves and flow meters

Day 14
- Secure piping and connect to pump and storage system
- Rest

Day 15
- Relocate tanks from drop off point onto the foundation where they will be placed

Day 16
- Modify the piping connections between tanks to allow 4 tanks to filled

Day 17

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- Secure outlets and general tank area from tampering
- Test system

Day 18

- Test system
- Cover piping back up

Day 19

- Finish covering pipe up
- Start building security fence for PV array

Day 20

- Finish building fence for security
- Final system check

5.2 Construction Safety Plan

A safety review will be conducted at the start of each day, using ahazard identification approach. The safety measures for the construction plan will be to wear safety glasses when cutting and drilling our materials. While we are hooking up the wiring for the project, the breakers for the panels will be off to prevent electrical shock from the system. Any work taking place on the solar mounting structure will be done from the bottom up to prevent the need for being under the panels during the installation.

6.0 OPERATION AND MAINTENANCE PLAN

An owner's manual is attached to this packet in Appendix G showing the scheduled maintenance that will be expected to be performed by the hired village maintenance employee. There is a detailed list of maintenance procedures to be completed on a weekly and monthly basis. This is supposed to be a rather small list as the village requested that the maintenance be fairly light. The solar panels require a simple cleaning, and it's also important that the hired maintenance employee check voltage and current output for each panel and record it regularly in order to detect when a solar panel might fail in advance. The pump is a simple helical rotor pump that also requires little maintenance. In order to detect failure in the pipeline, flow meters will be attached in sections of pipe. Every month the maintenance employee will check the flow meters and record the flow rate at each point. A procedure is written in the owner's manual to instruct maintenance personnel how to deal with decreased flow throughout the pipeline.

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7.0 SUSTAINABILITY

This project has been designed to last for 20 years with very little maintenance problems. Solar power will eliminate the need to purchase electricity or diesel fuel for the pump, meaning that all of the money collected through sale of water will go directly into repaying the village debt as well as going into purchasing replacement parts for the system. Under the assumption that the system provides the minimum of 8000 gallons per day that it was designed to provide the village can charge as little as one American cent per gallon of water and collect enough money to pay for system maintenance. The solar panels have a 25 year warranty and the expectation is that after 25 years the panels could all begin to fail in efficiency and power output around the same time. Therefore, a savings plan will need to be implemented by the village to ensure that this system continues to operate beyond 20 years.

8.0 COST ESTIMATE

Expense	**Total Cost**
Airfare - *Six people*	$13,200
On Ground – *food, travel, board*	$9,150
Materials	$25,950
- *Solar panels*	~16,000
- *Pumps*	~4,000
- *Piping*	~2,000
- *Tanks*	~2,000
- *Hardware/misc*	~2,000
Other – phones, unforseen expenses	$1,700
Total	$50,020

9.0 MENTOR ASSESSMENT

I have been working with this team of Senior Mechanical Engineering students since September 2009 on this project. They are involved in an intensive capstone design experience, with emphasis on going beyond "how to do engineering" to the professional and social skills that are critical in learning "how to be an engineer." The students also have an experimental methods course and a computer-aided design course clustered with the tear-long capstone course in which they apply the skills learned in those areas directly to their capstone project.

This team, known as Team Pump It Up, has a broad set of practical skills and has developed into an effective team. Some of the relevant experiences of the team members include construction excavation, general construction including concrete foundation

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pouring, roofing, framing, painting, as well as farming machinery maintence, vehicle maintenance and repair, general knowledge and practical use of all power tools, metal machining tools and operations, and several members have had numerous co-ops in various fields of mechanical engineering. I have confidence in the experiences, abilities and motivations of the team members and believe that we have a strong implementation team.

The team has done a good job interacting with members of the village to ensure acceptance of the solar powered pumping design solution. All major decisions that the team has made have been well researched and justified. My assessment of the current status of the design is that it is an acceptable final design, but there is some room for refinement. In the coming months as part of the capstone design course the team will continue working to refine and simplify some aspects of the design (especially the pump mounting structure and some details of the solar mounting components) and will continue testing various system components (including the pumps, control boxes, flow meters, etc.) to prepare for a successful implementation trip.

My assessment of the construction plan is that it is adequate but will also be refined both in the time before the trip (as our communications with American Field Service personnel in country continue) and after we are in the village. Our experiences with this village have shown us that relationship building is of paramount importance, and is necessary before a true partnership can develop. It is difficult to get meaningful feedback from the village elders on the schedule ahead of time. We have learned that it is best to include flexibility in our schedule and to frequently re-assess the schedule with the village elders after we are present in the village.

The students on the team have demonstrated professionalism and respect, so I am confident they will follow all guidelines, participate in safety reviews prior to construction activities, and will have a positive life experience on this implementation trip.

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Appendix A
1.0 Solar Structure Design and Drawings

Presented below are the technical drawings and design for the solar panel mounting structure. Figure A1 presents a 3D model of the entire system, followed by assembly drawings and individual part drawings. The panels will be mounted at an angle of approximately 6 degrees fixed facing south. They are mounted on steel c-channel rails between concrete footers. Steel was selected for the c-channel because it is available in country. This structure design was chosen to mimic other solar panel installations. The majority of large array structures support the panels in a similar manner. The footers will be aligned by bolt location and will have a tolerance of +-0.25 in in height. It is important that each set of footers per individual panel array is aligned, more than all of the sets of footers being perfectly aligned. The system is designed to allow for slight variation in the height of the footers. The panels will be wired in series according to the wiring diagram in Appendix D. Not pictured in the system is a fence surrounding the solar array, this will be implemented for security from humans, animals and unforeseen forces alike.

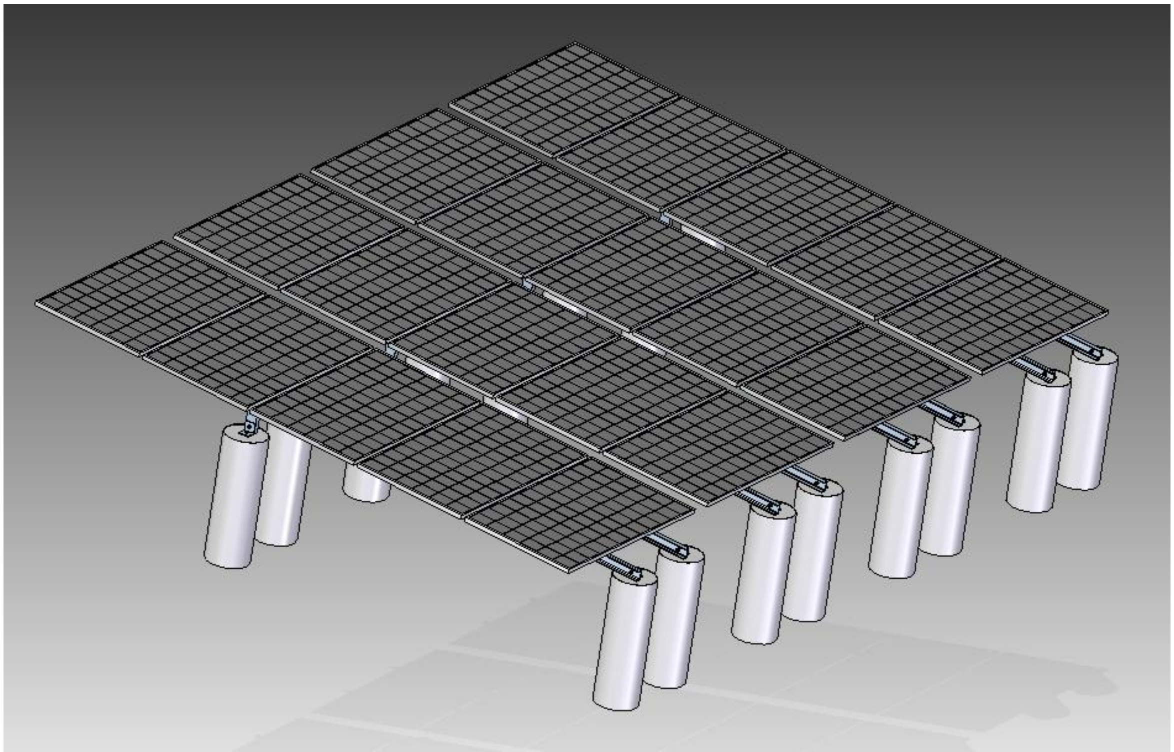

Figure A1: Solar panel array and mounting structure.

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Maase-Offinso, Ghana
Solar Water Pumping System

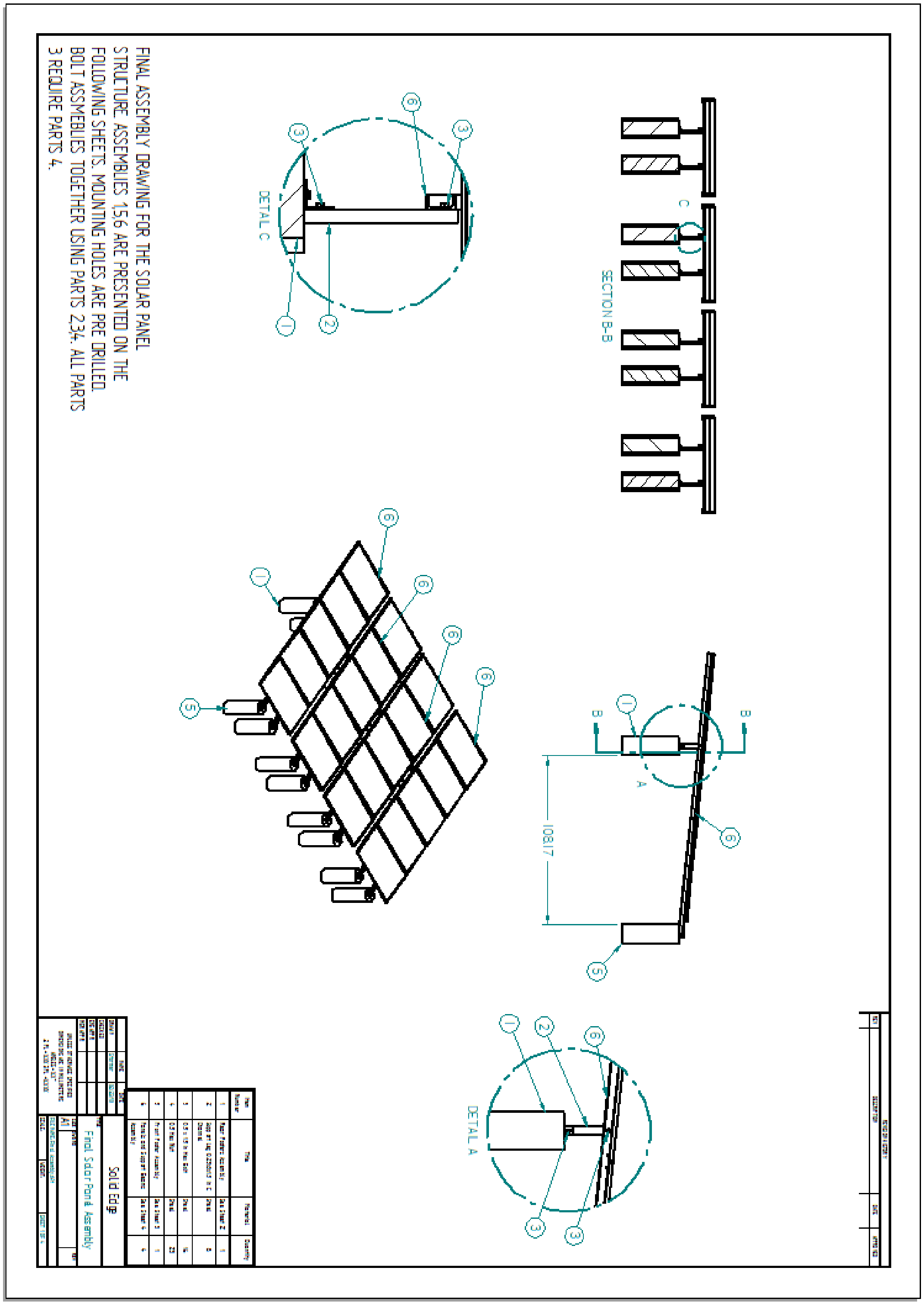

Figure A2: Final assembly drawing. Again as stated previously each set of footers at the front and rear of the panel will need to fit within the stated tolerance and the front and rear will be aligned by bolt location. All individual panel array sets will not need to be perfectly aligned as long as the sets pertaining to each panel array are within tolerance and correctly aligned.

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Item Number	Title	Material	Quantity
1	Rear Footers Assembly	See Sheet 2	1
2	Support Leg 0.25x3x1.5 in C Channel	Steel	8
3	0.5 x 1.5 in Hex Bolt	Steel	16
4	0.5 Hex Nut	Steel	24
5	Front Footer Assembly	See Sheet 3	1
6	Panels and Support Beams Assembly	See Sheet 4	4

Figure A3: Parts list for Final Assembly

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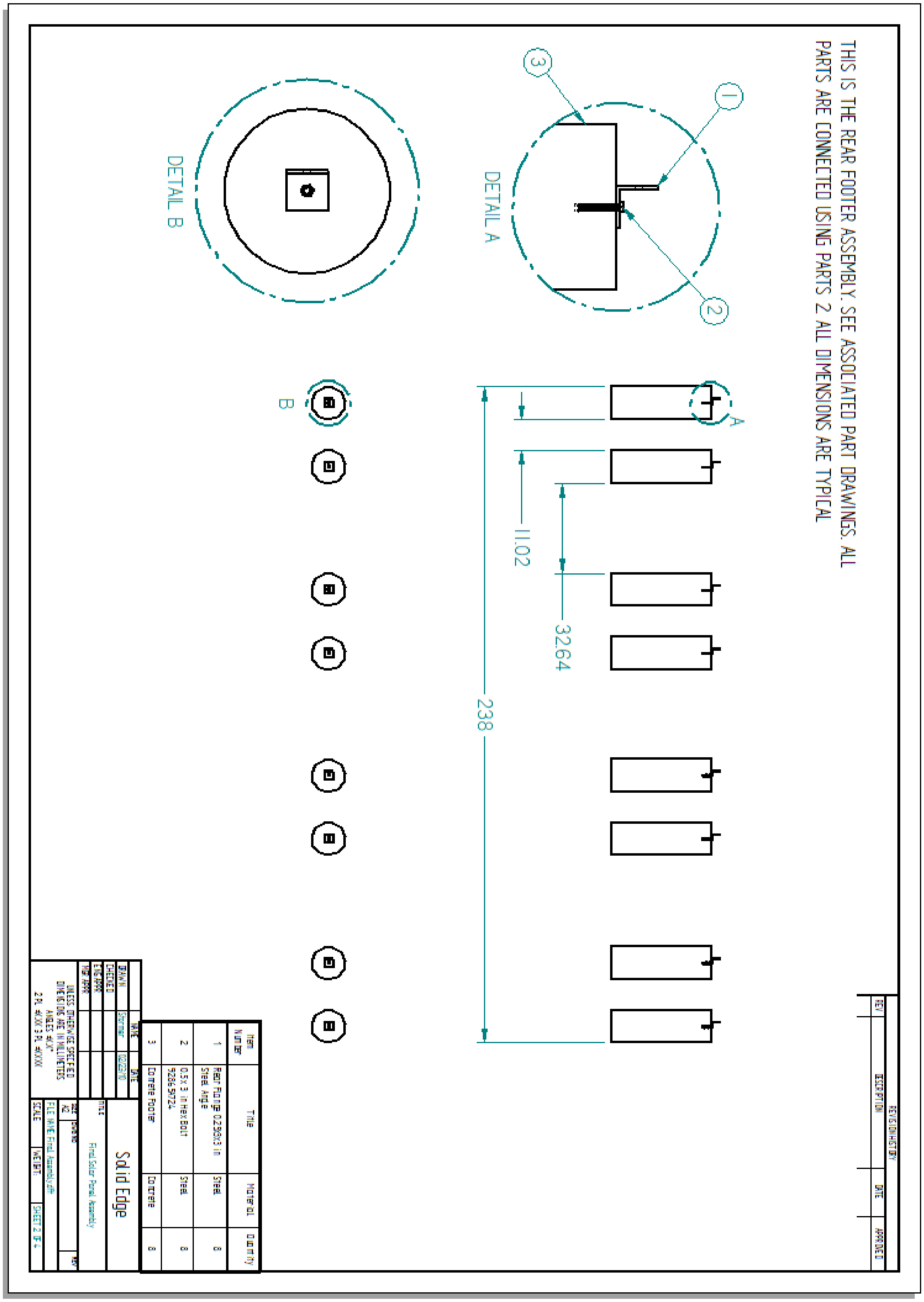

Figure A4: Rear footer assembly. Note dimensions and bolt locations are optimal, approximate and used to give a general reference.

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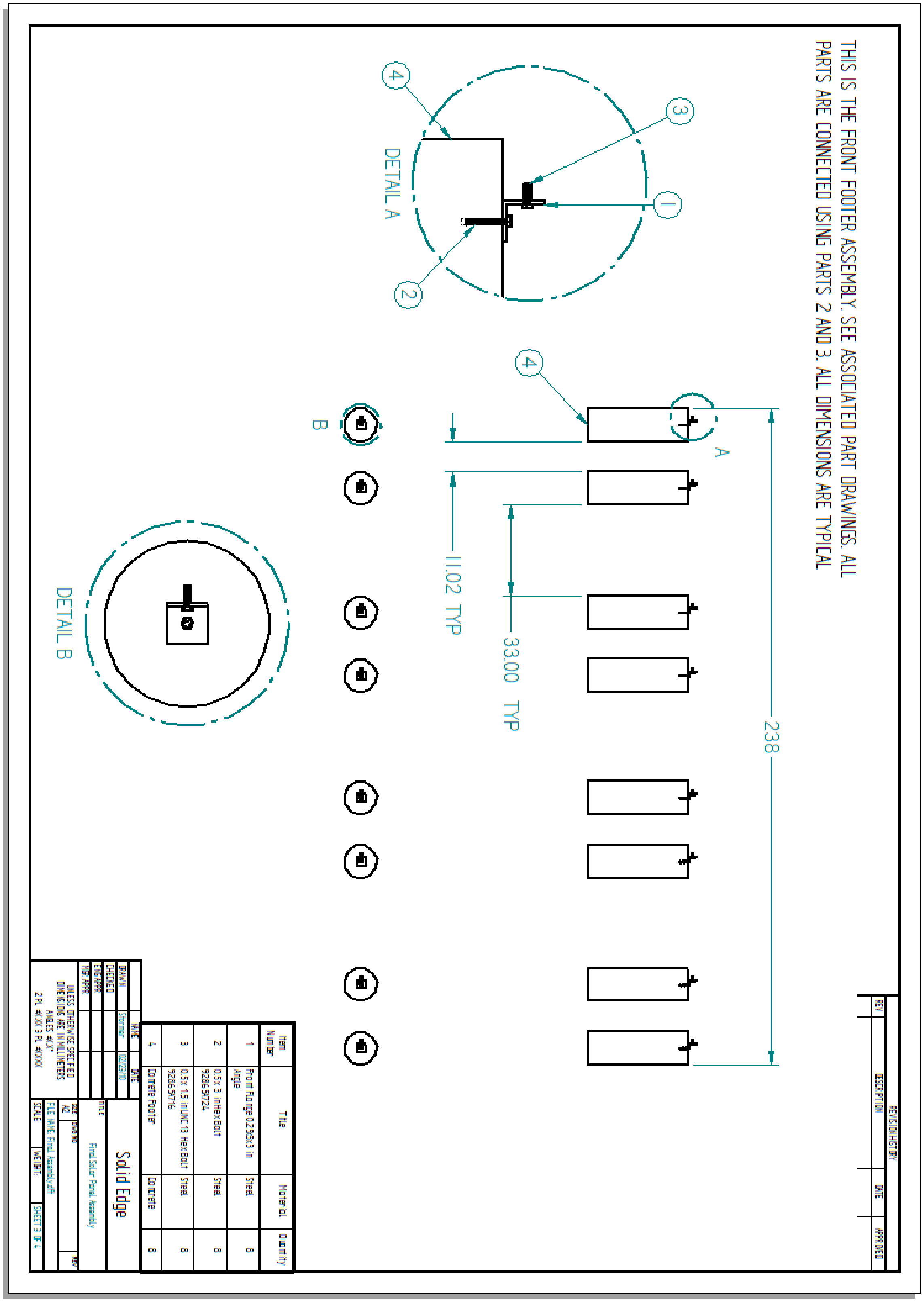

Figure A5: Front footer assembly. Note dimensions and bolt locations are optimal, approximate and used to give a general reference.

