Spring 4-25-2021

ENERCON Station Vacuum Pump Replacement

Clint Hembree
Kennesaw State University

Jared D'Amico
Kennesaw State University

Connor Moore
Kennesaw State University

Paul Jeffrey Fontenot
Kennesaw State University

Sydnee Castello
Kennesaw State University

See next page for additional authors

Recommended Citation

Hembree, Clint; D'Amico, Jared; Moore, Connor; Fontenot, Paul Jeffrey; Castello, Sydnee; and Clements, J.J., "ENERCON Station Vacuum Pump Replacement" (2021). *Senior Design Project For Engineers*. 58.
https://digitalcommons.kennesaw.edu/egr_srdsn/58

Author

Clint Hembree, Jared D'Amico, Connor Moore, Paul Jeffrey Fontenot, Sydnee Castello, and J.J. Clements

ENERCON Station Vacuum Pump Replacement

Final Design Review

Kennesaw State University Senior Design Group

Connor Moore, *Electrical*

Jeffrey Fontenot, *Electrical*

Sydnee Castello, *Civil*

JJ Clements, *Civil*

Jared D'Amico, *Mechanical*

Clint Hembree, *Mechanical*

Dr. Renee Butler, *Advisor*

Presented to Dr. Khalid, Instructor

ENGR 4490-02

April 26, 2021

Executive Summary:

This document details the progress of the ENERCON pump replacement project as completed by the Kennesaw State University interdisciplinary senior design group. This project is a two-semester capstone effort for the engineering program at Southern Polytechnic School of Engineering, overseen by Dr. McFall during Fall 2020 and Dr. Khalid during Spring 2021 semesters. The 2020-2021 KSU Interdisciplinary Senior Design team was tasked with completing an Engineering Change Package (ECP) for existing vacuum pumps at ENERCON Station. The mechanical, electrical, and civil students worked together, performing evaluations on existing plant systems to ensure the plant could support the new vacuum pumps. By tying into the plants existing Plant Service Water (PSW) System and electrical grid, and by reusing existing pipe supports as well as designing new ones, it has been determined that the existing ENERCON Station Systems will support the new Nash Liquid Ring Vacuum Seal Pumps and their supporting equipment. All evaluations have been submitted to ENERCON along with all necessary plant documents that have been revised to show the new equipment.

Table of Contents

List of Figures

List of Tables

Team Name

Kennesaw State University Senior Design Group 2020-2021

Project Title

ENERCON Station Vacuum Pump Replacement

Project Manager

Jared D’Amico

Kennesaw Faculty Advisor

Dr. Renee Butler

Table 1: Team Members and Roles

Team Member	Title
Connor Moore	Electrical Design & Drawing Editor
Jeffrey Fontenot	Electrical Ninja & Swiss Army Knife
JJ Clements	Civil Design & Structural Engineer
Sydnee Castello	Civil Design & Structural Engineer
Jared D’Amico	Mechanical Design & Project Manager
Clint Hembree	Mechanical Design & Report Editor

Table 2: Acronyms and Symbols used in Reports

Acronyms and Symbols	Description
SDG	Senior Design Group
PSW	Plant Service Water
TB	Turbine Building
EC	Engineering Change
HX	Heat Exchanger

Chapter 1: Project Overview

The Kennesaw State University (KSU) Senior Design Group (SDG) has received a Proposal Acceptance Letter (PAL) in response to proposal of work for replacing ENERCON Nuclear Generation Station (ENERCON Station) existing vacuum pumps. The vacuum pumps currently installed in the Turbine Building (TB) are original units and are designed to supply initial condenser vacuum during plant start-up and support condenser vacuum during shutdown. The vacuum pumps have been difficult to maintain and are delaying plant start-up activities.

To complete the work, the KSU SDG is designing an Engineering Change (EC) Package that will replace the three 33% capacity pumps with two 100% capacity NASH Liquid Ring Vacuum Pumps. The pumps and necessary supporting equipment (skids) have already been sized and selected by ENERCON and NASH. The electrical, civil, and mechanical disciplines each have deliverables including markups and evaluations to perform to determine whether the existing power supply, plant structure, and Plant Service Water system (PSW) will support the new pumps and skids.

Phase 1 was completed Fall Semester 2020 and consisted of taking the design to 30% completion. The SDG presented our 30% (Conceptual) Design in a Design Review Meeting (DRM) with ENERCON where we also submitted our 30% EC Package. The 30% EC package consisted of combing through 128 plant documents provided by ENERCON. The documents consist of plant arrangement drawings, P & I Diagrams, architectural and structural drawings, electrical schematics, along with others which the KSU SDG used to obtain information for design inputs. ENERCON accepted and reviewed the 30% EC Package and made comments that the SDG then incorporated into the EC Package and resubmitted to ENERCON.

Phase 2 is intended to be completed this semester and will take the project to 100% completion with a 60% (Detailed) DRM, 90% (Final) DRM and submission of the 100% EC Package. The 60% EC Package includes all completed evaluations and markups. ENERCON has reviewed and made comments on the 60% EC package. They have sent the SDG their comments which will then be incorporated and resubmitted as a 90% EC package. The 90% package will be reviewed one more time to ensure all comments were incorporated and any challenged comments are resolved. The KSU SDG will then submit the 100% EC Package.

Pump locations as shown in figures 1 and 2 were recommended by ENERCON. Due to the size and weight of the pumps, location options were limited. ENERCON suggested Mechanical Vacuum Pump Skid A to be placed in the Turbine Building at elevation 133’ at coordinate (G6) next to the cable area. The location Mechanical Vacuum Pump Skid B was suggested to be in the Turbine Building at elevation 113’ plant coordinates (F4). The KSU SDG accepted ENERCONS recommendations. Completing the markups and evaluations for the 60% detailed submittal will require using plant documents that coincide with these locations to determine whether the existing plant systems will support the new pumps skids. The 100% submittal will take in all ENERCON feedback for the submission of a final Engineering Change Package.

1.1 Pump Locations

Figure 1 shows the location of vacuum pump A in the Turbine Building at elevation 133'.

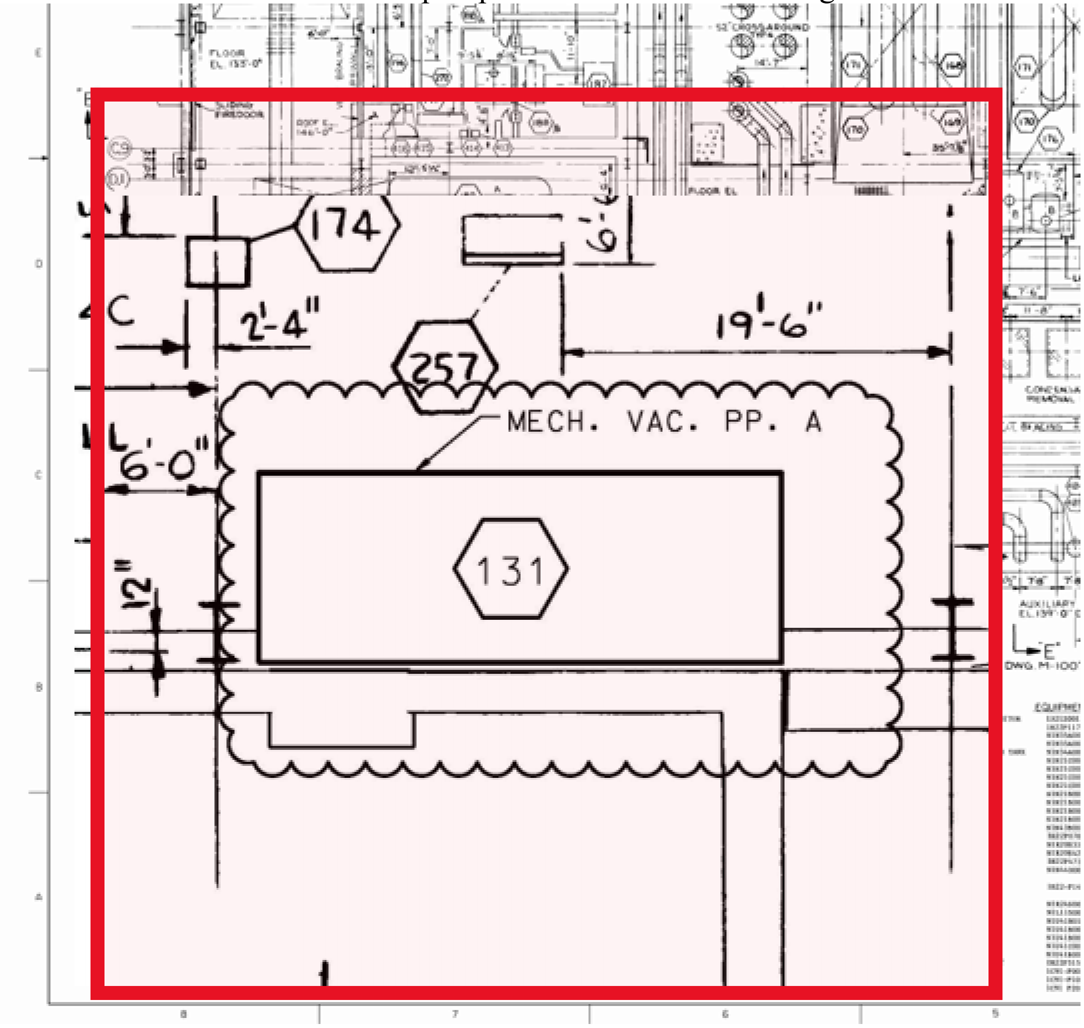


Figure 1: Document M-1003: Location of Pump A.

Figure 2 shows the location of vacuum pump B in the turbine building at elevation 113’.

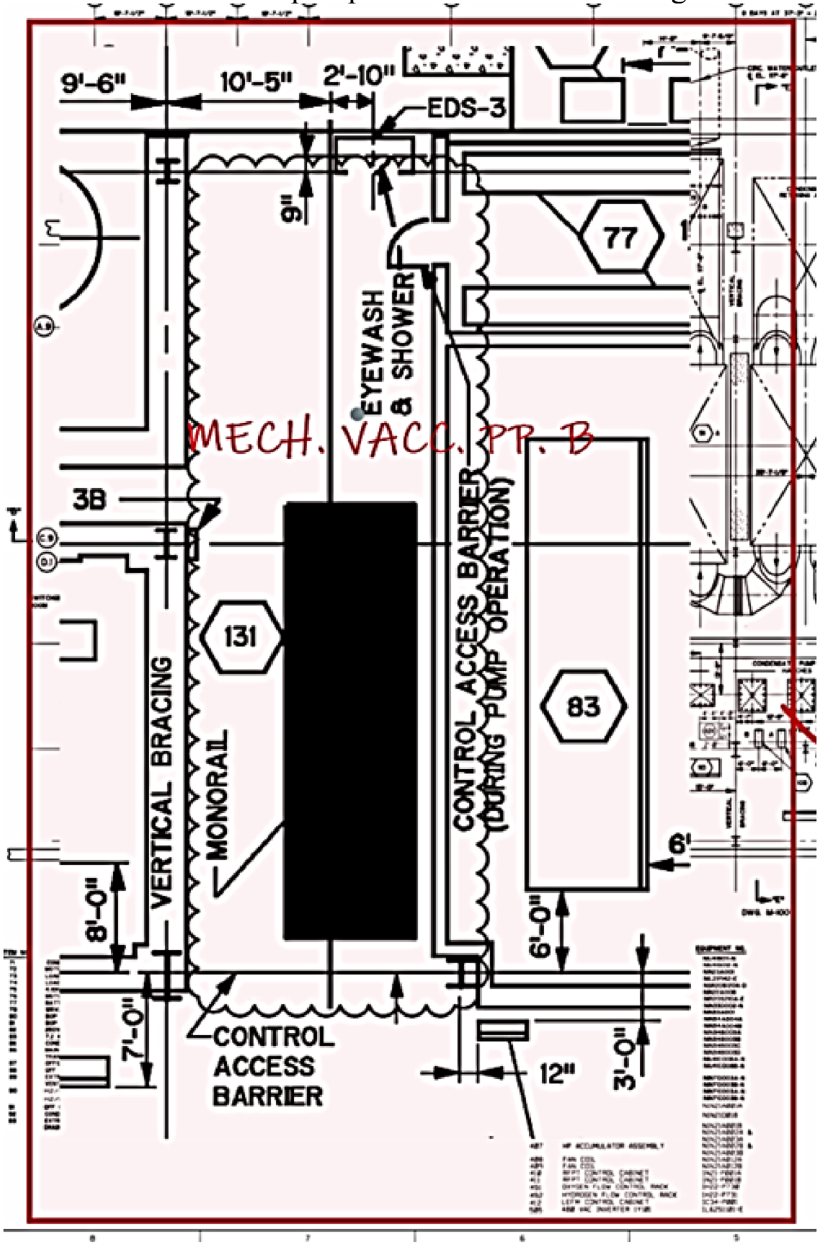


Figure 2: Document M-1002: Location of Pump B.

1.2 Component Decomposition Diagram

The diagram in figure 3 shows how the engineering disciplines components of the project rely on each other. The mechanical portion consists of water and air as working fluids for the system. The electrical breakers and motors supply the pumps with electricity and the civil portion includes a heavy haul path and pipe supports that are essential to supporting the equipment structurally.

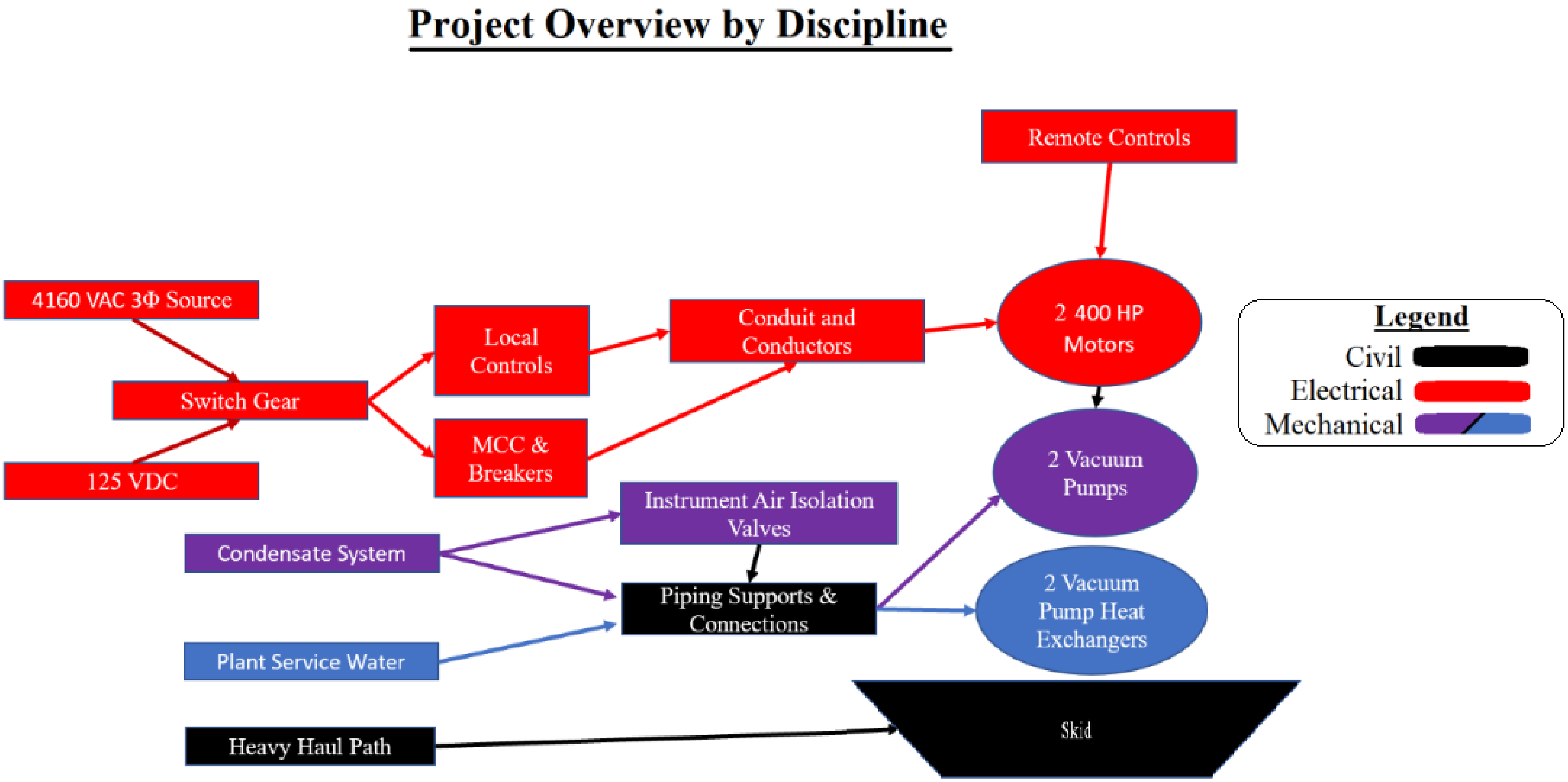


Figure 3: Component Decomposition Diagram.

Chapter 2: Literature Review

Chapter 2 is the Literature Review section of this report. The Student Design Group (SDG) was assigned to supply 15 literature references for this project. While there are many nuclear related research papers available, very few focus on the specifics of upgrading a pump system from vintage equipment to modern machinery. With that struggle in mind, the SDG presents a good-faith attempt at rounding up the most relevant research papers to this project.

This review starts with high level concepts as background for this project, then each review gets more and more technical to the specifics of this design project. American dominance in nuclear power has helped us set norms for nuclear use in less stable countries, as well as control nuclear weapon proliferation. America invented this technology and remains the biggest nuclear power generator. [Ellis] Supplying one-fifth of power used in a pollution-free and carbon-dioxide-free way. But on our current energy policies, nuclear plants are being retired faster than new ones are being built. [Ellis] There's no clear governmental licensing structure for new plant design, either that are safer and more efficient than this generation of plants. Why should we keep nuclear generation and expand it into our future? There is a long list of reasons: no pollution, lower radioactive emissions than coal (with $30+ billion already paid for disposal costs), safest method of power generation (including renewables), jobs for engineers and technicians, security of energy generations (i.e., low price volatility and long-term fuel supplies stored on-site), and advancement of the nuclear ecosystem that includes nuclear generation for defense purposes (ships and submarines). [Ellis] Nuclear power generation has unfortunately become politicized, with tribal attacks on what should be a welcome technology for all. The U.S. government needs to encourage this enterprise, private companies must continue develop safer and better plants and processes, and the public should support this endeavor and reap the benefits of clean, dependable energy access. [Ellis] With this in mind, nuclear energy faces the "Four Horsemen of the Energy Apocalypse." [Carl] The factors pushing nuclear energy into possible extinction are lower electricity prices by cheap natural gas and excessive subsidies to other energy technologies, primarily renewables. Second and related, nuclear faces loss of market in states with high renewables mandates and/or low demand growth. Third, regulatory costs are increasing and creating hardship for smaller and older plants. Last and most obvious, antinuclear activism lobbies lawmakers with great effect. One interesting rebuttal is that if nuclear energy can't exist on its own in the free market, and then it should be replaced with whatever is in demand. But this is a false argument since the U.S. energy market is not free. In fact, it is highly regulated and manipulated by Federal oversight for specific outcomes. The popular push for renewables should only be considered as augment a strong nuclear program - not replacing it. [Carl] Any perceived failure of recent nuclear projects in the United States - notably South Carolina and Georgia plants - is not a result of failure of nuclear technology. Rather it is a policy failure that has caused V.C. Summer and Vogtle plants to over-run budgets and be perceived poorly by the public. To contrast slow U.S. nuclear growth, China and Russia are rapidly expanding their nuclear use. China reportedly built 5 reactors alone in 2018. [Carl] The "nuclear genie is out of the bottle for good" and the U.S. should work hard to stay ahead of competitors when it comes to nuclear technology and clean energy production. [Carl] The SDG Senior Project is taking an active role in continuing the safe use of nuclear in the United States. However, many people celebrate the trend of decreasing nuclear energy. But there are real costs associated to the communities when nuclear generation is shut down. Approximately 100 government and commercial power plants have been decommissioned by 2020, resulting in a loss of thousands of megawatts of generating capacity. [Kotval] Some notable examples of public influence to shut down nuclear plants include the Saxton Reactor (Saxton, PA), the Humboldt Plant (Eureka, CA), and the Shoreham Plant (NY). The Shoreham plant never even operated at full capacity or generated enough revenue to pay for its own decommissioning. [Kotval] In Rowe, Massachusetts, Plant YAEC (Yankee Atomic Electric Company) operated as the country's oldest commercial generating plant. It was often cited as the countries safest plant, even if it was one of the smallest (200 megawatts). [Kotval] It was also the most efficient, producing power 74% of the time compared to the average of 66%. Plant YAEC was expected to be modernized and operated for years to come. [Kotval] But with public anti-nuclear pressure mounting, the NRC would not renew a 20-year operating license, and the plant was permanently closed February 1992. During it's time in operation Plant YAEC had contributed incredibly to the local economy. [Kotval] All purchases were expected to be sourced first from Franklin County where the plant was located. The employees at the plant had above-average salaries, with plant executives being the highest paid salaries on Franklin County. The plant rarely turned down charitable donations to local causes, including helping United Way meet its financial goals several years. The tax burden on Plant YAEC was in the millions and made up 33% of the tax income to the city of Rowe. Nearby Hampshire County also benefited from Plant YAEC. In 1991, the total benefit to both counties was over $9 million. [Kotval] Five years later, the town of Rowe had effectively shuttered: the local supermarket had closed, the schools were on bankruptcy (Plant YAAEC had subsidized students), and tax rates had skyrocketed to make-up for Plant YAEC's contributions. None of the medical concerns used by the anti-nuclear activists could be proven, even with extensive testing. No higher rates of cancer or radiation were detected in Rowe citizens. [Kotval] The takeaway from this study is that nuclear policy should be determined less by shifting public opinion, and more by engineering safety assessments, the benefit to the local economy, and projected demand for energy use. More case studies like this one will help policy makers in the future better evaluate whether to decommission nuclear plants. The SDG Senior Project is designed to specifically update an existing facility (and keep it in the community) instead of shuttering a productive plant. Sometimes shuttering a plant is driven by financial decisions instead of outdated technology. The Entergy Corporation retired its 852-megawatt FitzPatrick Nuclear Power Plant in New York when it reached the end of its fuel cycle. [Carson] This decision was driven primarily by financial factors, including significantly reduced revenues due to low natural gas prices. Also, a flawed regulatory market design unfairly subsidizes renewable energy, while hurting nuclear energy. Also, the high operating costs of FitzPatrick Plant were a factor in this decision. The lost nuclear generation will largely be replaced by natural gas-fired power generation. [Carson] Although the renewables market is growing, the intermittent nature of its energy production will not be enough to offset the loss of nuclear generation. And since renewable energy growth is not matching or exceeding nuclear losses, states will have increasing trouble meeting the Clean Power Plan zero-emission requirements. [Carson] Instead of shuttering plants in France, a thorough report of French nuclear power plants calls for "last resort" safety systems to be installed at all nuclear plants operating in France. [Butler] The safety backup to existing systems must be built in hardened bunkers to withstand extreme earthquakes, floods, and other threats. The report comes from France's Nuclear Safety Authority (ASN) in Paris as a reaction to the recent Fukushima nuclear disaster in Japan. Butler even states that some of the weakest nuclear plants in France could have a "core meltdown within a few hours in the most unfavorable cases." The only nuclear operator in France, Électricité de France (EDF), adopted these suggestions and has begun implementation. This is a giant undertaking, as 75% of France energy comes from nuclear, and France is a leading exporter of nuclear plant designs. This bunker design is a novel approach, as it augments existing shut-down and safety procedures. Theoretically if existing plant systems are destroyed or incapacitated in emergency, controls in the hardened bunker will be able to continue an orderly shutdown and prevent disaster. This new policy is expected to influence nuclear plant design across the whole European Union and even in the United States. [Butler] Again, the aim of this SDG Senior Project is to avoid an unnecessary shutdown by offering a modernized design package to ENERCON.

Zooming down a level of detail, it is often very difficult to make a substantial business case to justify improving the control rooms from an operator performance perspective. Even though the capabilities of modern digital Instrumentation and Control (I&C) systems greatly outweigh the capabilities of analog control systems, many utilities cannot make the upgrade without a solid business reason. [Thomas] This paper, sponsored by the U.S. Government Department of Energy, seeks to build a case for plant modernization that captures the total organizational benefits, including "targeted work processes, efficiencies gained in related work processes, and avoided costs through the improvement of work quality and reduction of human error." The paper is structured in three sections: discussion of various modernized tools for nuclear power plants, area where tool is integrated within plant, and cost/benefit analysis of integration. [Thomas] The hardware tools evaluated in this research are: High-Bandwidth Wireless Networks, Mobile Devices, Large Overview Displays, Component Identification Technology (i.e., QR, OCR, RFID technologies), and Mobile Wireless Video Cameras. The software tools evaluated are: Computer-Based Procedures, Mobile Work Packages, Task-Based Operator Displays, Digital I&C Systems, Advanced Alarm Systems, and Computerized Operator Support Systems. These tools were integrated in the follow seven control room operations for analysis: Integrated Computer-Based Procedures, Reduction in Corrective Action Program Work, Reduced Critical Path Time during Outages, Control Room Operation of Local Control Panels, Computerized Operator Support Systems, Reduced Control Room Support, and Paperless Control Room Processes. Once evaluated, the overall results were positive. The estimated conservative total annual benefit once implemented in a control room is $1,660,000. This includes annual labor benefit of $1,020,000 and annual non-labor benefit of $650,000. [Thomas] Labor savings come from a reduced workforce and a workload reduction of 21,000 workhours once modernized tools are implemented. Non-labor savings come from the elimination of paper from work processes and the avoidance of purchase of replacement power due to outage extension during plant restart. [Thomas] If utilities are looking to build a business case for control room modernization, this paper demonstrates there may be immediate large benefits from such improvements. ENERCON has partnered with this Kennesaw State University SDG particularly for this purpose. While upgrades are being made in a plant, human safety must be kept priority. Human Factors Engineering (HFE) is essential to the continued safety and success of nuclear power plants. [Jou] It is so essential, in fact, that the Department of Defense (DoD) requires human engineering plans for plants to comply with the DoD 5000 series directives. Similarly, the American Society of Testing and Materials (ASTM) has published a HFE design standard. But once a HFE plan is established, there are no complete checklists to ensure full implementation and compliance to the plan. Or, as noted in this paper, Human-System Interfaces (HSIs) are graded on a pass/fail basis when a more nuanced approach is acceptable. To remedy this problem for nuclear safety in new plants and plant upgrades, researchers suggest developing, evaluation, and implementing a comprehensive HFE checklist. Using the majority of US Nuclear Regulatory Commission (USNRC) related regulations, regulatory guides, and design guidelines as inputs (most heavily NUREG/CR-6637 (2000e) Section 9.8), a checklist is built with nine clauses, eleven check points, and six procedures. Stated in the paper, "these HFE program elements can be classified as planning and analysis phase, design phase, verification and validation phase, and implementation and operation phase." Next a panel of experts is collected to evaluate the plant against this checklist. Rather than a simple pass/fail, experts independently evaluate the facility against the given criteria. Each expert's scoring is weighted and compared against the group. This method highlights where the plant is lacking in HFE standards. (Interestingly, the study uses a 1-4 rating scale to avoid a neutral or ambivalent midpoint.) Once the experts have scored the plant, a threshold is set using a statistical analysis approach, and any items below the threshold are suspect for improvement. In a case study, all the experts agreed that using a HFE checklist according to this method effectively ensured the safety of HSI upgrades. It is worthwhile to implement this system to ensure continued safety in this industry. [Jou] Since this SDG is stopping at design and not moving to implementation stage, this is not a great concern for this project. One topic that is pertinent is the method of calculations. All calculations for this ENERCON project have been done by hand, as this next literature covers. But there are drawbacks. As of 1992 most electrical calculations for nuclear generating systems were done by hand, before computerized systems were available. [Jancauskas] Due to this fact, several issues arise from hand calculations: error and lack of detail, may not document safety functions, lagging as-built plant conditions, does not add up to coherent whole, or incomplete auditability and traceability of data. Computerized calculations eliminate the human limitation and produce a base set of calculations. Appropriate software training is supplied, so that the utility engineers can perform routine updates to power flow, voltage drop, short circuit, and coordination calculations. Using this set of base calculations, data can then be fed into specific applications. Storage in a central database allows access of information to all parties, as well as customized reports to be written. And the flexibility of software configurations means the programs are tailored directly for each specific plant. In addition to detailed AC power analysis, software to analyze DC is reducing risks at nuclear plants. Since DC systems are used primary in emergency backup, it is harder to spot weaknesses - yet even more important. DC backup power is difficult to calculate by hand, since the load can change dramatically in each stage of a nuclear plant shutdown/startup procedure. A complex software simulation gives engineers and managers much better insight into system behavior at critical junctions. There are however potential problems to software analysis: can engineers trust the analysis software assumptions and accuracy? Who has verified and validated the software? How do engineers filter through the increased documentation provided by software to have relevant data when the software can project thousands of 'what-if' scenarios? Similar, how do engineers see only relevant details when software can provide endless detail? What procedures are in place to keep the software updated to the as-built circuit(s)? How is the problem of configuration management handled i.e., is there one program to rule all programs? [Jancauskas] These are real and pressing questions for the future of software analysis in the nuclear industry. Yet the benefits outweigh the disadvantages, and the future is trending towards heavy software analysis in the nuclear power generation industry. [Jancauskas] This applies to the KSU SDG project directly: students are performing electrical hand calculations for ENERCON. Without access to ENERCON's data analysis software, these calculations should be reviewed carefully and verified to match a similar software analysis. While discussing calculations, the SDG would like to include this literature review. Although the plant location has already been chosen by ENERCON/other groups, this review shows a tentative relationship between plant location and mathematical calculations. Not surprisingly, nuclear power plants are built for prescribed conditions to a defined geographical area, i.e. targeted power demand, metallurgical limits of structural elements, statistical values of environmental conditions, etc. One design variable to determine is how the temperature of cooling water effects the efficiency of power generation. This particular fact is important to the SDG project, as the mechanical engineers must determine proper temperatures at several key points in the system. Durmayaz demonstrates that the temperature of the cooling water has a small but noticeable impact on the efficiency of a pressurized-water reactor at a nuclear power plant, developed specifically for a new nuclear power plant in Turkey with multiple locations in consideration. A model is developed to determine the difference between cooling water temperature and the condenser pressure and the effect of overall energy transfer in the loop. Analyzing a Combined Cycle Power Plant (CCPP) Pressurized-Water Reactor (PWR), a theoretical model is built from the first law of thermodynamics for steady-flow processes. Multiple inlets and exits are considered to create a four stage PWR loop: Preheating, Steam Generation, Power Generation, and Condensation. [Durmayaz] Analyzing the model for off-design heat balance equations provides data on how the cooling medium affects the overall energy transfer in the CCPP. The conclusion is that each 1C increase in coolant temperature results in 0.12% decrease in thermal energy efficiency in the PWR loop. [Durmayaz] For this specific design, it is recommended to build the new plant at the Black Sea instead of the Mediterranean Sea, since yearly mean temperature is 6.5-7C colder at the Black Sea. This will result in increased thermal efficiency of 0.78-0.84% of the CCPP PWR. [Durmayaz] This research applies to the KSU SDG project directly: mechanical students are calculating cooling temperatures for piping and pump applications. (The efficiency of the system is beyond the scope of this project, as location for the power plant has already been determined.) Another relevant literature review tackles the problem integrating new electronic controls technology in a pump replacement project. The Advanced power Reactor 1400 (APR1400) uses three condensate pumps as motive force to drive three pumps that draw down condensate from the hot well to deaerator storage tanks. [Barie] Each pump runs at 50% capacity of the condensate system, allowing for two primary pumps and one backup pump. The flow of condensate water in this system is controlled only by the Level Control Valves (LCV) in the tanks. In case of valve malfunction, the operator has access to operate the LVC's manually. This study intends to use a Variable Frequency Drive (VFD) to replace the LCV's. By replacing the LCV's with a VFD, pump life will be extended in addition to reducing energy use. The speed of the pump is adjusted by the VFD mechanism to shift the pump head curve to match system resistance. This saves energy and extends pump life since the new method with VFD must only match system resistance at the required system flow. (Previously energy use at the pumps exceeded system resistance.) Use of VFD's are not without drawbacks, as a VFD must rectify AC voltage to DC voltage then use Pulse Width Modulation (PWM) to recreate AC voltage and a specific variable frequency. The conversion process loses energy in the form of heat. However, the power input to the motor varies with the cube of the speed of the motor, so a minor change in speed can impact energy use. This study only replaces the LCV's with VFD's on two pumps, leaving the third pump as redundancy. Also, the LCV's are not removed from the system, only bypassed. This allows return to previous operational mode in case of VFD maintenance or failure. Using the VFD method resulted in 27% power use reduction. Over the course of one year with a VFD on two condensate pumps, this equates to over $500,000 USD (2018) in savings. [Barie] This research applies to the KSU SDG project directly: students are replacing condensate pumps. The particulars of the control scheme are beyond the given scope of this project, but it seems worthwhile to include a discussion of VFD use in the next iteration of this project. One very unique problem related to this project is how to keep the operator in the loop while controls are being updated for new equipment. How to tackle this problem in a 24/7 critical plant environment? Carruth helps the SDG understand the problem and the best way to approach. Designed in the late 1960's and commissioned in the mid 1970's, the two generating units at Donald C. Cook Plant are identical 1100-megawatt Westinghouse that uses a mix of electronics and pneumatic controls. [Carruth] In the 90's an upgrade was determined necessary because the early solid-state electronics used on the control and safety systems were increasingly prone to drift and incipient failure. (Drift is a primarily analog circuit failure mode as physical components slowly degrade. Significant digital equipment failures are more likely to be "prompt and significant.") The scope of the upgrade was limited to the signal processing portion of the plant safety system between the process sensors and the solid-state logic. To tackle the controls upgrade, intensive engineering studies covered the following aspects: physical constraints, retraining and human factors, and licensing and technology. The physical constraints were insignificant to this project. Several large staging areas allowed for new equipment to be prepped and swapped easily without disturbing other running systems. Another benefit was choosing Foxboro H-LINE digital control modules that needed very little inter-rack wiring, allowing for much easier swap-ability. The retraining and human factors were a tougher consideration. The 1960's control design mixing with new 90's control modules was considered an unnecessary hardship for operators, so the new equipment was designed to be integrated transparently to operators - effectively keeping the old control scheme in place. The intent was to replicate the original start-up and shut-down controls with the new technology, including keeping all failure modes the same as previous. One unexpected event was the high gain of digital controls, when replicated to analog gauges, made the output signals appear to "jump around" making operator uncomfortable and causing them to think the system was behaving abnormally. As a part of this transition, good interdepartmental communications, careful personnel turnovers, and even temporary instrumentation in the control room was necessary. From the licensing and technology angle, there was concern over the reliability and calibration of software-driven controls. To alleviate these concerns, upgrades were module-based, with multiple micro-processing units across the plant, instead of one integrated central processor. All software and controls were tested and installed under IEEE/ANSI 7-4.3.2 to assure reliability and allow for minor upgrades in the future. [Carruth] This analog-to-digital partial control upgrade was a major undertaking but implemented carefully and successfully. Lastly at this level, the SDG would like to point to a unique moment in history when two clashing superpowers came together to upgrade a nuclear plant. This unique partnership between the United States and Russia allowed the DC power supply to be updated to modern nuclear standards at the Russian Kola Nuclear Power Plant (NPP) at Murmansk, Russia in the 1990’s. [Scerbo] After the 1986 Chernobyl incident, the U.S. made commitments at the 1992 G-7 Conference to help other countries update their nuclear programs. Built between 1965-1974, Kola Units 1 & 2 did not have any safety regulations for the emergency DC power supply system. [Scerbo] The initial system consisted of 230VDC power supply that was unrated for any disasters. The battery cells were lead acid type with lead calcium grid plates in an open-container design that left all components exposed to the environment. The batteries were supported on ceramic insulators on an unguarded rack. There were also ceiling supports which were likely fail points. The batteries could easily have been dislodged and destroyed during any seismic or other natural event. [Scerbo] The initial batteries were rated for 30 minutes discharge, which did not include additional load that had been added since design. The solution, designed jointly by U.S. company Burns and Roe and "host countries of the former Soviet Union (FSU)", resulted in nuclear qualified Class 1E batteries with distribution boards to Kola. The new battery design increased emergency DC backup power duration to 2 hours, including initial heavy load as systems restarted. [Scerbo] A new rack system was also installed to adequately protect the batteries and equipment from natural disaster. Since Murmansk is located above the Arctic Circle, this caused issue for battery transportation as battery life can be severely degraded in extreme cold. To solve this, heated transport containers were used, monitoring equipment was installed to ensure proper temperature, and care was taken to plan ahead with any interested Customs departments for expedited delivery. Another barrier was translation issues between English and Russian. Great care and time have been put into making sure all translations were adequate for local Russian terminology. This project completed successfully and is considered a model of cooperation between the U.S. and Russia in the nuclear industry. [Scerbo] Highlighting this literature reference instructs the SDG (a group of beginning engineers) the importance of sturdy design as well as teamwork in the field to fix complex and potentially emotionally charged problems.