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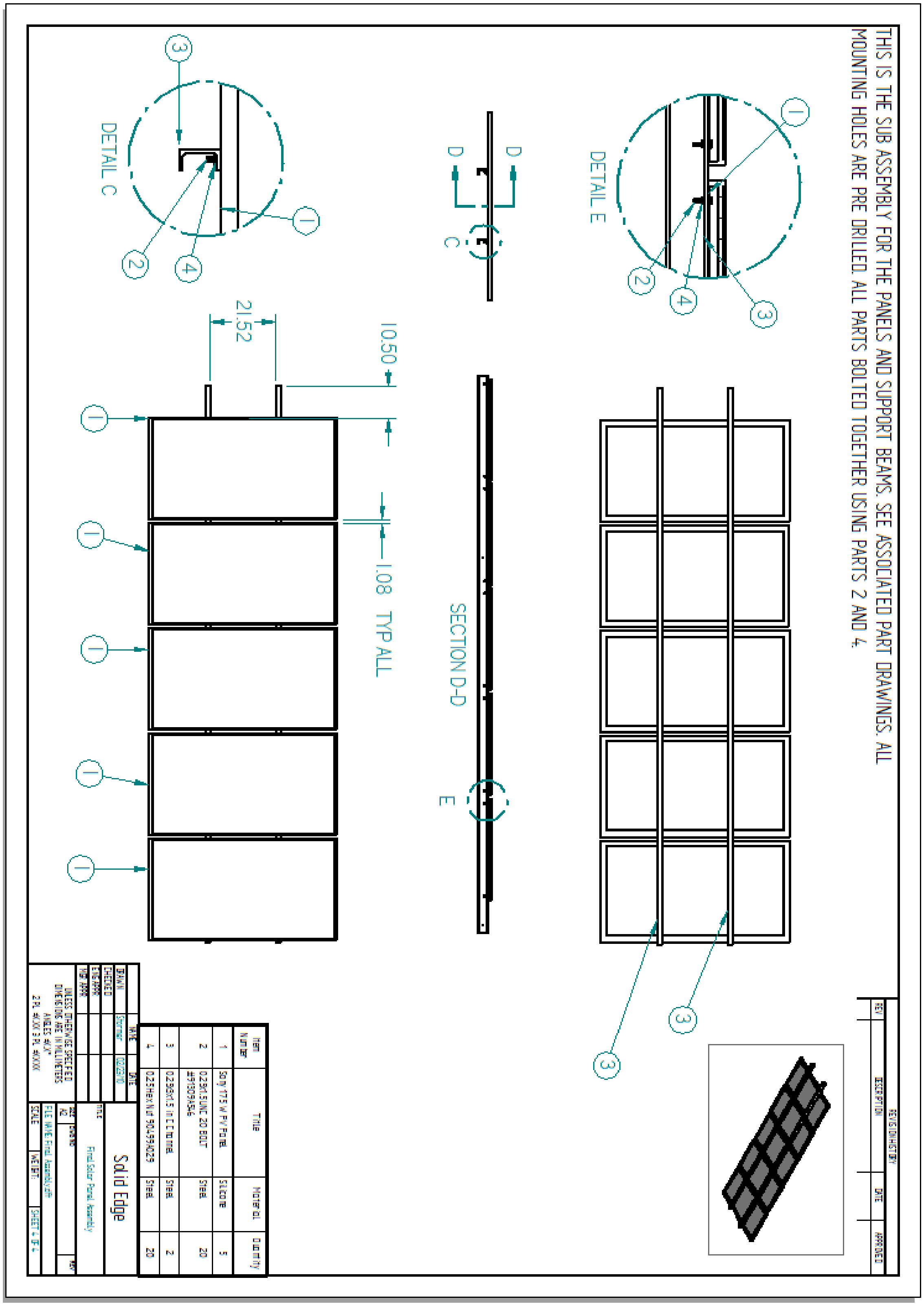

Figure A6: Panel and beam support assembly. Note: dimensions between c-channels are based from mounting hole locations predrilled on the solar panels.

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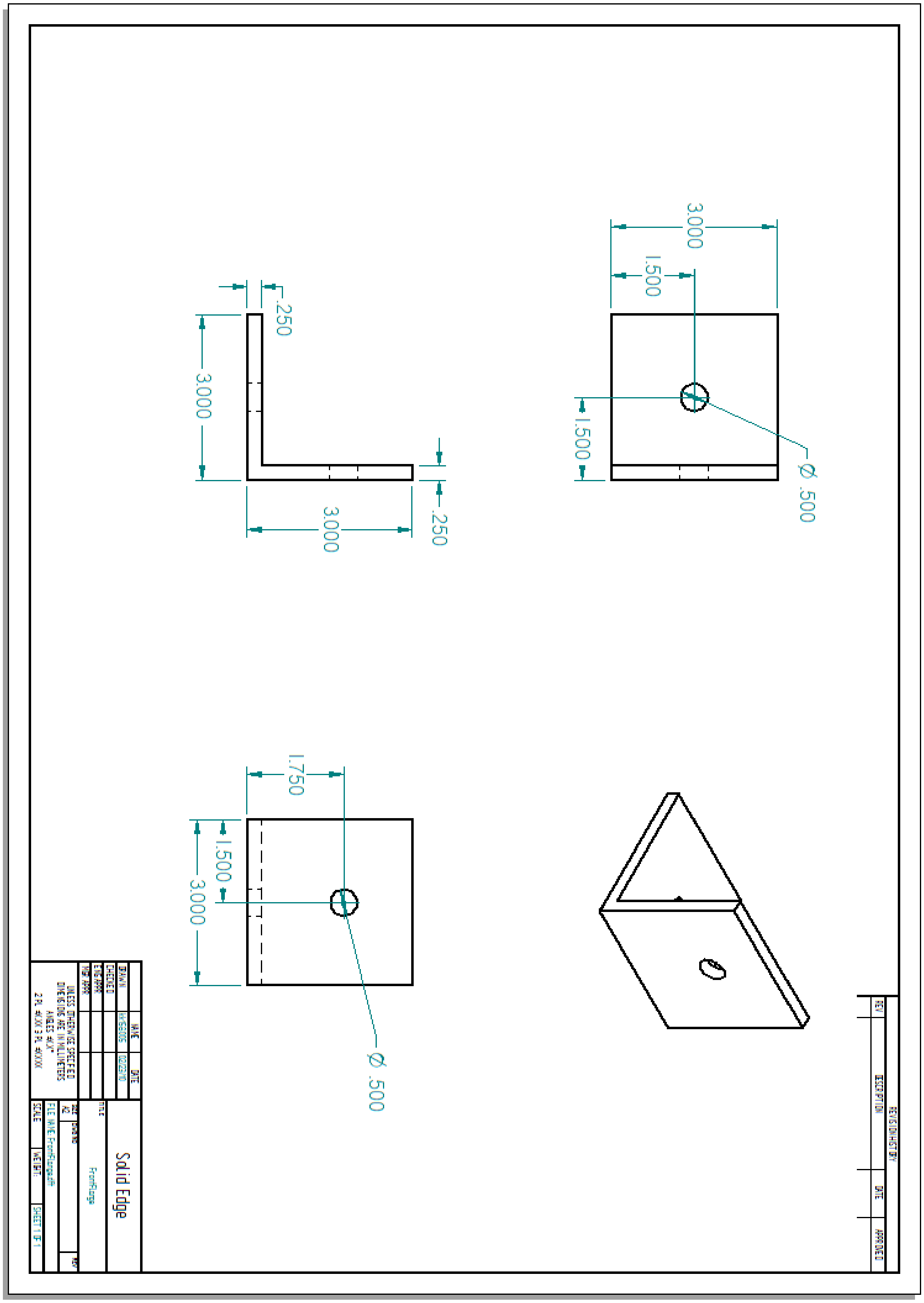

Figure A7: Front flange, used to attach the front footers to the PV support beams

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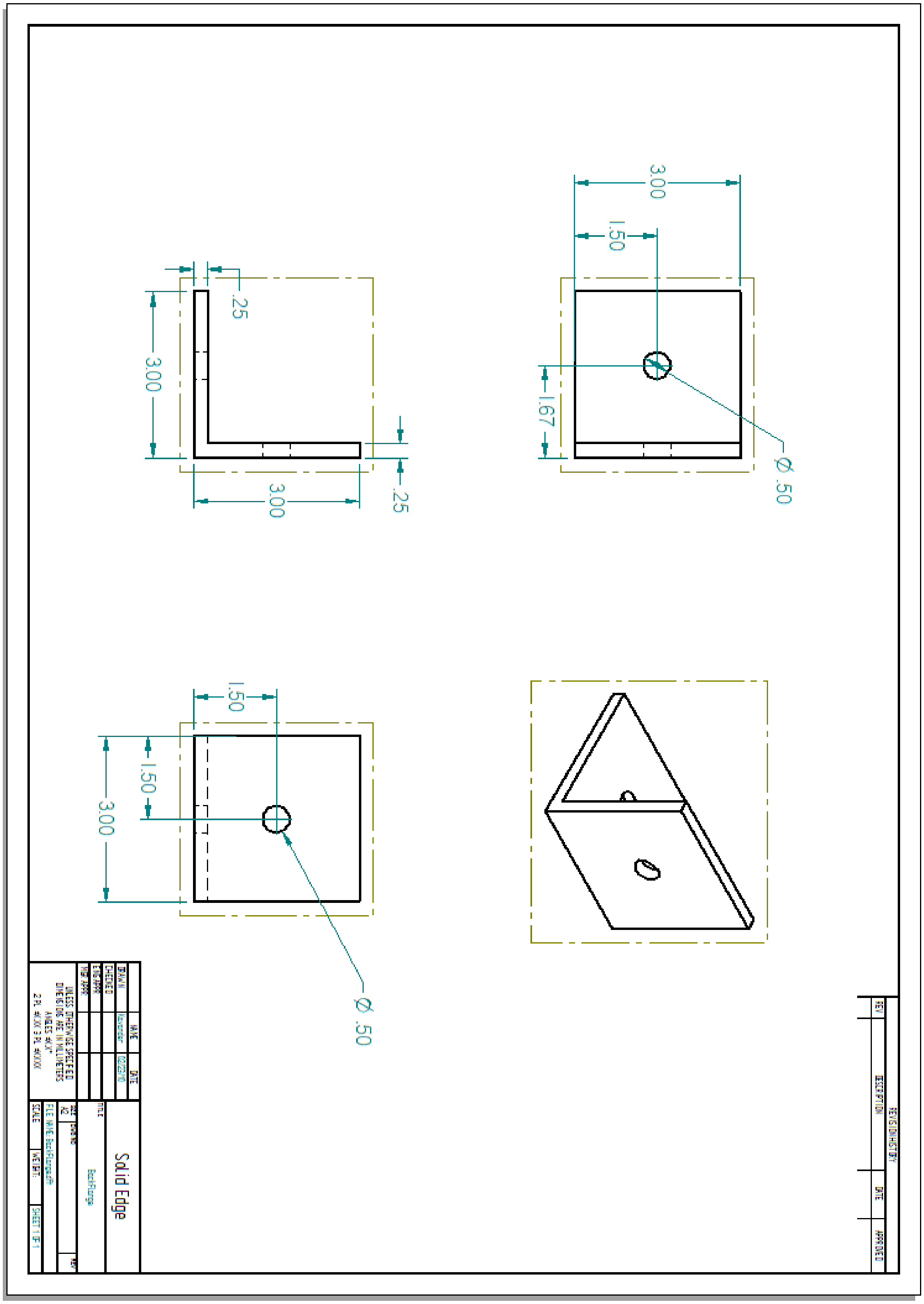

A8: Back mounting flange, used to connect footer and support leg

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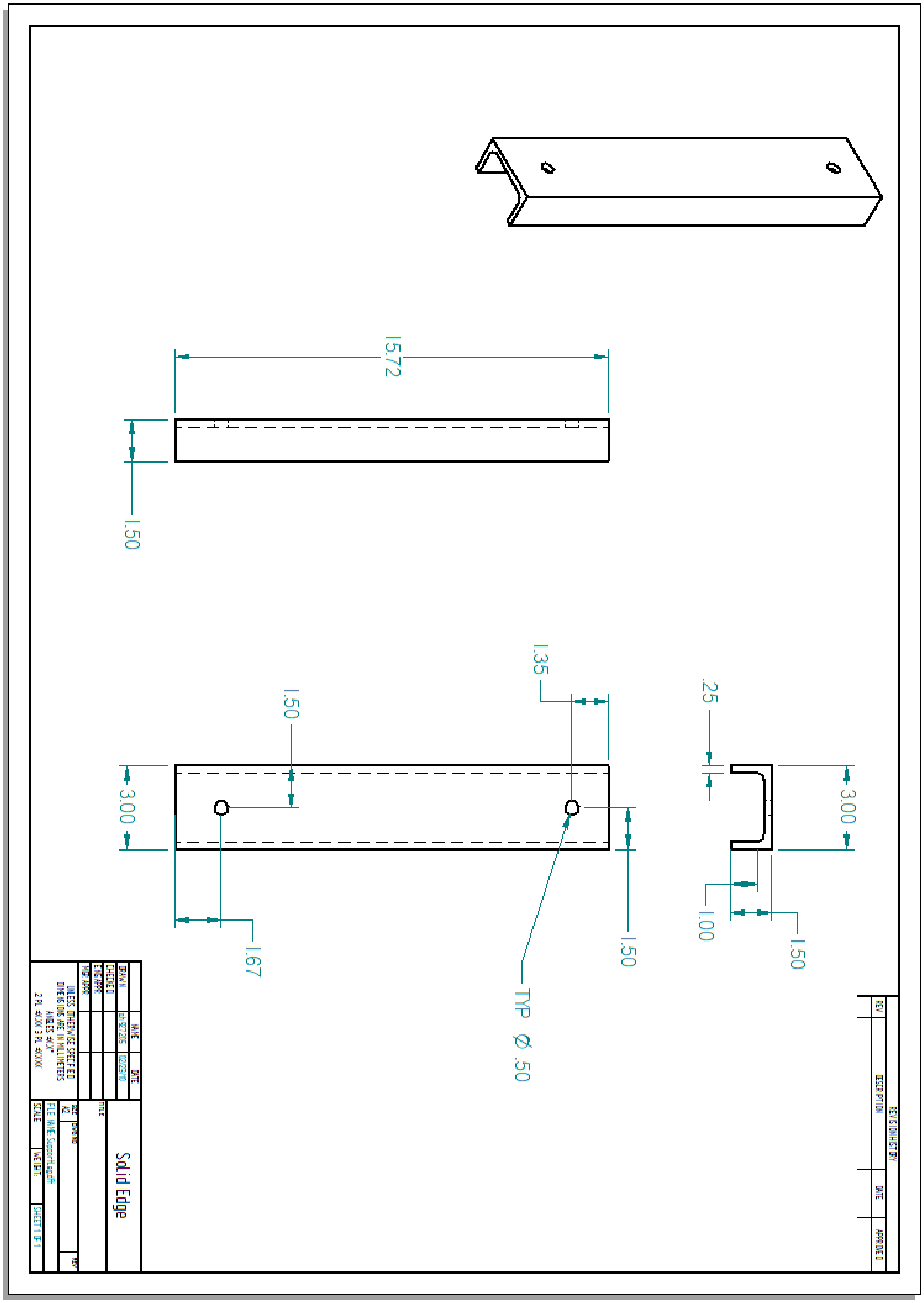

Figure A9: Support leg, attaches PV beam and rear footer

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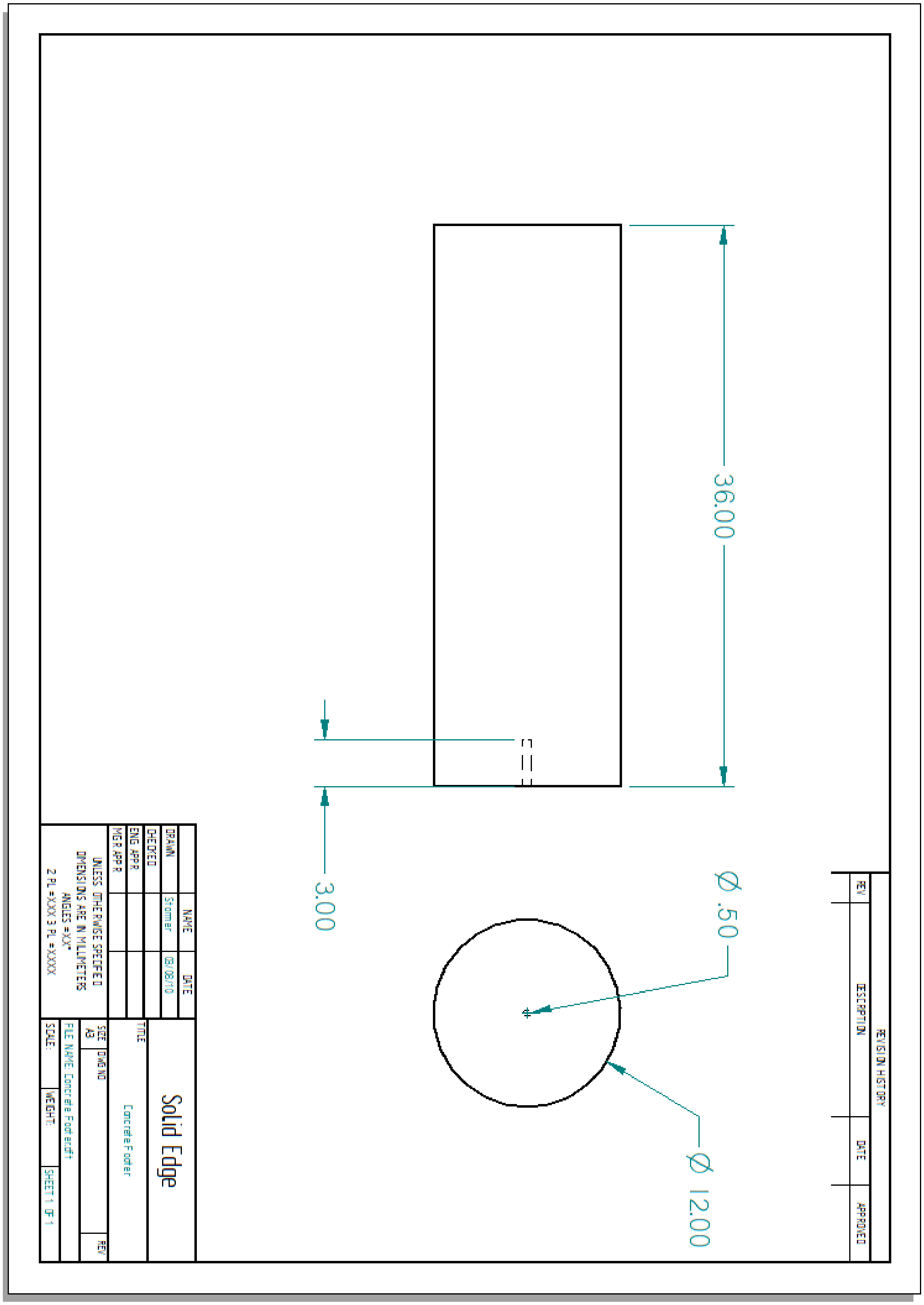

Figure A10: Concrete footer for front and rear

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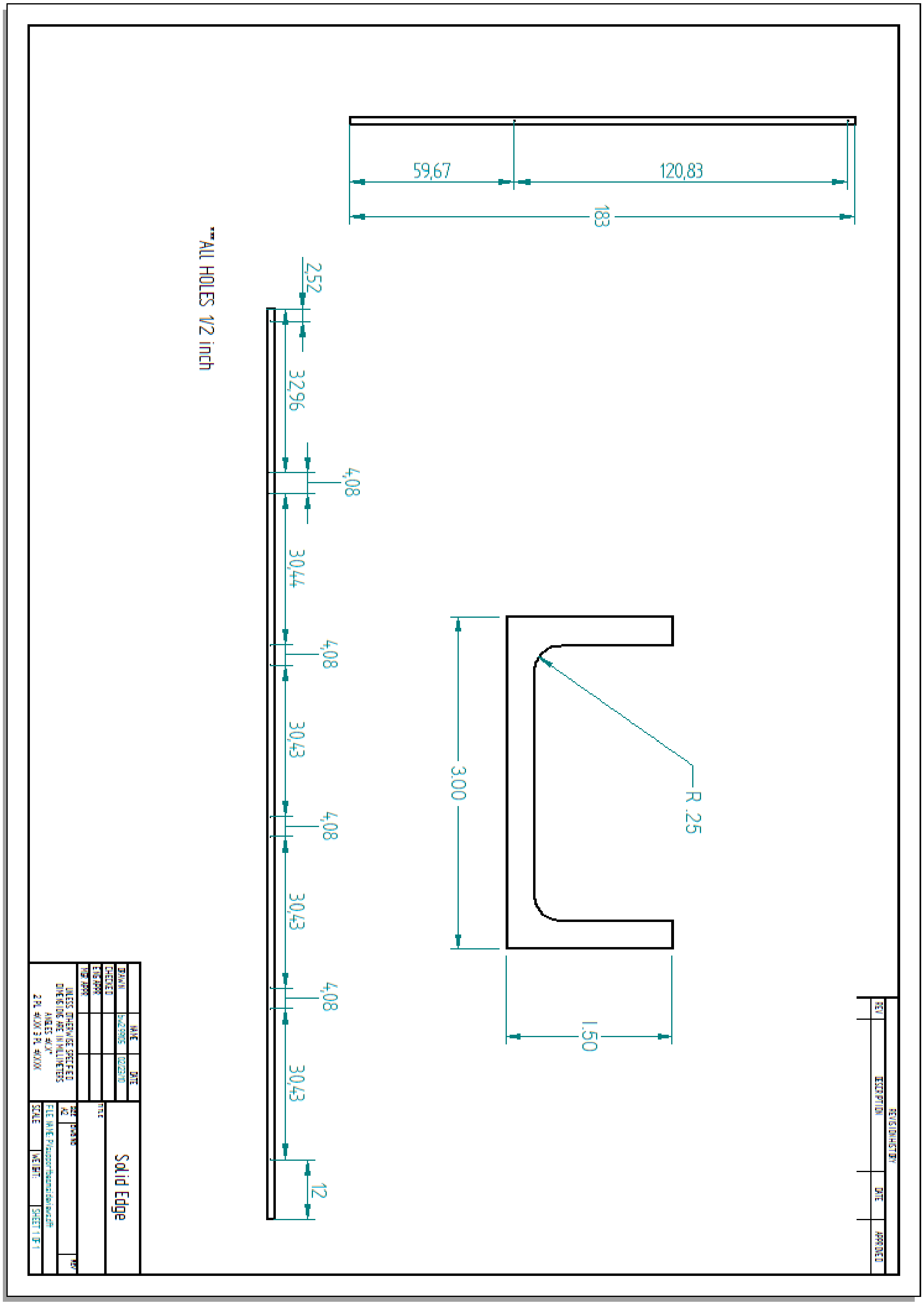

Figure A11: PV support beam

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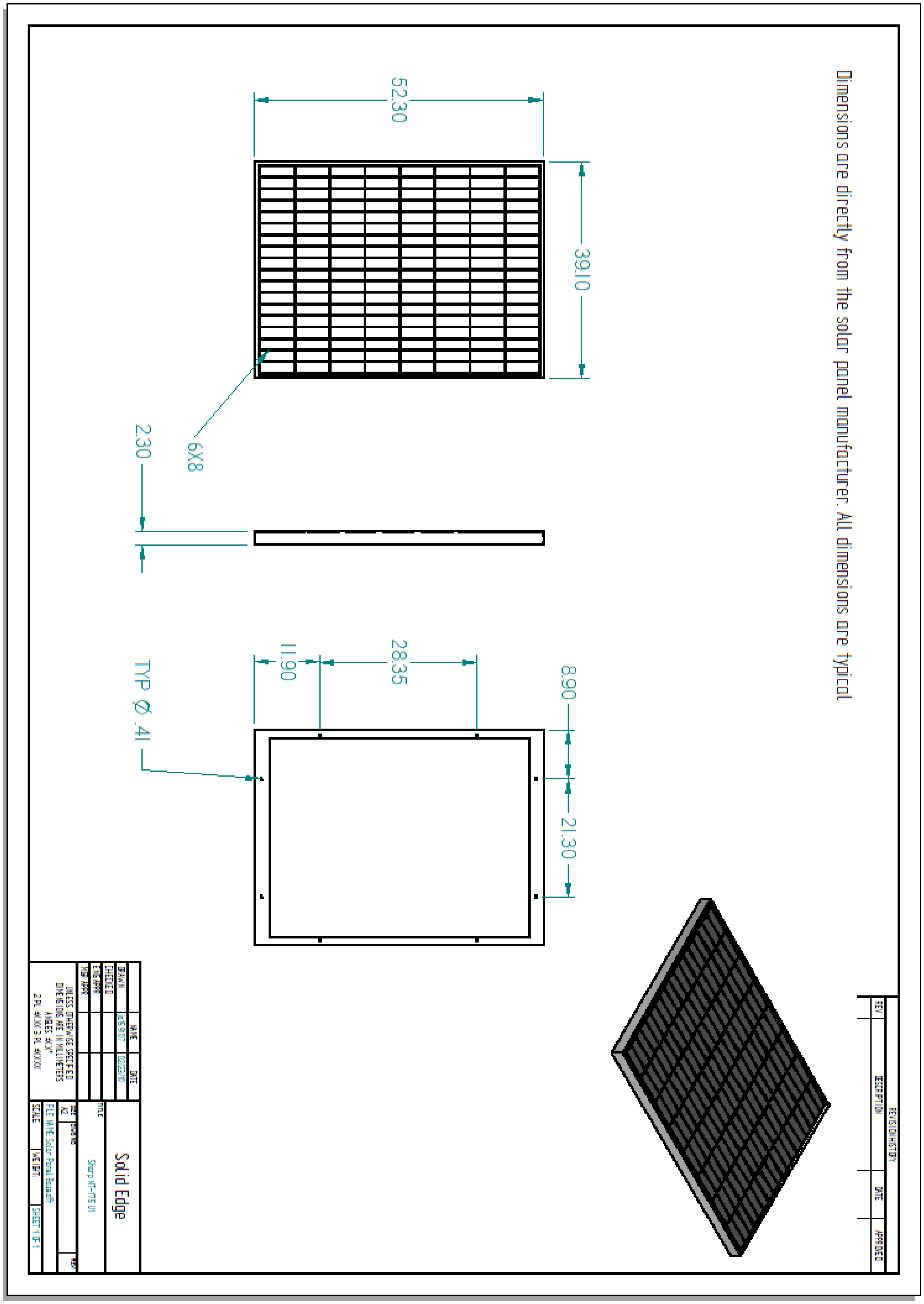

Figure A12: Sharp 175 W Mono-crystalline Solar Panel

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2.0 Structure Statics

The structure design is symmetrical and loaded uniformly. See Figure A17 for the statics of one beam supporting half the load of the solar panels. The maximum reactions were calculated based on the weight of the beam and the uniform load. The greatest resultant force was then applied to the bolts being used and it was calculated that the bolts will receive a maximum load of 678 psi, which is well below the yield stress of the material, 120,000 psi. The selected bolts will adequately hold the structure. Lastly the maximum von Mises stress in the support beam and the maximum deflection of the beam were calculated using Algor, a FEA modeling program. The maximum stress calculated was 4380 psi and the maximum yield stress for plain carbon steel is approximately 58,000 psi. The selected material and the design of the structure will withstand the load. The maximum deflection calculated in the beam is 0.018 in and occurs at the end of the free end of the beam. The deflection will not affect the solar structures function.

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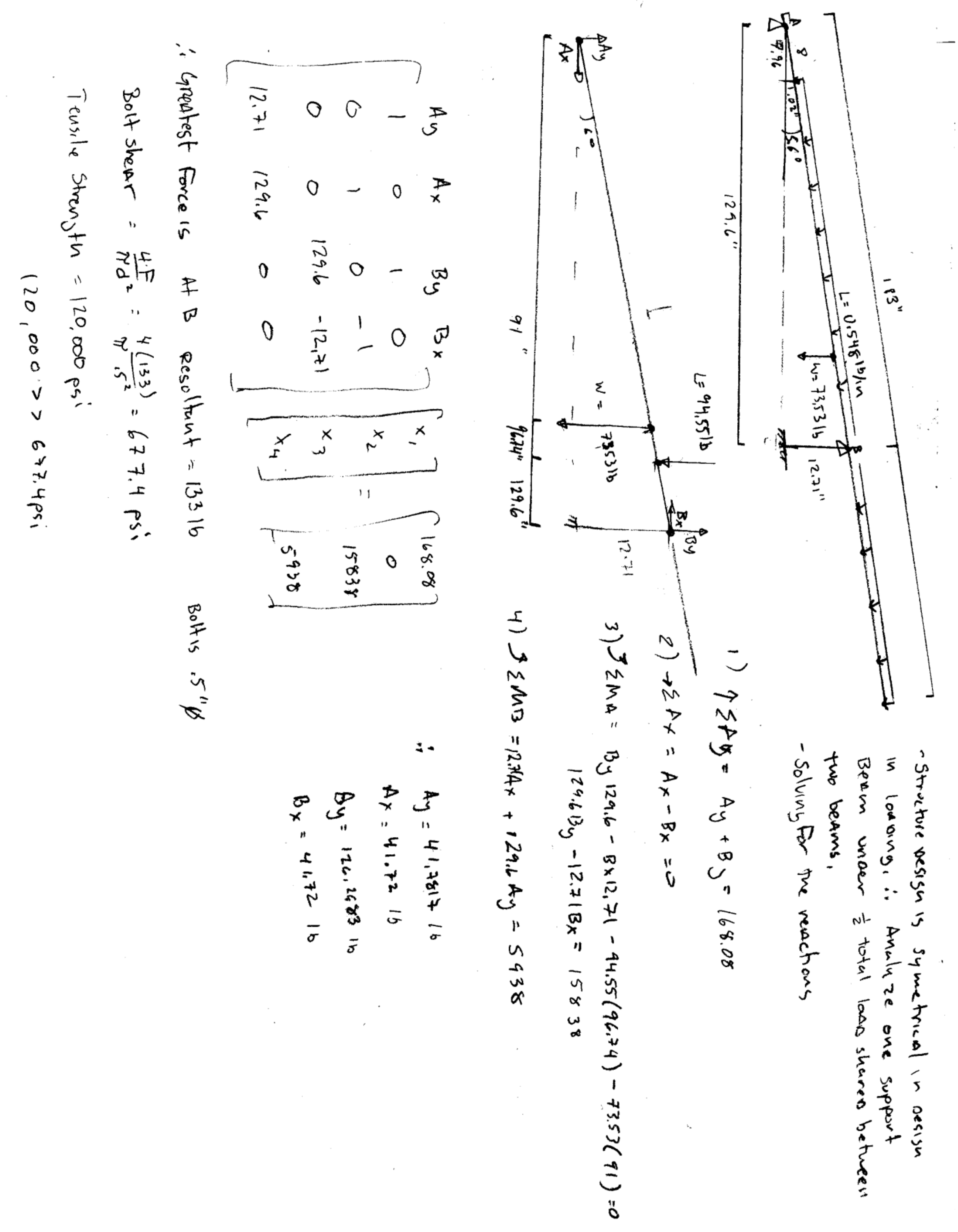

Figure A13: Statics of 1 beam of the solar mounting structure.

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Document 525 - Pre-Implementation Report
EWB Ohio
Maase-Offinso, Ghana
Solar Water Pumping System

3.0 Soil and Concrete Calculations

Presented below are the calculations performed to verify the load applied to the concrete footers and the surrounding ground. The dimension of the designed footers will more than adequately support the solar panel arrays.

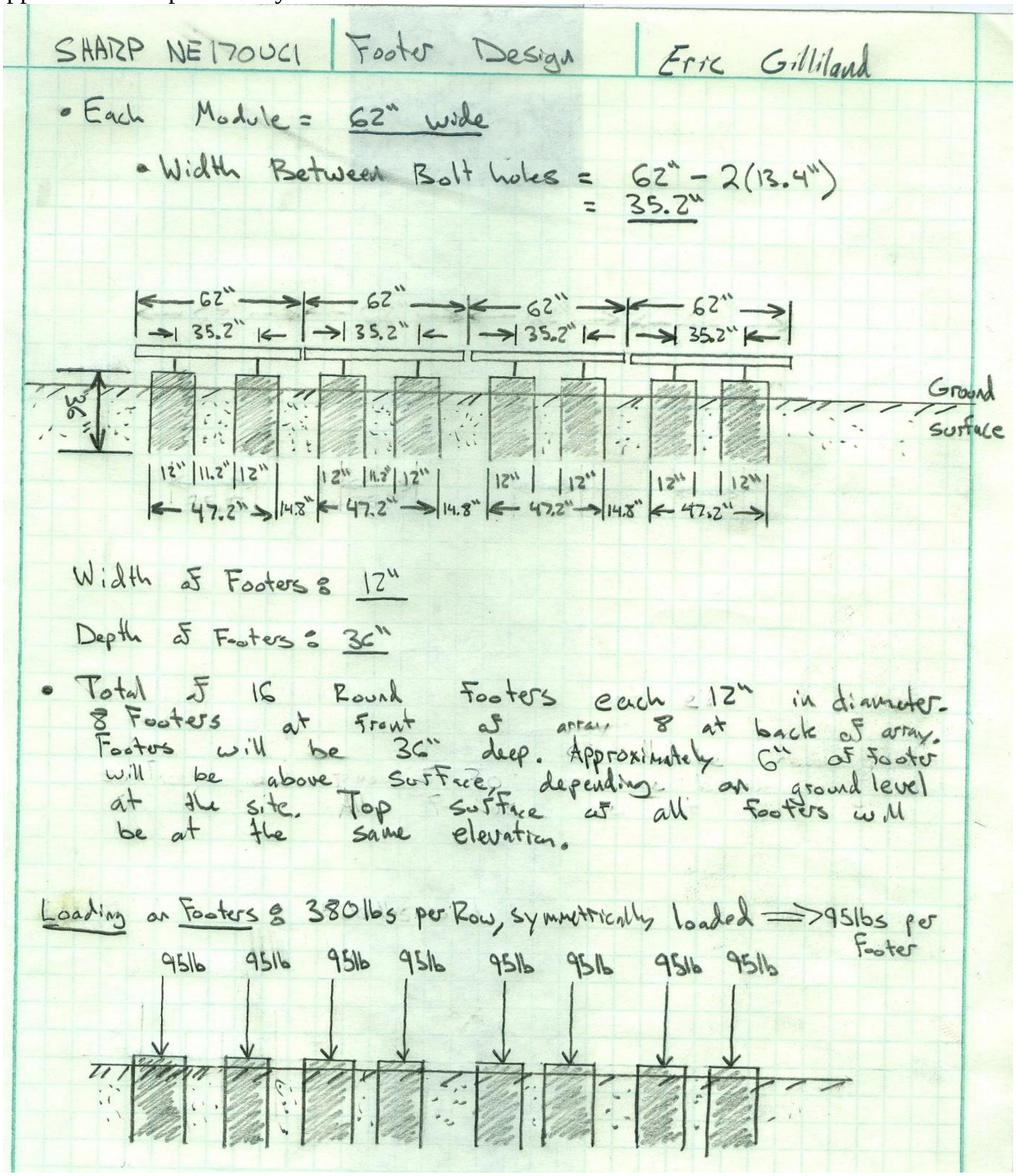

Figure A14: Intro to footer design and stress calculations to verify design.