Lastly the SDG highlights some highly technical literature on specific pieces of equipment in this project. This next piece of literature goes in depth about valve sizing and specifications. When selecting piping a utility plant, if water is the working fluid, the lowest piping specifications can be used. [Merrick] This text helped us decide to use schedule 40 clean commercial steel pipes. In the construction details section of the Valve Design and Specifications chapter, it is indicated that the connections to the valves should match or be at least comparable to the rest of the piping system. Using a 4" pipe and 4" valve was a result of these findings. Flanged joints are easier to connect valves larger than 2" rather than threaded joints. Connecting the 4" pipe and chosen 4" sleeved plug valve shall then be completed with a flanged 4' joint and a butt-weld. [Merrick] Also related, CRANE laboratories have been proving test data for a variety of valves and pipe sizes, but due to the extent of costs needed many piping and valve sizes go untested. [CRANE] CRANE nuclear lays out how to accurately calculate head losses for all size pipe and fittings using different formulas with clearly defined variables. This literature helped the SDG calculate all the systems' flow coefficients which lead to obtaining a total head loss. Finally, the technical literature instructs the SDG in the DURCO control valve. There are two basic requirements to determine how to properly size a DURCO control valve. The C_v required and the pressure drop across the valve. Upon completing the hydraulic evaluation which solved for the pressure drop across a 4" sleeved plug valve in the designed 109' system, the SDG was able to use equation 1-1.0 to obtain a C_v value confirming that we chose the correct size valve to control the flow to the heat exchangers. [DURCO]

Chapter 3: Project Management

Chapter 3 breaks down each engineering discipline's problem- solving approach followed by the scope required for each discipline to complete the project successfully. Included are the teams, Gantt chart, schedule, work breakdown structure, and budget.

3.1 Problem Solving Approach

3.1.1 Electrical

Electrical students began with a textbook approach to solving Engineering problems, dealing with theory and formulas found in the classroom. After initial ENERCON feedback, students discovered that calculations performed in industry use data from laboratories – real-world numbers that can easily be duplicated. This led to the electrical team almost having a "trial by error" approach, which allowed for a more complete understanding of the project.

Utilize all available resources to help complete the project and finish all tasks before deadlines. This will include all previous gained knowledge from KSU, using all available student software, and reaching out for help to Enercon, staff and teachers.

3.1.2 Civil

As engineers we are tasked with using knowledge, gained through experience whether that be school or other sources, to solve real world problems. With that in mind the civil team first started browsing our textbooks for applicable example problems and tried to apply them to our specific evaluations. Some of these require trial and error approaches whereas others are straight forward applications.

Using these textbook examples, as well as processes outlined in various code manuals such as: AISC, ACI, AWS, etc., each evaluation can be completed to ensure required loads do not exceed that of the design loads for each element be that steel or concrete.

3.1.3 Mechanical

As aspiring engineers, we began by looking at our text-book problems to try and relate information to the problems given to us. We the used our course experience in solving those and related that experience to this project.

Plausible plan includes completing pipe route to further help draw the pipe isometrics. The isometrics will help with head loss calculations in the flow rate evaluation. The evaluations and markup completion are well within reach.

3.2 Project Scope

3.2.1 Electrical

1. Design inputs shall be determined from PAL 2.0.
2. Appropriate industry standards shall be listed for each design input (i.e. NEC, IEEE).
3. Evaluation shall be performed to quantify 400hp 4.16kV pump initial voltage drop.
4. Evaluation shall be performed to quantify 400hp 4.16kV pump initial current.
5. Electrical students shall be in frequent correspondence with ENERCON engineering talent to solicit feedback and direction on progress of project.
6. Markups on 16 drawings shall be provided to ENERCON to reflect changes to pump electrical and control systems.
7. Simulations shall be reviewed with ENERCON to ensure correctness.
8. All hand calculations shall follow all mathematical rules and equations.

3.2.2 Civil

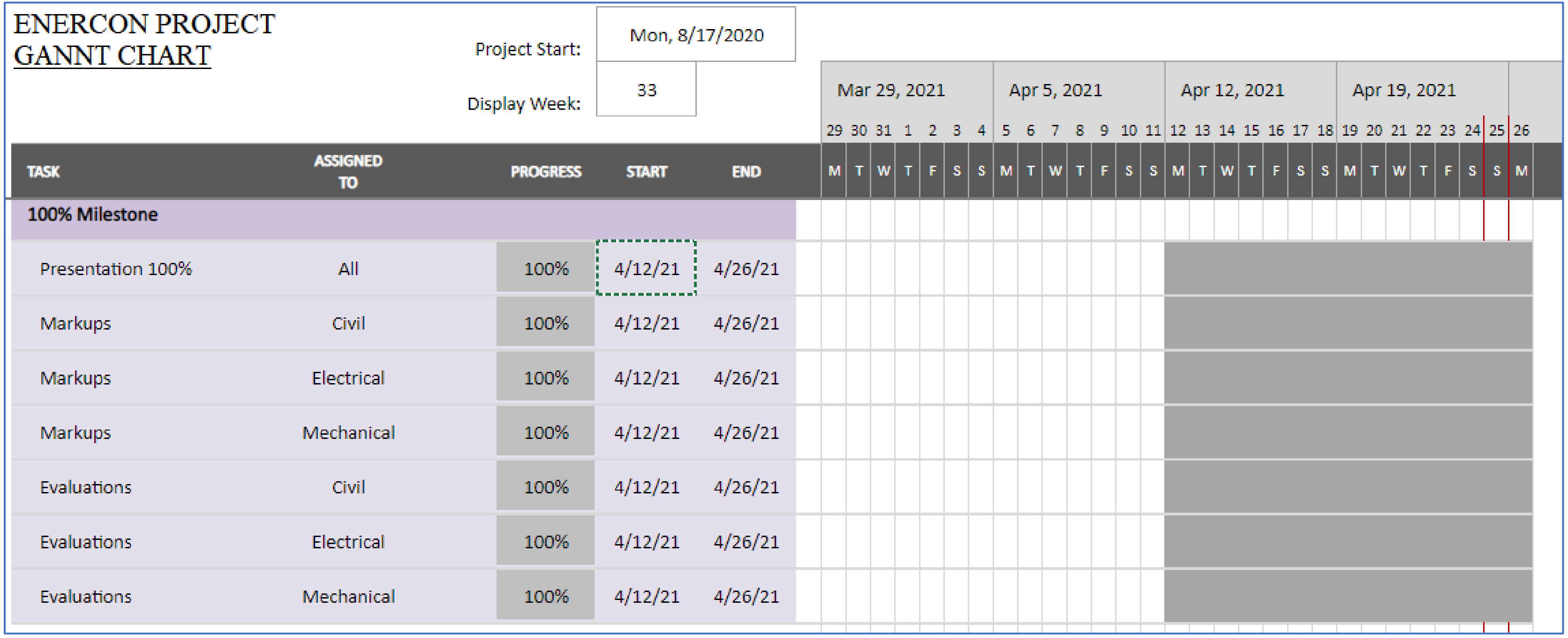
1. Design inputs shall be determined from PAL 2.0.
2. An evaluation shall be performed to ensure new loads do not exceed the allowable floor loads.
3. An evaluation shall be performed to evaluate if moving of equipment will exceed existing floor loads.
4. The hidden commodities in the existing floor slab shall be evaluated to ensure nothing is impacted.
5. The rebar in EL. 133’ shall be evaluated to see if rebar needs to be cut or not.
6. The new pipe supports shall be evaluated for the loads given to the SDG by ENERCON.
7. The existing pipe supports shall be evaluated for the loads given to the SDG by ENERCON.
8. Dimensions and design of new pipe supports shall be marked up.
9. Instructions for the heavy haul path and removal of existing equipment pads shall be provided.

3.2.3 Mechanical

1. Design inputs shall be determined from PAL 2.0.
2. Turbine Building documents shall show pipe route.
3. Two system flow diagrams shall have markups adding and deleting necessary components.
4. Evaluation shall be performed to confirm PSW’s ability to provide sufficient cooling water to vacuum pump heat exchangers, including conditions to downstream components in the plant.
5. Evaluation shall be performed to confirm heat exchanger’s ability to provide adequate cooling to liquid seal vacuum pump.
6. Isometric shall be created displaying the route and necessary components needed to provide cooling water to vacuum pump heat exchangers.
7. Evaluation from line two shall include head losses due to pipe fittings such as but not limited to: tees, y-strainers, elbows, isolation valves, throttling v-port valves, and reducers.

3.3 Gantt Chart

The team is utilizing a Gantt chart to keep track of progress per discipline on this project. Figure 4 demonstrates on-track progress up to completion date of April 26, 2021:



ENERCON PROJECT
GANNT CHART

Project Start: Mon, 8/17/2020
Display Week: 33

TASK	ASSIGNED TO	PROGRESS	START	END
100% Milestone				
Presentation 100%	All	100%	4/12/21	4/26/21
Markups	Civil	100%	4/12/21	4/26/21
Markups	Electrical	100%	4/12/21	4/26/21
Markups	Mechanical	100%	4/12/21	4/26/21
Evaluations	Civil	100%	4/12/21	4/26/21
Evaluations	Electrical	100%	4/12/21	4/26/21
Evaluations	Mechanical	100%	4/12/21	4/26/21

Figure 4: Gantt Chart Describing Progress to Completion Date of April 26, 2021

3.4 Project Management

The project is being directed by ENERCON engineer Peter Bertasi and supported by other ENERCON engineers specific to each discipline.

Jared D’Amico is the student project manager, responsible for weekly coordination and motivation of the team.

3.5 Responsibilities

Each student has the responsibility of fulfilling the in-class tasks detailed by Dr. Khalid. The design team must meet all requirements for ENERCON. This will include weekly assignments and meetings, along with large milestone projects to demonstrate project completion. Work Breakdown Structure (figure 5 shown below) visually represents the responsibilities of each discipline towards each ENERCON assigned milestone:

Project Title	**Pump Replacement**	**Company Name**	**KSU SDG/ENERCON**
Project Manager	**Jared D’Amico**	**Date**	**Spring 2021**

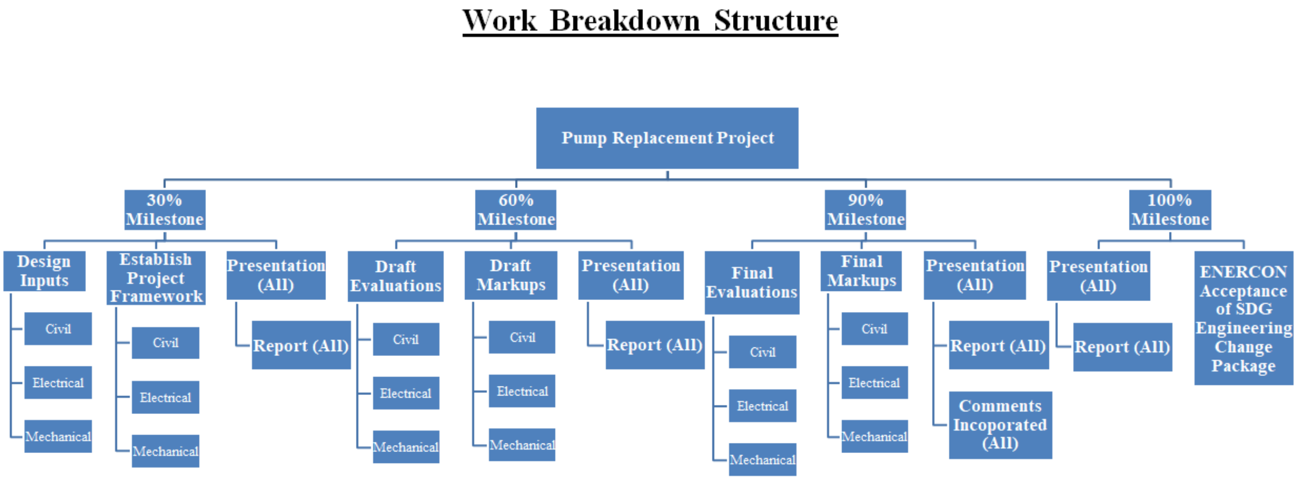


Figure 5: Work Breakdown Structure

3.6 Schedule

Table 3: Schedule of Items to be Submitted to ENERCON

Item	Date
Submittal of 60% Package to ENERCON	3/5/2021
60% DRM	Week of 3/17/2021
Incorporation of ENERCON 60% Package Comments	3/29/2021
Submittal of 90% Package to ENERCON	4/12/2021
90% DRM:	Week of 4/19/2021 @ 12:30 PM
Incorporation of ENERCON 90% Package Comments:	4/22/2021
Submittal of 100% EC Package for ENERCON Approval:	4/22/2021

3.7 Budget

3.7.1 Major Cost Items

The Kennesaw State Senior Design group is logging all hours for the project. The team has created an Excel sheet with two types of billable hours. The first is preparation work, this is a lower rate since a junior Engineer is usually assigned these tasks. The second are review hours, this is a higher rate as a senior engineer would need more training and experience to catch mistakes and approve work. Table 4 shows current work for both semesters at 1595 hours and $170,035.00 using hourly rates given by ENERCON (updated April 25, 2021):

Table 4: Billable hours in Lieu of Budget

Preparation Billing Rate	$100.00
Review Work Billing Rate	$135.00
2021 Preparation Hours	367.5
2021 Review Hours	301
2020 Total Hours	926.5
Total Billable Hours	1595
Total Cost	$ 170,035.00

3.7.2 Sponsors

This design project has no financial sponsor(s).

3.8 Material Required/Used

Not applicable for current project.

3.9 Resources Available

- The student design team has many software resources: MATLAB, Ram Elements, SolidWorks, and Adobe Acrobat are used make changes to the necessary drawings. Microsoft Office Suite gives documentation and presentation capability.
- ENERCON’s engineering team has provided us with access to their engineers' who have given us hours of their time to answer all questions and ensure we will be successful in completing the project. They have also provided us with all necessary plant information that they could share for us to complete all evaluations and plant drawing markups.
- KSU faculty have also aided in this project, giving students technical insights as we complete our evaluations.

Chapter 4: Minimum Success Criteria

The Minimum Success criteria was given initially by ENERCON included in the Project Acceptance Letter (PAL). The scope of the project was changed entering the second semester. This new scope wis given in the PAL 2.0 and the criterion for each discipline is shown below.

4.1 Electrical - Identify what needs to be done.

1. Markups of 17 main drawings.
2. Create supporting documentation to explain markups.
3. Complete 8 evaluations (pending ENERCON input).

4.1.1 Electrical - Explain why it needs to be done.

1. Changes to system shall be documented for correct implementation.
2. Changes to system shall not interfere with normal system operation.
3. Any new electrical load shall be evaluated to ensure no overload of circuit protection.
4. Circuit protection shall be sized according to new motor load.

4.2 Civil - Identify what needs to be done.

1. Markups for existing pipe support loads.
2. Floor load evaluation.
3. Hidden commodities assessment.
4. Calculation and markups for the cutting of rebar in existing slab on EL. 133'.
5. Sketches of new pipe supports.
6. New pipe support calculations.
7. Instructions for the heavy haul path and removal of existing equipment pads.

4.2.1 Civil - Explain why it needs to be done.

1. To ensure that total load on existing pipe supports does not exceed the design load for each specific pipe support type.
2. To ensure new equipment does not exceed allowable floor loading.
3. Hidden Commodities need to be assessed to ensure penetrations into the floor slabs on elevation 113' and 133' do not impact items in the slabs.
4. Rebar may need to be cut due to new penetrations in the floor slab which will require the new allowable floor loading to be calculated.
5. The new pipe supports with need to have dimensions according to the evaluated dimensions.
6. New pipe supports will need to be evaluated for the loads provided by ENERCON so that design loads may be created.
7. Instructions on how to move equipment through the plant will need to be provided to the Craft.

4.3 Mechanical - Identify what needs to be done.

1. Markup of document M-1002 (Turbine Building Plan Elevation 113') and M-1003 (Turbine Building Plan Elevation 133') to show new pipe routes to the vacuum pump HX's.
2. Isometric drawing of proposed pipe route to visualize and calculate the head losses in the flow rate evaluation.
3. Markup of System Flow Diagrams:
4. SFD1060
5. SFD1072A
6. Evaluations:
7. PSW adequate cooling water flow rate to pump HX evaluation.
8. PSW sufficient cooling to pump from HX evaluation.

4.3.1 Mechanical - Explain why it needs to be done.

1. Markup up documents M-1002 and M-1003 are essential to show where the two new vacuum pumps will be placed. With locations of the new pumps, the pipe routes to the pumps can be established. With established piping routes, all head losses in the system can be accounted for.
2. The isometric drawing of the proposed pipe route helps engineers visualize what will be implemented into the plant. Specific pipe length can be determined as well as where pipe supports will be placed.
3. The marking up of SFD diagrams are required because all changes to equipment need to be updated on current plant documents for future ease of maintenance and planning.
4. Evaluations of the plant's PSW are essential to ensure the existing plant systems can support the new equipment as well as not damage it by providing too much flow rate and excessive fouling in pump HX's.

Chapter 5: System Design Inputs

Chapter 5 highlight the Design Inputs required for this project. In the Project Acceptance Letter (PAL), ENERCON listed the end goal of this project (i.e. minimum success criteria). This chapter describes the means by how the SDG will accomplish this goal.

5.1 Design requirements and specifications e.g., dimensions, functions, capabilities etc.

This section of the IDR breaks down design inputs by engineering discipline. Each group (Electrical, Civil, Mechanical) lists their respective Design Inputs as detailed in the PAL. The 'Design Input' column states a basic engineering concept as it is applied in the vacuum pump station. The engineering group then finds the appropriate industry standard or document as a 'Requirement' to determine the appropriate approach to the Design Input. 'Supporting Documents' are also listed as guidelines to each engineering application.

5.2 Electrical Design Inputs:

Design Input	Requirement	Supporting Document(s)
Voltage Drops to: 4160VAC 400HP Pump Motors; 480VAC 5HP Make-Up Pump Motors	Motor input requirements from manufacturer, typical 10% tolerance	• IEEE 30027-2018 • NEMA MG 1-2009: 21.17.1
44160VAC Cable Ampacity Rating to Pump Motors	• **NEC 310.60 (C)**, Ampacities for conductors rated 2001 to 35,000 volts shall be as specified in Table 310.60 (C) and corrected for an ambient temperature of 70° Fahrenheit. • **NEC 430.22**, Conductors shall be sized for no less than 125% full-load current rating.	• IEEE Std 835-1994 (revised 2012)
480VAC Cable Ampacity Rating to Make-Up Motors	• **NEC 310.15 (B)**, Ampacities for conductors rated 0 to 2000 volts shall be as specified in 310.15 (B) • **NEC 430.22**, Conductors shall be sized for no less than 125% full-load current rating.	• IEEE Std 835-1994 (revised 2012)
Grounding of Pump Motor,	• **NEC 250.4 (A) (1)**,	• ANSI/IEEE C2-

Make-Up Pump, Motor Space Heaters, Switchgear Control Power, Junction Boxes, and Cable Trays	Grounded electrical systems shall be connected to earth in a manner that will limit voltage during lightening, line surges, or unintentional contact with higher-voltage lines and that will stabilize during normal operation. • **NEC 430.241,** Motor frame shall be grounded. • **NEC 430.244**, Motor controller enclosures shall be grounded. • **NEC 314.4,** Metal junction boxes shall be grounded and bonded. • **NEC 665.26,** Heater circuit shall be grounded per circuit design. • **NEC 408.40,** Metal panelboards shall be connected to an equipment grounding conductor. • **NEC 392.60 (A),** Metal cable trays shall be grounded.	2012 • IEEE Std 142-1991
Conduit Sizing of Pump Motor, Make-Up Pump Motor, Local Control Logic, Motor Space Heaters, and Switchgear Control Power	**NEC Chapter 9: Table 1,** Conduit cross-sectional area for conductors shall not exceed: 1 conductor, 53%; 2 conductors, 31%; more than two conductors, 40%.	• NEC Reference
Junction Box Sizing 1000 Volts and Less for: Make-Up Pump Motor, Local Control Logic, Motor Space Heaters, and	**NEC 314.28 (A), (1) & (2),** Length of the box shall not be less than 6 times (for straight pulls) or 8 times (for angle, u-pulls, and splices) the outside diameter of the largest	• NEC Reference

Switchgear Control Power	conductor.	
Junction Box Sizing 1000 Volts and Greater for: Pump Motors	**NEC 314.71 (A) & (B),** Length of the box shall not be less than 36 times (for straight pulls) or 48 times (for angle, u-pulls, and splices) the outside diameter of the largest conductor	• NEC Reference
Circuit Protection of Local Control Logic, Switchgear Control Power, and Motor Space Heaters	• **NEC 240.4,** Conductors shall be protected against overcurrent in accordance with their specified ampacities. • **NEC 310.15 (A) (2),** Lowest ampacity rating must be chosen for conductor. • **NEC Table 310.15 (B) (3) (a)**, Choose correct adjustment factor for more than three current-carrying conductors.	• IEEE Std 3004-2016
Circuit Protection of Pump Motor and Make-Up Pump Motor	• **NEC 430.52 (B)** Short-circuit, and ground-fault protection shall be capable of carrying starting current of motor. • **NEC Table 430.52,** Maximum rating of full-load current for AC polyphase motor instantaneous trip breaker shall be 800%. • **NEC 430.53,** Two or more motors shall be permitted on the same branch circuit, providing the branch-circuit protective device is fuses or inverse time circuit breakers. • **NEC 430.75 (A),** Motor control circuits shall be	• IEEE Std 37-2015 • IEEE Std 3004-2016

	arranged so they will be completely disconnected from all sources when disconnect device is in open position.	
Circuit Coordination	**NEC 240.12** An orderly shutdown is required to minimize hazards to people as well as equipment. This shall be based upon • Short Circuit Protection • Monitored Overload Indication	• IEEE C37-2018
Short Circuit Protection	**NEC 110.10** All components of circuit should be selected to protect the circuit, as well as clear faults without damaging circuit. All equipment shall be rated for intended use as following NEC 250.118 grounding guidelines	• IEEE C37-2018
Circuit Testing	• **NEC 110.41 (A):** The complete system shall be tested when first installed. • **NEC 110.41 (B):** A test report shall be available to the authority having jurisdiction prior to energization.	• IEEE PC37.09/D5.0 (High Voltage) • IEEE PC37.26/D2 (Low Voltage)
Safety Clearances Between Equipment	• **NEC Table 110.26 (A),** No less than 3 feet clear working space for exposed equipment up to 1000 volts • **NEC Table 110.34 (A),** No less than 4 feet clear working space for exposed equipment between 2501-9000 volts	• ANSI/IEEE C2-2012
Safety Signage and Workspace Guarding near	• **NEC 110.34 (B),** Separation shall be made between	• IEEE P3007.3/D4-

Equipment	equipment of 1000 volts and less and equipment of 1001 volts or greater by a physical barrier. - **NEC 110.34 (C),** High voltage equipment shall be marked with conspicuous signage. - **NEC 110.34 (D),** Illumination shall be provided for all workspaces about electrical equipment. - **NEC 665.25**, Dielectric heater element shall be shielded by protective cage or other means. - **NEC 665.27,** Each heating equipment shall be labelled with heater information.	D7 - IEEE Std 3007-2012

*NEC 2017 Edition Used for References

5.3 Civil Design Inputs:

Design Input	**Requirement**	**Supporting Document(s)**

Floor Loading	Calculation of new floor loads due to new skids being placed and heavy haul path	- C0356/7 Floor Live Loads 113' Elevation
		- Civil Structural Design Criteria Manual (CSDCM)
		  ○ ACI 318-14 Chapter 17
		  ○ Strength design

		parameters and variables of ESR-2302 ○ Hilti Simplified Design Tables • M1002_0_022 • M1003_0_024 • C-S362.0
Pump Skids and Mounting Details	Reinforce overstressed members to withstand established loads	• M1002_0_022 • M1003_0_024
Heavy Equipment Haul Path	Potential changes to haul path from HCA	• C0356 Floor Live Loads 113' Elevation • C0357 Floor Live Loads 133' Elevation
Typical Conduit Supports	Confirmation that new conduit loads do not exceed existing supports	• FSK-E-336(A-E)-0725-G
Hidden Commodities Assessment	Evaluation for new penetrations	• C1137B • HCA drawings for Civil, Mechanical, Electrical
Pipe Supports	• Fully established pipe hanger locations • Markups for existing affected supports	• Pipe Support Type 1-4 • Existing Pipe Supports 1-10 • Isometrics Folder • Anvil Pipe Hanger Figures

5.4 Mechanical Design Inputs:

Design Input	Requirement	Supporting Document(s)
Flow Requirement of Heat Exchangers	• Cold Side: 350 gpm • Hot side: 190 gpm	• N1N62B002A/B-1.1-001
Flow Requirements of Compressor	• 42 gpm @6.3 Hg to 93 gpm @ 24 Hg	• 460004522 Vacuum Pump operation manual (9.2 Technical Specifications)
Hydraulic Flow Requirements of Recirculation Pump	• Minimum of 32.2 gpm	• Recirculation Pump Data Sheet
Heat Exchanger connections	• 4”-150# Flanged Slip-on Carbon Steel • ASME Sect VIII Div. 1 • **ASME B31.1-2016: 108.1 Flanges**, shall be attached to the pipe by applicable standards specified in Table 126.1	• N1N62B002A/B-1.1-001
Heat Exchanger capacity	• ASME Sect VIII Div. 1 • 960,000 Btu/h	• N1N62B002A/B-1.1-001
Recirculation pump specifications	• Suction Pressure of 0.6 psig • Output Pressure of 35.1 psig (disch)	• Recirculation Pump Data Sheet
Vacuum Pump normal	• 3500-6000 gpm (should not	• 04-1-01-P44-1

operating conditions	fall below 3500 gpm to ensure long term reliability)	(Section 3.25)
Plant Service Water System	• Downstream temperature should not exceed 92 °F • Header pressure should remain between 103-120 psig	• 04-1-01-P44-1 (Section 5.10.5)

Chapter 6: Design Concepts and Trade Study Items

Chapter 6 details a mechanical design concept of the ring seal vacuum pump to highlight systems and components of it. Electrical trade study compares types of conduit best-suited for the nuclear environment. Both items were performed for an in-class prestation for Dr. McFall.

6.1 Mechanical Vacuum Pump Design Concept

The design of a liquid-seal vacuum pump is relatively simple. The purpose of the pump is to pull vacuum on an energy plant condenser at startups and shutdowns. The pump does not utilize any vane seals, but rather water to create a liquid ring seal against the casing while the unit is in operation. Due to water being heavier than the condensate air, it acts as a barrier between the vanes of the pump and thus, move air in the form of a vacuum. The benefit a liquid-ring setup is less maintenance since there are no vane seals to be replaced. Additionally, the vacuum pump is outfitted with an entrainment separator to filter out seal-liquid water particles from the discharge side of the vacuum pump. However, the seal-liquid water in the pump absorbs a lot of energy in the form of heat and requires a heat exchanger to keep the liquid-ring water cool. The heat exchanger as well as a recirculation pump has certain specifications to meet the cooling needs of the vacuum pump. Figure 6 neatly shows all components of these types of vacuum pumps.

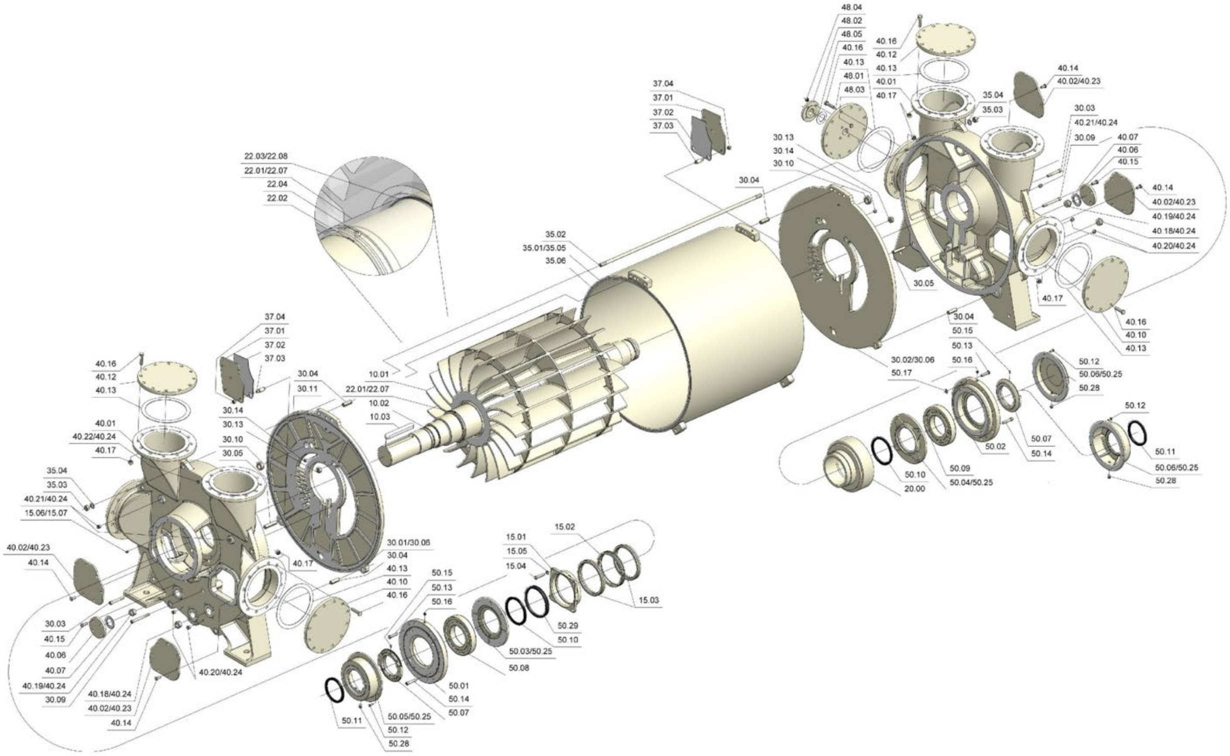


Figure 6: Exploded view of NASH Liquid Ring Vacuum Pump. Shows all components of the pump.

In addition to the liquid-ring vacuum pump, the vacuum pump's heat exchanger, entrainment separator, recirculation pump and other supporting equipment will be located on the vendor-supplied pump skid. Figure 7 shows an isometric view of all the components, with heat exchanger cold side and hot side inlets and outlets.

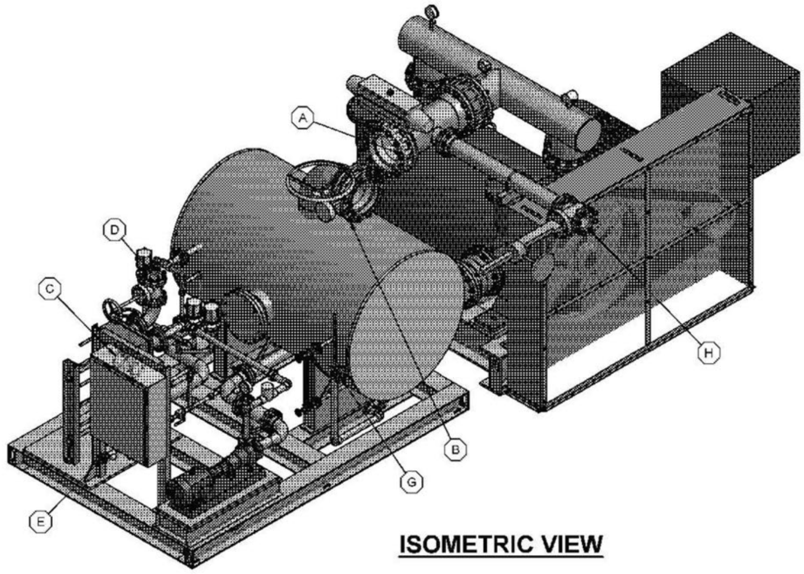
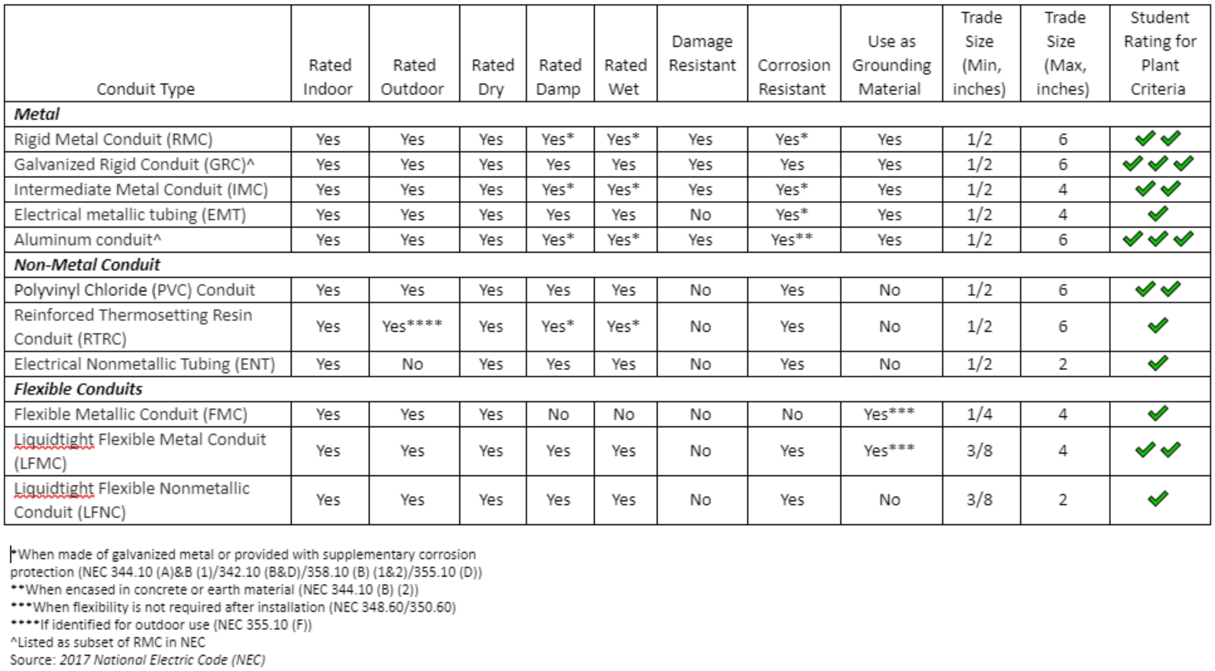


Figure 7: Isometric of Vacuum Pump Skid

6.2 Electrical Trade Study

The electrical trade study evaluated the suitability of different conduit materials for this project. Conduit well-suited for the nuclear environment is given 3 green marks. As performance decreases, the fewer green marks are given to each conduit type:



Conduit Type	Rated Indoor	Rated Outdoor	Rated Dry	Rated Damp	Rated Wet	Damage Resistant	Corrosion Resistant	Use as Grounding Material	Trade Size (Min, inches)	Trade Size (Max, inches)	Student Rating for Plant Criteria
Metal											
Rigid Metal Conduit (RMC)	Yes	Yes	Yes	Yes*	Yes*	Yes	Yes*	Yes	1/2	6	✓✓
Galvanized Rigid Conduit (GRC)^	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1/2	6	✓✓✓
Intermediate Metal Conduit (IMC)	Yes	Yes	Yes	Yes*	Yes*	Yes	Yes*	Yes	1/2	4	✓✓
Electrical metallic tubing (EMT)	Yes	Yes	Yes	Yes	Yes	No	Yes*	Yes	1/2	4	✓
Aluminum conduit^	Yes	Yes	Yes	Yes*	Yes*	Yes	Yes**	Yes	1/2	6	✓✓✓
Non-Metal Conduit											
Polyvinyl Chloride (PVC) Conduit	Yes	Yes	Yes	Yes	Yes	No	Yes	No	1/2	6	✓✓
Reinforced Thermosetting Resin Conduit (RTRC)	Yes	Yes****	Yes	Yes*	Yes*	No	Yes	No	1/2	6	✓
Electrical Nonmetallic Tubing (ENT)	Yes	No	Yes	Yes	Yes	No	Yes	No	1/2	2	✓
Flexible Conduits											
Flexible Metallic Conduit (FMC)	Yes	Yes	Yes	No	No	No	No	Yes***	1/4	4	✓
Liquidtight Flexible Metal Conduit (LFMC)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes***	3/8	4	✓✓
Liquidtight Flexible Nonmetallic Conduit (LFNC)	Yes	Yes	Yes	Yes	Yes	No	Yes	No	3/8	2	✓

*When made of galvanized metal or provided with supplementary corrosion protection (NEC 344.10 (A)&B (1)/342.10 (B&D)/358.10 (B) (1&2)/355.10 (D))
**When encased in concrete or earth material (NEC 344.10 (B) (2))
***When flexibility is not required after installation (NEC 348.60/350.60)
****If identified for outdoor use (NEC 355.10 (F))
^Listed as subset of RMC in NEC
Source: *2017 National Electric Code (NEC)*

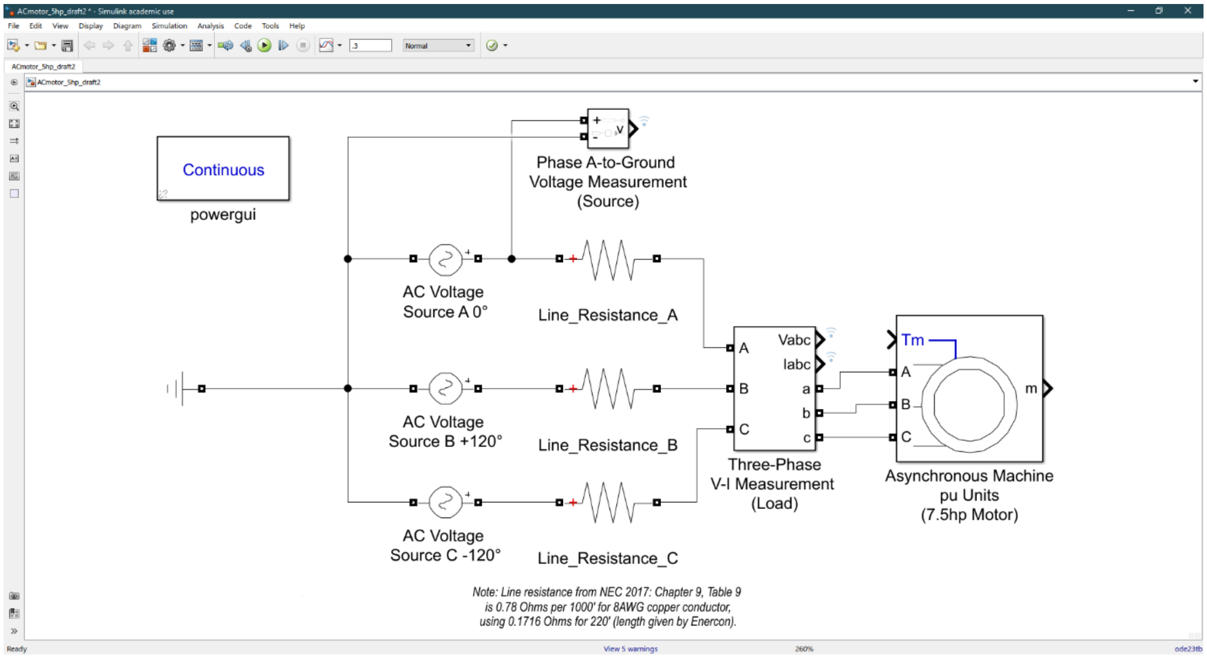
Figure 8: Conduit Trade Study

Chapter 7: Verification / Analysis / Simulations

The design group had to verify, analyze, and prove all evaluations. In this section each discipline lays out how the evaluations (described in the PAL 2.0) were verified and solved.