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Bearing Capacity of Shallow Foundations:

Ultimate Bearing Capacity: $q_u = 1.3c' N_c + q N_q + 0.3 \gamma B N_\gamma$

- q_u = Ultimate Bearing Capacity
- B = Diameter of Foundation
- c' = Cohesion of soil
- γ = unit weight of soil
- $q = \gamma D_F$
  - D_F = Depth of Foundation from surface
- N_c, N_q, N_γ = Non-dimensional bearing capacity factors that are a function of soil's internal friction

Soil Type: Sandy Clay

Ratio of Depth/Diameter = $36''/12'' = 3 \Rightarrow$ Shallow Foundation

Sandy-Clay:

Cohesion: Sand = 0 Clay = 96-102 kPa
$\Rightarrow$ 100 kPa
100 kPa = 14.504 PSI

$$c' = \frac{0 + 14.504}{2}$$

$$= 7.252\ psi = c'$$

Unit Weight: Sand Density = $1800 kg/m^3 = 0.065\ lb/in^3$

Clay Density = $1900 kg/m^3 = 0.0686\ lb/in^3$

$$\gamma = \frac{(0.065 + 0.0686)}{2} = 0.0668\ lb/in^3 = \gamma$$

Figure A15: Continued calculations

Angle of Internal Friction (ϕ') = Function of Density and Soil type

*Assume Soil is between Loose, and Compact *

30 - 40°

Clay → 20°

Sand → 30-40°

* Assume $\boxed{\phi' = 25°}$

Bearing Capacity Factors: $\phi = 25°$

$$\Longrightarrow \boxed{\begin{array}{l} N_c = 20.72 \\ N_q = 10.66 \\ N_\gamma = 10.88 \end{array}}$$

$$q_u = 1.3(7.252)(20.72) + (36'')(0.0668)(10.66) + (0.3)(0.0668)(12'')(10.88)$$

$$q_u = 195.34 + 25.64 + 2.62$$

$$\underline{q_u = 223.6 \text{ PSI}}$$

Safety Factor: $q_{all} = \dfrac{q_u}{FS}$ $\quad FS \geq 3.0$

* Assume $FS = 4.0$

$$q_{all} = \frac{223.6}{4}$$

$$q_{all} = 55.9 \text{ PSI}$$

$$\boxed{\text{Allowable Load Per Unit Area} \leq 55.9 \text{ PSI}}$$

Figure A16: Continued calculations presenting the max load per unit area

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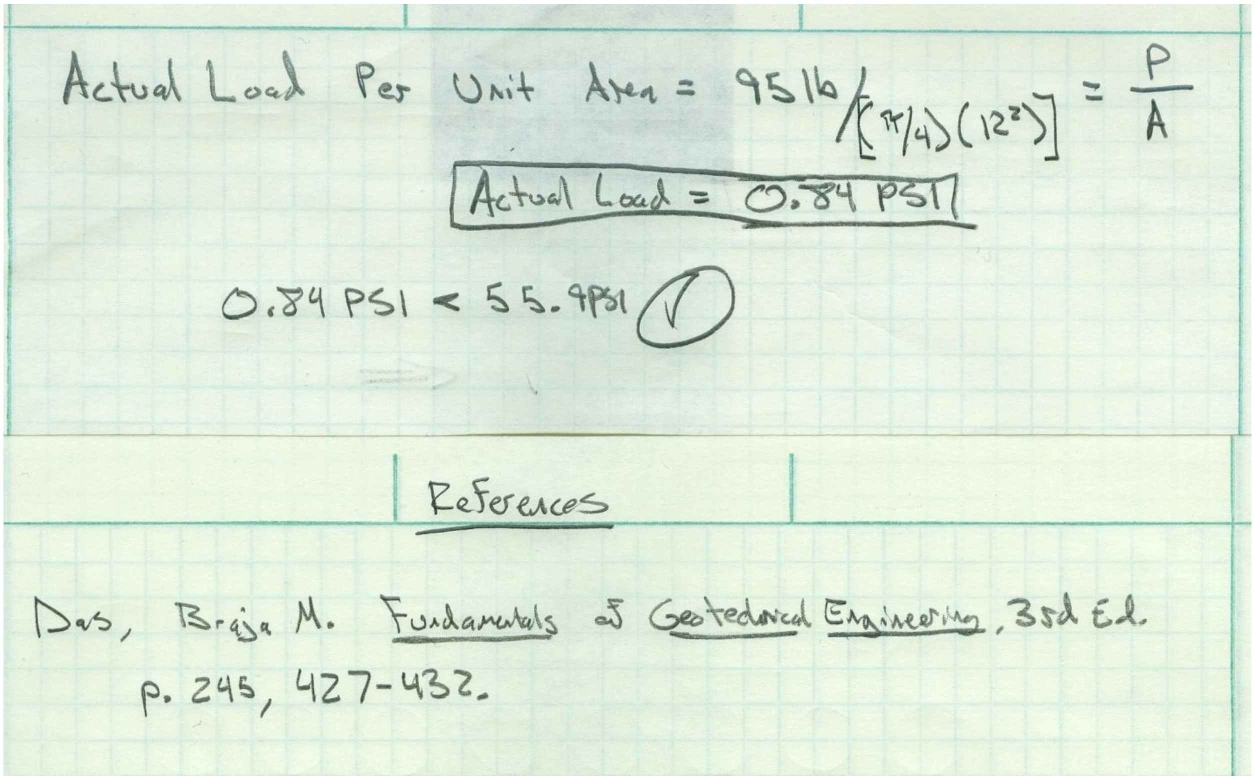

Actual Load Per Unit Area = $95\text{ lb} / [(\pi/4)(12^2)] = \frac{P}{A}$

Actual Load = 0.84 PSI

0.84 PSI < 55.9 PSI ✓

References

Das, Braja M. Fundamentals of Geotechnical Engineering, 3rd Ed.
p. 245, 427-432.

Figure A17: Final calculations verifying the design. The actual stress compared to the allowable stress is almost negligible.

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APPENDIX B

1.0 Solar/Pump head calculations and selection verification

Head Loss Calculations:

1) *Friction Loss*

   $F_{loss/100ft} = 0.2083\ (100/c)^{1.852}\ (q)^{1.852\ /}\ (d_h)^{4.8655}$

   $F_{loss\ =}\ 1100 * F_{loss/100ft}$

$F_{loss/100ft}$ = friction head loss in feet of water per 100 feet of pipe (ft_{h20}/100 ft pipe)
c = Hazen-Williams roughness constant (140 for polyethylene)
q = volume flow (gal/min) (24.6 gal/min)
d_h = inside hydraulic diameter (inches) (2.1 in for polyethylene water pipe)

F_{loss} = 12.518 ft

From www.EngineeringToolbox.com

2) Ground elevation is 87 ft according to the survey in the pre-assessment report.
3) Distance from bottom of spring-box to the ground level is 10-15 ft according to the chief of the village.
4) The distance from the ground to the storage tanks will be 8-10ft.
5) The head loss created by bends in the piping is being neglected due to the low number of bends in the pipe, approximately four 90^{O} bends.

Totaling for maximum head was found to be: 12.518 ft + 87 ft + 15 ft + 10 ft = 124.518 ft
We will assume this head loss is 130 ft for simplicity of selecting the pump and to account for any effect from the bends in the pipe.

Pump and Solar Module Selection:

The pump was selected based on two primary conditions. The first being that the operation of the pump will begin as early in the morning as possible so that it can utilize all sunlight hours available during the short days in the wet season. This gave the helical rotor pump an advantage over a centrifugal pump. The second condition was the ability to meet the goal of 8,000 gal/day during the wet season. One problem with a single helical rotor pump is that the flow rates are too low to achieve the required water therefore two pumps must be used to pump the required amount of water. This will also add redundancy to the system adding to the reliability of the overall design. The calculated head, shown above was found to be approximately 130 ft from the spring box to the top of the storage tanks.

The pump selection is made based on 4,000 gal/pump/day and 130 ft of total head. The Grundfos 11-SQF-2 will output 12.3 gal/min at 130ft of head given that the power input is at least 560 W. The total power will be 3,035.2 W if when pumping 4,000 gallons at 560 watts in 5.4 hours. To determine how much water one pump can pump during one day in the wet season solar data from the region was gathered. Using the program, PV Watts, from the National Renewable Energy Laboratory, one can estimate how much power a certain sized PV array can output based on the time of day. Since the system has no data for the village the data for the closest city must be used, Accra. This data will be slightly lower than data for the village because

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location of the village. The farther north in Ghana the greater the solar irradiance will be per day on average.

Using PV Watts for a 1.5 kW array the graph shown in Figure B1 below was formed for July 21, 2001 in Accra, Ghana, which is the worst solar irradiance day found in all the recorded data for Accra.

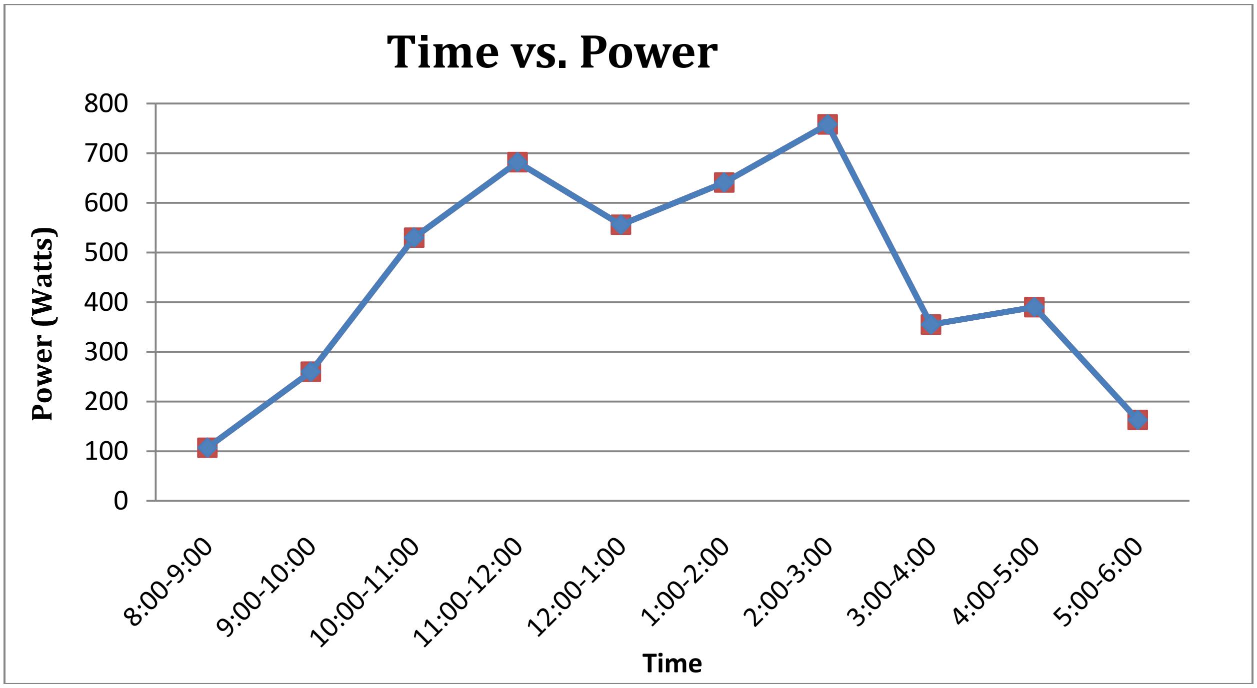

Figure B1: Single worst day in Accra for solar irradiance Time v Power output for a 1.5 kW solar array. The graph shows the average power during each hour long time span.

By using the pump curve supplied by the manufacturer the amount of water that can be pumped during each hour of the day was estimated using the data from Figure B1, and presented in we Figure B2.

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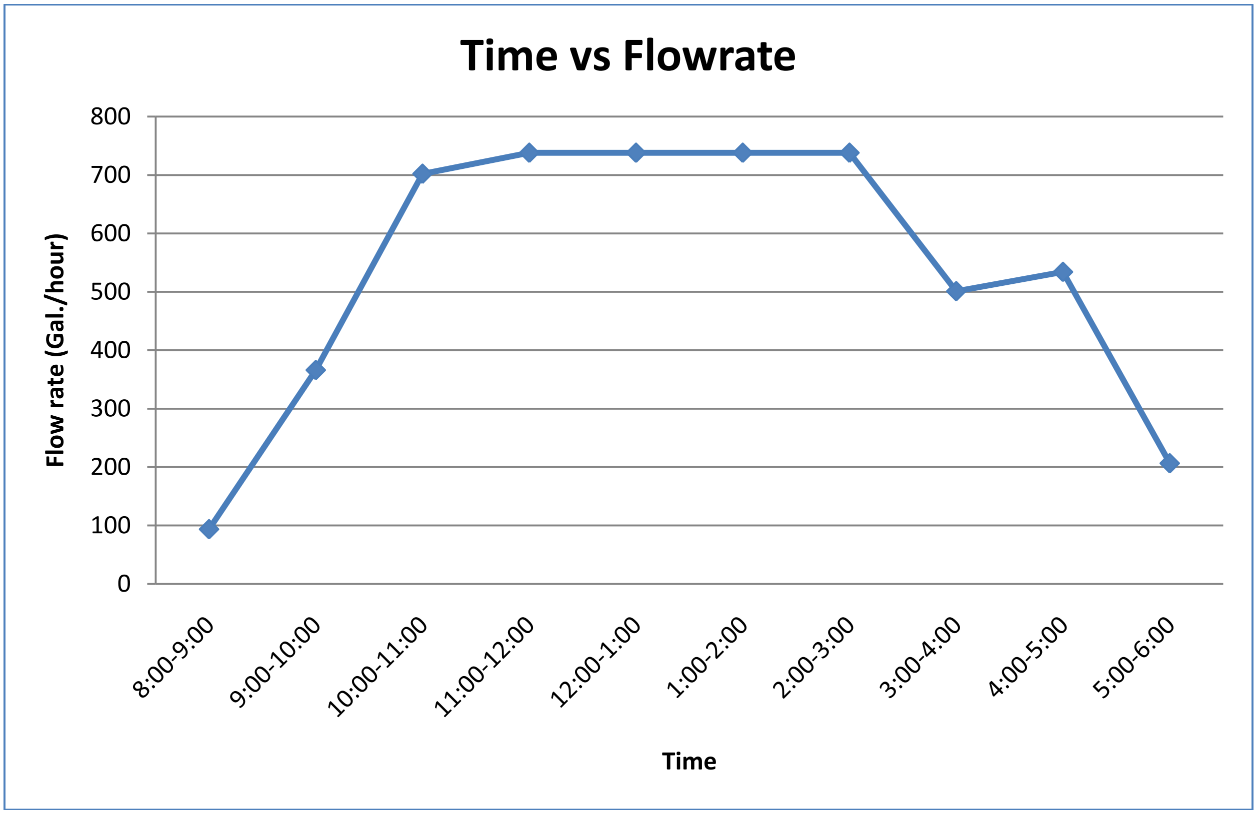

Figure B2: Flow rate per hour based on data presented in Figure B1. The graph shows that on the single worst solar day recorded the system design will supply the required volume of water.

Taking these values as the average flow rate per hour the total amount of water pumped is 5,352 gallons per pump totaling 10,704 gallons for both pumps, see Table B1. Therefore, the pumps selected will adequately supply the required volume of water during the worst possible day for solar irradiance recorded.

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Table B1: Table for justification of total of water pumped per day. This table used Figure B2 and the Grundfos pump curve to calculate results.

Time	Power (W)	Flow Rate (Gal./min.)	Gallons/hour
8:00-9:00	107	1.56	93.6
9:00-10:00	260	6.1	366
10:00-11:00	530	11.7	702
11:00-12:00	682	12.3	738
12:00-1:00	556	12.3	738
1:00-2:00	641	12.3	738
2:00-3:00	758	12.3	738
3:00-4:00	355	8.35	501
4:00-5:00	390	8.9	534
5:00-6:00	163	3.44	206.4
	Total Power (W) 4442		**Total(gal./day)- 5355**

Based on pump selection, the size of the solar arrays required can be selected. Using the pump curve it was calculated that the system needed 5.5 hours of pumping at 12.3 gal/min. requiring 560 watts. Applying a factor of safety to the system will allow for a 25% fluctuation in irradiance per day during the wet season while still meeting the 8,000 gallon per day goal. This factor of safety of 1.25 changed the amount of energy from (5.5x560W) = 3,080 W-hr to 3,850 W. To achieve this, the panels selected are 10 Sharp 175 W panels which output a PTC rated power of 151.8 W and 24 VDC, and all connected in series. Using PV Watts to study a PV array of 1.5 kW one can see that during July 21, 2001 the average power output per day is 4442 watt-hours. This is greater than our required irradiance with the factor of safety applied, and will supply approximately 240 volts per pump keeping us in the upper range of the operating envelope for our pumps. To sum up the solar module selection we will be buying 20 Sharp 175W Panels with 2 sets of 10 in series with each set powering 1 pump.

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2.0 Engineering Drawings

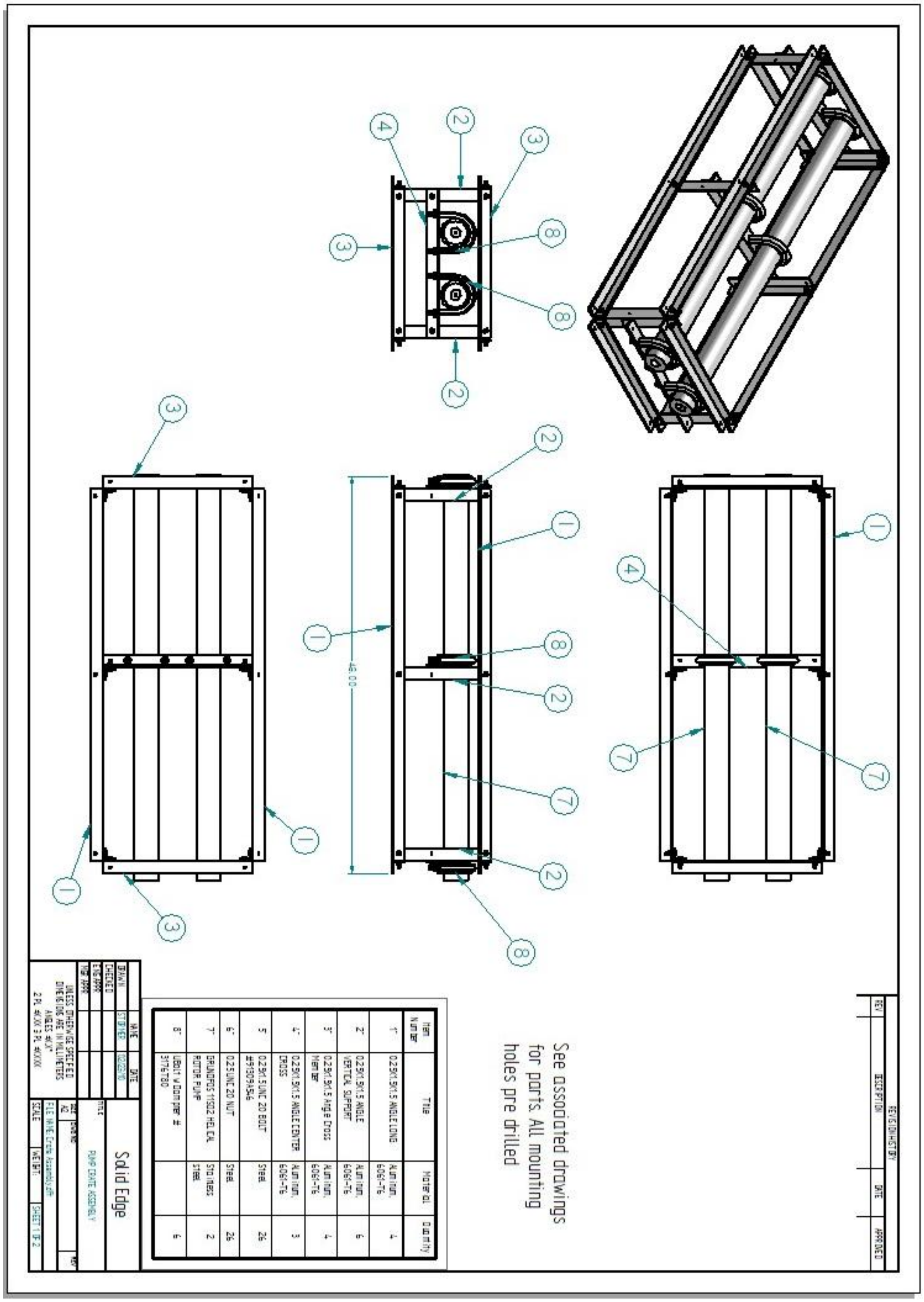

Figure B3: Assembly drawing of pump mounting structure. The final design concepts is still evolving to optimize weight and material costs.