7.1 Electrical

A model was created in MATLAB SimScape Electrical to simulate in-rush current and voltage drop for 480VAC motor (Scope Removed in PAL2.0). This simulation allowed detailed evaluation of conductor size, which plays a significant role in this evaluation. The figures below highlight the SimScape schematic, initial inrush current, and initial voltage drop. Figure 9 shows the SimScape schematic setup. Each line resistance is simulated individually and measured phase-to-ground (phase-to-phase value can be easily derived from this):



Note: Line resistance from NEC 2017: Chapter 9, Table 9 is 0.78 Ohms per 1000' for 8AWG copper conductor, using 0.1716 Ohms for 220' (length given by Enercon).

Figure 9: MATLAB SimScape Schematic

Figure 10 shows simulated voltage and inrush current. Note that inrush current peaks at approximately 114 amperes. Per NEC standards, circuit protection should be rated for 125% of highest current value (discussed further in Electrical Conductor evaluation):

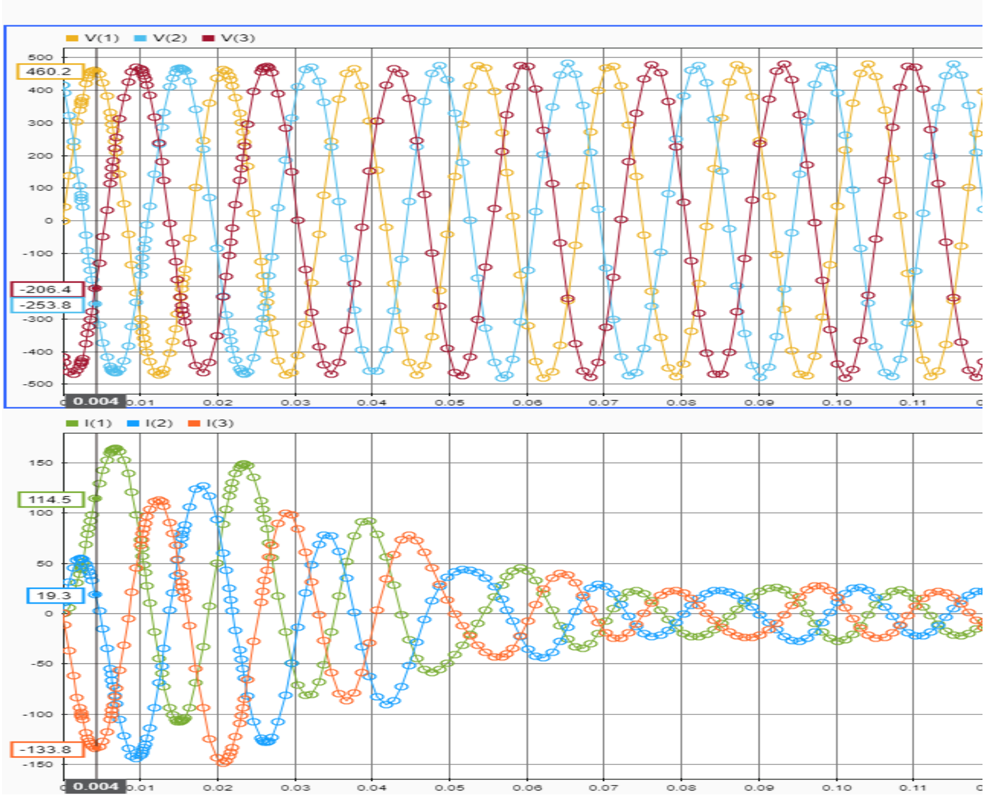


Figure 10: Inrush Current for Motor Startup Simulation

Figure 11 shows a voltage drop to approximately 468 volts (pink), with source voltage at approximately 480 volts (blue). The shaded green provides the range of allowable voltage gain/drop tolerance. This simulation demonstrates an acceptable voltage drop at startup:

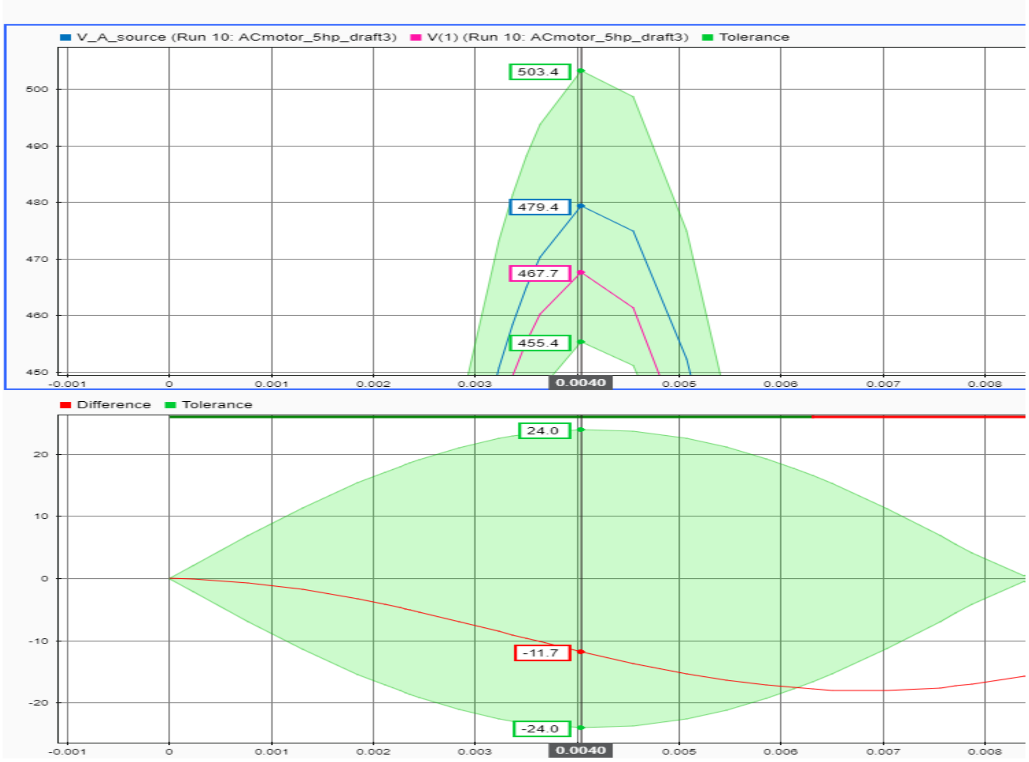


Figure 11: Voltage Drop for Motor Startup Simulation

7.2 Civil

The four types of pipe supports will be grouped based on the highest load present in the pump system and will be analyzed as 4 supports instead of 28. The analysis of the pipe supports using software is permitted apart from performing hand calculations for further verification. When evaluating the floor slab of the pump room, the rebar may need to be cut to allow core bores to be drilled into the slab. If that need arises then the senior design group will reevaluate the calculations on the slab.

7.3 Mechanical

To verify that the existing PSW can supply sufficient flowrate to the vacuum pump heat exchangers (HX's), the mechanical team is using Bernoulli's equation so solve for the velocity of water coming out of the HX.

To verify the PSW can supply sufficient cooling to the vacuum pump HX's, the LMTD method will be used. Through an iterative process, a calculated U-value (overall heat transfer coefficient) will be compared to that of the HX data sheet provided by ENERCON. By utilizing the values found in the HX data sheet such as the inlet and outlet temperatures, the mass flow rates for the seal liquid and cooling liquid, a U-value can be determined. Changes to the inlet temperatures of the cooling water or that of the seal liquid, will be slightly modified until the newly calculated U-value coordinates with that of the provided data sheet. From there, the supplied HX can be proven to work for the application.

Using Solidworks a concept model of water flow through the PSW from the 12" header to the 4" pipe that the HX's are designed for was drawn and simulated. The simulation still needs a lot of work. Correct input variables would need to be in place as well as a HX attached to the 4" pipe would need to be designed. ENERCON commented that for this scenario, a flow simulation is not needed (Figure 12).

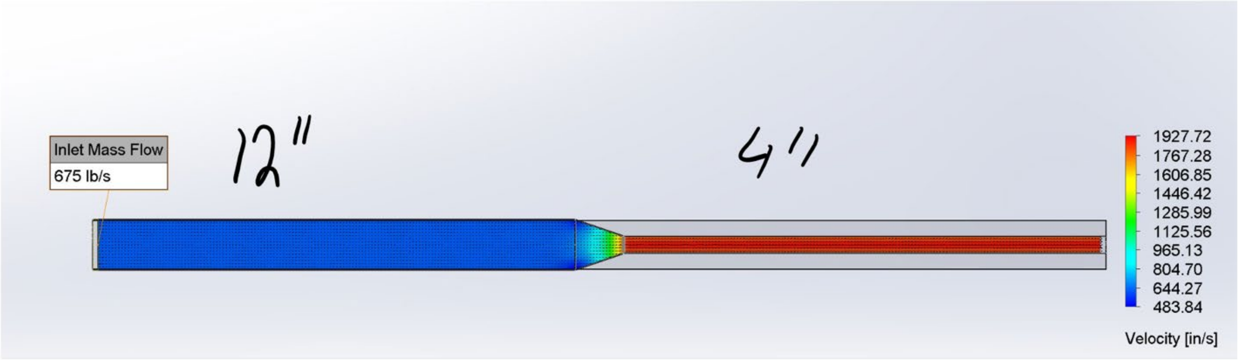


Figure 12: PSW water flow simulation.

Chapter 8: Completion to Date

Chapter 8 is a detailed list of all progress and changes made between the initial design review meeting and the critical design meeting.

8.1 Progress made up to Initial Design Review (IDR) – January 25, 2021

8.1.1 Electrical

1. Eleven markups have been documented (not yet approved by ENERCON).
2. Partial evaluations are complete, the remainder pending ENERCON input.

8.1.2 Civil

1. Existing supports have been analyzed seeing that the total loads, supplied by ENERCON, do not exceed the design loads of the existing support types.
2. The civil team met with Professor Kuemmerle and learned how to use RAM Elements to analyze and design the new pipe support types.
3. Floor loading evaluation for each additional new piece of equipment have been completed.

8.1.3 Mechanical

1. Two markups are completed.
2. Proposed pipe route for cooling water flow has been completed.
3. Isometric drawing in CAD has been completed.
4. Flow rate evaluation with all fittings and lengths of pipe and new throttling valve is 100% complete.
5. Heat exchanger adequacy evaluation is 100% complete.

8.2 Progress made up to Preliminary Design Review (PDR) – February 22, 2021

8.2.1 Electrical

The electrical team has successfully finished and submitted the 60% package and received great feedback. The team was overall congratulated but did have a few mistakes. The electrical team missed minor details explaining design input requirements and a few mathematical errors. Additionally, the new ENERCON electrical lead has tasked the SDG electrical team to create a succinct evaluation of the pump control scheme.

8.2.2 Civil

The civil team has completed and submitted all require markups and evaluations laid out in the PAL 2.0. There were some items that will need to be reevaluated to better convey the meaning of the evaluation. Like the electrical and mechanical teams there were some evaluations with unnecessary information.

8.2.3 Mechanical

The mechanical team has successfully completed all evaluations and markups that were laid out in the PAL 2.0. We did have some design inputs missing as well as unnecessary details in our evaluations. Some formatting issues were acknowledged as expected.

8.3 Progress made up to In Progress Review (IPR) – March 22, 2021

8.3.1 Electrical:

A controls evaluation was created for the 90% milestone to show the big picture view of this project and answer the question that, yes, the system will work as designed. To accomplish this, students have compiled in one control evaluation ("Controls Modification" evaluation) all the changes relating to the controls system: temperature, pressure, and level sensor updates; logic updates, including inputs and outputs; power source updates. The goal is to demonstrate that even though specifics on the system have changed (new pumps, new inputs, new power source), the overall functionality of a pump system controlled locally and remote will still pull the required vacuum and match the functionality described by the old system in schematic E-1150-006-016.

Additionally, comments were incorporated from ENERCON to address minor errors in electrical calculations, clarify phrasing, and overall improve the ECP for 90%. Examples of this include adding line-to-line calculations for voltage drop, not only line-to-ground. A markup on a control panel showed the incorrect control panel being removed – this was fixed, and the proper control room panel was updated. Phrasing throughout the 60% ECP was updated to show further progress on the project and clarify technical details.

8.3.2 Civil

Pipe support type 2 has been removed due to the lack of necessary inputs, but all other pipe supports remain approved by ENERCON. A new baseplate analysis method was shown to us by ENERCON which reflects the way baseplates are analyzed based on industry standards. This method still needs some work to be a fully finished product for our application that will be completed with the submittal of our final report. Formatting issues have been resolved as well to reflect the way that ENERCON wanted the Change Package formatted. Unnecessary calculations have been removed due to redundancy.

8.3.3 Mechanical:

Since the IPR the Mechanical team has made some adjustments to the hydraulic and cooling evaluations as well as some formatting updates.

The initial hydraulic evaluation used a website source to find the k value of a tee. The KSU mechanical team did not have the full CRANE technical paper that included the tee connection section. ENERCON commented the calculations should all come from the same source and provided the information necessary to adequately calculate tee connection head losses. While fixing these calculations, all design inputs and references were clearly called out in the evaluation bodies.

The mechanical team also performed a pressure vessel test on the chosen pipe schedule to ensure the pipes maximum tensile strength was not reached. The wrought stainless-steel schedule 40 pipe that was chosen has a max tensile strength of 16,000 psi. Calculating the hoop and axial stresses determined that with the systems conditions, the schedule 40 pipe chosen is adequate for the new system. Using formulas in ASME B31.1 the minimum wall thickness for the pipe was also calculated to be 0.0239 inches. The pipes actual wall thickness is 0.237 inches providing a factor of safety of 9.9.

8.4 Completion of Project for Final Design Review (FDR) – April 26, 2021

All evaluations and markups have been completed and submitted and accepted by ENERCON.

Chapter 9: Challenges Faced

This section lays out how each individual discipline faced numerous and different challenges. With such a large team for a senior design group the challenges have been unique for this sizable industrial project.

9.1 Electrical

The lead ENERCON electrical engineer, Shawn Sinclair, moved to a unique entrepreneurship opportunity just one week before the 60% milestone was due. While wishing him continued success, he left a major gap in what was needed to complete the 60% target. The electrical team was left short several drawings and continued input for evaluations.

The SDG (all disciplines) had hoped to visit the plant in person for a site tour. Unfortunately, with current restrictions, this was unable to happen. Some of us feel we would have greater initial understanding of the project with the visual inspection that most other engineers would have gotten when assigned this project.

When specifications were needed for various electrical equipment, vendors were hesitant to supply students with information. Repeated phone calls and emails either had no reply or very slow responses.

9.2 Civil

Of the four new pipe supports, support #2 included a member and design loads along the z axis of the elevation drawings that needed to be analyzed as a force and moment of a point. This is a key part of finding the dimensions of member 2 along the z- and x- axis.

When attempting to complete the new pipe support evaluations, several new topics were introduced to the civil team. Some of these challenges include but are not limited to learning how to evaluate a baseplate that is not a column baseplate in combination with HSS, learning how to evaluate concrete slabs when cutting rebar, and reading old drawings with very little information included on said drawings.

9.3 Mechanical

Mechanical team was faced with needing to reduce water flow to vacuum pump HX. The team chose to use a v-port plug valve for a throttling device. Initially team performed hydraulic calculations using 6” schedule 40 pipe, but this was causing the valve to underperform in restricting the flow of water. According to calculations, the v-port valve would have needed to be nearly closed to limit the flow rate to the requirement of 350 GPM. According to engineers at ENERCON, they recommended the valve’s percent-open to be near 50%.

Chapter 10: Overcoming the Challenges

Chapter 10 describes several challenges each discipline faced over the course of 2 semesters. To move forward, the team found creative ways to solve the problems and move forward successfully (and perhaps with adjusted expectations).

10.1 Electrical

As Shawn Sinclair, the main electrical engineer of ENERCON assisting with the project left, we needed to seek additional help. The assisting engineer was extremely helpful, but the amount of work he was being asked to do was unfair. Luckily ENERCON assigned another senior engineer who had more experience with this project. At first the team thought it would be a rough transition, but the new engineer has been a great help with the project. Although unable to provide a site tour, Shawn Sinclair and "Kaz" Costa were able to share some photographs of a similar control room to assist the electrical team with visuals. Regarding procuring equipment specifications, the electrical team was able to reach out to a vendor and received all the necessary documents from two helpful sales engineers. The challenge of finding a vendor willing to work with students on a senior design project didn't overly complicate the project. We were able to find the necessary breaker and wire sizing thanks to Nick at EMR Associates.

10.2 Civil

With all the information readily available on the internet through articles and reports, the civil team was able to learn how to evaluate niche aspects of steel design such as baseplates used in pipe support design. Using our textbooks, we were also able to learn how to evaluate concrete slabs when cutting rebar and installing penetrations. Looking back to our statics class we were also able to use the principle that the sum of forces in any direction, along with moment, should be equal to zero which we could then apply to solve the more complex forces in pipe support which included forces in 3 dimensions. The AISC manual was also of great use to us as it gave us a starting point when looking for answers on how to design some of the steel members that we had not encountered before that were used in the design of the new pipe supports.

10.3 Mechanical

The mechanical team overcame the challenge of the v-port valve flow restriction by sizing down to a 4" valve and changing to a standard plug valve instead. Making these changes resulted in the plug valve restricting the flow to 350 GPM at 68% rotation. Changing to a 4" schedule 40 pipe for the entire pipe route after teeing off 12" main header also saves cost that would be spent on reducers and expanders if a 6" valve was installed, since the HX inlet is requires a 4" pipe.

Chapter 11: Markups and Evaluations

This chapter highlights the calculations and markups of documents for the KSU SDG to provide ENERCON (the client) with a completed Engineering Change Package EC-001. All calculations and markups are complete along with references to effectively display the changes needed to implement the mechanical vacuum pumps into ENERCON Station. The markups and evaluations listed below are split up between discipline.

11.1 Electrical

11.1.1 Cable Ampacity Evaluation

The electrical team recommends using 500kcmil or equivalent conductor provides a sufficient ampacity limit of 535 amperes to the 4160VAC 400hp motor in a locked rotor condition. This is adequate for the size of the motor and amperage requirements per NEC 210.19 and NEC 310.60. The calculation is shown below in Figure 13:

$$Safety\ margin\ rating = locked\ rotor\ current \times 125\%$$

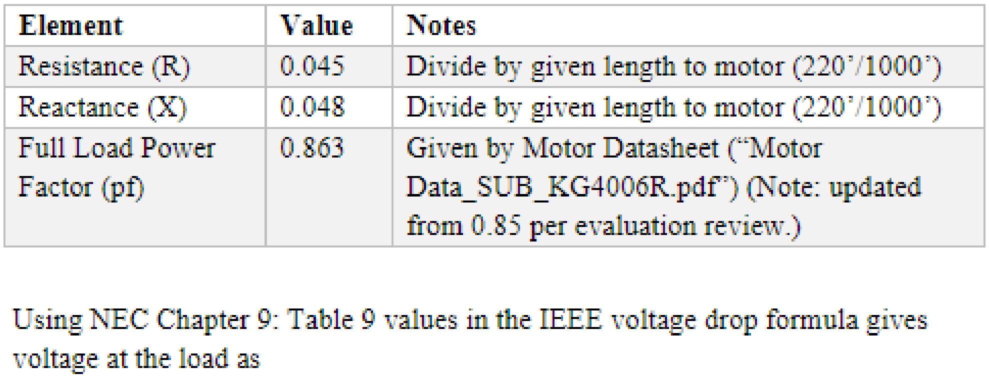
$$Safety\ margin\ rating\ = 346.000\ amps \times 1.250$$

$$Safety\ margin\ rating = 432.500\ amps$$

Figure 13: Cable Ampacity calculation

11.1.2 Voltage Drop Evaluation

Voltage drop calculated using conductor specification 500kcmil Type MV-105 conductor or equivalent cable is 9.732 volts drop line-to-line (0.234%). This is within the 5% allowable tolerance for voltage drop. This is adequate for the size of the motor and amperage requirements per NEC 210.19 and NEC 310.60. Figure 14 shows resistance and reactance values given in the NEC:



Element	Value	Notes
Resistance (R)	0.045	Divide by given length to motor (220'/1000')
Reactance (X)	0.048	Divide by given length to motor (220'/1000')
Full Load Power Factor (pf)	0.863	Given by Motor Datasheet ("Motor Data_SUB_KG4006R.pdf") (Note: updated from 0.85 per evaluation review.)

Using NEC Chapter 9: Table 9 values in the IEEE voltage drop formula gives voltage at the load as

Figure 14: Voltage drop specifications

$$V_{Load} = 4154.381\, VAC$$

The amount of total voltage drop to neutral (volts) is determined by

$$V_{Drop-to-Neutral} = V_{MCC} - V_{Load}$$

$$V_{Drop-to-Neutral} = 4160.000 - 4154.381$$

$$V_{Drop-to-Neutral} = 5.619 VAC$$

To find 3ϕ line-to-line voltage drop, multiply $V_{\text{Drop-to-Neutral}}$ by $\sqrt{3}$ (cf. Okonite Engineering Handbook, 2018 Edition, Page 12):

$$V_{Drop\ Line-to-Line} = V_{Drop-to-Neutral} \times \sqrt{3}$$

$$V_{Drop\ Line-to-Line} = 5.619 \times \sqrt{3}$$

$$V_{Drop\ Line-to-Line} = 9.732 VAC$$

$$V_{Drop\ Line-to-Line}\% = \left|\frac{V_{Load\ Line-to-Line} - V_{MCC}}{V_{MCC}}\right| \times 100\%$$

$$V_{Drop\ Line-to-Line}\% = \left|\frac{\left(V_{MCC} - V_{Drop\ Line-to-Line}\right) - V_{MCC}}{V_{MCC}}\right| \times 100\%$$

$$V_{Drop\ Line-to-Line}\% = \left|\frac{(4160.000 - 9.732) - 4160.000}{4160.000}\right| \times 100$$

$$V_{Drop}\% = 0.234\%$$

Figure 15: Voltage drop calculation

11.1.3 Conduit Sizing Evaluation

The conduit shall be a trade size 3 or metric 78 and carry no more than three total conductors of 500kcmil cable. Rigid Metal Conduit (RMC) shall be used as to match existing equipment. The calculation is shown in Figure 16 below:

$$Cross - section\ area\ (three\ conductors) = area\ one\ conductor\ \times 3$$
$$Cross - section\ area\ (three\ conductors) = 253.000\ mm^2\ \times 3$$
$$Cross - section\ area\ (three\ conductors) = 759.000\ mm^2$$

NEC Chapter 9 – Table 1 restricts total cross-sectional area of more than two conductors in conduit to 40% conduit fill. Finding the total allowable conduit cross-sectional area is given by

$$Total\ allowable\ cross - sectional\ area\ = \frac{total\ conductor\ area}{40\%}$$

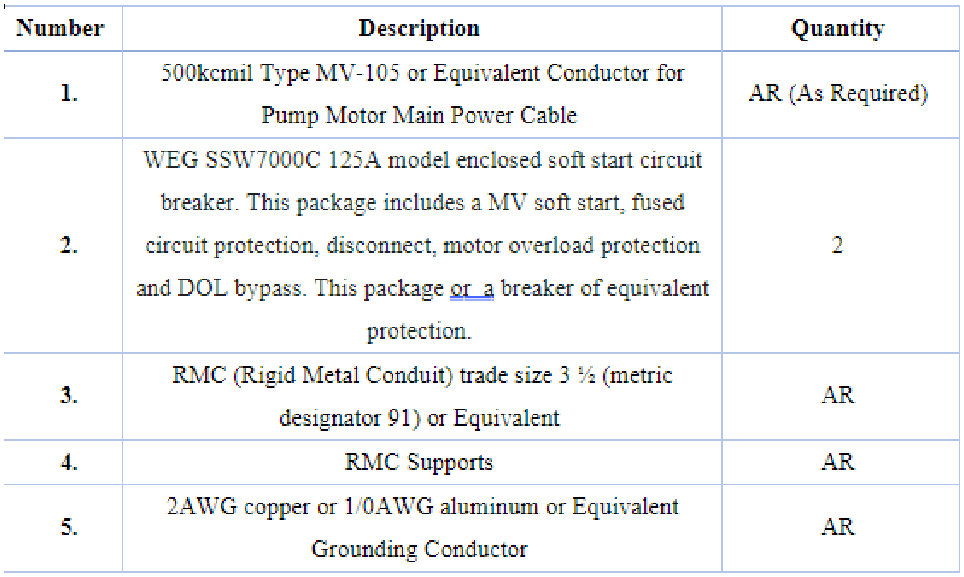
$$Total\ allowable\ cross - sectional\ area\ = \frac{759.000}{.400}$$

$$Total\ allowable\ cross - sectional\ area\ = 1897.500\ mm^2$$

Figure 16: Conduit size calculation

11.1.4 Electric Bill of Materials Evaluation

The electric Bill of Materials is the components gathered from all evaluations and shown below in Figure 17:



Number	Description	Quantity
1.	500kcmil Type MV-105 or Equivalent Conductor for Pump Motor Main Power Cable	AR (As Required)
2.	WEG SSW7000C 125A model enclosed soft start circuit breaker. This package includes a MV soft start, fused circuit protection, disconnect, motor overload protection and DOL bypass. This package or a breaker of equivalent protection.	2
3.	RMC (Rigid Metal Conduit) trade size 3 ½ (metric designator 91) or Equivalent	AR
4.	RMC Supports	AR
5.	2AWG copper or 1/0AWG aluminum or Equivalent Grounding Conductor	AR

Figure 17: Electrical Bill of Materials

11.1.5 Grounding Evaluation

All components of the system must be properly grounded as per NEC 250.4, NEC 430.241, IEEE Std 142-1991, and ANSI/IEEE C2-2012. All unaltered components should be thoroughly checked to ensure proper grounding per NEC guidelines.

11.1.6 Short Circuit Protection Evaluation

A WEG SSW7000C breaker or equivalent 125A model enclosed soft start is recommended for this application. This package includes a MV soft start, fused circuit protection, disconnect, motor overload protection and DOL bypass.

Circuits shall all be tested prior to startup per National Electric Code 2017 (NEC) 110.7 to ensure the system is clear of any short circuit scenarios.

This section is under an extended feedback period by ENERCON and will be updated by the next submittal date.

11.1.7 Circuit Protection and Coordination Evaluation

Conductors are rated to support 125% of highest load per NEC 210.20(A) (see also "SDG.CA-EC001 Cable Ampacity Evaluation"). Highest transient load occurs at locked rotor condition (346 amperes per motor datasheet), and highest continuous load occurs at full load condition (50.50 amperes per motor datasheet).

Circuit protection includes a circuit breaker at the Motor Control Center (MCC) programmed to trip at no less than 125% of full load current (63.125 amperes) and no more than 300% of full load current (151.5 amperes).

Each 4160VAC 300hp motor shall be placed on independent 4160VAC electrical buses and the bus service conductors shall be rated for the increased loading. A WEG SSW7000C breaker or equivalent 125A model enclosed soft start is recommended for this application. This package includes a MV soft start, fused circuit protection, disconnect, motor overload protection and DOL bypass.

11.1.7 Circuit Protection and Coordination Evaluation

New pump system will not require all implementations of old system but will function to create a vacuum in the plant. The new vacuum pump uses a more advanced technology using different controls; however, the system will still achieve the same task as the old system.

The new system shall include all controls and permissives from the drawing E-1105-006-016. Functionality has slightly changed, but pumps will still draw down vacuum as originally intended.

11.1.8 One Line Diagram Markups

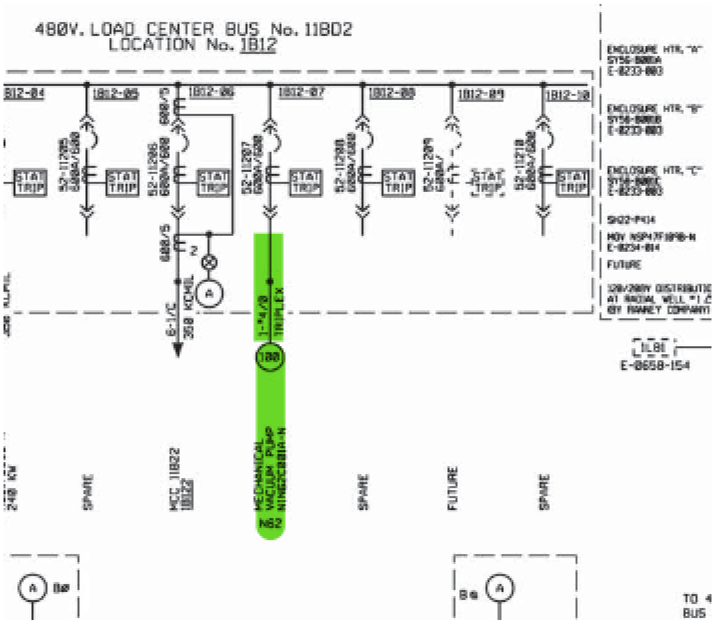


Figure 18: Capture from E0018

Figure 18 above shows the 480VAC motor (A) is removed from drawing E0018, this was done per the PAL to incorporate the new 4160VAC motors. The old 480VAC motors A, B, and C must be deleted from the drawings to implement the new system. The space where the motor was shall be left as spare.

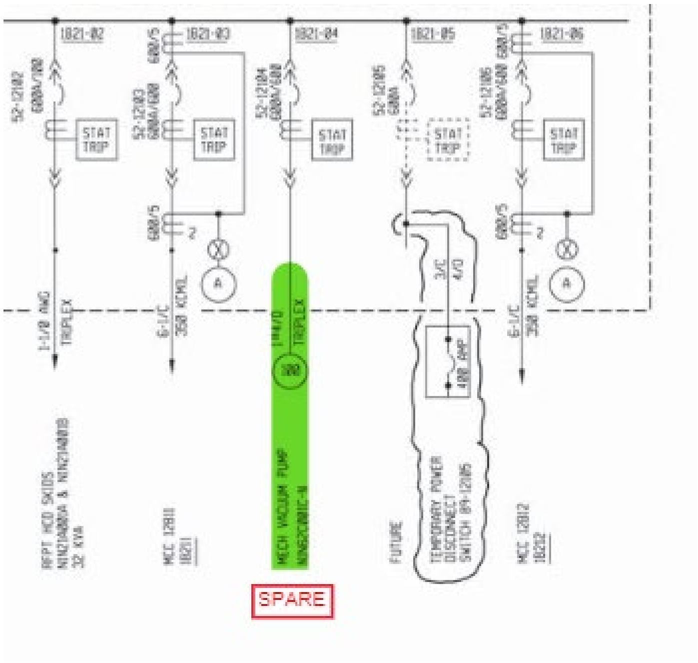


Figure 19: Capture from E0012

Figure 19 above shows the 480VAC motor (C) is removed from drawing E0012, this was done per the PAL to incorporate the new 4160VAC motors. The old 480VAC motors A, B, and C must be deleted from the drawings to implement the new system. The space where the motor was shall be left as spare. The space where the motor was shall be left as spare.

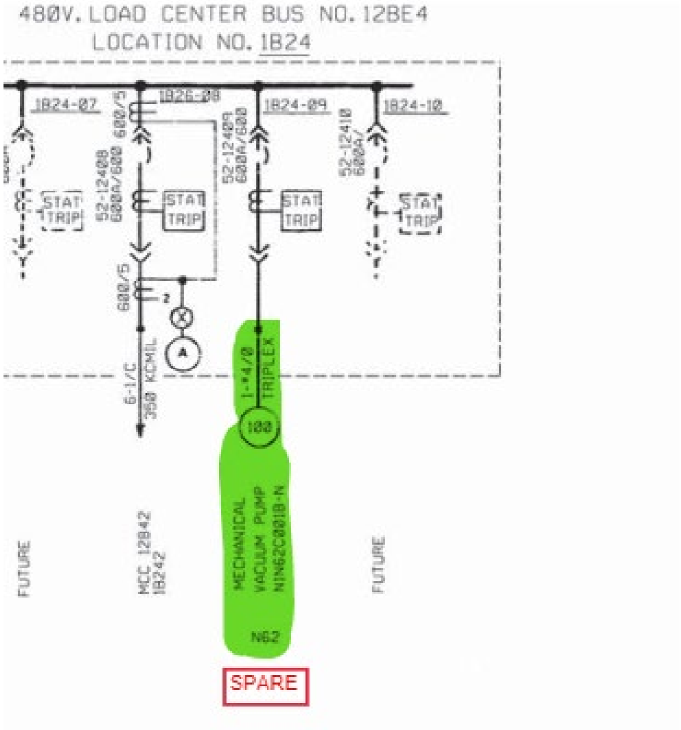


Figure 20: Capture from E0016

Figure 20 above shows the 480VAC motor (B) is removed from drawing E0016, this was done per the PAL to incorporate the new 4160VAC motors. The old 480VAC motors A, B, and C must be deleted from the drawings to implement the new system. The space where the motor was shall be left as spare.

11.1.9 P&IDs Markup

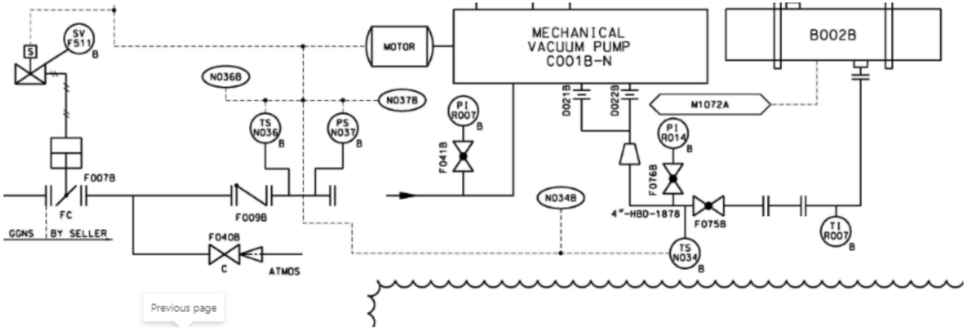
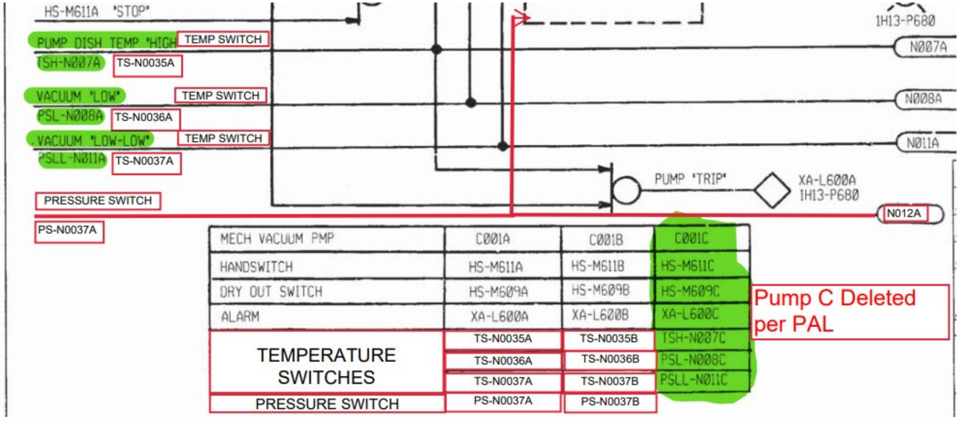


Figure 21: Capture from M1060B

Figure 21 above shows the mechanical Pin ID M1060B has been supplied by vendor and remains unedited by the electrical SDG. The drawing has been reviewed by the electrical team and is approved for submittal. The solenoids removed from drawings SDG.E1150-006-016 and are correctly reflected here on this drawing.

11.1.10 Logic Diagram Markups



MECH VACUUM PMP	C001A	C001B	C001C
HANDSWITCH	HS-M611A	HS-M611B	HS-M611C
DRY OUT SWITCH	HS-M609A	HS-M609B	HS-M609C
ALARM	XA-L600A	XA-L600B	XA-L600C
TEMPERATURE SWITCHES	TS-N0035A	TS-N0035B	TSH-N007C
	TS-N0036A	TS-N0036B	PSL-N008C
	TS-N0037A	TS-N0037B	PSLL-N011C
PRESSURE SWITCH	PS-N0037A	PS-N0037B	

Figure 22: Capture from J1218-004

Figure 22 above shows the logic drawing J1218-004 has been implemented per the PAL. The pump C has been deleted along with the various breakers and connections.

11.1.11 Schematic Markup

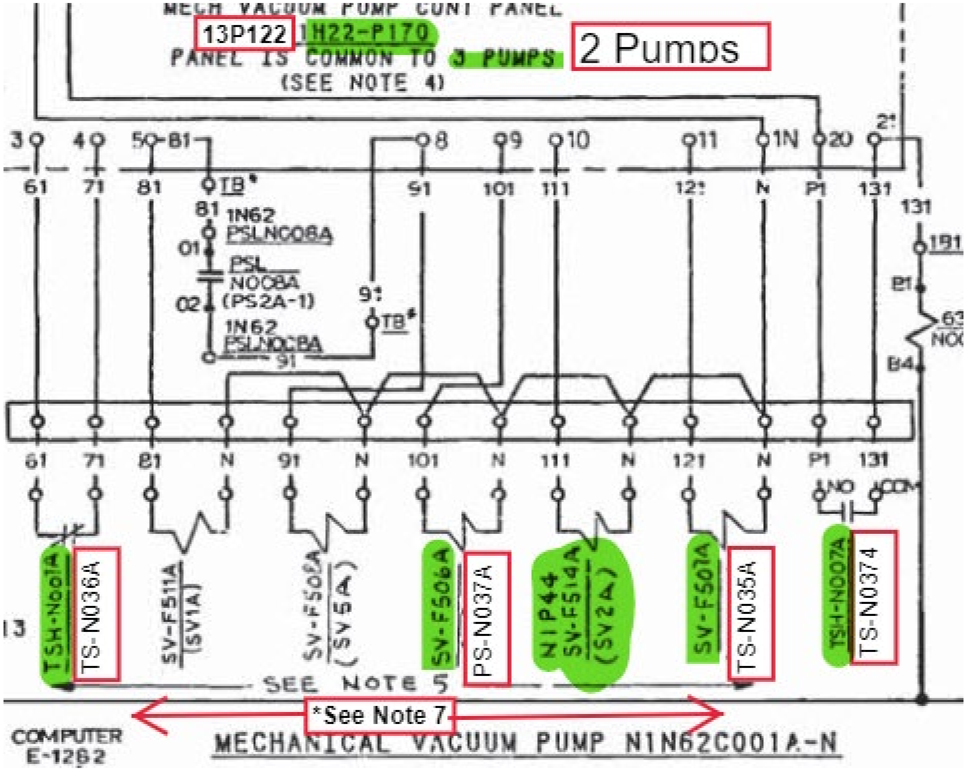
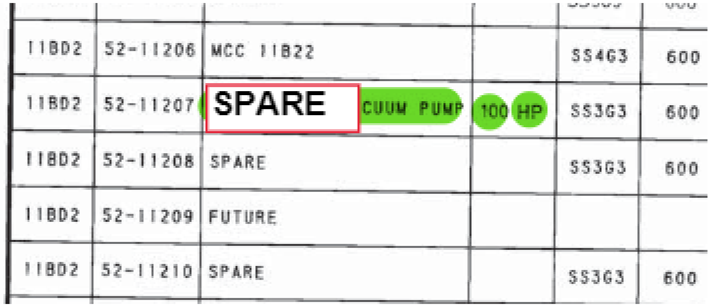


Figure 23: Capture from E1150_006_016

Figure 23 above shows the drawing E1150_006_016 shows how the existing 480VAC motor is implemented. The breaker name remains the same for Mechanical Vacuum pumps A and B. Per the PAL the 480VAC motors are removed as well as the three solenoids that will no longer be used. Solenoids SV-F506A, SV-F514A, and SV-F507A are removed per the mechanical drawing

M1060B and the PAL. The third mechanical vacuum pump name and related breakers are deleted from the drawing. The incoming power source of 480VAC is changed to a 4160VAC power source per the PAL.

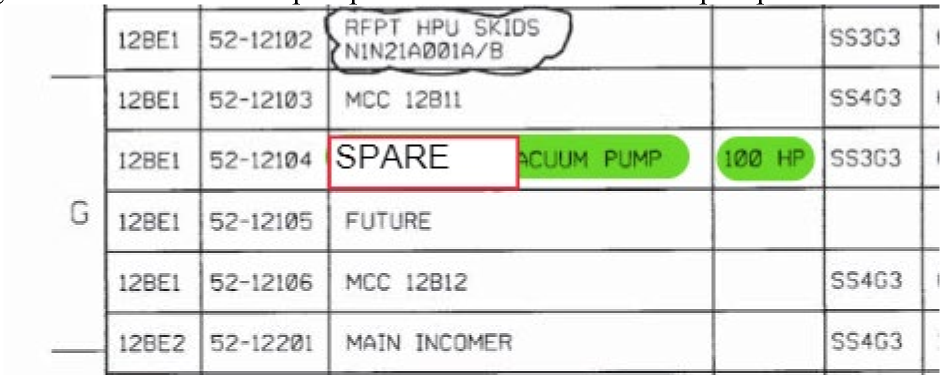
11.1.12 Load Tabulations Markup



11BD2	52-11206	MCC 11B22		SS4G3	600
11BD2	52-11207	SPARE CUUM PUMP	100 HP	SS3G3	600
11BD2	52-11208	SPARE		SS3G3	600
11BD2	52-11209	FUTURE			
11BD2	52-11210	SPARE		SS3G3	600

Figure 24: Capture from E1020-17

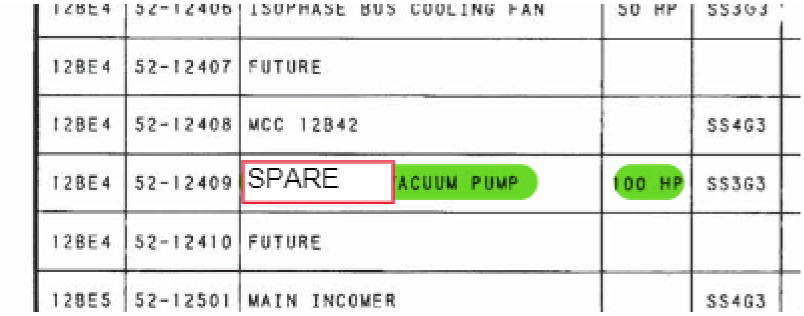
Figure 24 above shows drawing E1020-17 displays a summary of existing 480VAC load centers. The mechanical vacuum pump is removed as per KSU PAL. This is done as the new system will be replacing the 480VAC vacuum pumps with 4160VAC vacuum pumps.



12BE1	52-12102	RFPT HPU SKIDS N1N21A001A/B		SS3G3
12BE1	52-12103	MCC 12B11		SS4G3
12BE1	52-12104	SPARE ACUUM PUMP	100 HP	SS3G3
12BE1	52-12105	FUTURE		
12BE1	52-12106	MCC 12B12		SS4G3
12BE2	52-12201	MAIN INCOMER		SS4G3

Figure 25: Capture from E1020-21

Figure 25 above shows drawing E1020-20 displays a summary of existing 480VAC load centers. The mechanical vacuum pump is removed as per KSU PAL 2.0. This is done as the new system will be replacing the 480VAC vacuum pumps with 4160VAC vacuum pumps.



12BE4	52-12406	ISOPHASE BUS COOLING FAN	50 HP	SS3G3
12BE4	52-12407	FUTURE		
12BE4	52-12408	MCC 12B42		SS4G3
12BE4	52-12409	SPARE ACUUM PUMP	100 HP	SS3G3
12BE4	52-12410	FUTURE		
12BE5	52-12501	MAIN INCOMER		SS4G3

Figure 26: Capture from E1020-21

Figure 26 above shows drawing E1020-21 displays a summary of existing 480VAC load centers. The mechanical vacuum pump is removed as per KSU PAL. This is done as the new system will be replacing the 480VAC vacuum pumps with 4160VAC vacuum pumps.

11.2 Civil

11.2.1 Existing Pipe Support Evaluation

The table below shows the actual load applied to each of the existing pipe supports as well as the design load for each existing pipe support. Comparison of the actual load to the design load for each of the existing pipe supports shows that none of the actual loads exceed that of the design loads which have a factor of safety implemented in their calculation.

Table 5: Required loads and design loads on existing pipe supports in the plant.

Support	Support Type	Iso Drawing	Direction	Actual Load (lbs)	Design Load	Load Within Design Load
Existing Support 1	N/A	M-1329B	Y	-2246	2800	YES
Existing Support 2	N/A	M-1329B	Y	-1185	2800	YES
Existing Support 3	N/A	M-1329B	Y	-1332	2800	YES
Existing Support 4	N/A	M-1329B	Y	-592	1200	YES
Existing Support 5	N/A	M-1329B	Y	-2120	2800	YES
Existing Support 6	N/A	M-1329B	Y	-2202	2800	YES
Existing Support 7	N/A	M-1329B	Y	-2156	2800	YES
Existing Support 8	N/A	M-1329B	Y	-2235	2800	YES
Existing Support 9	N/A	M-1329E	Y	-2417	3000	YES
Existing Support 10	N/A	M-1329E	Y	-1440	2250	YES

11.2.2 Floor Loading Evaluation

The floor slabs on elevations 113’ and 133’ in the plant both have an allowable load of 350 psf. The approximate area that the pump skid takes up is 182.66 ft^2. Taking the assumption that the pumps will be running at full capacity gives a pump weight of 56,800 lbs per Table 6 below. This table was provided on the pump schematic given to the SDG by ENERCON.

Table 6: Pump Weight Under Various Conditions

Weight Chart	
COMPONENT	WEIGHT (lbs)
TOTAL SYSTEM –EMPTY	40,000
TOTAL SYSTEM - FULL	56,800
PUMP SKID - EMPTY	28,500
PUMP SKID - FULL	35,500
SEPERATOR SKID - EMPTY	11,500
SEPERATOR SKID - FULL	21,300
INLET PIPING	2,150
INLET MANIFOLD	875
PUMP	13,500
PUMP SKID BASE	5,250
MOTOR	5,275
SEPERATOR EMPTY	5,500
SEPERATOR SKID BASE	3,100
HEAT EXCHANGER	1,011

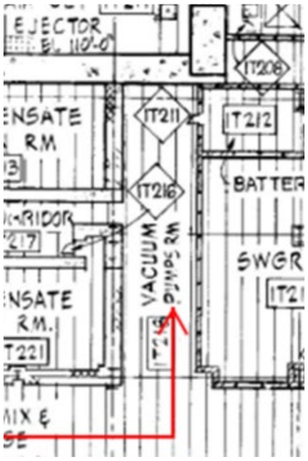


Figure 27: Drawing Location for the Pumps

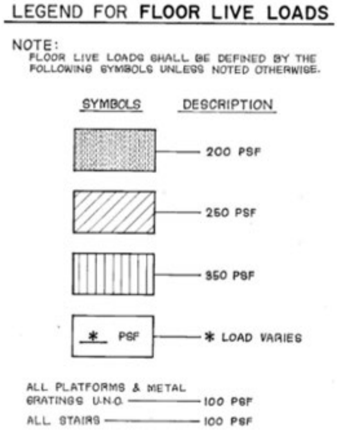


Figure 28: Legend for the Floor Live Loads

Calculation of pump load will apply to floor slabs when installed and running at full capacity

$$Area\ of\ Pump, A_p = 182.66\ ft^2$$

$$Weight\ of\ Pump\ Full, W_{P(Full)} = 56{,}800\ lbs$$

$$Total\ Load\ Pump\ Will\ Apply\ to\ Floor, L_p = \frac{56800\ lbs}{1822.66\ ft^2} = 310.96\ psf$$

This evaluation shows that when installed and running at full capacity the pump will not exceed the allowable floor load of 350 psf. Although the applied load is close to that of the allowable floor load, it is within specification according to ENERCON's standards.

11.2.3 Heavy Haul Path Evaluation

The figure below shows the Heavy Haul Path in which the pump will be brought to the pump room from the equipment hatches on elevations 113' and 133'. It is to be noted that the haul path layout is the same on both elevations and the allowable floor loading, 350 psf per Figure 29, is the same on both elevations. It is assumed that the pump is transported empty and that the pump is transported all at one time on each elevation.

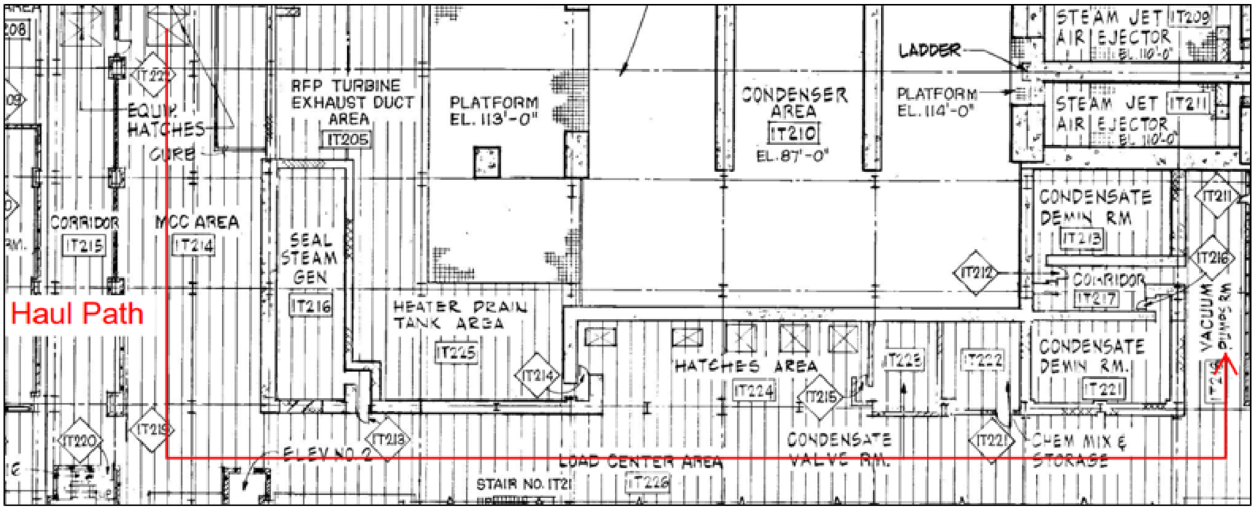


Figure 29: Heavy Haul Path on Elevation 113'

Calculation of Floor Loading on Heavy Haul Path Route

$$Area\ of\ Pump, A_p = 182.66\ ft^2$$

$$Weight\ of\ Pump\ Empty, W_{P(Empty)} = 40{,}000\ lbs$$

$$Total\ Load\ Pump\ Will\ Apply\ to\ Floor, L_p = \frac{40000\ lbs}{182.66ft^2} = 218.98\ psf$$

This evaluation shows that when being transported the pump applies 218.98 psf to the floor if transported in one piece. This pump load is the same for each elevation. This means that the pump load does not exceed the allowable floor load of 350 psf and allows the transportation vehicle to be at maximum, 131.02 psf.

11.2.4 New Penetration Evaluation

11.2.4.1 Hidden Commodities Assessment

Three new core bore penetrations in Figure 34 needed to be evaluated at elevation 133'. The core bore penetrations are made to allow the piping to run up through the slab from elevation 113'. Adding these penetrations requires a hidden commodities assessment to see what elements in the slab are impacted by the core bores. The evaluation of the hidden commodities returned the following impacted elements that need to be remediated:

- Core Bore 1:
    - Electrical Items Impacted:
        - DRWC78
        - INI9/P K012
        - DRNE15

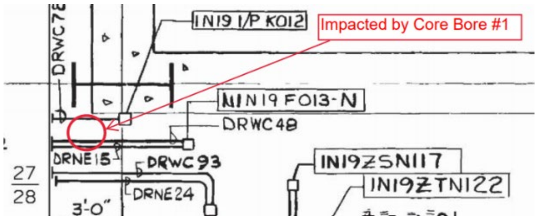


Figure 30: Electrical Items Impacted by Core Bore 1

- Mechanical Items Impacted:
    - ¾" vent

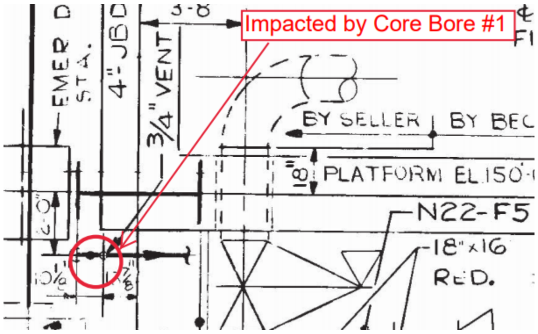


Figure 31: Mechanical Items Impacted by Core Bore 1

- Core Bore 2:
    - No items impacted

- Core Bore 3:
  - Electrical Items Impacted
    - #210 AWG

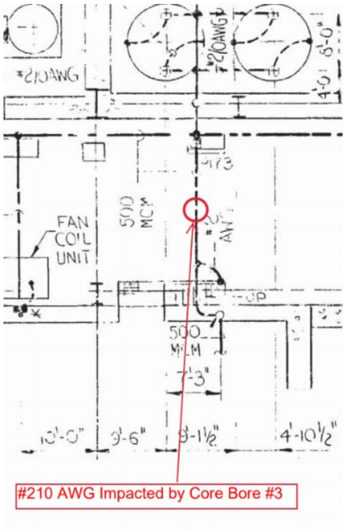
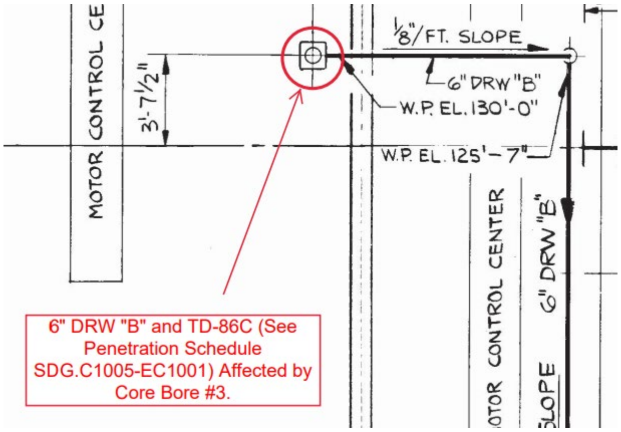


Figure 32: #210 AWG Impacted by Core Bore 3

  - Mechanical Items Impacted
    - Drainpipe: 6" DRW "B"
    - Penetration TD-86C: penetration for the 6" drainpipe.



6" DRW "B" and TD-86C (See Penetration Schedule SDG.C1005-EC1001) Affected by Core Bore #3.

Figure 33: Impacted Drainpipe and Penetration by Core Bore 3

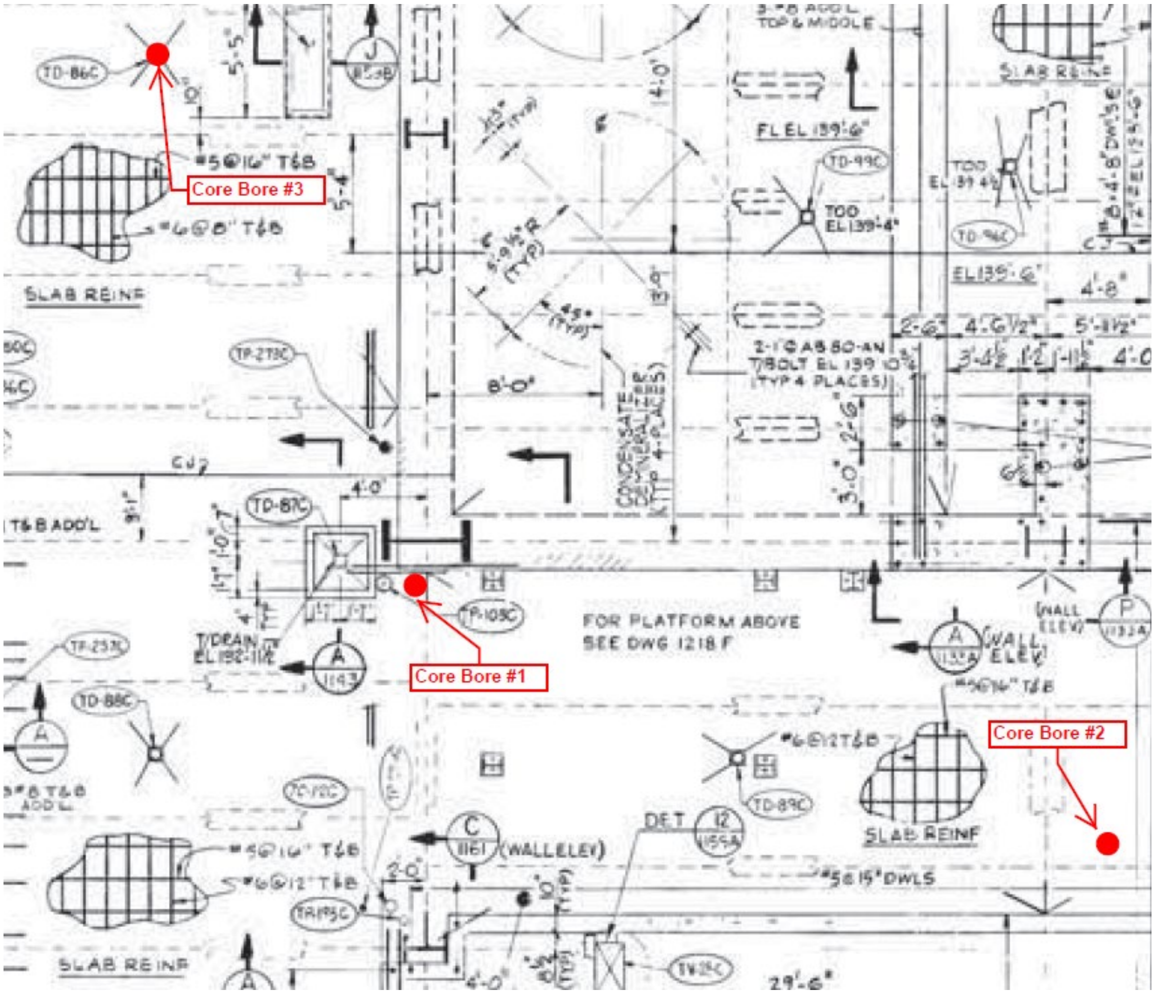


Figure 34: Core Bore Penetrations on Elevation 133'

11.2.4.2 Cutting of Rebar

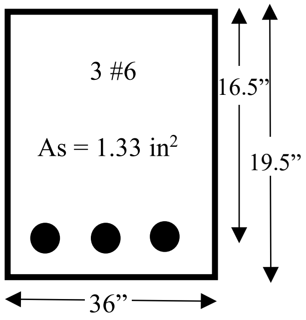
Core bore #1 and #3 does not require an evaluation of the rebar due to both penetrations being 4 in. in diameter with #6 @ 8 in. flexural reinforcement and temperature reinforcement with. #5 @ 16 in. on top and bottom of the slab. Core bore #2 requires its penetration to be 12 in. in diameter which would require the cutting of rebar within the floor slab.

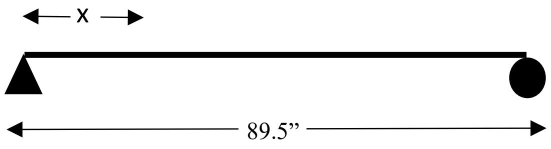
Because the flexural reinforcement is spaced #6 @ 12 in., the cutting of rebar is necessary by analyzing the floor slab as a reinforced concrete beam. Instead of the beam being analyzed at 12 in. in width per ACI standard, the beam should be analyzed at least 36 in. in width to model a beam with 3 steel reinforced bars in the section cut. The cutoff point within the slab is already known and estimated based on the structural framing plans for El. 133' shown in Figure 35.

By going through the bar selection process with a theoretical area of steel, As, the design moment capacity, ϕM_n, could be checked against the ultimate moment capacity, Mn, when assuming that one bar is cut 12 in. in the floor slab.

Although there is reinforcement embedded in the top and bottom of the slab, the top reinforcement does not contribute enough change in moment to affect the overall results when cutting rebar.

Based on the evaluations below, one steel bar needs to be cut for the new penetration of core bore #2. After cutting one steel bar of flexural reinforcement in the middle of the slab section shown below, the floor slab is still able to maintain itself with the small loss of reinforcement.





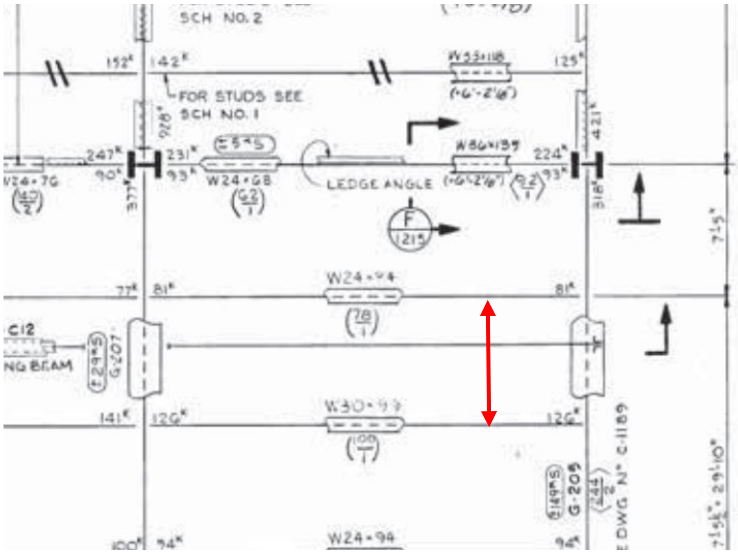


Figure 35: Steel Framing Plan of El. 133'

Normal Weight Concrete, f”c = 4 ksi

A36 Steel, fy = 60 ksi

Flexural Reinforcement - #6 @ 12” Top & Bottom

3 bars

$$\mathrm{a} = \frac{(1.33\ \mathrm{in}^2)(60\ \mathrm{ksi})}{0.85\ (4\ \mathrm{ksi})(36\ \mathrm{in})} = 0.652\ \mathrm{in.}$$

$$\text{Design Moment Capacity}, \phi M_n = \ (0.9)(1.33\ \mathrm{in}^2)(60\ \mathrm{ksi})\left(16.5\ \mathrm{in.} - \frac{0.652\ \mathrm{in}}{2}\right)$$
$$= 1161.62\ \mathrm{k-in} = 96.8\ \mathrm{k-ft}$$

2 bars (1 bar cut off)

$$\mathrm{a} = \frac{(0.88\ \mathrm{in}^2)(60\ \mathrm{ksi})}{0.85\ (4\ \mathrm{ksi})(36\ \mathrm{in})} = 0.43\ \mathrm{in.}$$

$$\text{Design Moment Capacity}, \phi M_n = \ (0.9)(0.88\ \mathrm{in}^2)(60\ \mathrm{ksi})\left(16.5\ \mathrm{in.} - \frac{0.43\ \mathrm{in}}{2}\right)$$
$$= 773.83\ \mathrm{k-in} = 64.5\ \mathrm{k-ft}$$

$$w_u\ (\mathrm{b} = 12\ \mathrm{in}) = 1.4\left(\frac{19.5\ in}{12\ {}^{in}/_{ft}}\right)(150\ \mathrm{psf}) + 1.7(350\ \mathrm{psf}) = 936.25\ \mathrm{psf} = 0.936\ \mathrm{ksf}$$

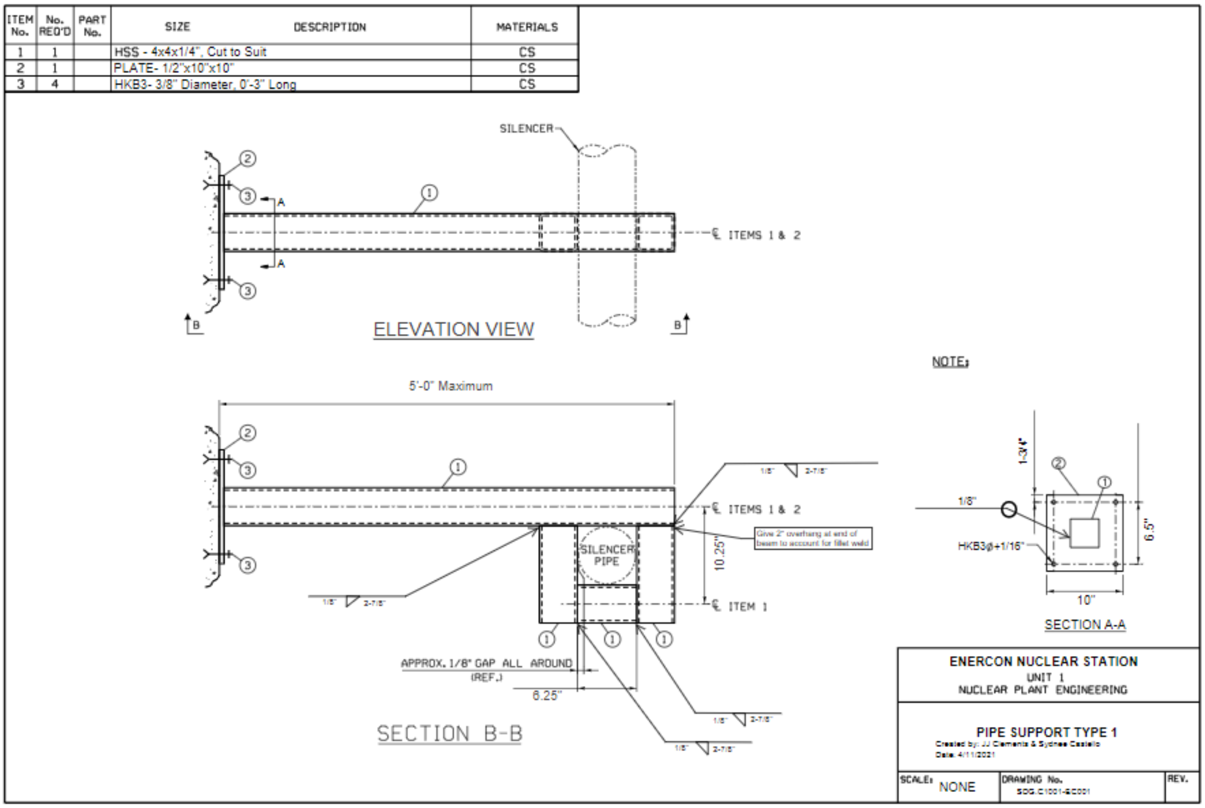
$$w_u\ (\mathrm{b} = 36\ \mathrm{in}) = \ (0.936\ \mathrm{ksf})(3\ ft) = 2.808\frac{k}{ft}$$

$$\text{Ultimate Moment Capacity}, \mathrm{M_u} = \frac{\left(2.808\frac{k}{ft}\right)\left(\frac{89.5\ in}{12\frac{in}{ft}}\right)^2}{8} = 19.52\frac{k}{ft}$$

Mu =19.52 k-ft < 64.49 k-ft $\therefore OK$

11.2.5 Pipe Support Type 1 Markup

The figure below shows the Pipe support type 1 markup including all dimensions. The HSS has been sized as well as the baseplate and bolts.

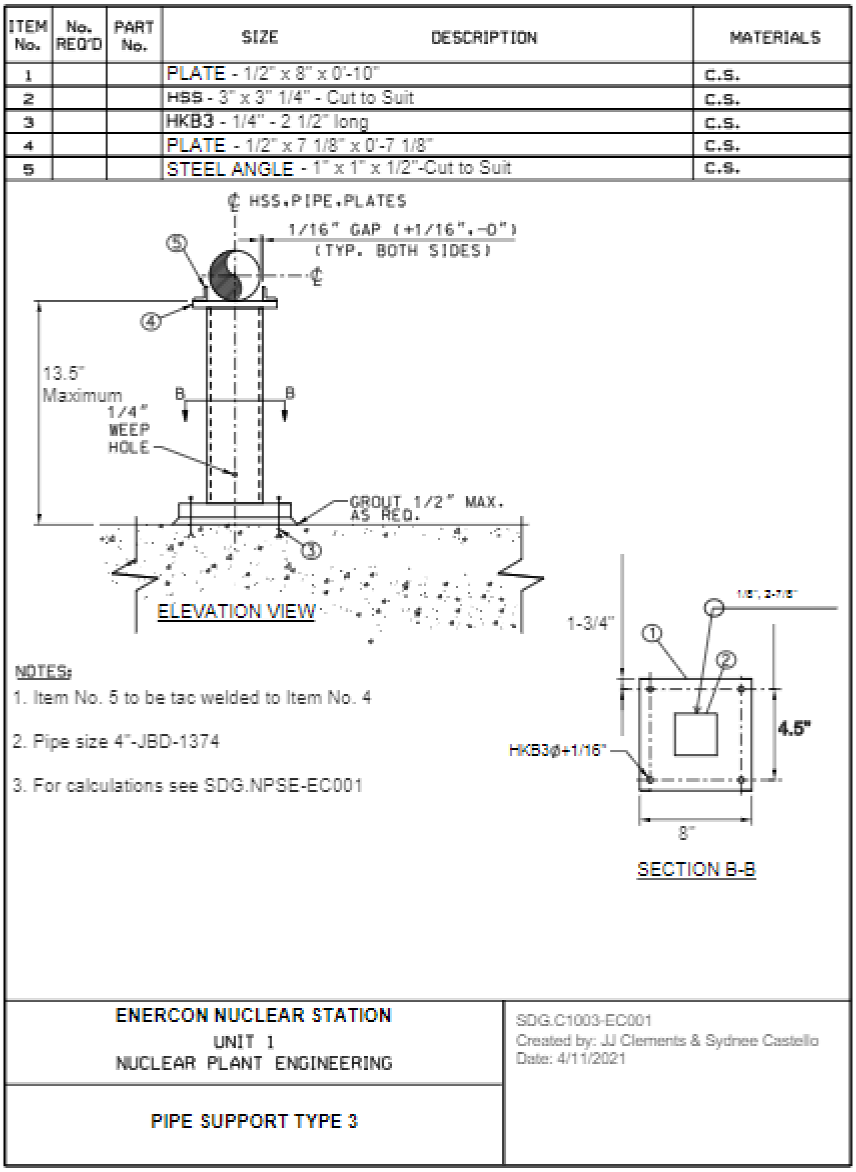


ITEM No.	No. REQ'D	PART No.	SIZE DESCRIPTION	MATERIALS
1	1		HSS - 4x4x1/4", Cut to Suit	CS
2	1		PLATE- 1/2"x10"x10"	CS
3	4		HKB3- 3/8" Diameter, 0'-3" Long	CS

Figure 36: Pipe Support Type 1 Markup

11.2.7 Pipe Support Type 3 Markup

Pipe support type 3 was idealized as a column in the evaluation. The evaluation led to needing to use HSS 3x3x1/4 with a plate on each end. The base plate chosen was ½”x8”x8” and the top plate was chosen to be ½”x7-1/8”x7-1/8” to accommodate the 1x1x1/2 angle used to keep the pipe from moving laterally. The Hilti specifications call for a ¼” bolt when mounted in this orientation.