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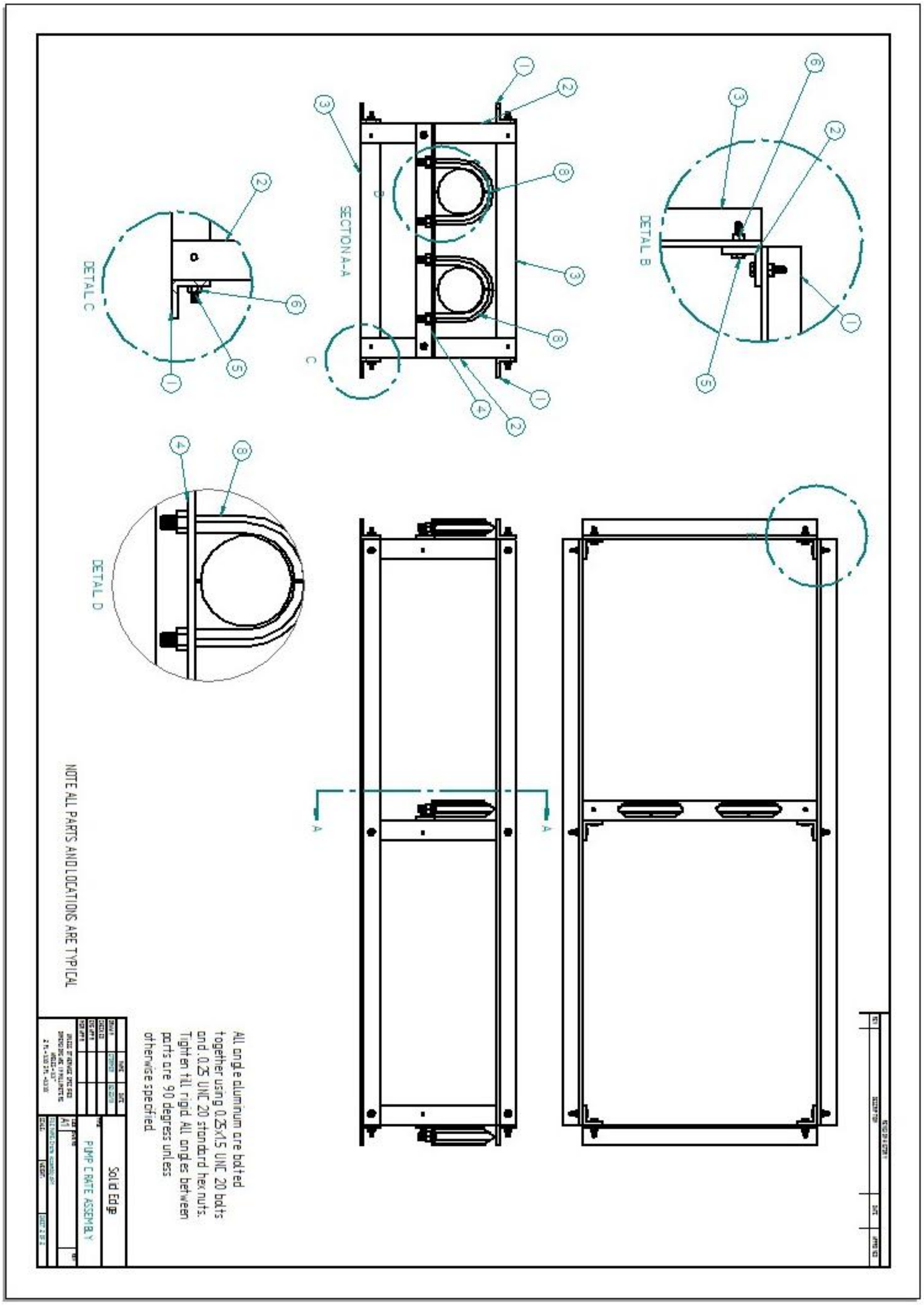

Figure B4: Sheet 2/2 of pump mounting assembly drawing

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Item Number	Title	Material	Quantity
1	0.25X1.5X1.5 ANGLE LONG	Aluminum, 6061-T6	4
2	0.25X1.5X1.5 ANGLE VERTICAL SUPPORT	Aluminum, 6061-T6	6
3	0.25x1.5x1.5 Angle Cross Member	Aluminum, 6061-T6	4
4	0.25X1.5X1.5 ANGLE CENTER CROSS	Aluminum, 6061-T6	3
5	0.25x1.5 UNC 20 BOLT #91309A546	Steel	26
6	0.25 UNC 20 NUT	Steel	26
7	GRUNDFOS 11SQ2 HELICAL ROTOR PUMP	Stainless steel	2
8	UBolt w Dampner # 3176T80		6

Figure B5: Enlarged view of parts list for the pump mounting structure

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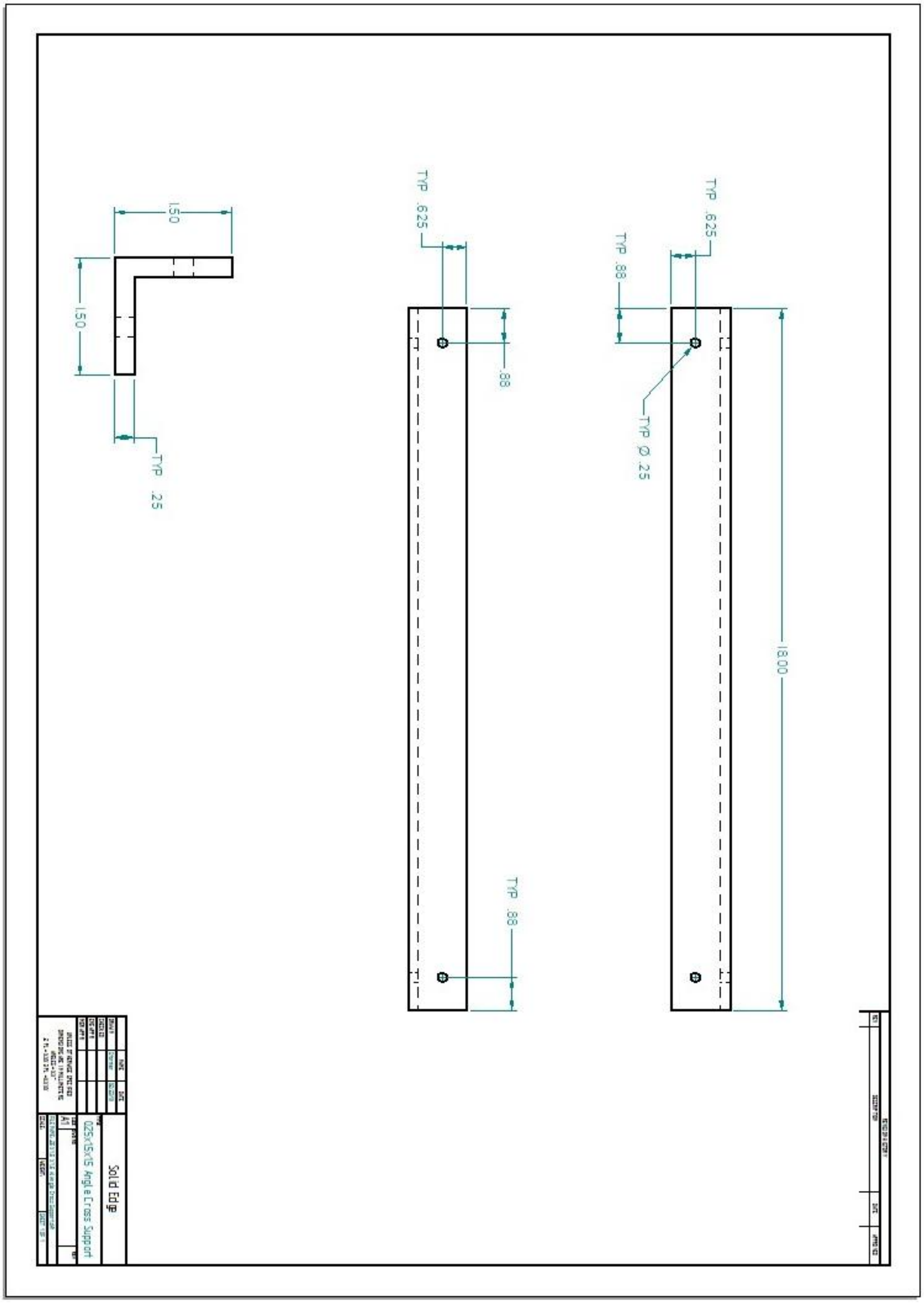

Figure B6: Cross member drawing for pump structure

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Document 525 - Pre-Implementation Report

EWB Ohio

Maase-Offinso, Ghana

Solar Water Pumping System

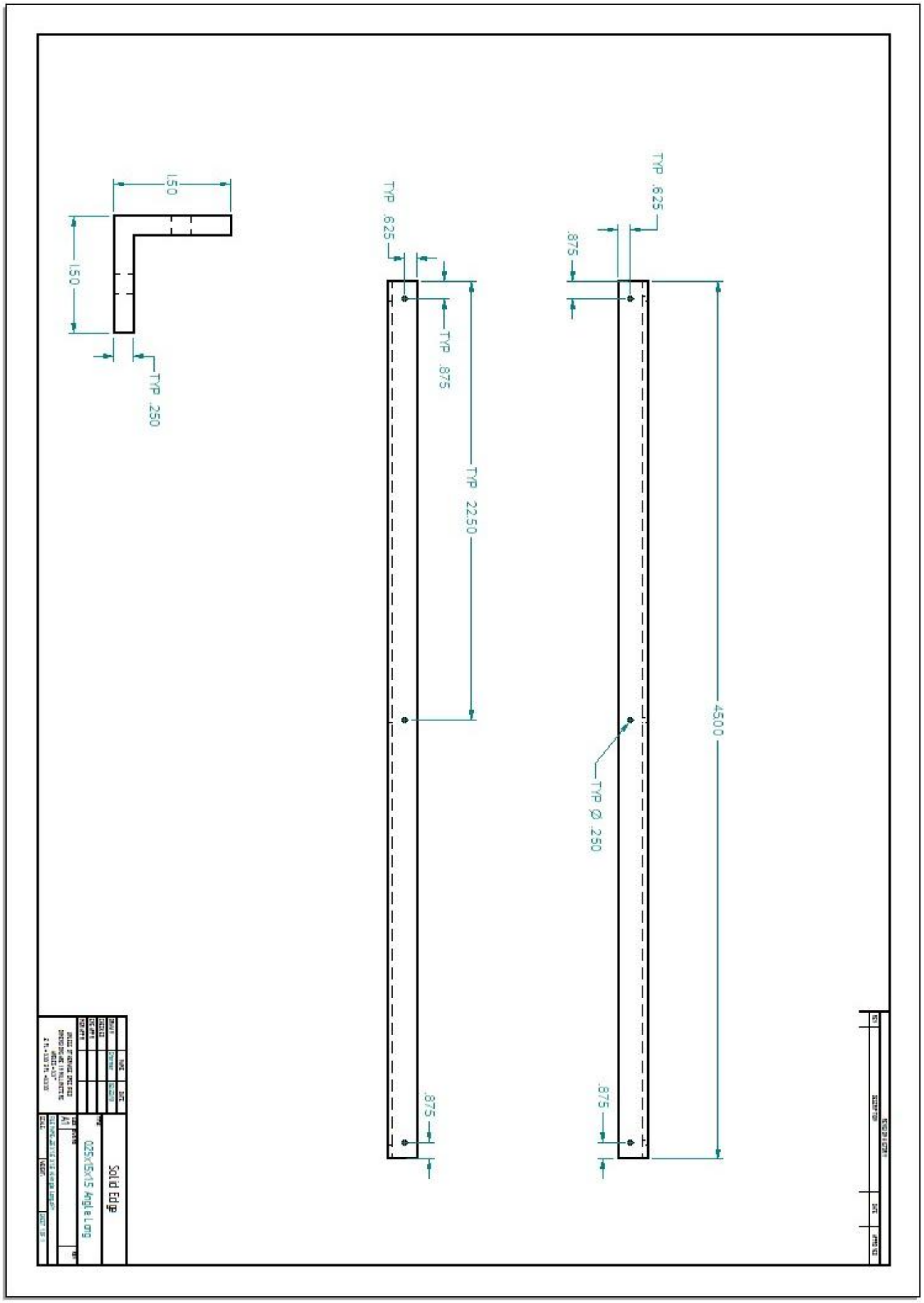

Figure B7: Long length angle for pump structure

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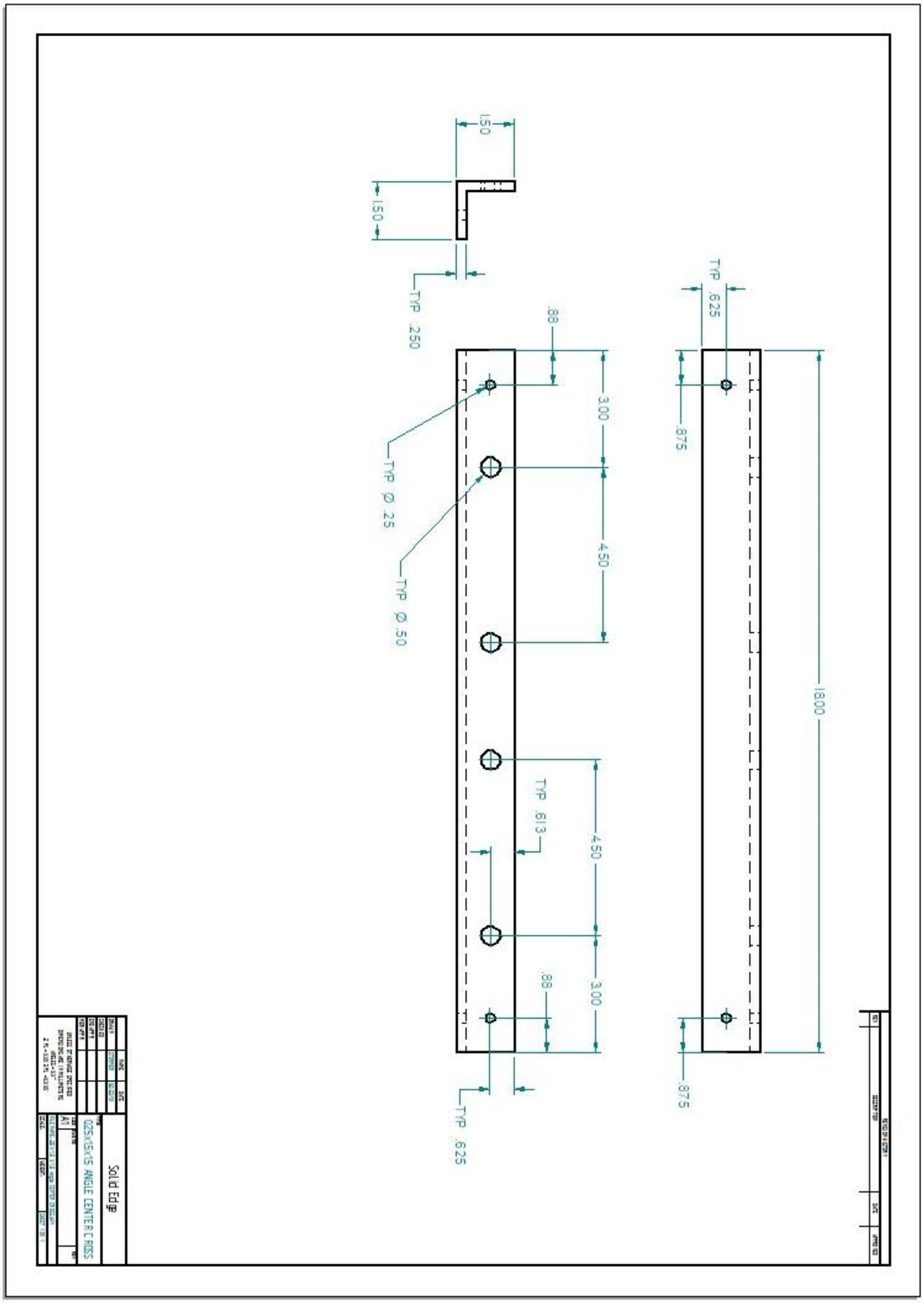

Figure B8: Center cross member for pump structure

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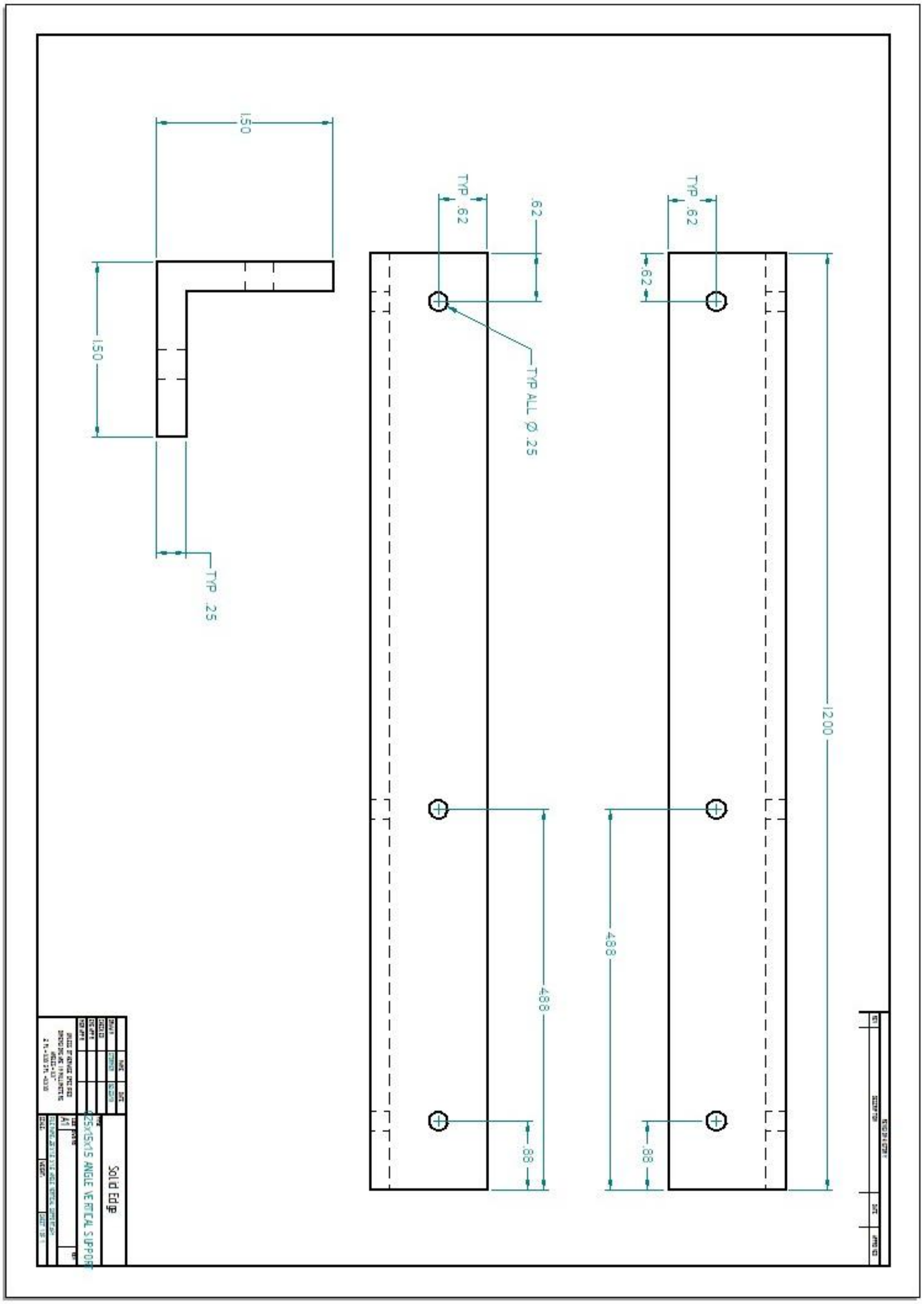

Figure B9: Vertical leg pump support structure

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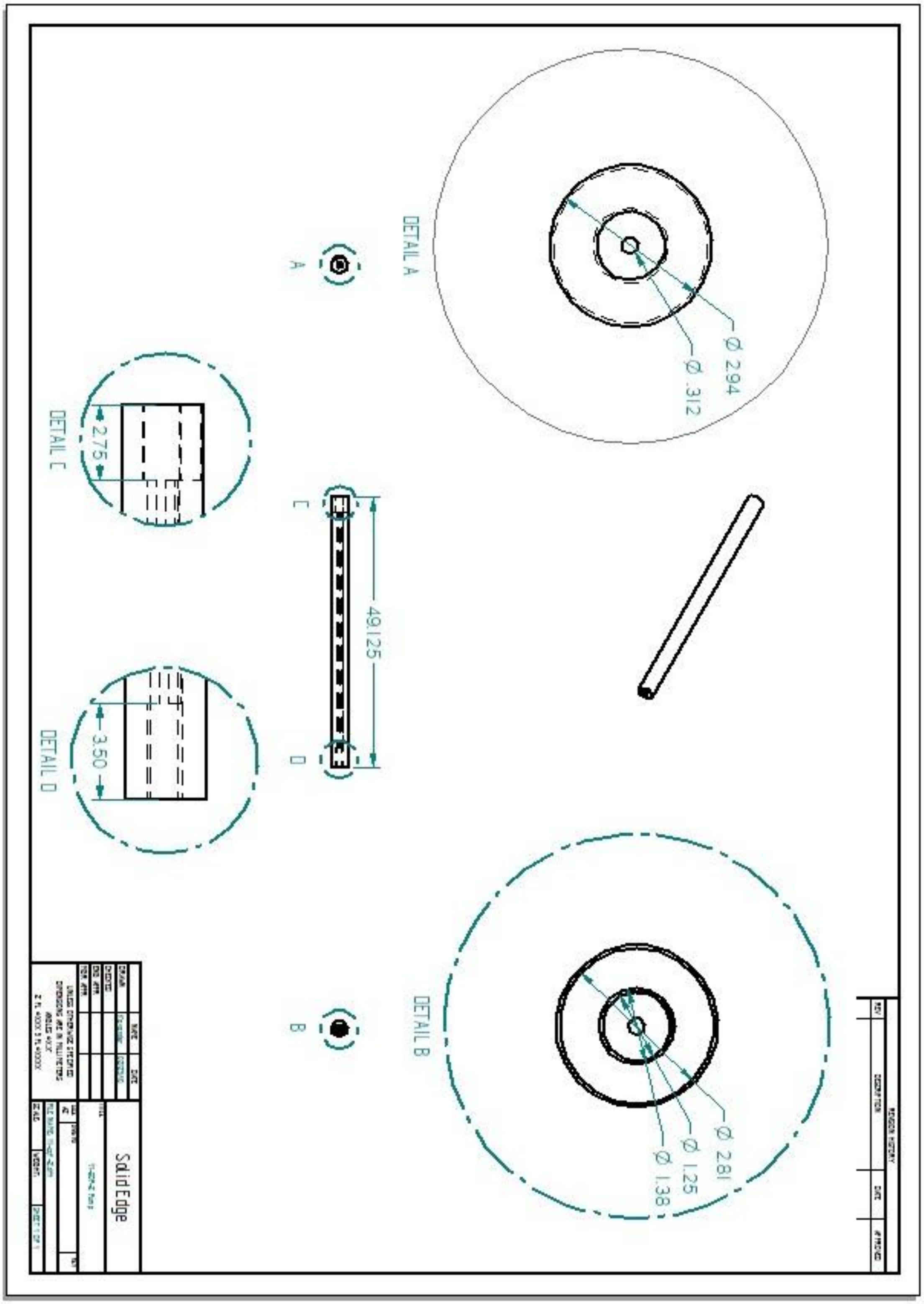

Figure B10: Grundfos 11-SQF-2 helical rotor pump

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3.0 Statics

Below the statics are presented for the pump mounting structure. All angle is made of 6061 Aluminum alloy with a tensile strength of 35,000 psi. This material was selected because it is light, inexpensive, and corrosion resistant. All calculations presented below show that the bolts and structure will withstand the maximum load of 44 lbs applied by the pumps. The maximum von Mises stress in the cross member which receives the greatest load was determined using Algor, a FEA modeling program, and calculated to be 1,710 psi near the inside of the mounting holes. The stress calculated is far below the yield stress of the material. The deflection of the center cross member, where the load is greatest, was also calculated using Algor, and found to be 9.64e-4 in, an acceptable deflection.

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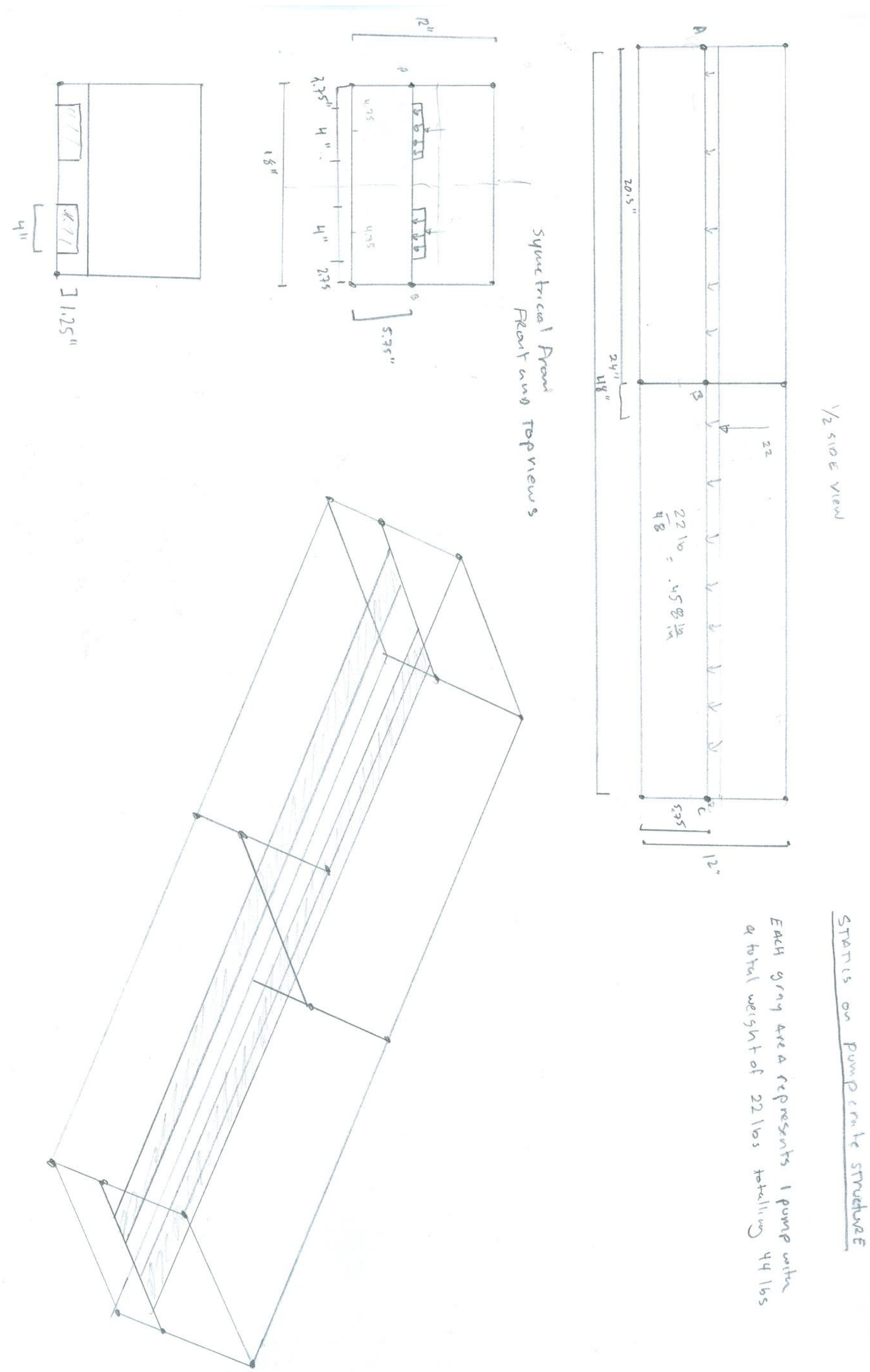

Figure B11: Statics of pump mounting structure

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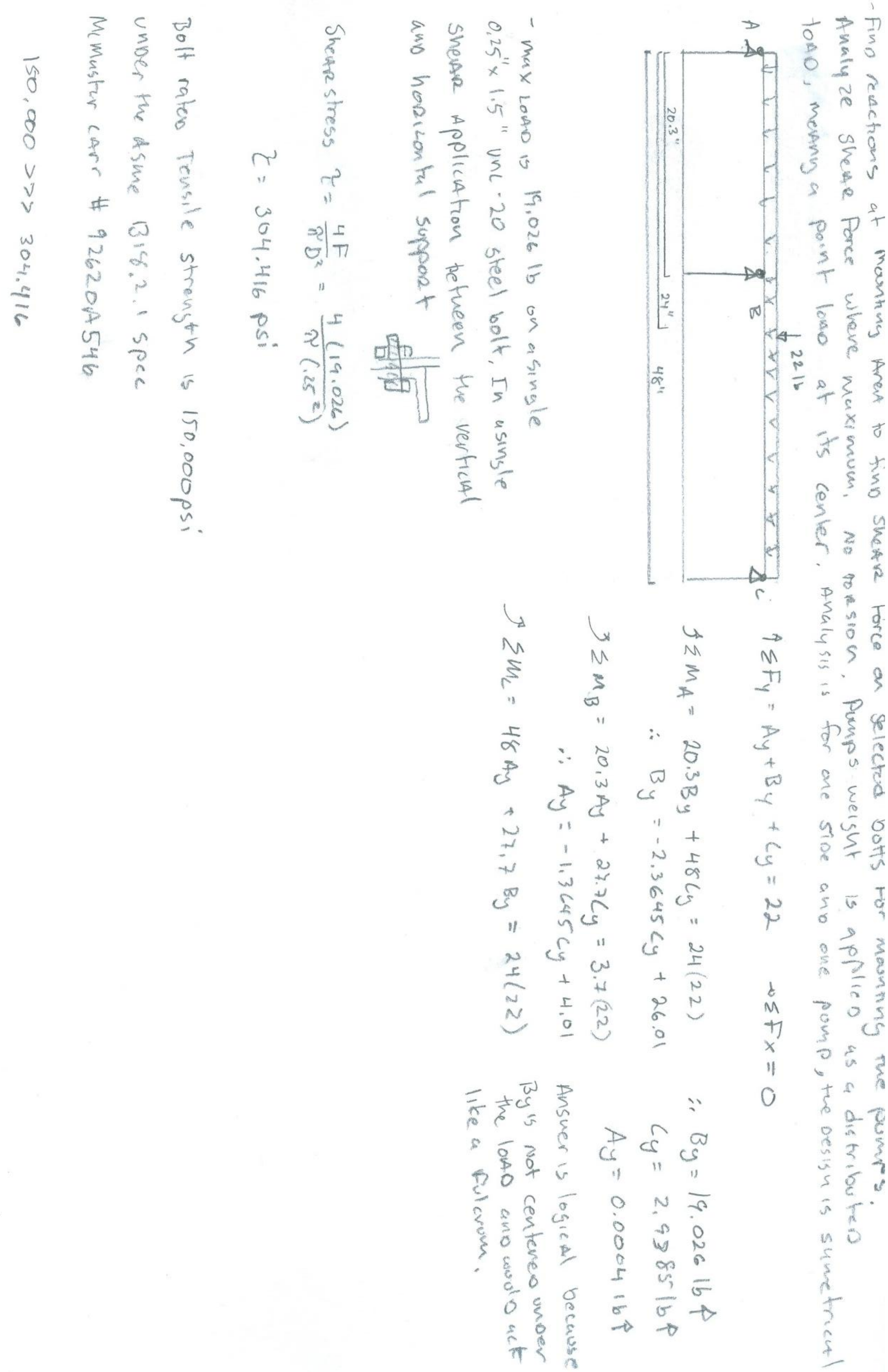

Figure B12: Statics continuation and bolt verification of pump mounting structure

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Document 525 - Pre-Implementation Report
EWB Ohio
Maase-Offinso, Ghana
Solar Water Pumping System

Appendix C

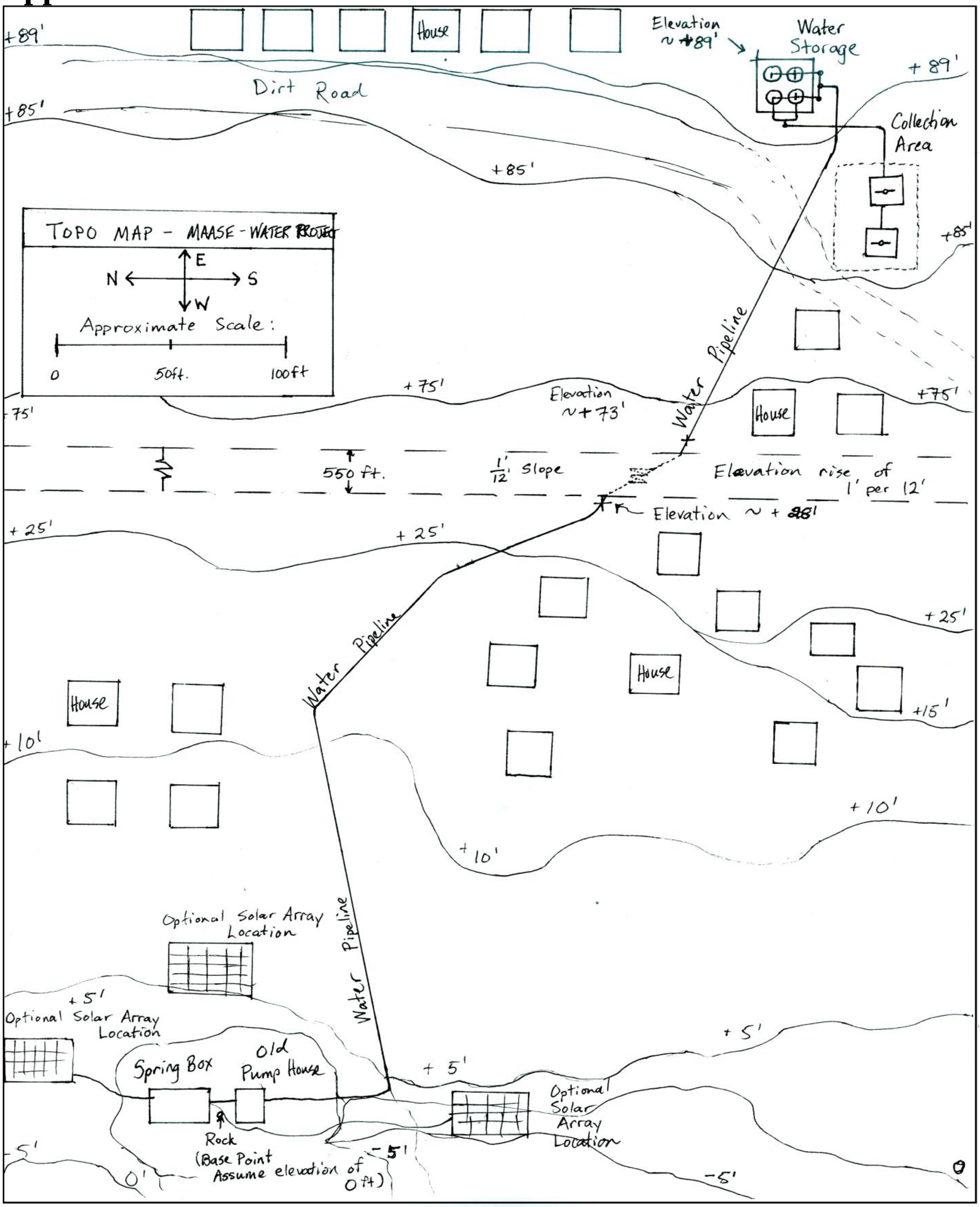

Figure C1: Topography map showing layout of the water pipeline and elevation of the land.

Appendix D

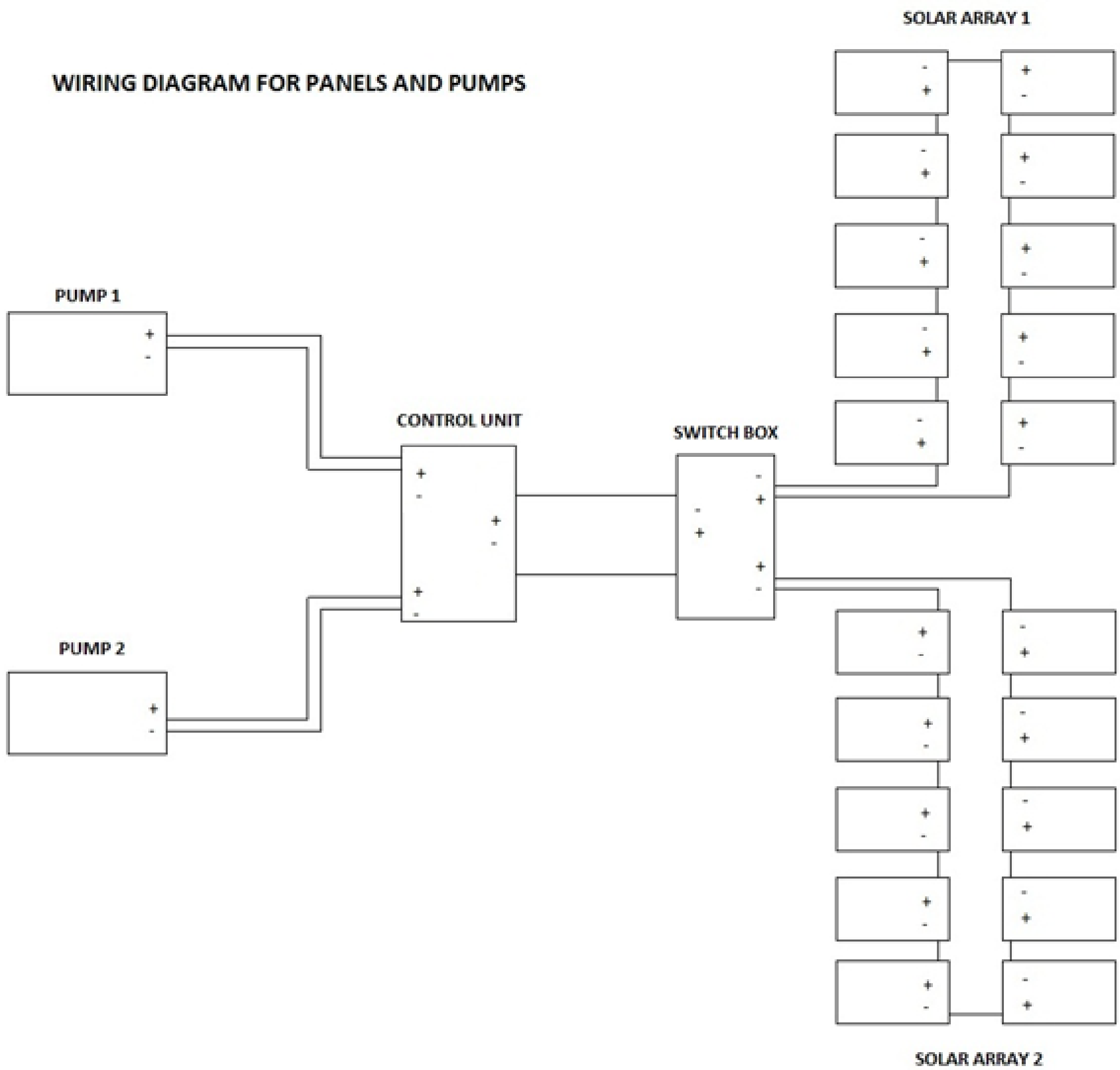

Figure D1: Wiring diagram for system

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Appendix E

Figure E1: Village children and Ohio EWB members in 2006.