ITEM No.	No. REQ'D	PART No.	SIZE DESCRIPTION	MATERIALS
1			PLATE - 1/2" x 8" x 0'-10"	C.S.
2			HSS - 3" x 3" 1/4" - Cut to Suit	C.S.
3			HKB3 - 1/4" - 2 1/2" long	C.S.
4			PLATE - 1/2" x 7 1/8" x 0'-7 1/8"	C.S.
5			STEEL ANGLE - 1" x 1" x 1/2"-Cut to Suit	C.S.

NOTES:

1. Item No. 5 to be tac welded to Item No. 4
2. Pipe size 4"-JBD-1374
3. For calculations see SDG.NPSE-EC001

ENERCON NUCLEAR STATION
UNIT 1
NUCLEAR PLANT ENGINEERING

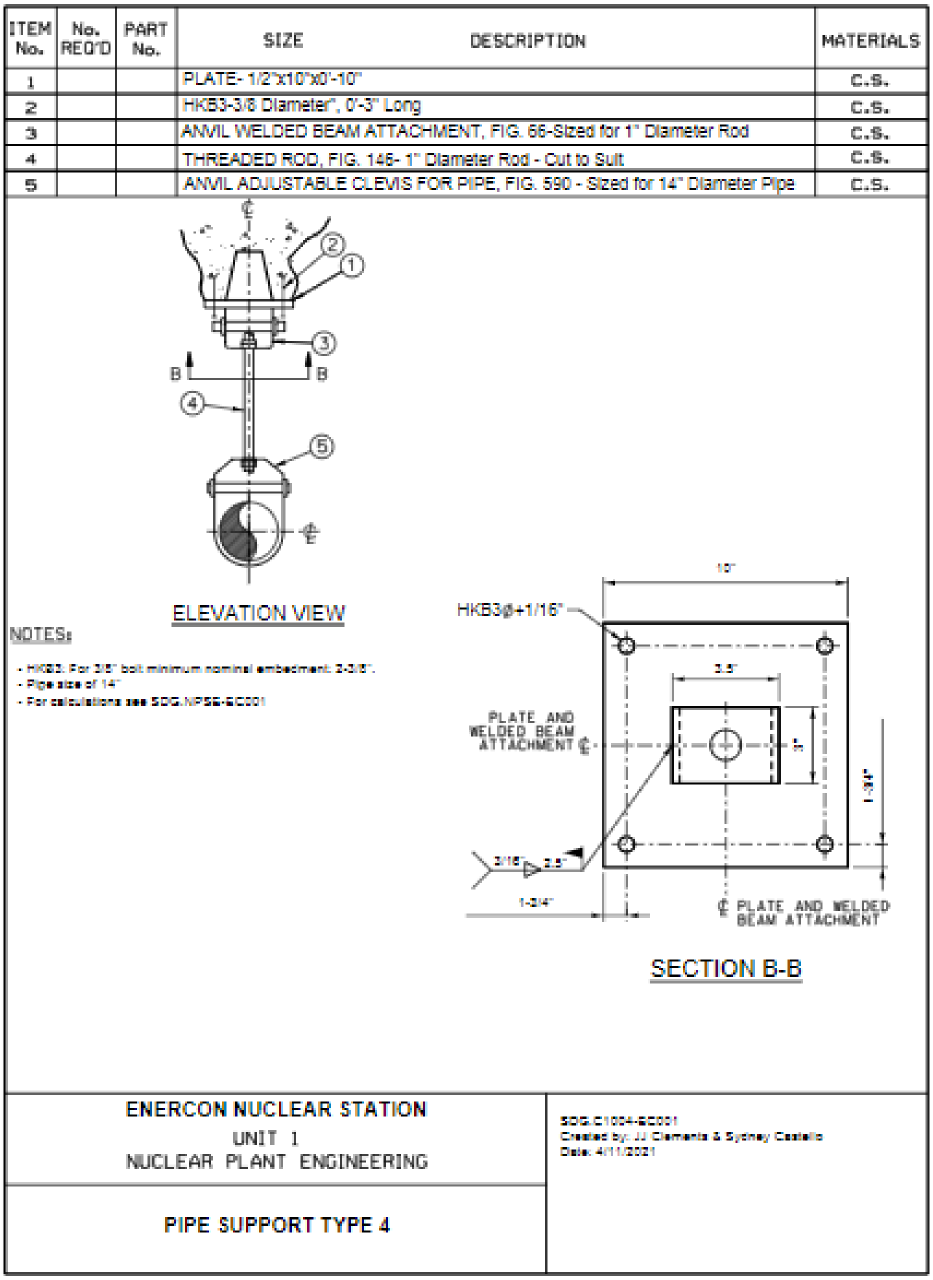
PIPE SUPPORT TYPE 3

SDG.C1003-EC001
Created by: JJ Clements & Sydnee Castello
Date: 4/11/2021

Figure 37: Pipe Support Type 3 Markup

11.2.8 Pipe Support Type 4 Markup

The design specifications for pipe support type 4 were provided in the CSDCM given to us by ENERCON. The specifications were found in the Anvil hanger catalog which give dimensions for each element which corresponds to the pipe size given in the figures below.



ITEM No.	No. REQ'D	PART No.	SIZE DESCRIPTION	MATERIALS
1			PLATE- 1/2"x10"x0'-10"	C.S.
2			HKB3-3/8 Diameter", 0'-3" Long	C.S.
3			ANVIL WELDED BEAM ATTACHMENT, FIG. 66-Sized for 1" Diameter Rod	C.S.
4			THREADED ROD, FIG. 146- 1" Diameter Rod - Cut to Suit	C.S.
5			ANVIL ADJUSTABLE CLEVIS FOR PIPE, FIG. 590 - Sized for 14" Diameter Pipe	C.S.

NOTES:

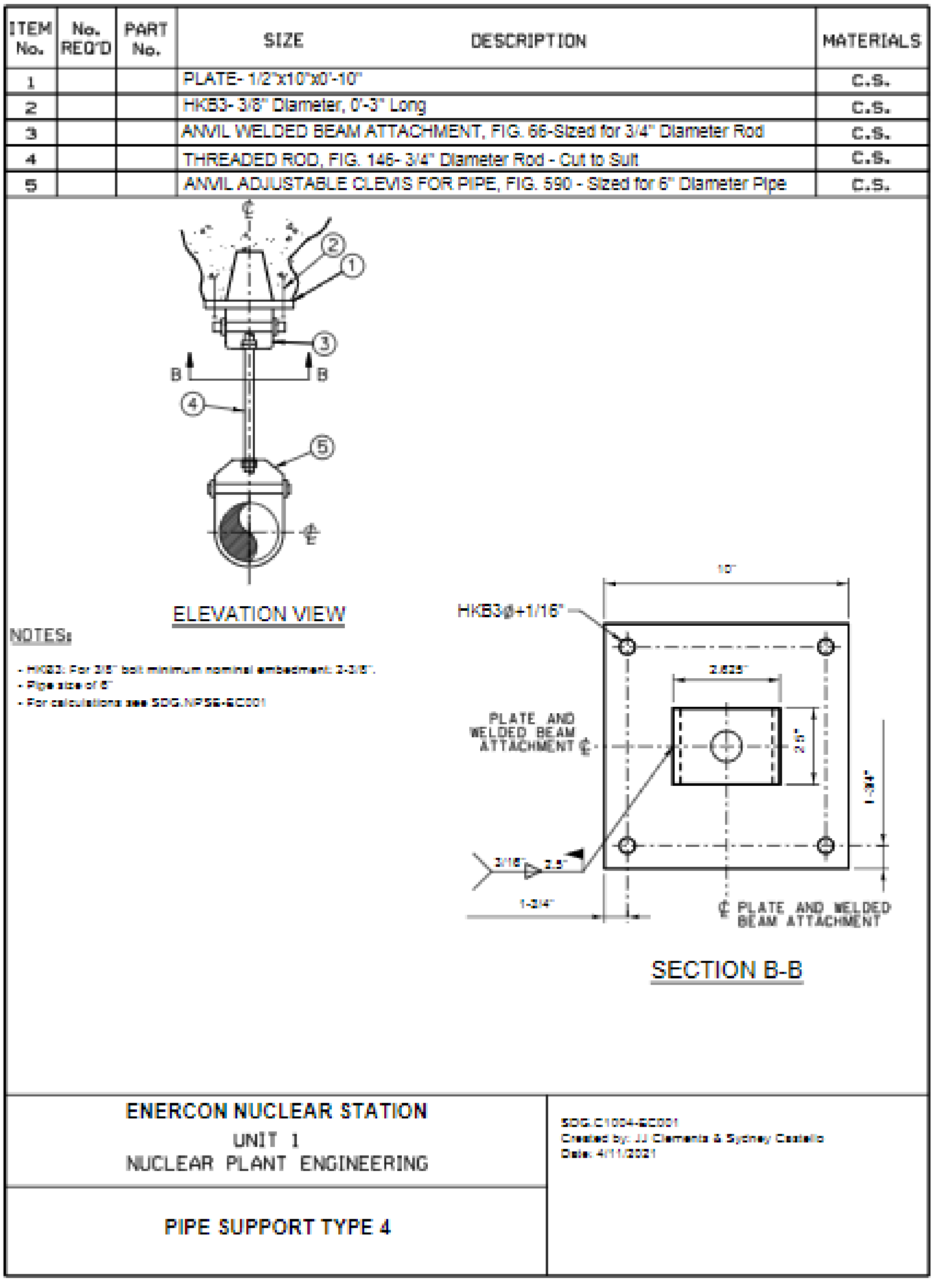
- HKB3: For 3/8" bolt minimum nominal embedment: 2-3/8".
- Pipe size of 14"
- For calculations see SDG.NPS56-SC001

ENERCON NUCLEAR STATION
UNIT 1
NUCLEAR PLANT ENGINEERING

PIPE SUPPORT TYPE 4

SDG.C1004-SC001
Created by: JJ Clements & Sydney Castello
Date: 4/11/2021

Figure 38: Pipe Support Type 4, 14" pipe Markup



ITEM No.	No. REQ'D	PART No.	SIZE DESCRIPTION	MATERIALS
1			PLATE- 1/2"x10"x0'-10"	C.S.
2			HKB3- 3/8" Diameter, 0'-3" Long	C.S.
3			ANVIL WELDED BEAM ATTACHMENT, FIG. 66-Sized for 3/4" Diameter Rod	C.S.
4			THREADED ROD, FIG. 146- 3/4" Diameter Rod - Cut to Suit	C.S.
5			ANVIL ADJUSTABLE CLEVIS FOR PIPE, FIG. 590 - Sized for 6" Diameter Pipe	C.S.

NOTES:

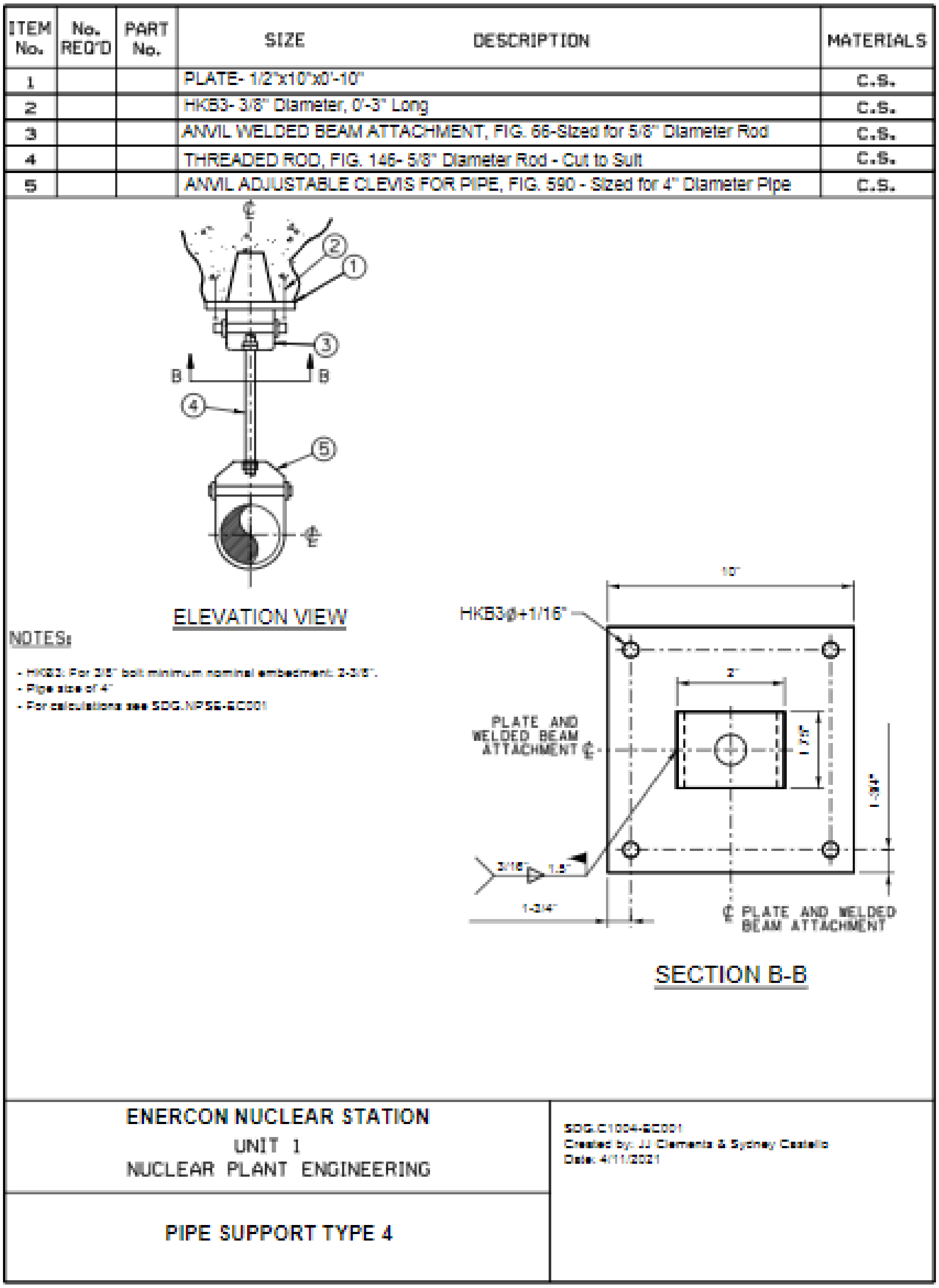
- HKB3: For 3/8" bolt minimum nominal embedment: 2-3/8".
- Pipe size of 6"
- For calculations see SDG.NPS6-6C001

ENERCON NUCLEAR STATION
UNIT 1
NUCLEAR PLANT ENGINEERING

PIPE SUPPORT TYPE 4

SDG.C1004-6C001
Created by: JJ Clements & Sydney Castello
Date: 4/11/2021

Figure 39: Pipe Support Type 4, 6" pipe Markup



ITEM No.	No. REQ'D	PART No.	SIZE DESCRIPTION	MATERIALS
1			PLATE- 1/2"x10"x0'-10"	C.S.
2			HKB3- 3/8" Diameter, 0'-3" Long	C.S.
3			ANVIL WELDED BEAM ATTACHMENT, FIG. 66-Sized for 5/8" Diameter Rod	C.S.
4			THREADED ROD, FIG. 146- 5/8" Diameter Rod - Cut to Suit	C.S.
5			ANVIL ADJUSTABLE CLEVIS FOR PIPE, FIG. 590 - Sized for 4" Diameter Pipe	C.S.

NOTES:

- HKB3: For 3/8" bolt minimum nominal embedment: 2-3/8".
- Pipe size of 4"
- For calculations see SDG.NPS6-6C001

ENERCON NUCLEAR STATION
UNIT 1
NUCLEAR PLANT ENGINEERING

PIPE SUPPORT TYPE 4

SDG.C1004-6C001
Created by: JJ Clemente & Sydney Castello
Date: 4/11/2021

Figure 40: Pipe Support Type 4, 4" pipe Markup

11.2.9 New Pipe Support Evaluation

11.2.9.1 Pipe Support Type 1 Evaluation

For pipe support type 1 the given loads are 194 lbs in the x-direction and 151 lbs in the y-direction.

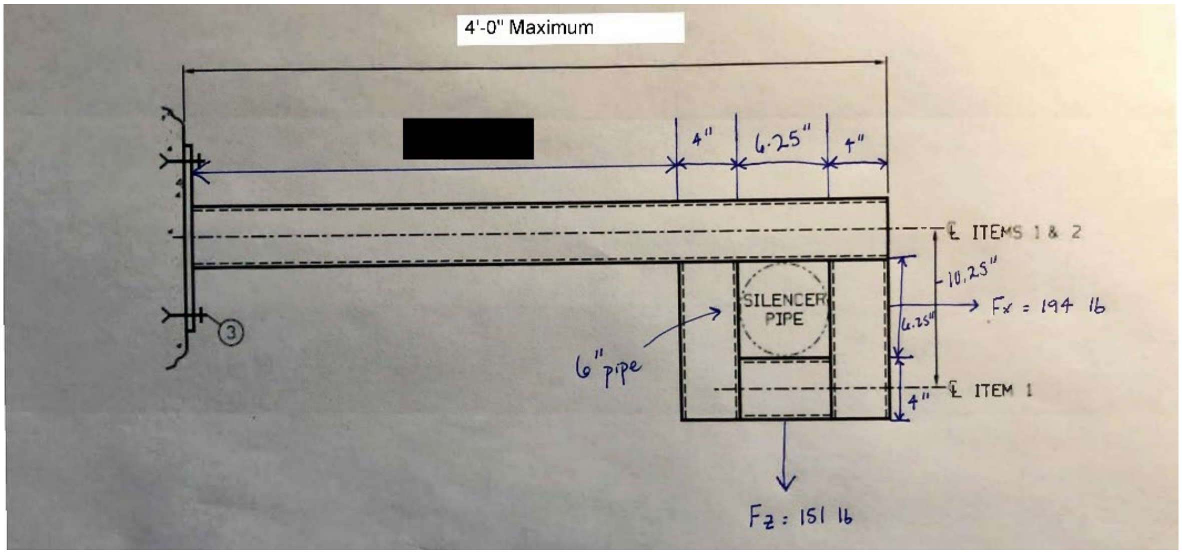

[redacted]

Figure 41: Dimensions for Pipe Support Type 1

<u>Choosing HSS 4x4x1/4:</u>

<u>Using slenderness ratio to find maximum length:</u>

$$\frac{L}{r} \leq 300\ (AISC\ Section\ 5)$$

$$with\ r = 1.52\ in\ (AISC\ Table\ 1-12),$$

$$\frac{L}{1.52\ in} \leq 300\ gives\ maximum\ length, L, of\ 38\ ft.$$

Finding reactions due to applied forces with a max length of 4 feet:

$$\Sigma F_x = -R_{Ax} + 194\ lb = 0,\ \ R_{Ax} = 194\ lb$$

$$\Sigma F_y = R_{Ay} - 151\ lb = 0,\ \ R_{Ay} = 151\ lb$$

$$\Sigma M_y = Fx(5.125\ in) + Fz(52.875\ in) = 194\ lb(5.125\ in) + 151\ lb(40.875\ in)$$
$$= 7166.375\ lb - in = 7.166\ kip - in$$

Checking shear strength:

From AISC G4:

$$h = Outside\ dimension - 3t$$

$$h = 4\ in - 3\left(\frac{1}{4} in\right) = 3.25\ in$$

$$\frac{h}{t} = 13$$

$$\frac{h}{t} \leq 1.10\sqrt{\frac{5(29000\ ksi)}{50\ ksi}} = 59.23$$

$$Since\ \frac{h}{t} \leq 1.10\sqrt{\frac{k_v(E_s)}{F_y}}\ \ , C_{v_2} = 1.0$$

$$V_n = 0.6F_yA_wC_{v2}$$

$$A_w = 2ht = 2\left(4 - 3\left(\frac{1}{4}\right)\right)\left(\frac{1}{4}\right) = 1.625\ in^2$$

$$V_n = 0.6(50\ ksi)(1.625\ in^2)(1.0) = 48.75\ kips$$

$$\phi V_n = 43.875\ kips > 0.151\ kips \therefore OK$$

End Plate Calculations:

From Design Guide 24, Section 5.5

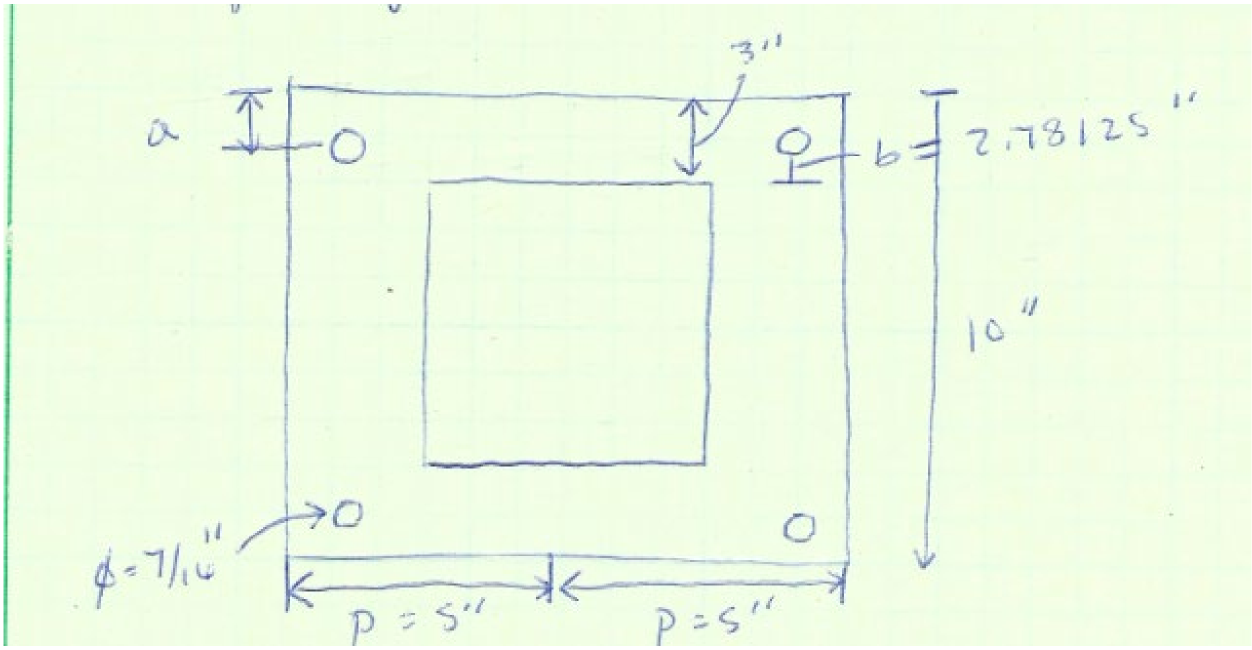


Figure 42: Baseplate Design for Pipe Support Type 1.

Checking required bolt strength and plate thickness:

$$M_y = 7.611\ kip - in$$

$$b_{eff} = \frac{10"}{2} - 1.75 = 3.25 \text{ in}$$

$$P_r = F_x = 194\ lb = 0.194\ kip$$

HKB3 Tensile Strength=2.415 kips

From AISC Steel Design Guide 1 Section 4:

Tensile force on one bolt:

$$T_{u_{bolt}} = \frac{M_y}{b_{eff}} + \frac{P_r}{4} = \frac{7.166\ kip - in}{3.25\ in} + \frac{0.194\ kip}{4} = 2.254\ kip$$

$$IC_{bolt} = \frac{T_{req_{bolt}}}{T_{bolt}} = \frac{2.254\ kip}{2.415\ kip} = 0.933 < 1\ OK$$

Moment induced on the plate:

$$M_{u_{plate}} = T_{u_{bolt}}\left(b_{eff}\right) = 2.254\ kip(3.25\ in) = 7.32\ kip - in$$

Minimum plate thickness required:

$$t_{req'd} = \sqrt{\frac{M_u(4)}{b_{eff}\phi F_y}} = \sqrt{\frac{7.32\ kip - in * (4)}{(3.25\ in)(0.9)(36\ ksi)}} = 0.527\ in\ plate$$

Selecting ¾” baseplate:

$$IC_{plate} = \frac{0.527\ in}{0.75\ in} = 0.703 < 1\ OK$$

<u>Weld Calculations:</u>

$$Minimum\ weld\ size = \frac{1}{8} in$$

$$Using\ an\ E70XX\ electrode\ the\ nominal\ weld\ strength\ R_n = 1.392(2) = 2.784\frac{k}{in}$$

$$Plate\ strength = 0.6(36\ ksi)\left(\frac{1}{2}\right) = 10.8\frac{k}{in}$$

$$Rupture\ strength = 0.45(58\ ksi)\left(\frac{1}{2}\right) = 13.05\frac{k}{in}$$

$$Required\ Length = \frac{P_u}{R_n} = \frac{0.194\ k}{2.784\frac{k}{in}} = 0.07\ in$$

$$Minimum\ Length = 4\left(\frac{1}{8} in\right) = \frac{1}{2}\ in$$

Welds of HSS to HSS to remain the same as above.

11.2.9.2 Pipe Support Type 3 Evaluations

Total Load = 993 lb concentric load in the y-direction

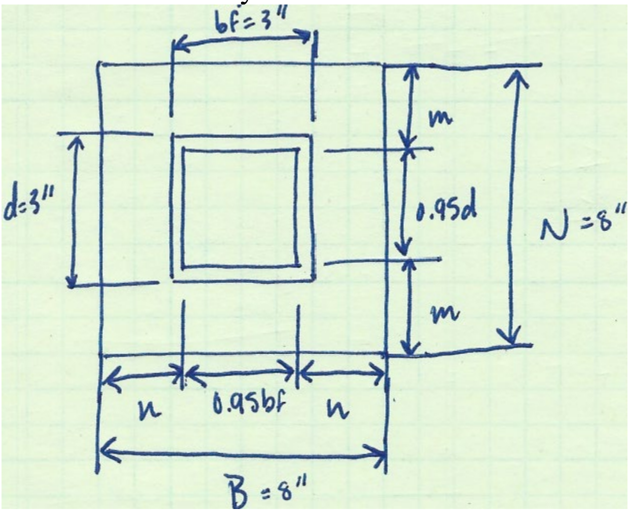


Figure 43: Baseplate design for pipe support type 3.

Required Base Plate Area

$$Area = \frac{P_u}{\phi(0.85)f'_c} = \frac{0.993\ kips}{0.65(0.85)(4\ ksi)} = 0.449\ in^2$$

$$Choosing\ an\ 8 \times 8\ baseplate\ \therefore OK$$

Base Plate Thickness

$$m = \frac{N - 0.95d}{2} = \frac{8\ in - 0.95(3\ in)}{2} = 2.575\ in$$

$$n = \frac{B - 0.95b_f}{2} = \frac{8\ in - 0.95(3\ in)}{2} = 2.575\ in$$

$$\lambda\ not\ required\ for\ HSS\ members$$

$$l_{max} = 2.575\ in$$

$$t_{min} = l\sqrt{\frac{2P_u}{\phi f_y BN}} = 2.575\ in\sqrt{\frac{2(0.993\ kips)}{0.9(36\ ksi)(8\ in)(8\ in)}} = 0.08\ in$$

$$IC_{t_{plate}} = \frac{0.08\ in}{0.5\ in} = 0.16 < 1\ OK.$$

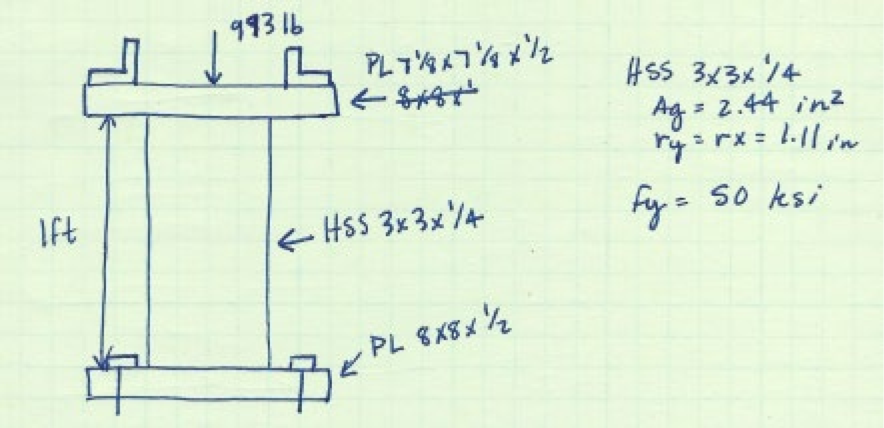


Figure 44: Design for pipe support type 3.

Using HSS 3”x3”x1/4” and evaluating based on compression design:

$$Effective\ Length = L_c = kL = 0.8(12\ in) = 9.6\ in$$

$$\frac{L_c}{r_{min}} = \frac{0.8(12\ in)}{1.11\ in} = 8.65$$

$$4.71\sqrt{\frac{29000\ ksi}{50\ ksi}} = 113.43,$$

$$since\ \frac{L_c}{r_{min}} = 8.65 \leq 4.71\sqrt{\frac{29000\ ksi}{50\ ksi}} = 113.43$$

$$F_{cr} = 0.658^{\frac{F_y}{F_e}} * F_y$$

$$F_e = \frac{\pi^2 * 29000\ ksi}{\left(\frac{L_c}{r_{min}}\right)^2}$$

$$F_{cr} = 0.658^{50\ ksi/_{38.25\ ksi}} \times 50\ ksi = 49.73\ ksi$$

$$P_n = F_{cr} \times A_g = 99.73\ ksi(2.44\ in^2) = 121.33\ kips$$

$$\phi P_n = 109.2\ kips$$

$$since\ P_u = 0.993\ kips \leq \phi P_n = 109.2\ kips\ \therefore OK$$

Since the load is applied eccentrically to the pipe support, there are no induced moments on the baseplate, and there are no tensile or shear loads that will affect the anchor bolts in the support. Therefore, no anchor bolt analysis is needed.

Weld Calculations

$$Minimum\ weld\ size = \frac{1}{8} in$$

$$Using\ an\ E70XX\ electrode\ the\ nominal\ weld\ strength = 1.392(2) = 2.784\frac{k}{in}$$

$$Shear\ Yield\ Strength\ of\ the\ Base\ Metal = 0.6(36\ ksi)\left(\frac{1}{2}\right) = 10.8\frac{k}{in}$$

$$The\ Shear\ Rupture\ Strength = 0.45(38\ ksi)\left(\frac{1}{2}\right) = 8.55\frac{k}{in}$$

$$With\ P_u = 0.993\ k$$

$$Required\ Weld\ Length = \frac{0.993\ k}{2.784\frac{k}{in}} = 0.357\ in$$

$$Minimum\ Length\ (AISC\ J2.2b) = 4\left(\frac{1}{8} in\right) = \frac{1}{2}\ in$$

$$Maximum\ Weld\ Size\ (AISC\ J2.2b) = t - \frac{1}{16} in = \frac{1}{4} in - \frac{1}{16} in = \frac{3}{16}\ in$$

$$Minimum\ Weld\ Size\ (AISC\ J2.2b) = \frac{1}{8} in$$

The angles on the top plate of the support, L1”x1”x1/2” are to be tack welded into places as there are no significant lateral forces acting upon them.

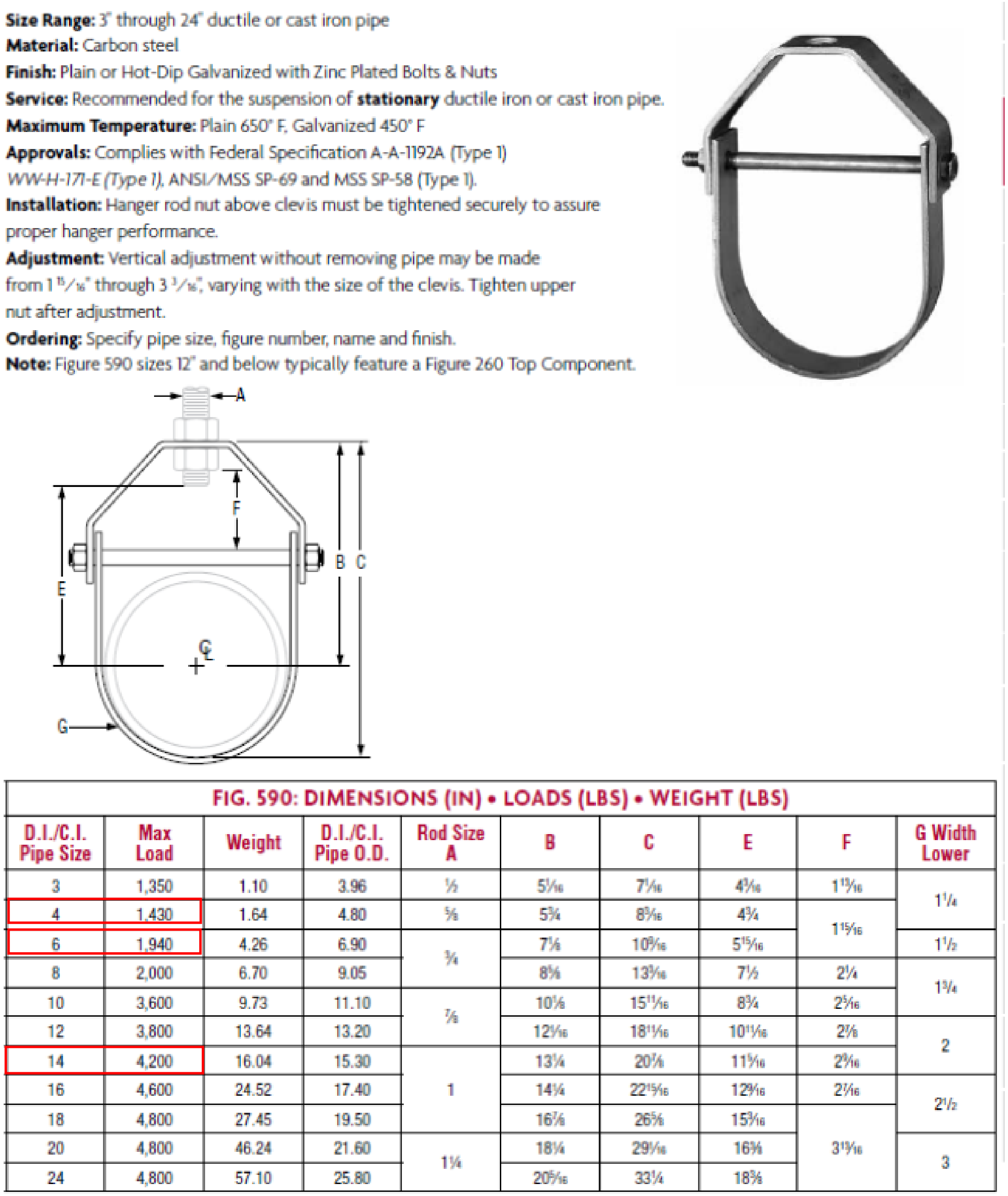
11.2.9.3 Pipe Support Type 4 Evaluations for pipe sizes of 4”, 6”, and 14”

For pipe support type 4 the maximum loading for each pipe size is:

- 14” pipe is 2311 lbs in the y-direction.
- 6” pipe is 962 lbs in the y-direction
- 4” pipe is 984 lbs in the y-direction

This allows us to select Anvil pipe hanger elements based upon this pipe size. Based on the figures below the following specifications were chosen from the Anvil Pipe Hanger Figures:

- Adjustable Clevis for Ductile or Cast-Iron Pipe:
  - 14” with corresponding max load of 4,200 lbs.
  - 6” with corresponding max load of 1,940 lbs.
  - 4” with corresponding max load of 1,430 lbs.