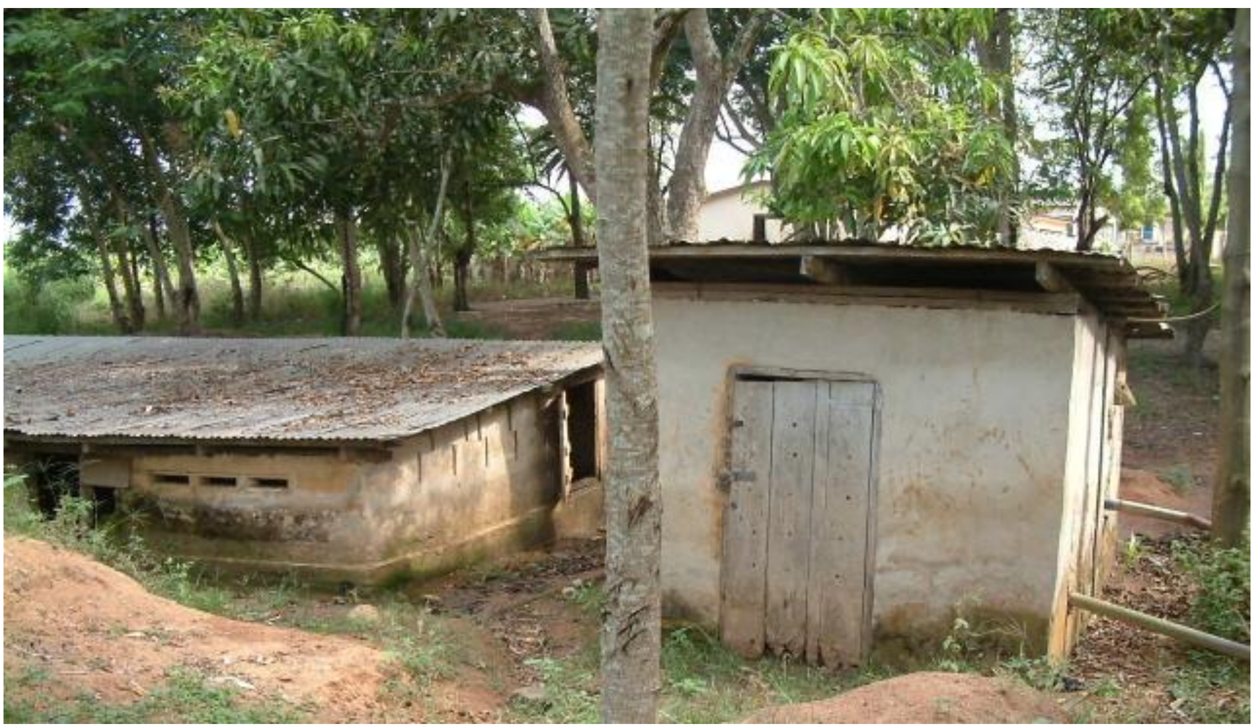

Figure E2: Existing spring box (left) and pump house (right). Notice the existing piping from the right side of the pump house.

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Figure E3: Current two 2,000 gal storage tanks in village, note the size of existing concrete support structure is made to support additional tanks.

Figure E4: Current water distribution site in village. Currently not in use because of nonexistent pump.

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Appendix F

Table F1: Bill of Materials for the project.

	BILL OF MATERIALS	
Assembly	Quantity	Description
PIPING		
	75	16 ft 2.5" HPVC 100PSI water pipe
	100	2.5" pipe connectors
	8	2.5" T Connectors
	15	2.5" Right angle connectors
	10	2.5" End Caps
	1Gal	PVC Glue
	5	Application Brushes
	.5 Gal	PVC Prep
	2	Gage Flow meters
PUMP		
	2	Grundfos 11sqf2 Pumps
	1	2.5"x20' Flex pipe 100 PSI
	1	1.25" connector
	4	0.25x1.5x1.5" 8' Angle Aluminum
	1	Controller
	1	Set connecting wires
	6	3" Corrosion Resistant and damping U-Bolt
	26	0.25" UNC 20 SS Hex Bolt
	26	0.25" UNC 20 Hex Nut
SOLAR		
	20	Sharp 175 W Mono Panels
	9	.25x3x3" x16' Steel C Chanel
	16	0.5x3" Steel Hex Bolt
	24	0.5x1.5" Steel Hex Bolt
	24	0.5" Steel Hex Nut
	2	0.25x3x3" x 16' Steel Angle
	1	Switch Box
	1	Wiring Harness

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	1	100'x8' Link Fencing
	8	2" x9' Pole cylinders
	24	0.5" UNC 13 Steel Hex Nut
	24	0.5"x 1.5" UNC 13 Steel Hex Bolt
	16	0.5"x3" UNC 13 Hex Bolt
Tools		
	2	Post hole digger
	Several	Cardboard forms
	1	Trowel
	2	Wheel Barrows
	8	Spade Shovels
	2	Picks or Mattock
	1	Drill
	1	Set metal bits
	1	set concrete bits
	2	set wrenches or ratchets
	1	Basic electric wiring kit
	1	digital multi meter
	1	Gallon oil based paint
	1	Paint brush

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Appendix G

Owner's Manual

Table of Contents

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Chapter 1 Introduction

Introduction-

Congratulations! You are the owner of a new 3 kW solar water-pumping system from Team Pump It Up. This system includes two Grundfos 11-SQF 2 helical rotor pumps and 20 Sharp NT-175 U1 solar panels. This guide will help you understand the important parts of this pumping system and how to maintain and care for them.

Parts List-

1. Pump
    - 1.1 2 Grundfos 11-SQF 2 helical rotor pumps
    - 1.2 Pump Mounting
2. Solar System
    - 2.1 20 Sharp NT-175 U1 solar panels
    - 2.2 CU 200 SQFlex control unit
    - 2.3 Mounting System
    - 2.4 Connectors
3. Piping
    - 3.1 1100 feet of pipe
    - 3.2 1 Y pipe connector
    - 3.3 448 pipe connectors

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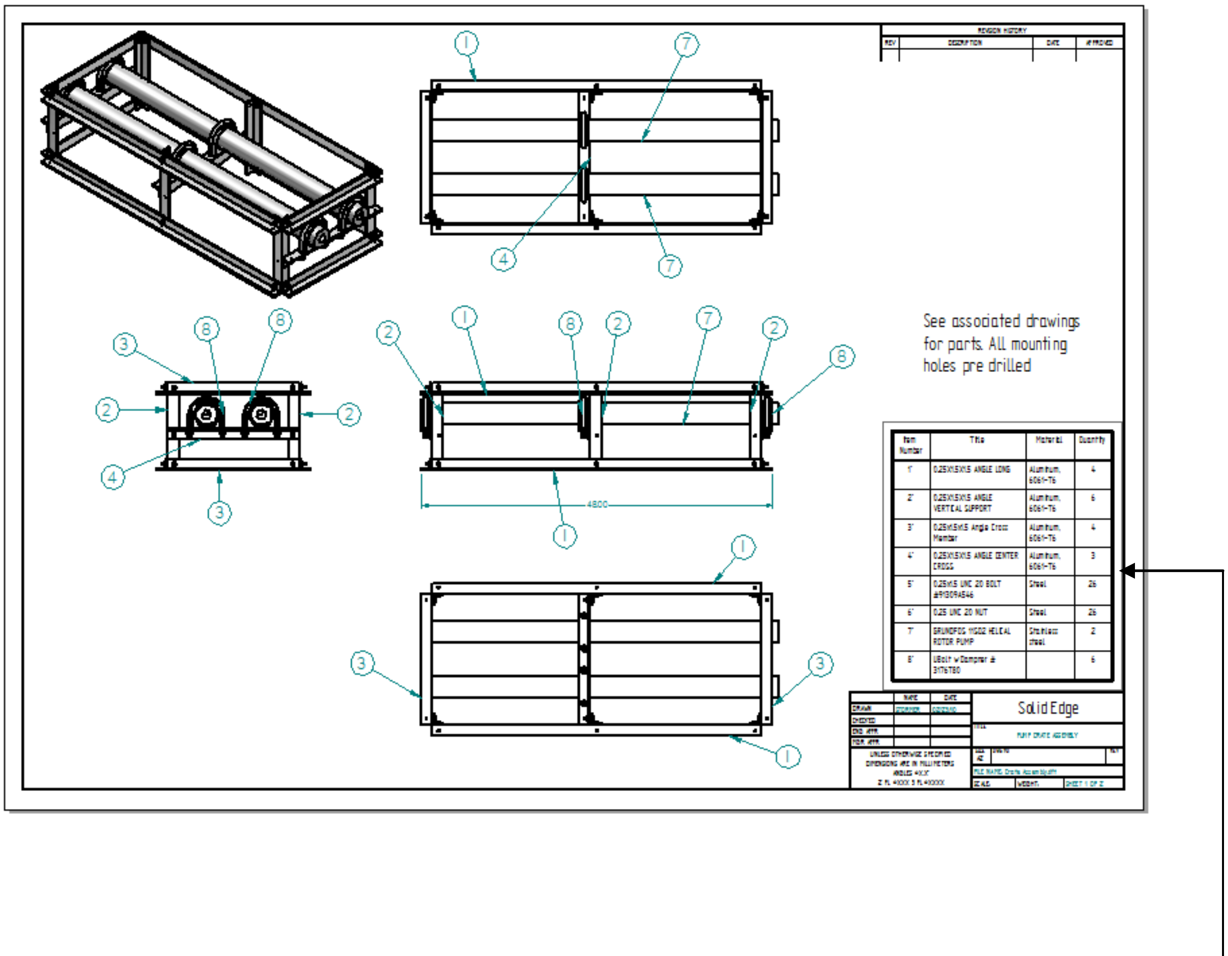
3.4 2 angle pipe connectors

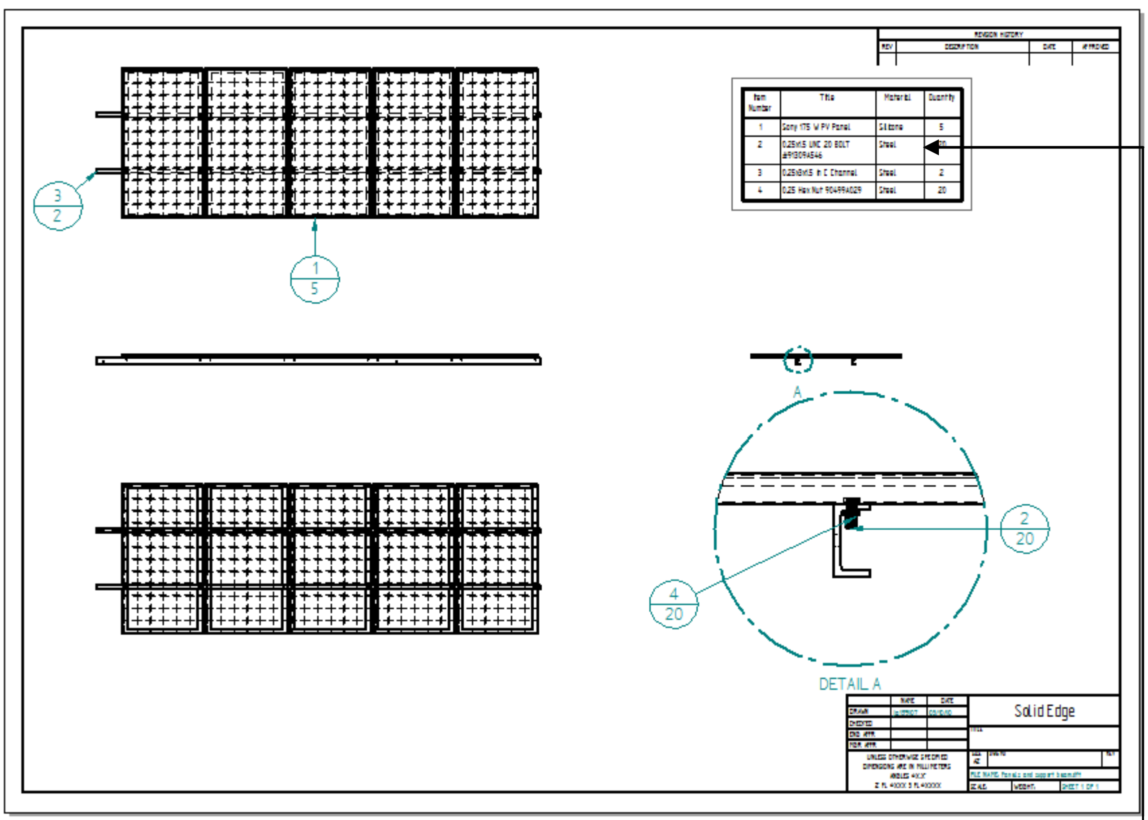
4 Storage Tanks

Part Diagrams



Item Number	Title	Material	Quantity
1*	0.25X1.5X1.5 ANGLE LONG	Aluminum, 6061-T6	4
2*	0.25X1.5X1.5 ANGLE VERTICAL SUPPORT	Aluminum, 6061-T6	6
3*	0.25x1.5x1.5 Angle Cross Member	Aluminum, 6061-T6	4
4*	0.25X1.5X1.5 ANGLE CENTER CROSS	Aluminum, 6061-T6	3
5*	0.25x1.5 UNC 20 BOLT #91309A546	Steel	26
6*	0.25 UNC 20 NUT	Steel	26
7*	GRUNDFOS 11SQ2 HELICAL ROTOR PUMP	Stainless steel	2
8*	UBolt w Dampner # 3176T80		6

Pumps and Crate Diagram and Bill of Materials



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Item Number	Title	Material	Quantity
1	Sony 175 W PV Panel	Silicone	5
2	0.25x1.5 UNC 20 BOLT #91309A546	Steel	20
3	0.25x3x1.5 in C Channel	Steel	2
4	0.25 Hex Nut 90499A029	Steel	20

Solar System Subassembly Diagram and Bill of Materials

Warranties-

Sharp NT-175 U1 Solar Panels: Power output warranty for 20 years, until 2030, contact African Energy if a panel fails to output power.

Grundfos 11-SQF 2: There is a 5-year limited warranty on the helical water pump. Contact Kwabena Osei for replacement.

Contact List-

Patrick Newman (African Energy)- Phone: (520) 720-9475

Andrew Etwire (Supplier)- email: andrewetwire@yahoo.com

Kwabena Osei (Grundfos)- Phone: 233 243 462254

Team Pump It Up- email: oupumpteam@gmail.com

Chapter 2 Solar Panels

Maintenance Schedule-

- Weekly

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  - Use multimeter to check voltage and current of each solar panel (see figure 2.1 for clarification). Record each of these values and compare results to other weeks, if one panel is on a peculiar downward trend contact Andrew Etwire.
- Monthly
  - On the first day of every month use a damp rag to clean the surfaces off each panel; this will increase the overall efficiency of the system.

Warnings-

- **Do not allow connections to rust. If you notice rust on any of the connections between the solar panels immediately replace them.**
- **Beware of flooding. If there is going to be standing water that approaches the solar panels detach them from the mounting and move them to a safer location.**

ELECTRICAL SHOCK WARNING!

Each system of ten panels can produce 1500 Watts of power with 240 Volts and 6.25 amps of current possible. THIS CAN KILL YOU! If exposed wire is discovered DO NOT ATTEMPT TO REPAIR IN DAYLIGHT. Wait until the pump stops then it is safe to remove the panel with the exposed wire and repair it.

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Chapter 3 Piping

Maintenance Schedule-

- Monthly

There are several flow meters along the pipe line check each of these on the tenth day of every month and record the flow rates (explanation in the next section). If a large drop in flow rate is noticed between two flow meters then there may be a crack in the pipeline in that area. If it becomes a continual problem it may be necessary to dig up the pipe and inspect it.

Flow Meter-

Figure 3.1 Flow meter

These flow meters are analog devices that will tell you what the flow rate is in gallons per minute. This will allow you to check if there is a downward trend in water flow rate.

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Table 3.1 gives an example of an expected flow for several months; table 3.2 gives an example if there were something wrong.

Month	Flow Rate (gal/min)
January	11
February	10.8
March	10.5
April	10.7
May	10.8
June	11

Table 3.1 Optimal

Month	Flow Rate (gal/min)
January	10
February	9.5
March	8.5
April	8
May	7.1
June	5.7

Table 3.2 Flow Problem shown by consistant downward trend

It may also be beneficial to compare similar months in different years.