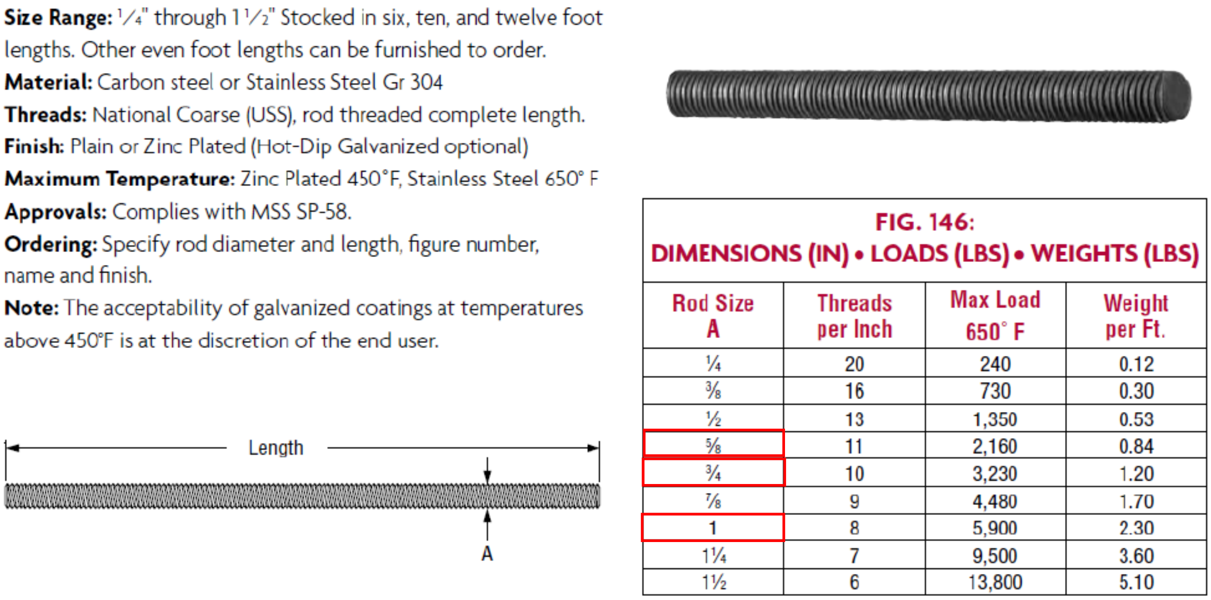
Size Range: 3" through 24" ductile or cast iron pipe
Material: Carbon steel
Finish: Plain or Hot-Dip Galvanized with Zinc Plated Bolts & Nuts
Service: Recommended for the suspension of **stationary** ductile iron or cast iron pipe.
Maximum Temperature: Plain 650° F, Galvanized 450° F
Approvals: Complies with Federal Specification A-A-1192A (Type 1) *WW-H-171-E (Type 1)*, ANSI/MSS SP-69 and MSS SP-58 (Type 1).
Installation: Hanger rod nut above clevis must be tightened securely to assure proper hanger performance.
Adjustment: Vertical adjustment without removing pipe may be made from 1 15/16" through 3 1/16", varying with the size of the clevis. Tighten upper nut after adjustment.
Ordering: Specify pipe size, figure number, name and finish.
Note: Figure 590 sizes 12" and below typically feature a Figure 260 Top Component.

FIG. 590: DIMENSIONS (IN) • LOADS (LBS) • WEIGHT (LBS)

D.I./C.I. Pipe Size	Max Load	Weight	D.I./C.I. Pipe O.D.	Rod Size A	B	C	E	F	G Width Lower
3	1,350	1.10	3.96	½	5 1/16	7 1/16	4 3/16	1 13/16	1 1/4
4	1,430	1.64	4.80	⅝	5 3/4	8 3/16	4 3/4	1 15/16	
6	1,940	4.26	6.90	¾	7 1/8	10 9/16	5 15/16		1 1/2
8	2,000	6.70	9.05		8 5/8	13 3/16	7 1/2	2 1/4	1 3/4
10	3,600	9.73	11.10	⅞	10 1/8	15 11/16	8 3/4	2 5/16	
12	3,800	13.64	13.20		12 1/16	18 11/16	10 11/16	2 7/8	2
14	4,200	16.04	15.30	1	13 1/4	20 7/8	11 1/16	2 9/16	
16	4,600	24.52	17.40		14 1/4	22 15/16	12 9/16	2 1/16	2 1/2
18	4,800	27.45	19.50		16 7/8	26 5/8	15 3/16	3 13/16	
20	4,800	46.24	21.60	1¼	18 1/4	29 1/16	16 5/8		3
24	4,800	57.10	25.80		20 5/16	33 1/4	18 5/8		

Figure 45: Adjustable Clevis for Ductile or Cast-Iron Pipe Specifications from Anvil.

- Rod Size:
    - The rod size for the 14” selected hanger is 1” in diameter with a max load of 5,900 lbs.
    - The rod size for the 6” selected hanger is 3/4” in diameter with a max load of 3,230 lbs.
    - The rod size for the 4” selected hanger is 5/8” in diameter with a max load of 2,160 lbs.



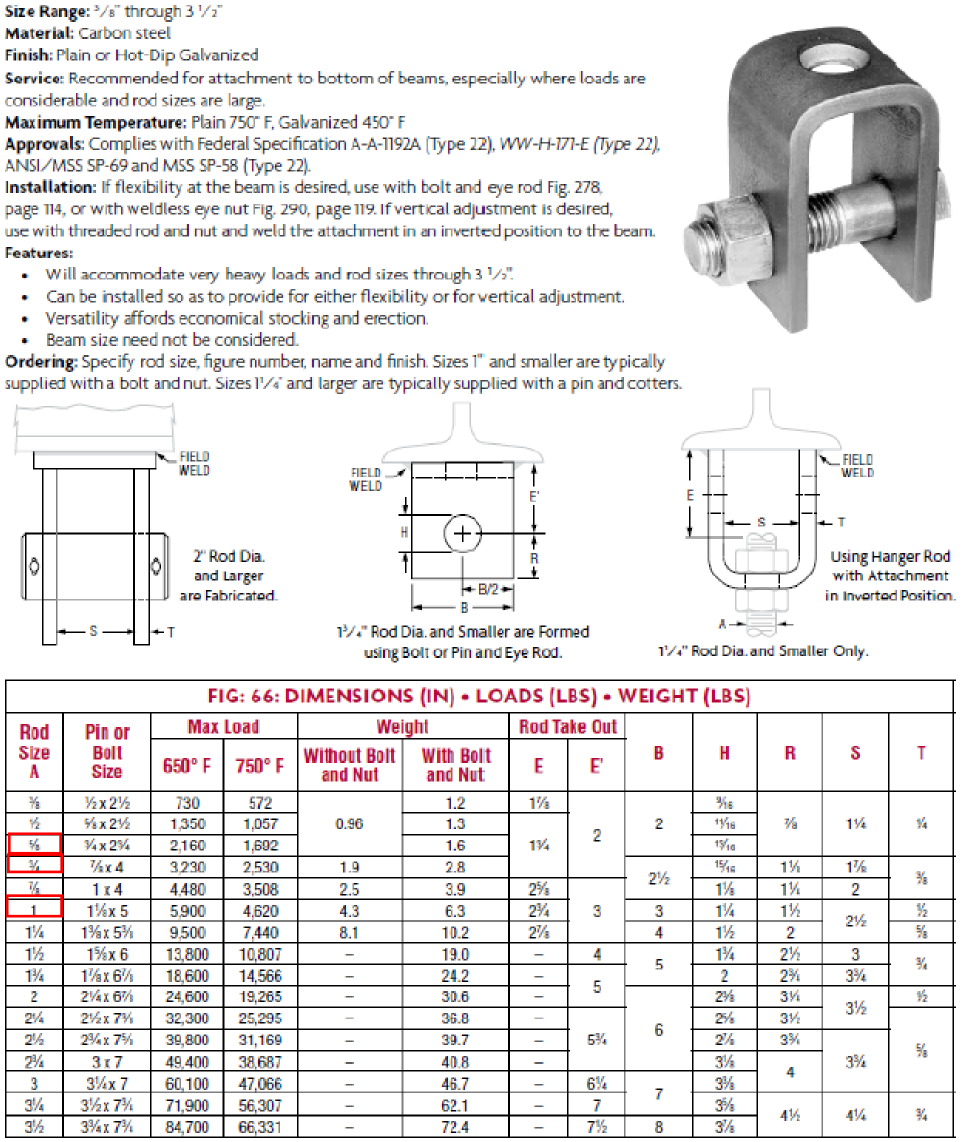
Size Range: ¼" through 1½" Stocked in six, ten, and twelve foot lengths. Other even foot lengths can be furnished to order.
Material: Carbon steel or Stainless Steel Gr 304
Threads: National Coarse (USS), rod threaded complete length.
Finish: Plain or Zinc Plated (Hot-Dip Galvanized optional)
Maximum Temperature: Zinc Plated 450°F, Stainless Steel 650° F
Approvals: Complies with MSS SP-58.
Ordering: Specify rod diameter and length, figure number, name and finish.
Note: The acceptability of galvanized coatings at temperatures above 450°F is at the discretion of the end user.

FIG. 146:
DIMENSIONS (IN) • LOADS (LBS) • WEIGHTS (LBS)

Rod Size A	Threads per Inch	Max Load 650° F	Weight per Ft.
¼	20	240	0.12
⅜	16	730	0.30
½	13	1,350	0.53
⅝	11	2,160	0.84
¾	10	3,230	1.20
⅞	9	4,480	1.70
1	8	5,900	2.30
1¼	7	9,500	3.60
1½	6	13,800	5.10

Figure 46: Anvil Continuous Threaded Rod Specifications from Anvil.

- Welded Beam Attachment:
    - The corresponding welded beam attachment size is listed below for each selected rod size, 1”, 3/4”, 5/8”.



Size Range: ⅜" through 3 ½"
Material: Carbon steel
Finish: Plain or Hot-Dip Galvanized
Service: Recommended for attachment to bottom of beams, especially where loads are considerable and rod sizes are large.
Maximum Temperature: Plain 750° F, Galvanized 450° F
Approvals: Complies with Federal Specification A-A-1192A (Type 22), *WW-H-171-E (Type 22)*, ANSI/MSS SP-69 and MSS SP-58 (Type 22).
Installation: If flexibility at the beam is desired, use with bolt and eye rod Fig. 278, page 114, or with weldless eye nut Fig. 290, page 119. If vertical adjustment is desired, use with threaded rod and nut and weld the attachment in an inverted position to the beam.
Features:

- Will accommodate very heavy loads and rod sizes through 3 ½".
- Can be installed so as to provide for either flexibility or for vertical adjustment.
- Versatility affords economical stocking and erection.
- Beam size need not be considered.

Ordering: Specify rod size, figure number, name and finish. Sizes 1" and smaller are typically supplied with a bolt and nut. Sizes 1¼" and larger are typically supplied with a pin and cotters.

1¾" Rod Dia. and Smaller are Formed using Bolt or Pin and Eye Rod.

1¼" Rod Dia. and Smaller Only.

FIG: 66: DIMENSIONS (IN) • LOADS (LBS) • WEIGHT (LBS)

Rod Size A	Pin or Bolt Size	Max Load		Weight		Rod Take Out		B	H	R	S	T
		650° F	750° F	Without Bolt and Nut	With Bolt and Nut	E	E'					
⅜	½ x 2½	730	572	0.96	1.2	1⅛	2	2	9⁄16	⅞	1¼	¼
½	⅝ x 2½	1,350	1,057		1.3	1¼			11⁄16			
⅝	¾ x 2¾	2,160	1,692		1.6				13⁄16			
¾	⅞ x 4	3,230	2,530	1.9	2.8			2½	15⁄16	1⅛	1⅞	⅜
⅞	1 x 4	4,480	3,508	2.5	3.9	2⅝	3		1⅛	1¼	2	
1	1⅛ x 5	5,900	4,620	4.3	6.3	2¾		3	1¼	1½	2½	½
1¼	1⅜ x 5⅜	9,500	7,440	8.1	10.2	2⅞		4	1½	2		⅝
1½	1⅝ x 6	13,800	10,807	–	19.0	–	4	5	1¾	2½	3	¾
1¾	1⅞ x 6⅞	18,600	14,566	–	24.2	–	5		2	2¾	3¾	
2	2¼ x 6⅞	24,600	19,265	–	30.6	–		6	2⅜	3¼	3½	½
2¼	2½ x 7⅜	32,300	25,295	–	36.8	–	5¾		2⅝	3½		⅝
2½	2¾ x 7⅝	39,800	31,169	–	39.7	–			2⅞	3¾	3¾	
2¾	3 x 7	49,400	38,687	–	40.8	–			3⅛	4		
3	3¼ x 7	60,100	47,066	–	46.7	–	6¼	7	3⅜			
3¼	3½ x 7¾	71,900	56,307	–	62.1	–	7		3⅝	4½	4¼	¾
3½	3¾ x 7¾	84,700	66,331	–	72.4	–	7½	8	3⅞			

Figure 47: Welded Beam Attachment Specifications from Anvil.

Evaluations for each pipe size based off the above specifications:

14” pipe:

Checking each part of the pipe support:

- Adjustable clevis hanger

$$Required\ load, P_u = 2311\ lbs$$
$$Max\ load\ the\ hanger\ can\ support, P_n = 4200\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

- Continuous threaded rod

$$Required\ load, P_u = 2311\ lbs$$

$$Max\ load\ 1"\ rod\ can\ hold, P_n = 5900\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

- Welded beam attachment

$$Required\ load, P_u = 2311\ lbs$$
$$Max\ load\ welded\ attachment\ can\ hold, P_n = 5900\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

6” pipe:

Checking each part of the pipe support:

- Adjustable clevis hanger

$$Required\ load, P_u = 962\ lbs$$
$$Max\ load\ the\ hanger\ can\ support, P_n = 1940\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

- Continuous threaded rod

$$Required\ load, P_u = 962\ lbs$$

$$Max\ load\ 3/4"\ rod\ can\ hold, P_n = 3230\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

- Welded beam attachment

$$Required\ load, P_u = 962\ lbs$$
$$Max\ load\ welded\ attachment\ can\ hold, P_n = 3230\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

4” pipe:

Checking each part of the pipe support:

- Adjustable clevis hanger

$$Required\ load, P_u = 984\ lbs$$
$$Max\ load\ the\ hanger\ can\ support, P_n = 1430\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

- Continuous threaded rod

$$Required\ load, P_u = 984\ lbs$$
$$Max\ load\ 5/8"\ rod\ can\ hold, P_n = 2160\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

- Welded beam attachment

$$Required\ load, P_u = 984\ lbs$$
$$Max\ load\ welded\ attachment\ can\ hold, P_n = 2160\ lbs$$
$$Since\ P_u \leq P_n \therefore OK$$

<u>Bolt evaluation based on tensile loading:</u>

Based off AISC Design Guide 1 Example 4.5

Tensile force applied to center of plate by the largest pipe:

$$P = 2311\ lbs = 2.311\ kips$$

Tensile force on each bolt assuming load is distributed evenly to each bolt:

$$T = \frac{P}{4} = \frac{2.311\ kips}{4\ bolts} = 0.577\ kips\ perbolt$$

For concrete compressive strength, f'c = 3000 psi, HKB3 specs are as follows:

$$3/8"\ HKB3\ design\ strength\ with\ concrete/pullout\ failure = 1.080\ kips$$

$$IC_{bolts} = \frac{0.577\ kips}{1.080\ kips} = 0.534 < 1.0\ OK\ Interaction\ ratio\ for\ anchor\ bolts$$

<u>Baseplate Design:</u>

Choosing a 10x10x1/2 baseplate:

Based off AISC Design Guide 1 section 3.1

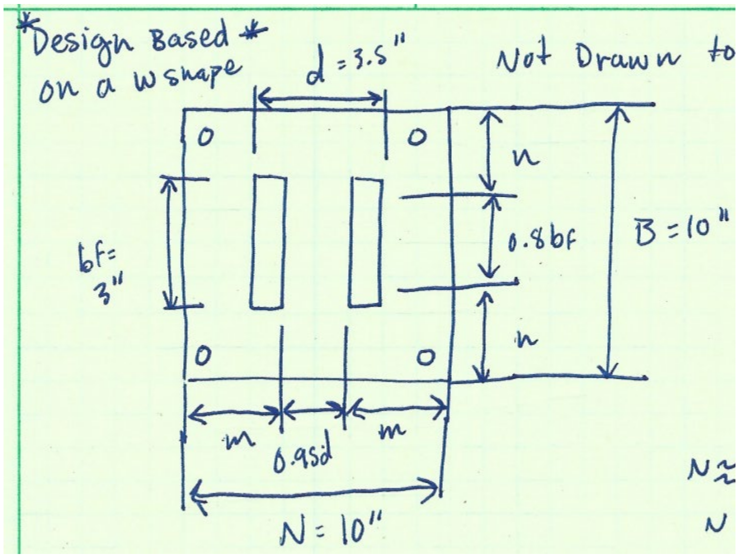


Figure 48: Baseplate design with the Anvil welded beam attachment.

Case 1: A_1=A_2

Calculating require baseplate area:

$$P_u = 2311\ lbs$$

$$A_{1(req)} = A_{2(req)} = \frac{P_u}{\phi 0.85 f'c} = \frac{2.311\ kips}{(0.65)(0.85)(3\ ksi)} = 1.01\ in^2$$

Optimizing baseplate dimensions:

$$N \approx \sqrt{A_{1(req)}} + \Delta$$

$$\Delta = \frac{0.95d - 0.8b_f}{2} = \frac{0.95(3.5) - 0.8(3)}{2} = 0.4625\ in$$

$$N \approx \sqrt{1.01\ in^2} + 0.4625\ in = 1.47\ in$$

$$B = \frac{A_{1(req)}}{N} = \frac{1.01\ in^2}{1.47\ in} = 0.69\ in$$

From a practicality standpoint we set N=B=10 in.

Calculating require baseplate thickness:

$$m = \frac{N - 0.95d}{2} = \frac{10 - 0.95(3.5\ in)}{2} = 3.3375\ in$$

$$n = \frac{B - 0.8b_f}{2} = \frac{10 - 0.8(3\ in)}{2} = 3.8\ in$$

$$\lambda = \frac{2\sqrt{X}}{1 + \sqrt{1 - X}} \leq 1$$

$$X = \left\{\frac{4db_f}{\left(d + b_f\right)^2}\right\} * \frac{P_u}{\phi P_p}$$

$$\phi P_p = \phi 0.85 f'cA_1 = 0.65(0.85)(3\ ksi)(1.01\ in^2) = 1.67\ kips$$

$$X = \left\{\frac{4(3.5\ in)(3\ in)}{(3.5\ in + 3\ in)^2}\right\} * \frac{2.311\ kips}{1.67\ kips} = 1.38$$

Since the bottom term in λ gives an imaginary result, the largest of *m* & *n* is taken as l_{max}. The minimum baseplate thickness can then be found as follows:

$$t_{min} = l\sqrt{\frac{2P_u}{\phi F_y BN}} = 3.8\sqrt{\frac{2(2.311\ kips)}{0.9(36\ ksi)(10\ in)(10\ in)}} = 0.14\ in$$

$$IC_{t_{plate}} = \frac{0.14\ in}{0.5\ in} = 0.28 < 1\ OK.$$

Therefore, choosing a ½” x 10” x 10” baseplate is acceptable for this application.

For welding of the welded attachment to the beam:

For 14” pipe:

$$maximum\ weld\ load = \frac{(T/bolt)}{b_{eff}} = \frac{0.577\ kips}{3.5\ in} = 0.164\frac{kip}{in}$$

$$minimum\ weld\ size\ for\ 1/2"\ material\ thickness = 3/16"$$

$$minimum\ weld\ length = 4 * weld\ thickness = 4 * 3/16" = 3/4"$$

$$nominal\ weld\ strength\ for\ 3/16"\ weld\ using\ E70\ electrode = R_n = F_w A_w$$

$$= 0.6(70)(0.14) = 5.88\frac{kip}{in}$$

$$\phi R_n = 0.75\left(5.88\frac{kip}{in}\right) = 4.41\frac{kip}{in}$$

$$Since\ maximum\ weld\ load, 0.164\frac{kip}{in} \leq \phi R_n \therefore weld\ size\ OK.$$

For 6” pipe:

$$maximum\ weld\ load = \frac{(T/bolt)}{b_{eff}} = \frac{0.241\ kips}{3.5\ in} = 0.069\frac{kip}{in}$$

$$minimum\ weld\ size\ for\ 1/2"\ material\ thickness = 3/16"$$

$$minimum\ weld\ length = 4 * weld\ thickness = 4 * 3/16" = 3/4"$$

$$nominal\ weld\ strength\ for\ 3/16"\ weld\ using\ E70\ electrode = R_n = F_w A_w$$

$$= 0.6(70)(0.14) = 5.88\frac{kip}{in}$$

$$\phi R_n = 0.75\left(5.88\frac{kip}{in}\right) = 4.41\frac{kip}{in}$$

$$Since\ maximum\ weld\ load, 0.069\ \frac{kip}{in} \leq \phi R_n \therefore weld\ size\ OK.$$

For 4” pipe:

$$maximum\ weld\ load = \frac{(T/bolt)}{b_{eff}} = \frac{0.237\ kips}{3.5\ in} = 0.059\frac{kip}{in}$$

$$minimum\ weld\ size\ for\ 1/2"\ material\ thickness = 3/16"$$

$$minimum\ weld\ length = 4 * weld\ thickness = 4 * 3/16" = 3/4"$$

$$nominal\ weld\ strength\ for\ 3/16"\ weld\ using\ E70\ electrode = R_n = F_w A_w$$

$$= 0.6(70)(0.14) = 5.88\frac{kip}{in}$$

$$\phi R_n = 0.75\left(5.88\frac{kip}{in}\right) = 4.41\frac{kip}{in}$$

$$Since\ maximum\ weld\ load, 0.059\ \frac{kip}{in} \leq \phi R_n \therefore weld\ size\ OK.$$

11.3 Mechanical Markups and Evaluations

11.3.1 Pipe Route Isometrics

Figure 49 shows the new pipe route isometrics used to help calculate the total head loss of the system. A bill of materials is still in the process of being completed for the system.

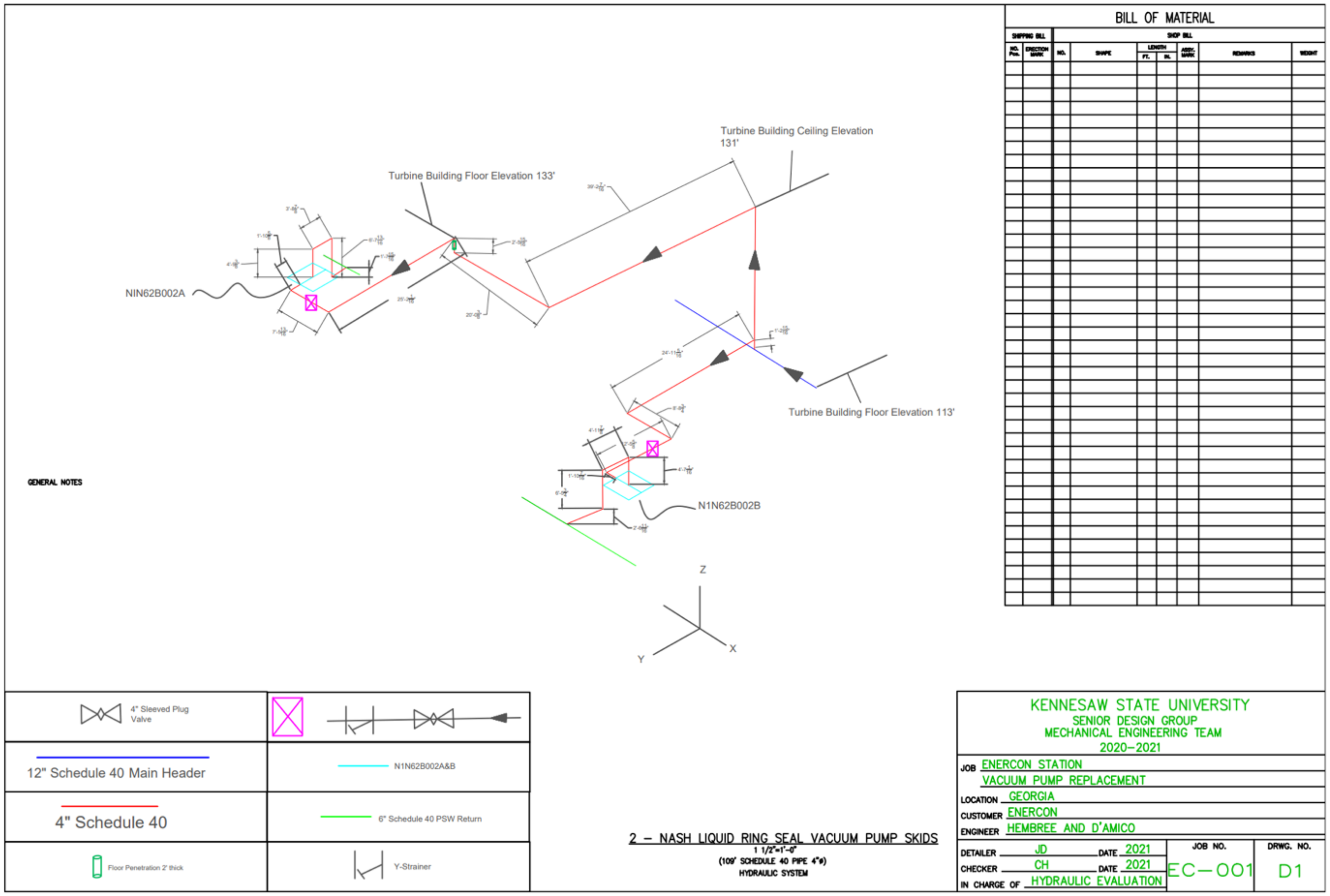


Figure 49: Pipe Route Isometrics

11.3.2 Markup of M-1002:

This markup shows the proposed pipe route from the 12" main header to the vacuum pump skid. Before the HX there will be a plug valve, y-strainer, and isolation valve.

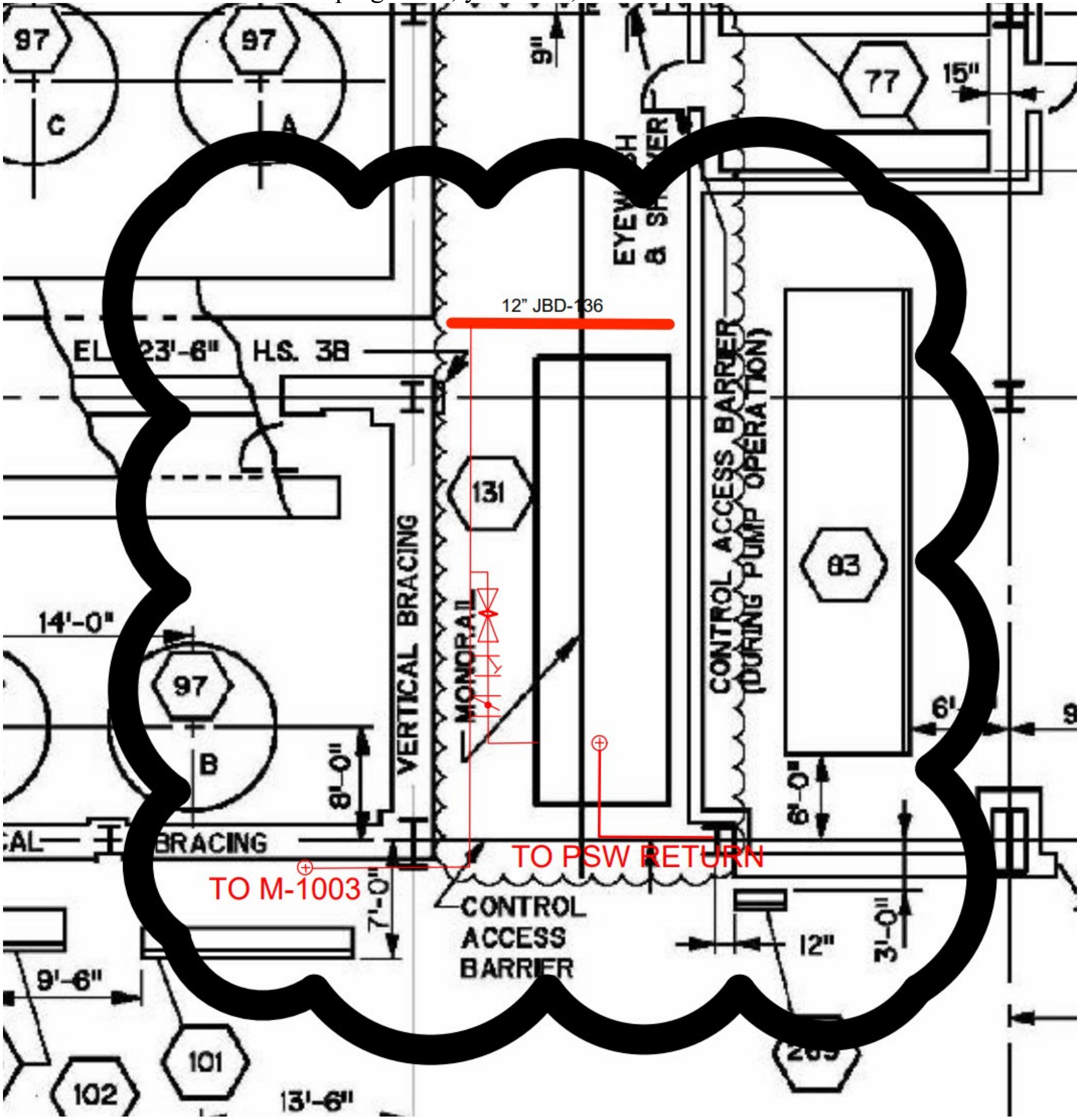


Figure 50: Pipe Route at TB elevation 113'.

11.3.3 Markup of M-1003

This markup shows the proposed pipe route come through the floor at elevation 133’ and route to the vacuum pump skid. Before the HX there will be a plug valve, y-strainer, and isolation valve.

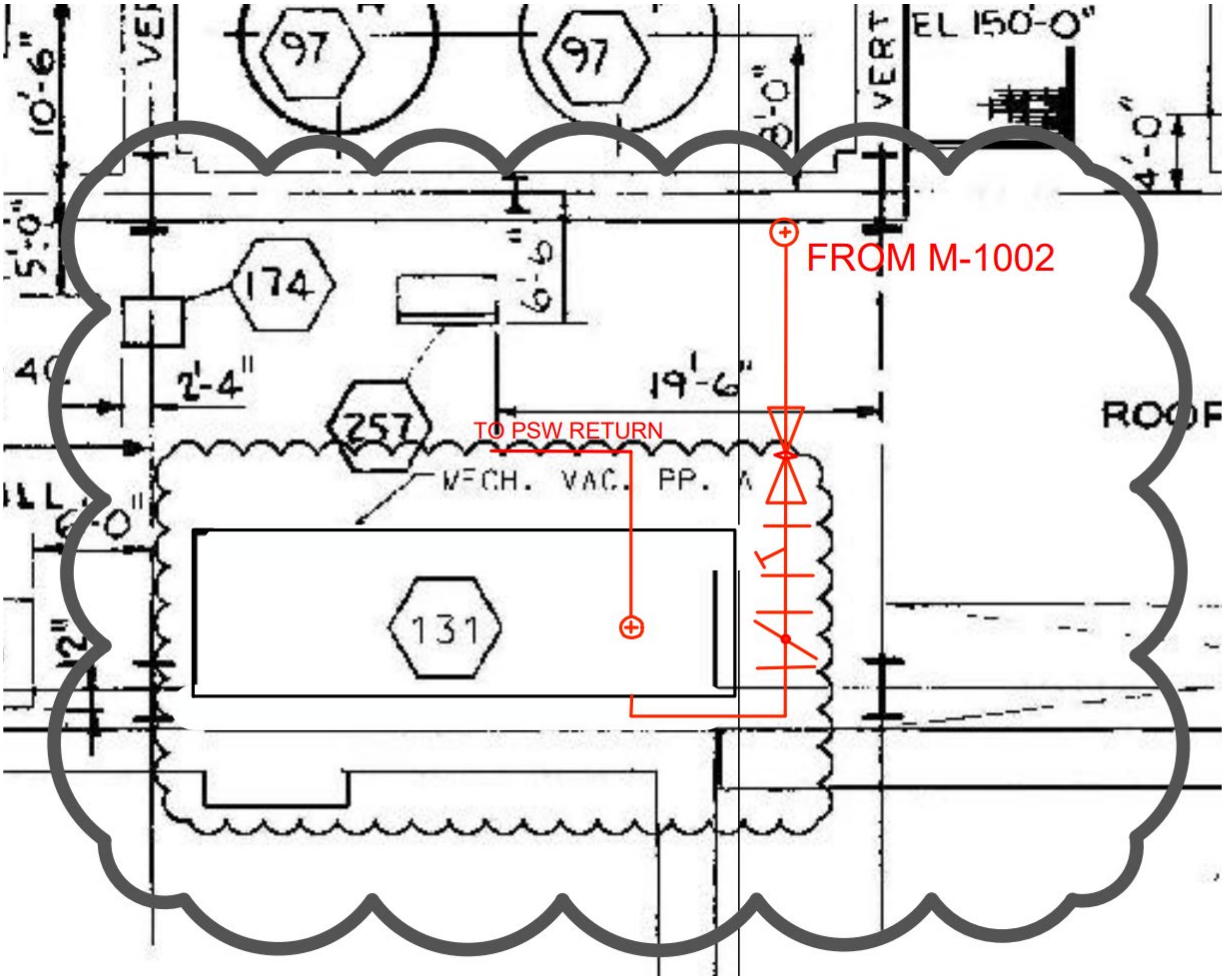


Figure 51: Pipe Route at TB elevation 133’.

11.3.4 Markup of SFD-1072A

This markup shows new piping being routed to the new HX and one of the old HX being deleted as well as the parameters being updated to reflect the new systems values.

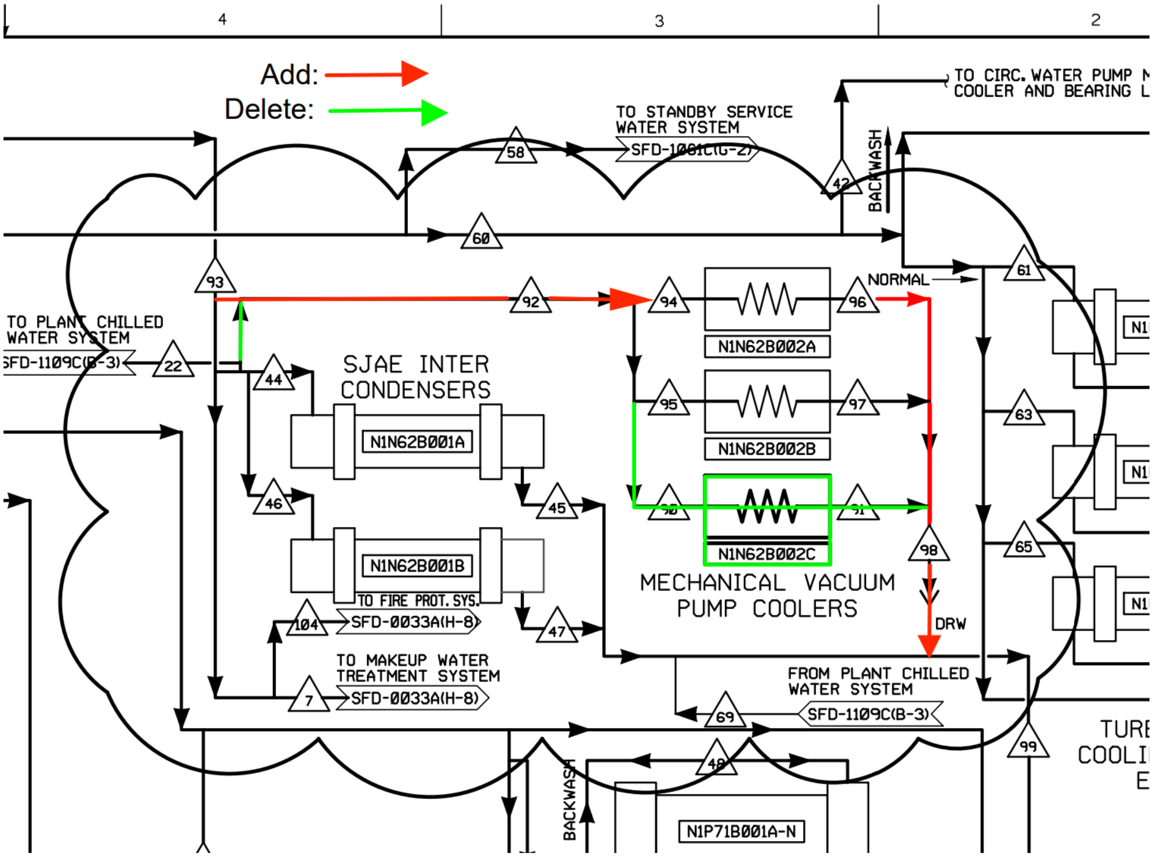
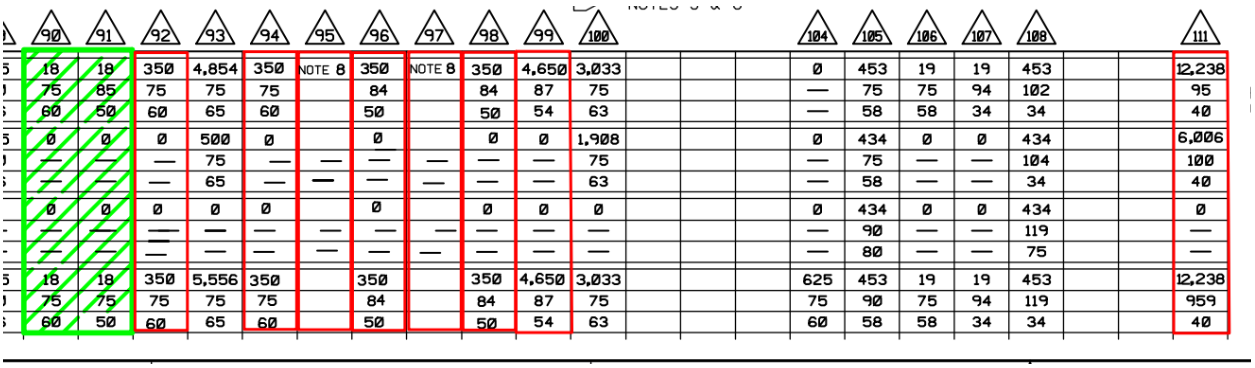


Figure 52: New pipe route and HX's.



90	91	92	93	94	95	96	97	98	99	100				104	105	106	107	108			111
18	18	350	4,854	350	NOTE 8	350	NOTE 8	350	4,650	3,033				0	453	19	19	453			12,238
75	85	75	75	75		84		84	87	75				—	75	75	94	102			95
60	50	60	65	60		50		50	54	63				—	58	58	34	34			40
0	0	0	500	0		0		0	0	1,908				0	434	0	0	434			6,006
—	—	—	75	—	—	—	—	—	—	75				—	75	—	—	104			100
—	—	—	65	—	—	—	—	—	—	63				—	58	—	—	34			40
0	0	0	0	0		0		0	0	0				0	434	0	0	434			0
—	—	—	—	—	—	—	—	—	—	—				—	90	—	—	119			—
—	—	—	—	—	—	—	—	—	—	—				—	80	—	—	75			—
18	18	350	5,556	350		350		350	4,650	3,033				625	453	19	19	453			12,238
75	75	75	75	75		84		84	87	75				75	90	75	94	119			959
60	50	60	65	60		50		50	54	63				60	58	58	34	34			40

Figure 53: Flow Parameters.

11.3.5 Markup of S*FD-1060B*

This markup shows the air removal system flow diagram being updated to delete the old pumps and add the new pumps.

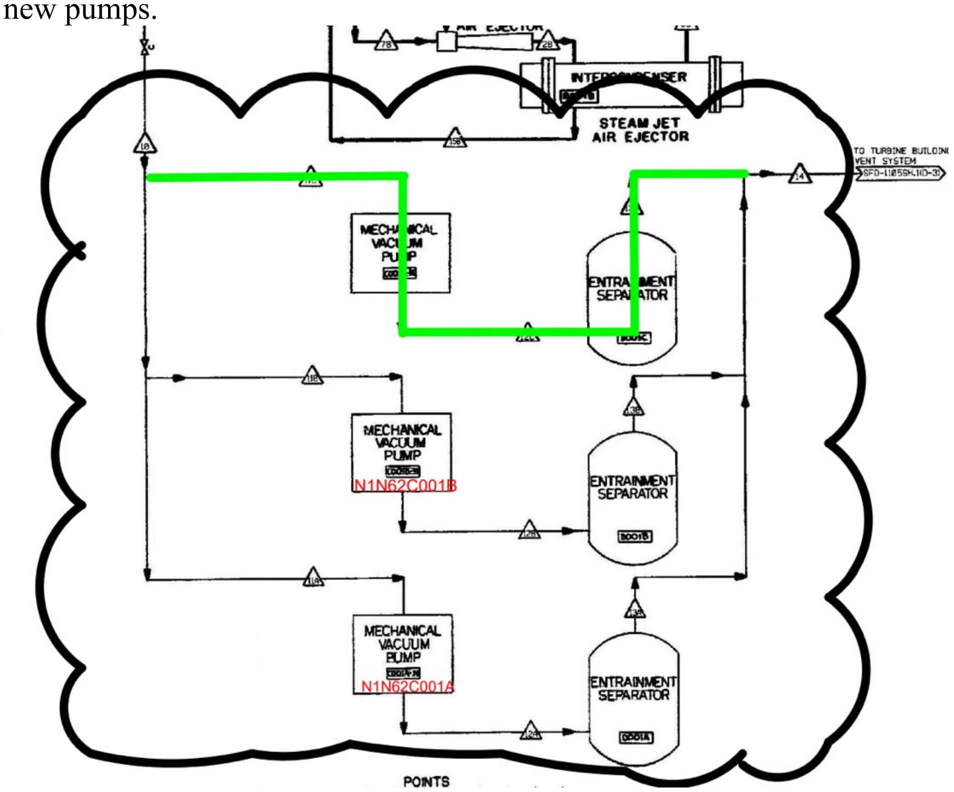
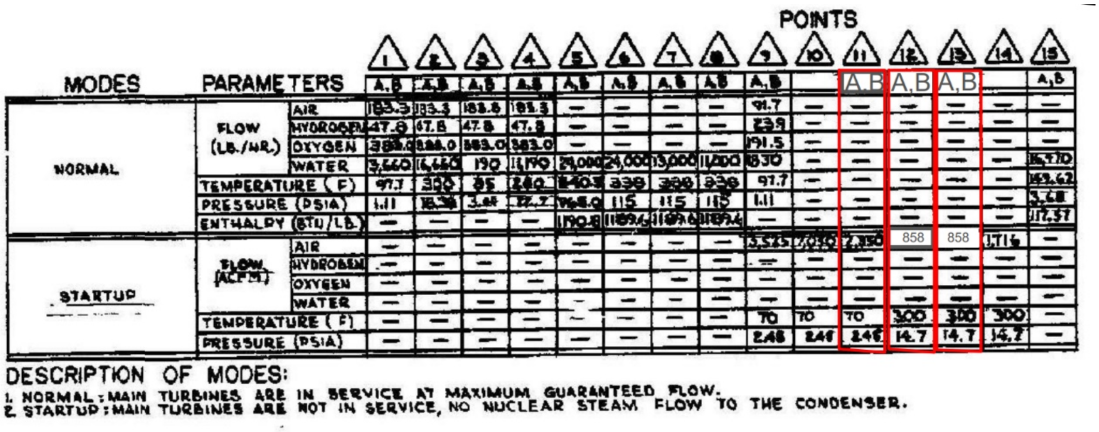


Figure 54: Old pump deleted; new ones added.



MODES	PARAMETERS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B		A,B	A,B	A,B		A,B
NORMAL	FLOW (LB./HR.)	AIR	183.3	183.3	183.3	183.3	—	—	—	—	91.7	—	—	—	—	—	—
		HYDROGEN	47.8	47.8	47.8	47.8	—	—	—	—	23.9	—	—	—	—	—	—
		OXYGEN	383.0	383.0	383.0	383.0	—	—	—	—	191.5	—	—	—	—	—	—
		WATER	3,660	16,660	190	11,190	24,000	24,000	13,000	11,200	1830	—	—	—	—	—	16,770
	TEMPERATURE (°F)		97.7	300	85	240	1240.5	338	338	338	97.7	—	—	—	—	—	163.62
	PRESSURE (PSIA)		1.11	18.38	3.48	17.7	765.0	115	115	115	1.11	—	—	—	—	—	3.68
	ENTHALPY (BTU/LB.)		—	—	—	—	1190.8	1189.6	1189.6	1189.6	—	—	—	—	—	—	117.57
STARTUP	FLOW (ACFM)	AIR	—	—	—	—	—	—	—	—	3,525	7,050	7,050	858	858	1,716	—
		HYDROGEN	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		OXYGEN	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		WATER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	TEMPERATURE (°F)		—	—	—	—	—	—	—	—	70	70	70	300	300	300	—
	PRESSURE (PSIA)		—	—	—	—	—	—	—	—	2.48	2.46	2.46	14.7	14.7	14.7	—

DESCRIPTION OF MODES:

1. NORMAL: MAIN TURBINES ARE IN SERVICE AT MAXIMUM GUARANTEED FLOW.
2. STARTUP: MAIN TURBINES ARE NOT IN SERVICE, NO NUCLEAR STEAM FLOW TO THE CONDENSER.

Figure 55: Flow Parameters.

11.3.6 Hydraulic Evaluation

The PSW Main Header tie-in location can provide 4,854 GPM (D.I. 3.7) which satisfies the required vacuum pump heat exchanger flow rate of 350 GPM (D.I. 3.5). To meter the flow to a desirable value, a throttling device will need to be sized so that the HX's are not damaged and do not take flow from downstream HX's. Bernoulli's equation will be utilized to help achieve the sizing of the throttling device. The valves K-value will be used to determine the percent open it will need to be to provide 350 GPM to the vacuum pump HX.

11.3.6.1 Design Inputs (D.I.)

11.3.6.1.1) 12" Main PSW Header (Ref. 1).

11.3.6.1.2) New pipe route will be 4" Schedule 40 Wrought Steel Pipe. (Ref 2) calls for 150# connections. On page 2-9 of CRANE Technical Paper 410, Schedule 40 pipe shall be used for Class 300 and below.

11.3.6.1.3) N1N62C001A (Pump A) location at plant elevation 133' in the Turbine Building (Ref 4).

11.3.6.1.4) N1N62C001B (Pump B) location at plant elevation in 113' in the Turbine Building (Ref 5).

11.3.6.1.5) HX connections are 4" 150# ANSI Flanges. (Ref 2).

11.3.6.1.6) (HX A&B) cold side inlets require a flowrate of 350 GPM. (Ref 2).

11.3.6.1.7) PSW Provides 4,854 GPM at desired tie in point (Ref 3, indicator 93).

11.3.6.1.8) Pressure at HX inlet (Ref 3, indicator 93) $P_1 = 65\, psig = 9360\ \frac{lb}{ft^2}$.

11.3.6.1.9) Pressure at HX outlet (Ref 3, indicator 98) $P_2 = 50\, psig = 7200\ \frac{lb}{ft^2}$.

11.3.6.1.10) Temperature at HX inlet (Ref 3, indicator 93) $T_1 = 75°F$

11.3.6.1.11) Temperature at HX outlet (Ref 3, indicator 98) $T_2 = 87°\mathrm{F}$

11.3.6.1.12) Gravitational Constant**:** $g = 32.4\frac{ft}{s^2}$; $2g = 64.8\frac{ft}{s^2}$ (Ref 17).

11.3.6.1.13) Specific Density of Water at 60°F, $\gamma = 62.4\ \frac{lb}{ft^3}$ (Ref 17, page B-10 & Assumption (11.3.6.2.4).

11.3.6.1.14) Nominal 4" Schedule 40 inside diameter is 4.026" (Ref 17)

11.3.6.1.15) Pressure Drop Across 4" Y-Strainer at 350 GPM is 1.75 psi (Ref 24).

11.3.6.1.16) $f_T = 0.016$ for Schedule 40 Pipe (Ref 17, page A-27)

11.3.6.1.17) Length of Pipe Route to Pump Skid A is 50 ft (Ref 23).

11.3.6.1.18) Nominal 12” Schedule 40 Pipe is 11.938” (ref 17).

11.3.6.1.19) Pressure Drop Across HX is 5.81 psi (ref 2).

11.3.6.1.20) Tee connection to main header has 12” straight and branch (ref 23)

11.3.6.1.21) F_t = 0.016 for a 4” pipe (ref 17, page A-27)

11.3.6.2 Assumptions

11.3.6.2.1) When calculating the total head loss, all piping, and connections to pump B are omitted. Pump A is much further away from the tie-in-point to the existing PSW main header and is therefore the bounding condition.

11.3.6.2.2) PSW main header tie-in is in same room as Mechanical Vacuum Pump B (N1N62C001B) as seen in Ref. 4.9. This was assumed due to plant censorship issues.

11.3.6.2.3) It is assumed that the flow is divided equally between the 12” header run and branch when calculating the header tee hydraulic resistance. This is acceptable because the flow velocities on the branch are reduced by the limited flow to the vacuum pump HX.

11.3.6.2.4) It is assumed that the change in water density from 60 °F (D.I, 11.3.6.1.13) to 87 °F $(\mathrm{D.I.}\,11.3.6.1.11)$ is negligible. This is because the density of water does not fall below 62 $\frac{lb}{ft^3}$ until it reaches about 100 °F.

11.3.6.3) Area of 4” Pipe (D.I. 11.3.6.1.14):

$$A = \frac{\pi}{4}d^2\,, \qquad A_{4"} = \frac{\pi}{4}\left(\frac{4.026}{12}\right)^2 \therefore\ A_{4"}\ = 0.088ft^2$$

11.3.6.4) Area of 12” Pipe (D.I. 11.3.6.1.18):

$$A = \frac{\pi}{4}d^2, \qquad A_{12"} = \frac{\pi}{4}\left(\frac{11.938}{12}\right)^2 \therefore\ A_{12"} = 0.777\ ft^2$$

11.3.6.5) 350 GPM to $\frac{ft^3}{s}$ conversion (D.I. 11.3.6.1.6):

$$Q_{4"\,Pipe} = 350\frac{gal}{min} * \frac{0.134ft^3}{1gal} * \frac{1\,min}{60\,s} = 0.781\frac{ft^3}{s}$$

11.3.6.6) 4,854 GPM to $\frac{ft^3}{s}$ conversion (D.I 11.3.6.1.7):

$$Q_{12"} = 4{,}854\ \frac{gal}{min} * \frac{0.134ft^3}{1gal} * \frac{1\,min}{60\,s} = \ 10.84\frac{ft^3}{s}$$

11.3.6.7) Velocity conversion from 4,854 GPM through 12" Pipe (D.I. 11.3.6.1.7):

$$V = \frac{Q}{A},\ V_{12"} = \frac{Q_{12"}}{A_{12"}} = \frac{10.84\frac{ft^3}{s}}{0.777\,ft^2}\ \therefore V_{12"} = 13.95\ \frac{ft}{s}\ \ \therefore\ {V_{12"}}^2 = 194.6\,\frac{ft^2}{s^2}$$

11.3.6.8) Velocity conversion from 350 GPM through 4" pipe (D.I. 11.3.6.1.5, 11.3.6.1.6):

$$V = \frac{Q}{A},\ V_{4"} = \frac{Q_{4"\,Pipe}}{A_{4"}} = \frac{0.781\frac{ft^3}{s}}{0.088\,ft^2}\ \therefore V_{4"} = 8.88\ \frac{ft}{s}\ \ \therefore\ {V_{4"}}^2 = 78.85\,\frac{ft^2}{s^2}$$

11.3.6.9) Pressure at tie-in-point to main header (D.I. 11.3.6.1.8):

$$P_1 = 65\,psig * \frac{144\frac{lb}{ft^2}}{1\,psi} = 9360\ \frac{lb}{ft^2}.$$

11.3.6.10) Pressure downstream HX (D.I. 11.3.6.1.9):

$$P_2 = 50\,psig * \frac{144\,\frac{lb}{ft^2}}{1\,psi} = 7200\ \frac{lb}{ft^2}$$

11.3.6.11) Equation for Head Loss (Ref. 17 Page 2-7 Equation 2-3):

$$h_l = k\left(\frac{v^2}{2g}\right)$$

11.3.6.12) HX Head Loss (D.I. 11.3.6.1.19)

$$h_{l,HX} = \Delta p(2.31)\ ft$$

$$\therefore\ h_{l,HX} = 5.81psi * \frac{2.31\,ft}{1\,psi} = 13.4\text{ ft}$$

$$h_{l,HX} = k_{HX}\left(\frac{{v_{4"}}^2}{2g}\right)$$

$$\therefore 13.4\,ft = \ k_{HX}\frac{78.85}{64.8}$$

$$\therefore k_{HX} = 16.305$$

11.3.6.13) Head Loss Calculation for Tee connection (Ref. 17, page 2-15 Equation 2-37):

From CRANE Technical Paper 410 Page 2-14:

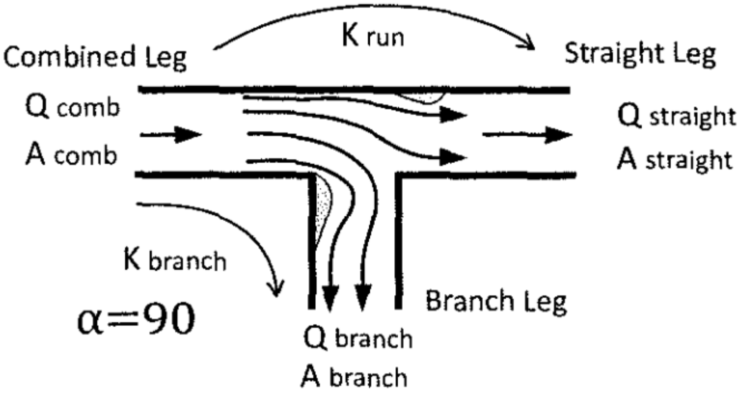


Figure 56: Used to obtain Tee connection head loss.

$$Q_{Branch} = 2{,}427\ (Assumption\ 11.3.6.2.3)$$

$$k_{Branch} = G[\,1 + H\left(\frac{Q_{Branch}}{Q_{Comb}} * \frac{1}{\beta^2{}_{Branch}}\right)^2 - J\left(\frac{Q_{Branch}}{Q_{Comb}} * \frac{1}{\beta^2{}_{Branch}}\right) cos \propto]$$

From (D.I. 11.3.6.1.20):

k_{Branch} is a 12” pipe

$Q_{12"\,Branch}$ is the flowrate through a 12” pipe (Assumption 11.3.6.2.3)

$\beta^2{}_{Branch}$ is a 12” pipe (D.I 11.3.6.1.1) = $\beta_1{}^2$

Q_{Comb} is the flowrate through a 12” pipe

Solving Equation 2-37 (Ref 17, page 2-15, Table 2-3)

Where:

$$\frac{Q_{12"\,Branch}}{Q_{12"\,Comb}} = \frac{2{,}427\ GPM}{4{,}854\ GPM} \approx 0.5$$

$\beta_1{}^2 = (\frac{d_{12"\,Branch}}{d_{12"\,Comb}})^2$ (Ref. 17 Equation 2-34)

$$\therefore\ {\beta_1}^2 = (\frac{11.938''}{11.938''})^2 = 1$$

$$\therefore G = 1.3, \qquad H = 0, \qquad J = 0, \propto = 90$$

$$\therefore\ k_{4''\,Branch} = G[\,1 + H\left(\frac{Q_{\,Branch}}{Q_{\,Comb}} * \frac{1}{\beta^2{}_{\,Branch}}\right)^2 - J\left(\frac{Q_{\,Branch}}{Q_{\,Comb}} * \frac{1}{\beta^2{}_{\,Branch}}\right)cos \propto]$$

$$\therefore\ k_{12''\,Branch} = 1.3[\,1 + 0.3\left(0.50 * \frac{1}{1}\right)^2 - 0]$$

$$\therefore\ k_{12''\,Branch} = 1.3975$$

Calculating the head loss of the tee:

$$h_l = k\left(\frac{v^2}{2g}\right)$$

$$\therefore h_{l,tee} = k_{12''\,Branch}\left(\frac{{V_{12''}}^2}{2g}\right)$$

$$\therefore h_{l,tee} = 1.3975\left(\frac{194.6\,\frac{ft^2}{s^2}}{64.8\frac{ft}{s^2}}\right)$$

$$\therefore h_{l,tee} = 4.196\,ft$$

11.6.3.14) Head Loss Calculation for Reducer from 12” pipe down to 4” pipe (Ref. 17, page A-27)

For a Sudden and Gradual Contraction:

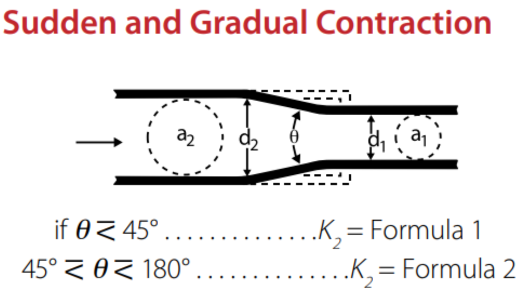


Figure 57: Ref. 17, Used to obtain reducer head loss.

Formula 1:

$$k_2 = \frac{0.8 * (\sin\frac{\theta}{2}) \ * (1 - \beta^2)}{\beta^4}$$

Where:

$\theta = 5°$ and $\beta = \beta_2 = \frac{d_{4"}}{d_{12"}}$ (D.I. 11.3.6.1.14 & 11.3.6.1.18)

$$\therefore \beta_2 = \frac{4.026}{11.938} = 0.337$$

$$\therefore \beta^2 \ = \ 0.1135$$

$$\therefore \beta^4 \ = \ 0.01289$$

$$\therefore k_2 = \frac{0.8 * (\sin 2.5) \ * (1 - 0.1135)}{0.01289}$$

$$\therefore k_{Reducer} \ = 2.39\, ft$$

$$h_{l,Reducer} = \ k_{Reducer}\left(\frac{v^2}{2g}\right)$$

Where: $v^2 \ = \ {V_{4"}}^2$

$$\therefore h_{L,Reducer} = \ 2.39\, ft\left(\frac{78.85\ \frac{ft^2}{s^2}}{64.8\ \frac{ft}{s^2}}\right) = 2.908\, ft$$

11.3.6.15) Head Loss Calculation for 90° Elbows (Ref. 17):

$$h_{l,elbow} = \ k_{Elbow}\left(\frac{v^2}{2g}\right)$$

Where: $v^2 \ = \ {V_{4"}}^2$

Standard 90° Elbow: $k = 30f_T$ (D.I. 11.3.6.1.16, Ref. 17, page A-27/30)

$$\therefore \ k_{Elbow} = 30f_T = 30 * 0.016 = 0.48$$

$$\therefore h_{L,Elbow} = \ 0.48\left(\frac{78.85}{64.8}\right) = 0.584\, ft$$

11.3.6.16) Head Loss Calculation for 4” Y-Strainer (D.I. 11.3.6.1.15):

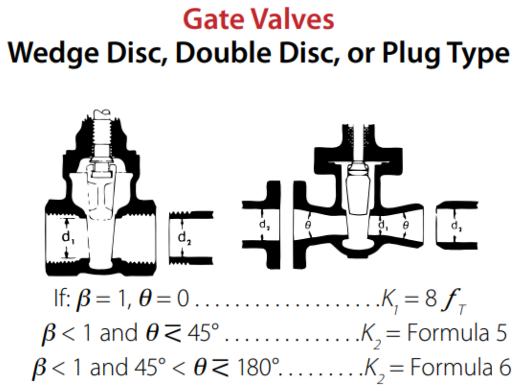
$$h_{l,Strainer} = 1.75\ psi * \frac{2.31\ ft}{1\ psi} = 4.042\ ft$$

11.3.6.17) Head Loss Calculation for 4” Isolation Valve (Ref. 17):

$$h_{l,Isolation} = k_{Isolation}\left(\frac{v^2}{2g}\right)$$

Where: $v^2 = {V_{4"}}^2$

From Ref 17, page A-27/28:



Gate Valves

Wedge Disc, Double Disc, or Plug Type

If: $\beta = 1, \theta = 0$ . . . . $K_1 = 8\, f_T$

$\beta < 1$ and $\theta \lessapprox 45°$ . . . . K_2 = Formula 5

$\beta < 1$ and $45° < \theta \lessapprox 180°$. . . . . K_2 = Formula 6

Figure 58: Used for isolation valve head loss calculation.

$$\beta = \beta_2 = \frac{d_{4"}}{d_{4"}}$$

$$\therefore \beta = \frac{4.026}{4.026} = 1.00$$

$$\therefore k = 8 * f_T$$

$$\therefore k = 0.128$$

$$\therefore h_{l,Isolation} = 0.128\left(\frac{78.85}{64.8}\right) = 0.1557\ ft$$

11.3.6.18) Head Loss from length of pipe (Ref. 17, 30):

$$h_{l,pipe} = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

Where: f = 0.016 (D.I. 11.3.6.1.16), L $L = 50$ ft (D.I. 11.3.6.1.17), D= 0.3355 ft (D.I. 11.3.6.1.18), $v^2 = {V_{4"}}^2$

$$\therefore h_{l,pipe} = 0.016\left(\frac{50\,ft}{0.3355}\right)\left(\frac{78.85\ \frac{ft^2}{s^2}}{64.8\ \frac{ft}{s^2}}\right)$$

$$\therefore\ h_{l,pipe} = 2.901\,ft$$

11.3.6.19) K-factor of the throttle valve (Ref. 28 Equation 5-14)

$$\frac{P_1}{\gamma} + \frac{{V_1}^2}{2g} = \frac{P_2}{\gamma} + \frac{{V_2}^2}{2g} + h_{l,total}$$

$$\frac{P_1}{\gamma} + \frac{{V_1}^2}{2g} = \frac{P_2}{\gamma} + \frac{{V_2}^2}{2g} + k_{Valve}\frac{(V_3)^2}{2g} + h_{l,total}$$

Where: $V_1 = V_{12"}$, $V_2 = V_{4"}$; $V_3 = V_{4"}$

(Ref. 30) for number of elbows before HX = 6

$$h_{l,total} = (h_{l,Hx}) + (h_{l,tee}) + (h_{l,Reducer}) + (6 * h_{l,Elbow}) + (h_{l,Strainer}) + (h_{l,Isolation}) + (h_{l,pipe})$$

$$h_{l,total} = (16.305\,ft) + (4.196\,ft) + (2.908\,ft) + (6 * 0.584\,ft) + (4.042\,ft) + (0.1557\,ft) + (2.901\,ft)$$

$$\therefore\ h_{l,Total} = 34.011\,ft$$

$$\therefore \frac{P_1}{\gamma} + \frac{{V_1}^2}{2g} = \frac{P_2}{\gamma} + \frac{{V_2}^2}{2g} + k_{Valve}\frac{(V_3)^2}{2g} + 34.011\,ft$$

$$\therefore \frac{9360\ \frac{lb}{ft^2}}{62.4\ \frac{lb}{ft^3}} + \frac{(13.8\frac{ft}{s})^2}{64.8\frac{ft}{s^2}} = \frac{7200\ \frac{lb}{ft^2}}{62.4\ \frac{lb}{ft^3}} + \frac{(8.83\frac{ft}{s})^2}{64.8\frac{ft}{s^2}} + k_{Valve}\frac{(8.83\frac{ft}{s})^2}{64.8\frac{ft}{s^2}} + 34.011\,ft$$

Solving for k_{Valve}

$$\therefore\ k_{valve} = 1.949$$

$$\therefore \Delta P_{valve} = k_{Valve}\frac{(V)^2}{2g} = 1.949 * \frac{\left(8.83\,\frac{ft}{s}\right)^2}{64.8\,\frac{ft}{s^2}} = 2.345\ ft * \frac{1\ psi}{2.31\ ft} = 1.015\ psi = \Delta P_{actual}$$

From (Ref. 21 page 6).

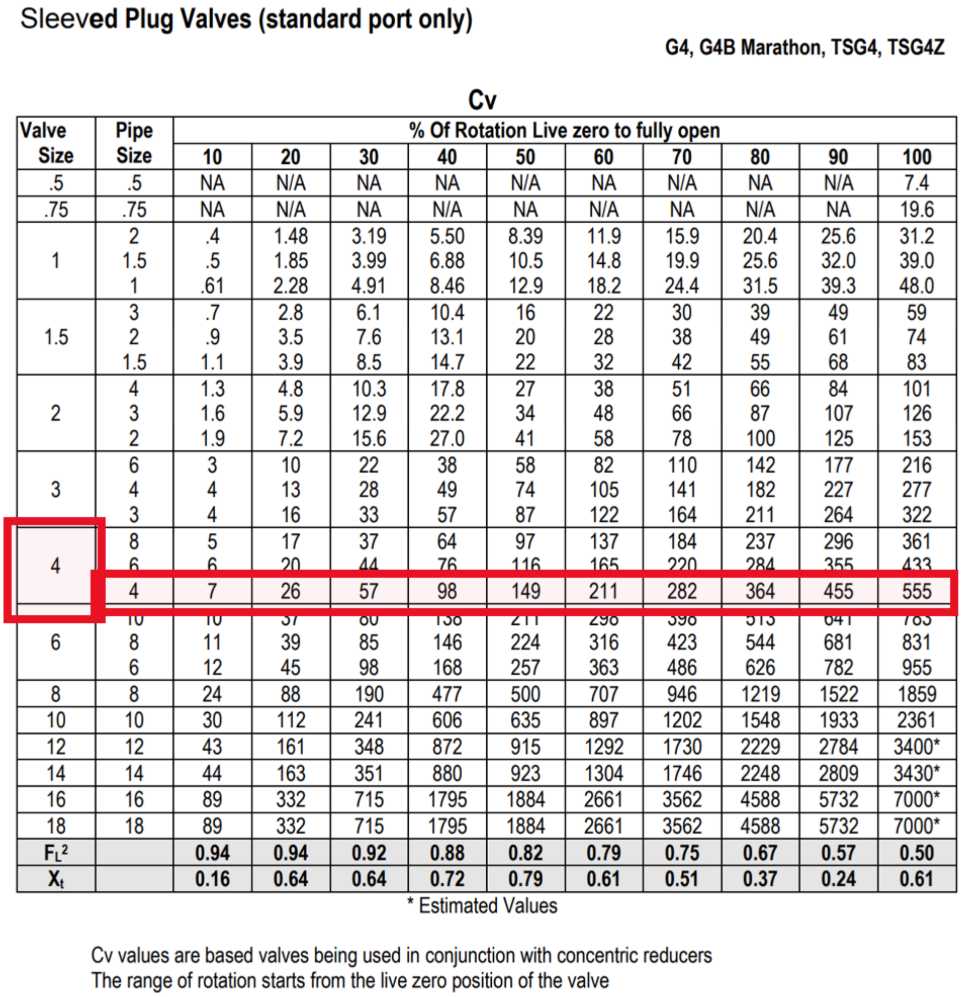
Equation 1-1.0 Shall be used to size Durco Valves.

$$C_v = \frac{Q}{\sqrt{\frac{\Delta P}{S.G.}}}$$

Where: $Q = 350\ GPM;\ \Delta P = 1.015\ psi\ ; S.G. = 1$

$$\therefore C_v = \frac{350}{\sqrt{\frac{1.015}{1}}}$$

$$\therefore C_v = 347.38$$



Sleeved Plug Valves (standard port only)

G4, G4B Marathon, TSG4, TSG4Z

Cv

Valve Size	Pipe Size	% Of Rotation Live zero to fully open									
		10	20	30	40	50	60	70	80	90	100
.5	.5	NA	N/A	NA	NA	N/A	NA	N/A	NA	N/A	7.4
.75	.75	NA	N/A	NA	N/A	NA	N/A	NA	N/A	NA	19.6
1	2	.4	1.48	3.19	5.50	8.39	11.9	15.9	20.4	25.6	31.2
	1.5	.5	1.85	3.99	6.88	10.5	14.8	19.9	25.6	32.0	39.0
	1	.61	2.28	4.91	8.46	12.9	18.2	24.4	31.5	39.3	48.0
1.5	3	.7	2.8	6.1	10.4	16	22	30	39	49	59
	2	.9	3.5	7.6	13.1	20	28	38	49	61	74
	1.5	1.1	3.9	8.5	14.7	22	32	42	55	68	83
2	4	1.3	4.8	10.3	17.8	27	38	51	66	84	101
	3	1.6	5.9	12.9	22.2	34	48	66	87	107	126
	2	1.9	7.2	15.6	27.0	41	58	78	100	125	153
3	6	3	10	22	38	58	82	110	142	177	216
	4	4	13	28	49	74	105	141	182	227	277
	3	4	16	33	57	87	122	164	211	264	322
4	8	5	17	37	64	97	137	184	237	296	361
	6	6	20	44	76	116	165	220	284	355	433
	4	7	26	57	98	149	211	282	364	455	555
6	10	10	37	80	138	211	298	398	513	641	783
	8	11	39	85	146	224	316	423	544	681	831
	6	12	45	98	168	257	363	486	626	782	955
8	8	24	88	190	477	500	707	946	1219	1522	1859
10	10	30	112	241	606	635	897	1202	1548	1933	2361
12	12	43	161	348	872	915	1292	1730	2229	2784	3400*
14	14	44	163	351	880	923	1304	1746	2248	2809	3430*
16	16	89	332	715	1795	1884	2661	3562	4588	5732	7000*
18	18	89	332	715	1795	1884	2661	3562	4588	5732	7000*
F_L^2		**0.94**	**0.94**	**0.92**	**0.88**	**0.82**	**0.79**	**0.75**	**0.67**	**0.57**	**0.50**
X_t		**0.16**	**0.64**	**0.64**	**0.72**	**0.79**	**0.61**	**0.51**	**0.37**	**0.24**	**0.61**

* Estimated Values

Cv values are based valves being used in conjunction with concentric reducers
The range of rotation starts from the live zero position of the valve

Figure 59: Ref. 21, Table used to determine percent open of valve to achieve 350 GPM.

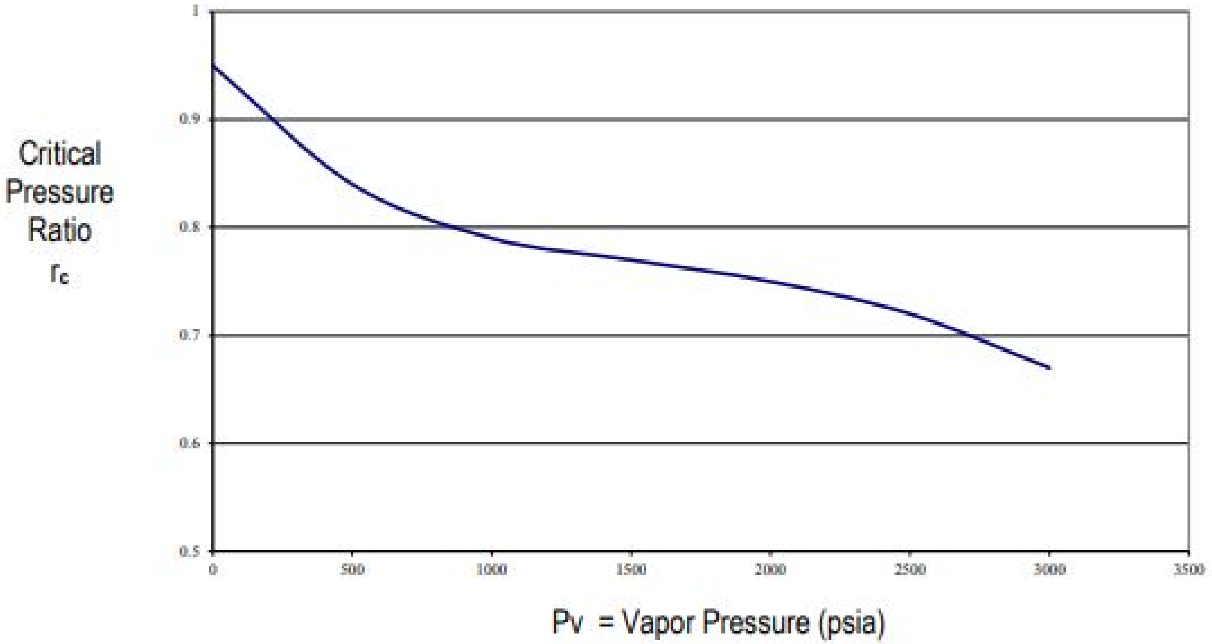
Interpolating between 70% and 80% the percent-open the valve needs to be to control the flow down to 350 GPM is 78%.

(Ref. 21) Equation 1-1.1 to solve for $\Delta P_{allow} = {F_L}^2(P_1 - r_c P_v)$

Where: $P_v = 0.43525 psia\ (from\ table\ A9-E\ on\ page\ 947,\ reference\ 4.4)$; $P_1 = 65 psig + 14.7\ psi = 79.7\ psia$; ${F_L}^2 = 0.76$; $r_c = 0.95$

$$\therefore\ \Delta P_{allow} = 0.76(79.7\ psia - (.95)(0.43525\ psia))$$

$$\Delta P_{allow} = 60.25\ psi > \Delta P_{actual}\ so\ no\ cavitation$$



CONTROL VALVE SIZING CAVITATING AND FLASHING LIQUIDS

FIGURE 1.2 - CRITICAL PRESSURE RATIOS FOR WATER

Figure 60: Ref. 21, Table from Flow Serve used to obtain r_c value for Vapor pressure of water at 75°F

11.3.7 HX Evaluation:

Through an iterative process using an energy balance equation, the LMTD (log-mean-temperature-difference) method based on a counterflow design, and the NTU (number transfer units) effectiveness method, the provided heat exchanger in document N1N62B002A&B-1.1-001 can be evaluated to determine the enthalpy values on both the cold and hot sides. Design values are determined from the heat exchanger specification sheet such as the mass flow rates, surface area, and inlet temperatures. From here, the enthalpy values are converted to temperature in °F and are used in a temperature-difference formula where a delta T value is determined and compared against a previously assumed value. Once the two numbers coincide, the outlet temps are then accurate. Next, the outlet temperatures are compared with that of the limitations in the system to determine the heat exchanger's capability to perform in the given environment.