(see tables 3.3 and 3.4 below)

Month/Year	Flow Rate (gal/min)
January 2015	11
January 2016	10.8
January 2017	10.5
January 2018	10.7
January 2019	10.8
January 2020	11

Table 3.3 Optimal

Month/Year	Flow Rate (gal/min)
January 2015	10
January 2016	9.5
January 2017	8.5
January 2018	8
January 2019	7.1
January 2020	5.7

Table 3.2 Flow Problem shown by consistant decrease in flow

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Chapter 4 Pump

Maintenance Schedule-

- Daily
    - Check for debris in the springbox and clear out the pumping area
    - Make sure the pump is angled downward with the water inlet below the water detector, see figure 4.1. (This will prevent the pump from dry running increasing the life of the pump).
    - Check all connections to the controller, make sure that none have corroded

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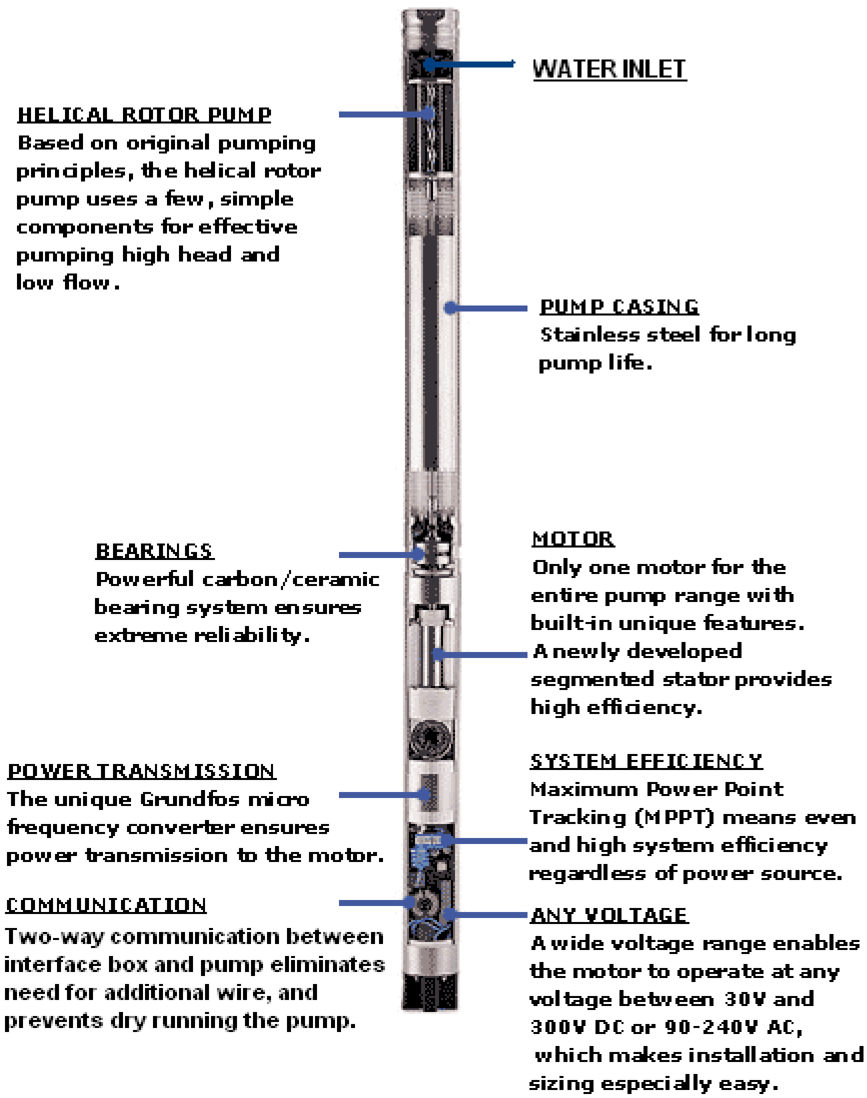

Figure 4.1 11 SQF-2 Helical Rotor Pump

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Chapter 5 Grundfos Recommended Maintenance and Repair

Important *Read Before You Continue*-

Nearly all of the text of this section comes from the Grundfos Service Literature. A few pages are also directly copied from the Service Literature as well. When these pages are referenced they will be given 2 page numbers, the first will be the page within this booklet. The second set of numbers in the parenthesis are the pages from Grundfos Service Literature, and they will be the actual page numbers at the bottom of the page.

5.1.1 Before dismantling

• Disconnect the electricity supply to the motor.

5.1.2 Before assembly

• Clean all parts and check them for fractures and wear.

• Order the necessary service kits and/or parts.

• Replace defective parts by new parts.

• Moisten rubber parts with soapy water before fitting them.

5.1.3 During assembly

• Lubricate and/or tighten screws and rubber parts according to section 5.3 Torques and lubricants on

page 13 (46/60).

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• Before connecting the pump to the motor, fill the motor with GRUNDFOS motor liquid SML

2.

Filling of motor liquid

5.1.4 After assembly

• Test the head and flow according to the test specifications, see section 5.9 Testing the pump by means of CU 200 SQFlex control unit on page 18 (52/60).

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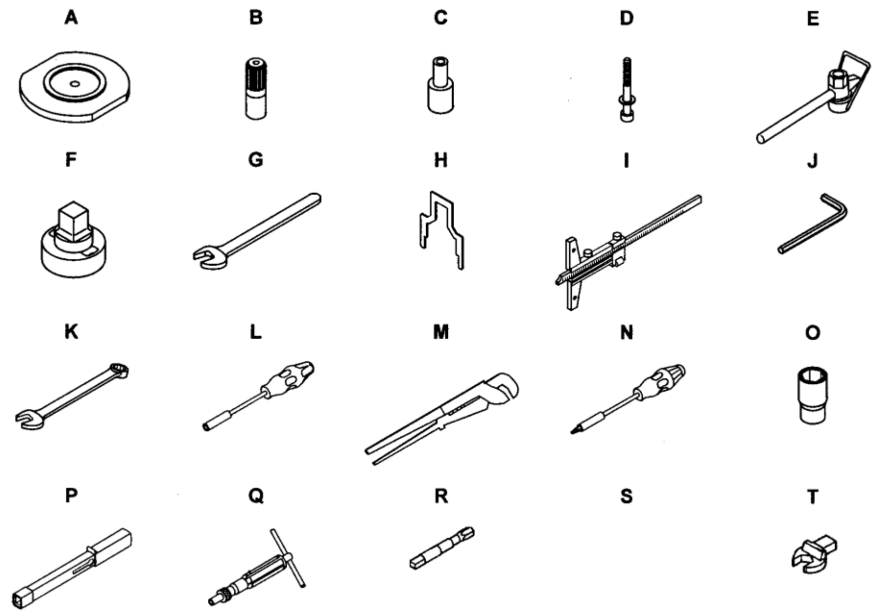
5.2 Service tools



Special tools

	Designation	To be used for	Supplementary information	Helical pump	25 SQF	40 SQF	75 SQF
A	Mounting plate				SV0049		
B	Spline pin with screw				SV0226		
C	Spacing pipe		∅ 13 / ∅ 8.5 x 39.5		SV0006[a]		
			∅ 13 / ∅ 8.5 x 39.0			SV0008	SV0008
D	Hexagon socket head screw with washer	J	M8 x 65		SV0074		
E	Key for split cone nut	11-12	22 mm		SV0182	SV0187	
			27 mm				SV0217
F	Key for discharge chamber	1a		SV0064			
G	Open-end spanner	1a	62 mm	SV2080			
H	Measuring template	24			96079961		
I	Depth gauge	14-16			Standard		

a. Only for 25 SQF N

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Standard tools

Pos.	Designation	To be used for	Supplementary information	Helical pump	25 SQF	40 SQF	75 SQF
J	Hexagon key	D	6 mm		SV1204		
K	Ring/open-end spanner	16-24	10 mm (two pcs. needed for pos.16)	SV0083			
		19-19a	13 mm		SV0055		
L	Nut driver with socket	250	7 mm	SV0065			
M	Pipe wrench	13	1"	standard			
		14a	4"		standard		
N	Screwdriver (torx)	18a	T10	SV0066			
O	Socket for hexagon head screws	250-R	7 mm 1/4"	SV0457			

Torque tools

Pos.	Designation	To be used for	Supplementary information	Helical pump	25 SQF	40 SQF	75 SQF
P	Torque wrench	R-T	4-20 Nm 9x12		SV0292		
		F	40-200 Nm14x18	SV0400			
Q	Torque screwdriver	R	1-6 Nm 1/4"	SV0438			
R	Adapter for torque screwdriver	N-O	1/4"	SV0437			
S	Ring insert tool	P-19-19a	13 mm 9x12		SV0294		
T	Open-end spanner	E-P-11-12	22 mm 9x12			SV0622	
		P-16	10 mm 9x12	SV0610			

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5.3 Torques and lubricants

This section shows the screws and nuts that must be tightened to a certain torque and the lubricants to be used.

Pos.	Description	Pump type	Torque [Nm]	Lubricant
	Pump / motor	Helical	55	
1a	Discharge chamber*	Helical	100	Rocol
13/16	Pump rotor / torsion shaft	Helical	18	
14a	Connecting piece	Centrifugal		
16	Torsion shaft / motor shaft	Helical	18	
19	Screw	Centrifugal, splined shaft	18	Gardolube
	Nut	Centrifugal, cylindrical shaft		
19a	Nut	Centrifugal	18	Gardolube
19b	Nut	Centrifugal, splined shaft	11	Gardolube
24	Shaft end (nut)	Centrifugal	18	
	End cover with cable	All		Rocol
	Nut	All	1,5	

Rocol Sapphire Aqua-Sil, part no. RM2924 (0.5 l).

Gardolube L 6034, part no. SV9995 (1 l).

It is not necessary to lubricate screws and nuts treated with "Delta Seal", as this coat is anti-corrosive and lubricating.

* The thread of the discharge chamber **must** be lubricated.

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5.4 Helical pump type

Helical pumps cannot be separated from the motor as a unit. If the motor or the pump must be replaced, the pump must be dismantled.

5.4.1 Dismantling

1. Fix the motor in a vice.

2. Refer to section 5.9.1 Drawings on page 20 (57/60). Unscrew the screws pos. 18a and 18b and remove them together with the cable guard pos. 18.

3. If the motor is intact, the cable need not to be removed. If the motor is defective, remove the nuts for end cover with socket at the bottom of the motor and pull the end cover with cable and socket out of the motor.

4. Remove the discharge chamber pos. 1a with valve casing complete using the key for discharge chamber

F. Hold the pump by means of the pipe wrench M on the weld just above the upper strainer.

5. Loosen the outer sleeve pos. 55 with pump stator pos. 9 from the motor using the pipe wrench M on the weld just above the upper strainer. Hold the motor with the open-end spanner G.

6. Pull the outer sleeve pos. 55 with pump stator pos. 9 free of the pump rotor pos. 13 and torsion shaft pos. 16 with a bump.

7. Remove the pump stator pos. 9 and flange pos. 6 by knocking the discharge end of the outer sleeve hard against a solid wooden surface such as a workbench or table.

8. Remove the torsion shaft pos. 16 from the motor shaft using two ring/open-end spanners K.

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9. Remove the pump rotor pos. 13 from the torsion shaft pos. 16 using the pipe wrench M. Hold the torsion shaft with the ring/open-end spanner K.

10. If the parts of the valve casing complete are defective, replace these parts. Prise the retaining ring pos.

7a out of the recess of the discharge chamber pos. 1a and press the parts down and out of the discharge chamber.

5.4.2 Assembly

1. Fill the motor with liquid

2. Fit the pump rotor pos. 13 to the torsion shaft pos. 16 and tighten to correct torque, see 5.3. Hold the pump rotor using the pipe wrench M on the cylindrical part below the pump rotor.

3. Fit the torsion shaft to the motor shaft and tighten to the correct torque, see 5.3.

4. Fit the pump stator pos. 9 with the conical stator inlet against the strainer into the outer sleeve pos. 55.

5. Fit the flange pos. 6 into the outer sleeve and press it on the upper part of the stator, fixing the stator in the centre of the outer sleeve.

11SQF-2: Turn the flange pos. 6 with the even surface against the stator pos. 9.

6. Assemble the valve and discharge chamber if it has been dismantled.

• Place the valve casing complete on a plane surface with the bearing pos. 6 downwards.

• Lubricate the O-ring pos. 1d with grease and fit it in the outside recess of the valve casing.

• Press the discharge chamber pos. 1a over the valve casing. Turn the discharge chamber and fit the retaining ring pos. 7a in the recess of the discharge chamber.

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• Grease the thread of the discharge chamber with valve casing complete and screw it into the top of the sleeve.

7. Fit the discharge chamber pos. 1a with valve casing complete and tighten to the correct torque by means of the key for discharge chamber F. Hold the pump using the pipe wrench M or fix it in a vice. The jaws must be placed on the weld just above the upper strainer.

8. Moisten the pump rotor pos. 13 with clean water and fit the pump on the motor. Tighten to the correct torque; see 5.3 by means of the key for discharge chamber F.

9. Push the end cover with socket and cable into the motor if it has been removed. Fit and tighten the nuts using the socket for hexagon head screws O, the adapter for torque screwdriver R and the torque screwdriver Q.

10. Fit the cable guard pos. 18. Press the two upper flaps under the outer sleeve and fit the screws pos. 18a and 18b. If the accessible holes in the outer sleeve at the lower strainer are not threaded, they must be tapped using the tapping screw included in the cable guard service kit and the assembly kit or by means of an M3 set screw.

11. Test the pump performance using a CU 200 control unit, if available. See section 5.9 Testing the pump by means of CU 200 SQFlex control unit on page 18 (52/60)

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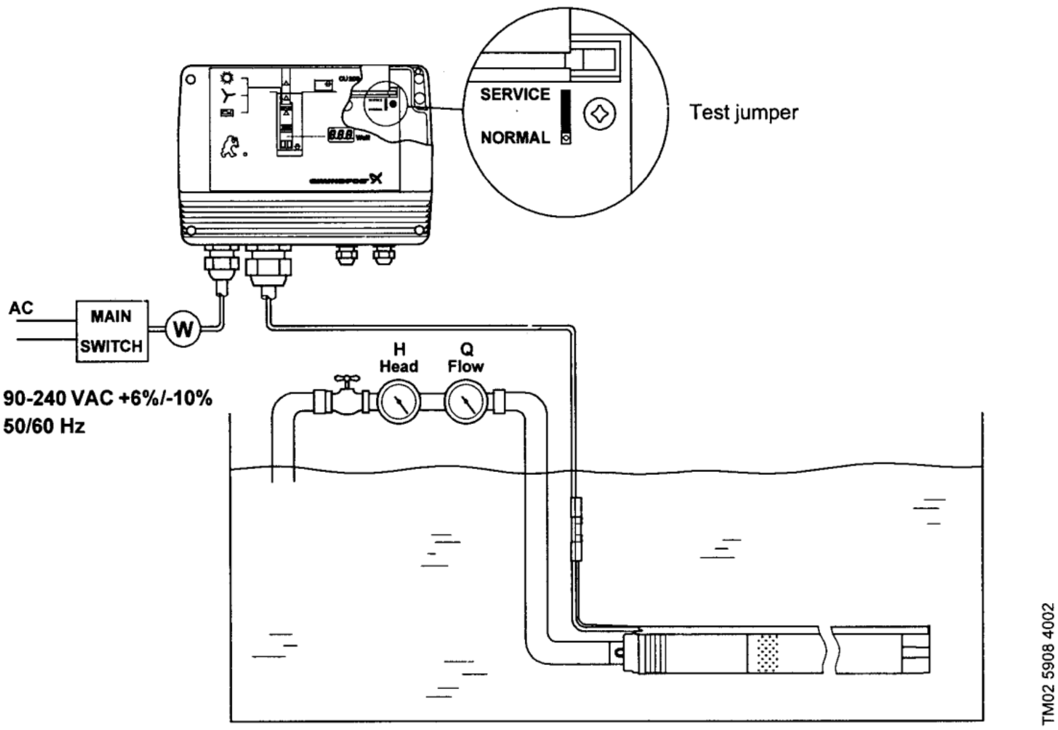
5.5 Testing the pump by means of CU 200 SQFlex control unit

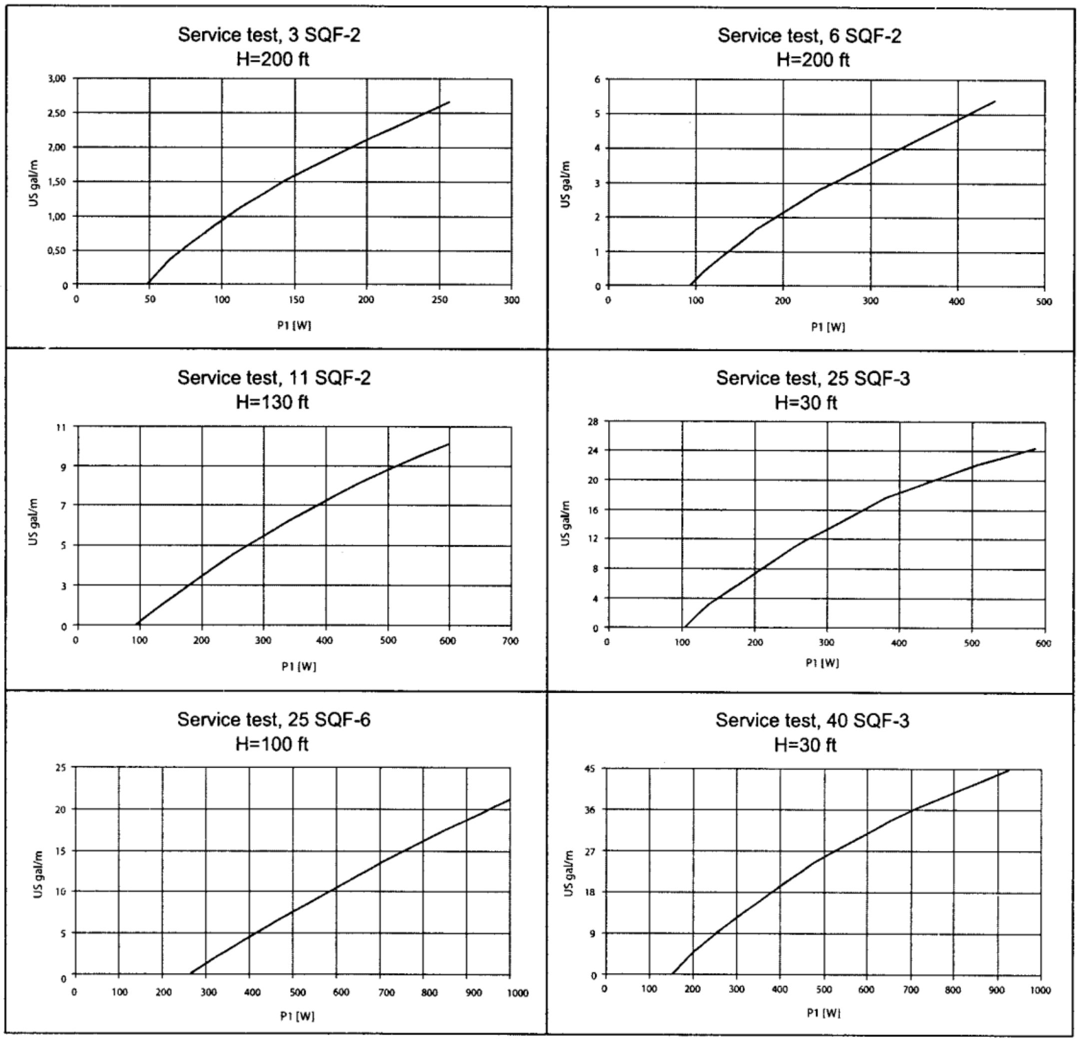
The pump must deliver a flow rate (m³/h) at a given power consumption and head. The "Test value curves ' on page 61 apply to the head stated for each pump. The curve values are minimum values.



1. Open the discharge valve completely to reduce the counter-pressure to a minimum.
2. Disconnect the power supply to the pump.
3. Remove the front cover of the CU 200, and set the test jumper to service position, see illustration. Refit the front cover.
4. Connect the power supply.
5. Make sure that the system is off. The red indicator light of the ON/OFF button must be on. If the system is not off, press the ON/OFF button once.
6. Press the ON/OFF button for at least four seconds. Release the button. The CU 200 is now in test mode. (The bottom flow indicator is permanently on, and the pump is running slowly.)
7. Press the ON/OFF button twice (the upper flow indicator is permanently on). The pump now adjusts its speed.
8. Adjust the counter-pressure to the value stated for each pump in the curves in section 5.9.1 Test value curves on page 61.
9. Read the flow rate Q [m³/h] using a flowmeter or a similar device and the power consumption P1 [W] using a wattmeter.
10. In the relevant curve chart, find the intersection point of the values read for flow (Q) and power consumption P1 [W].
    - If the intersection is above the minimum curve, the flow rate is sufficient.
    - If the intersection is below the minimum curve, the flow rate is insufficient, and the pump should be checked and defective parts replaced.
11. Press the ON/OFF button once. The CU 200 is no longer in test mode.
12. Disconnect the power supply, and disconnect the pump and the CU 200.
13. Move the test jumper from service to normal position.

5.5.1 Test value curves

The curve shown in the curve charts below is the minimum performance curve for the pump.



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Helical 3 SQF-2, 6 SQF-2, 11 SQF-2