Density values are determined in saturated water table A-9E from Ref 15, interpolated values not shown:

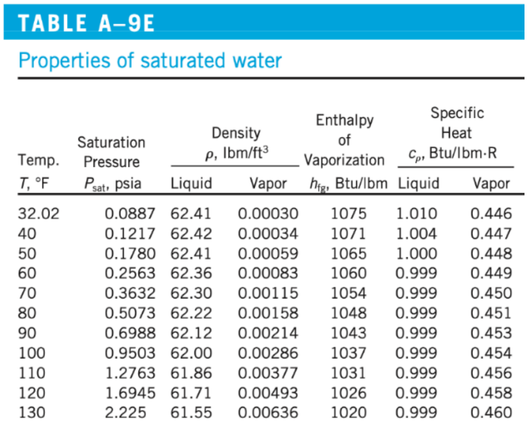


TABLE A–9E

Properties of saturated water

Temp. T, °F	Saturation Pressure P_{sat}, psia	Density ρ, lbm/ft³ Liquid	Density ρ, lbm/ft³ Vapor	Enthalpy of Vaporization h_{fg}, Btu/lbm	Specific Heat c_p, Btu/lbm·R Liquid	Specific Heat c_p, Btu/lbm·R Vapor
32.02	0.0887	62.41	0.00030	1075	1.010	0.446
40	0.1217	62.42	0.00034	1071	1.004	0.447
50	0.1780	62.41	0.00059	1065	1.000	0.448
60	0.2563	62.36	0.00083	1060	0.999	0.449
70	0.3632	62.30	0.00115	1054	0.999	0.450
80	0.5073	62.22	0.00158	1048	0.999	0.451
90	0.6988	62.12	0.00214	1043	0.999	0.453
100	0.9503	62.00	0.00286	1037	0.999	0.454
110	1.2763	61.86	0.00377	1031	0.999	0.456
120	1.6945	61.71	0.00493	1026	0.999	0.458
130	2.225	61.55	0.00636	1020	0.999	0.460

Figure 61: Saturated water table used to find the density of water at various temperatures

Enthalpy values of saturated water h_f are determined from Table A-4E found in Ref 14, interpolated values not shown:

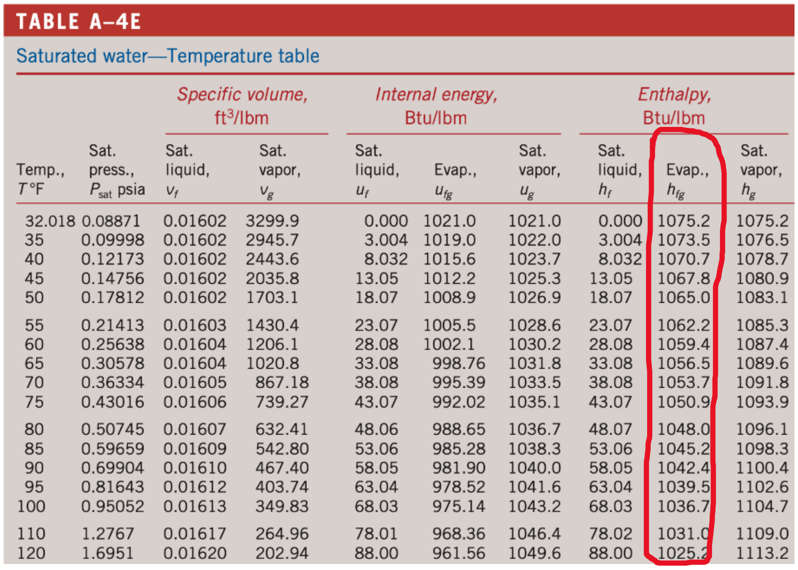


TABLE A–4E

Saturated water—Temperature table

Temp., T °F	Sat. press., P_{sat} psia	Specific volume, ft³/lbm: Sat. liquid, v_f	Specific volume, ft³/lbm: Sat. vapor, v_g	Internal energy, Btu/lbm: Sat. liquid, u_f	Internal energy, Btu/lbm: Evap., u_{fg}	Internal energy, Btu/lbm: Sat. vapor, u_g	Enthalpy, Btu/lbm: Sat. liquid, h_f	Enthalpy, Btu/lbm: Evap., h_{fg}	Enthalpy, Btu/lbm: Sat. vapor, h_g
32.018	0.08871	0.01602	3299.9	0.000	1021.0	1021.0	0.000	1075.2	1075.2
35	0.09998	0.01602	2945.7	3.004	1019.0	1022.0	3.004	1073.5	1076.5
40	0.12173	0.01602	2443.6	8.032	1015.6	1023.7	8.032	1070.7	1078.7
45	0.14756	0.01602	2035.8	13.05	1012.2	1025.3	13.05	1067.8	1080.9
50	0.17812	0.01602	1703.1	18.07	1008.9	1026.9	18.07	1065.0	1083.1
55	0.21413	0.01603	1430.4	23.07	1005.5	1028.6	23.07	1062.2	1085.3
60	0.25638	0.01604	1206.1	28.08	1002.1	1030.2	28.08	1059.4	1087.4
65	0.30578	0.01604	1020.8	33.08	998.76	1031.8	33.08	1056.5	1089.6
70	0.36334	0.01605	867.18	38.08	995.39	1033.5	38.08	1053.7	1091.8
75	0.43016	0.01606	739.27	43.07	992.02	1035.1	43.07	1050.9	1093.9
80	0.50745	0.01607	632.41	48.06	988.65	1036.7	48.07	1048.0	1096.1
85	0.59659	0.01609	542.80	53.06	985.28	1038.3	53.06	1045.2	1098.3
90	0.69904	0.01610	467.40	58.05	981.90	1040.0	58.05	1042.4	1100.4
95	0.81643	0.01612	403.74	63.04	978.52	1041.6	63.04	1039.5	1102.6
100	0.95052	0.01613	349.83	68.03	975.14	1043.2	68.03	1036.7	1104.7
110	1.2767	0.01617	264.96	78.01	968.36	1046.4	78.02	1031.0	1109.0
120	1.6951	0.01620	202.94	88.00	961.56	1049.6	88.00	1025.2	1113.2

Figure 62: Saturated water table to find the enthalpy of water at various temperatures

Mass flow rate of fluid entering heat exchanger on cold-side can be found by:

$$\dot{m} = \rho\dot{Q} = \frac{62.26\ lb}{ft^3} \times \frac{350\ gal}{min} \times \frac{60\ min}{hr} \times \frac{1\ ft^3}{7.48\ gal} = 174{,}794.12\ \frac{lb}{hr}$$

where water is entering at a temperature of 75°F according to indicator 93 in Ref 3

Mass flow rate of fluid entering heat exchanger on hot-side can be found by:

$$\dot{m} = \rho\dot{Q} = \frac{62.0024\,lb}{ft^3} \times \frac{190\,gal}{min} \times \frac{60\,min}{hr} \times \frac{1\,ft^3}{7.48\,gal} = 94{,}495.64\,\frac{lb}{hr}$$

where water is entering at a temp of 99.8°F according to Ref 2

From the below equation, a heat transfer rate can be determined using an assumed value for ΔT_{LMTD}:

$$\dot{Q} = UA_s\Delta T_{LMTD} = \frac{1153.11\,BTU}{ft^2 \cdot h \cdot °\mathrm{F}} \times 124.88\,ft^2 \times 11.1815°\mathrm{F} = 1{,}610{,}140.2\,\frac{BTU}{hr}$$

where U and A_s are from Ref 2 and delta T_{LMTD} is an assumed value

We determine the cold-side outlet temperature T_2 from:

$$\dot{Q} = \dot{m}_c\Delta h = \dot{m}_c(h_2 - h_1)$$

$$h_2 = \frac{\dot{Q}}{\dot{m}_c} + h_1 = \frac{1{,}610{,}140.2\,\frac{BTU}{hr}}{174{,}794.12\,\frac{lb}{hr}} + 43.07\,\frac{BTU}{lb} = 52.28\,\frac{BTU}{lb}\ or\ 84.22°\mathrm{F}$$

Using the Conservation of Energy Equation from Ref 14:

$$\dot{Q} - \dot{W} = \sum \dot{m}_o\left(h_o + \frac{{V_o}^2}{2} + gz_o\right) - \sum \dot{m}_\iota\left(h_\iota + \frac{V_\iota^2}{2} + gz_\iota\right)$$

Assuming no work is being done on the surroundings, and no change in elevation and velocity is constant we have:

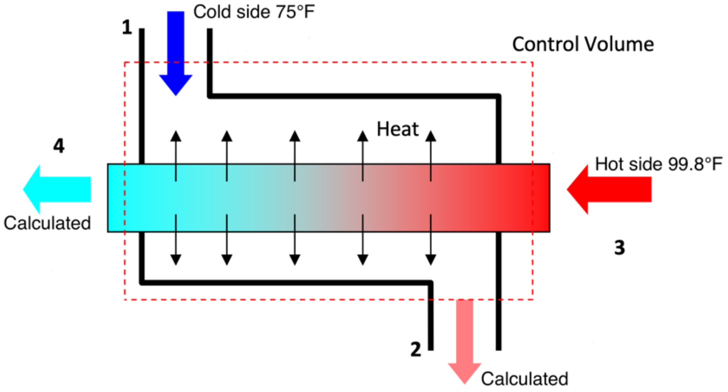


Figure 63: Image snipped and edited, originally a closed system diagram from Ref 14

$$\sum \dot{m}_i h_i = \sum \dot{m}_o h_o$$

$$\dot{m}_c h_1 + \dot{m}_h h_3 = \dot{m}_c h_2 + \dot{m}_h h_4$$

Rearranged to solve for hot-side outlet enthalpy:

$$h_4 = h_3 + \frac{\dot{m}_c(h_1 - h_2)}{\dot{m}_h} = 67.83\frac{BTU}{lb} + \frac{174{,}794.12\frac{lb}{hr} \times (43.07 - 52.28)\frac{BTU}{lb}}{94{,}495.64\frac{lb}{hr}}$$

$$= 50.79\frac{BTU}{lb}\ or\ 82.73°\text{F}$$

where h_3 is an enthalpy value of hot-side temperature of 99.8°F, and h_1 is an enthalpy value of cold-side inlet temperature of 75°F.

For the newly calculated outlet temperatures, we then apply the LMTD-method using the below equation to check our assumed delta T_{LMTD} value against our calculated value:

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{ln(\frac{\Delta T_1}{\Delta T_2})}\ where\ \Delta T_1 = T_{h,in} - T_{c,out}\ and\ \Delta T_2 = T_{h,out} - T_{c,in}$$

$$\Delta T_{LMTD} = \frac{15.54°\text{F} - 7.79°\text{F}}{ln(\frac{15.54}{7.79})} = 11.1815°\text{F}$$

Comparing the calculated value to the assumed value we have:

$$11.18157°\text{F} \cong 11.1815°\text{F}$$

11.3.8 Hoop/Axial Stress and Minimum wall thickness evaluation.

Design Input	Requirement	Supporting Document(s)
• 4” Schedule 40 pipe	• Nominal inside diameter: 4.026” • Wall thickness: 0.237” • Support 65 psig	• ASME/ANSI B36.10/19 • CRANE Technical paper 410 • Engineering toolbox • SDG.M.SFD-1072A-EC001
Evaluation of hoop and axial stresses for a schedule 40 wrought stainless-steel pipe indicates the schedule of piping is sufficient for the intended purpose of EC-001. The maximum allowable stress for a wrought stainless-steel pipe below 200°F is 16,000 psi. Hoop Stress: $\sigma_\theta = \frac{Pr}{t} = \frac{65psi*2.013''}{0.237''} = 552\ psi$ Axial Stress: $\sigma_{axial} = \frac{Pr}{2t} = \frac{65psi*2.013''}{2*0.237''} = 276\ psi$ Both stresses at the pressure of 65psi are well within the allowable stress of the pipe and		

therefore ensures 4” schedule 40 piping will be adequate for the design.

Additional analysis was performed on the minimum wall thickness required for the systems conditions to ensure the chosen schedule pipe is adequate. From ASME B31.1:

The minimum wall thickness required for design pressures and temperatures con be calculated using the following formula:

$$t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)}$$

Where:

$$P = 65psig$$
$$d = 4.026"$$
$$SE = 16{,}000\,psi$$
$$A = \frac{1}{64}\,in = 0.015625"$$
$$y = 0.4$$

$$\therefore t_m = \frac{65\frac{lb}{in^2} * 4.026\,in + 2 * 16{,}000\frac{lb}{in^2} * 0.015625in + 2 * 0.4 * 65\frac{lb}{in^2} * 0.015625\,in}{2(16{,}000\frac{lb}{in^2} + 65\frac{lb}{in^2} * 0.4 - 65\frac{lb}{in^2})}$$

$$\therefore t_m = 0.0239\,in$$

The minimum wall thickness is 0.0239 in. The chosen schedule pipe has a wall thickness of 0.237 inches. The chosen schedule is adequate for the intent desired with a factor of safety of 9.9.

Chapter 12: Resources

The resources presented below contain information in which the KSU SDG found useful throughout their endeavors in this project.

12.1 Software

Resources include:

- MATLAB SimScape Electrical for electrical modelling
- Solidworks Flow Simulation
- Autodesk for mechanical modelling
- Adobe PDF (Portable Document Format) Reader for drawing markups
- Microsoft Teams and Outlook for weekly meetings and communication
- Microsoft Office for Presentations and Reports

12.2 Hardware

No hardware resources needed for this project other than personal student devices and physical plant documents.

12.3 Other

Applicable Industry Codes:

- National Electric Code (NEC) 2017
- ASTM
- AISC Steel Construction Manual, 15th Edition
- ACI 318-14
- ENERCON Civil Structural Design Criteria Manual
- IBC 2018
- IEEE Standards
- ASME B31.1 & B16.5

Chapter 13: Processes and Controls

This chapter contains all controls present for this project. This included, but was not limited to, being audited by the ENERCON engineers, and quality assurances that are required for ENERCON specifications.

13.1 Build-to Baseline

Use data sheets provided by ENERCON such as specific wire routing, motor specifications, wire size, specific core bore placements, and vacuum pump skids specs i.e. weight, dimensions, etc.

13.2 Audited by ENERCON Engineers

These are vendor-produced (manufactured) components and have no access to manufacturing requirements for the provided equipment. We have specifications for equipment that will be used to control, support, and connect parts of said equipment, as all processes have been checked by the ENERCON engineers.

13.3 Processes and Controls sufficient to proceed to fabrication.

The team has edited and reviewed all comments from ENERCON. The process of design has been done by the SDG and checked multiple times by the ENERCON staff. The electrical team has created a new controls evaluation to clarify how the system will operate. This has since been checked and approved by ENERCON for functionality. The mechanical team has performed evaluations to ensure the existing plant systems can support the new pumps. All evaluations have been checked and by ENERCON engineers. The design is clear to head into the development and fabrication phase after the final check by ENERCON.

13.4 Quality Assurance

Each team member reviews the work of the other team member in their discipline to ensure accurate work. Once reviewed by a SDG member, evaluations and markups are submitted to ENERCON for review. ENERCON has a very thorough review process where SDG documents are reviewed by two ENERCON engineers in the same discipline. The SDG is then given a detailed comment form of suggested changes to incorporate into evaluations and markups. There is a 2-week window to incorporate changes, and the ENERCON engineers are available for any questions or further comments. Once all comments have been resolved, the SDG begins work towards the next milestone on a solid foundation of reviewed work. This iterative method of quality assurance ensures a body of work that is solid from the ground up. The ENERCON engineering talent welcomes all questions from the SDG and has been very helpful in improving the SDG's approach to the design problem in this project.

Chapter 14: Results & Discussion

This chapter presented below shows the results of the evaluations presented above.

14.1 Electrical Results

Multiple electrical evaluations have been performed for Enercon Station to ensure reliability and safety of the plant equipment and personnel. The three 480VAC motors are being replaced with two 4160VAC motors. This requires new electrical evaluations, and the SDG electrical evaluations conclude that the new equipment and designed configuration is acceptable for use at this plant. The naming scheme and load centers for the 4160VAC motors have changed, and the new locations can be seen on SDG.E1150-006-016. Two new static trip 70 amp (minimum), 4160VAC or equivalent static trip breakers must be purchased (based on vendor research, SDG recommends WEG-SSW7000C 125A model). Recommended breaker is seen on Electrical Bill of Materials. The 120VAC space heaters will retain the same breakers as well as cables. (This eliminates any need for further evaluation, as the space heater specifications remain the same.) Space heater A has been unretired shown on drawing SDG.E.E-0080-01 and space heater C has been spared as shown on drawing SDG.E.E-1030-004_011. The new 400hp vacuum pump motors have been evaluated, and a 500kcmil Type MV-105 or equivalent copper conductor has been recommended by the electrical SDG for the new 4160VAC motors. Conductors for space heaters and controls will reused from existing configuration. The new 4160VAC motors have a given locked rotor current of 346 amperes obtained from the motor data sheet. The cable has been sized to apply with ampacity ratings per NEC which includes 125% of the locked rotor current to prevent damage to the cable or machinery. A controls evaluation has been attached in addition to the required electrical evaluations, which adds further detail on how the system will connect and operate. Fully detailed descriptions of each evaluation are attached in Chapter 11 above.

Voltage Drop: SDG.VD-EC001 Voltage Drop Evaluation

Cable Ampacity: SDG.CA-EC001 Cable Ampacity Evaluation

Grounding: SDG.G-EC001 Grounding Evaluation

Conduit Sizing: SDG.CS-EC001 Conduit Sizing Evaluation

Circuit Protection/Circuit Coordination: SDG.CP&C-EC001 Circuit Protection and Coordination Evaluation

Short Circuit Protection: SDG.SCP-EC001 Short Circuit Protection Evaluation

Controls Modifications: SDG.CM-EC001 Controls Modifications Evaluation

Bill of Materials: SDG.BOM-EC001

14.2 Civil Results

14.2.1 Heavy Haul Path

Based on the assessment, a conclusion could be made that the actual loading, 218.99 psf, due to the 40,000 lb. empty weight of the pump does not exceed that of the allowable floor loading, 350 psf, on elevations 113’ and 133’. This also goes to show that the transportation vehicle can apply a maximum load of 131.01 psf to either of the floor slabs. If the transportation vehicle is going to exceed this allowable loading, then the engineering team is to be contacted to find an effective solution. Since the allowable floor load is the same on both the 113’ and 133’ elevations, the following evaluation applies to both elevations. The pump systems should be brought up to El 113’ and 133’ using the equipment hatch in Unit 1 along with the transportation vehicle.

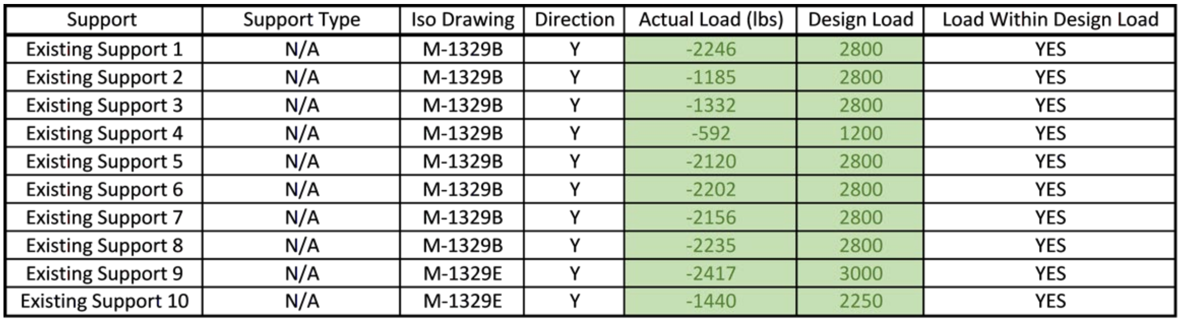
14.2.2 Floor Loading Evaluation

An evaluation of the existing floor slabs on EL. 113’ and EL. 133’ was performed assuming the pump system was at full capacity and carrying a load of 56,800 lbs. This concluded that the allowable floor loading of 350 psf was not exceeded with a pump load of 310.96 psf, being less than 90% of the allowable loading.

14.2.3 Existing Pipe Support Evaluation

Using the new loads provided by ENERCON, an evaluation was performed on the existing pipe supports. The evaluations in the table below concluded that the new loads induced on the supports do not exceed the design loads for the existing supports.

Table 7: Existing Pipe Support Loads



Support	Support Type	Iso Drawing	Direction	Actual Load (lbs)	Design Load	Load Within Design Load
Existing Support 1	N/A	M-1329B	Y	-2246	2800	YES
Existing Support 2	N/A	M-1329B	Y	-1185	2800	YES
Existing Support 3	N/A	M-1329B	Y	-1332	2800	YES
Existing Support 4	N/A	M-1329B	Y	-592	1200	YES
Existing Support 5	N/A	M-1329B	Y	-2120	2800	YES
Existing Support 6	N/A	M-1329B	Y	-2202	2800	YES
Existing Support 7	N/A	M-1329B	Y	-2156	2800	YES
Existing Support 8	N/A	M-1329B	Y	-2235	2800	YES
Existing Support 9	N/A	M-1329E	Y	-2417	3000	YES
Existing Support 10	N/A	M-1329E	Y	-1440	2250	YES

14.2.4 Hidden Commodities Assessment

The Hidden Commodities Assessment showed that there were several items that are possibly affected by the planned core bores on El 133’. Although the locations of these items are greatly important to the installation of the core bores, the task of remediating the impactions is outside the scope of this project. No rebar was impacted for core bore #1 and #3 as the flexural and temperature reinforcement spacing in the slab was greater than the diameter of the core bore. However, Core bore #2 is impacted by flexural reinforcement.

14.2.5 New Penetration Evaluation

One bar can be cut in the slab to satisfy the requirements of core bore #2 without significantly impacted the structural aspects of the slab. Core bore #1 and #3 have a diameter that is 4 in. smaller than the spacing of flexural reinforcement. Therefore, no analysis is needed for Core bore #1 and #3.

14.2.6 New Pipe Support Evaluation

All pipe supports that were evaluated are acceptable to provide structural support for their given pipe loads with all interaction ratios below 1.

14.2.7 Special Instructions

The pump pedestals for all three existing pumps should be removed and leveled to the existing floor elevation (El. 113'). Construction documents and schedule for demolition shall be submitted by the building official. Service utility connections shall be discontinued based on the appropriate governing authority. Fire Safety shall be applicable to the provisions of Chapter 33 of the International Fire Code. (IBC 2018, Section 33).

14.3 Mechanical Results

14.3.1 Hydraulic Evaluation

The Plant Service Water System can provide sufficient flow to the Vacuum Pump HX. Using 4" Schedule 40 Wrought Stainless-Steel pipe, a 4" sleeved plug valve will be placed before the HX to control the flow down to the required value of 350 GPM. The valve will need to be rotated 78% to control the flow and ensure flow is not taken from downstream HX's in the plant. To ensure no sediment enters the HX a y-strainer will be placed before the HX. Also, for maintenance purposes, an isolation valve will be placed before the HX to restrict flow to the HX and reroute to the backup HX.

14.3.2 Cooling Evaluation

The HX, N1N62C001A/B-1.1-001, chosen by the vendor will provide more than enough cooling to the mechanical vacuum pumps. The HX was evaluated at design flow rates and surrounding system temperatures. The HX is designed to operate with the cold-side and hot-side flow rates to be at 350 GPM and 190 GPM, respectively. The Plant Service Water system provides the HX's cold-side inlet with a temperature of 75°F per Ref 22 at indicator 93. The design temperature of 99.8°F is the closed-loop side of HX where the seal-liquid travel to and from the vacuum pump. From the evaluation, the HX had a heat-exchanged-rate of 1,610,140.2 BTU/hr which is much greater than the vendor-advertised value of 960,000 BTU/hr. This is evidence that HX is providing more heat transfer from the seal-liquid to the PSW cooling water than what it is advertised to do. Additionally, the outlet temperatures of the HX are well within the limitations of the system. The PSW shall not have an intrusion of fluid whose temperature is more than 95°F. The closed-loop system limitations are bounded by the recirculation pump of 120°F. The outlet temps of the cold-side and hot-side are 84.22°F and 82.73°F, respectively. Thus, HX N1N62C001A/B-1.1-001 is more than capable of the job.

Chapter 15: Conclusion

The Senior Design Group successfully evaluated and implemented the necessary changes to upgrade the ENERCON pump system. With all the design milestones complete and feedback incorporated from ENERCON, this project is ready to leave the design phase and move to planning/manufacturing.

Appendix A: Acknowledgements

The Electrical Team would like to acknowledge Professor Diong for his assistance with our MATLAB SimScape Electrical simulations.

The Civil Team would like to acknowledge Professor Daniel Kuemmerle for his assistance with our RAM Elements simulations, as well as Trey Bodenhamer and Reesha Ramatour, the civil leads from ENERCON, who helped guide the civil team through every step of this project.

Appendix B: Contact Information

- Jared D'Amico Personal Email: damicojared448@gmail.com
- Clint Hembree Personal Email: hotrodclint@aol.com
- Connor Moore Personal Email: Mooreconnor60@gmail.com
- Jeffrey Fontenot Personal Email: paulfontenot@gmail.com
- Sydnee Castello Personal Email: sydneecastello@gmail.com
- JJ Clements Personal Email: jjclements27@gmail.com

Appendix C: Reflections

Jared D' Amico:

Being part of an interdisciplinary team and working with a well renowned engineering company has been an incredible experience. Putting together an engineering change package really took me out of the solving textbook problems mind set. This project changed the way I approach problems and taught me that if you look and work hard enough, the answer will eventually surface. Working with students who are part of another engineering discipline also taught me to view the project in its entirety rather than just from a mechanical standpoint. I can say I have gained more knowledge and experience than I ever thought I would on this project. This is a great opportunity for students to gain some industry experience before graduating if they are willing to put in the long and I mean long hours. Over 1300 between the 6 of us over the entire duration of the project. I do want to thank all the Engineers at ENERCON for taking time out of their days to help us succeed (especially Jamie Fan and Peter Bertasi) and in the end deliver a sound Engineering Change Package.

Clint Hembree:

The opportunity that I was given to work alongside a company for a project has been very rewarding. Like my team members and I would agree on, it has been very frustrating at times. Simply put, we had no idea what the extent of this project entailed. And to add to the ENERCON side of the project, we were responsible for classroom assignments too. Last semester was a bit rough in getting the project started. The classroom assignments never aligned with that of the project that we had been working on. However, I strongly feel that we have had a really great team that was able to make the best of it. This team is definitely one to talk about in terms of coordination, communication, and most of all-hard working. This project has not been easy for any one of us. We have learned quite a bit over the last 8 months, and it has been well worth it. I am very thankful that I took the chance to take on this project, as I have learned so much from my own mistakes, but also engineers at ENERCON. Specifically, Jamie Fan and Peter Bertasi. The real-world experience that I have gained from the project is irreplaceable. I highly recommend this IESD class if the opportunity is given. Thank you to my team members, professors, and ENERCON staff for believing in us to create a great EC Package!

Connor Moore:

This has been a very eye-opening experience; I have had oppurtunities in the field of engineering but not to this extent. This project was a great learning experience, as I was introduced to the technical engineering field. The task was exceptionally large and frightening but as we kept working, we eventually created a very well put together project. Creating evaluations and calculations from scratch following all NEC and IEEE guidelines has helped me understand a lot more into the field of Electrical Engineering. The first semester was difficult there was too much workload placed on the students as deadlines fell onto of each other. This semester has gone much better as the workload was more reasonable and we were not being lectured on material not related to the project itself. This project was vastly different than the other task the other teams were working on which created a challenge. For the Enercon side of things, this overall process was at times frustrating as we could not accomplish any work, this was because the ENERCON staff was occupied with other tasks. However, this led to us as students trying to innovative ideas in how to solve the problems. The engineers that helped us on the electrical side have really taught me a lot and I am very thankful. This created a deeper understanding of the project and technical engineering for me personally, so the worst part of the project might have been the most beneficial. This dive into the engineering world was a wonderful experience for students ready to enter the workforce, and I would recommend it to anyone that is interested.

Jeffrey Fontenot:
A bumpy start, but overall good experience. The classroom work did not always line up with ENERCON expectations (and was on several occasions a large additional load for the students to carry). Students were coming into this project with little to no corporate design experience. The biggest learning curve was writing technical documents and the many presentations expected of the group. (The actual engineering work was relatively light comparatively.) The students gained lots of experience in industry codes (IEEE, NEC, etc), writing concise design inputs, and discussing technical problems with other engineering disciplines. The students 30% milestone was the toughest for the students because of a lack of experience presenting in corporate environments. ENERCON technical writing and presenting expectations seemed somewhat withheld at the beginning to allow students to learn through struggle. However, the individual engineers in the SDG weekly discipline meetings were much more accepting and understanding towards the SDG lack of corporate experience, and by the 60% milestone it seemed that students were performing to ENERCON expectations. This has overall been a great learning experience of what hands-on design engineering looks like in a large corporate engineering firm. This student is especially grateful to ENERCON electrical engineers Shawn Sinclair, “Kaz” Costa, and Casey McCurrin for sharing their time, experience, and patience to assist with a Senior Design project. This is a great opportunity for any future students interested in learning the technical details of professional engineering in a corporate environment for their senior project. Thank you and all the best!

Sydnee Castello:
Being a part of this senior design group has been an interesting experience. Although I have prior knowledge of working in the field, I do not have much experience working with other disciplines. When first reading the scope of the project, some of the topics were not specifically covered in our assigned courses, but that was the best part of this learning experience. We had to apply what we had already learned to scenarios that have not been shown to us in class and fill in the gaps by learning new skills in the process. During the first semester we had enough time and corresponding assignments that helped us to better understand the expectations from Enercon and the IESD class itself. Our in-class assignment due dates usually fell on the same day as important submissions deadlines given to us by Enercon. This created many different challenges as the other groups were based around different disciplines and industry practices. With more communication and coordination, we were able to freely express our concerns and complete the assignments based on the vast differences. By the second semester, we were ready to fully dive into the analysis portion of the project. Overall, this was a great experience, and I would highly recommend this class to any student who is interested in learning about working in an interdisciplinary group for a large-scale project.

JJ Clements:
During the summer of 2020, Dr. McFall sent out an email to the students asking if any of us would be interested in joining a class that would be an experimental senior design class. I immediately emailed him trying to get a spot as I did not know what this class had in store nor

how much work it would be, all I knew was that working with an industry partner would be invaluable to my educational and engineering career. From the beginning the coordination from the industry partner, ENERCON, has been very upfront. The expectations of the senior design group were admittedly probably low at first with the lack of experience in the industry, but with the effort put in by the group I think that thought has changed. There are aspects that we were complete strangers to such as the technical writing of an Engineering Change Package, but I feel the group learned how to tackle some of these challenges very quickly, while it took a while to pick up some of the others. I know there are aspects I struggled with personally, such as having to learn new material specific to structural engineering that we do not necessarily learn in school. As we got to work and started realizing how this project differed from the other groups, I could tell there was some disconnect between the class work and presentations and the work that ENERCON was requesting of us. However, as we got further into our ENERCON milestones things started to align with our in-class reports and presentations.

Overall, the pace has been much quicker on the industry side of things than it has been in class, but it gave us a good idea of how to plan out our work as if we were in the industry. Admittedly, I procrastinated a little at first trying to figure out how to balance the workload of classes and this project, but quickly found a good schedule to plan my week around getting things done for the project while still doing my schoolwork in a timely manner. I want to thank ENERCON for taking their time out of their busy schedules to help with this project and give us a taste of what it is like to work in the industry. It has been an incredible opportunity and I have gained knowledge that I will take with me the rest of my engineering career. To my fellow group members, I want to thank you all for your hard work in this project as I know personally there have been some trying moments. Lastly, to any student thinking of taking this class in the future I would highly recommend it. The knowledge you gain from working with a team of engineers of different backgrounds and different skill sets is something you just cannot learn from a textbook or from doing homework.

Appendix D: Contributions

Table 8: Member Contributions per Chapter

Chapter	Contributor(s)
1: Project Overview	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
2: Literature Review	Jeffrey Fontenot and Jared D'Amico.
3: Project Management	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
4: Minimum Success Criteria	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
5: System Design Inputs	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
6: Design Concepts and Trade Study Items	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico. , and Clint Hembree
7: Verification/Analysis/Simulations	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
8: Completion to Date	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
9: Challenges Faced	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
10: Overcoming the Challenges	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
11: Markups and Evaluations (Split per Discipline)	Electrical Evaluations: Connor Moore and Jeffery Fontenot Civil Evaluations: JJ Clements and Sydnee Castello Mechanical Evaluations: Jared D'Amico and Clint Hembree
12: Resources	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D'Amico, and Clint Hembree.
13: Processes and Controls	Jared D'Amico and Jeffery Fontenot.
14: Results and Discussion	Electrical Evaluations: Connor Moore and Jeffery Fontenot

	Civil Evaluations: JJ Clements and Sydnee Castello Mechanical Evaluations: Jared D’Amico and Clint Hembree
15: Conclusion	Connor Moore, Jefferey Fontenot, JJ Clements, Sydnee Castello, Jared D’Amico, and Clint Hembree.

Table 9: Technical Contributions

Connor Moore	Assessment of voltage drop, cable ampacity, grounding, short circuit, circuit protection, and all related markups for each.
Jeffery Fontenot	MATLAB SimScape Electrical Simulation for voltage drop evaluation, controls evaluation, miscellaneous evaluations, markups, and review.
JJ Clements	Floor Loading Evaluation, Heavy Haul Path Evaluation, Existing Pipe Support Evaluations, New Pipe Support Evaluations and Drawings.
Sydnee Castello	Hidden Commodities Assessment, New Penetration Evaluation, New Pipe Support Evaluations and Drawings, Special Instructions to the Craft.
Jared D’Amico	Drawing of pipe route in AutoCAD, marking up of documents in AutoCAD, Hydraulic Evaluation calculations and report.
Clint Hembree	Drawing of pipe route in AutoCAD, HX Evaluation calculations, and report.

Appendix E: References

1. (M-1072A) P&I Diagram Plant Service Water System.
2. (N1N62C001A/B-1.1-001) HX spec sheet.
3. (SDG.M.SFD-1072A-EC001) System Flow Diagram.
4. (SDG.M-1003-EC001) Equipment location in the Turbine Building (TB) at elevation 133'.
5. (SGD.M-1002-EC001) Equipment location in the TB at elevation 113'.
6. "Flowserve Instrument Engineers" Handbook for DURCO Quarter -turn Control Valves.
7. "Valve Selection and Specification Guide" by Ronald C. Merrick.
8. ACI Committee 318. (2014). *ACI CODE-318-14: Building Code Requirements for Structural Concrete and Commentary* (American Concrete Institute).
9. Barie, et al, "Application of variable frequency drive on the condensate pump motors of APR1400 nuclear power plants for energy savings", Journal of International Council on Electrical Engineering, 15 October 2018
10. Butler, "France Imagines the Unimaginable' - Regulator Demands Safety Upgrades", Nature News, January 2012.
11. Carl, "Keeping the Lights On - Nuclear Power has to Remain Part of Our Energy Mix", Hoover Digest, December 2018.
12. Carruth, et al., "Design Concepts for the Reactor Protection and Control Process Instrumentation Digital Upgrade Project at the Donald C. Cook Nuclear Plant Units 1 and 2", IEEE, June 1996.
13. Carson et al., "Nuclear Plant Retirements Reflect Need for Wholesale Market Reforms", EnerKnol Research Policy Brief, November 2015.
14. Cengel, Yunus, and Boles, Michael. Thermodynamics. McGraw-Hill Education, 2015.
15. Cengel, Yunus, and Ghajar, Afshin. Heat and Mass Transfer. McGraw-Hill Education, 2015.
16. CRANE Nuclear
17. CRANE: Technical Paper 410
18. Durmayaz, "Influence of cooling water temperature on the efficiency of a pressurized-water reactor nuclear-power plant," International Journal of Energy Research, 10 April 2006
19. Ellis, et al., "Chain Reactions: Before We Jettison Nuclear Energy, Let's Count the Costs", Hoover Digest, November 2018.
20. Fisher, James M, and Lawrence A Kloiber. Steel Design Guide: Base Plate & Anchor Rod Design. 2nd ed., vol. 1, American Institute of Steel Construction, 2006.
21. Flow Serve: Instrument Engineer's Handbook for DURCO Quarter-turn Control Valves.
22. Jancauskas, "Analyzing Auxiliary Systems in Nuclear Generating Stations," IEEE Computer Applications in Power, July 1992
23. Jou, et al., "The implementation of a human factors engineering checklist for human system interfaces upgrade in nuclear power plants", Elsevier Safety Science, 13 November 2008
24. Keckley Y-Strainers
25. Kotval, et al., "The Closing of the Yankee Rowe Nuclear Power Plant", Journal of the American Planning Association, Vol. 63, No. 4, September 1997.

26. Liquid Ring Mechanical Vacuum Pumps Installation, Operation, and Maintenance Manual. (460004522)
27. Packer, Jeffrey, et al. Steel Design Guide: Hollow Structural Section Connections. Vol. 24, American Institute of Steel Construction, 2010.
28. R.C. Hibbeler Fluid Mechanics Second Edition
29. Scerbo, et al., "Safety System Augmentation at Russia Nuclear Power Plants", IEEE Transactions on Nuclear Science, Vol.44, No.3, June 1997.
30. SDG.M-Isometrics-EC001
31. Segui, William T. Steel Design. 6th ed., Cengage Learning, 2018.
32. Steel Construction Manual. 15th ed., American Institute of Steel Construction, 2019.
33. Thomas, et al., “A Business Case for Nuclear Plant Control Room Modernization”, U.S. Department of Energy, June 2016

Appendix F: Supporting Details and Documents

Snippets of documents have been included in this report, however full documents will not be uploaded with this report as all documents are ENERCON proprietary information which is privileged, confidential, or subject to copyright belonging to ENERCON. All snippets used in this report have been approved for use by ENERCON.